

Quality & Productivity Improvement of Boring Machine using Six Sigma

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Abstract –There has been number of papers published related to Six Sigma applications in manufacturing and service organizations. However, very few studies are done on boring machine in all the areas including manufacturing, construction, education, financial service, BPOs and healthcare etc. Considering the contribution of Six Sigma in recent time, a more comprehensive review is presented in this paper. A systematic approach needs to be adopted, which optimizes systems as a whole, focusing the right strategies in the correct places. In this paper it is show how a boring process can be improved and optimized using six sigma. Even applications of Six Sigma tools are observed in this paper. In the research paper DMAIC Cycle is been used for process characterization & process optimization,

This paper contributes to knowledge by providing an insight into the evolution of the Six Sigma. A very few paper are available related to analysis of boring machine using six sigma. Literature exploring the environmental/green impact of quality management methods commonly used in industry is limited. There is also a lack of studies aiming to investigate the green impact of Six Sigma in top operations and quality management journals.

Keywords - Six sigma, DMAIC, boring machine, Productivity, Quality.

I. INTRODUCTION

In this competitive scenario, the markets are becoming global & economic conditions are changing fast. Customers are very quality conscious & demand for high

quality product at competitive prices with product variety and reduced lead-time. Companies are facing tough challenge to respond to the needs of customer while keeping manufacturing & other related costs down .The companies are striving for their very survival. Companies can cut down their costs by reducing the production of defective parts.

Quality is a necessary characteristic for Industrial Engineers to observe, study, and understand. For organizations that offer products and services to customers, a system within this company is a process that produces, maintains, or supports a product or service. According to Kirkpatrick (1970), a system is a physical or conceptual entity comprised of interdependent parts that interact within boundaries established to achieve some common goal or goals. This definition of system aids a proper definition of quality within the realm of Industrial Engineering topics. According to El-Haik (2005), quality can be defined as .the degree to which the design vulnerabilities do not adversely affect product performance. It is important to note that this definition is universally applicable to not simply products and product design, but also service and service process design. Also, the design vulnerabilities of a product or service can either be inherit in the type of product or services being created, or perhaps established by improper conceptual design. Regardless of which type of vulnerability may exist, the quality of a product or service is only decreased when it affects either the process that creates it by increasing costs, time, and constraints, or by affecting the end product or service that a customer uses. This implies that quality is not merely achieving the perfection of a product or service, but rather, high quality is achieving perfection of product

or service performance, or getting as close to it as possible.

Productivity is an average measure of the efficiency of production. It can be expressed as the ratio of output to inputs used in the production process, i.e. output per unit of input. When all outputs and inputs are included in the productivity measure it is called total productivity. Outputs and inputs are defined in the total productivity measure as their economic values. The value of outputs minus the value of inputs is a measure of the income generated in a production process. It is a measure of total efficiency of a production process and as such the objective to be maximized in production process.

Productivity measures that use one or more inputs or factors, but not all factors, are called partial productivities. A common example in economics is labor productivity, usually expressed as output per hour. At the company level, typical partial productivity measures are such things as worker hours, materials or energy per unit of production.

In machining, boring is the process of enlarging a hole that has already been drilled (or cast), by means of a single-point cutting tool (or of a boring head containing several such tools), for example as in boring a gun barrel or an engine cylinder. Boring is used to achieve greater accuracy of the diameter of a hole, and can be used to cut a tapered hole. Boring can be viewed as the internal-diameter counterpart to turning, which cuts external diameters.

There are various types of boring. The boring bar may be supported on both ends (which only works if the existing hole is a through hole), or it may be supported at one end (which works for both through holes and blind holes). Line boring (line boring, line-boring) implies the former. Back boring (back boring, back-boring) is the process of reaching through an existing hole and then boring on the "back" side of the work piece (relative to the machine headstock).

Because of the limitations on tooling design imposed by the fact that the work piece mostly surrounds the tool, boring is inherently somewhat more challenging than turning, in terms of decreased tool holding rigidity, increased clearance angle requirements (limiting the amount of support that can be given to the cutting edge), and difficulty of inspection of the resulting surface (size, form, surface roughness). These are the reasons why boring is viewed as an area of machining practice in its own right, separate from turning, with its own tips, tricks, challenges, and body of expertise, despite the fact that they are in some ways identical. The first boring machine tool was invented by John Wilkinson in 1775.

Boring and turning have abrasive counterparts in internal and external cylindrical grinding. Each process is chosen based on the requirements and parameter values of a particular application.

Six Sigma Methods -

Six Sigma is based on six basic principles that help the implementation of Six Sigma method to production companies or service industries. Six Sigma uses the base tools to improve the quality of products and processes as Measurement System Analysis (MSA), IPO Diagram (Input-process-output), Cause-and- Effect diagram (CE), Histogram, Pareto diagram, Define, Measure, Analyze, Improve, Control (DMAIC), Run chart, Control chart, Scatter diagram, Regression Analysis, Designing of Experiments (DOE), Failure Mode and Effect Analysis (FMEA), Standard Operating Procedure (SOP) and Quality Function Deployment (QFD).

