Discovery

Investigation of the quality of PET bottle-blowing and bottled water production process using Pareto diagram, control chart, and Power BI

Aderinkola Abdulazeez, Ishaya M Dagwa, Ibrahim D Muhammad

ABSTRACT

This research project investigates the quality of PET bottle-blowing and bottled water production processes. This study discusses using the Pareto-Lorenz diagram, control chart, and Power BI tool to identify and reduce product defects in the PET bottle production line and bottled water production process at Fabsi Water Production Company. The data from January 2023 to June 2023 for the blowing section and bottled water production process. Based on the analysis, Defective Preform, Thickness Variation Defect, Wrinkled Preform, and Incomplete Blowing/Overblowing collectively account for over 80% of the reported defects. Precisely, these defects correspond to 2,913 units, 1,726 units, 1,449 units, and 1,171 units, respectively for the blowing section in contrast for bottled water production, 60% of the documented defects are associated with Damaged Cap and Leakage. Specifically, these defects total 1,195 units and 747 units, respectively. To improve PET bottle-blowing quality and reduce non-conformities in the production of bottled water, corrective actions were proposed and put into practice. The conclusions of this research have substantial ramifications for both academia and industry. Organizations may put focused quality control plans into place by having a thorough grasp of the variables impacting faults in the manufacture of PET bottles and bottled water. When properly implemented, these tactics can improve the quality of the final product, cut down on waste, and eventually maximize organizational performance. Additionally, this study contributes valuable insights to the existing body of knowledge on quality control practices in the context of the food and beverage industry.

Keywords: Quality, Pet Bottle-blowing, Bottled Water, Bottled Water Production

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1. INTRODUCTION

The difficulty for businesses like Fabsi Table Water is ensuring their bottled water satisfies the necessary criteria of excellence in light of the growing demand for high-quality products. Because quality entails completing service criteria and satisfying customer needs, businesses must emphasize this factor. Quality control is a continuous process undertaken to ensure that the final products or services delivered are aligned with the desired quality specifications and standards (Sadikoglu and Olcay, 2014). It involves various techniques and methods to oversee and maintain the desired quality levels in the production process or service delivery (Montgomery, 2019).

Quality control in the manufacturing sector involves some of the measures and techniques that are implemented in the assurance of the final products being of the desired quality. Examining the process quality of bottled water and PET bottle-blowing is a relevant research problem since companies constantly look for ways to enhance their process efficiency and remain competitive in their markets (Sadikoglu and Olcay, 2014; Pyzdek and Keller, 2018; Monden, 2011). Quality control has shown its deep impacts on organizational performance, and in this research, an effort will be put forth to illustrate the suggested processes through which quality control influences and impacts organizational effectiveness. The research will comprise a literature review on organizational performance and quality control and data gathering from an organization.

Statistical analysis will be used to compare the data to establish the correlation between organizational performance and quality control interventions. The findings of the research will be significant in the sense that they will allow organizations to identify areas in which they can enhance their quality control interventions to enhance their overall performance. Quality control is one of the key determinants of the overall organizational performance of companies in many industries (Pyzdek and Keller, 2018). In the specific context of PET bottle manufacturing and bottled water production in Nigeria, the integrity of the final product is paramount; still, however significant quality control measures may be, defect in the PET bottle-blowing and bottled water production process continues to surface, raising an issue worthy of concern concerning their effect on performance at the organizational level (Monden, 2011).

These have been identified as those caused by bottle deformity, source of contamination, irregularity in filling, and package malfunction. Repeated defects contribute to the high cost of production, which compromises quality and safety, having attendant effects of reduced customer satisfaction, increased customer complaints, and regulatory enforcement actions. Thus, the central problem that features in the premise of this study is: "To what extent do defects in PET bottle-blowing and bottled water production processes in Nigeria affect organizational performance, and what are the causes for such defects?". This research seeks, through knowledge of the fundamental causes and consequences of aberrations in some of these crucial processes, to present some directed guiding principles for organizations in the Nigerian PET bottle and bottled water industry to tighten their quality control systems that will, in turn, enhance their performance.

The absence of implementation of various practices of quality control in Nigeria's organizations has caused problems such as poor product quality, poor service delivery, low productivity, high production costs, and low consumer/customer satisfaction. All these problems reduce the performance of an organization and affect its competitiveness and long-term sustainability. The goal of this study is to enhance the overall quality, efficiency, and sustainability of PET bottle-blowing and bottled water production processes. The specific objectives include identifying and quantifying common defects using a Pareto-Lorenz diagram, studying the causes of defects within PET bottle-blowing and bottled water production processes, optimizing temperature, pressure, and time effects, and utilizing Power BI for real-time data visualization and transforming raw data into actionable insights that can then lead to informed decision-making.

Optimizing the PET bottle-blowing and bottled water processes is essential for improving both process efficiency and product quality. Defect reduction, process stability, and overall production line performance are the goals of optimization strategies. Numerous techniques have been used in the literature, such as statistical process control (SPC), response surface methodology (RSM), and design of experiments (DOE). These tools assist the manufacturers in determining critical parameters. Design of experiments (DOE) can be briefly defined as a structured statistical approach allowing the experimentation and test to be planned, conducted, analyzed, and interpreted systematically to determine the influencing factors on a process/system. DOE will assist in determining what relationships exist between cause and effect and optimization of performance by systematically varying the input variables and observing the effects on output responses.

Response Surface Methodology (RSM) is being extensively utilized for identifying the best combination of process parameters. It creates a sequence of experimental trials to model and explore the influence of several variables, thus increasing the accuracy of making adjustments in the manufacturing process. It also helps in reducing variability. Control charts were first devised by Walter A. Shewhart in the 1920s in Bell Laboratories to separate variations caused by inherent factors in a process (common-cause variation) from those caused by outside disturbances or interference (special-cause variation) (Montgomery, 2019). Thereafter, control charts became the backbone of Statistical Process Control and Total Quality Management methodologies.

The Pareto chart is a diagrammatic tool widely used across industries and disciplines to prioritize issues according to their relative frequency or impact. Based on the Pareto the 80/20 rule argues that 80 percent of effects come from 20 percent of causes. Essentially, this tool is indispensable in decision-making and problem-solving, predominantly in quality management (Juran, 2019). Economist Vilfredo Pareto first introduced the principle, and, in due course, it developed into one of the dominant aspects of statistical analysis and business process enhancement. Since a Pareto chart is an analysis that shows where key focus areas for enhancement within business operations lie, it is significant enough as highlighted in the study by.

It makes organizations consider only the few crucial causes of most problems hence causes will be ranked based on relative degree of significance. This prioritization could mean management can assign their resources where they can count the most and tackle issues quicker. Business intelligence tools have gained immense popularity in the present data-driven business scenario, and Power BI has emerged as one of the frontrunners in terms of data analysis and reporting. Power BI has, since its inception, gained tremendous applause in terms of its ability to connect with different data sources, such as on-premises systems, cloud services, and databases. Through the deployment of interactive dashboards and reports by businesses, Power BI leverages real-time insights that are a key component of well-informed decision-making.

