Study of Statistical Control Charts and Process Capability to Improve Quality Control Techniques (Case Study Applied in Wool Textile Company– Baniwalid)

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Abstract

This paper includes the study of statistical control charts and process capability to improve the quality of the woven carpet which were produced in Wool Textile Company (line of weaving carpet). The task is dedicated and applied to enable the evaluation of the performance for the manufacturing machines. For the case study applied, manufacturing process is selected namely (weaving carpet) in order to evaluate their performance by application of (control charts) namely " average - range" charts. Two techniques are used to evaluate the actual performance of the operation by process capability calculations and statistical analysis based on histogram technique. MINTAB software was used to facilitate the statistical process control, and process capability analysis .The results show high degree of accuracy by using the program and the mathematical operations (primary and secondary) which used to draw the control charts limits and to reject the statistically uncontrolled samples . Moreover, a final chart was drawn to be used in the factory . The results showed that some of machines are unable to satisfy the specification tolerances due to obsolescence and deprecation, therefore, total maintenance for these machines.

Keywords: Quality, Quality Control, Statistical Quality Control, Control Charts, X-R Control Charts, Process Capability .

1. Introduction

Companies are constantly under pressure not only to design new products faster, but also accelerate their production in today's competitive environment. Minimization of time,

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which is necessary for the product introduction to the market, is required as well as cost prediction and last but not least the increasing demands on product quality.

To evaluate the quality of the manufacturing process, statistical process control is used. It is a set of tools to maintain process stability and to improve its capability by reducing process variability. The theory of statistical process control is based on the existence of variation parameter in the production process which is influenced by a number of effects which make it impossible to produce completely two identical products. Is it possible to evaluate these effects and create conditions to make the process stable and to be able to assume the behavior of the process and ensure the required level of production quality [1].

Knowledge of process capability is a very important basis for professional decisions when planning quality by manufacturers allowing them to choose a suitable process for the production of certain products to predict the likelihood of non-conforming units, to plan preventive and corrective arrangements and evaluate their effectiveness, to assess the stability of processes, etc.

In any manufacturing operation, variability exists in the processes output, the operated parts may appear to be identical, but close inspection reveals dimensional differences from one part to the next. Manufacturing variations can be divided into two types: random and assignable. There are four factors that contribute to these variation (processes, materials, operators and miscellaneous). As long as these four factors fluctuated in a normal or expected manner, a stable pattern of many random or chance cause of variation develops.

They are inevitable, very small in magnitude, and difficult to identify. Those causes of variation which are large in magnitude and therefore readily identified, are classified as assignable causes. As long as only chance variation exists, the process is said to be in statistically controlled. If there is an assignable cause of variation, the process is not in control and is unlikely to produce a good product [2], [3], [4].

Quality Control is an important function in factory as it deals with product inspection before the product was shipped to customers. Statistical process control is one of the tools widely used in Quality Control to monitor whether the production process is in control through the use of statistical control chart. The purpose of the statistic quality control is the following:

- Determine product manufacturing process ability that satisfies set requirements؛
- Monitor the process to reveal changes responsible for the process getting out of control؛
- Take adequate measures for process correction and its preservation under control.

We depend Four steps to develop control charts first Step Gather data Step two we Calculate control limits and after that Interpret for process control final step was Interpret for process capability[5], [6]. Process capability is also another important concept in SPC. Being in control of a manufacturing process using statistical process control is not enough. An "in-control" process can produce bad or out-of-spec product. Manufacturing processes must meet or be able to achieve product specifications. Further, product specifications must be based on customers' requirements. Process capability is the repeatability and consistency of a manufacturing process relative to the customer requirements in terms of specification limits of a product parameter. This measure is used to objectively measure the degree to which your process meets the requirements or not. Capability indices have been developed to graphically portray that measure. Capability indices let you place the distribution of your process in relation to the product specification limits. Capability indices should be used to determine whether the process, given its natural variation, is capable of meeting the established specifications. It is also a measure of the manufacturability of the product with the given processes [7], [8].

This paper includes application of statistical control charts and process capability used (X-R chart) for the implementation of quality control measures in Wool Textile Company (line of weaving carpet) for the advancement of the quality required by identifying deviations in the production process.

2. Statistical Control Charts

The field of statistical quality control can be broadly defined as those statistical and engineering methods that are used in measuring, monitoring, controlling, and improving quality. Statistical quality control is a field that dates back to the 1920s. Dr. Walter A. Shewhart of the Bell Telephone Laboratories was one of the early pioneers of the field. In 1924 he wrote a memorandum showing a modern control chart, one of the basic tools of statistical process control. Harold F. Dodge and Harry G. Romig, two other Bell System employees, provided much of the leadership in the development of statistically based sampling and inspection methods. The work of these three men forms much of the basis of the modern field of statistical quality control.

A control chart was developed specifically to determine whether process outputs exhibit common cause variation only, or whether, and when, special cause variation is occurring. When samples are taken periodically on a process, the average of the samples will tend to cluster about some overall average, or process level. The control chart consists of three parallel lines: two outside lines, called Upper Control Limit (UCL) and Lower Control Limit (LCL), and a Center Line (CL). The CL reflects the average of the data, while the control limits are calculated to have a high probability of the sample data being contained between them if the process is stable. If the process level shifts, however, points will plot outside the limits, indicating the need for corrective action on the process [9], [10].

The following are the various computational formulae involved in constructing the control charts [11].

$\bar{X} = \frac{\sum_{i=1}^{n} x_i}{n}$: Mean of i^{th} sample

$\bar{\bar{X}} = \frac{\sum_{i=1}^{N} x_i}{N}$: Grand Mean

$R_i = Max\ (x_i) - Min\ (x_i)$: Range of i^{th} sample

$\bar{R} = \frac{\sum_{i=1}^{k} R_i}{k}$: Mean of Range values

The Control limits for constructing (X - chart) and (R – chart) are as given below:

Control limits for (X - chart) :

$CL_x = \bar{\bar{X}}$: Center Line for X - chart

$UCL_x = \bar{\bar{X}} + A_2\bar{R}$: Upper Control Limit for X - chart

$LCL_x = \bar{\bar{X}} - A_2\bar{R}$: Upper Control Limit for X - chart

Control limits for (R – chart) :

$CL_r = \bar{R}$: Center Line for R-Chart

$UCL_r = D_4\bar{R}$: Upper Control Limit for R-Chart

$LCL_r = D_3\bar{R}$: Upper Control Limit for R-Chart

3. Types of Statistical Control Charts

There are two fundamental types of control charts [12] [13].

