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Applications of Statistics in Engineering

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***Abstract* - Statistics is the art of collecting information from data, and as a result, it has become a necessary tool for running modern engineering applications. It is an important tool for robustness analysis, measuring system error analysis, test data analysis, probabilistic risk assessment, etc. It also plays a significant role in producing nearly defect-free products. Some basic statistical tools which are used in engineering are discussed in this article with the aim of getting students comfortable using software to undertake statistical analysis in order to solve engineering challenges.**

Keywords: Statistical tools, Engineering, Statistical quality control, Six Sigma.

Introduction

Statistics is the backbone of major engineering applications. Whether it is system design, measuring dimensions, or quality control, it plays a significant role in producing nearly defect-free products. Quality is a non-debated, prominent aspect of every industrial or engineering product. No firm compromises the quality of its product. It is the quality of the product upon which the performance of the firm depends. This is the main reason why quality is considered a key performance indicator in the corporate world. Quality is nothing but consistency, reliability, and conformation of a product. In the 1980s, companies started to give emphasis to the quality standards of their products and services. It is at this point that statistics come into the picture. Statistics offer various quantitative techniques that contribute significantly to quality improvement or defect-free production. Such a technique of quality control with statistics is known as statistical quality control. Because of the widespread adoption of statistical methodologies such as Total Quality Management (TQM), Japan's manufacturing industry has improved tremendously in terms of quality (Zhan et al., 2011). Many other statistical techniques, e.g. Statistical Control Process, Six Sigma (Snee 2004), etc., have also been shown to be beneficial in improving processes, product quality, and business bottom lines.

Statistical Quality Control Techniques

Statistical quality control categorizes statistical tools for quality control into three main categories.

a) Descriptive Statistics: Descriptive statistics are used to determine quality features. We use the mean, standard deviation, Range of products to analyse the average deviation of quality characteristics of the final product from the mean or desirable standard.
b) Statistical Process Control: Under statistical process control, we analyse whether the production process produces parts with ore-determined specifications or if there are any variations (Wortman et al., 2001).

Process capability = It is defined as the ability of production process to meet predetermined product specification. Every company set up some acceptable range for quality of product.

Process capability is measured by process capability index.

C_p = Specified width / Process width = (Upper specification limit – Lower specification limit) / 6σ

[The majority of the process measurement (99.74%) falls within 3 standard deviations, for a total of 6 standard deviations]

In statistical process control the following techniques are used:

<u>Histograms</u> – these are a type of bar chart which is used to represent the frequency of data. With the help of histograms, one can evaluate the distribution of data over the different time periods.

Illustration - Suppose we have to analyze the frequency of failure of machine over a period of eight months. We will calculate the number of failure of machine in each month.

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Table-1

Month	No. of failure of machine
March	5
April	6
May	9
June	15
July	13
August	8
September	7

