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Improving Quality and Productivity in Manufacturing Process by using Quality Control Chart and Statistical Process Control Including Sampling and Six Sigma

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Keywords: statistical process control, control chart, tqm, 6-sigma, sampling, histogram, pareto diagram, cause and effect diagram, AQL, LTPD, process performance index, process potential index, process centering index.

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IMPROVINGQUALITYANDPRODUCTIVITYINMANUFACTURINGPROCESSBYUSINGQUALITYCONTROLCHARTANDSTATISTICALPROCESSCONTROLINCLUDING SAMPLINGANDSIXSIGMA

Strictly as per the compliance and regulations of:

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Ghazi Abu Taher [α] & Md. Jahangir Alam [σ]

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I. Introduction

The art of meeting customers' specification, which today is termed "quality". Quality is the symbol of human civilization, and with the progress of human civilization, quality control will play an incomparable role in the business. It can be said that if there is no quality control, there is no economic benefit. In the current world of continually increasing global competition it is imperative for all manufacturing and service organizations to improve the quality of their products. Construction projects are an extremely complex process, involving a wide range. There are plenty of factors affecting the quality of construction, such as design, materials, machinery, construction technology, methods of operation, technical measures, management systems, and so on. Because of the fixed project location, large volume and differen t location of different projects, the poor control of these factors may produce quality problems. During controlling the whole process of construction, only accord with the required quality standards and user promising requirements, fulfilling quality, time, cost, etc., construction companies could get the best economic effects. Construction companies must adhere to the principle of quality first, and insist on quality standards, with the core of artificial control and prevention, to provide more high quality, safe, suitable, and economic composite products.

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II. Objectives

The main purposes in accomplishing this study are shown below:

- To implement industrial engineering tools in selected manufacturing company.
- To identify the highest frequency of defects occurs at the workstations.
- To propose new methods to the selected manufacturing company.
- To improve the productivity of the company.

III. Quality Control

Because of the negative consequences of poor quality, organizations try to prevent and correct such problems through various approaches to quality control. Broadly speaking, quality control refers to an organization's efforts to prevent or correct defects in its goods or services or to improve them in some way. Some organizations use the term quality control to refer only to error detection, whereas quality assurance refers to both the prevention and the detection of quality problems. Organizations must have a department or employee devoted to identifying defects and promoting high quality. In these cases, the supervisor can benefit from the expertise of quality-control personnel. Ultimately, however, the organization expects its supervisors to take responsibility for the quality of work in their departments. In general, when supervisors look for high-quality performance to reinforce or improvements to make, they can focus on two areas: the product itself or the process of making and delivering the product.

a) Product Quality Control

An organization that focuses on ways to improve the product itself is using product quality control. Computer technology can greatly improve product quality control.

b) Process Control

An organization might also consider how to do things in a way that leads to better quality. This focus is called process control. The spur gear manufacturing company might conduct periodic checks to make sure its employees understand good techniques for setting up the machines. A broad approach to process control involves creating an organizational climate that encourages quality.

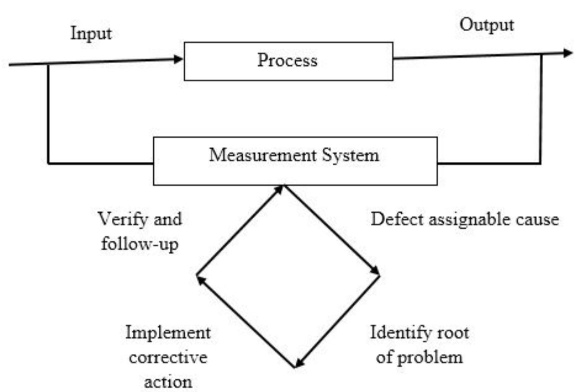


Figure 1 : Process improvement using the control chart

Process control techniques can be very effective. At Accurate Gauge and Manufacturing, process control is an important part of the company's efforts to plan for quality and correct the causes of defects in the precision parts it manufactures for heavy equipment and commercial and automotive vehicles. Quality teams meet weekly to prevent problems, but some process improvements are responses to problems. Even when a failure occurred in a product line the company was preparing to phase out, engineering manager led efforts to correct the process by setting up procedures for operators to check the parts were being produced. In addition to impressing the customer with this extreme commitment to quality, the effort established a process that became the standard procedure for making other defect-free parts.

IV. Consequences of Poor Quality

The consequences of poor quality are grave and of many folds in business term. Some are worth explaining [1]:

- Lower productivity.
- Loss of productive time.
- Loss of material.
- Loss of business.
- Liability.

V. Quality Improvement Methods

Within this broad framework, managers, researchers, and consultants have identified several methods for ensuring and improving quality. Today most organizations apply some or all of these methods, including statistical quality control, the zero-defects approach, employee involvement teams, Six Sigma, and total quality management.

a) Statistical Quality Control

It rarely makes economic sense to examine every part, finished good, or service to ensure it meets quality standards. For one thing, that approach to quality control is expensive. In addition, examining some products can destroy them. As a result, unless the costs of poor quality are so great that every product must be examined, most organizations inspect only a sample. Looking for defects in parts, finished goods, or other outcomes selected through a sampling technique is known as statistical quality control. The most accurate way to apply statistical quality control is to use a random sample. This means selecting outcomes (such as parts or customer contacts) in a way that each has an equal chance of being selected. The assumption is that the quality of the sample describes the quality of the entire lot [2].

b) Zero defect approach

A broad view of process quality control is that everyone in the organization should work toward the goal of delivering such high quality that all aspects of the organization's goods and services are free of problems. The quality-control technique based on this view is known as the zero-defects approach. An organization that uses the zero-defects approach provides products of excellent quality not only because the people who produce them are seeking ways to avoid defects but also because the purchasing department is ensuring a timely supply of well-crafted parts or supplies, the accounting department is seeing that bills get paid on time, the human resources department is helping find and train highly qualified personnel, and so on [2].

c) Employee Involvement Teams

Recognizing that the people who perform a process have knowledge based on their experiences, many organizations directly involve employees in planning how to improve quality. Many companies set up employee involvement teams such as quality circles, problem-solving teams, process improvement teams, or self-managed work groups. The typical employee involvement team consists of up to 10 employees and their supervisor, who serves as the team leader. In this role, the supervisor schedules meetings, prepares agendas, and promotes the participation and cooperation of team members.

d) Six Sigma

Applying the terminology and methods of statistical quality control and the strong commitment of the zero-defects approach, manufacturers and other companies have used a quality-control method they call Six Sigma. This is a process oriented quality-control method designed to reduce errors to 3.4 defects per 1 million operations, which can be defined as any unit of work, such as an hour of labor, completion of a circuit board, a sales transaction, or a keystroke. (Sigma is a statistical term defining how much variation there is in a product. In the context of quality control, to achieve a level of six sigma, the output of operations would be 99.9997 percent perfect.) Along with the basic goal of reducing variation from the standard to almost nothing, Six Sigma programs typically include a rigorous analytical process for anticipating and solving problems to reduce defects, improve the yield of acceptable products, increase customer satisfaction, and deliver best-in-class organizational performance [1].

e) Total Quality Management

Bringing together aspects of other quality-control techniques, many organizations have embraced the practice of total quality management (TQM), an organization- wide focus on satisfying customers by continuously improving every business process for delivering goods or services. Thus, it is not a final outcome but an ongoing commitment by everyone in the organization. Today most companies accept the basic idea of TQM that everyone in the organization should focus on quality [1].