Measurement system analysis

Diffusion of the watched commodities' parameter can be connected by the commodity itself or the system of measuring. The system of measuring is made by operator, benchmark and the method of measuring. Measuring System Analysis (MSA) is a tool for the evaluation of accuracy and advisability of the measuring system. It goes with testing or measuring the chosen parameter by the operator. It monitors the influence of repentance and reproducibility of the total variance. The goal of MSA is to estimate how the system of measuring contributes to the total variance of watched parameter. Most of the time, analysis of the measurement system is used in the phase of Measurements.

Analysis of the causes and consequences

CE is a tool to solve problems through finding the cause of their occurrence. It helps to find all possible causes, to split causes into categories and organize their relationships and impact on output, and to identify opportunities for improvement. In general, these categories are commonly known as

7 M causes:

- Man -people, job;
- Methods and mechanics, process;
- Machine – machines, equipment;
- Measurement;
- Management - system of organization and management;
- Material; and
- Mother Nature - environment.

Histogram

Histogram is a perfect tool for visualization of the frequency of the watched phenomenon in process. It is a bar chart made from number of categories, showing their splitting. Customer tolerance can be added (LSL, USL) to watched process.

Pareto diagram

Pareto diagram is a bar chart for discrete data, indicating the frequency of non-digital data. These categories are arranged in descending order. The tool that allows determining the impact of input factors to an endpoint.

DMAIC

It is the common option for the model of improving the process based on Deming's circle Plan-Do-Check-Act (PDCA). DMAIC is in the Six Sigma methodology being used as the standard routine for planning and implementation of the project.

II. METHODOLOGIES IN SIX SIGMA

The various researchers have applied different methodologies for the estimation of six sigma. The literatures are classified on the basis of methodology applied for the particular applications. From the literature it is proved that DMAIC are very popular in the field of six sigma. Lean six sigma is a modern and advance concept. As compare to DMADV is also familiar in the field of six sigma.

The phase of Six Sigma implementation

In order to reduce process variation and the associated high defect rate, Six Sigma focuses on improvement methodology application, then the DMAIC is mentioned most frequently now and a lasting improvement method (Starbird, 2002). The representative's meanings of five English letters are as follows:

Define

The top management shall identify the problem according to customer feedback, strategy and mission of company, define customer requirements, and set goal.

Measure

Measurement is a key transitional step on Six Sigma road, one that helps the project team refined the problem and being the search for root causes which will be the objective of Analyze step in DMAIC. Therefore, the project team needs to validate problem/process, refine problem/goal, and measure key steps/input.

Analyze

In analyses stage, the project team shall use data analysis tools and process analysis techniques to identify and verify root causes of the problem. For the reason, the project team needs to develop causal hypotheses, identify vital few root causes, and validate hypothesis.

Improve

The goal of the improve stage is to find and implement solutions that will eliminate the causes of problems, reduce the variation in a process, or prevent a problem from recurring. So the project team needs to develop ideas to remove root causes, test solutions, and standardize solution/measure result.

Control

Once the improvement has been made and results documented, continue to measure the performance of the process routinely, adjusting its operation. It is very important for the project team needs to establish standard measures to maintain performance and correct problems as needs. Without control efforts, the improved process may well revert to its previous state.

DFSS Process

Design for Six Sigma (DFSS) is a systematic methodology utilizing tools, training and measurements to enable the organization to design products and processes that meet customer expectations and can be produced at Six Sigma quality levels. DFSS is potentially far more effective than DMAIC as its application is in the early stage of new product/process development, thus the papers under this category aim to provide an explanation of DFSS and why it is different from DMAIC [12-15]. For example, Mader explains the DFSS methodology, its key aspects and how it enhances the design process, improving New Product Development (NPD). Antony presents DFSS using the Identify, Design, Optimize and Validate (IDOV) approach. Treichler et al. discusses the use of DFSS in the design function of major US corporations and Koch et al. explain DFSS in detail, using as an example the application of DFSS in automotive crashworthiness under an engineering design context. All of these studies of DFSS have been undertaken in a manufacturing context. Hence, there is a need for more extensive study to consider new areas of DFSS application, such as how DFSS can be applied to nonmanufacturing processes. (DFSS) is a systematic methodology utilizing tools, training and measurements to permit the association to design products and processes that meet customer expectations and can be produced at Six Sigma quality levels