Control chart for variables (of which the most popular are $\bar{X}$, R, S charts)

− Characteristics that you measure, e.g., weight, length, size, height, time, ...;

− Product characteristics that are continuous and can be measured;

− May be in whole or in fractional numbers;

− Continuous random variables.

Control chart for attributes (of which the most popular are p, np, c and u charts)

− Characteristics for which you focus on defects, e.g., good – bad; yes - no, ...;

− Categorical or discrete random variables;

− Characteristics that can be evaluated with a discrete response.

Once the quality characteristic to be studied has been determined; data is collected and samples must be properly selected by the principle of rational sampling. Rational samples are groups of measurements, the variation among which is attributable to one system of causes. Examples of non- rational sampling include sampling from parallel machines, sampling over extended period of time and sampling from products of several sources.If the quality related problems are not easily solved in numerical form, then Attribute Control Charts (ACC) are useful. ACC tools are effective for detecting quality improvement or degradation. ACC is used to evaluate the variation in a process where measurement is an attribute i.e. is in discrete or count (e.g. pass/fail, number of defects). In ACC defining sample size is a problem.

4. Process Capability Study

The process capability study is a longer-term study. In addition to variation arising from the machine, all other external factors that influence the production process over a longer operating time must be taken into account.

Process capability is important concept in statistical process control. Being in control of a manufacturing process using statistical process control is not enough. An "in-control" process can produce bad or out-of-spec product. Manufacturing processes must meet or be able to achieve product specifications. Further, product specifications must be based on customers’ requirements. Process capability is the repeatability and consistency of a manufacturing process relative to the customer requirements in terms of specification limits of a product parameter. This measure is used to objectively measure the degree to which your process meets the requirements or not. Capability indices have been developed to graphically portray that measure. Capability indices let you place the distribution of your process in relation to the product specification limits. Capability indices should be used to determine whether the process, given its natural variation, is capable of meeting the established specifications. It is also a measure of the manufacturability of the product with the given processes. Capability indices can be used to compare the product/process matches and identify the poorest match (lowest capability). The poorest matches then can be targeted on a priority basis for improvement. If we sample a group of items periodically from a production run and measure the desired specification parameter, we will get subgroup sample distributions that can be compared to that parameter's specification limits [14],[15].

The relationship between process capability and tolerances product simply setting up control charts to monitor whether a process is in control does not guarantee process capability. To produce an acceptable product, the process must be *capable* and *in control* before production begins. Fundamental requirement of process capability is $T \geq 6\sigma$(T = USL–LSL). Process is capable if requirement range T is greater or equal to process range 6σ.Process capability is estimated by calculating, the so called process capability indices.

Calculation and proper interpretation of process capability indices is based on following suppositions:

- Data distribution can be approximated by the normal distribution.
- Reliable estimation of process capability can be made only based on process monitoring using appropriate control chart and after bringing the process in the condition of statistical control (status under control).

It makes sense to estimate process capability only when special causes affecting process variations are removed and medium process brought to the environment of target value, then C_p can be calculated as follows: [11].

$$C_p = \frac{\text{total tolerance}}{\text{process capability}} = \frac{USL - LSL}{6\sigma}$$

Where:

• USL - upper specification limit,

• LSL - lower specification limit,

• σ - standard deviation.

The process capability index shows how able the process is to meet specifications.

The higher the value of the index, the more capable the process is [16]:

Values of C_p exceeding 1.33 indicate that the process is adequate to meet the specifications. Values of C_p between 1.33 and 1.00 indicate that the process, while adequate to meet specifications, will require close control. Values of C_p below 1.00 indicate the process is not capable of meeting specifications.

Histograms, before taking steps to improve processes, data is often collected to see how processes are doing at the present time. One way to describe and evaluate performance is to display this data in a chart called a “histogram”. Histograms can be valuable troubleshooting aids. Comparisons between histograms from different machines, operators, vendors, etc., often reveal important differences. A histogram is a picture of the data distribution that includes its spread and shape. This can provide clues about the variation that exists in the work performed. Distributions can be skewed in either a positive (tail of the distribution to the right) or negative (tail of the distribution to the left) direction from the center. By examining the spread and shape of a distribution, the extent of variation in a work process can be determined. This can provoke further discussions to identify the cause of variation and the measures needed to either control or reduce it. The histogram can be helpful in estimating process capability. If the quality engineer has access to the process and can control the data-collection effort [17].

5. Practical Application

5.1 Sample and Data Collection

We investigate the process capability assessment that may suit mass production model. The task is dedicated and applied to enable the evaluation of the performance for the manufacturing machines.

The use of statistical control techniques such as (Average chart [X-chart], Range chart [R-chart] and process capability) in quality control of the woven carpet (type 2m x 3m) which were produced in Wool Textile Company (line of weaving carpet) and in order to evaluate the performance of the manufacturing machines, for evaluating of quality control and process capability by using control charts namely (Average-Range) chart and process capability calculations and statistical analysis based on histogram technique.

The objective of the study to monitoring the quality of Product using statistical quality control charts; explain the concept of statistical process control and its application in a manufacturing industry to improve the quality levels and to reduce the variations and rejections in a critical process .

The data used for this study is data collected from the company's quality control department. The data used here are five days data collected from the company, recorded during each day production. Six samples randomly sampled each day for their respective parameters pile height.

Tables (1), (2) and (3) shows the collected data for pile height which is the critical character for this product from line of weaving carpet for three machines from line of production Shuttle Loom (16 Looms) . Thirty samples ($m = 30$) were measured and six sample size ($n = 6$)(the total measurement number is $6\times30=180$) were taken every one hour for five days. The tolerance of the pile height was (11 ± 2 mm).

5.2 Calculations and Results Discussion

The collected data in tables (1), (2) and (3) was entered to MINTAB software (version 16). The objective of the study to monitoring the quality of Product using statistical quality control charts; explain the concept of statistical process control and its application in a manufacturing industry to improve the quality levels and to reduce the variations and rejections in a critical process. The samples as were collected and calculated are presented below, on line of weaving carpet for three machines from line of production Shuttle Loom.

1- Machine (Loom No3)

The resulting data together with the sample means and sample range values are given below in Table (1). The grand mean $\bar{\bar{X}}$ and $\bar{R}$ calculated as follows:

$$\bar{\bar{X}} = \frac{\sum \bar{X}}{N} = \frac{\sum \bar{X}}{30} = CL = \frac{306}{30} = 10.2 \qquad \bar{R} = \frac{\sum R}{N} = \frac{53}{30} = 1.7666 \cong 1.767$$

The control limits are:

$$UCL_x = \bar{\bar{X}} + A_2\bar{R} = 10.2 + (0.483)(1.767) = 11.0534$$

$$LCL_x = \bar{\bar{X}} - A_2\bar{R} = 10.2 - (0.483)(1.767) = 9.346$$

$$UCL_r = D_4\bar{R} = (2.004)(1.767) = 3.541 \qquad LCL_r = D_3\bar{R} = (0)(1.767) = 0$$

Whereas, (D3, D_4, A2, $d_{2)}$ are constants depends on the sample size n [18].

