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RESEARCH ARTICLE

Application of Fuzzy TOPSIS and Harmonic Mitigation Measurement on Lean Six Sigma: A Case Study in Smart Factory

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ABSTRACT Customers' requirements for product quality are increasing and more and more manufacturing companies are improving the quality of processing conditions at each production process by applying advances in Internet Technologies, Internet of Things, Big Data, Industry 4.0, Industrial Engineering Tools, Multi-objective optimization algorithms, Digital Numerical Control (DNC) method, and Six Sigma tools to improve productivity and quality of product. Continuous improvement of the manufacturing process presents a huge opportunity for the transformation of the normal production model to smart manufacturing. Manufacturing condition data, production data, quality of product data, and power quality data are measured and collected in real-time forming big data fed into operation analysis of the development strategy of the manufacturing company. In this study, the implementation of the Hybrid DMAIC (Define-Measure-Analyze-Improve-Control) method in six sigma is presented in detail based on the statistical hypothesis testing techniques for analyzing production data applied at the measurement phase, Multi-objective decision Fuzzy TOPSIS techniques applied to choose the best improvement solution applied at the analysis phase, Multi-objective optimization technique optimizes production conditions, and the DNC method performs automatically program call by RFID system applied at improvement phase, measurement technique, real-time measurement result collection and analysis by Industry 4.0 system and the method of phase shift is used to keep Total Harmonic Distortion (THD) and Total Demand Distortion (TDD) less than 5% within the international standard limits defined by IEEE 519:2022 and IEC 61000 applied at control phase. A common data system linking all activities at a particular manufacturing process and hybrid DMAIC in Six Sigma continuous improvement model is proposed in this study. This research's results, the rate of occurrence of smaller-than-standard outer diameter defects decreased from 31.20% to 4.5% per month, the grinding process productivity achieved 610 pcs per day while the number of operators decreased from 4 people to 2 people per day, and productivity per person per hour increased from 15 PCS to 30 PCS. The profit is achieved at 11,184 USD per year. The Hybrid DMAIC method in Six Sigma is considered a model of continuous improvement that can be applied to production processes in manufacturing companies. The Hybrid DMAIC method in Six Sigma is simple to implement, easy to deploy into the real environment at production processes, and uses

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commercial software such as Minitab, LABVIEW, and SPSS. Manufacturing companies apply this research model to help improve competitiveness, improve business performance, and improve customer satisfaction.

INDEX TERMS RFID, smart manufacturing, six sigma, hybrid DMAIC, harmonic, fuzzy TOPSIS.

I. INTRODUCTION

The term quality has been defined by many different documents and authors [1]. For example: According to author Juran [2], the suitability of a product for use is called quality. According to author Mitra [3], a product that meets the appropriate level of a product or service that meets customer requirements or exceeds customer requirements is called quality. Activities to support quality assurance activities such as measuring performance, comparing work results with objectives, and implementing preventive and corrective actions when results are unsatisfactory or negative problems occur in production activities [4].

Currently, manufacturing innovation requires everyone to change the current situation. Every employee working on their innovation lifts the whole morale in the workplace and encourages product innovation [5]. Types of waste at the workplace are categorized into two areas. One is a waste of objects and the other one is a waste of motion and transportation. Improving redundancy operations at each stage and executing machines with the necessary functions will bring a great effect. The flow of product movement between stages is interrupted. Specifically, there are bottleneck processes [6]. The lines with WIP (work in process) stacked up and unidentified were ‘‘disturbed flow’’. Since such lines tend to cause defects and lengthen lead time (LT) make the flow while laying out each line. Furthermore, moving the lines closer to each other (which is called ‘‘efficient layout’’) eliminates stagnation and creates more useful spaces. Procedures of machine improvements are to separate humans from machines and separate human functions from machine functions. Meeting production capacity and improving capacity at each stage is necessary. To diversify the production capacity of each processing machine, improvement activities applying quality 4.0 technology are necessary. Mechanical manufacturing plants need to apply this new technique to production control activities, which is considered a new step in the application of information technology in production. Information in production is classified into main functions, and it is closely linked by a system connected by information technology. Manage, operate well, and bring high value to production operations. Data needs of departmental functions are stored in real-time and with data centralization in a common system, manufacturing companies have always turned to big data. My models of industrial system engineering and management show the overall linkage of functions and data, the information on the functions is concentrated on the total function of production management (PM) [7]. The production control information system in the company is implemented with the main goal of maximizing profits and minimizing costs. Production data is well collected, well managed, and well analyzed, helping managers make decisions easily and accurately [8]. However, the collection of product data in the field, data on product dimensions, and data on visual inspection is still limited, requiring researchers to find ways to suitable methods to improve the quality of input data for information systems in production. There are many studies on the application of information technology to production activities, but there are many limitations such as managing operators with the layout they are assigned and people with no skills or poor skills. The method of intelligent evolutionary algorithms to optimize the control factors of hard-turning operation including optimum cutting speed, feed rate, depth-of-cut and cutting temperature [9]. The novel ensemble deep learning model is for cutting tool wear monitoring using audio sensors [10]. Intelligent sensor systems are used to improve machine ability characteristics, for instance, surface integrity, tool wear, dimensional accuracy, and chip morphology [11]

Operating the machine will easily cause occupational accidents [12]. Quality control of products after completing processing at each stage has not been closely linked, or data is still recorded by hand and requires additional data entry into the computer for analyze and wasteful manipulation, which generates processing costs. The machining condition data at each line is disconnected and fragmented, and the method of collecting the machining conditions is fully manual or semi-automatic, leading to under-maximization of the machining step, causing many operations not bring added value and take many operations, making the operator unsatisfied. Mostly, at the processing stages in the process, the product is visually inspected by the operator [13].

The big question for manufacturers researching this project is that the big challenge for mechanical product manufacturers is that the factory produces defective products, what should the manufacturer do?, How to rehabilitate various defects and implement preventing the recurrence of different types of defects in the future. Lean Six Sigma (LSS) model is proposed for the continuous quality improvement activity. The DMAIC model is evaluated as the standard model of LSS. The Define (D) phase performs the description of the specific object of the manufacturing process of the mechanical product where the problem arises. Measure (M) phase deploys statistical tools, experimental sampling models in the field of real production environment for collection of real data at mechanical product manufacturing companies, statistical hypothesis testing models applied analyze data to identify problem points. Taguchi method is applied to determine the relevant optimal object that gives rise to the problem point. Analysis (A) phase is suggested to use multi-criteria analyze as an effective way to determine the root cause [14]. The Improve (I) phase recommends using quality 4.0 technologies such as computer vision, digital numerical control, and signal processing techniques to implement continuous quality design improvements. The Control (C) phase proposes implementing digital numerical control techniques such as RFID (Radio Frequency Identification) into an online measurement system that controls the results in real-time. All data from the above digital ERP (Enterprise Resource Planning) systems are saved on the SQL (Structured Query Language) system and are considered big data [15].

The question is about solving the problem of improving product quality in the production process by finding the optimal improvement method and finding the optimal conditions for that improvement method applied to the specific process at the production company. Research focuses on determining the quality aspects of mechanical products, and making quality improvement decisions. The data used for problem identification analyze is collected directly on the production line by the operator. Statistical tools are used to analyze data and run on MINITAB software. Statistical hypothesis testing tools and Taguchi method are used to analyze the data to find the optimal conditions that give rise to the problem point [16]. At the analyze phase, it is proposed to use multi-criteria analysis (Fuzzy TOPSIS) to decide on options for quality improvement [17]. The input of decision makers, machine operators, maintenance personnel, production managers and technical experts is necessary for the determination of mechanical product quality attributes. According to the authors Jing [18], Groups of decision-makers often have different prioritization scores on the same evaluation criteria and this issue has a significant impact on the final decision-making activity and decision making techniques are supposed to fill this gap. Many fields have used multi-criteria approach in decision support and many different researchers have proposed different approaches such as analytical hierarchical process (AHP) [19] and the technique of determining the order of precedence according to the similarity with the solution ideal law (TOPSIS) [20]. AHP is the most commonly used technique for multi-criteria analyze. TOPSIS is also widely used to solve many complex decision-making problems because of its effectiveness in multi-criteria problem solving and simplicity in calculation. In addition, the seamless construction processes of AHP and TOPSIS make them easily understood by scholars and professionals. However, the AHP and TOPSIS approaches are still heavily criticized for their inability to handle ambiguous variables. The AHP cannot deal with the uncertainty in the decision about the weights of the different attributes due to the use of a discrete scale from one to nine. Likewise, the classical TOPSIS method uses sharp numerical values rather than verbal judgments, and it can run into practical problems due to vague human perception and judgment. In this study, a fuzzy TOPSIS approach is proposed to support more rational decision making during the Analyze phase of the DMAIC cycle. In addition to traditional multi-criteria methods, fuzzy set theory has been used in studies that need to quantify qualitative variables. Therefore, it is a powerful modeling tool to deal with not exactly realistic situations. Fuzzy TOPSIS is used when it is necessary to use linguistic values in the measurement scales. Computer vision techniques using image and signal processing on LABVIEW software are considered for implementation in the redesign of production tools and continuous product quality improvement. RFID technology is considered as a real-time data collection model to monitor machining orders at each stage and an online measurement system using digital numerical control is also considered and deployed in this study.

Eliminate operations that do not add value, which means more business profits. Managers are always looking for methods to optimize production, apply Industry 4.0 techniques to process automation, shorten machining time, eliminate waste, improve productivity, and save data in processing according to the needs of customers [21]. Real-time machining data analyze, and data visualization. In this study, the application of the multi-criteria decision-making method (Fuzzy TOPSIS) and the application of computer vision technology to control the operator of the stage with the machining layout by face recognition method and set up a product inspection system at each processing line, collect and process data management into a real-time online measurement system. Redesigned machining jigs and implemented a system to control machining conditions such as dimensions, and the position of product racks into machining jigs, and apply a barcode management system, automatically calling machining programs, eliminating the dependency on people [13], [22], [23].

The aim of the paper and the contribution of this study have the following objects: (1) Optimizing the machining process at the mechanical factory by applying Industry 4.0. (2) Automating inspection product dimensions using soft computing technology and collecting data over time. (3) Automating the collection of machining conditions at each stage by applying information technology to the measurement and data collection system over time. (4) Re-engineering tool design, simplifying machining operations and improving operator satisfaction. (5) Automating the calling of outsourcing programs by applying barcode technology and information technology systems, eliminating dependence on humans. (6) Develop an enterprise resource integration system by developing technology systems in production control, data visualization, and support for managers to make accurate decisions. (7) Improve labor safety control activities in production by applying computer vision technology, facial recognition technology to control people with assigned stages and improve safety in operation. (8) Analyze production data by applying statistics and visualize data with graphs in statistics, applying statistical software such as minitab18.0, SPSS (Statistical Package for the Social Sciences) 20, Matlab2019a. (9) Eliminating the distance from the research environment and the practical environment, creating a close

TABLE 1. Summary literature review DMAIC research.

