Control Charts and Pareto Analysis in Enhancing Product Quality in Shop Floor Manufacturing

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ABSTRACT

The lightweight, durability and high resistance to corrosion are few attributes of aluminum that contributed to its wide acceptability in industries. Aluminium find applications in building, automobile, marine and aerospace industries. The importance of aluminium in modern day manufacturing can never be overstressed. Hence, the working of these materials should be related to product quality and reliability. Therefore, this study investigated the application of control charts and Pareto analysis in minimizing product defects in an Aluminium company. The production data for four consecutive years (2016 to 2019) was obtained from an Aluminium company located in Port- Harcourt. One hundred and twenty samples were collected in thirty 30 days per year for four years. The samples collected were analyzed by means of control charts, while analysis of variance was applied to assessed the influences of the defect type on number of defective items experienced. From P-chart and C-chart results, the highest number of defective items occurred in 2018, while the least occurred in 2019. Also, results of both P-chart and C-chart revealed two data points each were out of control in 2016 and 2019, while three points each were out of control in 2017 and 2018. Results from Pareto analysis showed that 10% of the defects experienced occurred on the fifth day of investigation. Also, 9 % of defective products occurred on the 23th day in 2017, while 11 % of the defectives experienced happened on the 11th day in 2019. Pareto results also showed that 25 % of the total number of defective products are to be prioritize each year to enable optimum improvement. Results from analysis of variance showed that material thickness has no significant effect on the number of defective items experienced per production batch. The C-chart is more effective for quality control analysis compared to P-chart. The company is advice to used C-hart and Pareto chart as control measures to aid quality products.

Keywords: Product quality, Control charts, Analysis of variance, Pareto analysis, Shop floor manufacturing

1.0 INTRODUCTION

Manufacturing industries are faced with the responsibility of producing goods and services that should meet customer’s satisfaction, however, overtime defective products have become a major source of complaint by customers. Defects can have a significant impact on both the cost and quality of products or services in procurement. It also can cause problems with delivery schedules, and appreciable risk of legal action being taken against the supplier. Quality is one prominent factor that can address the issue of product defects and enhance peace among the stakeholders and retention of customers. Quality can be viewed as fulfilling specifications, excellence of a product or service, conformance to specification or customer's loyalty. To expect a degree of extent to which products meets the requirements, control of quality should be embarked on. Control of quality have continued to play very significant role in in industries and businesses. Quality control implies the identification of the non-conforming products timely, the causes of non-conformity, and provide proactive measures for prevention and sometime correction (Gryna and Juran, 2001; Liu *et al.*, 2011).

This study investigated products defects in a case manufacturing firm through application of control charts and Pareto analysis to eliminate or minimize defects, then improve productivity, increase reliability and reduce cost of production generally.

Onyebuchi *et al.* (2019) used quality control technique to reduce product defects in the manufacturing industry. Statistical quality control including six sigma methods were applied for analysis. The results obtained showed that six Sigma was 3.55 on the average and the defect level ranges from 10,000 to 40,000 units with a mean of 2.17% out of one million outcomes, for the period of 2008 to 2012 investigated. The author observed that lesser number of defectives occurred during the beginning of the year and this was due to early maintenance conducted on production machine. However, more defectives were experienced in the later part of the year. Akinola (2009) examined the characteristics of a good quality service and methods used in controlling quality of service in the Nigerian Banking industry using quality control. It was found that most banks do not use the quality control technique to improve the services rendered to their customers.

Marire *et al.* (2014) examined the problems of quality control in the manufacturing sector using Nigeria Breweries plc, Enugu as case study. The study work was undertaken to examine the problems of quality control in manufacturing firms, the various techniques of quality control used and to assess the effectiveness and efficiency of their applications. Data were collected through questionnaires and analyzed by statistical method. The Chi-square technique was used to test the hypotheses formulated from the research. Results showed that quality control practice encountered problems due to limited awareness and cost associated with the technique. It was posited that regular training and seminars should be organized for the entire workforce. Nnadi *et al*. (2018) performed an empirical analysis of quality control techniques and product quality in manufacturing firms in South East Nigeria. The effect of inspection techniques on relationship between quality control techniques and product design was examined. A sample size of five hundred and sixty-four (564) was used. The data collected was analyzed through statistical tools. The results revealed that inspection techniques have positive effect on production control and quality control techniques has a significant effect on product design.

