IE 508: Quality Assurance
Mini-Project 5: Process Control
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Identify critical operations in a process where inspection might be needed. Select an operation in which the product or service will be negatively affected if the operation is performed improperly.

There are multiple processes we work on every day that require the use of water. Water is considered an essential product for our daily lives, it has multiple purposes for cooking, cleaning, gardening, drinking, bathing, and more. Natural water is made up of dissolved elements such as sodium, calcium, and magnesium. According to the United States Geological Survey (USGS), water hardness is defined by the number of elements in water [1]. There are numerous issues that arise due to the presence of hard water in the home such as the presence of limescale on various appliances such as showerheads, heaters, and dish waters, this limescale may cause damage to appliances and can also affect the plumbing system at home. The film observed on dishes when unloading a dishwasher is the scum effect of water hardness. Soap and shampoo may not later up easily cause one's hair and skin to appear dull and irritated, which can cause various skin inflammations and other similar skin conditions. Moreover, there has been evidence accumulating the fact that hardness of water is influencing mortality, in particular cardiovascular mortality [2]. In addition, the USGS suggests that heated hard water, in water heaters or coffee makers, form solid deposits of calcium carbonates and cause pipes to be clogged, reduce the efficiency and life of the equipment [1].

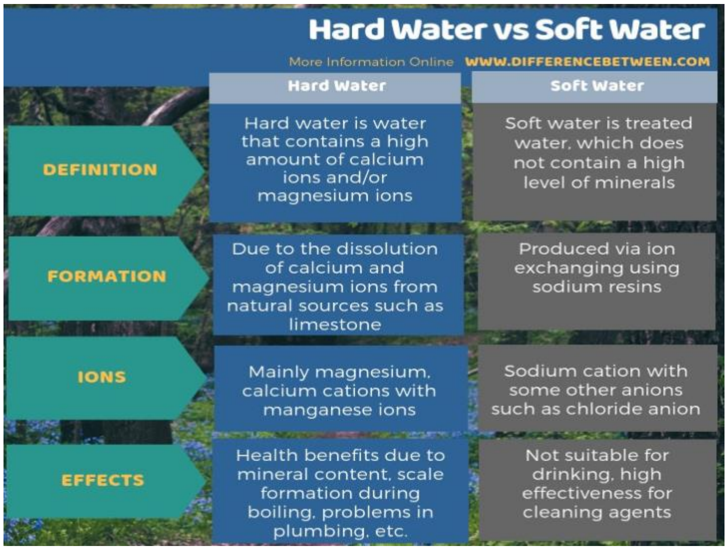

Figure 1. A comparison chart of Hard Water vs Soft water

For the purpose of this experiment, the processes are the different uses of water such as cooking, cleaning, watering the garden, laundry and other daily activities. The critical operation involves inspecting water hardness levels using a TDS meter for different uses. In other words, we have the inspection process of hard water that is used, at the same time we calculate the quantity of water needed for each process approximately.

Figure 2. TDS meter used to collect water hardness

If we are not able to collect the hardness levels from the tap water that is provided to our homes, we will not be able to estimate how much exact water we can need for the next processes. We can propose a variety of optimizations, for example if we want to reduce the consumption of water to pay less or if we want to boil vegetables.

Identify critical product or service characteristics. A critical characteristic will be an aspect of the product or service that will result in either good or poor functioning of the product or service if not performed well. Explain why (or how you know) the characteristic you have identified as "critical."

We can define hardness of water as the quantity or concentration of different minerals in tap water, common minerals we can find in tap water are calcium carbonate, magnesium and Lime. These characteristics define different processes results and can affect other factors depending on the use of the water, for example a hard water will have a different effect in comparison to soft water when you take a bath, or maybe we will have different boiling times depending on how hard the water is.

Water collected every hour, maybe characterized by color, temperature, hardness, and visual effect (scum or no scum). Watercolor was determined to be an attribute characteristic that was the result of water hardness, therefore the water hardness level was determined to be the critical characteristic. In addition, the water temperature that the water was dispensed at was another characteristic in this process. However, in this experiment the water temperature was kept the same for all samples at (room temperature or warm water or medium temperature).