Figures (1) and (2) shown the control charts for (X - chart) and (R– chart) which were used to control the process under study. It can be seen that there is two points (sample 6 and 25) outside control at the average chart(X - chart) and all points are within the limits at the range chart (R– chart), the process is not under control.

After the site investigation, the statistically uncontrolled samples to be rejected. Moreover a final chart was drawn to be used in the factory.

New control limit

$$\bar{\bar{X}} = \frac{\sum \bar{X}}{N} = \frac{\sum \bar{X}}{28} = CL = \frac{285.5}{28} = 10.196 \qquad \bar{R} = \frac{\sum R}{N} = \frac{50}{28} = 1.786$$

The control limits are:

$$UCL_x = \bar{\bar{X}} + A_2\bar{R} = 10.196 + (0.483)(1.786) = 11.0586 \cong 11.06$$

$$LCL_x = \bar{\bar{X}} - A_2\bar{R} = 10.196 - (0.483)(1.786) = 9.333$$

$$UCL_r = D_4\bar{R} = (2.004)(1.786) = 3.579 \qquad LCL_r = D_3\bar{R} = (0)(1.786) = 0$$

Whereas, (D3, D_4, A2, $d_{2)}$ are constants depends on the sample size n [18].

The results indicated that all points are within the limits and distributed randomly around the center line. The trend of the points indicates that the production process is under control; the condition for the study process capability was realized.

$$\bar{\sigma} = \frac{\bar{R}}{d_2} = \frac{1.786}{2.534} = 0.71048 \qquad \text{process capability} = 6\,\bar{\sigma} = 4.2628$$

Thus, the process capability is Low Relative Precision, where the tolerance band is less than 6σ , the result showed that machine is unable to satisfy the specification tolerances due to wide differences in the resulted values of the statistical parameter.

Figure (3) shows the histogram for the data under study which was analyzed and displayed by the MINTAB software program, display the histograms the observations with a density line and specification limits (LSL, T, USL).

The process mean is near to LSL. The number of non-conforming parts out of the LSL and there is no value out of the USL in the observed performance.

2- Machine (Loom No 6)

The resulting data together with the sample means and sample range values are given below in Table (2). The grand mean $\bar{\bar{X}}$ and $\bar{R}$ calculated as follows:

$$\bar{\bar{X}} = \frac{\sum \bar{X}}{N} = \frac{\sum \bar{X}}{30} = CL = \frac{313.5}{30} = 10.45 \qquad \bar{R} = \frac{\sum R}{N} = \frac{\sum R}{30} = \frac{64}{30} = 2.133$$

The control limits are:

$$UCL_x = \bar{\bar{X}} + A_2\bar{R} = 10.45 + (0.483)(2.133) = 11.481$$

$$LCL_x = \bar{\bar{X}} - A_2\bar{R} = 10.45 - (0.483)(2.133) = 9.419$$

$$UCL_r = D_4\bar{R} = (2.004)(2.133) = 4.275 \qquad LCL_r = D_3\bar{R} = (0)(2.133) = 0$$

Whereas, (D3, D_4, A2, $d_{2)}$ are constants depends on the sample size n [18].

Figures (4) and (5) shown the control charts for (X - chart) and (R– chart) which were used to control the process under study. It can be seen that all points are within the limits and distributed randomly around the center line. The trend of the points indicates that the production process is under control; the condition for the study process capability was realized.

$$\bar{\sigma} = \frac{\bar{R}}{d_2} = \frac{2.133}{2.534} = 0.8418 \qquad \text{process capability} = 6\,\bar{\sigma} = 5.0508$$

Thus, the process capability Low Relative Precision, where the tolerance band is less than 6σ , the result showed that machine is unable to satisfy the specification tolerances due to wide differences in the resulted values of the statistical parameter.

Figure (6) shows the histogram for the data under study which was analyzed and displayed by the MINTAB software program, display the histograms the observations with a density line and specification limits (LSL, T, USL).

The process mean is between LSL and USL. The number of non-conforming parts is out of the LSL and USL in the observed performance.

3- Machine (Loom No 15)

The resulting data together with the sample means and sample range values are given below in Table (3). The grand mean $\bar{\bar{X}}$ and $\bar{R}$ calculated as follows:

$$\bar{\bar{X}} = \frac{\sum \bar{X}}{N} = \frac{\sum \bar{X}}{30} = CL = \frac{289.167}{30} = 9.639 \; \bar{R} = \frac{\sum R}{N} = \frac{\sum R}{30} = \frac{43}{30} = 1.433$$

The control limits are:

$$UCL_x = \bar{\bar{X}} + A_2\bar{R} = 9.639 + (0.483)(1.433) = 10.332$$

$$LCL_x = \bar{\bar{X}} - A_2\bar{R} = 9.639 - (0.483)(1.433) = 8.946$$

$$UCL_r = D_4\bar{R} = (2.004)(1.433) = 2.872 \qquad LCL_r = D_3\bar{R} = (0)(1.433) = 0$$

Whereas, (D3, D_4, A2, $d_{2)}$ are a constants depends on the sample size n [19].

Figures (7) and (8) shown the control charts for (X - chart) and (R– chart) which were used to control the process under study. It can be seen that there is one point (sample 9) outside control at the average chart (X - chart) and all points are within the limits at the range chart (R– chart), the process is not under control.

After the site investigation, moreover a final chart was drawn to be used in the factory to reject the statistically uncontrolled samples.

New control limit

$$\bar{\bar{X}} = \frac{\sum \bar{X}}{N} = \frac{\sum \bar{X}}{29} = CL = \frac{280.3337}{29} = 9.667 \qquad \bar{R} = \frac{\sum R}{N} = \frac{41}{29} = 1.414$$

The control limits are:

$$UCL_x = \bar{\bar{X}} + A_2\bar{R} = 9.667 + (0.483)(1.414) = 10.35$$

$$LCL_x = \bar{\bar{X}} - A_2\bar{R} = 9.667 - (0.483)(1.414) = 8.984$$

$$UCL_r = D_4\bar{R} = (2.004)(1.414) = 2.287 \qquad LCL_r = D_3\bar{R} = (0)(1.414) = 0$$

Whereas, (D3, D_4, A2, $d_{2)}$ are a constants depends on the sample size n [19].

