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NEW FRAMEWORK FOR IMPROVING PRODUCTION EFFICIENCY BY INTEGRATING DEGREE OF CONTRIBUTION AND COST DRIVER FOR THERMAL PRINTER

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ABSTRACT

Production efficiency is a critical determinant of growth and competitiveness in assessing the success of Malaysia's manufacturing sector. The daily and weekly production reports including information such as working time, output, production efficiency and machine utilization. However, there is no information related to the parameters contributed to the production activities. In meantime, to address production costs, industrial practitioners apply activity-based costing (ABC) to determine the cost per unit of finished products. Obviously, the existing method presents challenges in accurately determining capacity utilization and unused capacity. Regrettably, the quality and costing tools often operate independently, thus the impact of factors to the industrial capacity is less appreciated. This research aims to develop a framework that integrates the degree of contribution and cost driver in production environment. MTS is employed to predict and diagnose system performance using multivariate data for quantitative decision-making. TDABC is utilized as a costing model, enabling companies to allocate costs by calculating the time spent on activities. Data collection is involved 25 workstations, 51 parameters, and 59 activities. As a result, in April 2023, the normal sample has the average MD of 1.000001, while the abnormal sample has the average MD of 53.401398. Increasing the number of parameters which are exceed the normal range will increase the MD value. There are 34% parameters are classified in positive degree of contribution, whereas 66% parameters are classified in negative degree of contribution. For the sub-activity of prepare printing inspection equipment has -22,757.63 minutes and MYR -4,323.95 of unused capacity of time and cost respectively. It was found that there are three types of unused capacity have been identified such as Type I which is the workstation is over-utilized, Type II which is the workstation is small-utilized, and Type III which is the workstation is largely-utilized the resources and cost of apportionment. The proposed framework is great because the degree of contribution reflected the increment or decrement to the cost driver in high production complexity for better product cost.

Keywords: *MTS, TDABC, Optimization, Integration, Capacity Utilization*

1. INTRODUCTION

As a major factor in determining growth and competitiveness, production efficiency is essential in assessing the success of Malaysia's manufacturing sector. Industry efficiency is demonstrated by metrics including labor productivity, resource use, and technological adoption. Suntherasegarun and

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Devadason [1] mentioned that manufacturing firms are likely to realize higher efficiency through high-skilled labor. The Malaysian economy is largely dependent on the electrical and electronic (E&E) industry for gross domestic product (GDP) development, and augmentation of export revenue. The Ministry of Economy states that the Malaysian economy is anticipated to exhibit moderate growth, estimated at a rate of 3.3%, as per the initial assessment of GDP growth for the third quarter of 2023, especially within the E&E industry and associated primary industries [2]. The E&E sector also plays as a major export contributor which has embraced high levels of automation and driving strong efficiency gains.

The degree of contribution in industry reflects the extent to which a particular factor, process, or resource adds value to the overall production or service system. In an industrial context, assessing the degree of contribution involves evaluating how specific inputs such as labor, capital, or raw materials impact efficiency, quality, and profitability. For industry, it is feasible to identify the degree of contribution toward sustainability within their operations and subsequently develop a comprehensive analysis and action plan aimed at enhancing production processes in alignment with sustainability objectives [3].

Capacity utilization is a critical factor in evaluating the efficiency of an organization's operations. It specifically highlights the significance of managing unused time and unutilized costs, which can have a profound impact on overall productivity. According to Lee et al. [4], increased in prompt demand industry lead to intensify machinery use, thereby temporarily raising capacity utilization. By optimizing capacity utilization, industry can enhance the operational efficiency, reduce waste, and improve profitability.

A well-defined framework is essential in manufacturing systems as it provides a structured approach to streamline operations, enhance efficiency, and facilitate decision-making processes. It serves as a blueprint that integrates multiple elements, such as resource allocation and production planning into a cohesive system. Mo et al. [5] mentioned that a framework for managing manufacturing system reconfiguration optimization for achieving reconfiguration across various cases to enhance both performance and accuracy.

Classification is a process that involves categorizing observations from a reference distribution into predetermined classes. This method is utilized for improving and maintaining the overall quality of a system or process, and it can be applied to quality engineering and fault detection. Optimization serves the overarching goal of enhancing the performance of a given system or process. The optimization of MTS attributes is accomplished using the orthogonal array (OA) and signal-to-noise ratio (SNR) to screen useful features. Cheng et al. [6] mentioned that feature selection strategy can be enhanced by using metaheuristic algorithms like the genetic algorithm, binary ant colony optimization and binary gravitational search algorithm. Many researchers also have suggested that MTS can be enhanced by integrating it with other techniques in order to increase the accuracy performance [7].

Costing is a branch of accounting for meticulously analyzes both variable and fixed costs throughout each stage of production by aiming to ascertain the comprehensive production costs for a company. One of the costing methods employed is time-driven activity-based costing (TDABC), wherein TDABC proves to be an effective technique for cost estimation, waste reduction and efficiency enhancement. Kuhait and Megabal [8] stated that expanding the effects of ABC and TDABC, the performance focus activity-based costing method gives economic entities more flexibility in selecting the sources of cost and overcoming the drawbacks of both ABC and TDABC. Efficient operations can lead to lower production costs per unit, increased operating margins, and improved profitability [9].

System integration is the process of merging various subsystems approach aimed at boosting productivity and operational efficiency within organizations. The integration of the Mahalanobis classification systems with binary particle swarm optimization as a technique that has demonstrated enhanced classification accuracy [10]. Furthermore, recent advancements in TDABC have introduced fuzzy logic into the system. According to Kropivšek et al. [9], this integration of fuzzy logic addresses the uncertainties related to time and quality parameters, thereby refining the TDABC methodology.

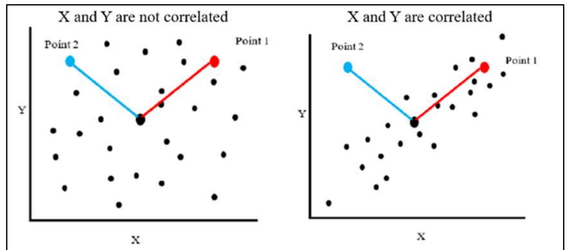
2. LITERATURE REVIEW

2.1 Mahalanobis-Taguhci System

The Mahalanobis-Taguchi system (MTS) is a comprehensive multidimensional method to system classification, diagnostics and forecasting by integrating Taguchi's robust engineering with Mahalanobis distance (MD. Professors Genichi Taguchi and Professor Mahalanobis collaborated to develop the MTS by a statistical method. In other perspectives, MTS was proposed by Genichi Taguchi for the study of multidimensional systems and has been effectively applied in many fields [11]. The MTS is a useful tool for researching multidimensional systems that was created by Genichi Taguchi. In the MTS, a reference MD space is created by utilizing a set of normal observations to determine their MD values [6]. New observations can be classified as normal or abnormal based on threshold. This integration of methodologies enhances the robustness of MTS, making it invaluable tools for anomaly detection and multidimensional analysis. In order to produce higher quality products, MTS classifies both normal and abnormal observations and optimizes various workstation parameters.

Moreover, there are two stages to the MTS. In the first stage, a multidimensional measurement scale is built using MD and a reference point is defined for the scale using a set of observations from a reference group. Stated differently, it establishes a normal or reference group that serves as the foundation to construct the Mahalanobis space (MS), a database that includes the correlation structure, means and standard deviations of the variables in the reference group [12]. In the second phase of MTS, the critical variables are chosen based on the suitability of OAs and SNR. Through the reduction of experimentation, OA is utilized to estimate the effects of features and interactions. According to MTS, every variable has a single column assignment and two levels which is level 1 denotes the presence of the variable, and level 2 denotes its absence. The OA experiments are used in the MTS approach to screen the most significant features [13].

The closest neighbours of a record are determined by all proximity-based methods for outlier identification, such as the k-NN algorithm, using an appropriate distance calculation metric, such as the Euclidean distance (ED), the MD, or another measure of dissimilarity [14]. Compared to the ED, the MD requires processing through every variable in the data set in order to determine the underlying inter-correlation structure, which makes it computationally more expensive to use for large data sets. MD is used to determine a data point's nearness to a group mean. Haldar et al. [15] found this method of measuring distance is superior to other existing methods, such as ED and it is highly sensitive to any inter-variable changes in the reference data. A common technique for measuring colour distances is the ED, which is an ordinary distance between any two points [16] as shown in Figure 1.



When X and Y are not correlated, the ED from the centroid can be useful to inter if a point is member of the distribution.

Point one and two have the same ED from centroid but only point one is a member of the distribution to detect point two as outlier, distance (point two, centroid) should be much higher than distance (point one, centroid), MD can be used here instead.

Figure 1: The distinction between the MD and ED

MTS is divided into two methods, which is RT-method for classification and T-method for optimization. The RT-method typically performs recognition function creation more quickly than artificial intelligence (AI). According to the Murata and Morita [17], many companies are unable to effectively analyze the big data acquired through internet of things using AI, thereby failing to fully realize its potential. In comparison, the RT-method requires comparatively fewer computational operations, whereas AI necessitates repeated computation processing [18]. Similar to multiple regression analysis, the T-method is a theory for multivariate-based output value prediction and estimation. T- method can integrated estimate SN ratio but multiple correlation coefficient adjusted for the degree of freedom [18].

MTS also has strength and limitation. It is the only method that can effectively be applied to the field of powder technology and identify patterns among data with multiple variables in addition to cause analysis [19]. The robustness of the remanufacturing system on pattern recognition using MTS achieved faster decision-making than the existing direct manual inspection [47]. MTS can obtained robust and stable results without considering the full or reduced model [49]. By utilizing the MTS, the critical and non-critical parameters can be identified in the remanufacturing process [52]. Meanwhile, the inability of the MTS method to be used with high-dimensional small-sample data [11]. Adoption BitABC provided better performance than traditional MTS [48].

