MAHALANOBIS-TAGUCHI SYSTEM AND TIME-DRIVEN ACTIVITY-BASED COSTING INTEGRATION OF PRINTED CIRCUIT BOARD

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ABSTRACT

System integration involves creating or implementing a customized architecture, as well as integrating hardware, packaged and customized software, and communications. The electronic component demand is rising nowadays. However, a weekly rejection report for rejected parts is necessary in reflect the severity level as it can influence the criteria used to identify relevant parameters. Meanwhile, activity-based costing (ABC) is outdated since it employs interviews or surveys to get numerical data, which can lead to erroneous corporate data. This research aim is to integrate Mahalanobis-Taguchi system (MTS) with time-driven activity-based costing (TDABC) at the electronic component workstation. MTS optimizes 22 printed circuit board (PCB) assembly top side workstation environments. After generating time equation and capacity cost rate, TDABC considers critical elements to identify underutilized capacity. As a result, October and December have the most significant parameters (16) and August the fewest (10). Next, the TDABC confirmed that the PCB input into auto loader machine sub-activity has a large unused capacity of time (239,550 minutes) and cost (MYR18,120.67), which allows this workstation to minimize unused capacity by shifting employees to another load workstation. In spite of to minimize capacity utilization in sub-activity solder paste preparation, extra labor should be given since it has an overutilized capacity of time (-790,100 minutes) and cost (MYR-1,000,535.13). Lastly, the reduction of waste and better forecasting is obtained after MTS and TDABC integration is implemented.

Keywords: *MTS, TDABC, Integration, Classification, Optimization.*

1. INTRODUCTION

There are a lot of contributing elements responsible for the enormous volume of electrical and electronic (E&E) goods that are manufactured. The total number of people who are employed in the manufacturing of the E&E components is one of the aspects that has a significant impact on output [1]. Since 2001, the electronic industry in China has seen rapid expansion, with growth rates in the double digits up to the onset of the global economic crisis in late 2008. However, as a result of the stimulus package that was implemented by the Chinese government in 2009, recovery was helped,

and beginning in the latter part of that year, the industry started to slowly revive. China imports electronic products from a diverse variety of nations, including Taiwan, South Korea, Japan, Malaysia, the United States, Thailand, the Philippines, Singapore, and Germany [2].

Several big electronics firms are now operating in Malaysia. The industry contributed 18% of the nation's gross domestic product (DGP) and 22% of exports in 2012. In terms of the proportion of all goods in the E&E sectors in which it revealed comparative advantage (RCA), Malaysia is now ranked fourth among the 14 countries that comprise up the product [3]. In a factory, a sequence of machines known as a production line are used to transport items from one machine to the next until the process is complete. Surface Mount Technology (SMT) is commonly used in PCB construction. Typical SMT manufacturing lines comprise a PCB loader, solder paste machine, SMT machines, and reflow oven [4]. Production lines include job-based planning, batch, flow, mass, and process manufaturing [5].

The classification issue, which uses a training dataset to predict the labels of unknown occurenses, .is a common machine learning research topic. Classification is an optimisation problem that needs better methods [6]. Tasmanian Archieves Heritage Office [7] defines several classification tools which are business classification as an organization's business activity, thesaurus as a semantic set of terms, and record classification scheme as a hierarchical categorization approach. Meanwhile, the optimisation approach determines the desired function's maximum or minimum value under limitations. Both the scientific and technical communities make frequent use of optimisation techniques [6]. The optimisation tools are the deterministic optimisation that employs linear algebra and the stochastic optimisation uses randomization-based search methods, which can be merged [8].

Multivariate data is diagnosed and predicted using the Mahalanobis-Taguchi system (MTS). MTS uses Mahalanobis (MD) and Taguchi scale-based predictions to determine the degree of contribution [9]. MTS uses MD to construct multi-dimensional measurement scales for classification and Taguchi scale-based predictions to identify critical characteristics using ortogonal arrays (OA) and signal-to-noise ratio (SNR) [10]. MTS is a cost-effective multidimensional pattern identication

method. Pattern recognition involves seeing, distinguishing, and intelligently classifying patterns [9]. Traditional MTS minimises multidimensional system dimenstionally and measures anomalous observation [11].

Cost accounting measures and provides financial and other resource acquisition and usage data for financial and management accounting. Cost accounting provides quantitative data for planning, controlling, and making economic decisions [12]. Continuous and systematic cost data gathering is needed for cost accounting [13]. Life cycle analysis (LCA) and life cycle costing (LCC) are used in building a design. LCC optimises cost, whereas LCA conserves the environment [14]. LCA evaluates the sociocultural environmental impact of different product systems that accomplish the same end-user function. LCC assesses business and investment options from manufactures and consumers [15].

One method developed for resolving limitations with activity-based costing (ABC) is called time-driven activity-based costing (TDABC) [16]. TDABC calculates costs by translating cost drivers into time equations that show how much time an activity requires [17]. The use of time is incorporated into this method for estimating management resource unit hours and capacity. TDABC method is not only easier and more cost-effective, but also significantly more effective [16]. TDABC is a methodology for handling daily complications and variations. This is since service firms may allocate resources by labour hours. TDABC provides a great opportunity to create and demonstrate complex cost model [18].

2. LITERATURE REVIEW

2.1 Mahalanobis-Taguchi Systems
MTS is broadly acknowledged after nearly two decades of development. It has a wide range of applications, some of which include product quality diagnostics, diagnostics of mechanical damage, diagnostics in the medical field, early warning in the financial sector, college admissions, site selection for projects, development of strategies, and quality evaluations. It is evaluating, assessing, and producing outcomes for a variety of characteristics and other factors [19].

In order to categorize data, MTS constructs and optimizes diagnostic systems using measurement scales. The MTS was established by Taguchi and Jugulum through the establishment of

a reference group (MS). In this method, the normal group and the abnormal group make up the two categories, and MS may be utilized to differentiate between the two groups [20].