2. METHODS

The research was conducted at Fabsi Table Water starting from the 2nd of January 2023 to the 29th of June 2023. It involved the collection of primary data during the investigation, coupled with using advanced analytical tools to reveal crucial insights. To determine the optimal temperature, pressure, and time for PET bottle production, the Taguchi orthogonal array method was utilized. This research is a quantitative study where the data used is obtained from the production of PET bottles, bottled water production, and the number of defective products that appear during the production process.

The study begins with a discussing production challenges and a preliminary investigation to identify potential problem-solving approaches. A purposive sampling technique was employed. First, pertinent information is gathered through data gathering, which is then processed and analyzed using tools like Power BI, the Pareto diagram, and a control chart to extract more insightful information. The manufacturing process for PET bottles includes the following steps:

Preform Production

Heating of Preform

Stretching and lengthening the preform

Blowing Preform

Cooling and trimming of bottles

Quality control

Taguchi's orthogonal array was used to get the optimal temperature, pressure, and time required for the different grams of PET. An experiment using a Taguchi orthogonal array, 3 factors, and 2 levels was carried out to identify the most suitable temperature and pressure for the blowing section of the PET bottle manufacturing process (Table 1). The experiment focused on three different bottle sizes: 35cl, 50cl, and 75cl. The results revealed the following optimal temperature and pressure conditions (Table 2): The Temperature, Pressure, and time to blow a 35cl (14g) crystal PET bottle being heated by an infrared lamp at 220v, 70v, and 13v at different levels.

Table 1 Variable Information

Name	Nbr. of category	Category 1	Category 2
Temperature (T)	2	105	90
Pressure (Mpa)	2	5.3	5.8
Time (s)	2	14	17

Table 2 Experimental design

Experiments	Temperature (T)	Pressure (Mpa)	Time (s)	Response 1	Response 2
Exp1	105	5.3	14	Good strength	Approved
Exp2	105	5.3	17	Poor creep resistance	Rejected
Exp3	105	5.8	14	Poor strength	Rejected
Exp4	105	5.8	17	Poor strength	Rejected
Exp5	90	5.3	14	Poor strength	Rejected
Exp6	90	5.3	17	Poor strength	Rejected
Exp7	90	5.8	14	Poor strength	Rejected
Exp8	90	5.8	17	Poor strength	Rejected

Interpreting the results of the analysis of the Taguchi plan

Based on the results, a 35cl (14g) PET bottle with high strength and desired properties was produced by heating it to 105–110°C, applying pressure of 5.3-5.8 MPa, and waiting 14–17 seconds. Time, pressure, and temperature were shown to be the most important variables affecting bottle strength. I recommend using the following settings to achieve optimal strength respectively:

Temperature: 105°C

Pressure: 5.3 MPa

Time: 14 seconds

The Temperature, Pressure, and time to blow a 50cl (19g) crystal PET bottle being heated by an infrared lamp at 220v, 70v, and 13 v at different levels (Table 3 and Table 4).

Table 3 Variable Information

Name	Nbr. of category	Category 1	Category 2
Temperature (T)	2	110	85
Pressure (Mpa)	2	5.8	6.3
Time (s)	2	12	15

Table 4 Experimental design

Experiments	Temperature (T)	Pressure (Mpa)	Time (s)	Response 1	Response 2
Exp1	110	5.8	12	Good strength, poor creep resistance	Rejected
Exp2	110	5.8	15	Good strength,	Approved
Exp3	110	6.3	12	Poor strength, low sliding friction	Rejected
Exp4	110	6.3	15	Poor strength	Rejected
Exp5	85	5.8	12	Poor strength, poor creep resistance	Rejected
Exp6	85	5.8	15	Poor strength	Rejected
Exp7	85	6.3	12	Good strength, poor creep resistance	Rejected
Exp8	85	6.3	15	Poor strength	Rejected

Interpreting the results of the analysis of the Taguchi plan

My observations indicate that a 50cl (19g) PET bottle produced at a temperature of 110°C, a pressure of 5.8 MPa, and a time of 15 seconds will exhibit high strength (Table 5). Based on these findings, I recommend the following settings for optimal strength:

Temperature: 110°C

Pressure: 5.8 MPa

Time: 15 seconds

The Temperature, Pressure, and time to blow a 75 (23g) crystal PET bottle being heated at 220v, 70v, and 13 v at different levels (Table 6).

Table 5 Variable Information

Name	Nbr. Of category	Category 1	Category 2
Temperature (T)	2	95	90
Pressure (Mpa)	2	6.0	5.8
Time (s)	2	14	16

Table 6 Experimental design

Experiments	Temperature (T)	Pressure (Mpa)	Time (s)	Response 1	Response 2
Exp1	95	6.0	14	Poor Strength	Rejected
Exp2	95	6.0	16	Poor creep resistance	Rejected
Exp3	95	5.8	14	Poor strength	Rejected
Exp4	95	5.8	16	Poor creep resistance	Rejected
Exp5	100	6.0	14	Good strength, good creep resistance	Approved
Exp6	100	6.0	16	Poor strength	Rejected
Exp7	100	5.8	14	Poor strength	Rejected
Exp8	100	5.8	16	Poor strength	Rejected

Interpreting the results of the analysis of the Taguchi plan

Based on my observations, a 75 (22g) PET bottle produced at a temperature of 95-100°C, a pressure of 6.0 MPa, and a time of 14 seconds will exhibit high strength. Temperature, pressure, and time were identified as the most critical factors influencing bottle strength. I recommend the following settings for optimal strength respectively:

Temperature: 100°C

Pressure: 6.0 MPa

Time: 14 seconds

3. RESULTS AND DISCUSSION

Numerical Results

Table 7 displays the total quantity of defects, and the percentage of cumulative recorded over six months at the PET blowing section.

Table 7 Total defectives and percentage of cumulative generated in the process of production of bottles

Kind of Defect	Jan 2023	Feb 2023	Mar 2023	April 2023	May 2023	June 2023	Total	% of Total	Cumulative %
Defective Preform	402	471	460	454	525	601	2913	34.24	34.24
Thickness Variation Defect	107	161	226	366	367	222	1726	20.29	54.53
Wrinkled Preform	327	277	261	332	339	190	1449	17.03	71.56
Incomplete/overblowing	137	184	232	253	235	130	1171	13.77	85.33
Blown out Preform	118	103	131	182	202	94	830	9.76	95.09
Preform Damaged by a Power cut	46	44	56	44	48	52	290	3.41	98.50
Preform Damaged by Machine	22	19	16	30	10	31	128	1.50	100

Source: Fieldwork

The most common defect was Defective Preforms, with 2,913 occurrences (34.24% of the total), causing significant production issues. Thickness Variation Defects occurred 1,726 times (20.29%), indicating variations in bottle thickness. Wrinkled Preforms were noted 1,449 times (17.03%), pointing to inconsistencies during preform handling. Incomplete/Overblowing defects were recorded 1,171 times (13.77%), due to incorrect bottle-blowing execution. Blown-out Preforms occurred 830 times (9.76%), showing preform failures during the blowing process. Preforms Damaged by Power Cuts accounted for 290 occurrences (3.41%), and Preforms Damaged by Machines caused 128 defects (1.50%) due to machine faults.

