Application of Mahalanobis-Taguchi System on Electrical & Electronic Industry

N.N. Nik Mohd Kamil¹, M.Y. Abu ¹, N.F. Zamrud ¹, F.L. Mohd Safeiee¹, Muchamad Oktaviandri ¹,²
¹Faculty of Manufacturing and Mechatronic Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia. Tel. +609-5492688/+6095492689, Email: nknurharyantie@gmail.com, myazid@ump.edu.my
²Fakultas Teknologi Industri, Universitas Bung Hatta, Padang, 25143, Indonesia, Tel. 6016-9524608, Email: oktaviandri@ump.edu

Abstract. Most of Malaysia’s activities in Electrical & Electronic (E&E) Industry more focused in manufacturing industry. The E&E Industry is one of Malaysia’s leading industries that has 24.5 percent in manufacturing sector production. With a rapid expansion of E&E Industry with a continuous innovation, there is no methodological that show the optimization procedure for a process that concern on E&E product in production area. The aim of this work is to develop the optimization parameter for a process of E&E product based on Mahalanobis-Taguchi System (MTS). In methodology, the optimization parameter will develop by using four stages which are construction Mahalanobis Space (MS), validation of Mahalanobis Space (MS), identify the useful characteristic, and predict and future diagnosis. The production in the industry can reduce the rejected product in parameter in a process. Consequently, significant parameters can be identified for E&E product.

1. Introduction
The increasing demand of E&E product caused of many rejected products in production. MTS method is used to optimize the critical parameter. By having this method, the significant parameter can be identified to reduce the rejected E&E product.

According to [1], the strong and rapid growth of industry is depending on country’s export in term of economy by the expansion of manufacturing sector. The E&E Industry is a key driver in development industrial in Malaysia and contributes to Growth Domestic Product (GDP) growth, investments, exports, and employment. Malaysia is a key player in a fast expanding of E&E market. The major countries where Malaysia export their E&E product are China, US, Hong Kong, Japan, and Singapore. The industry can be divided into four sub-sectors which are industrial electronics, electrical products, electronic components, and consumer electronic.

As mention by [2], MTS is a method to predict and diagnosis the system performance that use the multivariate data to make a quantitative decision with construction whose proposed by Genichi Taguchi. In multivariate system, decision making can be analyze when the information providing one or more variable. However, the system is incomplete when evaluation of variables is not related to each other. In a rapid growth technology, MTS is received a wide acceptance in the production environment.

Subsequently, the advantages of the MTS are in insensitive to variations in multidimensional systems, can handle many different types of datasets, effectively consolidating the data into a useful metric, and implementation of MTS requires limited knowledge of statistics [3,4].
[5] stated that MTS can be divided into nine application area which are manufacturing, agriculture, information technology, healthcare, automotive, finance, and others. Figure 1 shows the illustration of pie chart that show the percentage of distribution of nine categories. Based on pie chart, the information of percentage can be stated as the highest percentage that applied MTS in area of manufacturing, 32% followed in area automotive, 18%, information technology and others area sharing same percentage, 14%, healthcare, 11%, academic, 8%, agriculture, 3% while finance area is 0%. Based on the distribution of application, it is clearly stated E&E industry is not found based on 40 papers.

![Figure 1: Pie chart of distribution of MTS](image)

A concept of Mahalanobis Distance (MD) was established by a famous statistician, P.C Mahalanobis at India. This concept is used to calculate in calculation of two unknowns is similar with spatial orientation which far apart located [6]. The data sets can be divided into healthy data sets and unhealthy data sets. Consequently, the healthy data sets use to calculate and scale of MD. The scaling of the MD can be analysed by dividing the number of features used in MD calculations, so the average length for the scaled MD is approximately close to the one while scaled MD for unhealthy data sets suppose larger than one. The important feature is good when MTS is starts approach with a large number of features in each multivariable data set. So, the important features have large scaled MD of unhealthy data.

[19,20] applied MTS to the big-end diameter of connecting rod to distinguish between two distinct ranges within the re-manufacturability process spectrum. Then, [21] provided a systematic pattern recognition using MTS by constructing a scatter diagram which could support decision making of particular industry. By using different samples, [22] classified crankshafts’ end life into recovery operations. [23] developed a distinctive pattern of crankshaft and identify the critical and non-critical parameter of crankshaft using MTS, then applied the Activity Based Costing as a method of estimation for the remanufacturing cost of crankshaft. Similarly, [24] identified the critical and non-critical variables during remanufacturing process using MTS and simultaneously estimate the cost using Activity Based Costing method. [25] evaluated 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.