In multivariate statistics, the MD is primarily utilized to identify outliers. PC Mahalanobis, an Indian statistician, developed a statistical measure known as the Mahalanobis distance (MD) that takes into account the contribution of a number of different variables to the value of the distance depending on the variability of each variable. In contrast to the Euclidean distance, the MD takes into account the degree to which two variables are correlated with one another. The Euclidean distance and the MD distance of points on circles and ellipses that are about one unit and two unis apart from the centre of the data are compared in Figure 1. The MD modification for data correlation is the cause of the difference that appears to have been introduced [21].
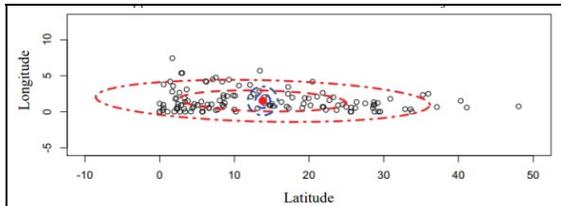

Figure 1: Mahalanobis (ellipse) and Euclidean (circle) Schematic Distances Comparison

Furthermore, MTS has the ability to be used as a binary classification method for uneven data. Support Vector Machine (SVM) and Naïve Bayes are two other algorithms whose efficacy has been compared to this approach. It has been determined to have exceptional performance, particularly when dealing with data sets that are extremely ratio unbalanced [22].

Importantly, MTS is able to quickly identify abnormalities without having rely in any preconceived concepts of statistics [19]. Any sample that falls outside of the threshold or range established for a parameter is considered to be abnormal. Despite this, it is not always possible for MTS to carry out feature selection making use of OA and SNR to evaluate the contribution of each feature when dealing with high-dimensional data [19]. Due to the fact that high dimensional data often contains a large number of features, which causes the data points to become sparser in the feature space. So, this will make it more difficult to decide which parameters are relevant.

2.2 Time-Driven Activity-Based Costing

The TDABC method is an extension of the ABC technique that takes into account the development of time. During the design phase, the TDABC technique was utilized to explore how the collective worker participation and leadership style effect the creation of operational improvements [17]. TDABC was proposed as an improvement over ABC due to the fact that it makes accurate cost analysis faster and simpler to update. This is accomplished via the use of estimations of two factors, namely the unit cost of resource inputs as well as the amount of time and resources that are required to carry out a transaction or activity [23].

TDABC is a method for estimating costs that simply makes use of two elements, which are the amount of time needed by staff personnel to carry out a process or activity as well as the cost per minute for that employee. TDABC consolidated the many different processes and people engaged in order to provide clarification for the amount of time and money spent on operational procedures. TDABC estimate necessitates the creation of process maps for the care cycle, the determination of the amount of time spent on each of the numerous separate processes, and an understanding of the salaries of the people that were involved in the process [24].

The primary motivation behind developing TDABC was the need to cut down in management efforts, both in terms of time and money. TDABC is a great platform on which to evaluate and demonstrate a model of expense for elaborate activities. According to TDABC, there are no need for reduces like there were in ABC, and cost planners can use the different time drivers to show each part of an action in the time equations [18].

Using TDABC, it could be possible to address the problems with the original approach that arise during implementation. It employs the time equation to automatically attribute resource usage to the cost object, taking into account variations across business classes [25]. TDABC has found applications in a wide variety of fields, such as the industrial sector, healthcare providers, and even libraries [26]. The TDABC process has been divided down into its various elements and illustrated in Figure 2.
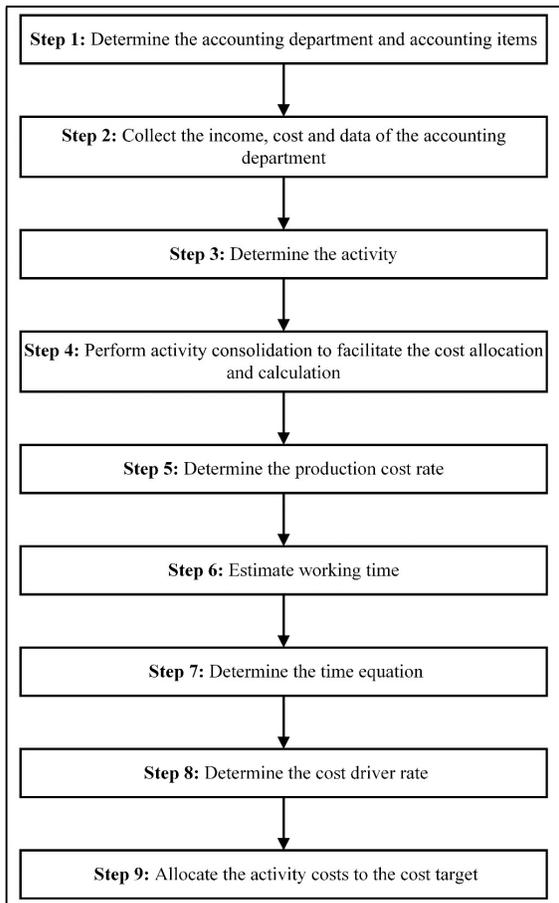
Figure 2: TDABC Concept

TDABC is able to identify potential areas for improving the precision of cost data [27]. Through a more precise analysis of cost drivers and activities, it is possible to zero in on the individual activities that need to be optimized for the process and reduced in cost. This will result in an improvement in the accuracy of the cost data. However, some companies may struggle with TDABC because of the necessity to estimate how long it takes to complete each job in a care cycle [28]. This is due the fact that the precision of time estimations is directly related to the accuracy of cost allocation, making it vitally important.

