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Yonatan Mengesha Awaj
Ajit Pal Singh[1]
Wassihun Yimer Amedie

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QUALITY IMPROVEMENT USING STATISTICAL PROCESS CONTROL TOOLS IN GLASS BOTTLES MANUFACTURING COMPANY

Abstract: *In order to survive in a competitive market, improving quality and productivity of product or process is a must for any company. This study is about to apply the statistical process control (SPC) tools in the production processing line and on final product in order to reduce defects by identifying where the highest waste is occur at and to give suggestion for improvement. The approach used in this study is direct observation, thorough examination of production process lines, brain storming session, fishbone diagram, and information has been collected from potential customers and company's workers through interview and questionnaire, Pareto chart/analysis and control chart (p-chart) was constructed. It has been found that the company has many problems; specifically there is high rejection or waste in the production processing line. The highest waste occurs in melting process line which causes loss due to trickle and in the forming process line which causes loss due to defective product rejection. The vital few problems were identified, it was found that the blisters, double seam, stone, pressure failure and overweight are the vital few problems. The principal aim of the study is to create awareness to quality team how to use SPC tools in the problem analysis, especially to train quality team on how to held an effective brainstorming session, and exploit these data in cause-and-effect diagram construction, Pareto analysis and control chart construction. The major causes of nonconformities and root causes of the quality problems were specified, and possible remedies were proposed. Although the company has many constraints to implement all suggestion for improvement within short period of time, the company recognized that the suggestion will provide significant productivity improvement in the long run.*

Key words: *Glass bottles, quality, statistical process control (SPC), Ishikawa diagram, Pareto chart, p-control chart, brainstorming.*

[1] Corresponding author: Ajit Pal Singh
email: singh_ajit_pal@hotmail.com

1. Introduction

The growing competition in the current global market is an issue translating into a vast need for the continuing evolution of the industry. Therefore, world business is continually in search for the competitive edge due to the growing demands of customer needs and expectations. Quality has an important role in the business process across the entire organization, to be more efficient and effective in the global market, thus improving productivity and customer loyalty as well as increase market share.

Quality is a concept whose definition has changed overtime. In the past, quality meant "conformance to valid customer requirements". That is, as long as an output fell within acceptable limits, called specification limits, around a desired value, called the nominal value, or target value, it was deemed conforming, good, or acceptable. We refer to this as the "goalpost" definition of quality (Deming, 1950).

According to Montgomery (2005), quality is one of the most important decision factors in the selection of products and services. Therefore, quality leads to business success, growth, and increases competitiveness, as well as improves the work environment. Additionally, it involves the employee in achieving the corporate goals and brings a substantial return of investment. The study and the analysis of quality must be aimed at understanding, meeting, exceed and surpassing customer needs and expectations (Kolarik, 1995).

Statistical tools allow measurement and evaluation of the performance in a process to improve its quality. The tools frequently used to support decision making. According to Montgomery (2005), statistical tools can be helpful in developing activities previous to manufacturing, in measuring process variability, in analyzing this variability relative to product requirements or specifications, and in eliminating or greatly reducing variability in process. These tools allow the interpretation of the process by detecting when the variables change and experimentation by knowing how the variables can change by experimental designs (Ott *et al*., 2000).

2. Advantages of Spc Implementation

SPC implementation is important as it could improve process performance by reducing product variability and improves production efficiency by decreasing scarp and rework. According to Attaran (2000), in their attempts to remain competitive, US business had embarked on TQM techniques such as SPC that leads to higher quality product by reducing-variability and defects; rework, failure, scrap, warranty claims and product recall costs, thus improving their overall business competitiveness (Booker, 2003).

Most of the production and quality cost that SPC aims to minimize such as rework, lost of sales and litigation are measurable. The success and failure in SPC implementation does not depend on company size or resources, but it relies on appropriate planning and immediate actions taken by workers with regards to problem solving. According to Benton (1991) and Talbot (2003), the advantages of implementing SPC could be categories into the following categories, viz., maintain a desired degree of conformance to design, increase product quality, eliminate any unnecessary quality checks, reduce the percentage of defective parts purchased from vendors, reduce returns from customers, reduce scrap and rework rates, provide evidence of quality, enable trends to be spotted, ability to reduce costs and lead times. In other words, SPC implementation can also help to accomplish and attain a consistency of products that meet customer's specifications and thus fulfill their expectations. In general, SPC can be used to monitor the natural variation of a process and minimize the deviation from a target value and thus play a major role in process improvement.

3. Company background

A bottles and glass manufacturing company was chosen to implement SPC tools and concepts in order to improve the product quality and reduce process variability. Bottles and glass company is private, owned by a group of investors, established in 1973 and was re-established for better production in 1992. Company is located in Addis Ababa, Ethiopia, Africa. The company was a producer of different glass bottles and jars-for beverages, canned foods, and cosmetics to fulfill the needs of different local industries in Ethiopia.

By using a sophisticated system, company is producing glass bottles and jars in a nonstop manufacturing environment. A company utilizes raw materials that are available locally in different areas of the country as natural resources which are obtained from quarries and from local industries. The main components use to manufacture glass bottles and jars in the production processes are-major raw materials are silca sand, soda ash, limestone, marble, and cullet; and minor raw materials include selenium, iron chromites, iron pyrites, iron sand, sodium sulfate, alumina, carbon, cobalt, and frit.

4. Seven basic quality control tools

Once the basic problem-solving or quality improvement process is understood, the addition of quality tools can make the process proceed more quickly and systematically. The company had used some of the "seven basic quality control tools" in their problem solving technique. The concept behind the seven basic tools came from Kaoru Ishikawa, a renowned quality expert from Japan. The seven quality tools are check sheet, Pareto chart, histogram, scatter diagram, process flow chart, cause-and-effect diagram or fish bone diagram, and control charts (Besterfield, 2003; Ishikawa, 1985). According to Ishikawa, 95% of quality-related problems can be resolved with these basic tools. The key to successful problem resolution is the ability to identify the problem, use the appropriate tools based on the nature of the problem, and communicate the solution quickly to others (Ishikawa, 1985).

The philosophy behind SPC concept is the output of a process can be brought into a state of statistical control by means of management and engineering intervention (Antony *et al*., 2000). Ishikawa (1985) points out that SPC's strength lies in its ability to monitor both process centre and its variation about that centre. It can be done by collecting data from samples at various points within the process; variations in the process that may affect the quality of end product can be detected and corrected. Thus, SPC will be able to reduce the probability of passing problems to the customers. SPC has a distinct advantage over other quality control techniques, such as final inspection, which utilize human resources for detecting and correcting problems at the end of the production cycle. SPC emphasize on early detection and prevention of problems. In other words, SPC is aimed at continuously improving the process to manufacture quality product for achieving high customer satisfaction (Karuppusami and Gandhinathan, 2006).