Ghazi and Alam (2014) assessed the improvement of product quality and productivity in manufacturing process by quality control charts and Six Sigma. Data were collected and analyzed using seven different quality control measures. The defeat with the highest frequency was the main target to be improved. The best solving method was chosen and compare to the previous results or production and then proposed to the company for adoption. Raiz and Muhammad (2012) used both range and x-bar control charts to a product of Swat Pharmaceutical Company. The variables studied were weight/ml, Ph, Citrate % and the amount of fill. In addition, exponentially weighted moving average control chart and the multivariate Hotelling's T2 control chart were used to analyzed the same data collected.

Isaac et al. (2018) investigated the application of quality control to reduce cost of production in First Aluminium Nigeria Limited. The C-chart was used to analyzed the data obtained from the company. Results showed that in 2013, the central score was 9.8, upper control level 19.19 and lower control level 0.41, the system was out of control. Also, in the year 2014, the central level was 7.65, upper control score 15.95, while lower control score. The system was out of control. Similarly, for the year 2015, the control level was 8.48, while the upper control and lower limits were 7.22 and 0, respectively. Touqir *et al.* (2014) assessed the control and improvement of the quality of bolt based on height, diameter and weight. During the study, X- bar chart, S and Range control chart for each three variables were considered. Weighted moving average was also used to detect any process shifts and multivariate Hotelling's T2 for simultaneous monitoring of height and diameter of bolt. For the out of control situation, the assignable reasons responsible identified.

2.0 MATERIALS AND METHODS

2.1 Materials

In line with the aim of this research, the essential materials were sought for from the company records of production and data of defective products for four years (2016-2019) is presented in Table.2.1.

Table 2.1: Raw Data of Non-Conforming Products for 2016-2019 from Company Records

Days	2016	2017	2018	2019
1	7	8	14	6
2	7	9	2	1
3	6	3	3	3
4	5	6	3	5
5	17	2	5	7
6	4	14	7	5
7	4	3	6	2
8	5	15	7	6
9	8	5	6	9
10	9	5	15	2
11	4	7	6	16
12	4	6	5	3
13	16	8	4	4
14	5	5	6	7
15	4	6	7	4
16	6	6	5	5
17	4	5	6	7
18	5	1	7	7
19	4	6	3	15
20	4	4	7	1
21	8	6	3	8
22	4	4	4	1
23	5	2	16	3
24	6	7	3	2
25	5	3	3	3
26	3	5	6	4

27	**4**	**6**	**4**	**6**
28	**1**	**16**	**3b**	**7**
29	**2**	**2**	**6**	**5**
30	**4**	**3**	**10**	**8**
	170	**178**	**182**	**162**

2.2 Methods

The data from the case company was analysed with quality control charts, Pareto analysis and analysis of variance.

2.2.1 Quality Control Charts and Theoretical Equations

For seamless analysis of data acquired, the average of the sample mean defects and mean range were obtained by equation (2.1) and equation (2.2), respectively.

$$\bar{\bar{x}} = \sum_{i=1}^{n} \bar{x}_i \tag{2.1}$$

where, $\bar{\bar{x}}$ is the average of the sample mean defects, $\bar{x}_1$ is the mean of subgroup defect, and n is the sample size.

$$\bar{R} = \frac{R_1 + R_2 + R_3 + \ldots + R_n}{n} \tag{2.2}$$

where, $\bar{R}$ is the mean range, and R is the group range. Similarly, the upper and lower control limits for the x-bar chart were determined from equations (2.3 and 2.4).

$$UCL = \bar{\bar{x}} + A_2\bar{R} \tag{2.3}$$

$$LCL = \bar{\bar{\bar{x}}} - A_2\bar{R} \tag{2.4}$$

The centre line in the control chart is the same as the mean of mean of the sample ($CL = \bar{\bar{x}}$). For the R- chart, the control limits were calculated using equations (2.5 - 2.7).

$$UCL = D_4\bar{R} \tag{2.5}$$

$$LCL = D_3\bar{R} \tag{2.6}$$

$$CL = \bar{R} \tag{2.7}$$

The constants in equations (2.4, 2.5, 2.6) actually depends on the number of units per sample and the values were obtained from statistical tables.