3. METHODOLOGY

3.1 Data Collection

The gross domestic product (GDP) of Malaysia is increased by 36.8% thanks to the nation's manufacturing sector. The outstanding outcome was driven by a rise of 4.1% in the manufacturing industry in December 2021, most notably a growth of 7.6% in the manufacturing product associated with electrical and electronic goods [29]. The company under discussion is a company based in

Pasir Gudang, Johor, that provides to the needs of the international electronic market by producing electronic components.

The is an established supplier of electronic components for thermal printers on a global scale, and there is a significant demand from customers for PCB assembly. In most cases, the thermal printer is utilized for the purpose of printing commercially accessible tags and labels produced by a variety of different vendors [30].

Figure 3 illustrates the process that is used in the manufacturing of thermal printer and has a total of 50 workstations accessible. On the other hand, for this research, the green color shows that there are 8 different workstations that are utilized for the top side processes.
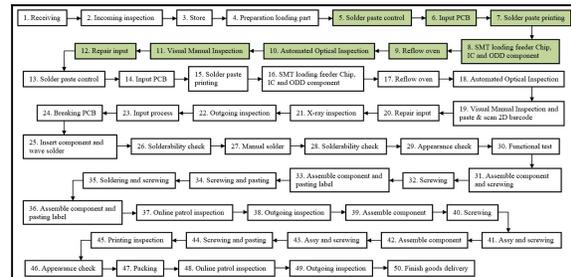
Figure 3: Thermal Printer Workstations

In compliance with the specifications, each workstation performs an inspection and test on the PCB as well as the electronic component. As shown in Table 1, the MTS implementation places an emphasis on the top side process parameters listed in a total 22 different parameters. The parameters may be categorized into two separate categories, namely qualitative and quantitative data. The qualitative data demonstrate that the observations can be computed, whilst the quantitative data demonstrate that it can be analyses.

Table 1: Top Side Process of Parameters

No.	Parameters	Unit	Normal Range
1.	Refrigerator temperature	Celsius (°C)	$0-10$
2.	Refrigerator humidity	Percentage (%)	$0-60$
3.	Room temperature	Celsius (°C)	$20-28$
4.	Room humidity	Percentage (%)	$0-60$
5.	Input PCB visual check	NA	- No scratch - No crack - No dust - No foreign objects
6.	Solder paste printing	NA	- Correct printing position

			- No excess solder
			- No cold solder
			- Avoid form mix solder
7.	Solder paste verification	NA	- No excess solder
			- No non-wetting solder
			- No smeared printing
8.	Solder paste inspection	NA	- No excess solder
			- Bonding
			- Alignment solder
			- Sufficient solder
9.	Check value and polarity	NA	- Correct material and polarity
			- Correct location part
			- No abnormality part
			- No part missing
10.	SMT program	NA	- Correct polarity
			- Correct value
			- Correct body marking and orientation
11.	Pre-heat temperature	Celsius (°C)	$150 - 190$
12.	Pre-heat time	Second (s)	$60 - 120$
13.	Reflow zone temperature	Celsius (°C)	220
14.	Reflow zone time	Second (s)	$30 - 60$
15.	Maximum peak temperature	Celsius (°C)	$230 - 250$
16.	Check running model	NA	- No wrong component
			- No abnormality
			- No excess solder
17.	AOI result checking	NA	- Correct material
			- Correct part
			- Correct location
18.	Solder fillet condition of 45°	Percentage (%)	≥75%
19.	PCB sampling stamp	NA	- Correct polarity location
			- No wrong component
			- No missing component
			- No dry solder
20.	Solder temperature specification	Celsius (°C)	$340 - 380$
21.	Soldering time	Second (s)	< 3
22.	Repair visual appearance	NA	- Confirm all changes
			- No abnormality
			- Correct polarity
			- No smear solder

3.2 MTS Methodolgy

RT method emphasizes pattern recognition. The RT method techniques divides items into two categories: those that are within the unit space and outside the unit space. RT method works when the true value of a measure output is unknown but its category is apparent and several unit spaces are available. Equation (1) gives the average parameter value in normal group unit space.

$$\bar{x}_j = \frac{1}{n}(x_{1j} + x_{2j} + \cdots + x_{nj}) \quad (j = 1, 2, \ldots, k) \qquad (1)$$

Calculating the sensitivity, β, for initial unit space samples in Equation (2) requires the linear formula, L, and effective divider, r from Equation (3) and Equation (4).

$$\text{Sensitivity} \quad \beta_1 = \frac{L_1}{r} \qquad (2)$$

$$\text{Linear equation} \quad L_1 = \bar{x}_1 x_{11} + \bar{x}_2 x_{12} + \cdots + \bar{x}_k x_{1k} \quad (3)$$

$$\text{Effective divider} \quad r = \bar{x}_1^2 + \bar{x}_2^2 + \cdots + \bar{x}_k^2 \qquad (4)$$

Evaluating Equations (5)–(7) and Equation (8) yields total variation, S_T element variation proportionate to S_β, error variance, S_e, and error variance, V_e, which are then replaced into standard SN ratio, η.

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

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

$$\text{Error variation} \quad S_{e1} = S_{T1} \quad S_{\beta 1} \qquad (f = k - 1) \quad (7)$$

$$\text{Error variance} \quad V_{e1} = \frac{S_{e1}}{k-1} \qquad (8)$$

The standard SN ratio, η, is calculated in Equation (9). A greater η value indicates a stronger correlation between input and output.

$$\text{Standard SN ratio} \quad \eta_1 = \frac{1}{V_{e1}} \qquad (9)$$

Calculate Y_1 and Y_2 produces a scatter diagram. Equation (10) and Equation (11) illustrate Y_1 and Y_2 formulas.

$$Y_{i1} = \beta_i \qquad (i = 1, 2, \ldots, n) \qquad (10)$$

$$Y_{i2} = \frac{1}{\sqrt{\eta_i}} = \sqrt{V_{ei}} \qquad (i = 1, 2, \ldots, n) \qquad (11)$$

Equation (12) and (13) calculate the average for Y_1 and Y_2 and estimate the origin.

