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Integrated Lean Six Sigma and Statistical Quality Control to Enhance Production Quality in the Beverage Manufacturing

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ABSTRACT

Continuous quality improvement is fundamental to maintaining competitiveness in the beverage processing industry, particularly in developing countries where process variability often leads to operational inefficiencies. This study aims to examine the implementation of Lean Six Sigma (LSS) integrated with Statistical Quality Control (SQC) as a comprehensive strategy to enhance production quality in a selected Indonesian beverage company. The research was conducted using purposive sampling and followed the DMAIC (Define, Measure, Analyze, Improve, and Control) framework to identify, measure, and mitigate causes of volume variation in bottled products and improve process yield. Quantitative analysis was performed on production records using control charts, process capability indices (C_{pk}), and defect probability calculations. The results showed that prior to improvement, the process capability index (C_{pk}) was 0.722 for 350 mL bottles and 0.636 for 450 mL bottles, with a rejection rate of approximately 3.00%, indicating poor process control. After a series of corrective actions, including mold and filler vacuum adjustments, the C_{pk} increased to 1.430 for 350 mL bottles and 1.338 for 450 mL bottles, while the rejection rate declined significantly to 0.562% and 0.438%, respectively. The findings demonstrate that the integration of LSS and SQC substantially improves process capability, reduces production waste, and enhances product quality. This study provides novel empirical evidence on the application of Lean Six Sigma in the beverage industry context and contributes both theoretical and practical insights into the use of data-driven quality approaches to achieve sustainable manufacturing excellence.

KEYWORDS *Lean Six Sigma, Statistical Quality Control, Beverages Industry, Process Capability, DMAIC*

INTRODUCTION

Fast-moving consumer goods (FMCG) constitute an industry category in which the product cycle in the market is very fast because the goods are consumed within a short period (Framinan et al., 2024). One example of this industry is the beverage manufacturing industry. Since these products are fast-moving and rely heavily on high sales volumes (high demand), manufacturers require a fast and continuous production process, which must be balanced with stable process performance. The performance of a production process in an industry is closely related to production costs. A stable production process can significantly reduce a company's production costs, and vice versa. In contrast, inefficiency and poor output quality lead to higher product selling prices, making it difficult for companies to compete in the market. In this case, one of the factors affecting product efficiency is the percentage of rejected products. If the percentage of rejects is minimized, it produces optimal output, and the company's performance becomes more efficient. One form of production reject in beverages occurs when there is a variation in product volume that fails to comply with standards, resulting in overfilled or underfilled bottles. To address this situation and minimize its impact to an acceptable level, manufacturers need to establish a measurable system to monitor production processes and enhance efficiency and effectiveness. Lean Six Sigma is a method for controlling process variability to create high-quality, superior products. The DMAIC method (Define, Measure, Analyze, Improve, and Control) is implemented within a work management system to identify deviations that occur in the production process. Lean Six Sigma and Lean Manufacturing use measurable methods in their control, enabling users in the manufacturing industry to conduct regular controls and make continuous improvements based on a quantitative foundation. This approach implies a significant reduction in product defects, allowing continuous performance improvement to be effectively measured (Achibat et al., 2023; Chen et al., 2023; David et al., 2024; Omoush, 2020).

The Statistical Quality Control (SQC) method integrated with Lean Six Sigma is also a robust approach for controlling production processes so that both product and process quality can be ensured. Control charts C_{pk}, and defect probability analyses, as discussed by Kehinde Adeleke et al. (2024) and Martins et al. (2020), are significant analytical tools used to evaluate the stability and capability of production process performance. Statistical Quality Control consists of several stages (data collection, analysis, and interpretation) for use in quality monitoring and specifically addresses the technical aspects of quality in manufacturing (Carballo-Meilan et al., 2022). Walter Shewhart introduced the control chart, which became one of the most extensively used and accurate tools in statistical quality control. The first use of a control chart was made by Shewhart to monitor the quality of Bell products in New Jersey, USA. It has since become a more common practice than most quality control approaches. The control chart remains a key tool in implementing a statistical quality control system (Addeh et al., 2022). Statistical methods are also relevant for ensuring the future sustainability of improvements within Six Sigma, as they establish monitoring systems that can track ongoing process performance (Panduru et al., 2024).

Studies discussing Lean Six Sigma and Statistical Quality Control in developing countries—particularly in Indonesia—remain limited, especially within the beverage manufacturing industry, compared to their application in developed countries. The contextual adaptation of these methods has been discussed by Buestan et al. (2025), along with the critical role of management commitment in supporting the growth of Six Sigma in developing economies. In this study, purposive sampling is used as the basis for research. This sampling method considers specific criteria to ensure that the selected sample is relevant and capable of representing the data required to address the research problem (Murniningsih et al., 2024). The Lean Six Sigma and Statistical Quality Control methods are chosen to address this research gap, explicitly focusing on process performance within the beverage manufacturing industry in developing countries. These methods serve as process control mechanisms, and their effectiveness in improving production quality is tested at an Indonesian beverage manufacturing company. Knowledge related to Lean Six Sigma and Statistical Quality Control becomes a vital resource for monitoring processes with measurable data to achieve continuous improvement, leading to superior production performance and competitiveness both nationally and internationally.