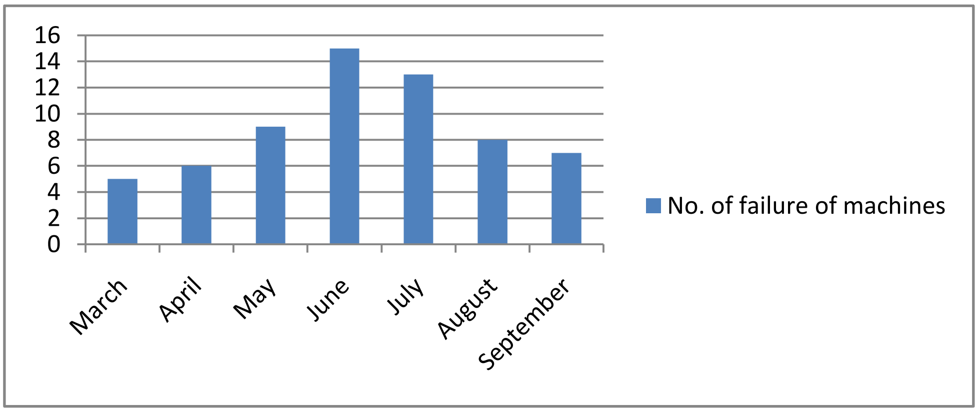

Figure 1

Pareto Charts - A Pareto chart is a data-driven statistical tool for determining the root cause of an issue. This tool follows 80/20 rule that is invented by Joseph Juran. 80/20 rule states that 80% of the defects occur in 20% of the causes like machines, Raw materials, machine operators etc. A Pareto Chart can be used to identify that 20% route causes of problem. Illustration – Suppose we have to analyze the causes of defects in our manufacturing slot. The following data is collected:

Table-2

Causes of defects	No. of failures
1. Failure of machinery	94
Absence of regular operator	67
2. Poor quality of raw material	22
3. Lack of Maintenance	10
4. Electricity Failure	5
Lack of monitoring	2

Table-3

Causes of defects	No. of failures	% of Failures	Cumulative % of failures
Failure of machinery	94	47%	47%
Absence of regular operator	67	33.5%	80.5%
Poor quality of raw material	22	11%	91.5%
Lack of Machine maintenance	10	5%	96.5%
Electricity Failure	5	2.5%	99%
Lack of monitoring	2	1%	100%
Total	200	100.0	

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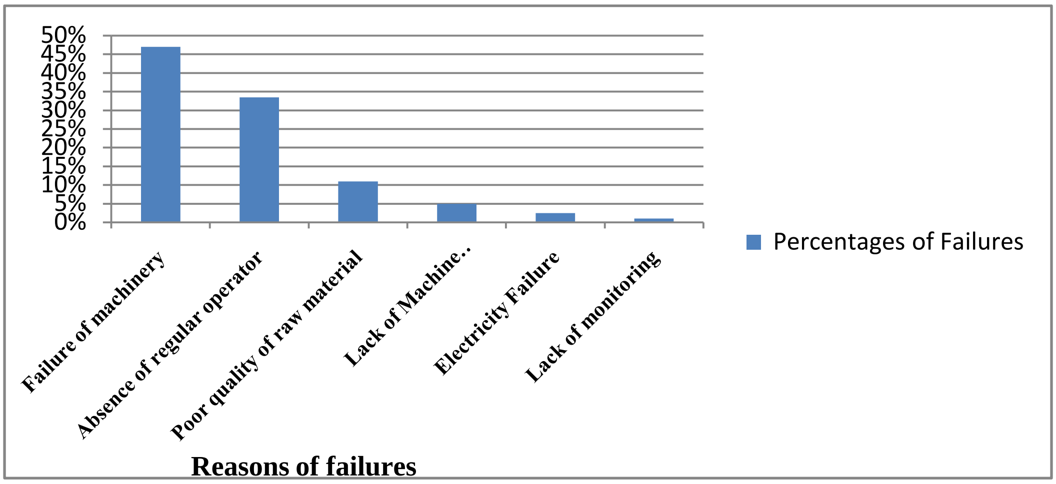

Figure-2

The above Pareto graph shows that more than 80% problems come due to first 3 reasons. So to improve the quality of product the company must have to tackle these three problems.

Control Charts – A control chart is one of the most common statistical process control techniques. It is a statistical tool to analyze whether a sample of data falls within the common or normal range of variation (Benneya, J. C., 1998). Upper control limit and lower control limits are defined in control charts. There are following types of control charts.

A) X-bar chart - The sample mean is used as the control limit in the Control Charts. While plotting X – bar grand mean of samples variations is calculated. That grand mean is the control limit. Then the upper control limit and lower control limit are defined.