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

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

The Mahalanobis distance is calculated using Equation (14) in normal group for the last step.

$$\text{Mahalanobis distance} \quad D^2 = \frac{YA^{-1}Y^T}{k} \qquad (14)$$

The abnormal group is calculated using the same equation as the normal group. However, before to any calculations being performed, the abnormal group need to be normalised. Note that the average values, $\bar{x}$ of samples and parameters in Equation (1) and the effective, r' in Equation (4) are similar to the normal group value.

After RT method identifies normal and abnormal MD, T method establishes significant parameter. This approach provides a uniform unit space with average output. The largest sample will be normal, while the others will be abnormal. Equation (15) and Equation (16) determine the parameter and output average values in normal group unit space.

$$\bar{x}_j = \frac{1}{n}(x_{1j} + x_{2j} + \cdots + x_{nj}) \quad (j = 1, 2, \ldots, k) \qquad (15)$$

$$\bar{y} = M_0 = \frac{1}{n}(y_1 + y_2 + \cdots + y_n) \qquad (16)$$

The reduction of unnecessary information from the data in order to make the information more flexible is the purpose of the abnormal group normalization technique. Normalized input and output data are computed in Equation (17) and Equation (18).

$$X_{ij} = x'_{ij} - \bar{x}_j \quad (i = 1, 2, \ldots, l)\ (j = 1, 2, \ldots, k) \qquad (17)$$

$$M_i = y'_i - M_0 \quad (i = 1, 2, \ldots, l) \qquad (18)$$

Steps in Equations (19)−(25) are used to get the proportional coefficient, β and SN ratio, η for each parameter.

$$\text{Effective divider} \quad r = M_1^2 + M_2^2 + \cdots + M_l^2 \qquad (19)$$

$$\text{Total variation} \quad S_{T1} = X_{11}^2 + X_{21}^2 + \cdots + X_{l1}^2 \quad (f=l) \qquad (20)$$

Variation of Proportional term

$$S_{\beta 1} = \frac{(M_1 X_{11} + M_2 X_{21} + \cdots + M_l X_{11})^2}{r} \qquad (f = 1) \quad (21)$$

$$\text{Error variation} \quad S_{e1} = S_{T1} - S_{\beta 1} \qquad (22)$$

$$\text{Error variance} \quad V_{e1} = \frac{S_{e1}}{l-1} \qquad (23)$$

$$\text{Proportional coefficient} \quad \beta_1 = \frac{M_1 X_{11} + M_2 X_{21} + \cdots + M_l X_{11}}{r} \qquad (24)$$

$$\text{SN ratio} \quad \eta_1 = \begin{cases} \frac{1}{r}(S_{\beta 1} - V_{e1}) & (\text{when } S_{\beta 1} > V_{e1}) \\ \frac{V_{e1}}{0} & (\text{when } S_{\beta 1} \leq V_{e1}) \end{cases} \qquad (25)$$

If β is positive, the slope is increasing to the right, but if it is negative, it is decreasing. Positive η values indicates a substantial connection between input and output, whereas negative values indicate zero.

The integrated estimate value of the abnormal group is calculated using the proportional coefficient, β and SN ratio, η for each parameter. The integrated estimate value is calculated in equation (26). Normalised values for each parameter are expressed as $x_{i1}, x_{i2}, \ldots, x_{ik}$.

$$\hat{M}_{i1} = \frac{\eta_1 \times \frac{x_{i1}}{\beta_1} + \eta_2 \times \frac{x_{i2}}{\beta_2} + \ldots + \eta_k \times \frac{x_{ik}}{\beta_k}}{\eta_1 + \eta_2 + \ldots + \eta_k} \quad (i = 1, 2, \ldots, l) \qquad (26)$$

The estimated SN ratio, η may be calculated using Equation (27)−(33). In point of fact, the basis for the predicted SN ratio, η is established by the appropriateness of the orthogonal array (OA).

$$\text{Linear equation} \quad L = M_1 \hat{M}_1 + M_2 \hat{M}_2 + \cdots + M_l \hat{M}_l \qquad (27)$$

$$\text{Effective divider} \quad r = M_1^2 + M_2^2 + \cdots + M_l^2 \qquad (28)$$

$$\text{Total variation} \quad S_T = \hat{M}_1^2 + \hat{M}_2^2 + \cdots + \hat{M}_l^2 \qquad (29)$$

$$\text{Variation of Proportional term} \quad S_\beta = \frac{L^2}{r} \ (f = 1) \qquad (30)$$

$$\text{Error variation} \quad S_e = S_T - S_\beta \qquad (31)$$

$$\text{Error variance} \quad V_e = \frac{S_e}{l-1} \qquad (32)$$

Integrated Estimate SN Ratio

$$\eta = 10\log\left(\frac{\frac{1}{r}(S_\beta - V_e)}{V_e}\right) (db) \qquad (33)$$

Parameter significance is determined by the decrease in estimated SN ratio, η when it is not utilised. The evaluations use level 1 and level 2 of OA. The predicted SN ratio, η is measured by OA under circumstances. Two-level OA means parameter level 1 is utilised while level 2 is not utilised. The relative significance of parameters is determined by the difference between level 1 and level 2 averages for each parameter in the predicted SN ratio, η. The degree of contribution is positive when using a greater SN ratio, η. Otherwise, the degree of contribution parameter is negative when it is not used.