Variation reduction is a key aspect to improve product quality. There are two main causes of variation, assignable/special and common/chance causes (Mason and Antony, 2000; Atienza *et al*., 1997). The two main objectives of control chart are to monitor due to assignable causes and to take the appropriate corrective actions. SPC is a statistical technique commonly used to control and reduce process variation (Mason and Antony 2000). Yang and Yang (2004) viewed control charts as a process monitoring and control tool has received much attention both by public and private sectors. In other words, control chart is useful because it can be used to distinguish between assignable and common causes of variation in the process. In general, this variability arises from three sources- improperly adjusted machines, operator errors, or defective materials (Montgomery, 2005). Pavletic *et al*. (2008) discussed the practical application of seven basic quality control tools in process industry (cement bags damages).

4.1. Pareto chart

Pareto chart is a special type of bar chart where the plotted values are arranged from largest to smallest. A Pareto chart is used to highlight the most frequently occurring defects, the most common causes of defects, or the most frequent causes of customer complaints. To identify the main problems which cause frequent defects of glass bottles production, a three months data had been collected (viz., January, February, and March, 2011). The actual rejection (Tables 1 and 2) is grouped in their respective type of defects identified (Tables 1a and 2a).

Table 1. Data collected for number of visual defective (glass bottles) over the past three months (January to March, 2011)

S.No.	Type of defects	Number of defective			Total number of defective
		January	Februar	March	
1	Ring crack	106	10	17	133
2	Body crack	68	7	21	96
3	Neck crack	86	10	59	155
4	Heavy seam	35	79	150	129
5	Folding	29	101	46	176
6	Blisters	171	174	181	526
7	Bird swing	-	111	2	113
8	Dirty mould	5	42	27	74
9	Double seam	-	293	41	334
10	Stone	178	56	22	256
11	Baffle mark	25	71	56	152
12	Shear mark	-	-	16	16
13	Chocked neck	34	-	10	44
14	Bottom crack	10	-	4	14
15	Wash board	83	-	23	106
16	Seeds	22	-	29	51
	Total production	223200	201600	223200	6480000
	Total number of samples inspected	5952	5378	5952	17282
	Total number of defective	852	954	704	2375
	Total percentage defective	14.31%	17.74%	11.82%	13.74%

Table 1a. Number of visual defective (glass bottles) in descending order, percentage of relative defective and cumulative defective over the past three months (January to March, 2011)

S. No.	Type of defects	Number of defective	Percentage defective to sample size	Percentage of relative defective	Cumulative percentage defective
1	Blisters	526	3.14%	22.14%	22.14%
2	Double seam	334	1.98%	14.06%	36.20%
3	Stone	256	1.51%	10.78%	46.98%
4	Folding	176	1.04%	7.41%	54.39%
5	Neck crack	155	0.92%	6.53%	60.92%
6	Baffle mark	152	0.90%	6.4%	67.32%
7	Ring crack	133	0.79%	5.6%	72.92%
8	Heavy seam	129	0.76%	5.43%	78.35%
9	Bird swing	113	0.67%	4.76%	83.11%
10	Wash board	106	0.57%	4.46%	87.57%
11	Body crack	96	0.49%	4.04%	91.61%
12	Dirty mould	74	0.47%	3.12%	94.73%
13	Seeds	51	0.20%	2.15%	96.88%
14	Chocked neck	44	0.13%	1.85%	98.73%
15	Shear mark	16	0.09%	0.67%	99.40%
16	Bottom crack	14	0.06%	0.59%	99.99%
Total sample size			17282		
Total			2375		
Average percentage defective			13.74%		

Table 2. Data collected for number of physical defective (glass bottles) over the past three months (January to March, 2011)

S. No.	Type of defects	Number of defective			Total number of defective
		January	February	March	
1	Pressure failure	684	1212	1350	3246
2	Over weight	755	77	72	904
3	Under weight	50	5	0	55
4	Over capacity	342	0	36	378
5	Under capacity	13	1	0	14
6	Height out of standard	83	0	0	83
Total production (lot size)		2232000	2016000	2232000	6480000
Total number of samples inspected		5952	5376	5952	17280
Total number of defective		1927	1295	1458	4680
Total percentage defective		32.37%	24.08%	24.49%	27.08%

Table 2a. Number of physical defective (glass bottles) in descending order, relative percentage and cumulative percentage over the past three (January to March, 2011)

S. No.	Type of defects	Number of defective	Percentage defective to sample size	Percentage of relative defective	Cumulative percentage defective
1	Pressure failure	3246	18.78%	69.36%	69.36%
2	Over weight	904	5.23%	19.32%	88.68%
3	Overcapacity	378	2.19%	8.08%	96.76%
4	Height out of standard	83	0.48%	1.77%	98.53%
5	Under weight	55	0.32%	1.18%	99.71%
6	Under capacity	14	0.08%	0.30%	100.01%[3]
Total sample size			17280		
Total			4680		
Average percentage defective			27.08%		

Based on the Pareto principle the "vital few" factors which have significance effect in the quality of the products are identified.

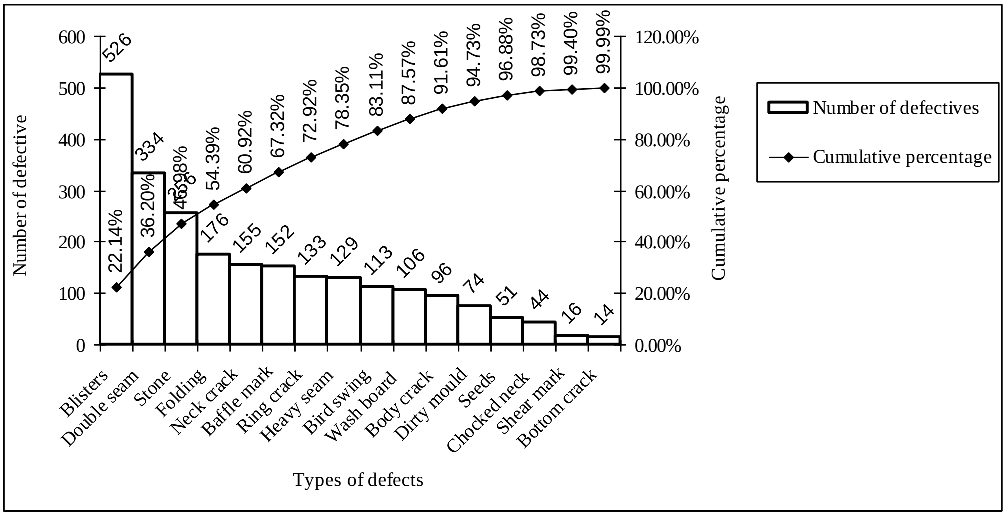

Figure 1. Pareto chart for types of visual defects observed over the past three months