To specify the upper and lower control limits of the chart, following formulas are used:

Upper control limit (UCL) = Grand Mean + $z*\sigma_x$
Lower control limit (LCL) = Grand Mean – $z*\sigma_x$

Table-4

Sample No.	Observations				Mean
	1	2	3	4	
1	60.23	59.86	60	60.44	60.1325
2	58.95	59.99	61.14	58.98	59.765
3	61.32	60.12	59.82	59.99	60.3125
4	59.91	60.67	61.09	61.03	60.675
5	60.11	60.05	59.89	58.98	59.7575
6	59.07	61.02	59.93	60.04	60.015
7	60.05	59.98	60.43	61.04	60.375
8	59.87	58.88	59.94	60.1	59.6975
9	58.97	60.04	60.13	59.99	59.7825
10	60.01	59.97	61.03	58.86	59.9675

Grand Mean = 60.048
Population standard deviation = 0.6535
Standard deviation of distribution of sample mean = (0.6535/ √4) = 0.32
Upper control limit = 60.048 + 2*0.32 = 60.68
Lower control Limit = 60.048 - 2*0.32 = 59.408

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Table-5

Sample No.	Mean
1	60.1325
2	59.765
3	60.3125
4	60.675
5	59.7575
6	60.015
7	60.375
8	59.6975
9	59.7825
10	59.9675

Control X- chart

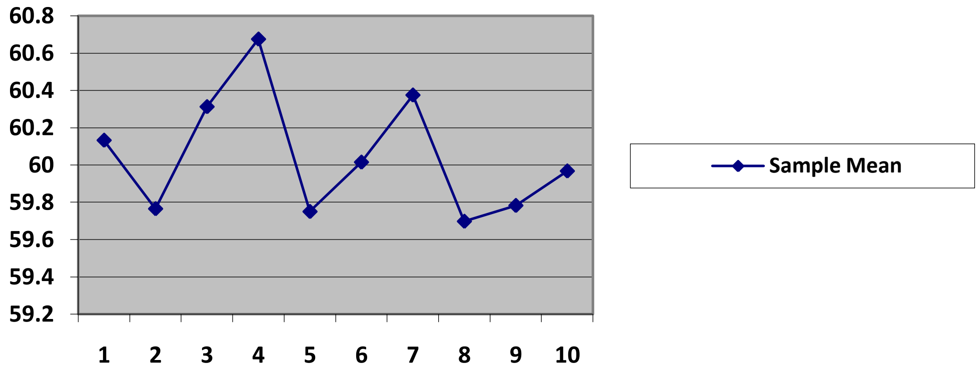

Figure-3

B) R chart - In R chart, the sample range is considered to control the variations in the manufactured lot.

Table -6

Sample No.	Observations				Mean	Range
	1	2	3	4		
1	60.23	59.86	60	60.44	60.1325	0.58
2	58.95	59.99	61.14	58.98	59.765	2.19
3	61.32	60.12	59.82	59.99	60.3125	1.50
4	59.91	60.67	61.09	61.03	60.675	1.18
5	60.11	60.05	59.89	58.98	59.7575	1.13
6	59.07	61.02	59.93	60.04	60.015	1.93
7	60.05	59.98	60.43	61.04	60.375	1.06
8	59.87	58.88	59.94	60.1	59.6975	1.13
9	58.97	60.04	60.13	59.99	59.7825	1.16
10	60.01	59.97	61.03	58.86	59.9675	1.16
Total						13.02

