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Pattern Recognition on Remanufacturing Automotive Component as Support Decision Making using Mahalanobis-Taguchi System

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Abstract

An unsystematic of pattern recognition system based historical data caused the industrial practitioners failed to predict in a short time either the part can be rejected or remanufactured. In a worst case, their justification is really weak without any particular analysis to convince the client because the current situation, they only depend on a traditional inspection to make a decision. Thus, the aim of this work is to provide a systematic pattern recognition using T Method-3 by constructing a scatter diagram which could support decision making of particular industry on 14 main journals of crankshaft belong to 7 engine models with different numbers of samples. Consequently, the outcome of this work is the client will be more convince on the development of remanufacturing process and the human's perspective will be that remanufactured product be thought as second hand, of poor quality and will be improved.

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1. Introduction

Nowadays, with the growing concern for environmental protection from the customer's perspective and stricter environment legislations, more and more world leading companies such as Honda and Continental Airlines have begun to pay attention to the strategy of product take back namely remanufacturing [1]. According to [2], there are 480 thousand people participating in the remanufacturing industry and from that, about 338 thousand are in automotive field in USA. Thus, remanufacturing can be defined as a specific type of recycling in which used durable goods are repaired to as close to new condition [3]. It has been reported by [4] that automotive remanufacturing alone could save an annual energy equivalent of five nuclear power plants. The issue happened on particular industry is that there is no scattered diagram provided in order to solve the problem on pattern recognition to support industry's decision making. Unfortunately, the industry only depends on traditional inspection which the tolerance is provided by Original Equipment Manufacturer (OEM) to convince their customer on remanufactured product but in the authors view point, the justification still can be strengthen especially most of the remanufacturers need relevant incentive from the government.

Consequently, this paper presents T Method-3 as sub-methods in Mahalanobis-Taguchi System is capable to solve the issue by distinguishing 7 engine models based on their Mahalanobis Distance. MTS is different from classical multivariate methods because it uses data analytic rather than being on probability based inference and the MD is suitably scaled and used as a measure of severity of various conditions [5].

1.1. Remanufacturing

Remanufacturing or reman is distinctly different from the repair operation, since products are completely disassembled and some of parts are returned to like-new condition, which may include cosmetic operations [6]. It is a process whereby companies can become more environmentally efficient through reusing and reduction the amount of material used, highly profitable [7], better than recycling and landfilling [8]

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and lower cost compared to original manufactured product [9]. According to [10], reman activity strongly promotes demand for labor, also reduces the level of inter-industry transaction and suppliers of sectors subject to competition from remanufacturing sectors have their industry transaction significantly reduced. That situation is exacerbated if the sector is also subject to reman activity.

Data from [11] predicted remanufacturing energy requirements of various engine components. The authors found that, the energy benefit of reman can be expressed through the ratio of reman energy to original manufacturing energy. Those ratios ranged between 2 and 25%. In addition, the use of remanufactured components for six cylinder heads diesel engine can potentially avoid approximately 16250 MJ of energy that would be required to create new components rather than remanufactured cores. Thus, reman is an efficient program, not just a cost effective means to reduce waste but as integral part of the firm's manufacturing and marketing strategy [12].

1.2. Mahalanobis-Taguchi System

MTS is a combination of Mahalanobis Distance (MD) which developed by well-known famous Indian statistician Prasanta Chandra Mahalanobis and Taguchi's robust engineering to make accurate predictions in multi-dimensional systems by constructing a measurement scale [13]. Pattern recognitions as one of the objectives in MTS diagnosed human health using MD were demonstrated by [14]. Thus, the pattern of observations in a multi-dimensional system really depends on the correlation structure of the variables in the system. It is impossible to make intelligent decisions if the variables are considered one at a time. The variables that have the greatest impact on performance must be identified and used in concert. To construct a multi-dimensional scale, it is important to have a distance measure. The distance measure is based on the correlation between the variables and the different patterns that are identified and analyzed with respect to a base or reference point [15].

Work by [16] examined the discriminant ability of MTS and Finite State Classifier for the detection of malignant melanoma which is the deadliest form of skin cancer. The authors found that, MTS performed poorly because of large number of different correlations occurred could be introducing additional variance and mixing different correlations within the data set. Similarly in pattern recognition, [17] proposed a face identification system based on the MTS using training data, including noise. Consequently, the method reduced the time required for identification and the attributes in facial image database effectively can be reduced from 120 to 40 attributes by performing the optimization. Work by [18] developed an alternative search procedure to be used within the MTS. The adaptive one factor- at-a-time (aOFAT) procedure replaces the orthogonal arrays traditionally utilized in MTS and features are individually added or removed from the classification system depending on their impact on the overall signal-to-noise ratio. The experimentation shows that the aOFAT procedure renders greater improvements over the median with the same or fewer design alternatives being explored and also exhibits good ability to generalize to new instances after training. MTS has also been used as a process control and improvement tool to aid manufacturing systems.