Pareto chart was constructed based upon data collected (Tables 1a and 2a) and to identify the most common defect as shown in Figures 1 and 2. The Pareto chart revealed that blisters defect-22.14%, double seam defect-14.06%, and stone defect-10.78%, contribute about 46.98% and the two major physically tested and identified defects are pressure failure-69.36% and overweight-19.32% (Figures 1 and 2). These two major defects contributed 88.68% of the overall rejection. Only the major defects identified are chosen for the case study. Therefore, at this stage, it is obvious that most of all rejections (defects) will decrease, if the causes for these major defects are reduced.

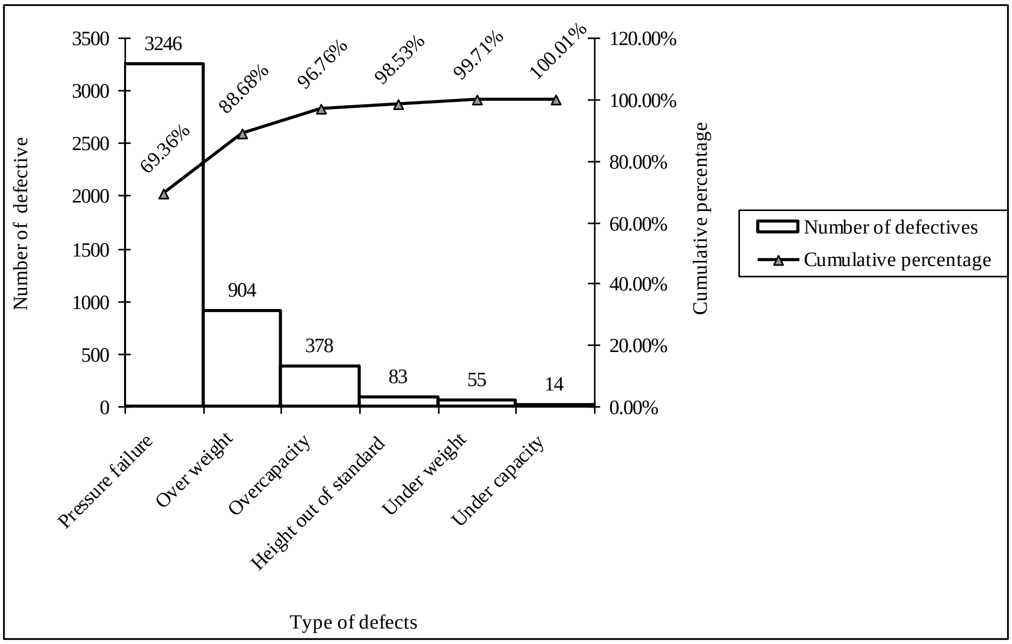

Figure 2. Pareto chart for types of physical defects observed over the past three months

4.2 Brainstorming and Ishikawa diagram

Brainstorming is a technique used to elicit a large number of ideas from a team using its collective power. It normally takes place in a structured session involving between three to twelve people, with five to six people being the optimal group size. The team leader keeps the team member focused, prevents distractions, keeps ideas flowing, and records the outputs (or make sure that team members record their own outputs). The brainstorming session should be a closed-door meeting to prevent distractions. Seating should be arranged in a U-shape or circle to promote the flow of ideas among group members (Gitlow and Levin, 2009).

There are specific steps that are recommended prior to a brainstorming session as to clarify the subject of brainstorming session. Moreover, many rules should be observed by the participants to ensure that participation is not inhibited.

These rules are as follows:

- Do not criticize anyone's ideas, by word of gesture.
- Do not discuss any ideas during the session, except for clarification.
- Do not hesitate to suggest an idea because it sounds "silly". Many times, such as an idea can lead to the problem solution.
- Do not allow any group member to present more than one idea at a time.
- Do not allow any group to be dominated by one or two people.
- Do not let brainstorming because a gripe session.

If it is the Pareto chart that helps us to prioritize our efforts and focus attention on the most pressing problem or symptom, it is the cause-and-effect diagram that helps to lead us to the root cause of the problem (Devor *et al.*, 2007). The data analyzed by the cause-and-effect diagram usually comes from a brainstorming session.

The quality team had been organized in the company, which was composed of production managers, quality control and line supervisors. Brainstorming rules were taught these team members at company as to establish the cause-and-effect diagram. The cause-and-effect diagrams were constructed by quality improvement team and through brainstorming sessions involving all employees taking part in the related production and test activities. Figures 3 to 7 shows the cause-and-effect diagrams for the top three visual defects and two physical defects. The root causes of these three visual defects and two physical defects can be grouped into machine operator/man, work method, material, and equipment.