Defective Preforms accounted for the highest percentage of defects at 34.24%, followed by thickness variation defects at 20.29%, and wrinkled preforms at 17.03%. These top three defect categories made up 71.56% of the total defects, while lesser issues like power cuts and machine damage contributed to a smaller portion of the overall defects (Figure 1). The orange cumulative percentage line shows that the top three defect categories (Defective Preforms, Thickness Variation, and Wrinkled Preforms) make up the majority (71.56%) of total defects, as seen where the line flattens out. This indicates that by addressing these top three defects, a significant portion of the overall production problems could be resolved. Table 8 displays the number of defects and percentage of cumulative recorded over six months for the bottled water process.

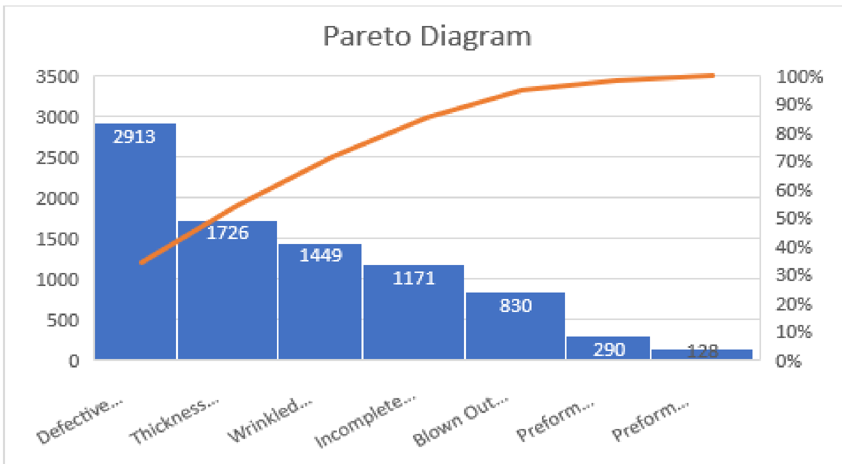

Figure 1 Pareto Diagram obtained for blowing section

Table 8 Total defectives and percentage of cumulative at the bottled water production section

Kind of Defect	Jan 2023	Feb 2023	Mar 2023	Apr 2023	May 2023	June 2023	Total	% of Total	Cumulative %
Damaged Cap	470	205	125	106	158	131	1195	35.90	35.90
Leakages	118	122	106	123	208	70	747	22.44	58.34
Damaged Bottles by Machine	200	143	78	68	85	77	651	19.56	77.89
Underfilling/Overfilling	115	65	50	60	72	45	407	12.23	90.12
Labeling and Packaging Defects	57	44	57	42	64	65	329	9.88	100

Source: Own research

From Table 8, the most common defect was Damaged Caps, with 1,195 occurrences (35.90% of the total), significantly affecting production. Leakages followed with 747 instances (22.44%), contributing to a substantial portion of defects. Damaged Bottles by Machine accounted for 651 cases (19.56%), while Underfilling/Overfilling issues were recorded 407 times (12.23%). Lastly, Labeling and Packaging Defects appeared 329 times (9.88%), rounding out the list of defects. Together, these categories represent all the quality issues observed in production (Figure 2).

The Pareto chart for bottled water production shows that Damaged Caps are the most frequent defect, with the highest bar indicating a significant number of occurrences. The cumulative percentage line (orange) rises sharply at first, showing that Damaged Caps and Leakages account for a substantial portion of the total defects. The line flattens out after (Damaged Bottles by Machine), indicating that these top three defect types contribute the most to production issues. The remaining categories, Underfilling/Overfilling and Labeling and Packaging Defects represent a smaller proportion of the total defects, as shown by the slower rise in the cumulative percentage line.

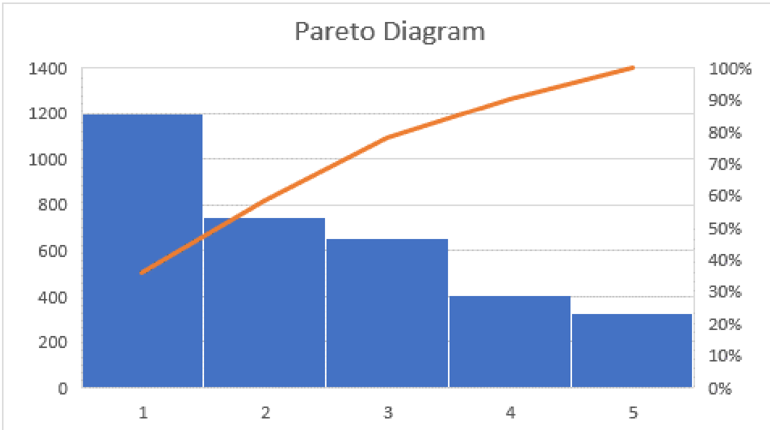

Figure 2 Pareto Diagram obtained for bottled water production process

Besides employing the Pareto diagram, we utilized QI Macros statistical software to generate control charts in the bottle-blowing section for the Upper Control Limit (UCL), Control Limit (CL), and Lower Control Limit (LCL) as outlined in (Figure 3):-

