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Minimizing Product Defects Based on Labor Performance using Linear Regression and Six Sigma Approach

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Abstract
The objective of this research is to minimize product defects based on labor performance and prove the hypothesis on how labor performance affects the quality of a product through a scientific calculation using Overall Labor Effectiveness (OLE). The primary data is obtained by interviewing the supervisor and labor directly. For secondary data is obtained from the company, such as labor working time, machine scheduled downtime, total production, and defective products. The approach to extract the data is using OLE and the continued regression method. Furthermore, it proceeds to Six Sigma using the DMAIC approach since the results show a significant correlation. The result from Failure Mode and Effects Analysis (FMEA) shows four of six potential failures caused by product defects are coming from labor. To prevent failure mode, it is recommended to have the regular machine checked by labor, check the temperature of the machine, and provide Standard Operating Procedures.

Keywords
Labor Performance, Overall Labor Effectiveness, Defective Products, Six Sigma, DMAIC Approach.

Introduction

Increasingly, managers and staff are under constant pressure to conceive and execute ways of improving business performance, including labor performance (Manual, 2006). Labor is one of the most influential assets in any industry due to a significant amount of the production cost spent on it (Rizzitano et al., 2021). Therefore, the improvement in labor productivity compensates for the incurred costs. Labor performance also affects product quality, which in turn, plays an important role as a function of cost (Rizzitano et al., 2021). The greater the total number of poor-quality products (product defect), the greater the cost that the company needs to spend and the lesser the income the company could get through its production (Bakiko et al., 2020). The concept applied by many companies to run their system is to have good labor performance, maximize the production rate, and minimize the cost spent (Bakiko et al., 2020). Both maximizing the production rate and minimizing the cost spent can be well resolved if the company has good labor performance. This means that those three factors are strongly correlated with each other. From the above explanation, labor performance should be good if the Overall Labor Effectiveness (OLE) value at least follows the world standard of 85%.

Overall Equipment Effectiveness (OEE) and the OLE are simple and practical production management tool, which has been widely used (Iryna et al., 2020). OLE has become a management tool that is designed to better understand the effects workforce performance has on overall manufacturing performance (Karbasian & Rostamkhani, 2020). OLE is categorized as one of the key performance indicators (KPI) that companies often use to evaluate labor performance. OLE has three main components which are availability, performance, and quality. In calculating

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OLE, those three components need to be calculated first. After that, OLE can be defined by multiplying those three components.

This research is conducted in a manufacturing company that serves mineral water. The observation is focused on labor performance in the production division. This paper focuses on the correlation between labor performance and the quality of the product.

Table 1 shows the data of OLE. The result of OLE is obtained by multiplying the Availability (A), Performance (P), and Quality (Q). This paper utilizes Eqs. (1)–(3) to evaluate the Availability, Performance, and Quality. The average value of OLE from January until November 2021 is 76%, which is below the world standard (85%) and has a direct impact on the production process, resulting in the quality of products. This problem needs to be evaluated so the company can have better performance in terms of labor productivity and product quality.

Table 1
Overall labor effectiveness data

Months	A	P	Q	OLE
January	86%	96%	92%	76%
February	85%	81%	93%	64%
March	86%	97%	93%	77%
April	85%	97%	94%	78%
May	84%	88%	95%	71%
June	86%	105%	95%	86%
July	85%	99%	94%	79%
August	84%	97%	95%	77%
September	83%	98%	95%	77%
October	83%	102%	94%	80%
November	82%	99%	94%	76%
			Average	76%

The data about product quality can be seen in Fig. 1. The total number of product defects is still high and fluctuating. The defects occur from several parties, such as suppliers, labor, and machines. Those factors that affect the existence of product defects can be controlled. Since suppliers are external factors, the company cannot control them. However, the company can control itself in terms of labor and machines. It is known that the machine also has an important regular maintenance schedule. Moreover, labor is a critical factor in optimizing overall performance.