Characteristics	Type	Process Step
Water Hardness	Variable: reading from the digital meter	When 4 consecutive samples are collected every hour
Color	Attribute: Clear, lightly colored, colored	When 4 consecutive samples are collected every hour
Temperature	Variable: reading from a thermometer	When 4 consecutive samples are collected every hour

The desired performance we want for our water will be based entirely on what it will be used for. If we use it for boiling and cooking food, it is obviously necessary to have a low to a moderate level so it boils in less time, on the other hand for drinking purposes, a moderate level of hardness will allow us to get more minerals for our body.

Determine whether the critical product characteristic is a variable or an attribute and justify this decision. Based on your understanding of the process and the characteristic, establish specification limits for the characteristic. State a quantitative objective relative to the specification limits that you believe needs to be achieved.

The hardness of water is categorized as a variable because it is represented as a numerical value of the unit milligrams per liter (mg/l), which is the standard unit to measure the quantity of minerals in water. According to the world health organization, hardness in water is classified by the following types according to its concentration value:

Quantity	Type
< 60 mg/l	Soft
60 to 120 mg/l	Moderate
> 180 mg/l	Hard

According to the U.S geological survey, the water hardness in Buffalo is estimated to be between 114-124 mg/l which according to the table is considered between moderate and hard water and a given average of 118 mg/l (average value is almost at the limit but it is considered still moderated). Values are determined by different factors such as the water treatment process, chemicals used for the treatment. These previous values will be a set standard for the control charts as well.

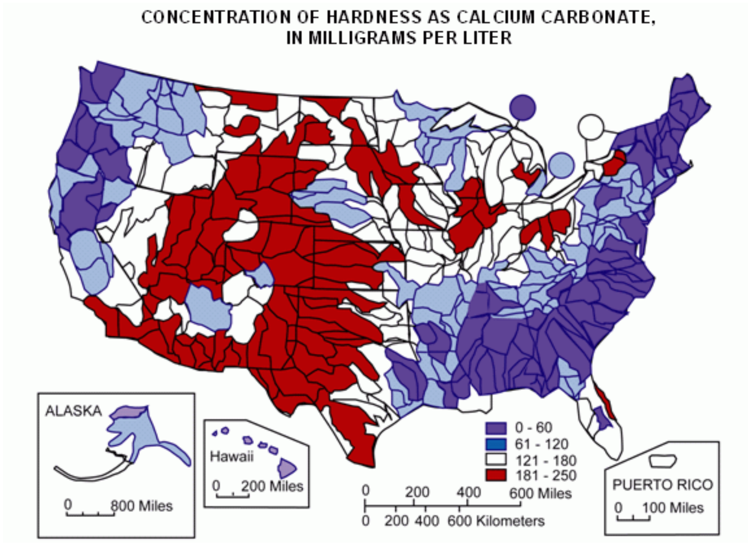

Figure 3. Water Hardness levels map

Specifications limits are initially selected as 114 to 124 mg/l, these will help us determine if the water process treatment is under control, we can make other specifications limits but these specifications will be considered based on the desired purpose for the water. For example; a suggested quantity of water to drink per day is 2 liters, considering a maximum ingested quantity of 6 liters per day, health-related issues can occur if we fall outside these 2 limits. So according to the previous values of the hard water, new specification limits can be obtained with the unit mg/l 236 mg/l to 708 mg/l (on an average value of 118 mg/l).

For each desired purpose many specifications limits can be made as an alternative with their respective objective value. To summarize, the current process we will define the objective as the average value provided by the U.S geological survey, which is 118 mg/l, what we are trying to prove with the future control charts is to see if the values provided are correct and they represent the estimated water level hardness in Buffalo.

Select the appropriate process control chart to use from among the many types of control charts available to determine the state of control and justify this decision. Explain why the chart you have chosen is the best control chart for the situation.