VI. Quality Control Plans

As with the other responsibilities of supervisors, success in quality control requires more than just picking the right technique. The supervisor needs a general approach that leads everyone involved to support the effort to improve quality.

a) Prevention versus Detection

It is almost always cheaper to prevent problems from occurring than it is to solve them after they happen; designing and building quality into a product is more efficient than trying to improve the product later. Therefore, quality-control programs should not be limited to the detection of defects. Quality control also should include a prevention program to keep defects from occurring. One way to prevent problems is to pay special attention to the production of new goods and services. In a manufacturing setting, the supervisor should see that the first piece of a new product is tested with special care, rather than wait for problems to occur down the line. Also, when prevention efforts show that employees are doing good work, the supervisor should praise their performance. Employees who are confident and satisfied are less likely to allow defects in goods or services.

b) Standard Setting and Enforcement

If employees and others are to support the quality-control effort, they must know exactly what is expected of them. This calls for quality standards. In many cases, the supervisor is responsible for setting quality standards as well as for communicating and enforcing them. These standards should have the characteristics of effective objectives: They should be written, measurable, clear, specific, and challenging but achievable. Furthermore, those standards should reflect what is important to the client.

c) Using Control Chart

Control chart is the most populated quality tool. The main reasons of their popularity are [2]:

i. A proven technique for improving productivity.
ii. Effective in defect prevention.
iii. Prevent unnecessary process adjustment.
iv. Provide diagnostic information.
v. Provide information about process capability.
vi. Problem Statement

A spur gear manufacturing company in Khulna wants to test their quality and productivity and wants to find the most effective way of their quality testing.

Figure 2 : A spur gear

The following procedure of quality testing and improving productivity is given below:

VII. Seven basic Tools of TQM used in Industry

If a product is to meet customer requirements, generally it should be produced by a process that is stable or repeatable. More precisely, the process must be capable of operating with little variability around the target or nominal dimensions of the product's quality characteristics. Statistical process control (SPC) is a powerful collection of problem solving tools useful in achieving process stability and improving capability through the reduction of variability.

SPC can be applied to any process. Its seven major tools are [2]:

1) Histogram.
2) Check sheet.
3) Pareto chart.
4) Cause and effect diagram.
5) Defect concentration diagram.
6) Scatter diagram.
7) Control chart.

These tools are called "the magnificent seven". SPC builds an environment in which it is the desire of all individuals in an organization for continuous improve-ement in quality and productivity. This environment is best developed when management becomes involved in an ongoing quality improvement process. Once this environment is established, routine application of the magnificent seven becomes part of the usual manner of doing business, and the organization is well on its way to achieving its quality improvement objectives.

The mostly used quality tools are described below for spur gear manufacturing industry:

a) Cause and Effect Diagram

Cause-Effect (CE) analysis is a tool for analyzing and illustrating a process by showing the main cause and sub-causes leading to an effect (symptom). It is sometimes referred to as the "fishbone diagram" because the complete diagram resembles a fish skeleton. The fishbone is easy to construct and interactive participation [1].

Once a defect, error, or problem has been identified and isolated for further study, we must begin to analyze potential causes of this undesirable effect. In situation where causes are not obvious, the cause and effect diagram is a formal tool frequently useful in unlayering potential causes.

The cause and effect diagram constructed to identify potential problem areas in the spur gear manufacturing process mentioned in the following figure:

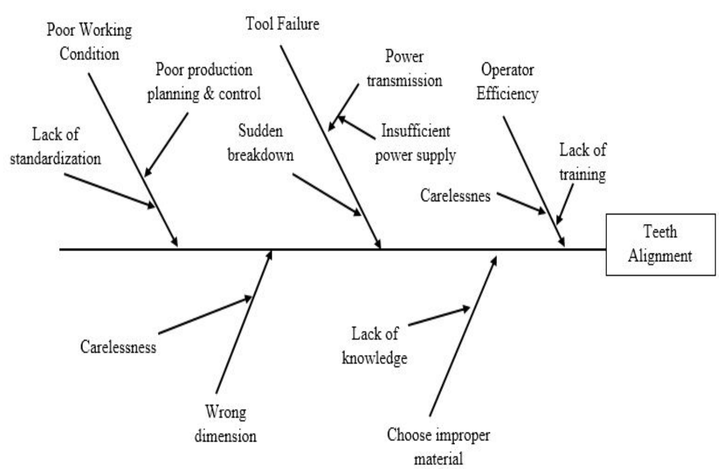


Figure 3 : Cause and effect diagram of spur gear defect problem for teeth alignment

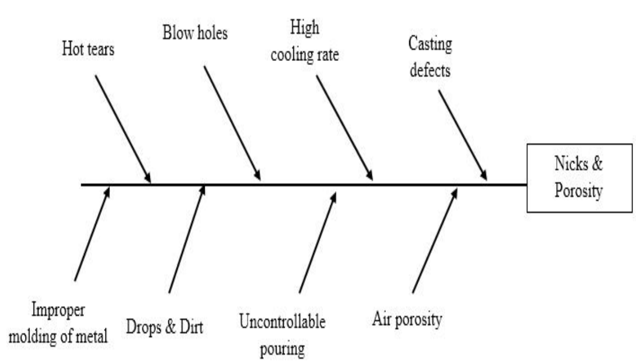


Figure 4 : Cause and effect diagram of spur gear defect problem for nicks and porosity.

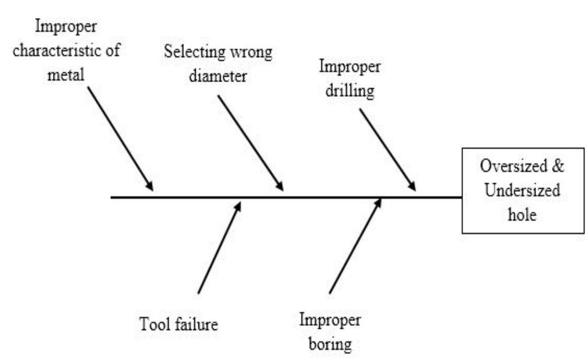


Figure 5 : Cause and effect diagram of spur gear defect problem for oversized and undersized hole.

In analyzing the spur gear defect problem, we elected to lay out the major categories of spur gear defects as man, machine, material, methods, measurement and environment. We got some effect such as teeth alignment, nicks and porosity, undersized and oversized hole and their causes. A brainstorming session ensured to identify the various sub-causes in each of these major categories and to prepare the diagram in Figure 3, Figure 4 and Figure 5. Then through discussion and the process elimination, we decided that materials and methods contained the most likely cause categories.

Cause and effect diagram analysis is an extremely powerful tool. A highly detailed cause and effect diagram can serve as an effective trouble-shooting aid. Furthermore, the construction of a cause and effect diagram as a team experience tends to get people involved in attacking a problem rather than in affixing blame.

b) Pareto Chart

The Pareto principle states that it is possible for many performance measure, such as scarp, machine failure, vendor's problems, and inventory cost and product development time, to separate the vital few causes resulting in unacceptable performance from the trivial many causes. Historically, this concept has also known as the 80/20 rule, which states that the performance measure can be improved 80% by eliminating only 20% of the causes of unacceptable performance [1].

This rules has been applied to a wide range of performance measures:

- Customer complaints
- Warranty repair and cost
- Quality defects
- Rework
- Machine downtime
- Material utilization
- Time utilization
- Energy use
- Product development time

i. *Choosing Pareto chart*

- When analyzing data about the frequency of problems or causes in a process is required.
- When there are many problems or causes and the quality analyst wants to focus on the most significant.
- When analyzing broad causes by looking at their specific components.
- When analyzing the characteristics of the shop or production process.

ii. *Data collection for Pareto chart:*

Identification of the vital few items from the Pareto principle is most easily conveyed using a Pareto diagram. We consider following defects for a spur gear machined part:

Table 1 : Data for Pareto analysis

Defect	Quantity
Undersized hole	224
Nicks	149
Teeth alignment	58
Porosity	52
Diameter	46
Oversized hole	5
Other	23
TOTAL	557

It is apparent that from this short list that under sized a holes are the main problem. However, real applications typically have many defects categories and many parts, all of which monitored over time. It is convenient to represent these data graphically as in (Figure 6). This graph has been prepared using the work sheet in (Table 2). The defects are arranged in rank order in column-1. The number of defects appears in column-2. The percentages that each defects represents of the total number of defects appears in column-3. The cumulative percentage of column-3 appear in column-4. One difficulty in collecting data by such categories as under size, nicks and oversize is that a particular part or item being evaluated may fit into several categories. In this case the preferred approach is to mark each defects. In (Figure 6) all defects are shown graphically to find out a most effective defect over these defects.