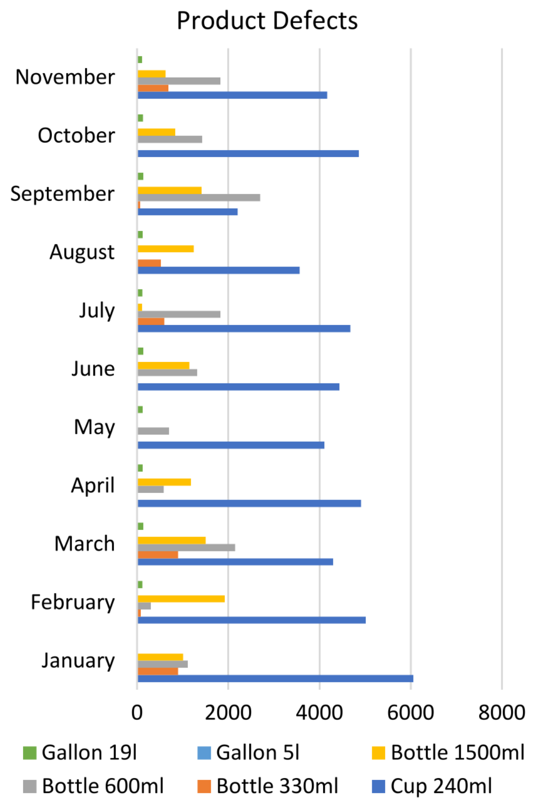

Fig. 1. Product Defects Data (units)
Source: Author's own conception, using Microsoft Excel

Literature review

Overall Labor Effectiveness

The OLE is one of the key performance indicators which focuses on the availability, performance, and quality of labor (Seyed Hosseini et al., 2021). It is related to labor productivity, which influences the quality of the products. OLE helps the manufacturer analyze the correlation between labor performance and the quality of the products (Rizzitano et al., 2021). As already mentioned, availability, performance, and quality are the three main components of OLE. Availability is the percentage of time spent by labor in making influential contributions. It can be calculated using total scheduled time and productive working time data. Productive working time is obtained from the total scheduled time minus the machine's break time and scheduled downtime. Performance is the percentage of products shipped. It can be calculated using data from the actual output of the products and the expected output from the company. In this performance factor, if the actual output is greater than the expected output, it means that the labor has good performance because it passed the targeted value from the company (Ulug'murodova & Rashidov, 2022). On the contrary, if the actual output is less than the expected output, it means that the labor has poor performance because it does not satisfy the targeted value. Quality is the percentage of products without defects, perfectly produced or sold. It can be calculated using data from defective products and total produced products. Eqs. (1)–(4) are the formula to calculate OLE and the detailed description of each component.

$$A = \frac{\text{Productive working time}}{\text{Total scheduled time}} \times 100 \tag{1}$$

$$P = \frac{\text{Actual output of the products}}{\text{The expected output (targeted value)}} \times 100 \tag{2}$$

$$Q = 100\% - \left(\frac{\text{Defective products}}{\text{Total produced products}} \times 100\right) \tag{3}$$

$$\text{OLE} = A \times P \times Q \tag{4}$$

Regression analysis

Regression is a prevalent method to be used in industry and performance management. Many firms have used it to quantify and rectify their performance (Mitra et al., 2019). It has been known that firms frequently prefer to use quantitative data rather than qualitative in measuring their performance. Quantitative data brings more objectivity than qualitative, and the insight given is more to the data. Thus, it can be more trusted.

In comparison, the qualitative is more stick to the opinion, which is that the value of subjectivity is higher than the quantitative. It is one of the reasons why the regression method is being used here. The linear regression formula is shown in Eq. (5).

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n \tag{5}$$

where: Y – dependent variable, β_0 – intercept, β_n – slope for X_n, X_n – independent variable.

Six Sigma

Six Sigma (6σ) is one of the continuous improvement methodologies. It was discovered around the 19th century, to be exact, in 1987. It is used to optimize the organizations' performance inside and out. This methodology has several benefits that have been proven by many companies, such as providing clear process mapping from the problems to solutions, portending the outcomes with high accuracy, and turning to the decision making which has less financial risk (The Council for Six Sigma Certification, 2018).