Lean Six Sigma

Lean Six Sigma is not new, it is a combination of Lean Management and Six Sigma methodologies which were first integrated in 1986 in the US-based George group. The term ‘Lean Six Sigma’ did not appear in literature until 2000 (Timans et al. 2012), and LSS teaching was not established until 2003 (Kubiak 2011). Since that time, there has been a noticeable increase in LSS popularity and deployment in the industrial world; especially in large western organizations such as Motorola, Honeywell and General Electric (Timans et al. 2012; Laureani and Antony 2012) and in some small and medium size manufacturing enterprise (SMEs) (Kumar et al. 2006). *Albliwi and Antony* LSS is “a methodology that focuses on the elimination of waste and variation, following the DMAIC structure, to achieve customer satisfaction with regards to quality, delivery and cost. It focuses on improving process, satisfying customers and achieving better financial results for the business” (Salah et al. 2010). Organizations give many reasons for implementing LSS; to improve business performance and operational efficiency for example, especially given the growth of global markets, to improve product quality, reduce production costs and so improve customer satisfaction (Antony 2008; Snee 2010; Laureani and Antony 2012; Jayaraman et al. 2012). The history of LSS and notable success stories of LSS implementation in the industrial world can be seen in many academic papers by authors such as Chakravorty

and Shah (2012) and Thomas et al. (2009). On the other hand, not all organizations can gain real benefits from LSS implementation; a poor attempt at LSS implementation can actually render it ineffective (Jayaraman et al. 2012).

III. MEASUREMENT, OBSERVATION & ANALYSIS

We have taken Boring machine as our subject for six sigma research paper. The Measurement, Observation & Analysis using six sigma is show below. We have specified the application of six sigma on a specific process i. e. boring process which is done over a boring machine. The boring machine is used for the boring of the engine cylinder internal surface i. e. liner. In the workshop where the boring machine is used for precise machining. But there are lot of quality problems observed. So for the analysis six sigma is applied on the boring process. Initially 25 readings were taken and one defect was observed. These readings were taken without any changes and only regular readings were taken. While taking these readings various problems were also identified and even the report was made. After taking initial readings, the reasons and causes were identified & controlled. Group discussion was organised and all the parameters were discussed and revised. After this again 25 readings were taken & six sigma standard was achieved. But this time our guidelines were used for the process.

Table 1 – Initial Observation

Job No	Cylinder 1 (X1)	Cylinder 2 (X2)	Cylinder 3 (X3)	Cylinder 4 (X4)	Cylinder 5 (X5)	Cylinder 6 (X6)	\bar{X}	R
1	96.95	96.94	96.95	96.96	96.96	96.95	96.95167	0.02
2	96.94	96.95	96.94	96.95	96.95	96.96	96.94833	0.02
3	96.95	96.94	96.95	96.95	96.94	96.94	96.945	0.01
4	96.95	96.95	96.94	96.93	96.95	96.95	96.945	0.02
5	96.95	96.96	96.95	96.95	96.93	96.94	96.94667	0.03
6	96.95	96.96	96.96	96.96	96.95	96.95	96.955	0.01
7	96.96	96.95	96.95	96.94	96.95	96.95	96.95	0.02
8	96.96	96.93	96.95	96.96	96.96	96.96	96.95333	0.03
9	96.95	96.94	96.95	96.95	96.94	96.94	96.945	0.01

10	96.94	96.95	96.95	96.95	96.93	96.95	96.945	0.02
11	96.95	96.97	96.94	96.95	96.95	96.96	96.95333	0.03
12	96.95	96.96	96.94	96.95	96.95	96.96	96.95167	0.02
13	96.95	96.95	96.96	96.96	96.96	96.95	96.955	0.01
14	96.94	96.96	96.95	96.97	96.95	96.95	96.95333	0.03
15	96.95	96.96	96.94	96.95	96.96	96.95	96.95167	0.02
16	96.95	96.98	96.95	96.95	96.95	96.96	96.95667	0.03
17	96.94	96.96	96.93	96.95	96.95	96.96	96.94833	0.03
18	96.96	96.95	96.95	96.96	96.96	96.99	96.96167	0.04
19	96.95	96.96	96.94	96.94	96.95	96.95	96.94833	0.02
20	96.94	96.95	96.96	96.95	96.93	96.93	96.94333	0.03
21	96.94	96.94	96.95	96.93	96.95	96.95	96.94333	0.02
22	96.95	96.94	96.95	96.96	96.93	96.94	96.945	0.03
23	96.94	96.95	96.94	96.95	96.95	96.96	96.94833	0.02
24	96.95	96.94	96.95	96.95	96.96	96.95	96.95	0.02
25	96.94	96.95	96.95	96.95	96.97	96.95	96.95167	0.03

Formulas:-

$$\bar{X} = \frac{\sum X}{n}$$

Range R = (Max R – Min R)

Where,

\bar{X} is Average of Six cylinder (X).

R is Range of Six Cylinder (X).

n is Subgroup (6).