Refs	Manufacturing	Goal	Methodology
[34]	Semiconductor industry	Reduce defect of electrical circuit when assembly inkjet printers	DMAIC
[35]	Forging manufacturing process	Reduce defects of dents from forging in parts	DMAIC
[36]	Precision tools and dies process	Improve quality of heat treatment process and hardness quality of tools and dies	Value stream mapping and DMAIC
[37]	Plastic injection molding manufacturing	Reduce defect rate in the factory	DMAIC
[38]	IT industry	Improve quality of IT operation in factory	DMAIC
[39]	Software industry	Develop a new model and methods or tools, in process improvement methodologies	IDDOV (Identity, Define, Develop, Optimize, Verify)
[40]	Boxes manufacturer	Reduce defect during production	DMAIC
[41]	Automobile industry	Emphasize the importance of Six Sigma experts in enhancing the productivity, customer satisfaction, and savings	Questionnaire
[42]	Thermal power plant	Reduce expensive de-mineralized water consumption to compensate for the losses during power generation	DMAIC
[43]	Aerospace industry	Reduce non-value added activities and improve delivery times	DMAIC with Lean thinking cycle
[44]	Garment industry	Reduce the scrap rates during production	DMAIC
[45]	Oil and gas industry	Detect process anomalies before failure occurs	Measure–validate–predict (MVP) and statistical process control (SPC) in Six Sigma
[46]	Telecommunication providers	Reduce the repeated complaint tickets issued through customer service	DMAIC and CRISP-DM
[47]	Banking	Evaluate a framework by solving organizational IT problems	Lean and Robotic Process Automation (RPA)

connection by applying re-search results to production activities and 10. Keep total harmonic distortion (THD) and total demand distortion (TDD) within the international standard limits defined by IEEE 519:2022 and IEC 61000 in electrical networks.

The research paper has the following organizational structure: Section II presents a literature review. Section III presents the raw material and methodology. Section IV presents the results of the experience and discussion. Section V presents the conclusion.

II. RELATED WORK

A. LEAN SIX SIGMA (LSS)

Lean Six Sigma (LSS) is implemented based on the DMAIC closed cycle [24]. It supports researchers in implementing LSS projects from collecting actual data at the production stage to applying analytical tools and fine-tuning production stages to bring high business efficiency [25], [26]. It helps to specifically identify the fluctuations occurring in the operations process at each location in the manufacturing process and focus on new measurements and new technology adoption for continuous improvement [27]. The DMAIC phase is seen as an extension of the Deming improvement cycle (PDCA: Plan-Do-Check-Action) and is divided into five phases. The "Define" (D) phase includes defining the project's goals and objectives. The "Measurement" (M), the goal is to measure a change in the system that could create a defect. For Cheng and Chang [28], goal is to understand and document the current state of processes that need improvement. In "Analyze" (A), a detailed analysis of the process or problem in question is performed based on a group of methods and tools [29], [30]. Barjaktarovic and Jecmenica [31] state that this phase identifies, validates, and quantifies the problem. In the "Improve" phase (I), the problems identified is in the Analyze phase need to be resolved. Therefore, this phase is involved identifying potential solutions and also implementing them through the use of different tools [32]. Proposed solutions are identified and tested, comparing the possible costs and benefits of implementing each solution [30], [33]. Therefore, the best option is established. Finally, the "Control" (C) phase is intended to prevent the return of the original (stale/defective) process. It also has a fundamental role in communicating successful project outcomes to employees. The techniques and achievements are disseminated, ensuring more management support in future implementation [4]. Summary literature review DMAIC research (Tab. 1). Table 1 show that the DMAIC phase in Six Sigma is commonly used in applied studies to implement continuous improvement in manufacturing companies in many different fields. It can be said that continuous improvement activities at manufacturing plants are indispensable for the DMAIC phase in Six Sigma. The DMIAC model is simple, easy to use, and highly effective in improving production processes. However, Industry 4.0 technology has developed rapidly, requiring big data to analyze production results to make decisions on production business strategies to meet the needs of the times. The production process at each stage must be implemented with continuous improvement activities and converted into a production process according to Industry 4.0 system. The previous studies of many authors shown in Table 1 used the DMAIC cycle to implement continuous improvement. There have not been any studies that have integrated fuzzy multi-objective decision-making into the analysis phase for selection. optimal improvement plan, there has not been any research using multivariate optimization techniques in the improvement phase to select the optimal machining conditions for the improved solution that has been selected in the analysis phase and finally, There are no studies using real-time power measurement techniques and implementing an online measurement system to monitor the stability of the results of the improvement option at a specific production process. This study solves all of the above shortcomings that previous studies have not done.

B. FUZZY TOPSIS

Hwang and Yoon [48] proposed the TOPSIS method, and Chen [49] revised the TOPSIS method to suit the use of fuzzy numbers, and allowed the use of linguistic variables as a way of collecting information. Language variables include natural languages or artificial language variables and are differentiated through hierarchical levels. A set of languages are specifically defined and their values measured. Managers can collect and combine information without verification, or incomplete information, or data that is partially ignored in decision models when applying fuzzy set theory. Fuzzy set and fuzzy logic is a powerful approach to modeling uncertain systems and capturing tacit knowledge from industry experts. The fuzzy set is also an extension of the sharp set. In different contexts, AHP is the preferred method of choice first, fuzzy VIKOR and fuzzy TOPSIS for selecting important elements in the production department of a mechanical manufacturing plant, and the second tool. two have developed an assessment tool for new product development tools for small and medium enterprises (SMEs) using fuzzy AHP and TOPSIS. Behzadian et al. [50] conducted an extensive literature survey to categorize research on TOPSIS applications. The classification scheme for this review includes 266 academic articles, of which only one addressed design improvement, but focused on optimizing product design rather than process. Therefore, there is a lack of studies using multi-criteria analyze in projects to improve the efficiency and quality of production processes.

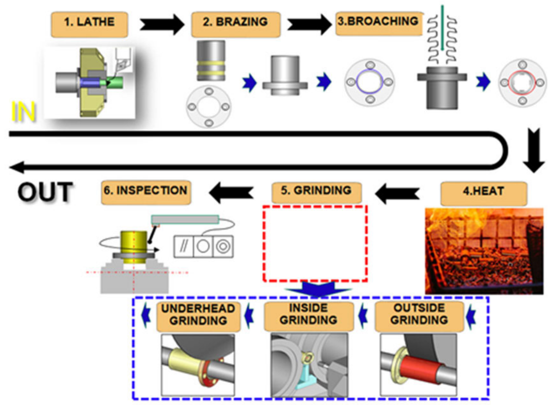

FIGURE 1. Mechanical product line production process.

III. RAW MATERIAL AND METHODOLOGY

A. MECHANICAL PRODUCT MANUFACTURING PROCESS AT GRINDING PROCESS

The mechanical product line is processed by 6 processes (Fig. 1). This study focuses on analysis and improvement at the 5th production process. The 3 steps are (1) Outside grinding the outer diameter body to a tolerance of ±0.005mm. (2) Inside grinding grinds the bore size to a small bore co-cylindrical tolerance of 0.003 mm and (3) Under-head grinding grinds the neck face dimension of the product to a square root tolerance to the outside diameter less than 0.005 mm. Carry out a comprehensive review of standard documents, processing regulations and production management results such as quality documents, production plan management documents, business management documents at the production line of blank mechanical products with the period from April 2021 to March 2022 and detected 3522 defective products (0.21%) and in which the percentage of defect products in outer diameter size accounted for 31.2% (1099 defective products).

Semi-automatic mechanical grinder is used, changing the grinding wheel distance is done manually by the operators, which affects the machining size of the product because it depends on human adjustment skills (according to the POKA-YOKE theory) (Fig. 2a and 2b). Factors that need to be considered in the grinding process such as the speed of entering and leaving the product surface of the grinding wheel without causing damage to the product, the contact distance between the surface of the grinding wheel and the surface of

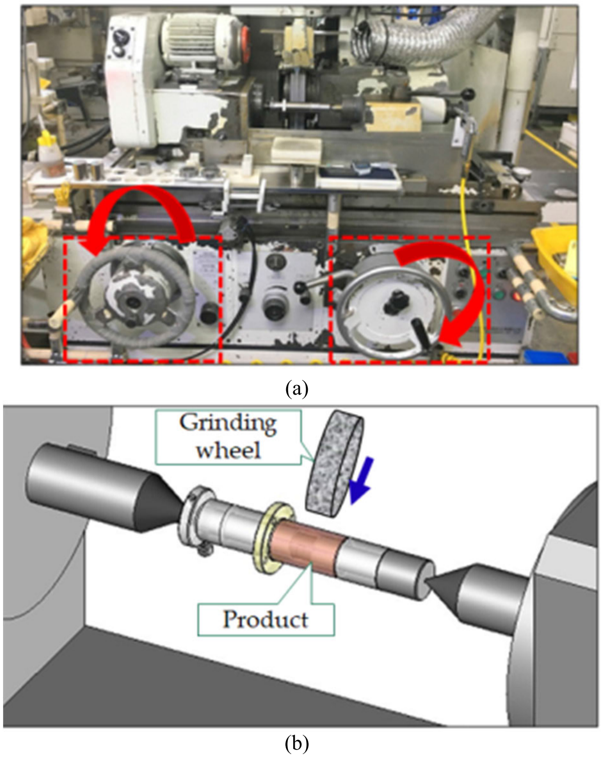

FIGURE 2. a. Outer diameter grinding machine. b. Outer diameter grinding process.

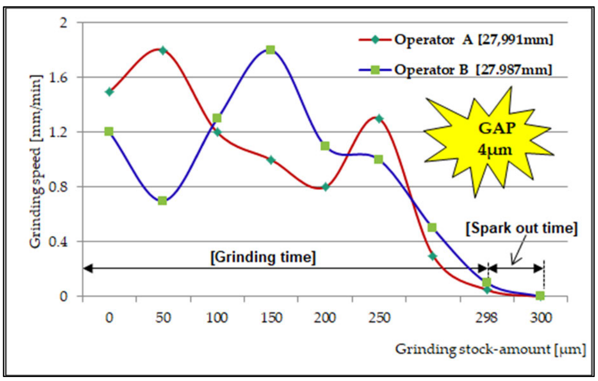

FIGURE 3. Compare skill of operator.

the product is not regulated and Improper type of grinding wheel, all of which cause defect products.

The seniority and skill of operators greatly affect the product size after processing, the average size difference after processing of operator A and operator B is 0.004mm (Fig. 3). Automation of machining conditions according to POKAYOKE theory is necessary to improve product quality.

Adjust the machining condition and check the grinding wheel surface with a special tool by hand operators, the minimum size adjustment unit for the tracing tool is 0.005 mm, so it is difficult for the operator to adjust the adjustment for each operation (Fig. 4a and 4b). After each scan of the stone surface and correct the position of the stone, the fine size must

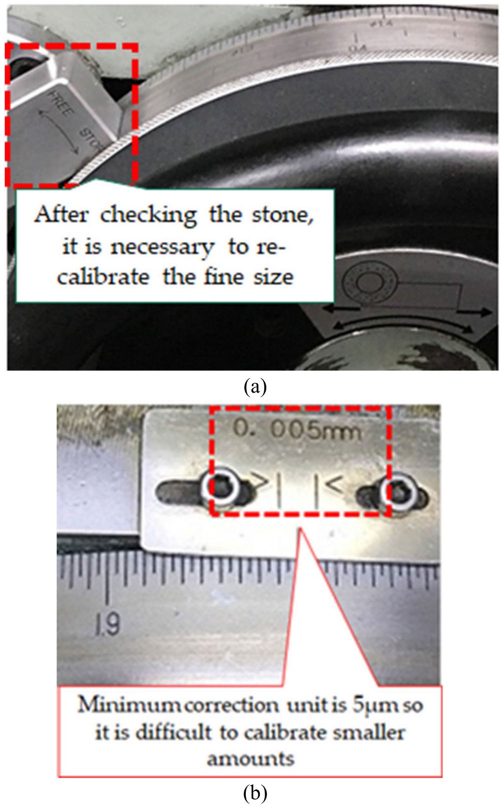

FIGURE 4. a. Grinding wheel surface. b. Conditions of grinding wheel surface.

be adjusted. Scrubbing of the stone surface is done entirely by hand of the operator, thus correcting for uneven stone size residuals. This leads to a large standard deviation of the final product size after fixing the stone size and a high risk of defects.