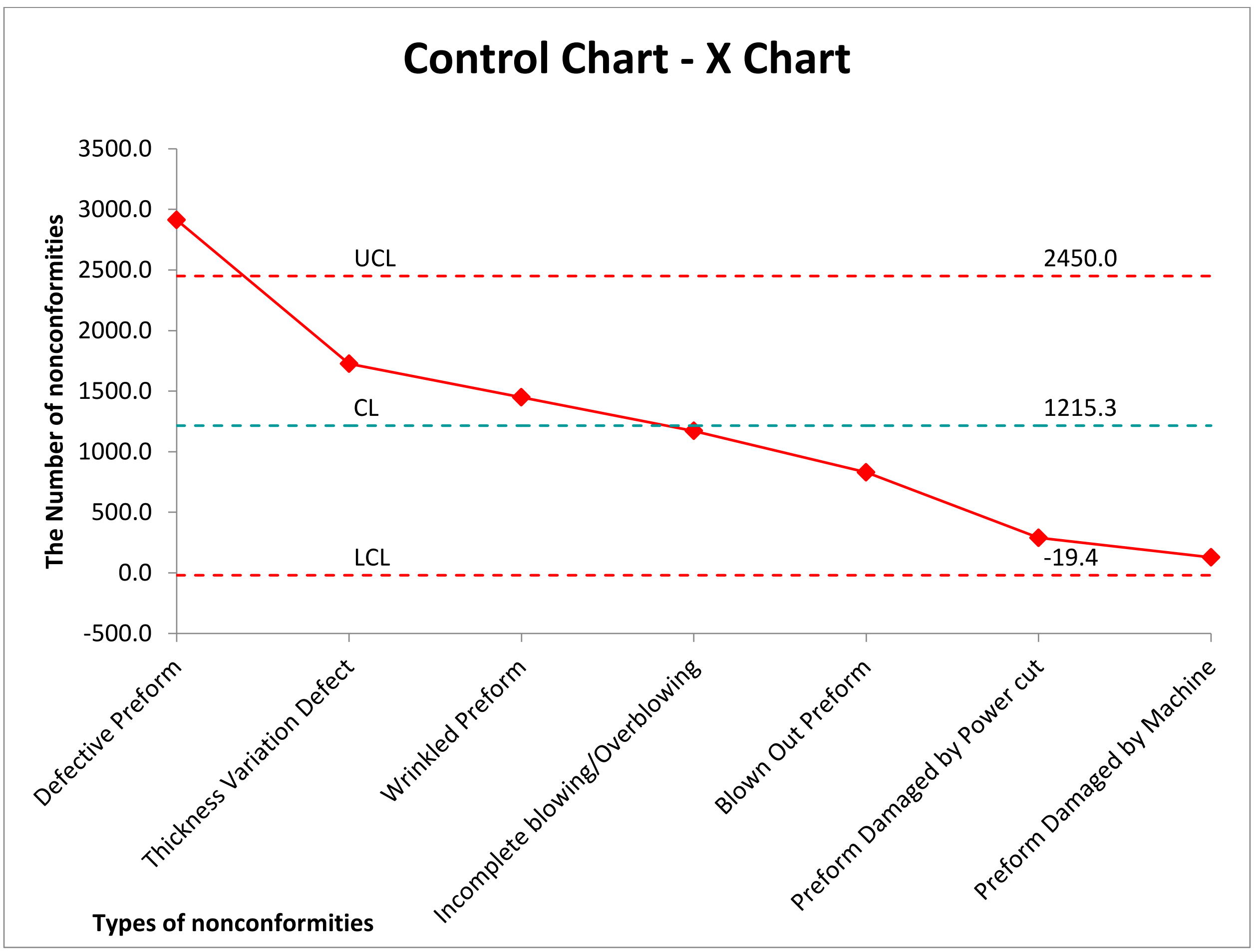

Figure 3 Control Chart obtained for blowing section.

This control chart is an X-bar chart, which monitors the mean (average) of a process to identify trends or variations over time.
The process is within control as no data points exceed the Upper Control Limit (UCL) or fall below the Lower Control Limit (LCL).
The overall trend is downward, meaning the number of non-conformity decreases as you move through the different types of defects.
The first type of non-conformity, Defective Preform, has the highest number of issues (around 3500).
Preform Damaged by machine at the end of the x-axis has the lowest number of nonconformity.

This control chart suggests that the process is stable, but efforts should focus on reducing defects such as Defective Preform and Thickness Variation, which have the highest number of nonconformity (Figure 4). Before employing the outcomes from the QI macro, computations were conducted utilizing the formulas for the Upper Control Limit (UCL), Control Limit (CL), and Lower Control Limit (LCL) as follows to validate:

Total non-conformities = 2913 + 1726 + 1449 + 1171 + 830 + 290 + 128 = 8507

Number of subgroups (types of nonconformities) = 7

Mean (CL) = Total non-conformities / Number of subgroups = 9457 / 7 = 1215.3

$$UCL= CL + 3 \sqrt{\frac{CL\ (1-CL)}{N}}$$

$$LCL= CL - 3 \sqrt{\frac{CL\ (1-CL)}{N}}$$

$$UCL= 1215.3 + 3 \sqrt{\frac{1215.3\ (1-1215.3)}{3}} = 2450.0$$

$$LCL= 1215.3 - 3 \sqrt{\frac{1215.3\ (1-1215.3)}{3}} = -19.4$$

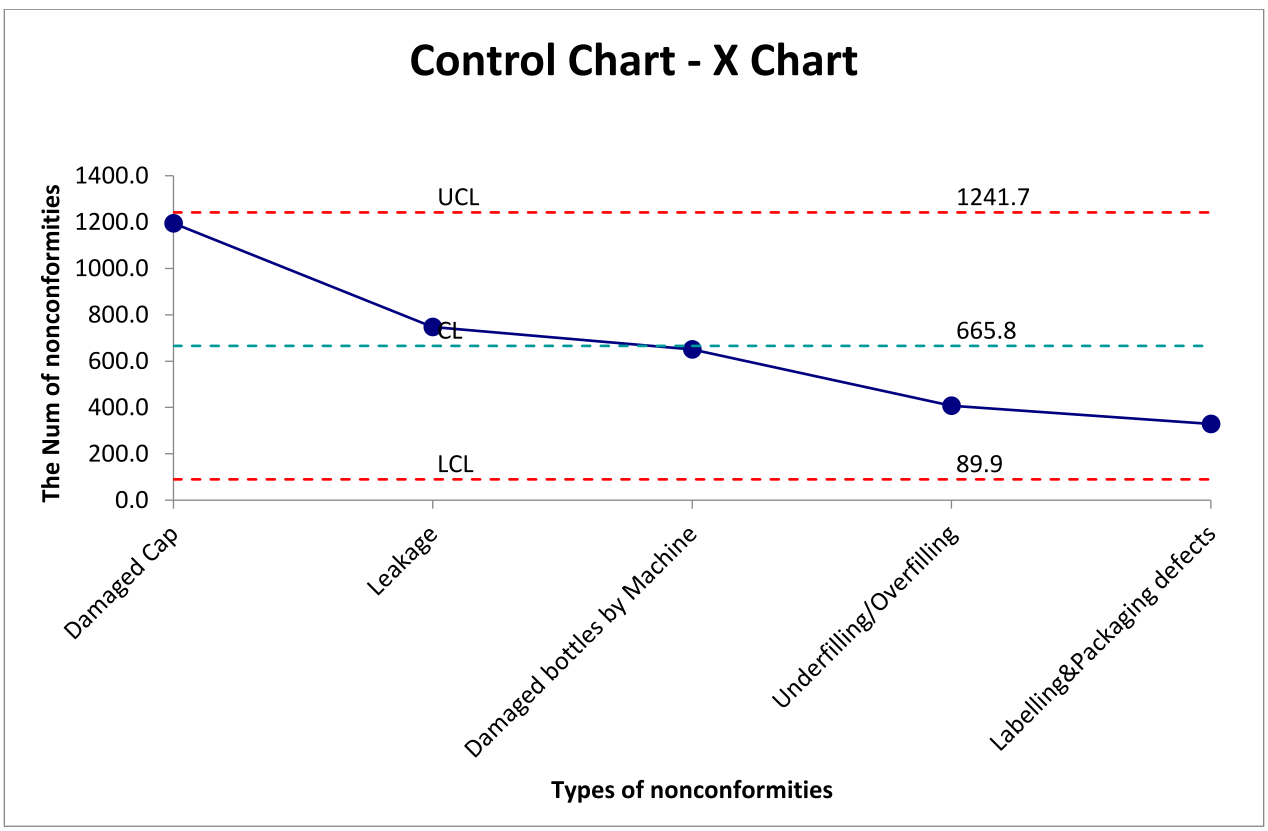

Figure 4 Control chart for bottled water production process

To validate the results obtained from QI macro for the bottled water process, computations were conducted utilizing the formulas for the Upper Control Limit (UCL), Control Limit (CL), and Lower Control Limit (LCL) as follows.