According to Chang et al. [20], research in MTS is divided into seven different categories such as Mahalanobis distance (MD), signal-to-noise ratio (SNR), Mahalanobis space (MS), feature selection, threshold, multi-class classification, and comparison with other methods as shown in Figure 2. 54 articles are considered from 2010 to 2023.

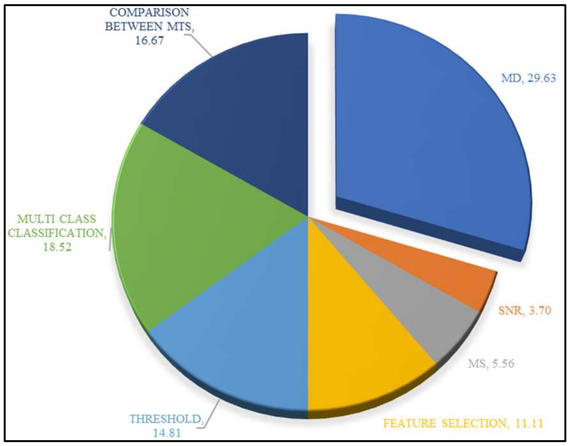


Figure 2: Research categories in MTS

This study focused on MD category for further analysis. Table 1 shows 7 selected articles are analysed based on author, application, MD measurement and optimization. YES and NO indicates that the author conducted the analysis or might not conducted the analysis respectively in their study.

Table 1: Selected articles under MD category

Author (Year)	Field	MD		Optimiz-ation
		Normal	abnormal	
Takai-Yamas-hita et al (2022)	Japanese rhinoceros beetles	YES	NO	YES
Liu et al (2022)	Wind turbine	YES	YES	NO
Kamil et al (2021)	Electronic	YES	YES	YES
Asakur-a et al (2020)	Logistic operating system	YES	YES	NO
Kuo (2019)	School	YES	YES	NO
Rizal et al (2017)	Cutting tool	YES	YES	YES
Ketkar and Vaidya (2014)	Ranking candidates for MBA program	YES	YES	YES

The first article is about the sex determination of Japanese rhinoceros beetles, Trypoxylus dichotomus, based on their dropping shape by Takai-Yamashita et al. [19]. As a result, GU20 with the highest abnormality rate could have more male features. The second article is about wind turbine anomaly detection using MD and SCADA alarm data by Liu et al. [21]. The finding shows that the MD technique can identify wind turbine malfunctions with a high accuracy rate of 97%. The third article is about the feasibility study on the implementation of MTS and TDABC in electronic industry by Kamil et al. [22]. As a result, the abnormal is 15.6538 with two significant parameters and a signal-to-noise ratio of 0.1244, while the typical MD is 0.9998 in February. The fourth articles is about anomaly detection in a logistic operating system using the MTS method by Asakura et al. [23]. In abnormal situations, the MD readings significantly exceed the 3.3 threshold value. Thus, it was verified that it was possible to identify the shift to the abnormal condition quite early on in the procedure.

The fifth article is about applying the Mahalanobis model to predicting school closure, an example of Taipei city by Kuo [24]. Only six of the 22 schools currently in existence operate regularly, with the remaining four classified as mild (25%) or moderate (50%), fairly severe (75%) or severely severe (100%), and closed. The sixth article is about cutting tool wear classification and detection using multi-sensor signals and MTS by Rizal et al. [25]. The experimental findings demonstrate the effectiveness of the suggested prediction system, with an average accuracy of 88.89% or a false detection error of 11.11% over the course of 18 trials. The seventh article is about evaluating and ranking candidates for MBA program, MTS approach by Ketkar and Vaidya [26]. The average MD value is 381.80, clearly surpasses the average MD value, 246.10, derived from all seven criteria. It is obvious that a lower MD value corresponds to a smaller departure from the ideal predicted values, increasing the probability that the candidate will be chosen. Thus, most MTS application generated the MD for normal and abnormal for parameter, and reduction of element to overcome their problem. Nevertheless, although previous research has used MTS method, particularly in E&E industry, it is frequently intended to develop a degree of contribution, yet its application remains limited.

2.2 Time-Driven Activity-Based Costing

Cost accounting methods commonly used by internal finance or management teams include activity-based costing (ABC), standard costing, historical costing, marginal costing, and absorption costing. The traditional ABC approach was employed several years ago at a sizable financial services company. The conventional cost accounting was unable to provide an accurate cost for effectively operating the business because it relies on a single cost driver, such as direct labor or output volume, to allocate overhead costs [27]. Ding et al. [28] mentioned that ABC systems are expensive to build and maintain for complex loading and unloading operations. Koolmees et al. [29] have verified that according to ABC methods, costs are determined by dividing a department's total expenses by the number of activities in which the department is involved. As a result, costs are generated for each activity and can be further divided into smaller groups for in-depth examination. Kaplan and Anderson [30] have developed, tested, and put into practice a brand-new strategy known as time-driven activity based-costing (TDABC).

TDABC is an exceptional example since it is less complicated, more affordable, and significantly more potent than the ABC method. Thus, TDABC's costing method simplifies budget planning for new marketing scenarios, showcasing the versatility and applicability of TDABC across diverse sectors [31]. the TDABC is a useful substitute when estimating the expenses of cost objects and processes. The time needed to complete each task is the only driver employed in this new strategy. In other terms, ABC was developed into the TDABC method by including time components [32]. This driver helps to more precisely capture the unique qualities that exist among the various cost objects [33]. According to Kissa et al. [34], ABC method neglect unused capacity while TDABC method may perform further capacity analysis.

The new model uses an elegant framework that requires only two sets of estimates, both of which are easy to obtain, to assign resource costs directly to the cost objects. It computes the cost of providing resource capacity first. To calculate the capacity cost rate, this total cost is divided by the capacity. Thus, the TDABC's fundamental is depicted in Figure 3.

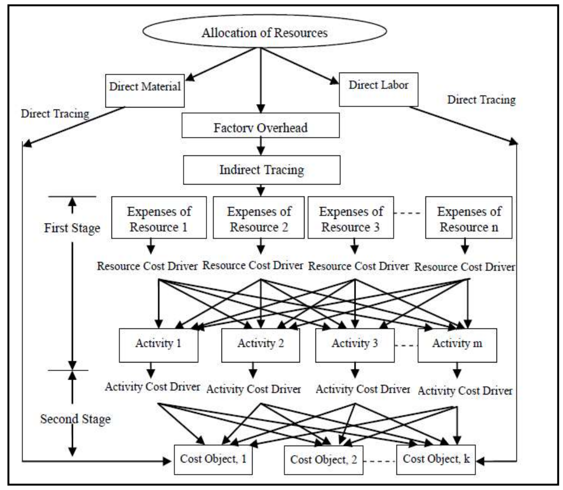


Figure 3: The TDABC'S fundamental

TDABC also has strength and limitation. The TDABC costing model provided more precise and transparent cost estimates while also managing the complexity and variability of daily operations [35]. TDABC is believed to be a cure for the shortcomings of traditional method in production that is too distorted for managers' planning and control decisions [50]. TDABC able to identify un-used capacity and loss manufacturing cost [51]. Meanwhile, TDABC needs a significant amount of data and can be subjective [36].

According to Keel et al. [37], research in TDABC is divided into five different categories such as support operational improvement, inform reimbursement policy, accurately capture the cost of care, more efficient and simple than traditional ABC as shown in Figure 4. 53 articles are considered from 2014 to 2024.

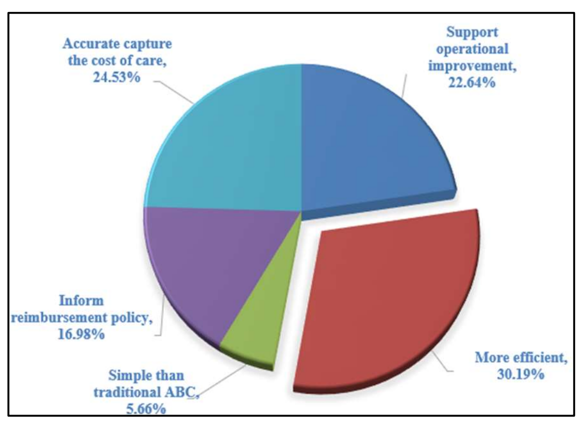


Figure 4: Research categories in TDABC

This study focused on more efficient category for further analysis. Table 2 shows 7 selected articles are analysed based on author, application, process map, cost resources supplied, capacity cost rate (CCR), time equation and estimate time. YES and NO indicates that the author conducted the analysis or might not conducted the analysis respectively in their study.

Table 2: Selected articles under more efficient

Author (Year)	Field	Concept				
		Process map	Cost resource supplied	Capacity Cost Rate	Time equation	Estimate Time
Ostadi et al. (2023)	Healthcare Services	YES	YES	YES	YES	NO
Kissa et al. (2023)	Academic Library	YES	YES	NO	YES	YES
Chen et al. (2023)	Proton Therapy	YES	YES	YES	NO	YES
Thaker et al. (2022)	Prostate brachytherapy	YES	YES	YES	NO	YES
Wedowati et al. (2020)	Ice cream products	YES	YES	NO	YES	YES
Adıgüzel and Floros (2020)	Small manufacturing firm	YES	YES	YES	YES	YES
Zamrud and Abu (2020)	Electronic Industry	YES	YES	YES	YES	YES

The first article is about a scenario-based simulation model for cost management of healthcare services through improving the efficiency of health centers [38]. The study's findings demonstrated that considerable gains in expenses, waiting times, the use of human resources, and overall system efficiency could be achieved by choosing each of the scenarios that were suggested and then making modifications to the system in accordance with these chosen categories. According to the results, the estimated and determined costs using the standard procedures varied by 0.60464%, 0.607238%, 0.667776%, 0.670421%, and 0.634811%. The second article is about business process management analysis with cost information in public organizations by Kissa et al. [34]. Based on its breakdown of transaction costs and ability to highlight inefficient and expensive operations, the authors came to the conclusion that TDABC might help lower the cost of library services. The third article is about the costs of newly funded proton therapy using time-driven activity-based costing in the Netherlands by Chen et al. [39]. Achieving maximum treatment capacity could result in a reduction of treatment expenses to 35% of present costs, as indicated by the calculation of the potential of the scale of economics implied by the high indirect costs. The fourth article is about improving efficiency and reducing costs of MRI-guided prostate brachytherapy using TDABC by Thaker et al. [40]. As a result, there are 18.2% costs are reduced. 10% of consultation costs and 77% of operation scheduling costs were decreased through personnel task downshifting.