The results indicated that all points are within the limits and distributed randomly around the center line. The trend of the points indicates that the production process is under control; the condition for the study process capability was realized.

$$\bar{\sigma} = \frac{\bar{R}}{d_2} = \frac{1.414}{2.534} = 0.558 \qquad \text{process capability} = 6\,\bar{\sigma} = 3.348$$

Thus, the process capability shows high capability, where the tolerance band is greater than 6σ , the result showed that machine is able to satisfy the specification tolerances.

Figure (9) shows the histogram for the data under study which was analyzed and displayed by the MINTAB software program, display the histograms the observations with a density line and specification limits (LSL, T, USL).

The process mean is near to LSL. The number of non-conforming parts out of the LSL and there is no value out of the USL in the observed performance.

6. Conclusions

This paper use control charts and process capability which is the most important statistical techniques to improve the quality where they can manufacture product with low percentage defect and it will be applied in Wool Textile Company (line of weaving carpet) and in order to evaluate the performance of the manufacturing machines , and because the importance of weaving carpet process which carried out on the Loom machine , and the large number of errors during this phase, will be determined the process capability for this machine through the application of the method of process capability, by using methods of Quality control in order to get the suitable Quality standard for the production qualifications; and to know whether the productive process is in a state of statistical control through controlling the allowed deviation for dimensions to be produced for studied samples. Consequently, managers of production & quality will get an idea about the extent of compatibility of production to the design criteria. Through using (X - chart) and (R– chart) and statistical analysis based on histogram technique. MINTAB software was used to facilitate the statistical process control, and process capability analysis for (X-R chart) was used to determine test quality level required for product specification to justify that the process that is statistically controlled. The results show that some of machines are unable to follow up production within the required specification tolerances due to obsolescence and deprecation, therefore, total maintenance for these machines, and increase the quality control activities such as testing the raw materials**.**

7. References

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Table 1. The collected data for Machine (Loom No3)

Date	Time	Sample Number	Right X_1	Middle X_2	Left X_3	Right X_4	Middle X_5	Left X_6	Range R	Mean $\bar{X}$
1st day	9	1	11	11	9	10	10	10	2	10.1667
	10	2	10	11	11	9	10	10	2	10.1667
	11	3	10	11	10	10	10	10	1	10.1667
	12	4	9	10	11	9	10	10	2	9.8333
	13	5	9	10	11	9	9	9	2	9.5000
	14	6	9	10	10	9	9	9	1	9.3333
2nd day	9	7	9	10	11	9	9	9	2	9.5000
	10	8	10	11	10	9	10	9	2	9.8333
	11	9	10	10	10	10	10	10	0	10.0000
	12	10	9	10	11	9	10	10	2	9.8333
	13	11	9	10	11	9	10	10	2	9.8333
	14	12	10	10	10	9	10	10	1	9.8333
3rd day	9	13	10	12	12	10	10	10	2	10.6667
	10	14	10	12	12	10	10	10	2	10.6667
	11	15	11	12	12	9	10	9	3	10.5
	12	16	9	10	11	9	10	10	2	9.8333
	13	17	9	10	11	9	10	10	2	9.8333
	14	18	10	11	10	10	10	10	1	10.1667
4th day	9	19	11	12	11	9	10	10	3	10.5000
	10	20	11	12	12	9	10	11	3	10.8333
	11	21	10	10	10	10	11	11	1	10.3333
	12	22	10	12	11	10	11	10	2	10.6667
	13	23	10	11	11	10	10	10	1	10.3333
	14	24	9	10	10	9	10	10	1	9.6667
5th day	9	25	11	12	12	10	11	11	2	11.1667
	10	26	11	12	12	10	10	11	2	11.0000
	11	27	10	12	11	10	10	10	2	10.5000
	12	28	10	12	12	10	10	10	2	10.6667
	13	29	10	12	11	10	10	10	2	10.5000
	14	30	10	11	10	10	10	10	1	10.1667
$\sum$									53	306

Remark : All dimensions in mm

Table 2. The collected data for Machine (Loom No 6)

Date	Time	Sample Number	Right X_1	Middle X_2	Left X_3	Right X_4	Middle X_5	Left X_6	Range R	Mean $\bar{X}$
1st day	9	1	10	10	10	9	10	10	1	9.8333
	10	2	10	10	10	12	12	11	2	10.8333
	11	3	9	10	10	10	10	10	1	9.8333
	12	4	9	10	10	12	12	11	3	10.6667
	13	5	9	10	10	12	12	11	3	10.6667
	14	6	9	9	9	11	10	10	2	9.6667
2nd day	9	7	9	10	10	11	11	10	2	10.1667
	10	8	9	10	10	11	11	10	2	10.1667
	11	9	9	10	9	12	11	10	3	10.1667
	12	10	9	10	10	11	11	10	2	10.1667
	13	11	9	10	10	11	11	10	2	10.1667
	14	12	10	10	10	11	11	10	1	10.3333
3rd day	9	13	10	10	10	13	12	11	3	11.0000
	10	14	10	10	10	13	12	11	3	11.0000
	11	15	10	10	10	13	12	10	3	10.8333
	12	16	10	10	10	11	11	10	1	10.3333
	13	17	9	10	10	11	11	10	2	10.1667
	14	18	10	10	10	11	10	10	1	10.1667
4th day	9	19	9	10	9	12	12	10	3	10.3333
	10	20	10	10	10	11	11	10	1	10.3333
	11	21	10	10	10	12	11	10	2	10.5000
	12	22	10	10	9	12	11	10	3	10.3333
	13	23	10	10	10	12	11	10	2	10.5000
	14	24	9	10	9	12	11	10	3	10.1667
5th day	9	25	10	11	10	13	12	11	3	11.1667
	10	26	10	10	10	13	12	11	3	11.0000
	11	27	10	10	10	12	12	11	2	10.8333
	12	28	10	11	10	12	12	11	2	11.0000
	13	29	10	10	10	12	12	11	2	10.8333
	14	30	10	10	10	11	11	10	1	10.3333
$\sum$									64	313.5

Remark : All dimensions in mm

Table 3. The collected data for Machine (Loom No 15)