Control charts for attributes was also used to measure the quality characteristics that are counted rather than measured. In this case, P-chart was used to measure the proportion of items in a sample that are defective. A proportion was then computed and used as the statistic of measurements. The fraction of defective products and the mean were obtained using equation (2.8) and Equation (2.9), respectively.

$$Df = \frac{p}{s} \tag{2.8}$$

$$\bar{P} = \frac{\sum P}{n.s} \tag{2.9}$$

where, $\overline{\mathrm{P}}$ is the mean of defective proportion, P is the number of defectives, and s represent the total number of items inspected sampled. Also, the standard deviation of P from the center line was obtained by equation (2.10).

$$\delta_{\overline{P}} = \sqrt{\frac{\overline{P}\,(1-\overline{P}\,)}{n}} \qquad (2.10)$$

where, $\delta_{\overline{P}}$ stand for the standard deviation from the mean $\overline{\mathrm{P}}$.

To plot P-chart for analysis, the upper and lower control limits were determined from equations (2.11 - 2.13).

$$CL = \overline{P} \qquad (2.11)$$

$$UCL = \overline{P} + 3\sqrt{\frac{\overline{P}\,(1-\overline{P}\,)}{n}} \qquad (2.12)$$

$$LCL = \overline{P} - 3\sqrt{\frac{\overline{P}\,(1-\overline{P}\,)}{n}} \qquad (2.13)$$

where, all the parameters retain their meaning earlier defined in this work, P is the fraction non-conforming in a batch. Again, the preparation for constructing the C- chart was considered. The control limits were determined by equations (2.15-2.17).

$$\overline{C} = \frac{\sum C_I}{n} \qquad (2.15)$$

$$UCL = \overline{C} + 3\sqrt{\overline{C}} \qquad (2.16)$$

$$LCL = \overline{C} - 3\sqrt{\overline{C}} \qquad (2.17)$$

where, C_i is the defective items and $\overline{C}$ represent the mean of the defective items.

2.2.2 Pareto Chart

This chart was used to analyzed the frequency of occurrence of product defects within the period investigated. It is a tool used to identified the most common defects, the section and period in which the defects occurred in process improvement. Since large amount of impact is often tied to relatively small number of problems that matter most, with Pareto analysis, if twenty percent of these problems or defects are identified and settled, then the remaining eighty percent will be settled seamlessly.

3.0 RESULTS AND DISCUSSION

The quality of products produces at the case study company from 2016 to 2019 was investigated and the data obtained was analyzed. The results of the analysis are reported in this section.

3.1 Analysis and Identification of Possible Product Defects

One hundred and twenty samples were randomly selected for a period of thirty days and examined for possible defects. The area observed were cut edge, strip tripping, and thickness. The average non-conformed items alongside the range of subgroup defects were evaluated and presented in Table 3.1.

Table. 3.1: Computed Mean defect and Range

Day	$\bar{x}$	R
1	8.75	8
2	4.75	8
3	3.75	3
4	4.75	3
5	7.75	15
6	7.50	10
7	3.75	4
8	8.25	10
9	7.00	4
10	7.75	13
11	8.25	12
12	4.50	3
13	8.00	12
14	5.75	2
15	5.25	3
16	5.50	1
17	5.50	3
18	5.00	6
19	7.00	12
20	4.00	6
21	6.25	5
22	3.25	3
23	6.50	14
24	4.75	5
25	3.50	2
26	4.50	3
27	5.00	2
28	6.75	15
29	3.75	4
30	6.25	7
	173.25	198

The total defective items found during the investigation for the years 2016, 2017, 2018, and 2019 were 170, 178, 182 and 162, respectively. The highest number of defects (182) occurred in 2018 and the least (162) defects occurred in 2019. Results revealed that the most common defects experienced at different period of the year include: strip breakage due to rolling (caused by present of foreign materials); edge cut due to corrosion; operator reading, line tripping; herringbone mark due to rough rollers and Squeezed roll. The company aluminium roll thicknesses: 0.25mm, 0.30mm, 0.35mm, 0.40mm and 0.45mm.

3.2 Construction of P-Chart for Defective Items in 2016

A total of one hundred and seventy (170) defective products was observed in 2016 based on which the control limits of defective items was computed and P-chart for attribute plotted and reported in Figure 3.1.