The fifth article is about product value analysis on customized products based on pleasurable design and TDABC in the food industry by Wedowati et al., [32]. In this study, integrated the idea of enjoyable design to create personalized goods with a TDABC cost analysis of personalized goods to assess the worth of the final product. The sixth article is about capacity utilization analysis through TDABC in a small-sized manufacturing company by Adıgüzel and Floros [36]. TDABC provided more precise product pricing data because it did not charge for idle capacity and it can boost operational efficiency by eliminating idle resources or increasing output volume in order to reduce idle capacity. The seventh article is about comparative study ABC and TDABC in electronic industry. TDABC is able to convey transparency more effectively than ABC in showing the duration of time for activities [41]. In summary, most applications that use TDABC for better efficiency reduce cost and time in industry. Nevertheless, the finding from previous research used TDABC, especially in electronic and electrical companies frequently intended to analyze the capacity utilization of time and cost in developing unused costs, and time remains limited.

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3. METHODOLOGY

Figure 5 shows the research methodology to solve the issue on parameter evaluation, capacity utilization and framework development.

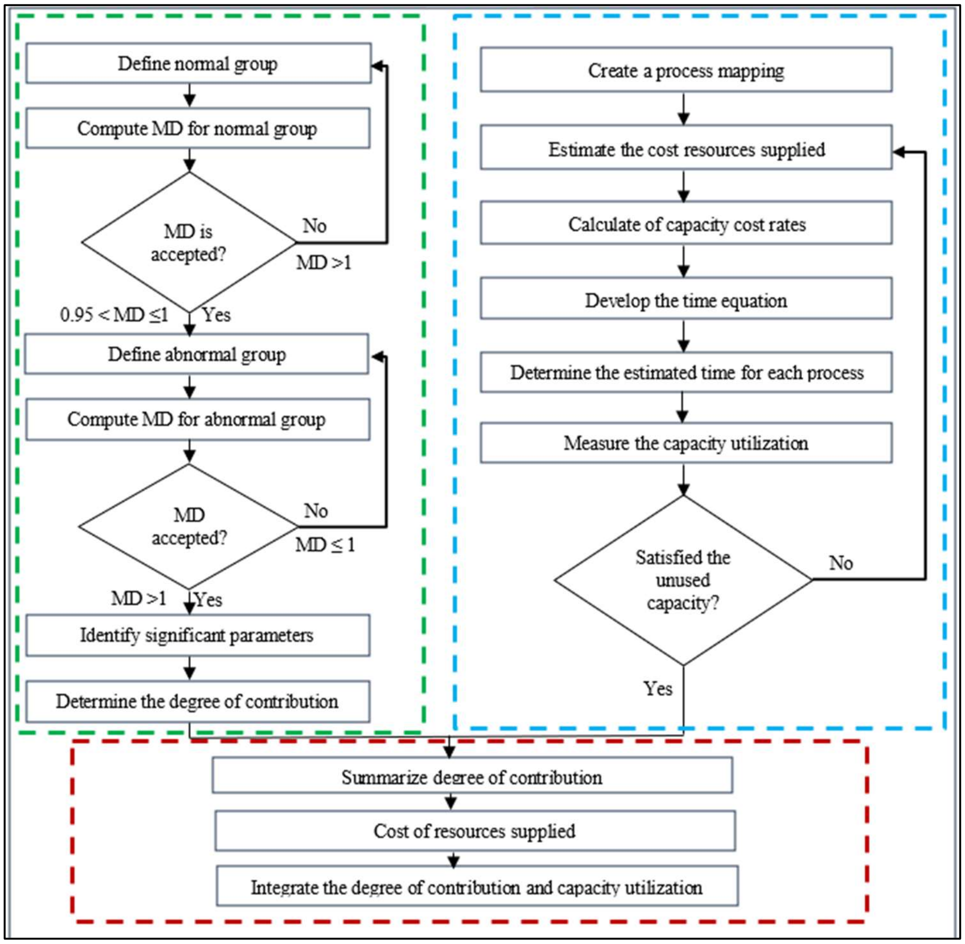

Figure 5: Research methodology

3.1 Data Collection

The company under study is located in Pasir Gudang, Malaysia. It was established since June 1995 which its core business in trading of electronic component as a supplier for thermal printer and significant demand from customers for PCB assembly. It also has more than 25 years of experience in managing E&E manufacturing. Therefore, the thermal printer model SII is chosen. For this study, the process selection starts from bottom side of x-ray inspection until outgoing inspection (red dotted), excluding the assemble component and screw, screwing, and online patrol inspection (2 times), as shown in Figure 6.

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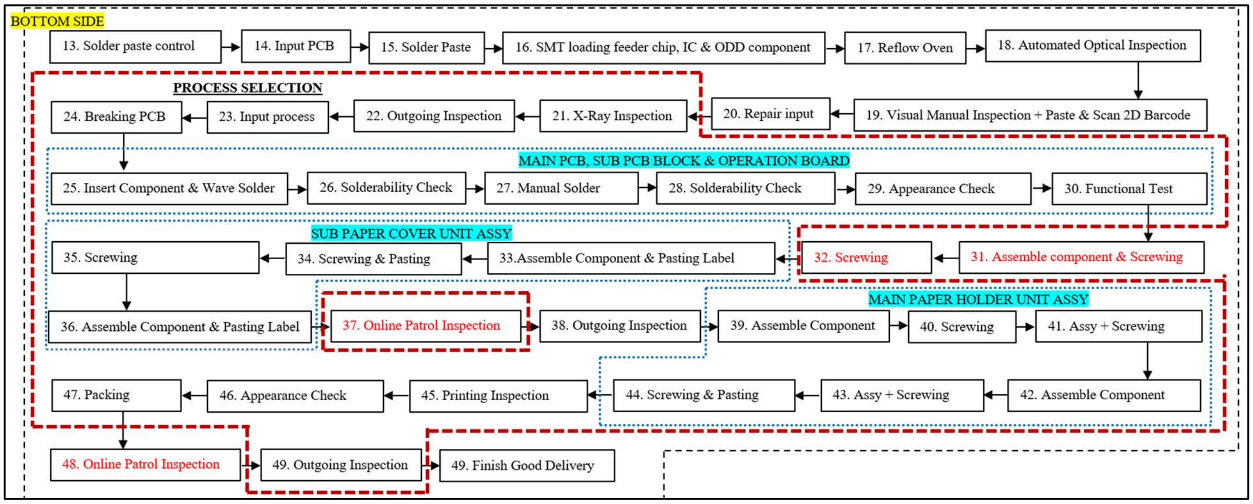

Figure 6: Process flow of thermal printer

In MTS implementation, the parameter selection is based on the thermal printer's bottom-side process. There are 51 parameters in 25 workstations as shown in Table 3. The parameter is classified into two categories: quantitative and qualitative data. Quantitative data is numbers-based, countable or measurable. Qualitative data is characterized by its interpretation, descriptive nature, and connection to language and cannot be measurable. Generally, qualitative data does not have standard units like quantitative data does because it represents non-numeric information. For normal data, the criteria include no solder missing and correct location, with an acceptable range of 1-2, classified as "pass." In contrast, abnormal data involve solder missing and incorrect location, corresponding to a range of 3-4, which leads to a "fail" unit. In other words, smaller the grouping number indicates the normal condition while larger the grouping indicates the abnormal condition because the average length for the scaled MD is approximately close to the 1 for normal dataset while the scaled MD is larger for the abnormal data [42].

Table 3: Parameter used for bottom-side process

No	Type of parameters	Normal Range	Abnormal Range	Unit
1.	Solder check	1-2	3-4	Pass/fail
2.	Solder paste quality	50-100	0-49	Percentage (%)
…	……	……	……	……
13.	Temperature IN	264-266	267-269	Celsius (°C)
14.	Peak height	15.0-17.0	18.0-20.0	Hertz (Hz)
15.	Solder conditions	1-5	6-10	Pass/Fail
…	……	……	……	……
43.	Screw loosening torque	13.1-15.1	10.1-12.1	Centinewton meter (cN.m)
44.	Screw tightening torque	40.5-42.5	37.5-39.5	Centinewton meter (cN.m)
…	……	……	……	……
50.	Box condition	1-3	4-6	Pass/fail
51	Batch classification	1-3	4-6	Pass/fail

In TDABC implementation, the activity selection is based on the thermal printer's bottom-side process as shown in Table 4. There are 25 main activities with 59 sub-activities.