Table 2 - Example

Job No	Cylinder 1 (X1)	Cylinder 2 (X2)	Cylinder 3 (X3)	Cylinder 4 (X4)	Cylinder 5 (X5)	Cylinder 6 (X6)	\bar{X}	R
1	96.95	96.94	96.95	96.96	96.96	96.95	96.95167	0.02
2	96.94	96.95	96.94	96.95	96.95	96.96	96.94833	0.02

Table 5 - R Chart

$$\bar{X} = \frac{96.95+96.94+96.95+96.96+96.96+96.95}{6} = 96.95167$$

$$R = (96.96-96.94) = 0.02$$

Formulas:-

$$\bar{\bar{X}} = \frac{\sum \bar{X}}{n} = 96.94986667$$

$$\bar{R} = \frac{\sum R}{n} = 0.0228$$

Where,

$\bar{\bar{X}}$ is Average of Average for 25 Jobs.

\bar{R} is Average of Range for 25 Jobs.

n is 25.

Table 3 - Formulas

For R Chart	
UCL_R	$D4 * \bar{R}$
CL_R	\bar{R}
LCL_R	$D3 * \bar{R}$

Table 4 - Appendix

For n=6 From Table of Control Chart Constants	
A2	0.48
D2	2.534
D3	0
D4	2

Where,

UCL_R is Upper Control Limit.

CL_R is Control Limit.

LCL_R is lower Control Limit.

\bar{R} is Average of Range.

R Chart				
JOB No	R	UCL_R	CL_R	LCL_R
1	0.02	0.0456912	0.0228	0
2	0.02	0.0456912	0.0228	0
3	0.01	0.0456912	0.0228	0
4	0.02	0.0456912	0.0228	0
5	0.03	0.0456912	0.0228	0
6	0.01	0.0456912	0.0228	0
7	0.02	0.0456912	0.0228	0
8	0.03	0.0456912	0.0228	0
9	0.01	0.0456912	0.0228	0
10	0.02	0.0456912	0.0228	0
11	0.03	0.0456912	0.0228	0
12	0.02	0.0456912	0.0228	0
13	0.01	0.0456912	0.0228	0
14	0.03	0.0456912	0.0228	0
15	0.02	0.0456912	0.0228	0
16	0.03	0.0456912	0.0228	0
17	0.03	0.0456912	0.0228	0
18	0.04	0.0456912	0.0228	0
19	0.02	0.0456912	0.0228	0
20	0.03	0.0456912	0.0228	0
21	0.02	0.0456912	0.0228	0
22	0.03	0.0456912	0.0228	0
23	0.02	0.0456912	0.0228	0
24	0.02	0.0456912	0.0228	0
25	0.03	0.0456912	0.0228	0