Total nonconformity = 1195+ 747+ 651 + 407 + 329 = 3329

Number of subgroups (types of nonconformities) = 5

CL = Total nonconformities / Number of subgroups = 3331 / 5 = 665.8

$$UCL = 665.8 + 3\sqrt{\frac{665.8\,(1-665.8)}{3}} = 1241.7$$

$$LCL = 665.8 - 3\sqrt{\frac{665.8\,(1-665.8)}{3}} = 89.9$$

This X-bar control chart helps monitor and analyze the variation in the number of nonconformity (defects) across different defect categories.

No Points Exceed the Control Limits: All data points fall between the UCL (1241.7) and the LCL (89.9), which indicates the process is under control and doesn't exhibit any significant variation that suggests it is out of control.

Decreasing Trend: There is a downward trend from "Damaged Cap" (around 1400 nonconformity) to "Labeling & Packaging" (around 0 nonconformity). This means fewer defects in the latter categories.

Focus on Damaged Cap and Leakage: The highest number of nonconformity comes from "Damaged Cap" (about 1400) and "Leakage" (around 1000). These are areas where quality enhancements should be prioritized.

Relatively Stable Process: The rest of the process seems stable, with the nonconformity from "Damaged Bottles," "Underfilling/Overfilling", and "Labeling & Packaging" decreasing and being well below the CL.

Implementing successful corrective and enhancement measures requires accurate identification of the underlying cause of noncompliance, which was accomplished with the use of the Power BI tool, a powerful business intelligence (BI) solution created by Microsoft that enables users to visualize and analyze data, enabling informed decision-making (Figure 5).

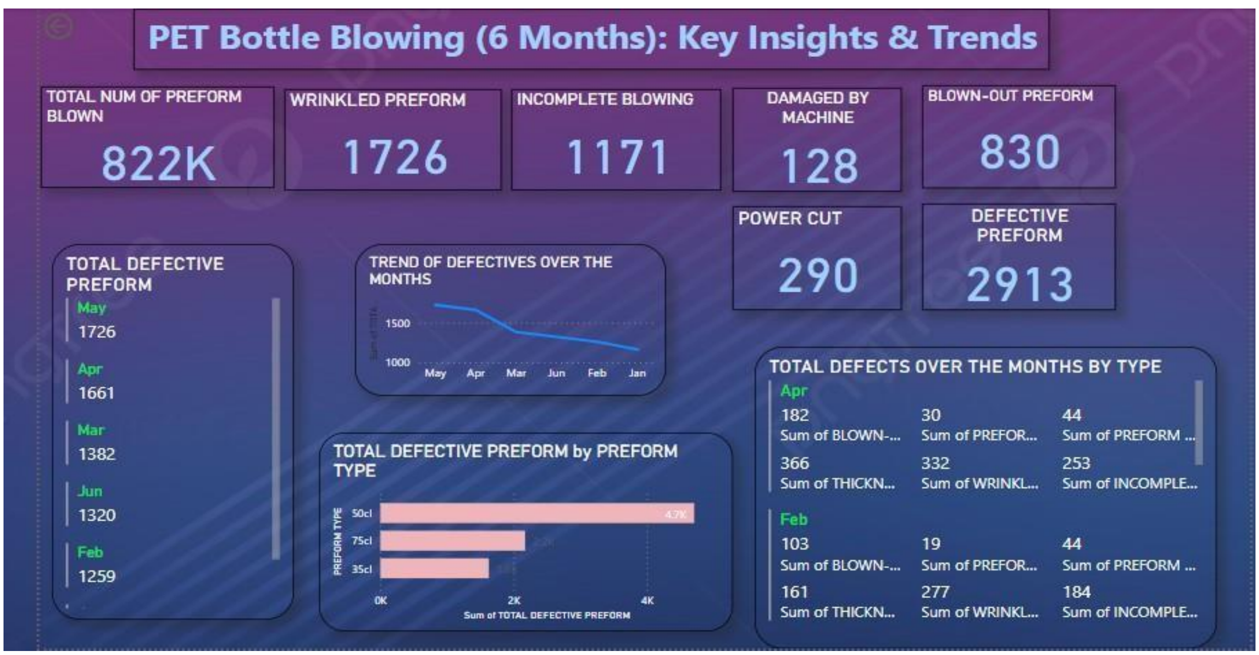

Figure 5 An interactive dashboard revealing insights into PET bottle production.

This Power BI dashboard provides insights into defects and trends in PET bottle-blowing over 6 months (January to June). Here's an interpretation of the key sections:

- A total of 822,000 preforms were processed, out of which 1,726 were defective due to wrinkles, 1,171 had issues with incomplete blowing, and 128 were damaged by the machine. Additionally, 830 preforms were blown out during production, while 290 were affected by power outages, resulting in a total of 2,913 defective preforms overall.
- The month-wise breakdown of defectives shows that May had 1,726 defects, followed by April with 1,661, January with 1,159, March with 1,382, June with 1,320, and February with 1,259 defectives.

- This line graph indicates a downward trend in the number of defective preforms from May to June, suggesting that corrective measures were taken to reduce defects.
- The breakdown of specific defects by month shows that in April, there were 332 wrinkled preforms, 253 cases of incomplete blowing, 44 cases of power cut, 30 cases of preform damaged by machine, 366 cases of thickness variation defect, and 182 blown-out preforms.
- In February, there were 277 wrinkled preforms, 184 cases of incomplete blowing, 44 cases of power cut, 19 cases of preform damaged by machine, 161 cases of thickness variation defect, and 103 blown-out preforms.
- In March, there were 261 wrinkled preforms, 232 cases of incomplete blowing, 56 cases of power cut, 16 cases of preform damaged by machine, 226 cases of thickness variation defect, and 131 blown-out preforms.
- In May, there were 339 wrinkled preforms, 235 cases of incomplete blowing, 48 cases of power cut, 10 cases of preform damaged by machine, 367 cases of thickness variation defect, and 202 blown-out preforms.
- In June, there were 190 wrinkled preforms, 130 cases of incomplete blowing, 52 cases of power cut, 31 cases of preform damaged by machine, 222 cases of thickness variation defect, and 94 blown-out preforms.
- In January, there were 327 wrinkled preforms, 137 cases of incomplete blowing, 46 cases of power cut, 22 cases of preform damaged by machine, 107 cases of thickness variation defect, and 118 blown-out preforms (Figure 6).

The dashboard offers a thorough rundown of the PET bottle-blowing procedure, focusing on 35 bottles over six months. It tracks various metrics related to bottle quality, production efficiency, and potential bottlenecks. Key metrics include the total number of bottles blown 176,000, the number of defective preforms 482, 380 wrinkled preforms, 240 incomplete blowings, 25 damaged by machine, 161 blown-out preforms, and 49 power cut. Defective preforms have generally been declining over time, as indicated by the line chart (Figure 7), which suggests process improvements.