The purpose of this study is to examine the implementation of an integrated Lean Six Sigma and Statistical Quality Control approach to improve production quality in the Indonesian beverage manufacturing industry, specifically focusing on reducing volume variation and rejection rates in bottled products. This research aims to demonstrate how the DMAIC framework, supported by SQC tools, can systematically identify, measure, analyze, and control process deviations to achieve sustainable improvement in process capability. The benefits of this research are threefold. From a theoretical perspective, it contributes to the growing body of knowledge on Lean Six Sigma applications in the beverage industry—a context that remains underexplored in developing country settings. It provides empirical evidence on the effectiveness of integrating LSS and SQC methodologies and extends understanding of process capability improvement in high-speed filling operations. From a practical perspective, this research offers actionable insights for beverage manufacturers and similar process-based industries seeking to reduce waste, optimize production costs, and enhance product quality through data-driven decision-making. The documented improvement mechanism—including mold and filler vacuum adjustments—provides a replicable technical reference for addressing overfill issues. From a managerial perspective, the findings highlight the importance of cross-functional team collaboration, structured problem-solving methodologies, and sustained management commitment in achieving manufacturing excellence. The total cost of ownership (TCO) analysis presented in this study also equips industry practitioners with a financial justification framework for process improvement investments.

METHOD

The research method used in this study was Lean Six Sigma, employing the DMAIC (Define, Measure, Analyze, Improve, Control) cycle as the foundational framework, complemented by Statistical Quality Control tools. This study focused on the beverage manufacturing industry, selected through purposive sampling. CNZ Company (pseudonym) was chosen as the research object because it is a beverage manufacturing company in a developing country (Indonesia) that faces challenges related to process performance in reducing production rejection rates. Process performance improvements were measured using Statistical Quality Control (SQC) tools, including p-charts, $\bar{x}$-charts, and R-charts, as part of a continuous improvement approach. CNZ Company also maintained comprehensive production quality records for analysis, making it a reliable object for process performance evaluation, consistent with the background provided in the introduction. According to Jacobs and Chase (2018), there is a relationship between the sigma value and the capability index value, where a higher capability index corresponds to a higher sigma value, as shown in Table 1.

Table 1. Fraction of Defective Units for Various Design Specification Limits (Jacobs & Chase, 2018)

Design limit	Capability Index (C_{pk})	Defective Parts	Fraction Defective
± 1σ	,333	317 per thousand	,3173
± 2σ	,667	45 per thousand	,0455
± 3σ	1,0	2,7 per thousand	,0027
± 4σ	1,333	63 per million	,000063
± 5σ	1,667	574 per billion	,000000574
± 6σ	2,0	2 per billion	,000000002

From **Table 1**, it was observed that the higher the capability index value, the smaller the defective fraction becomes, as does the number of defective parts. Data collection included secondary data, namely production report records, quality department reports, and financial reports from CNZ Company. The analysis method used a quantitative approach. Company data were collected from the results of a 2025 trial of improvements made by the company to reduce the percentage of rejections on excess bottle volumes to measure its performance, whether it was stable and met the minimum capability index of 4σ or C_{pk} ≥1,333 (**Table 1**). A Capability Index 4σ or C_{pk} 1,333 was an industry's best practice, which served as manufacturing performance benchmark where the Capability Index was the minimum value limit that had to be achieved by a company to be considered capable. This indicated that the production output results were more than 99,994% within the specification range, and if the manufacturing industry had a range below the benchmark value, the company needed to make improvements in terms of the process (Fisher et al., 2020). The methodology of research that was conducted was illustrated in **Figure 1** below.