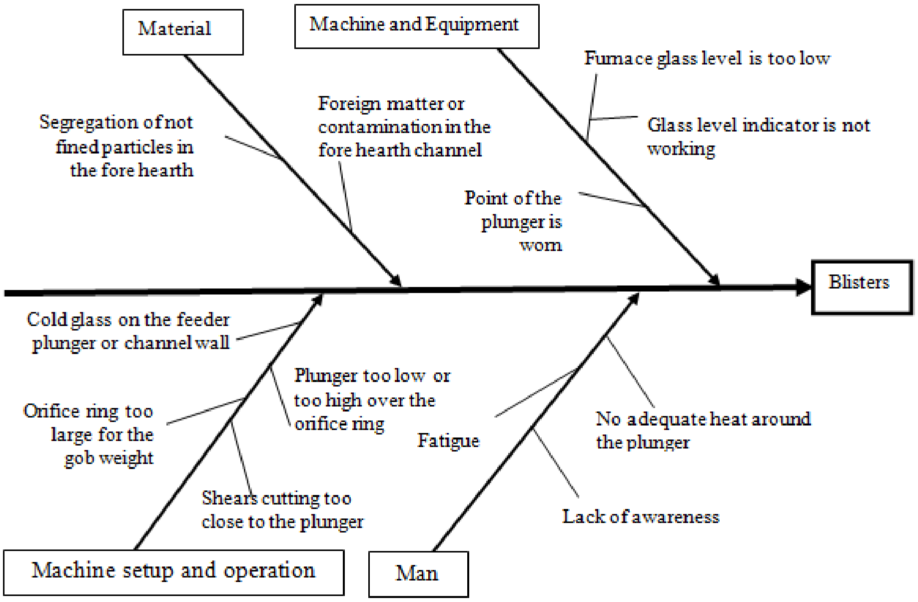

Figure 3. Cause-and-effect diagram for blister defect

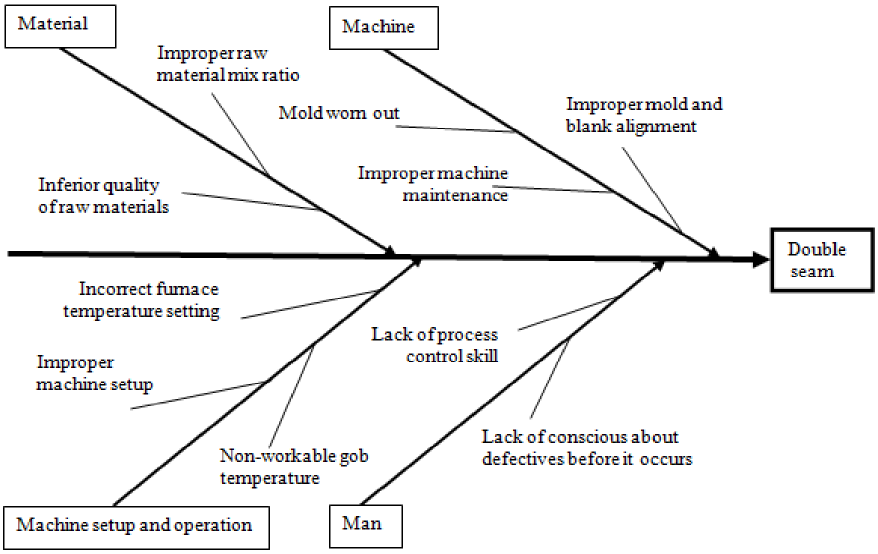

Figure 4. Cause-and-effect diagram for double seam defect

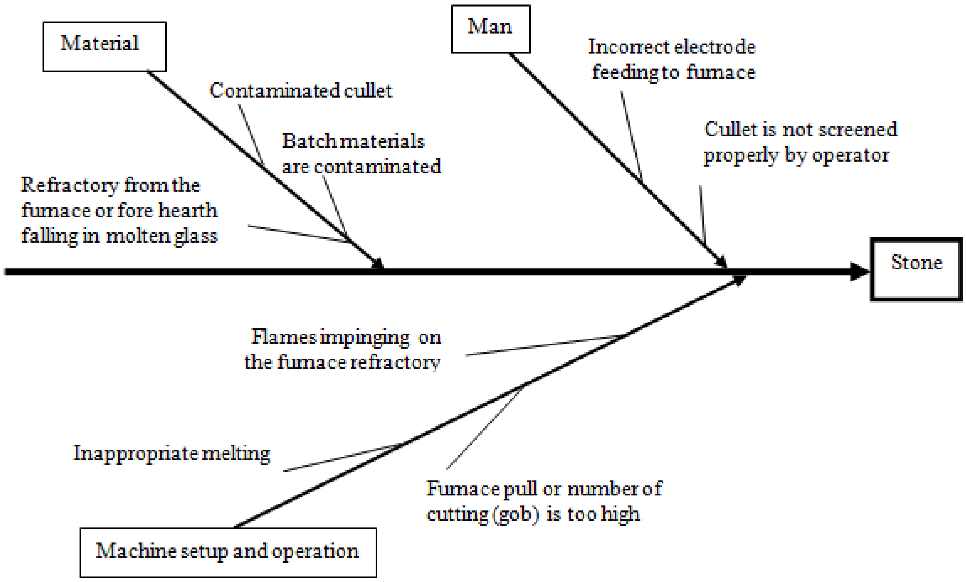

Figure 5. Cause-and-effect diagram for stone defect

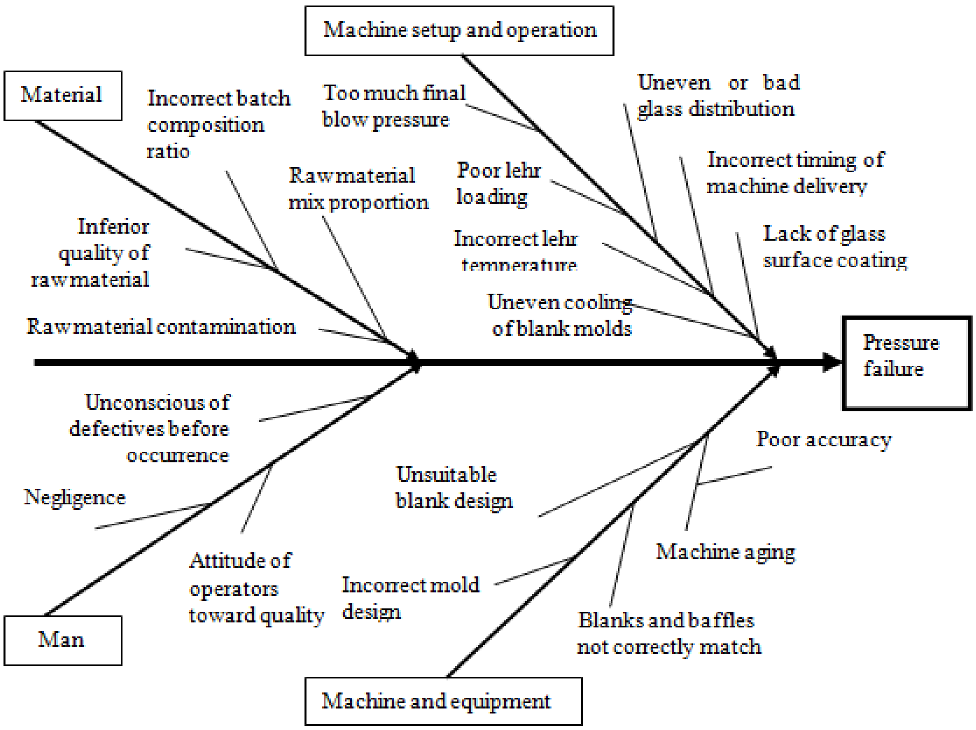

Figure 6. Fishbone diagram for pressure failure defect

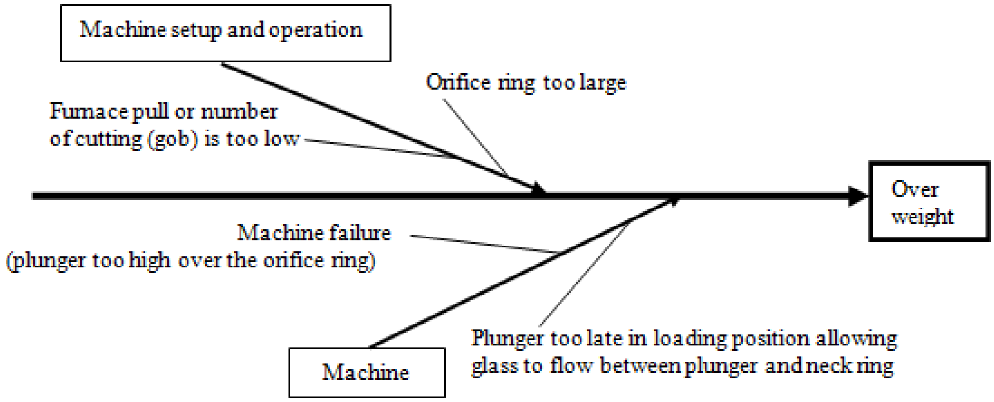

Figure 7. Fishbone diagram for overweight defect

4.3. Control chart

In the present study the data has been collected in March, 2011 from production line (Table 3) and for each subgroup the fraction defective is calculated. As per SPC techniques for better analysis and interpretation of data, the minimum size of the subgroup is 25 taken (ISO 8258:1991-E). For the purpose of constructing attribute control chart (*p*-chart) with constant subgroup (ISO 8258:1991-E), SPSS software has been used. *P-chart* is established (using SPSS, Version 16) to control the fraction defective for a group of quality characteristics visual defects (blisters, stone, double seam, heavy seam, folding, and wash board etc.).

Table 3. Computing fraction defective for March, 2011

Subgroup number	Number inspected (*n*)	Number defective (*np*)	Fraction defective (*np/n*)	Subgroup number	Number inspected (*n*)	Number defective (*np*)	Fraction defective (*np/n*)
1	192	20	0.1042	14	192	30	0.1563
2	192	18	0.0938	15	192	17	0.0885
3	192	10	0.0521	16	192	16	0.0833
4	192	24	0.1250	17	192	29	0.1510
5	192	39	0.2031	18	192	33	0.1719
6	192	25	0.1302	19	192	43	0.2240
7	192	18	0.0938	20	192	37	0.1927
8	192	34	0.1771	21	192	29	0.1510
9	192	17	0.0885	22	192	22	0.1146
10	192	38	0.1979	23	192	27	0.1406
11	192	32	0.1667	24	192	23	0.1198
12	192	16	0.0833	25	192	29	0.1510
13	192	16	0.0833				

p-chart has been constructed with control limits (*UCL*=0.21, *CL*=0.13, and *LCL*= 0.06) shown on upper right side of the chart (Figure 8).

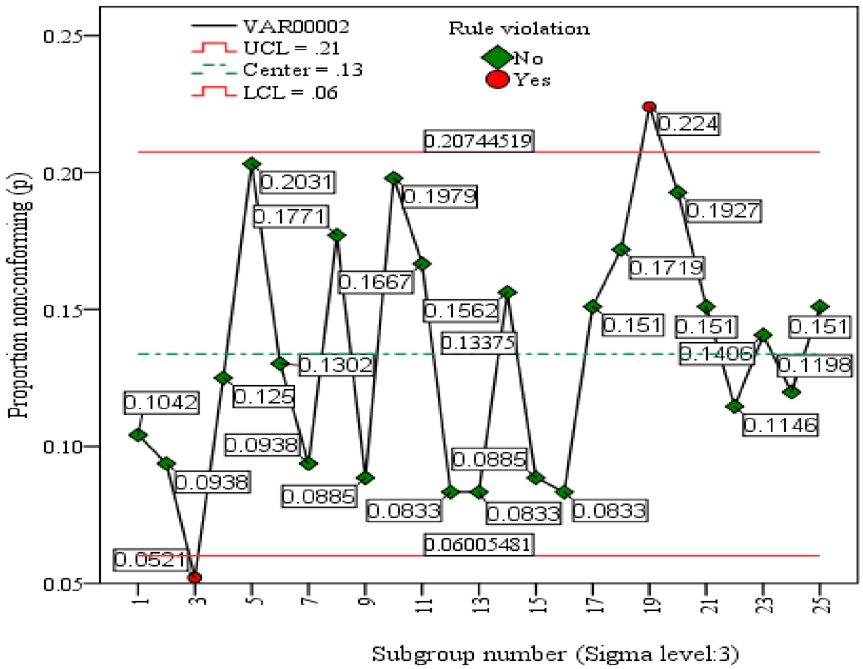

Figure 8. P-chart to illustrate process condition for March, 2011

