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APPLICATION OF PDCA METHOD IN IMPROVING THE QUALITY OF VALVE PRODUCTION

Dian Putrawangsa[1], Agustinus Caniago[2], Samuel Aprilio[3], Thedy Yogasara[4]
Faculty of Industrial Technology, Parahyangan Catholic University[1,2,3,4]
Email: dian_20190275@unpar.ac.id[1], agustinuscaniago98@gmail.com[2], apriliosamuel1304@gmail.com[3], thedy@unpar.ac.id

ABSTRACT

Plastic is one of the most widely used raw materials for a product. Human life cannot be separated from products or equipment made from plastic. Company X often has problems with the quality of the products produced, especially valve products as products that are produced every day. The corrective step used to assist Company X in improving the quality of valve products is the application of the PDCA method. PDCA method consists of the plan, do, check, and act stages. The proposed improvement design was carried out based on the results of data processing and obtained as many as 9 proposed improvements. In the do stage, implementation of the proposed improvements that have been designed is carried out, five proposed improvements can be implemented and the other four in the form of recommendations. Next is the check stage, which is the process of collecting data again on the results of the implementation of the proposed improvement. Based on the results of the check stage, a standardization process was carried out at the act stage to improve the performance of the proposed improvement and the quality of the valve product. Standardization is done by changing or improving the proposed improvements that have been implemented. Research has succeeded in reducing the number of defective valve products with the proportion of defects that were previously 1.16% to 0.57%.

KEYWORDS Total Quality Management, PDCA, Plastic, Improvement

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INTRODUCTION

In general, plastic is used as the basic material for a product that is used in everyday life. The plastics used have basic materials or materials that vary greatly in terms of characteristics, properties, and functions. Examples of these plastic base materials are Polyethylene (PE), Polypropylene (PP), Polyvinyl chloride (PVC), and many others. The use of these plastic base materials can be adapted to the products that will be used in everyday life. In addition, plastics have flexible properties so they can be a special solution that can be considered to meet needs in limitless products, applications, and sectors.

Human life cannot be separated from products or equipment that support daily life, especially products made of plastic. According to Schmaltz et al. (2020), the use of plastic has increased sharply because of its benefits in various fields. Along with the times, the use of plastic is increasing so plastic companies are increasingly advancing in the process of producing plastic-based equipment. The higher the level of plastic use in the world, the higher the level of plastic production in the world. This is by the high demand which causes the supply (supply) to be higher as well.

Plastics Europe (2021) explains that the world's plastic production in 2020 has reached 367 million tons produced for various types of products used by various groups of people. Asia itself has contributed to plastic production of around 52% of global plastic production, one of which was contributed by Indonesia (Plastics Europe, 2021). Plastic production in parts of the world is expected to continue to increase from year to year. Of course, this is a good opportunity for plastic companies in the world. Plastic companies can be referred to as manufacturing companies, where companies carry out the production process from raw materials, and semi-finished goods, to certain finished goods. Company X is a company engaged in the production of plastic products, such as household appliances and other daily necessities. In producing a product, of course, a company has a production target that is useful to meet the level of demand and customer satisfaction.

Of the various plastic molding methods, injection molding is a prevalent method to apply. According to Lee et al. (2022), injection molding is a method of making plastic products by injecting hot plastic melt through the cavity into the mold, the plastic melt follows the shape of the mold and undergoes cooling to become a finished product. This plastic injection process is carried out in three stages, namely charging, pressing, and holding with the help of piston pressure during these processes (Alonso-González, Felix, & Romero, 2022; Lee et al., 2022).

A company has problems to deal with. If there is no improvement or development, then the problem can hamper the existing processes within the company, both in terms of meeting daily targets or target consumers that have been determined. In the implementation of the company's production process, various problems can be found and one of them is the poor production process. Problems in the production process have an impact on other processes in the company so it is considered very disturbing because it affects the delivery of finished goods to consumers and the accuracy of completing existing orders. Therefore, the products produced by the company must comply with existing standards and specifications to be accepted by consumers during the marketing process. This is also like what is happening in industries in the world that want to achieve improved performance and product quality to achieve profitability, sustainability, market share, and competition with competitors (Costa, Lopes, & Brito, 2019; Daniyan, Adeodu, Mpofu, Maladzhi, & Kana-Kana Katumba, 2022)

Several general problems have been identified in Company X. These problems were collected before further research was carried out, which are as follows:

1. Excessive number of defects in the product.

The observations made were to observe the production of plastic products in Company X and it was found that defective products were often produced. There are many defective products for each type of product produced by an injection molding machine. Defects that often occur are flashing, short mold, black dot, splay, and many others.