Table 2 : Example Pareto analysis worksheet

Column-1	Column-2	Column-3	Column-4
Defect	No of defects	% Composition	Cumulative %
Undersized hole	224	224/557 = 40	40
Nicks	149	149/557 = 27	67
Teeth alignment	58	58/557 = 11	78
Porosity	52	52/557 = 9	87
Diameter	46	46/557 = 8	95
Oversized hole	5	5/557 = 1	96
Other	23	23/557 = 4	100
TOTAL	557		100

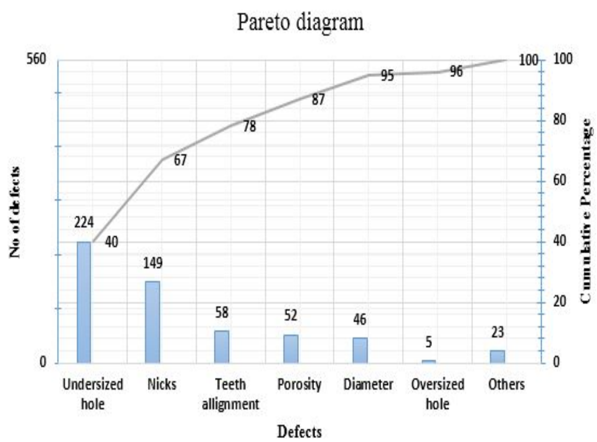


Figure 6 : Typical Pareto diagram for spur gear

c) *Histogram*

A histogram is the most commonly used graph to show frequency distributions and its pattern and shape. The shape determines its statistical nature of the collected data sets. It looks very much like a bar chart, but there are important differences between them.

Table 3 : Observation data of spur gear diameter

Sample No	Observations			
	1	2	3	4
1	4.9	4.8	5.1	5.4
2	5.0	5.8	5.3	5.3
3	4.4	4.7	4.8	4.6
4	4.6	5.8	5.4	4.9
5	5.2	5.3	6.1	5.2
6	5.0	5.9	5.8	4.8
7	4.3	4.6	4.7	4.5
8	4.9	4.9	5.5	5.7
9	5.9	6.4	6.1	6.5
10	5.3	5.9	6.1	4.8
11	4.6	4.6	5.3	5.0
12	5.3	5.8	5.4	5.1
13	4.9	5.3	5.2	5.7
14	5.2	5.4	4.6	5.5
15	5.4	4.8	4.4	5.1
16	4.6	4.4	4.9	5.1
17	5.7	5.4	5.0	4.8
18	5.1	4.3	5.7	5.8
19	5.9	6.4	6.2	6.1
20	5.0	5.1	4.5	4.8
21	4.9	5.9	5.3	5.2
22	5.4	5.9	4.4	5.0
23	5.2	4.7	5.7	5.8
24	4.0	4.8	5.1	5.8
25	5.3	5.8	6.0	6.3

Table 3 represents 100 observations on the diameter of spur gear used in lathe machine. The data were collected in 25 samples of four observations each. Notice that there is some variability in spur gear diameter. However, it is very difficult to see any pattern in the variability or structure in the data, with the observations arranged as they are in Table 3.

Table 4 : Frequency distribution for spur gear diameter

Diameter range, x (inch)	Tally	Frequency	Cumulative Frequency	Relative Frequency	Cumulative Relative frequency
3.75-4.25	I	1	1	0.01	0.01
4.25-4.75	IIII IIII IIII IIII II	18	19	0.18	0.19
4.75-5.25	IIII IIII IIII IIII IIII IIII IIII IIII II	34	53	0.34	0.53
5.25-5.75	IIII IIII IIII IIII IIII III	23	76	0.23	0.76
5.75-6.25	IIII IIII IIII IIII IIII	20	96	0.20	0.96
6.25-6.75	IIII	4	100	0.04	1.00
TOTAL		100		1.00	

A frequency distribution is an arrangement of the data by magnitude. It is a more compact summary of data than a stem-and-leaf display. For example, a frequency distribution of the spur gear data is shown in Table 4. From this table we note that there was one gear that had a diameter between 3.75 inch and 4.25 inch, eighteen gears having diameters between 4.25 inch and 4.75 inch, and so forth.

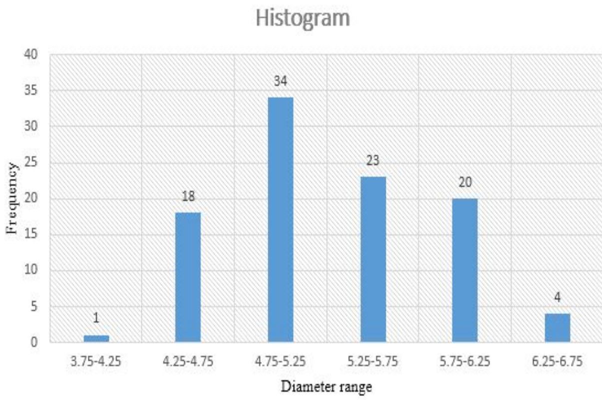


Figure 7 : Histogram for spur gear diameter data

A graph of the observed frequencies versus the spur gear diameter is shown in Figure 7. This display is called histogram. The height of each bar in Figure 7 is equal to the frequency of occurrence of spur gear diameter. The histogram represents a visual display of the data in which one may more easily see three properties [2]:

i. Shape.
ii. Location, or central tendency.
iii. Scatter, or spread.

In the spur gear diameter data, the distribution of gear diameter is roughly symmetric with skewed distribution tendency very close to 5.25 inch. The variability in gear diameter is apparently relatively high, as some gears are as small as 4.00 inch, while others are as large as 6.50 inch. Thus, the histogram give some insight into the process that inspection of the raw data in Table 3 does not.

d) Control Chart

Control chart is the seventh and most effective tool of Total Quality Management (TQM). This chart displays of a quality characteristic that has been measured or computed from a sample versus the sample number or time. The chart contains a center line that represents the average value of the quality characteristic corresponding to the in-control state (That is, only chance causes are present). Two other horizontal lines, called the upper control limit (UCL) and the lower control limit (LCL). These control limits are chosen so that if the process is in control, nearly all the sample points will fall between them. As long as the points plot within the control limits, the process is assumed to be in control and no action is necessary. However, a point that plots outside of the control limits is interpreted as evidence that the process is out of control, and investigation and corrective action are required to find and eliminate the assignable cause or causes responsible for this behavior. It is customary to connect the sample points on the control chart with straight-line segments so that it is easier to visualize how the sequence of points has evolved over time. Different types of control charts can be used depending upon the type of data. The two broadest groupings are:

i. Variable chart.
ii. Attribute chart.

i. *Variable Chart:*

Variable data are measured on a continuous scale in variable chart. For example: time, weight, distance or temperature can be measured in fraction or decimals. The possibility of measuring to greater precision defines variable data [1].

Based on mean (μ) and deviation (σ), commonly used variable charts are:

a. $\bar{X} - R$ Chart.
b. $\bar{X} - S$ Chart.
c. Moving Range (MR) Chart.
d. Cumulative Sum (CUSUM) Chart.
e. Exponentially Weighted Moving Average (EWMA) Chart.

