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Application of Six Sigma Methodology in an Automotive Manufacturing Company: A Case Study

Yung-Tsan Jou [1], Riana Magdalena Silitonga [1,2,*], Ming-Chang Lin [1], Ronald Sukwadi [2,*] and Jovian Rivaldo [2]

[1] Department of Industrial and Systems Engineering, Chung Yuan Christian University, Taoyuan City 320314, Taiwan
[2] Department of Industrial Engineering, Atma Jaya Catholic University of Indonesia, Jakarta 12930, Indonesia
* Correspondence: riana.magdalena@atmajaya.ac.id (R.M.S.); ronald.sukwadi@atmajaya.ac.id (R.S.)

Abstract: Continuous improvement is the prime requirement for all industries to sustain and grow in the competitive global market. This paper is a case study of a manufacturing industry in Taiwan, facing the problem of rejection in the brushless motor product. The DMAIC (Define, Measure, Analyze, Improve, and Control) cycle was used to improve processes to reduce the rejection rate. In the Define phase, anything related to processes, products, suppliers, customers, and customer needs related to good quality products were determined. SIPOC diagrams (Supplier, Input, Process, Output, and Customer) and Critical to Quality (CTQ) were identified. The Measure phase focused on data collection by determining the baseline of the process and determining the root causes of the process. DPMO and the Control Chart were applied in this phase. In the Analyze phase, the causes of production process failures that result in defective products were identified. Tools like Pareto Diagram, Fishbone Diagram, and FMEA were used in this phase. In the Improve phase, the improvement solutions in overcoming priority problems were determined by using the 5W + 1H tool. Several improvement solutions were implemented, such as improvement in inspection methods, re-selection for the supplier, increasing the number of workers, providing training to workers, and others. In the control phase, the Six Sigma values were improved. In January–May 2022, the Six Sigma level increased from 5.11 to 5.44.

Keywords: Six Sigma; DMAIC; quality; brushless motor

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1. Introduction

Every company strives to provide good quality products to customers to meet customer satisfaction. Companies must know the criteria for good quality products according to customer specifications. One of the efforts that can be made to complete customer satisfaction is providing good quality products. Defective products are directly related to Quality Control at the company. Good Quality Control will not allow defective products to pass to customers.

TQM triggered the evolution of quality management, which has been widely adopted by industries and non-profit organizations worldwide. The development of TQM was also influenced by Western quality experts such as Deming, Juran, and Crosby [1], especially the Deming 14 points and Juran's quality trilogy [2,3]. TQM was thus an integrated model of management philosophies, quality concepts, and practices. Since Kaizen (continuous improvement) is the core activity, it is thus constant improvement that is the critical quality practice of TQM [4]. Several methodologies are used for Quality Improvement, for example, Quality Improvement Team (QIT), Quality Control Circle (QCC), and project management.

From the late-1990s onward, Six Sigma activity has become the robust improvement methodology adopted by most enterprises and non-profit organizations due to the very successful implementation of the Six Sigma program by General Electric (GE) in 1995 [5].

However, the Six Sigma program was initiated by Motorola in 1987. The gap in product quality between Japan and USA stimulated Motorola to drive a five-year improvement program, named the "Six Sigma program". This program aimed to achieve the quality of their products to the Six Sigma level within five years [6,7]. Motorola implemented this program very successfully. The Six Sigma improvement resulted in immense contributions, especially financial results, as evidenced by- Motorola, GE, and other organizations implementing the Six Sigma improvement.

The basic difference between Total Quality Management and Six Sigma is that TQM delivers superior quality manufactured goods whereas six sigma results in better results. Total Quality management refers to the continuous effort by employees to ensure high quality products. The process of Six Sigma incorporates many small changes in the systems to ensure effective results and better customer satisfaction.

Six Sigma is known to deliver better and effective results as compared to total quality management. The process of Six Sigma is based on customer feedback and is more accurate and result oriented. Customer feedback plays an important role in Six Sigma. Experts predict that Six Sigma will outshine total quality management in due course.

Six Sigma is one of the methods used to improve a process, system, or product that focuses on scientific and statistical methods to reduce the defect rate [8,9]. This method can reduce the level of defective products produced by the company. One approach to the Six Sigma method is DMAIC (Define, Measure, Analyze, Improve, and Control). The DMAIC approach is similar to several methods commonly used in manufacturing, such as the Plan-Do-Check-Act and the Seven Step Method of Juran and Gryna, because they aim to improve [8].

The Six Sigma method has been applied in many cases and studies for different aims and targets. Pranavi and Umasankar already used this method to reduce painting peel-off defects to 230 pieces a month. The DMAIC establishes, evaluates, and exterminates the root cause of defects in the process. Hence, it can reach more excellent quality by improving productivity [10,11]. On the other hand, Six Sigma can help a new Standard of Operation (SOP) by scheduling the maintenance time to prevent any defective process. It was implemented to minimize the reduction rate of soy sauce packaging. By knowing the Six Sigma level, the researcher can identify the progress of implemented improvement [12]. In other cases, implementing the Six Sigma method can be started by figuring out the comparison of Key Performance Indicator (KPI) Customer Satisfaction (CF) to compare and adjust between the KPI and current condition, if there was an impropriate condition of the product, Six Sigma would be used to identify the root cause for optimizing the production process [13]. Applying the Six Sigma supports quality control and continuous improvement. Previous researchers also research the number of defective products by improving the production process [14]. In addition, the Six Sigma DMAIC was also used to minimize the waste of the process bead splice by generating the potential solutions of improvement in the process [15].

Due to some implementation of Six Sigma in several companies, MTM initiates for trying to reduce the value of Defects per Million Opportunities (DPMO). This is in line with the 2022 Implementation Plan that they have outlined. Some of the contents of the 2022 Implementation Plan are reducing the value of Failure Costs, reducing the number of customer complaints, and improving the quality of suppliers. The decrease in DPMO value will indirectly affect several of these things and have an impact on increasing the company's Sigma Level [16].

This research focuses on one of the products of MTM, which is the brushless motor. The brushless motor is a motor product usually used to drive medical equipment, electric scooters, electric wheelchairs, and elevators. In 2020, MTM produced brushless motors with a DPMO of 301.24 which decreased in 2021 to 152.65. MTM wants this value to continue to decline to provide good quality products for customer satisfaction.

2. The Concept and Methods

Six Sigma DMAIC is a methodology used to improve processes, systems, or products and is usually suitable for manufacturing processes [8,9]. Six Sigma could be an easy to use and adaptable framework for accomplishing, maintaining, and boosting achievement. It is characterized by the understanding of customers' needs and composed of actualities, information and factual investigation, and is based on management, streamlining, and always making a novelty solution with reference solution to all the processes in the company [9]. This method is used to wipe out the defect causes and the other problems about quality in the production, services, and management aspects [16–18]. Six Sigma or six times the standard deviation represents the value of 3.4 DPMO, which means that it can produce good quality products according to customer specifications of 99.99966% [9,11].

The Six Sigma method has two main strategies, DMAIC and DMADV. The Define, Measure, Analyze, Improve, and Control (DMAIC) strategy is used for process improvement. However, Design, Measure, Analyze, Design, and Verify was used for product improvement [19]. This research elaborates the DMAIC strategy to improve the production process in the automotive company.

Six Sigma DMAIC was originally a method for process variation but later development of the methodology led to its recent application in generic problem-solving and an approach to improvement. Actions aimed at achieving improvement are derived from detected relationships between process input(s) and output. The method prescribes that problems are clearly described by quantified parameters. Six Sigma underscores the application of quantitative metrics, such as process variation measurements, Critical to Quality (CTQ) metrics, critical-to-process parameters, defect rates, as well as traditional quality measures such as process capability. These metrics are used to define improvement goals and they are followed up during the journey of the improvement project.

DMAIC has a similar function with Plan-Do-Check-Action and the seven step method of Juran and Gryna as problem solver tools [20]. The aim of DMAIC is to adopt to improve the production process, effectively devoting to the diminishment of the number of non-compliant products and decreasing production cost [19–21]. The DMAIC approach has five stages, namely Define, Measure, Analyze, Improve, and Control, which aims to understand what is important from the customer's point of view as shown in Figure 1 [22]. Each of these stages has a different goal which is ultimately to improve the process, system, or product [23].

Figure 1. Six Sigma method.

The define stage is the first step in DMAIC which aims to identify anything related to processes, products, suppliers, customers, and others and aims to find out customer needs related to good quality products [22]. There are two tools used in the Define stage, namely SIPOC diagrams (Supplier, Input, Process, Output, and Customer) and Critical to Quality (CTQ). The SIPOC diagram serves to describe the scope of the entire business process from suppliers to customers and helps to understand the process boundaries [24]. CTQ describes the characteristics needed in a good quality product to be able to meet customer specifications [12].

The Measure phase is the precarious phase of the project and focuses on data collection by determining the baseline of the process and figuring out the root causes of the process [22]. The aims are to measure the current condition of the company's Quality Control by using several tools, such as DPMO and the Control Chart. DPMO is used to find out how many possibilities the production process has to produce defective products in one million opportunities as shown in Formula (1) [14,15]. The DPMO value can be converted to Sigma Level by considering the DPMO result with the Sigma table in Table 1 [25]. The Control Chart is used to determine whether the production process that occurs is controlled or not. The formula that is used in calculating the Control Chart is shown in Formula (2, 3, 4, and 5) [26].

Table 1. Sigma table.