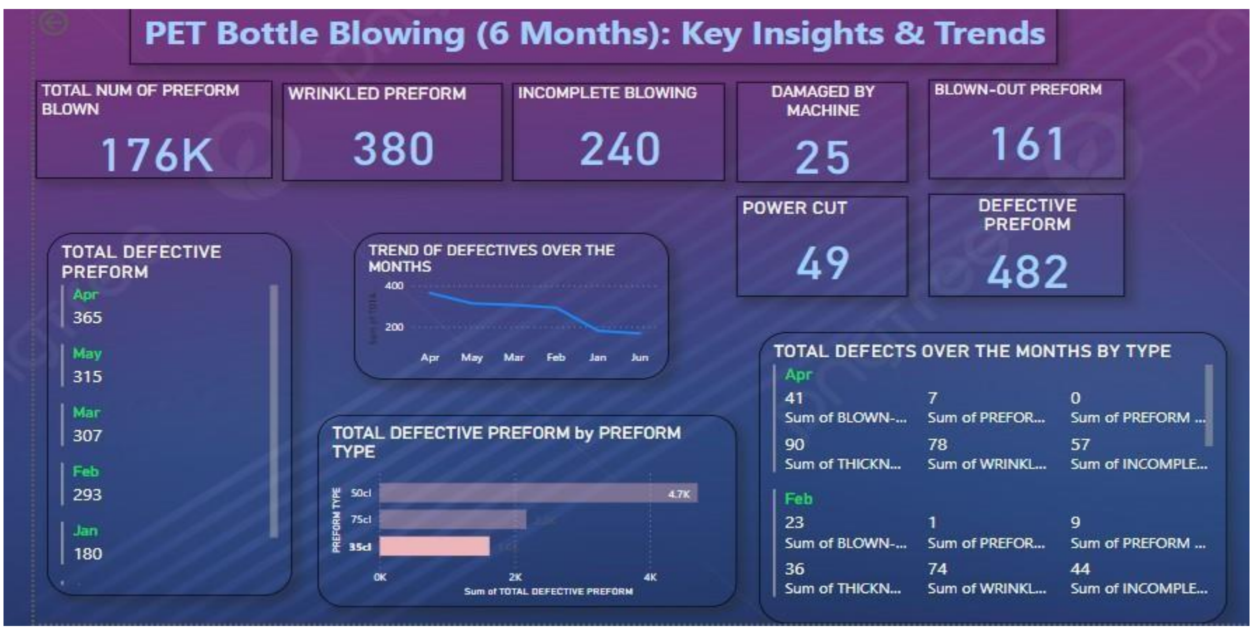

Figure 6 A glimpse into the overall production of 35cl pet bottles from Jan to June

This dashboard provides a thorough rundown of the 75 PET bottle-blowing procedure over six months, tracking various metrics related to bottle quality, production efficiency, and potential bottlenecks. Through the process of blowing, there were produced a total of 195,000 bottles with the rejection of 763 preforms. The categories of defects are as follows: 452 wrinkled preforms, 326 incomplete-blown preforms, 26 preforms damaged from machines, 09 blown-out preforms, and 53 from power outages. The defect pattern showed a general decline that reflects progressive enhancement in the process.

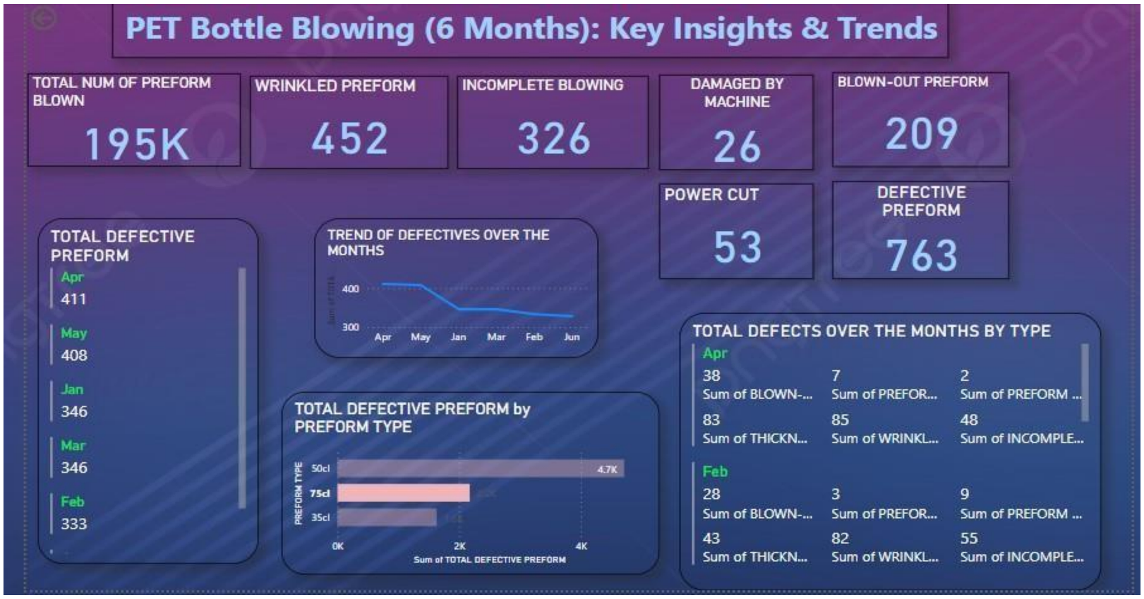

Figure 7 Insight into the total production of 75cl

Some areas for future enhancement are the systematic reduction of the most dominant defect-wrinkled preforms' through the inspection of preform quality and heating conditions. Incomplete blowing, it may involve through monitoring of air pressure, equipment maintenance, etc., and regular power cuts are able must be minimized by investing in backup power equipment to reduce the downtime and a smaller number of faults (Figure 8).

With important indicators like the total number of blown bottles (451,000) and the number of damaged preforms (1,668), the dashboard provides a thorough assessment of the PET bottle-blowing process. Defects are broken down as follows: 894 wrinkled preforms, 605 incomplete blowings, 77 preforms damaged by machines, 460 blown-out preforms, and 188 affected by power cuts. A general downward trend in defective preforms over time is indicated by the line chart, reflecting enhancements in the process. The bar chart visually compares the frequency of each defect type. Key areas for enhancement include identifying the root causes of wrinkled preforms, maintaining proper air pressure and equipment for incomplete blowing, and implementing backup power solutions to reduce the impact of power outages.