2. There is no display of information about the condition of the machine during the production process.

PPIC, Materials, QC, and other parties who need to know the condition of the machine, the products produced, and other necessary information must always come to the production site of each machine and ask the operator who works on the machine for the required information.

3. Layout of machines and supporting facilities that are not neat.

Based on the observations made, the placement of machines and equipment on the production floor is very irregular. The production floor is often blocked by packaging or storage of finished goods so that it interferes with travel on the production floor.

4. Inventory of raw materials and finished goods is often insufficient.

Observations were made at the raw material storage warehouse and it was found that the company ran out of raw materials to produce one of the products which caused the company to have to wait for additional raw materials to arrive, so additional time was needed to be able to fulfill consumer orders.

5. Personal Protective Equipment (PPE) is not completely available.

The company only provides gloves at the start of work. Meanwhile, other protective equipments, such as masks and earplugs are not provided by the company.

6. Lack of communication between each division.

In the communication flow that exists on the production floor, information is still managed manually and independently so that any data needed in a particular division must be asked directly to the relevant division.

After identifying several problems that occur in Company X, the next stage is to choose one problem that has the highest priority compared to other problems. Based on the selection of priority problems, the problem that is the subject of research is the problem of defects in the product in an excessive number of defects in the product. Based on the the proportion of defective products from Company X, it was found that valve products have the highest proportion of defective products, which is 1.53% compared to other products.

RESEARCH METHOD

This research uses quantitative research methods by applying the tools and analytical methods included in the selected method. Several methods can be used to reduce defects in the production process. The methods in question are the PDCA method (Tague, 2005) and Six Sigma DMAIC (Webber & Wallace, 2007). PDCA is a method to improve product quality by implementing the plan, do, check, and act processes. (Tague, 2005). The Six Sigma DMAIC method is a method that can also be used to make process improvements so that defective products can be reduced (Webber & Wallace, 2007). However, of the two methods, the PDCA method was chosen because the time difference in PDCA implementation was less than the DMAIC method considering the time limitations of the study. PDCA offers significant advantages for attracting stakeholders, quickly verifying concepts, and generating new improvement ideas (Rajagopalan, 2020; Raza, Malik, & Bilberg, 2021).

The plan stage in PDCA includes the define, measure, and analyze stages in DMAIC, thus indicating that PDCA requires a more concise implementation stage than DMAIC. However, in its implementation, the PDCA cycle is still carried out in the same way as DMAIC (Scheller, Sousa-Zomer, & Cauchick-Miguel, 2021).

RESULT AND DISCUSSION

The research will enter the implementation of the stages in PDCA, which is as follows:

A. Plan

The research was conducted by collecting data on the number of defective valve products and the types of defects during the period of practical work carried out. The step after data collection is done is to process it into the form of a control chart or control chart. The purpose of making this control chart is to become a comparison performance parameter between the production results before the proposed improvement is implemented and after the improvement proposal is implemented. The data obtained during the data collection process is attribute data. Table 1 is a recapitulation of the calculation of the LCL, CL, and UCL proportion values for all replications after deletion of OOC (*out of control*) events.