2. Methodology

In this section, a detail methodology is presented. This the methodology of MTS was discussed detail to implement of magnetic components in production line.

2.1. MTS
In this section, MTS consider 40 papers which published from 2011-2018 to analyze based on types of different journals publications. Table 1 shows classification of MTS papers based on journals publications.

According to [8], stage 1 which is MS construction develop from the feature data from healthy products are collected to form the normal data set. MDs that constitute reference space is known as MS. The value of MDs is around one. The normal data is donated as $P$, $p_{ij}$ can be defined as the $i$th observation on $j$th feature, where $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$. $P_j$ and $S_j$ can be defined as mean and standard deviation, respectively, of the $j$th feature ($P_j$), where $j = 1, 2, \ldots, n$. Then, each individual feature in each data vector ($P_j$) is normalized by the mean ($P_j$) and the standard deviation $S_j$. Equation 1 shows the calculation of normalized value.

$$z_{ij} = \frac{p_{ij} - \bar{P}_j}{S_j}, \quad i = 1, 2, \ldots, m \quad j = 1, 2, \ldots, n$$

$$\bar{P}_j = \frac{1}{m} \sum_{i=1}^{m} p_{ij}$$

$$S_j = \sqrt{\frac{\sum_{i=1}^{m} (p_{ij} - \bar{P}_j)^2}{m - 1}}$$

Equation 2 shows the calculation of MDs of normal data set.

$$MD_i = \frac{1}{n} z_i C^{-1} z_i^T$$

where $z_i = [z_{i1}, z_{i2}, \ldots, z_{in}]$, $z_i^T$ can be defined as transpose vector of $z_i$, and $C^{-1}$ is the inverse of the covariance coefficient matrix $C$. Equation 3.5 shows the calculation of $C$.

Stage 2, validation by observation of abnormal item are selected first. Their feature data sets are normalized using the mean and standard deviation of the normal data set. Then, the MDs are calculated using the normalized feature data and the covariance coefficient matrix of the normal data set. Then, the MD corresponding to the abnormal condition will be considered as out of MS. In other words, these abnormal condition associated MDs will have higher values.

For stage 3, the useful features will be selected out using orthogonal arrays (OAs) and signal -to-noise ratios (S/N ratios). OAs is used to identify the important features by minimizing the different combination of original set of features. The number of columns in OAs in depend on the number of features. There are two levels factors in OAs which are level 1 and level 2. Level 1 can be described as used which means including the feature in the calculation while level 2 can be described as unused which means excluding the feature in the calculation. The S/N ratios calculated only using the abnormal condition.

For stage 4, MS reconstructed and the MDs of monitored product are calculated by using the useful features that identified in stage 3. If the value of MDs is within the MS, the monitor product will consider the normal product while the value of MDs is out of MS, the product will consider exhibit abnormal behaviors. In a conclusion, the higher the MDs are, the more deviation between the monitored product and the normal one is. Figure 2 shows the flowchart methodology of MTS.
3. Results and Discussion
In this section, this section discuss the magnetic components have 14 parameters that consider in a visual mechanical inspection workstation.

3.1. Normal group data
These parameters can be classified based on numeric data and categoric data. Numeric data can be defined as the parameters of magnetic components that can be measured, counted while the categoric data can be defined as the parameters that cannot be measured or counted but the data can be taken by observation of condition of magnetic components. Table 1 shows the limits parameters for numeric data that consist of seven parameters which are number of scratches, height of insulator wire, number of epoxies at header corner, number of epoxy spot on winding coil, distance of winding gap, number of crack core, and height of excess plastic header. The limits of parameters for categoric data is illustrated in Table 2. There are seven parameters of categoric data which are condition of stripping, no epoxy at the core, yellowish marking, solder ball, orientation of header, high tinning level, and low tinning level at production E&E industry. The limits of numeric data are provided at the production while the limits of categoric data can be defined 0 because the normal data MD is closer to 1 while the abnormal condition is defined as 1 because MD for abnormal condition is larger than 1.
Table 1: Limits of parameters for numeric data

| Parameter                        | Lower limit (normal) | Upper limit (abnormal) |
|----------------------------------|----------------------|------------------------|
| Number of scratches              | 0-3                  | >3                     |
| Height of insulator wire         | <1.30                | >1.30                  |
| Number of epoxies at header corner| 4                    | 1-3                    |
| Number of epoxy spot on winding coil| 0-2                 | >2                     |
| Distance of winding gap          | <3                   | >3                     |
| Number of crack core             | 0                    | 1                      |
| Height of excess plastic header  | <1.30                | >1.3                   |

