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REDUCING PRODUCT DEFECT RATE IN BEER PRODUCTION USING SIX SIGMA METHODOLOGY

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ABSTRACT

This research work is on the application of Six Sigma Define-Measure-Analyze-Improve-Control (DMAIC) methodology in the reduction of product defects within the beer manufacturing industry. Product defects result from reduction in the quality of material, operational conditions, operator's behaviour and several other factors in the beer manufacturing process. Reduction of product defect is of great importance in the improvement of yield & financial conditions of any company. Product defects rate causes a direct effect on the profit margin of the company & decreases the quality cost during the manufacturing of the product. The work implemented DMAIC methodology in investigating defects, and their root causes while providing solution to eliminate these defects. The analysis from employing Six Sigma DMAIC indicated that the crowner height and crimp gauge influenced the number of defective products. Design of experiments (DOE) and the analysis of variance (ANOVA) techniques were combined to statistically determine the correlation of the crown height and crimp gauge with defects as well as to define the optimum values needed to eliminate the defects. Thus, a reduction of 57.1% in the beer quality defect was achieved, which helped the organization studied to reduce its general defects thereby improving its Sigma level from 2.6 to 3.0.

KEYWORDS: Defects reduction, DMAIC, ANOVA, Beer Production, Six Sigma.

1.0 INTRODUCTION

Rigorous competition and more complex customer needs and demands have forced entire industries and organizations to continuously improve the quality of their products and services as a means to gaining a strategic competitive advantage. The beer manufacturing company used as a case study in this research work has to maintain the quality of its products so as to be able to delight customers and thus effectively compete in the market. As such reduction of common product defects such as leaking bottles/can/keg beer, dirty bottles/can/keg/crates, rusty crown/ wrong crown/can/lid, wrong alignment or missing label, foreign matters (broken glass or debris), defect shrink wrap film, low fill, wrong or unreadable code etc is of utmost importance.

In quality control, the term sigma (s) has been traditionally used to measure the variation in a process or its output (Omachonu and Ross, 2004). In the Six Sigma's terminology, the "sigma level" is denoted as a company's performance (Pyzdek and Keller, 2010). Particularly, a Six Sigma level refers to 3.4 Defects per Million Opportunities (DPMO) (Stamatis, 2004), or in other words, to have a process which only produces 3.4 defects per every one million products produced. The measure of performance and process variability, according to Brue and Howes, (2006) is only one of the three meanings of Six Sigma. According to them, besides being a measure of performance and process variability, Six Sigma is also a management philosophy and strategy that allows organizations to achieve lower cost, as well as a problem solving and improvement methodology that can be applied to every type of process to eliminate the root cause of defects.

Six Sigma focuses on the critical characteristics that are relevant for the customers. Based on these characteristics, Six Sigma identifies and eliminates defects, mistakes or failures that may affect processes or systems. Bailey et al. (2001), comments that among the most widely used improvement approaches (i.e. total quality management, business process re-engineering and lean enterprise), Six Sigma has the highest record of effectiveness. Therefore, some authors argue that the main benefits that an organization can gain from applying Six Sigma are: cost reduction, cycle time improvements, defects elimination, an increase in customer satisfaction and a significant rise in profits(Pyzdek and Keller, 2010; Stamatis, 2004; Dale et al., 2007; Breyfogle et al., 2001). In addition, Kumar et al. (2008) state that although Six Sigma is normally used in defects reduction (i.e. industrial applications), it can also be applied in business processes and to develop new business models. In this context, Garza-

Reyes et al. (2010) applied the Six Sigma philosophy, and some of its principles, to improve (by reducing errors) the business process employed by an SME to define and produce the specifications and documentation for its custom-made products. Banuelas et al. (2005) claim that other benefits such as: an increase in process knowledge; Participation of employees in Six Sigma projects; and problem solving by using the concept of statistical thinking can also be gained from the application of Six Sigma. In this work several tools were employed to illustrate these points during the utilization of Six Sigma.

2.0 LITERATURE REVIEW

An integral part of Six Sigma is DMAIC. The DMAIC model refers to five interconnected stages that systematically help organizations to solve problems and improve their processes. Dale et al. (2007) briefly defines the DMAIC phases as follows:

i. **Define**. This stage defines the team's role; project scope and boundary; customer requirements and expectations; and the goals of selected activities (Gijo et al., 2011). .
ii. **Measure**. At this stage measurement factors to be improved are selected (Omachonu and Ross, 2004) and a structure to evaluate current performance as well as assessing, comparing and monitoring subsequent improvements and their capability is provided (Stamatis, 2004).
iii. **Analyze.** This stage centers on determining the root cause of problems (defects) (Omachonu and Ross, 2004), understanding why defects have taken place as well as comparing and prioritizing opportunities for advance betterment (Adams et al., 2003).
iv. **Improve.** This step focuses on the use of experimentation and statistical techniques to generate possible improvements to reduce the amount of quality problems and/or defects (Omachonu and Ross, 2004).
v. **Control.** Finally, this last stage within the DMAIC process ensures that the improvements are sustained (Omachonu and Ross, 2004) and that ongoing performance is monitored. Process improvements are also documented and institutionalized (Stamatis, 2004).

