INTEGRATION OF MAHALANOBIS-TAGUCHI SYSTEM AND TIME-DRIVEN ACTIVITY-BASED COSTING FOR THERMAL PRINTER IN REDUCING VARIATION

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Thesis submitted in fulfillment of the requirements
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ABSTRAK

Sistem integrasi ialah proses pengembangan atau pelaksanaan seni bina atau aplikasi yang disesuaikan, serta penyatuan dengan perkakasan, perisian dan komunikasi baharu atau sedia ada, yang dikemas dan disesuaikan. Pencetak termal biasanya digunakan untuk mencetak tag dan label yang tersedia secara komersial daripada pelbagai pengeluar. Permintaan untuk komponen elektronik semakin meningkat. Oleh itu, penyediaan laporan penolakan mingguan untuk bahagian yang ditolak menujukkan tahap keterukan diperlukan. Tahap keterukan boleh menyumbang kepada penentukan parameter yang dapat mengenal pasti faktor penting. Sementara itu, pengekosan berdasarkan aktiviti (ABC) yang diterapkan sudah ketinggalan zaman kerana kaedah ini menggunakan wawancara atau tinjauan dalam memperoleh data bernombor yang mungkin mengakibatkan data yang salah digunakan untuk rujukan syarikat. Oleh itu, pengekosan berdasarkan aktiviti bersandarkan masa (TDABC) digunakan untuk pendekatan kerumitan produk yang berbeza. Oleh itu, terdapat tiga elemen yang perlu diutamakan dalam pertumbuhan perniagaan, iaitu masa, kualiti, dan kos. Hal ini kerana, integrasi adalah antara proses (parameter) yang boleh memberi implikasi kepada keuntungan (kos). Objektif utama penyelidikan ini adalah mengintegrasikan sistem Mahalanobis-Taguchi (MTS) dan TDABC di stesen kerja komponen elektronik. Terbukti, data pengumpulan diperoleh dari syarikat elektronik di Pasir Gudang, Johor Bahru yang memfokuskan kepada pengeluaran pemasangan papan litar bercetak (PCB). MTS mengoptimumkan 22 parameter di stesen kerja sisi atas termasuk suhu peti sejuk (°C), kelembapan peti sejuk (%), suhu bilik (°C) dan lain-lain. Data sampel yang digunakan untuk analisis parameter ialah sampel data 2022. Sementara itu, TDABC menentukan kapasiti yang tidak digunakan dengan mempertimbangkan parameter penting setelah persamaan waktu dan kadar kos kapasiti dihasilkan. Kos yang digunakan dalam pengiraan adalah kos tahunan. Kos sumber yang perlu dipertimbangkan adalah kos buruh, kos penyelenggaraan, kos material dan kos pakai habis. Hasilnya, analisis menunjukkan bahawa terdapat pertindihan ambang MD berlaku antara normal dan tidak normal pada setiap bulan. Hal ini disebabkan sampel data yang tidak normal mempunyai parameter bilangan kecil yang sepadan dengan keadaan yang tidak normal. Pada bulan Mac, pusat ambang MD normal dan tidak normal masing-masing ialah 2.827 dan 18.059. Pusat ambang MD normal dan tidak normal bagi bulan Jun pula ialah 2.826 dan 11.151, manakala pada bulan September ambang MD ialah 3.000 dan 183.137 sepadan. Tahap sumbangan menunjukkan parameter signifikan tertinggi dengan 16 parameter adalah pada bulan Oktober dan Disember. Sebaliknya, parameter yang paling tidak signifikan dengan 10 parameter adalah pada bulan Ogos. Seterusnya, TDABC digunakan untuk melakukan analisis penggunaan kapasiti dalam mendiagnosis kapasiti masa dan kos yang digunakan dan tidak digunakan. Kajian ini memperakukan bahawa kemasukan PCB ke dalam sub-aktiviti mesin pemuat automatik mempunyai kapasiti masa yang tidak digunakan yang tinggi (239,550 minit) dan kos (RM18,120.67) yang menjadikan stesen kerja ini dapat mengurangkan kapasiti yang tidak digunakan dengan memindahkan bilangan pekerja ke stesen kerja beban lain. Sebaliknya, tenaga kerja tambahan perlu disediakan dalam sub-aktiviti penyediaan tampal pateri kerana ia mempunyai kapasiti masa yang digunakan (-790,100 minit) dan kos (RM-1,000,535.13) untuk meminumkan penggunaan kapasiti. Akhirnya, sistem integrasi antara tahap sumbangan dan kapasiti yang tidak digunakan telah mengurangkan sisa dan membuat ramalan yang lebih baik untuk rujukan syarikat pada masa akan datang.

ABSTRACT

System integration is the process of creating or deploying a customized application or architecture, as well as combining packaged and customized software, communications, and new or pre-existing hardware. The thermal printer is ordinarily used for printing commercially available tags and labels from various manufacturers. The demand for electronic components is increasing. Thus, the preparation of weekly rejection report for rejected parts to indicate the severity level is needed. The severity level can contribute in deciding the parameters that can identify the significant factors. Meanwhile, the activity-based costing (ABC) approach currently in use is outdated since it relies on interviews or surveys to acquire numerical data, which might result in erroneous data for the company's reference. As a result, time-driven activity-based costing (TDABC) is applied to various product complexity techniques. So, there are three elements that need to prioritize in business growth, which are time, quality, and cost. This is because, the integration between process (parameter) can give impact to the profit (cost). The primary objective of this study is to merge the Mahalanobis-Taguchi system (MTS) with the TDABC at an electronic component workstation. The data was gathered from an electronics company in Pasir Gudang, Johor, that specializes in printed circuit board (PCB) assembly manufacture. MTS optimizes a total of 22 parameters at the top-side workstation, which includes refrigerator temperature (°C), refrigerator humidity (%), room temperature (°C), and others. The sample data used for the parameter analysis is 2022. On the other hand, TDABC calculates underutilized capacity by taking into account the main factors provided by the time equation and capacity cost rate. The costs used in the calculation are annual costs. The resource costs to consider are labor costs, maintenance costs, material costs, and consumable costs. As a result, the analysis shows that there are MD threshold overlaps occurred between normal and abnormal for each month. This is because the sample of abnormal data has a small number parameters corresponding to the abnormal condition. In March, the centre of normal and abnormal MD threshold is 2.827 and 18.059 respectively. The June MD thresholds for normal and abnormal are 2.826 and 11.151, whereas the September MD thresholds are 3.000 and 183.137. The degree of contribution shows the highest significant parameters with 16 parameters is in October and December. In contrast, the least significant parameters with 10 parameters are in August. TDABC is then utilized to perform capacity utilization analysis in order to diagnose the used and unused capacity of time and cost. It is acknowledged that the PCB input into auto loader machine sub-activity has a high unused capacity of time (239,550 minutes) and cost (MYR18,120.67) which makes this workstation able to reduce the unused capacity by transferring the number of workers to another load workstation. On the contrary, additional labor should be provided in the solder paste preparation sub-activity as it has overutilized capacity of time (-790,100 minutes) and cost (MYR-1,000,535.13) in order to minimize the capacity utilization. Lastly, the system integration between degree of contribution using MTS and unused capacity utilization using TDABC has reduced the waste and improve forecasting for the company reference in the future.

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LIST OF SYMBOLS

β	Sensitivity
η	Signal to Noise Ratio
L	Linear formula
r	Effective divider
S_T	Total variation
S_B	Variation of proportional term
S_e	Error variation
V_e	Error variance

LIST OF ABBREVIATIONS

ILO	International Labour Organisation
E&E	Electrical and Electronics
GDP	Gross Domestic Product
RCA	Revealed Comparative Advantage
PCB	Printed Circuit Board
SMT	Surface Mount Technology
MTS	Mahalanobis-Taguchi System
MD	Mahalanobis Distance
LCA	Life Cycle Assessment
LCC	Lice Cycle Cost
TDABC	Time-Driven Activity-Based Costing
ABC	Activity-Based Costing
IPU	Integrated Practice Unit
IC	Integrated Circuit
ALBP	Assembly Line Balance Problem
PMI	Purchasing Managers' Index
FMCO	Full Movement Control Order
OA	Orthogonal Array
SNR	Signal To Noise Ratio
DOC	Degree of Contribution
MSPC	Multivariate Statistical Process Control
NPMPC	Nonparametric Prediction-based Multivariate Process Control
ACLR	Anterior Cruciate Ligament Restoration
CCR	Capacity Cost Rate
EMS	Electronics Manufacturing Services
IPO	Initial Public Offering
CCTV	Closed Circuit Television
SOP	Safety Operating Procedure
AOI	Automated Optical Inspection
VMI	Visual Manual Inspection
PE	Polyethylene

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The large number of electrical and electronics (E&E) products that are produced is a consequence of multiple contributing factors. One of the factors that greatly affects the production is the total of employment in manufacture the E&E components. The estimated total employment from the International Labour Organization (ILO) sectoral activities branch in the manufacture of E&E products worldwide is 18 million workers. According to sector source statistics, the great majority of workers in this large industrial area are heavily concentrated in just 20 nations, which account for about 87 percent of the global total in 2004. These 20 nations include Japan (9%), the United States (7%), the Russia Federation (5%), Germany (4%) and the Republic of Korea (4%), which are among the major employers. Together, these five nations and China (35%) account for almost two-thirds of total employment in this sector (International Labour Organisation, 2007).

China's electronics industry has risen rapidly since 2001, with double-digit growth rates until the global economic crisis struck in late 2008. However, as the Chinese government's stimulus package encouraged recovery, the industry began to slowly rebound in the second half of 2009. Analysts predict that the industry will grow by 6% in 2010. Even in the middle of the global economic crisis, China's electronics industry accounted for more than 30% of overall trade in prior years. China imports electronics from a wide range of countries, including Taiwan, South Korea, Japan, Malaysia, the United States, Thailand, the Philippines, Singapore, and Germany. Meanwhile, China sold electronics mostly to Hong Kong, the United States, Japan, South Korea, the Netherlands, Germany, Singapore, Taiwan, the United Kingdom, and India in 2009 (APCO worldwide, 2010).

Malaysia's remarkable history of development and transformation over the previous half-century has been driven mostly by two factors which are Malaysia's conventional industries and E&E industry. Oil and gas, tree crops (rubber, oil palm), and E&E are some of Malaysia's conventional industries. In 1972, intel established its first offshore assembly plant on the island of Penang. Malaysia currently houses many of the world's largest electronics manufacturers. Approximately 18% of Malaysia's gross domestic product (GDP) and 22% of its total exports were attributed to this industry in 2012. Among the 14 nations, Malaysia comes in fourth for the percentage of every product in the E&E sectors where it has revealed comparative advantage (RCA). It transported an astounding 73% of all products in this category in 2012. Malaysia now has RCA in ten of the twelve items in the semiconductors and electric circuits cluster (Director General Economic Planning Unit, 2014).

A production line is a series of machines in a factory that move things from machine to machine until it has been finalised. In the printed circuit board (PCB) assembly process, Surface Mount Technology (SMT) has been widely utilized. A PCB loader, a solder paste machine, SMT machines, and a reflow oven are common parts of SMT production line (Li et al., 2019). These actions are called as workstation. A workstation is any location on the production line where operators perform a task on a manufactured component. E&E (15.5%), transport equipment and other manufactured products (12.4%), and non-metallic mineral products, basic metal and fabricated metal products (5.2%) were the major subsectors that contributed to the growth of the Manufacturing sector. Both the domestic and export-oriented industries grew by 8.7% and 6.1%, respectively.

Production lines include job-based planning, batch methods, flow methods, mass production methods, and process manufacturing methods. Thus, the mass production method will be applied in this research as the PCB manufacturing focus will used in this research. In the area of mass production, there are typical manufacturing procedures dedicated to the fabrication of a single type product and/or its variants. Furthermore, there are other components of a conventional manufacturing system that must be thoroughly considered (Mokhena et al., 2016).

The classification issue is a widely researched topic in machine learning that attempts to create a formula or algorithm from an initial dataset for predicting the categories of unknown occurrences. In reality, classification is an optimization issue that requires improved method. Meanwhile, the aim of optimization approach is to identify the largest or least value of the objective function given limitations. Science and technology frequently employ optimization approach (Xue et al., 2022).

Classification and optimization can be classified into several techniques to assist researchers choose the appropriate tools. The classification tools are thesaurus that list words semantically not alphabetically like dictionaries, business classification is an organization’s business activity, and record classification scheme is a hierarchical categorization method (Tasmanian Archives Heritage Office, 2014). Next, optimization tools are deterministic that uses linear algebra and stochastic which uses randomization-based search methods that may be combined in different ways (Cavazzuti, 2013).

The Mahalanobis-Taguchi system (MTS) is a multivariate diagnostic and predicting approach. MTS measures degree of contribution using the Mahalanobis distance (MD) and scale-based predictions using the Taguchi method. MTS is a very cost-effective method to multivariate recognition of patterns systems. The study of hoe to perceive, differentiate, and intelligently classify patterns is known as pattern recognition. An example application of MTS is predicting wafer yield by determining electrical and dust variations. For diagnostics, MD pattern recognition diagnoses human health. MD summarizes multivariate functional test findings into one scale (Cudney et al., 2009).

According to Luo et al. (2023), traditional MTS reduces multidimensional system dimensionality and measures abnormal degree of observations. The paper aim is to improve the standard MTS approach using Mason-Young-Tracy based weighted MD decomposition approach in identifying abnormal data. The diagnosis system components are then reduced by 37.5% and abnormal circumstances are discriminated from the health group by 102%. The RT method is a perceptual T method that can categorise objects into two categories of within and outside of unit space while T method is utilised to identify relevant parameters, and the unit space is uniform with average output values (Teshima et al., 2012).

Cost accounting is described as the estimation and provision of costs and other resource procurement and utilisation data for financial and management accounting. Cost accounting is a quantitative information system that assists in the planning, control, and making of economic option (Lew et al., 2017). Financial accounting provides adequate cost accounting, typically integrated with management accounting tools. Cost accounting requires continuous and systematic cost data collection. Properly prepared information is utilised to regulate costs, optimized structure and size (Lew, 2019).

Life cycle analysis (LCA) and life cycle costing (LCC) techniques are often utilised in building designs. The first focuses on environmental conservation, while the second optimises cost. LCA and LCC evaluations assessed numerous residential construction concepts for economic and environmental effect (Dejaco et al., 2020). From a perspective of society, LCA analyses the environmental performance of different product systems that accomplish an identical end-user function. However, LCC assesses different investments and decisions about business made by economic decision-makers such as manufacturers and customers (Norris, 2001).

Time-driven activity-based costing (TDABC) is a technique that aims to solve difficulties in activity-based costing (ABC). This approach estimates management resource unit hours and capacity using time. TDABC is easier, affordable, and far more effective than traditional ABC. TDABC simply requires to estimate the price of capacity unit and activity time unit (Wu et al., 2011). TDABC provides a platform for identifying process improvements in health care delivery. TDABC applied to a patient care episode identifies rate-limiting procedures, reduces duplication, and may result in cost reductions (Martin et al., 2018).

Jayakumar et al. (2023) claims, integrated practice units (IPU) for specialist conditions-based care are required to understand the total care costs. The aim of the research was to develop a TDABC approach to compare IPU nonoperative management with conventional management and IPU operative with conventional management for hip and knee osteoarthritis treatment costs and savings. According to the suggested technique, IPU nonoperative management had lower weighted average costs than conventional nonoperative management and operative management than conventional operative management.

1.2 Problem Statement

The company under study identified the failures in components by preparing weekly rejection reports. As illustrated in Figure 1.1, there are 17 detectable rejected parts, including misalignment, missing parts, tombstones, and others. However, the report does not indicate how bad the severity of each rejected part. If this continues, the impacts will prevent the company to be unaware of the severity level and also it is not possible to identify the significant factors that are important for long-term use in deciding which parameters can be resolved to save insignificant financial cost, time of operational function or the company's reputational damage (Gupta, 2023). Besides, initial failures or infant mortality related to product malfunctions in the field create warranty issues and have an impact on the company's financial situation. It might have long-term consequences for the company's reputation in its sector (Hegde, 2023).

ITEMS	0		0		0		0		35		36		37		38		39	
Total no. of Comp.	0		0		0		0		725,868		2,200,728		1,251,452		1,495,836		1,418,776	
	qty	ppm	qty	ppm	qty	ppm	qty	ppm	qty	ppm	qty	ppm	qty	ppm	qty	ppm	qty	ppm
Misalignment	0	0	0	0	0	0	0	0	2	3	5	2	4	3	1	1	3	2
Missing	0	0	0	0	0	0	0	0	0	0	3	1	1	1	4	3	0	0
Tombstone	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0
Inverted Comp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Wrong Comp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Solder Short	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cold Solder	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dry Joint	0	0	0	0	0	0	0	0	0	0	3	1	3	2	0	0	3	2
Insufficient Solder	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Solder Ball	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wrong Orientation	0	0	0	0	0	0	0	0	0	0	1	0	2	2	0	0	2	1
Lifted Lead	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Excess Solder	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Overturn	0	0	0	0	0	0	0	0	1	1	2	1	5	4	5	3	4	3
Flying Chip	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reverse	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Others	0	0	0	0	0	0	0	0	1	1	0	0	1	1	0	0	1	1
TOTAL	0	0	0	0	0	0	0	0	5	7	16	7	16	13	10	7	15	11
TARGET < ppm >	75		75		75		75		75		75		75		75		75	

Figure 1.1 Printed circuit board rejected types

The connection between the reliability of financial accounting data exposure and the efficacy of allocate resources effects a company's development. As a result, the corporation has to regulate this connection and intuitively combine both in order to assist with corporate manufacturing and operational management (Malhotra, 2023). Yet, some companies used ABC method to allocate overhead and indirect expenses to relevant products and services. ABC system is estimated through interviews or surveys based on product complexity with the workers at the company. From the interviews or surveys, the approximate number of hours the machine breaks down monthly or how much production can be produced in one shift is acquired. This method will arise in inaccurate data for the company's reference.

In addition, the company need to prioritize three important elements that are related to time, quality, and cost for the growth of the business. Time reflects the project completion time, cost symbolises the available money or resources, and quality implies the project need to be fit-to-purpose to success. Furthermore, system integration is also important since it can successfully create profit while balancing the market (Vatandoust et al., 2023). Nevertheless, the company under study did not clarify clearly the relationship between quality and costs, since the total cost are confidential. Therefore, the relationship between processes (parameter) in the impact on profitability (cost) is not visible without the system integration.

1.3 Objective of the Research

1. To determine the degree of contribution of parameters in the production environment using MTS.

2. To analyse the capacity utilization of time and cost in the production environment using TDABC.

3. To integrate the degree of contribution and capacity utilization of time and cost in the production environment for thermal printer.

1.4 Research Question

1. How far the degree of contribution of parameters relatable to the production environment?

2. How does the unused capacity effect the time and cost in the production environment?

3. How does the degree of contribution and unused capacity of time and cost influence the production environment?

1.5 Scope of Study

1. The research focused on production line of thermal printer.
2. The industry company location of data collection is in Pasir Gudang, Johor.
3. The methods used are MTS and TDABC.

1.6 Organization of the Thesis

This research is separated into five chapters. Firstly, chapter 1 delivers an overview of the research background and conceptual framework. The analyses research papers are conducted in chapter 2. Alternatively, chapter 3 describes in outline research methodology in details. The collected findings will be documented in chapter 4. Finally, chapter 5 summarises the findings of the research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the contribution factors towards production of electronic component in Global, ASEAN and Malaysia are described. The efficiency of production line and mass production benefits also been explained in this chapter. The MTS and TDABC definition from different authors, concept, method, application, advantages and disadvantages is elucidated thoroughly. MTS's research gap focuses on case studies/applications, while TDABC focuses on verify unused capacity.

2.2 Production of Electronic Component

2.2.1 Global

Due to high COVID-19 immunisation rates, a service rebound, and economic measures, the economy of the United States, Europe, and other sections of the developed world remained strong in 2021. While coronavirus variations impeded recovery and parts and materials supply delays hampered production in some locations, the impact on economic activity was minimal in the developing countries. Demand for solution service is expected to rise in the face of growing investment in digitization to build the essential telecommunications infrastructure for 5G and telework, which will aid in the prevention of pandemic spread and attain carbon neutrality throughout society as a whole. From Figure 2.1, electronic components and devices are predicted to increase rapidly as a result of the transition to electric cars and the increasing percentage of electrical componentry in automobiles utilised for better safety performance, as well as demand for eco-friendly products such as renewable energy, and others (JEITA, 2020).

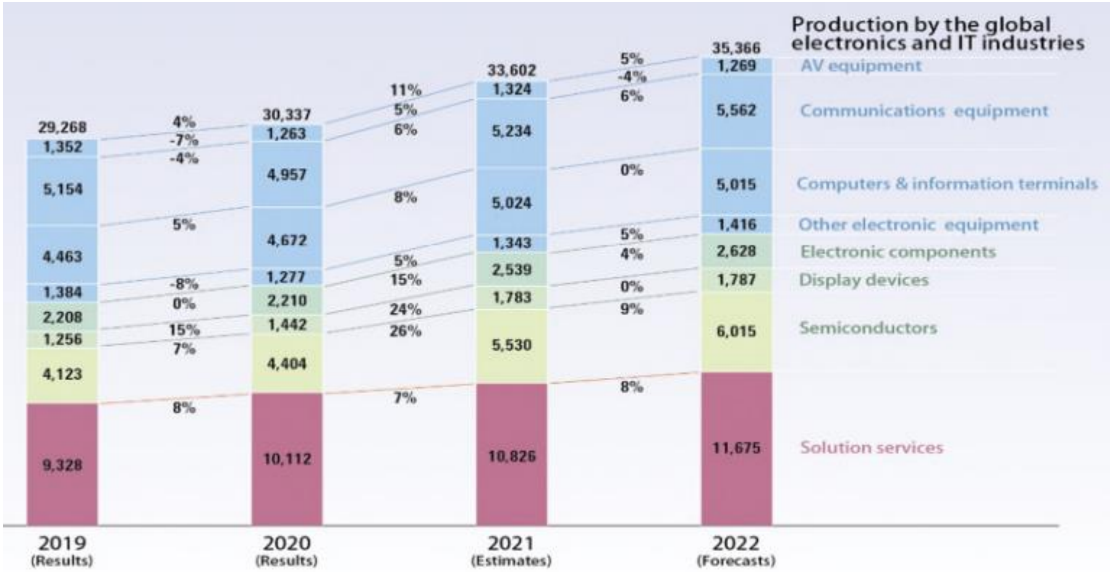


Figure 2.1 Global electronics and IT production

Source: JEITA (2020)

In recent years, the solutions mentioned in the trends have evolved from a tabulating machine to a more programmable system. These developments are accelerating, resulting in computers that are more intelligent and capable of processing the massive volumes of data created by smartphones and other devices. Figure 2.2 depicts similar patterns, where estimates made some years ago predicted a significant increase in the number of devices accessible internationally. These forecasts are very accurate in that they show the path to increasing integration as the device or product type changes. They support the concept and extension of the bring your own device paradigm, and usability improvements will drive growth as traditional (x86 legacy) desktop computing capabilities become less important (Kobeda et al., 2016).

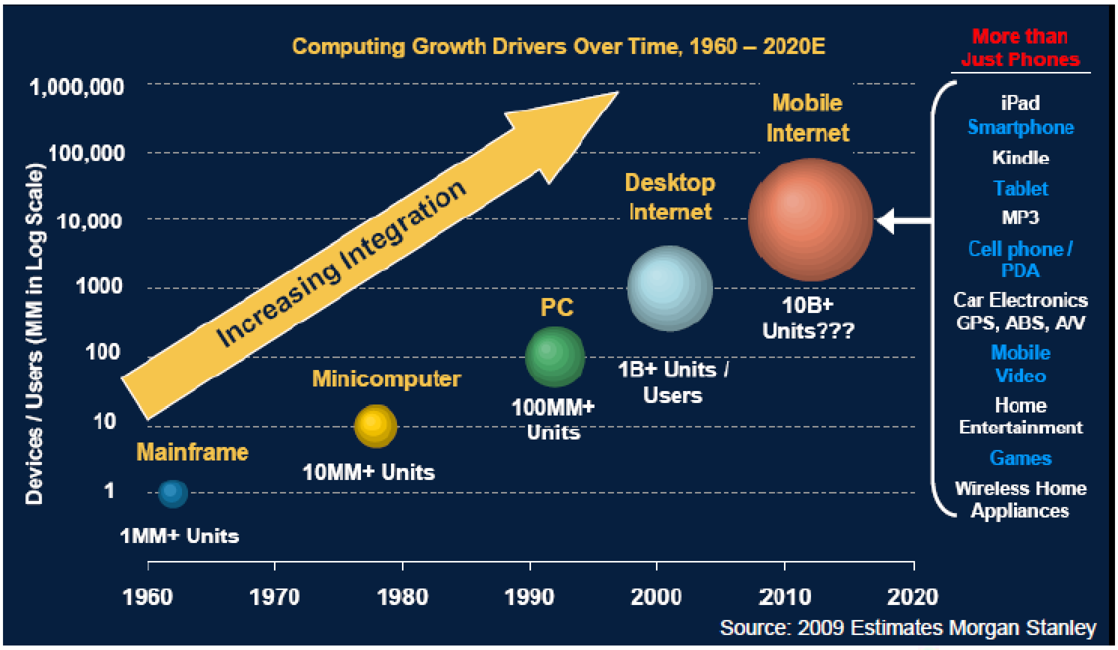


Figure 2.2 New and emerging technologies in electronics
Source: Kobeda et al. (2016)

2.2.2 ASEAN

Manufacturing of E&E is an important goods-producing industry. A product may be produced by hundreds of companies in various nations. One factor that makes this feasible is the substantial value-to-weight ratio of electronics components and most finished products, resulting in shipping across borders highly affordable. Manufacturing of E&E components is one of the most renowned industries in ASEAN and a significant contributor to economic development. This is especially true as the sector evolves along the supply chain in manufacturing and moves beyond low-cost manufacturing. As shown in Figure 2.3, the industry employs over 2.5 million individuals across ASEAN. The majority of ASEAN E&E production is focused on parts such as integrated circuits (IC), semiconductor devices, and printed circuit boards (PCB) (Indorf, 2018).

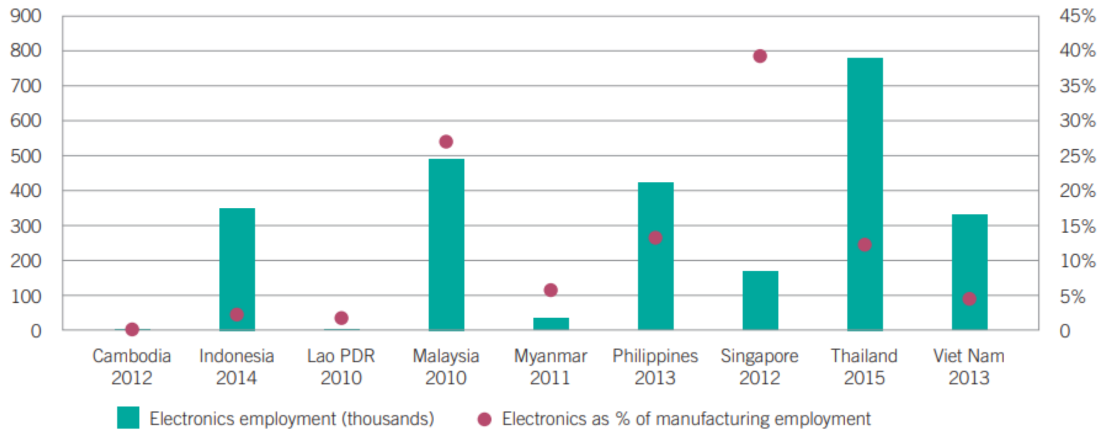


Figure 2.3 ASEAN total manufacturing and E&E product manufacturing employment

Source: Indorf (2018)

The diversified E&E activities of ASEAN make it particularly appealing location for manufacturers and investors. Each member nation provides its unique skills and experience, from advanced technologies design discovery and creativity to less-skilled assembly and packaging, allowing the whole area to serve varied E&E sub-sectors. Singapore's production capabilities are in ICs, semiconductor components, and PCBs. Vietnam's appeal comes from its minimal labour costs. In term of the final issue, ASEAN's low labour costs have become a big draw and crucial investment consideration for many electronics manufacturers. Table 2.1 provides an overview of the E&E expertise of each ASEAN member state (Indorf, 2018).

Table 2.1 ASEAN E&E sector preview

Country	Indonesia	Malaysia	Philippines	Singapore	Thailand	Viet Nam
Key Production	IC, semi-conductor, PCB	Semi-conductor, microchip, conductor, valve, household appliances, radio equipment, solar cell, PCB	IC, semi-conductor, electronic data processing (PCB, printer, hard disk)	Semi-conductor, silicon wafers, hard disk component	Hard disk drives, IC, microchip, air conditioning unit, refrigerator	IC, semi-conductor, PCB
Contribution to GDP (%)	2.1 (2014)	9.8 (2013)	13.8 (2013)	5.3 (2013)	15 (2015)	23.4 (2014)

Table 2.1 Continued

Country	Indonesia	Malaysia	Philippines	Singapore	Thailand	Viet Nam
Contribution to total exports (%) (2014)	7.0	36.5	52.5	41.2	24.1	25.4
Major export markets	China and Japan	China, Hong Kong (China), Japan, Singapore and United States	China, Hong Kong (China), Taiwan (China), Japan and Republic of Korea	China, Hong Kong (China), and Malaysia	ASEAN, China, Hong Kong (China), Japan, and United States	China, Malaysia and Singapore
Major players	Toshiba, LG, Sony, Panasonic, Samsung	Bosch, Fairchild, Hewlett Packard, Hitachi, Silterra, Intel	Texas Instrument, Fairchild, Amkor, Toshiba, Epson, Fujitsu	Avago, Fairchild, Micron, Seagate, Hitachi, Flextronics, Sanmina, Lite-On, Wistron	Fujitsu, LG, Electronics, Samsung, Seagate, Sony, Western Digital Bosch, Daikin, Electrolux, LG, Panasonic, Samsung, Siemens, Toshiba	Intel, Microsoft, LG, Panasonic, Samsung, Hitachi, Active-Semi, Hanel, Fuji, Xerox

Source: Indorf (2018)

Since the 1970s, Malaysia's E&E sector has contributed significantly to exports. Malaysia exported E&E supplies worth 372.67 billion Malaysian ringgit (MYR) (about US$87 billion) in 2019, accounting for 37.8% of total exports and 44.7% of maufactured exports. China, the United States, Singapore, Hong Kong SAR, China, and Japan are the country's major export destinations. Figure 2.4 depicts the composition of the country's E&E exports in 2018: electronic components (57.2%), final electronic goods (30.6%), final electrical products (6.4%), and electrical equipment (5.6%). Electronic ICs and micro assemblies accounted for more than 80% of all electronic components shipped. Malaysian exports have continuously increased over the last 30 years, however sales to certain marketplaces (such as computers and consumer electronics) have been decreasing since 1999 (Eltgen et al., 2021).

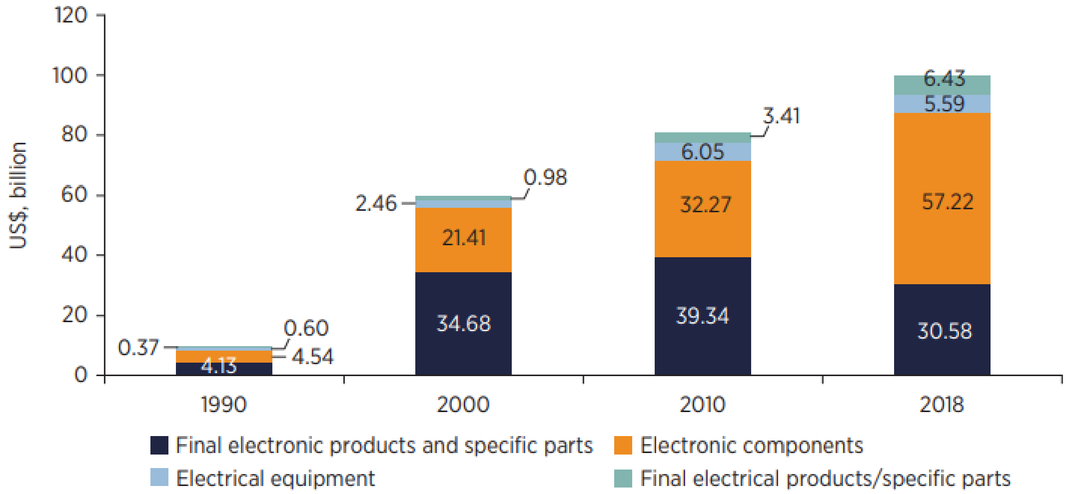


Figure 2.4 Malaysia's electrical and electronics exports structure

Source: Eltgen et al. (2021)

AS indicated in Table 2.2, Malaysia is a prominent worldwide stakeholder in E&E products, contributing to 2.8% of global E&E exports in 2018 (4% of global E&E component exports and 2% of global E&E final products and subassemblies). However, although Malaysia's total exports have increased considerably, its percentage of E&E exports to East Asia and the Pacific region, as shown in Figure 2.5, has fallen over the previous two decades. The main cause for this drop is due to a considerable shift in worldwide and region revenues to China during the exact same period, According to Table 2.2, China's sales of E&E components went up from 4% worldwide and 8% in East Asia and Pacific in 2000 to 17% globally and 28% in the region in 2018. China's proportion of E&E final products and subassemblies exports has increased much further (Eltgen et al., 2021).

Table 2.2 East Asian and Pacific nation's E&E exports and market share

	Value (US$, billion)				CAGR (%)	World (EAP) market share (%)			
	1990	2000	2010	2018		1990	2000	2010	2018
E&E components									
Malaysia	5.14	23.87	38.33	62.80	9	7 (11)	5 (11)	4 (8)	4 (7)
China	–	18.18	144.98	249.51	22	0 (0)	4 (8)	16 (31)	17 (28)
Japan	26.27	72.94	88.06	77.35	4	35 (58)	14 (33)	10 (19)	5 (9)
Korea, Rep.	6.54	29.06	58.88	144.26	12	9 (14)	6 (13)	6 (13)	10 (16)
E&E final products and subassemblies									
Malaysia	4.50	35.67	42.75	37.00	8	3 (4)	4 (12)	3 (6)	2 (3)

Table 2.2 Continued

	Value (US$, billion)				CAGR (%)	World (EAP) market share (%)			
	1990	2000	2010	2018		1990	2000	2010	2018
China	–	50.64	446.97	694.88	26	0 (0)	6 (17)	31 (62)	34 (58)
Japan	67.72	39.16	60.55	50.31	-1	42 (65)	5 (13)	4 (8)	2 (4)
Korea, Rep.	10.54	89.39	66.01	59.55	6	7 (10)	11 (30)	5 (9)	3 (5)

Source: Eltgen et al. (2021)

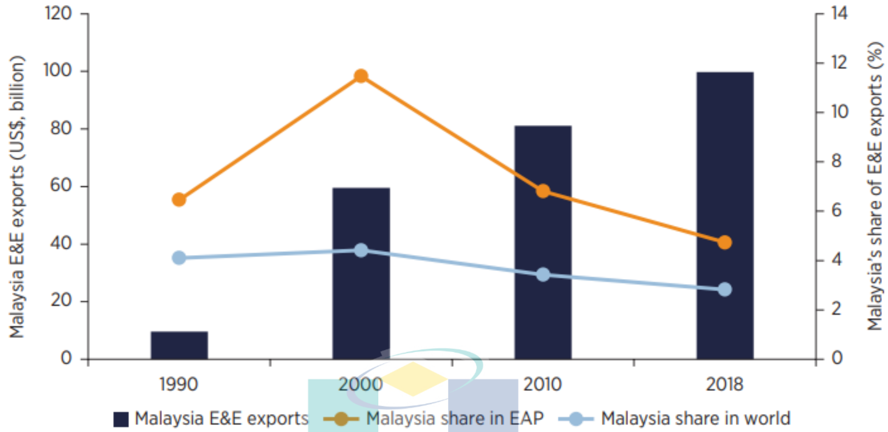


Figure 2.5 Malaysian total E&E exports and share in East Asia and Pacific

Source: Eltgen et al. (2021)

This section highlights the global growth of electric components is driven by the rising use of electric vehicles and eco-friendly products. The dominance of ASEAN countries, particularly Malaysia, in the E&E manufacturing industry in East Asia and the Pacific highlights the sector's importance in driving economic development and progress.

2.3 The Efficiency of Production Line

A manufacturing system in which parts are consecutively assembled on unidirectional stages until the finished product completed is known as an assembly line. A conveyor belt connects these stations. Each station conducts a subset of activities periodically over a predetermined time period known as the cycle time. The duration of time allotted to accomplish a work is referred to as the task time, and the station time is calculated by adding up all of the task durations that are assigned to a certain station. To describe the sequence of tasks, partial precedence constraints are added that is represented by a precedence graph. Figure 2.6 shows 10 assembly tasks, with the numbers above the circles representing task timeframes and the directed edges representing assembly precedence constraints (Li et al., 2017).

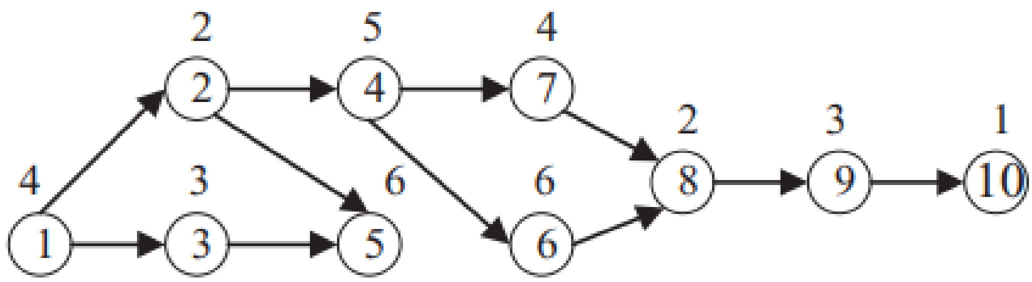


Figure 2.6 Precedence graph

Source: Li et al. (2017)

Standard straight assembly lines and U-shaped assembly line are two types of assembly lines. Every operator on a conventional straight assembly line operates in the same direction. However, since the U-shaped assembly line is separated into two sub-lines (receiving and shipping), operators may work on one or both of these sub-lines simultaneously. Because of the strict precedence constraints within activities in a U-shaped assembly line, every task can only be performed on the entry sub-line after all of its predecessors are finished, or an exit sub-line when all of its successors are finished as well. For simplicity, a task with completed predecessors or successors are referred to as the entry task or exit task.

As shown in Figure 2.7, the 10 activities bound by the precedence relations in Figure 2.6 will be executed in a straight or U-shaped assembly line. When the cycle period is set to 12, the straight line necessitates four stations, but the U-shaped line necessitates just three. Furthermore, in a straight line, task 6 is limited to being assigned to station III, but in a U-shaped line, it may be the entry and departure task. In compared to straight lines, U-shaped lines may assign more eligible activities to stations while maintaining higher balancing efficiency. If compared with straight assembly lines, U-shaped lines convey various benefits, including greater assignment versality, reduced work-in-process inventory, better equipment utilisation, and lower handling of materials costs (Li et al., 2017).