Date	Time	Sample Number	Right X_1	Middle X_2	Left X_3	Right X_4	Middle X_5	Left X_6	Range R	Mean $\bar{X}$
1st day	9	1	10	10	9	10	11	11	2	10.1667
	10	2	9	10	11	9	9	9	2	9.5000
	11	3	9	9	9	9	10	10	1	9.3333
	12	4	9	10	10	10	10	10	1	9.8333
	13	5	9	10	10	10	10	11	2	10.0000
	14	6	10	9	9	10	10	10	1	9.6667
2nd day	9	7	10	9	9	9	10	10	1	9.5000
	10	8	10	9	9	9	10	10	1	9.5000
	11	9	9	8	8	9	9	10	2	8.8333
	12	10	10	8	9	9	9	9	2	9.0000
	13	11	10	9	9	9	10	10	1	9.5000
	14	12	10	9	9	10	10	10	1	9.6667
3rd day	9	13	9	9	9	10	11	11	2	9.8333
	10	14	9	9	9	10	10	10	1	9.5000
	11	15	10	9	9	10	10	11	2	9.8333
	12	16	10	9	9	9	10	10	1	9.5000
	13	17	10	9	9	9	10	10	1	9.5000
	14	18	9	9	9	10	10	10	1	9.5000
4th day	9	19	10	9	9	10	10	10	1	9.6667
	10	20	10	9	9	10	11	11	2	10.0000
	11	21	10	9	9	11	11	11	2	10.1667
	12	22	11	9	9	11	11	10	2	10.1667
	13	23	10	9	9	10	10	10	1	9.6667
	14	24	10	10	9	10	10	10	1	9.8333
5th day	9	25	10	9	9	10	11	10	2	9.8333
	10	26	10	9	9	10	10	10	1	9.6667
	11	27	10	9	9	10	10	10	1	9.6667
	12	28	10	9	8	10	10	10	2	9.5000
	13	29	10	9	8	10	10	10	2	9.5000
	14	30	9	9	9	9	10	10	1	9.3333
$\sum$									43	289.167

Remark: All dimensions in mm

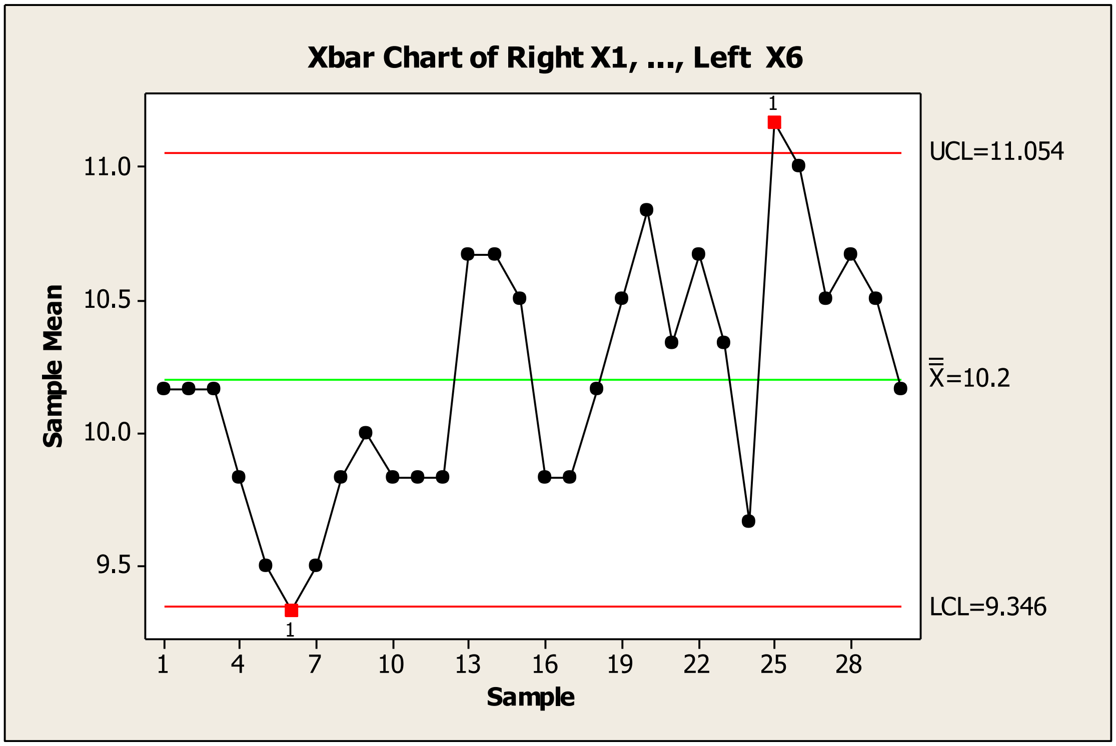


Figure 1. (X - chart) for pile height (Loom No 3)

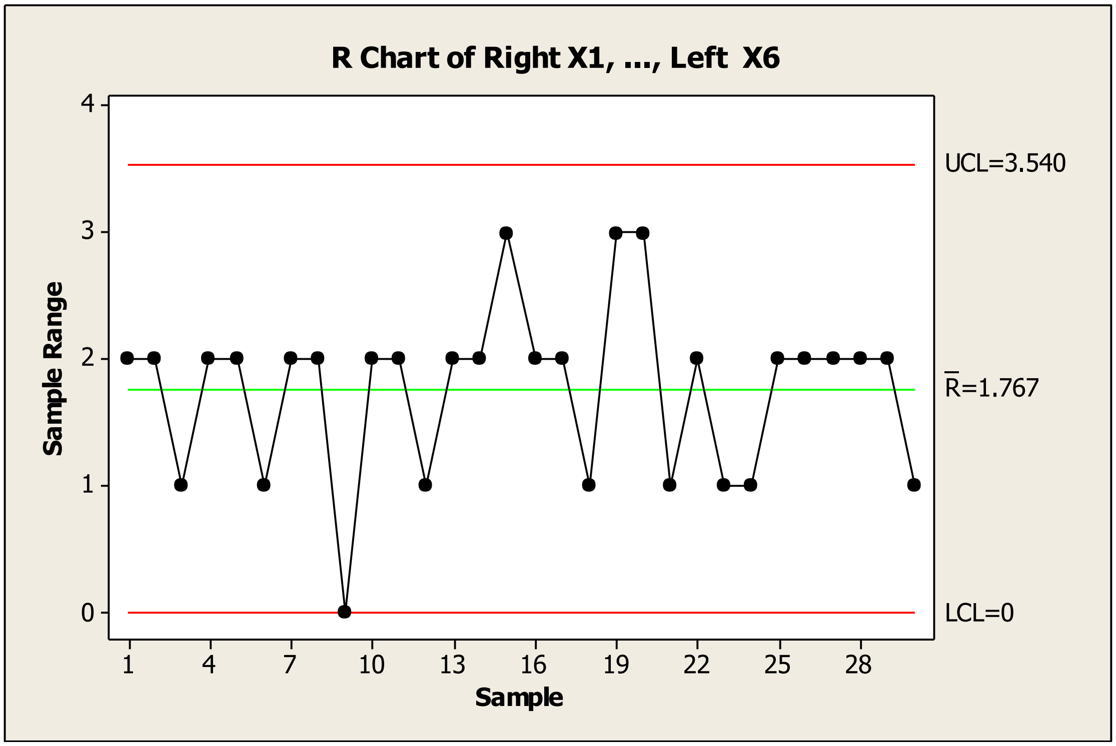


Figure 2. (R- chart) for pile height (Loom No 3)