DMAIC resembles the Deming's (1993) continuous learning and process improvement model, PDCA (plan, do, check, act). Within the Six Sigma's approach, the DMAIC model indicates, step by step, how problems should be addressed, grouping quality tools, while establishing a standardized routine to solve problems (Bezerra et al., 2010). Thus, DMAIC assures the correct and effective process execution by providing a structured method for solving business problems (Hammer and Goding, 2001). This rigorous and disciplined structure, according to Harry et al. (2010) is what many authors recognize as the main characteristic which makes this approach very effective. Pyzdek, (2003) considers DMAIC as a learning model that although focused on “doing” (i.e. executing improvement activities), also emphasizes the collection and analysis of data, previously to the execution of any improvement initiative. This provides the DMAIC’s users with a platform to take decisions and courses of action based on real and scientific facts rather than on experience and knowledge, as it is the case in many organizations, especially Small and medium side enterprises (SMEs) (Garza-Reyes et al., 2010).

Although many other process improvement and problem-solving methodologies such as QC story (Tadashi and Yoshiaki, 1995), seven steps method (Westcott, 2006), Xerox quality improvement process and problem-solving process (Palermo and Watson, 1993), FADE (Schiller et al., 1994), among others, have been developed by organizations to improve their manufacturing and business processes, DMAIC may arguably be considered the most widely used and popular approach. This is because it is an essential element of Six Sigma, which has been extensively implemented in industry (Black and Revere, 2006; Antony, 2004) and lean Six Sigma, which has also received considerable attention from academics, researchers and industrialists (George et al., 2005; Na¨slund, 2008).

In production processes, the slightest deviation in the quality of raw material, production conditions, operator behaviour and other factors can result in product defects. If eventually these defective products are sent to the market and rejected by customers, losses will be incurred by the company in terms of time, materials and capital. It also creates customers dissatisfaction, which negatively affects the organization’s image. In the organization studied, customer complaints on product defects (leakages to be specific) have been the major challenge which led to a huge loss of 13.5% between June and September 2019.

3.0 METHODOLOGY

SIX SIGMA – DMAIC analysis process improvement project tool was used to investigate and improve product quality in beer manufacturing process.

3.1 Define

The voice of the customer and goals of the project were defined using the project charter as shown in Tab.1 and the Supply, Input, Process, Output and Customer (SIPOC) diagram as shown in Tab.2.

Table1: Project Charter.

Project Charter	
Project Title: Reduction in Defect Rate Using Six Sigma DMAIC in Beer Production	
Background and reasons for selecting the project: There have been high rejections of defective beer products by customers. This problem causes several types of losses to the company, for example: time, materials, capital as well as it create customers' dissatisfaction, which negatively affects the organization's image.	
Project Goal: To reduce the defects by 50% after applying Six Sigma into the beer manufacturing process	
Voice of the Customer (VOC)	Product Quality
Project Boundary	Focus on bottled beer
Team Members	Production Manager, an experience Shop floor Operator, A quality personnel and the improvement project leader
Expected Financial Benefits	A considerable cost saving due to defect reduction
Expected Customer Benefits	Receiving the product with expected quality

Table 2: SIPOC diagram for Beer Packaging.

Supplier	**Input**	**Process**	**Output/Product**	**Customers/Clients**
Brewing	Quality Product from BBTs, Daw – Liquor, Hot Water, CIP Caustic	De-palletizing, Unpacking, Crate Washing, Bottle Washing, Bottle Inspection, Bottle Filling, Checkmating, Pasteurization, Labeling, Coding, Packing, Palletizing	Packaged Quality RGB Beer	Logistics Department
Energy & Fluid	Compressed air, CO2, Power, Water, Refrigeration, Steam,	De-palletizing, Unpacking, Crate Washing, Bottle Washing, Bottle Inspection, Bottle Filling, Checkmating, Pasteurization, Labeling, Coding, Packing, Palletizing	Packaged Quality RGB Beer	Logistics Department
Packaging Raw Material Supplier	Crowns, Labels, Glue, Ink and Makeup	Same Above	Packaged Quality RGB Beer	Logistics Department

The project charter tool was used to present the project information structure and to document the target/ objective of the project. The SIPOC diagram gives information flow within the various departments as well as the role of customers and manufacturers.