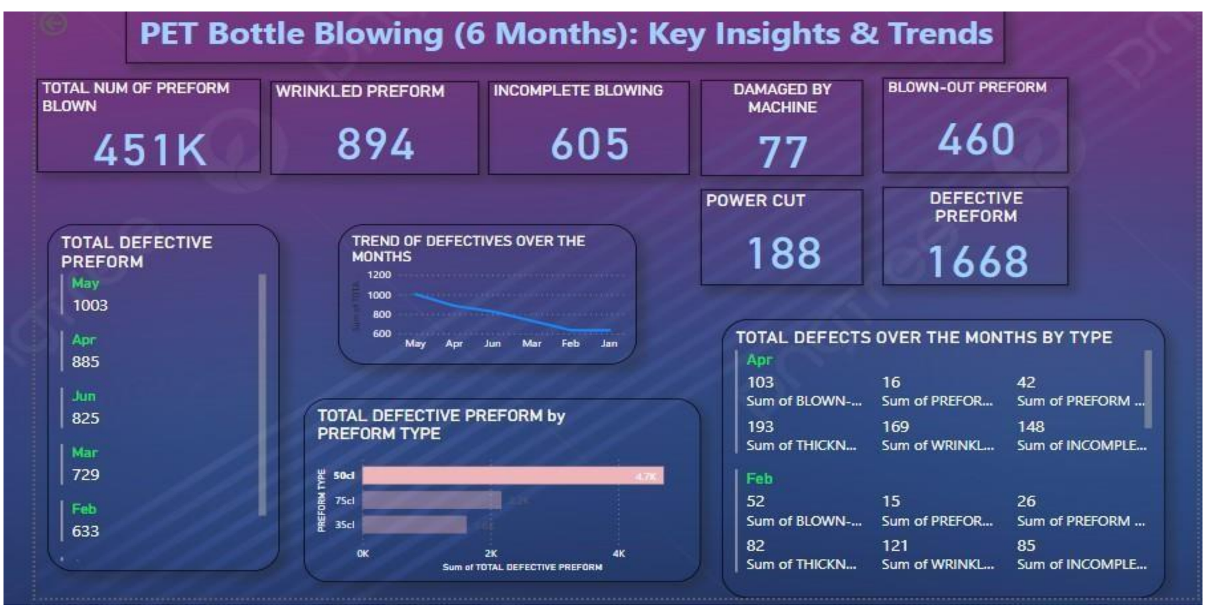

Figure 8 Insight into the total production of 50cl

The performance of 35cl, 50cl, and 75cl PET bottles, along with the total production for each month was illustrated in (Figures 6, 7, and 8). Analysis of defect trends over the months reveals noteworthy insights. Specifically, during June when experiments were conducted to optimize temperature and pressure settings for PET bottle-blowing across various sizes, the lowest number of defects was observed for 75cl and 35cl bottles (Table 9). Additionally, the defect count for 50 bottles remained within the acceptance limit, indicating a positive outcome for this bottle size.

Table 9 Total defects generated from January to June by bottle size

Kind of defeats	50cl	35cl	75cl	Total
Defective preform	1668	482	763	2913
Wrinkled preform	894	380	451	1726
Incomplete blowing	605	240	326	1171
Power cut	188	49	53	290
Blown outpreform	460	240	209	830
Preform damaged by machine	77	25	26	128

Power BI was utilized to provide real-time insights into the bottled water production process, enabling the identification and analysis of defects occurring during production. By integrating live data feeds, Power BI allowed operators and managers to monitor key production metrics such as the number of bottles produced, defect rates, and the types of defects occurring in real-time (Figure 9). The Power BI dashboard presents a six-month summary of the bottled water production process, focusing on key production defects. A total of 747 leakages were recorded, along with 1,191 bottles affected by damaged caps, 326 bottles with labeling errors, and 651 damaged bottles.

The overall defect count was tracked monthly, with January having the highest number of defects of 960, followed by May 587, March 579, April 416, and June 399. A line chart indicates a downward trend in defects over time, suggesting enhancements in production quality. A bar chart shows defects by bottle size, with the 50cl bottle having the most defects, followed by the 75cl and 35cl bottles. In April, 106 total defects were recorded, including 68 damaged caps, 42 labeling errors, and 123 damaged bottles. February saw 205 total defects, with 143 damaged caps, 44 labeling errors, and 125 damaged bottles. January had the most defects, with damaged caps, leakages, and labeling errors being the major issues (Figures 10 and 11).

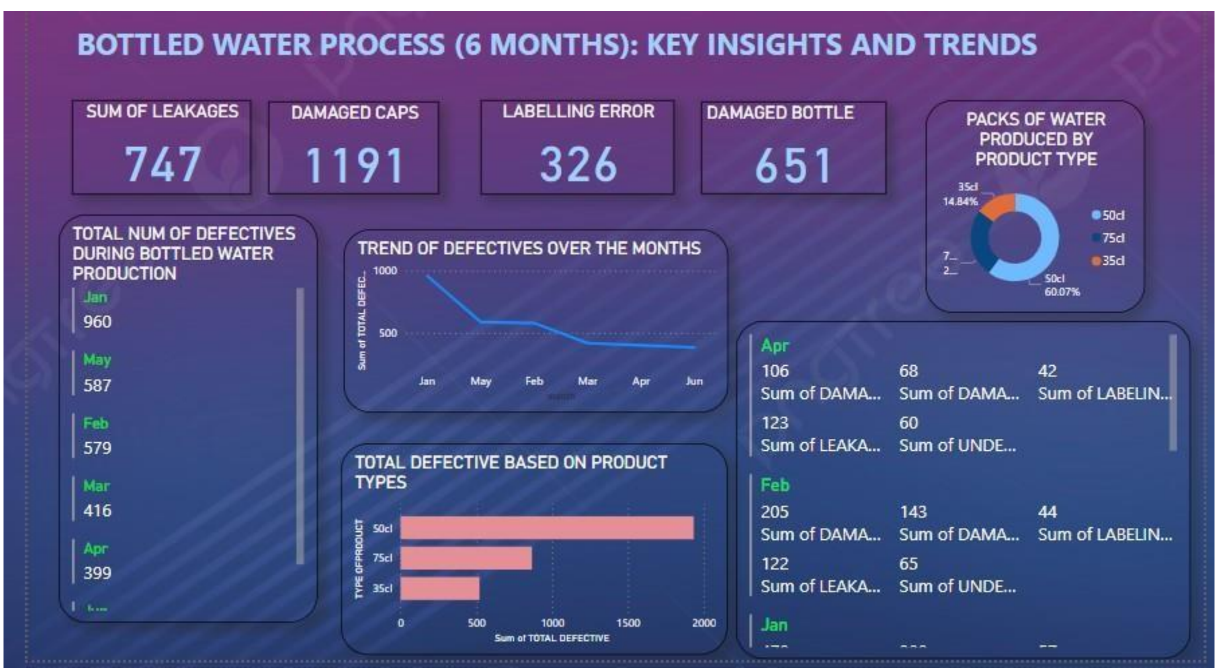

Figure 9 Bottled water production from January to June.

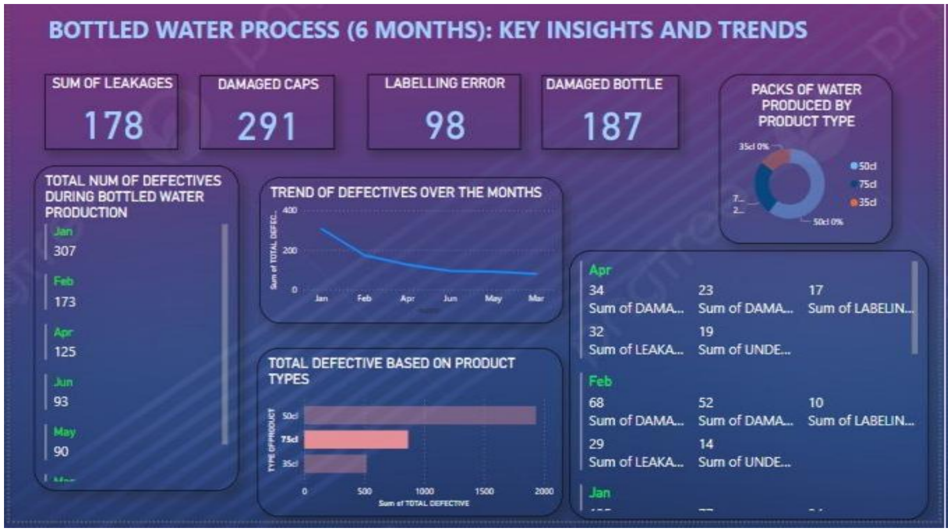

Figure 10 75cl bottled water production

Figure 11 35cl bottled water production dashboard

A six-month overview of the 75cl bottled water production process was provided in Figure 10, where a total of 178 leakages, 291 damaged caps, 98 labeling errors, and 187 damaged bottles were recorded. The line chart indicates a steady decline in defects from January to June, showing enhancements in production quality. January had the highest number of defects with a total of 307, primarily due to leakages and damaged caps, March had the least number of defects with a total of 79. The bar chart reveals that the 75cl bottles had a significant number of defects during this period. In contrast, Figure 11 presents data for the 35cl bottled water production over the same period. It recorded 105 leakages, 203 damaged caps, 38 labeling errors, and 109 damaged bottles.