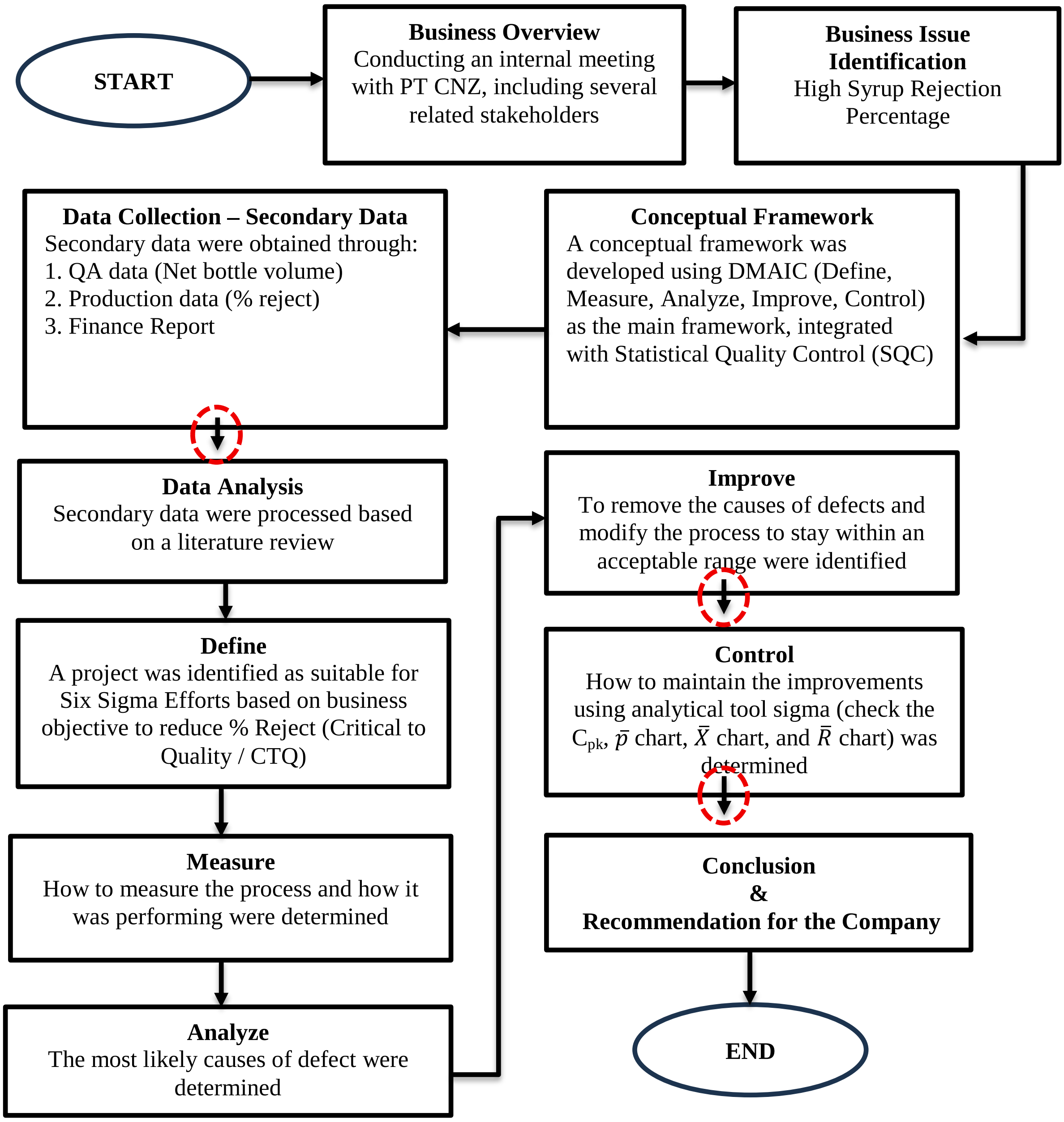


Figure 1. Research Method
Source: Developed by the author (2025)

RESULT AND DISCUSSION

The letters DMAIC were an acronym for five steps**: Define, Measure, Analyze, Improve, and Control**. These steps were illustrated in **Figure 2**.

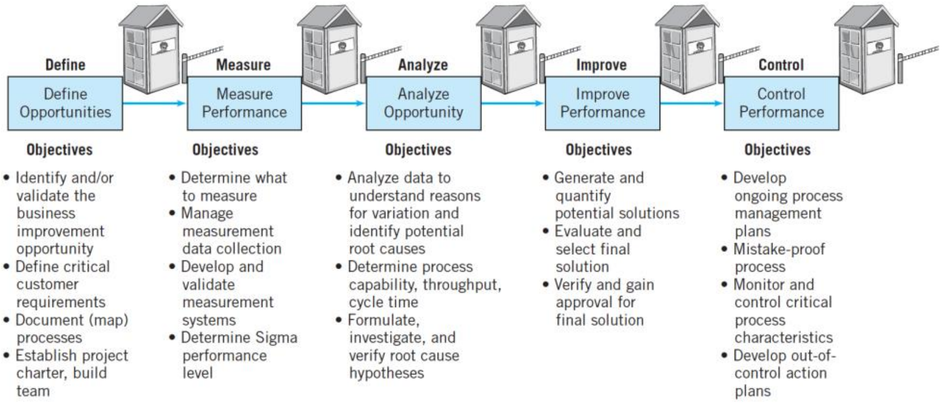


Figure 2. The DMAIC Process
Source: (Montgomery, 2013)

In **Figure 2**, there were tollgates between each of the significant steps in DMAIC. These tollgates indicated that at each important step, the project team presented its performance to the managers and process owners. Tollgates served as process monitoring to ensure the project was on track (Montgomery, 2013). In the "**Define**" step, CNZ identified Critical-to-Quality Characteristics (CTQs). In this case, the CTQ was a net product volume exceeding the standard, resulting in a high syrup reject rate of 3%, while the company's standard was below 1%. In the **Define stage**, the steps taken were to create a **Project Charter** that 3087escribed the scope, start/finish dates, potential customer and financial benefits, milestones that had to be met, team members and their duties, other resources that would likely be needed to finish the project, and a preliminary description of the primary and secondary measures of success and their connection to business unit and corporate objectives. The project charter served as the company's background on why a project was important to solve its problems (Montgomery, 2013; Salleh & Nohuddin, 2019). In **Table 2**, the Project Charter in Company CNZ was divided into Business Case, Goal Statement, Project Plan, Opportunity Statement, Project Scope, and Team.

Table 2. Project Charter

Business Case Encountered a high syrup rejection at 3% of the net bottle volume when the target was <1%. The higher net volume meant a waste of materials in using more raw materials for manufacturing each bottle. It also led to less efficient production and to lower profits for the company.	**Opportunity Statement** There was an opportunity to reduce the rejection rate gap from 3% to 1%. Based on total cost of ownership calculations, the company could save approximately ± 8.36 billion rupiah.
Goal Statement Improved production performance was needed to achieve the target rejection rate of <1% with a $\boldsymbol{C_{pk}}$(Capability Index) of ≥	**Project Scope** The scope of this project covered the process performance of a PET bottle line in the beverage manufacturing industry. The bottle filling process

<table>
<tr><td>1.33 or 4σ.</td><td>occurs upstream (filling and blowing). This project did not cover the downstream areas (packaging area).</td></tr>
<tr><td>Project Plan
<table>
<tr><td>Activity</td><td>Start</td><td>End</td></tr>
<tr><td>Define</td><td>25/08/2025</td><td>04/09/2025</td></tr>
<tr><td>Measure</td><td>08/09/2025</td><td>16/09/2025</td></tr>
<tr><td>Analyze</td><td>17/09/2025</td><td>24/09/2025</td></tr>
<tr><td>Improve</td><td>25/09/2025</td><td>02/10/2025</td></tr>
<tr><td>Control</td><td>03/10/2025</td><td>10/10/2025</td></tr>
</table>
Track Benefits
11/10/2025 onward (The benefits of this improvement will await full-scale implementation, because it is still awaiting investment approval from management)</td><td>Team
1. QA Supervisor
2. QC Analyst
3. Production Manager
4. Production Foreman
5. Operations Manager</td></tr>
</table>

Source: Primary data from CNZ Company internal documents (2025)

Total Cost of Ownership (TCO) was calculated using the formula (Li et al., 2023) modified by the author to the conditions of the CNZ company:

$$TCO = CAPEX + \sum_{t=1}^{n} \frac{OPEX_t + CoPQ_t}{(1+r)^t}$$

CAPEX stood for Capital Expenditures, which were the investment costs required by a company to improve production machinery. OPEX stood for Operational Expenditures, which were the company's routine operational costs in carrying out production. R was the discount rate value of the company with a value of 5,5%. CoPQ stood for Cost of Poor Quality, which was the cost incurred by a company due to waste/rejects generated from the production process (Zulkarnaen et al., 2023). The TCO value before the improvement (3% reject) was compared with the TCO value (maximum reject target 1%). If the TCO value before the process modification was higher than after the modification, it meant that the difference was the cost saved from this process. In this company, there were two sizes (mL): size 350 mL and size 450 mL. **Table 3** showed the TCO calculation for a size of 350 mL (Before Modification).