2. Case study methodology

Crankshaft is one of the automotive components that capable to be remanufactured [19] as it fulfilled the criteria. As the crankshaft is received into the facility, the cleaning process takes place approximately 10 minutes to remove out any oils and other foreign contaminants using hot water high pressure jet cleaner. When it has dried, measurements at 14 different positions of the main journals diameter are taken using the Digimatic Micrometer MS55. There are 7 engine models involved such as Cat, Det, Haz, Man, Mer, Mtu and Per engine model with 286, 257, 280, 285, 302, 312 and 274 numbers of samples respectively. Subsequently, It is a very important to recognize their pattern according to their tolerance through the mathematical equations of T Method-3. Thus, Table 1 shows the lower and upper limit of main journal diameter of crankshaft.

Table 1. The upper and lower limit of remanufacturability of crankshaft.

Engine model	Main journal diameter (mm)	
	Lower limit	Upper limit
Cat	159.975	160.025
Det	114.262	114.305
Haz	71.981	72.000
Man	104.020	104.040
Mer	103.730	103.750
Mtu	103.980	104.000
Per	76.159	76.190

The T method-3 is the T method for recognition that has the ability to classify objects into two categories, one inside and the other outside the unit space. Unlike the T method-1, the T method-3 proves of use when the real value (measured value of the output) of a signal is unknown but the category to which it belongs is clear and when multiple unit spaces (more than just one) exist. It starts with define the unit space and computation of the average value of each item. As shown in Table 2, n numbers of sample have been acquired for the unit space. The k-items have to be in same dimension or in no dimension.

Table 2. Average values of samples and items in the unit space.

Data No.	Item				Linear formula
	1	2	…	k	
1	x_{11}	x_{12}	…	x_{1k}	L_1
…	…	…	…	…	…
n	x_{n1}	x_{n2}	…	x_{nk}	L_n
Average	$\bar{x}_1$	$\bar{x}_2$	…	$\bar{x}_k$	

Then, the average values for each item is calculated from n number of sample in the unit space. The equation of average values is shown in Equation 1 below.

$$\bar{x}_j = \frac{1}{n}\left(x_{1j} + x_{2j} + \cdots + x_{nj}\right) \quad (1)$$

To compute the sensitivity β, linear equation and effective divider should be calculated first as shown in Equation 2 and Equation 3 respectively for each sample.

$$\text{Linear equation, } L_1 = \bar{x}_1 x_{11} + \bar{x}_2 x_{12} + \cdots + \bar{x}_k x_{1k} \quad (2)$$

$$\text{Effective divider, } r = \bar{x}_1^2 + \bar{x}_2^2 + \cdots + \bar{x}_k^2 \quad (3)$$

Hence, sensitivity β as shown in Equation 4 can be referred as below.

$$\text{Sensitivity, } \beta_1 = \frac{L_1}{r} \quad (4)$$

To calculate the standard S/N ratio η sample by sample from the unit space, total variation, variation of proportional term, error variation and error variance should be calculated first as shown in Equation 5, Equation 6, Equation 7 and Equation 8 respectively.

$$\text{Total variation, } S_{T1} = x_{11}^2 + x_{12}^2 + \cdots + x_{1k}^2 \quad (5)$$

$$\text{Variation of proportional term, } S_{\beta 1} = \frac{L_1^2}{r} \quad (6)$$

$$\text{Error variation, } S_{el} = S_{T1} - S_{\beta 1} \quad (7)$$

$$\text{Error variance, } = \frac{S_{el}}{k-1} \quad (8)$$

Subsequently, the standard S/N ratio η is given as the following Equation 9.

$$\text{S/N ratio, } \eta_1 = \frac{1}{V_{el}} \quad (9)$$

Use of the expression standard S/N ratio to treat the average values of the items of the unit space as the standard signals; the dividend might as well be represented by r but the numeral one has been chosen because it is common to all members. Sample by sample in the unit space, sensitivity β and standard S/N ratio η are then found in a similar manner with the result shown in Table 3.

Table 3. Sensitivity β and standard SN ratio η for all samples in the unit space.