3.3 TDABC Methodolgy

Identification of product-related activities and sub-activities is the first stage in TDABC. The company divides product production into three activity centres which are product preparation, top side production, and retail packing and delivery. Following that, cost resources were assigned by activity type. There are 50 primary activities represented by workstations at this company, and 69 recognized as secondary activities. By aggregating annual hours worked, actual capacity is evaluated. This company operates Monday through Saturday from 8 a.m. to 6 p.m. Equation (34) calculates capacity cost rate (MYR per minute).

$$\text{Capacity cost rate} = \frac{Cost\ of\ capacity\ supplied}{Practical\ capacity\ of\ resources\ supplied} \quad (34)$$

Further, the TDABC time equation estimation effectively accounts for transaction time needs. TDABC model unit time estimates vary by order and activity. The time-driven technique predicts department resource need with a simple equation (35).

$$Tt = \beta_0 + \beta_i \chi_i \quad (35)$$

where:
Tt = time needed to perform an activity (minute)
β_0 = standard basic activity time (minute)
β_i = estimated incremental activity time (minute)
χ_i = quantity of the incremental activity (time)

In order to compute the estimated duration of time needed for production, a time equation needs to be established. Average material transport time from warehouse to production line is calculated. Create the time equation by multiplying the suitable variables or cost-drivers. The monthly frequency of each activity was used to assess its capacity.

Multiplying the activity amount by the time spent gives the total time spent. The equation (36) gives the total production cost.

$$\text{Total cost of production}$$
$$= \text{cost of direct materials} + \text{cost of direct labour}$$
$$+ \text{cost of manufacturing overheads}$$
$$\quad (36)$$

4. RESULTS AND DISCUSSION

4.1 MTS Discussion

Using the RT method for the top side process, the scatter diagram exhibits normal and abnormal MD data. Both normal and abnormal Y1 and Y2 were used to create the scatter diagram. The x-axis displays Y1 and the y-axis displays Y2. The related patterns are categorized by orange and blue. The graph shows blue dots for normal and orange are for abnormal. The implementation method created using this approach has 22 parameters. For normal data, the scatter diagram utilizes the existing lot size, whereas abnormal data uses AQL samples. Both of this information require input are from the company that is being researched.

Figure 4 shows March normal and abnormal results. The highest classification MD value for normal data is 5.6533, and the lowest classification MD value is 0.0011. However, the MD value for abnormal classification ranges from a low of 0.3863 to a high of 35.9151. The scatter diagram shows that the normal data and the abnormal data overlap one another. There are 10 samples of data that overlapped. During the month of March, the average MD value was 1 for normal group, while the abnormal value was 8.3527.

The correlation coefficient for normal data is -0.0031. This shows a lowest negative connection between Y1 and Y2. On the contrary, Y1 and Y2 have an abnormal correlation value of -0.2261, which also shows that the factors have a weak negative connection.
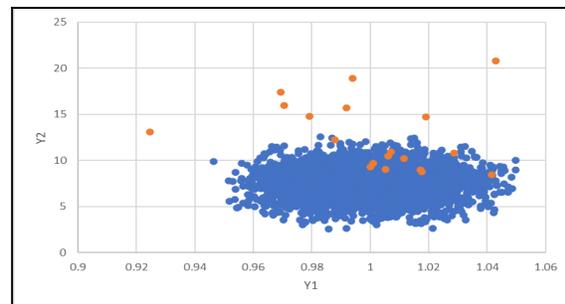

Figure 4: March Scatter Diagram

Figure 5 display June normal and abnormal results. The highest MD classification of normal data is 5.651898 and the lowest is 0.0004. MD values for abnormal categorization vary from a lowest of 0.0557 to a highest of 22.7144. There is overlap between normal and abnormal data in the scatter diagram. In total, there are 9 instances of redundant data. The normal average MD value for June is 1, while the abnormal average is 7.0835.

Therefore, the normal data correlation coefficient is -0.0036. It is clear that Y1 and Y2 are lowest negative connected. The abnormal correlation coefficient of 0.0611 has a positive connection among Y1 and Y2.
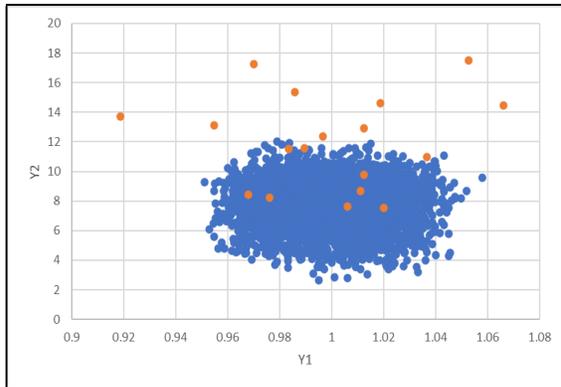

Figure 5: June Scatter Diagram

The normal and abnormal of September data is shown in Figure 6. The highest value for normal data under MD classification is 6.0002, and the lowest value is 0.0002. For abnormal classification, the lowest MD value is 0.3582 and the highest is 365.9161. The normal and abnormal data also have some overlap in the scatter diagram. There are 5 overlapping data samples. The normal group average MD value for the month of September is 1. Meanwhile, 34.3745 is the average of abnormal group.