Table 3. TCO Size 350 mL (Before Modification)

t	**CoPQ – Reject 3% (IDR)**	**OPEX (IDR)**	$\sum_{t=1}^{n}\frac{OPEX_t+CoPQ_t}{(1+r)^t}$ **(IDR)**
1	570.214.582	913.116.941	1.406.001.444
2	627.235.423	913.116.941	1.383.933.303
3	689.959.377	913.116.941	1.365.201.697
4	758.955.315	913.116.941	1.349.724.721
5	834.850.743	913.116.941	1.337.430.125
6	918.335.921	913.116.941	1.328.253.556
7	1.010.168.998	913.116.941	1.322.137.548
8	1.111.186.310	913.116.941	1.319.033.712
9	1.222.304.426	913.116.941	1.318.898.721
10	1.344.534.560	913.116.941	1.321.698.226
Total	**9.087.745.655**	**9.131.169.410**	**13.452.313.053**

Source: Primary data from CNZ Company financial and production reports (2025)

Table 3 showed that the TCO value for Size 350 mL was **IDR 13.452.313.053**. This cost represented the company's costs incurred under the status quo in producing size 350 mL for 10 years. The t value of 10 years was the time period used by the finance team at Company CNZ as determining the basis for the length of time the company would benefit from the modifications it would invest in modifying its production process. Production output was obtained from the company's internal forecast data made by the marketing department, where the annual sales were projected to increase 10% per year. **Table 4** showed the TCO calculation for a size of 450 mL (Before Modification).

Table 4. TCO Size 450 mL (Before Modification)

t	CoPQ – Reject 3% (IDR)	OPEX (IDR)	$\sum_{t=1}^{n} \frac{OPEX_t + CoPQ_t}{(1+r)^t}$ (IDR)
1	573.684.558	833.039.805	1.333.388.022
2	631.053.695	833.039.805	1.315.418.342
3	694.158.611	833.039.805	1.300.583.039
4	763.574.472	833.039.805	1.288.813.777
5	839.932.032	833.039.805	1.280.048.226
6	923.925.122	833.039.805	1.274.231.492
7	1.016.318.201	833.039.805	1.271.316.766
8	1.117.949.568	833.039.805	1.271.262.472
9	1.229.745.092	833.039.805	1.274.036.312
10	1.352.719.941	833.039.805	1.279.610.595
Total	**9.143.061.291**	**8.330.398.050**	**12.888.709.043**

Source: Primary data from CNZ Company financial and production reports (2025)

In **Table 4**, the TCO value of size 450 mL in 10 years was **IDR 12.888.709.043**. This cost was the cost incurred by the company with the status quo in producing size 450 mL for 10 years. The TCO value of size 350 mL and size 450 mL was **IDR 26.341.022.096**. This value was then compared with the TCO value after sizes 350 mL and 450 mL were modified. The following was the calculation table after the modification. **Table 5** showed the TCO calculation for a size of 350 mL (After Modification).

Table 5. TCO Size 350 mL (After Modification)

t	CoPQ – Reject 1% (IDR)	OPEX (IDR)	$\sum_{t=1}^{n} \frac{OPEX_t + CoPQ_t}{(1+r)^t}$ (IDR)
1	193.835.320	927.013.394	1.062.415.843
2	213.218.642	927.013.394	1.024.444.228
3	234.540.646	927.013.394	989.195.293
4	257.994.711	927.013.394	956.558.383
5	283.794.147	927.013.394	926.430.446
6	312.173.597	927.013.394	898.715.202
7	343.390.782	927.013.394	873.322.592
8	377.730.000	927.013.394	850.169.322
9	415.502.825	927.013.394	829.177.301
10	457.053.002	927.013.394	810.274.793
Total	**3.089.233.671**	**9.270.133.943**	**9.220.703.403**

Source: Primary data from CNZ Company financial and production reports (2025)

In **Table 5**, the CAPEX value after modification was **IDR 66.435.592**. This CAPEX value includes the costs incurred by the company in purchasing parts for machine modification purposes, resulting in a **TCO of size 350 mL after modification of IDR 9.287.138.995**. **Table 6** showed the TCO calculation for a size of 450 mL (After Modification).

Table 6. TCO Size 450 mL (After Modification)

t	CoPQ – Reject 1% (IDR)	OPEX (IDR)	$\sum_{t=1}^{n} \frac{OPEX_t + CoPQ_t}{(1+r)^t}$ (IDR)
1	195.014.883	845.717.588	986.476.276
2	214.516.603	845.717.588	952.569.970
3	235.968.109	845.717.588	921.178.320
4	259.564.919	845.717.588	892.202.546
5	285.521.450	845.717.588	865.549.851
6	314.073.556	845.717.588	841.133.695
7	345.481.105	845.717.588	818.873.828
8	380.029.061	845.717.588	798.695.132
9	418.032.160	845.717.588	780.528.823
10	459.835.492	845.717.588	764.310.696
Total	**3.108.037.337**	**8.457.175.884**	**8.621.519.137**

Source: Primary data from CNZ Company financial and production reports (2025)