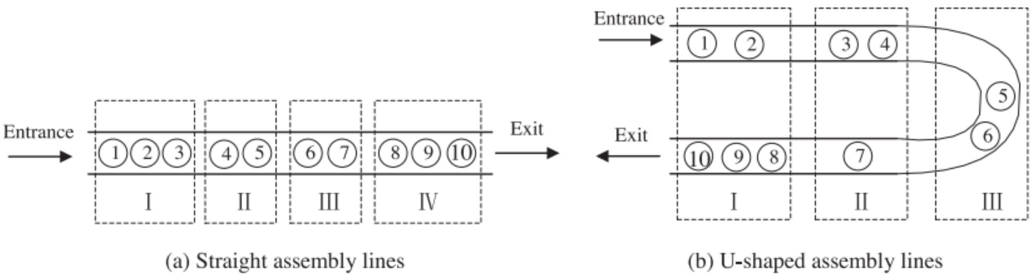


Figure 2.7 Task assignments on two assembly lines in same cycle period
Source: Li et al. (2017)

It is critical to design and balance an assembly line for any industrial product since it minimises unnecessary trial and error processes as well as the high expenses connected with it. The assembly line balance problem (ALBP) entails a number of critical factors that needs to be resolved within the constraints of a certain industry's actual time. Total efficiency determines the selection of the best line balancing method to obtain the highest production rate. ALBP should be handled in light of the importance of the relationship between production targets and the various types of constraints with varied degrees of difficulty involved in the particular assembly process. The majority of industrial issues are handled by three fundamental methods, which are as follows, among the various solutions available for line balance difficulties (Nithish Kumar et al., 2021):

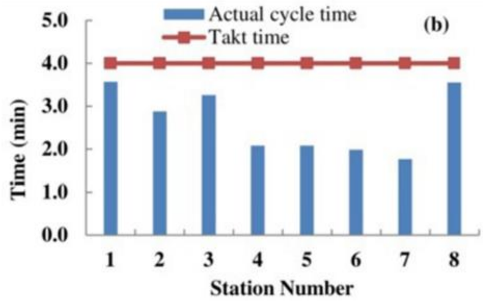
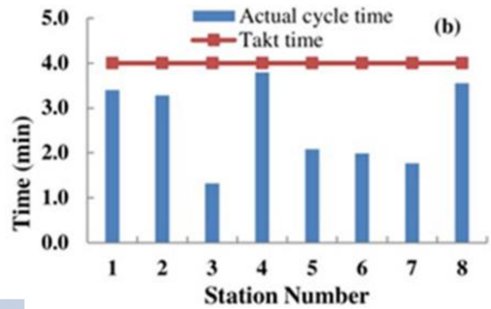
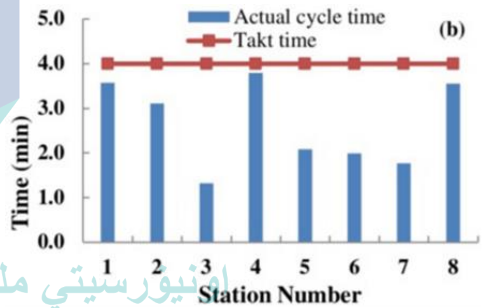
(i) Kilbridge and Wester Column (KWC)

(ii) Ranked Positional Weight (RPW)

(iii) Largest Candidate Rule (LCR)

Table 2.3 elaborate the details of the three main techniques of line balance problem. The difference of the three techniques can be seen clearly by analyse the Yamazumi chart.

Table 2.3 Three main techniques of line balancing problem

Techniques	Definitions	Yamazumi Chart
Kilbridge and Wester Column (KWC)	The KWC method is a heuristic technique that assigns task components to different stations depending on their position in the precedence diagram	
Ranked Positional Weight (RPW)	The RPW method assigns a rating to work elements based on their relevance in the assembly and organises them into a line	
Largest Candidate Rule (LCR)	The LCR method is owing to its dependability in supplying many types of layouts.	

Source: Nithish Kumar et al. (2021)

2.4 Benefits of Mass Production

Malaysia benefited from the US-China trade war in 2019, which resulted in trade diversions and investment relocations to Malaysia. Based on Figure 2.8, the headline Purchasing Managers' Index (PMI) increased for three months in a row in 4Q19, reaching its highest level in over a year. Additionally, Malaysia has been prepared to make the most of the opportunities presented by Industry 4.0. Government assistance in the part of public partnerships and investment-friendly policies, together with Malaysia's strong E&E industry, prepares the country to fully capitalise on the fourth industrial revolution (Federation of Malaysian Manufacturers (FMM), 2020).

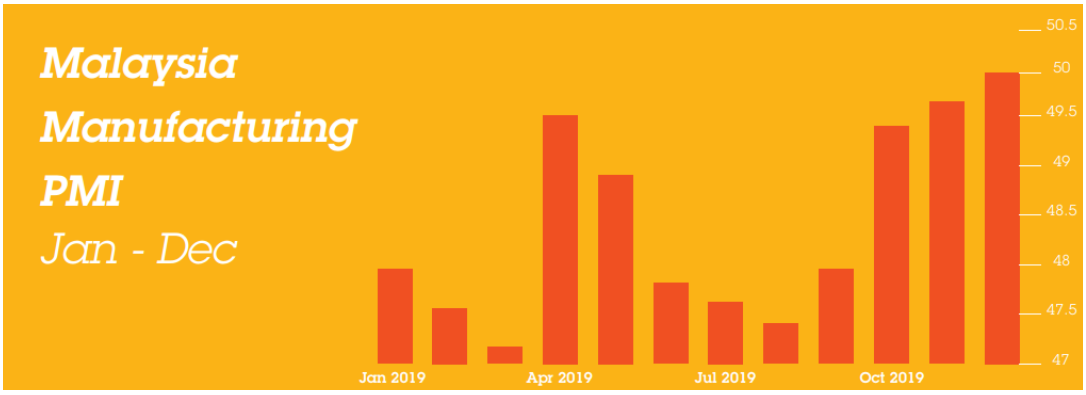


Figure 2.8 Malaysia Manufacturing PMI 2019
Source: Federation of Malaysian Manufacturers (FMM) (2020)

Figure 2.9 shows that Malaysia's GDP increased by 16.1% in the second quarter of 2021 (-1.5% in the first quarter). Economic growth improved at the beginning of the second quarter, but fell with the reinstatement of tougher countrywide containment measures, most notably Phase 1 of the Full Movement Control Order (FMCO). Overall, all economic sectors improved in the second quarter, notably the manufacturing sector. Increased private sector spending and robust trade activity drove expenditure growth (BNM, 2020).

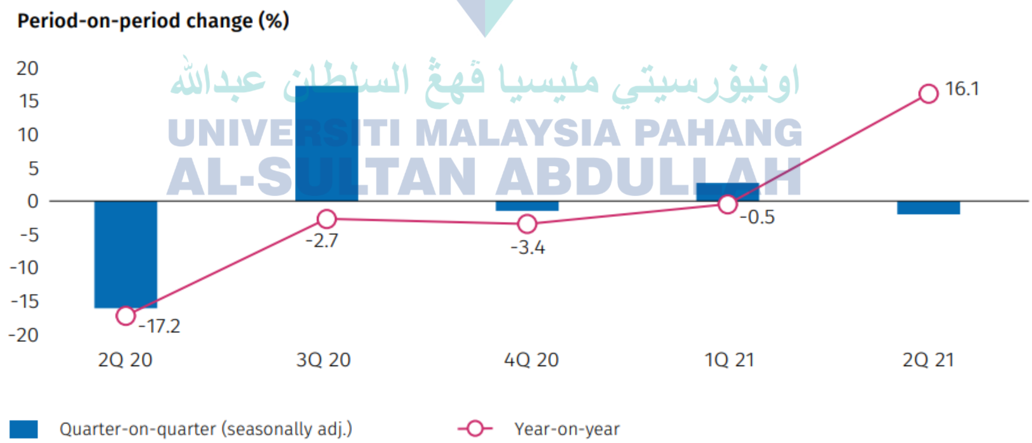


Figure 2.9 Real GDP growth
Source: BNM (2020)

Consequently, in Figure 2.10 manufacturing growth increased by 26.6% (1Q 21: 6.6%) and agriculture growth fell by 1.5% (1Q 21: 02%) on a seasonally adjusted quarterly basis. This was due to the implementation of MCO 3.0, which impacted domestic demand for products in the consumer and construction-related clusters. Demand for export-oriented industries remained resilient despite the prolonged global tech upcycle and global economy recovery. Production growth continued to be impacted by FMCO Phase 1. Bring them into the global value chain (BNM, 2020).

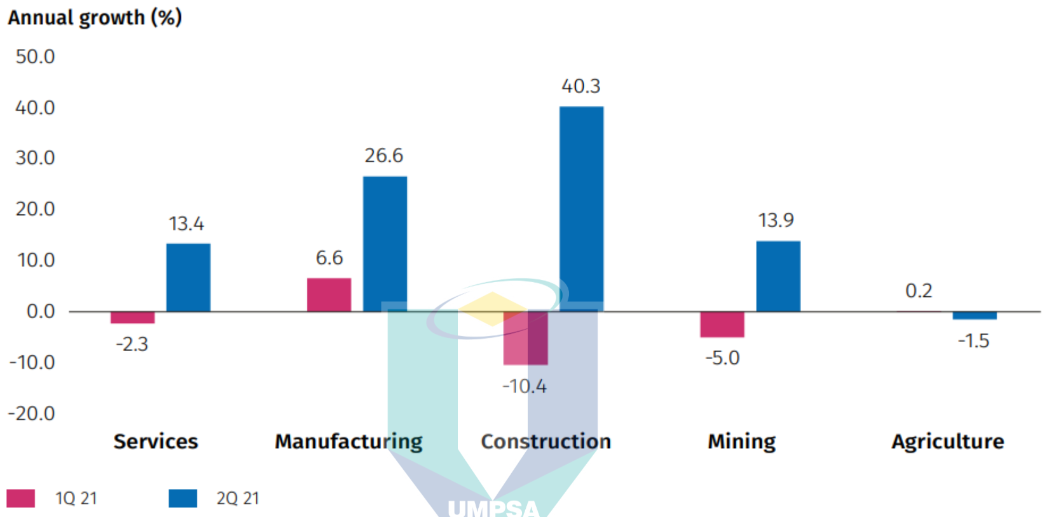


Figure 2.10 Annual growth of economic sector
Source: BNM (2020)

2.5 Thermal Printer

One kind of printing is known as direct thermal printing, which involves the use of heat to generate pictures or text on paper that has been properly coated. Due to its speed, minimal noise, produces clear printing, and simplicity of use, this printing technology is frequently utilised in receipt printers, mobile label printers, and fax machines. Direct thermal printing is a method of printing that involves applying heat to heat-sensitive paper, which subsequently reacts and changes colour in order to produce the image or text desired. Direct thermal printers are designed to apply heat to certain sections of heat-sensitive paper in response to the initiation of a print command (Ren et al., 2021). Figure 2.11 illustrates the fundamental operation of the thermal printer.

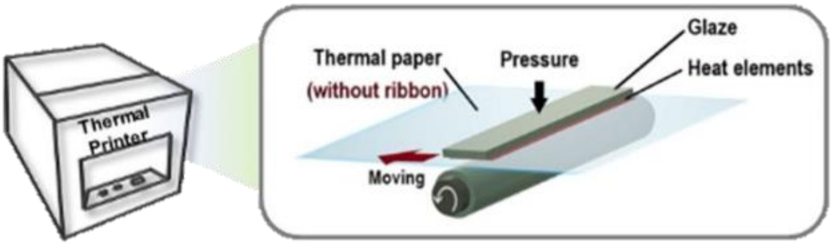


Figure 2.11 Fundamental operation of thermal printer
Source: Ren et al. (2021)

In order to create the printed picture or text, the coating on the paper undergoes a reaction and darkens as a result of the heat. This process is accomplished by utilising a thermal printer head, which is made up of tiny heating components that are controlled by temperature. The heating elements are triggered once the paper is passed over the thermal print head, which causes the heating elements to deliver heat to particular sections of the paper. Following the utilisation of heat, the heat-sensitive coating on the paper undergoes a reaction, which results in a change colour as well as the production of the picture or text that is intended. A thermal print head and heat-sensitive paper are the two components that are utilised by the direct thermal printer in order to generate pictures or text (Hussain et al., 2022).

Direct thermal printers are well-known for their simplicity and cost-effectiveness, although it has certain inherent disadvantages or defects. So, these are some typical defects with direct thermal printers include thermal head wear, thermal paper jams, picture fading, and uneven printing or discoloration on the paper. In order to avoid these problems, it is necessary to use high-quality thermal paper, keep the printer clean and well-maintained, and follow the manufacturer's instructions for usage and storage (Liu et al., 2019). There are several parameters that should be observed for thermal printers, including the temperature and humidity of solder in a climatic chamber, the frequency range to monitor impedance characteristics, leakage current measurements to detect coating damage (Mantis et al., 2021), and the thickness of the copper layers of the PCBs (Hollstein et al., 2020).

2.6 Mahalanobis-Taguchi System

2.6.1 Theory of Mahalanobis-Taguchi System

The Mahalanobis-Taguchi System (MTS) is a diagnostic and predictive approach that uses multivariate data without assuming statistical distribution. After almost 20 years of development, MTS is widely accepted. It is used in a variety of applications including product quality diagnostics, mechanical damage diagnostics, college admissions, medical diagnostics, economic early detection, venue selection, strategy development, and product reviews. Rating, contentment rating, creating results for different attributes and other areas (Chang et al., 2019).

The MTS is a multidimensional pattern recognition approach that makes no presumption about distribution of statistics. MTS is the Mahalanobis distance (MD) and Taguchi Robust Engineering. In MTS, MD to create multi-dimensional measurement scales for classification. However, the multivariate scale for measurement was developed using one type of class sample rather than the whole sample data set. As a result, MTS may be utilised to address the issue of unbalanced classes. Taguchi engineering is utilised to determine critical characteristics that can be obtained using orthogonal arrays (OA) and signal-to-noise ratio (SNR) (Chang et al., 2020).

MTS is a novel statistical approach that integrates mathematical principles and classification into a multivariate system. MTS is a recognition of patterns tool that aids statistical decision making by generating multidimensional scales via the use of data analysis methods. The purpose of the MTS is to construct and improve systems for diagnostics that make use of scales for measurements in order to make data classifications. By identifying a reference group (MS) and quantifying the level of abnormality in each observation, Taguchi and Jugulum created the MTS. The two categories in this technique are the normal and abnormal groups. The group to be targeted is designated as normal, and MS may be utilised to differentiate between normal and abnormal groups (Muhamad et al., 2018).

In the field of multivariate statistics, the MD is primarily used to detect outliers. The MD is a statistical measure that determines the number of standard deviations that the observed value deviates from the mean of the distribution. This metric may be used to identify outliers since outliers perform less than normal observations in at least one dimension. The Euclidean distance within the two points is the smallest distance between them from a geometric viewpoint. One limitation of Euclidean distance metrics is that these do not take into consideration correlations between strongly correlated variables. In this case, Euclidean distance gives the variables equal weight, and because each of these variables calculate basically the same feature, additional weight is given to that single feature (Ghorbani, 2019).

Another approach is to scale each variable's contribution to the distance value by its variability. In the context of multivariate statistics, the MD is commonly applied. It varies from Euclidean distance as it considers versatile relationships. The MD is reduced to the Euclidean distance if the matrix of covariance is an identical matrix. The difference of the two distances may be seen in Figure 2.12. At distances of 1 and 2 units from the data centre are the Euclidean and Mahalanobis points on ellipses and circles. The observed variation is due to the MD's contribution to the data's covariance (or correlation) structure. The two lines of the circle and the ellipse correspond to the Euclidean and MD 1 and 2 units from the data centre (Ghorbani, 2019).

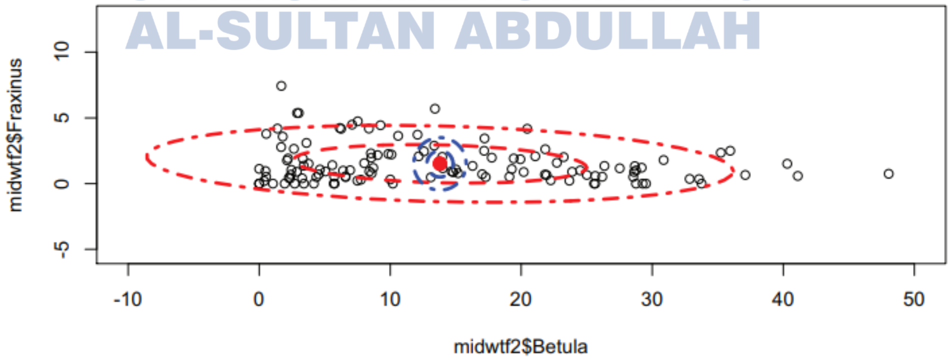


Figure 2.12 Comparison of Mahalanobis and Euclidean distances schematically
Source: Ghorbani (2019)

2.6.2 RT Method

The T-3 method, also known as the RT method, is a T detection method that may classify objects into two different categories: those that are either inside or outside of unit space. The RT method is useful when the true value of the signal (output measurement) is undefined but the class that corresponds is clear and there are many unit spaces.

However, the RT method does enable records to be recognition function. That means, mathematically reliable set of data is needed. On the other hand, the RT method highlights inputs and outputs (causality) in relation to cognitive functions. In artificial intelligence, learning outcomes are hidden. The recognition function can be explained mathematically without RT (Teshima et al., 2012).

The recognition function formation is typically faster with RT methods than with artificial intelligence. Artificial intelligence requires repeated processing of computations, while RT methods require relatively few computational operations. Table 2.4 summarizes the main differences between RT methods and artificial intelligence (Teshima et al., 2012).

Table 2.4 The main differences between RT methods and artificial intelligence

Item	RT Method	Artificial intelligence
Principle recognition function formation tenet	Computation based on correlation matrices	Pedagogic data learned based on learning convergence theory
Amount of data needed for recognition function formation	Theoretically required amount of data exists	Even one piece of data (a single set) will suffice
Nature of recognition function	Explicit and uniquely interpretable	Not explicit and individualistic
Computation time	Short	Long

Source: Teshima et al. (2012)

A multivariate control charts are used to aggregate and manage different observations into a single value. It can also be utilised to calculate the reference state from the value that is observed of the normal state and to calculate the distance between that state and the controlled object. Based on the distances found, anomalies can be found due to deviations from existing correlations.

Multicollinearity problems develop when the true value of the correlation coefficient between various variables is "1" or when one variable is the sum of other variables. Multicollinearity prevents inversion of the correlation matrix during the Mahalanobis distance calculation process. Aggressive handling of multicollinearity is recommended in RT systems. This attitude distinguishes it from statistical mathematics such as multivariate control charts and multiple regression analysis. Table 2.5 compares the RT method to the multivariate control chart (Teshima et al., 2012).

Table 2.5 Comparison of RT Method and multivariate control chart

Item	RT Method	Multivariate Control Chart
Purpose (areas of application)	Pattern recognition, prediction	Process control
Definition of normal state	Homogeneous state	Normal state
Result evaluation	SN ratio used	–
Item selection	Yes	–
Diagnosis for causes of abnormality	Yes	–
Feature extraction	Yes	–
How multicollinearity is addressed	Proactively addressed	Avoided

Source: Teshima et al. (2012)

2.6.3 T Method

The T method creates a unit space with moderate and evenly distributed (dense) outputs. The T method is a multivariate theory used for forecasting and estimating output values (objective variables) that serves the same function as multivariate regression analysis. However, their computing methods vary enormously. There are no limits such as the amount of data in a unit space or multicollinearity difficulties since the method does not use a correlation matrix or its inverse matrix. This means that T Method enables conventional analysis of issues with limited accessible data that were previously thought unanalysable by taking full advantage of the information provided.

The T method enables the characterization of analytes without subjecting them to new experiments. Instead, the method uses accumulated historical test data and daily manufacturing data. It should be emphasized that if the choice of spatial unit space remains to the operator's discretion, the resultant estimations will be influenced. The differences between the T method and multiple regression analysis are summarised in Table 2.6 (Teshima et al., 2012).

Table 2.6 Comparison of T Method and multiple regression analysis

	T Method	Multiple regression analysis
Unit Space	Selection made out of homogeneous, dense population with the output value in the median range	“Unit Space” concept not adopted. Total data used to compute regression formula
Restrictive conditions	Number of Unit Space samples n ≥ 1 Number of Signal Data samples 1 ≥ 2 (Multicollinearity does not occur)	Restriction in effect that total number of items n > number of items k No solution possible if multicollinearity is present. Elimination of items may make it possible, but the influence of important items may become impossible to analyse
Correlation between items	Correlation between items not made use of Single regression is used involving Signal Data outputs and items (proportional equations with zero as the reference point) If correlation close to “1” exists, it may affect accuracy of the integrated estimate value	Correlation between items made use of If correlation close to “1” exists, the signs of a partial regression coefficient and a single regression coefficient will not match
Adopted evaluation function	Integrated estimate SN ratio η	Multiple correlation coefficient, or, multiple correlation coefficient adjusted for the degrees of freedom

Source: Teshima et al. (2012)

2.6.4 Application of Mahalanobis-Taguchi System

After almost 20 years of development, MTS is widely accepted not only in science but also in industry and used for various applications. The quality of products diagnosis, mechanical fault identification, university application system, health diagnosis, economic early-warning, project site selection, development of strategies, quality auditing assessment, satisfaction evaluation, multi-attribute making decisions, and other fields are among the applications. As a consequence, different researchers undertook comprehensive and in-depth research and obtained excellent research findings, that have considerably contributed to the growth and advancement of MTS’s conceptual framework.

MTS is easy to use and does not require complex statistical knowledge from the operator (Chang et al., 2019). The basic steps are as Figure 2.13:

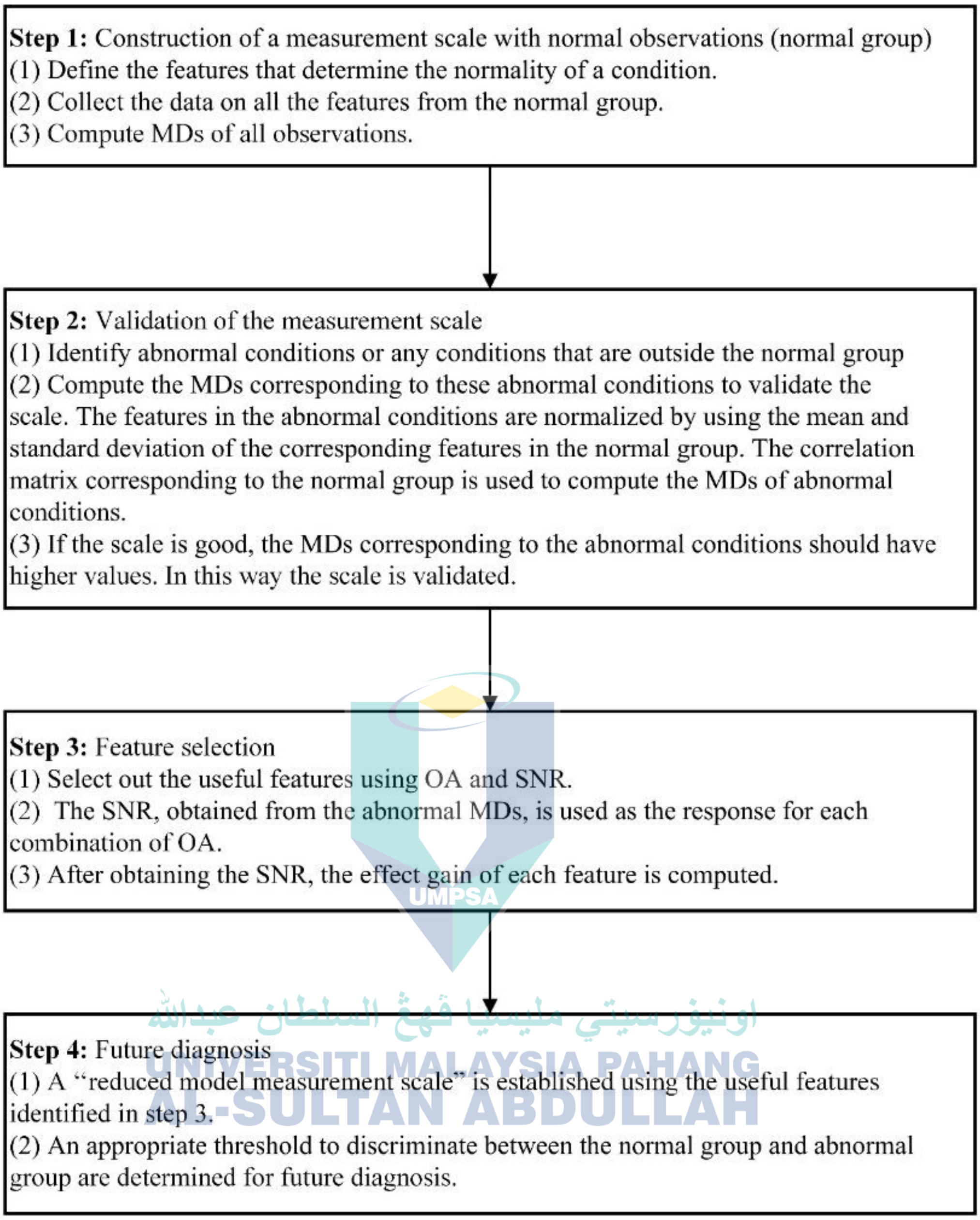


Figure 2.13 Basic steps of Mahalanobis-Taguchi system

Source: (Chang et al., 2019)

The most common orthopaedic surgery is anterior cruciate ligament restoration (ACLR). In virtually all cases, modern ACLR procedures allow for stable ligament regeneration. Nonetheless, the effectiveness of ACLR rehabilitation is not universally favourable. There was no significant new research in this review study that utilised an analytical method to concentrate on the patients' return back to work after ACLR. Taguchi demonstrated that the MD may be utilised to distinguish a certain group's pattern, that is similar as the approach applied by medical professionals in determining if an individual has a particular type of situation. The proposed method uses the MD separate the ACLR routine where significant features may be determined using SNR and OA.

The data was analysed using the MTS, which is a combination of MD and Taguchi techniques. The MTS is employed to improve ACLR diagnosis and analysis. This technique is separated into two phases: first phase utilises the MD to differentiate between typical instances of ACLR, and the second uses OA and SNR to choose important characteristics. The next stage demonstrates how to apply the framework created in the previous phase. Figure 2.14 is a flow chart outlining this method in further detail.

ACLR diagnosis and classification were accomplished by constructing feature data and employing MD related to various health conditions. Taguchi methods were used to enhance the MD in order to identify the features that had the greatest influence. The findings revealed that the MD in the ACLR group differed from those in the healthy group. Furthermore, the magnitude of the MD represented the level of abnormalities. As a result, MD can determine the severity of an abnormality. This MTS approach may one day assist physiotherapists in developing complete treatment programmes (Hamzah Sakeran, Osman, & Majid, 2019).

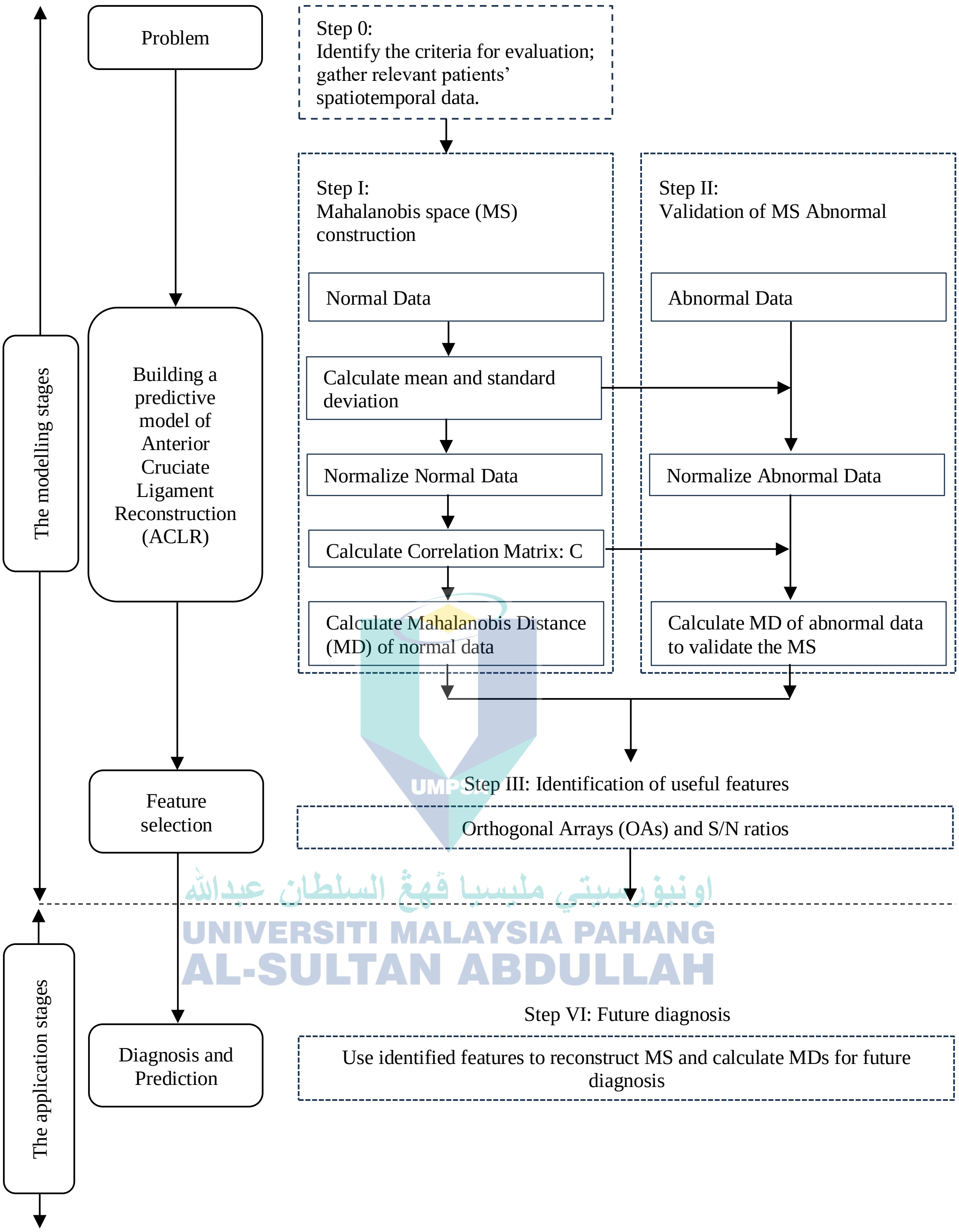


Figure 2.14 Flow chart to enhance ALCR using MTS method

Source: Sakeran et al. (2019)

The quality of a final product can be described by many important outcomes or responses (Yt) at any time (t) in a normal discrete or continuous production process. Continuous monitoring and control of those interconnected different characteristics can be vital and challenging for practitioners. The optimum setup parameters for control variables (Xoptt) at each time point (t) during production are influenced as well by the current condition of the inputs or covariates (lt) and noises (Nt). Multivariate statistical process control (MSPC) is subfield that deals with the monitoring and management of numerous linked responses. MSPC's 'diagnostic' phase uses multiple acceptable methods to identify 'influential' response variables that lead to an uncontrollable signal.

The MTS is suggested for multivariate processes diagnostics and signal alarm-based process monitoring and control. They provided a simple guideline for process 'correction' in the case of uncontrollable detectable signals (depending on statistical regression and a conventional optimisation technique). The purpose of this paper is to provide a comprehensive nonparametric prediction-based multivariate process control (NPMPC) technique which encompasses all three phases of MSPC. The thorough stages in the NPMPC approach are shown in Figure 2.15a and 2.15b. The NPMPC technique is divided into two different parts. The first retrospective stage is referred to as 'offline', whereas the following stage of monitoring and control is referred to as 'online'.

The paper presented a NPMPC for implementation in real time. As a consequence, the MTS-based quality controller is an acceptable MSPC alternative for irregular circumstances. The recommended approach's implementation improves process performance as well. Then, the conditions of the inputs (or Covariates) impact the ideal controllable variables setting condition and process adjustment. In future research, the decision of 'useful' factors (using OA) to develop the ideal MD range may be disputed, and various alternative indices may be examined and compared (Sikder et al., 2020).

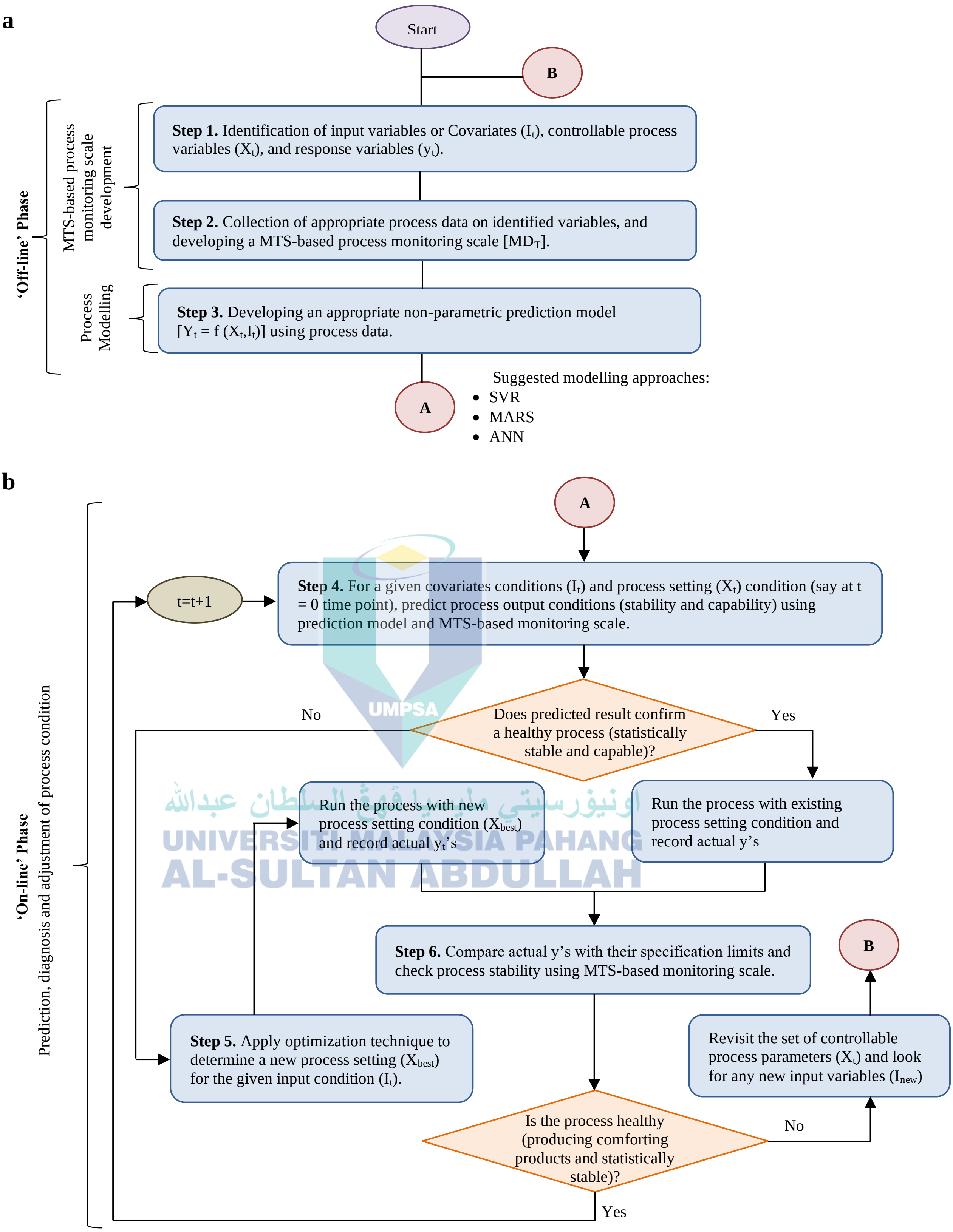


Figure 2.15 a) A detail flow diagram of the proposed NPMPC (Off-line Phase)
b) A detail flow diagram of the proposed NPMPC (On-line Phase)

Source: Sikder et al. (2020)

In additional to the traditional way in determining detection criteria using cutting expertise, a cutting anomaly may be detected using machine learning and recognition of patterns. However, given the variety of possible occurrences, it is almost impossible to assure that all cutting abnormalities are found throughout mass manufacturing. In this paper, the researcher utilised a system to monitor the machining situation without interfering with the machining process and analyse the relationship between turning abnormalities and motor output. The emphasis was on the unstable abnormalities that arise in mass manufacturing, such as chip biting and tool vibration. To avoid thorough investigation that depends on understanding of cutting occurrences, formal approaches for identifying abnormalities using conventional statistics and systemized methods using Mahalanobis-Taguchi (MT) method and automatic tuning of parameters using discretization and pattern recognition were developed.

Figure 2.16 demonstrates the systemization of anomaly detection using a discretization and recognition of patterns technique based on the MT method with an auto parameter-tuning algorithm. It is essentially divided into three phases. First, distinguish between normal and abnormal waveforms. Second phase involves detecting abnormalities during mass manufacturing utilising an optimised model.

A method that can built a non-contact indirect measuring method employing motor current that may be used in mass manufacturing without interfering with the cutting process is developed in this research. It can formalize correlation for anomaly identification by accounting for cutting phenomena in every abnormal waveform style and generating statistical analysis that adequately describe cutting phenomena while optimising data validity. Following that, systemized anomaly detection based on discretization and recognition of patterns accomplished by auto parameter adjustment is implemented in an attempt to reduce the dependency on specialist persons. The suggested formalised and systemized identification of anomalies approaches were utilised to construct an abnormal detection system with an abnormal-corresponding function for a large-scale manufacturing line. Both approaches have a 98% correct-detection rate (Watanabe et al., 2020).

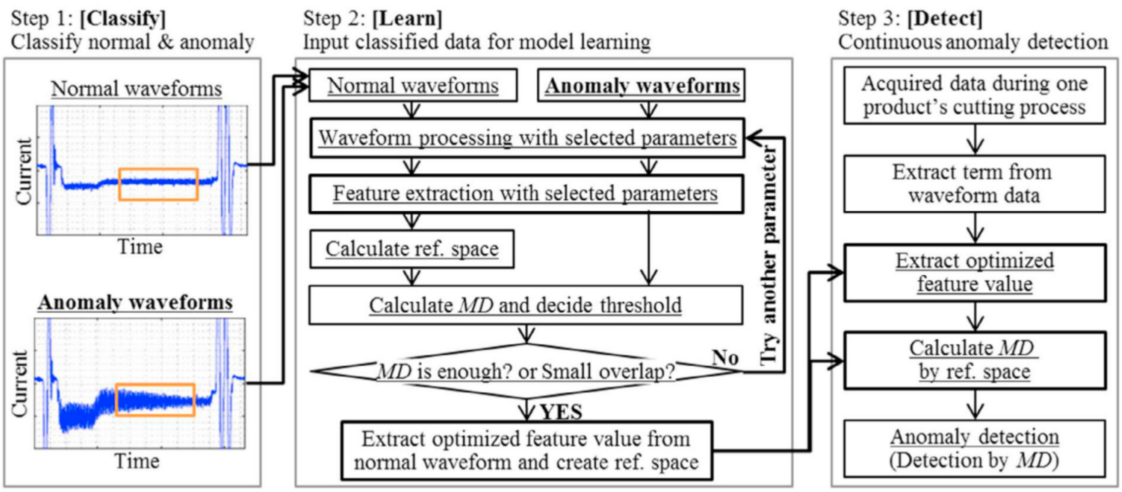


Figure 2.16 Systemized flow for pattern recognition with auto parameter selection
Source: Watanabe et al. (2020)

2.6.5 Advantages and Disadvantages of Mahalanobis-Taguchi System

Table 2.7 shows both the advantages and disadvantages of the Mahalanobis-Taguchi system.

Table 2.7 Advantages and disadvantages of MTS

Advantages	Disadvantages
MTS can filter important evaluation indicators to optimize the evaluation system during evaluation (Peng et al., 2021)	There is no comprehensive quantitative theoretical basis for MS design, selecting features, or boundary setting (Chang et al., 2019)
MTS can easily detect abnormalities without making any statistical assumptions (Chang et al., 2019)	MTS is not usually feasible to use OA and SNR to estimate the importance of every characteristic in such high-dimensional data (Chang et al., 2019)
The most promising binary classification techniques for dealing with imbalanced data (El-Banna, 2017)	MTS lacks a structured and thorough technique for determining the discriminating limit within both categories (El-Banna, 2017)
MTS serves to emphasize the change in damage-sensitive properties due to damage (Delgadillo & Casas, 2020)	The selection initial parameters require expert knowledge (Delgadillo & Casas, 2020)

2.6.6 Statistic of Mahalanobis-Taguchi System

There are various sectors in Malaysia that affect the growth rate of quarter gross domestic (GDP). Among those sectors are services, manufacturing, agriculture, mining and quarrying, and construction. Thus, according to the GDP of the third quarter of 2022 in Malaysia, 13.2% percent has been allocated to the manufacturing sector.

