King Fahd University of Petroleum & Minerals

System Engineering Department

Quality Control and Industrial Statistics, ISE 320

Term 221

Course Project

Topic: Coffee Shops

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Abstract

The objective of this project is to present several applications of statistical process control (SPC) in maintaining and improving the quality in coffee shops. It is found that the critical quality characteristic can be observed in the weight of the coffee in every shot of espresso. The goal here is to minimise the variation by constructing a full SPC plan, determining the cause of variation, designing an active out-of-control action plan, and executing the X bar and S chart with the phase I analysis.

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I. Introduction

Statistical process control (SPC) is the application of statistical methods to monitor and control a process to ensure that it operates to the fullest potential while reducing variability and improving customers experience [1], product quality is a critical factor nowadays, poor product quality can affect the reliability of the product, the safety of the consumer and the profitability of the business, on the other hand, high-quality products can improve the perceived value of the product in the consumer's eyes and reduce scrap and rework rates[2]. Control charts are an essential tool to monitor a process [3]. There are different types of control charts: X-bar (mean) chart, R (range) chart, S (standard deviation) chart, EWMA (exponentially weighted moving average) chart, among others.

The coffee industry has been growing immensely in the past few years in Saudi Arabia with the industry being valued at 6 billion riyals in 2020 and with many new competitors entering an already swarming market [4], quality management and control have emerged as an essential part of the success and growth of new and existing coffee businesses.

The objective of the report is to utilize the tools of statistical process control and apply them practically in a real-world example using data obtained from a coffee shop.

Ame House, A café in Riyadh, were generous enough to help in this study by allowing us to collect the data needed and providing us with some information regarding their processes.

II. Source of Variation

There are multiple sources of variation that contribute to the quality of the final cup of coffee, where they affect the quality of the process, and some of which can be controlled, and others cannot be controlled. Such as:

1. **The barista:** A barista is a person whose job involves preparing and serving different types of coffee. This is the human factor involved in making the coffee. The barista is contributing in every stage of the coffee making process, starting from grinding to tampering the coffee all the way to inserting the portafilter in the machine.

2. **The portafilter:** is a spoon-looking device harbors a basket which is actually what holds the coffee grounds during the pulling or extracting of the espresso shot. There are different sizes of portafilters and different openings which serves different purposes.

3. **Filter basket:** a metal filter designed to be used with ultra-fine coffee and under high pressure. Clogged filter is considered a critical issue, preventing the pressurized water to pass through.

4. **Automated coffee grinder:** A device that is used to grind whole coffee beans into a suitable size for brewing. In our case, an automated grinder is used. The source of variation here can be observed in the accuracy of the grinder and the radius in which the coffee is existing.

5. **Tamper:** A tool used to create resistance (with evenly compacted coffee) that makes the brewing water work hard to saturate the grounds and extract all of the coffee flavor. The radius and the allowance (the different between the diameter of tamper and diameter of the portafilter opening) play a huge role, controlling the amount of the excess coffee.

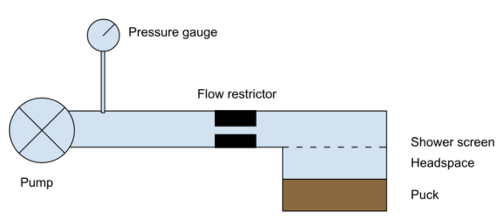
6. **The coffee beans:** The coffee itself is a very important factor in quality, whether in terms of the coffee source, or the preparations. When it comes the source of the coffee, multiple factors can cause a variation in the quality such as, the soil, the region in which the coffee was grown in, and the season of the harvest. In terms of preparations, coffee quality can significantly varies due to the grind size, the temperature of the water, the pressure of the water and other factors.

7. **The espresso machine:** A machine that brews coffee by forcing pressurized water near boiling point through a "puck" of ground coffee and a filter in order to produce a thick, concentrated coffee called espresso. According to the head barista at Ame House café, different machine results in different profile of flavors. In the high quality machine, an adjustable water pressure can be optimized to achieve the desired flavor.