Figure 4 is a tool available in Minitab 19, used to select a control chart type. Control charts are selected by the data collection type; such as continuous process data, multivariate process data, or attribute process data. In the water hardness inspection process, measurements were recorded at every hour from 2:00 PM to 2:00 AM, therefore the data type in our process is categorized as continuous. Measurements were recorded at every hour from 2:00 PM to 2:00 AM. Since a subgroup size of $n = 4$ measurements was recorded every hour (under the same conditions), **the Xbar-R chart was used to analyze the data.**

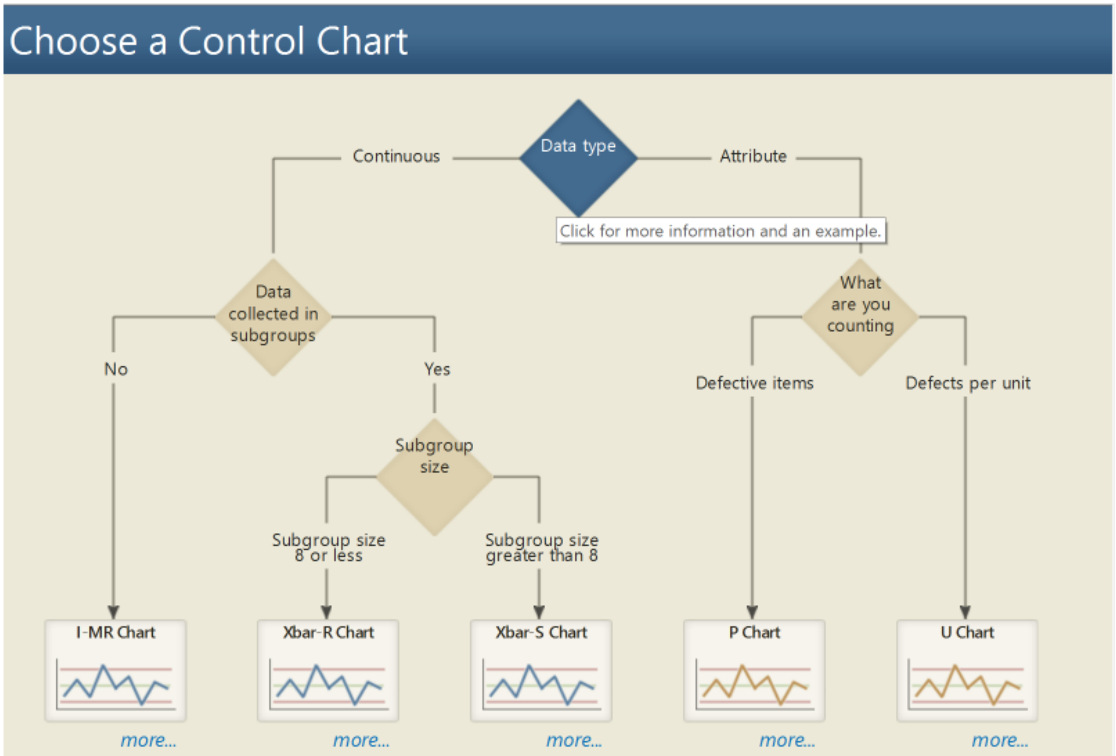

Figure 4. Choose a Control Chart from Minitab 19, Assistant > Control Chart

Figure 4 illustrates the preliminary Xbar-R chart of hardness level. From the R-chart, an average range being 7.92 mg/l was obtained. However, the R-chart suggests the process variation may not be stable since point 3 failed test 1 for falling 3 standard deviations away from the center line and may affect the validity of the control limits in the X-bar chart. Looking at the X-bar chart, a process mean of 121.85 mg/l was obtained. However, the figure suggests the process mean may not be stable because subgroups 1, 4, and 8 failed test 1. Compared to the specification limits of 114 to 124 mg/l, the upper control limit of 127.62 mg/l does not fall within the specification limit. In addition, a cyclical and shift/drift trend can be observed in the R-chart, indicating possible special causes. A possible special cause identified was not calibrating the measuring device at each hour. Therefore, point 3 was omitted, and an R-bar value of 7.0 mg/l was obtained in Figure 6. The updated R-chart suggests the process variation is not in control since subgroup number 3 failed test 1. Next, a process mean of 121.85 mg/l was obtained in the Xbar-chart. However, the chart suggests the process mean may not be stable because subgroups 1,3, and 7 fail test 1. In addition, the estimated upper control limit does not fall within the acceptable specification limit.