Implement Lean Six sigma (LSS) project to apply innovative tools and options to eliminate waste, improve product quality, and improve productivity. Redesign the tool at the grinder and determine the optimal grinding conditions using Taguchi techniques. Redesign the stone surface detection system from semi-automatic to fully automatic and use the contact sensor and sensor signal processing to control the contact interval. Perform harmonic measurement of power supply to load and implement load shifting method to reduce harmonics improve power quality and complete system control with RFID system and digital numerical control (DNC) system.

B. METHODOLOGY

The grinding stage of Blank products (Fig. 1) was analyzed for quality control results from April 2021 to March 2022, and found that 31.29% defect products occurred in terms of outside diameter size that did not meet the tolerance ±0.005mm. This study proposes implementing Lean Sig Sigma method with DMAIC cycle to solve the root causes of quality problems in the grinding process. Statistical tools, statistical hypothesis testing are used to analyze data, the data actually collected by the operator at the grinding process meets the researcher's sampling standards, this work is done at measure phase. In the analyze phase, the TOPSIS fuzzy multi-criteria analysis method is implemented and helps managers and researchers make decisions to choose the right improvement option. Improve phase implements Taguchi method for empirical analyze to select optimal conditions for each option selected above (TOPSIS fuzzy multi-criteria analyze method). Digital process control is implemented to transform tools from semi-automatic to fully automatic. Digital numerical control techniques are deployed at the control phase such as RFID techniques to control the program and collect data from machining conditions as well as manage production information. Table 2 describes in detail the proposed tools used in this study.

In the Define phase, we focus on determining grinding process management data on quality, output, revenue and grinding process efficiency from April 2021 to March 2022. In the Measure phase, we use statistical tools, statistical testing to analyze real data obtained from the grinding process by the operator from April 2021 to March 2022 and set a goal to reduce defect of outside diameter from 31.29% to zero defects. In the Analysis phase, (evaluating and analyzing data from April 2021 to March 2022 at Measure phase), Defect arising can be due to a number of potential causes arising and all of them related to production condition in the grinding process. However, to prioritize the implementation of which improvement action is really the priority to improve the best product quality. Lean six sigma project team members have difference of opinions on which improvement actions will be best implemented, and we recommend using the Fuzzy TOPSIS methodology as a guideline for guidance throughout the decision-making process and this also contributes to the formation of a new research model in Lean six sigma tools. Each parameter at the grinding stage makes an important contribution to the quality of the product. Therefore, there is no certainty about meeting the priority criteria for product quality improvement action. This leads us to suggest using the Fuzzy TOPSIS method to solve this uncertain problem. However, there are many misconceptions about the Fuzzy TOPSIS method about the logical accuracy of incorrect inference and approximate inference. First, Fuzzy TOPSIS helps make sound decisions in an inaccurate environment with ambiguity, incomplete information, conflicting information, part's truth or part possibility. Second, Fuzzy TOPSIS is capable of performing a wide variety of physical and mental tasks without any measurements or calculations. In the Improve phase, we implement the use of Taguchi techniques to optimize the condition of the option that is prioritized from the Analysis phase. Specifically, Fuzzy TOPSIS makes prioritizing decisions in an uncertain environment to become more certain. This can also be called the Taguchi Fuzzy TOPSIS model in Lean Six sigma. In the Control phase, we implement RFID technology into the data collection and overall information management of the production process.

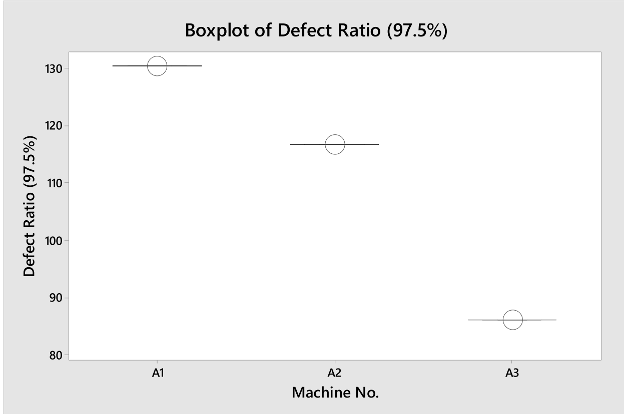

FIGURE 5. Boxplot chart.

Digital numerical control method performs dimensional measurement and production process condition measurement. Implementation of harmonic measurement of power supply to electronic components and implementation of load shifting method for harmonic control are within 519:2022 standards.

IV. RESULT AND DISCUSSION

A. DEFINE PHASE (D)

Apply descriptive statistical analysis of sample values with the frequency of discrete random variables in the product quality data set from April 2021 to March 2022, (Eq. 1), where P is the frequency of defect occurrence and PARETO chart shows that the defect generation rate is increasing and the defect accounts for the highest rate is Outside diameter (31.29%).

$$P_i = \sum_{j=1}^{i} p_j \tag{1}$$

B. MEASURE PHASE (M)

In the grinding process, there are 3 machining machines (A1, A2, A3) to process the outside diameter, the Boxplot chart analyzes the data (from April 2021 to March 2022) and detects that A1 accounts for the highest defect generation rate (Fig. 5).

Performing statistical hypothesis testing with the method of testing the expected deviation with a small sample size (t student) when the post-processing quality test is not known about the outside diameters of machines A2 and A3, (Eq. 2). With the sample mean and sample variances on machine A1 being 26.38 and 3.45 and similarly for machine A2 25.42, 3.06 with each machine running 25 product samples. Outside diameter measurement results are subject to metrological regulation. As a result, Sample Mean Deviation R=[D<-1.606; D>1.606] and does not fall into the rejection region R. Conclusion H0 is not rejected, which means that the product quality is expected to be the same at machine A2 and machine

TABLE 2. Deployment model of analytical tools in the DMAIC phase of Lean Six Sigma.

Define phase (D)	Measure phase (M)	Analyze phase (A)	Improve phase (I)	Control phase (C)
Project Charter	Measurement and evaluation of the system	Process flow chart	Brainstorm	Suppliers, inputs, processes, outputs and customers
Project scope	Data collection plan	Value stream mapping	Ishikawa Diagram	Capacity index
Economic analyze	Process flow chart	Cycle time analysis	5W2H	Key Performance Indicator
GRIP analysis	Reset goals and income	5 Why	Priority Matrix	Poka-Yoke
Voice of the customer	Sample	Stratification diagram	Stakeholders analysis	Checklist
Suppliers, inputs, processes, outputs and customers (SIPOC)	Key Performance Indicators (KPIs)	Brainstorming	Investment project analysis	Standard operating procedures
	Brainstorm	Ishikawa Diagram	Gantt	The meeting
	Ishikawa Diagram	**Multi-criteria fuzzy TOPSIS analysis**	Standard operating procedures	**Digital numerical control**
	Statistical hypothesis testing tool		**Taguchi techniques**	**RFID Techniques**
			Sensor signal processing	**Harmonic mitigation measurement**

A3.

$$R = \left[(\bar{X}_1 - \bar{X}_2) < -t\alpha_{/2,v} S\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}, (\bar{X}_1 - \bar{X}_2) > t\alpha_{2,v} S\sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \right] \quad (2)$$

At machine A1, we take 480 samples of outside diameter and run probability plot test on MINITAB 18.0 software and calculate standard Gaussian distribution to evaluate whether the data set has a normal distribution (Eq. 3), with, r is the rank of the sample, n is the number of samples.

$$p_i = \frac{r_i - 3/8}{n + 1/4}, \quad i = 1, 2, \ldots, n \quad (3)$$

The result P-Value value is less than 0.05 (Fig. 6), which proves that the data is not normally distributed and non-parametric Anderson-Darling normalization method is used to perform the analysis.

The Chi-Square test with goodness of fit checks whether an empirically observed distribution fits a predicted distribution (Eq. 4), where f is the frequency of observations in time interval i, e is the expected frequency in time interval i.

$$x^2 = \sum_{i=1}^{k} \frac{(f_i - e_i)^2}{e_i} \quad (4)$$

In this study, we perform a 1-year sampling period from April 2021 to March 2022 and the frequency distribution of the sample mean (Fig. 6) and the resulting deviation of the distribution. The observed frequency distribution with the expected frequency distribution is negligible with an acceptance level of $\alpha = 0.05$.

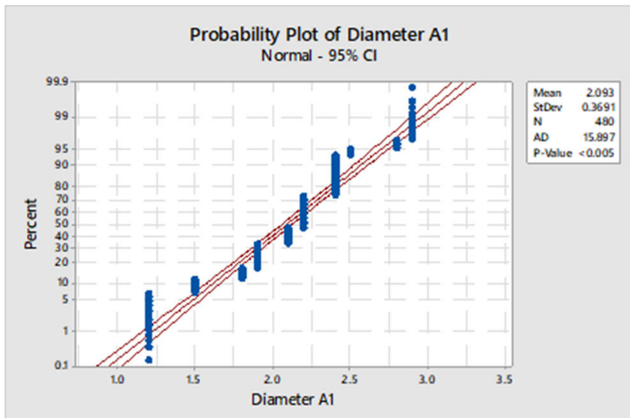

FIGURE 6. Probability Plot.

From the results of the statistical test models in the data analysis from April 2021 to March 2022, it shows that the A1 grinder in the grinding process gives rise to a defect about the outside diameter. The Fish-bone analysis and Brainstorming method were deployed to analyze and find the causes of defects in the outside diameter at machine A1, (Fig. 7) and the members identified there are 3 main causes of defects arising about the outside diameter are: (1) Depends on the skill of the staff when operating the grinder, (2) The grinding speed

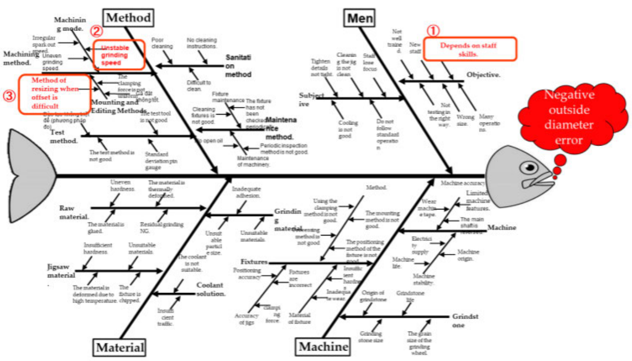

FIGURE 7. Fish-bone diagram.

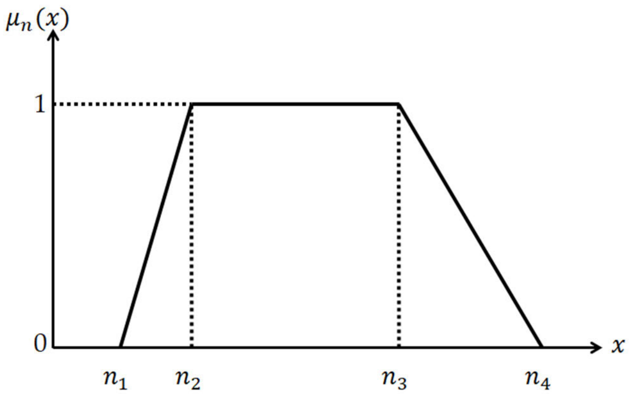

FIGURE 8. The trapezoidal fuzzy number $\tilde{n}$.

is not stable and (3) The method of adjusting the size when the offset is difficult.

C. ANALYSIS PHASE (A)

From the results of the analysis of the causes and results for 3 possible causes of defects in the outside diameter, we use Fuzzy TOPSIS to make a decision to choose the preferred solution. Perform Fuzzy set and fuzzy number to analyze problem points.

Definition 1: Set Fuzzy set $\tilde{A}$ in language variable X and defined as feature variable in member function variables $\mu\tilde{A}(x)$, associated elements x in the real number X in the interval [0, 1]. The values of member function variable $\mu\tilde{A}(x)$ are considered to be the membership degrees of x in $\tilde{A}$ [50].