Based on 55 papers published from 2018 to 2023 in Appendix A, Figure 2.17 shows the application of MTS. There are eight application categories including Manufacturing, Services, Industrial Revolution, Construction, Automotive, Agriculture, Mining and Quarrying, and others based on GDP (Datu, 2023). MTS pie charts have the highest proportion of 18 manufacturing journal articles at 33%. However, mining and quarrying and agriculture have the lowest shares of 2% and 1 journal publication respectively. The percentage of services, automotive, industrial revolution, construction, and others are 20%, 14%, 13%, 11%, and 5% correspondingly. This highlights the widespread use of MTS in industries such as welding, mechanical materials, steel products, rotating machinery, and rolling bearings fault diagnosis.

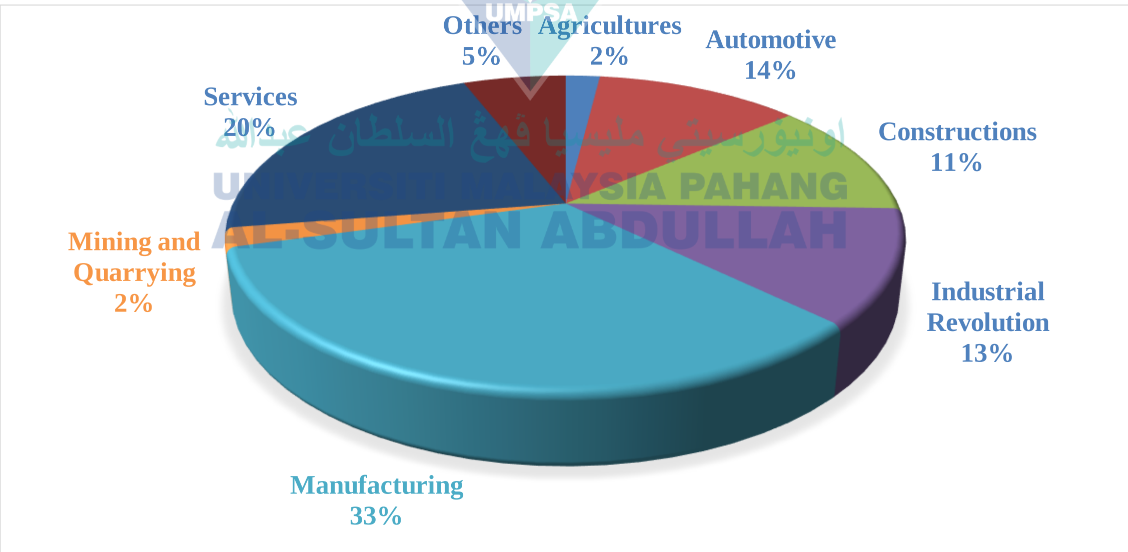


Figure 2.17 The distribution of MTS applications

2.6.7 Research Motivation of Mahalanobis-Taguchi System

The MTS is divided down into seven different fields in this research. These categories include an introduction to the method, construction of MS, dimensional reduction (optimization), threshold establishment, integration and development with other methods, comparison with other methods, and case study/application (Mota-Gutiérrez et al., 2018).

Figure 2.18 shows the categories used in this research for summarising the research gaps issued between 2018 and 2023. Integration and development with other methods had the greatest proportion of 27% for MTS application areas. Following, dimensional reduction (18%), case study/application (16%), construction of MS (13%), threshold establishment (11%), introduction to the method (9%), and comparison with other methods (6%).

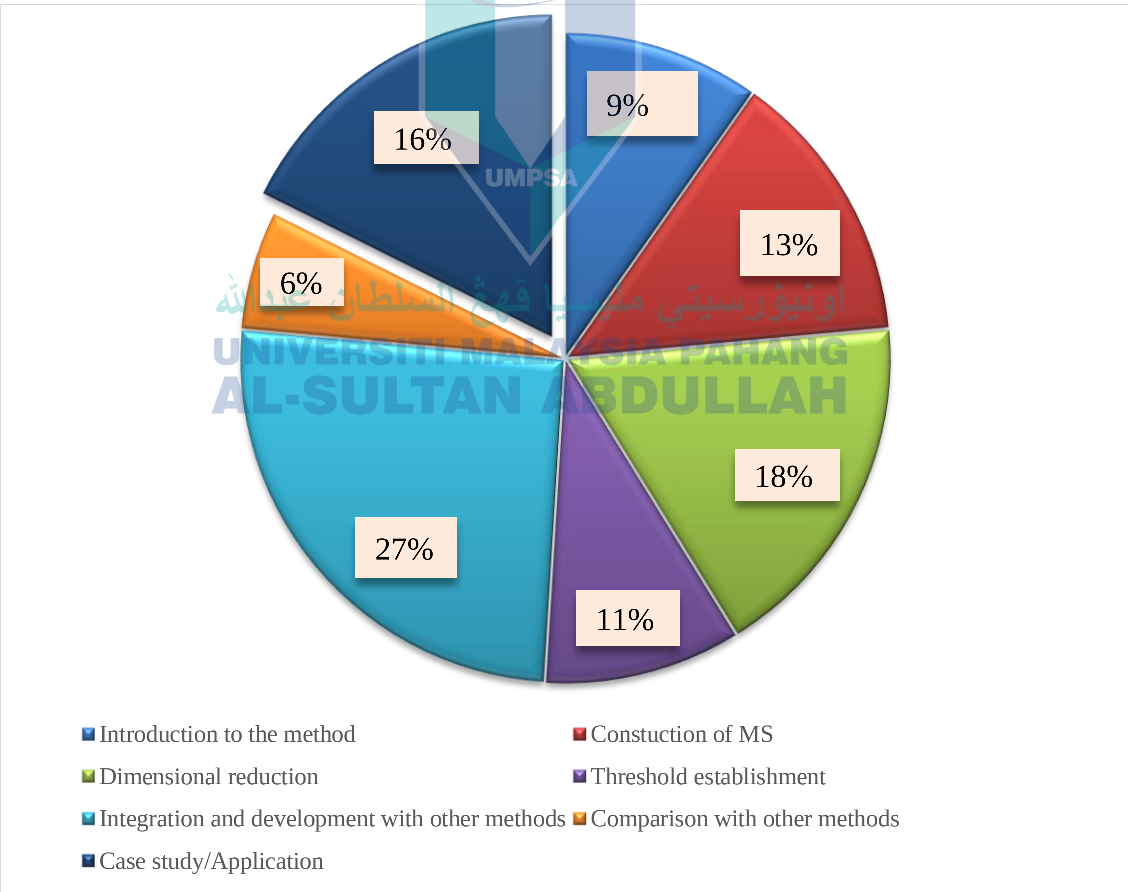


Figure 2.18 Variety application field of MTS

Firstly, the introduction to the method is explained with an initial description of MTS, which uses multivariate data to optimize and classify. Secondly, there is Mahalanobis distance in the construction of MS which is used to measure the degree of contribution into two groups of data whereas “normal” and “abnormal” observations. Thirdly, the dimensional reduction/optimization eventually is the T method-1 of MTS T method. The T method presents a theory for estimating outputs (objective variables) from multivariate that making calculations feasible even with limited sets of known data. Meanwhile, RT method is a way of detecting T method that is able to categorise objects within and outside the unit space. It is also known as threshold establishment. Next, the integration and development with other methods is used to identify or improve the efficiency, quality characteristics, possible damage or health conditions regarding material components. Subsequently, the comparison with other applied to big data for feature identification or selection. Finally, the construction on the case study/application is eventually utilised in the automotive industry, the E&E industry, and the mechanical component industry.

Based on Figure 2.18, the category of case study/application (16%) was chosen to satisfy the research gap identified by the existing work’s accomplishments. The reason it is the most compatible elements because it focuses on the MTS mostly in the field of industry. Then, some of the published work that included a case study/application as part of its research on literature has been identified and classified based on the methodologies used in the MTS as in Table 2.8.

Table 2.8 Elements of case study/application

Author (Year)	**Application**	**Method**		
		Generate MD		**Reduction of element**
		Normal	**Abnormal**	
(Okubo et al., 2021)	Adaptive beam	√	√	X
(Kikuchi & Ishihara, 2020)	Strains of tower shell	√	√	√
(Watanabe et al., 2020a)	Turning	√	√	X
(Sakeran et al., 2020)	Anterior cruciate ligament reconstruction (ACLR)	√	√	√
(Ji et al., 2020)	Reservoir	√	X	√
(Toma, 2019)	Motor fan	√	√	√

Okubo et al. (2021) used the method for producing MD in the research related to adaptive beam application. The primary constraint of model-based approaches is that fault detection performance is heavily reliant on the quality of the system framework, and those methods need considerable data processing possibilities to provide continuous operation. Thus, in this paper the generating MD is used to detect the damage in the adaptive beam. The statistical models and practical observations proved that the MTS is particularly effective in detecting damage. The bar graph's threshold value for indicating MD for every single segmentation data is set at 4. As a result, the quantity of data with MD of 4 or higher is used to determine whether the system is normal or abnormal based on the waveforms.

The architectural modal technique, vibration and impedance response technique, and ultrasonic guided wave technique, according to Kikuchi and Ishihara (2020), are not susceptible to the defective bolt location in the application of tower shell strains. Furthermore, this application also requires a significant amount of labour. An identification of anomalies algorithm based on T Method-1 and T Method-3 is described in the MTS system. The T Method-1 formula, on the other hand, is developed using the finite element method model. The suggested threshold successfully detects the abnormal bolts on the tower-top flange, and the predicted residual axial bolt force by the strain that was observed fits with the data. The assessed MD and condition judgement are normal if the residual axial bolt force is more than 80%. The thresholds are 0.119 for 20 mm and 0.152 for 100 mm under the tower-top flange.

Following the application in turning, Watanabe et al. (2020) pointed out that because of the numerous occurrences that may occur, it is hard to ensure that all cutting abnormalities are identified during the production process. As a result, a non-touch indirect measurement technique based on motor current is developed that may be used in mass manufacturing without compromising with the cutting operation. The anomaly detection technique on a mass manufacturing line with an anomaly-corresponding feature uses formalised and systemized detection approaches. Both approaches have a 98% correct-detection rate. The accuracy of detection for both approaches was evaluated using the validation method on a mass manufacturing line with the turn chuck anomaly as the object of study. The total number of goods produced for this validation was 2,829 units.

Next, the multivariate factors, physicians and physiotherapists use a lot of time in accessing patients, are the encountered challenge in the application of anterior cruciate ligament reconstruction (ACLR). Generating MD is employed in the studies of Sakeran et al. (2020). MTS is entirely quantitative in their studies and is readily comprehended. It assists doctors and physiotherapists in making short-term diagnoses and recommending rehab programmes, and it performs objectively with crucial qualities. The targeted group is referred to as the normal group, and it is comprised of patients who have healthy limbs. On the other hand, the off-target group, which is more frequently referred to as the abnormal group, is comprised of individuals who have ACL treated. The measurement scale will be certified only if the calculated MD for the off-target group is larger than Mahalanobis space. This is clearly illustrated by the fact that the off-target group's MD value (26.05) is greater than the target group's MD value (0.93).

Ji et al. (2020) claim that in the use of reservoir, challenges such as reducing decision information loss in order to increase decision efficiency and the difficulty of applying interval values for distinguishing are mentioned. MTS-GEM is then utilised to lessen the uncertainty caused by interval numbers. MTS-GEM may also generate clearly distinct judgment outputs, demonstrating the model's abundance of decision information. The mapping distance brings the approach suggested in this study closer to the reference scheme, generating more accurate and acceptable decision outcomes. As a result, Scheme 3 is recommended as the best choice, with the highest possible water level limit in flood season raised by 0.8 m over Scheme 1.

According to Toma (2019), for motor fan quality inspection, the sensory test takes a lot of expertise to differentiate between small noises (sound pressures) generated by the fans, and the evaluation varies depending on the inspector and the circumstances. depending on the inspector and the circumstances. This study uses MTS's feature quantity extraction from waveform shape information to quantify motor fan sound and vibration. The outcome of calculating the MD value by using the variable whose SNR has a positive reading as the characteristic amount from the effectiveness analysis of all abnormal aspects of the data. The obtained results show that discrimination is effective when normal values are at or below the threshold value and abnormal values have MD values that are at or above the threshold value.

In a nutshell, most applications that generate both normal and abnormal contributions are used for the parameters required. Only the reservoir application used the normal group for the parameters. However, it is difficult to discover previous studies that use the MTS especially in the E&E sectors to assess the degree of contribution of parameters in a production line. This is because the MTS has not been widely applied.

2.7 Time-Driven Activity-Based Costing

2.7.1 Theory of Time-Driven Activity-Based Costing

One method for calculating costs is known as time-driven activity-based costing (TDABC), which depends on the translation of cost drivers into time equations. These equations reflect the demand for duration to carry out a task as an expression of time drivers. The TDABC approach expands on the activity-based costing (ABC) method by incorporating temporal factors. During the planning phase, the TDABC technique was utilised to investigate how collaborative employee involvement and managerial approaches influence the development of modifications to operations. TDABC has also been used in the sector of medical (Wedowati et al., 2020)

There are two aspects that are used in the TDABC method of cost estimation. These aspects include the amount of time that staff employees need to spend on an operation or activity, as well as the staff employee's cost per minute. TDABC explained the time and expense spent on operational procedures by combining the various processes and employees involved. The TDABC merely considers employee time devoted to patient-related processes, and the overhead cost of employee time spent not interacting handling patients or on patient-related duties (holidays, illness, breaks, research and education) is neglected. TDABC estimate requires the development of process maps in the handling process, the calculation of the duration consumed by the numerous separate operations, and information of the pay of the employees involved (Husted et al., 2018).

The TDABC approach suggests more precise data as well as direct and indirect cost accounting through detecting specific to a patient utilised resources over the length of the treatment track. This allows for more precise accounting of costs. TDABC was proposed as an improvement to ABC as it provides precise cost estimation quicker and simpler to execute by estimating two parameters which is the unit cost of supplies and the total duration, as well as the amount of supplies required in order to finish an order or operation. The TDABC assists by finding chances to improve the flow of patient episodes of care by reducing the amount of time used in every process in accordance with actual requests from patients (Etges et al., 2020).

TDABC is speculated to be the next stage of ABC. This novel approach was created mainly to shorten the setup process as well as the time-consuming and costly administration. TDABC is recognised as an example in coping with the complexities and diversity of routine tasks. This is because resources in service firms may be allocated depending on working hours. TDABC is an enhanced accounting approach for business services than it is for manufacturing organisations. TDABC gives an excellent chance to develop and illustrate a cost model for complicated activities. Unlike ABC, TDABC does not require reductions, and cost planners have the authority to include the multiple time drivers that describe each aspect of a process in the time equations.

Figure 2.19 depicts the support and operational department categories. All departments that were not included in the figure are considered as corporate-sustaining expenditures, which are costs sustained regardless the level of the organization's activities and are not meant to be assigned to operational departments. The sequence of expenses for resources up to the spending items is shown in the figure using the approaches provided. However, this approach divides the logistics and distribution department from the maintenance, sales, and transportation departments. This is not suggesting that the model cannot be applied to those sectors. A list of activities that encompassed all of the processes of the business for the shipping of its product or service was required to create time equations and assigns resource consumption to each costing item (Barros et al., 2017).

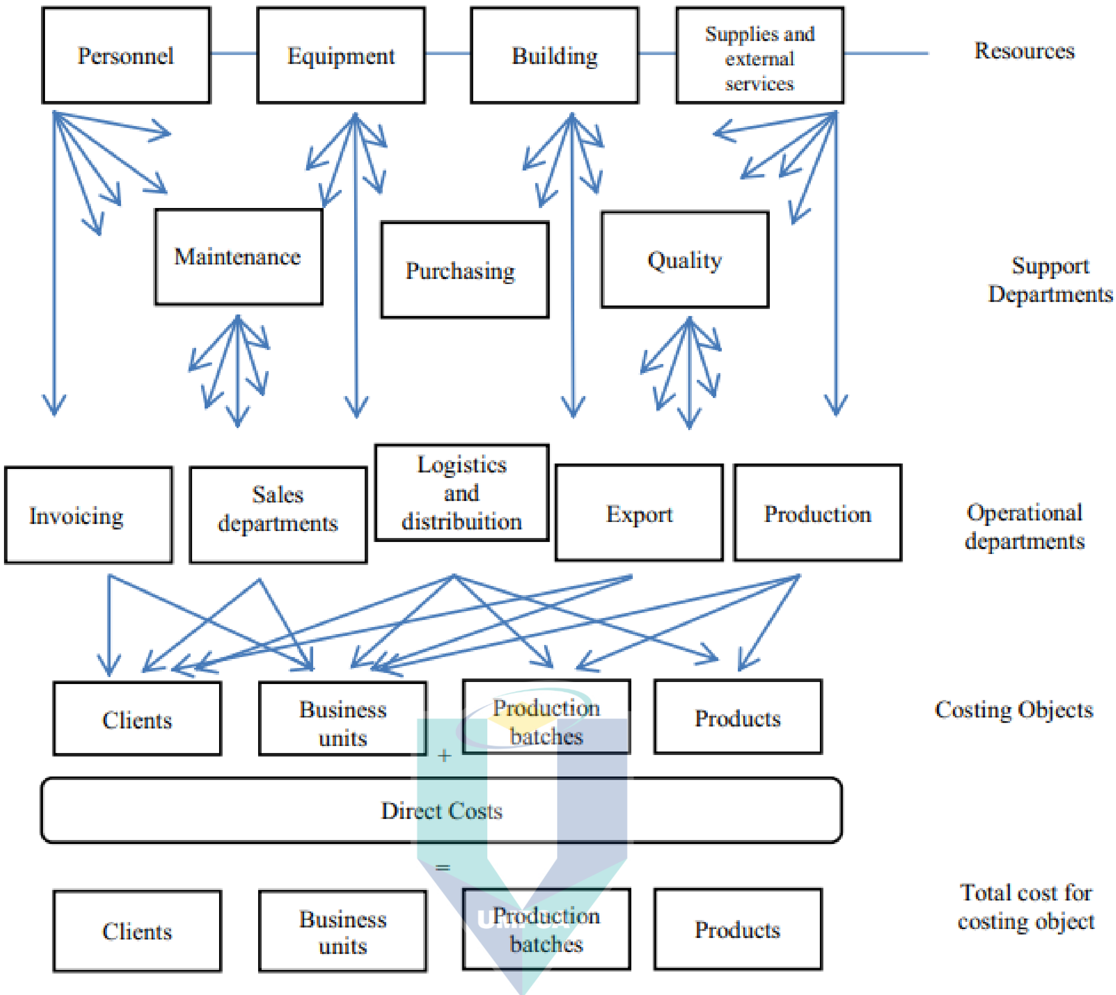


Figure 2.19 The process of TDABC
Source: Barros et al. (2017)

Management innovation has been indicated to have an advantageous impact on organisation productivity and efficacy, and that enhancing organisational efficiency could substantially improve organisational performance. According to TDABC, it may overcome the disadvantages of the initial approach throughout the process of implementation, such as unnecessary costs, time waste, weak reliability. It combines the variations between companies into the time equation and uses the equation to allocate the use of resources to the cost object automatically. (Jiang et al., 2022). TDABC has been used in a multitude of sectors, including healthcare, industrial, and libraries, among others (Areena & Abu, 2019). Figure 2.20 shows the concept of the TDABC with the following steps.

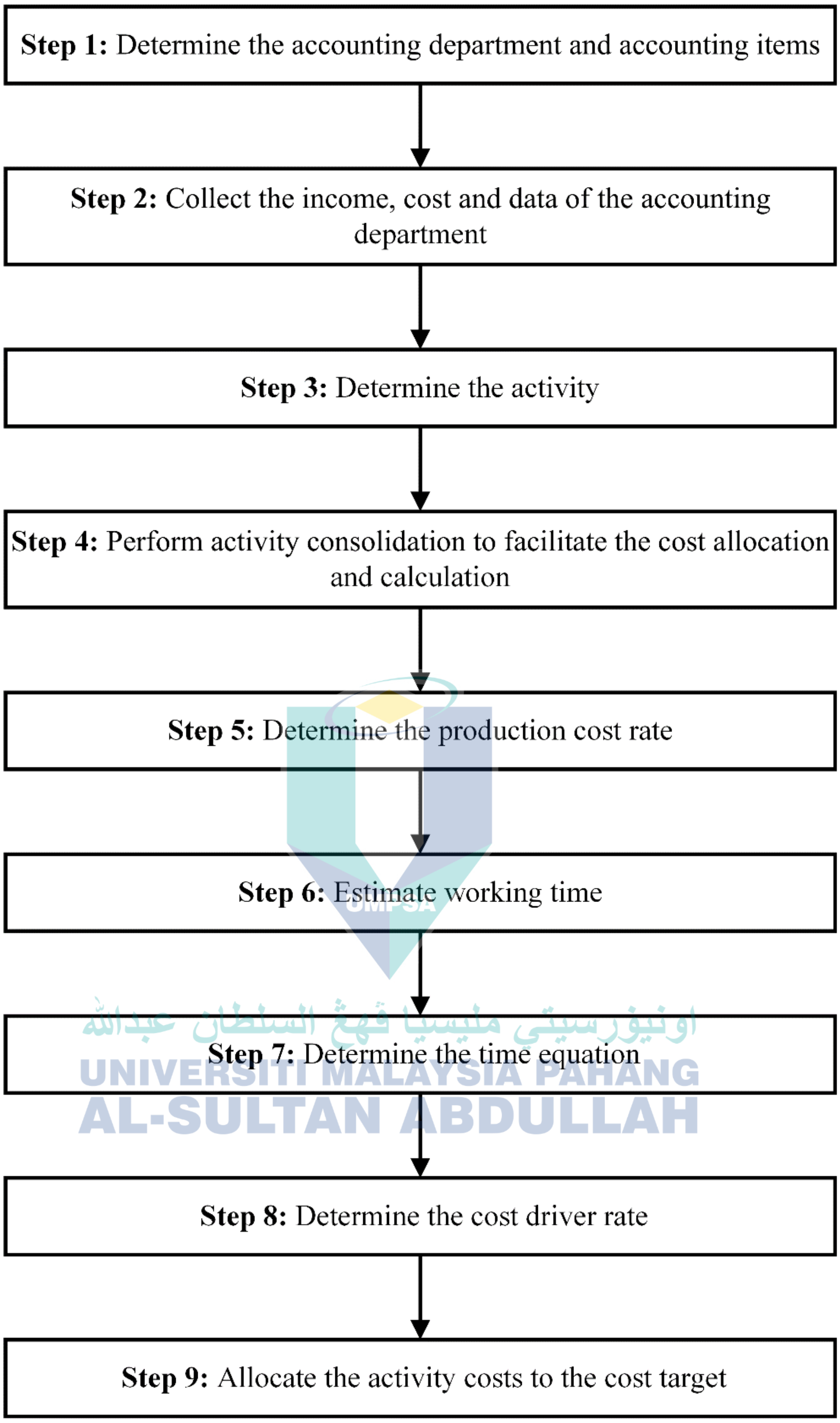


Figure 2.20 The concept of TDABC

Source: Jiang et al. (2022)

2.7.2 Comparison with Other Methods

Activity-Based Costing (ABC) is aimed at providing costing statistics to managers in order to make planning as well as other alternatives that influence capacity, fixed costs, and variable costs. ABC is often utilised as a complement to the business entity's operating cost scheme when there is no other option. A practical problem is the high cost of application. ABC essentially links resources and tracks activities. This is done through interviews and direct observations of employees. This includes calculating the time employees spend performing activities that make those activities very expensive.

Therefore, an alternative approach in overcoming hurdles and fulfilling goals is required for resolving the difficulties and challenges related to the use of ABC. TDABC was a revolutionary method of computing ABC that utilised time indicators to ensure the newcomers could more easily discover cost issues utilising time equations. TDABC's ability combines ABC's benefits while overcoming the majority of its shortcomings. Because of these contrasts, the ABC technique was inappropriate for the demands of today's corporate climate. Table 2.9 shows the comparison (Al Askary et al., 2020).

Table 2.9 The comparison of ABC and TDABC

Comparison	**ABC**	**TDABC**
Capacity	Depends on the concept of total capacity, the products are loaded by the costs of the utilization and idle capacity	Depends on the concept of practical capacity, the products are loaded by the costs of actual capacity
Short term pricing	Increasing the volume of work leads to a change in the unit cost, thus increasing the price of the product	Increasing the volume of work leads to the reduction of untapped resources and its transformation into exploited resources
Update	Difficulty of update	Easy of update
Accurate	Less accurate in cost measurement	More accurate in cost measurement
Expansion	Difficulty of operations expanding	Easy of expanding operations
Reports	Preparing annual or semi-annual reports	Preparing reports when needed

Source: Al Askary et al. (2020)

Following that, several costing techniques have been applied in the restaurant sector to estimate menu pricing, either qualitatively or quantitatively. These qualitative approaches depend on "trial and error" as well as "market positioning perspectives," while the quantitative approaches are revenue and expenditure focused. The intuitive technique, which is based upon the user's interactions regarding the accessible objects, is firmly linked to the trial-and-error perspective in terms of the qualitative approach. The quantitative approach, on the other hand, includes a variety of approaches such as the gross mark-up method, ratio method, factor method, or menu engineering method that depend on amounts of food cost, gross sales, and contribution rate to determine the profitability of every product.

Although this approach suggests managers can identify profitable products. In practice, however, commodity prices are not analysed in detail, regardless of whether qualitative or quantitative approaches are followed. This is because when pricing a menu using this approach, important operational costs (indirect resources such as labour and fixed costs) are ignored. A simple comparison between conventional methods and TDABC is then described in Table 2.10 (Elshaer, 2022).

Table 2.10 Comparison between TDABC and traditional methods of costing

Comparison	TDABC	Traditional Costing
Concept	An integration with value stream methodology.	Costs are generally allocated on the basis of the volume.
Cost pools	Less accounting transactions.	A limited number of cost pools.
Cost drivers	Accurate computation of product unit costs.	Few cost drivers.
Focus	Managing value resources.	Managing departmental costs.
Decision making	Relating to value product and process level.	Relating to cost level.

Source: Elshaer (2022)

2.7.3 Application of Time-Driven Activity-Based Costing

TDABC provides the ability to assist in the health-care cost-crisis. In today's economic compensation circumstances, practitioners and policymakers have been searching for cost-accounting systems that may guide enhancements to processes while simultaneously meeting cost-control policy agendas. TDABC has been successful in both the services and industrial sectors. It prioritises precision above accuracy. Precision refers to the number of decimal places in the computation, while accuracy to how near the cost estimate is to the actual cost. TDABC necessitates fewer capacities since it just requires two important parameters: the capacity cost rate (CCR) and the time required to carry out the provision of services activities.

TDABC has been used, not the quantitative impact of its use. As a result, an analytical qualitative approach was employed to examine how various TDABC implementations differ from one another and adhering to the conceptual basis. Figure 2.21 depicts the processes for health care organisations (Keel et al., 2017).

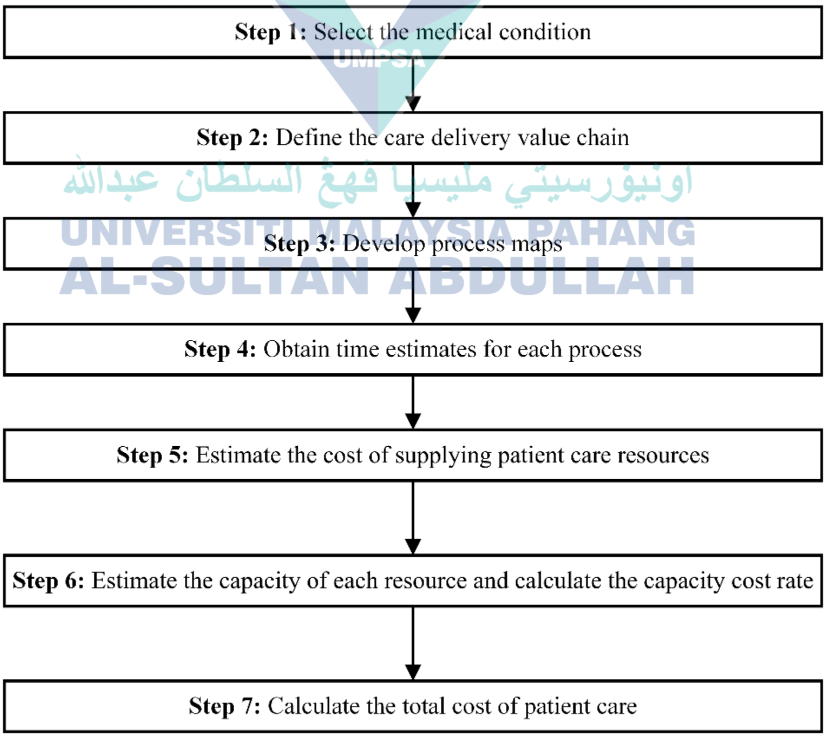


Figure 2.21 Health care organisations of TDABC steps
Source: Keel et al. (2017)

Academic library systems have seen essential cost reductions in the last ten years as a consequence of fewer funds and the digitization of facilities and materials. Employee training, electronic resource subscriptions, operational expenditures, and other costs have reduced due to low financial capacities. Many academics believe that TDABC is a straightforward and practical costing approach that could assist library administrators accomplish more effective cost analyses, especially in library circulation. Since it employs the most librarians and consequently has the highest employment expenses, library circulation is an essential aspect and a critical element of any academic library.

The development of the TDABC system and its implementation in the library department of the University of Macedonia in Thessaloniki, Greece are examples of library applications. Figure 2.22 shows the TDABC framework in practice at University of Macedonia library (Kissa et al., 2019).

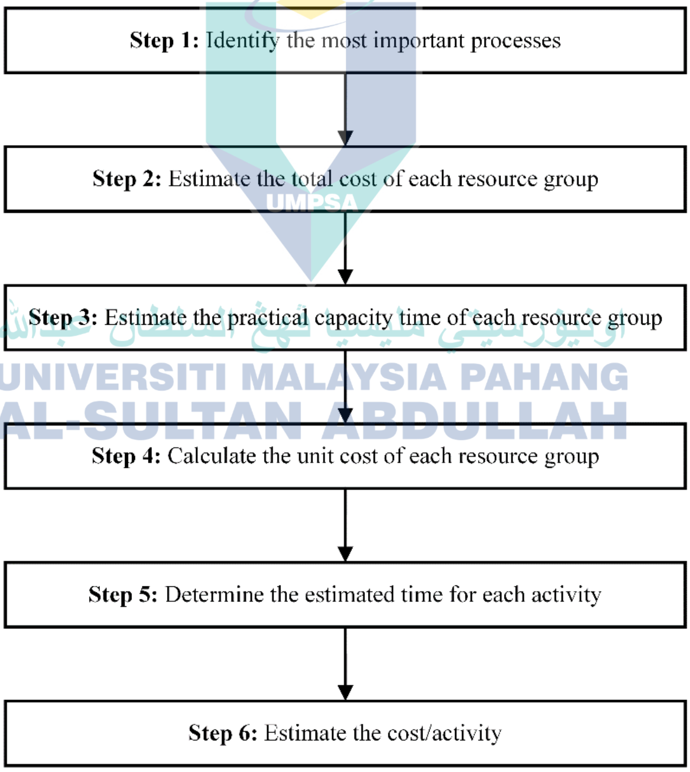


Figure 2.22 TDABC steps in library application
Source: Kissa et al. (2019)

2.7.4 Advantages and Disadvantages of Time-Driven Activity-Based Costing

Although TDABC has the many advantages, it also has some disadvantages that can be seen as in the Table 2.11.

Table 2.11 Advantages and disadvantages of TDABC

Advantages	Disadvantages
TDABC may assist managers in focusing on value-added activities while limiting non value-added ones (Ridderstråle, 2017)	TDABC provides fairly data inaccuracy and uncertainty in determining the expenses of hospital treatment (Ostadi et al., 2019)
TDABC can improves decision making in such businesses (Ridderstråle, 2017)	TDABC needs a calculation of the time involved to complete every activity in a care cycle (Choudhery et al., 2020)
TDABC can identify opportunities to improve cost data accuracy (Yu et al., 2017)	"Time equations" require user understanding of syntax rules (Balicevac & Rude, 2019)
TDABC is easy to establish and can reduces the waste of personnel time (Masthoff et al., 2021)	TDABC need a single departmental cost rate for all types of activities within the same department (Balicevac & Rude, 2019)

2.7.5 Statistic of Time-Driven Activity-Based Costing

A total 54 research articles published from 2019 until 2023 in Appendix A that used TDABC as their cost accounting technique were reviewed for literature. The distribution has been further divided into seven particular applications, namely academic, business, health care, hospitality, industrial revolution, manufacturing, and others based on research cluster that have been conducted. Figure 2.23 depicts the TDABC technique distribution in seven different applications.

Compared to the other six applications, the industrial revolution sector uses TDABC technique in cost accounting system the least with 2%, which is 1 out of 54 research publications. The health care sector has the highest percentage at 50% with 27 research publications. Meanwhile, hospitality is 24%, manufacturing is 9%, academic is 5%, business is 4% and others 6%. TDABC is clearly demonstrated to be widely used in the healthcare field, including radiotherapy, oncology, diabetes, bone cancer, prostate cancer, breast cancer, spine surgery, pancreatic surgery, parathyroid surgery, cardiovascular diseases, hip and knee arthroplasty, head computed tomography, ACLR, and others. However, TDABC in this research studies are in E&E sectors.

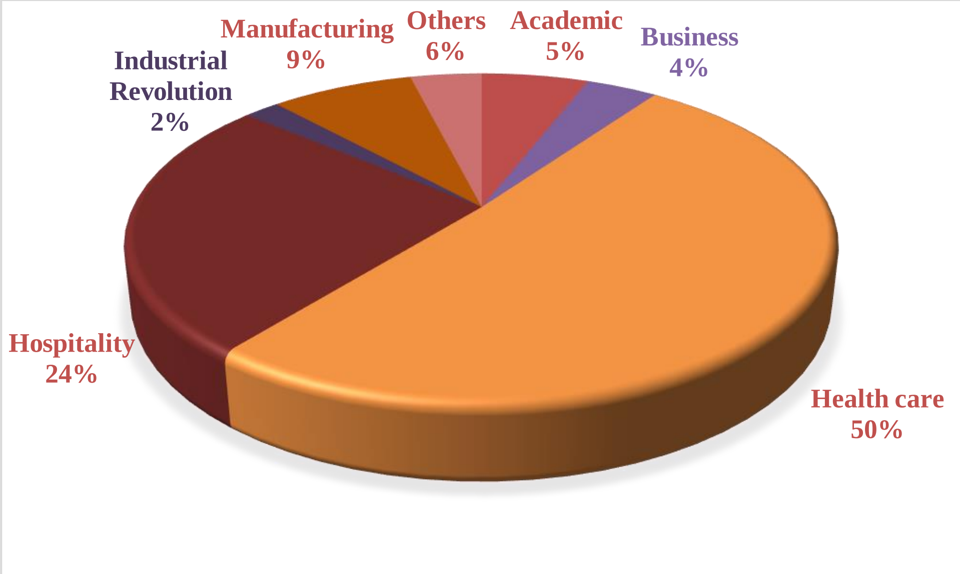


Figure 2.23 The distribution of TDABC

2.7.6 Research Motivation of Time-Driven Activity-Based Costing

TDABC is sorted into five categories in this study based on its benefits, which include reduced measurement error, improved operational efficiency (Berg & Madsen, 2020), accurate unused capacity, lower implementation costs (Adıgüzel & Floros, 2020), and capturing business complexity (Barros & Da Costa Ferreira, 2017). The categories used in this research to summarise the research gap reported from 2019 to 2023 can be seen in Figure 2.24. The capturing business complexity obtained the highest percentage of 26% for TDABC application areas. Following that, there was reduced measurement error (20%), lower implementation costs (19%), improved operational efficiency (18%), and accurate unused capacity (17%).

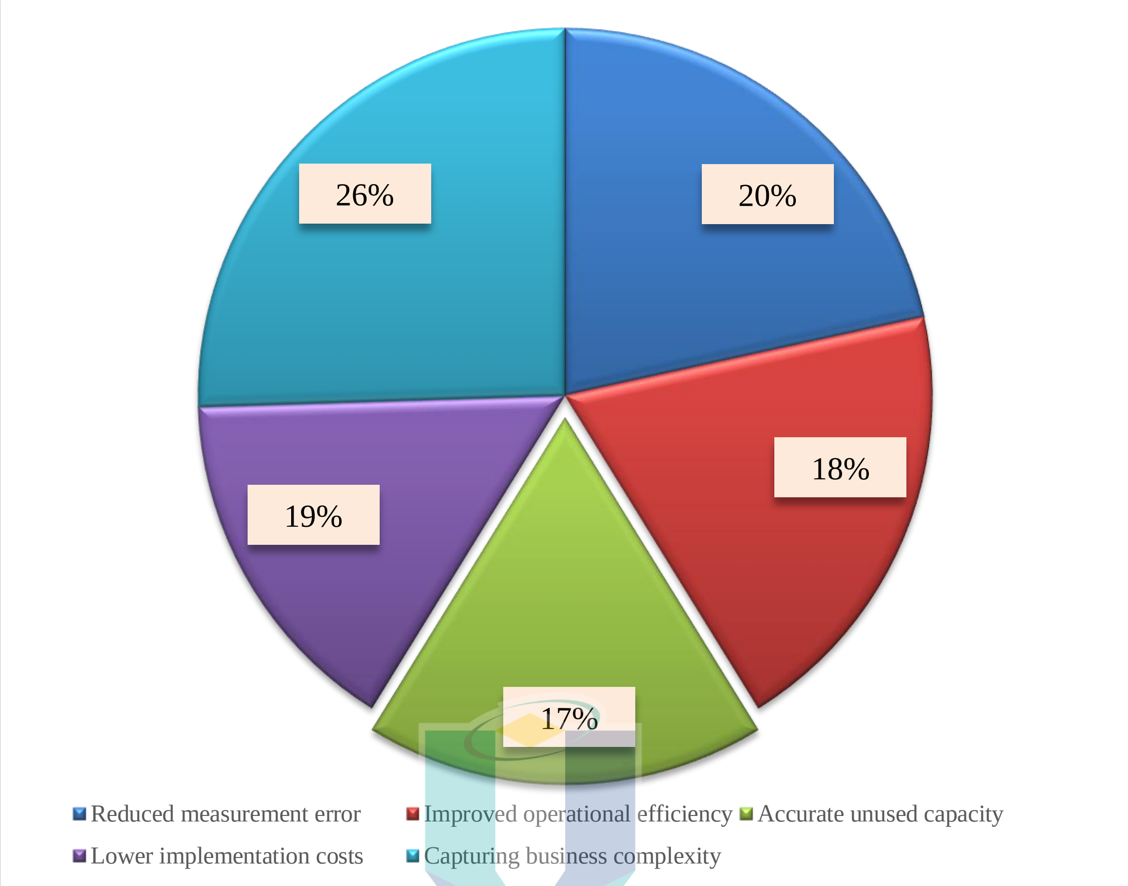


Figure 2.24 Variety of application field in TDABC

Based on accurate unused capacity, for instance TDABC, a patient-specific instrumentation cost reductions limit range is determined, with patient-specific instrumentation price providing net savings. TDABC is used in less cost implementation to conduct a cost calculation of maintenance costs, initial capital, and supplier costs. Minor variations within preoperative settings in departments are highlighted in the construction on capturing business complexity such as TDABC. TDABC is useful in dealing with the variety of industrial processes.

The research gap was filled by selecting the accurate unused capacity category (18%) from Figure 2.24. It is the most compatible since it fulfils the second research objective. Table 2.12 shows 6 published research on accurate unused capacity, in terms of process mapping, time equation, capturing business complexity, and forecasting.