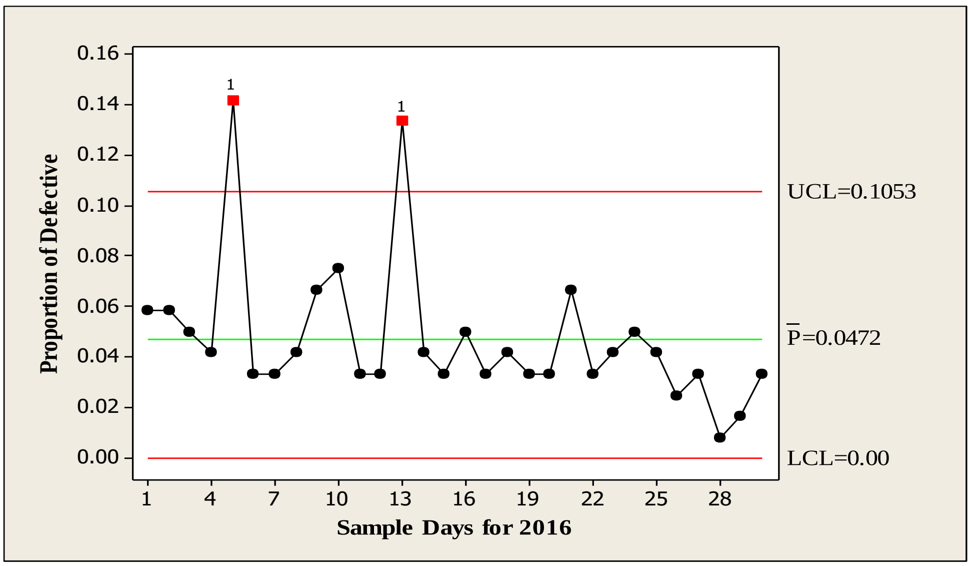

Figure 3.1: Preliminary P-Chart of defective Products for the year 2016.

The mean of means was found to be 0.0472, the standard deviation 0.0194, the upper control limit 0.1053, and the lower control limit 0.00, instead of - 0.0110. From Figure 3.1, two points (5th and 13th) were observed to be statistically out of control (i.e., above the upper control limit) expected. One point was found to be more than three Sigma (3 standard deviations) from the center line. However, majority of the data points were of course found to be within the control limits. Since P-charts are attribute control chart, assignable causes must be responsible for the out of control observed. To ensure quality of the products, action was taken to restored the system to statistical control. These points (5th and 13th), with defective values of 17 and 16 were eliminated, new control limits computed and new P- chart constructed as depicted in Figure 3.2.

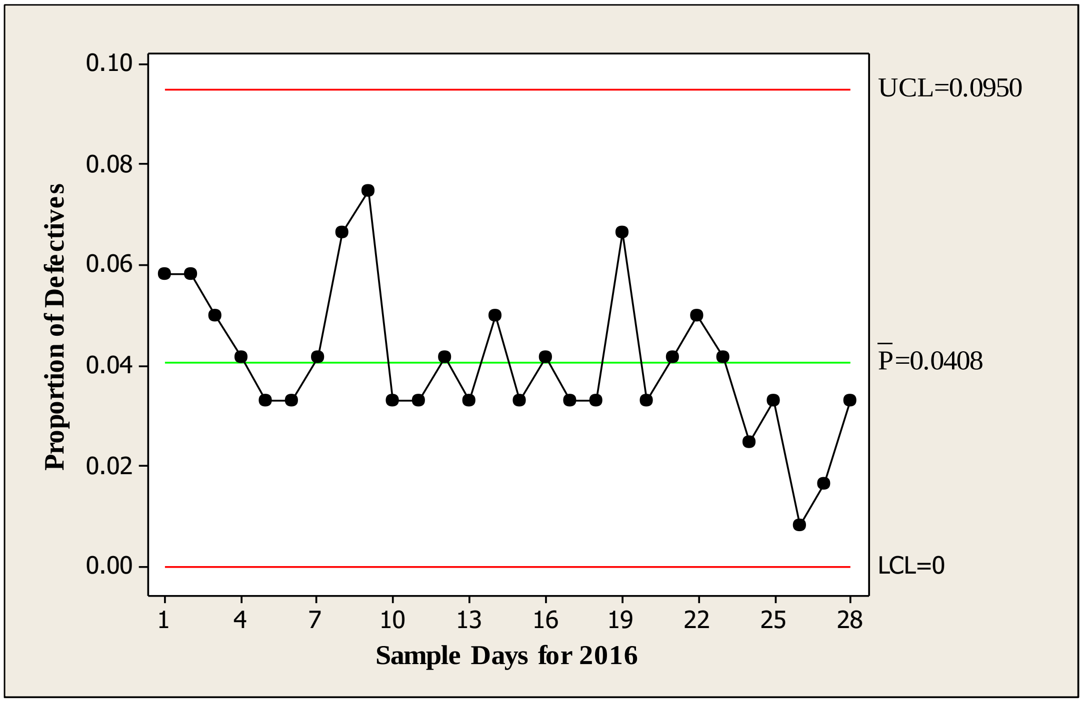

Figure 3.2: Improved P- Chart of Defective Products for the Year 2016

The new control limits were found to be: upper 0.0950, lower 0.00, and standard deviation 0.0408. From Figure 3.2, all the data points were in statistical control. This revealed that P-chart is an adequate tool to monitor product quality. The measured taken has improved the quality of products if the P-chart is adopted.