Table 4: Sub-activity used for bottom-side process

Mian Activity	Sub-activity
1.X-ray inspection	1.Detect porosity and voids in solder
	2.Check geometric measurement of solder thickness and volume
	3.Check correct location of solder
2.Outgoing inspection	1.Random check the carton or box
	2.Stamp ID chop at control tag production
3.Input process	1.Check model name and quantity received with production label
	2.Visual checking for all PCB
4.Breaking PCB	1.Divide the PCB using breaking jig
	1. Put PCB into a wave pallet

5.Insert component and wave solder	2. Insert all component into PCB
	3. Close the PCB with cover wave pallet
	4.Enter the PCB into wave solder through conveyer
……	……
21.Screwing and pasting	1.Install front cover onto bottom case unit and screw 2 point
	2.Screw IF unit
	3.Clean bottom case pasting surface with ethanol
	4.Paste product label to bottom case
22.Printing inspection	1.Prepare printing inspection equipment
	2.Perform printing inspection
	3.Check the printing result confirmation
23.Appearance check	1.Check printer appearance
24.Packing	1.Put the set into PE Bag and enter to individual box
	2.Paste SCM label at outer box
	3.Scan SCM label and No. serial
	4.Put every set into outer box
25.Outgoing inspection	1.Random check the carton or box
	2.Stamp ID chop at production label

3.2 MTS Methodology

The MTS divided into two category which is RT method and T-method. RT method known as classification and T-method as optimization technique. Reyes-Carlos et al. [43] stated MTS developed in four steps.

The first step is construction of Mahalanobis space (MS). MDs of normal data is create a measurement scale as a reference space. The k variables, used for classification in a multivariate system, are denoted as X_j (j=1,2..., k). From normal data, the observations pertaining to k variables are gathered. Let X_{ij} denote the j_{th} variable of the i_{th} normal observation (i=1,2, 3…., n; j=1,2, 3,…..k). The vector Xi= [X_{i2} ,X_{i2} ,…, X_{ik}]t can be obtained, and its standardized form given by equation (1) and (2).

$$z_{ij} = \frac{x_{ij} \;\; \bar{x}_j}{s_j}, i = 1,2,3,..,n\,; j = 1,2,3,\dots,k \quad (1)$$

where,

$$\bar{X}_j = \frac{1}{n}(X_{1j} + X_{2j} + ..,X_{nj})$$

$$S_j = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(X_{ij} \;\; \bar{X}_j)^2} \quad (2)$$

Then, standardized vector Z_i is obtained as $Z_i = [Z_{i1,}Z_{i2,..,}Z_{ik}]^T$. In the RT method, the sensitivity β, and standard SN ratio η need to be calculated. The equations (3)-(5) will be used to calculate the sensitivity β.

Sensitivity β:

$$\beta_1 = \frac{L_1}{r} \quad (3)$$

where,

Linear equation, L_1:

$$L_1 = \bar{x}_1\, x_{11} + \bar{x}_2\, x_{12} + \cdots, + \bar{x}_k\, x_{1k} \quad (4)$$

Effective divider, r:

$$r = \bar{x}_1^2 + \bar{x}_2^2 + \cdots + \bar{x}_k^2 \quad (5)$$

Standard SN ratio n is calculated after equations (6)-(9) have been calculated.

Total variations, S_{T1} :

$$S_{T1} = x_{11}2 + x_{12}2 + \cdots, x_{1k}2\ (f = k) \quad (6)$$

Variation of proportional term $S_{\beta 1}$:

$$S_{\beta 1} = \frac{L_1}{r} \quad (f = 1) \quad (7)$$

Error variation S_{el} :

$$S_{el} = S_{T1} - S_{\beta 1}\ (f = k - 1) \quad (8)$$

Error variance V_{el} :

$$V_{el} = \frac{S_{el}}{k-1} \quad (9)$$

Therefore, the standard SN ratio, η calculated using the equation (10).

Standard SN ratio, η:

$$\eta_l = \frac{1}{V_{el}} \quad (10)$$

The Y_1 and Y_2 are calculated to produce the scatter diagram for RT method of MTS. Equation (11) and (12) shows the formula will be used.

$$Y_{i1} = \beta_1\ (i = 1, 2, \dots, n) \quad (11)$$

$$Y_{i2} = \frac{1}{\sqrt{\eta_1}} = \sqrt{V_{ei}}\ (i = 1, 2, \dots, n) \quad (12)$$

In MTS, the MDs are scaled by dividing by the number of variables k using the following equation (13) normal group for last step.

$$MD_i = \frac{1}{k}(Z_i^T R^{-1} Z_i), i = 1,2,3,\dots,n; \quad (13)$$

Where Z_i^T is the transposed vector of Z_i, R^{-1} is the inverse of the correlation matric. As a frame of reference for the MTS measuring scale, these MDS are therefore defined as MS.

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The second step is validation of the MS constructed. The first thing that is chosen out are observations of abnormal conditions. The standard deviation and mean from the original data set are applied to their sets of data. In RT -method, the same equation (1)-(13) in step one is repeated to calculate the abnormal data.

Next, the normal data set covariance coefficient matrix and the normalized function data are used to measure the MDs. Stated otherwise, these abnormal MDs will have greater values. As a result of the irregular condition, the MD will be deemed out of MS. Once the MD of normal and abnormal is defined using the RT method, the important parameter is determined by the T method. The T method produces average output values and a uniform unit space as shown in Equation (14) and Equation (15).

$$\bar{x}_j = \frac{1}{n}\,(x_{1j} + x_{2j} + \ldots, + x_{nj})\ (j = 1, 2, , k) \quad (14)$$

$$\bar{y} = M_0 = \frac{1}{n}\,(y_1 + y_2 + \ldots, + y_{nj}) \quad (15)$$

In abnormal data for T-method, the normalization using the average values of item and output values of sample in normal data are needed. Equation (16) and Equation (17) shows the formula normalization of signal data.

$$X_{ij} = \acute{x}_{ij} - \bar{x}_j \quad (i = 1, 2, \ldots, l) \quad (16)$$

$$M_i = \acute{y}_i - M_0 \quad (i = 1, 2, \ldots, l) \quad (17)$$

$\bar{x}_j$ is average value of item j in the normal data from value $\acute{x}_{ij}$ of item j of the i-th signal data. Normalization also performed by subtracted average value M_0 of the output from the normal data from output value $\acute{y}_i$ of the i-th abnormal data.

The third step is feature selection. SNR and OA are used to optimize feature selection. Usually, a two-level OA is used to find important features. As an example, level 1 and level 2 denote the related feature's inclusion and exclusion, respectively. For this study, the relevant parameter is determined using OA68. The response of every OA combination is then computed to determine the SNR. Equation (18)-(23) for integrated estimate SN ratio.

$$\eta = 10 \log \left(\frac{\frac{1}{r}(S_\beta - V_e)}{V_e} \right) (db) \quad (18)$$

Where,

Effective divider, r:

$$r = M_1^2 + M_2^2 + \cdots + M_k^2 \quad (19)$$

Variation of proportional term, $S_{\beta 1}$:

$$S_{\beta 1} = \frac{(M_1 X_{11} + M_2 X_{21} + \cdots . M_l X_{l1})2}{r} \quad (f=1) \quad (20)$$

Error variation S_e :

$$S_e = S_T - S_\beta \quad (f= l-1) \quad (21)$$

Error variance V_e :

$$V_e = \frac{S_e}{l-1} \quad (22)$$

Proportional coefficient β_1 :

$$\beta_1 = \frac{M_1 X_{11} + M_2 X_{21} + \cdots + M_l X_{l1}}{r} \quad (23)$$

The fourth step is future diagnosis. The reconstructed MS is obtained based on the features found in step 3. A threshold is introduced to enable the distinction between normal and abnormal samples. Over the threshold, observations are deemed abnormal; under the threshold, observations are regarded normal.

3.2 TDABC Methodology

TDABC is a cost-calculation methodology that bases activity costs on the time required to complete the sub-activity and the unit cost of supplying capacity. In this TDABC, 25 mainly activities with 59 sub-activities were involved. There are five steps were used to apply the TDABC method [44].

Step 1 is creating a process map for each workstation. The process map was constructed based on observation and investigation on each workstation. Step 2 is estimating the cost resources supplied consists of labor, maintenance, material, and consumable cost. Step 3 is computed of capacity cost rate (CCR). Before calculate the CCR, the practical capacity estimation needs to be determined. The operators at this company are working from Monday to Friday and starting from 8.30 a.m. until 6.00 p.m. There are two shifts per day for SMT department and one shift per day for another departments. Thus, Equation (24) compute the CCR (MYR per minute).

$$CCR = \frac{\textit{cost of total resources supplied}}{\textit{Practical capacity}} \quad (24)$$

Step 4 is development the equation of time. The amount of time required for an activity can be described as a function of various component properties using time equations. It refers to these as time drivers. The basic time equation will be used as shown in Equation (25) by Dur and Afonso [33].

$$Tt = \beta_0 + \beta_i X_i \quad (25)$$

where,

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

Step 5 is determining the estimated time for each sub-activity. A time equation is needed to be developed to calculate the estimated production time. Then, measure capacity utilization for unused time and cost.

4. RESULT AND DISCUSSION

4.1 MTS Discussion

The RT-method is a useful multipurpose recognition technique that can handle image and character recognition. It works best when there are many units space. The unit space of MTS can indeed consist of normal data to a multivariate normal distribution. The two variables Y_1 and Y_2 can exist by using sensitivity β and SN ratio η. The new variable Y_1 will keep sensitivity β in intact form, but Y_2 will lose its intact form of SN ratio η. In other word, the variable Y_2 is defined as the square root of the error variance ($\sqrt{V_{ei}}$). The implementation method using this method consists of 51 parameters for normal and abnormal samples. Blue dotted represent the normal sample, while the red dotted represent the abnormal sample.

Figure 7 illustrates the normal and abnormal sample in April 2023. There are 3040 normal and 521 abnormal sample. The normal sample has the average MD of 1.000001, while the abnormal sample has the average MD of 53.401398. For normal data, the lowest MD value is 0.000756, and the highest is 5.470593. For abnormal data, the lowest MD value is 0.272195, and the highest is 166.35796. The reason for the highest MD of abnormal is that the samples consist of 51 parameters which exceed the normal range.