In **Table 6**, the CAPEX value after modification was **IDR 66.435.592**. This CAPEX value included the costs incurred by the company in purchasing parts for machine modification purposes, resulting in a **TCO of size 450 mL after modification of IDR 8.687.954.729**. In the TCO calculation table for sizes 350 mL and 450 mL after modification, production output was greater than the TCO of sizes 350 mL and 450 mL before modification. This was because the reject rate decreased to a maximum of 1%, as targeted by the company, resulting in higher output. Based on the TCO calculation of size 350 mL and size 450 mL after modification, the combined TCO value of size 350 mL and size 450 mL after modification was **IDR 17.975.093.724**. Therefore, based on the project chart, the opportunity cost the company would gain from making modifications could be calculated as follows:

$$Saving\ Cost = TCO\ Before\ Modification - TCO\ After\ Modification$$
$$Saving\ Cost = IDR\ 26.341.022.096 - IDR\ 17.975.093.724$$
$$Saving\ Cost = IDR\ 8.365.928.372$$

The company's cost savings amounted to **IDR 8.365.928.372**. This positive value indicated that the company's costs for producing sizes 350 mL and 450 mL over 10 years decreased to **IDR 8.365.928.372**. This represented the **cost savings** the company was able to achieve by improving production process performance through machine modifications. In the Define stage, a **SIPOC diagram** functioned as a high-level process map. SIPOC stood for Supplier, Input, Process, Output, and Customer. The simple SIPOC diagram served as a reference tool for understanding the process and visually helped to remind of key aspects of the process itself (Novirani et al., 2024). Based on (Montgomery, 2013), **the suppliers** were those who provided the information, material, or other items that were worked on in the process. **The Input** was the information or material provided. **The Process** was the set of steps required to do the work. **The Output** was the product, service, or information sent to the customer. **The Customer** was either the external customer or the next step in the internal business. **Table 7** showed a SIPOC diagram that illustrated the correlation between suppliers, inputs, processes, outputs, and customers in this study.

Table 7. SIPOC Diagram

Parameter	Description
Supplier	Raw material and packaging material suppliers, utility department (which supplied CNG, steam, water, and electricity), Quality Assurance Laboratory (which provided equipment calibration for data validation checks), Production Planning (which created production schedules and production output targets).
Inputs	Preform, Cap, Syrup (liquid), utilities, machine parameters (temperature, pressure, flow rate)
Process	Blowing Process → UHT Process → Filling Process → Capping and Sealing Process → Volume Verification
Outputs	Filled PET Bottles, production performance data (% reject, capability index, average volume)
Customer	1. **Internal Customer** • Production department: Focused on the % reject • QA department: Ensured volume meets specifications • Finance department: Evaluated lost material costs (cost impact) 2. **External Customer** • End Consumers: Purchased finished products where the volume complied with the BDKT (Peraturan Menteri Perdagangan Republik Indonesia Nomor 31/M-DAG/PER/10/2011 tentang Barang dalam Keadaan Terbungkus, 2011)

Source: Developed by the author based on CNZ Company process mapping (2025)

Based on the **Define** stage, it was identified that the CTQ of this issue was related to the high % rejected syrup, which reached 3% and based on the TCO calculation, it was stated that the project to improve the % rejected syrup from 3% to 1% with the investment made was feasible. The next step of the DMAIC cycle was **Measure**, to check the actual condition of the net volume performance of the production of 350 mL and 450 mL size bottles before improvements were made. The data used in this study were obtained from the results of trial modifications conducted on production machines, such as blower modifications (adding shims), adjustments to blowing process parameters, such as air-cooling flow, preform temperature, mold temperature, adjust filler vacuum, adjust stretch rod, and adjust air pressure. Data were taken from production report data and the results of QA department checks, where the trial was carried out for 7 days, and samples per day were taken, as many as 30 samples for sizes 350 mL and 450 mL, thus the total samples owned per size was 210 samples. The number of samples was based on the **Central Limit Theorem**, where if the number of $n \geq 30$, then the sample distribution can be considered normal (Putri Maharani et al., 2024). The sample size was 210, so by using the Central Limit Theorem, the data were considered normally distributed. A control chart was then created to see the performance of the existing machine, which included $\bar{p}\ chart, \bar{x}\ chart, and\ \bar{R}\ chart.$ $\bar{p}\ chart$ was used to check how many are defective (ok/reject), while $\bar{x}\ chart$ functioned to see the average net volume of bottles, and $\bar{R}\ chart$ was used to measure the magnitude of the variation in the size of the net volume in the sample range. The Capability index was defined as the ratio of the range of values allowed by the design specifications divided by the range of values produced by a process. The following were the formula for $\bar{p}\ chart, \bar{x}\ chart,\ \bar{R}\ chart, and\ capability\ index$ based on (Jacobs & Chase, 2018):

$\boldsymbol{\bar{p}\ chart}$

$$\bar{p} = \frac{Total\ number\ of\ defective\ units\ from\ all\ samples}{Number\ of\ samples\ \times\ Sample\ size}$$

$$S_p = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \qquad UCL = \bar{p} + zS_p \qquad LCL = \bar{p} - zS_p\ or\ 0\ if\ less\ than\ 0$$

Where,

$\bar{p} = fraction\ defective$

$S_p = Standard\ deviation$

$n = Sample\ size$

$z = number\ of\ standard\ deviation\ typically\ 3\ (99.7\%\ confidence)$

$\boldsymbol{\bar{x}\ chart}$ **and** $\boldsymbol{\bar{R}\ chart}$

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n} \qquad \bar{\bar{X}} = \frac{\sum_{j=1}^{n} \bar{X}_j}{m} \qquad \bar{R} = \frac{\sum_{j=1}^{n} R_j}{m}$$

$$UCL_{\bar{X}} = \bar{\bar{X}} +\ zS_{\bar{X}} \qquad LCL_{\bar{X}} = \bar{\bar{X}} -\ zS_{\bar{X}}$$