3.3 Control Factors and Construction of C-Chart

In furtherance, the data was analyzed using C-chart. The control parameters were obtained and the initial C-chart was plotted and presented in Figure 3.2.

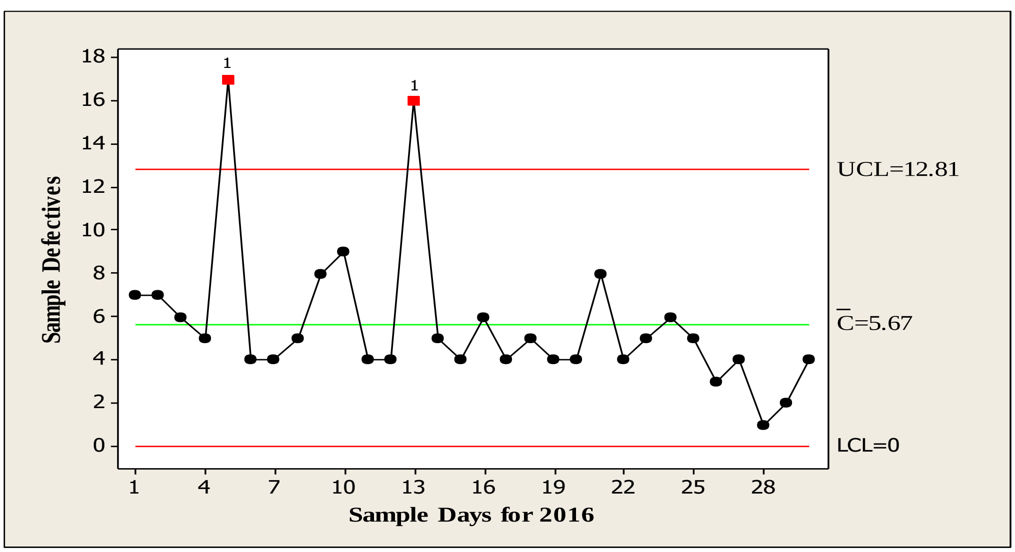

Figure 3.3: Preliminary C-Chart of Defective Products for the Year 2016

Figure 3.3 showed that two points (5th and 13th) were also out of control (above the upper control limit). Similarly, these points (5th and 13th) with defective values of 17 and 16 were eliminated and the procedure used for the preliminary computations was followed to determine the new control limits. The new C-chart was plotted and presented in Figure 3.4.