Table 2.12 The methodology of TDABC

Author (Year)	Application	Process mapping	Time equation	Capturing business complexity		Unused capacity	Forecasting
				Resources	Practical		
(Elshaer, 2022)	Restaurant	√	√	√	√	√	√
(Defourny et al., 2022)	Radiation oncology	√	X	√	√	√	√
(Mohammad pour et al., 2022)	Rehabilitation services	√	√	√	√	√	X
(Masthoff et al., 2021)	Interventional radiology care	√	√	√	X	√	X
(Fang et al., 2021)	Hip and knee arthroplasty	X	X	√	√	√	√
(Kamil et al., 2021)	Electronic industry	√	√	√	√	√	√

In the application of restaurant, Elshaer (2022) uses process mapping in analysing the restaurant operations. Due to the importance on price and quality, managers of restaurants had to discontinue outdated accounting in exchange for improved methods in order to keep up beneficial collaborations. After implementing TDABC, restaurant operational costs and value-added activity mapping seem feasible. According to the tabulated data, the average earnings of a product is 1.57 USD and the average time of creating a single product is 4.27 minutes, with an average daily sale of 144 sandwiches. The allocated time is related to two primary expense pools/activities, and production activities consume 50% and 41.66% of the total activity time, correspondingly.

According to Defourny et al. (2022), the increasing expenses in radiation oncology, particularly as a result of new health care interventions, necessitate authorities estimating the resource requirements and the costs of alternative circumstances that take into consideration for modifications in the profiles of patient, protocols for treatment, and technological advances. Thus, the TDABC model provides external beam radiotherapy treatments a consistent, transparent and flexible nationwide tool financially and resource utilization. The personnel's practical capacity is 80% of theoretical capacity (contractual work hours). Inefficiency that cannot be avoided, such as breaks and sick leave accounts for another 20% of the total.

Following the application in rehabilitation services, Mohammadpour et al. (2022) claimed that there are no strong relationships involving the processes and the quantity of resources consumed, and that conventional ways are only feasible in circumstances with limited activities and restricted costs. Thus, TDABC is implemented as it provides more accurate cost financial data as well as other essential details, such as an accurate profit/loss overview, unused human potential, and an overview for enhanced resource management for health care professionals. When unused capacity is compared, the cashier at the clinic has the greatest proportion of unused time. The clinic's full cashier operations account for just 14.2% of the practical capacity. For receptionists, the proportion was less than 17%. The number of employees for rehabilitation specialists are similarly high. Meanwhile, within all of the departments, mental health occupational therapists work the least amount of time (83% of total practical capacity).

According to Masthoff et al. (2021), conventional costing technique in diagnostic radiology and IR are top-down methods that disregard physician expertise, relate to expenses with respect to charges, and thus are inaccurate in actuality. TDABC showed important organisational and economic flaws, allowing for significant improvements in the workflow, reduced expenses, profit advancement, and important details to make decision-making. TDABC aided in the accurate estimation of interventional radiologic treatment cycles, as well as the optimization of internal processes, minimising expenses and profit. TDABC-based treatment process improvement reduces individual time requirements by 16% and 30%, and also reduced costs by 5.5% and 15.7% for AVM and VM treatments.

Institutions using hip and knee arthroplasty have to comprehend the financial burden of revision total joint arthroplasty with its high costs and possible uneven reimbursement is stated by Fang et al. (2021). The TDABC plan represents every procedure step by the cost related to the resource consumed and the amount of time the patient devotes on the resource. TDABC's cost-measurement approach has been found in TJA tests to be more accurate than usual hospital accounting methods. The expenses of implant have been proved to account for 40%-52% of overall hospital expenditures for main operations. This statistic rises in revision implants, probably due to the complicated constructions required.

The existing costing approach makes it impossible to access all of the activities necessary for each workstation according to Kamil et al., (2021), that necessitating an additional analysis to determine the unused capacity in terms of resources and costs. TDABC is used to calculate unused capacity by combining the time equation and the capacity cost rate. According to the study, the analysis of the drum core winding with auto epoxy workstation discloses an unused capacity of time is 578,898.58 minutes, indicating that the workstation has excess operating time. Meanwhile, epoxy inspection workstation finds an unused capacity of cost is -MYR36,630.83. It indicates that an additional expense has been incurred at this workstation.

In a word, there is only two applications out of six is applied all the methodology of TDABC whereas restaurant and electronic industry. But, all the six published work application enact the unused capacity. Hence, it is challenging to acquire any prior research that use the TDABC in the E&E sector especially in assessing the unused capacity of time and cost in the production line. This is because the TDABC has not been widely applied.

2.8 Summary

In this chapter, the literature review on MTS and TDABC is delivered in a proper way so that the reader may get more understanding. Both of these approaches have been discussed in a variety of applications, including the explanations and methodologies. In addition, both the advantages and disadvantages of the approaches have been discussed in order to guarantee that each approach is sufficiently prepared to achieve a certain goal. Therefore, the research gap serves as the motivation for this research, which aims to assist resolve the existing issues.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The knowledge on the MTS and TDABC research methodologies that were used in this research is provided in much detail in this chapter. The approach that has been suggested follows a four-stage process, which includes defining the issue, collecting data, analysing the data, and finally coming up with interpretations and conclusions. The initial stage in the process involves defining the issue in relation to the procedures exists in the electrical and electronics industry that present a need for meaningful understanding. Meanwhile, data collection consists of practical engagement, parameter selection, and data collection in electronics companies. The process of systematically using the MTS and TDABC procedures in order to define and assess data is included of the process known as data analysis. MTS is comprised of four phases, however TDABC accomplishes its goal using a total eight processes. Then, the integration between the degree of contribution and capacity utilization is been done. Lastly, interpretations and conclusions are developed to explain the research studies, ultimately summarizing the overall conclusions and recommendations.

3.2 Flowchart

Figure 3.1 illustrate the flowchart for this research study. Overall, there are four phases used in implementing this research. The first phase is to define the issue, then involves the phase of collecting and analysing the data, and finally follows the phase of doing interpretation and making conclusion.

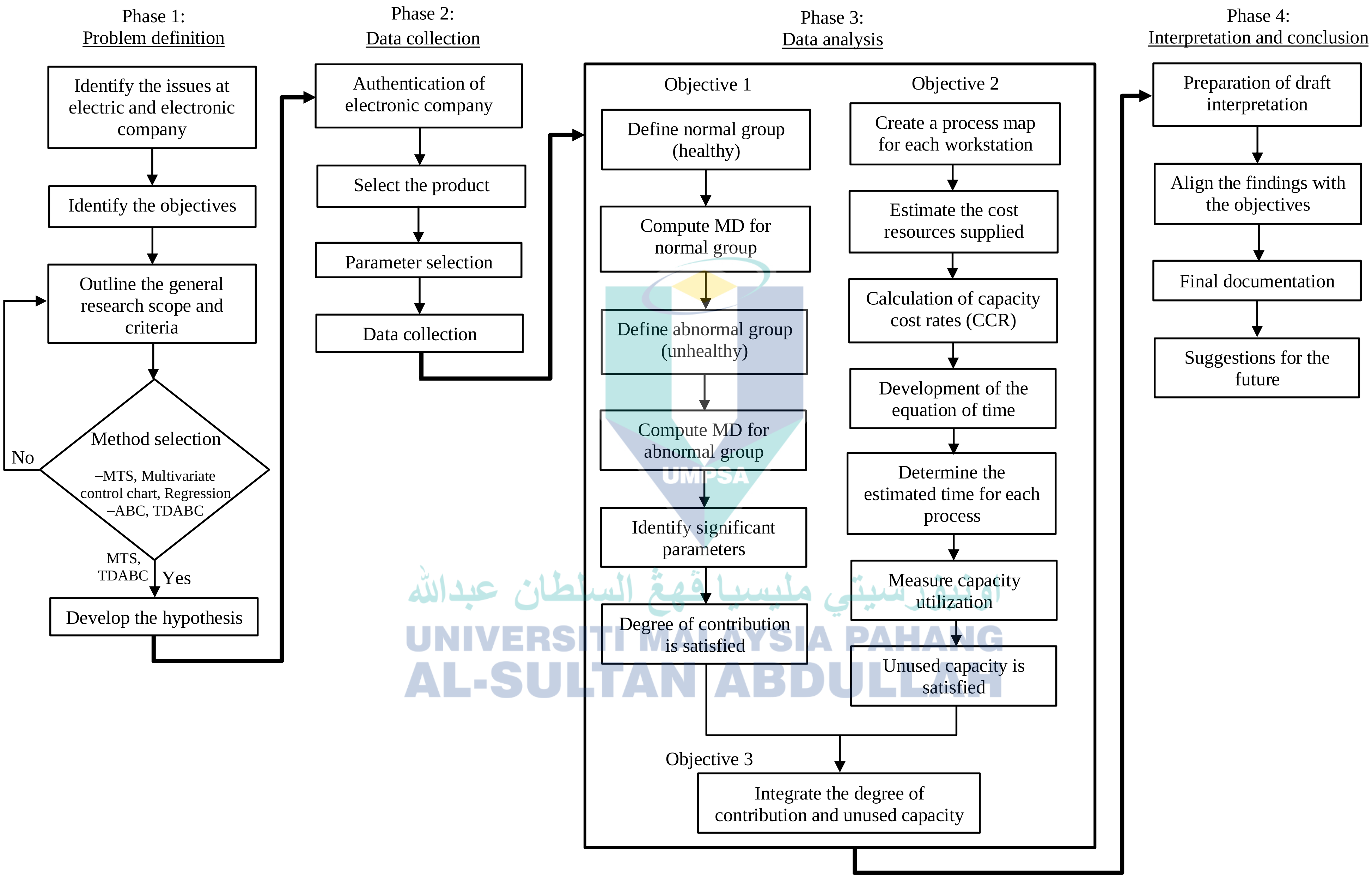


Figure 3.1 Research methodology flowchart

3.3 Phase 1: Definition of Hypothesis

Hypothesis 1

The degree of contribution parameters is measured by using Mahalanobis distance. Whereas, the abnormal group is the rejected sample. The Mahalanobis distance able to segregate the abnormal group from the normal group. Thus, orthogonal array and signal-to-noise ratio is implemented in order to identify the "best" selection of parameters and calculate the Mahalanobis distance.

Hypothesis 2

The overall activity of product costs is described by process map. The accurate capacity cost rates by visualizing resource supply costs and actual capacity. The accuracy of the unused capacity of time and cost depends on the details of the activities included in the time equation. Therefore, the overhead cost of products is allocated when the cost driver of each activity is specified.

Hypothesis 3

The degree of contribution in the MTS application and the selection of activities, including time and cost, were identified. Important parameters are taken into account in the costing structure. Therefore, an integration can be made between degree of contribution and capacity utilization time and cost capacity on the production line.

3.4 Phase 2: Data Collection

3.4.1 Authentication of Electronic Company

Malaysia's manufacturing sector contributes for 36.8% of the country's gross domestic product (GDP). The extraordinary result was led by 4.1% increase in the manufacturing industry in December 2021, notably 7.6% growth in the electrical and electronics manufacturing product (Teoh et al., 2021). XXX Sdn Bhd is a company that has been trading electronic products since 1995. It is located in Pasir Gudang, Johor. Currently, the company has five affiliates in several countries, including Tokyo, Shanghai, Hong Kong & Shenzen, Singapore, and Malaysia. Figure 3.2 shows the company front entrance.

Figure 3.2 Authentication electronic company

The authentication company manufactures electronic products and provides EMS and IPO services to the global electronic market. The company also provides secure warehousing services with guaranteed reliability based on value-added services such as VMI service, competitive cost, own-land building, CCTV security and safety, sufficient facility equipment, self-regulation and SOP quality services, and a warehouse area that can fit 1490 pallets. Lastly, as an electronic trade company, they aim to contribute to social development.

3.4.2 Selection of Product

XXX Sdn. Bhd. is a global manufacturer of electronic components for thermal printers with high customer demand for PCB assembly. The optimisation procedures for thermal printers are difficult to observe while looking at the production line. The thermal printer is ordinarily used for printing commercially available tags and labels from various manufacturers (Monju et al., 2023).

This thermal printer production line process has 50 work stations, and each workstation symbolises its major activity as illustrated in Figure 3.3. However, in this research, there are 8 selected workstations that are used for top side process as indicated in the green box colour. This research covered 22 parameters from 150 available parameters for process inventory, top, bottom and packaging.

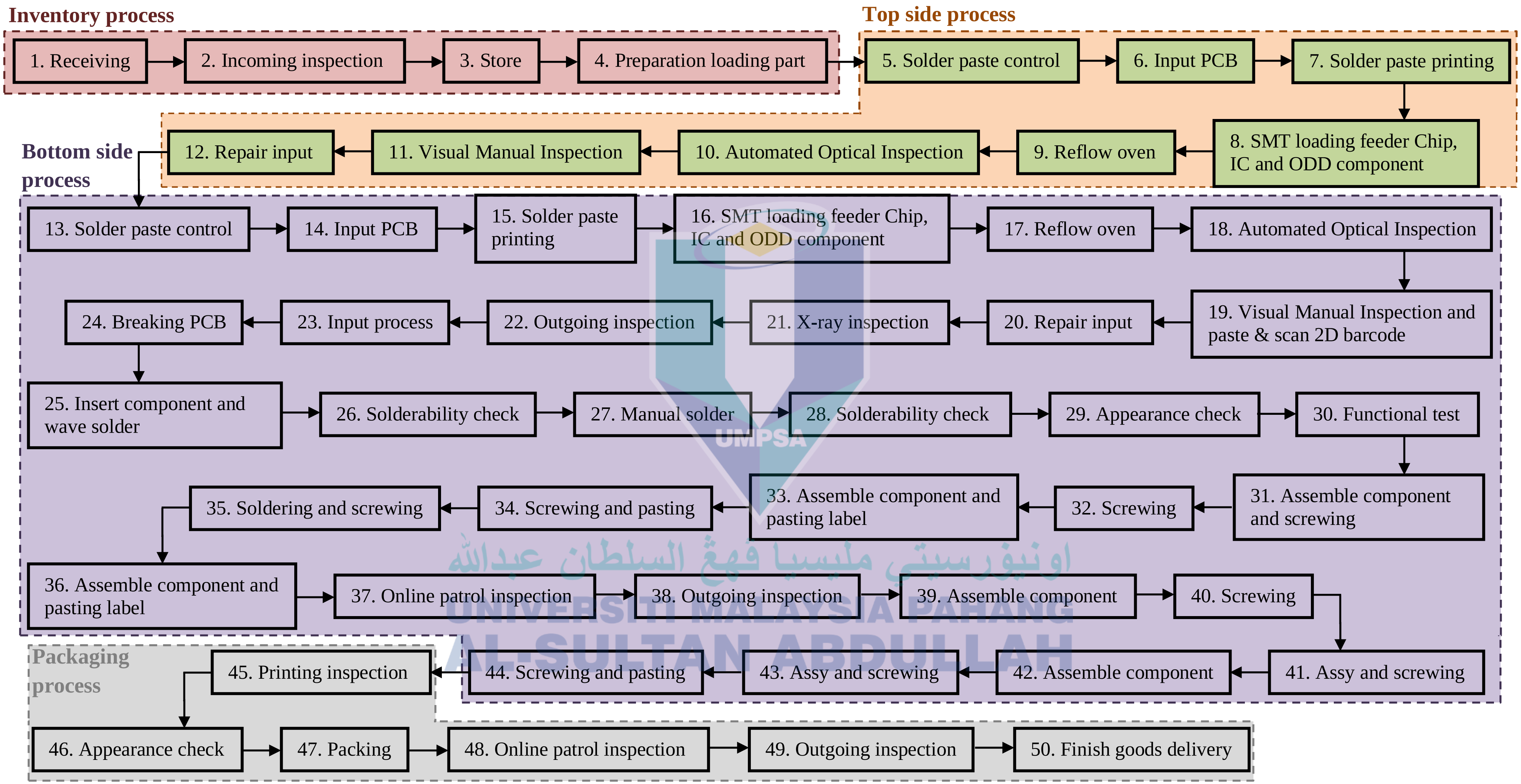


Figure 3.3 Production line of thermal printer

3.4.3 Parameter Selection

A standard operating procedure is provided for each workstation. It is to make sure the quality meets the acquired specifications. There are 22 parameters of top side process which are highlighted in Table 3.1.

Table 3.1 Parameters of top side process

Workstation	No.	Parameters	Unit	Normal Range
1	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
2	5.	Input PCB visual check	NA	- No scratch - No crack - No dust - No foreign objects
3	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
4	9.	Check value and polarity	NA	- Correct material and polarity - Correct location part - No part abnormality - No part missing
	10.	SMT program	NA	- Correct polarity - Correct value - Correct body marking and orientation
5	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
6	17.	AOI result checking	NA	- Correct material - Correct part - Correct location

Table 3.1 Continued

Workstation	No.	Parameters	Unit	Normal Range
7	18.	VMI Solder fillet condition of 45°	Percentage (%)	≥75%
	19.	VMI PCB sampling stamp	NA	- Correct polarity location - No wrong component - No missing component - No dry solder
8	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

3.5 Phase 3: Data Analysis

MTS and TDABC are frequently utilised to evaluate the degree of contribution and analyse the unused capacity respectively.

3.5.1 Mahalanobis-Taguchi System Methodology

The software used to generate the data analysis is MT system All-Purpose software (MTRT-AddIns) which will be used in Microsoft Excel. The RT method is a perceptual T method that can categories objects into two groups: inside and outside of unit space. The RT method, unlike the T method, occurs when the true value of a signal (measured output) is unknown, but the group it belongs to is unambiguous and multiple unit spaces are available. Here are the phases for applying the method:

1. Classification using RT method.
   a. Define healthy group.
   b. Computation of sensitivity, β and standard SN ration of the healthy group.
   c. Computation two variables of healthy group.
   d. Computation of distance in the healthy group.
   e. Define unhealthy group.
   f. Computation of sensitivity, β and standard SN ratio of the unhealthy group.
   g. Computation two variables of unhealthy group.
   h. Computation of distance in the healthy group.

2. Optimization using T method

a. Define healthy group.
b. Define unhealthy group.
c. Normalized unhealthy group.
d. Compute proportional coefficient and SN ratio.
e. Compute integrated estimate value of unhealthy group.
f. Compute SN ratio of integrated estimate value.
g. Evaluation importance variable using orthogonal array.

Establishing the unit space and compute the average value of each item is the first stage. Suppose *n* samples are taken for the unit space as shown in Table 3.2. The k-elements must have the same dimension or be dimensionless.

Table 3.2 Average values of samples and elements in the unit space

Data No.	Element/variable				Linear formula L
	1	2	…	k	
1	x_{11}	x_{12}	…	x_{1k}	L_1
2	x_{21}	x_{22}	…	x_{2k}	L_2
…	…	…	…	…	…
n	x_{n1}	x_{n2}	…	x_{nk}	L_n
Average	$\bar{x}_1$	$\bar{x}_2$	…	$\bar{x}_k$	

Source: Teshima et al. (2012)

Find the average of $\bar{x}_1$, $\bar{x}_2$, …, $\vec{x}_k$ for each element of *n* samples in the unit space. This average formula can be expressed as equation (3.1):

$$\bar{x}_j = \frac{1}{n}(x_{1j} + x_{2j} + \cdots + x_{nj}) \qquad (j = 1, 2, \ldots, k) \tag{3.1}$$

The linear formula, L can be obtained by equation (3.3) in second step in finding the sensitivity, β and the standard SN ratio for the first η samples of the unit space.

$$\text{Sensitivity} \quad \beta_1 = \frac{L_1}{r} \tag{3.2}$$

where:

$$\text{Linear equation} \quad L_1 = \bar{x}_1 x_{11} + \bar{x}_2 x_{12} + \cdots + \vec{x}_k x_{1k} \tag{3.3}$$

$$\text{Effective divider} \quad r = \bar{x}_1^2 + \bar{x}_2^2 + \cdots + \vec{x}_k^2 \tag{3.4}$$

The standard SN ratio, η_1 is calculated after the first meeting of all variations, S_T, where the element variation is proportional to S_β, as shown below.

Total variations $S_{T1} = {x_{11}}^2 + {x_{12}}^2 + \cdots + {x_{1k}}^2$ (f = k) (3.5)

Variation of proportional term $S_{\beta 1} = \frac{L_1^2}{r}$ (f = 1) (3.6)

Error variation $S_{e1} = S_{T1} - S_{\beta 1}$ (f = k – 1) (3.7)

Error variance $V_{e1} = \frac{S_{e1}}{k-1}$ (3.8)

A standard SN ratio η1 is therefore given by equation (3.9):

Standard SN ratio $\eta_1 = \frac{1}{V_{e1}}$ (3.9)

The use of the phrase "standard SN ratio" reflects the fact that for this purpose we have chosen to consider the mean of the unit space term as the standard signal. In equation (3.9), the dividend might alternatively be expressed by r, however the value 1 was selected since it is shared by all members.

The sensitivity, β and the reference SN ratio, η were obtained in the same way for each sample in unit space, and the results are shown in Table 3.3.

Table 3.3 β and η (duplicate ratio) of all samples in unit space

Data No.	Sensitivity β	SN ratio η
1	β_1	η_1
2	β_2	η_2
:	:	:
:	:	:
n	β_n	η_n

Source: Teshima et al. (2012)

The next step is to calculate the two variables Y_1 and Y_2 using the two items in Table 3.3, sensitivity, β and standard SN ratio, η. β is used unchanged for the new variable Y_1. Y_2 is first transformed in order to be able to evaluate the deviation from standard conditions (items in unit space using the items in Table 3.2) as follows:

$Y_{i1} = \beta_i$ $(i = 1, 2, \ldots, n)$ (3.10)

$Y_{i2} = \frac{1}{\sqrt{\eta_i}} = \sqrt{V_{ei}}$ (i = 1, 2, …, n) (3.11)

Y_1 and Y_2 are calculated over all unit space samples, one of which is averaged. The results are shown in Table 3.4.

$$\bar{Y}_1 = \frac{1}{n}(Y_{11} + Y_{21} + \cdots + Y_{n1}) \tag{3.12}$$

$$\bar{Y}_2 = \frac{1}{n}(Y_{12} + Y_{22} + \cdots + Y_{n2}) \tag{3.13}$$

Table 3.4 Y1 and Y2 for all samples in the unit space

Data No.	Y_1	Y_2
1	Y_{11}	Y_{12}
2	Y_{21}	Y_{22}
:	:	:
:	:	:
n	Y_{n1}	Y_{n2}
Average	$\bar{Y}_1$	$\bar{Y}_2$

Source: Teshima et al. (2012)

From the steps above, the number of k elements is summarized in two variables, Y_1 and Y_2 for each sample in unit space. Then, the MT method measures the Mahalanobis distance, D of each sample in unit space from the centre $(\bar{Y}_1, \bar{Y}_2)$. The individual MT distance measurement in unit space is shown in Table 3.5.

Table 3.5 Distances of samples in unit space

Data No.	Distance D^2	Distance D
1	D_1^2	D_1
2	D_2^2	D_2
:	:	:
:	:	:
n	D_n^2	D_n

Source: Teshima et al. (2012)

As shown in Table 3.6, the amount of signal data obtained l is used to assess the selectivity. The linear form of L is found in equation (3.15) given.

Table 3.6 Signal data items and linear formula

Data No.	Element/variable				Linear equation L´
	1	2	…	k	
1	x'_{11}	x'_{12}	…	x'_{1k}	L'_1
2	x'_{21}	x'_{22}	…	x'_{2k}	L'_2
…	…	…	…	…	…
l	x'_{l1}	x'_{l2}	…	x'_{lk}	L'_l

Source: Teshima et al. (2012)

Next, finding the sensitivity, β and the standard SN ratio, η of the first signal data gives:

Sensitivity $\beta_1 = \frac{L'_1}{r}$ (3.14)

where:

Linear equation $L'_1 = \bar{x}_1 x'_{11} + \bar{x}_2 x'_{12} + \cdots + \bar{x}_k x'_{1k}$ (3.15)

Total variations $S_{T1} = x'^2_{11} + x'^2_{12} + \cdots + x'^2_{1k}$ (f = k) (3.16)

Variation of proportional term $S_{\beta 1} = \frac{L'^2_1}{r}$ (f = 1) (3.17)

Error variation $S_{e1} = S_{T1} - S_{\beta 1}$ (f = k – 1) (3.18)

Error variance $V_{e1} = \frac{S_{e1}}{k-1}$ (3.19)

A standard SN ratio η_1 is therefore given by equation (3.20):

Standard SN ratio (duplicate ratio) $\eta_1 = \frac{1}{V_{e1}}$ (3.20)

The sensitivity, β and the standard SN ratio, η are determined separately for each signal data set as shown in Table 3.7.

Table 3.7 β and η (duplicate ratio) for each signal data

Data No.	Sensitivity β	SN ratio η
1	β_1	η_1
2	β_2	η_2
:	:	:
:	:	:
l	β_l	η_l

Source: Teshima et al. (2012)

Calculate Y_1 and Y_2 using the two sensitivity categories β from Table 3.7 and the standard SN ratio, η. Here, the new variable Y_1 keeps the sensitivity β intact, while Y_2 does not keep the standard SN ratio η intact, but first converts the irregularity from the standard condition (unit space category-by-category average value, as in Table 3.2) into analysable deviations:

$Y_{il} = \beta_i$ (i = 1, 2, …, l) (3.22)

$Y_{i2} = \frac{1}{\sqrt{\eta_i}} = \sqrt{V_{ei}}$ (i = 1, 2, …, l) (3.23)

Both Y_1 and Y_2 are computed for each and every signal data. All of the results of the calculations can be seen in Table 3.8.

Table 3.8 Y1 and Y2 for each separate signal

Data No.	Y_1	Y_2
1	Y_{11}	Y_{12}
2	Y_{21}	Y_{22}
:	:	:
:	:	:
l	Y_{l1}	Y_{l2}

Source: Teshima et al. (2012)

After the previous manipulation, the *k* variables of each signal data set were reduced to Y_1 and Y_2. Then, each signal data set in Table 3.9 calculates its Mahalanobis distance, *D* from the centre of the unit space $(\bar{Y}_1, \bar{Y}_2)$ using MT method.

Table 3.9 Distance of each signal data item

Data No.	Distance D^2	Distance D
1	D_1^2	D_1
2	D_2^2	D_2
…	…	:
l	D_l^2	D_l

Source: Teshima et al. (2012)

After the Mahalanobis distance is defined, the T method is used to define the parameters that are considered significant. Through the use of T method, a uniform unit space that is densely populated and has average output values is defined. The calculation of T Method is described below.

The unit space was subjected to the collection of *n* data, as can be observed in Table 3.10. In order to avoid missing any dimension data, it is essential that all data items contain the same dimension as the image density.

Table 3.10 Data for the unit space and averages values of the items and outputs

Data No.	Element/variable				Output value
	1	2	…	k	
1	x_{11}	x_{12}	…	x_{1k}	y_1
2	x_{21}	x_{22}	…	x_{2k}	y_2
…	…	…	…	…	…
n	x_{n1}	x_{n2}	…	x_{nk}	y_n
Average	$\bar{x}_1$	$\bar{x}_2$	…	$\bar{x}_k$	$\bar{y} = M_0$

Source: Teshima et al. (2012)

Find the mean $\bar{x}_1, \bar{x}_2, ..., \bar{x}_k$ of all items and the mean output value $\bar{y} = M_0$ from n samples in the unit space. So, the average works like this:

$$\bar{x}_j = \frac{1}{n}(x_{1j} + x_{2j} + \cdots + x_{nj}) \qquad (j = 1, 2, \ldots, k) \tag{3.23}$$

$$\bar{y} = M_0 = \frac{1}{n}(y_1 + y_2 + \cdots + y_n) \tag{3.24}$$

Signal data is considered to be any and all data items that are identified with l and are not selected for unit space. In Table 3.11, the signal data are shown. For the purpose of determining the proportionality coefficient, β and the SN ratio, n, "signal data" refers to all of the data that is used.

Table 3.11 Signal data

Data No.	Element/variable				Output value
	1	2	…	k	
1	x'_{11}	x'_{12}	…	x'_{1k}	y'_1
2	x'_{21}	x'_{22}	…	x'_{2k}	y'_2
…	…	…	…	…	…
l	x'_{l1}	x'_{l2}	…	x'_{lk}	y'_l

Source: Teshima et al. (2012)

The mean of the term and the sampled unit space output are used to normalise the signal data. The normalization is performed by subtracting the mean value $\bar{x}_j$ of element j in unit space from the value x'_{ij} of element j of the i-th signal data.

$$X_{ij} = x'_{ij} - \bar{x}_j \qquad (i = 1, 2, \ldots, l)\ (j = 1, 2, \ldots, k) \tag{3.25}$$

Similarly, normalization is achieved by subtracting the mean value M_0 generated from the space unit from the i-th signal data output value y'_i.

$$M_i = y'_i - M_0 \qquad (i = 1, 2, \ldots, l) \tag{3.26}$$

Table 3.12 shows the normalized signal data.

Table 3.12 Normalized signal data

Data No.	Element/variable				Output value
	1	2	…	k	
1	X_{11}	X_{12}	…	X_{1k}	M_1
2	X_{21}	X_{22}	…	X_{2k}	M_2
…	…	…	…	…	…
l	X_{l1}	X_{l2}	…	X_{lk}	M_l

Source: Teshima et al. (2012)

Next, calculate the coefficient, β and the SN ratio, n for all elements. The calculation is elucidated in element 1 as an example.

$$\text{Proportional coefficient} \quad \beta_1 = \frac{M_1X_{11}+M_2X_{21}+\cdots+M_1X_{11}}{r} \tag{3.27}$$

$$\text{SN ratio } \eta_1 = \begin{cases} \dfrac{\frac{1}{r}(S_{\beta 1}-V_{e1})}{V_{e1}} & (\text{when } S_{\beta 1} > V_{e1}) \\ 0 & (\text{when } S_{\beta 1} \leq V_{e1}) \end{cases} \tag{3.28}$$

where:

$$\text{Effective divider} \quad r = M_1^2 + M_2^2 + \cdots + M_l^2 \tag{3.29}$$

$$\text{Total variation} \quad S_{T1} = {X_{11}}^2 + {X_{21}}^2 + \cdots + {X_{l1}}^2 \qquad (f = l) \tag{3.30}$$

$$\text{Variation of Proportional term} \quad S_{\beta 1} = \frac{(M_1X_{11}+M_2X_{21}+\cdots+M_1X_{11})^2}{r} \quad (f = 1) \tag{3.31}$$

$$\text{Error variation} \quad S_{e1} = S_{T1} - S_{\beta 1} \tag{3.32}$$

$$\text{Error variance} \quad V_{e1} = \frac{S_{e1}}{l-1} \tag{3.33}$$

The proportionality coefficients β and SN ratio η can be found from element 2 to point *k*. The outcomes that are produced by this procedure are presented in Table 3.13.

Table 3.13 Proportional coefficient β and SN ratio η, element by element

B, η	Element/variable			
	1	2	…	k
Proportional β	β_1	β_2	…	β_k
SN ratio η	η_2	η_2	…	η_k

Source: Teshima et al. (2012)

For each item, the proportional coefficient β and the SN ratio η were used to obtain element by element estimates for each portion of the signal data. The estimated output value for element 1 of the *i*-th signal data is:

$$\widehat{M}_{i1} = \frac{x_{i1}}{\beta_1} \quad (3.34)$$

Estimates are also made for element 2 to *l* of the *i*-th signal data. The last step is the combination of the results by including the weights of $\eta_1, \ldots, \eta_l$ that act as an approximate measurement of the accuracy for each element. Therefore, the integrated estimate is $\widehat{M}_i$ of the *i*-th signal data output as equation 3.35.

$$\widehat{M}_{i1} = \frac{\eta_1 \times \frac{x_{i1}}{\beta_1} + \eta_2 \times \frac{x_{i2}}{\beta_2} + \ldots + \eta_k \times \frac{x_{ik}}{\beta_k}}{\eta_1 + \eta_2 + \ldots + \eta_k} \qquad (i = 1, 2, \ldots, l) \quad (3.35)$$

The values that were measured for the signal data $M_1, M_2, \ldots, M_l$ are shown in Table 3.14, together with the integrated estimates from the measurements taken for $M_1, M_2, \ldots, M_l$.

Table 3.14 Measured values and integrated estimate values of signal data

Data No.	Measured value	Integrated estimate values
1	M_1	$\widehat{M}_1$
2	M_2	$\widehat{M}_2$
…	…	:
l	M_l	$\widehat{M}_l$

Source: Teshima et al. (2012)

The integrated estimate SN ratio is calculated by applying the formula that is derived from Table 3.14. The result of the calculation flows into the evaluation of the relative importance presented in the next step.

Integrated Estimate SN Ratio $$\eta = 10\log\left(\frac{\frac{1}{r}(S_\beta - V_e)}{V_e}\right) \quad (db) \quad (3.36)$$

where:

Linear equation $$L = M_1\widehat{M}_1 + M_2\widehat{M}_2 + \cdots + M_l\widehat{M}_l \quad (3.37)$$

Effective divider $$r = M_1^2 + M_2^2 + \cdots + M_l^2 \quad (3.38)$$

Total variation $$S_T = \widehat{M}_1^2 + \widehat{M}_2^2 + \cdots + \widehat{M}_l^2 \qquad (f = l) \quad (3.39)$$

Variation of Proportional term $$S_\beta = \frac{L^2}{r} \qquad (f = 1) \quad (3.40)$$

Error variation $$S_e = S_T - S_\beta \quad (3.41)$$

Error variance $$V_e = \frac{S_e}{l-1} \quad (3.42)$$

The relative importance of a parameter is determined by how much it affects the estimated SN ratio when it is not utilised. The analysis is conducted using a two-level OA structure, featuring levels 1 and 2. The OA allows for measuring the estimated SN ratio under different circumstances. Take into account 22 parameters were assigned, as indicated in Table 3.15.

Table 3.15 Orthogonal array L_{44} and parameters arrangement

No.	**Parameters**							**Estimated SN ratio (db)**
	1	**2**	**…**	**…**	**…**	**22**	**23**	
1	1	1	…	…	…	1	1	η_1
2	1	1	…	…	…	2	2	η_2
3	1	1	…	…	…	1	1	η_3
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
42	2	2	…	…	…	1	2	η_{42}
43	2	2	…	…	…	2	1	η_{43}
44	2	2	…	…	…	1	2	η_{44}

According to the two-level OA, the level 1 parameters will be utilised, while level 2 parameters will not be utilised. The expected SN ratio is based on the difference between the averages of level 1 and level 2 for each parameter, indicating the importance of each parameter. A descending line from left to right implies that the parameter has an impact of increasing the output as in the factorial effect graph. The degree of contribution becomes positive when the parameter is employed with higher SN ratios and not with lower SN ratios. On the contrary, ascending line from left to right implies that the parameter lowers the output. In other words, when the parameter is employed with SN ratios and not with higher SN ratios, the degree of contribution becomes negative.

3.5.2 Time-Driven Activity-Based Costing Methodology

The first stage of TDABC is identifying produce-related activities and sub-activities. This company produces this product in three activity centres: 1. Product preparation activity centre, warehouse products are physically inspected and the part number and quantity are determined before temperature and humidity measurements. 2. The top side processing activity centre applies solder from the refrigerator to the PCB, then checks SMT program, loading list, and component replacement. The reflow oven melts solder without damaging PCB electrical components. The AOI machine tests the PCB, and VMI reduces and prevents faults to avoid rejects and also hand soldering is for repairing defect. 3. The bottom side processing, retail packaging and delivery activity centre PCB sub-parts are assembled. The product is packaged in PE bags and boxes after assembly and inspection. A holding area stores it until delivery.

Next, the allocated cost resources for every activity are separated into two groups which are labour costs, and equipment, machinery, and other equipment expenses. This company has 50 primary and 69 secondary workstations. The cost of supply resources like manpower, machine maintenance, raw materials and consumables is obtained from the ledger. Actual capacity is estimated by adding the number of hours worked per year. The working hours of the company are 8 a.m. to 6 p.m for every Monday to Saturday. Calculating the capacity cost rate (MYR per minute) is accomplished through the use of equation (3.43) (Dubron et al., 2021).

$$Capacity\ cost\ rate = \frac{Cost\ of\ capacity\ supplied}{Practical\ capacity\ of\ resources\ supplied} \tag{3.43}$$

Further, the time equation estimate required for the TDABC conveniently connects variation in the time needs caused by various kinds of transactions. It is not necessary to make the simplistic assumption that all of the requests or payments take the same period of time to process. In a TDABC model, unit time estimates vary according on sequence and activity variables. A simple equation is used to estimate the department's resource requirement in the time-driven method (3.44) (Al Askary et al., 2020).

$$Tt = \beta_0 + \beta_i \chi_i \tag{3.44}$$

where;

Tt = time needed to perform an activity (minute)

β_0 = standard time to perform the basic activity (minute)

β_i = estimated time to perform the incremental activity (minute)

χ_i = quantity of the incremental activity (time)

The development of a time equation is required in order to compute the estimated duration of time required for production. The ideas of the Motion and Time study principles were used in order to meet with an estimate of time required for every activity. In other words, estimations are made about the average length of time it takes for the supplies to go from the warehouse to the production line. The time equation may then be developed by multiplying the cost-drivers factors. Quantifying the number of times that each activity occurs in a month was another method that was utilised in getting at an estimate of the capacity needed for each activity. By multiplying the amount of time spent on a certain activity by the amount of time spent, then the overall amount of time spent on the activity is calculated. Lastly, the equation (3.45) can be used to find the total cost of production (Kissa et al., 2019).

$$\text{Total cost of production} = \text{cost of direct materials} + \text{cost of direct labour} + \text{cost of manufacturing overheads} \quad (3.45)$$

3.6 Phase 4: Interpretation and Conclusion

The study concludes with data analysis from XXX Sdn. Bhd. electronic company in Pasir Gudang, Johor, collected utilising MTS and TDABC methodologies. The thorough analysis of the final documentation will be discussed in the following chapter.

3.7 Summary

This chapter describes an explanation of the selection of parameters as well as the approaches of beginning data collection. The data analysis of the electronic company also discussed in this research. Detailed process and method descriptions for analysing the data using the MTS and TDABC systems were discussed. Subsequently, in the next chapter the results of data are elucidated in detail.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the findings that were produced from the cumulative data collected over a period of 12-months from XXX Sdn. Bhd. obtained from SII workstations for thermal printer productions. First, the normal and abnormal data was analysed using MTS method to find the MD values for each group. Then, the significant and insignificant parameters are estimated after SNR are generated. TDABC is applied to the top-side process across 8 workstations. The detailed description of production activities, practical capacity, capacity cost rate, estimated time and capacity for each activity, and capacity utilization for analysing unused time and cost capacities. Further, the proposed solution is implemented as a guideline for future forecasting in creating a normal sample. Lastly, the integration is developed between degree of contribution (DOC) and capacity utilization as in the framework in this chapter.

4.2 RT Method

The RT method creates scatter diagram and line graph of normal and abnormal data obtained from MD values. The Y1 and Y2 values from the normal and abnormal are used to create the scatter diagram. Related patterns are divided into two colours, red and blue. Red colour indicates abnormal data while blue indicates normal data. Meanwhile, the yellow line shows the farthest MD value from the centre of obtained data. In this method, there are 22 parameters related to the creation of the implementation method. The number of samples used for this scatter diagram comes from the existing lot size for normal data while AQL samples are used for abnormal data. All available information comes from the industry.

Figure 4.1 shows normal and abnormal results in March. From the scatter diagram, the farthest MD value from centre is 35.9151. There is also overlap between normal and abnormal data. There are as many as 10 samples overlapping data that occur. The average MD value for March is 1 in the normal group while 8.352678 in the abnormal group. Next, line graph of Figure 4.2 shows the minimum classification MD value for normal data is 0.001052 and the maximum is 5.653321. On the other hand, the minimum MD value for abnormal classification is 0.386322 and the maximum is 35.915106.