Where,

$S_{\bar{X}} =\ s/\sqrt{n} = Standard\ deviation\ of\ sample\ means$

$s = Standard\ deviation\ of\ the\ process\ distribution$

$n = Sample\ size$

$m = Total\ number\ of\ sample$

$i = Item\ number$

$j = Sample\ number$

$R_j = Gap\ between\ the\ highest\ and\ lowest\ measurement\ in\ the\ sample$

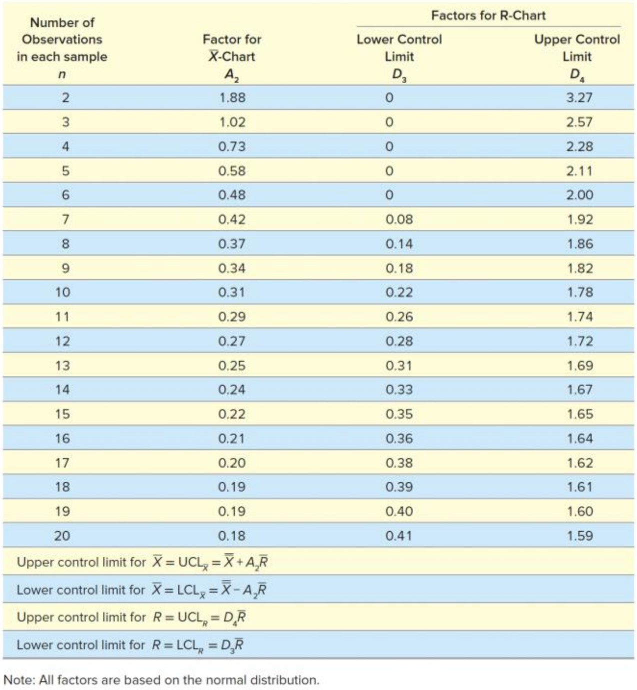
$\bar{R} = Average\ of\ the\ measurement\ differences\ R\ for\ all\ samples$

$\bar{X} = Means\ of\ the\ sample$

$\bar{\bar{X}} = Average\ of\ sample\ means\ or\ a\ target\ value\ set\ for\ the\ process$

$z = Standard\ deviation\ for\ a\ specific\ confidence\ level\ \ (typically, z = 3)$

The following were factors for determining $\bar{R}$ the Three-Sigma Control Limits for $\bar{X}\ chart$, and the $R\ chart$ as presented in **Figure 3** (Jacobs & Chase, 2018)



Number of Observations in each sample n	Factor for $\bar{X}$-Chart A_2	Factors for R-Chart: Lower Control Limit D_3	Factors for R-Chart: Upper Control Limit D_4
2	1.88	0	3.27
3	1.02	0	2.57
4	0.73	0	2.28
5	0.58	0	2.11
6	0.48	0	2.00
7	0.42	0.08	1.92
8	0.37	0.14	1.86
9	0.34	0.18	1.82
10	0.31	0.22	1.78
11	0.29	0.26	1.74
12	0.27	0.28	1.72
13	0.25	0.31	1.69
14	0.24	0.33	1.67
15	0.22	0.35	1.65
16	0.21	0.36	1.64
17	0.20	0.38	1.62
18	0.19	0.39	1.61
19	0.19	0.40	1.60
20	0.18	0.41	1.59

Upper control limit for $\bar{X} = UCL_{\bar{X}} = \bar{\bar{X}} + A_2\bar{R}$

Lower control limit for $\bar{X} = LCL_{\bar{X}} = \bar{\bar{X}} - A_2\bar{R}$

Upper control limit for $R = UCL_R = D_4\bar{R}$

Lower control limit for $R = LCL_R = D_3\bar{R}$

Note: All factors are based on the normal distribution.

Figure 3. Factor for Determining from $\bar{R}$ the Three-Sigma Control Limits for $\bar{X}$ – and $\bar{R}$ Charts
Source: Jacobs & Chase (2018)

In **Figure 3**, the values A_2, D_3, and D_4 were used to calculate the UCL and LCL in calculating the R-Chart. The following was the formula for calculating the Capability Index:

$\boldsymbol{Capability\ Index\ (C_{pk})}$

Mean or Average **Standard Deviation** **Capability Index**

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n} \qquad \sigma = \frac{\sqrt{\sum_{i=1}^{n}(x_i - \bar{X})^2}}{n} \qquad C_{pk} = min\left[\frac{\bar{\bar{X}} - LSL}{3\sigma}, \frac{USL - \bar{\bar{X}}}{3\sigma}\right]$$

Where,

LSL = Lower Specification Limit

USL = Upper Specification Limit

Based on the measurement results, it was found that the performance of the existing workflow process for sizes 350 mL and 450 mL was as follows in **Table 8**:

Table 8. Control Parameter Before Modification

Parameter	Size 350 mL (As is)		Size 450 ml (As is)		Remarks
CTQ	361 ± 2	mL	464 ± 2	mL	Target tolerance was ±2 mL from nominal fill
LSL	359	mL	462	mL	The lower limit was still high
USL	363	mL	466	mL	The upper limit was still high
$\boldsymbol{\bar{\bar{X}}}$	361,382	mL	464,179	mL	Cumulative mean fill volume was higher than nominal target which indicated excess fill across both SKUs
σ	0,748	mL	0,954	mL	The deviation was high, which indicated that the process model

					was not stable
C_{pk}	0,722		0,636		In both cases, the obtained values were lower than the required minimum C_{pk} value of 1,33, which indicated that the process was not capable of holding to the specifications
% Reject	3,084	%	2,991	%	Very high rejection rate, higher than 1%, indicated of unstable process, poor process capability, and excessive variation
Probability < LSL	0,072	%	1,118	%	Low underfill probability, but the process mean was still shifted to the upper side
Probability > USL	1,520	%	2,818	%	There was a much higher likelihood of overfill, which was the primary driver of waste and costly inefficiency
Probability < LSL and > USL	1,592	%	3,936	%	The primary defect was out-of-spec units, overfill rather than underfill