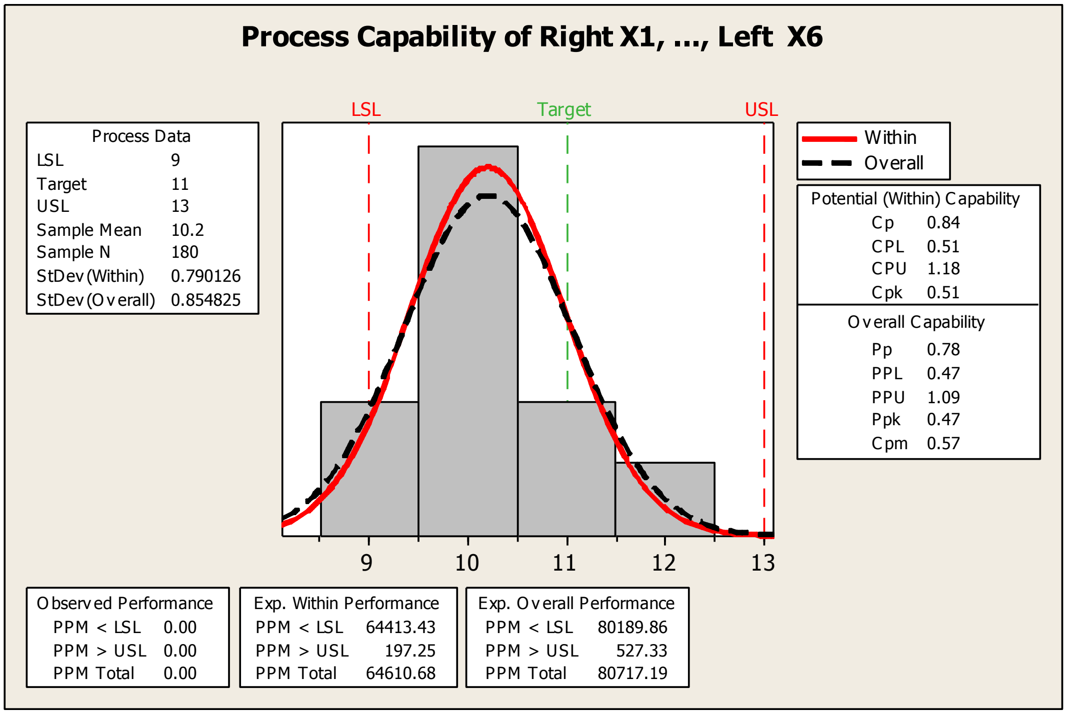


Figure 3. Histograms and process-capability analysis for quality (Loom No 3)

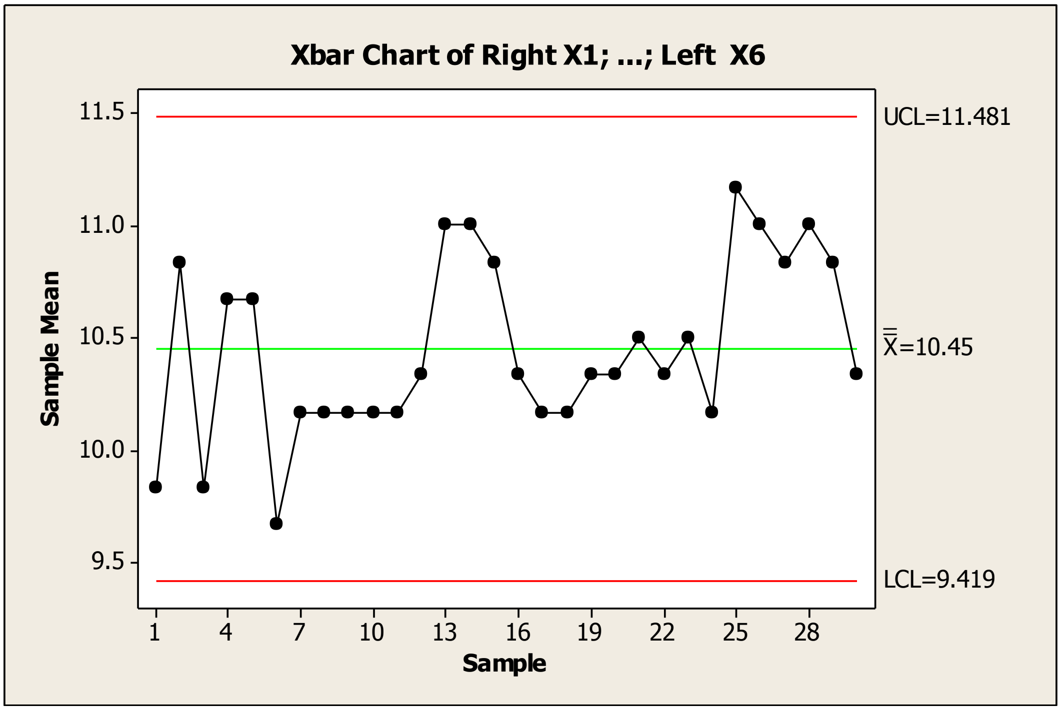


Figure 4. (X - chart) for pile height (Loom No 6)