Definition 2: The value of the trapezoidal fuzzy number $\tilde{n}$ is defined as (n_1, n_2, n_3, n_4) (Fig. 8) and the value of member function variable $\mu\tilde{A}(x)$ is determined in Figure 8 [50], As far as trapezoidal fuzzy has $\tilde{n} = (n_1, n_2, n_3, n_4)$ and the case $n_2 = n_3$ and then $\tilde{n}$ is called triangular fuzzy number and an un-fuzzy r is considered as (r, r, r, r) expressed. According to the expansion principle [32], the fuzzy sum (+) and fuzzy subtraction (-) of any two trapezoidal fuzzy numbers are also equal to the fuzzy value of the trapezoid. However, in the multiplication (x) of two trapezoidal fuzzy numbers, only one trapezoidal fuzzy number is formed. The case of forming any two trapezoidal fuzzy numbers like $\tilde{m} = (m_1, m_2, m_3, m_4)$ and $\tilde{n} = (n_1, n_2, n_3, n_4)$ and a positive real number r. Then, form some main operations of fuzzy numbers $\tilde{m}$ and $\tilde{n}$ as follows:

$$\tilde{m}\,(+)\,\tilde{n} = [m_1 + n_1, m_2 + n_2, m_3 + n_3, m_4 + n_4] \tag{5}$$

$$\tilde{m}\,(-)\,\tilde{n} = [m_1 - n_4, m_2 - n_3, m_3 - n_2, m_4 - n_1] \tag{6}$$

$$\tilde{m}\,(x)\,r = [m_1 r, m_2 r, m_3 r, m_4 r]\,, r \geq 0 \tag{7}$$

$$\tilde{m}\,(x)\,\tilde{n} = [m_1 n_1, m_2 n_2, m_3 n_3, m_4 n_4] \tag{8}$$

Definition 3: A variable whose values are expressed in linguistic expressions is called a linguistic variable and it is useful in dealing with complex situations or in situations where it is not definite enough to describe it properly logic for regular quantitative expressions [51]. For example, the Language Variable Weight represents values such as very low, low, medium, high, and very high. Other grave variables can also be represented as this Weight variable.

Definition 4: In the case of two trapezoidal fuzzy numbers like $\tilde{m} = (m_1, m_2, m_3, m_4)\, and \tilde{n} = (n_1, n_2, n_3, n_4)$, and then the interval between 2 trapezoidal fuzzy numbers is calculated by formula 9 as follows:

$$d_v(\tilde{m}, \tilde{n}) = \sqrt{\frac{1}{4}\left[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2 + (m_4 - n_4)^2\right]} \tag{9}$$

The method used to calculate the distance between two trapezoidal or triangular fuzzy numbers with high efficiency and simplicity in calculation is the vertex method. According to this vertex method, the case where two trapezoidal fuzzy numbers $\tilde{m}$ and $\tilde{n}$ are the same if and only if $d_v(\tilde{m}, \tilde{n}) = 0$. In a field with three fuzzy numbers such as $\tilde{m}, \tilde{n}, \tilde{p}$, then the fuzzy number $\tilde{n}$ is closer to the fuzzy number $\tilde{p}$ than the fuzzy number $\tilde{p}$ if and only if $d_v(\tilde{m}, \tilde{n}) < d_v(\tilde{m}, \tilde{p})$ [45].

Following the Fuzzy TOPSIS method, perform decision making, the force of choosing the best alternatives is related to their distance value with a positive ideal solution and the distance value must be greater than the negative ideal solution. In particular, problems are initially structured, grouped, specified criteria, and a clear set of changes. Measure the importance of the criteria and perform an evaluation of the activities of the alternatives relative to the criteria by choosing linguistic variables accordingly. In this study, we use linguistic variables such that they are associated with positive trapezoidal fuzzy numbers and this is the model that has been developed for the Fuzzy TOPSIS method [22].

Do a sort of fuzzy rank and the weight of the decision maker *kth* respectively, $\tilde{x}_{ijk} = \left(a_{ijk}, b_{ijk}, c_{ijk}, d_{ijk}\right) and \tilde{w} = \left(w_{ij1}, w_{ij2}, w_{ij3}, w_{ij4}\right); i = 1, 2, .., m, j = 1, 2, .., n$. Therefore, the $\tilde{x}_{ij}$ composite fuzzy ranking of the choices that change with each specific criterion is calculated according to the following formulas:

$$\tilde{x}_{ij} = \left(a_{ij}, b_{ij}, c_{ij}, d_{ij}\right) \tag{10}$$

where

$$a_{ij} = \{a_{ijk}\}, b_{ij} = \frac{1}{k}\sum_{k=1}^{k} b_{ijk}, c_{ij} = \frac{1}{k}\sum_{k=1}^{k} c_{ijk}, d_{ij}\{d_{ijk}\}$$

The formula for calculating the combined fuzzy weight $(\tilde{w}_j)$ of each criterion is as follows:

$$\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}, w_{j4}) \quad (11)$$

where

$$w_{j1} = \{w_{jk1}\}, w_{j2} = \frac{1}{k}\sum_{k=1}^{k} w_{jk2}, w_{j3} = \frac{1}{k}\sum_{k=1}^{k} w_{jk3}, w_{j4} = \{w_{jk4}\}$$

The composite matrix is shown below:

$$\tilde{D} = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix}, \quad \tilde{w} = [\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n]$$

The following index values can be approximated with positive trapezoidal fuzzy numbers, $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}, d_{ij})$ $and \tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}, w_{j4})$, $i = 1, 2, .., m, j = 1, 2, .., n$.

The normalized fuzzy decision matrix was constructed to consider the different importance of each criterion, and the matrix was constructed as follows:

$$\tilde{V} = [\tilde{v}_{ij}]_{mxn}, \quad i = 1, 2, \ldots, m, j = 1, 2, \ldots, n \quad (12)$$

where : $\tilde{v}_{ij} = \tilde{x}_{ij}(x)\tilde{w}_j$

According to the weighted normalized fuzzy decision matrix, the value of normalized positive trapezoidal fuzzy numbers can be approximated for the $\tilde{v}_{ij}, \forall_{ij}$ elements. The definitions of fuzzy positive (A^*) ideal solutions and fuzzy negative (A^-) ideal solutions are as follows:

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^*) \quad (13)$$
$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-) \quad (14)$$

where

$$\tilde{v}_j^* = \{v_{ij4}\} \, and \tilde{v}_j^- = \{v_{ij1}\}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n$$

The distance of the values in each of the variants of A^* and (A^-) is calculated according to the following formula:

$$d_i^* = \sum_{j=1}^{n} d_v\left(\tilde{v}_{ij}, \tilde{v}_j^*\right), i = 1, 2, \ldots, m \quad (15)$$

$$d_i^- = \sum_{j=1}^{n} d_v\left(\tilde{v}_{ij}, \tilde{v}_j^-\right), i = 1, 2, \ldots, m \quad (16)$$

where: d_v is called the measure of the distance between two fuzzy numbers.

The coefficients used to determine the rank in the order of one-time alternatives $d_i^* and d_i^-$ of each alternative $A_i, i = 1, 2, \ldots, m$ have been calculated. The coefficient represents the proximity to the positive fuzzy solution (A^*) and the ideal solution negates the fuzzy (A^-) and the temporality by

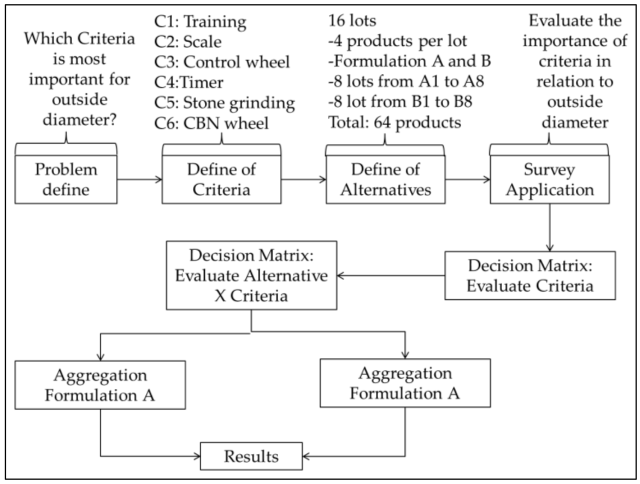

FIGURE 9. Fuzzy TOPSIS process to prioritize improvement actions during the Analysis phase of the DMAIC cycle.

taking the relative proximity of the opacity. The coefficient of proximity to (CC_i) is calculated using the following formula:

$$CC_i = \frac{d_i^-}{d_i^- + d_i^*}, \quad i = 1, 2, \ldots, m \quad (17)$$

The alternative selection terms are sorted in descending order by the sequential (CC_i) closeness coefficient value obtained from the values of the most important factor in order to compute the quality of the best choice. Therefore, it supports the lean six sigma technique to decision making, selecting improvement actions to consider the best product quality rankings. The implementation of the Fuzzy TOPSIS method into Lean Six Sigma at the analysis phase of the DMAIC cycle presented in the study is detailed in Figure 9.

From the information shown in Figure 9, the iteration phase identifies the specific criteria in the outside diameter sizing process and together with the lean six sigma related criteria of the DMAIC cycle. The members of the lean six sigma projects include 2 mechanical maintenance staff, including 1 electromechanical maintenance staff, 3 grinding machine operators, 1 production supervisor (leader), and one employee data analysis (production control) and 2 production process managers (industrial engineering) and the criteria selected by project team members include: C1: Training to improve staff capacity, C2: Using scale feedback to adjust the size, C3: Controlling the grinding wheel and automatic machine table, C4: Using the operation timer, C5: Checking the surface automatic grinding wheel and C6: Using CBN grinding wheel, reducing the number of times to check the stone. During the identification of alternatives, data collection is performed by the operator on the ground during the process of grinding the outside diameter of the blank product. Data was collected from 16 lots at 4 different time points, a total of 64 products were selected for analysis according to the criteria C1, C2, C3, C4, C5, and C6. These study samples were representative of different dates, and the sampling rules were specified by the researchers specifying the

TABLE 3. Language variables give the weight of each criterion.

Language variable	Fuzzy number trapezoid
None (N)	(0.0, 0.0, 0.1, 0.2)
Very low (VL)	(0.1, 0.2, 0.2, 0.3)
Low (L)	(0.2, 0.3, 0.4, 0.5)
Mean (M)	(0.4, 0.5, 0.5, 0.6)
High (H)	(0.5, 0.6, 0.7, 0.8)
Very High (VH)	(0.7, 0.8, 0.8, 0.9)
Absolute (AB)	(0.8, 0.9, 1.0, 1.0)

method of sampling and instructing the operator performing specific sampling at the grinding process and the researchers re-evaluate sample quality. Each of these samples represents 16 product lots. The lots are divided into formula A and formula B. During the research period, due to a change in the formula, 8 lots were numbered from A1 to A8 for formula A and the remaining 8 lots were numbered from A1 to A8 and B1 to B8 use for formula B

For the content of Training to improve staff capacity used documents on grinding process standards, operating instructions for grinding processes, and trained by the leader for the operator on a monthly basis and recorded the results in the skill map. For the content about Using scale feedback to adjust the size, we use scale to measure the distance of the grinding wheel surface to the product surface. For the content of Automatic grinding wheel and table control, the tool has been redesigned and the table is connected to a servo motor and controlled by a PLC by digital numerical control. For the content about use an operation timer with the goal of monitoring the completion time of each operator's operation with timers. For the content on using CBN grinding wheels, reducing the number of stone cleaning times is a recommendation to replace a new type of grinding wheel. For the content of Automatic Stone Surface Scanning by redesigning the rock tracing tool by DC motor and controlled by digital numerical control program on LABVIEW software interface with Fuzzy control algorithm.