Many experts frequently called Six Sigma (6σ) the "perfect" process. It correlates with defects per million opportunities (DPMO). Theoretically, Six Sigma only has 3.4 defects per million opportunities. It means that out of 1 million, there are only 3.4 defects. In percentage, Six Sigma equals 99.99966%, which means it is almost 100% (The Council for Six Sigma Certification, 2018). In the arrangement, the smaller the sigma value, the bigger the value of the defects.

Table 2 explains the sigma level and DPMO. The gap in each sigma looks insignificant because the range is only 1. However, in each sigma, there is a DPMO whose gap is quite far. The DPMO value will affect the company because each defective product will cost the company financially. Therefore, the company must calculate the sigma level, so the company knows at which sigma level they currently are. Eqs. (6)–(7) explain the formula to calculate the sigma level.

Table 2
Sigma Level and DPMO

Sigma level	DPMO	Percentage
1	690,000	30.85%
2	308,000	69.15%
3	66,800	93.32%
4	6,210	99.38%
5	230	99.977%
6	3.4	99.999%

$$\text{Sigma level} = \frac{\#\text{ of opportunities} - \#\text{ of defects}}{\#\text{ of opportunities}} \times 100 \tag{6}$$

$$\text{Sigma Level} = \text{NORMSINV}\big((1000000 - \text{DPMO})/1000000\big) + 1.5 \tag{7}$$

In Six Sigma, two approaches can be used such as DMAIC and DMADV. DMAIC can evaluate existing products; meanwhile, DMADV can be used to evaluate new products. In this research, DMAIC is used due the observed and evaluated product is the existing one.

DMAIC is the abbreviation of define, measure, analyze, improve, and control. DMAIC is one of the system tools that can be used to evaluate simple and complex problems starting with the define phase (Hakimi et al., 2018). It focuses on specific problems and goal statements (Yadav et al., 2019). The define phase is then followed by the measure phase. The measure phase is used to validate the problem statement using quantitative data (Andry et al., 2022b). In analyze phase, this paper constructs the hypothesis about the relation between inputs (Xs) and outputs (Ys) (The Council for Six Sigma Certification, 2018). It can be about the correlation between the first and second stages. Thus, this phase generally focuses on identifying the root causes of the problem and why they are linked with each other (Ahmed et al., 2018). After analyzing the correlation between Xs and Ys, which can be called the main problem, it comes to the improvement phase [21](Uluskan & Oda, 2020). The control phase is the last phase of the DMAIC. It is the integration of the improving phase, which means it adjusts the solution provided in the improvement phase to the actual production system (Hakimi et al., 2018).

Related works

Table 3 shows the related works for the manufacturing metric or measurement, the decision on the scope of the study, and the DMAIC approach. Some metrics that are used in the previous paper utilized OEE (Nurprihatin et al., 2019) and OLE (Hanna et al., 1999). OLE as the extension of the OEE is used in this paper. This paper focuses on the quality rate based on the regression analysis. Regression analysis was used to properly select the focus on availability, performance, and quality rate (Dinulescu et al., 2018; Hanna et al., 1999; Mitra et al., 2019).

This paper tackles the quality factor by implementing the Six Sigma approach. Under the Define phase, the Pareto chart is used to obtain the most valuable problem that needs improvement (Mohinuddin et al., 2021). The Measure phase is done by calculating the UCL, CL, LCL, DPO, DPMO, sigma level, and control chart (Andry et al., 2022a). During the Analyze phase, the fishbone diagram is utilized to discover the root cause as valuable information for the next phase (Andry et al., 2022a; Mohinuddin et al., 2021). The Improve phase discusses the exploitation of FMEA, which is explaining the value of severity, occurrences, and detection (Andry et al., 2022a).