Sigma	Defects per Million	Yield
6.0	3.4	99.9997%
5.0	233.0	99.977%
4.0	6210.0	99.379%
3.0	66,807.0	93.32%
2.5	158,655.0	84.1%
2.0	308,538.0	69.1%
1.5	500,000.0	50.0%
1.4	539,828.0	46.0%
1.3	579,260.0	42.1%
1.2	617,911.0	38.2%
1.1	655,422.0	34.5%
1.0	691,462.0	30.9%
0.5	841,345.0	15.9%
0.0	933,193.0	6.7%

$$\text{DPMO} = \frac{\text{Total Defective Products}}{\text{Total Production } \times \text{Opportunity}} \times 1,000,000 \quad (1)$$

$$p = \frac{\text{Total of nonconforming unit in} - \text{i sample}}{\text{Total of units in} - \text{i sample}} \quad (2)$$

$$\overline{p} = \frac{\text{Total of nonconforming unit in all sample}}{\text{Total of units in all sample}} \quad (3)$$

$$\text{Upper Control Limit} = \overline{p} + s\sqrt{\frac{\overline{p}(1-\overline{p})}{n}} \quad (4)$$

$$\text{Lower Control Limit} = \overline{p} - s\sqrt{\frac{\overline{p}(1-\overline{p})}{n}} \quad (5)$$

According to Equations (4) and (5), s variable means the Sigma standard as determined as 3. The Analyze stage aims to analyze the causes of production process failures that result in defective products [27]. This stage is required to characterize process capability, clarify the objectives based on the real data from the measure stage, and begin root causes that have affected the process [22]. The tools used to analyze the causes are Pareto Diagrams, Fishbone Diagrams, and Failure Mode Effect Analysis (FMEA) [12]. Pareto diagrams are used to find out what problems most often occur. Then, an analysis is carried out to find out the cause of the problem by using a Fishbone Diagram. FMEA is used to determine priority problems so that they must be resolved first based on the RPN value obtained through Severity, Occurrence, and Detection.

$$\text{RPN} = \text{ Severity } \times \text{Occurrence } \times \text{Detection} \quad (6)$$

The Improve stage aims to find improvement solutions in overcoming priority problems. The goal of this stage is to arrange and develop an action plan to enhance the functioning of the organization, financial matters, and customer relationship issues [22]. The 5W + 1H (What, Who, Why, When, Where, and How) tools are used [28].

The Control phase is the last step in DMAIC which aims to monitor the implementation of the proposed improvement that has been successful. This stage also aims to keep the implementation running well [15,17].

3. Results

MTM is a manufacturing company that produces brushed DC motors and brushless DC motors, where these products are found in medical equipment, scooters, electric wheelchairs, and all types of elevators. The products produced by this company have a high level of precision, this is what makes MTM have a very good quality control system [29].

MTM itself already has various kinds of certifications, such as ISO-9001, ISO-14001, and others. This is what supports MTM to produce good quality products and control 80% of the world market share for Electric Auxiliary Motors in South Korea and 30% market share in Europe. However, MTM feels that this is not a very sufficient achievement. The company is targeting revenues in 2021 of 27,668,605 USD, which means an increase of more than 40% from revenue in 2020 which only received revenues of around 18,864,958 USD [29]. In addition, MTM also plans to expand and register itself to enter the Taiwan stock exchange.

In addition, to improve quality management, MTM plans to improve customer complaints' handling. Handling customer complaints is one of the things that can be done to improve the company's quality management. The presence of customer complaints means that customer satisfaction is not achieved, so to be able to overcome this, the company must be able to meet customer satisfaction. One way to achieve this is to produce products according to criteria that can meet customer specifications (good quality products). However, to find out the extent of the quality of the products produced by this company, the Six Sigma method is used to determine the quantitative value and the root cause of existing customer complaints.

To implement the Six Sigma method, several stages must be identified first, including define, measure, analyze, identify, and control.

3.1. Define

The define stage is the first step in DMAIC, which aims to identify the processes, products, suppliers, customers, and others and also to determine customer specifications related to good quality products.

3.1.1. SIPOC Diagram

SIPOC stands for Supplier, Input, Process, Output, and Customer. SIPOC is a tool that explains the overall flow of business processes from suppliers to customers, from left to right [14]. In this research, the SIPOC diagram is shown in Figure 2, which describes the brushless motor.

3.1.2. Critical to Quality (CTQ)

CTQ is used to guide us in indicating the targeted area for doing some improvement specifically [30]. Figure 3 provides information related to customer needs or customer specifications for good quality brushless motor products described in the Critical to Quality (CTQ) tree diagram. Five criteria become specifications for a brushless motor of good quality, such as the motor works properly, no appearance defect, normal voltage, brake works properly, and normal motor sound.

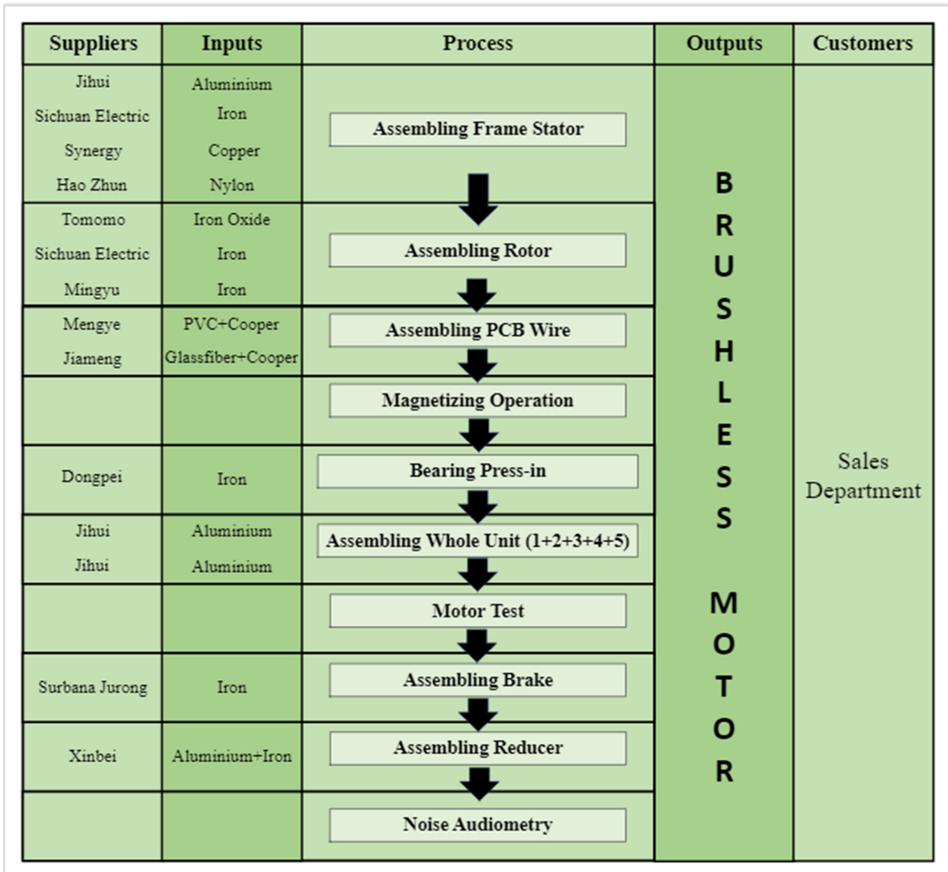


Figure 2. SIPOC diagram brushless motor.