III. Quality Characteristics

1. **Espresso brewing time:** The total time the coffee grinds spent in contact with the water. Espresso brewing or extraction time is of primary importance when it comes to enjoying quality coffee. Espresso is not just an espresso, it also forms the basis for many types of coffee. That's why espresso extraction time is so important for delicious coffee. The brewing methods of the coffee are as important as the brewing time. Shorter brew times are ideal for darker roasts, while lighter ones need longer brewing time. Roasts are shallower or less dense, and it is easier to extract flavour from them. On the other hand, lighter roasts are denser. Hence, it requires more time to extract its flavours. Just like everything in this world, coffee has its "unique spot" in terms of brew time.

2. **Pump Pressure and Flowrate:** The flow rate of an espresso machine is a measurement of how much water passes through the grouphead while the pump is active. Pressure requires two things to exist: something to generate the movement of water (the pump) and something downstream that tries to stop it. The power of the pump to move the water, and the resistance it encounters, determines the amount of pressure in the system — no restriction, no pressure. For example, the pressure of a fluid after its last restriction is always zero. It is the restriction itself that is necessary to build pressure, which means that if the outlet of the pump is wide open, it is not developing any pressure at all. In fact, the bypass is completely closed.



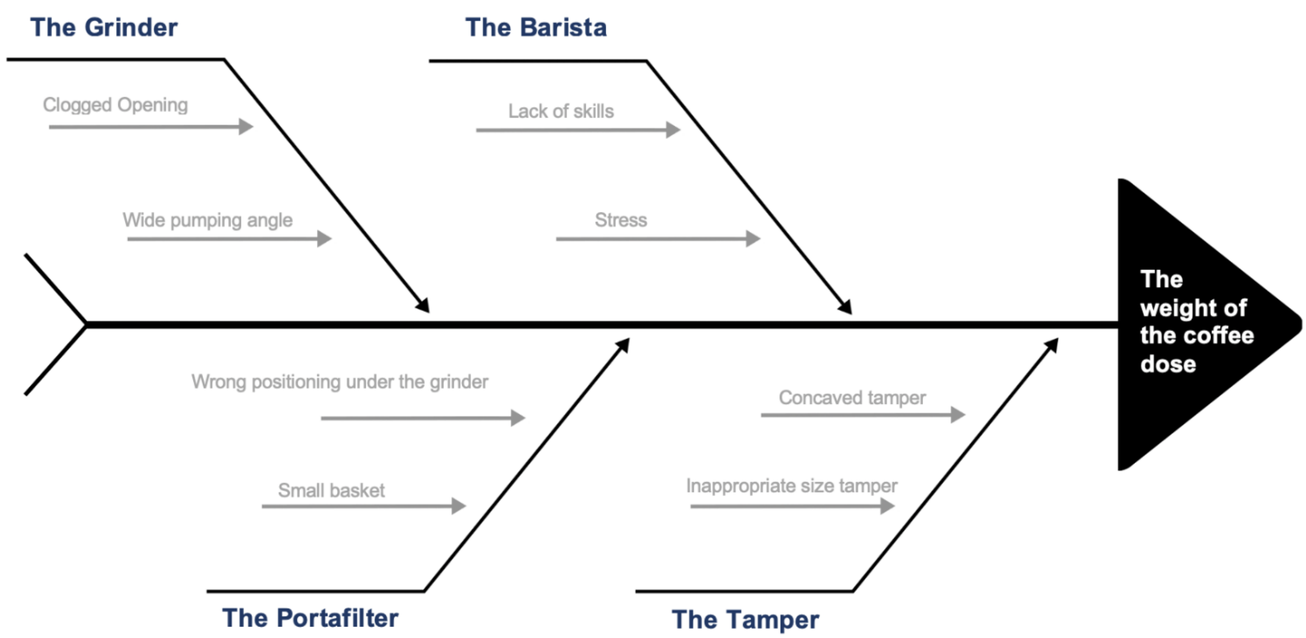
"Schematic of the route water takes to reach the coffee"