Methods

A flow chart is a diagram used to show the process flow. Here, a flow chart shows all the processes

Table 3
Related works

Author(s)	Manufacturing Metric/ Measurement	Scope of Study Decision	Define	Measure	Analyze	Improve	Control
Nurprihatin et al., 2019	OEE	The largest gap with the world-class standard	No	No	No	No	No
Hanna et al., 1999	OLE	Regression Analysis	No	No	No	No	No
Mitra et al., 2019	No	Regression Analysis	No	No	No	No	No
Dinulescu et al., 2018	No	Regression Analysis	Voice of Customer	Variability	Comparative study	ANOVA	No
Mohinuddin et al., 2021	No	No	Pareto chart, Value Stream Mapping (VSM)	Process capability,	Fishbone diagram, Design of Experiment	VSM	Control Plan
Andry et al., 2022a	No	No	SIPOC diagram, Critical to Quality	DPMO, Sigma level	Fishbone diagram	Failure Mode and Effects Analysis (FMEA)	Decision Support System
This Paper	OLE	Regression Analysis	Pareto chart	DPMO, Sigma level, Control chart	Fishbone diagram	FMEA	Control Plan

carried out during the research. Fig. 2 explains the flow chart that consists of several details. The research starts with the OLE analysis and focuses on the quality part. In this regard, to improve the quality rate, the DMAIC approach is launched.

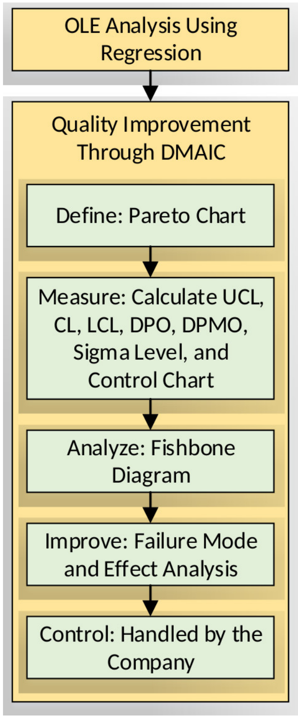

Fig. 2. Flow Chart
Source: Author's own conception, using Microsoft Visio

First thing first, this paper discusses OLE based on the raw data that has been collected from the company using Eq. (4). However, to calculate Eq. (4), it needs to calculate Eqs. (1)–(3) first. After getting the result, it is evaluated using the regression method. The regression analysis pairs the hypothesis that links OLE and products' quality such as:

- H_0 : $\mu_1 = \mu_2$, there is no significant correlation between OLE and products' quality.
- H_1 : $\mu_1 \neq \mu_2$, there is a significant correlation between OLE and products' quality.

Results

Hypothesis testing

To verify which hypothesis is more substantial, the evaluation uses the software Minitab's regression method. The following are the detailed results. The equation is obtained after inputting and running the data, as shown in Eq. (8).

$$\text{Total product defects} = 105095 + 5569(A) + 8034(P) + 11740(Q) \quad (8)$$

Based on Eq. (8), the dependent data is the total defective product. The intercept value is equal to 105095 assuming the Availability, Performance, and Quality are independent variables. The slopes of the independent variables are 5569, 8034, and 117470, respectively.

Table 4 shows the p-values of Performance and Quality are 0.013 and 0.000, respectively. It means that the p-value is less than α, which is 0.05, and rejects the null hypothesis. Thus, it can be said that there is a statistically significant relationship between performance, quality, and product defects. The Pareto chart of the Standardized Effects shows the standardized effects from the largest to the smallest effect. There is also a line that indicates that the effects are statistically significant.

The reference line shown in Fig. 3 is 2.365 where A and B factors cross the reference line. It means that both factors are statistically significant at the 0.05 level with the current level. Using the Pareto chart of Standardized Effects indicates which effects are large and small. However, it cannot indicate which effects could increase or decrease the response.