Table 2: Limits of parameters for categoric data

| Parameter                        | Lower limit (normal) | Upper limit (abnormal) |
|----------------------------------|----------------------|------------------------|
| Condition of stripping           | 0                    | 1                      |
| No of epoxy at the core          | 0                    | 1                      |
| Yellowish marking                | 0                    | 1                      |
| Solder ball                      | 0                    | 1                      |
| Orientation of header            | 0                    | 1                      |
| High tinning level               | 0                    | 1                      |
| Low tinning level                | 0                    | 1                      |

The 300 pieces of samples data were taken randomly for 14 parameters from production line at E&E industry. Within these pieces of samples data, 250 samples were normal samples while 50 samples were abnormal samples of magnetic components at workstation visual mechanical inspection.

The 250 normal samples of 14 parameters were used as a basis to construct MS that contain mean, standard deviation, and correlation coefficient inverse matrix of the data group. In this work, Figure 3 shows the scatter diagram of MD value for normal data. The threshold of normal MD value is (0.307746, 2.332292) for all parameters. The MD value must be generated in six decimal places because only smaller difference MD among all samples. If the MD results were generated in five decimal places, the scatter diagram of normal group will not illustrate properly. Sample number 139 shows the lower normal MD group while sample number 250 shows the highest normal MD group.

Figure 3: Scatter diagram of normal group MD
3.2. Abnormal group data
Figure 4 illustrates the scatter diagram of abnormal data for all parameters. In this work, the 50 samples abnormal group were identified from 300 samples of 14 parameters. The threshold of abnormal MD is (15.30015, 6826578). Sample number 1 shows the highest abnormal MD group.

3.3. Combination of normal and abnormal
Figure 5 illustrates the scatter diagram of normal data and abnormal data for all parameters. In this work, the scatter diagram of normal group and abnormal illustrate separately because the MD value of abnormal group is larger than MD normal group. The sample number 1 shows the lowest MD value of normal group because the raw data collected for 14 parameters within normal limit while sample number 250 shows the largest abnormal MD value because the raw data collected for 14 parameters show the largest limit of abnormal limit.

3.4. Optimization
Optimization is a stage that screening the useful variables of data. In this work, only 4 major critical variable contributions were considered from 14 parameter of workstation visual mechanical inspection of magnetic component in production line of E&E industry.
Table 3: Critical Variables Contribution