The trend is similar to that in Figure 10, with a decrease in defects from January to June. February had the most defects, mainly due to leakages and damaged caps while April had the least with a total of 47. The bar chart shows that the 35cl bottles experienced fewer defects compared to the 75cl bottles. In summary, the 75cl bottles (Figure 10) experienced more defects, particularly in damaged caps with 291 and leakages 178, while the 35cl bottles (Figure 11) had fewer defects overall. There is room for improvement in repairing broken caps and leaks, since both dashboards show a declining trend in faults, indicating improvements in manufacturing quality (Figure 12).

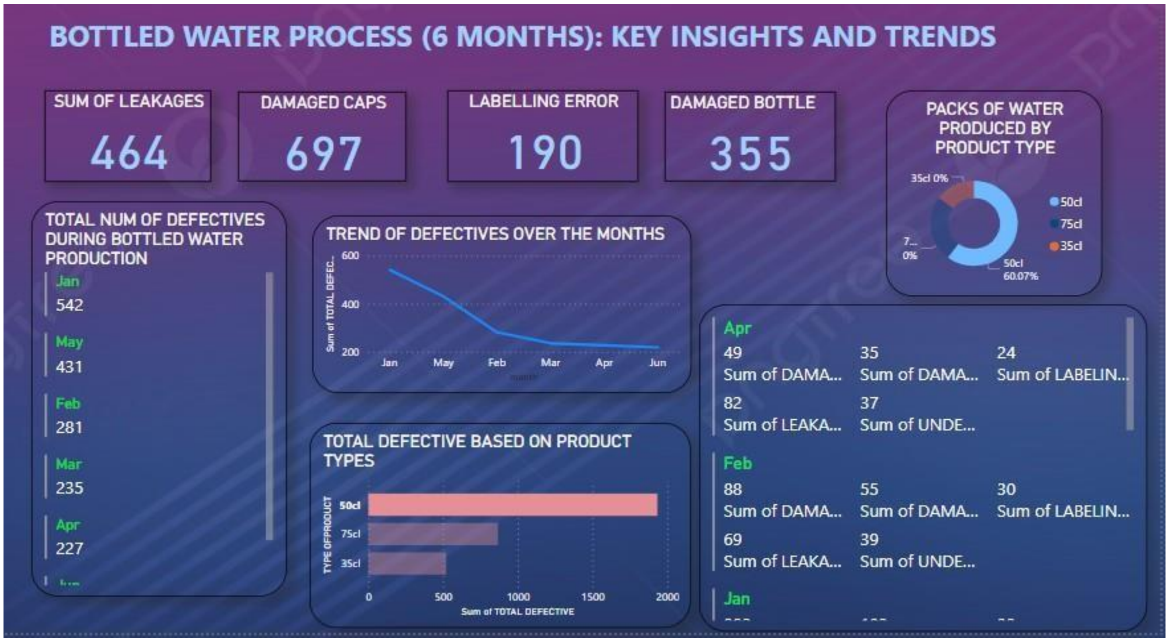

Figure 12 50cl bottled water production dashboard

The dashboard provides a comprehensive overview of the bottled water production process, focusing on 50 bottles over six months. It tracks various metrics related to product quality, production efficiency, and potential bottlenecks. The total number of defective bottles is 542 and the breakdown of defects leakages amounts to 464, damaged caps are 697, labeling errors are 190, and damaged bottles are 355. The line chart shows a general downward trend in defective bottles over time, indicating enhancements in the process. Additionally, the bar chart visualizes the distribution of defects across different product types. Potential areas for enhancement include addressing damaged caps, leakages, and labeling errors through root cause analysis, process adjustments, and training.

4. CONCLUSION

This research was carried out to examine and enhance the effectiveness of PET bottle-blowing and bottling water production processes, with the study aimed at a water production factory. Using three significant quality management tools, the Pareto-Lorenz diagram, control charts, and Power BI we made a detailed analysis of product quality and determined key production defects. These machines posed major quality problems such as wrinkled preforms, incomplete blowing, and defective preforms, all of which were affecting the efficiency of production. The defects in the PET bottle-blowing process, including wrinkled and defective preforms, incomplete blow, and blown preforms, not only slowed down production but also resulted in economic losses and product quality compromise (Familusi et al., 2024).

Likewise, in the production of bottled water, defects like damaged caps, leakage of bottles, and machine damage to bottles were common, impacting production slowdowns and compromising product quality. The research promotes the need to remove these imperfections by introducing systematic reform in the PET bottle-blowing and bottled water production process. Removing the issues will demand specific intervention at different stages of production to enhance overall efficiency and product quality. To enhance quality control and avoid process parameter selection contradictions, the following are recommended:-

- Utilize Detailed Checklists: There should be checklists for every production run to ensure that significant production parameters like pressure and temperature are closely regulated. This will allow operators to utilize the right parameters to prevent errors. Furthermore, routine audits with the checklists will allow process deviations to be detected early.

- o Standardize Process Parameters: Standardization of process parameters like temperature, air pressure, and cooling time is highly critical in gaining consistency in the quality of bottles. Optimal values of these parameters, either derived from trial data or best practice, are established so that production variability is reduced. Training of operators also becomes easier since the same procedures are being carried out everywhere.
- o Utilize High-Quality Crystal PET Preforms: High-quality PET preforms minimize defects in the form of wrinkles, insufficient blowing, and preform damage. High-quality preforms translate into more uniform thickness and greater resistance to deformation, which translates into stronger and better-looking bottles. Better raw materials can help decrease production loss caused by defective bottles substantially.
- o Preform Employee Performance Appraisals and Training: There should be regular performance appraisals of employees to determine areas where skills need to be enhanced. Special training sessions should be organized to enhance the knowledge and efficiency of personnel, especially in the operation of machinery, quality control processes, and defect detection. Trained employees will be better equipped to detect problems early and implement corrective actions promptly.

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Author Contributions
AA: Conceptualization, Design; IMD: Methodology, Review; IDM: Review, Proofreading, Visualization

Informed consent
Not applicable.

Conflicts of interests
The authors declare that there are no conflicts of interests.

Ethical approval
Not applicable.

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Data and materials availability
All data associated with this study are present in the paper.

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