Table 4
Analysis of variance result

Source	Degree of freedom	Adjusted SS	Adjusted MS	f-value	p-value
Regression	3	13964298	4654766	19.90	0.001
Availability	1	46759	46759	0.20	0.668
Performance	1	2558971	2558971	10.94	0.013
Quality	1	10325130	10325130	44.15	0.000
Error	7	1636976	233854		
Total	10	15601275			

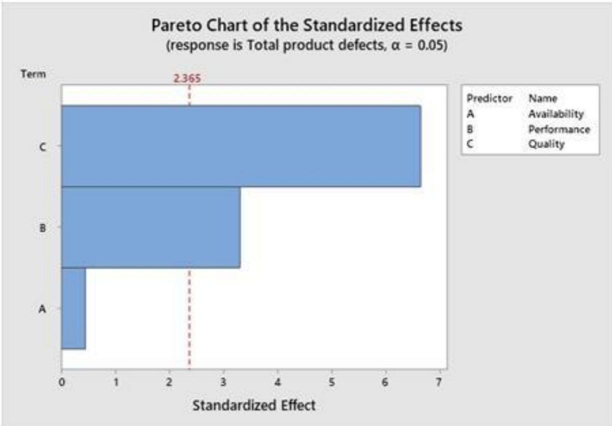

Fig. 3. Pareto Chart of the Standardized Effects Result
Source: Author's own conception, using Minitab

Data analysis

Define phase

The first phase is the define phase. This paper elaborates on the problem identification and continues to the Pareto chart. The problem identification focuses on calculating the proportion of defects. It only focuses on the largest proportion of defects from the 6 types of products. This is because each product has its characteristics and processes. Thus, focusing on the largest proportion will make this research more specific. The calculation is done by dividing the defective product and the total production.

It would be better if quality control is carried out for all products, but considering the limited time and resources, this paper focuses on the highest proportion of defects, which is 600 ml, as shown in Table 5. The highest defect proportion is 0.204773, compared to other values.

During the research, six defects occur such as a broken lid, broken seal, dented bottle, broken label, broken cardboard, and leaky bottle. These defects make the product not pass quality control.

Figure 4 exhibits that a broken lid has 35% of the total defective products. Then, followed by broken seals as much as 24.1%. Dented bottles as much as 21.9%. Furthermore, the defect type of broken labels, broken cardboard, and leaky bottles has a percentage of 21.9%, 0.6%, and 0.4%, respectively. As shown in the Pareto chart in Fig. 4, this paper focuses on 80% of the problems that occur. Therefore, it will focus on the problem of broken lids, broken seals, and dented bottles. In an enormous scope, the factors that cause defects come from the environment, man, method, material, and machine.

Table 5
Defect Product Proportion Calculation

No	Product	Proportion
1	Cup 240 ml	$P = \frac{48284}{312306} = 0.154605$
2	Bottle 330 ml	$P = \frac{3746}{18540} = 0.202050$
3	Bottle 600 ml	$P = \frac{13934}{68046} = 0.204773$
4	Bottle 1500 ml	$P = \frac{9481}{47300} = 0.200444$
5	Gallon 5 liter	$P = \frac{35}{21058} = 0.001662$
6	Gallon 19 l	$P = \frac{12376}{843706} = 0.001466$

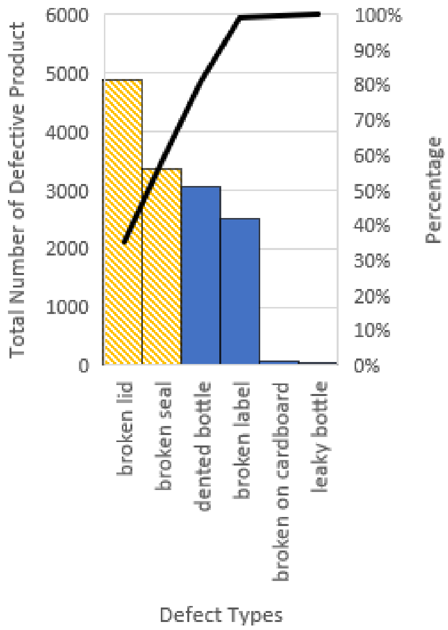

Fig. 4. Pareto chart
Source: Author's own conception, using Microsoft Excel

Measure phase

In the measure phase, this paper elaborates on the calculation of the upper control limit (UCL), control limit (CL), Lower Control Limit (LCL), Defects per Opportunity (DPO), Defects per Million Opportunities (DPMO), Sigma Level, and Control Chart, as shown in Table 6. The DPMO and sigma level value is 34.129 and 3.3233, respectively.