3.2 Measure

In the measure phase, clarifications were carried out on the major defect that needed to be optimized through effective data collection. The quality department had a data collection plan already in existence. Defect data collection system has the following parameters date and time, brand, Operator, beer product count, shift, production line, machine type, machine number, no of affected cases and person responsible. While conducting the six sigma project, one of the methods defined was simply number *of* defects per type. The quality level, which is measured through Defect Per Million Opportunity (DPMO) and the Six Sigma level of the process were the two factors used to compare the before and after state of the beer manufacturing process. After determining the total number of defects, the DPMO and Six sigma level of the beer manufacturing process per department. Packaging department had the highest defect percentage as seen below.

a. **Defect in Energy and Fluid Section (E&F):-** Low Fill and Unfilled bottles
b. **Defects in Brew Section:-** Out of Spec beer, High Dissolved Oxygen (DO) and Particles in beer
c. **Defects in Packaging Raw Material Section (PRM):-** Label out of spec, Bad crown corks and Bad glue
d. **Defects in Packaging Section:-** Leakers, Dirty bottles, Rusty crowns, Flying label, Corking defect (Police cap), Missing label, No code and Foreign matters

From the above, the process performance was measured through data collection of different defects that critically impact on customer value.

a) Data Collection

The data is collected to find the current rate of rejection and sigma level of all sections to measure that which one is most critical.

i. Formula for Calculating DPMO and Sigma Level

$$DPMO = \left(\frac{TDO}{TO}\right) * 1000000$$

Where DPMO = Defect Per Million Opportunity

TDO = Total Defects Observed

TO = Total Opportunities

Table 3: Rate of defect produce per department and their sigma level Source :(Quality Department Operator Work Station (OWS)).

Department	Defects	Production	Defect %	Dpmo	Sigma level
E & F	40	216000	0.019	185	5.0
Brew	55	216000	0.026	255	4.9
PRM	20	216000	0.0093	93	5.2
Packaging	1200	216000	0.56	5556	4.0

ii. Sigma Level gotten by checking the DPMO value at the Sigma

Tab.4 and fig.1 ashows that defect percentage is highest and the sigma level is low in the packaging department. Therefore packaging defects are the most critical defects which are to be reduced.

Table 4: Sigma level and defect percentage.

Departments	E &F	Brew	PRM	Packaging
Defects %	0.019	0.026	0.0093	0.56
Sigma Level	5.0	4.9	5.2	4.0

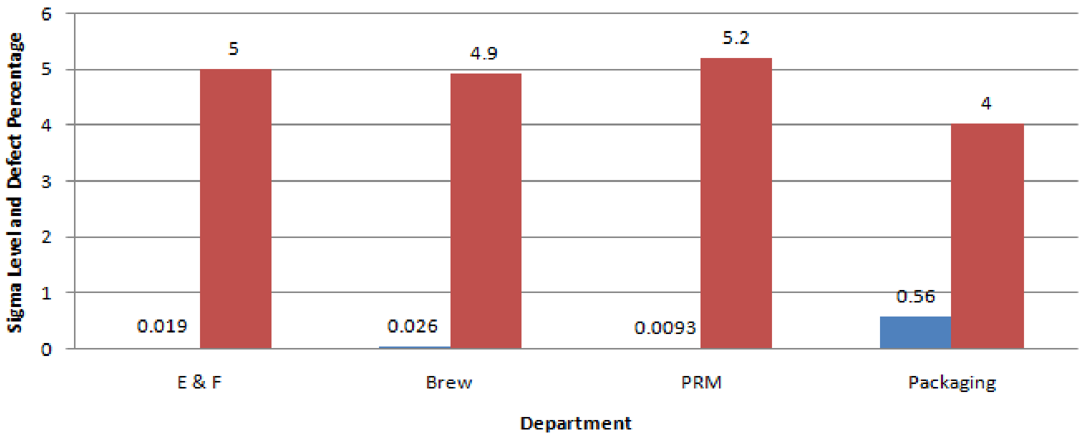

Figure 1: Chart between defect percentage and sigma level.

b. Defect Rate in Packaging Department

Data collected from the quality department shows that there are two major defects which contribute to the rejection of beer products by customers. These are leakers and corking defect. Other observed defects were categorized as miscellaneous. For this research Leakers is define as those product without pressure and carbonate due to leaking crown cork. While corking defect are those products with police cap and improper crowner crimping. Finally the miscellaneous category consist of other type of defects such as missing label, rusted crown, flying label, no code, foreign matters and dirty bottles. Nine (9) months' customer complaints data were collected as shown in Tab.5 and fig.2.

Table 5: January to September customer complaints source: (Quality Department OWS).