Table 1. p-Chart of Valve Products in Current Condition

No	Production (Unit)	Defective Product (Unit)	$\hat{p}$	LCL	CL	UCL
1	20.593	263	0,0128	0,0093	0,0116	0,0138
2	24.373	326	0,0134	0,0095	0,0116	0,0136
3	24.309	300	0,0123	0,0095	0,0116	0,0136
4	23.497	301	0,0128	0,0095	0,0116	0,0137
5	24.993	323	0,0129	0,0096	0,0116	0,0136
6	24.508	303	0,0124	0,0095	0,0116	0,0136
7	22.622	241	0,0107	0,0095	0,0116	0,0137
8	20.768	254	0,0122	0,0094	0,0116	0,0138
9	25.029	208	0,0083	0,0096	0,0116	0,0136
10	24.448	309	0,0126	0,0095	0,0116	0,0136
11	26.508	285	0,0108	0,0096	0,0116	0,0136
12	19.528	221	0,0113	0,0093	0,0116	0,0139
13	26.514	293	0,0111	0,0096	0,0116	0,0136
14	22.378	221	0,0099	0,0094	0,0116	0,0137
15	24.351	280	0,0115	0,0095	0,0116	0,0136
16	22.724	265	0,0117	0,0095	0,0116	0,0137
17	22.634	281	0,0124	0,0095	0,0116	0,0137
18	19.683	156	0,0079	0,0093	0,0116	0,0139
19	19.004	110	0,0058	0,0093	0,0116	0,0139
20	16.744	216	0,0129	0,0091	0,0116	0,0141
21	20.892	147	0,0070	0,0094	0,0116	0,0138
22	12.517	157	0,0125	0,0087	0,0116	0,0145
23	12.350	165	0,0134	0,0087	0,0116	0,0145
24	15.354	167	0,0109	0,0090	0,0116	0,0142
25	12.783	184	0,0144	0,0087	0,0116	0,0144
26	15.291	211	0,0138	0,0090	0,0116	0,0142
27	13.641	162	0,0119	0,0088	0,0116	0,0143
28	15.259	214	0,0140	0,0090	0,0116	0,0142
29	12.935	171	0,0132	0,0088	0,0116	0,0144
30	14.674	171	0,0117	0,0089	0,0116	0,0142
31	15.368	189	0,0123	0,0090	0,0116	0,0142
32	13.547	151	0,0111	0,0088	0,0116	0,0143
33	14.217	160	0,0113	0,0089	0,0116	0,0143

34	13.761	179	0,0130	0,0088	0,0116	0,0143
35	14.874	210	0,0141	0,0090	0,0116	0,0142
TOTAL	672.671	7.794				

The next step after calculating all the new proportion values, CL, UCL, and LCL is making a control chart as a visualization of the calculation. Figure 1 is the p-chart on the valve product.

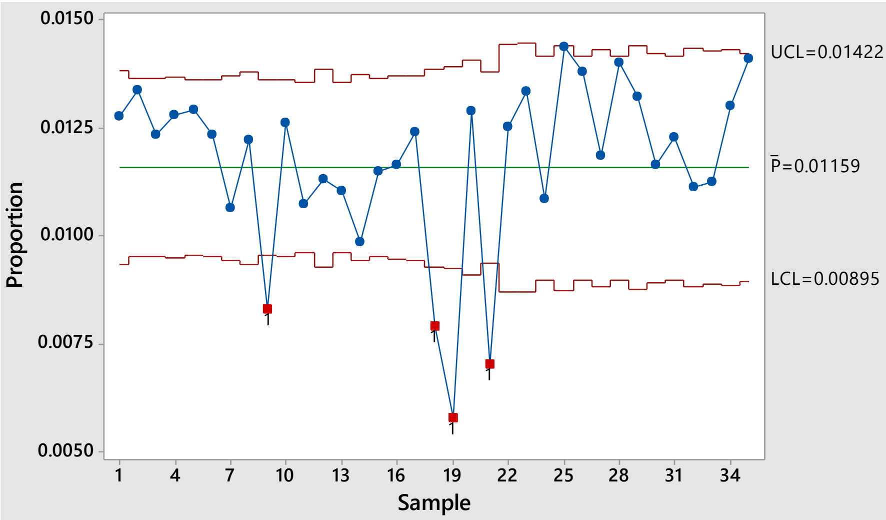


Figure 1. p-Chart for Valve Product in Current Condition

Next, a Pareto diagram is designed to identify which types of defects are the most common or most common for valve products. Figure 2 is a Pareto diagram for the types of defects in valve products. Based on Figure 2, short mold, flashing, and black dot defects are the most common types of defects, so they were chosen to be the focus of improvement in the research. For this research, short mold was chosen as the type of defect that would be more focused to be improved. Examples of short mold defects in valve products can be seen in Figure 3.