The control chart evaluation is done using Minitab software by inputting the product defects and total production. Fig. 5 shows almost all the observed products are out-of-control and only one piece of data is in-

Table 6
Statistical process control parameters

Parameters	Values
CL	$CL_c = \bar{c} = \frac{\#\text{ of defect product}}{\#\text{ of samples}}$ $CL_c = \bar{c} = \frac{13934}{11}$ $CL_c = \bar{c} = 1266.7272 \approx 1267$
UCL	$UCL_c = \bar{c} + 3\sqrt{\bar{c}}$ $UCL_c = 1267 + 3\sqrt{1267}$ $UCL_c = 1373.78 \approx 1374$
LCL	$LCL_c = \bar{c} - 3\sqrt{\bar{c}}$ $LCL_c = 1267 - 3\sqrt{1267}$ $LCL_c = 1160.215 \approx 1160$
DPO	$DPO = \frac{D}{U \times O}$ $DPO = \frac{13934}{68046 \times 6}$ $DPO = 0.034129$
DPMO	$DPMO = DPO \times 1,000,000$ $DPMO = 0.034129 \times 1,000,000$ $DPMO = 34,129$
Sigma Level	Sigma Level $= \text{NORMSINV}\big((1000000 - \text{DPMO})/1000000\big) + 1.5$ Sigma Level $= 3.3233\sigma$

control, indicating the products require further evaluation.

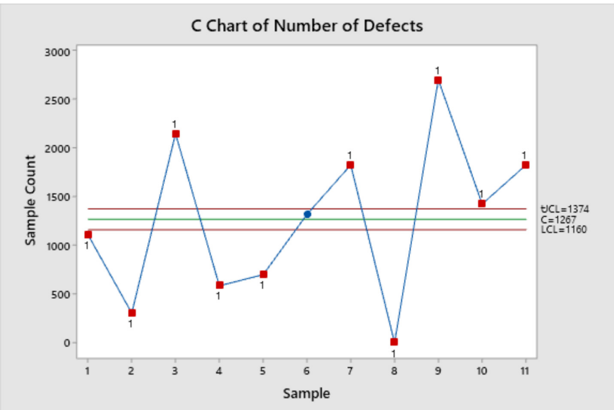

Fig. 5. c-Chart
Source: Author's own conception, using Minitab

Analyze phase

The next phase is the analyze phase. The tool used is a fishbone diagram to analyze the interrelated relationship between labor and defects in the product. The fishbone diagram in Fig. 6 shows the relationship between cause and effect in the production process. The analysis carried out covers all the reasons for product defects. Fig. 8 shows that the most influential factor comes from labor, mainly because the labor is the new operator who is inexperienced and has less training, less focus (labor force limit), is careless and is unskilled.

Environment

The quality of the products is also affected by the temperature. Therefore, putting the product in place at the right temperature is crucial. All products must be placed indoors in the rainy season to maintain product quality. If placed outdoors, this can damage the quality of the product that is ready to be distributed.

Man

As shown in Fig. 6, workers contribute the most to product defects. This is related to labor performance, which is careless, unskilled, less focused, and new operators who are inexperienced and have less training. Besides, the workers' performance could be decreasing due to the monotony and tedious work (Nurprihatin et al., 2020). Man is the factor that dominates the cause of product defects because everything that is done in the product manufacturing process still uses human labor as the basis. Technology is still a secondary thing in this company to run its product manufacturing operations.

Method

The lack of supervision makes some workers careless in doing their jobs. It would be better if supervision were carried out to check the methods applied by the workers when carrying out the production process.

Material

Since the company does not make the entire product itself, the quality of the materials obtained from the sourcing partner is also quite a problem for the company's product quality. For instance, many labels of different thicknesses (some are too thin to be used). If it is used, it will not pass the quality control at the packing station.