From the process control chart, *p*-chart (Figure 8) constructed for March, 2011 it has been found that quality characteristics in the manufacturing processes tended not to be in statistical control (subgroup number 3 and 9 out of control). Hence, the process has to be brought into state of statistical control by finding the root cause and eliminating from the process. Brainstorming session has been carried out to find root causes and remedies have been identified. Based on these remedies identified, improvement action plan suggestion has been made (Tables 4 to 8) and provided to the company's quality controlling department.

After implementing the action suggestion plans (Tables 4 to 8) for the top three visual and two physical defects, considerable improvement was observed. The *p*-chart was constructed to analyze the process and help to determine how to yield further improvement. The *p*-hart was constructed before and after the action suggestion plans implementation. To plot control chart, data has been collected again for the month of April, 2011 (Table 9).

Table 4. Action plan suggestion for blisters defect

Type	Action plan suggestion for blisters
Man (operator)	- Must have skill in identifying causes of defects before it occurs/provide training. - Pay full attention. - Must have good attitude toward quality improvements.
Machine setup and operation	- Increase blank cooling and plunger cooling. - Increase the fire in the spout of the furnace. - Avoid power interruption/must have reserve power supply while interruption occurs.

	- Raise or lower plunger height and correct gob weight and shape. - Lower the shear height. - Centralize the plunger. - Change orifice ring of feeder to smaller one. - Change the feeder plunger.
Machines and equipments	- Furnace glass level indicator operation must be maintained. - Furnace overall parts must be properly maintained. - A preventive maintenance to ensure machine always in good condition.
Material	- Must use raw material with appropriate quality. - Care should be given in raw material preparation. - Cullet should be cleaned with appropriate cleaning agents to remove contaminations that may cause bubbles while melting the raw materials.