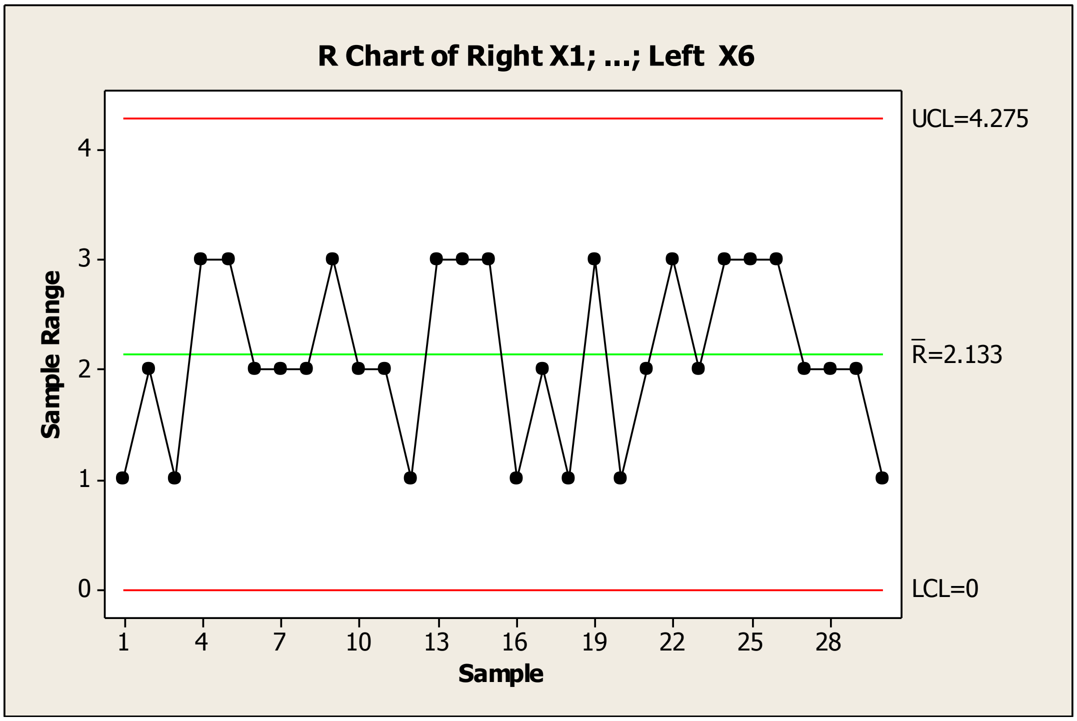
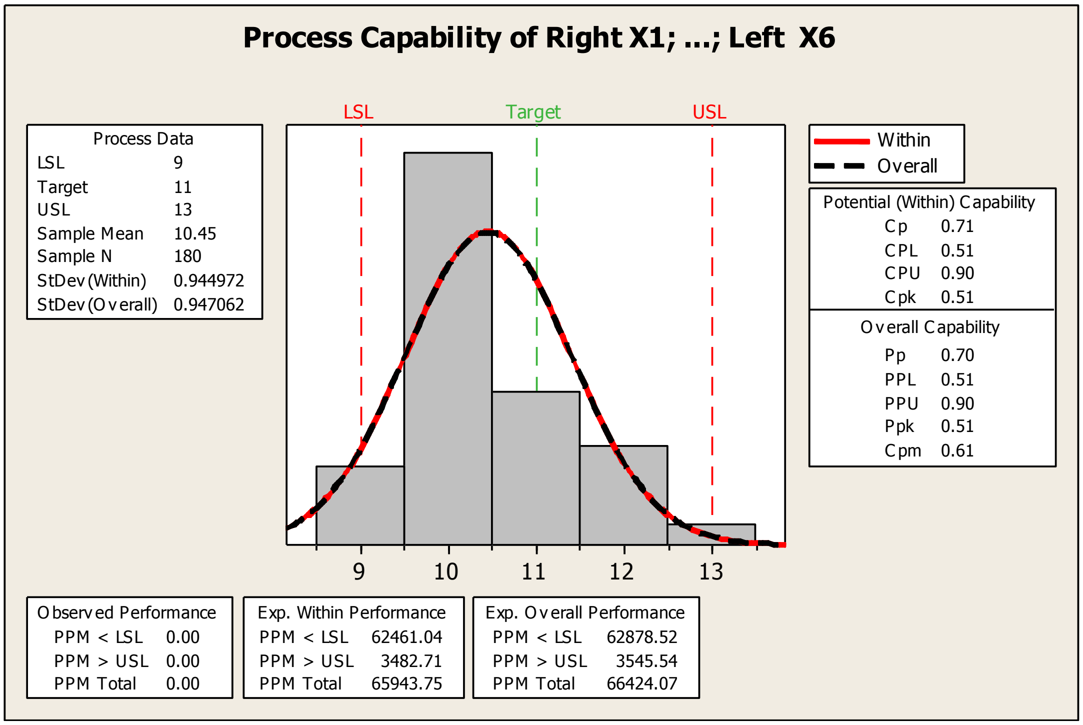


Figure 5. (R- chart) for pile height (Loom No 6)



Process Data	
LSL	9
Target	11
USL	13
Sample Mean	10.45
Sample N	180
StDev(Within)	0.944972
StDev(Overall)	0.947062

Potential (Within) Capability	
Cp	0.71
CPL	0.51
CPU	0.90
Cpk	0.51

Overall Capability	
Pp	0.70
PPL	0.51
PPU	0.90
Ppk	0.51
Cpm	0.61

	Observed Performance	Exp. Within Performance	Exp. Overall Performance
PPM < LSL	0.00	62461.04	62878.52
PPM > USL	0.00	3482.71	3545.54
PPM Total	0.00	65943.75	66424.07

Figure 6. Histograms and process-capability analysis for quality (Loom No 6)

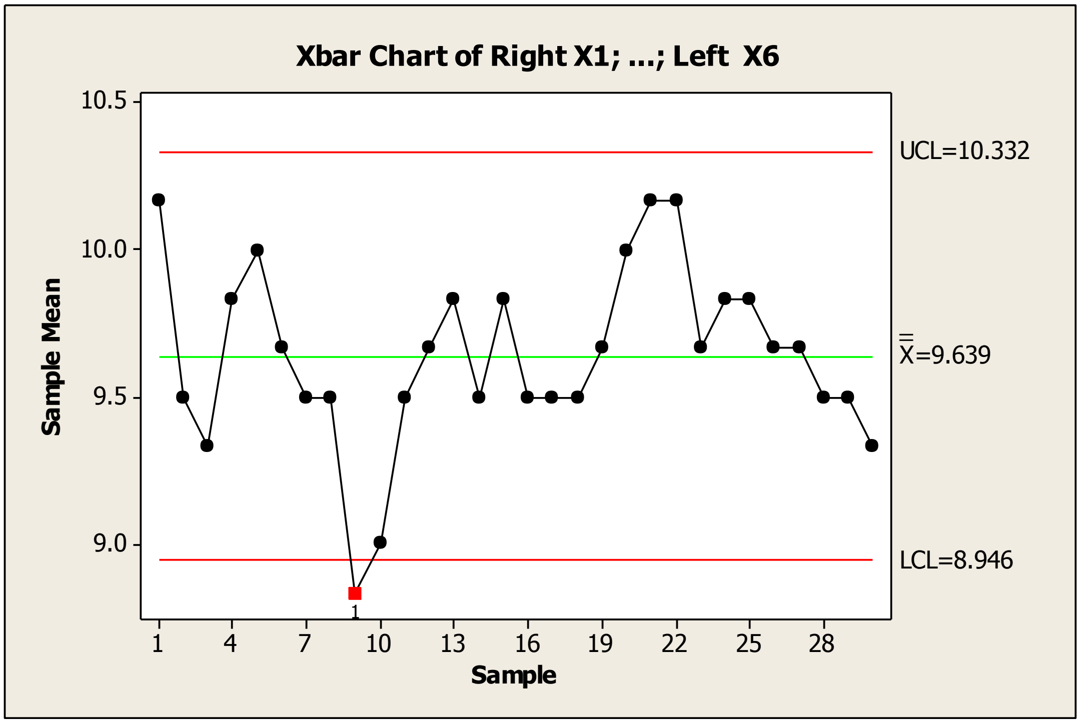


Figure 7. (X - chart) for pile height (Loom No 15)