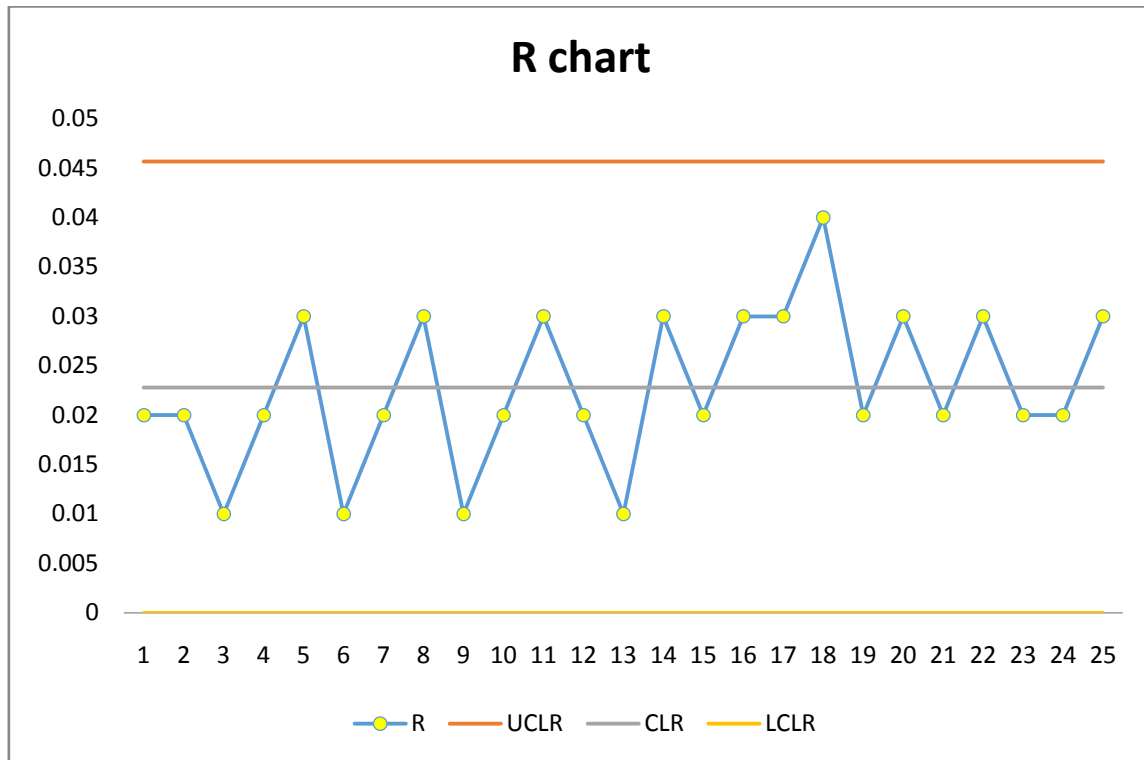


Fig. 1 – R Chart

Table 6 - Formula

For X Chart	
UCL_X	$\bar{\bar{X}}+(A_2*\bar{R})$
CL_X	$\bar{\bar{X}}$
LCL_X	$\bar{\bar{X}}-(A_2*\bar{R})$

Using Table 4 we get,

Where,

UCL_X is Upper Control Limit.

CL_X is Control Limit.

LCL_X is lower Control Limit.

$\bar{\bar{X}}$ is Average of Average.

Table 7 - X Chart

X Chart				
job no	$\bar{\bar{X}}$	UCL_X	CL_X	LCL_X
1	96.95166 667	96.96087 907	96.94986 667	96.93885 427
2	96.94833 333	96.96087 907	96.94986 667	96.93885 427
3	96.945	96.96087 907	96.94986 667	96.93885 427

4	96.945	96.96087 907	96.94986 667	96.93885 427
5	96.94666 667	96.96087 907	96.94986 667	96.93885 427
6	96.955	96.96087 907	96.94986 667	96.93885 427
7	96.95	96.96087 907	96.94986 667	96.93885 427
8	96.95333 333	96.96087 907	96.94986 667	96.93885 427
9	96.945	96.96087 907	96.94986 667	96.93885 427
10	96.945	96.96087 907	96.94986 667	96.93885 427
11	96.95333 333	96.96087 907	96.94986 667	96.93885 427
12	96.95166 667	96.96087 907	96.94986 667	96.93885 427
13	96.955	96.96087 907	96.94986 667	96.93885 427
14	96.95333 333	96.96087 907	96.94986 667	96.93885 427
15	96.95166 667	96.96087 907	96.94986 667	96.93885 427
16	96.95666 667	96.96087 907	96.94986 667	96.93885 427
17	96.94833 333	96.96087 907	96.94986 667	96.93885 427
18	96.96166 667	96.96087 907	96.94986 667	96.93885 427

19	96.94833 333	96.96087 907	96.94986 667	96.93885 427
20	96.94333 333	96.96087 907	96.94986 667	96.93885 427
21	96.94333 333	96.96087 907	96.94986 667	96.93885 427
22	96.945	96.96087 907	96.94986 667	96.93885 427
23	96.94833 333	96.96087 907	96.94986 667	96.93885 427

24	96.95	96.96087 907	96.94986 667	96.93885 427
25	96.95166 667	96.96087 907	96.94986 667	96.93885 427