Then, the correlation coefficient (r) for normal data is -0.003136. This indicates that the lowest negative relationship between Y1 (new variable of keeps β intact) and Y2 (new variable of does not keep η intact). On the other side, the abnormal correlation coefficient is -0.2261, indicating a weak negative relationship between Y1 and Y2.

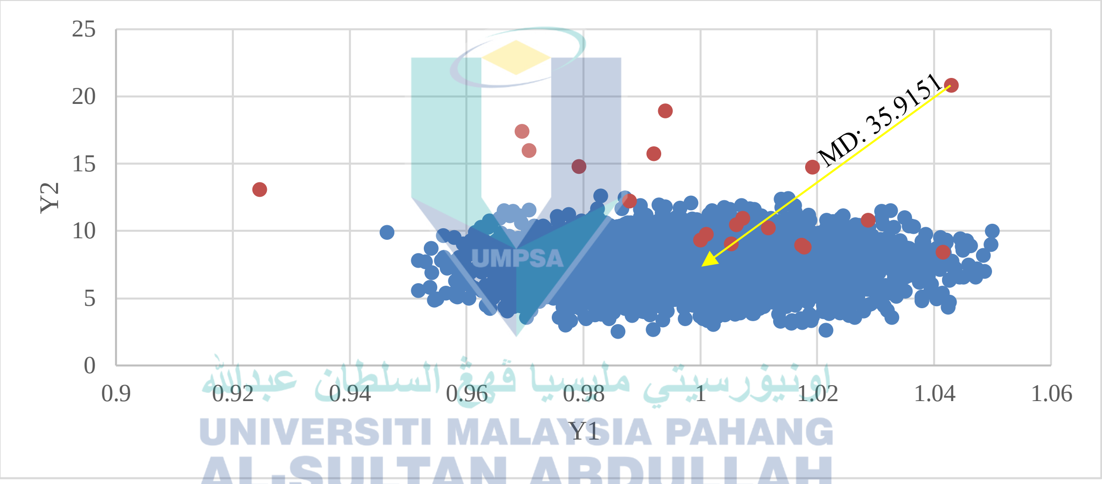


Figure 4.1 Scatter diagram of March

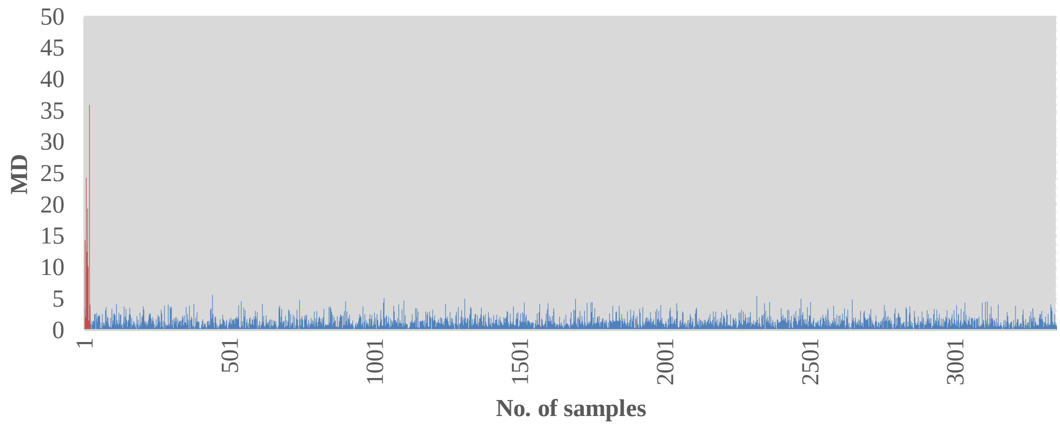


Figure 4.2 Line graph of March

Figure 4.3 depicts normal and abnormal June findings. The farthest MD value from centre in the scatter diagram is 22.7144. There is overlap between normal and abnormal data, as seen in the scatter diagram. There are up to 9 instances of overlapping data. In the normal group, the average MD value for June is 1, but in the abnormal group is 7.083479. From Figure 4.4, the normal data of minimum classification MD value is 0.000355, and the maximum is 5.651898. Nevertheless, for abnormal categorization, the minimum MD value is 0.055739 and the maximum is 22.714396.

For normal data, the correlation coefficient is -0.003575. This means that Y1 and Y2 have the lowest negative relationship. Meanwhile, there is a positive relationship between Y1 and Y2 in abnormal with 0.0611 of correlation coefficient.

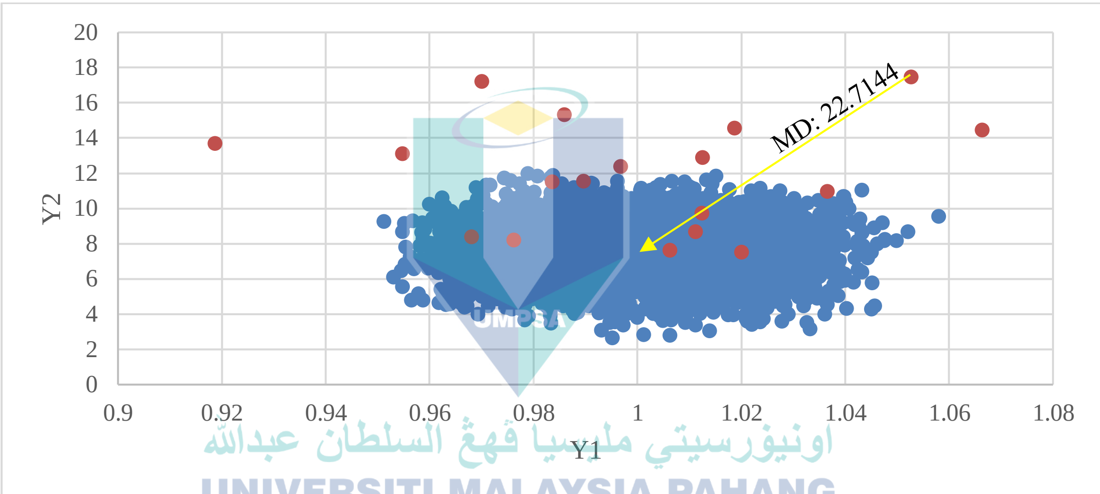


Figure 4.3 Scatter diagram of June

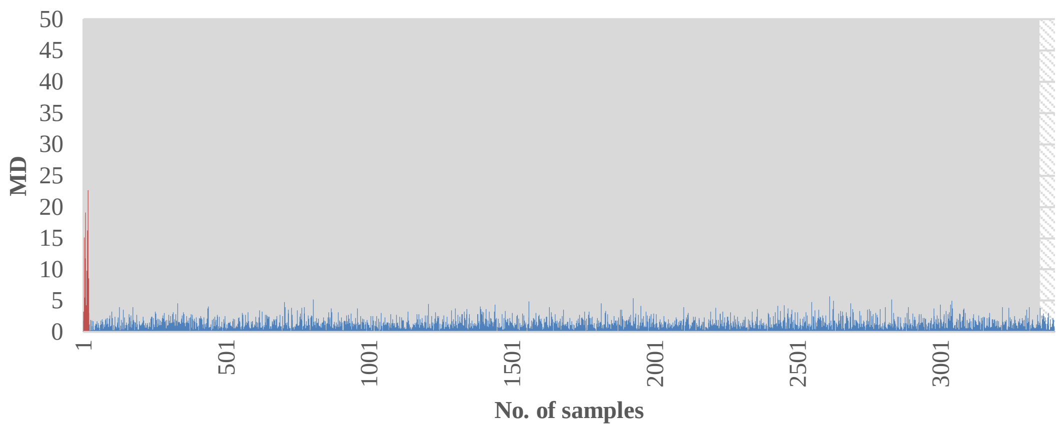


Figure 4.4 Line graph of June

Normal and abnormal September results is shown in Figure 4.5. The scatter diagram shows that the farthest MD value from centre is 365.9161. There are up to 5 samples of overlapping data between normal and abnormal. The mean September MD value in the normal group is 1 while in the abnormal group it is 34.374484. Figure 4.6 shows that the minimum classification MD value for normal data is 0.000171 and the maximum is 6.000181. On the contrary, the minimum MD value for abnormal classification is 0.358151 and the maximum is 365.916107.

The correlation coefficient for normal data is -0.008562 that specify the lowest negative relationship between Y1 and Y2. Besides, there is a -0.7792 correlations coefficient between Y1 and Y2 in abnormal. This correlation shows a moderate negative relationship.

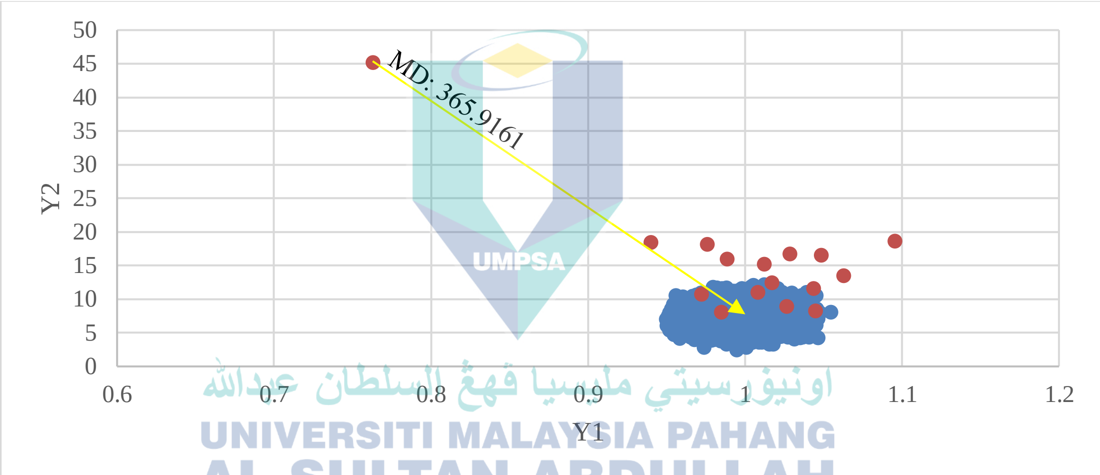


Figure 4.5 Scatter diagram of September

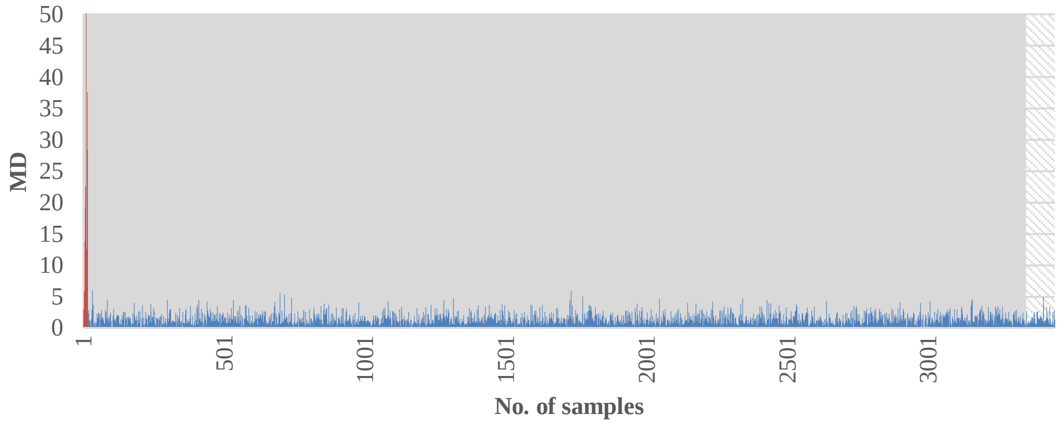


Figure 4.6 Line graph of September

Figure 4.7 shows the distribution of normal and abnormal for each month in 2022. Based on the figure, the blue pattern indicates normal distribution and the red pattern indicates abnormal distribution. The normal distribution rate is higher than the abnormal distribution rate. As in the figure, the highest MD value for abnormal is in September because there is a process that has outliers in the specific range of the parameters.

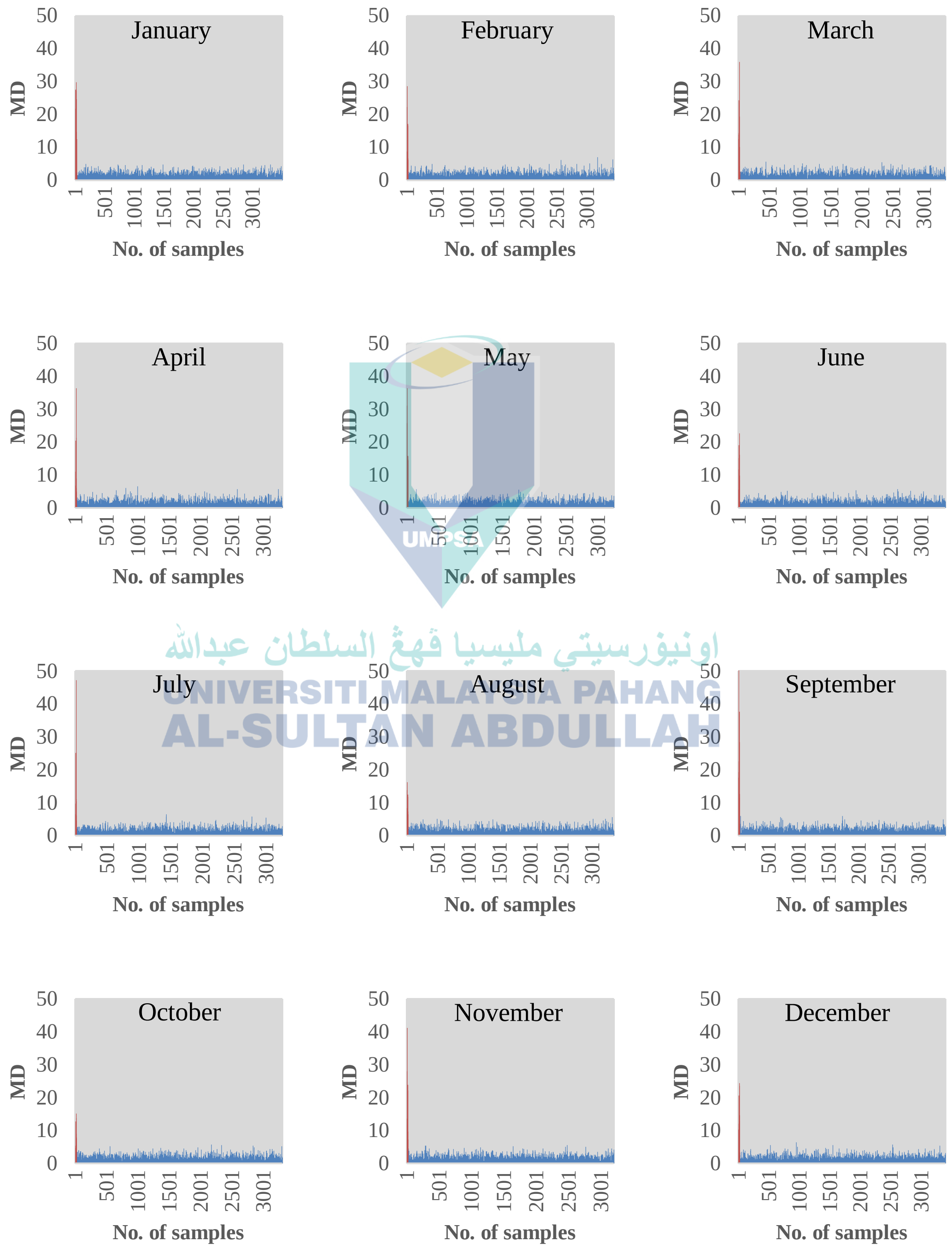


Figure 4.7 MD of normal and abnormal in 2022

4.3 T Method

There are 3500 number of normal groups, whereas the abnormal group number is 20 and 22 parameters used in T Method. Figure 4.8 shows the output distribution which is MD for January. The figure shows that high MD concentrations occur in the range of 0 to 5 MD. There is a large number of data entries (3520). Considering the MD distribution, 3505 samples were found ranging from 0 to 5 MD.

The output of the original data with site number 2871 turned out to be the minimum MD value which is 0.000112 and the output value for number 15 is 29.848876 with maximum MD output value. At the same time, site number 145 output value is 1.074859, that is the closest to the average output value of all data (1.0754152). The details of these data can be referred in Appendix B.

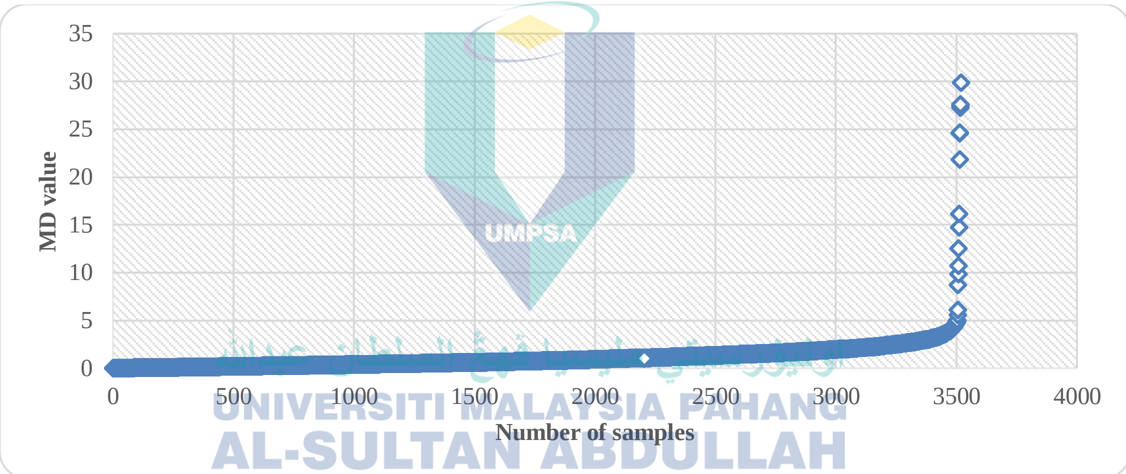


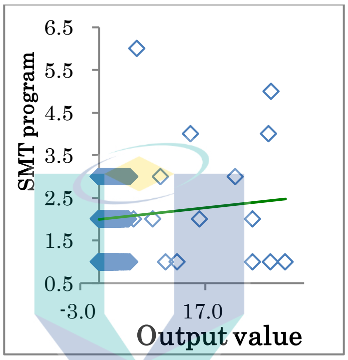
Figure 4.8 Distribution of outputs

The signal data is then normalised using the average values derived from the unit space samples. Normalization is accomplished by subtracting the average of the parameter and unit space outputs from the signal data output values for each parameter. The data is arranged by output value in ascending order. The following shows how the X_{11} refrigerator temperature and M_1 output for sample number 2871 are calculated based on Equations 3.25 and 3.26 in Chapter 3.

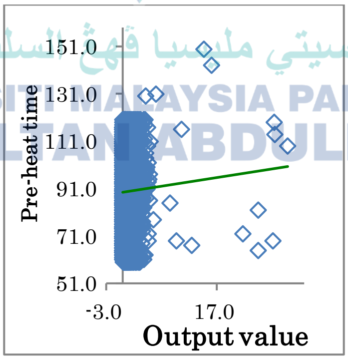
$$X_{11} = 10 - 1.6 = 8.4$$
$$M_1 = 0.000112 - 1.0754152 = -1.0753032$$

Normalization often happens in statically-based approaches by dividing the parameter's standard deviation with what remains after subtracting the average values, but the T Method omits this calculation. This is because parameters with a unit space standard deviation of zero that are unable to computed are often important for prediction and estimation purposes.

The proportional coefficients, β and SN ratio, η is implemented to find useful elements for prediction and estimation. Figure 4.9 depicts the connection between parameters and output values graphically. The output value is shown by the horizontal axes, while the origin is represented by the vertical axes.

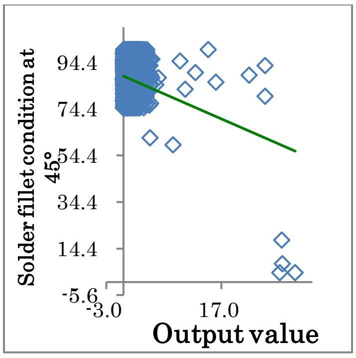


(a)



(b)

Figure 4.9 Scatter of output values and parameters (normalized data)



(c)

Figure 4.9 Continued

The proportional coefficient, β is positive in Figures 4.9 (a) and (b) because it is a straight line rising to the right. The plot of (a) also shows that the data has a uniform distribution throughout the regression line, which approaches zero, and that outlier variance is limited. Regardless, the regression line plot for (b) goes far beyond zero although the data is uniformly distributed. Significantly, both graph leads to the assumption that the SN ratio, η is large and that the SMT program, and the pre-heat time of the machine is very suitable for general yield estimation purposes.

Next, the line in Figure 4.9 (c) is tilted to the right, then the proportional coefficient, β becomes negative. Furthermore, the data exhibit a quite uniform distribution along the regression line, although with a relatively small amount of variation, as can be seen from the graph. This suggests that the SN ratio, η is large and the VMI solder fillet condition is also very well suited for output value estimates.

The proportional coefficient, β and the SN ratio, η can also be determined for other parameters. The assumption is that the value is zero if the SN ratio, η is found out to be negative. Therefore, this parameter is not used in the calculation of the output value *M*. Table 4.1 shows the proportional coefficient, β and the SN ratio, η determined for each parameter for January.

Table 4.1 The proportional coefficients β and the SN ratios η

No.	Parameters	Proportional constant, β	SN ratio, η
1.	Refrigerator temperature (°C)	0.11751	0.0005
2.	Refrigerator humid (%Rh)	0.4229282	0.0003815
3.	Room temperature (°C)	-0.0073	-0.0001
4.	Room humid (%Rh)	0.5205399	0.0007501
5.	PCB visual check	0.03078	0.00034
6.	Solder paste printing	0.03377	0.00062
7.	Solder paste verification	0.01324	0.00013
8.	Solder paste inspection	0.02361	0.00028
9.	Check value & P/N of feeder	0.01714	0.00011
10.	SMT program	0.01616	0.00019
11.	Pre-heat zone temperature (°C)	0.20598	0.00016
12.	Pre-heat zone period (s)	0.3640887	0.000304
13.	Reflow zone temperature (°C)	0.08947	0.02227
14.	Reflow zone period (s)	0.04456	-0.0001
15.	Maximum peak temperature (°C)	0.07485	8.7E-06
16.	Check running model	0.02196	0.00033
17.	AOI result checking	0.007701415	-8.63169E-05
18.	VMI solder fillet condition	-1.079724	0.014678
19.	VMI stamp first PCB sampling	0.04897	0.00164
20.	Solder dotting mark temperature (°C)	0.07165	-0.0001
21.	Solder dotting mark period (s)	0.08876	0.01091
22.	Visual appearance repair input	0.01036	-5E-05

The initial value of the integrated estimate of the signal data is determined for each parameter with the proportional coefficient, β and the SN ratio, η (duplicate ratio). The integrated estimate of the output value $\widehat{M}_i$ for the i-th signal data entry is obtained by dividing the value X_{ij} of a given term by the incline β_j, weighting it by the SN ratio η_j, and then summing according to Equation 3.36 in Chapter 3. Table 4.2 displays several integrated estimations of M data. The error shows the difference between the actual and estimated value.

Table 4.2 Actual and integrated estimate output value of signal data

Data No.	Actual value M	Estimated value M	Error (%)
1	27.5818	45.4563	64.81
2	21.8275	6.8249	-68.73
5	8.6700	11.8081	36.19
6	16.1152	9.4184	-41.56
9	24.6102	5.4025	-78.05
10	14.7005	1.6002	-89.11
13	9.8289	0.4116	-95.81
14	4.2438	3.6279	-14.51

Figure 4.10 is a scatter diagram with the actual value on the horizontal axis and the estimated $\widehat{M}$ value on the vertical axis. As the estimation on a straight line, it implies that a good estimation was produced. This is because the correlation is fairly strong and the distribution is approaching the green. This illustrates that the actual value and estimated value for the signal data distribution have strong connections with each another, as demonstrated by the fact that they have a strong correlation with one another.

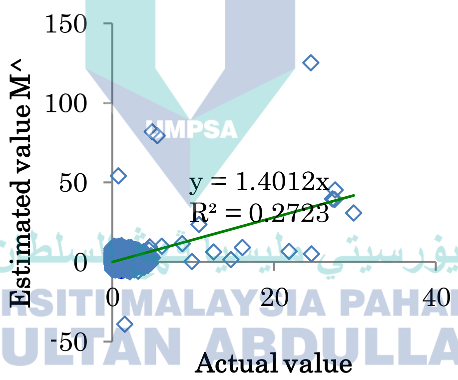


Figure 4.10 Distribution of actual and estimated values of signal data

Thus far, general estimates have been made using all 22 parameters. However, the integrated estimation makes use of a subset of the 22 parameters and ignores the rest of the data. Therefore, the parameter importance is evaluated using orthogonal arrays. The purpose of using orthogonal arrays is to study how each parameter is related to maximize the accuracy of prediction and estimation. An orthogonal array of type L_{44} is selected for parameter allotment. The reason for choosing orthogonal L_{44} arrays, which 4 x prime-type arrays, is that it can maximize the effect of interactions between parameters. The number "1" and "2" indicate at which level a specific parameter is assigned to a column. Level 1: Items are used and Level 2: Items are not used.

An additional table for integrated estimates of the SN ratio (db) was found based on the orthogonal array L_{44}. The resulting data are presented in Table 4.3.

Table 4.3 Integrated estimate SN ratio (db) auxiliary table (averages by level)

No.	Parameter	Level 1	Level 2
1.	Refrigerator temperature (°C)	-16.48677	-16.78137
2.	Refrigerator humid (%Rh)	-16.33506	-16.93307
3.	Room temperature (°C)	-16.91302	-16.35512
4.	Room humid (%Rh)	-16.54036	-16.72777
5.	PCB visual check	-16.58679	-16.68134
6.	Solder paste printing	-17.09525	-16.17288
7.	Solder paste verification	-16.56329	-16.70485
8.	Solder paste inspection	-16.40856	-16.85958
9.	Check value & P/N of feeder	-16.87781	-16.39033
10.	SMT program	-16.58561	-16.68252
11.	Pre-heat zone temperature (°C)	-16.91511	-16.35302
12.	Pre-heat zone period (s)	-16.68083	-16.5873
13.	Reflow zone temperature (°C)	-14.2774	-18.99073
14.	Reflow zone period (s)	-16.621	-16.64714
15.	Maximum peak temperature (°C)	-16.82115	-16.44699
16.	Check running model	-16.56043	-16.7077
17.	AOI result checking	-16.65666	-16.61147
18.	VMI solder fillet condition	-14.93312	-18.33502
19.	VMI stamp first PCB sampling	-16.60344	-16.66469
20.	Solder dotting mark temperature (°C)	-16.35946	-16.90867
21.	Solder dotting mark period (s)	-15.29143	-17.97671
22.	Visual appearance repair input	-16.39214	-16.876

Then, based on this additional table, SN ratio broken-line graph is created as in Figure 4.11. In this graph, the incline decreases from level 1 to level 2 and plays an important role in predicting output. The descending inclined occurred when level 1 subtracts with level 2 produced positive degree of contribution which is significant parameters. Meanwhile, insignificant parameters are obtained when level 1 subtracts with level 2 produced negative positive degree of contribution. This figure is for March, that have 9 ascending (negative degree of contribution) which are parameter 2, 4, 7, 11, 13, 15, 16, 20, and 22. Nevertheless, 13 descending (positive degree of contribution) that is parameter 1, 3, 5, 6, 8, 9, 10, 12, 14, 17, 18, 19, and 21. Parameter 18 (VMI solder fillet condition) shows descending inclined as the subtraction between level 1 (-17.7465) and level 2 (-25.1900) produced positive degree of contribution (7.4435).

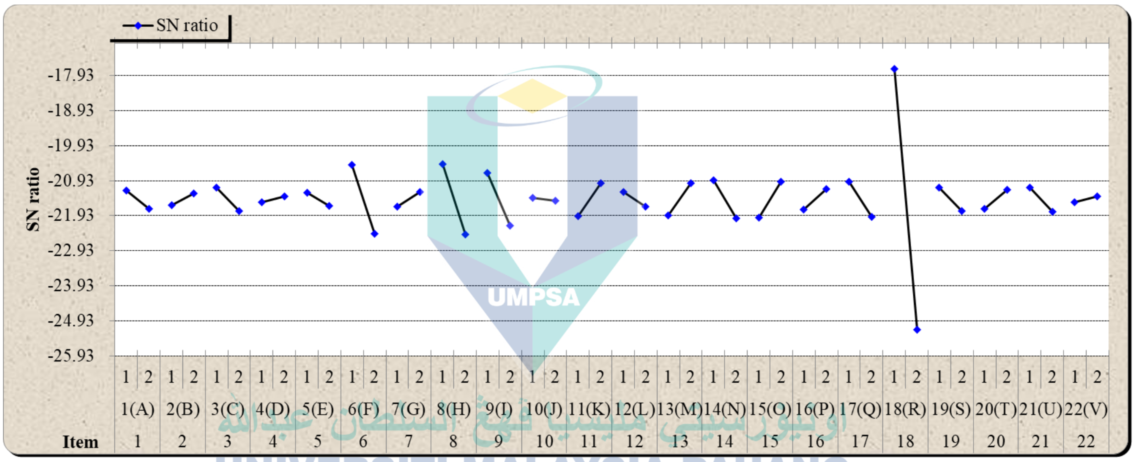


Figure 4.11 SN ratio broken-line graph for March

Figure 4.12 shows that 7 ascending (negative degree of contribution) while 15 descending (positive degree of contribution) of parameter in June respectively. Parameter 12 (Pre-heat zone period) shows ascending inclined as the subtraction between level 1 (-22.0806) and level 2 (-21.62008) produced negative degree of contribution (-0.4605).

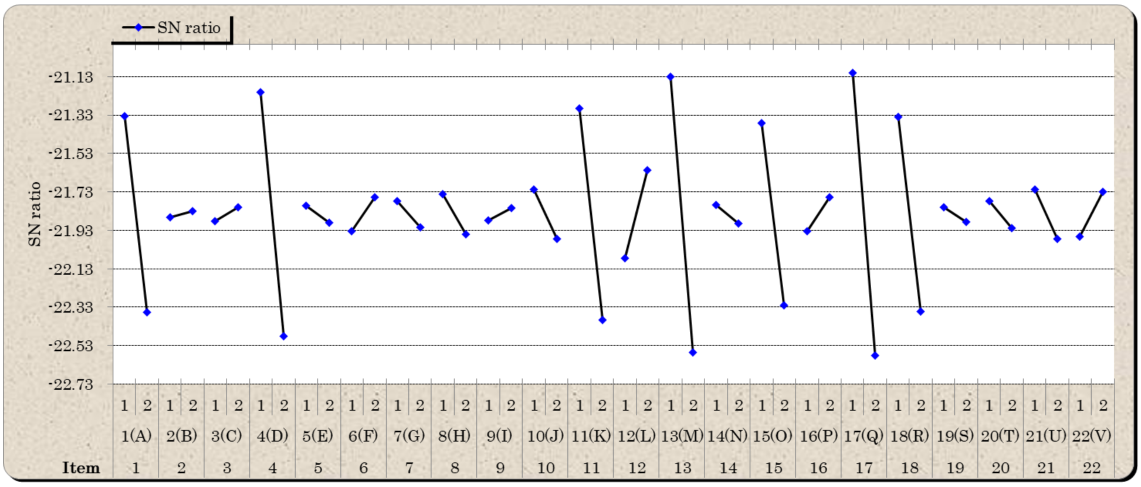


Figure 4.12 SN ratio broken-line graph for June

Further, in September there are 10 ascending (negative degree of contribution) and 12 descending (positive degree of contribution) parameters. Parameter 15 (Maximum peak temperature) shows descending inclined as the subtraction between level 1 (-20.6476) and level 2 (-38.7021) produced positive degree of contribution (18.0546).

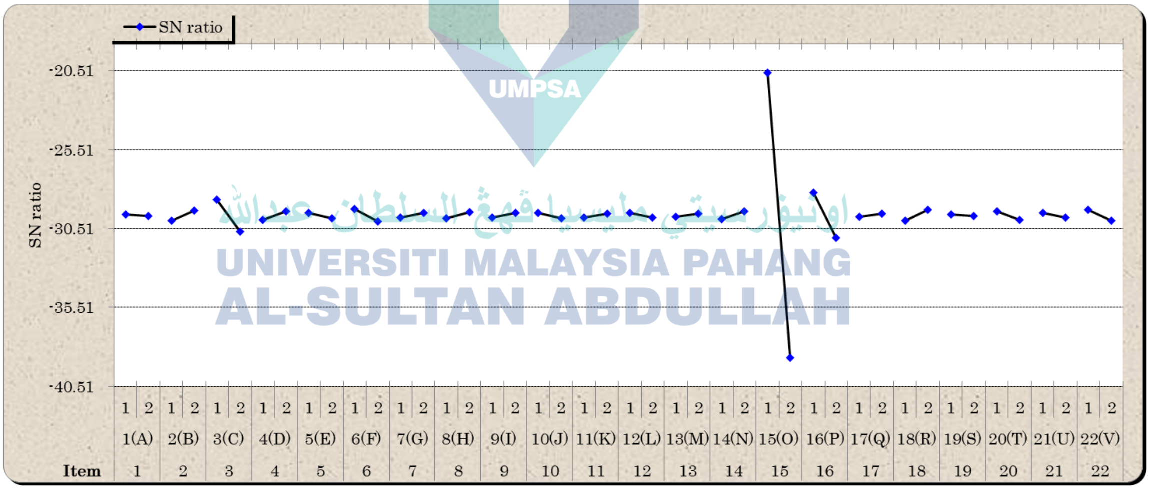


Figure 4.13 SN ratio broken-line graph for September

On the whole, Table 4.4 summarize all degree of contribution of parameters for all months. The shade of green represents a positive degree of contribution, whereas the shade of red represents a negative degree of contribution. Green implies that the parameter is significant and the parameter can retain its input. However, since red represents insignificant parameters, it can be used as a guideline for positive or negative degree of contribution in order to achieve MD that is close to normal. So, when the MD is close to normal, the parameter eventually passes as a not rejected parameter.

Table 4.4 Degree of contribution for a year

Month	Parameters																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Jan	0.295	0.598	-0.558	0.187	0.095	-0.922	0.142	0.451	-0.487	0.097	-0.562	-0.094	4.713	0.026	-0.374	0.147	-0.045	3.402	0.061	0.549	2.685	0.484
Feb	0.441	-0.253	-0.082	2.823	0.311	-0.246	0.135	0.361	0.363	0.231	-0.287	0.570	-0.025	0.298	-0.286	0.177	0.474	3.807	1.260	0.241	-0.229	-0.618
Mar	0.522	-0.322	0.671	-0.185	0.367	1.974	-0.433	2.012	1.504	0.087	-0.940	0.429	-0.915	1.071	-1.024	-0.574	1.019	7.444	0.666	-0.557	0.690	-0.159
April	0.378	0.275	-0.077	-0.528	-0.954	0.077	0.251	0.070	-1.107	-0.097	-0.649	-0.316	12.818	-0.740	0.224	0.321	0.432	3.299	0.404	0.878	0.191	0.651
May	0.154	0.654	-0.581	0.188	0.185	-0.825	0.338	0.092	-0.153	0.106	-0.321	0.340	6.356	-0.064	-0.301	-0.056	-0.161	1.446	0.104	0.159	2.505	0.453
June	1.023	-0.031	-0.072	1.269	0.091	-0.176	0.135	0.211	-0.065	0.256	1.100	-0.461	1.433	0.094	0.949	-0.175	1.472	1.010	0.077	0.120	0.259	-0.232
July	0.346	0.921	-0.492	0.790	0.247	-0.485	-0.072	0.795	-0.378	1.002	-0.278	-0.270	0.619	0.896	0.086	-0.269	0.212	3.308	0.046	0.247	2.041	-0.070
Aug	0.123	-0.095	-0.192	0.414	0.599	-0.025	0.950	0.570	-0.356	0.491	-0.080	-0.177	7.941	0.234	1.102	-0.211	-0.058	-0.210	-0.182	-0.051	0.870	-0.337
Sep	0.085	-0.652	2.026	-0.553	0.343	0.787	-0.301	-0.376	-0.316	0.339	-0.241	0.307	-0.233	-0.515	18.055	2.865	-0.184	-0.696	0.098	0.540	0.280	0.693
Oct	0.783	0.303	-0.298	0.132	-0.169	-0.101	0.102	0.614	0.963	0.793	-0.134	-0.067	5.721	0.548	0.220	0.105	-0.013	0.018	0.081	0.258	0.123	0.175
Nov	1.396	0.693	-0.722	-0.239	1.766	-0.663	-0.331	-0.125	-0.668	0.993	0.088	0.099	-0.098	0.742	2.263	0.116	1.010	2.875	0.235	0.079	-0.068	-0.174
Dec	0.279	0.271	0.550	-0.023	0.171	0.086	0.374	-0.031	-0.283	0.213	0.102	-0.154	0.382	0.353	0.786	-0.041	-0.104	2.338	0.109	1.603	2.307	0.146

4.4 Production Activities Used

The TDABC approach begins by analysing and identifying the industrial activity for the purpose to comprehend its scope and the particular order of circumstances that occur. However, all activities differ, yet these all have a reason to exist.

At the top side workstation, the first step is solder paste control where the solder is prepared before production. The life control sticker for the solder is updated after the removal and the maximum period after removal from the refrigerator is 4 hours. After that, insert the PCB into the automatic loader. PCBs will be visual examinations to prevent dust or foreign objects before being loaded into PCB magazines to supply PCBs to machines. Next, solder paste is used to print on PCB. The solder is placed on the stencil using a spatula and the solder is printed to the PCB. The stencil will be cleaned when the solder paste printing is done. Then, the components of the loading part provided are inserted into the feeder. The value and polarity of the loading material are checked and the barcode is scanned to confirm each part is the same as the loading list.

The fifth step of top side workstation is the reflow oven process. This process is used to melt the adjoining surface solder without overheating and damaging the electrical components with a set temperature. The next process is the Automatic Optical Inspection (AOI) which is performed to test PCBs using AOI machines and automatic inspections. After the AOI process, Visual Manual Inspection (VMI) is performed to check all possible risk points using a magnifying glass to reduce defects and ensure that no reject PCBs. Finally, the last step is the repair input process. This process requires manual soldering for defective PCBs found at AOI or VMI workstations. The repaired PCB will be marked according the colour of ID and been verified after the repair process based on the visual appearance. This process is shown in the Figure 4.14 with the total of cycle time in each workstation, while Figure 4.15 shows the sub-activities of each process with the total of cycle time.