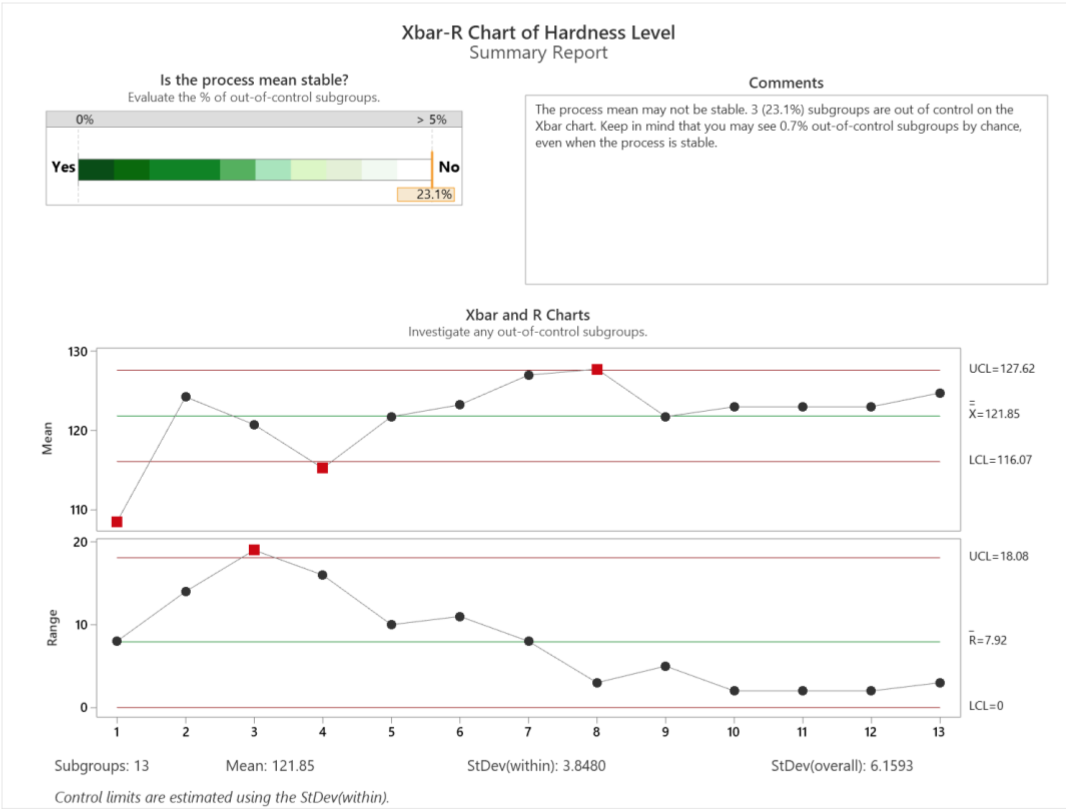

Figure 5. Xbar-R Chart of Hardness Level

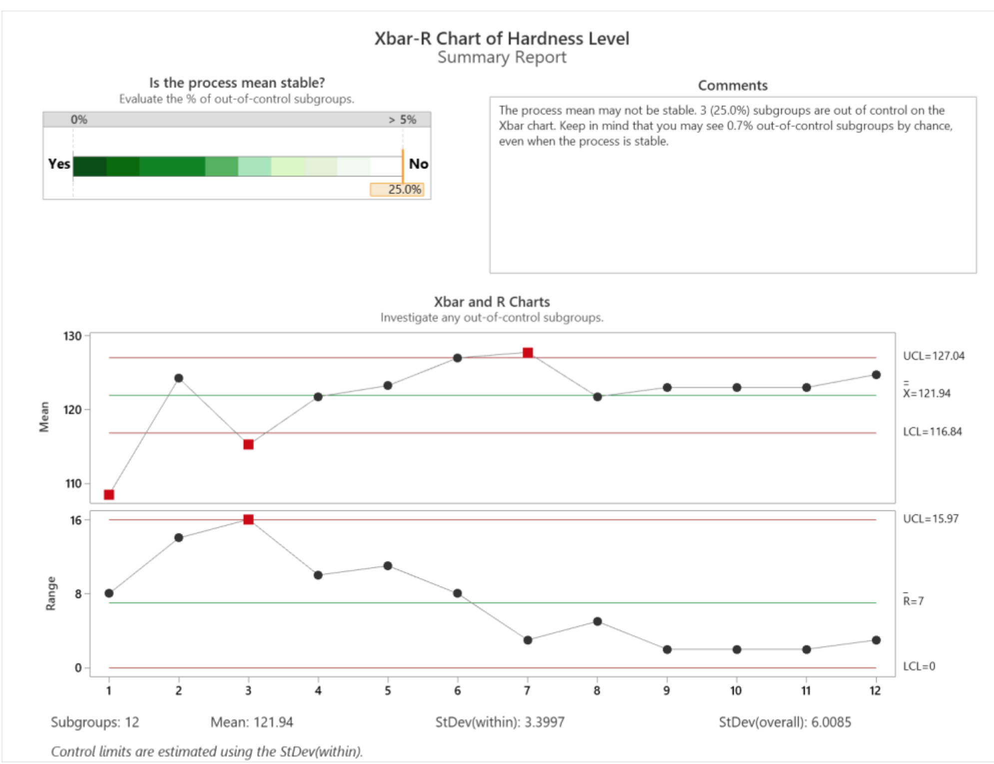

Figure 6. Xbar-R Chart of Hardness Level with data point 3 (4:00 PM) omitted.

The following data considerations for the Xbar-R charts were verified:

1) Data should be continuous.
2) Data should be in time order.
3) Data should be collected at appropriate time intervals.
4) Data should be in rational subgroups.
5) The subgroup size should be 8 or fewer observations.
6) Collect the appropriate amount of data.
7) Data does not need to be normally distributed.
8) The observations within each subgroup should not be correlated with each other.

Requirement numbers 1, 2, 3, 4, 5, and 7 were met. Data was collected in rational subgroups of subgroup size = 4 at each time interval of 1 hour. However, Figures 5 and 6 suggest more data should be collected to obtain precise control limits to satisfy requirement number 6. In addition, a degree of correlation of r = 0.7 was observed between consecutive data points subgroups resulting in narrow control limits. However, additional data points need to be collected to estimate the standard deviation and control limits of the observations.

Collect data and establish control limits. Use the chart to continually monitor the process for at least 4 days and determine process capability using the specification limits determined in step c above. Interpret both the control chart results for the 4 days performance and the process capability.

The data was collected through the 4 consecutive days and has the following specifications: 4 consecutive cups of tap water are tested each hour and recorded for 10 hours. The measuring cup was used to take a sample of water of 100 ml. To prevent any possible variation, we have to make the measurements at the expected times to obtain the desired data value.