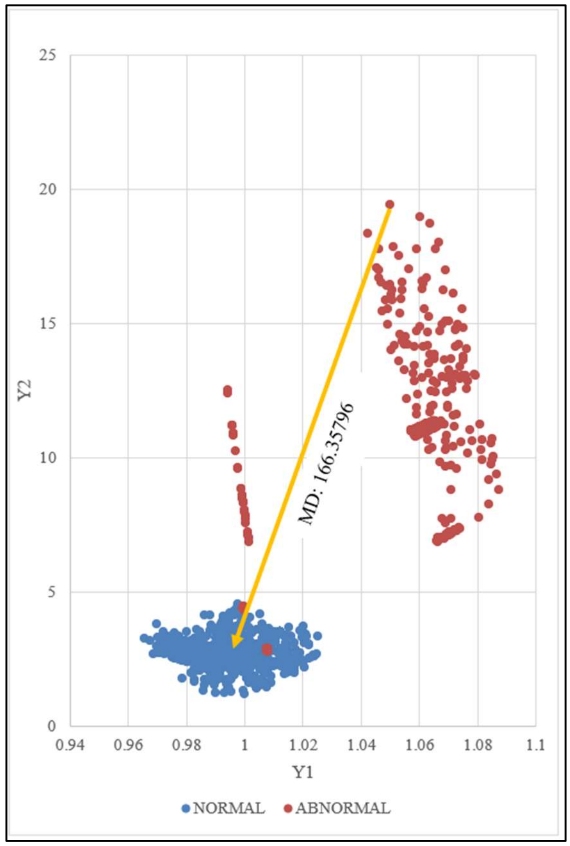

Figure 7: Scatter diagram of April 2023

Figure 8 illustrates the distribution of normal and abnormal samples for each month in 2023. The blue pattern represents the normal samples, while the red pattern represents the abnormal samples. Figure 8 (d) shows that 68 samples are overlapped between the normal and abnormal samples. The correlation coefficient (*r*) for normal samples is 0.0447974. This indicates that Y_1 and Y_2 has not a linear relationship. The *r* for abnormal sample is 0.6125943. This indicates that Y_1 and Y_2 has distinct positive linear relationship. It is found that for normal samples, 8 months have positive relationship *r* while 4 months have negative relationship *r*. On the other hand, for abnormal samples all 12 months have positive relationship *r*. It is found that increasing the number of overlapped samples for normal and abnormal will increase the *r*.

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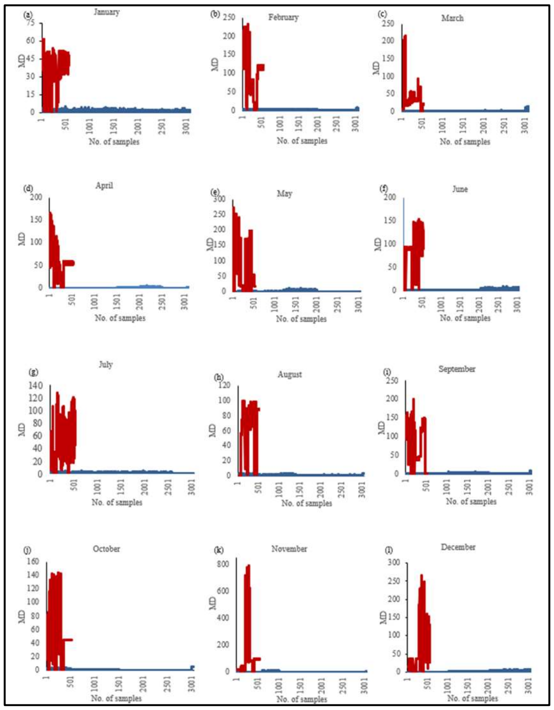

Figure 8: MD of normal and abnormal in 2023

Figure 9 shows a scatter diagram for normal and abnormal sample in 2023. In total, there are 36684 samples for normal and 6361 samples for abnormal. Meanwhile, there are 929 samples are overlapped between normal and abnormal samples. Point 1 is an abnormal sample and it has MD value of 0.343626. It is also overlapped with normal samples and has 25 out of 51 parameters exceed the normal range. Nevertheless, point 2 is an abnormal sample and it has MD value of 41.12292. It is also not overlapped with normal samples and has 43 out of 51 parameters exceed the normal range. Moreover, point 3 is an abnormal sample and it has MD value of 55.574924. It is also not overlapped with normal samples and has 29 out of 51 parameters exceed the normal range. Lastly, point 4 is an abnormal sample and it has MD value of 166.35796. It is also not overlapped with normal samples and has 51 out of 51 parameters exceed the normal range. It is found that increasing the number of parameters which are exceed the normal range will increase the MD value.

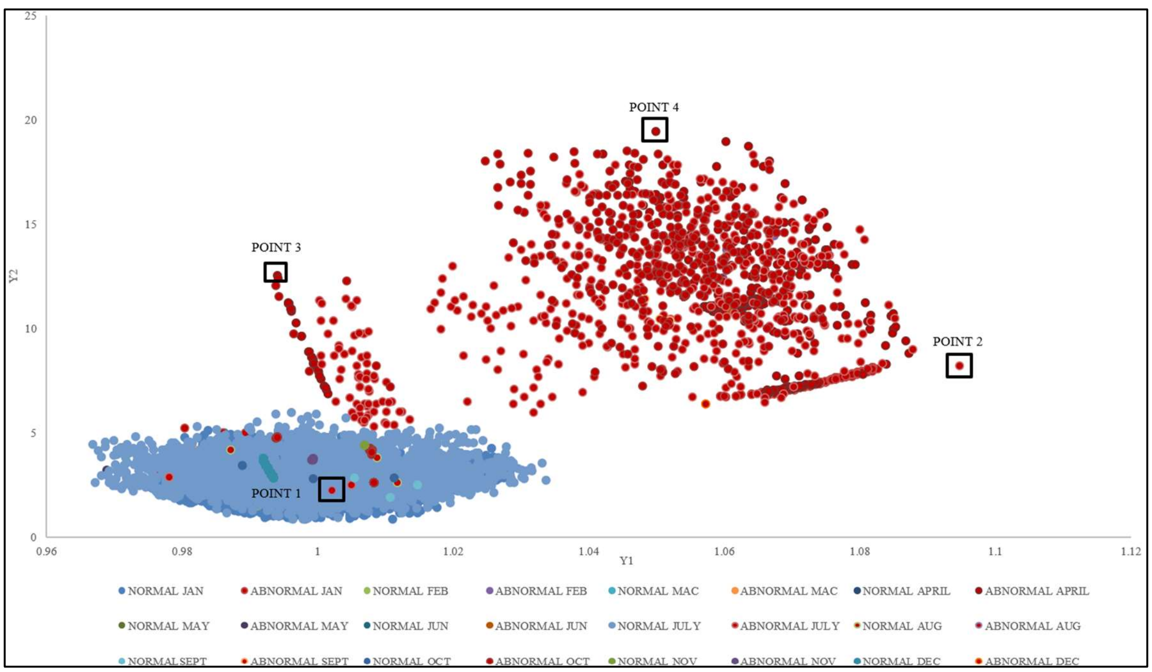

Figure 9: Scatter diagram of year 2023

Next, the T-method uses Taguchi's OA design to optimize the model through a variable selection process. It combines the regression principle with robust quality engineering elements to formulate a predictive model.

As shown in Figure 10, there are 3039 normal samples, 521 abnormal samples, and 51 parameters involved in September 2023.

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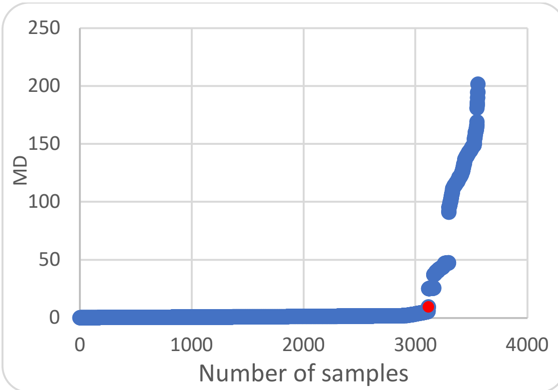
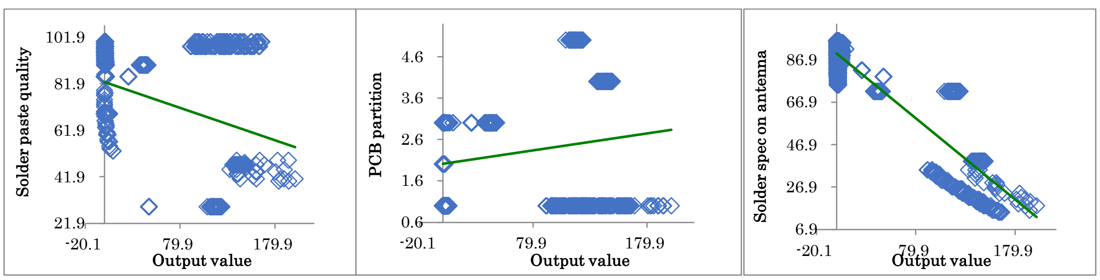


Figure 10: Distribution of outputs for September

The remaining 3555 samples are classified as abnormal. The samples are normalized by subtracting with average value of normal samples. The normalized value is used to determine the proportional coefficient β, and SN ratio η for each parameter.