Table 5. Action plan suggestion for double seam defect

Type	Action plan suggestion for double seam
Man (operator)	- Be able to identify defects quickly and accurately and how to remedy them/must have been provided. - Must have attention.
Machine setup and operation	- Adjust feeder and glass temperature. - Check blank and mold supporting for wear. - Reduce counter blow pressure. - Check blank and mold linkage aligning fixture. - Increase venting of mold.
Machine and equipments	- Correct mold design. - Check blank and mold halves for alignment. - Check fit for plunger lock or blank lock. - Change mold holders and check the old ones against repair dimensions.
Material	- Use batch correctly proportioned. - Use appropriate quality raw material.

Table 6. Action plan suggestion for stone defect

Type	Action plan suggestion for stone
Man (operator)	- Must have attention. - Use machine for raw materials screening and selection (reduce human in raw material preparation).
Machine setup and operation	- Avoid inappropriate electrode advancement (feeding) into the furnace. - Increase the cooling wind. - Clean delivery equipments and mold. - Clean the underside of the spout casing. - Adjust furnace pull.
Machine and equipments	- Use better grade of furnace materials. - Use better grade of mold materials. - Change mold. - Improve polishing of mold.
Material	- Check for contamination of the materials.

Table 7. Action plan suggestion for pressure failure defect

Type	Action plan suggestion for pressure failure defect
Man (operator)	- Use machines for screening and separating from impurities rather than labor intensive. - The operator must frequently the containers/bottles passing along the conveyor from machine to stacker. - Be able to identify defects quickly and accurately and know how to remedy them (providing training for the operators). - Must have attention and good attitude toward quality.
Machine setup and operation	- Apply cooling air evenly on the blank mold/adjust cooling system to be uniform. - Increase the machine speed at the appropriate level. - Adjust feeder temperature. - Improve lehr loading and use more suitable lehr belt. - Adjust lehr temperature and speed. - Apply glass layer coating (hot end and cold end coating with very thin layer of tin tetra chloride and polyethylene wax respectively. - Facilitate uniform or even glass distribution.
Machine and equipments	- Batching scales/balances must have correct calibration. - Check for correct mold design. - Avoid excessive mold worn out/replace over used molds by proper mold. - Check for correct match of blank and mold halves.
Materials	- Use better quality raw materials/increase silica sand purity to the appropriate level. - Increase silica sand proportion in the mix ratio up to appropriate level. - Good preparation of raw materials/must have been properly separated, washed and screened from impurities and dirt. - Appropriate cleaning/washing agents must be used.

Table 8. Action plan suggestion for overweight defect

Type	Action plan suggestion for overweight defect
Man (operator)	- Must have awareness about defects. - Pay full attention. - Must have refreshment.
Machine setup and operation	- Adjust timing between feeder and machine for correct loading position. - Adjust glass and feeder temperature. - Reduce gob weight.
Machine and equipments	- Adjust design of mold equipments. - Adjust plunger and feeder tube design.
Material	- Must have proper and uniform melt flow index. - Free from contamination. - Must have proper mix ratio that deliver proper density.

Table 9. Computation of fraction defectives for control p-chart for April, 2011

Subgroup number	Number inspected (*n*)	Number defective (*np*)	Fraction defective (*np/n*)	Subgroup number	Number inspected (*n*)	Number defectives (*np*)	Fraction defectives (*np/n*)
1	192	39	0.2031	14	192	22	0.1146
2	192	27	0.1406	15	192	34	0.1771
3	192	28	0.1458	16	192	36	0.1875
4	192	19	0.0990	17	192	40	0.2083
5	192	36	0.1875	18	192	38	0.1979
6	192	32	0.1667	19	192	39	0.2031
7	192	32	0.1667	20	192	32	0.1667
8	192	37	0.1927	21	192	31	0.1615
9	192	38	0.1979	22	192	18	0.0938
10	192	39	0.2031	23	192	36	0.1875
11	192	40	0.2083	24	192	37	0.1927
12	192	33	0.1719	25	192	40	0.2083
13	192	35	0.1823				

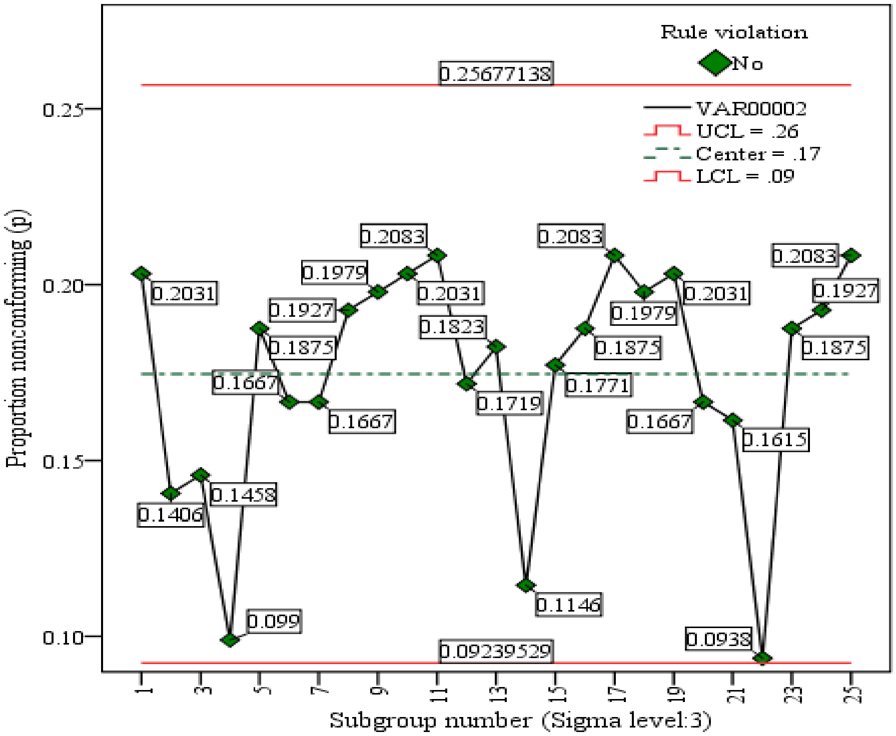

Figure 8. Control chart (p-chart) for April, 2011 (Table 7)

Again data was collected for the month of April, which revealed that improvement is in pressure failure defect and blister defect where company has given their attention (Tables 10 and 11). After slight improvement in defects the revised control charts (*p*-chart) indicate that the process is in-control (Figure 8).

