

Using Control Charts to Determine if a Process is in
Statistical Process Control

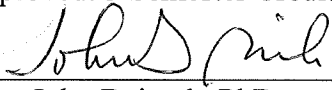
by

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ABSTRACT

Product performance and reliability of a product are the foundations that consumers use to identify and become loyal to a brand. A design that is easy to manufacture along with a robust process can ensure that a product meets its performance metrics consistently over time. Dr. Jeffrey Liker, Director of the Japan Management Program at the University of Michigan, understands the negative impact process variation has on consumers and products, and Like Dr. Liker, XYZ Company wants to minimize their variation.

XYZ Company has been manufacturing window units for over 80 years. The company is struggling with design and process capabilities in some of their window products. XYZ Company wants to know if the current process is capable of repeating its subassembly operations or if the window frame needs to be redesigned.

The researcher's intent is to determine if the process is capable of repeating the same operation within a set of upper and lower control limits. The study will use X-bar and R charts to calculate Cp and CPK. The researcher will analyze the data to determine if the amount of silicone is within the upper and lower control limits. Data collected at the product performance test wall will be used to isolate the location of the failure on the window units.

The amount of silicone applied by weight and the placement of the silicone at the side jamb and sill joint will be used to create the X-bar and R charts. The researcher will make and derive conclusions from the Cp and Cpk results and make recommendations for corrective action

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Chapter I: Introduction

XYZ is a window and patio door manufacturing company that has over 16,000 employees around the United States and Canada. The company has several assembly lines and several crews that operate either two or three shift operations in a five day work week. Each line has a slightly different function although they all have the ability to make each other's product. XYZ is an industry leader in the window and patio door market. It is important for XYZ to live up to the brand so customers can continue to enjoy the peace of mind of choosing the right brand when they purchase windows from XYZ. The researcher is going to focus the study to one double hung window assembly line.

Statement of the Problem

XYZ tests each of its products monthly for water and air infiltration. Units that fail the water infiltration design pressure (DP) level advertised for that unit need to have a 5-why analysis and corrective actions in place so the unit can be tested again. The findings from the 5-why analysis show the units that fail water infiltration have a poor silicone seal at side jamb and sill joints or side jamb and head jamb joints. The silicone sealant is either placed in the wrong location or the incorrect amount is applied during assembly.

The researcher wants to know if the amount of silicone applied to the joint causes a failure because it is a process issue or is a design issue with the window. In other words, if the process is capable of applying the correct amount of silicone in the correct place every time, will the unit still experience water infiltration failures that require a design change of the siliconed joints? XYZ is concerned that window units may be installed into a consumers home that does not meet water infiltration requirements. It is very important that the window units meet customer's expectations.

Purpose of the Study

The purpose of the study is to observe and record the amount of silicone applied to each joint and then to test the unit for water infiltration. The study will analyze the amount of silicone application and record the percent of failure for water infiltration, then analyze the process capability. Based on the study's finding, the researcher will recommend that the process be improved or that the joints need to be redesigned utilizing a different type of seal.

Research Objectives

- 1) To determine if the amount of silicone injected into the joints has a correlation to product performance.
- 2) To determine if the silicone placement results in failure.
- 3) To determine if unit size affects silicone amount and placement.
- 4) To provide recommendations to XYZ Company.

Assumptions of the Study

- 1) The historical data retained by XYZ Company is accurate.
- 2) The crew is unchanged and stays together.
- 3) The manufacturing conditions remained unchanged.
- 4) The associates at XYZ Company understand control charts and how to read them.

Limitations of the Study

- 1) The study is limited to one manufacturing plant.
- 2) The XYZ Company has limited budget dollars for testing.
- 3) The study is limited to the left side jamb and sill joint.
- 4) The study is limited to one shift and one work crew.
- 5) The study is limited to one size unit.

Definition of Terms

Sash: Sash is the glass and frame that slides up and down inside the window frame.

Side Jamb: A side jamb is the part of the frame of a window unit that is on each side of the sash.

Sill: The sill is the bottom part of the frame of a window or door.

Head: The head is the top part of the frame of a window or door.

Design Pressure: Design pressure (DP) is the combination of the amount of rain falling in a one hour period and the speed of the wind putting pressure on a window unit. For example, a DP of 40 is about one inch of rain per hour with a 49 mile per hour wind.

Crew: A crew is a group of associates that work together on one assembly line producing the same product every day.

Shift: The shift is a specific start and end time. Typically, a manufacturing company may run two or three shifts in a 24 hour day. XYZ Company calls the day shift 1st shift, and the afternoon shift 2nd shift. An over night shift is then the 3rd shift.

Venting: A term used to describe if sash in a window unit that opens.

Stationary: A term used to describe sash in a window unit that does not open.

Unit: A window unit comprises a window frame of left and right side jambs, a sill, a head jamb, and sash.

C_p: Process capability which is used as an indicator to determine if a process is capable.

C_{pk}: Process capability index that measures how close a process is running to its limits.

X-bar chart: The X-bar chart shows the means for the variable of interest, where the center line is the average of the subgroup means.