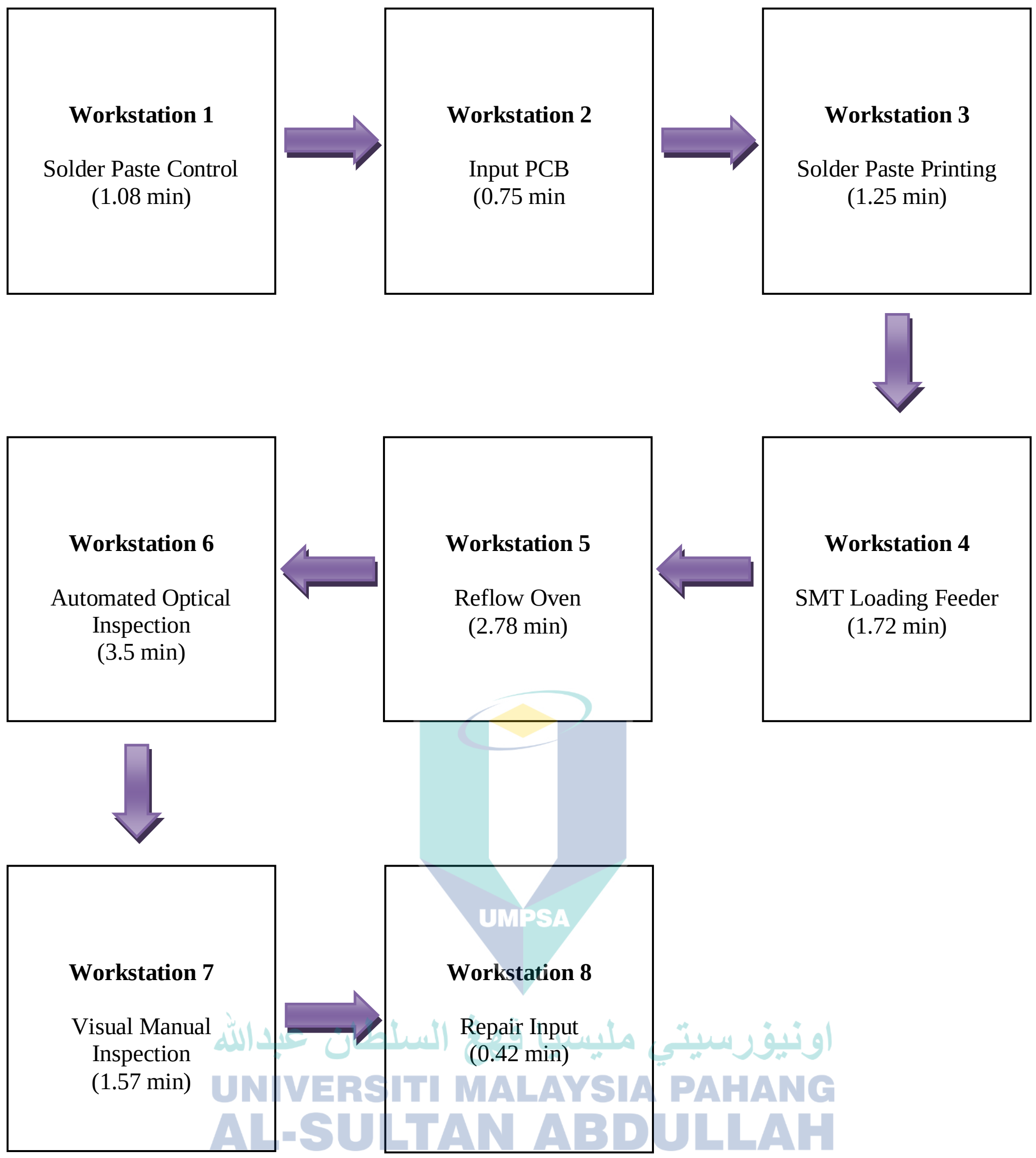


Figure 4.14 Production of top side workstation

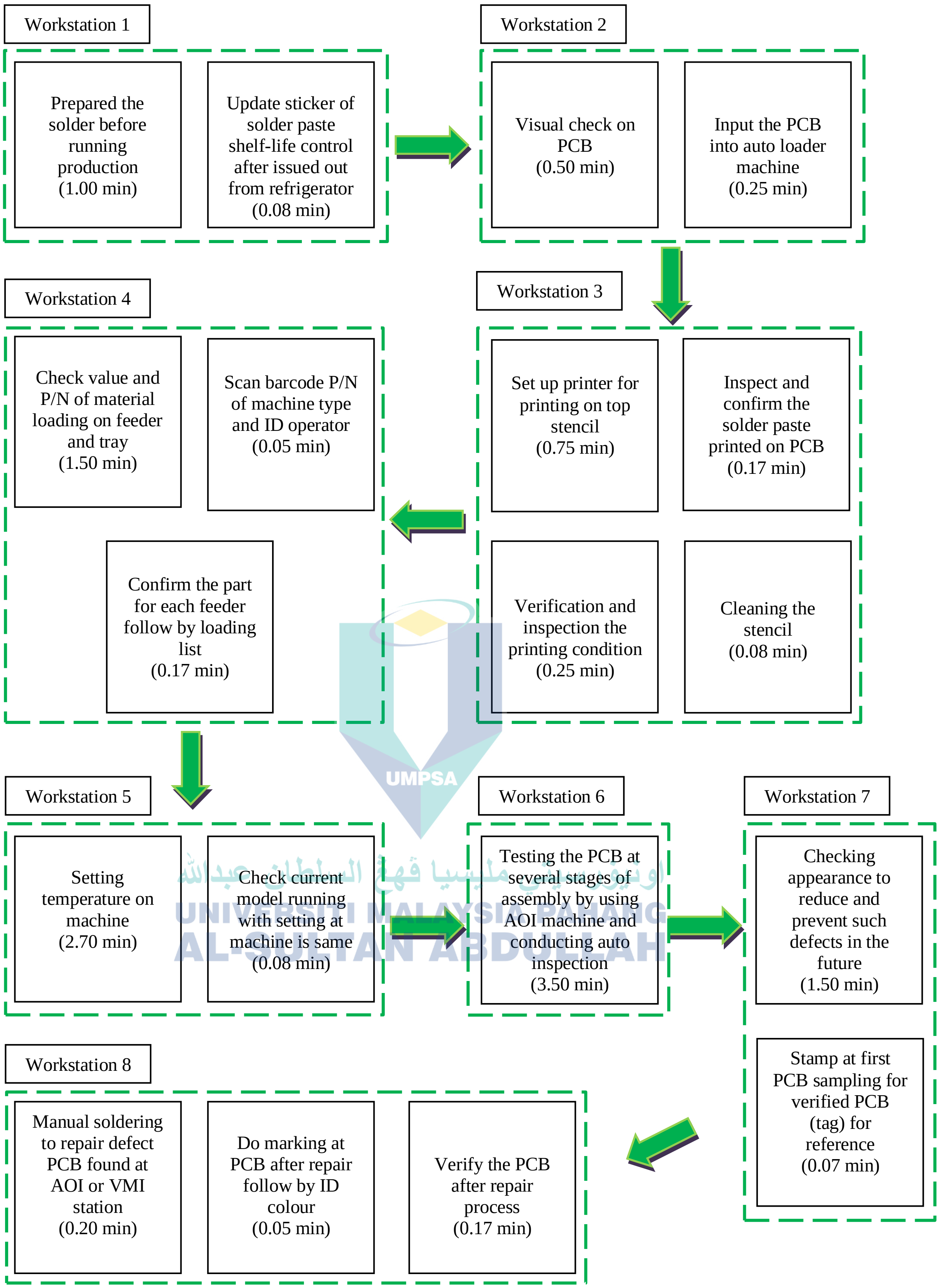


Figure 4.15 Sub-activities for each workstation for top side

4.5 Estimated Total Cost Resources Supplied

In this research, the types of resources used for each activity at 8 workstations are used to estimate the cost of supplied resources. Labour, maintenance, material, and consumable costs are the resource costs used for each sub-activity and are used to calculate the total cost of supplied resources, as shown in Table 4.5.

Table 4.5 Cost resources supplied for top side workstations

Main activity	Sub-activities	Labor cost (MYR)	Maintenance cost (MYR)	Material cost (MYR)	Consumable cost (MYR)	Cost resources supplied (MYR)
1. Solder paste control	1. Prepared the solder before running production	9,000	nil	146,000	nil	155,000
	2. Update sticker of solder paste shelf-life control after issued out from refrigerator	9,000	nil	nil	417.60	9,417.60
	Total	18,000	nil	146,000	417.60	164,417.60
2. Input PCB	1. Visual check on PCB	18,000	nil	nil	nil	18,000
	2. Input the PCB into auto loader machine	18,000	208	nil	309.80	18,517.80
	Total	36,000	208	nil	309.80	36,517.80
3. Solder paste printing	1. Set up printer for printing on top stencil	9,000	208	nil	60	9,268
	2. Inspect and confirm the solder paste printed on PCB	9,000	208	nil	nil	9,208
	3. Verification and inspection the printing condition	9,000	208	nil	nil	9,208
	4. Cleaning the stencil	9,000	208	nil	19.80	9,227.80
	Total	36,000	832	nil	79.80	36,911.80
4. SMT loading feeder (Chip, IC and ODD component)	1. Check value and P/N of material loading on feeder and tray	6,000	nil	2,646	nil	8,646
	2. Scan barcode P/N of machine type and ID operator	6,000	216.25	nil	nil	6,216.25
	3. Confirm the part for each feeder follow by loading list	6,000	nil	nil	94.80	6,094.80
	Total	18,000	216.25	2,646	94.80	20,957.05

Table 4.5 Continued

Main activity	Sub-activities	Labor cost (MYR)	Maintenance cost (MYR)	Material cost (MYR)	Consumable cost (MYR)	Cost resources supplied (MYR)
5. Reflow oven	1. Setting temperature on machine	18,000	99	nil	nil	18,099
	2. Check current model running with setting at machine is same	18,000	99	nil	nil	18,099
	Total	36,000	198	nil	nil	36,198
6. Automated Optical Inspection (AOI)	1. Testing the PCB at several stages of assembly by using AOI machine and conducting auto inspection	18,000	52	nil	nil	18,052
	Total	18,000	52	nil	nil	18,052
7. Visual Manual Inspection (VMI)	1. Checking appearance to reduce and prevent such defects in the future	9,000	nil	nil	nil	9,000
	2. Stamp at first PCB sampling for verified PCB (tag) for reference	9,000	nil	nil	nil	9,000
	Total	18,000	nil	nil	nil	18,000
8. Repair input	1. Manual soldering to repair defect PCB found at AOI or VMI station	12,000	nil	nil	320.28	12,320.28
	2. Do marking at PCB after repair follow by ID colour	12,000	nil	nil	28.40	12,028.40
	3. Verify the PCB after repair process	12,000	nil	nil	nil	12,000
	Total	36,000	nil	nil	348.68	36,348.68

The SMT loading feeder workstation costs MYR18,000 for three sub-activities and requires one operator. The annual feeder maintenance cost is MYR216.25. This workstation material costs is MYR2,646 per year for component inputs such chip, IC and ODD, and MYR94.80 per year for consumable cost. This equates to a total resource cost of MYR20,957.05.

4.6 Practical Capacity Estimation

The electrical and electronics company's hours are 8.30 a.m. to 6 p.m., Monday through Friday. There are two shifts operate throughout work hours. In 2022, Johor state has 125 days of public holidays, including weekends. The operator works 9 hours and 30 minutes with a 1-hour break. Thus, an operator works 240 days per year, 20 days per month, and 8 hours and 30 minutes in a day. The practical capacity of an operator is 10,200 minutes per month, or 8 hours times 60 minutes plus 30 minutes multiplied by 20 days. Then, 10,200 minutes multiplied by 12 months is 122,400 minutes of practical capacity in a year. Table 4.6 illustrates Johor's public holidays.

Table 4.6 Public holidays for Johor state in 2022

Date	Day	Public Holidays
18 January	Tuesday	Thaipusam
1 February	Tuesday	Lunar New Year Holiday
2 February	Wednesday	Second Day of Lunar New Year
23 March	Wednesday	Birthday of the Sultan of Johor
3 April	Sunday	First Day of Ramadhan
1 May	Sunday	Labour Day
2 May	Monday	Hari Raya Puasa
3 May	Tuesday	Hari Raya Puasa Day 2
4 May	Wednesday	Labour Day observed
15 May	Sunday	Wesak Day
6 June	Monday	The Yang di-Pertuan Agong's Birthday
10 July	Sunday	Hari Raya Haji
30 July	Saturday	Muharram
31 August	Wednesday	Malaysia's National Day
3 September	Saturday	Almarhum Sultan Iskandar Hol Day
16 September	Friday	Malaysia Day
18 September	Sunday	Malaysia Day holiday
9 October	Sunday	The Prophet Muhammad's Birthday
24 October	Monday	Deepavali
18 November	Friday	Occasional Day (PRU-15)
19 November	Saturday	Occasional Day (PRU-15)
20 November	Sunday	Occasional Day (PRU-15)
28 November	Monday	Occasional Day 28 November
25 December	Sunday	Christmas Day

4.7 Calculation of the Capacity Cost Rate

The capacity cost rate (in MYR/min) is estimated using Equation 3.43. According in the equation, the cost of capacity comprises of labour, material, maintenance, and consumable costs, whereas actual capacity is based on the quantity of workers at every workstation. As the quantity of operators increases, so will the practical acceptable capacity. Table 4.7 summarises the capacity cost rates of very sub-activity for the top-side workstation.

Table 4.7 Capacity cost rate for each sub-activity

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
	Total	164,417.60	244,800	
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
	Total	36,517.80	367,200	
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
	Total	36,911.80	734,400	
4. SMT loading feeder Chip, IC and ODD component	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
	Total	20,957.05	367,200	
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
	Total	36,198	367,200	
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
	Total	18,052	122,400	

Table 4.7 Continued

Main activity	Sub-activities	Cost resources supplied (MYR)	Practical capacity (min/year)	Capacity cost rate (MYR/min)
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
	Total	18,000	244,800	
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
	Total	36,348.68	734,400	

Using equation 3.43, the capacity cost rate for sub-activity of soldering preparation before operation in production is MYR155,000 / 122,400 minutes, which corresponds to MYR1.27 per minute.

4.8 Estimated Time for each Activity

The development of a time equation is necessary for the estimation of the production time. The predicted duration for every activity was computed using motion and time learning concepts. The total production time is obtained by solving the time equation for every sub-activity. The time equation is produced for every sub-activity while taking the cycle time into consideration, as shown in Table 4.8.

Table 4.8 Time equations for sub-activities of top side workstation

Main activity	Variable	Sub-activities	Cycle time (min)	Time equation
1. Solder paste control	X_1	1. Prepared the solder before running production	1.00	$1.0X_1$
	X_2	2. Update sticker of solder paste shelf-life control after issued out from refrigerator	0.08	$0.08X_2$
2. Input PCB	X_3	1. Visual check on PCB	0.50	$0.5X_3$
	X_4	2. Input the PCB into auto loader machine	0.25	$0.25X_4$
3. Solder paste printing	X_5	1. Set up printer for printing on top stencil	0.75	$0.75X_5$
	X_6	2. Inspect and confirm the solder paste printed on PCB	0.17	$0.17X_6$
	X_7	3. Verification and inspection the printing condition	0.25	$0.25X_7$
	X_8	4. Cleaning the stencil	0.08	$0.08X_8$

Table 4.8 Continued

Main activity	Variable	Sub-activities	Cycle time (min)	Time equation
4. SMT loading feeder Chip, IC and ODD component	X_9	1. Check value and P/N of material loading on feeder and tray	1.50	$1.5X_9$
	X_{10}	2. Scan barcode P/N of machine type and ID operator	0.05	$0.05X_{10}$
	X_{11}	3. Confirm the part for each feeder follow by loading list	0.17	$0.08X_{11}$
5. Reflow oven	X_{12}	1. Setting temperature on machine	2.70	$2.7X_{12}$
	X_{13}	2. Check current model running with setting at machine is same	0.08	$0.08X_{13}$
6. Automated Optical Inspection (AOI)	X_{14}	1. Testing the PCB at several stages of assembly by using AOI machine and conducting auto inspection	3.50	$3.5X_{14}$
7. Visual Manual Inspection (VMI)	X_{15}	1. Checking appearance to reduce and prevent such defects in the future	1.50	$1.5X_{15}$
	X_{16}	2. Stamp at first PCB sampling for verified PCB (tag) for reference	0.07	$0.07X_{16}$
8. Repair input	X_{17}	1. Manual soldering to repair defect PCB found at AOI or VMI station	0.20	$0.2X_{17}$
	X_{18}	2. Do marking at PCB after repair follow by ID colour	0.05	$0.05X_{18}$
	X_{19}	3. Verify the PCB after repair process	0.17	$0.17X_{19}$

Following that, for every workstation, Table 4.9 illustrated the formula for calculating the total time equation for every sub-activity.

Table 4.9 Time equations for main activities of top side workstation

Main activity	Time equation
1. Solder paste control	$1.0X_1 + 0.08X_2$
2. Input PCB	$0.5X_3 + 0.25X_4$
3. Solder paste printing	$0.75X_5 + 0.17X_6 + 0.25X_7 + 0.08X_8$
4. SMT loading feeder Chip, IC and ODD component	$1.5X_9 + 0.05X_{10} + 0.08X_{11}$
5. Reflow oven	$2.7X_{12} + 0.08X_{13}$
6. Automated Optical Inspection (AOI)	$3.5X_{14}$
7. Visual Manual Inspection (VMI)	$1.5X_{15} + 0.07X_{16}$
8. Repair input	$0.2X_{17} + 0.05X_{18} + 0.17X_{19}$

The time equation for the input PCB is represented as $0.5X_3 + 0.25X_4$. Therefore, if the values of drivers X_3 and X_4 increase, the total activity will increase proportionally.

4.9 Estimated Capacity Required by each Main Activity

The estimated needed capacity for every activity is obtained through observing the frequency of activity throughout the year. The total amount of time spent on an activity may be computed by multiplying the amount of the activity by the spent doing it. Table 4.10 shows the number of cost drivers needed for every sub-activity depending on its consumption over the year. The quantity of machines that operate in a given year is defined as the frequency.

Table 4.10 Quantity of cost drivers for each sub-activities

Main activity	Variable	Sub-activities	Driver	Quantity (year)	Description
1. Solder paste control	X_1	1. Prepared the solder before running production	Quantity of solder (grams/year)	912,500	1,825 unit × 500g
	X_2	2. Update sticker of solder paste shelf-life control after issued out from refrigerator	Number of shelf-life control sticker (pieces/year)	1,825	1,825 unit
2. Input PCB	X_3	1. Visual check on PCB	Number of PCB (pieces/year)	21,000	42,000 / 2 *One plate has 2 PCB
	X_4	2. Input the PCB into auto loader machine	Number of PCB (pieces/year)	21,000	42,000 / 2
3. Solder paste printing	X_5	1. Set up printer for printing on top stencil	Quantity of solder (grams/year)	912,500	1,825 unit × 500g
	X_6	2. Inspect and confirm the solder paste printed on PCB	Number of PCB (pieces/year)	42,000	3,500 pieces × 12 months
	X_7	3. Verification and inspection the printing condition	Number of verified pass printing condition (pieces/year)	42,000	3,500 pieces × 12 months
	X_8	4. Cleaning the stencil	Quantity of solder (grams/year)	365,000	1825 unit × 200g
4. SMT loading feeder Chip, IC and ODD component	X_9	1. Check value and P/N of material loading on feeder and tray	Number of tray (pieces/year)	840	42,000 PCBs / 50 magazines
	X_{10}	2. Scan barcode P/N of machine type and ID operator	Number of scanned barcode (pieces/year)	120	30 feeder × 4 machines
	X_{11}	3. Confirm the part for each feeder follow by loading list	Number of feeder (pieces/year)	120	30 feeder × 4 machines
5. Reflow oven	X_{12}	1. Setting temperature on machine	Number of reflow ovens operations (frequency/year)	6	
	X_{13}	2. Check current model running with setting at machine is same	Number of PCB (pieces/year)	42,000	3,500 pieces × 12 months

Table 4.10 Continued

Main activity	Variable	Sub-activities	Driver	Quantity (year)	Description
6. Automated Optical Inspection (AOI)	X_{14}	1. Testing the PCB at several stages of assembly by using AOI machine and conducting auto inspection	Number of PCB (pieces/year)	42,000	3,500 pieces × 12 months
7. Visual Manual Inspection (VMI)	X_{15}	1. Checking appearance to reduce and prevent such defects in the future	Number of defects PCB (pieces/year)	1,500	125 pieces × 12 months
	X_{16}	2. Stamp at first PCB sampling for verified PCB (tag) for reference	Number of PCB pass with VMI (pieces/year)	42,000	3,500 pieces × 12 months
8. Repair input	X_{17}	1. Manual soldering to repair defect PCB found at AOI or VMI station	Number of manual soldering PCB (pieces/year)	1,500	125 pieces × 12 months
	X_{18}	2. Do marking at PCB after repair follow by ID colour	Number of marked PCB (pieces/year)	1,500	125 pieces × 12 months
	X_{19}	3. Verify the PCB after repair process	Number of verified PCB after repair (pieces/year)	1,500	125 pieces × 12 months

Following that, the total annual time for solder paste control is calculated by substituting the number of cost drivers from Table 4.10 into Table 4.9.

Time spent for solder paste control:

$= (1 \times 912{,}500) + (0.08 \times 1{,}825) = 912{,}646$ minutes

Therefore, converting the time into hours or days gives 15,210.77 hours or 633.78 days. Meanwhile, Table 4.11 displays the overall time and cost for the top side workstation's main activities. Each sub-activity's cost is calculated by multiplying the amount of time spent by the capacity cost rate.

Table 4.11 Total time and cost for each main activity

Main activity	Sub-activities	Used time (min)	Capacity cost rate (MYR/min)	Total cost (MYR/year)
1. Solder paste control	1. Prepared the solder before running production	912,500.00	1.27	1,155,535.13
	2. Update sticker of solder paste shelf-life control after issued out from refrigerator	146.00	0.08	11.23
	Total	912,646.00		1,155,546.36
2. Input PCB	1. Visual check on PCB	10,500.00	0.15	1,544.12
	2. Input the PCB into auto loader machine	5,250.00	0.08	397.13
	Total	15,750.00		1,941.25

Table 4.11 Continued

Main activity	Sub-activities	Used time (min)	Capacity cost rate (MYR/min)	Total cost (MYR/year)
3. Solder paste printing	1. Set up printer for printing on top stencil	684,375.00	0.08	51,820.16
	2. Inspect and confirm the solder paste printed on PCB	7,140.00	0.04	268.57
	3. Verification and inspection the printing condition	10,500.00	0.04	394.95
	4. Cleaning the stencil	29,200.00	0.08	2,201.40
	Total	731,215.00		54,685.08
4. SMT loading feeder Chip, IC and ODD component	1. Check value and P/N of material loading on feeder and tray	1,260.00	0.07	89.00
	2. Scan barcode P/N of machine type and ID operator	6.00	0.05	0.30
	3. Confirm the part for each feeder follow by loading list	20.40	0.05	1.02
	Total	1,286.40		90.32
5. Reflow oven	1. Setting temperature on machine	16.20	0.15	2.40
	2. Check current model running with setting at machine is same	3,360.00	0.07	248.42
	Total	3,376.20		250.81
6. Automated Optical Inspection (AOI)	1. Testing the PCB at several stages of assembly by using AOI machine and conducting auto inspection	147,000.00	0.15	21,680.10
	Total	147,000.00		21,680.10
7. Visual Manual Inspection (VMI)	1. Checking appearance to reduce and prevent such defects in the future	2,250.00	0.07	165.44
	2. Stamp at first PCB sampling for verified PCB (tag) for reference	2,940.00	0.07	216.18
	Total	5,190.00		381.62
8. Repair input	1. Manual soldering to repair defect PCB found at AOI or VMI station	300.00	0.05	15.10
	2. Do marking at PCB after repair follow by ID colour	75.00	0.05	3.69
	3. Verify the PCB after repair process	255.00	0.05	12.50
	Total	630.00		31.28

Calculated in the same way, the total time and cost per year of top side workstation are 1,817,093.60 min and MYR1,234,606.83. Hence, the time equation for calculating the total time spent on the top side workstation is shown below.

$$T_{\text{top side workstation}} = X_1 + 0.08X_2 + 0.5X_3 + 0.25X_4 + 0.75X_5 + 0.17X_6 + 0.25X_7 + 0.08X_8 + 1.5X_9 + 0.05X_{10} + 0.08X_{11} + 2.7X_{12} + 0.08X_{13} + 3.5X_{14} + 1.5X_{15} + 0.07X_{16} + 0.2X_{17} + 0.05X_{18} + 0.17X_{19}$$

4.10 Cluster Identification from Unused Capacity

Capacity utilization should measure unused capacity for future forecasting. This implies that the present capacity utilization may be utilised to improve future plans. Table 4.12 shows a capacity utilization analysis for unused capacity.

Table 4.12 Analysis of capacity utilization with unused capacity

Main activity	Sub-activities	Practical capacity (min/year)	Used time (min)	Unused time (min)	Capacity cost rate (MYR/year)	Unused cost (MYR)
1. Solder paste control	1. Prepared the solder before running production	122,400	912,500	-790,100	1.27	-1,000,535.13
	2. Update sticker of solder paste shelf-life control after issued out from refrigerator	122,400	146.00	122,254.00	0.08	9,406.37
	Total	244,800	912,646.00	-667,846.00		-991,128.76
2. Input PCB	1. Visual check on PCB	122,400	10,500.00	111,900.00	0.15	16,455.88
	2. Input the PCB into auto loader machine	244,800	5,250.00	239,550.00	0.08	18,120.67
	Total	367,200	15,750.00	351,450.00		34,576.55
3. Solder paste printing	1. Set up printer for printing on top stencil	122,400	684,375.00	-561,975.00	0.08	-42,552.16
	2. Inspect and confirm the solder paste printed on PCB	244,800	7,140.00	237,660.00	0.04	8,939.43
	3. Verification and inspection the printing condition	244,800	10,500.00	234,300.00	0.04	8,813.05
	4. Cleaning the stencil	122,400	29,200.00	93,200.00	0.08	7,026.40
	Total	734,400	731,215.00	3,185.00		-17,773.28
4. SMT loading feeder Chip, IC and ODD component	1. Check value and P/N of material loading on feeder and tray	122,400	1,260.00	121,140.00	0.07	8,557.00
	2. Scan barcode P/N of machine type and ID operator	122,400	6.00	122,394.00	0.05	6,215.95
	3. Confirm the part for each feeder follow by loading list	122,400	20.40	122,379.60	0.05	6,093.78
	Total	367,200	1,286.40	365,913.60		20,866.73
5. Reflow oven	1. Setting temperature on machine	122,400	16.20	122,383.80	0.15	18,096.60
	2. Check current model running with setting at machine is same	244,800	3,360.00	241,440.00	0.07	17,850.58
	Total	367,200	3,376.20	363,823.80		35,947.19

Table 4.12 Continued

Main activity	Sub-activities	Practical capacity (min/year)	Used time (min)	Unused time (min)	Capacity cost rate (MYR/year)	Unused cost (MYR)
6. Automated Optical Inspection (AOI)	1. Testing the PCB at several stages of assembly by using AOI machine and conducting auto inspection	122,400	147,000.00	-24,600.00	0.15	-3,628.10
	Total	122,400	147,000.00	-24,600.00		-3,628.10
7. Visual Manual Inspection (VMI)	1. Checking appearance to reduce and prevent such defects in the future	122,400	2,250.00	120,150.00	0.07	8,834.56
	2. Stamp at first PCB sampling for verified PCB (tag) for reference	122,400	2,940.00	119,460.00	0.07	8,783.82
	Total	244,800	5,190.00	239,610.00		17,618.38
8. Repair input	1. Manual soldering to repair defect PCB found at AOI or VMI station	244,800	300.00	244,500.00	0.05	12,305.18
	2. Do marking at PCB after repair follow by ID colour	244,800	75.00	244,725.00	0.05	12,024.71
	3. Verify the PCB after repair process	244,800	255.00	244,545.00	0.05	11,987.50
	Total	734,400	630.00	733,770.00		36,317.40
	Total	3,182,400	1,817,093.60	1,365,306.40		-867,203.90

In solder paste printing, the printer set up for printing on the top stencil sub-activity has -561,975 minutes and MYR-42,552.16 of unused capacity of time and cost. This showed that the sub-activity consumes more of the resources and expense than the apportionment that was provided for it. Then, inspect and confirm the solder paste printed on PCB has an unused capacity of 237,660 minutes and MYR8,939.43. These partial activities consume large resources and at the same time take into account small expenses in the department. The verification and inspection printing conditions sub-activity has 234,300 minutes and MYR8,813.05 of unused capacity of time and costs. The sub-activity also utilised large resource and accounted for a small percentage of costs. The final sub-activity on this workstation uses 93,200.00 minutes of unused time capacity and MYR7,026.40 of unused cost capacity. This implies that this sub-activity consumes the small resources and costs.

In terms of unused time capacity, the most extensively utilised partial activity is red with -790,100 minutes of sub-activity that prepared the solder before running production. On the other hand, orange represents the smallest resource consumed by PCB marking after repaired sub-activity at 244,725 minutes. Next, the PCB visual checked has a green colour of 111,900 minutes, which indicates it as the largest resource used.

In terms of unused cost capacity, the most extensively utilised partial activity is red, with MYR-1,000,535.13 the sub-activity for prepared the solder before running production. In contrast, orange shows the smallest percentage utilised in auto loader machine's PCB input sub-activity at MYR18,120.67. The green colour of the check the parts of each feeder with view the loading list sub-activity is MYR6,093.78, indicating the greatest percentage to be utilised.

The TDABC implementation discovered three types of unused capacity clusters, namely Type I, Type II, and Type III. Type I is a workstation that is extensively utilised by regulations such as solder paste control and AOI workstations. Input PCB, SMT loading feeder, reflow oven, VMI, and repair input workstations are all examples of Type II workstation which utilized small regulations. Type III workstation are largely utilised the provided apportionment such as solder paste printing workstation.

4.11 Analysis of Unused Time Capacity for all Workstations

Figure 4.16 illustrates the amount of time capacity that has been used as well as that which has been unused throughout all 8 workstations. The time capacity that has been utilised is shown by the blue bar represents, while the time capacity that has not been used is represented by the red bar.

Workstation 1 is classified into Type I because the workstation extensively utilised the provided time apportionment. This research suggested that additional labour should be provided to ensure the time of preparing the solder before running in production can be minimised. Workstation 2 is classified into Type II because the workstation utilised small regulations of provided time apportionment. The number of labours in sub-activity input the PCB into auto loader machine can be reduced or transferred to other workstation to minimize the unused capacity. Next, workstation 3 is classified into Type III which has largely utilised the provided apportionment. Then, the number of labour and machines operate is in good desired condition. Workstation 4 is classified into Type II because the workstation utilised small regulations of provided time apportionment. So, this research suggested the cycle time during SMT loading feeder should be revised to ensure the unused time capacity is reduced in the future. Workstation 5 is classified into Type II. The labour of check the identical of current model with the machine should be reduced or transferred to another workstation to minimize the unused time capacity. Workstation 6 is classified into Type I. This workstation is extensively utilised the provided time apportionment. It is suggested that additional labour should be provided in testing the PCB using the AOI machine. Workstation 7 is classified into Type II. The labour of this workstation should help other workstations, such as workstation 6 in reduce the unused time capacities. The last workstation, which is workstation 8 is classified into Type II. Whereas, the number of labours can be reduced or transferred to another workstation.

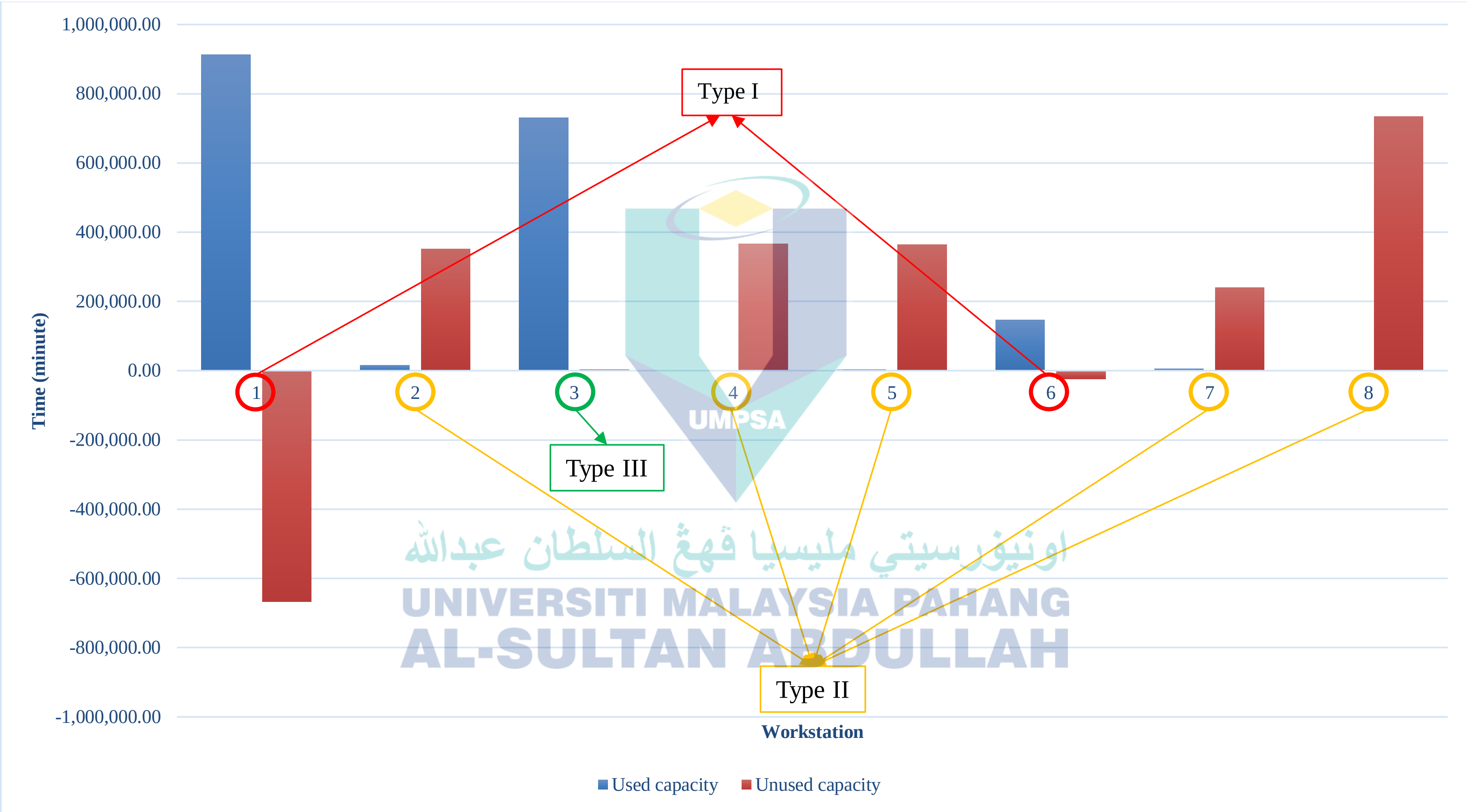


Figure 4.16 Used and unused capacities of time

4.12 Analysis of Unused Cost Capacity for all Workstations

Figure 4.17 depicts the total cost capacity of all workstations, whether used and unused. The blue bar reflects used cost capacity, whereas the red bar reflects unused cost capacity.

Workstation 1 is classified as Type I because it extensively utilised the provided cost allocation. The research suggests that to neutralize the unused cost capacities, the supplied resources should be increased. Workstation 2 is classified as Type II because the workstation uses a small provided cost allocation regulation. It is proposed that the labour costs of inserting PCB into the partial activity of the auto-loader machine be reduced in order to decrease the capacity of unused costs in the future. Next, workstation 3 is classified into Type I. The research suggests that the labour cost of inspecting and verify solder paste printing conditions can be reduced because the annual supply capacity needs to be reduced for better forecasting. Workstation 4 and 5 is classified as Type II. since the workstation used small of the provided cost apportionment. So, this workstation is suggested to reduce the allocation costs since this workstation used small of the provided cost apportionment. Workstation 6 is classified as Type I and the amount of the electric used should be reduce when the AOI workstation is not in used. Workstation 7 is classified as Type II. The labour cost for the inspection and verification of these PCBs can be reduced to a combination with other workloads. Lastly, workstation 8 is classified as Type II, the cost of providing recourses to improve unused capacity in the future should be reduced.

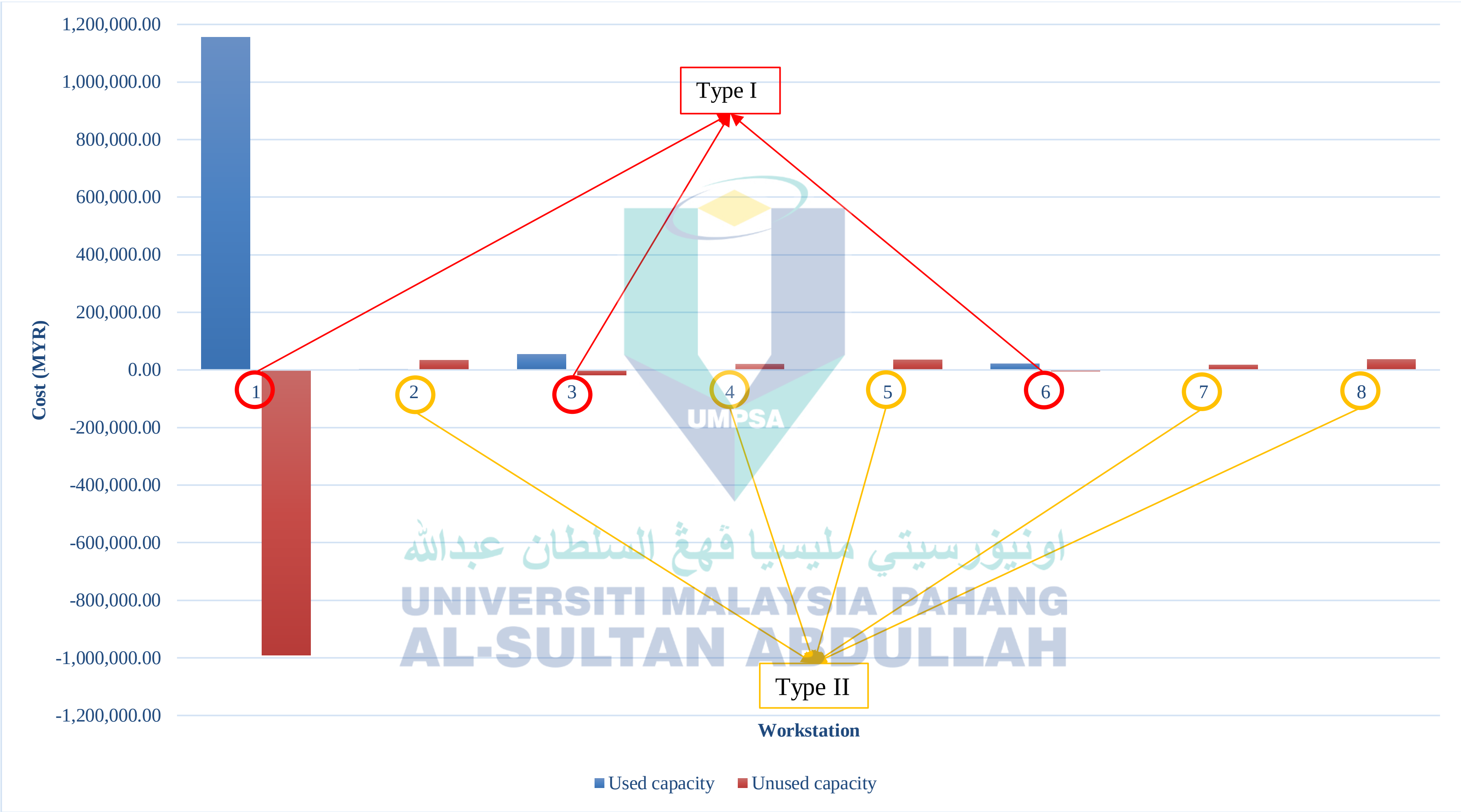


Figure 4.17 Used and unused capacities of cost

Therefore, this enabled TDABC to determine all the workstations for top side unused time and cost capacity.

4.13 Prove of Proposed Solution

There are two distinct types of contribution. The first is the positive degree of contribution, this indicates that the use of this parameter increases the output. This means that increasing the value of this parameter will increase the MD value as well. Secondly, the negative degree of contribution indicates that using this parameter lowers the output. This means that decreasing the value of this parameter also decreases the value of MD. The purpose of this section is to prove that the proposed changes to top side workstations that reduce the contribution are optimal solutions. Therefore, the subject of this research was the most abnormal MD values that occurred in the September. Figure 4.18 shows the unknown data in September that is used as a guideline for future forecasting in creating a normal sample.