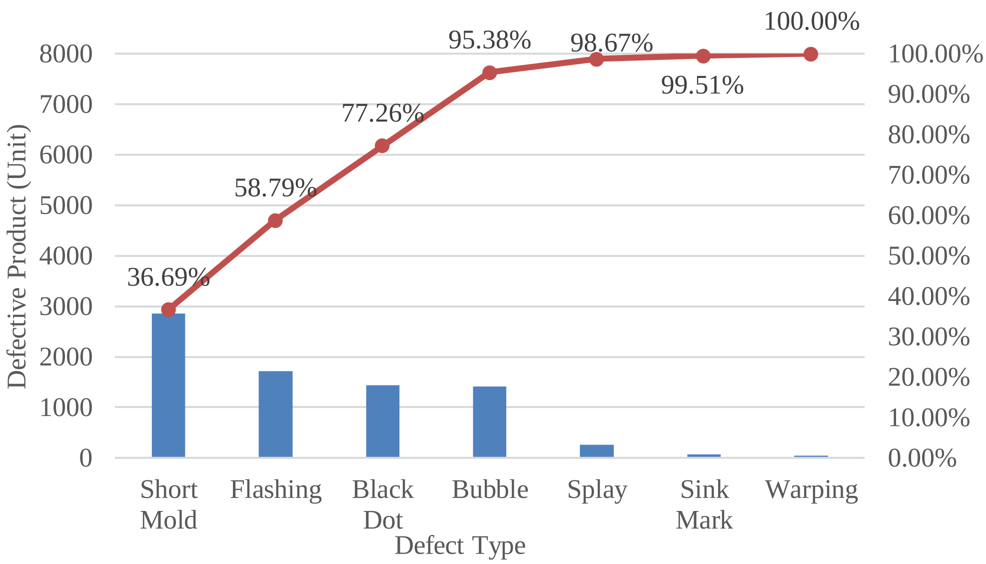


Figure 2. Pareto Diagram of Valve Products in Current Condition

The root causes of the short mold defects were found along with proposed improvements based on the root causes of the existing problems. Proposed improvements for each root cause can be the same if the root causes are interconnected. Table 2 is a proposed improvement for each existing root cause.

Table 2. Proposed Solution of Short Mold Defects in Valve Products

No	Cause of Defective	Suggestions for Improvement
1	Newly employed operators	Provide training that contains counseling, direction, and guidance regarding the plastic production process using an injection molding machine
2	Buttons and displays on machines using foreign languages that are difficult to understand	Create a visual display on the injection molding machine button
3	There is no SOP for engine calibration	Creating SOPs about injection molding machine calibration
4	The use of an old machine	Perform regular maintenance of the old injection molding machine
5	The mold locking system is not functioning properly	Make a visual display for mold locking on the injection molding machine
6	Nozzle is not cleaned regularly	Making SOPs for nozzle cleaning on injection molding machines
7	The material sack is not closed	Practicing the habit of closing the sack of material before and after use using a sack binding aid
8	There is no fixed place to store material for production	Provide direction to the operator to always directly use the material from the material sacks that have been opened so that they are neatly arranged and clean
9	The operator forgot to find a cover to close the hopper	Make SOPs and Visual Display regarding the closing of the hopper on the injection molding machine

Based on Table 2, the following are ten improvements that can be described to overcome the short mold defects of valve products.

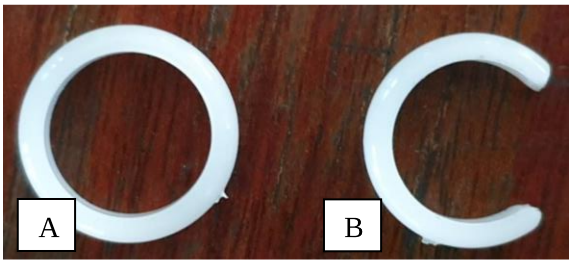


Figure 2. Comparison of Valve Product: Good Quality (A) and Short Mold (B)

1. Newly employed operators

The proposed solution is given in the form of providing training that contains counseling, direction, and guidance regarding the process, way of working, and how to overcome defects in the plastic production process using an injection molding machine. The aim is to make new operators can understand how to prevent and overcome the defects that occurs in the product produced. The following is a procedure for carrying out training for new operators:

a. The training is conducted in the first shift (07.00 to 15.00) on Saturday when there are new operators who want to work. Therefore, it is very possible that orders have been fulfilled or production needs have decreased so that permanent operators or those who have worked in the company for a long time can assist the company in training new operators.
b. The training was carried out by bringing new operators around the production floor and trying to operate the machine with the help and guidance of the permanent operator.
c. New operators are explained about the possibilities of frequent engine damage and how to prevent or overcome them precisely and quickly.
d. The new operator is explained about the type of defect in the product that occurs during the production process and how to identify and overcome the possibility of the defect again.