With the early collected data, we proceed to build the control charts

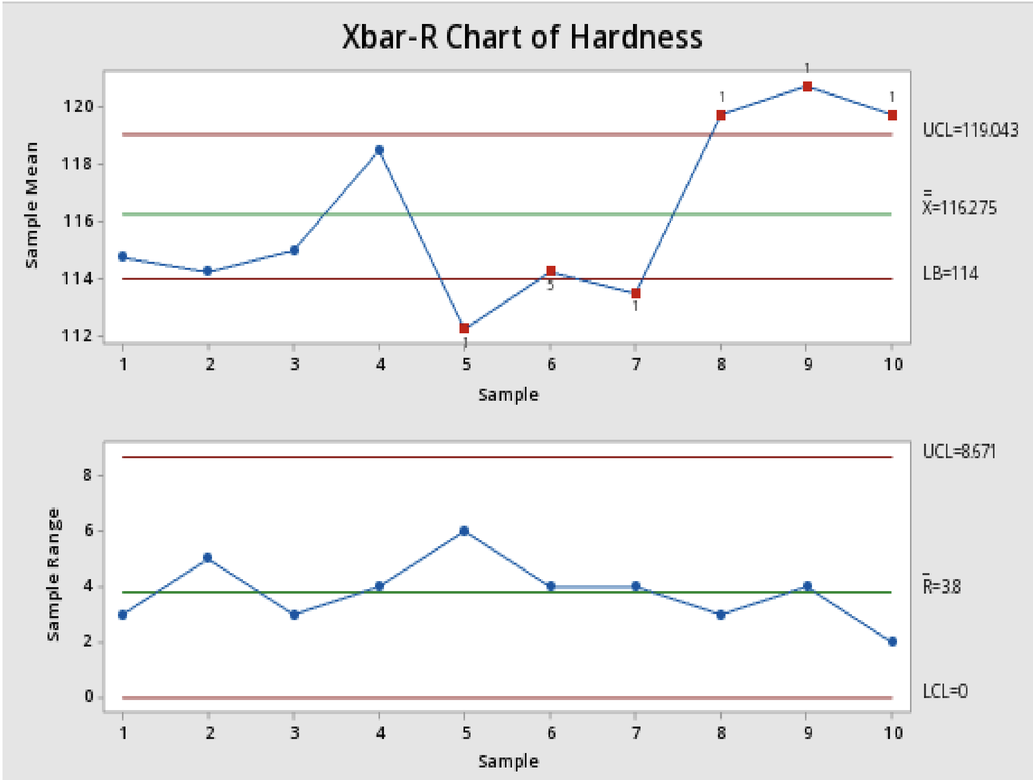

Figure 7. Xbar-R Chart of Hardness Level (After improvement)

The R chart shows that the **process variation is in control**. Thus, the control limits set are accurate. In this case, we set the control limits based on the general understanding of water hardness levels as described above.

No data points are out of control and fall within the control limit in a random pattern.

We use the X-bar chart to assess if the process center is in control. Minitab 19 conducts upto 8 special-cause variation tests.

The data-points 5, 8 and 9 failed ‘Test 1’ (One point more than 3 standard deviations from center line) which suggests that the process is still not in control due to the possibility of some special cause. Further analysis is required to identify the special causes and bring the process in control.

‘Test 5’ (2 out of 3 points more than 2 standard deviations from center line) provides additional evidence that the process needs improvement.

However, we observe that the UCL is 119.043 which is well below our acceptable UCL.

Further, we carry our process capability analysis to quantify the capability of our process.

The process capability analysis will give us the following chart:

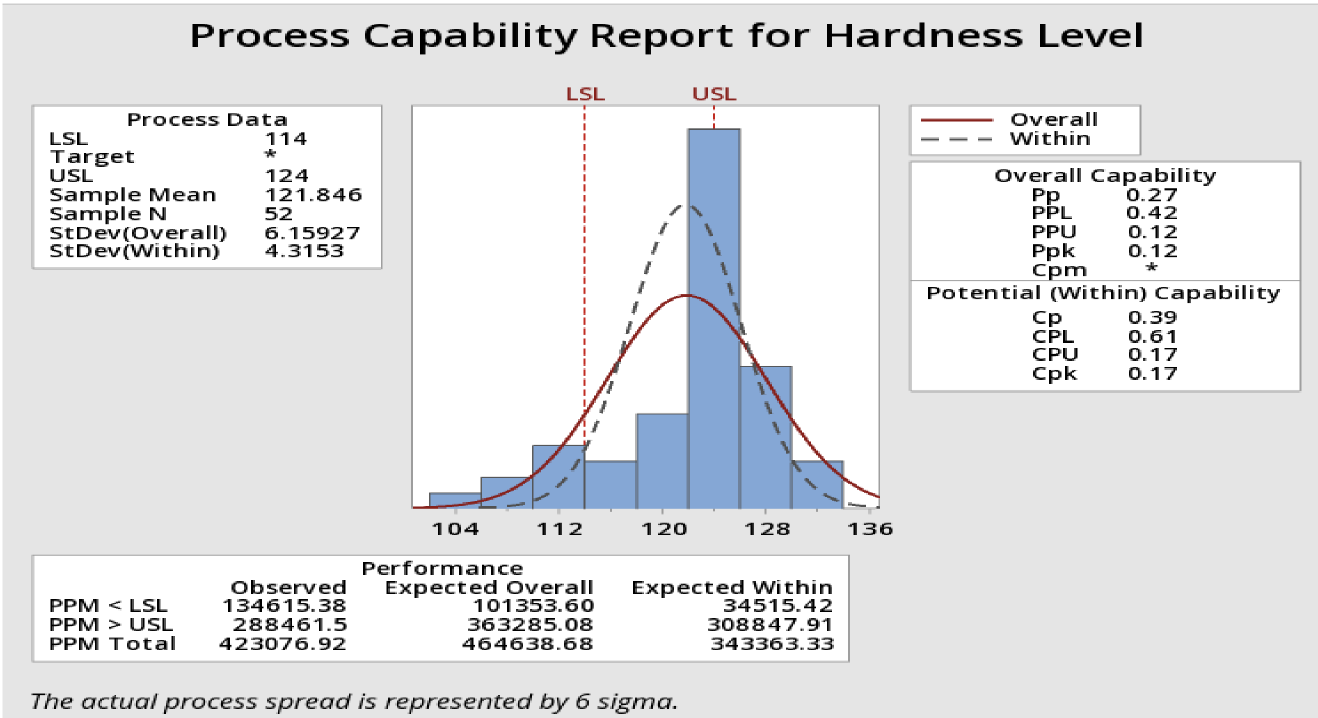

Figure 8: Process Capability Report for Hardness Level of Initial Data

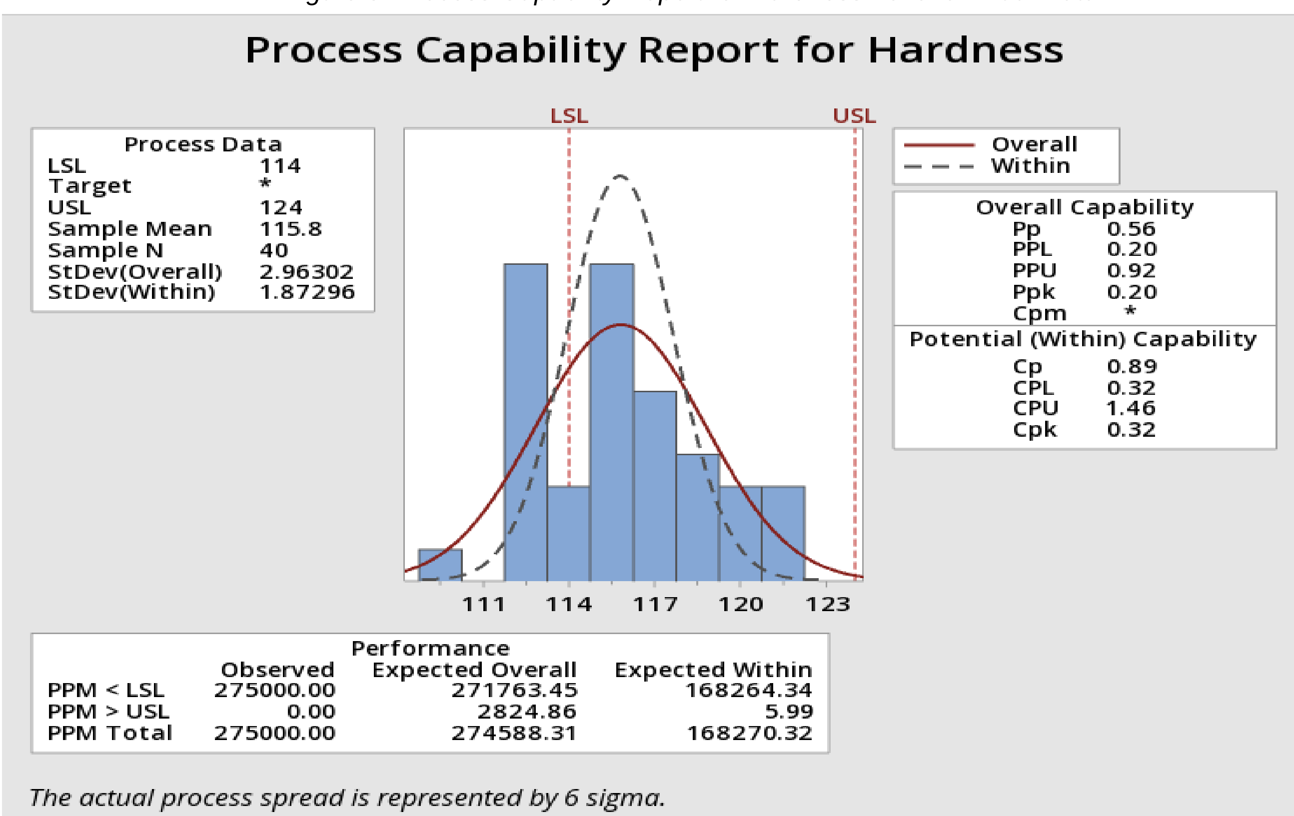

Figure 9: Process Capability Report for Hardness Level collected through 4 days

The first important step is to visually examine the distribution fit. We first compare the solid overall curve to the bars of the histogram to check if the data is normal. If the bars are varying greatly then the data may not be normal and estimates of capability wont be reliable for process. In the above report we can see our data is normally distributed.

Next we compare the within and overall curves . We compare the solid overall curve and dashed within the curve to see if they are closely aligned. If the difference is substantial then it indicates that the process is not stable and we need to verify the process stability by using a control chart.

We examine the process spread by visually examining the lower and upper specification limit. Ideally spread of the data is narrower than the specification spread which means all data are inside the specs limit. The data outside the these limits are nonconforming items. Then we access the center of the process i.e targeted value. This is estimated by the sample mean at the peak of distribution.

CpK is a standard index to state process capability. A higher CpK value indicates a good in-control process. It used specification limits and parts variation. The initial CpK value was 0.17. After identifying certain causes of variation, we got a value of 0.32. It is evident that there is a need to identify other special causes of variation, to further improve process capability.

<u>Chart analysis summary:</u>

- Capability analysis: Cpk values are lower than 1.33, meaning that the process still needs improvement to reduce variation or shift
- Cp is different from Cpk in a moderate quantity, meaning that the process is not centered.