R chart: The R chart shows the range of values for the variable of interest, where the center line is an average range of the subgroups and shows variability of the process.

Quality Improved

Dr. Joseph Juran states there are two critical meanings for managing quality, the features of products that meet customer's needs and the product being free from deficiencies, Juran (1999). At XYZ Corporation, meeting the customer's needs and doing it right the first time have become a mantra on the manufacturing floor.

The cost of poor quality can be easy to calculate when one considers initial failure and warranty costs, but it is hard to determine as it affects the product brand. Usually, higher quality requires an investment which in effect increases the cost of a product. On the other hand, manufacturing a product that is not free of defects requires rework, which is costly. Juran notes that in the early 1980s, it was estimated that in manufacturing industries, one third of the work being done consisted of rework.

Juran (1999) states to attain quality, it is well to begin by establishing the "vision" for the organization, along with policies and goals. Conversion of goals into results (making quality happen) is then done through managerial process-sequences of activities that produce the intended results. The three points that Juran makes for quality activities are planning, control, and improvement. These points are called Juran's trilogy.

Variation

Dr. Walter Shewart looked at variability as being either within the limits set by chance, or outside those limits, Wheeler (1992). Dr. Shewart concluded that every process displays variation, some display controlled variation, some displayed uncontrolled variation. Controlled variation is considered to be stable and consistent over time and is referred to as random variation. Random variation is chance variation and is inherent to the process. Uncontrolled variation is variation that changes over time, called intermittent variation. Intermittent variation, assignable to a cause, is often referred to as special cause variation.

Assignable cause variation can be contributed to several different factors that have an impact on product performance. Most notably are differences in the four M's, man, machine, material, and method. The assignable cause variation not only causes defects in products, they are unpredictable. Shewart notes that when a process has assignable variation, that variation needs to be identified and either removed or exploited. To do this, a researcher needed to first determine if the processes was capable or incapable. Shewart developed control charts in 1924 to do just that.

Control Charts

A control chart is a chart with upper and lower limit on which values of some statistical measure for a series of samples or sub groups are plotted, Juran (1999). In essence, a control chart graphically shows variation by the computed and recorded statistics being produced by the process. Dr. Deming lectured that the control chart was a key concept to statistical process control.

Deming continued to state that “zero defects” is not good enough Wheeler (2000). The reduction of variation in the process results in parts that are nearly alike. To continue to reduce the variation, charts should be used to help search for and eliminate variation. Deming took his message to Japan in 1950 and the upper management understood the message and have been implementing it ever sense.

What makes the control chart such a useful tool is the fact that the chart can reveal the amount of variation by time, thus enabling the user to observe patterns for interpretation and the discovery of changes in the process. In addition, conducting a control chart analysis prior to conducting a six sigma calculation allows the six sigma calculation to reveal the true inherent process capability.

Deming did use caution for creating control charts, “Proliferation of charts without purpose is to be avoided” Walton (1986). Deming also placed emphasis on stopping people for chasing down causes and to properly understand a control chart.

Starting a Control Chart

A control chart is a tool to be used for continuous improvement of a process because it can reveal the chance and random variation, when the variation was introduced into the process by time, and what type of improvement may be necessary to eliminate the random variation. Control charts are used to:

- Establish a measurement baseline.
- Detect special or random cause variation.
- Monitor process over time.
- Confirm the impact of process improvement activities.
- To determine if the quality improvement activities should prevent specific problems or make changes to the process.

It is also important to determine the type of data that will be collected so the correct control chart will be used. Data can either be measurable, like length, and weight, and is considered continuous. Data can also be called classification data, like number of defects, and is considered attribute data.

Components of a Control Chart

The control chart has four main components:

1. The upper control limit (UCL): The UCL is the upper threshold or above which the process output is considered random variation and is three sigma above the data mean.
2. The lower control limit (LCL): The LCL is the lower threshold or below which the process output is considered random variation, and is three sigma below the data mean.
3. The center line: The center line is the characteristic mean of all the data collected.

4. Points on the chart: Data measurements collected over time plotted on the control chart.

The control chart has other components like a chart title and legend. A chart title helps the user determine the information displayed on the chart and the legend is used to provide information to the user about the data. The X-axis is the horizontal axis that shows time, and the Y-axis is the vertical axis that represents measurements, percentages, or frequency.

It is important to understand that the UCL and LCL are used to assist the researcher when looking for random variation. What the researcher does not want to do is search for random variation where there is not any, and not to search when there may be random variation present. Once the special cause variation has been found and eliminated, then the process is considered to be statistically controlled.

Interpreting Control Charts

Control charts are used to provide a graphical depiction of special cause variation. Special cause variation again is anything that is above or below the control limit. The control limits are set at three sigma above and below the data mean and the researcher will assume normal distribution. Control charts are a running record of the performance of a process and through data collection, offer a massive amount of information for possible continuous improvement activities. Interpreting control charts is an art that can only be developed by looking at many control charts and studying patterns to identify the underlying system of causes at work Pyzdek (2003).