2. Buttons and displays on machines using foreign languages that are difficult to understand

A visual display is needed to overcome this. One of them is making a sticker for the engine operating instruction button using Indonesian. Making a visual display in the form of a sticker for the injection molding machine button follows the size of the button that already exists on the machine. Figure 3 is the example of visual display used on egnine's buttons.

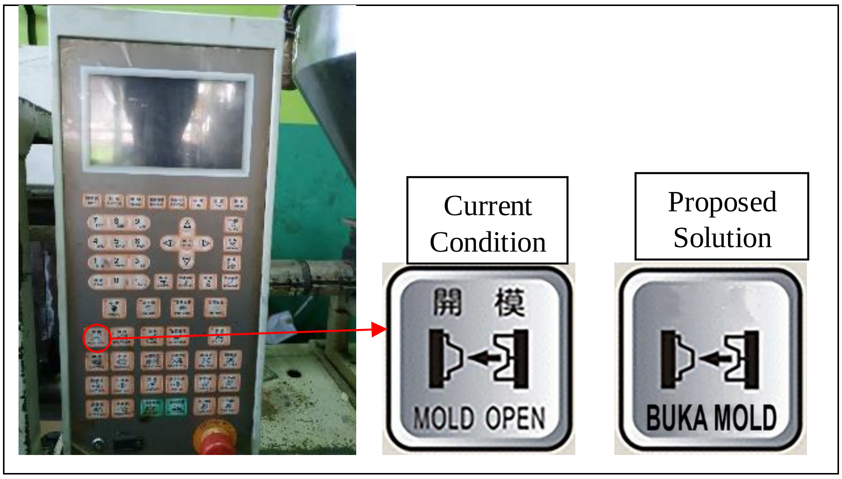


Figure 3. Proposed Solution for Visual Display on the Button

3. There is no SOP for engine calibration

The proposed improvement that can be designed is to create an SOP (Standard Operating Procedure) regarding the machine setup process carried out at the beginning of the production week or every time the machine is needed a setup process.

4. The use of an old machine

The proposed improvement that can be designed is to carry out regular maintenance of the injection molding machine to prevent the occurrence of a sudden broken-down, and other things.

5. The mold locking system is not functioning properly

The corrective step that needs to be done is making a visual display that is useful to remind the operator to always make sure the mold lock is functioning and locked properly. The following is a calculation for determining the font size on the print lock visual display and an example of the visual display.

Snellen acuity (S)	= 20
Distance from eyes to object (D)	= 900 mm
Ratio (R)	$= \frac{1}{8}$
Letter thickness (Ws)	$= 1{,}45 \times 10^{-5} \times 20 \times 900$
	= 0,261 mm
Letter height (H_L)	$= \frac{0{,}261}{\frac{1}{8}}$
	= 2,088 mm
Letter width (W)	$= \frac{3}{5} \times 2{,}088$
	= 1,2528 mm
Distance between letters	$= \frac{1}{4} \times 2{,}088$
	= 0,522 mm
Distance between words	$= \frac{2}{3} \times 2{,}088$
	= 1,392 mm
Distance between lines and sentences	$= \frac{2}{3} \times 2{,}088$
	= 1,392 mm

The following is a visual display for locking the mold on an injection molding machine with a paper size of 290 x 90 mm.

Figure 4. Proposed Visual Display for Mold Locking System

6. Nozzle is not cleaned regularly

Proposed improvements that can be made to overcome these causes are to create and design an SOP that discusses the obligations in the process of checking the readiness of the machine before the injection molding machine is used. In addition, it can also contain the injection molding machine maintenance process, especially on the nozzle part properly and correctly regularly.