$\bar{X} - R$ Chart is applicable when the sample size (n) is between 2 to 10 and $\bar{X} - s$ chart is applicable when the sample size is more than 10. For spur gear problem the sample size is 4. So, here $\bar{X} - R$ chart is used to obtain the quality limit of spur gear diameter.

a. *The $\bar{X} - R$ Chart*

A quality characteristic is normally distributed with mean μ and standard deviationσ, where both μ and σ are known. If $x_1, x_2,\ x_3,\ldots\ldots\ldots\ldots x_n$ is a sample of size n, then the average of this sample is [1],

$$\bar{x} = \frac{x_1 + x_2 + \cdots \ldots \ldots \ldots . + x_n}{n}$$

and we know that $\bar{x}$ is normally distributed with μ and standard deviation $\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$. Furthermore, the probability is 1-α that any sample mean will fall between

$$\mu + Z_{\alpha/2}\sigma_{\bar{x}} = \mu + Z_{\alpha/2}\frac{\sigma}{\sqrt{n}}$$

and $\mu - Z_{\frac{\alpha}{2}}\sigma_{\bar{x}} = \mu - Z_{\alpha/2}\frac{\sigma}{\sqrt{n}}$

If $x_1, x_2,\ x_3,\ldots\ldots\ldots\ldots x_n$ is a sample of size n, then the range of this sample is the difference between the largest and the smallest observations and that is, R = $x_{max} - x_{min}$

Let R_1, R_2,……..R_m be the ranges of the m samples. The average range is [1],

$$\bar{R} = \frac{R_1 + R_2 + \cdots \ldots \ldots \ldots . + R_m}{m}$$

- Control limits for the $\bar{x}$ chart
- Upper Control Limit, UCL = $\bar{\bar{x}} + A_2\bar{R}$
- Center Line, CL = $\bar{\bar{x}}$
- Lower Control Limit, LCL = $\bar{\bar{x}} - A_2\bar{R}$
- Control limit for R chart

- Upper Control Limit, UCL = $D_4\bar{R}$
- Center Line, CL = $\bar{R}$
- Lower Control Limit, LCL = $D_3\bar{R}$

- *Data collection for $\bar{X} - R$ chart*

The diameter of the gear of a spur gear manufacturing company was monitored. During the base period 25 samples are observed the sample size is 4. The measurements of individual diameters are as follows:

Table 5 : Data for $\bar{X} - R$ chart of spur gear diameter

Sample No	Sample Size				$\bar{x}$	R
	1	2	3	4		$(x_{max} - x_{min})$
1	4.9	4.8	5.1	5.4	5.05	0.6
2	5.0	5.8	5.3	5.3	5.35	0.8
3	4.4	4.7	4.8	4.6	4.63	0.4
4	4.6	5.8	5.4	4.9	5.18	1.2
5	5.2	5.3	6.1	5.2	5.45	0.9
6	5.0	5.9	5.8	4.8	5.38	1.1
7	4.3	4.6	4.7	4.5	4.53	0.4
8	4.9	4.9	5.5	5.7	5.25	0.8
9	5.9	6.4	6.1	6.5	6.22	0.6
10	5.3	5.9	6.1	4.8	5.53	1.3
11	4.6	4.6	5.3	5.0	4.88	0.7
12	5.3	5.8	5.4	5.1	5.40	0.7
13	4.9	5.3	5.2	5.7	5.23	0.8
14	5.2	5.4	4.6	5.5	5.18	0.9
15	5.4	4.8	4.4	5.1	4.93	1.0
16	4.6	4.4	4.9	5.1	4.75	0.7
17	5.7	5.4	5.0	4.8	5.23	0.9
18	5.1	4.3	5.7	5.8	5.23	1.5
19	5.9	6.4	6.2	6.1	6.15	0.5
20	5.0	5.1	4.5	4.8	4.85	0.6
21	4.9	5.9	5.3	5.2	5.33	1.0
22	5.4	5.9	4.4	5.0	5.12	1.5
23	5.2	4.7	5.7	5.8	5.35	1.1
24	4.0	4.8	5.1	5.8	4.93	1.8
25	5.3	5.8	6.0	6.3	5.85	1.0
					$\bar{\bar{x}} = 5.241$	$\bar{R} = 0.912$

After observing and calculating the following data we found that,

- *Control limits for the $\bar{x}$ chart*

Upper Control Limit, UCL = $\bar{\bar{x}} + A_2\bar{R}$

= 5.241 + 0.483 × 0.912 = 5.682

Center Line, CL = $\bar{\bar{x}}$ = 5.241

Lower Control Limit, LCL = $\bar{\bar{x}} - A_2\bar{R}$

= 5.241 - 0.483 × 0.912 = 4.800

- *Control limit for R chart*

Upper Control Limit, UCL = $D_4\bar{R}$

= 2.004 × 0.912 = 1.828

Center Line, CL = $\bar{R}$ = 0.912

Lower Control Limit, LCL = $D_3\bar{R}$ = 0 × 0.912 = 0

Where, (for sample size 4)

A_2 = 0.483

D_3 = 0

D_4 = 2.004

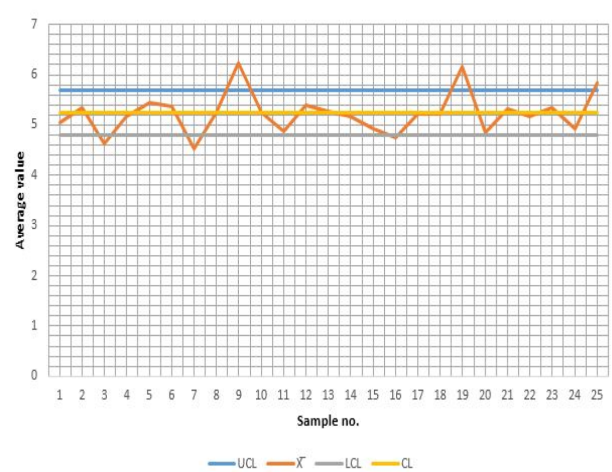


Figure 8 : Average-Control chart for spur gear diameter

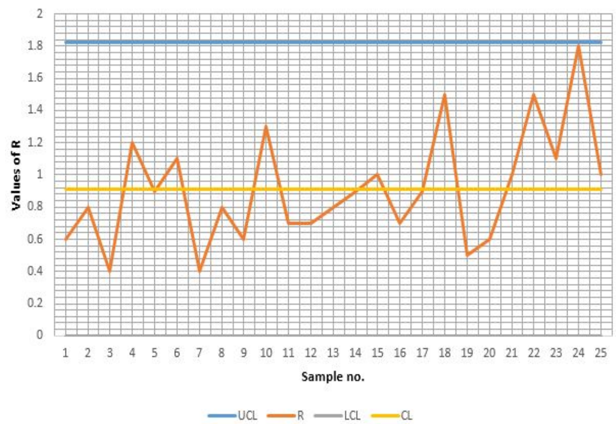


Figure 9 : Range-Control chart for spur gear diameter.

ii. *Attribute Chart*

This type of control chart is applicable equally to manufacturing and service organizations. In a manufacturing organization, manufacturing time and quality may be accepted as good or bad. Attributed data are counted and cannot have fractions or decimals. Attributed data arise when to determine only the presence or absence of something, success or failure, accept or reject, correct or not correct.

There are many types of attribute control charts. The most commonly used ones are-

a. P chart (proportion non-conforming)
b. np chart (number non-conforming)
c. c chart (count chart)
d. u chart.
e. *P Chart*

P chart is the most commonly used attribute control chart. There are companies which use hundreds of such P charts to measure hundreds of quality characteristics of attribute type.