Data No.	Sensitivity β	S/N ratio η
1	β_1	η_1
⋮	⋮	⋮
n	β_n	η_n

By using previous sensitivity β and standard S/N ratio η, the two variables Y_1 and Y_2 can be calculated. For Y_1, β is used directly as shown in Equation 10 whereas Y_2 will first be converted as follows to allow an evaluation of any scatter from the standard conditions as shown in Equation 11.

$$Y_{i1} = \beta_i \quad (10)$$

$$Y_{i2} = \frac{1}{\sqrt{\eta_i}} = \sqrt{V_{ei}} \quad (11)$$

Equation 12 and Equation 13 shows the average of Y_1 and Y_2 for each sample to predict their origin.

$$\bar{Y}_1 = \frac{1}{n}(Y_{11} + Y_{21} + \cdots + Y_{n1}) \quad (12)$$

$$\bar{Y}_2 = \frac{1}{n}(Y_{12} + Y_{22} + \cdots + Y_{n2}) \quad (13)$$

Consequently, Mahalanobis Distance can be calculated based on Equation 14 below.

$$D^2 = \frac{YAY^T}{k} \quad (14)$$

Next is when the amount of signal data has been acquired as shown in Table 4, toward evaluating discriminating ability.

Table 4. Signal data items and linear formula.

Data No.	Item				Linear equation
	1	2	…	k	
1	x'_{11}	x'_{12}	…	x'_{1k}	L'_1
…	…	…	…	…	…
l	x'_{l1}	x'_{l2}	…	x'_{lk}	L'_l

To compute the sensitivity β, linear equation and effective divider should be calculated first as shown in Equation 15 and Equation 16 respectively for each sample.

$$\text{Linear equation, } L'_1 = \bar{x}_1 x'_{11} + \bar{x}_2 x'_{12} + \cdots + \bar{x}_k x'_{1k} \quad (15)$$

$$\text{Effective divider, } r = \bar{x}_1^2 + \bar{x}_2^2 + \cdots + \bar{x}_k^2 \quad (16)$$

Hence, equation of sensitivity β as shown in Equation 17 can be referred as below.

$$\text{Sensitivity, } \beta_1 = \frac{L'_1}{r} \quad (17)$$

The standard S/N ratio η, sample by sample from the unit space, total variation, variation of proportional term, error variation and error variance should be calculated first as shown in Equation 18, Equation 19, Equation 20 and Equation 21 respectively.

$$\text{Total variation, } S_{T1} = x'^2_{11} + x'^2_{12} + \cdots + x'^2_{1k} \quad (18)$$

$$\text{Variation of proportional term, } S_{\beta 1} = \frac{L'^2_1}{r} \quad (19)$$

$$\text{Error variation, } S_{e1} = S_{T1} - S_{\beta 1} \quad (20)$$

$$\text{Error variance, } V_{e1} = \frac{S_{e1}}{k-1} \quad (21)$$

Finally, the standard S/N ratio η is given as the following Equation 22.

$$\text{S/N ratio, } \eta_1 = \frac{1}{V_{e1}} \quad (22)$$

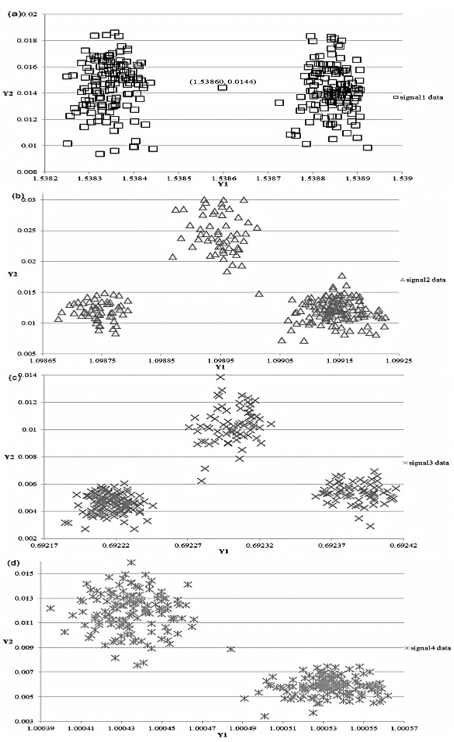
By using sensitivity β and standard SN ratio η belong to signal data, the two variables Y_1 and Y_2 can be calculated. For Y_1, β is used as shown in Equation 10 whereas Y_2 will first be converted as follows to allow an evaluation of any scatter from the standard conditions as shown in Equation 11 as previous. Similarly, using Equation 12 and Equation 13 shows the average of Y_1 and Y_2 for each signal data to predict their origin. Finally, Mahalanobis distance can be calculated based on Equation 14 as well. Finally, the pattern of main journals of crankshaft belongs to 7 engine models can be recognized through constructing scatter diagram.