When an engineer does not interpret the charts correctly, the manufacturing company can spend time and money on eliminating a common cause variation that has no effect on customer quality or product performance. In retrospect, that same manufacturing company can ignore random cause variation that results in rework, low product reliability, and employee frustration.

To assist the user in determining if the process is stable, run tests are preformed on the data and the control chart is broken into three zones from the data sets mean. Zone C is the zone that is plus or minus one sigma from the mean. Zone B is the zone that is plus or minus two sigma from the data mean, and Zone A is plus or minus three sigma from the data mean. Of course, any point outside of plus or minus three sigma is an indication of special cause variation. Using normal distribution, we can expect that 68.26% of the data points will be in Zone C, 95.44% of the data points will be in Zone B, and 99.72% of the data will be in Zone A. This helps the engineer to use run test to analyze the patterns of variation of the zones to see if a non-random pattern exists.

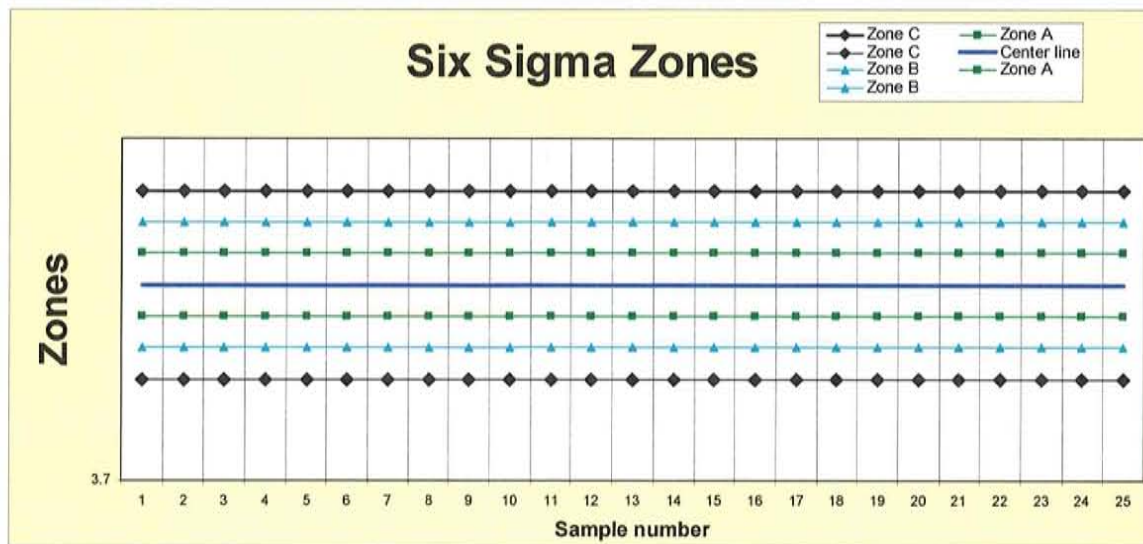


Figure 1: Six Sigma Zones

Control Chart Patterns

The control chart is used to assess a process's capability to repeat itself over time. Since every process has variation, it is important to understand how the data points on the control chart can be used to determine if a process is indeed stable. The data on a control chart should exhibit certain characteristics according to Juran (1999):

- Most of the plotted points occur near the centerline.
- A few of the points occur near the limits.
- Only an occasional rare point occurs beyond the control limits.

- The plotted points occur in a random manner with no clustering, trending, or other departure from a random distribution.

Again, data points that are above or below the control limits indicate special cause variation and have assignable factors. The chart can also indicate to the researcher out of control processes where the data is within the control limits as listed in George (2005).

Freak. Freak patterns are special cause variation that happen infrequently but have a large effect. In most cases, the freak pattern is an event that has taken place during the process. This event can simply be an introduction of an electrical surge into an electromagnetic coating booth, or a door being open to a paint chamber, or a manufacturing associate bumping a dial and quickly moving it back.

Drift. Drift happens in a process where the current process value is partly determined by the previous process state. For example, a dip tank that is used to dip metal parts into it before painting will collect debris over time, increasing its paint defects over time. Once the tank is cleaned; the data points resume normal distribution.

Cycles. Cycles occur when the process is modified, either the inputs or methods, according to a regular schedule. For example, autonomous maintenance to a machine may happen once per shift, showing a change in the data every eight hours.

Repeating patterns. A repeating pattern is a pattern where every n th data point is different. This type of pattern is non-random and can be hard to identify. It is sometimes useful to look for the average fraction defective is close to some known number of process streams.

Discrete data. Discrete data are data points that have only a few numbers that repeat over and over. This can cause problems because the R chart will underestimate the range. The UCL and LCL will be too close together and there may be false alarms of random variation. To resolve this issue, obtain gages with greater resolution and do not round numbers.

Planned changes. Planned changes on the control chart are used to document improvements. Since control charts serve as historical documents, realized improvements should be written on the control chart and the effect will be seen as less variation.

Suspected differences. Random patterns on a control chart are evidence of unknown causes and reflect instability. These so-called common causes need to be identified and then have planned improvement activities around them. This type of variation can be caused by different operators.