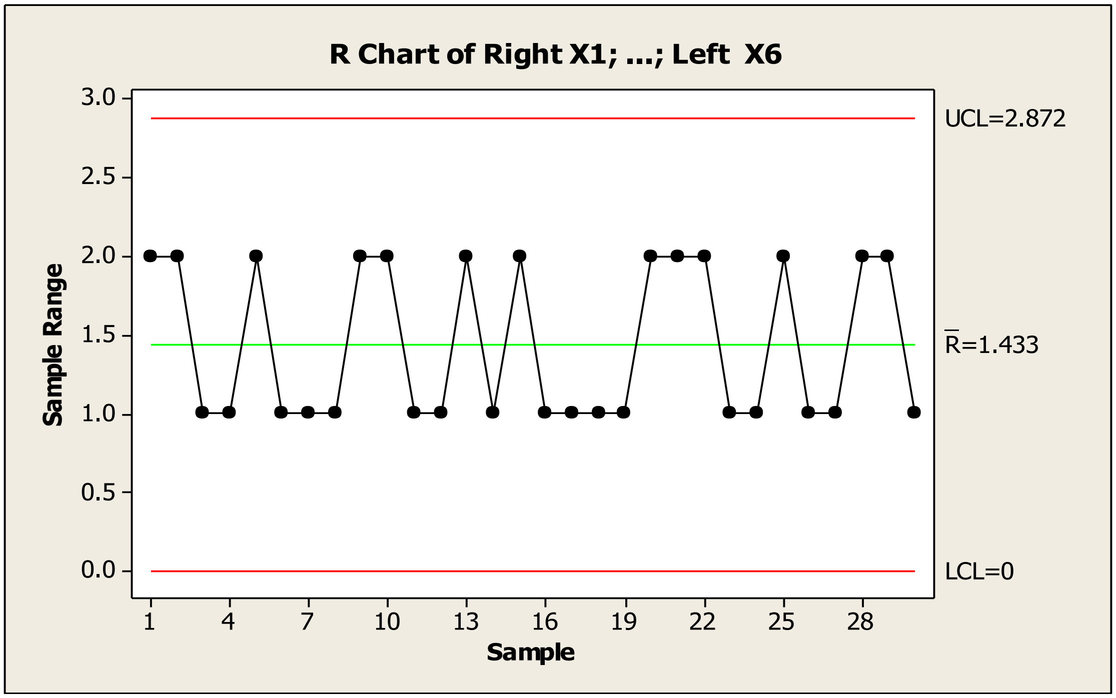
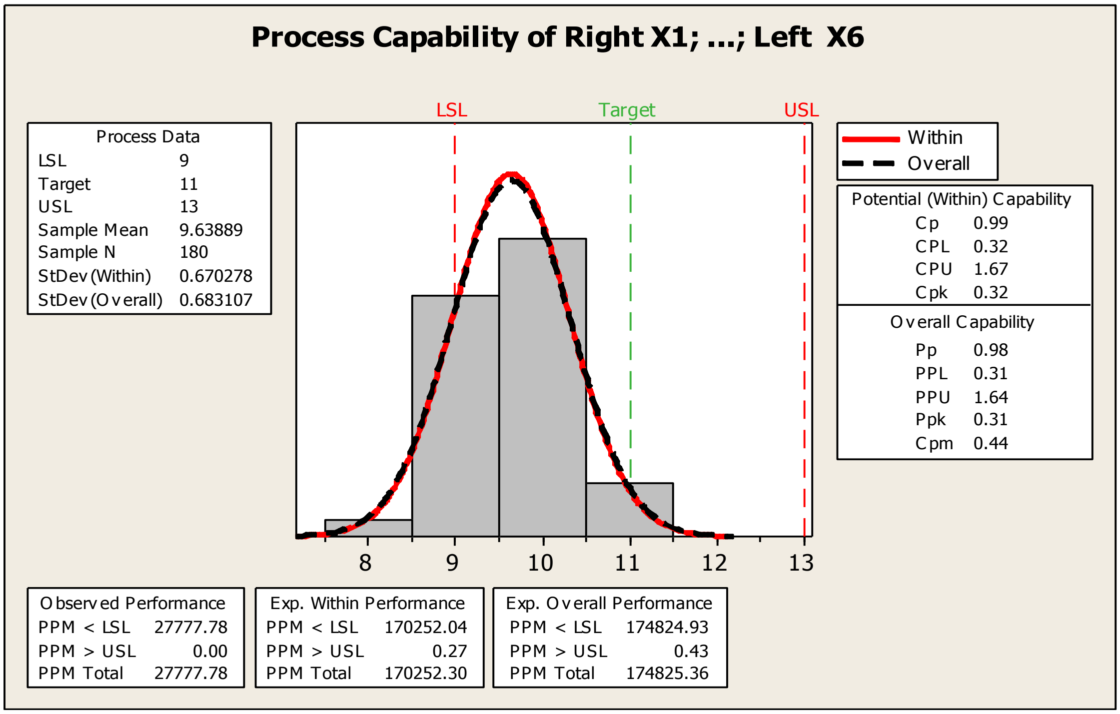


Figure 8. (R- chart) for pile height (Loom No 15)



Process Data	
LSL	9
Target	11
USL	13
Sample Mean	9.63889
Sample N	180
StDev(Within)	0.670278
StDev(Overall)	0.683107

Potential (Within) Capability	
Cp	0.99
CPL	0.32
CPU	1.67
Cpk	0.32

Overall Capability	
Pp	0.98
PPL	0.31
PPU	1.64
Ppk	0.31
Cpm	0.44

Observed Performance	
PPM < LSL	27777.78
PPM > USL	0.00
PPM Total	27777.78

Exp. Within Performance	
PPM < LSL	170252.04
PPM > USL	0.27
PPM Total	170252.30

Exp. Overall Performance	
PPM < LSL	174824.93
PPM > USL	0.43
PPM Total	174825.36

Figure 9. Histograms and process-capability analysis for quality (Loom No 15)