Type of Defects	Jan to June	July	August	September
Leakers	4370	3660	4840	5740
Corking Defect	30	50	30	80
Miscellaneous	5	10	12	0

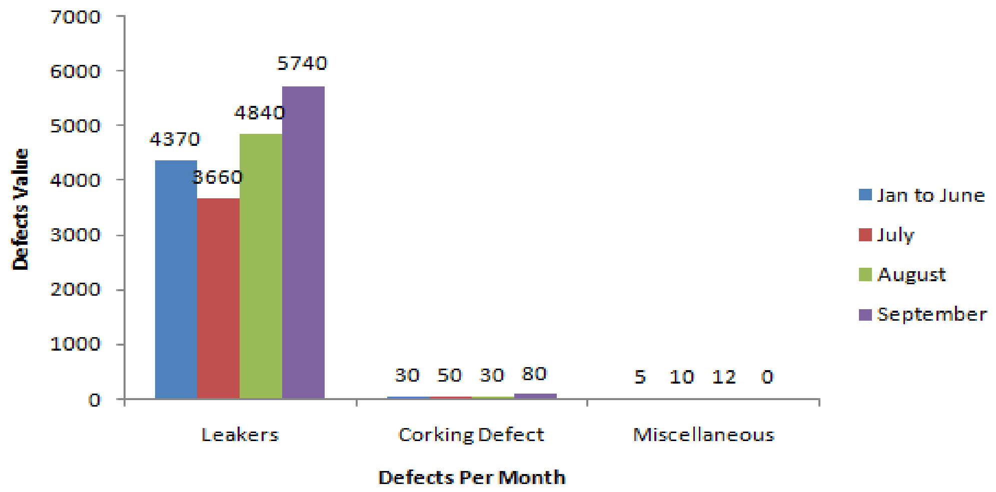

Figure 2: Customer Compliant on Defects from January to September.

Table 6: Current and Expected performances.

Major type of Defect	Number of the major Defects(Units)		Quality levels (DPMO)		Sigma Level	
	C*	**E***	**C***	**E***	**C***	**E***
Leakers	18610	9305	135000	67500	2.6	2.9

C*= Current process performance; E*=Expected process performance after the completion of the six sigma project.

3.3 Analyze

In order to illustrate and categorize the possible causes of the problem, a cause-and-effect (Ishikawa or fishbone diagram) diagram was constructed. There are five main categories normally used in a cause-and-effect diagram, namely: machinery, manpower, method, material and measurement (5M) plus an additional parameter: environment. The possible root causes in this case study are shown in fig.3. It was discovered that the crowner assembly, crimp gauge measurement and the rejection table at both ex-filler and labeler within the beer packaging process had an impact on causing the leaking beer product. In particular, it was determined that two process factors (i.e. crowner height adjustment per stock keeping unit (SKU) and crimp gauge) had a direct effect on the number of leaking beer produced. Interestingly, these parameters had a relationship between each other as the beer has to be crowned to specification with the required height adjustment per SKU. Consequently, the relationship between the SKU produced, crimp gauge measurement and crowner height adjustment, and their impact on the number of leaking beer produced was investigated in the following DMAIC's "improve" phase.

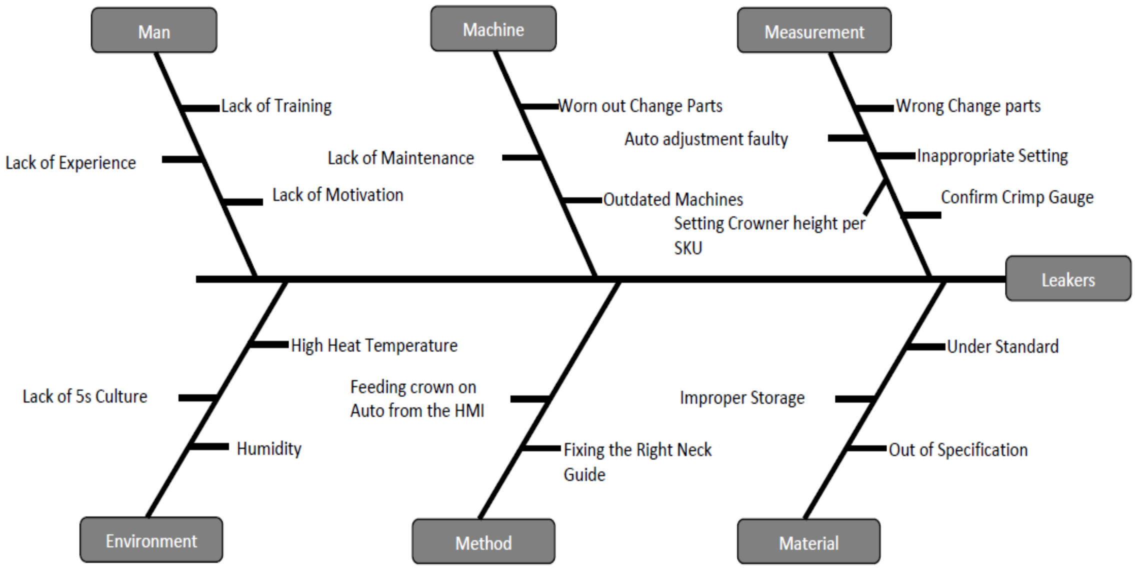

Figure 3: Cause and effect (Fish Bone) diagram of the defects (Leakers).

3.4 Improve

After the root cause(s) has/have been determined, the DMAIC's "improve" phase aims at identifying solutions to reduce and tackle them. A statistical technique known as Design of Experiment (DOE) was used to investigate the effect of multiple factors in the improve phase.