Range = 13.02/10 = 1.302

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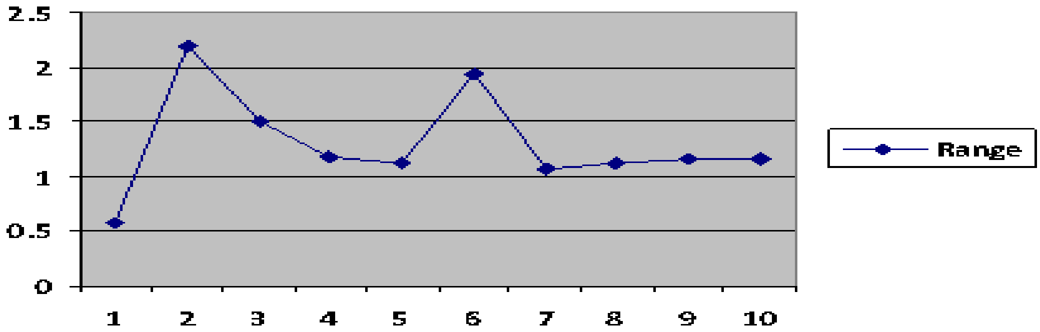

Figure-4: R-Chart

Run Charts – Run charts are statistical tools for evaluating the going trend of a certain item. It may be in terms of raw material consumption or defect analysis before and after implementing a specific quality control technique. These can also be referred as trend charts.

Illustration - Suppose we have to analyze the consumption of natural rubber in manufacturing tyres per year.

Table-7

Year	Consumption of rubber in million tons
2005	813,789
2006	825,456
2007	849,197
2008	861,455
2009	871,720
2010	894,730

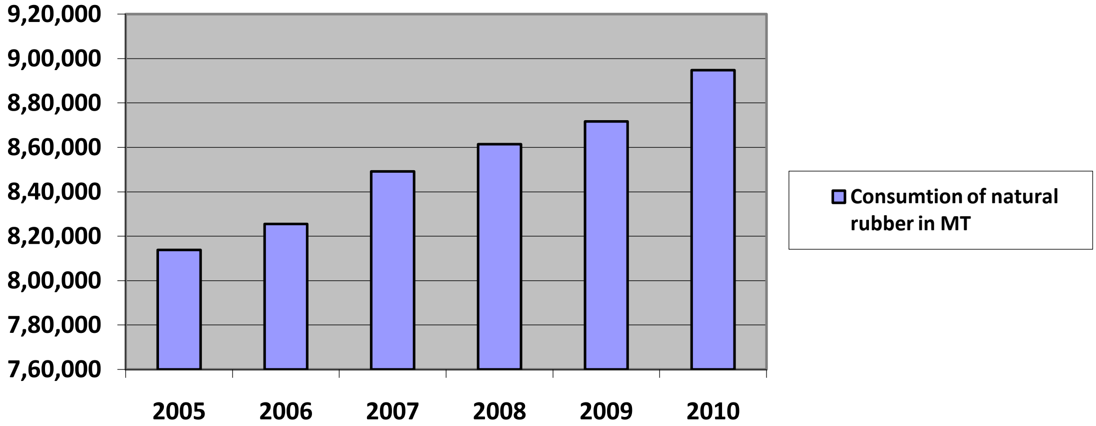

Figure-5: Run Chart

Acceptance Sampling – Acceptance sampling is a method of deciding whether to accept or reject produced components based on the inspection of a sample batch. Acceptance sampling is performed either before or after the manufacturing process has begun. Before we begin the production process, we conduct an acceptance sample procedure to ensure that the raw materials we get from our suppliers are of high quality. We assess whether the quality of the raw material meets our requirements. If we are not satisfied, we will reject everything. When we undertake the acceptance sampling procedure after completion of the manufacturing process we verify the quality of the final product. We assess if the end product's quality corresponds to the initial product's quality. If we are not satisfied then we can reject the lot.

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Six sigma - The Greek letter "sigma" is used by statisticians to denote standard deviation from the mean. A higher sigma means that there are fewer faults and that procedures are more efficient.

Table – 8

SIGMA	Defective Parts Per Million
1	5,00,000
2	3,08,537
3	66,807
4	6,210
5	233
6	3.4

ANOVA Gage R&R - It is statistical measurement technique which is used as a six sigma tool. It measures the amount of variability in measuring the dimensions of finished or semi-finished product because of the measurement tool defects or the use of measurement tool by different operators. There may be the case where two operators give different readings while working on same instrument. We consider two important aspects under ANOVA Gage R&R.

a) Reproducibility – It is the variation that comes in picture when two or more instruments measure same product or when two or more operators measure same product with same measuring tool.
b) Repeatability – It is the variation that comes in picture when a single operator measures the same product by same measuring instrument more than one time.