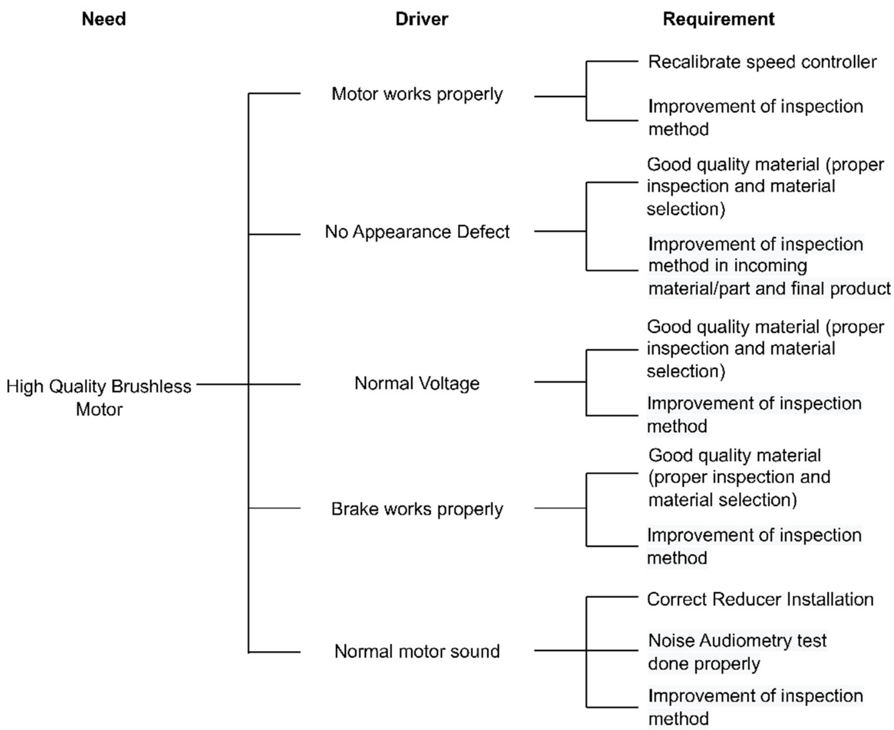


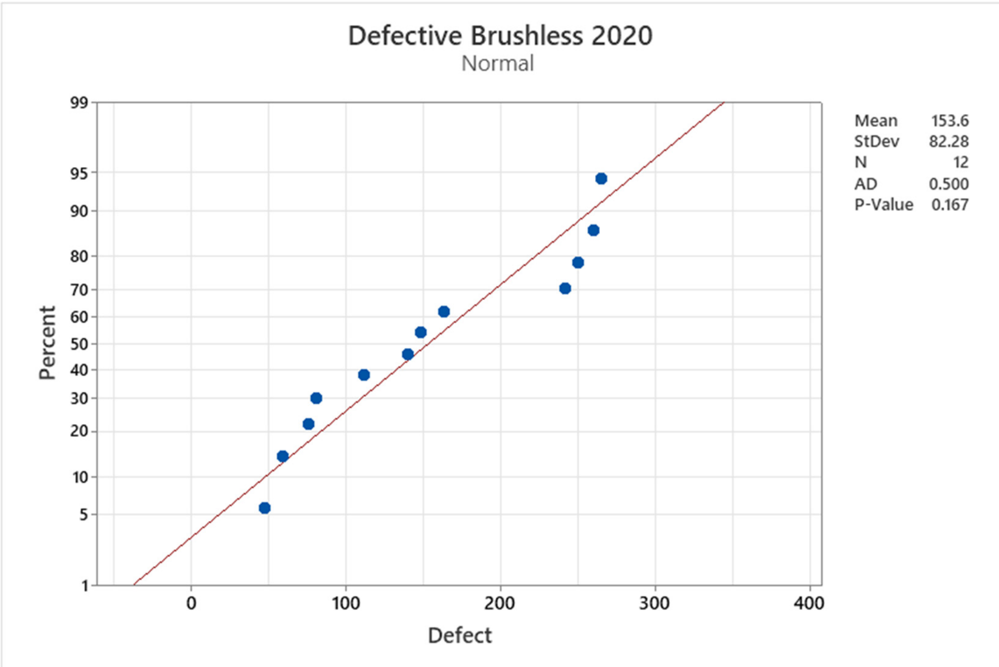
Figure 3. CTQ of high-quality brushless motor.

3.2. Measure

The Measure phase aims to measure the current condition of the company's Quality Control by using several tools.

3.2.1. Defect per Million Opportunities (DPMO)

Before performing calculations using the data that have been obtained, production data and data on defective products will be tested first. The test carried out is a normality test, to find out whether the data are normally distributed or not as shown in Figures 4 and 5. If the data are normally distributed, then the data can be used for the next stage.



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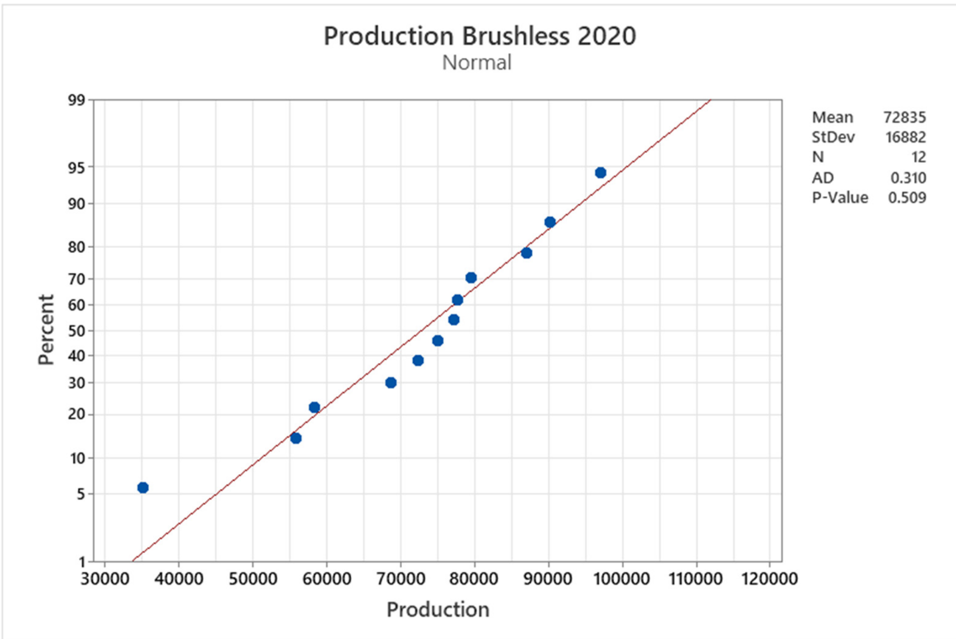
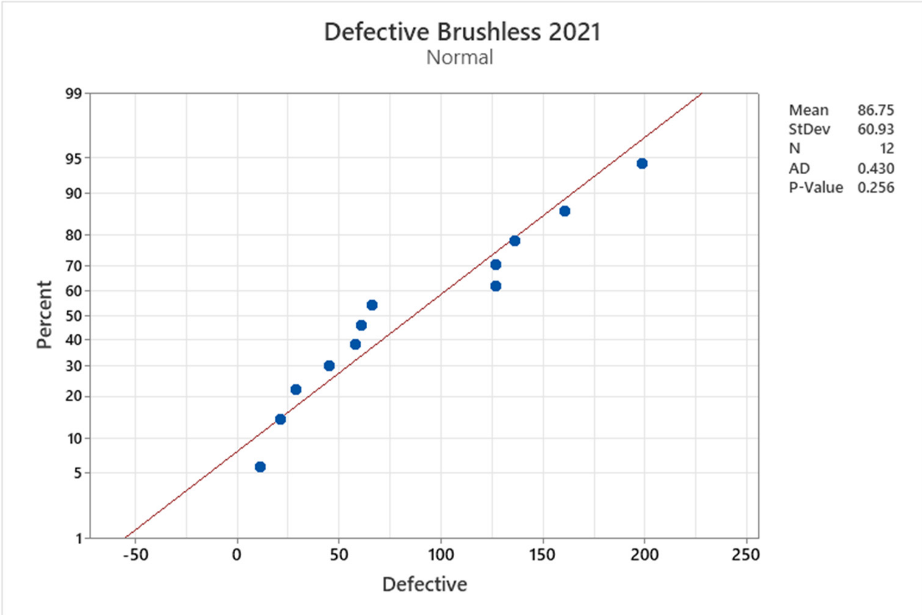


(**b**)

Figure 4. Normality test for 2020 brushless motor data: (**a**) defective products; (**b**) production.



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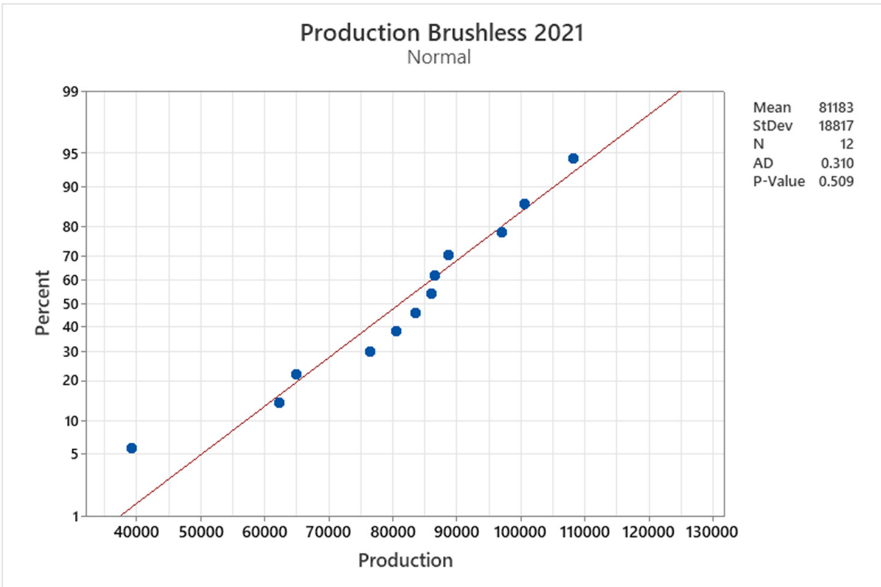

(**b**)

Figure 5. Normality test for 2021 brushless motor data: (**a**) defective products; (**b**) production.

Figures 4 and 5 show that production data and defective product data in 2020 and 2021 are normally distributed after being tested using the Minitab application. If the *p*-value is greater than 0.05, it can be concluded that the data are normally distributed. All the data tested have a *p*-value greater than 0.05, so it can be concluded that all the data used are normally distributed.

Table 2 shows the value of DPMO in 2020 for MTM for brushless motor products, while Table 3 shows the value of DPMO in 2021. On average, DPMO decreased from 301.24 in 2020 to 152.65 in 2021. The decrease in the DPMO value indicates that the production process is running better and produces fewer defective products and increases the Sigma level.

Table 2. DPMO brushless motor 2020.

Month	Production	Defects	DPMO
1	68,620	47	97.85
2	35,060	163	664.17
3	79,575	148	265.70
4	74,977	250	476.34
5	90,250	260	411.56
6	97,097	265	389.89
7	87,119	76	124.62
8	77,238	112	207.15
9	58,275	242	593.25
10	72,300	140	276.63
11	77,680	81	148.96
12	55,825	59	150.98
Average	72,835	154	301.24
Sigma Level		4.93	

Table 3. DPMO brushless motor 2021.

Month	Production	Defects	DPMO
1	76,485	66	123.27
2	39,078	45	164.51
3	88,695	29	46.71
4	83,571	11	18.80
5	100,594	136	193.14
6	108,226	199	262.68
7	97,104	127	186.84
8	86,091	21	34.85
9	64,955	61	134.16
10	80,587	127	225.13
11	86,583	58	95.70
12	62,224	161	369.63
Average	81,183	87	152.65
Sigma Level		5.11	

3.2.2. Control Chart

The Control Chart can show whether the production process is running well or not based on the amount of production and defective products produced as shown in Tables 4 and 5 for the calculation. The Control Chart will show the points representing the month whether the production process is still within the control limits or not in that month, which is shown in Figures 6 and 7.