3. **Grind size:** Coffee grind size is no small matter. Controlling this variable allows you to improve the taste of your coffee, ensure repeatability, experiment with recipes, and more. With an array of different brewing methods, knowing which grind size to use is crucial to getting the best possible cup. There are seven major sizes of coffee grinds, extra coarse, coarse, medium-coarse, medium grind, medium-fine grind, fine grind, and extra-fine grind. Espresso is a brewed through using pressure (approximately 9 bar) to force water through compacted coffee grounds. The contact time is very short, requiring an extra fine grind size.

4. **The weight of the coffee dose:** The dose or dosage refers to how much ground coffee is being used in our brewing system. A larger dose will allow you to brew more espresso and a smaller dose will yield less espresso. Espresso recipes generally speaking can be scaled. In the case of espresso, we must first decide on which portafilter we want to use; either the single or double spouted portafilter. Sitting inside the portafilter is a filter basket held in place with a spring. This is the most critical quality characteristic. The weight of the portion can be affected by the barista, the grinder, and almost every other source of variation.

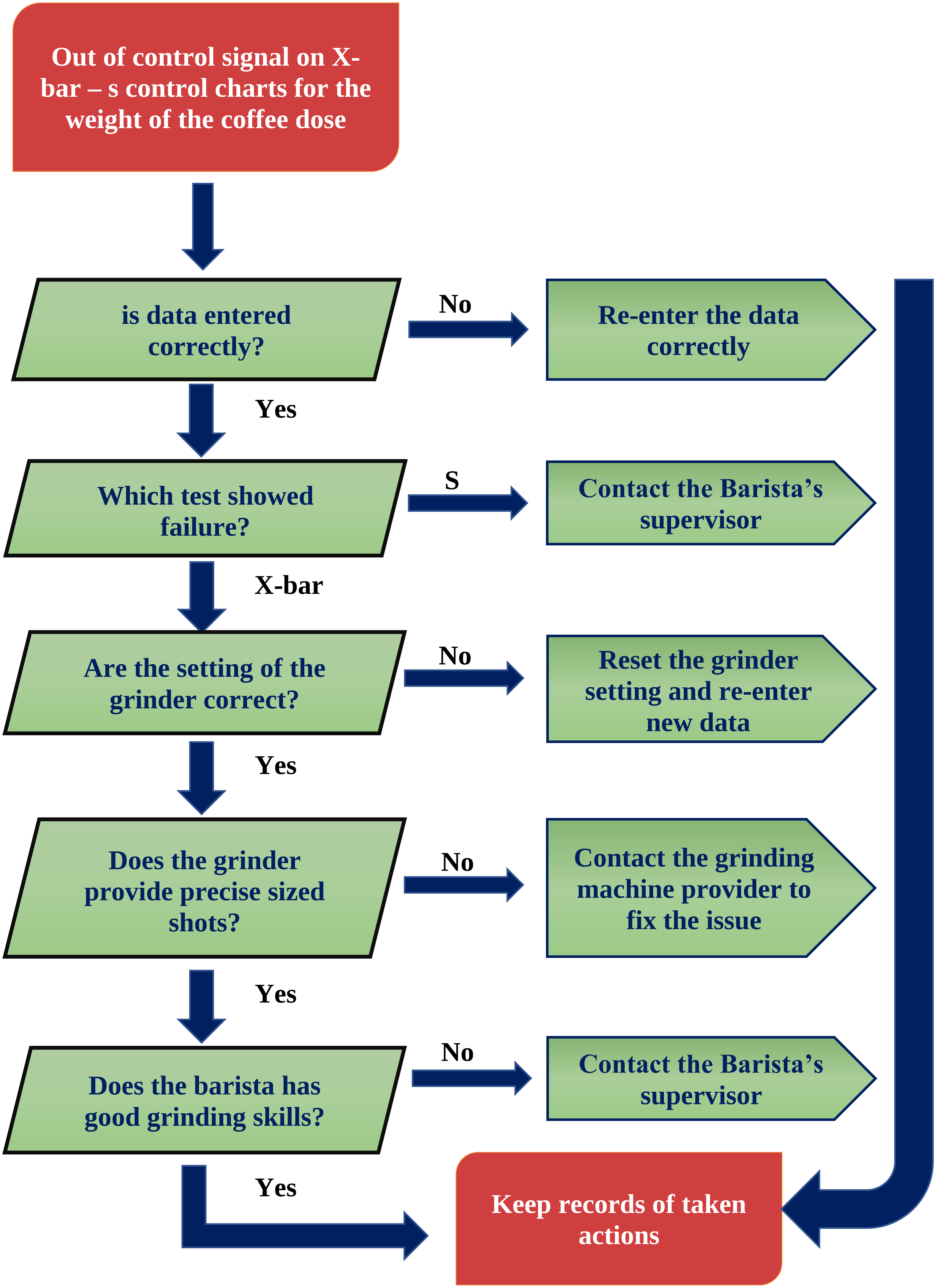
IV. Fishbone Diagram

Fishbone diagram which called causes and effects diagram is a way to illustrate the major causes of a problem placed in the head of the fish, and some branches come out of these problems to denote what caused these problems. Here, the diagram was devolved to highlight some causes contributing to the quality characteristics we have chosen, which is the weight of the coffee dose:



V. Out of Control Action Plan

Out of control action plan (OCAP) is the plan which will be followed when we have a signal (process is out of control). This plan should ensure that the process returns in control by fixing the errors by a certain procedure.


Out of control signal on X-bar – s control charts for the weight of the coffee dose
is data entered correctly?
No
Re-enter the data correctly
Yes
Which test showed failure?
S
Contact the Barista's supervisor
X-bar
Are the setting of the grinder correct?
No