Shift. A shift in the mean is a characteristic of nine points in a row on one side of the average in Zone C or above. A shift in the mean may happen if a new process is implemented, new equipment, or different raw material introduced into the process.

Control Chart Types

There are two different types of data to be considered when determining the chart type, continuous and discrete. Continuous data can be measured on a continuum or scale and is infinitely divided. Examples of continuous data include characteristics like weight, height, density, and temperature. This type of data is preferable to discrete data because it is easy to measure and interpret. Researchers will select individual and moving range charts (ImR) for data with one subgroup, X-bar and R charts for data with subgroups less than 8-10, X-bar and S charts for data with subgroups greater than 8-10.

Discrete data or attribute data are other types of data that are not continuous. Examples are percentages and a count, like number of defects. Researchers will use c-chart and u-chart with a Poisson distribution, and np-chart and p-chart with a binomial distribution.

Successful Control Charts

At XYZ Corporation, reducing variability is a principal objective in the assembly area. It goes hand in hand with building quality into the process. Using control charts helps the associates and supervisor monitor their process to help with continuous improvement. By building quality into the process, the process immediately lets an operator know when a bad part is made. An operator can then determine what caused the defect on the spot, thus preventing the cause of the defect from recurring.

Control charts at XYZ Corporation are used everyday successfully to help managers determine what defects are going to be the focus for improvement activities. Control charts help to determine if the defect is related to process, operators, raw material, environmental factors, or endless other responsible factors.

Chapter III: Methodology

The problem that XYZ Company is experiencing is water infiltration on side jamb joints near the head and sill on window units. These joints have automated silicone applied to seal the joint and prevent water and air infiltration. The question that the researcher wants to answer is about the manufacturing process and the design of the joints. If the process is capable of applying the correct amount of silicone at the correct location every time, will the units still experience water infiltration errors at those joints? To make the process easier, the researcher wants to focus on only one joint, the head and side jamb, or the sill and side jamb. The following methodology will help the researcher decide which joint to focus on.

Shainin Methodology

Finding the right tool to attack and eliminate a quality error in your manufacturing process can be the most challenging aspect of problem solving. Dorian Shainin, founder of Shainin LLC in Anacortes, Washington, developed Shainin's methodology in 1957 where the researcher focuses on the root cause of a problem, the Red X, and eliminating it. Vinas (2003) notes that Shainin observed multiple sources of a problem, but one of the sources, called the Red X, accounted for nearly all of the undesired effects.

Finding the Red X. One of the methods of locating the Red X was to do a component search. The research would have two parts, a worst of worst (WOW) and a best of best (BOB), and begin to measure and identify the differences. For example, if a window unit had a water leak, the unit would become the WOW unit. The researcher would then find a BOB unit that did not leak and performed and start to examine the components. The units would start trading components one at a time. The researcher might take one sash from the WOW unit and install it in the BOB unit a look for a leak. The component swap would continue until the failure was replicated.

Finding a failing component does not mean the engineer has found the Red X.

Shainin LLC instructs their students that they need to earn the right to attack the Red X, meaning “take the Red X to court”. By proving that the problem that was identified as the Red X is the actual problem, the investigator needs to be able to turn the defect on and off like a light switch. Using this methodology helped the researcher define the problem and the key element causing the problem, the Red X.

Data Collection

The researcher was able to measure the amount of silicone applied to the area by weighing the corner key component. The corner key component has silicone applied to both sides and it will need to weigh 3.95 grams $\pm$.10 grams. The researcher then used a sample size (n) of 10 and collected 25 random groups (m) for a combined 250 recorded samples.

Chart Calculations

X-bar chart. The researcher used the recorded weights of the 25 subgroups with 10 samples in each to plot an X-bar chart. The centerline is calculated by first calculating the average value of each subgroup, and then finding the average of the 25 subgroup averages.

$$\bar{\bar{X}} = \sum \bar{X} / m.$$

The UCL and LCL of the X-bar chart was calculated using the A2 factor for n = 25, multiplied by your $\bar{R}$, which is the average of your ranges of the 25 subgroup. We now have our 3 σ estimate for $\bar{X}$. The formula for the UCL and LCL are calculated using the formulas:

$$UCL_{\bar{X}} = \bar{\bar{X}} + 3\sigma \bar{X}$$

$$LCL_{\bar{X}} = \bar{\bar{X}} - 3\sigma \bar{X}$$

The LCL is considered to be zero when the value of the calculated LCL is less than zero.