- *Control limit for p chart*

Upper Control Limit, UCL $= \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$

Center Line, CL $= \bar{p}$

Lower Control Limit, LCL $= \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$

Where,

$\bar{p}$ = fraction non-conforming

1- $\bar{p}$ = fraction conforming

Table 6 : Number and fraction defective (non-conforming)

Sample No.	No. of failures, (d_i)	Fraction nonconforming
1	2	0.05
2	0	0
3	4	0.10
4	2	0.05
5	0	0
6	1	0.025
7	4	0.10
8	2	0.05
9	3	0.075
10	2	0.05
11	2	0.05
12	0	0
13	1	0.025
14	1	0.025
15	2	0.05
16	3	0.075
17	1	0.025
18	1	0.025
19	3	0.075
20	2	0.05
21	1	0.025
22	1	0.025
23	1	0.025
24	2	0.05
25	1	0.025
TOTAL	42	1.05

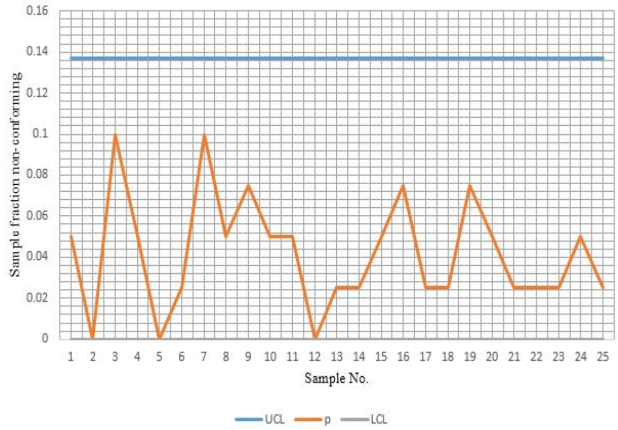


Figure 10 : Control chart (p-type) for the data set of Table 6

VIII. Process Capability Analysis

a) *Measurement of process capability analysis*

Measurement of process capability analysis basically means quantification of the capability of a stable process to produce parts within the specification limits.

These are:

- C_P = Process Potential Index
- C_{PK} = Process Performance Index
- CPU = Upper Process Performance Index
- CPL = Lower Process Performance Index
- K = Process Centering Index

b) *Basic concepts of process capability*

Process capability is a statistical analysis tool. It requires collecting data from the process, constructing a histogram, drawing a curve that fits in the histogram, and then finally finding out what percentages of data goes outside the upper specification limit (USL) and lower specification limit (LSL). For any part, upper specification limit, lower specification limit and allowable process spread are of two important concern. Traditionally, a process is called "capable" if the process spread 6σ is equal to the width of the specification limit (Figure 11).

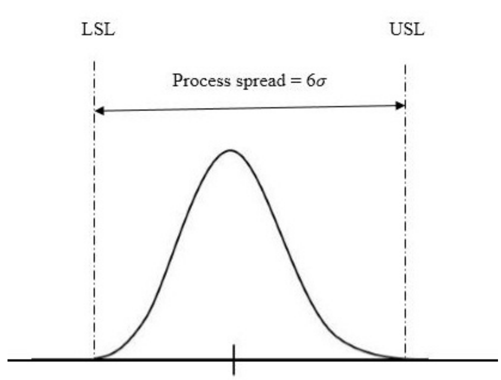


Figure 11 : Concept of process capability

There are three ways in which a process can be judge not capable:-

- The process is not stable
- The process is centered too close to a specification limit (Figure 12)
- The process variability is excessive (Figure 13)

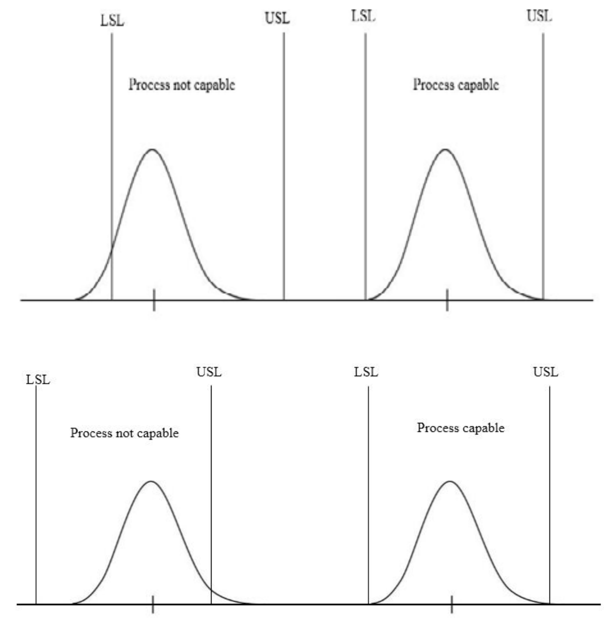


Figure 12 : Influence of location on process capability

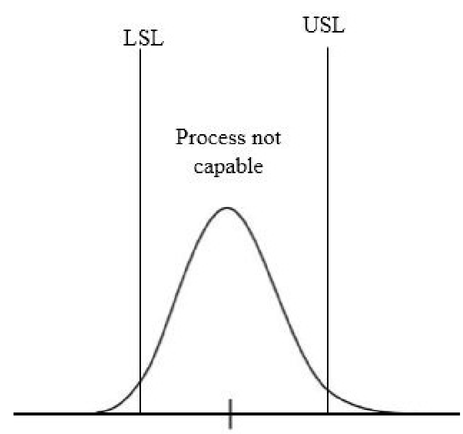


Figure 13 : Influence of variability on process capability

c) *Process Potential Index, C_P*

The potential of a stable process to be capable depends only on the variability of the process. A simple method of evaluating this potential is to relate the actual process spread (6σ) to the allowable process spread (USL- LSL).

C_P = allowable process spread / actual process spread = (USL-LSL) / 6σ

Values of C_P greater than 1 imply a desirable process in which the actual spread is less than the allowable spread (Fig-4). It is generally believed that a minimum C_P of 1.33 is required for most manufacturing process.

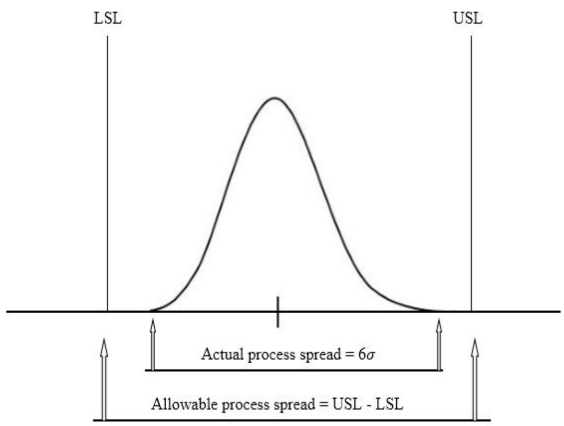


Figure 14 : Relationship of C_p parameters

- The values of C_P with respect to (σ) which is shown below (Table 7):

Table 7 : Value of Cp

	2σ	3σ	4σ	5σ	6σ
C_p	0.67	1.0	1.33	1.67	2.0

- Typical process spread diagram with respect to C_P value which is shown below (Figure 15):

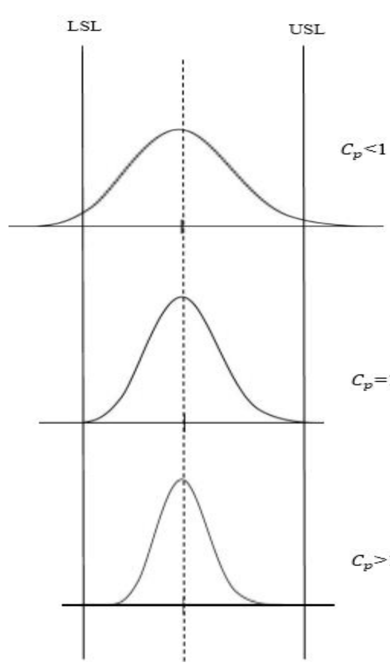


Figure 15 : Typical process spread diagram with respect to C_P

d) Process Performance Index

The performance of a process must relate the process potential to the location, measured by$\bar{X}$. We can relate the actual process spread to the allowable spread for a process with only an upper specification limit.