Table 10. Data collected after improvement for visual defect (glass bottles) for April, 2011

S. No.	Type of defects	Number of defective	Percentage defective to sample size	Percentage of relative defective	Cumulative percentage defective
1	Blisters	170	2.95	20.14%	20.14%
2	Double seam	141	2.45	16.71%	36.85%
3	Heavy seam	135	2.34	16.00%	52.85%
4	Folding	84	1.46	9.95%	62.80%
5	Baffle mark	60	1.04	7.20%	70.00%
6	Body crack	51	0.89	6.04%	76.04%
7	Neck crack	49	0.85	5.81%	81.85%
8	Wash board	47	0.82	5.57%	87.42%
9	Stone	37	0.64	4.38%	91.80%
10	Ring crack	25	0.43	2.96%	94.76%
11	Dirty mould	13	0.23	1.54%	96.30%
12	Bottom crack	13	0.23	1.54%	97.84%
13	Shear mark	10	0.17	1.18%	99.02%
14	Seeds	7	0.12	0.83%	99.85%
15	Chocked neck	2	0.03	0.24%	100.09%
16	Bird swing	0	0.00	0.00%	100.09%
Total		844			
Sample size		5760			
Lot size		74880			
Average percentage defectives		14.65%			

Table 11. Data collected after improvement for physical defect (glass bottles) for April, 2011

S. No.	Type of defects	Number of defective	Percentage defective to sample size	Percentage of relative defective	Cumulative percentage defective
1	Pressure failure	778	13.51%	31.60%	31.60%
2	Under capacity	587	10.19%	23.84%	55.44%
3	Over weight	569	9.88%	23.11%	78.55%
4	Over capacity	479	8.32%	19.46%	98.01%
5	Under weight	49	0.85%	2.00%	100.01%
6	Height out standard	0	0.0%	0.00%	100.01%
Total		2462			
Sample size		5760			
Lot size		74880			

Note: As per data collected for glass bottles manufacturing, there are more than 100 defects (visual and physical) in glass bottles manufacturing processes. Keeping the priority of major defects percentages as per historical data, we have selected sixteen visual and six physical defects for visual for the study.

5. Economic analysis

Loss incurred from non-conforming or defective glass bottles:

A large loss incurred due to non-conforming or defective glass bottles production. In company, the IS machine average production capacity is 54 bottles per minute or 54×60=3240 glass bottles per hour. As per percentage defective analysis was made for the three months, a percentage visual defective glass bottles is 13.74% and that of physical defective is 27.08%, the average of the two is 20.41%.

Information from the company indicates that the company's quality acceptance level is ±10%. Therefore, the difference between average defective analyzed and company quality acceptance level (20.41%-10%) is 10.41% which is percentage of product (glass bottles) rejection due to defective bottles.

Average production cost of a glass bottle is 2.20 Birr (company's information). As a result total loss from non-conforming product or defective glass bottles was $3240\times0.1\times2.20$ =712.8 Birr per hour.

Annual total loss from non-conforming glass bottles or defective glass bottles was equal to $712.8\times24\times30\times12$ =6158592 Birr. This loss will ultimately affect the total profit of the company. So in today's competitive manufacturing, this is of outmost importance to reduce total non-conforming glass bottles or defective glass bottles by continuous monitoring production through SPC tools.

Action plan suggestion has been suggested for all identified five major defects to the company. Because of company's own limits/unknown reasons, focus is given only on pressure failure and blister defects, and improvement was observed in these two defects only. In March 2011, number of defective glass bottles due to pressure failure defect was 1350 glass bottles and in month of April 2011, number of defective glass bottles reduced to 778. As a result improvement was 572 glass bottles per month only due to pressure failure defect and irrespective of the others defects.

The difference of the two months of defects (1350-778=572) glass bottles was improvement made on a particular pressure failure defect irrespective of the others defects. That is 572 glass bottles were saved per month only from defective caused by pressure failure.

Where as in case of blister defect in the month of March 2011, the number of defectives glass bottles were 181 and it came reduced to 170 glass bottles as a result an improvement of 11 glass bottles indicated.

The amount of loss reduced in Birr (currency) was (11 bottles +572 bottles)$\times2.20$ Birr=1282.6 Birr per month. The total gain annually due to reduction in pressure failure is $583\times2.20\times12$=15391.2 Birr (where 2.20 Birr is average production cost per bottle, excluding material cost).

6. Results and discussion

- After detail observation and interview has been conducted, it is possible to identify that the company has many problems, specifically there is high rejection rate or high waste has been observed in the production processing line i.e. in the melting process which causes waste due to trickle and forming process which causes waste due to defective bottles rejection (Tables 1 and 2).
- As per the observation made on the company the concentration is only given on final glass bottles (product) inspection, daily activities and solving of the causes of defective glass bottles. But this is not the right way to minimize the causes of non-conforming or defective glass bottles.
- More efficient technique is long run corrective or preventive action through SPC tools needed to minimize or reduce the problem.

- It was also observed that there is glass bottles' sampling problem for quality analysis. Sampling has not been carried out, that the sample is representative of the lot.
- Eight glass bottles samples have been taken from a row of glass bottles arranged on conveyor (stacker) which is not being representative of the lot.
- As per Ethiopian Standard (ES 117:2001) the number of samples should be twenty and should be taken from diagonals by random sampling techniques.
- As per discussion with quality controlling department persons, the problem is because of stacker (conveyor on which bottles travels from one work centre to another centre where sample has been taken) does not allow doing so. It needs maintenance or replacement.
- The company does not set acceptance and rejection number for critical defect glass bottles, which is very useful tool for the management decisions to reject or accept the batch under inspection by sample. As per ES 839:2002 shows that sampling and acceptance level for defects can be used.
- A sampling plan is a plan for acceptance sampling that precisely specifies the parameters of the sampling process and the acceptance/rejection criteria. The variables to be specified include the size of the lot (*N*), the size of the sample inspected from the lot (*n*), the number of defects above which a lot is rejected (*c*), and the number of samples that will be taken. The company lacks acceptance/rejection criteria for processed sample for each defect types.
- It was observed that molds are highly over used and get worn out and this causes many defects viz., double seam, neck ring seam, misshaped bottles, dirty or rough finish defects, bent or cracked finish bottle defects, and folding, etc.
- From frequent observation, it has been possible to identify many quality checking tests have not been conducted such as annealing test, thermal shock test, thickness test, finish coating test and impact test. Besides these tests some essential process were by-passed like hot end coating and cold end coating which gives appreciable strength and surface quality of bottles. Those processes give significant quality characteristics such as resistance to breakage and scratches.
- From economic analysis it is possible to understand that the company incurring high loss (about 6158592 Birr annually) due to non-conforming or defective glass bottles. This economic analysis clearly affirmed the fact that preventive measure assuming in the reduction of causes of defective glass bottles helps the company in generating revenue.
- From the Pareto chart, major or vital few problems have been identified such as blisters, double seam, stone, pressure failure, and over weight defect (Figures 1 and 2). It has been observed that the three major visually identified defects are blisters-22.14%, double seam-14.06%, and stone-10.78% contribute about 46.98%. These two defects contributed 46.98% of the overall due to visual defect rejection.
- Using fishbone diagram the root causes for the problems were identified. Although many causes were identified, the major causes for each type of defects were identified as follows:
  - For blisters defect the major cause is machine setup and operation i.e. problem of feeder such as foreign matter contamination in the fore hearth channel, cold glass on feeder plunger or channel walls, not enough heat around the plunger, plunger too low or too high over the orifice ring, shears cutting too close to the plunger, orifice ring too large for the gob weight, point of the plunger is worn and hot blanks and plunger (Figure 3).