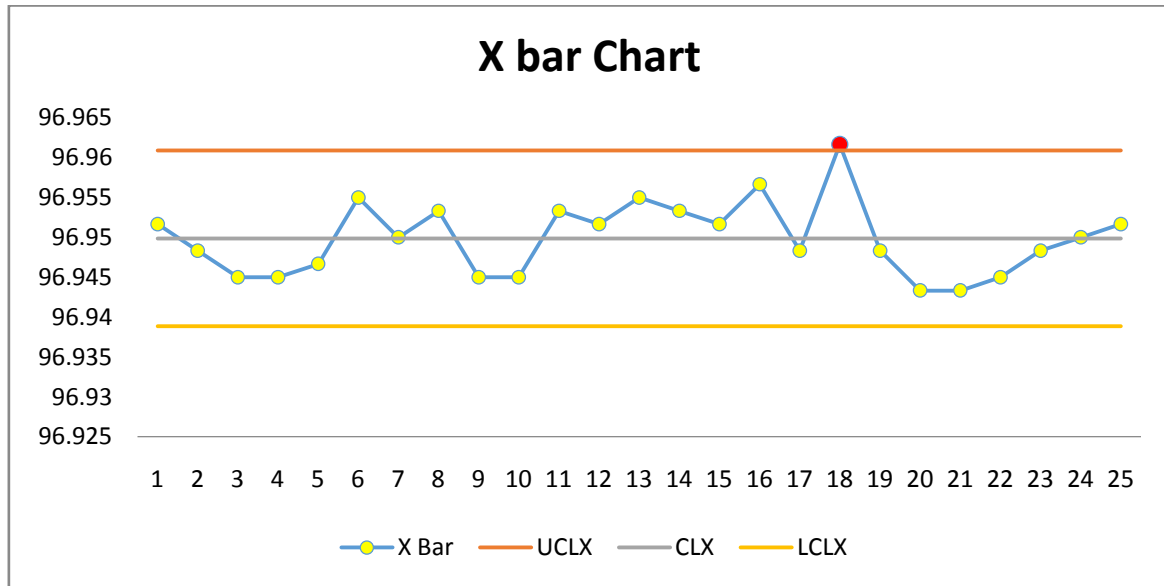


Fig. 2 – X Bar Chart

Process Capability

Formulas:-

$$\sigma' = \frac{\bar{R}}{D2} = \frac{0.0228}{2.534} = 0.009$$

$$3\sigma' = 3 * 0.009 = 0.02699$$

$$6\sigma' = 6 * 0.009 = 0.05399$$

Where,

σ' is standard Deviation.

Table 8 – limit table

USL (Upper Specification Limit)	Specification Limit	LSL (Lower Specification Limit)
96.96	95.00±0.01	96.94

$$cP = \frac{(USL - LSL)}{6\sigma'} = \frac{(96.96 - 96.94)}{0.05399} = 0.3704678$$

$$CpU = \frac{(USL - \bar{X})}{3\sigma'} = \frac{(96.96 - 96.9498667)}{0.02699} = 0.37541$$

$$CpL = \frac{(\bar{X} - LSL)}{3\sigma'} = \frac{(96.9498667 - 96.94)}{0.02699} = 0.36553$$

$$CpK = \text{Minimum}(CpU, CpL) = 0.36553$$

Where,

cP is Process Capability.

CpU is Upper Limit of Process Capability.

CpL is Lower Limit of Process Capability.

CpK is Process Capability Index.

Table 9 – Second Observation

Job No	Cylinder 1 (X1)	Cylinder 2 (X2)	Cylinder 3 (X3)	Cylinder 4 (X4)	Cylinder 5 (X5)	Cylinder 6 (X6)	\bar{X}	R
1	96.95	96.95	96.96	96.95	96.96	96.95	96.95333333	0.01
2	96.95	96.95	96.96	96.96	96.96	96.95	96.955	0.01
3	96.95	96.94	96.95	96.95	96.95	96.96	96.95	0.02
4	96.95	96.95	96.96	96.96	96.96	96.95	96.955	0.01
5	96.94	96.95	96.94	96.95	96.95	96.96	96.94833333	0.02
6	96.94	96.95	96.95	96.95	96.95	96.95	96.94833333	0.01
7	96.95	96.95	96.95	96.95	96.96	96.96	96.95333333	0.01
8	96.95	96.95	96.94	96.96	96.95	96.95	96.95	0.02
9	96.95	96.95	96.95	96.95	96.96	96.96	96.95333333	0.01
10	96.95	96.94	96.95	96.95	96.94	96.95	96.94666667	0.01
11	96.95	96.94	96.96	96.95	96.96	96.94	96.95	0.02
12	96.96	96.95	96.95	96.96	96.96	96.95	96.955	0.01
13	96.95	96.94	96.95	96.95	96.95	96.94	96.94666667	0.01
14	96.95	96.94	96.95	96.95	96.95	96.94	96.94666667	0.01
15	96.96	96.95	96.95	96.97	96.95	96.95	96.955	0.02
16	96.95	96.95	96.95	96.95	96.96	96.95	96.95166667	0.01
17	96.95	96.96	96.95	96.95	96.95	96.95	96.95166667	0.01
18	96.96	96.96	96.96	96.94	96.95	96.96	96.955	0.02
19	96.95	96.95	96.94	96.94	96.95	96.95	96.94666667	0.01
20	96.95	96.95	96.95	96.95	96.94	96.94	96.94666667	0.01
21	96.96	96.94	96.96	96.95	96.95	96.96	96.95333333	0.02
22	96.95	96.95	96.95	96.95	96.96	96.96	96.95333333	0.01
23	96.95	96.95	96.95	96.95	96.94	96.94	96.94666667	0.01
24	96.95	96.94	96.96	96.95	96.95	96.94	96.94833333	0.02
25	96.95	96.95	96.95	96.95	96.96	96.96	96.95333333	0.01

Formulas:-

$$\bar{X} = \frac{\sum X}{n}$$

Range R = (Max R – Min R)

Where,

\bar{X} is Average of Six cylinder (X).

R is Range of Six Cylinder (X).

n is Subgroup (6).

Table 10 - Example

Job No	Cylinder 1 (X1)	Cylinder 2 (X2)	Cylinder 3 (X3)	Cylinder 4 (X4)	Cylinder 5 (X5)	Cylinder 6 (X6)	\bar{X}	R
1	96.95	96.95	96.96	96.95	96.96	96.95	96.95333333	0.01
2	96.95	96.95	96.96	96.96	96.96	96.95	96.955	0.01

$$\bar{X} = \frac{96.95+96.95+96.96+96.94+96.96+96.95}{6} = 96.95333333$$

$$R = (96.96-96.95) = 0.01$$

Formulas:-

$$\bar{\bar{X}} = \frac{\sum \bar{X}}{n} = 96.95093333$$

$$\bar{R} = \frac{\sum R}{n} = 0.0132$$

Where,

$\bar{\bar{X}}$ is Average of Average for 25 Jobs.