Table 4. The calculation for Control Chart 2020.

Month	Production	Defects	p	$\overline{p}$	UCL	LCL
1	68,620	47	0.000685	0.002109	0.002634	0.001583
2	35,060	163	0.004649	0.002109	0.002844	0.001374
3	79,575	148	0.001860	0.002109	0.002596	0.001621
4	74,977	250	0.003334	0.002109	0.002611	0.001606
5	90,250	260	0.002881	0.002109	0.002567	0.001651
6	97,097	265	0.002729	0.002109	0.002550	0.001667
7	87,119	76	0.000872	0.002109	0.002575	0.001642
8	77,238	112	0.001450	0.002109	0.002604	0.001613
9	58,275	242	0.004153	0.002109	0.002679	0.001539
10	72,300	140	0.001936	0.002109	0.002620	0.001597
11	77,680	81	0.001043	0.002109	0.002602	0.001615
12	55,825	59	0.001057	0.002109	0.002691	0.001526

Table 5. The calculation for Control Chart 2021.

Month	Production	Defects	p	$\overline{p}$	UCL	LCL
1	76,485	66	0.000863	0.001069	0.001423	0.000714
2	39,078	45	0.001152	0.001069	0.001564	0.000573
3	88,695	29	0.000327	0.001069	0.001398	0.000739
4	83,571	11	0.000132	0.001069	0.001408	0.000730
5	100,594	136	0.001352	0.001069	0.001378	0.000760
6	108,226	199	0.001839	0.001069	0.001367	0.000771
7	97,104	127	0.001308	0.001069	0.001383	0.000754
8	86,091	21	0.000244	0.001069	0.001403	0.000735
9	64,955	61	0.000939	0.001069	0.001453	0.000684
10	80,587	127	0.001576	0.001069	0.001414	0.000723
11	86,583	58	0.000670	0.001069	0.001402	0.000735
12	62,224	161	0.002587	0.001069	0.001462	0.000676

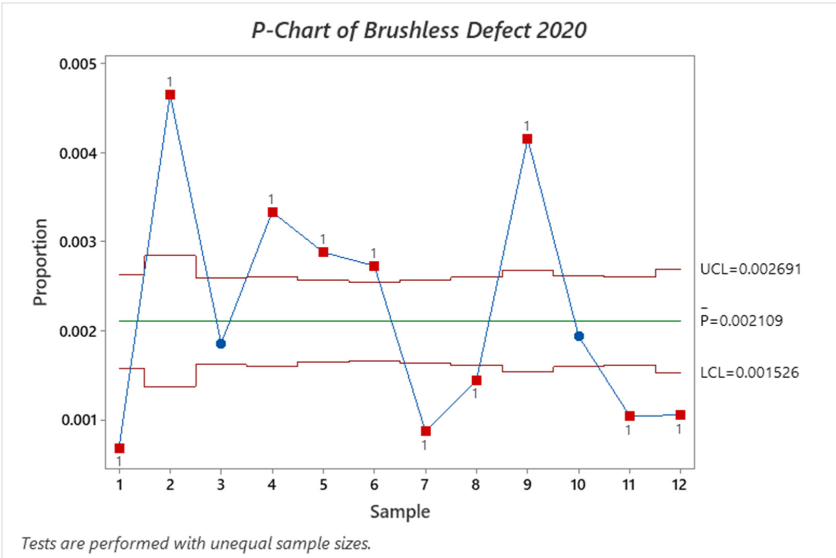

Figure 6. Control Chart 2020.

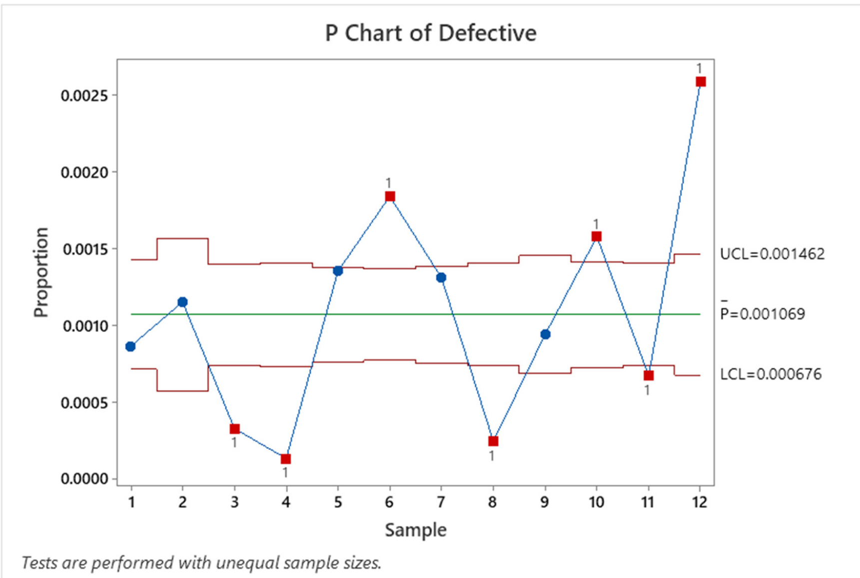

Figure 7. Control Chart 2021.

Figures 6 and 7 show that the production process is not going well. This is indicated by the number of dots representing the month that are out of the control limit.

3.3. Analyze

3.3.1. Pareto Diagram

Pareto diagrams are used to find out what problems most often occur. Five issues are most experienced in brushless motor products, as shown in Table 6 and Figure 8.

Table 6. Complaints for 2020–2021.

No	Type of Complaint	Number of Complaints	Percentage
1	Bad Appearance	13	33.31%
2	Abnormal Sound	8	20.51%
3	Abnormal Motor	7	17.95%
4	Abnormal Brake	6	15.38%
5	Abnormal Voltage	5	12.82%
Total		39	100.00%

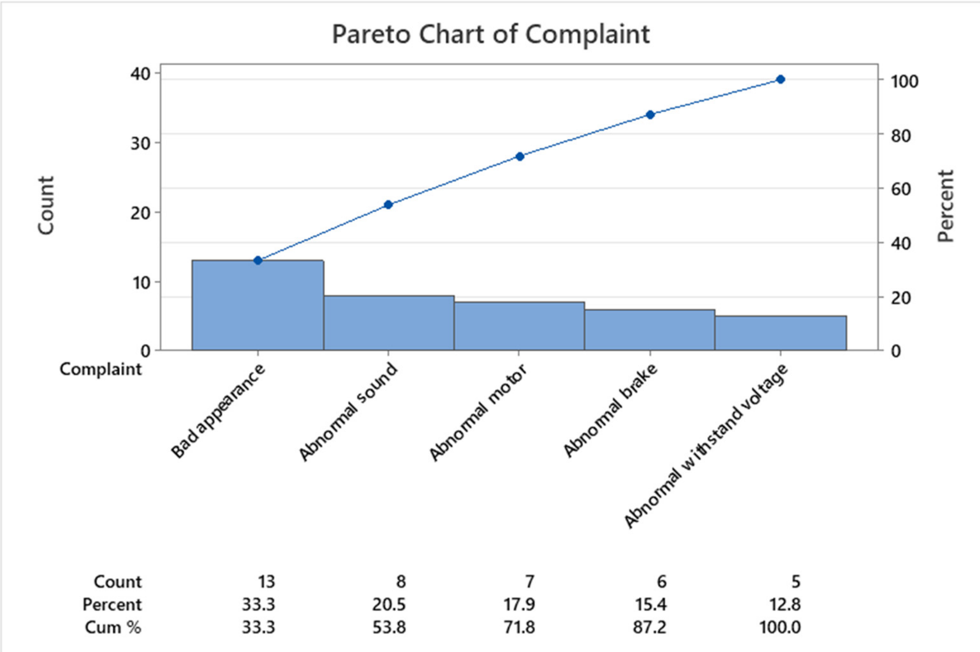

Figure 8. Pareto diagram of complaints for 2020–2021.

According to Figure 8, bad appearance is the highest problem cause that happened in the brushless motor. It is proven by the highest percentage of 33.33%. The five top complaints will be searched for the cause of the problem from the complaint by using a Fishbone Diagram.

3.3.2. Fishbone Diagram

The Fishbone Diagram is used to find out the cause and explore all reasons intensely [31]. Four factors will be analyzed for each complaint, namely, man, method, machine, and material in the complaint against the brushless motor product. Fishbone Diagrams for each complaint are shown in Figures 9–13.