- The major cause for double seam defect is machine setup and operation such as mould halves misalignment, blank seam out of line, improper pressure flow process (Figure 4).
- The major possible causes for stone defect are refractory from the furnace or fore hearth are falling into the molten glass, batch materials are contaminated or incorrectly melted, and furnace pool may be too high and contaminated cullet (Figure 5).
- Uneven or bad glass distribution is a major cause of pressure failure defect. Uneven wall thickness is the result of incorrect glass temperature and uneven gob temperature which mostly causes pressure failure defect. The raw material mix proportion and machine setup and operation are also the major causes for pressure failure (Figure 6).
- The major cause of over weight defect is usually machine setup and operation such as incorrect gob delivery, incorrect plunger adjustment, and gob is overweight and glass is too hot (Figure 7).
- Attribute control chart indicated, that the process was out of control at two points at subgroup number 3 and 19 initially (Figure 8) because of assignable cause i.e. power interruption as identified, after further investigation double seam was the factor on day 19^{th} production process having *UCL*=0.21, *CL*=0.13 and on day 3^{rd} having *LCL*=0.06. Remedies for the root causes were identified and action plan suggestion has been provided for improvement.
- After the implementation of the action plan suggestion for the identified defects, improvements have been observed on blisters defect and significant improvement observed on pressure failure defect. The pressure failure defect had reduced from 23.44% (March) to 13.51% (April) (Tables 2 and 10), blisters defect had reduced from 3.14% (March) to 2.51% (April) (Tables 1 and 9).
- The *p*-chart for April, 2011 was also constructed to analyze the process and help determine how to yield further improvement. After improvement the control chart, *p*-chart (Figure 8) indicates that the process is in-control because the assignable causes were resolved.

7. Summary

- The company has been running since 1973 without replacing very old machines, because of this some production lines get out of production. For instance, previously the company was producing wine bottles. Now a day this production line is out of use, molds and molding blocks are over used, this is resulted in defective products and inefficiency.
- Although the company has many constraints to implement all suggestion for improvement within short period of time, the company recognized that the suggestion provided will bring significant productivity improvement in the long run.
- This study resulted in designing the use of SPC tools viz. Pareto chart, fishbone diagram, brain storming and control chart (*p*-chart). The resulting analysis leads to operating procedures that significantly reducing rejections and rework due to defective glass bottles.

8. Conclusion

- The questionnaire survey, interview, direct observation, brain storming, control chart, Pareto chart and fishbone diagrams analysis have provided useful information in identifying causes for rejection, remedies and in proposing optimal solution to be implemented for productivity improvement.

- The main contributors to the rejection are due to blisters, double seam, stone, and pressure failure and overweight defects are identified. The main factors for these defects can be categorized into material, machine, human factor, machine setup and operation.
- Raw material preparation in the company has problems. Machine for washing silica sand, marble and lime stone is not working properly. This affects raw material quality, which results defects in most of the cases.
- Furnace has been working since 1973 it get very old. The furnace is being bottle neck for the individual section (IS) machine, moulds overused and get worn out, and operators need training to be skillful in machine setting and operation control.
- From direct observation the two final glass bottles production processes viz., hot end and cold end coatings were not carried out properly. Those processes give significant quality characteristics such as resistance to breakage and scratches.
- Company lacks the required management involvement, commitment to learning and using SPC tools. The company also lacks the ongoing education and training of management and line staff on SPC tools. With all these problems the company couldn't satisfy the needs of its customers in quality and quantity.
- Training is required to implement SPC tools to improve productivity. The company can be benefited a lot from cause-and-effect diagram as it viz., encourages team work through different departments in the company, created by teams widely divergent in their expertise, helps organizing the random ideas for intelligent decisions, visualizes the various factors associated with a process affect the glass bottles quality, can be made in surprisingly short time, and reveals relationships that had previously not been obvious.
- It is also important to think of the benefits of using a Pareto analysis in economic terms. A Pareto analysis breaks a big problem down into smaller pieces, identifies the most significant factors, shows where to focus efforts, and allows better use of limited resources.
- It can be concluded that quality control chart is an effective statistical technique for locating any trouble or variation in time due to assignable causes.
- Implementation of SPC tools at the company is expected to improve its processes and reduce variability or waste because it may not be possible to completely eliminate variability. With reduced variability the cost of dealing with scrap, rework, and other losses created by defectives which is an enormous drain on the company will be greatly reduced.

In conclusion the company should strive for the implementation of SPC tools for productivity improvement. SPC implementation is important as it could improve process performance by reducing product variability and improves production efficiency by decreasing scrap and rework.

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Yonatan Mengesha Awaj
Department of Mechanical and Vehicle Engineering,
School of Engineering and Information Technologies,
Adama Science and Technology University,
Adama,
Ethiopia, Africa
yonatan.mengesha@gmail.com

Ajit Pal Singh
Manufactruing Engineering Section,
Production Engineering Department,
Defence Engineering College,
Defence University College,
Debre Zeit, Ethiopia, Africa.
singh_ajit_pal@hotmail.com

Wassihun Yimer Amedie
Department of Mechanical and Vehicle Engineering,
School of Engineering and Information Technologies,
Adama Science and Technology University,
Adama,
Ethiopia, Africa
wassihunyimer@yahoo.com