\bar{R} is Average of Range for 25 Jobs.

n is 25.

Using Table 3 & 4 we get,

Where,

UCL_R is Upper Control Limit.

CL_R is Control Limit.

LCL_R is lower Control Limit.

\bar{R} is Average of Range.

Table 11 - R Chart

R Chart				
JOB No	R	UCL_R	CL_R	LCL_R
1	0.01	0.0264528	0.0132	0
2	0.01	0.0264528	0.0132	0
3	0.02	0.0264528	0.0132	0
4	0.01	0.0264528	0.0132	0

5	0.02	0.0264528	0.0132	0
6	0.01	0.0264528	0.0132	0
7	0.01	0.0264528	0.0132	0
8	0.02	0.0264528	0.0132	0
9	0.01	0.0264528	0.0132	0
10	0.01	0.0264528	0.0132	0
11	0.02	0.0264528	0.0132	0
12	0.01	0.0264528	0.0132	0
13	0.01	0.0264528	0.0132	0
14	0.01	0.0264528	0.0132	0
15	0.02	0.0264528	0.0132	0
16	0.01	0.0264528	0.0132	0
17	0.01	0.0264528	0.0132	0
18	0.02	0.0264528	0.0132	0
19	0.01	0.0264528	0.0132	0
20	0.01	0.0264528	0.0132	0
21	0.02	0.0264528	0.0132	0
22	0.01	0.0264528	0.0132	0
23	0.01	0.0264528	0.0132	0
24	0.02	0.0264528	0.0132	0
25	0.01	0.0264528	0.0132	0

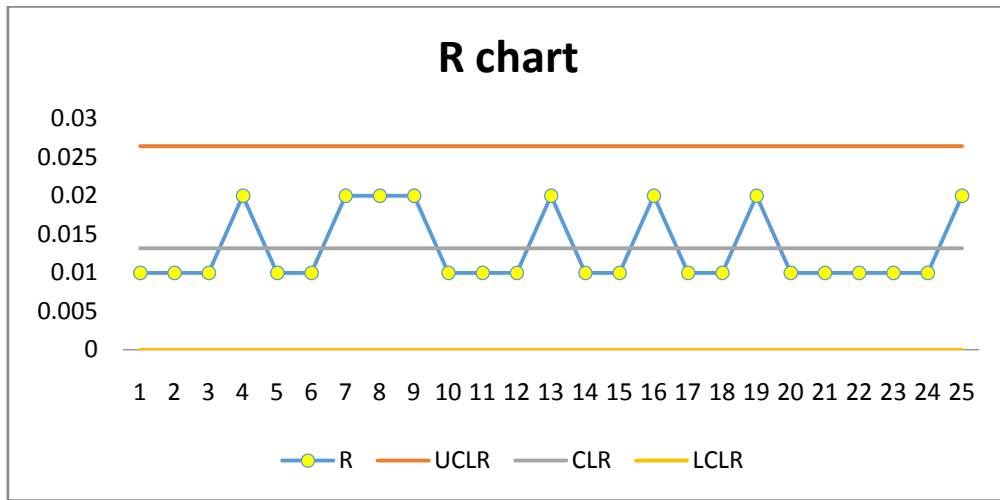


Fig. 3 R Chart

Using Table 4 & 6 we get,

Where,

UCL_X is Upper Control Limit.

CL_X is Control Limit.

LCL_X is lower Control Limit.

$\bar{\bar{X}}$ is Average of Average.

Table 12 – X Chart

X Chart				
JO B No	$\bar{\bar{X}}$	UCL_X	CL_X	LCL_X
1	96.953333	96.957308	96.950933	96.944557
2	96.955	96.957308	96.950933	96.944557
3	96.95	96.957308	96.950933	96.944557
4	96.955	96.957308	96.950933	96.944557
5	96.948333	96.957308	96.950933	96.944557
6	96.948333	96.957308	96.950933	96.944557
7	96.953333	96.957308	96.950933	96.944557
8	96.95	96.957308	96.950933	96.944557
9	96.953333	96.957308	96.950933	96.944557