Reset the grinder setting and re-enter new data
Yes
Does the grinder provide precise sized shots?
No
Contact the grinding machine provider to fix the issue
Yes
Does the barista has good grinding skills?
No
Contact the Barista's supervisor
Yes
Keep records of taken actions

VI. Statistical process control

The weight of the coffee dose could be the most important characteristic in the process of making the espresso shot, any insufficient manipulation on the dose's weight will strongly damage the quality of the coffee. If a customer orders an espresso shot or any drink which involves an espresso shot, he's expecting he's coffee to be balanced, not too heavy not so light, so if the weight of the espresso shot is not inside the specification limit, the customer will not be pleased with the product he was served and he won't come back to the coffee shop again.

a) Procedure

Firstly, we developed our x-bar control chart based on out critical characteristic (the weight of the espresso shot). Our "m" we used was seven days, or seven samples. Moreover, each day we took 14 sample (n=14). Then, we calculated the average of each induvial day to obtain each sample's x-bar, and we also calculated the variability in between each sample and used the average to obtain S-bar. The we estimated sigma by (S-bar/c4). We also estimated the mean by averaging all x-bars and we calculated the control limits using L=3 which corresponds to alpha = 0.0027.

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10	Sample 11	Sample 12	Sample 13	Sample 14	SUM	AVERAGE	STD
DAY 1	18.3	17.1	18.2	17.9	18.9	19.1	18.7	18.2	18.3	17.2	18.2	17.4	19.3	19.1	255.9	18.27857	0.704031
DAY 2	18.1	16.9	18.9	18.4	19	20.1	18.3	19.2	19.6	18.5	19.2	18.3	18.5	18.2	261.2	18.65714	0.770329
DAY 3	17.2	16.9	19.1	18.9	19.1	19.8	19.2	17.5	17.2	19.7	17.2	19.2	17.4	18.7	257.1	18.36429	1.060194
DAY 4	19.5	17.2	19.1	19.3	19.5	19.4	19.2	18.7	18.1	*19.4*	17.6	18.4	19.3	17.8	262.5	18.75	0.788133
DAY 5	16.7	18.2	16.2	19.5	17.8	19.5	19.6	18.3	18.9	17.4	18.2	19.4	17.4	18.3	255.4	18.24286	1.072534
DAY 6	16.3	16.4	17.2	18.1	17.6	17.9	16.2	19.5	19.2	18.6	18.7	17.3	18.3	19.2	250.5	17.89286	1.106251
DAY 7	19.7	18.5	19.4	19.2	18.4	18.3	17.1	17.8	18.6	19.2	18.3	18.3	19.2	18.6	260.6	18.61429	0.687087