Figure 11 shows the graph of the relationship between the parameter and output value (MD). The normalized output value is represented by the x-axis, while the normalized parameter values are represented by the y-axis. Figure 11 (a) and (c) show the line is descending from left to the right because both figures have negative proportional coefficients β and their values are -0.0234 and -0.4023 respectively. However, Figure 11 (b) show the line is ascending from left to the right because the figure has positive proportional coefficients β and the values is 0.000120507. By comparing the SN ratio η among all the figures, Figure 11 (c) is the highest with 0.00207, Figure 11 (a) is the lowest with 0.00000034 and Figure 11 (b) in moderate value with 0.00011. It shows that larger the SN ratio, closer the distribution to the straight line.



(a) (b) (c)

Figure 11: Output values and parameters scatter (normalized data)

The proportional coefficient β and SN ratio η are determined for the other parameters, as shown in Table 5.

Table 5: Proportional coefficient and SN ratio

No	Parameter	Proportional coefficient, β	SN ratio, η
1.	Solder check	0.00555	5.4E-05
2.	solder paste quality	-0.02338	3.4E-07
3.	Batch classification	0.00384	2.7E-05
…	…	…	…
49.	Packaging configuration	0.02618	0.001
50.	Box conditions	0.02641	0.00057
51.	Batch classification	0.02883	0.00066

Then, the estimated value of integrated MD is determined using the proportional coefficient β and SN ratio η, parameter by parameter. Figure 12 shows the distribution of actual and estimated values of integrated MD for 3560 samples. The model provides R^2 values of 0.8045. It means the model has a high level of correlation because the value is close to 1. The model also has SN ratio of -25.81 db. A high SN ratio means that the signal is clear and easy to detect or interpret, while a low SN ratio means that the signal is corrupted or obscured by noise and may be difficult to distinguish or recover.

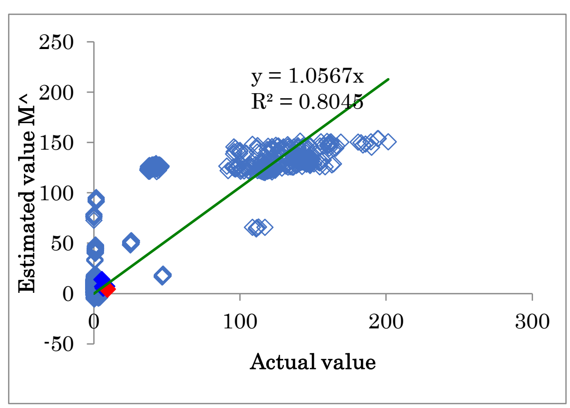


Figure 12: Distribution of actual and estimated values of integrated MD

All 51 parameters have been used for general estimation. Some of selected parameters are effectively for estimated values of integrated MD, while the others are not very effective. Thus, the L_{68} is selected to determine the degree of contribution. As shown Table 6, level 1 indicates the parameters will be used and Level 2 indicates the parameters will not be used to determine the degree of contribution.

Table 6: Proportional coefficient and SN ratio

No	Parameter	Level 1	Level 2
1.	Solder check	-26.2086	-26.2785
2.	solder paste quality	-26.2205	-26.2667
3.	Batch classification	-26.2251	-26.2620
…	…	…	…
49.	Packaging configuration	-26.1200	-26.3671
50.	Box conditions	-26.3664	-26.1208
51.	Batch classification	-26.2807	-26.2064

Furthermore, the creation of a SN ratio broken-line graph is illustrated in Figure 13. This graph demonstrates the ascending and descending line from Level 1 to Level 2 that significantly affects the output prediction. It has 27 ascending lines for parameters 6, 7, 9, 11, 14, 18, 19, 21, 24, 25, 27, 28, 29, 30, 32, 33, 36, 37, 38, 40, 42, 44, 45, 47, 50, and 51. However, there are 24 descending lines, for parameters 1, 2, 3, 4, 5, 8, 10, 12, 13, 15, 16, 17, 20, 22, 23, 26, 31, 34, 35, 39, 41, 43, 46, 48, and 49.

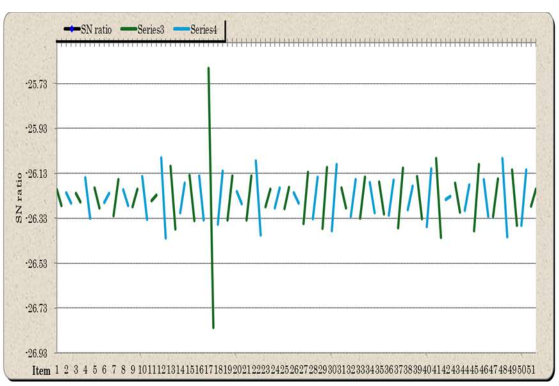


Figure 13: SN ratio broken graph for September

Therefore, Table 7 shows a summary the degree of contribution for 51 parameters in 2023. Red box indicates a negative degree of contribution to the parameter, whereas green box indicates a positive degree of contribution. In other words, positive degree of contribution has the impact of increasing the MD value, whereas negative degree of contribution has the impact of decreasing the MD value. It was found that parameter 38 and parameter 40 are consistently appeared as negative degree of contribution throughout the year. Parameters 17 and parameter 18 have minimum number of negative degree of contribution at least for 2 months. On the other hand, there are none of parameters are consistently appeared as positive degree of contribution throughout the year. Parameters 25 has minimum number of positive degree of contribution at least for 1 month. In overall, there are 34% parameters are classified in positive degree of contribution, whereas 66% parameters are classified in negative degree of contribution.

Table 7: Sub-activity used for bottom-side

Month	Parameters						
	1	2	3	…..	49	50	51
Jan	0.21	-0.05	0.11	…..	-0.51	-0.36	-0.63
Feb	-0.10	-0.10	-0.16	…..	0.11	-0.16	0.15
Mar	1.09	-0.27	0.21	…..	-0.11	-0.29	-0.38
April	-020	-0.31	-0.16	…..	-0.26	-0.23	-0.33
May	0.05	-0.19	0.69	…..	-0.07	1.03	-0.24
June	-0.07	-0.13	-0.22	…..	-0.14	-0.07	-0.12
July	-0.24	-0.01	-0.38	…..	-0.14	-0.30	-0.32
Aug	-0.03	-0.16	-0.15	…..	-0.35	-0.35	-0.04
Sept	0.07	0.05	0.04	…..	0.25	-0.25	-0.07
Oct	-0.02	0.002	-0.06	…..	0.07	-0.12	-0.09
Nov	-0.14	-0.02	-0.04	…..	-0.05	0.04	0.04
Dec	-0.02	0.08	0.15	…..	-0.05	-0.09	-0.09

4.2 TDABC Discussion

The TDABC technique begins with an analysis and identification of the industrial to comprehend its scope and precise sequencing of activities. Then, the cost of supplied resources refers to the total expenses incurred by an organization to make resources available for use in its operations or production processes. In this study, the cost of supplied resources are limited to labor, maintenance, material, and consumable as shown in Table 8. Due to private and confidential related to costing, some maintenance, material and consumable cost cannot be exposed to the public and declared as no applicable (NA). There is no maintenance cost because the machine is under the supplier's warranty and some sub-activity is not used the machine.

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Table 8: Total cost of resources supplied

Main activity	Sub-activity	Labor cost (MYR)	Maintenance cost (MYR)	Material cost (MYR	Consumable cost (MYR)	Cost resources supplied (MYR)
…	…	…	…	…	…	…
5. Insert component and wave solder	1. Put PCB into a wave pallet	9000.00	NA	NA	NA	9000.00
	2.Insert all component into PCB	9000.00	NA	176054.05	NA	185054.05
	3. Close the PCB with cover wave pallet	9000.00	NA	NA	NA	9000.00
	4. Enter the PCB into wave solder through conveyer	9000.00	NA	NA	1040.00	10040.00
…	…	…	…	…	…	…
12. Screwing and Pasting	1.Assemble platen block onto paper cover unit and screw	9000.00	NA	83937.75	4304.50	97242.25
	2.Paste NFC tag onto paper cover unit	9000.00	NA	27936.21	NA	36936.21
13. Screwing	1. Assemble OP PCB assy onto paper cover	9000.00	NA	120095.55	NA	129095.55
	2.Install paper cover support base onto paper cover and screw	9000.00	NA	1371844.15	8609.00	1389453.15
…	…	…	…	…	…	…

The main activity of inserting components and wave soldering (workstation 5) has labor cost of MYR9000.00 for every sub-activity. This main activity requires two operators with MYR1500 per month each of them. Subsequently, the annual cost is MYR 36000 for four sub-activities. There is no maintenance cost as the machine wave solder model WS-450 is under the supplier's warranty. The material cost is MYR176054 (43045 annual pieces * MYR4.09 per unit) for inserting all components into PCB. The consumable cost during sub-activity of inserting PCB into wave solder using conveyer is MYR1040.00 (200kg of solder * MYR5.2 per kg).

Next, a practical capacity is expressed as a proportion of actual productive work scheduled. It is true that a worker does not work eight hours straight without stopping for a break. In 2023, there are 241 working days, 20 public holidays and 104 weekends in Johor, Malaysia. The operators are working 20 days per month, and 8 hours and 30 minutes per day. The company allocated 1 hour for lunch break per day and 10 percent of training hours per day. Therefore, the net working hour for one day is 6 hours and 39 minutes for one shift.

The CCR calculates the cost of providing resources for an activity per unit of time using Equation 25. To determine practical capacity, subtract the time for breaks and training from the actual capacity, which is the total number of hours per year that workers and machines are available to work. Thus, the CCR for each sub-activity is summarized in Table 9.