Actual upper process spread = 1/2 * actual process spread =1/2 * 6σ = 3σ

Allowable upper process spread = USL- $\bar{X}$

Upper process performance index (CPU) = (USL-$\bar{X}$) / 3σ

Lower process performance index (CPL) = ($\bar{X}$-LSL) / 3σ

Hence process performance index (C_{PK}) = minimum (CPL, CPU)

- The values of C_{PK} with respect to (σ) which is shown in Table 8.

Table 8 : Value of Cpk

	2σ	3σ	4σ	5σ	6σ
C_{pk}	-0.17	0.5	0.83	1.17	1.5

- Typical process spread diagram with respect to C_{PK} value which is shown in Figure 16:

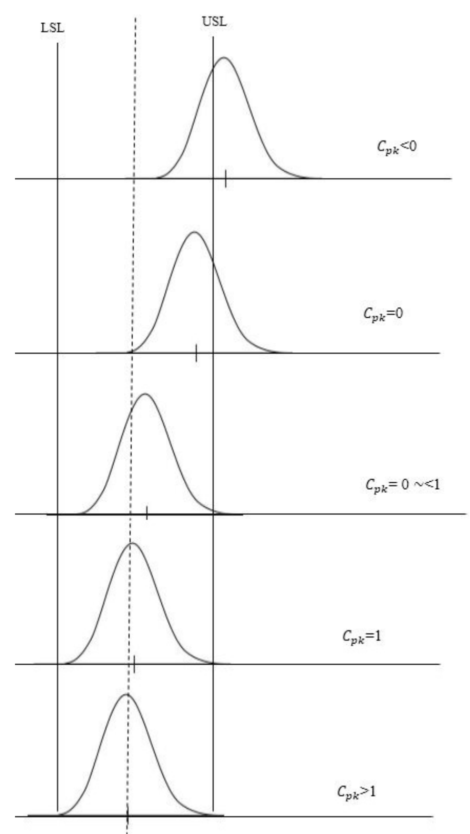


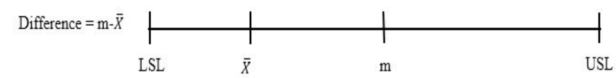
Figure 16 : Typical process spread diagram with respect to C_{PK}

e) Process Centering Index

Another equivalent approach for obtaining C_{PK} allows relating the process potential C_P to the process performance index $C_{PK.}$ Consider the midpoint of the specification limit,

$$m = (USL+LSL) / 2$$

If the process is exactly centered, $\bar{X}$ = m and there are the possible parts beyond the specification limits. The distance between the m and $\bar{X}$ can be computed by the difference.



This difference can be related to one half the allowable spread, as with CPU, CPL, to form a centering index (Process Centering Index):

$$K = \frac{\text{Distance of process mean from midpoint of the specification limit}}{\frac{1}{2} * \text{allowable process spread}}$$

$$= \frac{2|m-\bar{X}|}{USL-LSL}$$

The values of C_{PK} and C_P are related: $C_{PK} = C_P$ (1-K).

For stable process, if the process spread is sufficiently narrow (C_P> 1.33) and process mean sufficiently Close to the nominal value (C_{PK}>1.33), process is capable, though possibility and scope For further improvement may be investigated and if not, the process through common causes should be improved. If the process is not stable then special causes should be eliminated.

- *Data collection for process capability analysis*

A manufacturing company wants to monitor the diameter of the spur gear. During the base period 25 samples are observed the sample sizes is 4. If USL = 6.5 inch and LSL= 3.5 inch and the measurements of individual diameter are as follows:
From Table-5,

$$\text{Range value } \bar{R} = 0.912$$

$$\text{Now } \sigma = \frac{R}{d_2} = \frac{0.912}{2.059} = 0.4429$$

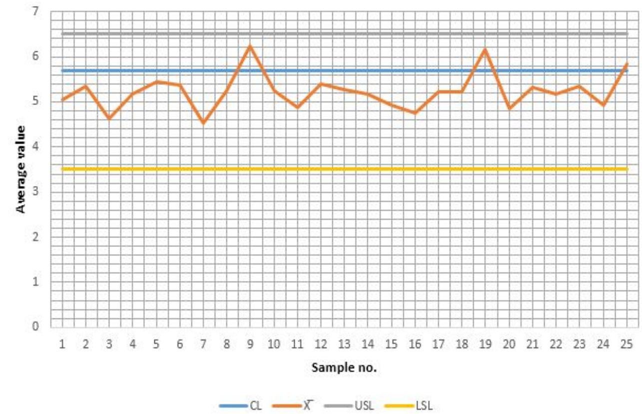


Figure 17 : Average-Control chart for spur gear diameter

- *Calculating C_P and C_{PK}*

$$m = \frac{USL+LSL}{2} = 5$$

$$K = \frac{2|m-\bar{X}|}{USL-LSL} = 0.16$$

$$C_P = \frac{USL-LSL}{6\sigma} = 1.13$$

$$C_{PK} = C_P\,(1\text{-}K) = 0.94$$

Since the process is within the specification limit and C_P > 1, hence the process is capable. And C_P may not be equal to zero and C_{PK} is always less than or equal to $C_{P.}$

f) Variation in process

Two types of causes are responsible for variation in a process. These are:

i. Chance cause or common cause:

Variation because of this type of causes are quite natural and very difficult to control fully. Temperature, environment, noise, vibration are some examples of common causes [1].

ii. Assignable cause:

Variation from this type of causes are identifiable and may be significant for product or service quality. Assignable causes occur due to machines, tools and operator and for ineffective operation [1].

The above tables and figures shown that the random variation occurred due to only chance cause or common causes.

g) Errors in control chart

Two types of error occur in quality control chart. Type-I error occurs when a sample value falls outside the control limit when the process is still in control. The type-II error occurs when a sample value falls within the control limits while the process is actually out of control. This type of wrong signaling happens because of sampling errors [1].

Table 9 : Summary of errors in sampling for control chart

God's view (Process reality)			
		Process in control	Process out of control
Results from sample	Process in control	Right signal	Type-II error (Failure to detect)
	Process out of control	Type-I error (False signal)	Right signal

IX. Acceptance Sampling

Acceptance sampling is concerned with inspection and decision making regarding products one of the oldest aspects of quality assurance. It is represented by operating characteristic curve. It is related to sampling plan such as AQL (Acceptable Quality Level) and LTPD (Lot Tolerance Percent Defective). AQL can be considered as a person defective that is the base line requirement for the quality of the producer product whereas LTPD is a designated defect level for a lot beyond which the lot is unacceptable to the consumer. An attribute sampling is done for spur gear manufacturing company.

- *Data collection for acceptance sampling*

A batch of 1000 products are manufactured by a spur gear manufacturing company. An agreement between the producer and the customer specified by the following:

Batch size, N = 1000 where sample size, n = 40. Acceptance number, c = 2 (from Nomo-graph).

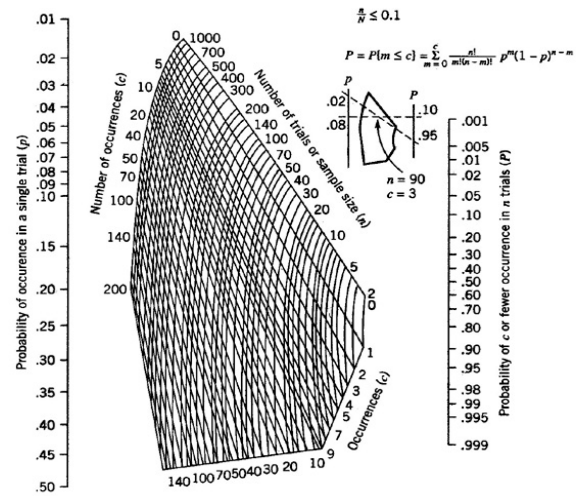


Figure 13-9 Binomial nomograph.