3. Result and discussion

3.1. Pattern recognition

The primary objective of T method-3 in this work is to construct a scatter diagram as evidence to confirm that the engine component can be categorized as remanufactured, rejected or mixed group based on the historical data. In addition, it would help to convince clients on the company's decision.

Due to the many reasons, such as the continuous movement of the engine mechanism with low maintenance, the diameter of main journal may be decreased in size. During the analysis, the minimum number of items for evaluation on pattern recognition is three with no restriction on the number of samples. Unit space is selected based on the highest frequency and the other engine models can be categorized as signal data. In addition, there will be no restriction on how many signal data may be required but the number of unit space must only be one. With more signal data, a clear scale based on their MD can be obviously be observed. Thus, there are 14 main journals diameter to be grinded during analysis. In pattern recognition, the number of plots represents the number of samples in the scatter diagram. In addition, from that diagram also, prediction either the plotting is good or bad also based on their coefficient correlations.



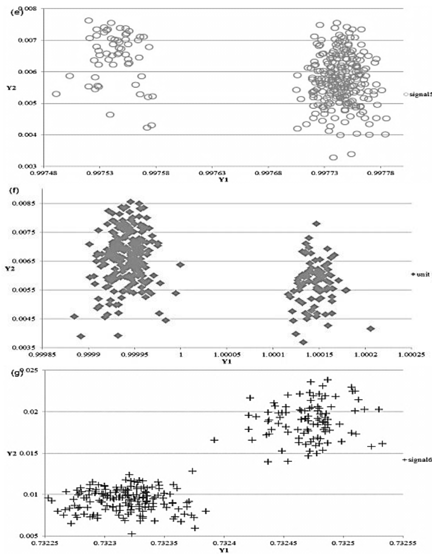


Fig. 1. Scatter diagram of (a) Cat; (b) Det; (c) Haz; (d) Man; (e) Mer; (f) Mtu and (g) Per engine model.

Cat is one of the engine models used during this pattern recognition analysis. However, this model is categorized as a signal data. By referring to Fig. 1 (a), since the numbers of sample remanufactured and rejected of the main journal diameters are approximately equal, the distribution of samples in the scatter diagram is also quite even. Based on the center point of samples distribution located at coordinate (1.53860, 0.0144), the classification on the right side belongs to the remanufactured group whereas the left side belongs to the rejected group. However, it was found that for each sample, it was either exclusively remanufactured or rejected. There is no mixture of remanufactured and rejected samples. Consequently, the threshold of MD for a Cat engine model with 286 samples is between 19724933.3 and 19792715, with an average 19762647.7, located quite far from the unit space.

The second engine model subject to this pattern recognition analysis is Det. However, this model is also categorized as a signal data. According to Fig. 1 (b), since the number of main journal diameters remanufactured are greater than that rejected, the distribution of samples in the scatter diagram is more dense on the right side. Using as reference the center point of samples at coordinate (1.09902, 0.0148), the classification on the right side belongs to the remanufactured group whereas the left side belongs to the rejected group. In general, the points located above the center point are made up of a mixture of both rejected and remanufactured samples. Consequently, the threshold of MD for a Det engine model with 257 samples is between 664798.57 and 679691.98, with an average of 671657.7, which is located quite far from the unit space.

The Haz engine model also known as signal data number 3 has 280 samples during pattern recognition analysis due to the lower number of samples compared to the Mtu engine model. Referring to Fig. 1 (c), as the number of rejects of the main journal diameters are greater than that remanufactured, the distribution of samples in the scatter diagram is denser on the left side. Based on the center point of samples at coordinate

(0.69228, 0.0062), the classification on the right side belongs to the remanufactured group whereas the left side belongs to the rejected group. In that classification, both the remanufactured and rejected groups are not mixed in their samples. However, those located above the center point actually consist of a mixture of rejected and remanufactured samples, a mixed group. Consequently, the threshold of MD for the Haz engine model is between 6430535 and 6452890.2, with the average 6443665 located quite far from the unit space.