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Table 9: Capacity cost rate for each sub-activity

Main Activity	Sub-activity	Cost resources supplied (MYR)	Practical capacity (Min/ Year)	Capacity cost rate (MYR/min)
…	…	…	…	…
3. Input Process	1.Check model name and quantity received with Production label	84328.75	48079.50	1.75
	2.Visual checking for all PCB	9000.00	48079.50	0.19
…	…	…	…	…
13. Screwing	1.Assemble OP PCB Assy onto paper cover	129095.55	48079.50	2.69
	2.Install paper cover support base onto paper cover and screw	1389453.15	48079.50	28.90
…	…	…	…	…

The highest CCR is determined for sub-activity of install paper cover support base onto paper cover and screw with 28.90 MYR/min. This happened because the material cost is very high with MYR1371844.15.

Moreover, the TDABC approach uses time estimation as a standard measurement for all sub-activities, and the time equation combines the unique characteristics of various sub-activities. Table 10 shows the time equation for each sub-activity.

Table 10: Time Equation for each sub-activity

Main activity	Sub-activity	Cycle time (Minute)	Time equation
1.X-ray Inspection	1.Detect porosity and voids in solder	4.00	$4.00X_1$
	2.Check geometric measurement of solder thickness and volume	5.00	$5.00X_2$
	3.Check correct location of solder	4.67	$4.67X_3$
…	…	…	…
25. Outgoing Inspection	1.Random check the carton or box	2.33	$2.33X_{58}$
	2.Stamp ID chop at production label	1.33	$1.33X_{59}$

The time equation is reflected by different complexity for each sub-activity. For example, the highest time equation is belong to main activity of x-ray inspection with 13.67 minutes because it has three sub-activities with high cycle time. The time equation for main activity is determined as shown in Table 11.

Table 11: Time Equation for each main activity

Main activity	Cycle time (Minute)	Time equation
1.X-ray Inspection	13.67	$4.00X_1 + 5.00X_2 + 4.67X_3$
…	…	…
25.Outgoing Inspection	3.67	$2.33X_{58} + 1.33X_{59}$

After that, capacity utilization is determined. The quantity needed for each cost driver is identified. By multiplying the quantity needed and cost driver, the time spend for each sub-activity is determined as shown in Table 12.

Table 12: Quantity needed and cost driver

Main activity	Variable	Sub-activity	Driver	Quantity	Description
…	…	…	…	…	…
6. Solderability check	X_{13}	1.Touch up solder at critical point if necessary	Quantity of solder (Kg/year)	36	3kg x 12 months
	X_{14}	2.Remove PCB from wave pallet and clean the solder place using solvent, cloth and brush	Quantity PCB on wave pallet (pcs/year)	7175	43045/6 (1 wave pallet have 6 PCB)
…	…	…	…	…	…
14. Assemble component and pasting label	X_{30}	1.Assemble paper roller	Number of paper cover (pcs/year)	43045	43045pcs of paper cover
	X_{31}	2.Clean paper cover support base pasting surface with ethanol	Quantity of ethanol (bottle/year)	24	2 bottles for 1 month
	X_{32}	3.Paste caution label B and roll set label	Quantity of label (pcs/year)	86090	2 type of label x 43045pcs of label
…	…	…	…	…	…

The total time and total cost are calculated for each main activity as shown in Table 13. For example, the total time for x-ray inspection is calculated through Equation 26.

$$\begin{aligned} Total\ time &= 4.00X_1 + 5.00X_2 + 4.67X_3 \\ &= 4.00(43045) + 5.00(43045) + 4.67(43045) \\ &= 588425.15 \text{ minutes} \end{aligned} \quad (26)$$

Table 13: Total time and total cost for each main activity.

Main activity	Sub-activity	Used time (Minute)	CCR (MYR/Minute)	Total cost (MYR)
1. X-ray Inspection	1. Detect porosity and voids in solder	172180.00	0.10	17218.00
	2. Check geometric measurement of solder thickness and volume	215225.00	0.10	21522.50
	3. Check correct location of solder	201020.15	0.10	20102.02
	Total	**588425.15**		**58842.52**
…	…	…	…	…
25. Outgoing Inspection	1. Random check the carton or box	41940.00	0.19	7968.60
	2. Stamp ID chop at production label	23940.00	0.19	4548.60
	Total	**65880.00**		**12517.20**

The total time and total cost for bottom side per year are 1,929,010.89 minutes and MYR 2,743,177.18. Lastly, the forecasting plan was developed to optimize the unused capacity of time and cost for better utilization as shown in Table 14.

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Table 14: Unused capacity for time and cost

Main Activity	Sub-activity	Practical capacity (Minute/year)	Used time (Minute)	Unused capacity of time (Minute)	Capacity cost rate (MYR/ minute)	Unused capacity of cost (MYR)
1. X-ray Inspection	1. Detect porosity and voids in solder	128212.00	172180.00	-43968.00	0.10	-4396.80
	2. Check geometric measurement of solder thickness and volume	128212.00	215225.00	-87013.00	0.10	-8701.30
	3. Check correct location of solder	128212.00	201020.15	-72808.15	0.10	-7280.82
	Total	**384636.00**	**588425.15**	**-203789.15**		**-20378.92**
…	…	…	…	…	…	…
17. Screwing	1. Assemble printer block onto paper holder emboss and hook	48079.50	10170.00	37909.50	0.19	7202.81
	2. screw all point	48079.50	11970.00	36109.50	2.02	72941.19
	Total	**96159.00**	**22140.00**	**74019.00**		**80144.00**
…	…	…	…	…	…	…
25. Outgoing Inspection	1. Random check the carton or box	48079.50	41940.00	6139.50	0.19	1166.51
	2. Stamp ID chop at production label	48079.50	23940.00	24139.50	0.19	4586.51
	Total	**96159.00**	**65880.00**	**30279.00**		**5753.01**

For the main activity of printing inspection, sub-activity of prepare printing inspection equipment has -22,757.63 minutes and MYR -4,323.95 of unused capacity of time and cost respectively. The sub-activity utilizes over resources and cost than the apportionment by the financial department. For the main activity of input process, sub-activity of perform printing inspection has 3212.85 minutes and MYR 867.47 of unused capacity of time and cost respectively. The sub-activity utilizes small resources and cost than the apportionment. For the main activity of assemble component and pasting label, sub-activity of paste caution label B and roll set label has 8808.70 minutes and MYR 2,202.18 of unused capacity of time and cost respectively. The sub-activity utilizes large resources and cost than the apportionment.

It was found that there are three types of unused capacity been identified. Type I declared as workstation is over-utilized the resources and cost of apportionment such as workstation 1, workstation 3, workstation 18, and workstation 21. This type is undesirable to be practised. Type II declared as workstation is small-utilized the resources and cost of apportionment such as workstation 2, workstation 4, workstation 6, workstation 7, workstation 8, workstation 9, workstation 12, workstation 15, workstation 17, workstation 19, workstation 20, workstation 23, and workstation 24. This type is undesirable to be practised. Type III declared as workstation is largely-utilized the resources and cost of apportionment such as workstation 5, workstation 10, workstation 11, workstation 13, workstation 14, workstation 16, workstation 22 and workstation 25. This type is desirable to be practised.

Figure 14 shows the used and unused capacity of time for all workstations. Workstation 1 is classified as Type I because it is over-utilized the resources of apportionment. This study suggests to consider additional one operator to enhance the productivity. Workstation 2 is classified as Type II because it is small-utilized the resources of

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apportionment. This study suggests to reduce the operator salary because it is directly proportional to the time equation. Workstation 25 is classified as Type III because it is largely-utilized the resources of apportionment and this is the desired condition.

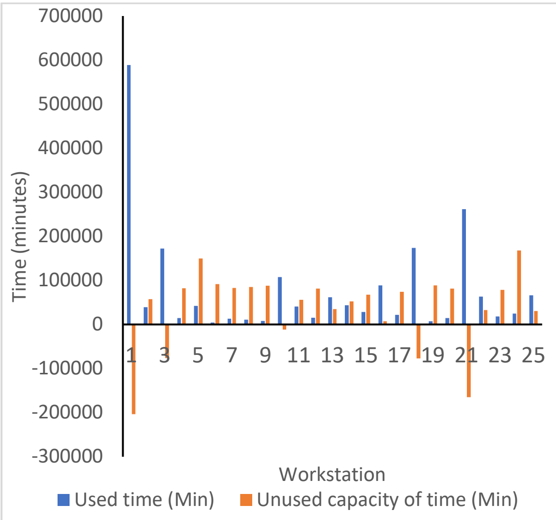

Figure 14: Used and unused capacity of time

Figure 15 shows the used and unused capacity of cost for all workstations. Workstation 1 is classified as Type I because it is over-utilized the cost of apportionment. This study suggests to reduce the cycle time which is less than 13.67 minutes. Workstation 12 is classified as Type II because it is small-utilized the cost of apportionment. This study suggests to reduce the material cost which is less than MYR1.95. Workstation 22 is classified as Type III because it is largely-utilized the cost of apportionment this is the desired condition.

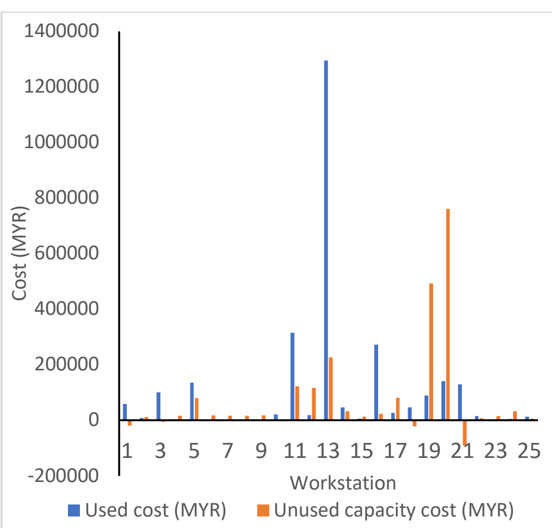

Figure 15: Used and unused capacity of cost

4.3 Framework of Integration

There are two types of degree of contribution. The first is positive degree of contribution means the increasing magnitude of parameter produces the effect of elevating the output of MD. The second is negative degree of contribution means the decreasing magnitude of parameter produces the effect of lowering the output of MD. Figure 16 shows the degree of contribution in 2023, is served as a reference for forecasting in creating a normal sample.