SUM	1803.2
X-BAR	18.4
S-BAR	0.88408
SIGMA	0.915502

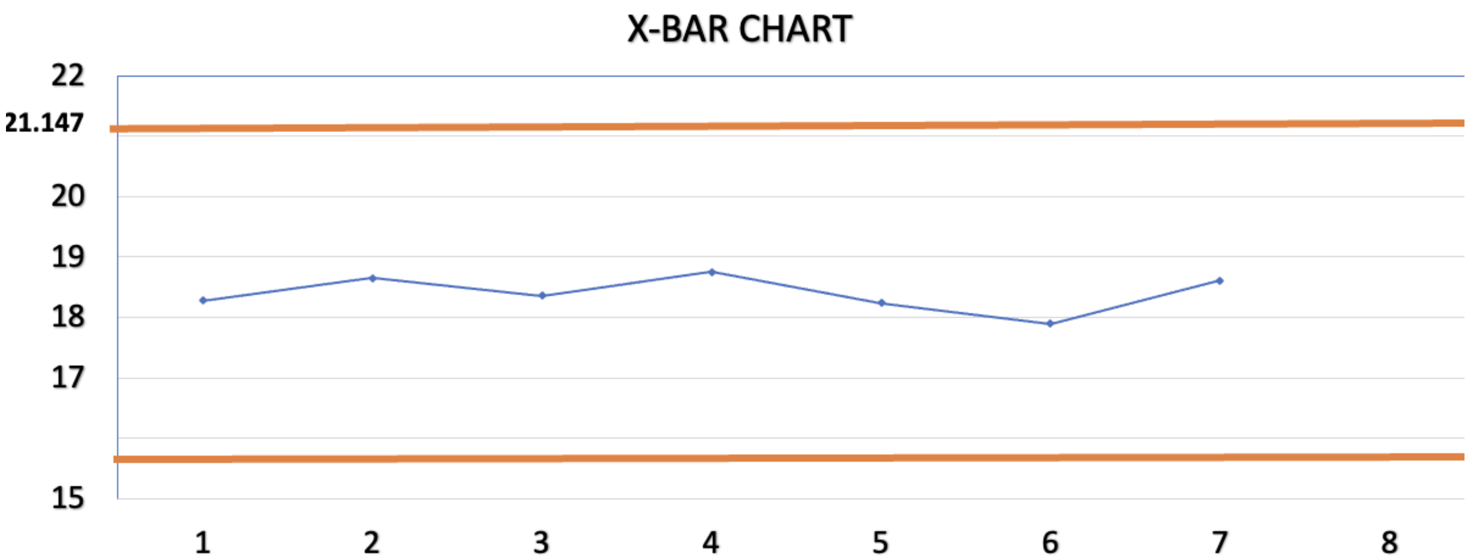
B3	0.41
B4	1.59
c4	0.9823
A3	0.789

	X-BAR	S
UCL	21.147	1.455649
CL	18.4	0.915502
LCL	15.653	0.375356

b) Calculations

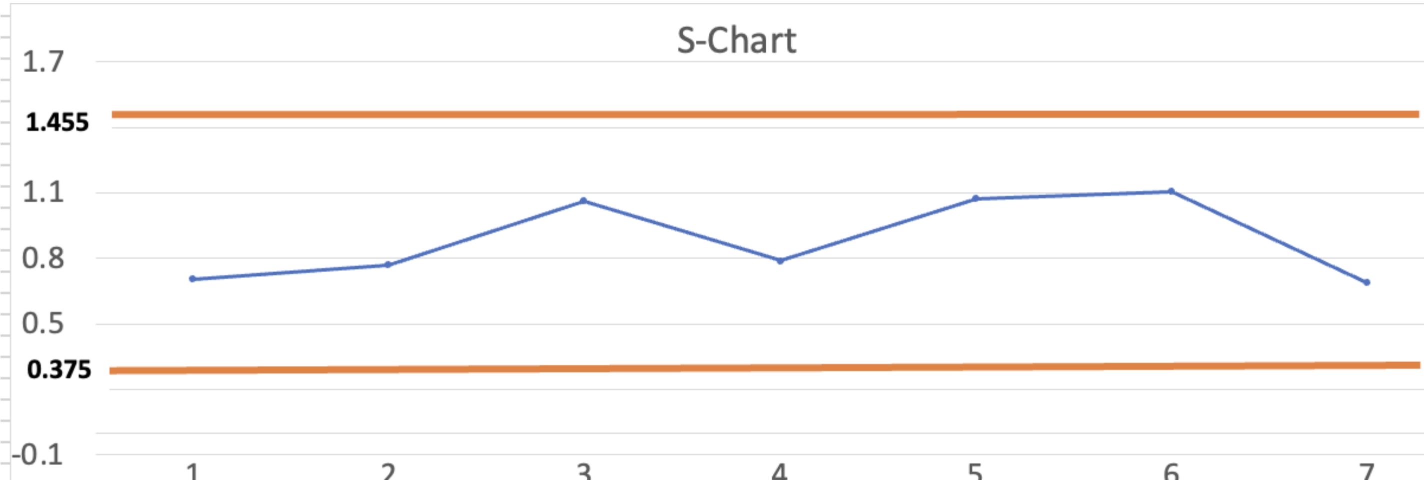
Using the numbers we obtained previously above, we used the following formulas to compute the control limits.

X bar and s Charts	$CL_{\bar{X}} = \bar{\bar{X}}$	$UCL_{\bar{X}} = \bar{\bar{X}} + A_3\bar{S}$	$LCL_{\bar{X}} = \bar{\bar{X}} - A_3\bar{S}$	$\frac{\bar{s}}{c_4}$
	$CL_s = \bar{s}$	$UCL_s = B_4\bar{s}$	$LCL_s = B_3\bar{s}$	



c) X-Bar Control chart

d) S- chart



Since our sample size is more than 10, S is better in estimating the standard deviation than R.

VII. False alarm and delay costs

Currently on Saudi Arabia, the coffee industry could be described as one of the hugest industries in terms of growth, you can find coffee shops everywhere around you, this indicates that the customer has many options which means it's easy to lose a customer of he hasn't been served the way he expects, which will lead the coffee shop to lose profits. In terms of false alarms, one could be that the barista puts some weight from his body while weighing the espresso dose, this will result on lowering the actual amount of coffee on the dose, which will change the quality of the drink causing the customer to be upset.

VIII. Comprehensive study

The sampling method is one of two aspects that can influence our ability to detect changes in our mean. The frequency (h) denotes the amount of time between samples, while the sample size (n) represents the number of orders for each sample. We can either raise the orders or decrease the sampling frequency to detect changes.

A. Number of orders on each sample

In recent years, business at large coffee retailers has begun to give way to smaller mom-and-pop shops all over the country. Although 60% of American coffee drinkers say they visit a branded coffee shop at least once a month (Beverage Daily), consumers have begun to gravitate towards boutique coffee shops for several reasons that ultimately affect how much coffee is being sold at each. Statistics from the National Coffee Association show that 53% of coffee drinkers now choose to purchase their morning java from smaller retailers that either are environmentally conscious in their business practices or that support the coffee farmers from whom they purchase beans. Though that means that nearly half of all consumers (47%) don't take either of these factors into account when making their purchase, the aging millennial population has and will continue to drive conscientious coffee-buying trends causing the gap in that statistic to grow even further.