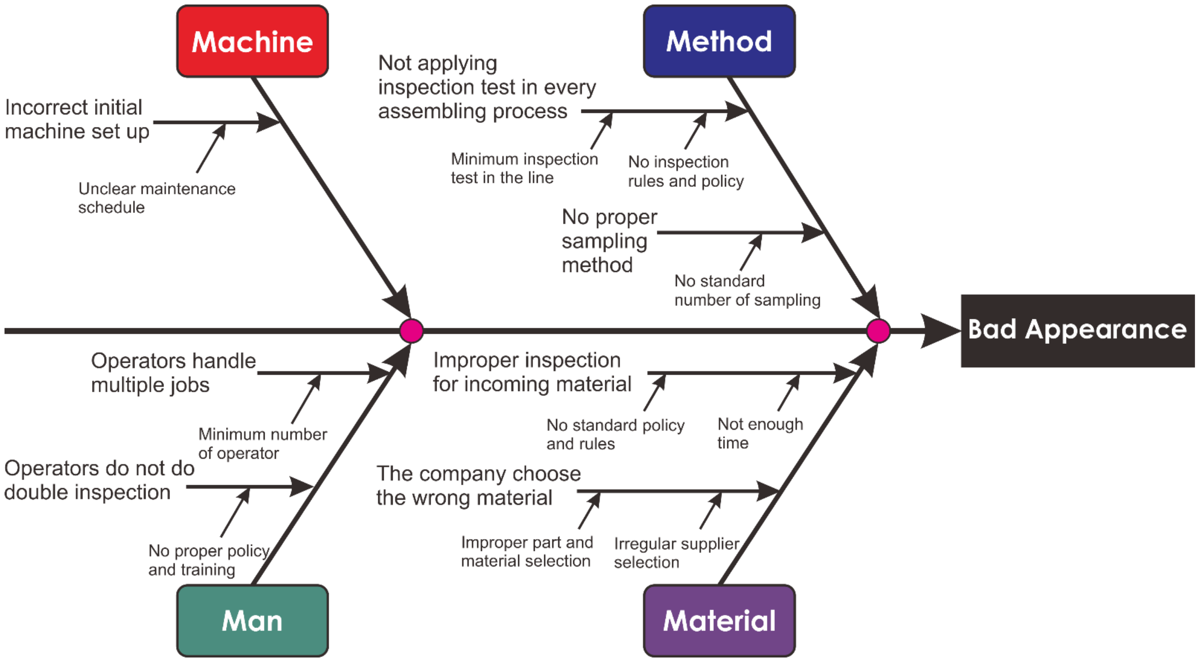

Figure 9. Fishbone Diagram of bad appearance complaint.

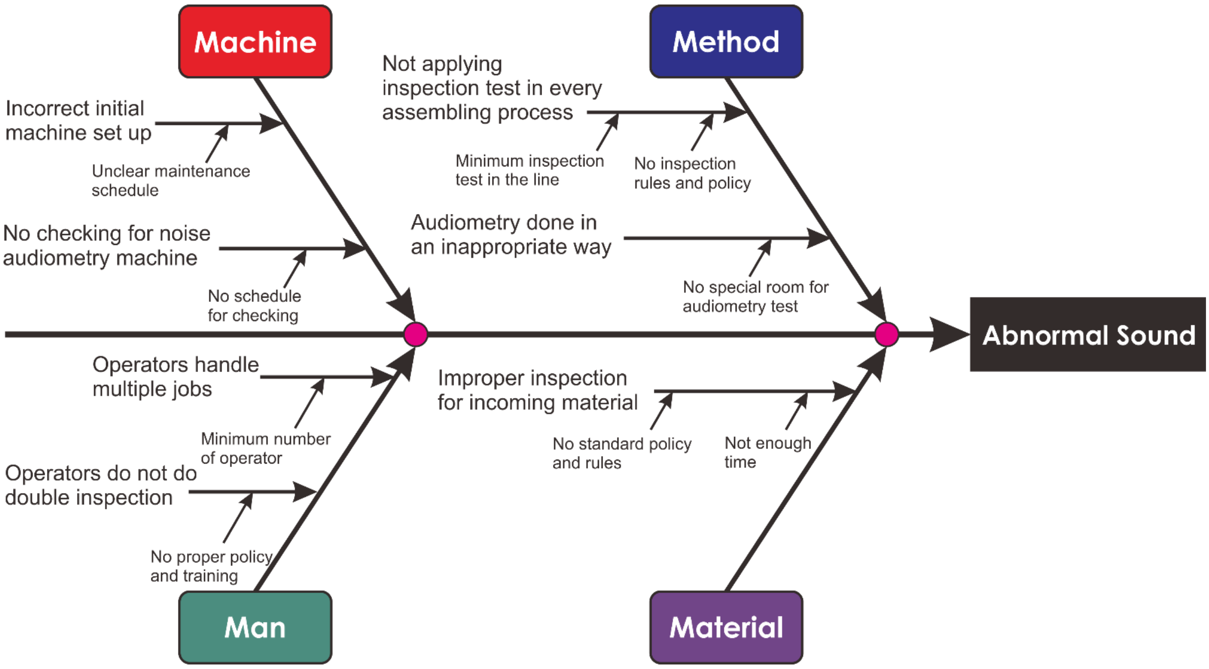

Figure 10. Fishbone Diagram of abnormal sound complaint.

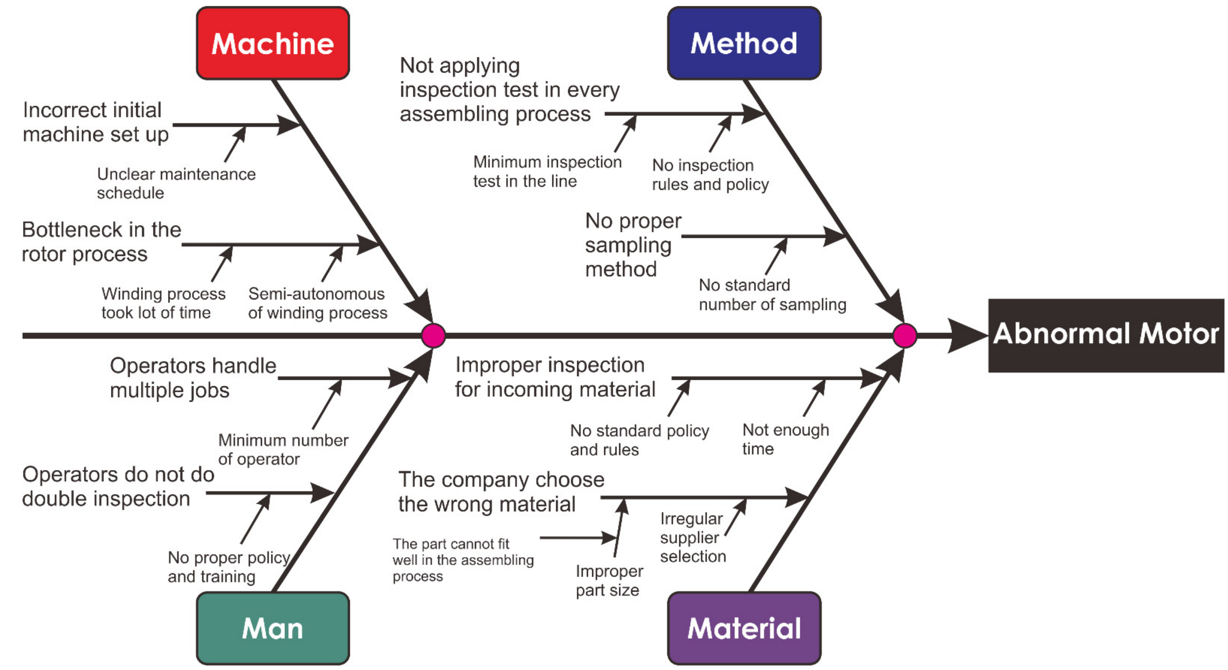

Figure 11. Fishbone Diagram of abnormal motor complaint.

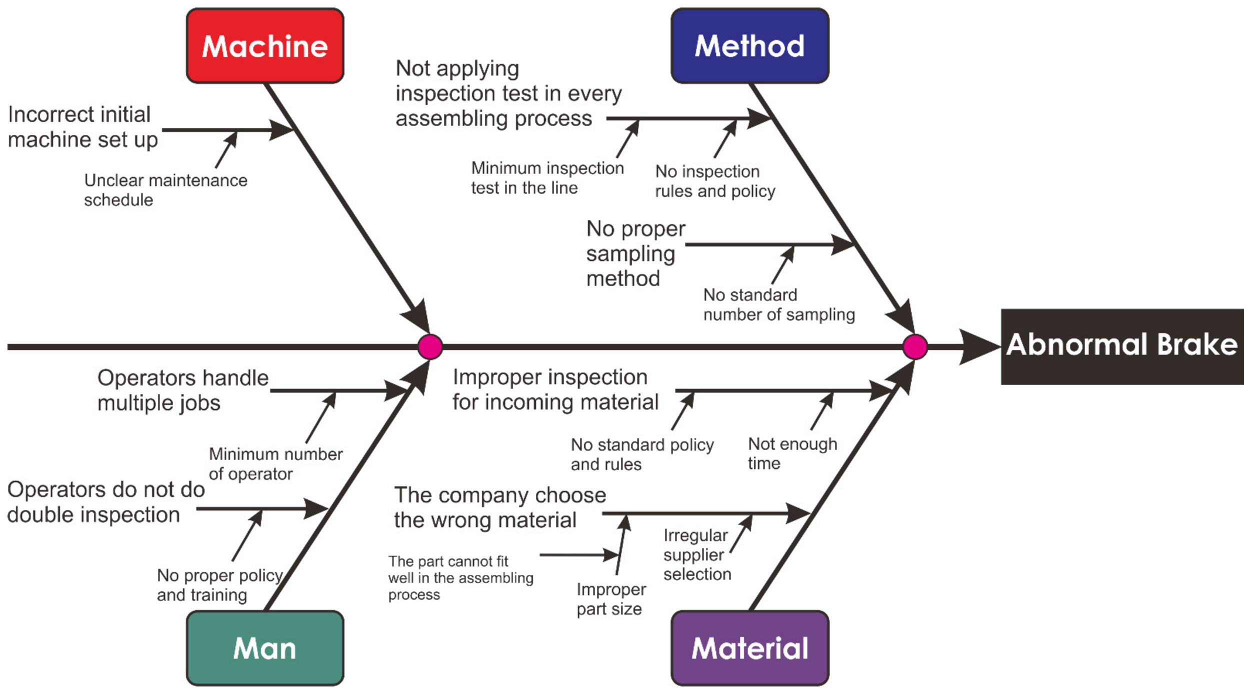

Figure 12. Fishbone Diagram of abnormal brake complaint.