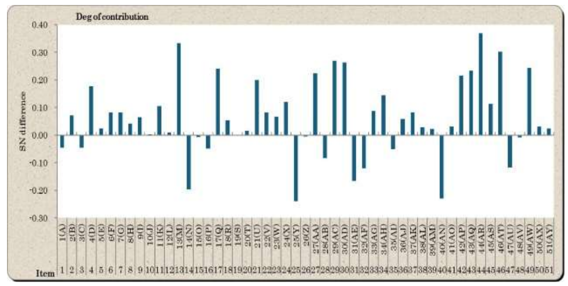

Figure 16: Degree of contribution in 2023

Table 15 shows a comparison of few models with their MD. The original model (sample with highest MD) with MD of 195.60 is selected because the intention of this study is to reduce the MD or lowering the rejection rate in production environment.

Table 15: Comparison of the original and modified versions

Model	MD
Original	195.60
1	139.81
2	161.16
3	120.96
4	87.98
5	105.53
6	129.78
7	131.92
8	168.38

The MD value of model 1 is 139.81, which is smaller than the MD value of original model. This model shows that the positive degree of contribution of higher level is increased the magnitude with two points (parameter 17, 21, 27, 29, 30, 42, 43, 44, 46, and 49), and with five points (parameter 13). The positive degree of contribution of lower level is increased the magnitude with one point (parameter 4, 5, 6, 7, 8, 9, 18, 20, 22, 23, 24, 33, 34, 36, 37, 38, 39, 41, 45, 50, and 51), and with seven points (parameter 10, 11, and 12). The magnitude for negative degree of contribution is maintained as it is. As a result, this model is rejected as the best model.

The MD value of model 4 is 87.98, which is smaller than the MD value of original model. The magnitude for positive degree of contribution is maintained as it is. The negative degree of contribution of higher level is decreased the magnitude with two points (parameter 14, 25, 31, 32, and 40). The negative degree of contribution of lower level is decreased the magnitude with one point (parameter 1, 2, 3, 15, 16, 19, 26, 28, 35, 47, and 48). As a result, this model is accepted as the best model.

Consequently, model 4 is the best model to reduce the rejection rate. It was found that the magnitude for positive degree of contribution is maintained as it is, the negative degree of contribution of higher level is decreased the magnitude with two points and the negative degree of contribution of lower level is decreased the magnitude with one point.

Figure 17 shows a framework by integrating the degree of contribution and cost driver for better product costing. The yellow colour indicates the parameters which reflected to the sub-activities in blue colour.

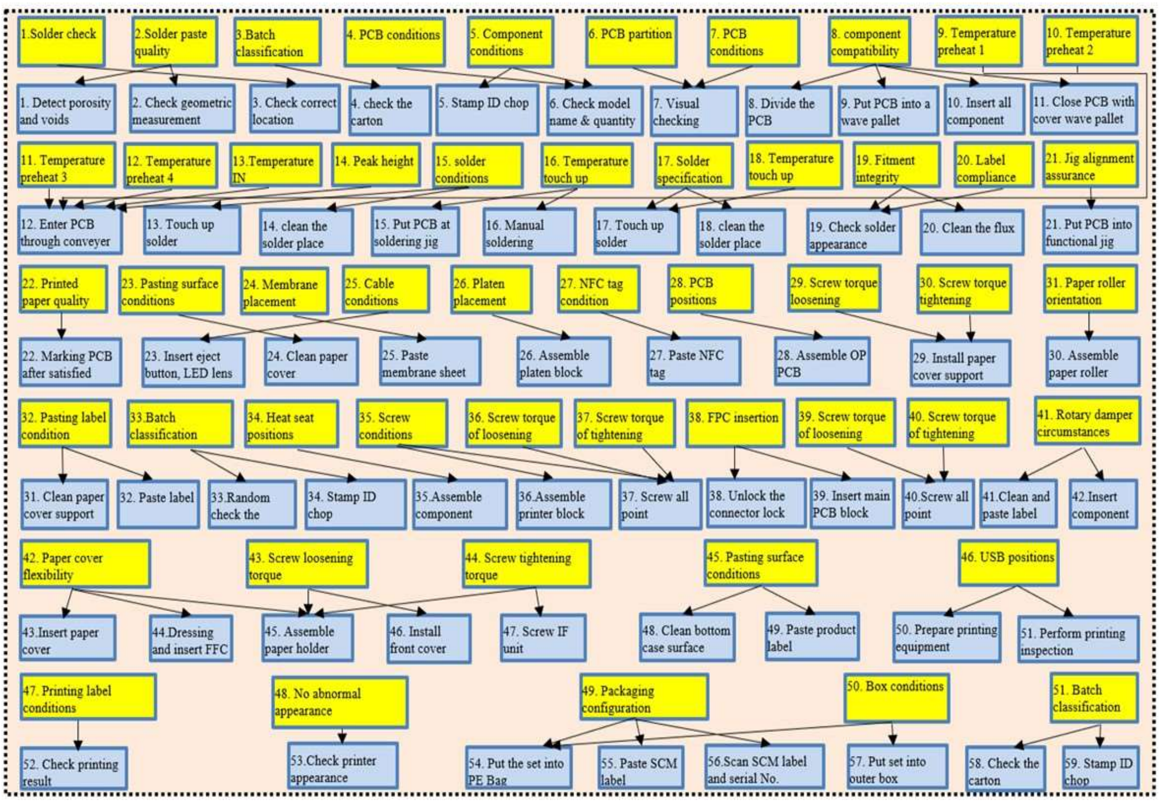

Figure 17: Framework of integration

Sub-activity 5, 6, 7, 8, 9, 10, 11, 17, 18, 21, 22, 24, 25, 27, 29, 33, 34, 35, 38, 39, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, and 52 are maintained their quantity of cost driver. Sub-activity 12, 23, 30, 31, 32, and 40 are generally decreased the quantity of cost driver by equivalenting two point with 100. Sub-activity 1, 2, 3, 4, 13, 14, 15, 16, 19, 20, 26, 28, 36, 37, 52 and 53 are generally decreased the quantity of cost driver by equivalenting one point with 100. Table 16 shows the result of unused capacity of time and cost.

Table 16: Unused capacity of time and cost

Main Activity	Sub-activity	Practical capacity (Minute/year)	Used time (Minute)	Unused capacity of time (Minute)	Capacity cost rate (MYR/ minute)	Unused capacity of cost (MYR)
1. X-ray Inspection	1. Detect porosity and voids in solder	128212	171780.00	-43568.00	0.10	-4356.80
	2.Check geometric measurement of solder thickness and volume	128212	214725.00	-86513.00	0.10	-8651.30
	3. Check correct location of solder	128212	200553.15	-72341.15	0.10	-7234.12
	Total	**384636.00**	**587058.15**	**-202422.15**		**-20242.22**
…	…	…	…	…	…	…
17. Screwing	1. Assemble printer block onto paper holder emboss and hook	48079.5	9492.00	38587.50	0.19	7331.63
	2. Screw all point	48079.5	11172.00	36907.50	2.02	74553.15
	Total	**96159.00**	**20664.00**	**75495.00**		**81884.78**
…	…	…	…	…	…	…
25. Outgoing Inspection	1. Random check the carton or box	48079.5	41940.00	6139.50	0.19	1166.51
	2. Stamp ID chop at production label	48079.5	23940.00	24139.50	0.19	4586.51
	Total	**96159.00**	**65880.00**	**30279.00**		**5753.01**

In order to verify that MTS and TDABC have a significant contribution to the final cost, a comparison between types of integration from previous works such as Kamil et al,. [45], and Zaini et al,. [46] is shown in Table 17.

Table 14: Cost through multiple integrations from previous works.

Author	Method	Conventional		MTS	
		ABC	TDABC	ABC	TDABC
	Component	Integration A	Integration B	Integration C	Integration D
Current study	Thermal printer	230.13	-	-	122.40
Zaini (2023)	Inductor	1.70	1.67	0.80	0.76
Kamil (2021)	Magnetic	2.50	-	-	2.00

To access the benefit of MTS and TDABC, the comparison is made between integration A and integration D. Integration A is actually the system being applied by the company, while integration D is the proposed solution from the current study, Zaini (2023) and Kamil (2021). It shows that the cost through integration D is cheaper than integration A because the MTS considers degree of contribution for each parameter which influence to the increment or decrement to the cost driver. TDABC develops capacity cost rate from the related cost of capacity supplied and time equations with high complexity which also influence to the increment or decrement to the final cost. This finding also has been supported by the cost per unit for both inductor and magnetic components which proved that integration D is cheaper than integration A.

5. CONCLUSION

This study concludes the research contribution by integrating the degree of contribution and cost driver for better forecasting. As a result, there are 34% parameters are classified in positive degree of contribution, whereas 66% parameters are classified in negative degree of contribution. For the main activity of printing inspection, sub-activity of prepare printing inspection equipment has -22,757.63 minutes and MYR -4,323.95 of unused capacity of time and cost respectively. There are three types of unused capacity have been identified such as Type I, Type II and Type III. Thus, the proposed framework is great because the degree of contribution reflected the increment or decrement to the cost driver in high production complexity for better product cost.

The limitation of this study is that it exclusively analyzes the process for the bottom side of the thermal printer to minimize complexity. It is recommended that future research compare the selected method with alternative quality and costing approaches, such as Grey relational analysis for multi-criteria decision-making and Variance Analysis for cost performance evaluation.

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