The Man engine model is also categorized as a signal data with 285 samples during T method-3 analysis. This method of pattern recognition is capable of discriminating between the normal and abnormal observations. According to Fig. 1 (d), the distribution of samples in the scatter diagram is quite even because the numbers of remanufactured and rejected main journal diameters are approximately equal. In general, the center point of the samples is at coordinate (1.00048, 0.0089), the classification on the right side belongs to the remanufactured group whereas above the center point the samples are actually mixed with rejected and remanufactured ones. Consequently, the threshold of MD for the Man engine model with 285 samples is between 13.883824 and 92.702696, with an average of 32.60958, which is located quite far from the unit space.

With 302 samples, the Mer is one of the engine models involved in pattern recognition analysis. However, this model is categorized as a signal data due to its lower frequency. By referring to Fig. 1 (e), the distribution of samples in the scatter diagram is more dense on the right side because the number of remanufactured samples of the main journal diameters is greater than that rejected. Based on the coordinate (0.9977, 0.0059) as a center point of samples, the classification on the right side belongs to the remanufactured group whereas the left side belongs to the rejected group. However, it was found that for each group, the samples were exclusively either remanufactured or rejected. Consequently, the threshold of MD for the Mer engine model with 302 samples is between 329.29531 and 443.59316, with an average 365.0065, which is quite far from the unit space.

Fortunately, the Mtu engine model has been selected as a unit space because it has the highest data frequency amongst the others with 312 samples. According to Fig. 1 (f), two distinct groups have been produced. From the center point of samples which is at coordinate (1, 0.0064), the classification on the right side belongs to the remanufactured group whereas the left side belongs to the rejected group. However, whether remanufactured or rejected, the groups have no mixture in their samples. The number of rejected main journal diameters are greater than that remanufactured, thus the distribution of samples in the scatter diagram is more dense on the left side. Consequently, the threshold of MD for the Mtu engine model with 312 samples is between 0.099845 and 6.147076 with an average 1.0 as the unit space.

The Per engine model, also known as signal number six is one of the engine models during this pattern recognition analysis. Referring to Fig. 1 (g), since the number of remanufactured and rejected samples of the main journal diameters are approximately equal, the distribution of samples in the scatter diagram is also quite uniform. Based on the midpoint of samples which is at coordinate (0.732374, 0.0128), the classification on the left side belongs exclusively to the rejected group whereas the classification higher than the midpoint is actually mixed with rejected and remanufactured samples. Consequently, the threshold of MD for the Per model engine with 274 samples is between 4844736.6 and 4877296.8 with an average 4864532, which is located quite far from the unit space.

3.2. Scatter diagram combination

By isolating each engine models in a scatter diagram as in the previous analysis, a distinctive pattern on the whole situation cannot not be seen. Therefore, in Fig. 2 the normal and abnormal figures of all engine models have been integrated in a scatter diagram.

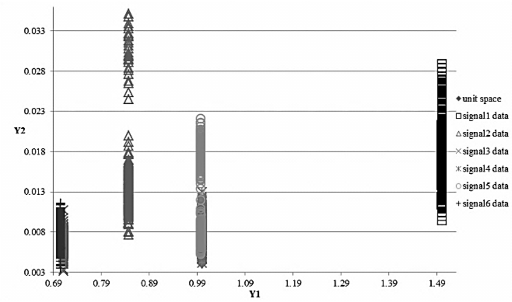


Fig. 2. Integration of the main journal of 7 engine models.

Based on rough assumptions it can be seen that data signal 1 is the most distant from the unit space. This is followed by data signals 3, 6 and 2. There is also considerable overlap between the order of the data signals 4 and 5 from the unit space. Both tolerances are closer in relation to the unit space compared to others showing similarity of patterns.

This observation is backed by the threshold MD values for each engine model, which can be identified in ascending order in terms of proximity to the respective engine model space unit beginning with signal data 4, 5, 2, 6, 3 and finally 1.

4. Conclusion

T method-3 has produced the MD for each numbers of samples belong to 7 engine models to be used in a scatter diagram on the basis of historical data to ensure that information are made available to the industry to make decisions to either remanufacture or reject based on the diagram.

Generally, based on the observation of the results of the analysis on scatter diagrams, the midpoint of the sample is a key determinant to predict the location of a sample point in a scatter diagram. Samples lying to the right and below of the midpoint can be remanufactured. Those lying to the left and below of the midpoint can be rejected. Finally, points above the midpoint contain a mixture of remanufactured and rejected samples. In conclusion, if a sample contains a tolerance in excess of or less than the rate or both, this research is able to accurately predict the location on a scatter diagram.

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