R chart. The researcher used the same data collected from the 25 subgroups to calculate the $\bar{R}$ value and the UCL and the LCL for the R chart. The centerline for the R chart is the sum of the 25 ranges from the subgroups divided by the (m).

$$\bar{R} = \sum R / m$$

The control limits for the R chart are calculated using the formulas:

$$UCL_R = D_4 \times \bar{R}$$

$$LCL_R = D_3 \times \bar{R}$$

Control Chart Factors							
n	A2	D3	D4	d2	A3	B3	B4
2	1.88	0	3.267	1.128	2.659	0	3.267
3	1.023	0	2.574	1.693	1.954	0	2.568
4	0.729	0	2.282	2.059	1.628	0	2.266
5	0.577	0	2.114	2.326	1.427	0	2.089
6	0.483	0	2.004	2.534	1.287	0.03	1.97
7	0.419	0.076	1.924	2.704	1.182	0.118	1.882
8	0.373	0.136	1.864	2.847	1.099	0.185	1.815
9	0.337	0.184	1.816	2.97	1.032	0.239	1.761
10	0.308	0.223	1.777	3.078	0.975	0.284	1.716

Table1. Control Chart Factors

Plotting X-bar and R Points on the Chart

The researcher is ready to plot the data on the X-bar and R charts once the mean of the subgroups is calculated and the mean of the ranges of the subgroups is calculated. Since the researcher collected samples from 25 subgroups, each chart will have 25 data plots.

Interpreting Capability Indexes

Cp. This capability index has been widely used and is considered one of the first capability indexes. The researcher used the Cp because it uses the natural tolerance of a process to be computed at six sigma. If the researcher assumes normal distribution and the process mean is centered, a Cp of 1 would be an indication of a capable process. To account for process drift, a Cp of 1.33 is generally accepted.

The larger the C_p , the more capable the process is. Using a six sigma process that produces 3.4 defects for every one million opportunities, the C_p is 2. If the process is centered, 99.73% of the population would fall between ± 3 sigma from the normal specification. The researcher needs to calculate the $\bar{R}$ value to use in the calculation to find the standard deviation and then the six sigma of the process.

$$s = \bar{R} / d_2$$

$$C_p = \text{Upper specification} - \text{Lower specification} / 6 * s$$

Cpk. Similar but slightly different than the C_p is the C_{pk} capability index. The C_{pu} and C_{pl} need to be calculated to find the C_{pk} . The C_{pu} is the index measure of the process location in relationship to the standard deviation of the upper specification. The C_{pl} then is the index measure of process location in relationship to its standard deviation of the lower specification. The C_{pu} and C_{pl} are calculated using the following formulas:

$$C_{pu} = (\text{upper specification} - \bar{\bar{X}}) / 3 * s$$

$$C_{pl} = (\bar{\bar{X}} - \text{lower specification}) / 3 * s$$

The researcher is now ready to calculate the C_{pk} , using the minimum value between C_{pu} and C_{pl} as follows:

$$C_{pk} = \text{Minimum} (C_{pu}, C_{pl})$$

The value of C_{pk} lets the researcher know if the process is truly capable of meeting the engineering requirements. Like the C_p value, +1 is necessary, +1.33 is desired, and +2 value is considered to be six sigma. The C_{pk} is different from the C_p value because the C_p will show the researcher the possible gain in the process by centering the process.

Chapter IV: Results

The purpose of this chapter is to use the data collected, enter the data in our X-bar and R charts, and calculate the Cp and Cpk. The results of the data will be used by the researcher to give a recommendation on the possible courses of action XYZ Company may execute in order to solve a critical quality issue. Before any recommendation can be made, the researcher wants to know if the current process is in statistical process control (SPC). Knowing if the process is in a state of SPC will determine the next course of action by the researcher.

Data was collected by the researcher on a double hung window unit that was produced on one assembly line by the same crew during the same shift. The researcher decided that 10 samples from 25 subgroups was sufficient data to develop an X-bar and R chart. The X-bar and R chart calculations are necessary to determine the process Cp and Cpk and since the data is variable and not attribute data, the researcher cannot use a p-chart

Determine the Red X

The first thing the researcher needed to do was find the Red X. Finding the Red X is different than using a fishbone diagram in the sense the researcher eliminates or does not investigate what is not causing the problem. A fishbone diagram has 5 categories:

- Facilities and Equipment
- Procedures
- Policies
- Workforce
- Effect

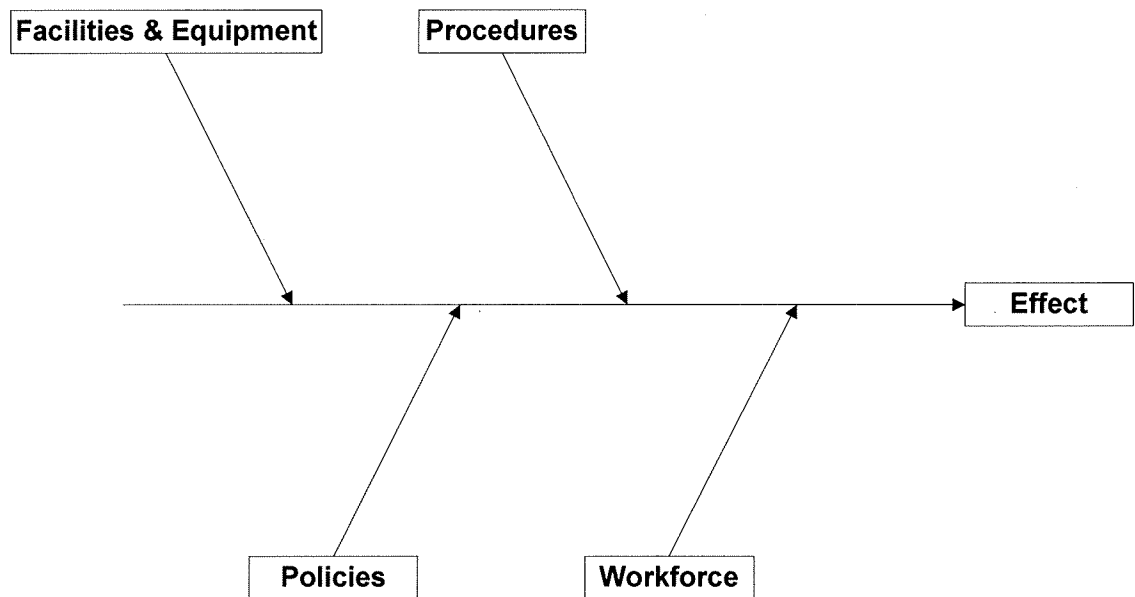


Figure 2: Fishbone Diagram

When using a fishbone diagram, a cross functional team is used to determine all the possible variables that could be causing the defect and lists them in the proper category. The researcher then goes to each possible cause, tests it, and determines if that is the cause of the unwanted defect. It is similar to a police officer trying to solve a crime by walking down the street and asking each person encountered if they committed the crime. Eventually the researcher will find the cause of the defect, but precious time and resources will be used when attacking a problem this way.

The idea behind the Red X is that one variable is causing the pain. When using a Pareto chart, an engineer will see that 80% of the defects are caused by only 20% of the variables. The Red X methodology uses this mindset to look for that one variable that is giving us the most pain. Once that variable is found and eliminated, the engineer can move to the next Red X and eliminate another variable giving the manufacture pain. Before a project can be started, a problem statement needs to be considered.

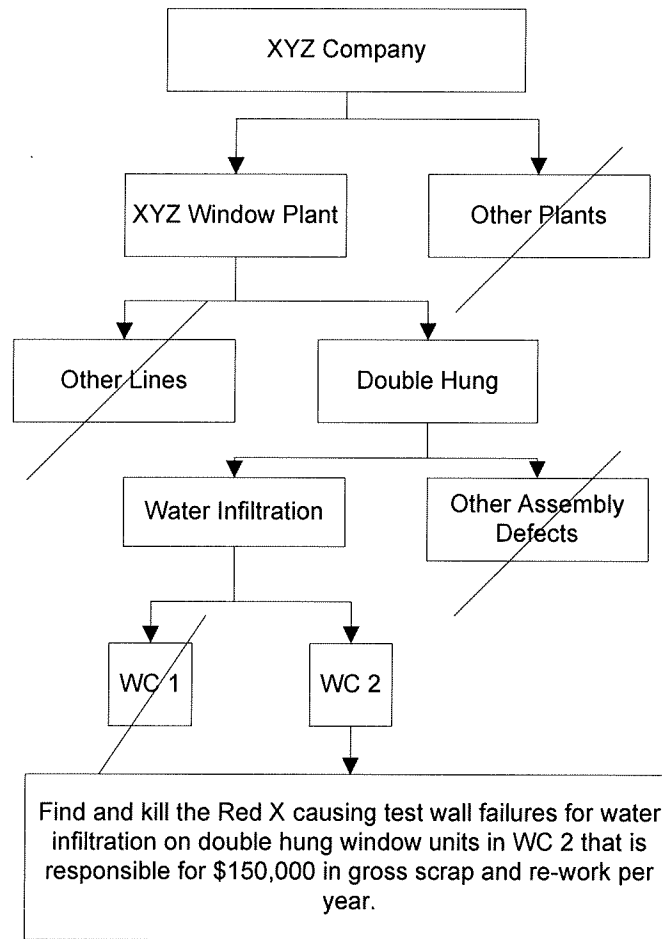


Figure 3. Problem Definition Tree

Now that we know what problem management wants the researcher to solve, it is time to find the Red X that is causing water infiltration. The researcher now collects BOB window units and WOW window units. The researcher would look for contrast between the BOB and WOW units. The following strategies are employed when looking for contrast:

- Point to point, same region. Where is the unit leaking?
- Region to region, same part. Is the leak at the head or sill?
- Part to part, same model. Does the leak vary by components?
- Model to model, same batch. Does the leak vary by unit size?
- Batch to Batch, same shift. Does the leak vary by line change over?
- Shift to shift, same time. Does the leak vary by shift?
- Time to time, same crew. Does the leak vary during the shift?