Following, it is discovered that the correlation value for normal data is -0.0086. This indicates a lowest negative connection between Y1 and Y2. The abnormal correlation coefficient between Y1 and Y2 is -0.7792, indicating moderate negative connection.
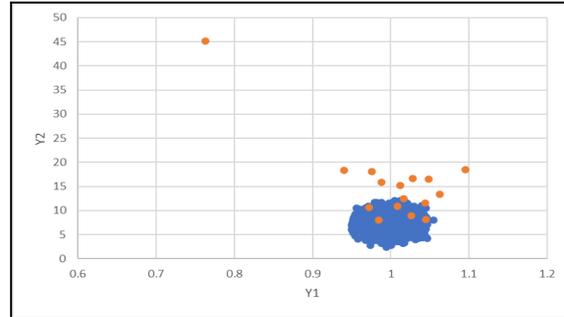
Figure 6: September Scatter Diagram

The top side process has 3500 normal groups, 20 abnormal groups, and 22 parameters. Figure 7 displays the data in an ascending sequence, which correlates to an increasing output value. There was a wide range of MD values, which the lowest being 0.0001 at site 2871 and the highest being 29.8489 at site 15. In the meanwhile, the output value at site 145 is 1.0749, which was the closest of all sites to the average value (1.0754).
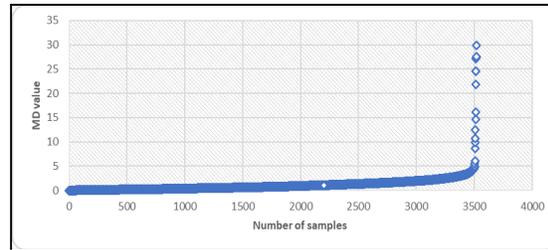
Figure 7: January Distribution Outputs

The signal data is then normalized using the average values from the unit space samples. It is normalized by removing the average of the parameter and unit space outputs. The output values are sorted in increasing order. Unlike statically-based approaches, the T method normalizes without dividing the standard deviation parameter by what remains after eliminating the average values. Unit space standard deviations of zero frequently significant for prediction and estimation.

The proportional coefficient, β and SN ratio, η are used to find the prediction and estimate elements. Figure 8 depicts how parameters influence output values. The horizontal axis contains the output value, while the vertical axis contains the origin.

Figure 8 (a) and (b) is positive β because it is a straight line rising to the right. The plot in (a) shows that the data are well distributed along the regression line, which approaches zero, and that the outlier variance is minimal. Although the regression line plot for (b) is far from zero, the data is evenly

distributed. So, both graphs imply that the η is high and that that the VMI solder fillet condition, as well as the SMT programmed, are ideal for general yield estimate. When the line in (c) tilts to the right, the β becomes negative. The graph also shows that the data are well distributed and have a low variation along the regression line. This implies that the η is high, and the pre-heat zone duration machine is ideal for estimating output values.
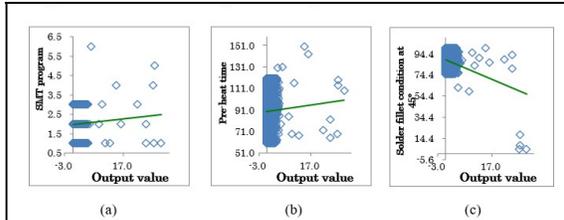
Figure 8: Scatter of Output Values and Parameters

Figure 9 is a scatter diagram that shows what happens when real values are shown on the x-axis and estimated values are expressed on the y-axis. Estimated values that align above a straight line indicate that a reasonable approximation was produced. In general, the model yields 0.2723 R^2 or -12.69 db. It shows that the connection is strong and the distribution is nearing the green line. The line equation is shown in equation (37).

Line equation   y = 1.4012x   (37)
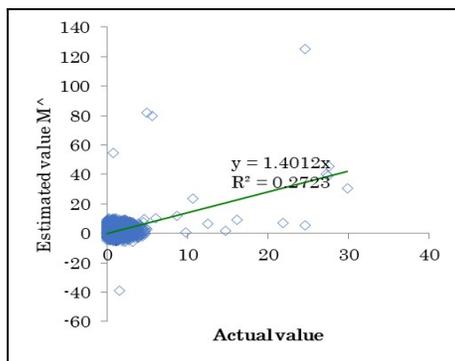
Figure 9: Actual and Estimated Signal Data Distribution

However, only a subset of parameters may be used for integrated estimate, whereas the others cannot be used. As a consequence, the parameters are evaluated using L44 of OA, where level 1 indicates the parameter will be used and level 2 indicates the parameter will not be used. The discovered results, -12.69 db of integrated estimate η was determined from the first run in L44. The degree of contribution was then turned into a bar graph as shown in Figure 10.

A positive degree of contribution increases MD production, whereas a negative reduces MD production. As outcome, parameters 3, 6, 9, 11, 12, 15, and 17, and 7 positive degree of contribution. Meanwhile, parameters 1, 2, 4, 5, 7, 8, 10, 13, 14, 16, 18, 19, 20, 21, and 22, and 15 negative degree of contribution. This study found that in order to attain a lower MD, the positive degree of contribution should be lowered while the negative degree of contribution should be increased.
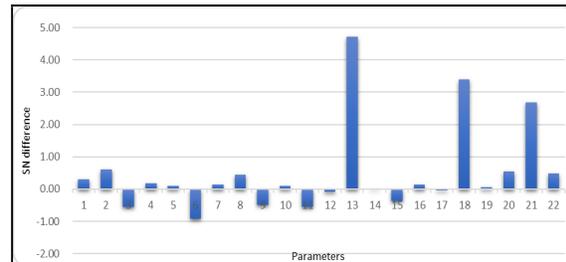
Figure 10: January Degree of Contribution

4.2 TDABC Discussion

The TDABC technique starts with analyzing and identifying the industrial in order to understand its scope and the specific sequence of events that occur. All activities differ, yet it all have a purpose. The top side process has 8 workstations and Figure 11 illustrates the process in details.
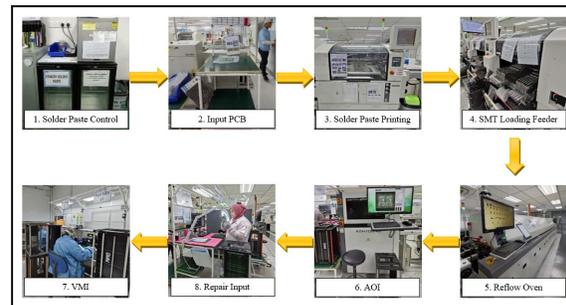
Figure 11: Top Side Workstation Line Production

The capacity cost rate (in MYR/min) is calculated using equation (34). According to the equation, the cost of capacity supplied comprises of labor, material, maintenance, and consumable expenses but actual capacity is determined by the number of workers in each workstation. As the number of operators increases, so will the practical acceptable capacity. Table 2 summarizes the capacity cost rates for each sub-activity for the top side workstation.