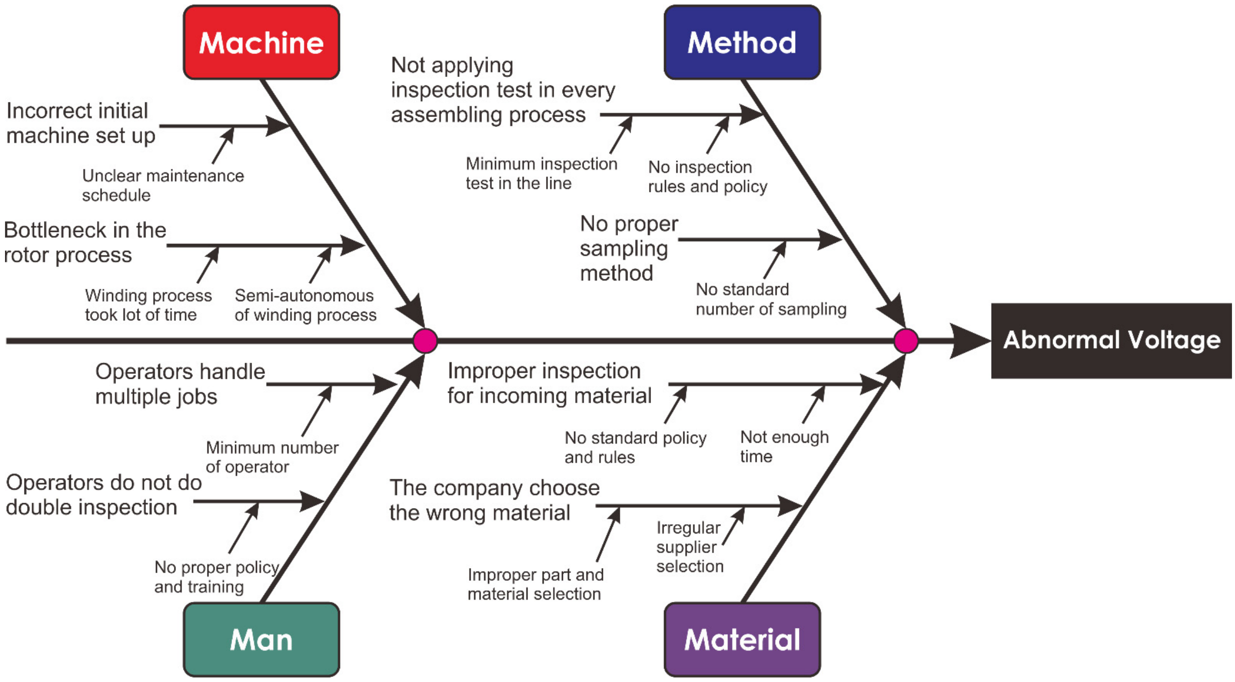

Figure 13. Fishbone Diagram of abnormal voltage complaint.

According to Figures 9–13, the main problems of the product and process are in the inspection process, maintenance, and standard or regulation during the assembling process. The low inspection level of the process caused many defective products to go to the customer. Therefore, customer complaints were coming in. Moreover, the raw materials and supplied materials that were used did not fit well enough to produce the brushless motor, such as the wrong size of screw, frame, etc.

3.3.3. Failure Mode Effect Analysis

FMEA will provide an assessment of each contributing factor to each complaint using the Severity, Occurrence, and Detection (SOD) assessment rubrics [32]. The caused problems used in FMEA are based on the Fishbone Diagram in Figures 9–13.

FMEA gives results in the form of a priority order of problems that have the highest risk so that they must be resolved first by the MTM. This priority order is based on the Risk Priority Number (RPN) value derived from the SOD assessment as found in Tables 7–11.

Table 7. FMEA of abnormal motor complaint.

Factor	Cause	Impact	Solution	S	O	D	RPN
Machine	Improper maintenance schedule	Poor initial machine setup	Setting a maintenance schedule Set up the machine before starting production	7	8	5	280
	Winding process takes a lot of time Semi-autonomous during the winding process	Bottleneck in the rotor process	Assigning autonomous on the winding process	8	9	5	360
Men	Lack of number of operators	Operators handle a lot of work, so they cannot focus on their work	Increase the number of operators	3	9	5	135
	No proper policies and training for operators	The operator does not do a double inspection check	Establish appropriate policies and provide training to operators	4	7	5	140
Method	Less inspection test, no inspection rules and policies	Defective products will enter the assembly process	Inspection is carried out on every assembly process	6	9	5	270
Material	Inappropriate selection of materials and suppliers	The company chose the wrong material and suppliers	Companies must be able to choose good materials and suppliers	8	9	5	360
	No standard policies and rules for inspection and lack of time	Materials that come in bad condition pass the inspection and are accepted by the company	Establish standard policies and rules for inspection	4	7	5	140

Table 8. FMEA of abnormal sound complaint.

Factor	Cause	Impact	Solution	S	O	D	RPN
Machine	Improper maintenance schedule	Poor initial machine setup	Setting a maintenance schedule Set up the machine before starting production	7	8	5	280
	No Noise Audiometry Test machine check schedule	No noise check audiometry machine	Set a noise audiometry test machine check schedule	8	9	5	360
Men	Lack of number of operators	Operators handle a lot of work, so they cannot focus on their work	Increase the number of operators	3	9	5	135
	No proper policies and training for operators	The operator does not do a double inspection check	Establish appropriate policies and provide training to operators	4	7	5	140
Method	There is no special room for audiometry tests	Audiometry test is not done properly	Provide a special room for audiometriy tests	5	9	5	225
	Less inspection test, no inspection rules and policies	Defective products will enter the assembly process	Inspection is carried out on every assembly process	6	9	5	270
Material	Inappropriate selection of materials and suppliers	The company chose the wrong material and suppliers	Companies must be able to choose good materials and suppliers	8	9	5	360
	No standard policies and rules for inspection and lack of time	Materials that come in bad condition pass the inspection and are accepted by the company	Establish standard policies and rules for inspection	4	7	5	140

Table 9. FMEA of abnormal brake complaint.

Factor	Cause	Impact	Solution	S	O	D	RPN
Machine	Improper maintenance schedule	Poor initial machine setup	Setting a maintenance scheduleSet up the machine before starting production	7	8	5	280
Men	Lack of number of operators	Operators handle a lot of work, so they cannot focus on their work	Increase the number of operators	3	9	5	135
	No proper policies and training for operators	The operator does not do a double inspection check	Establish appropriate policies and provide training to operators	4	7	5	140
Method	Less inspection test, no inspection rules and policies	Defective products will enter the assembly process	Inspection is carried out on every assembly process	6	9	5	270
Material	Inappropriate selection of materials and suppliers	The company chose the wrong material and suppliers	Companies must be able to choose good materials and suppliers	8	9	5	360
	No standard policies and rules for inspection and lack of time	Materials that come in bad condition pass the inspection and are accepted by the company	Establish standard policies and rules for inspection	4	7	5	140

Table 10. FMEA of abnormal voltage complaint.

Factor	Cause	Impact	Solution	S	O	D	RPN
Machine	Improper maintenance schedule	Poor initial machine setup	Setting a maintenance schedule Set up the machine before starting production	7	8	5	280
	Winding process takes a lot of time	Bottleneck in the rotor process	Assigning autonomous on the winding process	8	9	5	360
	Semi-autonomous during the winding process	Bottleneck in the rotor process	Assigning autonomous on the winding process	8	9	5	360
	Rough jig material	Uncomfortable grip tool	The jig is made of material that is comfortable to grip	7	7	5	245
Men	Lack of number of operators	Operators handle a lot of work, so they cannot focus on their work	Increase the number of operators	3	9	5	135
	No proper policies and training for operators	The operator does not do a double inspection check	Establish appropriate policies and provide training to operators	4	7	5	140
Method	Less inspection test, no inspection rules and policies	Defective products will enter the assembly process	Inspection is carried out on every assembly process	6	9	5	270
Material	Inappropriate selection of materials and suppliers	The company chose the wrong material and suppliers	Companies must be able to choose good materials and suppliers	8	9	5	360
	No standard policies and rules for inspection and lack of time	Materials that come in bad condition pass the inspection and are accepted by the company	Establish standard policies and rules for inspection	4	7	5	140

Table 11. FMEA of bad appearance.

Factor	Cause	Impact	Solution	S	O	D	RPN
Machine	Improper maintenance schedule	Poor initial machine setup	Doing the correct initial machine setup	7	8	5	280
Men	Lack of number of operators	Operators handle a lot of work, so they cannot focus on their work	Increase the number of operators	3	9	5	135
	No proper policies and training for operators	The operator does not do a double inspection check	Establish appropriate policies and provide training to operators	4	7	5	140
Method	Less inspection test, no inspection rules and policies	Defective products will enter the assembly process	Inspection is carried out on every assembly process	6	9	5	270
Material	Inappropriate selection of materials and suppliers	The company chose the wrong material and suppliers	Companies must be able to choose good materials and suppliers	8	9	5	360
	No standard policies and rules for inspection and lack of time	Materials that come in bad condition pass the inspection and are accepted by the company	Establish standard policies and rules for inspection	4	7	5	140

Based on the RPN value on the FMEA of each complaint, it was found that the type of complaint with the highest RPN value was abnormal voltage and abnormal sound. These two complaints needed immediate improvement because they had the highest number of complaints among others.

3.4. Improve

5W + 1H (What, Why, Who, When, Where, and How)

5W + 1H will be used to find the best solution to overcome the two complaints with the largest RPN. 5W + 1H is followed by understanding and identifying the process, and problem for improvement [33]. The solution to overcome the abnormal voltage complaint obtained through 5W + 1H is shown in Tables 6–8. The solution to overcome the abnormal sound complaint obtained through 5W + 1H is shown in Tables 12–17.