7. The material sack is not closed

Proposed improvements that can be made are to establish good habits by closing the sacks of materials or raw materials needed before and after use. The suggestion given was also in the form of providing an alternative sack cover in the form of a rope. The purpose of the sack cover is to maintain and guarantee the quality of the raw materials in the sacks even though they are already open so that it is more likely that dirt or foreign components will enter the sacks of the materials used.

8. There is no fixed place to store material for production

The proposed improvement given is to direct the operator to always immediately use raw materials or materials from material sacks that have been opened so that they are not scattered and do not become mixed with other materials. In addition, operators who still need material sacks are advised to place the material sacks in the corner of the production floor room so as not to interfere with the material handling process or operator movement on the production floor.

9. The operator forgot to find a cover to close the hopper

Proposed improvements that can be made to the root of the problem are making SOPs for hopper closures so that operators always follow these directions. This hopper closing SOP is made and combined with other SOPs in the same place so that operators who want to carry out production activities on the machine concerned can immediately read all existing SOPs because they are placed in the same place and easy to pick up. In addition, it is necessary to have a visual display that is easily seen by the operator to close the hopper before and after use. The following is an example of a visual display measuring 290 x 80 mm for the closure of the hopper based on calculations that have been carried out previously, which is the same as forming a visual display for locking molds or molds on an injection molding machine.

Figure 5. Proposed Visual Display for Closing the Hopper

B. Do

After planning improvements, then the next process is the implementation or application of the proposed improvements that have been made in the plan section of the production process. Proposed improvements to be implemented are the application of SOPs to properly carry out the machine setup process, SOPs and visual displays for hopper closures, visual displays for locking molds or molds, and suggestions for repairing sack binders to overcome open material sacks. Figure 6 is the implementation of the SOP installation of the setup process on the injection molding machine for valve production at Company X.

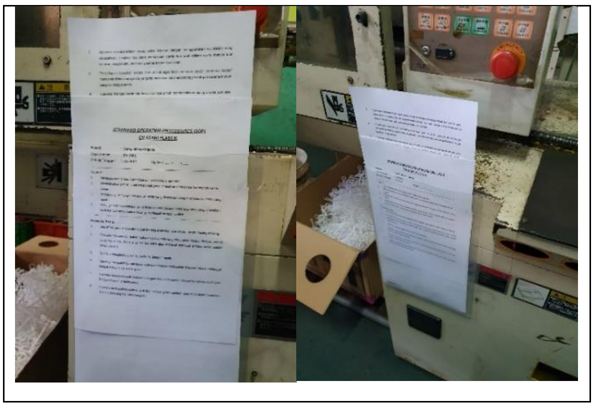


Figure 6. SOP Implementation Machine Setup Process

A visual display for closing the hopper is mounted on the neck of the hopper so that the operator always remembers to close the hopper when in use or not when in use. The following is an implementation of the installation of a visual display for closing the hopper on an injection molding machine.

Figure 7. Hopper Closing Visual Display Implementation

The mold locking visual display is mounted on the cover glass of the injection molding machine so that the operator always remembers to check the condition of the mold when it is used or when trying to set up the machine. Figure 8 is an implementation of a mold locking visual display mounted on the cover glass of an injection molding machine.

Figure 8. Mold Locking System Visual Display Implementation

The final improvement proposal that was implemented was the process of tying sacks as anticipation to overcome the root cause of the problem of open material sacks which could cause dirt or dust to enter the mixed material sack. The proposed improvement is to provide raffia rope as a tool to bind and cover material sacks. Figure 9 is a comparison of the current condition of the material sacks with the proposed improvements that have been applied to Company X.

Figure 9. Sack Binding Implementation

In addition to the proposed improvements that have been implemented as described previously, there are suggestions for improvements that become recommendations and are only submitted directly to the company manager.

C. Check

After the implementation stage or the implementation of the proposed improvements made to the company, an examination will be carried out on the condition of the production process at Company X in producing valve products. The check process is carried out by re-observing the valve product production process after the proposed improvement has been applied for a certain period to find out whether the proposed improvement is indeed effective or not. After making observations to get new data, the next step is making a new control chart to show the changes. The check stage is also carried out on proposed improvements in the form of recommendations only, namely by verifying the company represented by the company manager.

The new control chart was designed based on 17 new data taken during the period of re-observation at the company after the recommendations for improvement were implemented. Table 3 is a recapitulation of the calculation of proportion, CL, UCL, and LCL for all data.