Lean Six Sigma project team members are also decision makers, members of the LSS organization focus on improving the quality of the outside diameter of blank products at the grinding process. Those who know the standards and operating methods of the grinding process have answered the survey, evaluating the criteria related to the quality of outside diameter by using linguistic variables. Opinions of experts arises differing opinions on quality-related questions outside diameter. Table 3 is formed from fuzzy numbers of linguistic variables identified to form the rating. Trapezoidal saving functions are used to represent linguistic variables with the goal of evaluating linguistic variables in an uncertain environment [32], [51].

In this study, in order to evaluate from the lot used to select the alternative, the samples were valued at a specific value using a specific metric for analysis. This result is used to identify each language variable. The range of values used to relate each sample corresponds to the corresponding language variables (Tab. 4).

Perform analysis of samples on each alternative in relation to the criteria. The different alternatives are rated based on linguistic variables and the equivalent trapezoidal fuzzy number (Tab. 5).

Criterion variables, decision makers, language variables, and alternatives are all defined. In the next step, the decision maker establishes a fuzzy decision matrix to perform the analysis of the criteria variables and assigns weights to the criteria variables. The decision maker builds the values of the linguistic variable according to each criterion that is associated with the trapezoidal fuzzy number and is synthesized by formula 11 and the details are shown in Table 6.

The results from stage 5 show that C5: Checking the surface automatic grinding Criterion gives the outstanding value above all and the decision makers consider it as the most influential factor affecting the outside diameter quality of the blank product after machining at the grinding process. The analysis results generated from formulas A and formula B within the range of measured values decided by decision makers in the LSS project team.

Those sample bushels are then aggregated to produce a value associated with each of the six criteria for each lot of the different formulations. Determine the distances of each alternative from A^* and A^- using formula 15 and formula 16 and the value of the asymptotic coefficient CC_i calculated using formula 17, and specify the values of the options to replace (See Tab. 7 and Tab. 8).

The analysis results show that the A2 index has the most prominent value and ranks first in Table 6 and the main feature of this index is to bring the most favorable points for the quality of outside diameter and the defect value of A2 gives the lowest value. This results in a well-analyzed CC_i value and more stable product quality as the defect rate is smaller. The 2nd and 3rd positions are followed by A7 and A8, along with their similarity of values in Table 7, including the value of the CC_i index. For the analysis results in Table 8, category B3 gives the best results and is rated as first. However, the defect rate of the corresponding value is higher than that of formula A and the CC_i value is higher than the analysis result of formula A.

In this study, we propose to use the Fuzzy TOPSIS method as a decision aid for members of the LSS project team. Improvements identified in the Analysis phase are applied to the grinding process and with the analysis results in an uncertain environment. Fuzzy TOPSIS assisted the LSS team in making the decision to select option C5 as the first improvement.

D. IMPROVE PHASE (I)

The process of grinding the outer diameter of the Blank product is carried out through the following steps: Step 1 align the grinding wheel contact position with the balance center of the product mounted on the main shaft of the grinding

TABLE 4. Range of values for the correlation of linguistic terms.

Criteria	Terrible (T)	Very Bad (VB)	Bad (B)	Reasonable (R)	Good (G)	Very Good (VG)	Great (G)
C1	0 – 0.45	0.46 – 0.58	0.6 – 0.75	0.76 – 0.89	0.8 – 1.03	1.06 – 1.28	> 1.4
C2	9 – 10.5	10.6 – 11.8	12 – 13.5	13.6 – 14.8	15.1 – 16.5	16.6 – 17.98	> 18.2
C3	0 – 0.45	0.46 – 0.58	0.6 – 0.75	0.76 – 0.88	0.8 – 1.03	1.06 – 1.28	> 1.4
C4	0 – 1.48	1.4 – 1.98	2 – 2.48	2.6 – 2.99	3.1 – 3.48	3.6 – 3.98	> 5
C5	< 15.6; > 21	15.5 – 16.01; 19.4 – 20.02	16.2 – 16.6; 19.2 – 19.6	16.7 – 17.01	18.5 – 19.2	17.2 – 17.6; 18.2 – 18.6	17.7 – 18.3
C6	< 6; > 10.6	5.01 – 5.05; 10.02 – 10.5	5.6 – 5.8; 9.5 – 9.8	6.6 – 6.8; 8.7 – 9.1	6.6 – 6.9; 8.7 – 9.2	7.1 – 7.6; 8.2 – 8.6	7.7 – 8.3

TABLE 5. Language variables for evaluating alternatives.

Language variables	Fuzzy number trapezoid
Terrible (T)	(0.0, 0.0, 0.1, 0.2)
Very Bad (VB)	(0.1, 0.2, 0.2, 0.3)
Bad (B)	(0.2, 0.3, 0.4, 0.5)
Reasonable (R)	(0.4, 0.5, 0.5, 0.6)
Good (G)	(0.5, 0.6, 0.7, 0.8)
Very Good (VG)	(0.7, 0.8, 0.8, 0.9)
Great (G)	(0.8, 0.9, 1.0, 1.0)

machine and select the right type of grinding wheel with rock hardness from 58 HRC to 62 HRC. Step 2, Check the relevant conditions on the grinding machine such as pressure must be within the range of 0.5 MPA to 0.8 MPA, the concentration of cooling water when grinding is from 0.3% to 0.8% and check the ambient temperature of the grinding machine can be in the standard from $28C^0$ to $32C^0$. Step 3, operator performs a standard spark-out time check from 1 second to 3 seconds. All details about the factors and their levels are shown in Table 9.

The Taguchi method responds well to many factors in the same system at the same time. It also ensures that the study of factors is independent and that the influence of factors is reliable. The L_{32} (2^5) orthogonal matrix table designed for 5 factors is presented in Table 10. In this study, the quality characteristics of the outside diameter of the Blank product line (E6) in the standard region are less than 0.005 mm. The test prototype is sampled directly from production at the grinding process, the results are converted to signal-to-noise ratio (S/N), according to formula (18).

$$^{S}/_{N} = -10 \times log\left[(\mu - m)^2 + S^2\right] \quad (18)$$

Outside diameter tolerance is 0.005mm measured with micrometer. The results of S/N analysis (Figure 10) show that the response of spark out time strongly affects the quality of outside diameter. The results of one-way ANOVA analysis (Table 11) show a 95% confidence interval for the machining conditions at the grinding process

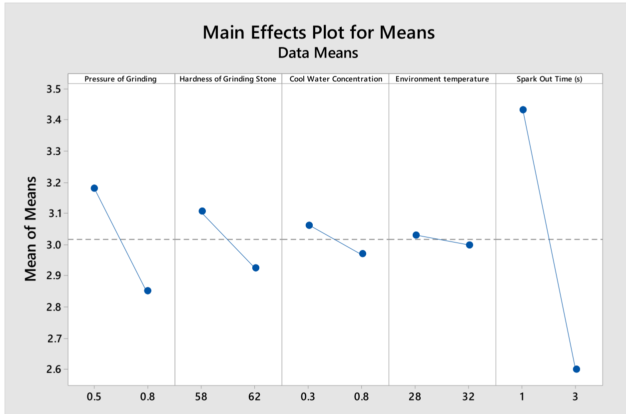

FIGURE 10. S/N analysis.

The results of running Taguchi techniques and shown in Figure 10, that the longer the Spark out time, the more stable the outside diameter quality. Spark out time is the time between the stone surface and the surface to be sharpened. In this study, we used a DC motor with an encoder feedback and controlled by a Fuzzy set running on LABVIEW software. The Multi-sensor system is implemented to measure the outside dimension and feedback this dimension to the Fuzzy controller. The servo motor combines with the PLC system to control the stone checker table according to the outside line size of the product received from the multi-sensor system (Fig.11).

Magnetic ruler to measure the distance between the grinding wheel and the product surface and reflect the results on the Fuzzy control system on LABVIEW (Fig. 12a), and Adjust the distance between the grinding wheel surface and the product's outside diameter with a Magnetic ruler and signal feedback system, fully automatic operation (Fig. 12b).

This probe sensor is deployed to check the position and measure the actual outside diameter. Then, the results are fed to the system as input data for the Fuzzy control system for the DC motor and the servo motor to adjust the grinding wheel checker operation (Fig. 13a), and Determine the

TABLE 6. Evaluate the criteria of the decision maker.

Criteria	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	Fuzzy composite weight ($\widetilde{w}_j$)
C1	VH	M	H	VH	H	M	H	AB	H	AB	(0.40, 0.69, 0.75, 1.00)
C2	H	H	M	VH	M	M	M	H	L	H	(0.3, 0.56, 0.61, 0.92)
C3	M	M	H	VH	M	H	M	AB	M	H	(0.42, 0.61, 0.65, 1.00)
C4	M	H	M	H	M	M	M	M	VL	H	(0.1, 0.62, 0.54, 0.83)
C5	**AB**	**AB**	**AB**	**M**	**M**	**VH**	**H**	**VH**	**VH**	**AB**	**(0.5, 0.77, 0.83, 1.00)**
C6	H	M	M	M	L	VH	VH	VH	H	AB	(0.30, 0.64, 0.65, 1.00)

TABLE 7. The results obtained for the formula A.

Formulation A	d_i^*	d_i^-	CC_i	Ranking	Defects (%)
A1	3.933	2.266	0.367	8	17.2
A2	3.165	3.164	0.501	1	9.6
A3	3.687	2.486	0.404	6	15.6
A4	3.634	2.489	0.409	5	16.1
A5	3.793	2.231	0.369	7	16.3
A6	3.475	2.693	0.429	4	12.0
A7	3.476	2.774	0.449	3	9.8
A8	3.457	2.824	0.460	2	9.7

TABLE 8. The results obtained for the formula B.

Formulation B	d_i^*	d_i^-	CC_i	Ranking	Defects (%)
B1	3.508	2.656	0.432	6	15.7
B2	3.598	2.662	0.426	7	16.1
B3	3.342	3.059	0.479	1	11.1
B4	3.397	2.875	0.458	4	15.2
B5	3.672	2.625	0.418	8	17.1
B6	3.422	2.897	0.459	3	14.8
B7	3.509	3.048	0.463	2	13.0
B8	3.474	2.707	0.438	5	15.7

TABLE 9. Experimental factors and their level for L_{32}.

Factor	Level 1	Level 2
E1: Pressure of Grinding (MPA)	0.5	0.8
E2: Hardness of Grinding stone (HRC)	58	62
E3: Cool water concentration (%)	0.3	0.8
E4: Environment temperature (C^0)	28	32
E5: Spark-out time (Second)	58	62

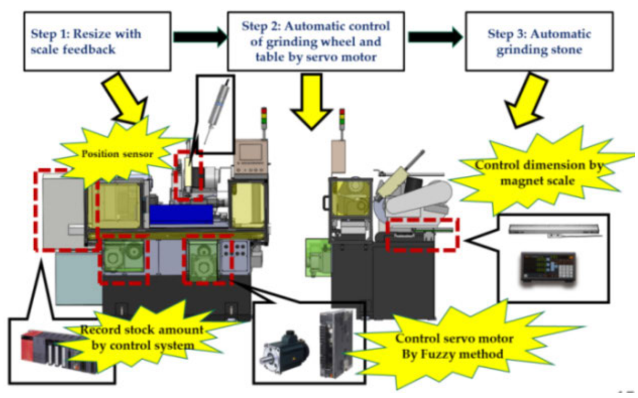

FIGURE 11. Design model for automatic grinding wheel improvement system.

grinding wheel contact position on the product surface and the diameter size automatically by the sensor (Fig. 13b).

Digital numerical control system with functions based on RFID signal acquisition system and signal processing by inspection system and data storage on SQL system. The RFID system collects data for each corresponding order (No.1) and transmits the order signal to the measuring system and identifies the type of control program for the grinding wheel system built on the Fuzzy control program and program access to the interface (No.2) and start grinding at the corresponding grinding process (Fig. 14).