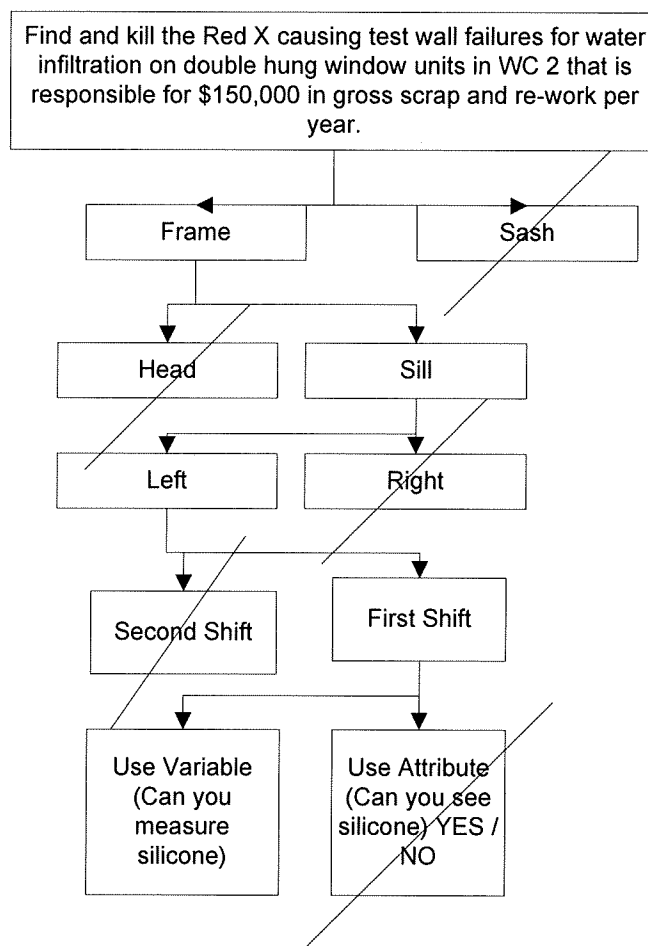


Figure 4. Project Definition Tree

The researcher is using this strategy to look for contrast between the BOB and WOW units. The method saves time because the researcher can eliminate possibilities that do not show contrast.

Using X-bar and R Charts

The X-bar and R charts are the most frequently used control charts because they are based on the Central Limit Theorem, where data has a non-normal distribution. Taking the averages of subsets, the X-bar, allows the data to normalize for statistical analysis.

When interpreting the X-bar graph, look for plots outside the upper and lower control limits. This is an indication that a general change has occurred that affects all the aspects of the product, like material, personnel, machine settings, temperature, and tool wear Juran (1951).

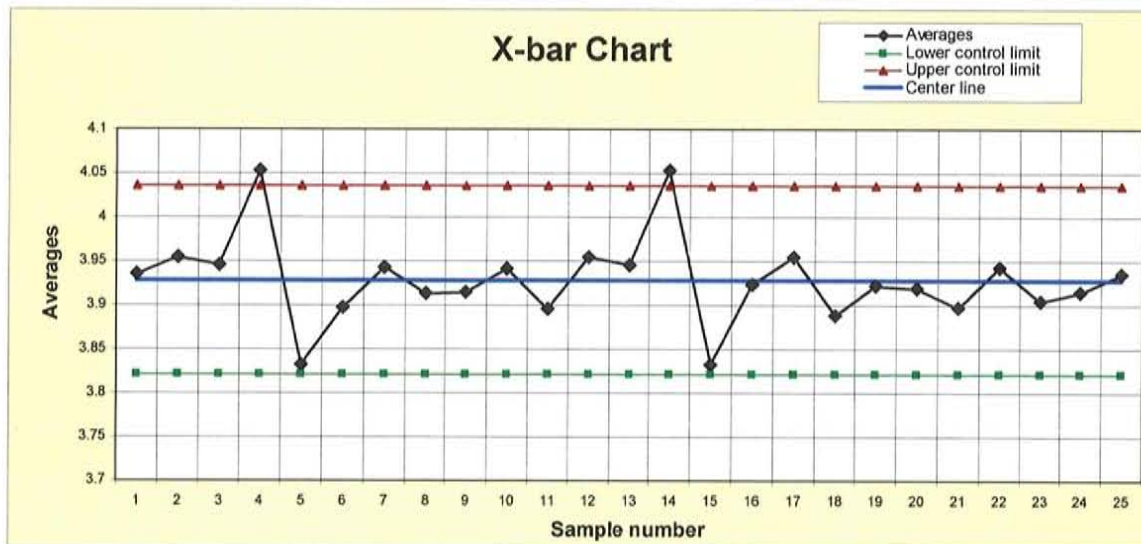


Figure 5. X-bar Chart

Looking at Figure 3, the researcher observes that subgroup 4 is above the upper control limit and the subsequent subgroup 5 is near the lower control limit. The pattern is repeated at subgroup 14 and 15. The plotted data tells the observer an event happened and the event repeated itself again.

The researcher discovered that the event was the switching over silicone barrels resulting in a surge of silicone and a large amount of silicone being applied and then trapped air in the line causing low silicone being applied.

When interpreting R charts, plotted points outside the control limits are a signal that the process has changed. Examples of this would include a change in personnel, increased variability in material, or excessive wear in the process machinery Juran (1951).