Figure 18 : Nomo graph

From Nomo-graph,

n = 40 and c=2 with respect to $P_1 = 0.05$, $P_2 = 0.15$, $\alpha = 0.05$, $1-\alpha = 0.95$, $\beta = 0.20$.

Table 10 : Probability of acceptance value

Fraction nonconforming, p	Probability of acceptance, p_a
0.01	0.9925
0.03	0.8821
0.05	0.6767
0.07	0.4625
0.09	0.2894
0.10	0.2281
0.11	0.1688
0.13	0.0929
0.15	0.0485

a) *Operating Characteristics curve*

It shows the characteristics of a production process in terms of statistical reasoning. Typical example of OC curve is shown (Figure 19). From OC curve, only type-I error is present.

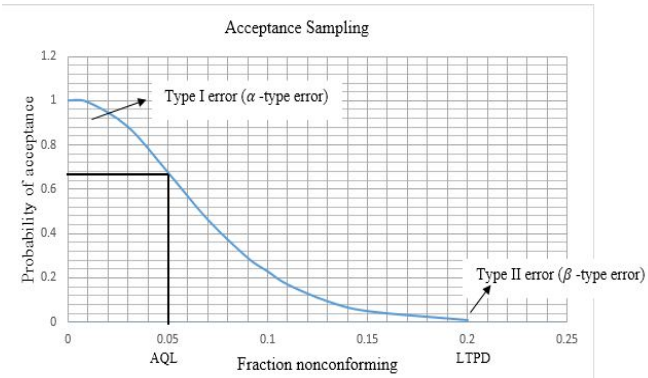


Figure 19 : Operating characteristic (OC) curve for acceptance sampling of spur gear diameter

b) *Hypothesis testing*

- *Basic concept of hypothesis testing*

This test is used to test whether a target value is achieved or not. The two sided hypothesis testing are

$$H_0 = \mu$$

$$H_1 = \mu$$

Since the hypothesis testing is based on sample data, there is always a chance of committing an error. Two types of error may be committed while testing hypothesis are:

1. If the null hypothesis is rejected (erroneously because of sampling limitations) when it is actually true, then a type-I error occurs. It is also called producer risk and α type error.
2. If the null hypothesis is not rejected, when it is false then a type-II error occurs. It is also called consumer risk and β type error. Type-II error is more serious than type-I error.

Thus, α = p {type-1 error} = p {reject $H_0 \mid H_0$ is true}

β = p {type-2 error} = p {accept $H_0 \mid H_0$ is false}

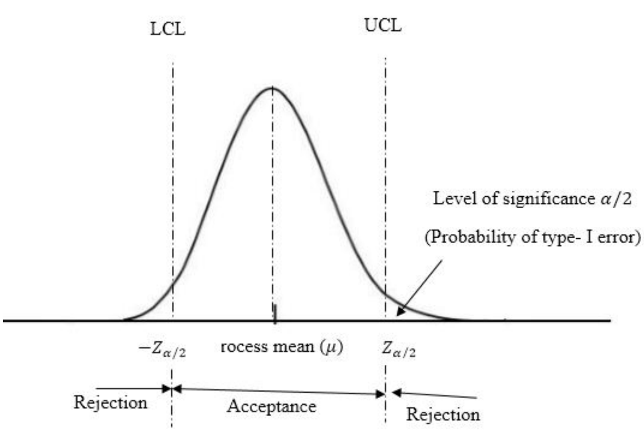


Figure 20 : Probability of type-I error [1]

c) *Case study*

A manufacturing company producing spur gear with mean diameter of the spur gear are 4.9 inch. The standard deviation of diameter of spur gear are 0.4429 inch. As a part of statistical quality control, a sample sizes 4 are taken and the mean diameter is obtained as 5.241 inch. Probability of type-I error is 0.05. Test was performed if the process is producing spur gear as per target mean diameter and also measured type-II error.

$$H_0: \mu = 5$$

$$H_1: \mu \neq 5$$

This is a two tail test, thus level of significance on both sides is $\frac{\alpha}{2}$

$$\frac{\alpha}{2} = 0.05/2 = 0.025$$

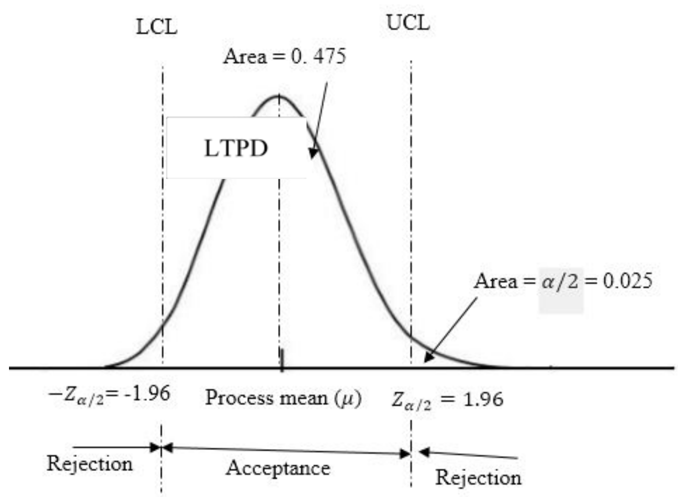


Figure 21 : Probability of type-I error for spur gear manufacturing

Here, $Z = \frac{\bar{X}-\mu}{\frac{\sigma}{\sqrt{n}}} = 2 > Z_{Critical}$ (1.96)

Since Z = 2 is greater than $Z_{Critical}$ =1.96 (From standard normal distribution chart), the null hypothesis is rejected. That means the process mean has really shifted. However a sample size of 4 should not be enough to justify a normal distribution. So sample size should be increased in all future estimation.

Now, for type-II error,

$$Z_{\alpha/2} = 1.96, \mu_0 = 4.8, \mu_1 = 5.241, \sigma = 0.4429, n = 4$$

So, probability of type II error,

$$\beta = \emptyset\left(Z_{\frac{\alpha}{2}} - \frac{\delta\sqrt{n}}{\sigma}\right) - \emptyset\left(-Z_{\frac{\alpha}{2}} - \frac{\delta\sqrt{n}}{\sigma}\right)$$

$$= \emptyset\left(1.96 - \frac{0.4429\sqrt{4}}{0.4429}\right) - \emptyset\left(-1.96 - \frac{0.4429\sqrt{4}}{0.4429}\right)$$

$$= \emptyset(-0.04) - \emptyset(-3.96)$$

$$= 0.0054$$

Here, $\emptyset(-3.96)$ denotes the area on the left side of LCL under the left tail of sample distribution which is very small and thus negligible.

So, probability of detecting the shift of process mean or probability of not accepting the bad lot,
$= 1-\beta$ = 1- 0.0054 = 0.9946 = 99.46%.

X. Sigma

Sigma (σ) means standard deviation. It indicates the quality limit of control chart. Increase or decrease of sigma maintain the characteristics of products or services. Two sets of limits on control chart, such as those shown in Figure 22. The outer limit called 3-sigma, are the usual action limit; that is, when a point plots outside of this limit, a search for an assignable cause is made and corrective action is taken if necessary. The inner limits, usually at 2-sigma are called warning limit. In Figure 22, we have shown the 3-sigma upper and lower control limits and 2-sigma upper and lower warning limits for $\bar{x}$ chart for the spur gear diameter.