10	96.946666	96.957308	96.950933	96.944557
11	96.95	96.957308	96.950933	96.944557
12	96.955	96.957308	96.950933	96.944557
13	96.946666	96.957308	96.950933	96.944557
14	96.946666	96.957308	96.950933	96.944557
15	96.955	96.957308	96.950933	96.944557
16	96.951666	96.957308	96.950933	96.944557
17	96.951666	96.957308	96.950933	96.944557
18	96.955	96.957308	96.950933	96.944557
19	96.946666	96.957308	96.950933	96.944557
20	96.946666	96.957308	96.950933	96.944557
21	96.953333	96.957308	96.950933	96.944557
22	96.953333	96.957308	96.950933	96.944557
23	96.946666	96.957308	96.950933	96.944557
24	96.948333	96.957308	96.950933	96.944557
25	96.953333	96.957308	96.950933	96.944557

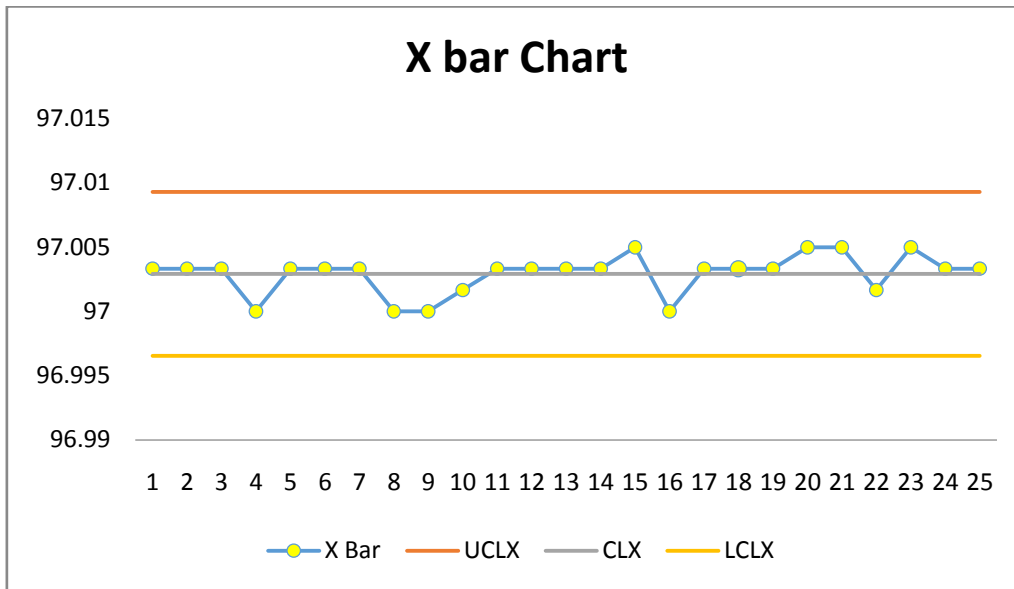


Fig. 4 X Bar Chart

Process Capability

Formulas:-

$$\sigma' = \frac{\bar{R}}{D2} = \frac{0.0132}{2.534} = 0.0052$$

$$3\sigma' = 3 * 0.0052 = 0.0156$$

$$6\sigma' = 6 * 0.0052 = 0.0312$$

Where,

σ' is standard Deviation.

Table 13 – Limit Table

USL (Upper Specification Limit)	Specification Limit	LSL (Lower Specification Limit)
96.96	95.00±0.01	96.94

$$C_p = \frac{(USL - LSL)}{6\sigma'} = \frac{(96.96 - 96.94)}{0.0312} = 0.6398$$

$$CpU = \frac{(USL - \bar{X})}{3\sigma'} = \frac{(96.96 - 96.95093333)}{0.0156} = 0.5802$$

$$CpL = \frac{(\bar{X} - LSL)}{3\sigma'} = \frac{(96.95093333 - 96.94)}{0.0156} = 0.6996$$

$$CpK = \text{Minimum} (CpU, CpL) = 0.5802$$

Where,

C_p is Process Capability.

CpU is Upper Limit of Process Capability.

CpL is Lower Limit of Process Capability.

CpK is Process Capability Index.

Conclusion

With any position, practically all the products manufactured will meet specification as long as the process stays in control.

IV. GAPS IN LITERATURE RESEARCH

The following are few research gaps in the research

- The methodologies used by different authors are difficult to understand and to apply.
- The simplified and precise methodology for training and application purpose was not available.
- There are many papers available in the field of six sigma but very few papers are available in the field of boring machine or boring operation & even based on X chart & R Charts.
- Very few papers explain basic application of six sigma.
- Comparative analysis is not done in most of the papers.










- The areas for future research can be summarized as Applications of Six Sigma in manufacturing & service sectors areas which are not explored yet with full potential, areas of Six Sigma enhancement and integration of Six Sigma with other quality initiatives, critical success factors for successful deployment of Six Sigma and Six Sigma implementation strategies.
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V. OBJECTIVE OF RESEARCH PAPER

- To study the concept of six sigma.
- To present simplified way of application of six sigma.
- To prepare a research paper on boring machine or boring operation.
- To prepare a paper in which X chart & R Charts application is explained
- To apply the concept of six sigma in case of automated assembly. Example, TATA Motor bus assembly.

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