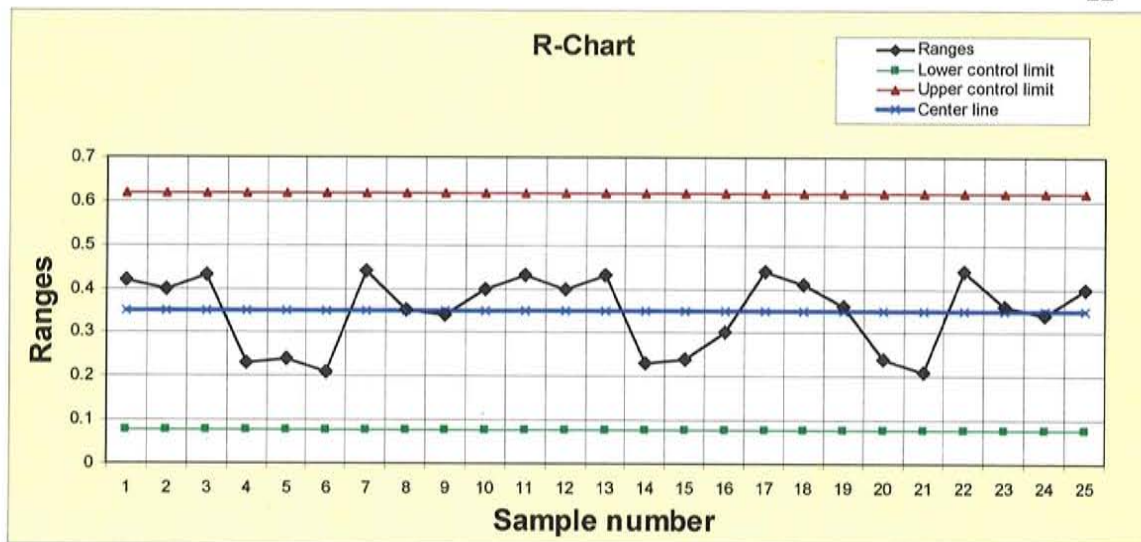


Figure 6. R Chart

The R chart does not indicate a significant change in the range of the process telling us that the event causing change in the X-bar is not a change in the process.

Cp and Cpk

The data that was collected is great; the X-bar and R chart help the researcher look at variations in the process and can make changes when the variation shows, but what management wants to know is if the process is capable of repeating itself over and over again without 100% inspection of each part.

The Cp will tell the researcher if the process is capable using six sigma and a mean that can be easily moved. The Cpk will tell the researcher if the process is capable using the minimum of the Cpu and Cpl using three sigma.

X-bar Average	3.928	A2	D3	D4	d2
Average Range	0.348	0.308	0.223	1.777	3.078

Figure 7. X-bar Mean, Range Mean and Factors

Process Capability Calculations			Six sigma	0.68
Upper specification	4.05		Cp	0.30
Lower specification	3.85		Cpu	0.36
			Cpl	0.23
			Cpk	0.23

Figure 8. Process Capability

The Cp and Cpk results show the managers and the researcher that the process being used to apply 3.95 grams of silicone to the sill joint is not capable over time. At a minimum, the researcher would like to see a Cp and Cpk of +1 and better yet, +1.33. The result of a Cp of +.30 and a Cpk of +.23 indicates that a change in the process mean will have little effect on the Cp and therefore a new process or design will be required.

Conclusion

The resulting data and statistical analysis using X-bar, R charts, Cp, Cpk give evidence that the process is not in statistical control and therefore is not repeatable. The engineering factor for the amount of silicone placed at the sill and side jamb is 3.95 grams $\pm$.010 grams. The average of the subgroup averages was 3.93 grams, within in .02 grams of the engineering requirement. The upper specification is then 4.05 grams and the lower specification is 3.85 grams, a range of .20 grams. The average range of the subgroup ranges was .35 grams, .15 grams greater than the engineering requirement.

The next step for the manufacturing engineers is to determine what is causing the process to have a significant difference in the range of silicone applied. The manufacturing area has temperature and humidity changes and machines heat up over the course of production. The viscosity of the silicone is affected by temperature and humidity. Unfortunately, in order for the process to have a Cp of + 1.28 and a Cpk of + 1.10, the range of the amount of silicone would need to be .08 grams, which is a delta of .23 grams from the current state.

Recommendation

The recommendation the researcher will make to management is to look at design changes that incorporate different ways to seal joints. Besides silicone, improved gaskets have the ability to seal joints and prevent air and water infiltration. Another suggestion would be to incorporate current technology and use an outer frame with a vinyl skin over the side jamb, sill, and head area and eliminate the joint altogether.

The researcher may want to do a design of experiment (DOE) to determine if and what the interaction may be with regards to air temperature, humidity, and machine temperature and how it affects the viscosity of the silicone and if the change in viscosity results in a change in the amount of silicone applied to the subject area. The null hypothesis is that there is no difference in the factors and there is no interaction. The researcher can also do an analysis of variance (ANOVA) one factor or two factor to determine the variables that are affecting the range of the silicone application. The null hypothesis would be that the air temperature does not affect silicone viscosity.

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