Table 12. 5W + 1H on abnormal voltage due to poor material.

No	5W + 1H	Number of Complaints
1	What	The unstable or abnormal voltage on the machine
2	Why	Poor material selection
3	Who	Quality Control Department
4	When	When selecting materials and suppliers and when receiving incoming materials
5	Where	Motion Technology Electric & Machinery Co., Ltd., Taiwan
6	How	The above problem can be solved by: • Making a better selection of materials and suppliers • Do a better incoming material inspection

Table 13. 5W + 1H at abnormal voltage due to lack of inspection policy.

No	5W + 1H	Number of Complaints
1	What	The unstable or abnormal voltage on the machine
2	Why	There is no policy for inspection
3	Who	Quality Control Department
4	When	When receiving the material and after the final process
5	Where	Motion Technology Electric & Machinery Co., Ltd., Taiwan
6	How	The above problem can be solved by: • Form policies or rules in conducting inspections • Provide training to workers to carry out a brief inspection at each completion of assembly

Table 14. 5W + 1H at abnormal voltage due to lack of number of inspections.

No	5W + 1H	Number of Complaints
1	What	The unstable or abnormal voltage on the machine
2	Why	Insufficient inspections due to lack of time and workers
3	Who	Quality Control Department and machine operator
4	When	When receiving the material and after the final process
5	Where	Motion Technology Electric & Machinery Co., Ltd., Taiwan
6	How	The above problem can be solved by: • Adding workers to carry out inspections

Table 15. 5W + 1H on abnormal sound due to poor material.

No	5W + 1H	Number of Complaints
1	What	Abnormal sound from the machine on products
2	Why	Poor material selection
3	Who	Quality Control Department
4	When	When selecting materials and suppliers and when receiving incoming materials
5	Where	Motion Technology Electric & Machinery Co., Ltd., Taiwan
6	How	The above problem can be solved by: • Making a better selection of materials and suppliers • Do better incoming material inspection

Table 16. 5W + 1H on abnormal voltage due to unprovided audiometry test.

No	5W + 1H	Number of Complaints
1	What	Abnormal sound from the machine
2	Why	Audiometric tests are not carried out in a particular room
3	Who	Machinery operator
4	When	When performing an audiometric test
5	Where	Motion Technology Electric & Machinery Co., Ltd., Taiwan
6	How	The above problem can be solved by: • Provide a particular room for audiometric tests

Table 17. 5W + 1H on abnormal sound due to unscheduled maintenance time poor material.

No	5W + 1H	Number of Complaints
1	What	Abnormal sound from the machine
2	Why	There is no schedule for maintenance or inspection of the audiometric noise machine.
3	Who	Quality Control Department
4	When	When checking machines
5	Where	Motion Technology Electric & Machinery Co., Ltd., Taiwan
6	How	The above problem can be solved by: • Schedule regular machine maintenance and inspections

3.5. Control

3.5.1. Check Sheet for the Inspection Schedule for the Noise Audiometry Test Machine, Carried Out Once a Week

This check sheet is used to monitor the implementation of the noise audiometry test machine inspection, which is carried out every week. The form of the Check Sheet is shown in Figure 14.

WEEKLY AUDIOMETRIC NOISE MACHINE CHECK SHEET			
Month:			
Week	Date	Operator	Machine Condition
1			
2			
3			
4			
Month:			
Week	Date	Operator	Machine Condition
1			
2			
3			
4			
Month:			
Week	Date	Operator	Machine Condition
1			
2			
3			
4			

Figure 14. Weekly audiometric noise machine check sheet.

3.5.2. Check Sheet for Training Provided to Operators for One Month, Carried Out Every Two Weeks

This sheet monitors workers to keep up with the training according to the specified schedule, which is held twice a week for one month. The form of the Operator Training Sheet is shown in Figure 15.

OPERATOR TRAINING SHEET	
Name :	
Training Type :	
Date	Sign

Figure 15. Operator Training Sheet.

3.5.3. Sigma Level Control Sheet

This Sigma Level control sheet is used to control the company's Sigma Level on brushless motor products for each month. The goal is to find out what changes occur every month and whether the production process has decreased performance or increased performance. The form of the Sigma Level Control Sheet is shown in Figure 16.

Sigma Level Control Sheet (Year)				
Month	Production	Defects	DPMO	Sigma Level
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
Total				

Figure 16. Sigma Level Control Sheet.

After the company received the proposed improvement, MTM implemented the proposed improvement in January–May 2022. Production data and defective product data are shown in Table 12. Then, fill in the Sigma Level Control Sheet to determine the company's performance on brushless motor products after implementation, as shown in Table 18.

Table 18. Production and product defects data after implementation on January–May 2022.

Month	Production	Defects
1	76,363	20
2	51,041	13
3	89,649	23
4	88,674	17
5	63,670	33

Table 19 shows that the DPMO on brushless motors in January–May 2022 decreased from 2020 and 2021. In addition, there is an inclination toward the Sigma Level, the level in January–May 2022 rose to 5.44 from 301.24 in 2020 and 152.65 in 2021. This shows that the implementation of the proposed improvements can have a positive impact on MTM, especially brushless motor products.

Table 19. DPMO brushless motor January–May 2022.

Month	Production	Defects	DPMO
1	76,363	20	37.415
2	51,041	13	36.386
3	89,649	23	36.651
4	88,674	17	27.388
5	63,670	33	74.042
Average	73,879	21	40.993

4. Discussion

The Define stage serves to identify specifications from customers for good quality products or to find out what problems are in a process, system, or product. This stage is critical so that the initial identification is not wrong and affects the next step. The SIPOC diagram describes the scope of the MTM's business process flow, starting from ordering materials from suppliers, sending materials to companies, production processes at the company, and production results to shipping finished products to customers.

CTQ is used to describe what customers need for brushless motor products. In other words, CTQ can describe product standards expected by customers that are useful for providing satisfaction to customers. By fulfilling this CTQ, it can be said that the products produced are of high quality and follow the needs or standards of the customer. A good quality brushless motor based on CTQ is a brushless motor whose motor can function adequately, there are no physical defects in its appearance, stable electrical voltage, brakes on the engine that function properly, and do not make abnormal noises.

The Measure stage is the second stage that is useful for measuring the condition or level of quality control of the MTM for brushless motor products. However, before entering data processing, the data need to be tested first. The test carried out is the normality test of the data to determine whether the data used are normally distributed or not. The results of the data normality test show that the production data and defective products in 2020 and 2021 are normally distributed based on the normality test using the Minitab application.

DPMO is used in the Measure stage to determine the Sigma Level of the brushless motor product at the MTM. The MTM provides production data and data on defective products produced in 2020 and 2021 which are presented monthly. These data are used to research and measure the quality control of MTM in those two years. In 2020, the company produced a DPMO of 301.24 which decreased to 152.65 in 2021. If it is converted to a Sigma Level, in 2020, the Sigma Level for brushless motor products is 4.93, and in 2021, it is 5.11.

Furthermore, measurements were made using a Control Chart to determine whether the company's production process was running well. Based on the resulting Control Chart, in 2020, there are many points outside the control limit, which is 10 points. Five points are above the control limit, namely February, April, May, June, and September. Meanwhile, five points are under the control limit, namely January, July, August, and December. In 2021, there will be a decrease in the number of points that are outside the control limit, namely seven points, which is still considered quite a lot. Three points are above the control limit: June, October, and December. The four points that are under the control limit are in March, April, August, and November.

The Analyze stage is used to analyze the causes of process failures or the causes of product defects. The Pareto Diagram is used to show the number of complaints in the form of a graph. Based on the Pareto Diagram, it was found that most complaints were on poor product appearance, which was 33.3% of the total complaints, then the abnormal sound was 20.5%, motors that did not run well were 17.9%, brakes were not working well by 15.4% and unstable electricity voltage by 12.8%.

This Fishbone Diagram will describe the roots of the problem according to the factors that have been grouped. This study groups four factors that can be the root of the problem, namely workers, machines, methods, and materials. The Fishbone Diagram is done for every complaint that is already contained in the Pareto Diagram.

Failure Mode Effect Analysis (FMEA). FMEA explains the causes, impacts, and solutions to overcome the problems faced by the company. Then, FMEA will sort these problems based on the value of the Risk Priority Number (RPN). The RPN will show which problems cause the greatest risk, the greater the value of the RPN, the greater the risk and the problem becomes a priority to be overcome. The RPN value is the result of the multiplication of the Severity, Occurrence, and Detection values. Severity is a value that shows how much impact is caused by the problem, the greater the impact, the greater the Severity value. Occurrence is a value that shows how often the problem occurs, the more often it occurs, the greater the Occurrence value. Detection is a value that indicates how likely the system is to fail to detect the occurrence of the problem (failed to be detected), the more likely the system fails to detect it, the higher the Detection value will be. The three values are rated on a scale of 1–10. The assessment is carried out with the help of the SOD (Severity, Occurrence, Detection) scoring rubric table. The FMEA results on the MTM show that the unstable voltage problem in the product has the largest RPN value, which is 1930. The second largest RPN value is the sound produced by the abnormal product, which is 1910. The third largest RPN value is the problem of the motor not running normally, which is 1685. The fourth largest RPN value is the problem of poor product appearance, with a value of 1325. The fifth-largest RPN value is the problem of brakes not working normally, with a value of 1325. Through these results, it is found that the priority problem to be solved by the MTM is the occurrence of unstable electrical voltages in the product and the production of abnormal sound in the product. Both problems will be overcome by processing them at the Improve stage.