With experience and common sense, we could dictate the existence of a correlation between crowner height adjustment and crimp gauge with respect to leaker in beer production. But to get the statistical significant whether the assumed correlation was correct, a DOE was used. An experiment was carried out using analysis of variance (ANOVA) which is a statistical tool of DOE to investigate whether the parameters of both crowner height and crimp gauge had a negative effect on the process, causing leakers in beer. A two-way ANOVA was used considering that there are two sources of data that needs to be investigated. The two factors as mentioned earlier are (crowner height and crimp gauge) with three different ranges of height; 1405mm, 1409mm, 1413mm and five crimp gauge; Ǿ28.58, Ǿ28.64, Ǿ28.70, Ǿ28.78, Ǿ28.83. These parameters were defined based on experience and process knowledge by the team members specifically the line manager and the filler operators. Since performing a large number of experiment trials can be expensive, time consuming and disrupt normal production, the improvement team determined, based on production capacity, that the experiment could be replicated two times for each combination of factors, where 2400 units (i.e. bottles) were collected i.e. 10% of the hourly output for every replication, which resulted in a total of 30 replications. The aim of the test is to investigate whether the two factors (crowner height and crimp gauge) resulted in defective products, null and alternative hypothesis were formulated as presented below:

Hoa: There is no interaction between the crowner height and the number of defects (leakers)(a1405mm = a1409mm = a1413)

Hob: There is no interaction between the crimping gauge and the number of defects (leakers)(b28.58Ǿ = b28.64Ø = b28.70Ø = b28.76Ǿ = b28.83Ø)

H1: There is interaction between crowner height and crimping gauge

Note: a = variance derived from the crowner height

b= variance derived from the crimp gauge.

3.5 *Control*

The aim of the control phase is to sustain the gains from processes which have been improved by institutionalizing process or product improvements and controlling ongoing operations. Design controls can then be used to monitor the processes and ensure that the improved processes remained in-control. In the case of this work, the case study organization, institutionalized the improvements made by including the optimum parameters for the crowner height and crimp gauge in the process sheets such as checklist, standard operating procedure etc, to be used during the calibration of the crowner height and crimp gauge. In addition, control charts were also implemented to track and detect abnormalities in the process so that appropriate actions can then be taken to eliminate them. In particular, control charts were implemented to monitor the performance of the beer packaging production process as shown in tab.7 and fig.4. This has and would continue to allow the organization studied to sustain the improvements achieved.

Table 7: Control Chart Simulation Table.

Date	Measurement	Mean	UCL(3σ)	LCL(3σ)
2/12/2019	11	7.714286	13.286981	2.141591
3/12/2019	6	7.714286	13.286981	2.141591
4/12/2019	9	7.714286	13.286981	2.141591
5/12/2019	8	7.714286	13.286981	2.141591
6/12/2019	8	7.714286	13.286981	2.141591
7/12/2019	5	7.714286	13.286981	2.141591
8/12/2019	10	7.714286	13.286981	2.141591
9/12/2019	8	7.714286	13.286981	2.141591
10/12/2019	4	7.714286	13.286981	2.141591

11/12/2019	8	7.714286	13.286981	2.141591
12/12/2019	7	7.714286	13.286981	2.141591
13/12/2019	9	7.714286	13.286981	2.141591
14/12/2019	7	7.714286	13.286981	2.141591
15/12/2019	8	7.714286	13.286981	2.141591

Formulation for Control Chat Analysis using Microsoft Excel

i. Mean μ = $(\frac{\sum D)}{n} = \frac{sum\ of\ all\ defects\ measured}{number of days\ measured}$