Source: Primary data from CNZ Company quality assurance reports (2025)

Results of the measurements conducted on the 350 and the 450 mL lines confirmed an overfilling of the product. The nominal volume was slightly higher for net volume (361,382 mL and 464,179 mL, respectively) than the average value. The large standard deviations (σ = 0,748 and 0,954) showed notable variation in the processes. Capability index values were C_{pk} 0,722 and 0,636 so these values were much below the C_{pk} = 1,33 which indicated that the process was not capable of performing within specified limits. While the risk of underfilling was less, the percentage of bottles above the upper specification limit was much higher (1,52% and 2,818%), showing that most defective bottles were overfilled, which was a significant waste of material and also the most costly of all defects. Due to the condition of the machine, the distance between USL and LSL could not be made closer to 350 mL or 450 mL, so repairs were needed. The next step was to **analyze**. In this step, the fishbone analysis/Ishikawa Diagram was used to identify the potential causes of volume variations in the bottle (Imamoto et al., 2002). The following was a picture of fishbone analysis in **Figure 3**.

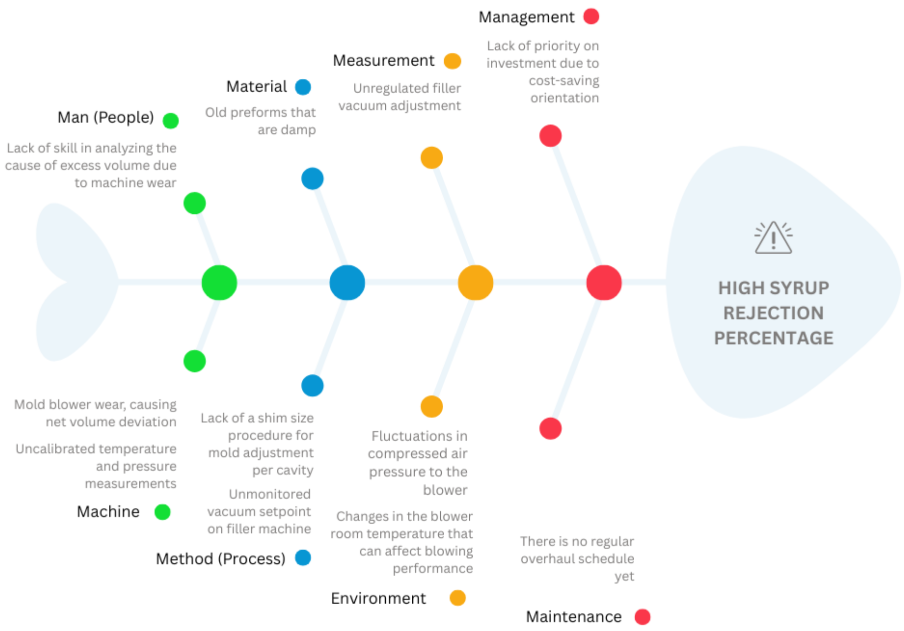


Figure 4. Fishbone Analysis
Source: Developed by the author based on root cause analysis with CNZ Company team (2025)

Based on **Figure 4**, namely Fishbone Analysis, the issue of high syrup rejection percentage was caused by eight categories: Man, Material, Measurement, Management, Machine, Method, Environment, and Maintenance. These eight categories synergized to cause a high % of rejects. Based on this analysis, the company needed to adjust. The next step in the DMAIC Cycle was **improvement**, where, based on the findings from the fishbone analysis results, the company needed to make improvements in these eight categories. The final step in the DMAIC cycle was **control**. At this stage, the results of the improvement were controlled with the help of SQC. The following were the results of the blowing process performance after adjustments through trials, presented in **Table 9**.

Table 9. Control Parameter After Modification

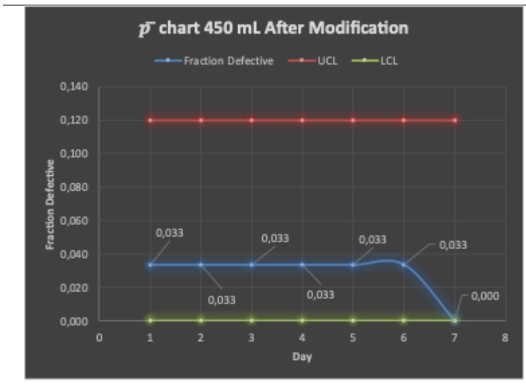
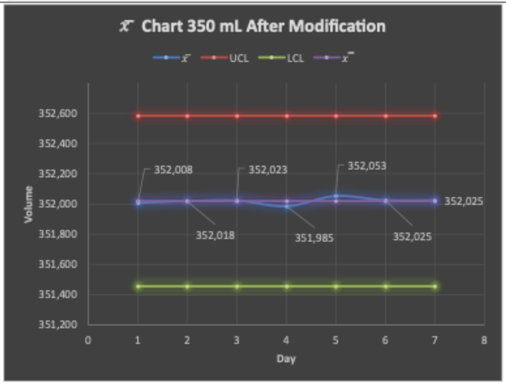
Parameter	Size 350 mL (To be)	Size 450 ml (To be)	Remarks
CTQ	352 ± 1 mL	452 ± 1 mL	The CTQ range limit became narrower and was closer to the target.
LSL	351 mL	451 mL	The minimum limit could be close to the net volume stated on the label
USL	353 mL	453 mL	The maximum limit could be close to the net volume stated on the label
$\bar{\bar{X}}$	352,019 mL	452,023 mL	The average value was stable near the specification target
σ	0,229 mL	0,243 mL	The deviation was minimal, indicating that the process model was stable
C_{pk}	1,430	1,338	The capability index value was above 4σ or $C_{pk} > 1{,}333$, which indicated that performance was good and there were very few defects
% Reject	0,562 %	0,438 %	The percentage of rejects dropped to below the target of 1%