Machine

In many cases, a defective product is caused by improper machine settings. For example, from the engine speed. Frequently, the engine settings are too fast, which impacts the time of laying the bottle.

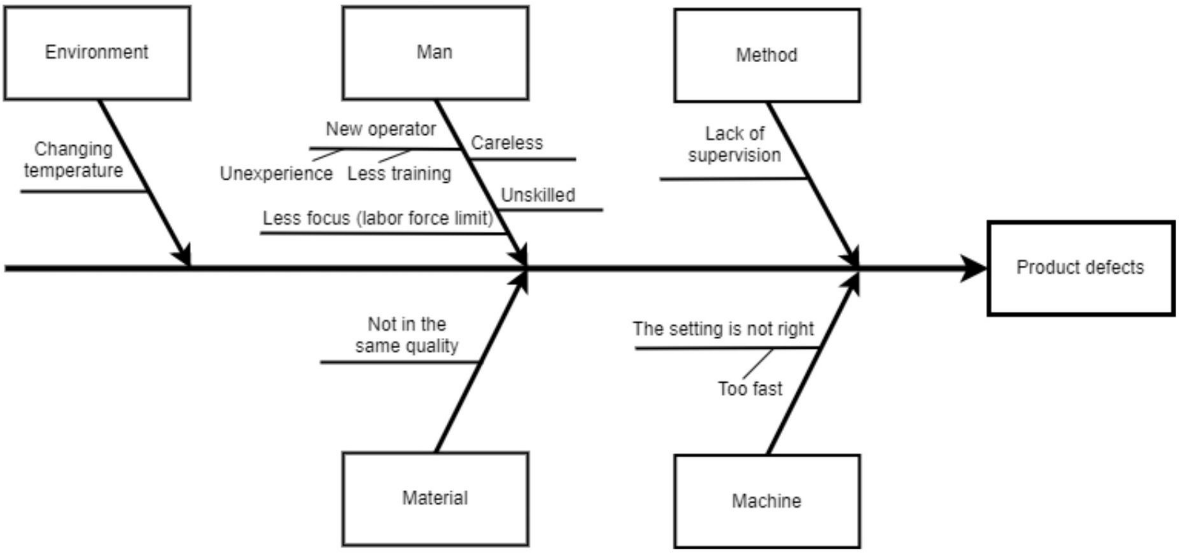

Fig. 6. Fishbone diagram. Author's own conception, using *draw.io*

Improve phase

In elaborating on FMEA, this paper focuses on 80% of the existing defects that have been listed in the Pareto chart at the Define phase. The three defects are a broken lid, broken seal, and dented bottle. Then, an assessment is made based on the rubric of the FMEA itself concerning Severity (S), Occurrence (O), and Detection (D). The results of the FMEA itself are seen from the Risk Priority Number (RPN), which is obtained by multiplying S, O, and D (Filz et al., 2021). The greatest value of RPN will be the critical concern for further evaluation. Table 7 has also listed proposed corrective actions that the company can apply to reduce the potential for defects in the future.

Table 7 shows the defect that should be overcome in the first place is a broken lid with an RPN value

Table 7
FMEA Results

Potential failure mode	Potential causes	S	O	D	RPN	Proposed corrective action
Broken lid	The machine setting does not install properly.	8	7	8	448	Before use, the machine must be checked and ensured that the settings are installed properly.
	Extreme temperatures affect the flexibility of the bottle lid.	5	4	4	80	Store bottle lids at a safe temperature (normal room temperature 20–25°C) and should not be too hot.
Broken seal	Engine temperature setting is too hot.	7	8	6	336	Before use, it must be ensured that the engine temperature is in line with the temperature control panel, which is ±150°C.
	The quality of the material of the seal is not the same.	6	5	6	180	Discuss this issue with the supplier regarding the raw material for the seal.
Dented bottle	Careless placement in the warehouse by the labor.	4	6	5	120	Labor is given supervision and direction in the arrangement of bottles in the warehouse.
	Squashed by the machine due to misplacement by labor.	7	6	7	294	Provision of written standards on how to use the machine. It will remind the workers to use the machine carefully. Thus, the machine will not damage the bottle.

of 448. It is caused by the engine settings, which are often not installed correctly. After conducting further analysis, the proposed corrective action is that the labor must check the machine before using it.