The improvement system from semi-automatic grinding machine to automatic grinding machine was implemented by

TABLE 10. L_{32} (2^5) **orthogonal array experimental parameter.**

Exp.	E1	E2	E3	E4	E5	E6	S/N
L1	0.5	58	0.3	28	1	4.1	-12.26
L2	0.5	58	0.3	28	3	3.0	-9.54
L3	0.5	58	0.3	32	1	3.7	-11.36
L4	0.5	58	0.3	32	3	2.9	-9.25
L5	0.5	58	0.8	28	1	3.6	-11.26
L6	0.5	58	0.8	28	3	3.1	-9.83
L7	0.5	58	0.8	32	1	3.2	-10.10
L8	0.5	58	0.8	32	3	2.9	-9.25
L9	0.5	62	0.3	28	1	3.5	-10.88
L10	0.5	62	0.3	28	3	2.9	-9.25
L11	0.5	62	0.3	32	1	3.2	-10.10
L12	0.5	62	0.3	32	3	2.6	-8.30
L13	0.5	62	0.8	28	1	3.5	-10.88
L14	0.5	62	0.8	28	3	2.6	-8.30
L15	0.5	62	0.8	32	1	3.5	-10.88
L16	0.5	62	0.8	32	3	2.6	-8.30
L17	0.8	58	0.3	28	1	3.2	-10.10
L18	0.8	58	0.3	28	3	2.1	-6.44
L19	0.8	58	0.3	32	1	3.7	-11.36
L20	0.8	58	0.3	32	3	2.4	-7.60
L21	0.8	58	0.8	28	1	3.1	-9.83
L22	0.8	58	0.8	28	3	2.5	-7.96
L23	0.8	58	0.8	32	1	3.6	-11.13
L24	0.8	58	0.8	32	3	2.6	-8.30
L25	0.8	62	0.3	28	1	3.2	-10.10
L26	0.8	62	0.3	28	3	2.7	-8.23
L27	0.8	62	0.3	32	1	3.5	-10.88
L28	0.8	62	0.3	32	3	2.3	-7.24
L29	0.8	62	0.8	28	1	3.1	-9.83
L30	0.8	62	0.8	28	3	2.3	-7.24
L31	0.8	62	0.8	32	1	3.2	-10.10
L32	0.8	62	0.8	32	3	2.1	-6.44

TABLE 11. **Mean value of One-way ANOVA analysis.**

Factor	N	Mean	StDev	95%CI
E1	32	2.04	1.06	(-0.064, 4.061)
E2	32	100.03	10.19	(97.96, 102.07)
E3	32	2.04	1.05	(-0.064, 4.065)
E4	32	70.04	10.19	(67.96, 72.08)
E5	32	6.02	1.05	(3.948, 8.069)
E6	32	3.05	0.54	(0.956, 5.075)

Pooled StDev = 5.92340

6 members of the project team in 6 months. Total investment cost for the project to improve is 13 500 USD (Cost of tools to implement improvement for the whole project is 13000 USD and 500 USD is the cost of raw materials used to evaluate the quality before and after development. report improvement project results).

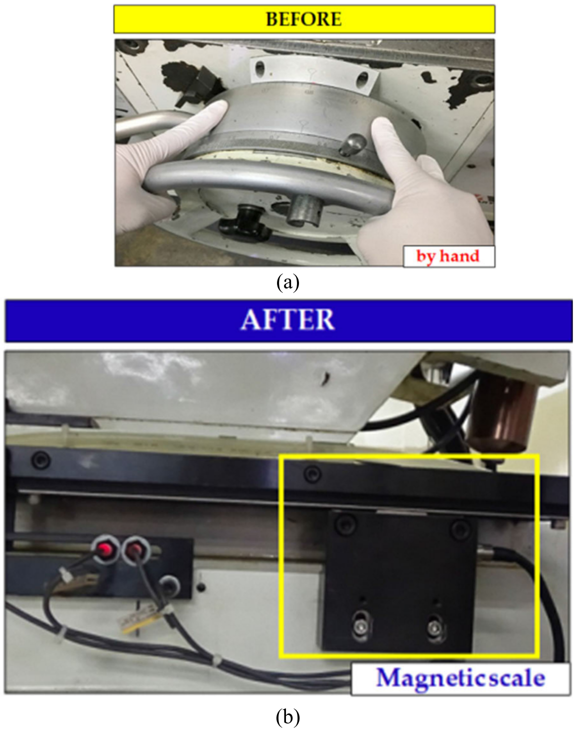

FIGURE 12. **a). Adjust the distance between the grinding wheel surface and the product's outside diameter surface manually. b. Magnetic ruler.**

Deploy a post-improvement grinding machine system to process blank products with an outer diameter of 30 mm with the number of samples of 30 products. Hypothesize H0 that the outer diameter size of the product is stable and meets the required quality of the machining tolerance is 0.005 mm. The standard test formula (Eq. 19) with the 5% significance level, the result is 0.8267 and the rejection domain of hypothesis H0 calculated according to the formula (Eq. 20) gives the result 2.064. The value of the test criterion does not belong to the domain of rejection value H0. It is concluded that H0 has no basis to reject and thus can be considered as stable product quality.

$$T = \frac{(\bar{X} - \mu)\sqrt{n}}{\sigma} \quad (19)$$

$$W_a = \left\{ T : |T| > t_{\alpha/2}^{(n-1)} \right\} \quad (20)$$

Consulted with 40 operators related to the grinding roofs and grinding process to evaluate whether the improved after ground roof meets the standards. The hypothesis H0 is that the product quality related to the defect outside is not up to the requirements and still has a defect rate of 0.2%. Applying the formula to calculate the statistical test value (Eq. 21) gives the calculated result of 2.5. Meanwhile, deploying the formula to calculate the rejection domain value (Eq. 22) gives the result of 1.65. This shows that the statistical test value is larger than the rejection value of hypothesis H0 and concludes that, H0 is rejected. The conclusion is that the opinions of users of the improved grinder agree with the results of stable product

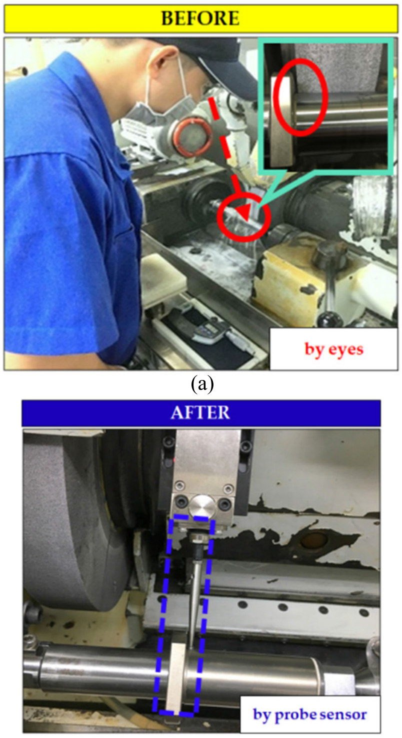

FIGURE 13. a). Locate the grinding wheel contact on the surface of the product and then measure the dimensions with a micrometer and repeat the calibration and measurement cycle. b. Probe sensor.

FIGURE 14. RFID System inline.

quality.

$$Z = \frac{(f_A - p_0)\sqrt{n}}{\sqrt{p_0(1-p_0)}} \tag{21}$$

$$\varphi(z_\alpha) = \frac{1-2\alpha}{2} \tag{22}$$

The improvement system is implemented and the stability assessment in machining has been completed. Product quality in terms of outside diameter was stable and there were no waste products. Meeting the goal set by the LSS project improvement board is zero defects.

E. CONTROL PHASE (C)

Highly integrated electrical equipment based on electro-electronics on the demand side (grinder at grinding process) such as scale feedback, servo motor, dc motor, magnet scale, PLC, sensor, barcode recorder, tablet, Light and all they have nonlinear voltage-current characteristics. As a result, they have caused harmonic pollution, which is one of the most important power quality problems in distribution system operations. To solve this problem, measures should be taken to keep the total Harmonic Distortion Level (THD) and Total Demand Distortion (TDD) within the international standard limits defined by IEEE 519:2022 and IEC 61000. In this study, we propose a load-shifting method to improve the system performance significantly in the smart grid model. Load configurations vary with a degree of accuracy based on measured voltage and current, active, reactive, and apparent power. Odd and even harmonics have in electrical systems due to the connection of nonlinear loads such as power electronic components, static VAR compensators, converters and arc furnaces. Distortion conditioning caused by many non-linear loads in the power grid can lead to adverse problems for both the power system and the consumer [52]. In terms of electrical systems, degraded power quality can lead to overloading of transformers, rotating equipment, neutral conductors, and damaged capacitors, which can even affect the reliability and efficiency of the power system [53], [54]. For consumers, lower power quality can add to the economic loss. To solve this problem, international standards define maximum allowable limits for harmonic distortion levels based on IEEE 519:2022. (Table 12) [55].

a: For $h \leq 6$, even harmonics are below 50% of the harmonic limit; b: Current distortion has resulted in a dc offset; Where I_{sc}: Maximum short circuit current is current that flows through a conductor with very low resistance, almost zero at the point of common coupling (PCC). I_L: Maximum demand load current at PCC under normal operating conditions, a function of many factors over time P(t), so they do not obey a certain law. Therefore, it is very difficult to identify them. The electrical load is an important parameter in selecting the equipment for the power system at PCC.PCC (Point of Common Coupling): In many cases, when there is enough source reactance calculated at the point we consider to reduce harmonics, a filter placed at this point can absorb harmonics from many different harmonic sources flowing to them. Even harmonics are limited to 25% of the odd harmonic limits above. Current distortions that result in a dc offset. I_{sc}/I_L: All power generation equipment is limited to these values of current distortion.

In this study, the problems in the power system at the grinding roof of the improved post-grinding process caused by harmonics of the electrical control devices were examined in different studies. Test and determine technical losses in

TABLE 12. Current distortion limits for systems rated 120 V–69 KV (IEEE 519-2022, pg.19).

I_{sc}/I_L	Harmonic Limits a,b					TDD Required
	$2 \le h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	
<20	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

power distribution systems due to harmonic components of integrated non-linear equipment in micro-grid environment. Device models are created based on actual measurement of data associated with different load scenarios. Current harmonics measurements and analyzes of their components have been carried out for several types of high, medium and low voltage loads, and also harmonic generating sources and related standards [56]. Many household appliances have a non-sinusoidal power converter that increases the harmonic voltage level, and the total effect depends on the power value of the device and the variety of harmonics.

Harmonics originate from devices such as (Industrial loads) power electronics, arc furnaces, welding machines, electronic starters, switching operations of large power transformers and (The civil loads) gas discharge lamps, televisions, photocopiers, computers, and microwave ovens. With a variety of measures, one can reduce the harmonics to an insignificantly small value. It is not possible to completely eliminate them. Harmonic is an unwanted interference that directly affects power quality, occurs when using non-linear loads and adversely affects equipment and machinery used in the plant such as engine life. Overload CB, overheating and causing transformer explosion. Circuit breakers, aptomats, fuses can be tripped for unknown reasons. Reduce capacitor life, even causing abnormal capacitor explosion. Interference affects telecommunications equipment, and automation systems. The measuring devices are not working correctly. Waste of energy. The main contributions of this study are (1) True harmonic measurements of linear and non-linear devices are used to improve the grind at the analyzed grinding process. (2) The conveying methods presented are aimed at minimizing harmonics and reducing the TDDi value so that it can meet the relevant standards and the taxonomic review of related studies is summarized in Table 13 as follows:

The power quality measurement of the devices was measured by testing using the HIOKI PQ3100 POWER QUALITY ANALYZER. A managed setup for any device to measure current and voltage harmonics with phase angles, active, reactive, apparent as well as power factor and frequency. Thanks to the capabilities of the equipment involved, measurements are made (Fig. 16).