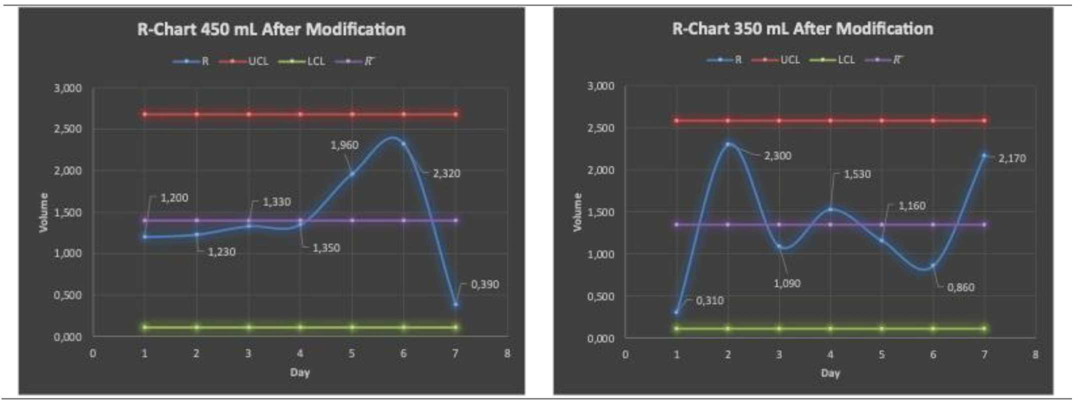
Probability < LSL	0,0004	%	0,001	%	Very infrequent underfill occurrence
Probability > USL	0,001	%	0,003	%	Very infrequent overfill occurrence
Probability < LSL and > USL	0,001	%	0,004	%	The total defect count was negligible

Source: Primary data from CNZ Company quality assurance reports (2025)

Based on **Table 9**, as indicated in the fishbone analysis, the problem was solved by installing a modification, such as using a shim, recalibration/enhancement in the filler head, and the process began to perform with correct fill volume and filling consistency. Mean value of 350 mL and 450 mL SKUs were well around the desired specification (352,019 mL and 452,023 mL, respectively), with a significant decrease in the standard deviation. Both C_{pk} indicated (1,430 and 1,338) were greater than 1,333 or 4σ indicating a capable and stable process. The final reject rate decreased under 1%, thus confirming the mechanical modification as an efficient tool for reducing overfill losses and allowing a highly reliable production. **Table 10** showed the control chart for sizes 350 mL and 450 mL after carrying out the modification or improvement process on the production process performance.

Table 10. Control Chart After Modification

450 mL	**350 mL**
	
	



Source: Primary data from CNZ Company quality control monitoring (2025)

The control charts described in **Table 10** confirmed that the process of filling the beverages had obtained statistical stability after the modifications of the blower and the filler. Both $\bar{p}\ chart$ displayed a consistent downward trend in the fraction defect, all well within the control limits that apply to them throughout the monitoring time frame. From both $\bar{X}\ chart\ and\ R\ chart$, the averages of the filling volume for 350 mL and 450 mL were close to the target specifications with a very low variability. No observations lay outside the control limits, suggesting that the process was in statistical control or was no longer subject to variations that could result in special causes. The apparent success of these mechanical changes was also confirmed by the former results. In terms of both the fill-grade quality and the filling performance uniformity improvement they achieved.

CONCLUSION

The research showed that Lean Six Sigma and Statistical Quality Control could be successfully integrated into beverage manufacturing to improve process performance. The DMAIC analysis identified that syrup rejection and overfill were caused by mechanical issues in the filler and blower units. Process capability studies using control limits and process capability indices were conducted, clearly showing variations and pinpointing where in the process the drift from specifications occurred. Prior to the improvement, the process exhibited significant variability and an average fill volume above the target value, leading to material waste and a limited capacity factor. This indicated quality issues that made the firm uncompetitive in terms of cost and efficiency.

After adjusting the blower mold by adding shims and recalibrating the filler heads, stability and capability improved. Variation was notably reduced, process capability indices exceeded the adapted standard, and the rejection rate dropped to less than one percent. This demonstrated that fact-based decisions and cross-functional collaboration could drive meaningful operational and financial outcomes. These preventive measures helped the company maintain competitive pricing, enabling consistent optimization and productivity. Better coordination among production, maintenance, and quality teams—combined with specific technical training for operators to detect early signs of equipment wear—was also needed from management. Real-time monitoring of process capability should be applied daily to maintain consistency, prevent future losses in cost and productivity, and build long-term manufacturing reliability.

Before this research was conducted, the machine performance showed a low Cpk value of 0.722 (350 mL) and 0.636 (450 mL), indicating that the process was not capable. The high reject percentages were 3.084% (350 mL) and 2.991% (450 mL). The CTQ (Critical to Quality) value was far from the target—361 ± 2 mL for 350 mL and 464 ± 2 mL for 450 mL. The Total Cost of Ownership (TCO) over 10 years for the 350 mL and 450 mL sizes amounted to IDR 26,341,022,096. After implementing the improvements, the production process performance increased, with the Cpk value rising to 1.430 (350 mL) and 1.338 (450 mL), indicating a highly capable process (between 4σ and 5σ). The reject percentages decreased to 0.562% (350 mL) and 0.438% (450 mL), while the CTQ values approached the target—352 ± 1 mL for 350 mL and 452 ± 1 mL for 450 mL. The Total Cost of Ownership for the same 10-year period fell to IDR 17,975,093,724. Without these improvements, the company could potentially face a loss of IDR 8,365,928,372 over 10 years due to the high reject rate.

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