At the RPN value of 336, the defect that should be overcome is a broken seal caused by an engine temperature that is too hot. After conducting further analysis, the proposed corrective action must be checked whether the engine temperature follows the temperature control panel, which should be ±150°C. However, this can cause product defects in the production process. Thus, checking the temperature cannot be ignored before conducting the production process.

Lastly, the defect that should be overcome is the dented bottle caused by being squashed by the machine due to a misplacement made by labor (RPN value of 294). After conducting further analysis, the proposed corrective action must be given a written standard for using the correct machine so that labor is more careful in placing the bottle. The provision of written standards can help the workers remember how to place bottles in the production process properly.

Control phase

The proposed improvement points can be implemented to improve the existing system. After implementing the proposed improvement, the control phase is carried out, which is the final stage of this Six Sigma method. The control phase can be carried out to continue monitoring the production process, which can be a reference for continuing to make improvements to reduce the level of product defects. The proposed improvement points also need some consultation by the company so that they can be widely applied for production. Thus, the control phase is left entirely to the company in this case. There are three components from the control phase that need to be carried out. First, regular machine checks before starting the production process by labor. Second, make sure the machine temperature should be ±150°C on the control panel before the production process by labor. Third, there must be written standards for machines so that workers will be more careful in placing bottles in the machine.

The limitation of the research comes from several factors. First, the limited time to do the observation in the company. Second, the pandemic condition makes access to the company complicated. Third, the data collected is limited to the production division. For further improvement, it will be better to minimize the above limitations and try to get larger data to increase accuracy.

Conclusions

The value of OLE presented by the company is 76%. It means that it is still below the world standard of 85%. Then, the regression results also show that quality is the most significant factor that affects the company's OLE results. Therefore, there is a strong correlation between labor performance and product defects. The beta value from the calculation of OLE when using the regression method are $\beta_1 = 5569$, $\beta_2 = 8034$, and $\beta_3 = -117470$. β_1 is the regression coefficient (beta estimates) of availability. β_2 is the regression coefficient (beta estimates) of performance. β_3 is the regression coefficient (beta estimates) of quality. The positive coefficient indicates that the greater the value of the independent variable, the higher the value of the dependent variable. While the negative value indicates the greater the value of the independent variable, it will make the value of the dependent variable decrease. The sigma level value of the company is 3.3233σ with a DPMO equal to 34,129. Then, to raise its sigma level, the company must reduce the number of product defects in the manufacturing process. This topic is related to labor performance, which causes product defects.

To improve the sigma level of the company, there are three proposed corrective actions based on FMEA results. First, regular machine checks before starting the production process by labor. Second, make sure the machine temperature should be ±150°C on the control panel before the production process by labor. Third, there must be written standards for machines so that workers will be more careful in placing bottles in the machine.

In manufacturing, preventive action is always better than a corrective one. The practitioner must be willing to pay with consistency by doing regular checking. In many cases, the impact of regular checking may not be seen directly. However, it is effective to prevent fatal losses for the company. For instance, the fatal losses coming from a broken Filling Machine required the company to buy the new one with a cost of around IDR 243,912,075. By performing proper maintenance activities such as regular checking by the workers, the company could save more. Without proper planning, the decision will affect the factory operating costs, building costs, the cost of loss, and the cost of product defects due to being stored for too long which will eventually become a loss (Nurprihatin et al., 2022).

Furthermore, the procedure will always be the first guidance to manage the company. Before making big or small decisions, personnel must reflect on the guidance to provide the best decision. Thus, it is important to have written standards for something. The written standard will be used as the Standard Operating Procedures (SOP) so every worker will have the same indicator during completing their work.

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