The main objective of this study was to examine the effect of strategically varying loads on the TDD value. First, measure the electrical power of the electrical equipment used in the grinding improvement of the Blank line grinding process

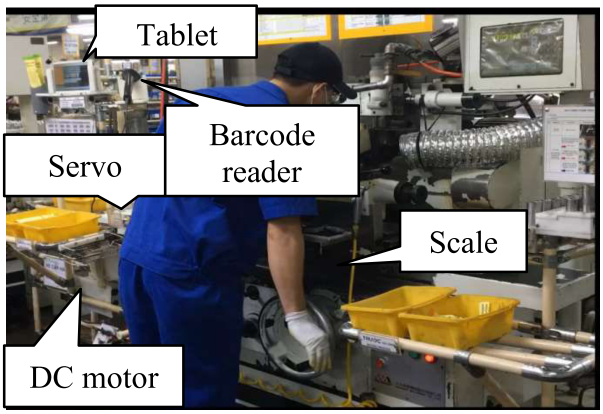

FIGURE 15. Grinding process.

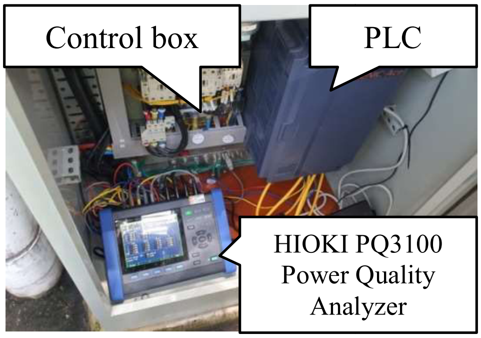

FIGURE 16. HIOKI PQ3100 power quality analyzer.

at a mechanical product manufacturer (Fig.11 & Fig. 15). These measurements are taken at 3 seconds intervals to produce more realistic harmonized behaviors of a variety of devices and evaluate their characteristics by avoiding modeling errors. Almost all the equipment used in the improvement of the grinding roof at the process itself is shown in Table 13.

The instantaneous values of voltage and current are determined by the following formula:

$$v(t) = \sum_{n=1}^{\infty} v_n(t) = \sum_{n=1}^{\infty} \sqrt{2} V_n sin(n\omega_1 t + \theta_n) \tag{23}$$

$$i(t) = \sum_{n=1}^{\infty} i_n(t) = \sum_{n=1}^{\infty} \sqrt{2} I_n sin(n\omega_1 t + \delta_n) \tag{24}$$

TABLE 13. Classification of specialized literature in the proposed research area.

Reference	Demand side management	Analyses of harmonics	TDD (%)	Measurement of smart factory appliances	Complying with standards
[57]	-	v	-	v	-
[58]	-	v	v	-	v
[59]	-	v	-	v	-
[60]	-	v	-	v	-
[61]	-	v	-	v	-
[62]	-	v	-	v	v
[63]	-	v	-	v	-
[64]	-	v	-	v	-
[65]	-	v	-	v	v
[10]	-	v	-	v	v
[67]	-	v	v	v	-
[68]	-	v	-	-	-
[69]	v	-	-	v	-
[70]	v	-	-	v	-
[71]	v	-	-	-	-
This research	**v**	**v**	**v**	**v**	**v**

where: v_n: nth order instantaneous voltage, i_n: nth order instantaneous current, ω_1: angular frequency of the fundamental frequency, θ_n: the phase origin of the nth voltage and δ_n: the phase origin of the nth current.

The current and voltage r.m.s related values of an AC source of nonlinear harmonic generating components are constructed as follows [72].

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T v^2(t)\,dt} = \sqrt{V_1^2 + V_2^2 + V_3^2 + \ldots + V_n^2} \tag{25}$$

$$I_{rms} = \sqrt{\frac{1}{T}\int_0^T i^2(t)\,dt} = \sqrt{I_1^2 + I_2^2 + I_3^2 + \ldots + I_n^2} \tag{26}$$

The active power consumption of the harmonic generating loads is calculated by the formula (Eq. 27), the value of the reactive power consumption of the harmonic generators is calculated by the formula (Eq. 28), apparent power value including active, reactive and strained power is calculated using the formula (Eq. 29) and another formula can also be used to calculate apparent power (Eq. 30).

$$P = \sum_{n=1}^{\infty} V_n I_n cos(\theta_n - \delta_n) = \sum_{n=1}^{\infty} P_n \tag{27}$$

$$Q = \sum_{n=1}^{\infty} V_n I_n sin(\theta_n - \delta_n) = \sum_{n=1}^{\infty} Q_n \tag{28}$$

$$S = V_{rms} I_{rms} \tag{29}$$

$$S^2 = P^2 + Q^2 + D^2 \tag{30}$$

where: D expresses distortion power.

The value of the power factor is calculated by the formula (Eq. 31). A power factor value close to 1 indicates that the overall power quality is rated as high. In case, the value of the power factor is low, the system will operate at low efficiency by supplying the same amount of demand with higher capacity from the grid side. To improve the power factor plays an important role in promoting system efficiency and reducing power consumption costs [73], [74].

$$PF = \frac{P}{S} = \frac{P_1}{V_{rms} \times I_{rms}} \tag{31}$$

The value of THD is needed to evaluate the square root of the sum of squares of voltage and current for all electronic components; however, harmonics were considered by IEEE 519:2022 until the 50th century ingredient. Knowing that voltage and current magnitudes tend to decrease with increasing harmonics and can be ignored after a certain value (Eq. 32 & Eq. 33)

$$THD_v = \frac{\sqrt{\left(\sum_{n>1}^{n_{max}} V_n^2\right)}}{V_1} = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \ldots + V_n^2}}{V_1^2} \tag{32}$$

$$THD_i = \frac{\sqrt{\left(\sum_{n>1}^{n_{max}} I_n^2\right)}}{I_1} = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \ldots + I_n^2}}{I_1} \tag{33}$$

In fact, the TDD value is also calculated for the distorted current waveforms (THD_i) [75] and the TDD value is calculated as the Ratio of the total r.m.s. the values of the current harmonic components and the maximum load current (I_L)

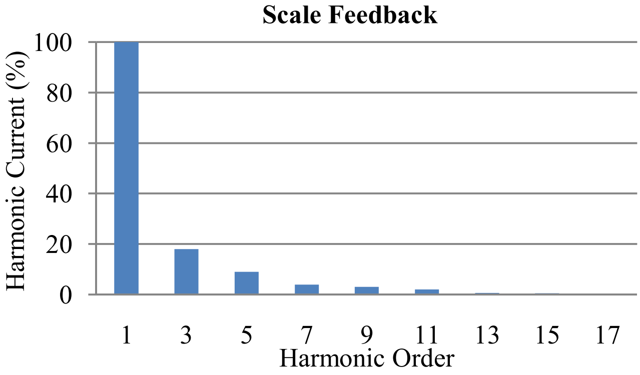

FIGURE 17. Current spectrum of the scale feedback.

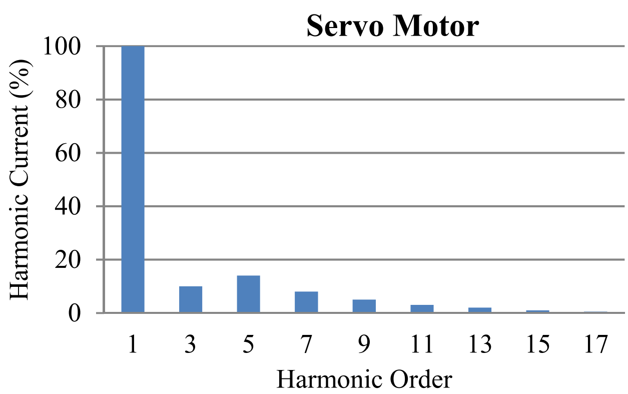

FIGURE 18. Current spectrum of the servo motor.

according to the formula (Eq. 34)

$$TDD_i = \frac{\sqrt{\left(\sum_{n>1}^{n_{max}} I_n^2\right)}}{I_L} = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \ldots + I_n^2}}{I_L} \quad (34)$$

The continuous current (I_L) was measured at 3-second intervals from the point of common coupling (PCC) and the base average points according to IEEE 519:2022.

Confirm the effectiveness of the transfer strategy on minimizing harmonics. Harmonic generators are considered to work together and the duty cycle of some harmonic generators is shifted to different times. In these studies, each load profile was created using electromechanical devices that improved the grinding roof at the grinding process of mechanical products manufacturing company and the total demand capacity has the highest load exceeds 2.5 kW, which is the highest load condition.

The electric harmonic ratio of the devices used in improving the grinder at the grinding process such as scale feedback, servo motor, dc motor, magnet scale, PLC, sensor, barcode recorder, tablet, and Light are shown in the Figure 17 to Figure 25. The odd-order components up to the 50th order are the subject of this study and the even-order harmonics are ignored in this study because of their low value.

Figure 17 shows the current harmonic components of the feedback scale, the 3rd and 5th harmonic components are the most dominant and the remaining components are found to be negligible. Figure 18 shows the content of the current harmonic ratio of the servo motor. Interestingly, the servo motor works frequently to adjust the grinding wheel angle but the 5th harmonic component is dominant. Figure 19 shows the content of DC motor current harmonic ratio. The 3rd and 5th harmonic components dominate and especially the 3rd order accounting for 45% and the 11th harmonic components are higher than the 7th and 9th harmonics. Figure 20 shows the current harmonic ratio of the magnet scale. The dominant 3rd harmonic component is high, however, the 5th and 7th harmonic components are also quite high. Figure 9 shows the content of the harmonic component of the tablet. It is easy to see that most of the harmonics are high and the

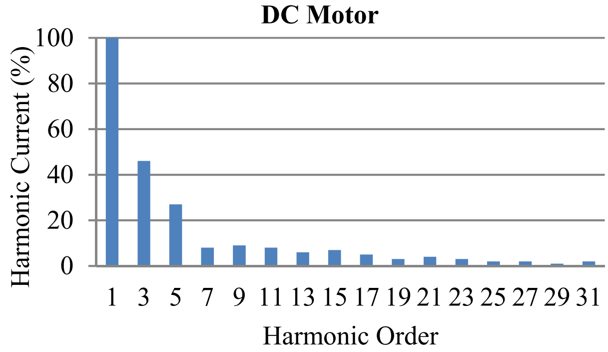

FIGURE 19. Current spectrum of the DC motor.

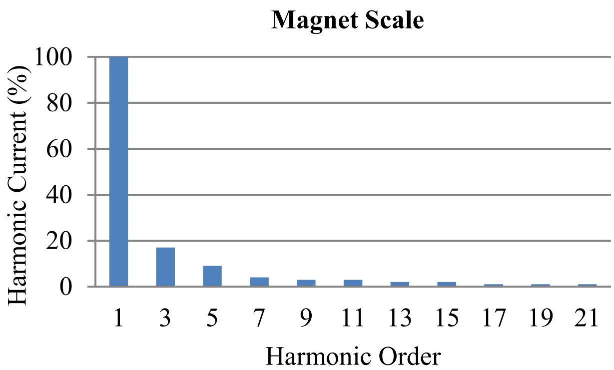

FIGURE 20. Current spectrum of the magnet scale.

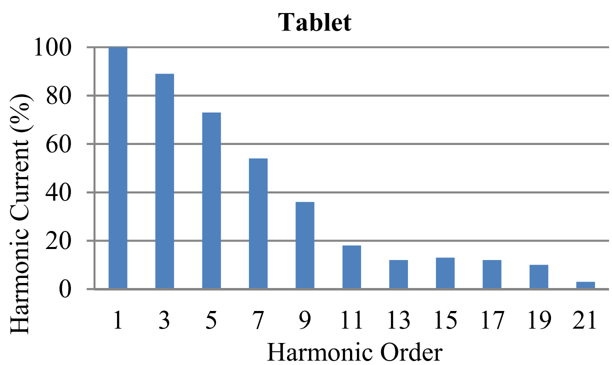

FIGURE 21. Current spectrum of the tablet.