Table 2: Sub-Activities Capacity Cost Rate

Main activity	Sub-activities	Cost resources supplied (MYR)	Practical capacity (min/year)	Capacity cost rate (MYR/min)
1. Solder paste control	1. Prepared the solder before running production	155,000	122,400	1.27
	2. Update sticker of solder paste shelf-life control after issued out from refrigerator	9,417.60	122,400	0.08
2. Input PCB	1. Visual check on PCB	18,000	122,400	0.15
	2. Input the PCB into auto loader machine	18,517.80	244,800	0.08
3. Solder paste printing	1. Set up printer for printing on top stencil	9,268	122,400	0.08
	2. Inspect and confirm the solder paste printed on PCB	9,208	244,800	0.04
	3. Verification and inspection the printing condition	9,208	244,800	0.04
	4. Cleaning the stencil	9,227.80	122,400	0.08
4. SMT loading feeder	1. Check value and P/N of material loading on feeder and tray	8,646	122,400	0.07
	2. Scan barcode P/N of machine type and ID operator	6,216.25	122,400	0.05
	3. Confirm the part for each feeder follow by loading list	6,094.80	122,400	0.05
5. Reflow oven	1. Setting temperature on machine	18,099	122,400	0.15
	2. Check current model running with setting at machine is same	18,099	244,800	0.07
6. Automated Optical Inspection (AOI)	1. Testing the PCB at several stages of assembly by using AOI machine and conducting auto inspection	18,052	122,400	0.15
7. Visual Manual Inspection (VMI)	1. Checking appearance to reduce and prevent such defects in the future	9,000	122,400	0.07
	2. Stamp at first PCB sampling for verified PCB (tag) for reference	9,000	122,400	0.07
8. Repair input	1. Manual soldering to repair defect PCB found at AOI or VMI station	12,320.28	244,800	0.05
	2. Do marking at PCB after repair follow by ID colour	12,028.40	244,800	0.05
	3. Verify the PCB after repair process	12,000	244,800	0.05

In order to compute the expected production time, a time equation needs to be created. The total production time is obtained by solving the time equation for each sub-activity.

The estimated necessary capacity for each activity is obtained by calculating the frequency of activity throughout the year. The total amount of time spent on an activity may be computed by multiplying the amount of time spent on the activity by the amount of time spent performing it. The cost drivers are required for each sub-activity depending on its utilization throughout the year.

For future forecasting, capacity utilization should assess unused capacity. This implies that future plans may be optimized based on present capacity use. Table 3 depicts a capacity utilization analysis for underutilized capacity.

Table 3: Capacity Utilization with Unused Capacity

Main activity	Sub-activities	Unused time (min)	Unused cost (MYR)
1. Solder paste control	1. Prepared the solder before running production	-790,100	-1,000,535.13
	2. Update sticker of solder paste shelf-life control after issued out from refrigerator	122,254.00	9,406.37
	Total	-667,846.00	-991,128.76
2. Input PCB	1. Visual check on PCB	111,900.00	16,455.88
	2. Input the PCB into auto loader machine	239,550.00	18,120.67
	Total	351,450.00	34,576.55
3. Solder paste printing	1. Set up printer for printing on top stencil	-561,975.00	-42,552.16
	2. Inspect and confirm the solder paste printed on PCB	237,660.00	8,939.43
	3. Verification and inspection the printing condition	234,300.00	8,813.05
	4. Cleaning the stencil	93,200.00	7,026.40
	Total	3,185.00	-17,773.28
4. SMT loading feeder	1. Check value and P/N of material loading on feeder and tray	121,140.00	8,557.00
	2. Scan barcode P/N of machine type and ID operator	122,394.00	6,215.95
	3. Confirm the part for each feeder follow by loading list	122,379.60	6,093.78
	Total	365,913.60	20,866.73
5. Reflow oven	1. Setting temperature on machine	122,383.80	18,096.60
	2. Check current model running with setting at machine is same	241,440.00	17,850.58
	Total	363,823.80	35,947.19
6. Automated Optical Inspection (AOI)	1. Testing the PCB at several stages of assembly by using AOI machine and conducting auto inspection	-24,600.00	-3,628.10
	Total	-24,600.00	-3,628.10
7. Visual Manual Inspection (VMI)	1. Checking appearance to reduce and prevent such defects in the future	120,150.00	8,834.56
	2. Stamp at first PCB sampling for verified PCB (tag) for reference	119,460.00	8,783.82
	Total	239,610.00	17,618.38
8. Repair input	1. Manual soldering to repair defect PCB found at AOI or VMI station	244,500.00	12,305.18
	2. Do marking at PCB after repair follow by ID colour	244,725.00	12,024.71
	3. Verify the PCB after repair process	244,545.00	11,987.50
	Total	733,770.00	36,317.40
	Total	1,365,306.40	-867,203.90

Red had the highest utilised time capacity with -790,100 minutes of sub-activity that prepared the solder before running production. The orange colour indicates the least resource spent by the visual check on PCB sub-activity with 244,725 minutes. Following that, the PCB input sub-activity for the auto loader machine has green colour of 111,900 minutes, indicating that the resource is utilised the most.

The highest utilised cost capacity with MYR-1,000,535.13 of red colour in preparing the solder before running production sub-activity. The least percentage used in confirming the component for component for each feeder followed by the loading list sub-activity is orange colour at MYR18,120.67.

The auto loader PCB input machine sub-activity is green colour with MYR6,093.78, indicating the greater proportion to be used.