Table 3. p-Chart of Valve Products After Improvements

No	**Production (Unit)**	**Defective Product (Unit)**	$\hat{p}$	**LCL**	**CL**	**UCL**
1	15.387	68	0,0044	0,0039	0,0057	0,0075
2	16.712	78	0,0047	0,0040	0,0057	0,0075
3	14.531	93	0,0064	0,0038	0,0057	0,0076
4	12.668	68	0,0054	0,0037	0,0057	0,0077
5	15.094	105	0,0070	0,0039	0,0057	0,0076
6	13.842	53	0,0038	0,0038	0,0057	0,0076
7	13.007	75	0,0058	0,0037	0,0057	0,0077
8	11.986	76	0,0063	0,0037	0,0057	0,0078
9	14.418	108	0,0075	0,0038	0,0057	0,0076
10	15.817	88	0,0056	0,0039	0,0057	0,0075
11	16.228	76	0,0047	0,0039	0,0057	0,0075
12	15.667	88	0,0056	0,0039	0,0057	0,0075
13	14.223	97	0,0068	0,0038	0,0057	0,0076
14	16.543	112	0,0068	0,0040	0,0057	0,0075
15	13.693	86	0,0063	0,0038	0,0057	0,0076
16	14.237	90	0,0063	0,0038	0,0057	0,0076
17	12.984	51	0,0039	0,0037	0,0057	0,0077
TOTAL	247.037	1.412				

After obtaining all the values needed for each data, the next step is to create a control chart. Figure 10 is a p-chart produced with the help of the MINITAB program. Based on Figure 10, it can be seen that there are no processes outside the UCL and LCL limits, it can be concluded that all processes on the control chart are already in control condition, so there is no need for a revision process on the control chart. After the formation of a control chart for production results after the implementation of the proposed improvement, a comparison of the results with the current condition or before the proposed improvement is carried out.

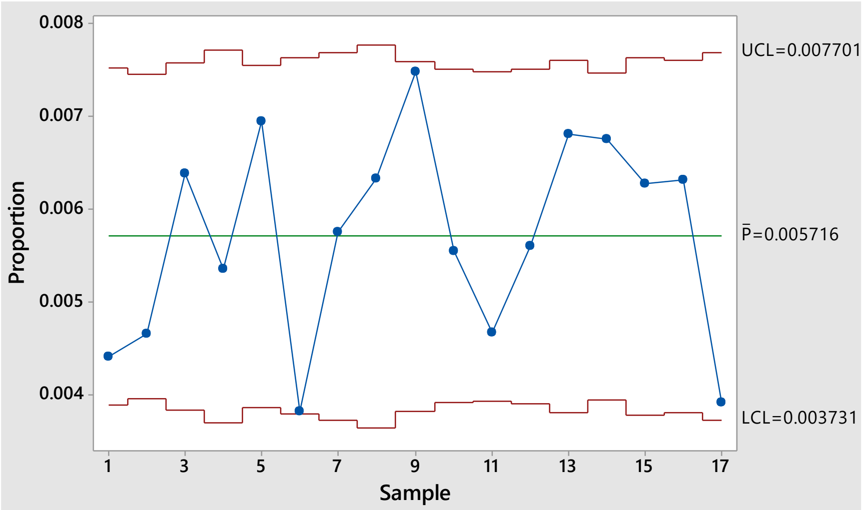
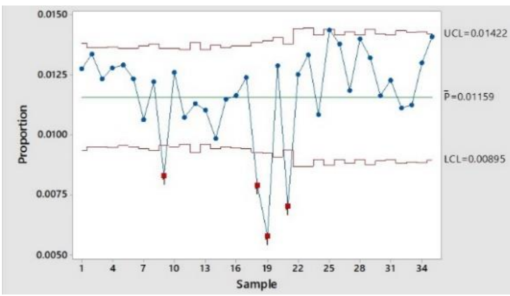
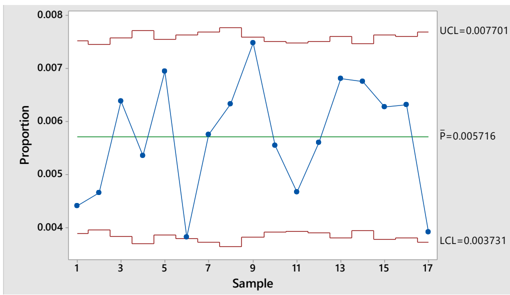