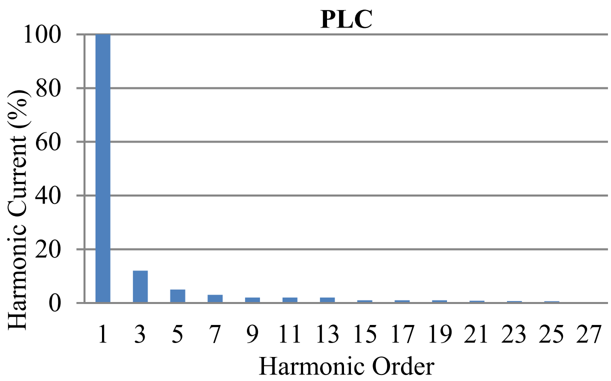

FIGURE 22. Current spectrum of the PLC.

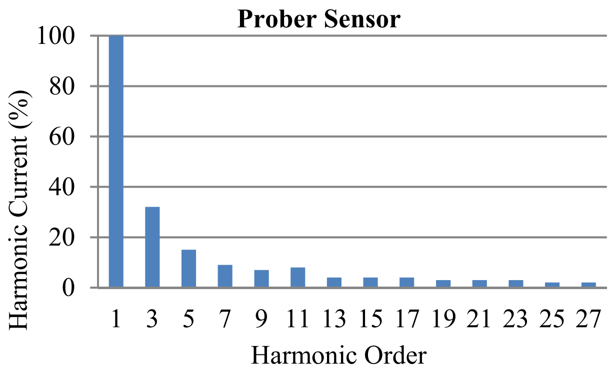

FIGURE 23. Current spectrum of the prober sensor.

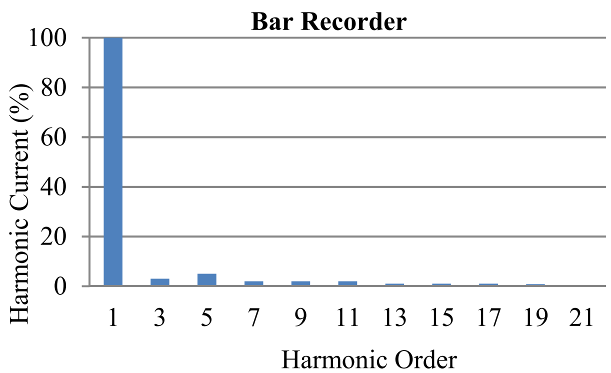

FIGURE 24. Current spectrum of the bar recorder.

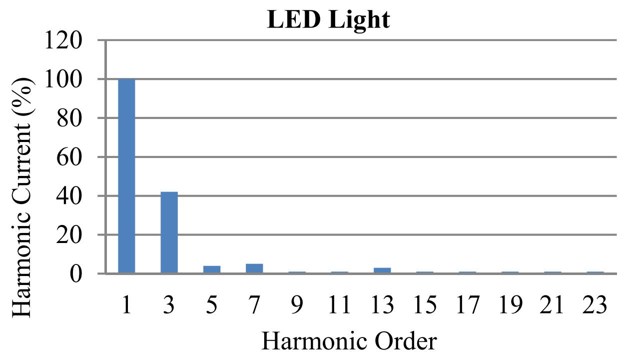

FIGURE 25. Current spectrum of the LED light.

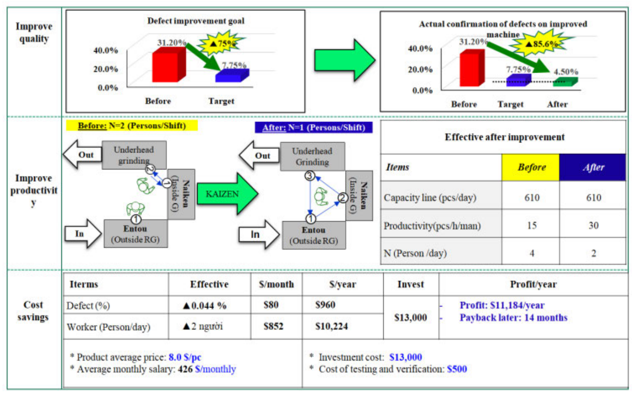

FIGURE 26. Overall effect after improvement.

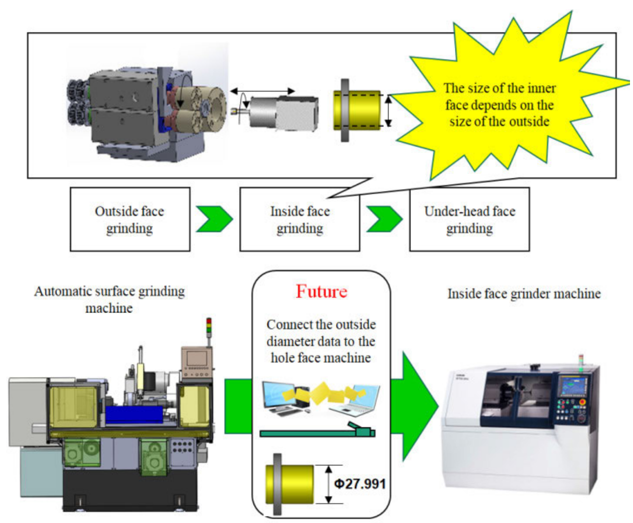

FIGURE 27. Future research topic.

distortion between the electronics and the THD_i of this device is 135.873%. Figure 22 shows the harmonics of the PLC, it is a switching device but controlled by software and outputs the control port in-out DC voltage value and small. The 3rd and 5th harmonics are dominant. The other harmonic components are of no concern because they are of small value. Figure 23 shows the content of the wave component of the prober sensor, the 3rd harmonic component is dominant and close to 30% compared to the 1st order, and the other harmonic components are also relatively high.

Figure 24 shows the harmonic component of the bar recorder. The 5th harmonic component is dominant and it can be said that the harmonic distortion of the device is not too high. Figure 25 shows the harmonic component of the led light. The 3rd harmonic component is dominant and equal to 42% of the 1st order and the other harmonic components are relatively small.

It is observed that these types of electronic devices are increasingly used in smart factories and production system operators are faced with harmonic pollution and this problem arises more often compared to the past. To address the above power quality issue, a comprehensive harmonic analysis was carried out, and assessments were presented from different perspectives in this study. Specifically at the grinding process and at a grinding machine that has just been converted from a semi-automatic machine to a fully automatic one. Current and voltage harmonics have their phase angles. Harmonic sources were operated at different times and TDD_i values were calculated for the study. The differences of the connection points in the grid at short circuit current levels are also different, the TDD_i values are assessed at 5%, 8% and 12% limits. As a result of this study, more than 97% of the limit was reached for each study that considered the 8% and 12% limits. On the other hand, the 5% limit is only offered in this case and TDD_i has been greatly improved. It is therefore worth noting that these transfer strategies have the potential to provide a particularly promising solution to power quality requirements

V. CONCLUSION

The Hybrid DMAIC method in Six Sigma is implemented into continuous improvement at the grinding process, and decision problem to make improvements using Multi-objective decision Fuzzy TOPSIS and optimum production conditions by Multi-objective optimization methods. The result, converting the grinding process into a grinding process using Industry 4.0 system with the function of calling the grinding program by the RFID system controlled by the DNC method, the online measurement system collects, analyzes, and evaluates the results of measurement of all production data in real-time. Data on production operating conditions, production data, product quality data, and quality of power from electrical devices at the same process are measured and collected in real-time, and saved in the same data source in Industry 4.0 system and can interact with each other called big data source in a production process to meet the requirements of data analysis for strategic decision making for product development strategy to improve the efficiency of the manufacturing industry in the company.

The main contributions of the research paper applying Hybrid DMAIC to continuous improvement of the grinding process are as follows: (1) Building a continuous improvement model using the Hybrid DMAIC method in Six Sigma can be applied to various industries to improve production efficiency. (2) From the historical point of view of traceability data, the data of operations at the grinding process are measured, collected, and analyzed in real-time to meet Industry 4.0 and the big data era. (3) From the perspective of big data in production analytics, linking data of all operations at the grinding process such as production conditions data, production data, quality of product data, and power quality data into a common and interoperable data system for analysis to make strategic decisions.

Continuous improvement in the manufacturing plant is a cross-cutting activity and is always of interest to managers. The Lean Six Sigma model is known as an innovative model that has been implemented in manufacturing plants for decades. Six Sigma tools control variation and identify the causes that give rise to variation in the process. Lean tools are known as tools that make improvements to eliminate fluctuations. Combine these two models into a Lean Six Sigma model. This study is to propose the Fuzzy TOPSIS multi-criteria decision-making method into the analysis phase of the DMAIC cycle of the Lean Six Sigma model with the aim of improving the analysis results and supporting decision-making for LSS organizers on the plan should prioritize the implementation of improvements. At the same time, this study proposes the Taguchi technique to find optimal operating conditions when burying an improved solution from the Fuzzy TOPSIS model and combining with harmonic interference measurement tools in electronic devices to bring comprehensive efficiency to the improved model of roof grinding from semi-automatic to automatic. This research model brings high efficiency in improvement activities and is considered a model research model for other improvement projects with different environments that can also be deployed and implemented to bring efficiency.

This study brings specific results in the production process at the mechanical manufacturing company, the rate of occurrence of smaller-than-standard outer diameter defects in the process decreased from 31.20% per month to 4.5% per month, productivity at the grinding stage remained at 610 pcs per day while the number of people operating the grinder decreased from 4 people per day to 2 people per day, and productivity per person per hour increased from 15 pcs per hour per person to 30 pcs per hour per person at an improved post-grinding process. Research results show that after improving the grinding machine from semi-automatic to automatic grinding machine in USD, the outer diameter defects are reduced by 0.044% per month, reducing 80 USD per month and 960 USD per year, labor at the grinding stage is reduced by 2 people, saving USD 852 per month and reducing USD 10,224 per year, investment cost for this improvement is USD 13,000, the average selling price of products is 8.0 USD per 1 pcs, average machine operator salary is 426 USD per month, cost of product inspection and evaluation while making improvements is 500 USD, amortize cost for this improvement project over 14 month and the profit for the project is 11,184 USD per year (Fig. 26).

This study was carried out in a grinding process at a mechanical manufacturing. This is considered the limit point of the thesis, expanding many stages, many types of processing machines and many machining sizes, promising future research directions for researchers. Measurement of harmonics generated at loads in grinding process and using load shifting method to control harmonics is in IEEE 519:2022 standard.

Future research is suggested using harmonic filters such as shunt adaptive power filter that combines soft computing for harmonic current control and compensation for smart factory river harmonic rejection. Although the proposed plan is only implemented for electrical devices at one grinding machine in the grinding process more grinding machines in different processes in the production process are being considered for future research. Most PCC values can be considered under different conditions to investigate whether the relevant criteria are met, not by means of a transport algorithm. A system based on model framework optimization and consideration of network constraints can be realized in a future study. A future study is to apply computer vision system in the control phase of this research model, computer vision performs the function of checking product surface quality and saves the results on the online inspection system. The intended result is the elimination of man-made dimensional and appearance checks. The first continuous improvement result was the control of negative outside diameter size defects at the grinding stage. However, positive external diameter defects still arise, accounting for 28% per month, the next improvement project needs to improve the grinding method and connect the outer diameter data to the holes grinding machine (Fig. 27).

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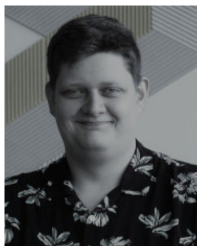

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