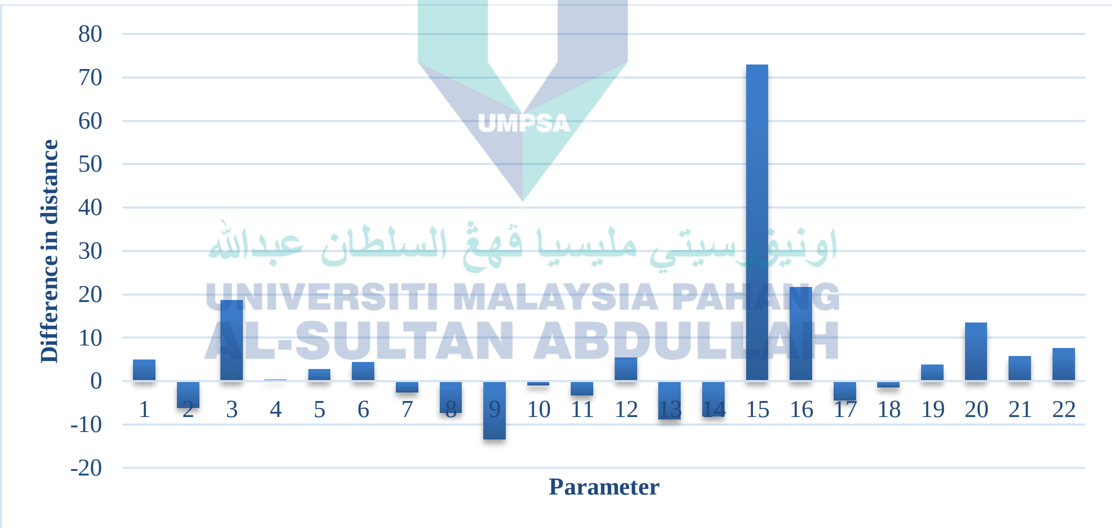


Figure 4.18 Degree of contribution for unknown data in September

As indicated in Table 4.13, the original output for unknown data in September is 399.71. The value is contrasted with the other types of alteration.

Table 4.13 Comparison between original and types of alteration

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

The MD value of type 1 alteration is 396.90, which is less than the MD value of the original data. This alteration indicates that the high level of the positive contribution has increased by two points (parameter 15) and the low level of the positive contribution by one point (parameter 1, 3, 4, 5, 6, 12, 16, 19, 20, 21, and 22). In contrast, the negative contribution at the higher level decreased by two points (parameter 8, 9, 13, 14, and 18) and the negative contribution at the lower level decreased by one point (parameter 2, 7, 10, 11, and 17). As a result, these alterations are rejected as a proposed solution.

The MD value of the type 2 alteration is 402.53, which is greater than the MD value of the original data. This alteration shows that the positive contribution of the higher level is subtracted by two points (parameter 15) and the positive contribution of the lower level is subtracted by one point (parameter 1, 3, 4, 5, 6, 12, 16, 19, 20, 21, and 22). Conversely, the negative contribution level is added with two points (parameter 8, 9, 13, 14, and 18) and the lower the negative contribution level is added with one point (parameter 2, 7, 10, 11, and 17). Consequently, this alteration as proposed solution has been rejected.

The MD value of the type 3 alteration is 395.29, which is smaller than the MD value of the original data. This alteration indicates that the higher positive degree of contribution is added up by two points (parameter 15) and the lower positive degree of contribution is added up by one point (parameter 1, 3, 4, 5, 6, 12, 16, 19, 20, 21, and 22). On the other hand, the higher negative degree of contribution and the lower negative degree of contribution, both are set to zero. As a result, these alterations are accepted as a proposed solution.

The MD value of the type 4 alteration is 413.11, which is greater than the original data. This higher positive contribution level and the lower positive contribution level are set to zero in this alteration. On the contrary, the negative contribution of higher level is deducted with two points (parameter 8, 9, 13, 14, and 18) and the negative contribution of the lower level is deducted with one point (parameter 2, 7, 10, 11, and 17). Consequently, this alteration as proposed solution has been rejected.

The MD value of the type 5 alteration is 397.92, which is smaller than the MD value of the original data. This alteration shows that the positive contribution of the higher level has increased by two points (parameter 15) and the positive contribution of the lower level by one point (parameter 1, 3, 4, 5, 6, 12, 16, 19, 20, 21, and 22), while the high and low values of the negative contribution retain its value. As a result, these alterations are rejected as a proposed solution.

The MD value of the type 6 alteration is 398.90, which is smaller than the MD value of the original data. This alteration means that high and low positive contribution retain its value. Conversely, the higher negative degree of contribution is subtracted by two points (parameter 8, 9, 13, 14, and 18) and one point is subtracted for lower negative degree of contribution (parameter 2, 7, 10, 11, and 17). Consequently, this alteration as proposed solution has been rejected.

As a result, alteration type 3 is the ideal solution for the top side workstation. However, the sum of positive and negative degree of contribution might also have an impact on the proposed solution. The total of the higher and lower degree of contribution as well might have an impact. Furthermore, the proposed solution may differ from the real practice.

4.14 Framework

Figure 4.19 shows the combination framework of MTS (objective 1) and TDABC (objective 2). The orange colour indicates the degree of contribution from MTS while purple colour indicates the process mapping from TDABC. The figure shows the details of the integration between the connected MTS and TDABC.

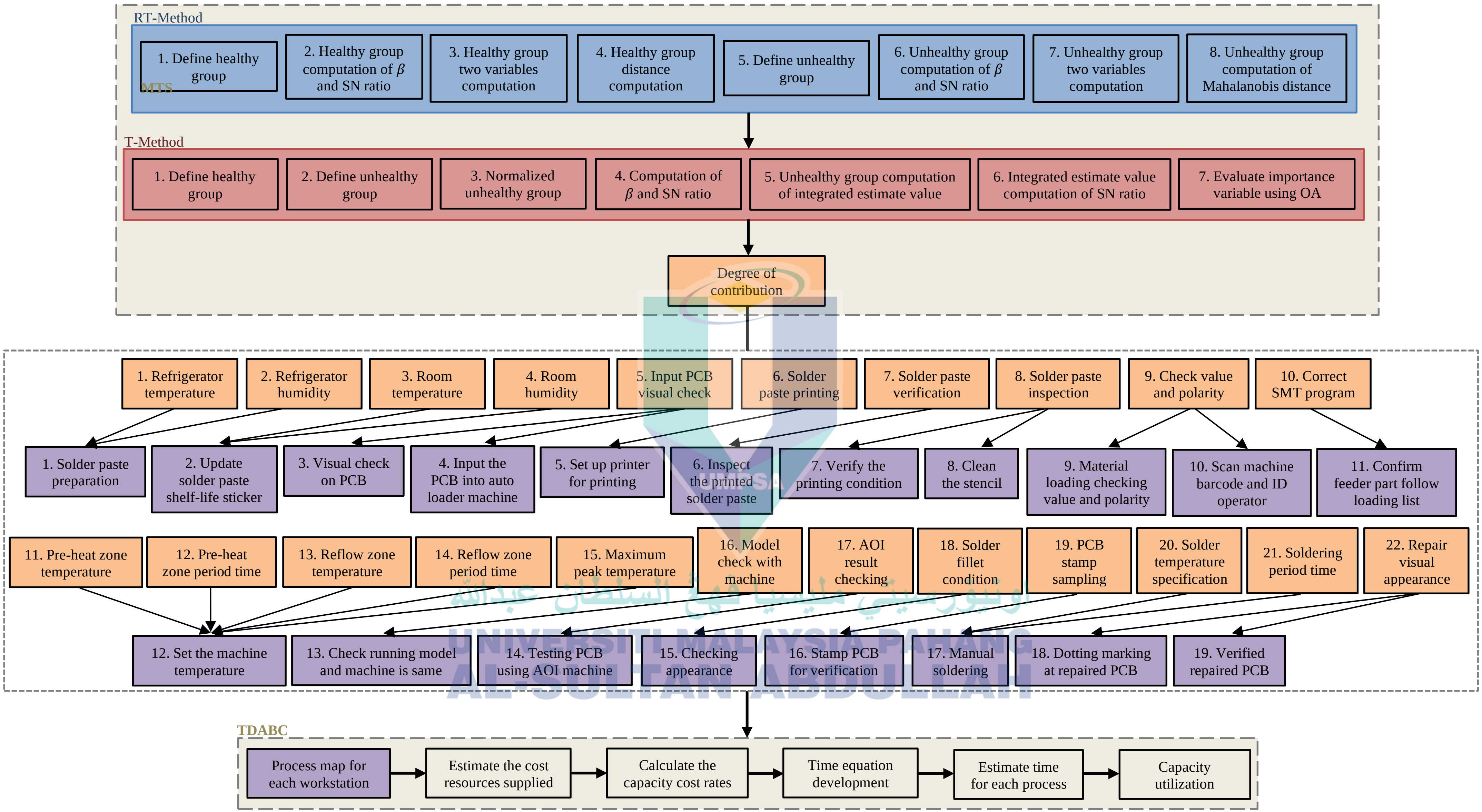


Figure 4.19 MTS and TDABC framework

Based on the MTS and TDABC connected in Figure 4.19, the sub-activities 1, 2, 3, 5, 13, 16, 17, 18, and 19 is added one point each of the parameters. However, only sub-activity 12 is added with the two points of parameter. Meanwhile, other sub-activities are set zero as follow the type alteration selection in Table 4.13.

4.15 Integration of MTS and TDABC

Table 4.14 shows the analysis of modified capacity utilization for unused capacity. The new most extensively utilised partial activity, the largest resource consumed and the smallest resource used have been found in the table.

Table 4.14 Analysis of new capacity utilization with unused capacity

Main activity	Sub-activities	Practical capacity (min/year)	New used time (min)	New unused time (min)	Capacity cost rate (MYR/year)	New unused cost (MYR)
1. Solder paste control	1. Prepared the solder before running production	122,400	913,000.00	-790,600	1.27	-1,001,168.30
	2. Update sticker of solder paste shelf-life control after issued out from refrigerator	122,400	146.08	122,253.92	0.08	9,406.36
	Total	244,800	913,146.08	-668,346.08		-991,761.94
2. Input PCB	1. Visual check on PCB	122,400	10,500.50	111,900	0.15	16,455.81
	2. Input the PCB into auto loader machine	244,800	5,250.25	239,550	0.08	18,120.65
	Total	367,200	15,750.75	351,449		34,576.46
3. Solder paste printing	1. Set up printer for printing on top stencil	122,400	684,750.00	-562,350	0.08	-42,580.55
	2. Inspect and confirm the solder paste printed on PCB	244,800	0	244,800	0.04	9,208.00
	3. Verification and inspection the printing condition	244,800	0	244,800	0.04	9,208.00
	4. Cleaning the stencil	122,400	0	122,400.00	0.08	9,227.80
	Total	734,400	684,750.00	49,650.00		-14,936.75
4. SMT loading feeder Chip, IC and ODD component	1. Check value and P/N of material loading on feeder and tray	122,400	0	122,400	0.07	8,646.00
	2. Scan barcode P/N of machine type and ID operator	122,400	0	122,400	0.05	6,216.25
	3. Confirm the part for each feeder follow by loading list	122,400	0	122,400.00	0.05	6,094.80

Table 4.14 Continued

Main activity	Sub-activities	Practical capacity (min/year)	New used time (min)	New unused time (min)	Capacity cost rate (MYR/year)	New unused cost (MYR)
	Total	367,200	0	367,200.00		20,957.05
5. Reflow oven	1. Setting temperature on machine	122,400	24.30	122,375.70	0.15	18,095.41
	2. Check current model running with setting at machine is same	244,800	3,360.96	241,439	0.07	17,850.51
	Total	367,200	3,385.26	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	0	122,400	0.15	18,052.00
	Total	122,400	0	122,400		18,052.00
7. Visual Manual Inspection (VMI)	1. Checking appearance to reduce and prevent such defects in the future	122,400	0	122,400	0.07	9,000.00
	2. Stamp at first PCB sampling for verified PCB (tag) for reference	122,400	2,940.84	119,459	0.07	8,783.76
	Total	244,800	2,940.84	241,859		17,783.76
8. Repair input	1. Manual soldering to repair defect PCB found at AOI or VMI station	244,800	302.40	244,498	0.05	12,305.06
	2. Do marking at PCB after repair follow by ID colour	244,800	75.60	244,724	0.05	12,024.69
	3. Verify the PCB after repair process	244,800	257.04	244,543	0.05	11,987.40
	Total	734,400	635.04	733,765		36,317.15
	Total	3,182,400.00	1,620,607.97	1,561,792.03		-843,066.36

Figure 4.20 depicts the new time capacity used and unused, while Figure 4.21 depicts the new cost capacity used and unused for all 8 workstations of top side process. The blue bar represents the utilised capacity of and red bar represent the unused capacity of time and cost respectively.

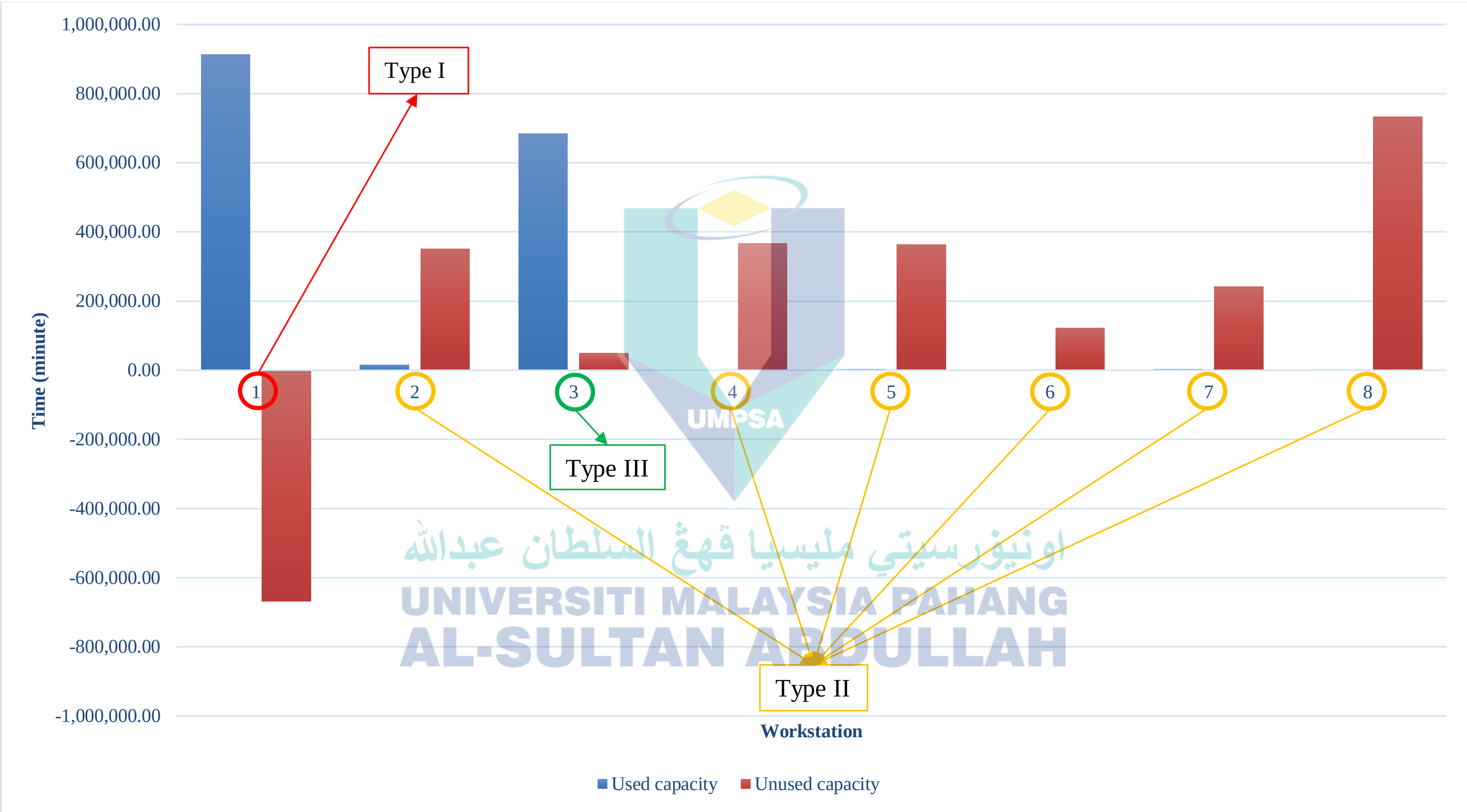


Figure 4.20 New capacity utilization of time

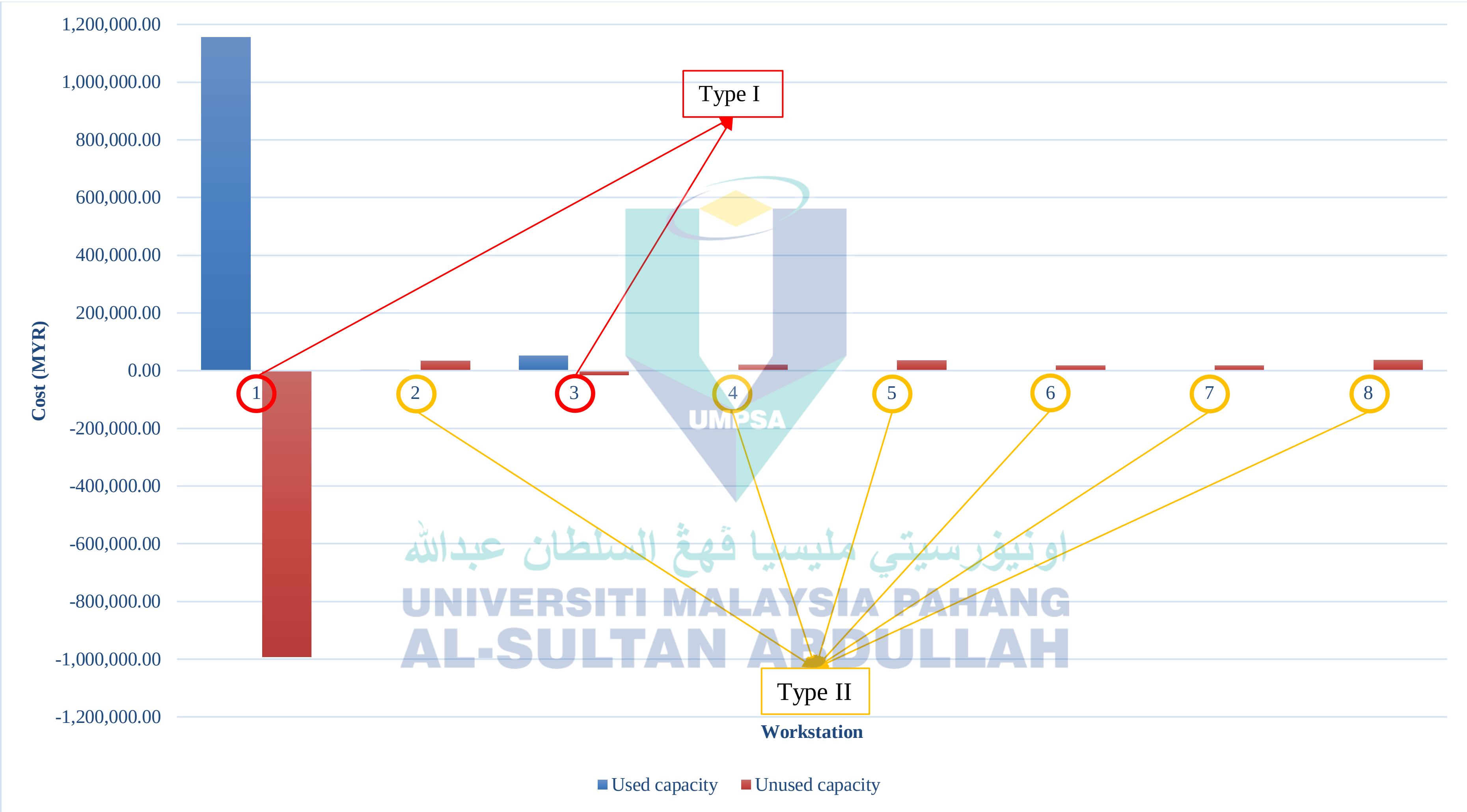


Figure 4.21 New capacity utilization of cost

Based on the new calculated time and cost capacity utilization, there are some differences in values at the workstations. Notably, there are 4 workstations that have been reduced in both time and cost capacity utilization. As in time capacity utilization, workstations 2, 5, 6, and 8 which have unused time capacity reduction. Meanwhile, workstations 2, 3, 5, and 8 have reduced unused capacity costs. This suggests that the integration between MTS and TDABC is a good idea in reducing capacity utilization because there are workstations that can be reduce waste and to obtain better forecasts.

4.16 Summary

In this chapter, the degree of contribution for 22 parameters for 12 cumulative months using MTS has been achieved. The significant and not significant of each parameter for every month also can be observed. Then, TDABC is implemented to compute the capacity utilization of time and costs for each sub-activity in each main workstation. From that, the unused capacity of time and cost can be analysed for future prediction using the cost capacity rate and time equation. Lastly, the alteration types and framework are used as the guideline in integrate the MTS and TDABC in order to obtain new capacity utilization for reduction of necessary waste.

CHAPTER 5

CONCLUSION

5.1 Introduction

This research introduces novel research that integrate MTS classification into TDABC optimization to reduce waste and better forecasting. The conclusion of each objective are as follows:

1. The analysis shows that there are MD threshold overlaps occurred between normal and abnormal for each month. This is because the sample of abnormal data has a small number parameters corresponding to the abnormal condition. In March, the centre of normal and abnormal MD threshold is 2.8272 and 18.0590 respectively. The centre of normal and abnormal in June MD threshold are 2.8261 and 11.1507, while in September MD threshold are 3.0002 and 183.1371 correspondingly. The degree of contribution shows the highest significant parameters with 16 parameters is in October and December. In contrast, the least significant parameters with 10 parameters are in August.
2. TDABC is used to perform the capacity utilization analysis in diagnosing the used and unused capacity of time and cost. It is acknowledged that the PCB input into auto loader machine sub-activity has a high unused capacity of time (239,550 minutes) and cost (MYR18,120.67) which makes this sub-activity able to reduce the unused capacity by transferring the number of workers to another load workstation. On the contrary, additional labour should be provided in the solder paste preparation sub-activity as it has over utilised capacity of time (-790,100 minutes) and cost (MYR-1,000,535.13) in order to minimise the capacity utilization.
3. The system integration between degree of contribution and unused capacity has reduced the waste and make a better forecasting for the company reference in the future. The significant parameter obtained is possible to reduce the waste generated at occurred at particular workstation. On the other hand, the analysis of used and unused capacity such as additional labours or shift works can plan better forecasts.

5.2 Fulfilment of Research Objectives

Table 5.1 shows the fulfilment of the research objectives that have been discussed in Section 1.3, Chapter 1.

Table 5.1 The fulfilment of the research objectives

Objectives	Results	Objective Achieved
To **DETERMINE** the degree of contribution of parameters in identifying the significant parameters	The normal and abnormal MD for each month is able to generate by using Teshima software in classification of RT method. Besides, the optimization of T method able to identify the significant parameters of degree of contribution for each month.	Chapter 3 Section 3.5.1 Figure 3.1 Chapter 4 Section 4.2, and 4.3 Figure 4.4 Table 4.4
To **ANALYSE** the unused capacity of time and cost for improving the better recommendations	The capacity utilization of time and cost for a year is calculated by reconsidering the cost of labour, maintenance, materials, and also consumable.	Chapter 3 Section 3.5.2 Figure 3.1, and 3.3 Chapter 4 Section 4.4 until 4.12 Figure 4.11, 4.12, 4.14, and 4.15 Table 4.5 until 4.11
To **INTEGRATE** the degree of contribution and unused capacity of time and cost in reducing the generated waste and better forecasting	The significant parameter obtained is able to reduce the waste in time and cost capacity utilization at the particular workstation.	Chapter 4 Section 4.13 until 4.15 Figure 4.16 until 4.19 Table 4.12, and 4.13

5.3 Recommendation and Future Work

It is clear that MTS is widely used in manufacturing industry (33%), such as welding, mechanical materials, steel products, rotating machinery, and rolling bearings fault diagnosis. However, MTS is difficult to discover in the production environment. It should be useful if more research in the production environment can be further expanded. While the TDABC used in manufacturing sector at a rate of roughly (8%). Research that highlighting the issues of TDABC should be explored, so it could provide more knowledge in this area. This signifies that the application in production environment is necessary.

This research contributes to the practicality of MTS and TDABC on data collection from an electronics company in Pasir Gudang, Johor. In the future, the calculated capacity utilization can be reduced by eliminating or combining the workstations. Thus, workstation that can be eliminated are such as workstation 1 and 5 because these workstations do not require manpower to stay at the workstation for long periods of the day. For 2 and 3 workstations can be combined into one workstation because the machines used are located on the same production line. Workstation 6 and 7 can also be combined as a place to test, inspect and verify PCBs as those activities are in one workplace. Last but not least, this workstation recommendation hopes to help reduce capacity utilization in the future with the company's endorsement.

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APPENDICES

Appendix A: Research motivation

Table 1: Research motivation of MTS and TDABC papers

No.	Author (Year)	Application	Method	Issue	Findings
1.	(Scott et al., 2023)	Fault detection and diagnostics	- Mahalanobis-Taguchi system (MTS)	Inappropriate sensor variables cause various complicated errors and commonly correlate.	1. MTS mitigates limitation that associated with fault identification, outlier contamination in training data, clustered or grouped training data, collinearity between factors, and high dimensionality.
2.	(Harudin et al., 2023)	Weld bead surface	- Mahalanobis-Taguchi system (MTS) - Feature extraction technique	The direct evaluation of specimens' quality of work and an instructor's expertise is very subjective.	1. The auto grading system improved the quality lab evaluation. 2. The auto grading system is applied to any similar assessments of image pattern extraction and MD scale measurement.
3.	(Mao et al., 2023)	Hydraulic system	- Fast Mahalanobis classification system (FMCS)	The data generated is more complex and imbalanced, posing a challenge for fault diagnosis due to hydraulic system complexity.	1. FMCS had better classification performance and shorter computing timed compared with 24 baseline algorithms. 2. The important features of dimensionality reduction is achieved by FMCS.
4.	(Mao & Cheng, 2023)	Truck air pressure system (APS)	- Modified Mahalanobis-Taguchi system (MMTS) - Mahalanobis space (MS) - Particle swarm optimization (PSO)	Truck fault detection obtained data is high-dimensional imbalanced.	1. The threshold determination is reduced the subjectivity using PSO algorithm. 2. MMTS had better classification performance and

					more suitable for truck APS
5.	(Sheng & Cheng, 2022)	Health care	- Mahalanobis Space (MS) - Mahalanobis Distance (MD)	The selection of normal samples depends on the experience and subjective judgment of experts and lacks an objective selection mechanism.	1. The improved MTS method is applied to a real medical diagnosis case.
6.	(Sun et al., 2022)	Multi-classification method	- Optimized binary tree Mahalanobis-Taguchi system (Optimized BT-MTS)	The diversity of categories may further aggravate the difficulty of classifying imbalanced data.	1. The method significantly reduced the overall misclassification cost. 2. The performance of imbalanced data multi-classification is improved.
7.	(Wang et al., 2022)	Rolling bearing	- Modified Mahalanobis-Taguchi system (MTS) - Mahalanobis Distance (MD)	The traditional MTS have a serious overlap, the model will perform imbalanced classification ability to identify the sample.	1. The result proved the effectiveness and superiority of the modified model.
8.	(Takai-Yamashita et al., 2022)	Sex determination	- Mahalanobis-Taguchi system (MTS)	The difficulty to understand the relationship between particles' structures and functionalities, not only classification but also key structures which improve accuracy of classification.	1. Classified MTS has the great ability to the powders' minor difference and will be an effective tool for particle design in the near future.
9.	(Reséndiz-Flores et al., 2022)	Manufacturing processes	- Mahalanobis-Taguchi system (MTS) - Kernel Mahalanobis distance (KMTS) - Sequential feature selection (SFS)	A wrapper approach to feature selection, the accuracy metric in classification is crucial in order to obtain the	1. KMTS-PSO technique can work with a complicated real multivariate problem. 2. KMTS can efficiently and easily identify observations which

			- Random Forest (RF)	important feature subset.	are out of specifications. 3. KMTS-PSO computational strategy is powerful numerical tool for optimal feature screening.
10.	(Peng et al., 2022)	Health care	- Mahalanobis-Taguchi system (MTS) - Quantum particle swarm optimization (QPSO) algorithm	The enlarge feature variables of optimization in misclassification.	1. A new prediction system based on Mahalanobis-Taguchi metric is established, and the task of accurate discrimination is accomplished.
11.	(Labidi et al., 2022)	Artificial Intelligence	- Mahalanobis-Taguchi system (MTS)	When MTS is used for anything other than fully automated AI control, the several interactions between the control factors in the MTS make highly accurate control difficult.	1. The effectiveness of the proposed method was evaluated by using a mathematical model.
12.	(Zhang et al., 2021)	Multiple Attribute Decision-Making	- Mahalanobis-Taguchi system (MTS) - Analytic Hierarchy Process (AHP)	The lack of attribute weight information	1. The multi-attribute decision-making problem with different forms of evaluation information and completely unknown attribute weight information is been solved effectively.
13.	(Ohkubo & Nagata, 2021)	Robust estimation	- Mahalanobis-Taguchi system (MTS)	The conventional MT method, historical data acquired and accumulated from sensors and smart devices cannot be analysed appropriately.	1. The labelling is redundant in anomaly detection after the approach method is applied. 2. The practicality of the MT method can be improved.
14.	(Ramlie et al., 2021)	Thresholding methods	- Mahalanobis-Taguchi system (MTS)	An inaccurate threshold value could lead to	1. The study recommended the use of the Type I–

				misclassification and eventually resulting in a misjudgement decision which in some cases caused fatal consequences.	Type II error method due to its less computational complexity as compared to the other three thresholding methods.
15.	(Kim et al., 2021)	Smart manufacturing	- Mahalanobis-Taguchi system (MTS) - Mahalanobis distance (MD) classifier	Many faults in motors or rotating machinery like industrial robots, aircraft engines, and wind turbines can be diagnosed by analysing signal data such as vibration and noise.	1. The experimental results showed the MD-based classifiers became more effective than binary classifiers in cases in which there were much fewer defect data than normal data, which is often common in the real-world industrial field.
16.	(Okubo et al., 2021)	Adaptive beam	- Mahalanobis-Taguchi system (MTS)	The main limitation of the model-based methods is that the fault diagnosis performance is largely dependent on the accuracy of the system model and these methods require significant data processing capabilities to ensure real-time operation.	1. The numerical simulations and experimental results showed MT system is highly effective in the damage detection.
17.	(J. Liu et al., 2021)	Steel plate	- Mahalanobis-Taguchi system (MTS) - Chaos quantum-behavior particle swarm optimization (CQPSO) algorithm	The computational speed in the feature selection of Mahalanobis-Taguchi system (MTS) using standard binary particle swarm optimization (BPSO) is slow and it is easy to fall into the locally optimal solution.	1. The experimental results showed proposed method can effectively enhance the iterative speed. 2. The optimization precision of the particles, and the prediction accuracy of the optimized MTS is significantly improved.

18.	(Yang et al., 2021)	Airbus	- Improved Mahalanobis-Taguchi System (MTS) - Analytic Hierarchy Process (AHP)	To avoid the decrease of system reliability due to insufficient component maintenance and the resource waste caused by excessive component maintenance.	1. The critical components identification problem with different types of evaluation information and completely unknown weight information of attributes is solved effectively which provides the implementation of protection measures for the system reliability of complex products.
19.	(Peng et al., 2021)	Review paper	- Mahalanobis-Taguchi system (MTS) - Mahalanobis space (MS)	The aforementioned papers lack a systematic review covering what the problems exist in the application of MTS, what methods can be utilised to improve MTS, and what problems can be solved by MTS.	1. The key technologies, four processes and application research are reviewed in this paper. 2. This paper provided the researchers with a discussion of the current situation, upcoming challenges and possible future trends.
20.	(Gao et al., 2021)	Milling chatter detection	- Mahalanobis-Taguchi system (MTS) - Sensor signal sensitive feature data set	Difficult to accurately predict the processing stability and then select appropriate processing parameters.	1. This method is detected the cutting processing state accurately. 2. The research results laid the foundation for advancing the industrialization of intelligent cutting processing.
21.	(Yao et al., 2021)	Rolling bearing	- Mahalanobis-Taguchi system (MTS) - Mahalanobis distance (MD) - Hidden Markov model (HMM)	Bearings have a huge impact on the working state of the entire mechanical equipment and	1. The experimental results showed the method can detect an early failure and has good sensitivity.

			- Empirical mode decomposition (EMD)	even the entire production line.	
22.	(Sikder et al., 2020)	Manufacturing process	- Mahalanobis-Taguchi System (MTS) - Support vector regression (SVR) - Prediction interval (PI) - Nelder-Mead (NM)	Multivariate statistical process control (MSPC) is a specific research area that addresses problems related to the monitoring and control of multiple correlated responses.	1. This easy-to-implement distribution-free predictive quality control approach is provided necessary flexibility to industry practitioners for real-life implementation in discrete or continuous manufacturing processes. 2. An MTS-based quality controller is a suitable MPC alternative for non-normal scenarios.
23.	(Kikuchi & Ishihara, 2020)	Strains of tower shell	- Mahalanobis-Taguchi System (MTS)	The structural modal method, the vibration and impedance response method, and the ultrasonic guided wave method are not sensitive to the damaged bolt location and also still need considerable manpower.	1. Abnormal bolts are successfully detected by the Mahalanobis-Taguchi system with a proposed threshold based on the FEM model and a proposed formula that accurately predicts the axial bolt residual force.
24.	(Asakura et al., 2020)	Logistic operating system	- Mahalanobis-Taguchi method	The continuous operation of logistic equipment, however, can lead to mechanical stoppages due to excessive use.	1. The applicability of the approach to a case involving continuous long-term operation is discussed using a simulation in which the target vertical transfer system is in continuous operation over a two-year period.
25.	(Watanabe et al., 2020)	Turning	- Mahalanobis-Taguchi method	Difficult to guarantee all	1. The proposed formalized and

				cutting anomalies can be detected during mass production due to various events that can occur.	systemized anomaly detection methods for a mass production line is implemented using an anomaly detection system with anomaly-corresponding function.
26.	(Nik Mohd Kamil et al., 2020)	Electrical & electronic industry	- Mahalanobis-Taguchi system (MTS) - Mahalanobis Space (MS)	No methodological that show the optimization procedure for a process that concern on E&E product in production area	1. The rejected product in parameter in a process of production in the industry is reduced. 2. The significant parameters can be identified for E&E product.
27.	(Safeiee et al., 2020)	Electrical & electronic industry	- Mahalanobis-Taguchi system (MTS) - Time driven activity-based costing (TDABC)	The electronic sector, is shifted into a higher value-added products and activities accordingly to the rapid globalization and increasing cost pressures.	1. The analysis for managerial decisions is produced by using diagnosis MTS method with ABC and TDABC.
28.	(Garain & Halder, 2020)	Forensic science	- Mahalanobis space (MS)	Document authentication is one such problem where has many reference samples, and with the big data scenario probably that would have even more number of reference samples but number of defective or forged samples will remain an issue.	1. The results showed a suitable reference modelling approach is efficient to tackle this type of forensic problems.
29.	(Wang & Zhang, 2020)	Bearing	- Improved Mahalanobis-	The influence of irregular distribution of the	1. The accuracy and sensitivity of the improved model for

			Taguchi system (MTS) - Mahalanobis space (MS)	sample data and abnormal variation of the normal data on accuracy of MTS	state identification is greatly enhanced compared with the traditional model.
30.	(Sakeran et al., 2020)	Anterior Cruciate Ligament (ACLR)	- Mahalanobis-Taguchi system (MTS) - Kanri distance calculator (KDC)	The multivariate parameters, doctors and physiotherapists consume lots of time in accessing patients.	1. The suitable rehabilitation protocol is suggested for quicker recovery to specific subjects.
31.	(Hsiao et al., 2020)	Health care	- Mahalanobis-Taguchi system (MTS) - Bagging-based ensemble	The learning schemes of most classification algorithms tend to optimize the overall accuracy, and thus, identification of important but rarely occurring examples is ignored.	1. An early warning system for in-hospital cardiac arrest is successfully implemented by leveraging the minority class identification ability of MTSbag.
32.	(Susanto & Kurniati, 2020)	Mining industry	- Mahalanobis-Taguchi system (MTS) - Mahalanobis distance (MD)	Heavy equipment is complicated and expensive equipment.	1. The failure of excavator components under study is detected, identified, and isolated by MD based Condition Based Maintenance (CBM).
33.	(Deepa et al., 2020)	Agriculture	- Improved Mahalanobis Taguchi system (IMTS) - Mahalanobis distance (MD)	The calculation of orthogonal array and signal-to-noise ratio in MTS makes the algorithm complicated when a greater number of factors are involved in the classification problem.	1. The limitation of the model is applied to decision problems with a limited number of alternatives and decision classes. 2. Feature selection methods can be applied to find a useful set of features for decision making.
34.	(Ji et al., 2020)	Reservoir	- Mahalanobis-Taguchi system (MTS) - Grey entropy method (GEM)	The problems such as to reduce the loss of decision information to	1. The uncertainty created by interval numbers is reduced effectively through MTS-GEM.

				improve decision accuracy and the difficulty of using interval numbers for sorting.	2. MTS-GEM can produce markedly distinctive decision results, which demonstrates the sufficiency of decision information contained in the model.
35.	(Cheng et al., 2020)	Turbine blades	- Mahalanobis-Taguchi system (MTS) - Mahalanobis distance (MD) - Integrated Mahalanobis classification system (IMCS)	A set of normal observations are used to obtain their MD values and construct a reference Mahalanobis distance space, for which a suitable classification threshold can then be introduced to classify new observations as normal/abnormal.	1. The achieved classification accuracy is far from satisfactory if the reference MD space is based on only defective samples. 2. An appealing classification result was obtained using IMCS based on a reference MD space constructed from both healthy and defected samples.
36.	(Reséndiz-Flores et al., 2020)	Industrial foam injection	- Mahalanobis-Taguchi system (MTS) - Based on particle swarm optimization and gravitational search algorithm (BPSOGSA)	Select a sub-set of input variables that describe the data in a correct manner and to reduce the noise effects or irrelevant variables and provide good prediction results.	1. The feature selection effect is validated through other widely used machine learning algorithms which improve their accuracy performance when they are trained with the subset of detected variables by the proposed system.
37.	(Xiao et al., 2020)	Data classification	- Optimized Mahalanobis-Taguchi system (MTS)	The Mahalanobis-Taguchi system (MTS) is a multivariate data diagnosis and prediction technology, which is widely used to optimize large sample data or unbalanced data, but it is rarely	1. The results showed the optimized MTS outperforms the classical MTS and the other 3 machine learning algorithms.