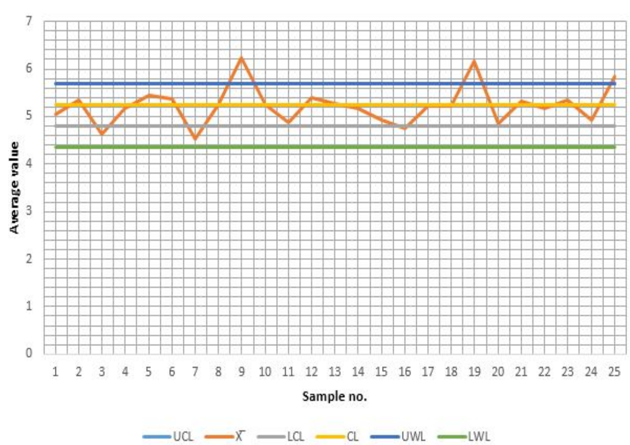


Figure 22 : Average-Control chart with 2 sigma and 3 sigma for spur gear diameter

UCL= 5.682
LCL= 4.800
UWL= 5.6839
LWL= 4.3552

XI. Improving Productivity

Productivity is the ratio of output and input.

$$\text{Productivity} = \frac{Output}{Input}$$

When supervisors and other managers look for ways to boost productivity, they often start by looking at their costs per unit of output. Productivity improves when the department or organization can do as much work at a lower cost and when output rises without a cost increase. Another way to improve productivity is to improve process quality so that employees work more efficiently and do not have to spend time correcting mistakes or defects. Mistakes, errors, and rework are a drag on productivity. Poor quality can slow the output of both individuals and the firm as a whole. For that reason, one of the supervisor's most important tasks is to think of and implement ways to get the job done right the first time.

a) Use Budgets

Before a supervisor can make intelligent decisions about how to trim costs, he or she has to know where the money is going. The most important source of such information is budget reports. By reviewing budget reports regularly, a supervisor can see which categories of expenses are largest and identify where the department is spending more than it budgeted. Then a supervisor should spend time with workers, observing how they use the department's resources, including their time. The process of gathering information about costs and working with employees to identify needed improvements is part of a supervisor's control function.

b) Increase Output

The numerator in the productivity equation (output/input) represents what the department or organization is producing. The greater the output at a given cost, the greater the productivity. Thus, a logical way to increase productivity is to increase output without boosting costs. Sometimes, by applying themselves, people can work faster or harder. A supervisor must also communicate the new goals carefully, emphasizing any positive aspects of the change. Some companies use technology to ensure productivity. Software programs that monitor e-mail and Internet usage have many uses, including applications that identify computer use that is not work related or that violates company rules. Electronic monitoring can also provide basic productivity measures such as how long order takers spend processing each customer order.

c) Improve Methods

Process control techniques for improving quality also can improve productivity. A process called *kaizen*, in which teams map the details of each work process, looking for ways to eliminate waste. Like managers at all levels, supervisors should be constantly on the lookout for ways to improve methods. Some ideas will come from supervisors themselves. Employees often have excellent ideas for doing the work better because they see the problems and pitfalls of their jobs. Supervisors should keep communication channels open and actively ask for ideas.

d) Reduce Overhead

Many departments spend more than is necessary for overhead, which includes rent, utilities, staff support, company cafeteria, janitorial services, and other expenses not related directly to producing goods and services. Typically, an organization allocates a share of the total overhead to each department based on the department's overhead expenses. However, a supervisor can periodically look for sources of needless expenses, such as lights left on in unoccupied areas or messy work areas that mean extra work for the janitorial staff. By reducing these costs to the company, a supervisor ultimately reduces the amount of overhead charged to his or her department.

e) Minimize Waste

Waste occurs in all kinds of operations. A factory may handle materials in a way that produces a lot of scrap. A costly form of waste is idle time, or downtime—time during which employees or machines are not producing goods or services. This term is used most often in manufacturing operations, but it applies to other situations as well. In a factory, idle time occurs while a machine is shut down for repairs or workers are waiting for parts. Idle time may occur because jobs and work processes are poorly designed. Detour behavior is a tactic for postponing or avoiding work. Wasted time may be an even more important measure of lost productivity than wasted costs. They can set a good example for effective time management and make detecting waste part of the control process. Often, employees are good sources of information on how to minimize waste. The supervisor might consider holding a contest to find the best ideas.

f) Regulate or Level the Work Flow

A supervisor can take several steps to regulate departmental work flow:

1) A supervisor should first make sure that adequate planning has been done for the work required.
2) A supervisor may also find it helpful to work with his or her manager and peers or form teams of employees to examine and solve work-flow problems. Cooperation can help make the work flow more evenly or at least more predictably.
3) If the work flow must remain uneven, a supervisor may find that the best course is to use temporary employees during peak periods, an approach that can work if the temporary employees have the right skills.

g) Install Modern Equipment

Work may be slowed because employees are using worn or outdated equipment. If that is the case, a supervisor may find it worthwhile to obtain modern equipment. Although the value of installing modern equipment is obvious for manufacturing departments, many other workplaces can benefit from using modern equipment, including up-to-date computer technology. In deciding to buy new equipment or recommending its purchase, a supervisor needs to determine whether the expense will be worthwhile. One way to do this is to figure out how much money per year the new equipment will save in terms of, for example, lower repair costs, less downtime, and more goods produced.

h) Train and Motivate Employees

To work efficiently, employees need a good understanding of how to do their jobs. Thus, a basic way to improve productivity is to train employees. Training alone does not lead to superior performance; employees also must be motivated to do good work. In other words, employees must want to do a good job. Motivation is a key tactic for improving productivity because employees carry out most changes and are often in the best position to think of ways to achieve their objectives more efficiently.

i) Minimize Tardiness, Absenteeism, and Turnover

When employees dislike their jobs or find them boring, they tend to use excuses to arrive late or not at all. Lost time is costly; in most cases, the organization is paying for someone who is not actually working. In addition, other employees may be unable to work efficiently without the support of the missing person. As a result, minimizing Absenteeism and Tardiness is an important part of the supervisor's job. Recent research indicates that the degree to which employees feel supported by their organization and supervisor can play an important role in whether they choose to leave their current job. In general, when an employee is feeling unsupported by his or her organization or supervisor, that employee is more likely to look for a new employment opportunity. Therefore, as a supervisor, it is important to be aware of how supported his or her employees feel about their relationship with him or her and the company as a whole. Supervisors can also minimize turnover by applying the principles of motivation.

XII. Result

For spur gear manufacturing problem, after observing all the data and analysis we find that its production quality is very close to the six sigma limits. Some variation occurs due to natural causes which can be eliminated. Type-I error occurred. So, if the spur gear manufacturing company continuing their quality research, it will help them to acquire a best product quality and make a highest position in the market.

XIII. Discussion

In this paper, the most effective way of quality control and productivity improvement has tried to find by experimenting on a manufacturing company. Using all quality tools and sampling plan is an expensive procedure. For any industry, using the control chart is the best way for quality testing. Cause and effect diagram, histogram are used to determine the causes and effects of production process. Acceptance sampling is used to determine the errors in control chart.

Statistical process control is a powerful tool to achieve sig sigma level. The following improved tools used in spur gear manufacturing can be used in any industry to achieve their desired level of quality and productivity.

XIV. Conclusion

There are several approaches to choose from when the goal is to increase the quality and productivity of a spur gear manufacturing company. The techniques used in this paper have been limited due to insufficient time and resources. In this paper only the quality tools have been used and tried to find the most effective way of quality testing and improving productivity. These have given a better solution. But if any one uses other technique of industrial engineering then he will get more benefit than this paper. If it is decided to use the data in future studies it would be interesting .By this way it may be possible to specify high quality and productivity. The quest for higher quality and productivity will never stop and the project extreme spur gear manufacturing will proceed. An important suggestion for future work is to test if the findings are applicable to other products and machines within the factory. A deeper understanding could possibly make the conclusions from this study more understandable and easier to apply to other products.

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