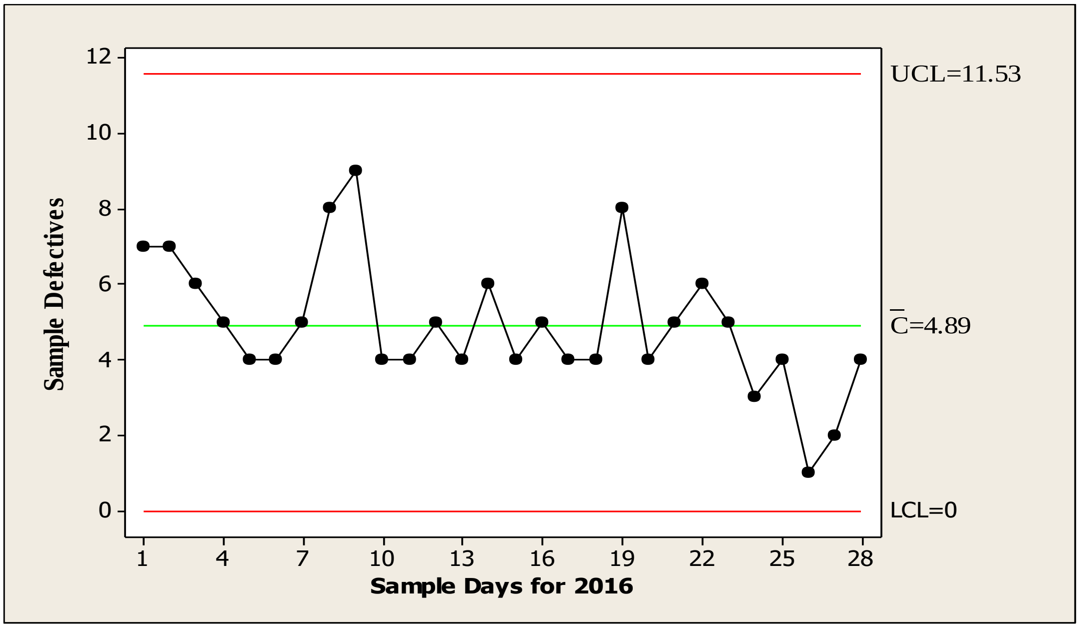

Figure 3.4: Improved C-Chart of Defective Products for the Year 2016

From Figure 3.4, elimination of the points (5th and 13th) has brought the system to control statistically. This reveal that C-chart is adequate for used to monitor product quality.

3.4 Period of High Product Defects and Possible Improvement using Pareto Analysis

To ascertain the period of high product defects and measure of improvement, further analysis was conducted using Pareto principle. Based on data of product defects, Pareto chart was constructed for 2016 and presented in Figure 3.5.

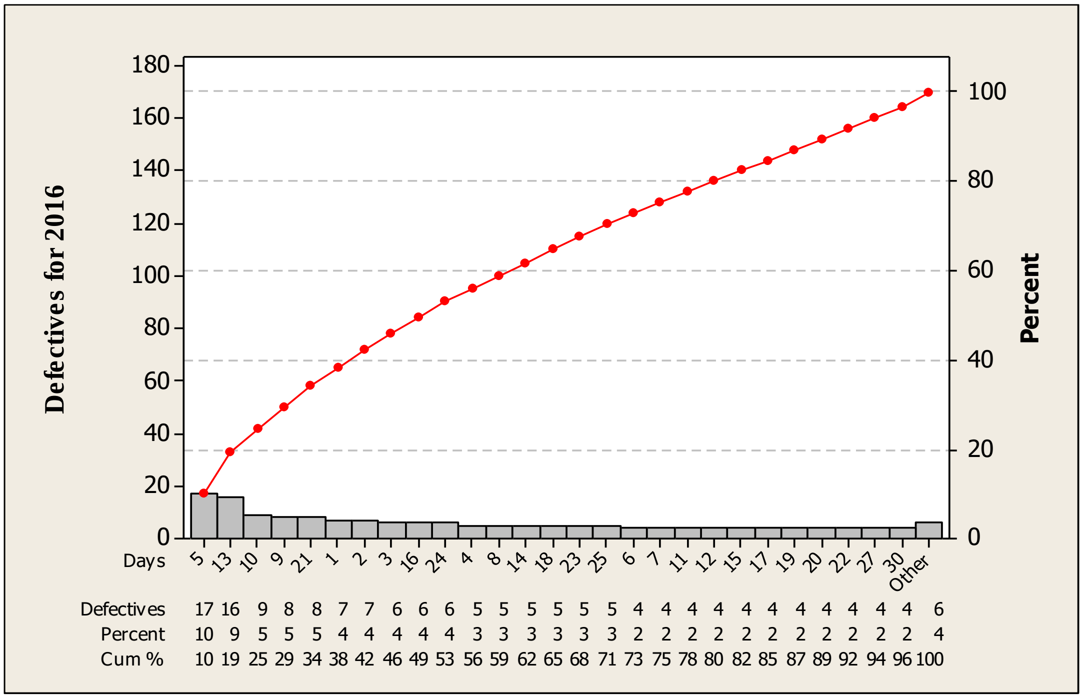

Figure 3.5: Pareto Chart of Defectives Products for the Year 2016

From Figure 3.5, It was found that 10 percent of the defectives occurred on the 5th day, 9 percent on the 13th day. Pareto presents 19 percent cumulative problems, if solved will have greater effect on the rest 81 percent. Pareto presented the problems or defect in bars and their frequency in line. With Pareto principle, it is easy to identify the major defects.

CONCLUSION

In this study, product defects in an aluminium company located in Port Harcourt was analyzed using control charts and Pareto Analysis and the following were reached:

i. Strip breakage, edge cut, line tripping, and herringbone mark were identified as the most common product defects.
ii. C- chart was found to be the most effective attribute chart to monitor quality of aluminum product.
iii. Pareto chart was able to picked out the most essential problems to be solved to enhance greater effect on the enter system.
iv. Sheet thickness has no significant effect on the number of product defects recorded.

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