ii. Standard Deviation σ=$\sqrt{\frac{1}{N}\sum_{i=1}^{n}(xi-\mu)2}$

Where μ= mean

D = Sum of all defects measured

n = number of days measured

Xi =are the individual measured x values

N = number of x values

iii. Upper Control Limit (UCL) =$mean + (3 * standarddeviation)$

iv. Lower Control Limit (LCL) = $mean - (3 * standarddeviation)$

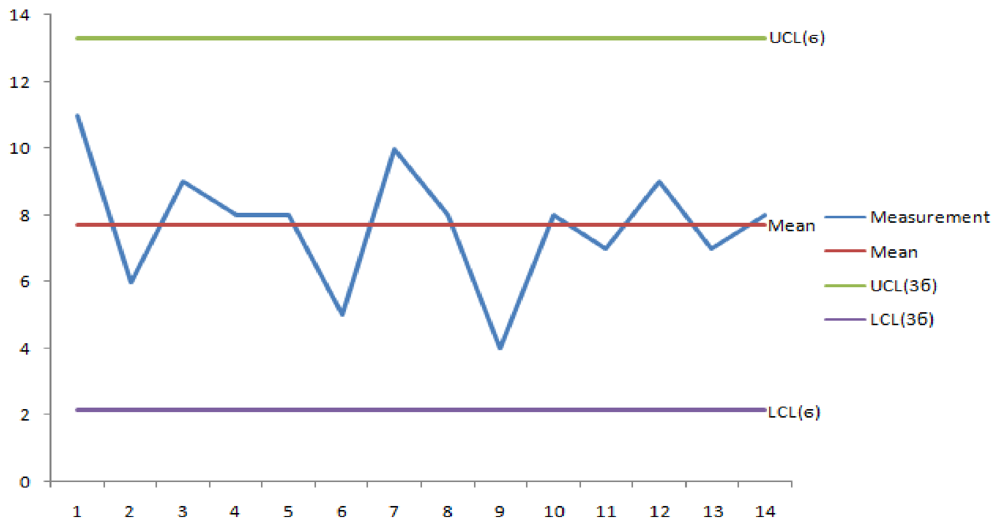

Figure 4: The Process improvement control chart.

4.0 RESULT

This research work presented a case study of defects reduction in a beer manufacturing process using Six Sigma principles DMAIC problem-solving methodology. From analyze and improve phases of DMAIC, the ANOVA analysis carried out shows that the crowner height and crimp gauge had a statistically significant impact on the production of leaking beer. By considering this, a reduction in the amount of defects was obtained by determining the optimum crowner height per SKU and crimp gauge which were defined as 1409mm and 28.64Ǿ respectively. Though, to totally eradicate defect in a process improvement, the goal is to reach a target sigma level of 6 and 3.4 DPMO respectively. However, moving from one sigma level to another does need a whole lot of work to be done. So from the result in tab.8, the target expectation of reducing the defect by 50% was exceeded.

Table 8: Defect Result from crimp gauge and crowner height.

		CRIMP GAUGE (Ǿ)					
Crowner Height Values(Mm)	**ORDER**	**28.58**	**28.64**	**28.70**	**28.76**	**28.83**	**No. of defect in unit**
1405	1	18	17	15	12	19	**160**
	2	16	15	21	10	17	
1409	1	20	7	14	22	16	**147**
	2	16	4	9	20	19	
1413	1	15	9	12	14	15	**119**
	2	9	8	11	10	16	
Total No. of Defect in Unit		**94**	**60**	**82**	**88**	**102**	**426**

Table 9: Results of two way ANOVA analysis with replication.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample(Crowner Height)	87.8	2	43.9	7.747059	0.004887	3.68232
Columns(Crimp Guage)	168.8	4	42.2	7.447059	0.001638	3.055568
Interaction	255.2	8	31.9	5.629412	0.002041	2.640797
Within	85	15	5.666667			
Total	596.8	29				

In this research, a comparison of F value and F critical, P value and significance value were used to test the hypotheses. This resulted in H0a to be rejected (Fa = 7.747.59 > Fa critical 3.68232), H0b to be rejected (Fb = 7.447059 > Fb critical = 3.055568) and Ho to be rejected (Fab = 5.629412 > Fab critical = 2.640797). Therefore, the two-way ANOVA analysis shown in tab.9 indicated that there was a correlation between the crowner height and crimp gauge at a significance level = 0.05. As a result, the analysis helped to statistically conclude that both crowner height and crimp gauge influenced the amount of leakers.

The number of defects from the experiment replications are summarized in the line and Pyramid plot charts presented in Fig.5 (a) and 5 (b). These figures denote that a crowner height 1409mm and crimp gauge of 28.64Ǿ provided the lowest amount of leakers.

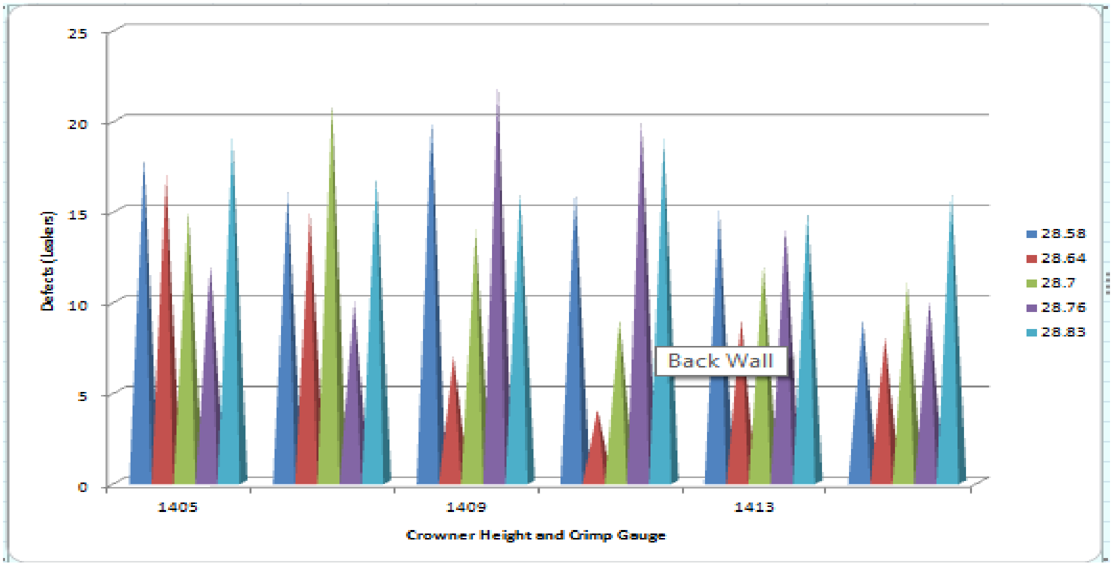

Figure 5(a): Crowner height of 1409 has the lowest number of defects.