4.3 Integration of MTS and TDABC Discussion

There are two kinds of contributions. The first is the positive contribution degree, which implies that using this parameter increases the product. Second, the negative contribution degree implies that applying this parameter reduces the product. As a consequence, the most abnormal md values that occurred in September were the focus of this research.
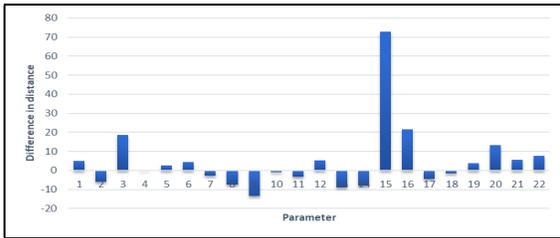
Figure 12: September Unknown Data of Contribution Degree

The original output for unidentified data in September is 399.71 as shown in Table 4. The value is compared to the other sorts of modification. In this regard, modification type 3 is the best choice for the top side workstation. However, the total positive and negative contribution degrees may have an effect on the proposed solution. More importantly, the recommend solution may differ from actual implemented.

Table 4: Comparison Between Original and Alteration Types

Original	MD	Alteration	MD
1	399.71	Type 1	396.90
		Type 2	402.53
		Type 3	395.29
		Type 4	413.11
		Type 5	397.92
		Type 6	398.69

Figure 13 presents the MTS and TDABC combined structure. The green shading represents MTS degree of contribution, whereas the yellow shading represents TDABC process mapping. The

figure demonstrates the details of the integration between the interconnected MTS and TDABC.

The sub-activities 1, 2, 3, 5, 13, 16, 17, 18, and 19 is added one point each of the parameters based on the MTS and TDABC linked in Figure 13. Meanwhile, sub-activitiy 12 are the sub-activities added with two points of parameter. Finally, other sub-activities are set as zero.
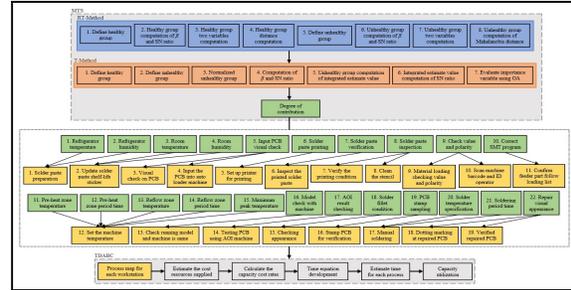
Figure 13: Framework of MTS and TDABC

The analysis of modified capacity utilization for unused capacity is shown in Table 5. The table shows the most often utilised partial activity, the highest resource spent, and the smallest resource used.

[31] showed that the integration of MTS and TDABC is great because the MTS considers degree of contribution for each parameter which influence to the increment or decrement to the final cost. Moreover, TDABC develops capacity cost rate from the related cost of capacity supplied and time equations with high flexibility which also influence to the increment or decrement to the final cost.

Table 5: Modified Unused Capacity Utilization

Main activity	Sub-activities	Unused time (min)	Unused cost (MYR)
1. Solder paste control	1. Prepared the solder before running production	-790,600	-1,001,168.30
	2. Update sticker of solder paste shelf-life control after issued out from refrigerator	122,253.92	9,406.36
	Total	-668,346.08	-991,761.94
2. Input PCB	1. Visual check on PCB	111,900	16,455.81
	2. Input the PCB into auto loader machine	239,550	18,120.65
	Total	351,449	34,576.46
3. Solder paste printing	1. Set up printer for printing on top stencil	-562,350	-42,580.55
	2. Inspect and confirm the solder paste printed on PCB	244,800	9,208.00
	3. Verification and inspection the printing condition	244,800	9,208.00
	4. Cleaning the stencil	122,400.00	9,227.80
	Total	49,650.00	-14,936.75
4. SMT loading feeder	1. Check value and P/N of material loading on feeder and tray	122,400	8,646.00
	2. Scan barcode P/N of machine type and ID operator	122,400	6,216.25
	3. Confirm the part for each feeder follow by loading list	122,400.00	6,094.80

	Total	367,200.00	20,957.05
5. Reflow oven	1. Setting temperature on machine	122,375.70	18,095.41
	2. Check current model running with setting at machine is same	241,439	17,850.51
	Total	363,814.74	35,945.92
6. Automated Optical Inspection (AOI)	1. Testing the PCB at several stages of assembly by using AOI machine and conducting auto inspection	122,400	18,052.00
	Total	122,400	18,052.00
7. Visual Manual Inspection (VMI)	1. Checking appearance to reduce and prevent such defects in the future	122,400	9,000.00
	2. Stamp at first PCB sampling for verified PCB (tag) for reference	119,459	8,783.76
	Total	241,859	17,783.76
8. Repair input	1. Manual soldering to repair defect PCB found at AOI or VMI station	244,498	12,305.06
	2. Do marking at PCB after repair follow by ID colour	244,724	12,024.69
	3. Verify the PCB after repair process	244,543	11,987.40
	Total	733,765	36,317.15
	Total	1,561,792.03	-843,066.36

5. CONCLUSION

This research is to integrate MTS classification into TDABC optimization in order to decrease waste and improve forecast. As a result, October and December have the most significant parameters (16) and August the fewest (10). TDABC is the used to perform capacity utilization analysis in order to diagnose used and unused time and cost capacity. The TDABC confirmed that the PCB input auto loader machine sub-activity has a large unused capacity of time (239,550 minutes) and cost (MYR18,120.67) which allows this workstation to minimize unused capacity by shifting employees to another load workstation. In order to reduce capacity utilization, extra employees should be given in the solder paste preparation sub-activity since it has an over-utilized capacity of time (-790,100 minutes) and cost (MYR-1,000,535.13).

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