				used for high-dimensional small sample data.	
38.	(Habib et al., 2020)	Concrete beams	- Mahalanobis-Taguchi system (MTS)	A major concern while using acoustic emission (AE) features is that each of them responds differently to the fractures in concrete structures.	1. The results showed the proposed degradation indicator (DI) based on AE features and MTS is capable of detecting early-stage cracks as well as development of damage in concrete beams.
39.	(Kamil et al., 2020)	Electrical & electronic industry	- Mahalanobis-Taguchi system (MTS) - Time-driven activity-based costing (TDABC)	The high contribution of diagnosis parameters at VMI must be focus to avoid many rejected component and profit loss at E&E industry.	1. The diagnosis parameters are identified by MTS while the unused capacity in term of resources and time for each process in a workstation is measured by TDABC.
40.	(Bajic et al., 2020)	Predictive manufacturing	- Mahalanobis-Taguchi system (MTS) - Edge computing	The propose development of real-time predictive models based on small dataset without faulty data is to eliminate the need for large and varied datasets for development of predictive models.	1. The two models were applied in industry conditions, and the performances of these two models were assessed and compared.
41.	(Wang et al., 2019)	Bearing	- Mahalanobis-Taguchi system (MTS)	The aforementioned methods are effective for bearing faults diagnosis, the feature selection part is often non-adaptive or unexplainable.	1. The result showed bearings fault diagnosis under variable conditions is accurate.
42.	(Hamzah et al, 2019)	Health care	- Mahalanobis-Taguchi system (MTS)	Modern ACLR techniques allow steady ligament	1. MTS enabled doctors or physiotherapists to

				reconstruction in nearly all cases; however, the outcome of ACLR rehabilitation is not uniformly excellent.	provide a clinical assessment of their patients with more objective way.
43.	(Bhallavi, 2019)	Robust design	- Mahalanobis-Taguchi system (MTS)	The potential for robust design techniques in the domain of cybersecurity has remained unexplored.	1. The results showed the proposed method gives a high degree of accuracy at par with or even better than existing intrusion detection methods.
44.	(Lim et al., 2019)	Chemical hazard	- Mahalanobis-Taguchi system (MTS) - Globally harmonized system (GHS)	The lack of physical and chemical characterization information relating to chemicals has limitations that cannot be modeled.	1. Relative hazards are then identified using MTS multivariate analysis with GHS information, even when there is insufficient information about the chemical's characteristics, and the method can be applied to a large number of different chemicals.
45.	(Peng et al., 2019)	Rolling bearing	- Binary-tree and Mahalanobis-Taguchi system (BT-MTS)	The extraction methods have shortcomings, for example, the EMD has the end effect and mode mixing problems.	1. The experimental results demonstrated the proposed method is effective in recognizing the different categories of rolling bearings faults.
46.	(Hamzah et al., 2019)	Health care	- Mahalanobis Taguchi system (MTS) - Kanri distance calculator (KDC)	The clinician's capacity to provide safe and high-quality care relies on their ability to reason, think, and judge appropriately may be lacking among	1. The results indicated that by focusing on the contributing factors that affect the rehabilitation performance of the patients, it is possible to provide individualized and

				less experienced clinicians.	need-based treatment.
47.	(Zhuang et al., 2019)	Health care	- T method of Mahalanobis-Taguchi system (MTS) - Deep neural network (DNN)	Rehabilitation is a long-term and difficult work, and the patients are required to maintain their mental states for completion of the tasks involved.	1. The method provided is a useful treatment effect information for robots or assistive apparatus serving activities of daily living.
48.	(Toma, 2019)	Motor fan	- Mahalanobis-Taguchi system (MTS)	The sensory test for quality inspection of motor fans requires a lot of experience to accurately diagnose differences in subtle sounds (sound pressures) of the fans, and the judgment varies depending on the condition of the inspector and the environment.	1. The vibration waveform of analysis result showed the fluctuation of the vibration width of the waveform tends to become small as the angle of oscillation increases.
49.	(Wang et al., 2018)	Road quality detection	- Mahalanobis-Taguchi system (MTS)	While high-end automobiles are already equipped with road detection function, most mid-range cars can only detect and evaluate road conditions leveraging remodelled or additional hardware devices built on vehicles, thereby constraining the road quality detection.	1. A method for data pre-processing using wavelet transform is utilized to improve detection accuracy. 2. The detailed information on road conditions (e.g., deceleration zone and potholes) is marked on the existing map navigation system providing services.
50.	(Ohkubo & Nagata, 2018)	High-dimensional data	- Mahalanobis-Taguchi system (MTS)	The MT method cannot be applied to high-	1. Numerical experiments have confirmed that the

			- Sparse principal component analysis (SPCA)	dimensional small-sample.	proposed procedure is useful for both anomaly detection performance and detecting the cause of an anomaly.
51.	(Huh et al., 2018)	Health care	- Mahalanobis-Taguchi system (MTS) - Chemical ranking and scoring (CRS)	CRS methods have a few limitations which only use some of the variables to calculate the hazard of chemicals or use the most conservative score without consideration of the correlation between chemical toxicities.	1. The results indicated that the new method evaluated the health hazards of chemicals more accurately, and expected that the MTS method could be applied to a greater range of chemicals than the existing CRS methods.
52.	(Reséndiz-Flores et al., 2018)	Automobile	- Mahalanobis-Taguchi system (MTS) - Support vector data description (SVDD) - Gompertz binary particle swarm optimization (GBPSO)	The use and development of efficient strategies for dimensional reduction on the characteristics for processes quality in order to gain a substantial improvement at the moment of fault detection is crucial.	1. The better performance for fault detection is achieved by SVDD-GBPSO in terms of misclassification values and number of selected features.
53.	(Reyes-Carlos et al., 2018)	Automobile	- Mahalanobis-Taguchi system (MTS)	A crucial and important stage in MTS is the selection of variables or dimensional reduction process in order to assess the diagnosis and future prediction, efficiently.	1. The problem of dimensional variation and correct classification in quality control problems is reduced.
54.	(Mota-gutiérrez & Reséndiz-flores, 2018)	Review	- Mahalanobis-Taguchi system (MTS)	Aspects that have been criticized is the use of OAs and SNR for optimal reduction of variables in	1. MTS have been highlighted considering the way Mahalanobis distance is computed, different

				order to achieve an effective diagnosis.	criteria for dimensional reduction and different manners to determine the limits of phase control for process monitoring by different authors over time.
55.	(Konovalov et al., 2018)	Electrochemical	- Mahalanobis-Taguchi - Mahalanobis metric	Ensuring the quality of electrochemical protection processes by developing and selecting options for the location of control, measuring and automation equipment for multiparameter and multichannel systems using pipelines.	1. The stages of diagnostics of possible options for the location of control, measurement and automation equipment for pipeline systems are determined.
56.	(Xu et al., 2023)	Automatic container terminals (ACT)	- Time-driven activity-based costing (TDABC)	ACT lack of comprehensive comparison of different container terminal layouts from aspects of operation cost and energy consumption.	1. The cost-effectiveness is improved by using automated guided vehicles. 2. The long-term profitability bottleneck of ACT is identified.
57.	(B. Li et al., 2023)	Radiation therapy delivery	- Time-driven activity-based costing (TDABC)	Inadequate financial support stifle utilization of sophisticated techniques that significantly reduce morbidities and improve outcomes.	1. TDABC improved the relative cost of care delivery that differ from high-income country settings. 2. Low CCR is minimised the effect on overall costs of treatment.
58.	(Varriale et al., 2023)	Dairy industry	- Time-driven activity-based costing (TDABC) - Internet of Things (IoT) - Radio Frequency	The high cost required for blockchain implementation make its low adoption in supply chain.	1. The cost is optimized the entire supply chain. 2. The specific areas such as warehouse, management and

			Identification (RFID) - Blockchain		logistics are not economically optimized.
59.	(Elshaer, 2022b)	Restaurant	- Time-driven activity-based costing (TDABC) - Value Stream Mapping (VSM)	The current scenario which imposes emphasis on price and quality, restaurant managers had to reduce traditional accounting systems by creating more advanced approaches to achieve profitable relations.	1. The results revealed that TDABC appears to be a very feasible approach for both setting the correct cost of operations in restaurants and mapping the source of value-added activities.
60.	(Vedernikova et al., 2022)	Assembly industry	- Time-driven activity-based costing (TDABC) - Corporate social responsibility (CSR) - Quality management (QM)	Traditional costing systems are not enough to meet the need for conducting capacity utilization analyses since they allocate overhead costs to products based on a volume-based cost driver.	1. The results highlight that TDABC can be extended to perform a cost analysis with QM and CSR processes. 2. The cost and impact of incorporating CSR and QM in assembly processes is simulated by managers and thus the implementation degree and its corresponding planning according to the needs and available resources is decided.
61.	(Nielsen, 2022)	Business analytics	- Time-driven activity-based costing (TDABC) - Balanced scorecard (BSC)	Exploring the difficulties for the decision-maker to choose which scenarios to follow in order to improve the outcome and the decision process.	1. The assumptions of each decision-maker are considered when setting out to conduct the analysis. 2. The output is depended on input variables even with small changes.

62.	(Squeo et al., 2022)	Health care	- Time-driven activity-based costing (TDABC) - Precision breast intraoperative radiation therapy (PB-IORT)	Clinicians are encouraged to follow guideline-concordant care, which has been shown to reduce overall costs, use of healthcare resources, and even reduce mortality in cancer patients, thus creating a balance in developing the most effective yet inexpensive course of treatment for each individual patient.	1. TDABC is utilized by institutions to ensure the delivery of higher value care when integrating new technologies.
63.	(Goh et al., 2022)	Medical robotic	- Time-driven activity-based costing (TDABC)	Alignment accuracy in UKA remains crucial as subtle malalignment or mispositioning of more than 3° in the coronal plane or excessive tibial slope can predispose to mechanical failure or progression of arthritis in the adjacent compartment	1. The overall facility is lowed despite the longer operative time of RA-UKA by using TDABC. 2. The implant manufacturers may negotiate lower implant costs based on volume commitments when robotic assistance is used to facilitate wider adoption of this technology.
64.	(Defourny et al., 2022)	Radiation oncology	- Time-driven activity-based costing (TDABC)	Increasing costs, especially related to the continuous influx of new health care interventions, require the governments be well-equipped to estimate the resource needs as well as the costs of alternate scenarios, which account for	1. TDABC is implemented for other health care specialties that require medical devices as the core and ancillary activities are clearly defined.

				changes in patient profiles, treatment protocols, and technologies.	
65.	(Zerka et al., 2022)	Medical transportation	- Time-driven activity-based costing (TDABC)	A significant number of road accident victims die at the scene of the accident or during transport to the hospital.	1. The mapping obtained is adapted to the various situations of pre-hospital transport of victims of road accidents by basic vehicle. 2. TDABC applied to the pre-hospital transport process favours a better knowledge of all the activities and tasks necessary for pre-hospital pickups of victims by basic vehicles.
66.	(da Silva Etges et al., 2022)	Health care	- Time-driven activity-based costing (TDABC)	- The elective interventional coronary procedure (ICP) was chosen considering its high prevalence, low individual variability, high volume and cost.	1. The detailed cost information can contribute to driving health care management to value by identifying cost-saving opportunities.
67.	(Foglia et al., 2022)	Hospitalization costs	- Time-driven activity-based costing (TDABC)	Within the Italian epidemic peaks, the virus overloaded hospitals, with the saturation of hospital beds, the increasingly demand for medical devices and equipment (from complex equipment like ventilators or extracorporeal membrane oxygenation devices, to hospital staples,	1. Data represented the baseline cost for COVID-19 hospital management, thus being useful for the further development of proper reimbursement tariffs devoted to hospitalized infected patients.

				like saline drip bags), as well as the lack of trained healthcare professionals.	
68.	(Huebschmann et al., 2022)	Staf time estimation	- Time-driven activity-based costing (TDABC)	A recent TDABC review found that conventional methods for estimating staff time remain resource-intensive and called for simpler alternatives.	1. The field remains pressed to innovatively and pragmatically measure costs of program delivery that rate favourably across all of the 5 R's domains.
69.	(Mohammadpour et al., 2022)	Rehabilitation services	- Time-driven activity-based costing (TDABC)	The traditional approaches, where there are no solid connections between the activities and the number of resources used, can be only be employed in cases with limited activities and confined costs.	1. TDABC method provided more realistic cost structure information and other valuable information, such as a realistic profit/lost overview, unused human capacity and a basis for improved resources management for health care providers.
70.	(Simões Corrêa Galendi et al., 2022)	Cancer-induced bone pain	- Time-driven activity-based costing (TDABC)	The thermal damage monitoring on the treated and surrounding healthy tissues, and modulation of the energy level in case the temperature rise is insufficient.	1. The opportunity of benchmarking the provision of MR-HIFU to bone tumour is created by present TD-ABC model.
71.	(Ali et al., 2022)	Spine Surgery	- Time-driven activity-based costing (TDABC)	Institutions do not routinely track patient-level costs.	1. Institutions embarking on TDABC for spine surgery should consider the breadth of methodologies highlighted in this review to determine which type of

					calculations are appropriate for their practice.
72.	(Cronin et al., 2022)	Health care	- Time-driven activity-based costing (TDABC)	As shoulder arthroplasty continues to grow, the cost and value must be critically evaluated.	1. The private and public insurers with data that can be used to fairly adjust reimbursement when shoulder arthroplasty is performed on an outpatient basis is provided in this paper.
73.	(Pachito et al., 2022)	Health care	- Time-driven activity-based costing (TDABC)	The granularity embedded in this approach underpins the high accuracy of cost measures associated to micro-costing, when compared to gross costing, but it is still dependent of methods applied for distributing indirect costs.	1. Strategies to optimize management of referral cases to specialized care in public healthcare systems are still needed. 2. The need of accurate estimates of costs to underpin decision making in telehealth strategies is advantageous.
74.	(Hawranko et al., 2022)	Primary pancreatic cancer	- Time-driven activity-based costing (TDABC)	Stereotactic body radiation therapy (SBRT) technique is still restrained by the possibility of normal structure encroachment into the treatment site.	1. The TDABC analysis showed a 19.3% increase in personnel cost for adaptive treatment over non-adaptive treatment.
75.	(Priyadarshini et al., 2022)	Production process	- Time-driven activity-based costing (TDABC) - Life cycle assessment (LCA)	It is critical to conduct its environmental and economic evaluation for assessing the practicality of any specific process in catering.	1. The approach adopted can be employed for other innovative technologies and approaches to determine their suitability prior to commercial exploitation.
76.	(Kumar et al., 2022)	Cardiovascular diseases	- Time-driven activity-based costing (TDABC)	There is dearth of data regarding cost analysis of	1. The guidance for developing packages for

			- Traditional costing	treating various diseases including cardiac diseases from developing countries.	implementing insurance programme or reimbursement schemes through govt sponsored schemes is provided.
77.	(Thaker et al., 2022)	MRI-guided prostate brachytherapy	- Time-driven activity-based costing (TDABC) - Quality improvement (QI)	Modern QI interventions do not typically measure cost, and hospital cost accounting, which uses traditional costing methods such as the ratios of cost to-charges or relative value units, provides estimates of actual resource consumption by clinical and administrative processes based on charges rather than the cost of underlying resource utilization.	1. TDABC complemented the traditional QI initiatives by quantifying the highest cost steps and focusing QI initiatives to reduce costs and improve efficiency.
78.	(Doyle et al., 2022)	Health care	- Time-driven activity-based costing (TDABC)	Measuring cost incurred to achieve a significant focus of healthcare management research to date has received less attention.	1. The understanding of the drivers of cost in chronic illness care is facilitated by TDABC approach. 2. The stages in the care pathway where different settings, decision making and a more optimal use of resources could assist with achievement of better patient outcomes is highlighted in the paper.

79.	(Masthoff et al., 2021)	Interventional radiology care	- Time-driven activity-based costing (TDABC)	Traditional costing methods in diagnostic radiology and IR are top-down approaches, exclude clinician expertise, refer to costs in proportion to charges and thereby do not reflect reality.	1. TDABC facilitated the precise costing of interventional radiologic treatment cycles and optimized internal processes, cost reduction, and revenues. 2. TDABC revealed major organizational and economic shortcomings and thereby, enabled considerable improvement of process flow, cost reduction, revenue enhancement, and fundamental information for strategic decisions.
80.	(Nagra et al., 2021)	Breast cancer	- Time-driven activity-based costing (TDABC)	Traditional cost accounting techniques in healthcare, such as ratios of costs to charges (RCC) or relative value unit (RVU) costing, do not accurately measure the costs of resources used to treat a patient's medical condition.	1. The value in breast cancer care delivery and work towards evidence-based VBHC is defined by combining cost evaluation and linking the costs to patient outcomes after treatment with a clear understanding.
81.	(Alves et al., 2021)	Metastatic prostate cancer	- Time-driven activity-based costing (TDABC)	Limitations in the information technology available and the opportunity to collect quality time data are frequent challenges.	1. Accurate cost information is obtained with TDABC in guiding disease management to guarantee better use of ever-scarcer resources.
82.	(Kukreja et al., 2021)	Health care	- Time-driven activity-based costing (TDABC)	Determine the major drivers of cost surrounding	1. Surgical costs, inpatient care and readmissions all

				radical cystectomy in a cystectomy care pathway for the 90-day episode.	remain significant sources of expense for cystectomy and efforts to reduce cystectomy costs is focused in radical cystectomy pathway and operating room costs.
83.	(Magarò et al., 2021)	Academic	- Time-driven activity-based costing (TDABC)	ECP has shown encouraging results in solid organ rejection after transplantation and in a variety of immune-mediated diseases.	1. Potential non-monetary benefits include reduced time burden on patients, increased availability of hospital staff and improved patient safety.
84.	(Berkowitz et al., 2021)	Acute urolithiasis cycle of care	- Time-driven activity-based costing (TDABC)	Activity-based costing (ABC) often assumes processes are operating at full capacity, and it can introduce complexity in accounting systems based on the number of activity drivers.	1. Time-driven ABC is considered, even if only for internal use. 2. These data also should inform the discussion for appropriate reimbursement rates from CMS and other insurers.
85.	(Fang et al., 2021)	Revision total joint arthroplasties (rTJAs)	- Time-driven activity-based costing (TDABC)	Accurate cost data regarding hospital expenses for differing age groups are needed to deliver optimal care within value-based healthcare (VBHC) models.	1. The episode-of-care costs in older patients undergoing revision total joint arthroplasties (TJAs) is identified in delivering value-based health care.
86.	(Sj, 2021)	Prostate cancer	- Time-driven activity-based costing (TDABC)	The economic assessment of the real costs of health care, recognized as increasingly important in sound decision-making on the allocation of limited societal	1. MRI-only workflow is feasible and economic way to perform clinical radiation therapy (RT) for localized prostate cancer.

				resources, has not been carefully examined.	
87.	(Fang et al., 2021)	Hip and knee arthroplasty	- Time-driven activity-based costing (TDABC)	It is important for institutions to understand the financial burden of revision total joint arthroplasty (rTJA) with the high costs and conceivably unequal reimbursement of revision surgery.	1. The methodology of TDABC to measure costs has shown to have greater accuracy than traditional hospital accounting methodologies in TJA studies. 2. The patient access is limited if hospitals cannot perform revision services under the current reimbursement model. 3. Strategies are needed to reduce revision implant costs to improve value of care.
88.	(Cricco-lizza et al., 2021)	MRI-targeted prostate biopsy	- Time-driven activity-based costing (TDABC)	The first series of outcomes from MRI-ultrasound software fusion targeted transperineal biopsy under local anesthesia was published, however, no direct comparison of this technique to the more common method under sedation has been reported at a single institution.	1. Transperineal biopsy with local anesthesia is safe with comparable outcomes to sedation. 2. There was no statistical difference in the detection of clinically significant cancer while the number of cores taken differed.
89.	(Cidav et al., 2021)	Ostomy self-management training	- Time-driven activity-based costing (TDABC)	For cost assessment, micro costing estimates are the gold standard for cost valuation because they provide a high degree of	1. The selection of videoconferencing platforms and adequate staffing for participant technical support is considered for institutions without

				detail and transparency especially where human resources are of higher weight.	established telemedicine programs.
90.	(Karabachev et al., 2021)	Parathyroid surgery	- Time-driven activity-based costing (TDABC)	Comparison of surgical outcomes as well as operative times and associated costs in patients with and without ioPTH in the setting of co-localizing studies for primary hyperparathyroidism.	1. The use of ioPTH did not improve the success rate of minimally invasive parathyroid surgery, while the operative times and cost is increased.
91.	(Hayatghaibi, 2021)	Head computed tomography	- Time-driven activity-based costing (TDABC)	When a clinician places an advanced diagnostic imaging order through the electronic health record system, a clinical decision support module displays appropriate examinations for the indication selected.	1. The volume of CT exams by incorporating appropriate is reduced may have major positive effects on future health expenditures.
92.	(Chirenda et al., 2021)	Provider cost estimation	- Time-driven activity-based costing (TDABC) - Process maps	Insufficient cost data and limited capacity constrains the understanding of the actual resources required for effective TB control.	1. Considerable variations were observed among the facilities in how health care professionals performed client registration, taking of vital signs, treatment follow-up, dispensing medicines and processing samples. 2. The TDABC process maps and treatment costs revealed several

					opportunities for innovative improvements in the NTP under public health programme settings.
93.	(Hernández-lara, 2021)	Cost determination	- Time-driven activity-based costing (TDABC) - Activity-based costing (ABC)	Consequently, not all companies found ABC useful for decision-making or considered it appropriate for guiding their actions make this system not universally accepted and explain its low adoption rate.	1. TDABC present greater opportunities for publication compared with ABC.
94.	(Dziemianowicz et al., 2021)	Altered fractionation in breast cancer	- Time-driven activity-based costing (TDABC)	Although reimbursement differences have been examined for accelerated whole breast irradiation (AWBI) and conventional whole breast irradiation (CWBI), the cost of care delivery is poorly understood.	1. This analysis showed TDABC is used to evaluate resource requirements for different radiation therapy fractionation schedules. 2. The opportunities to reduce costs and increase clinical efficiency in the emphasis in health care shifts toward value-based care is identified by TDABC.
95.	(Fang, et al., 2021)	Hip and knee revision arthroplasty	- Time-driven activity-based costing (TDABC) - Traditional hospital cost accounting (TA)	Traditional hospital cost accounting (TA) has innate disadvantages that limit the ability to meaningfully measure care pathways and quality improvement.	1. TDABC for rTJA provided valuable bottom-up information on cost centers in the care pathway 2. The targeted interventions are led to a more optimal delivery of value-based health care.

96.	(Zimmerman et al., 2021)	Health care	- Time-driven activity-based costing (TDABC)	The technical component of these procedures is reimbursed at the same rate by the Centers for Medicare and Medicaid Services (CMS).	1. The direct cost of performing CCTA is significantly higher than CECT 2. The reimbursement schedules that treat these procedures similarly undervalue the resources required to perform CCTA and possibly decrease access to the procedure.
97.	(Guo et al., 2021)	Anterior cruciate ligament reconstruction (ACLR)	- Time-driven activity-based costing (TDABC) - Activity-based costing (ABC)	Measuring costs in health care can be extremely challenging owing to the opacities of direct and indirect costs and limitations of traditional accounting methods.	1. When compared with TDABC, the hospital's traditional cost-accounting estimate for ACLR is nearly twice as costly. 2. For the traditional accounting method, the direct variable cost was the main cost driver, whereas for the TDABC method, the direct fixed cost was the main cost driver.
98.	(McClintock et al., 2021)	Health care	- Time-driven activity-based costing (TDABC)	Conventional hospital cost accounting, based on billing and reimbursement data, is inaccurate and unsuited for care optimization.	1. Reliable cost accounting data and an understanding of variability in clinical pathway costs can inform value-based care redesign as payors move away from pure fee-for-service reimbursement.
99.	(Ljuboja et al., 2021)	Hepatocellular carcinoma therapies	- Time-driven activity-based costing (TDABC)	Traditional American health care accounting uses charges or relative value units (RVUs) as cost surrogates, despite the	1. The negligible effect of procedure-to-procedure variability on bottom-line costs and determined that TARE costs far

				questionable accuracy of this approach.	exceeded those of TACE and ablation. 2. The true costs of treatment and enable the creation of a representative national or regional bundled payment model to improve utilization of locoregional therapies for patients with HCC is determined by TDABC.
100.	(Riesener et al., 2021)	Cost calculation	- Time-driven activity-based costing (TDABC)	Process-oriented costing methods enable better results according to which products are profitable and which are not, the effort for the implementation and maintenance of these methods is extremely high.	1. A reduction of effort for maintaining an advanced costing system as well as an increase of accuracy and reliability are reached by TDABC.
101.	(Etges et al., 2020)	Review paper	- Time-driven activity-based costing (TDABC)	When a particular procedure is valued at a set amount, yet the amount of time, human resources, and materials needed to provide the service significantly vary from patient to patient, the provider of services who participates in complex and high-risk patient care can be financially penalized.	1. TDABC provided a clearer idea of the costs, help with resource allocation and waste reduction, and might support clinicians and managers in increasing value in a more accurate and transparent way.
102.	(Wedowati et al., 2020b)	Food industry	- Time-driven activity-based costing (TDABC)	The implementation of the modularization	1. Product value was analysed based on product benefits and costs needed to

				concept to produce various types of products according to the wants and needs of customers, of course, it will affect the terms of production costs.	realize these benefits. 2. TDABC provided the cost modularity model based on a basis for assessing product value.
103.	(Al Askary et al., 2020)	Bank service	- Time-driven activity-based costing (TDABC) - Activity-based costing (ABC)	ABC has been criticized for the high costs of access to the appropriate cost guides for various activities and the difficulty of adapting to any change in operations and resource uses	1. TDABC approach is less costly, faster to implement and easier to use. 2. TDABC assisted in determining the cost rates based on the actual capacity to supply resources
104.	(Choudhery et al., 2020)	Ultrasound-guided breast biopsy practice	- Time-driven activity-based costing (TDABC)	Calculating true costs is challenging in health care due to the complexities of resources involved in the care cycle of a patient.	1. TDABC provided a logical process for calculating true costs associated with each step in a patient's care cycle. 2. TDABC is a practical way to calculate costs and identify non-value-added steps, which can foster strategies to improve efficiency and minimize waste.
105.	(Carducci et al., 2020)	Academic	- Time-driven activity-based costing (TDABC)	Despite rapid increases in the demand for total shoulder arthroplasty, data describing cost trends are scarce.	1. The importance of stronger negotiation strategies to drive down the price of implants and maximize the value of care is highlighted in this paper.
106.	(J. Scott et al., 2020)	ICU chest radiographs	- Time-driven activity-based costing (TDABC)	The clinical team changed resident education,	1. The performance improvement initiative

				ordering protocols, and workflows to discontinue the use of routine daily chest radiography, emphasizing that it should be ordered only in specific situations, such as on admission or after central line placement.	successfully increased the value of care delivered to ICU patients by aligning institutional clinical practice with evidence-based medicine. - This resulted in decreased utilization and the cost associated with delivering care without a concomitant increase in complications.
107.	(Areena & Abu, 2019)	Review paper	- Time-driven activity-based costing (TDABC)	There is no paper show the methodology uses of Time-Driven Activity-Based Costing in palm oil plantation.	1. TDABC provided an accurate cost accounting starting point for providers.
108.	(Kissa et al., 2019)	Academic libraries	- Time-driven activity-based costing (TDABC)	Library managers should rely on valid information to keep the library's activities, resources and costs under control to provide high quality services despite their limited budget.	1. Implementing TDABC in the lending and return processes helped the library managers to determine which activities demand more time and are costly, and to analyse their respective causes.
109.	(White et al., 2019)	Health care	- Time-driven activity-based costing (TDABC)	Despite potential benefits, most CTR procedures continue to be performed in the OR, suggesting underutilization of an opportunity to decrease cost of care.	1. In clinic CTR using WALANT techniques resulted in lower cost as determined by TDABC without changing patient reported pain during or after the procedure

Appendix B: Signal data

Table1: Signal data for January

	Item											
Parameter	1	2	3	4	5	6	7	8	9	10	11	12
Average unit data	1.6	36.6	21.4	29.8	3.4	2	2	2.8	2.4	2.4	167.2	89.4
Use of an item / Data (post-sort)	1	1	1	1	1	1	1	1	1	1	1	1
2871	10	15	26	52	1	1	3	1	4	3	171	106
528	1	34	20	58	3	4	2	1	3	3	159	79
1683	8	14	23	57	2	2	3	3	3	2	166	101
1451	3	20	21	11	1	4	1	1	3	3	157	72
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…	…	…	…	…	…	…	…	…	…	…	…	…

	Item										Unit space member designation (* indicates nearest)	Output value
Parameter	13	14	15	16	17	18	19	20	21	22		
Average unit data	220	36.6	238.8	2.6	3	91.6	2.2	346.8	1	2		1.0754152
Use of an item / Data (post-sort)	1	1	1	1	1	1	1	1	1	1		
2871	220	59	237	2	3	87	4	355	2	1		0.000112
528	220	45	240	1	1	98	1	363	2	2		0.000919
1683	220	46	231	2	4	92	1	363	0	3		0.001112
1451	220	37	245	2	2	83	3	372	1	3		0.001311
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…	…	…	…	…	…	…	…	…	…	…		…
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Continue…

	Item											
Parameter	1	2	3	4	5	6	7	8	9	10	11	12
Average unit data	1.6	36.6	21.4	29.8	3.4	2	2	2.8	2.4	2.4	167.2	89.4
Use of an item / Data (post-sort)	1	1	1	1	1	1	1	1	1	1	1	1
…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…
1692	0	30	23	30	4	3	1	1	2	1	176	60
145	0	19	24	24	4	3	1	2	3	1	170	110
1960	0	55	20	42	4	2	2	4	3	3	169	90
679	3	24	20	0	2	3	3	1	1	2	180	73
…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…

	Item										Unit space member designation (* indicates nearest)	Output value
Parameter	13	14	15	16	17	18	19	20	21	22		
Average unit data	220	36.6	238.8	2.6	3	91.6	2.2	346.8	1	2		1.0754152
Use of an item / Data (post-sort)	1	1	1	1	1	1	1	1	1	1		
…	…	…	…	…	…	…	…	…	…	…		…
…	…	…	…	…	…	…	…	…	…	…		…
1692	220	41	233	1	1	94	2	348	2	1		1.073031
145	220	44	241	3	3	91	4	359	2	3	*	1.074859
1960	220	30	237	2	4	84	1	341	2	2	*	1.075034
679	220	37	239	3	3	100	1	343	0	2	*	1.075576
…	…	…	…	…	…	…	…	…	…	…		…
…	…	…	…	…	…	…	…	…	…	…		…

Continue…

Parameter	Item 1	2	3	4	5	6	7	8	9	10	11	12
Average unit data	1.6	36.6	21.4	29.8	3.4	2	2	2.8	2.4	2.4	167.2	89.4
Use of an item / Data (post-sort)	1	1	1	1	1	1	1	1	1	1	1	1
…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…
12	18	36	23	45	4	6	1	4	2	4	176	69
8	8	1	29	36	1	6	2	4	3	1	156	119
1	2	56	17	26	2	5	2	3	3	5	187	114
15	9	21	27	44	6	2	2	1	5	1	189	109

Parameter	Item 13	14	15	16	17	18	19	20	21	22	Unit space member designation (* indicates nearest)	Output value
Average unit data	220	36.6	238.8	2.6	3	91.6	2.2	346.8	1	2		1.0754152
Use of an item / Data (post-sort)	1	1	1	1	1	1	1	1	1	1		
…	…	…	…	…	…	…	…	…	…	…		…
…	…	…	…	…	…	…	…	…	…	…		…
…	…	…	…	…	…	…	…	…	…	…		…
12	220	44	241	5	2	4	4	343	6	2		27.215263
8	220	50	204	1	2	18	3	351	9	4		27.45757
1	220	54	231	6	1	8	1	367	10	3		27.581769
15	220	40	220	3	2	4	8	374	2	2		29.848876

Appendix C: Modified calculated estimated capacity utilization of integration

Table 1: New estimated capacity required by each main activity

Main activity	Variable	Sub-activities	Driver	Quantity (year)	Description
1. Solder paste control	X_1	1. Prepared the solder before running production	Quantity of solder (grams/year)	913,000	1,826 unit × 500g
	X_2	2. Update sticker of solder paste shelf-life control after issued out from refrigerator	Number of refrigerator operations (frequency/year)	1,826	1,826 unit
2. Input PCB	X_3	1. Visual check on PCB	Number of PCB (pieces/year)	21,001	42,002 / 2 *One plate has 2 PCB
	X_4	2. Input the PCB into auto loader machine	Number of auto loader machine operations (frequency/year)	21,001	42,002 / 2
3. Solder paste printing	X_5	1. Set up printer for printing on top stencil	Number of printing operations (frequency/year)	913,000	1,826 unit × 500g
	X_6	2. Inspect and confirm the solder paste printed on PCB	Number of PCB (pieces/year)	0	
	X_7	3. Verification and inspection the printing condition	Number of verified pass printing condition (pieces/year)	0	
	X_8	4. Cleaning the stencil	Number of stencils (frequency/year)	0	
4. SMT loading feeder Chip, IC and ODD component	X_9	1. Check value and P/N of material loading on feeder and tray	Number of tray (pieces/year)	0	
	X_{10}	2. Scan barcode P/N of machine type and ID operator	Number of scanned barcode (pieces/year)	0	
	X_{11}	3. Confirm the part for each feeder follow by loading list	Number of feeder (pieces/year)	0	
5. Reflow oven	X_{12}	1. Setting temperature on machine	Number of reflow ovens operations (frequency/year)	9	
	X_{13}	2. Check current model running with setting at machine is same	Number of PCB (pieces/year)	42,012	3,501 pieces × 12 months
6. Automated Optical Inspection (AOI)	X_{14}	1. Testing the PCB at several stages of assembly by using AOI machine and conducting auto inspection	Number of operating AOI machines (frequency/year)	0	

7. Visual Manual Inspection (VMI)	X_{15}	1. Checking appearance to reduce and prevent such defects in the future	Number of defects PCB (pieces/year)	0	
	X_{16}	2. Stamp at first PCB sampling for verified PCB (tag) for reference	Number of PCB pass with VMI (pieces/year)	42,012	3,501 pieces × 12 months
8. Repair input	X_{17}	1. Manual soldering to repair defect PCB found at AOI or VMI station	Number of manual soldering PCB (pieces/year)	1,512	126 pieces × 12 months
	X_{18}	2. Do marking at PCB after repair follow by ID colour	Number of marked PCB (pieces/year)	1,512	126 pieces × 12 months
	X_{19}	3. Verify the PCB after repair process	Number of verified PCB after repair (pieces/year)	1,512	126 pieces × 12 months

Table 2: New total time and cost for each main activity

Main activity	Sub-activities	Used time (min)	Capacity cost rate (MYR/min)	Total cost (MYR/year)
1. Solder paste control	1. Prepared the solder before running production	913,000.00	1.27	1,156,168.30
	2. Update sticker of solder paste shelf-life control after issued out from refrigerator	146.08	0.08	11.24
	Total	913,146.08		1,156,179.54
2. Input PCB	1. Visual check on PCB	10,500.50	0.15	1,544.19
	2. Input the PCB into auto loader machine	5,250.25	0.08	397.15
	Total	15,750.75		1,941.34
3. Solder paste printing	1. Set up printer for printing on top stencil	684,750.00	0.08	51,848.55
	2. Inspect and confirm the solder paste printed on PCB	0	0.04	0.00
	3. Verification and inspection the printing condition	0	0.04	0.00
	4. Cleaning the stencil	0	0.08	0.00
	Total	684,750.00		51,848.55
4. SMT loading feeder Chip, IC and ODD component	1. Check value and P/N of material loading on feeder and tray	0	0.07	0.00
	2. Scan barcode P/N of machine type and ID operator	0	0.05	0.00
	3. Confirm the part for each feeder follow by loading list	0	0.05	0.00
	Total	0		0.00
5. Reflow oven	1. Setting temperature on machine	24.30	0.15	3.59
	2. Check current model running with setting at machine is same	3,360.96	0.07	248.49
	Total	3,385.26		252.08
6. Automated Optical Inspection (AOI)	1. Testing the PCB at several stages of assembly by using AOI machine and conducting auto inspection	0	0.15	0.00
	Total	0		0.00

7. Visual Manual Inspection (VMI)	1. Checking appearance to reduce and prevent such defects in the future	0	0.07	0.00
	2. Stamp at first PCB sampling for verified PCB (tag) for reference	2,940.84	0.07	216.24
	Total	2,940.84		216.24
8. Repair input	1. Manual soldering to repair defect PCB found at AOI or VMI station	302.40	0.05	15.22
	2. Do marking at PCB after repair follow by ID colour	75.60	0.05	3.71
	3. Verify the PCB after repair process	257.04	0.05	12.60
	Total	635.04		31.53

Appendix D: Interview questions

1. How many types of costs are involved?
2. How many main processes are involved?
3. How many sub-processes are involved?
4. What are the allocated costs for each sub-process?
5. How many products are produced in a month or a year?

Appendix E: Time study

Table 1: Time taken per cycle for each sub-activites

Main activity	Sub-activities	Time taken per cycle (min)	Cycle time (min)
1. Solder paste control	1. Prepared the solder before running production	1.10	
		0.90	1.00
		1.00	
	2. Update sticker of solder paste shelf-life control after issued out from refrigerator	0.10	
		0.06	0.08
		0.07	
2. Input PCB	1. Visual check on PCB	0.60	
		0.50	0.50
		0.40	
	2. Input the PCB into auto loader machine	0.35	
		0.25	0.25
		0.15	
3. Solder paste printing	1. Set up printer for printing on top stencil	0.75	
		0.90	0.75
		0.60	
	2. Inspect and confirm the solder paste printed on PCB	0.13	
		0.20	0.17
		0.17	
	3. Verification and inspection the printing condition	0.20	
		0.32	0.25
		0.24	
	4. Cleaning the stencil	0.08	
		0.09	0.08
		0.07	
4. SMT loading feeder Chip, IC and ODD component	1. Check value and P/N of material loading on feeder and tray	1.48	
		1.45	1.50
		1.55	
	2. Scan barcode P/N of machine type and ID operator	0.04	
		0.05	0.05
		0.07	
	3. Confirm the part for each feeder follow by loading list	0.19	
		0.15	0.17
		0.18	
5. Reflow oven	1. Setting temperature on machine	2.5	
		2.8	2.70
		2.7	
	2. Check current model running with setting at machine is same	0.08	
		0.11	0.08
		0.06	
6. Automated Optical Inspection (AOI)	1. Testing the PCB at several stages of assembly by using AOI machine and conducting auto inspection	3.51	
		3.59	3.50
		3.41	
7. Visual Manual Inspection (VMI)	1. Checking appearance to reduce and prevent such defects in the future	1.53	
		1.47	1.50
		1.50	
	2. Stamp at first PCB sampling for verified PCB (tag) for reference	0.06	
		0.09	0.07
		0.07	

8. Repair input	1. Manual soldering to repair defect PCB found at AOI or VMI station	0.22 0.26 0.13	0.20
	2. Do marking at PCB after repair follow by ID colour	0.04 0.06 0.05	0.05
	3. Verify the PCB after repair process	0.19 0.17 0.15	0.17

Appendix F: List of publications

1. **N.H. Aris**, M.Y. Abu, S.N.A.M. Zaini, M.A.M. Jamil, N.S. Pinueh, W.Z.A.W. Muhamad, F. Ramlie, N. Harudin, and E. Sari, (2023), Mahalanobis-Taguchi system and time-driven activity-based costing of Printed Circuit Board, *Journal of Theoretical and Applied Information Technology (JATIT)*, Vol. 101 No. 24 (2023): December, pp. 8247-8261.
2. **N.H. Aris**, M.Y. Abu, M.A.M. Jamil, S.N.A.M. Zaini, N.S. Pinueh, W.Z.A.W. Muhamad, F. Ramlie, N. Harudin, and E. Sari, (2023), Application of Mahalanobis-Taguchi system in rainfall distribution, *Journal of Modern Manufacturing Systems and Technology (JMMST)*, Vol. 7 No. 2 (2023): September, pp. 1-8.
3. N.S. Pinueh, M. Y. Abu, **N.H. Aris**, M.A.M. Jamil, E. Sari, (2024), Comparison of Activity-Based Costing and Time-Driven Activity-Based Costing for Printed Circuit Board Assembly Production, *Journal of Theoretical and Applied Information Technology (JATIT)*, Vol. 102 No. 9 (2024): May, pp. 3954-3971.
4. M.A.M. Jamil, M. Y. Abu, S.N.A.M. Zaini, **N.H. Aris**, N.S. Pinueh, N.N. Jaafar, W.Z.A.W. Muhamad, F. Ramlie, N. Harudin, E. Sari, N.A.A.A. Ghani, (2024), Prediction of Rainfall Trends using Mahalanobis-Taguchi System, *Journal of Engineering and Technological Sciences (JETS)*, Vol. 56 No. 2 (2024): April, pp. 287-303.
5. M.A.M. Jamil, M. Y. Abu, S.N.A.M. Zaini, **N.H. Aris**, N.S. Pinueh, W.Z.A.W. Muhamad, F. Ramlie, N. Harudin, E. Sari, N.A.A.A. Ghani, N.N. Jaafar, (2023), Application of Mahalanobis-Taguchi System in Rainfall Trends at UMP Gambang Campus, *Mekatronika*, Vol. 5 No. 2 (2023): July, pp. 6-13.