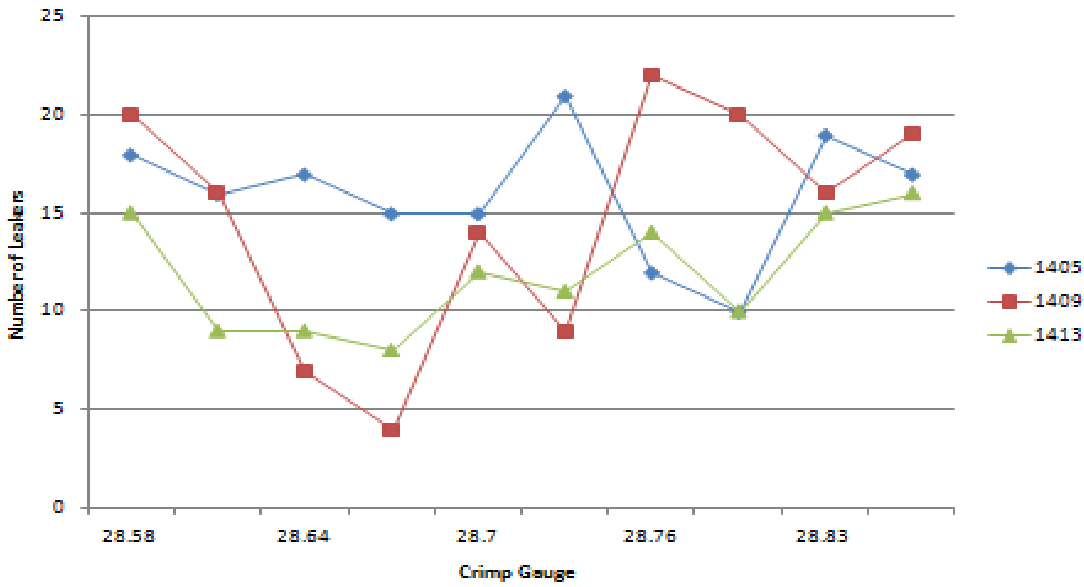

Fig 5(b): Crimp gauge of 28.64 has the lowest number of defects.

After the optimum parameters were defined, a trial was performed in order to test whether the optimum parameters (i.e. 1409mm and 28.64Ǿ) defined by the experiment were the best options to provide an improvement for the beer manufacturing process and reduce defects. In order to avoid disrupting production and taking into consideration that the previous experiment had already determined the optimum crown height and crimp gauge, a sample size of only 2400 units were taken as a base for the investigation. Tab.10 presents the results of the trial and a comparison between the "before and after" setting of the new parameters. The results indicate that the optimum parameters gotten in the experiment improved the beer manufacturing process by reducing the amount of leakers by 57.1%. This resulted in a reduction of DPMO from 135000 to 57915 and a Sigma level improvement from 2.6 to 3.0.

Table 10: Trial comparison of before and after improvement percentage.

Types of Defects	Percentage of defects before the improvement	Percentage of Defects after improvement
Leakers	13.5	5.8
Cork Defect	0.138	-7.562

Therefore, setting up the crowner height at 1409mm and crimp gauge at 28.64Ǿ not only did the amount of leakers' defects in beer declined but also the other types of defects. The improvement also demonstrated that the utilization of Six Sigma and DMAIC problem solving methodology was effective and efficient in minimizing the number of defects and thus enhancing productivity. A comparison between the "before and after" the Six Sigma improvement is illustrated in fig.6. Fig.7and 8 Shows the graphical Result of the DPMO and Sigma Level.