1. Calculations

We got 18 is the true mean by the barista

To compute beta, we know that type II mistake means the method is inefficient.

While it is out of control, you are in command. As a result, we must calculate the likelihood that our sample x bar will fall between the LCL and the UCL

When the sample size is 14, the sample size is 7.

Our calculations show that:

2. Beta(β)

When n = 14

B = P(LCL<X<UCL) = P(15.653 <X<21.147) = P((15.653-18)/0.244678 <Z<(21.147 -18)/ 0.244678) = 0.99918-0.00939 = 0.98979

When n=7

B = P(LCL<X<UCL) = P(15.12 <X<21.577) = P ((15.12 -18)/0.406650 <Z< (21.577-18)/ 0.406650) = 0.99981-0.00199 =0.99782

3. ARL1 (Average run length)

for n =14 = 1/power = 1/0.01021 =97.9432 samples on average till we detect an out-of-control signal

for n =7 = 1/power = 1/0.00218 = 458.7156 sample on average till we detect an out-of control signal

4. Average time to signal ATS

h =24 hours

For n = 14

ATS = h * ARL1 = 24*97.9432=2350.6368 hours on average till we detect an out of control

For n= 7

ATS = h* ARL1 = 24*458.7156 = 11009.1744 hours on average till we detect an out of control

This is our conclusion:

	n=14	n=7
UCL	21.147	21.577
LCL	15.653	15.12
CL	18	18
Beta	0.98979	0.99782
Power	0.01021	0.00218
ARL1	97.9432 samples	458.7156 samples
ATS	2350.6368 hours	11009.1744 hours

B. Rational subgrouping

The concept of rational subgrouping is focused on limiting variance within samples while maximizing diversity between them. As a result, we want to make sure that this concept is accurately associated with our quality. It is preferable to split the barista's shifts into two. Rather than collecting orders at random periods throughout the day, We can use the morning shift orders as our first sample, and the night shift orders as our second. As a result, sample variation will be reduced but sample variation will be increased. The benefit of using this idea is that the assignable cause can be determined.

● IX. Phase I Analysis

In Phase one analysis after calculating the control limits of the x bar chart,

we observed that there is a problem with the grinder, we fixed it to be not clogged and then we noticed that the variation in the process has been minimized.

● X. Conclusion

Finally, the full research of daily distances traversed by baristas as a quality characteristic will analyze false alarms, detection delay charges, sampling frequency, and sample size in each sample. The increased sampling frequency will result in less time between samples, which may be desirable when coffee businesses wish to notice an issue as soon as possible. The sample size in each sample will be a significant aspect in terms of the time covered by the barista, because the information will become clearer as the sample size grows. Finally, the sample size will influence the number of samples required to detect a shift (ARL1), the time required to detect a shift (ATS), and the power of detection throughout the procedure (1-Beta).

References:

1. Postlewaite, J., Lyon, B., & Kalelkar, S. (2013). Cleanroom Wiper Applications for Removal of Surface Contamination. In Developments in Surface Contamination and Cleaning: Applications of Cleaning Techniques (pp. 549-590). Elsevier.
2. Yang, C. M., & Chen, K. S. (2021). An Integrated Contract Manufacturer Selection and Product Quality Optimization Methodology for the Mechanical Manufacturing Industry. Expert Systems with Applications, 115336.
3. Hossain, M. P., & Riaz, M. (2021). On designing a new VEWMA control chart for efficient process monitoring. Computers & Industrial Engineering, 162, 107751.
4. The increase in coffee consumption in the Kingdom will exceed 30% during 2020. (2019, Dec 24). Alriyadh.https://www.alriyadh.com/1795142.