When we perform Gage R&R test we use 2 or 3 trials on 5-10 different parts by 2-3 operators.

We calculate Precision to tolerance ratio

$P/T = 6\sigma / (USL-LSL)$

Here: P = Precision, T = Tolerance,
USL = Upper Specified Limit
LSL = Lower Specified limit

R&R gage is also used in measuring attribute variables. The firm set a standard measure for each part but it is kept secret from operator.

Operator repeatability = No. of measurement matches within trials / No. of parts inspected

Overall system repeatability = Sum of all Operator's reliability / n

Individual effectiveness = Number of matches with standard / Number of parts inspected

(10% rule – Anova R&R gage follows 10% rule. As per 10% rule if measuring instrument gave measurement more than 10% of tolerance measurement limit of particular product then there is some error in measuring instrument. If measuring instrument gave measurement less than 10% of tolerance measurement limit of particular product then the measuring instrument is considered reliable).

Operating Characteristic Curve

Operating Characteristic Curve is a statistical tool used for quality control in reliability engineering. The Operating Characteristic (OC) curve expresses the likelihood of accepting a lot as a function of Lot/ Batch quality. The chance of accepting the lot in question diminishes as the amount of faulty increases. While plotting Operating curve on Y-axis we plot probability of accepting the lot and on X-axis we plot percentage of defective parts (Lyman, G. et al., 2011)

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Consumer Risk = Accepting the bad lot

In statistics we describe consumer risk as type II error means accepting null hypothesis when it is false.

Producer Risk = Rejecting a good lot

In statistics we describe Producer risk as type II error means rejecting null hypothesis when it is true.

Illustration – Suppose company XYZ has following parameters of accepting the lot from its suppliers.

Table -9

Probability of acceptance P(A)	% of defective parts
0.98	3%
0.80	5%
0.79	10%
0.65	12%
0.50	18%
0.40	20%

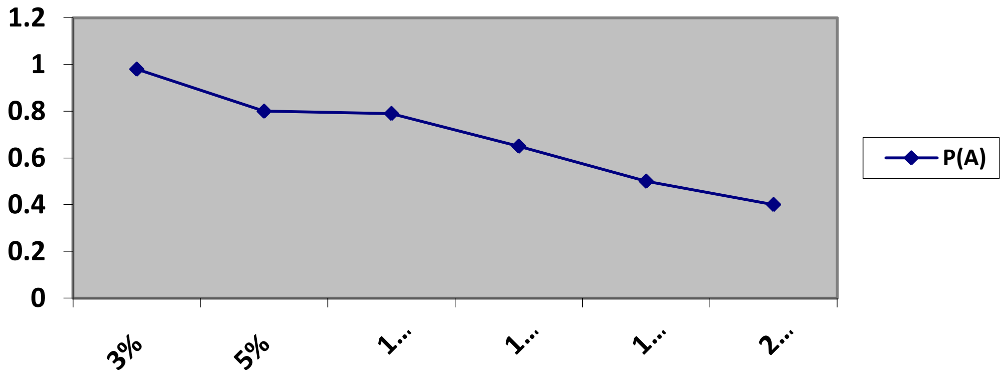

Figure-6: OC curve

Conclusion

In nutshell we can say statistics plays an important role in the field of engineering. Quality control is very vulnerable area in which statistics is very crucial. Six Sigma, Statistical process control set up a high quality measurement standard in the field of engineering. Despite its importance of quality engineering, statistics has a critical role in the design of engineering components and systems, as well as the establishment of standards in various manufacturing operations.

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