At abnormal voltage, 5W + 1H was carried out to find out how to overcome the problem of using bad materials, the absence of policies related to inspections, and the insufficient number of inspections carried out due to a lack of workers. With 5W + 1H, a solution is found to deal with these problems, namely by re-selection for better material and supplier selection and conducting good inspections when the material enters and is received by the company so that the company does not receive materials of poor quality or defects. In addition, the establishment of policies and rules for the inspection process so that inspections will be carried out by existing policies and rules, as well as providing training to workers to be able to carry out brief inspections at the end of each assembly process to prevent the escape of defective products. The next solution is to add workers so that workers do not do several jobs at once, so workers can focus on their work.

Meanwhile, to overcome the problem of abnormal sound in the product, 5W + 1H is used to overcome poor material selection, audiometric tests that are not carried out properly, and the absence of a schedule for maintenance of the Noise Audiometry Test machine. The solution obtained is to re-select the selection of materials and suppliers better and carry out inspections properly when the material enters and is received by the company so that the company does not receive a material of poor quality or defects. Then, provide a special room to do the Noise Audiometry Test so that the test results obtained are more accurate. Furthermore, forming a maintenance and inspection schedule for the Noise Audiometry Test machine regularly so that the machine becomes more well-maintained and can work optimally. After providing solutions and suggestions to the MTM at the Improve stage, the solution will be implemented by the MTM. After 5 months of implementing the solution, the results were obtained for the number of productions and the number of defective products produced at the MTM for brushless motor products, namely from January to May 2022.

Based on the results of the DPMO, it was found that the MTM experienced a decrease in DPMO in 2022 after the implementation of Six Sigma than the previous two years, which means that the proportion of defective products produced during the production process is decreasing. This has an impact on the value of the company's Failure Costs, where one of the 2022 Implementation Plans is to reduce the value of Failure Costs both internally and externally. Indirectly, the decrease in the proportion of defects in brushless motors has an impact on the company's Internal Failure Cost, which is because the value of Internal Failure Cost comes from costs incurred by the company when the production process cannot produce products by the company quality standards (producing defective products). It also quite affects the value of External Failure Cost, which is because the value of External Failure Cost comes from the costs incurred by the company when products whose quality does not meet company standards (defective products) are received by consumers (complaints, returns of goods, and so on).

Through the implementation of the Six Sigma method, MTM can also realize an implementation plan, namely improving the quality of suppliers as indicated by the reduction in the average number of defective materials received by the company from the supplier. The suggestion given to the company to overcome this is to conduct a re-selection for the selection of suppliers or materials. However, the company objected to being able to do this because there had been a long-standing cooperative relationship with the supplier company and it was difficult to find another supplier for some materials, so the company overcame this problem by negotiating with the supplier company to improve the quality of its products or the level of inspection so that the defective products received by MTM are minimal or even non-existent. The success of reducing the average number of defective materials from suppliers is shown in the 2021 data, the average defective material received by MTM per month is 31.17 while in January–May 2022, it becomes 21.2, which means it decreases by about 43%.

Another implementation plan that can be achieved by the company through the implementation of the Six Sigma method is the improvement of the inspection process where the number of samples taken is still insufficient, so several defective brushless motor products still pass the inspection process. This is one of the suggestions given to the company from the results of data processing with Six Sigma. The company increases the number of samples for inspection so that fewer defective products are produced. This is shown by the reduced proportion of defects produced by the company for brushless products in 2022 compared to 2021 or 2020, as seen in Table 20.

Table 20. Critical success factor improvement.

Critical Success Factor	2020–2021 (TQM/ISO 9001)	2022 (Six Sigma)	The Percentage Improvement
Operational efficiencies	7.2	7.5	3%
Cost optimization	6.8	7	2%
Revenue	7.5	8	5%
Product compliance	7.3	7.5	2%
On-time deliveries	7	7.5	5%

The implementation of Six Sigma started in the beginning of 2022. The implementation in MTM improves several metrics and aligns them with the goal of the organization. The score is collected from the expert, management staff, and Quality Assurance (QA) staff in the MTM company. The auditor of the MTM company places TQM using ISO 9001 as the current quality implementation method as the comparison. Therefore, based on the collection, it is shown that the Six Sigma method provides good improvement in the following metrics rather than TQM (Table 20).

There are several suggestions for MTM so that MTM can implement Six Sigma more deeply. When a company wants to measure the conditions on the Failure Cost value using Six Sigma, MTM must be able to prepare the necessary data related to the complete Failure Cost measurement. So, what must be done by MTM is to collect data better and more completely because, so far, the company has not been able to present complete data and data collection has not been carried out properly. This is because MTM has only conducted data collection related to Quality Costs for 2020 and 2021 so it cannot be carried out optimally.

Six Sigma can be used for more specific analysis of a certain number of products. Through this more specific analysis, it can produce more specific and more accurate results, so that the problems experienced can be resolved more optimally. So, to be able to apply and get specific results, MTM must be able to collect data better so that the data presented are more complete and specific.

Companies also need to do better data collection related to receiving complaints from customers. Data collection related to receiving customer complaints must be carried out specifically and can be integrated directly into production data. This is intended to be able to find out which product the complaint came from in the production process so that it can be easier to find out the cause of the problem that occurred.

The company's inspection process has been successfully improved by the company as evidenced by the decrease in the number of defective products produced. However, the company only increases the number of samples or the number of inspection processes carried out. This addition is not based on a standard. Companies need to implement a standard that can determine the number of samples needed for the inspection process so that the inspection process can be carried out optimally but with efficient time. Companies can use a standard that is the Acceptable Quality Level (AQL). AQL can determine the number of samples the company needs for each lot, so the company conducts the number of samples according to the standard so that the sampling or inspection process can run efficiently and maximally.

One of the biggest problems experienced by the company is that many defective materials are received from suppliers. The company has made a decision by negotiating or communicating related to the quality of the material sent to the supplier so that it can send material with good quality and few or no defects. This is done by the company because the company cannot replace suppliers. After all, long cooperation has been established. However, this decision was quite successful, as evidenced by the decrease in the number of defective materials received by the MTM. Even so, the company must dare to decide to change suppliers or conduct re-election selection for suppliers, if something similar happens. Companies can make choices using the Analytical Hierarchy Process (AHP), which is a method used in decision-making when the situation or problem experienced is not structured and grouped into a hierarchical arrangement by setting the highest priority. That way, MTM can make a supplier selection based on material quality, price, on-time delivery, after-sales process (warranty), and several other important elements that need to be considered in supplier selection.

The main advantage of Six Sigma compared to other approaches to quality control is that Six Sigma is customer driven. Six Sigma is defined as a limit of 3.4 defects per one million products or service processes, where anything not acceptable to the end customer is considered a defect. Six Sigma addresses the entire process behind the production of an item or completion of a service, rather than just the final outcome. The phased thinking and clear roadmap provided by the basic DMAIC method can be a valuable tool when applied to any business case. The right basic of DMAIC as the problem-solving approach can drive Lean Six Sigma. So, it can make it easier for Lean Six Sigma to streamline their processes and offer as much value to the customer as possible.

When the company experiences improvements in its brushless motor products and can consistently be in that position by using Six Sigma, then MTM can continue it to the Lean Six Sigma stage. However, when MTM cannot improve their quality with the implementation of Six Sigma, marked by a significant increase in the proportion of defects, or the company cannot maintain the positive impact of the proposed results implemented in the future, then the company is advised to replace the Six Sigma method with Design for Six Sigma (DFSS). The DFSS method is recommended to be applied when the Six Sigma method cannot have a positive impact on the company. Six Sigma serves to measure the quality of a process or a system, while DFSS serves to obtain customer satisfaction from a process so that at this stage, design and improvement suggestions are obtained. The initial stage that will be carried out in DFSS is to redesign the production system and product.

5. Conclusions

The incoming customer complaints to MTM related to brushless motor products made a new dilemma for the company. Therefore, the implementation of SixnSigma is done to identify the root cause of incoming customer complaints. According to the CTQ tree diagram, the customers need a high-quality brushless motor, which meets the requirements such as the motor can work well, there are no physical defects in the product, the stable electrical voltage on the product, brakes can work well, and no abnormal sound.

1. The Pareto Diagram presents data that the most complaints received by MTM on brushless motor products are poor physical appearance at 33.33%, then the sound is not normal at 20.51%, the motor does not run normally at 17.95%, brakes do not work normally by 15.38%, and unstable voltage by 12.82%. To overcome those root causes problem, the 5W + 1H tool is used in this research. This tool is used to support determining a needed improvement to be applied in the MTM company.
2. 5W + 1H solves to overcome these problems by conducting better material and supplier selection, conducting material inspections every time it enters the company, establishing policies and rules related to inspections, providing training to workers to carry out inspections at the end of the assembly process, enhancing the number of workers, providing a special room to carry out Noise Audiometry Tests, and making maintenance and checking schedules for Noise Audiometry Test machines.
3. After the MTM implements the proposed improvement, the Control stage is carried out to ensure that the proposed improvement runs as expected, such as a check sheet for the inspection schedule for the Noise Audiometry Test, which is carried out once a week, and a check sheet for training provided to operators for one month, which is carried out every two weeks. The implementation leaves a good impact for the company, especially at the Sigma Level.
4. Sigma Level control shows that there is an increase in the Sigma Level in brushless motor production because the DPMO value produced has decreased between 2020 and 2021. The Sigma Level from January to May 2022 is 5.44, which increased from 2020, which is 4.93, and 5.11 in 2021. Due to the improvement of the Sigma Level in MTM, it is proven that Six Sigma is a good method to be applied in overcoming the customer complaints problem.

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