| Sample No | Distance | Number of scratches | Height of insulator wire | Number of epoxy spot on winding coil | Distance of winding gap |
|-----------|----------|---------------------|--------------------------|-------------------------------------|------------------------|
| 1         | 16       | 5                   | 3                        | 7                                   | 2                      |
| 2         | 16       | 5                   | 3                        | 8                                   | 1                      |
| 3         | 24       | 14                  | 0                        | 8                                   | 1                      |
| 23        | 27       | 0                   | 16                       | 5                                   | 5                      |
| 24        | 28       | 0                   | 16                       | 8                                   | 2                      |
| 17        | 29       | 19                  | 2                        | 1                                   | 9                      |
| 25        | 29       | 0                   | 16                       | 9                                   | 1                      |
| 15        | 31       | 11                  | 4                        | 12                                  | 5                      |
| 18        | 31       | 15                  | 0                        | 2                                   | 15                     |
| 4         | 32       | 11                  | 4                        | 13                                  | 3                      |
| 16        | 32       | 16                  | 0                        | 2                                   | 13                     |
| 37        | 32       | 18                  | 0                        | 3                                   | 11                     |
| 39        | 33       | 6                   | 9                        | 11                                  | 7                      |
| 19        | 34       | 10                  | 4                        | 4                                   | 17                     |
| 20        | 34       | 9                   | 4                        | 3                                   | 18                     |
| 38        | 34       | 11                  | 3                        | 5                                   | 16                     |
| 9         | 35       | 4                   | 13                       | 3                                   | 16                     |
| 27        | 36       | 0                   | 24                       | 9                                   | 1                      |
| 26        | 37       | 0                   | 24                       | 9                                   | 1                      |
| 40        | 37       | 4                   | 14                       | 13                                  | 5                      |
| 28        | 38       | 3                   | 16                       | 15                                  | 2                      |
| 7         | 39       | 8                   | 1                        | 1                                   | 30                     |
| 8         | 39       | 5                   | 19                       | 1                                   | 13                     |
| 31        | 39       | 8                   | 1                        | 1                                   | 30                     |
| 34        | 39       | 7                   | 1                        | 1                                   | 30                     |
| 6         | 40       | 23                  | 1                        | 12                                  | 4                      |
| 21        | 40       | 2                   | 20                       | 11                                  | 7                      |
| 29        | 40       | 16                  | 4                        | 16                                  | 2                      |
| 22        | 41       | 2                   | 19                       | 14                                  | 5                      |
| 36        | 41       | 2                   | 17                       | 6                                   | 15                     |
| 30        | 42       | 3                   | 7                        | 0                                   | 30                     |
| 33        | 42       | 3                   | 7                        | 0                                   | 31                     |
| 43        | 42       | 19                  | 3                        | 15                                  | 5                      |
| 35        | 45       | 1                   | 23                       | 7                                   | 13                     |
| 32        | 46       | 1                   | 16                       | 1                                   | 26                     |
| 41        | 50       | 12                  | 11                       | 20                                  | 5                      |
| 44        | 50       | 11                  | 12                       | 19                                  | 6                      |
| 5         | 53       | 32                  | 1                        | 15                                  | 5                      |
| 14        | 53       | 1                   | 10                       | 3                                   | 35                     |
| 11        | 54       | 12                  | 26                       | 2                                   | 10                     |
| 42        | 54       | 8                   | 17                       | 21                                  | 6                      |
| 48        | 54       | 20                  | 3                        | 3                                   | 12                     |
| 13        | 57       | 2                   | 20                       | 1                                   | 30                     |
The major critical variable is the number of scratches, height of insulator wire, number of epoxy spot on winding coil, and distance of winding gap. 16.0 is the lowest distance for sample number 1 because the gap of distance among each parameter is small while 69.0 is the highest distance for sample number 45 because the gap of distance among each parameter is large. The critical parameter for sample number 1 is the number of epoxy spot on winding coil and the distance is 7.0. The distance is highest because the operator had to put the epoxy manually. So, if the operator does not concentrate while doing their job, the largest number of epoxy spot will produce on the coil. The critical parameter for sample number 45 is the distance of winding gap and the distance is 51.0. This is because a setting of winding coil machine is frequently must be repaired by technician.

3.5. Parameter Adjustment

Table 4 is referring adjustment parameters of 4 major critical parameters. This result indicates the stage of diagnosis and prognosis of major parameters. The impact of in control means that the raw data is normal. The impact of above +3, the limit of raw data of number of scratches, number of epoxy spot on winding, and height insulator must be increase until the raw data reach in control while the impact of below -3, the limit of raw data of distance winding gap must be decrease.

Table 4: Adjustment parameter

| Impact     | Number of scratches | Height of insulator wire | Number of epoxy spot on winding coil | Distance of winding gap |
|------------|---------------------|--------------------------|--------------------------------------|-------------------------|
| In control |                     |                          |                                      |                         |
| Above +3   | 31                  | 31                       | 9                                    | 6                       |
| Below -3   |                     |                          | 18                                   | 31                      |
| Total      | 31                  | 31                       | 27                                   | 37                      |

As mention by [9], the normal data can be identified when the MD value is closer to 1. The closer MD value, the better value of normal data.

The results of abnormal MD values show larger than 1. According [10], the MD value for abnormal data must be larger than normal group. This validates of measurement scale.

As mention by [11], the aim of this step is to identify the optimum number of variables required for the measurement scale.

4. Conclusions

In this study, MTS is used to identify the critical parameters for a workstation visual mechanical inspection on production line. The major critical parameters must be more focus to reduce the rejected product at this workstation. In this work, the insignificant of parameters to reduce which are number of scratches, height of insulator, number of epoxy on winding coil, and distance of winding gap. The significant of parameters are condition of stripping, number of epoxies at header corner, the number of crack core, height of excess plastic header, number of crack core, no epoxy at the core, yellowish marking, solder ball, orientation of header, high tinning level, and low tinning level.
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