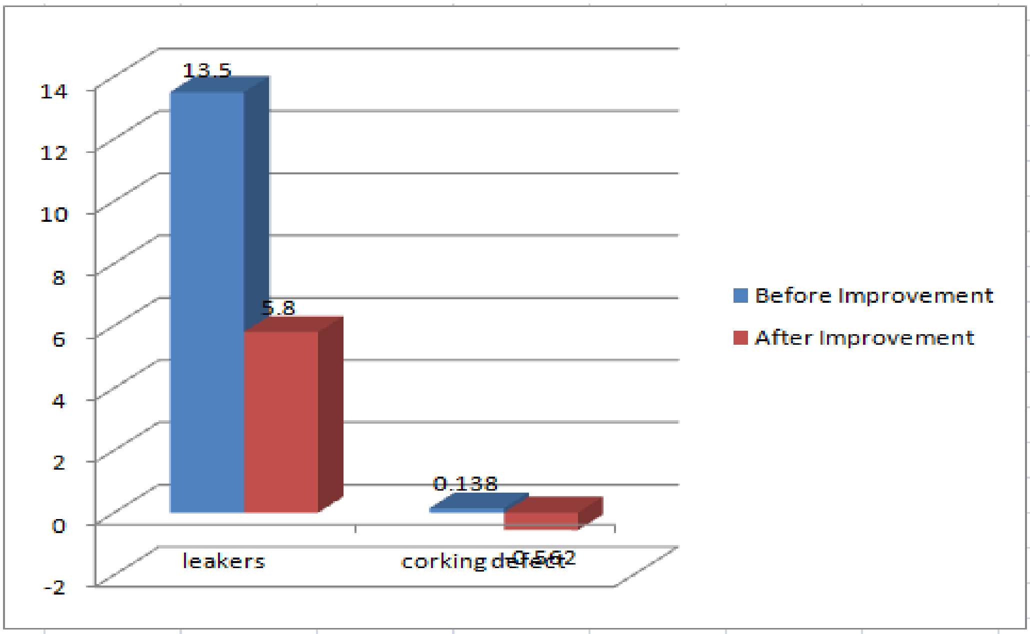

Figure 6: Final result after improvement.

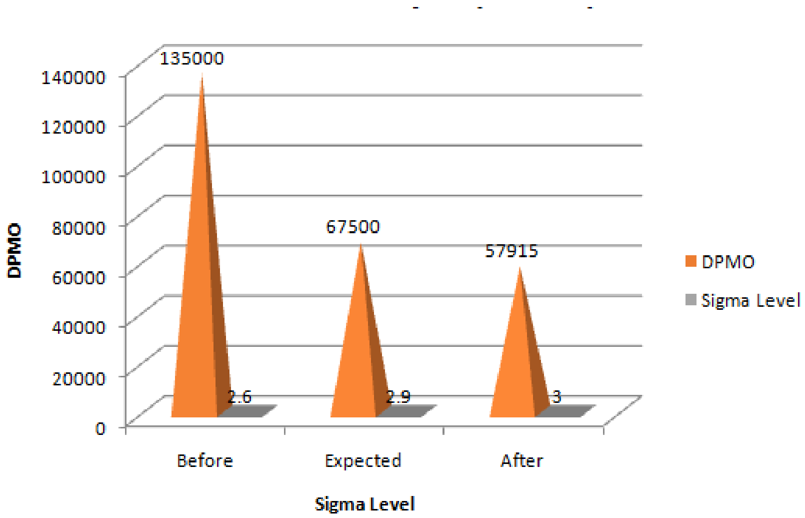

Figure 7: Final Sigma level result achieved.

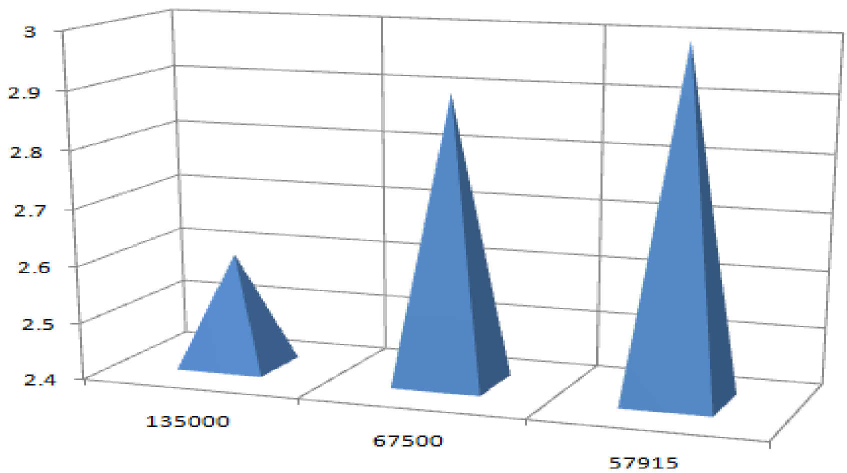

Figure 8: Final DPMO result achieved.

5.0 CONCLUSION

In an effort to remain competitive in a highly globalized world, process improvement has become an area of concern for companies. This work showed that the implementation of Six Sigma DMAIC problem solving methodology on the shop floor improved the production process of the beer manufacturing industry used as a case study in this work. From the overall analysis in this research, the implementation of Six Sigma, DMAIC methodology drastically reduced the percentage of product defects by 57.1% while increasing product quality, company's profit and customer's satisfaction. This methodology can also be implemented in other manufacturing firms. The case study presents the way in which the Six Sigma DMAIC implementation can help organizations to improve their processes and thus contribute to their effort towards achieving business excellence.

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