Figure 10. p-Chart for Valve Product After Improvements

Table 4 is a comparison of the control chart of the valve production results. Based on Table 4 it can be seen that the values of CL, UCL, and LCL generated on the p-Chart after the proposed improvement on the valve product production process are smaller or decreased compared to the current condition or before the proposed improvement was implemented, so it can be said that the proposed improvement that has been implemented have been effective in reducing the number of defective products produced and improving the quality of the resulting valve products. This shows that the implementation of proposed improvements to overcome the types of short mold, flashing, and black dot defects have succeeded in reducing the proportion of defective valve products as a whole. The percentage of defective products as a whole has decreased compared to those in the current condition or before the repair, which is 0.57% compared to 1.16%. In addition, this decrease has also succeeded in bringing valve products to the target desired by the company, which is to produce a proportion of defective products that are below 1% as the maximum limit for the proportion of defective products desired by the company.

Table 4. Control Chart Comparison of Valve Production Results

Comparison	
Before Improvements	**After Improvements**
 CL = 0,0116 UCL = 0,0140 LCL = 0,0092	 CL = 0,0057 UCL = 0,0076 LCL = 0,0038

D. Act

The last step is to carry out the act stage which is useful for carrying out adjustment actions when needed. After the implementation process or implementation and examination of the proposed improvements that have been applied to Company X, it can be seen that quality problems that occur in valve products can be minimized, especially in the problem of the number of defective valve products of short mold, flashing, and black dot types. In addition to maintaining the proposed improvements that have been implemented, steps in the act are also carried out by making improvements or developments from the proposed improvements that have been implemented.

Table 5. Standardization of Implemented Improvements

No	Implemented Improvements	Impact of Implementing Improvements	Standardization
1	Installation of machine setup process SOPs	Machines rarely undergo a re-setup process in the middle of the production process	Coating the SOP sheet with plastic or laminate and fixing it all over the injection molding machine
2	Hopper closing SOP installation	Operators close the hopper more often after loading the material into the hopper	Coating the SOP sheet with plastic or laminate and fixing it all over the injection molding machine
3	Visual display installation for hopper closing	Operators close the hopper more often after loading the material into the hopper	Covering the visual display mounted on the hopper with plastic
4	Visual display installation for mold locking system	Mold rarely loosens	Covering the visual display mounted on the hopper with plastic
5	The use of binders on material sacks	Material sacks are rarely spilled and scattered	Replacing raffia rope as a material sack binder with a clamp tool

CONCLUSION

Based on the research objectives that have been described in the introduction and the data collection and processing process as well as the preparation of improvement proposals, several conclusions can be drawn, namely, the types of defects in valve products that have been identified in Company X are short mold defects, flashing, black dot, bubble, splay, sink marks, and warping with the most defects occurring are short mold defects, flashing, black dot. The causes of defects in valve products are newly employed operators, buttons and displays on machines using foreign languages that are difficult to understand, there is no SOP for engine calibration, the use of an old machine, the mold locking system is not functioning properly, nozzle is not cleaned regularly, the material sack is not closed, there is no fixed place to store material for production, the operator forgot to find a cover to close the hopper.

Proposed improvements that can be given to Company X in reducing the number of defective valve products are: provide training that contains counseling, direction, and guidance regarding the plastic production process using an injection molding machine; create a visual display on the injection molding machine button; creating SOPs about injection molding machine calibration; perform regular maintenance of the old injection molding machine; make a visual display for mold locking on the injection molding machine; making SOPs for nozzle cleaning on injection molding machines; practicing the habit of closing the sack of material before and after use using a sack binding aid; provide direction to the operator to always directly use the material from the material sacks that have been opened so that they are neatly arranged and clean; make SOPs and Visual Display regarding the closing of the hopper on the injection molding machine.

The number of defective valve products resulting from the proposed improvement compared to the current condition effectively decreased with the percentage of the proportion of defects produced being 0.57% compared to the previous 1.16%. The proportion of defects in valve products is also below the maximum limit for defective products tolerated by the company, which is below 1%.

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