We can clearly see with the collected data and with the specification limits that the process has a lot of variability this means that the inspection process will need to be improved as well the determination of the reference values, the reference specification limits are levels suggested by the government, but is seems these values are not as exact as it its mentioned. A final recommendation would be to use our own set of values for limits to determine the hardness of water and to see if the water provided has a lot of variation within its hardness levels, since the limits provided by the government has a lot of variability and does not match with the water we have in our homes.

References

1. “Hardness of Water.” *Hardness of Water*, The United States Geological Survey (USGS), www.usgs.gov/special-topic/water-science-school/science/hardness-water?qt-science_center_objects=0#qt-science_center_objects.

2. Potential Health Impacts of Hard Water

   https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3775162/

Collected Data

1. Initial data collected to determine the control charts

Time	Rep 1	Rep 2	Rep 3	Rep 4	Avg.
2:00 PM	104	106	112	112	108.5
3:00 PM	117	124	131	125	124.25
4:00 PM	125	112	115	131	120.75
5:00 PM	108	112	117	124	115.25
6:00 PM	128	121	120	118	121.75
7:00 PM	121	118	125	129	123.25
8:00 PM	132	124	126	126	127
9:00 PM	126	128	128	129	127.75
10:00 PM	119	124	122	122	121.75
11:00 PM	122	124	123	123	123
12:00 AM	117	118	121	122	119.5
1:00 AM	131	127	128	128	128.5
2:00 AM	127	124	124	124	124.75
11:00 AM	115	121	119	119	118.5
12:00 PM	108	116	115	116	113.75
1:00 PM	121	117	119	119	119

2:00 PM	118	121	119	120	119.5
3:00 PM	112	116	116	119	115.75
4:00 PM	122	118	120	120	120
5:00 PM	119	115	108	110	113
6:00 PM	110	114	116	116	114
7:00 PM	112	118	119	119	117
8:00 PM	117	121	119	120	119.25
9:00 PM	121	117	119	119	119

2. Summary of data collected through the 4 days (subgroup size 4)

Hardness			
116	114	112	118
116	117	113	120
114	117	116	119
113	117	116	121
112	119	116	120
113	121	113	117
115	109	113	115
117	112	112	115
114	113	121	119
115	115	120	117