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Application of Control Charts in Supply Chain

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Abstract A supply chain is a network that connects a firm with its suppliers to produce and deliver a specific product to the end consumer. In other words, the supply chain represents the steps that provide products and services to customers. The most concerning in the supply chain management is always be the variation in the process of supply chain and the performance. Therefore, the performance of the supply chain has to be continuously monitored to minimize and reduce variation, which has a negative impact on the supply chain process. Physicist Walter Shewhart introduced the statistical Process Control (SPC) chart, and its application is to ensure the quality of manufactured products by reducing variations that exist in the process design. This study aims to develop the SPC approach beyond the manufacturing process by presenting examples of the application of control charts to common supply chain issues. This study will show the results of applying two different control charts (P chart and XmR Chart) to monitor supply chain performance, detect out-of-control performance, and enhance the performance quality.

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Keywords: supply chain; control chart; statistical process control; variation

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1. Introduction

1.1. General Introduction

The supply chain is a process by which a company and its suppliers distribute their products to their customers. In other words, the supply chain represents the steps that provide products and services to customers. Several entities are involved in the supply chain, including manufacturers, suppliers, transporters, warehouses, wholesalers, retailers, etc. The concept of "supply chain" is well established in the literature and is generally referred to as the alignment of firms that bring products or services to market [1]. The supply chain can help the companies involved reduce their operating cost and boost their customer service. The main concern that the supply chain faces is the variation in the supply chain. When the retailers involved in the supply chain send the demand information upstream to the factory or suppliers, the demand information will be more

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variable, which will increase further upstream of the company. Eventually, the increase in the upstream of the company will cause the companies involved in the same supply chain system to have a large number of inventories. When a company engaged in the supply chain delivers its products to other companies in the same supply chain, the delivery lead time will be affected by external factors, including weather influence, traffic jams, and transportation breakdown. When external factors have delayed the delivery lead time, it will affect customer satisfaction because customers receive their products late. Therefore, the supply chain performance must monitored continuously and improved simultaneously to minimize the concern. Statistical Process Control, also known as SPC tools, is one of the techniques to reduce the variability in supply chain performance and provide clear information about supply chain performance. The use of SPC tools improves and controls the quality of goods and services. However, the SPC control chart has not been applied much in supply chain study. This study aims to develop the SPC approach beyond the manufacturing process by showing some examples of the application of control charts to supply chain issues. In essence, the performance of the supply chain can be monitored constantly and consistently in every step of the supply chain by using a control chart. If a shift in the process average is detected, the company can execute appropriate corrective action immediately. After an overview of the use of SPC tools in the supply chain, this study will discuss the construction of the two types of control charts by using the example from the supply chain dataset.

1.2. Importance of the study

This study will illustrate the importance of the control chart as a valuable statistical tool for monitoring the performance of the supply chain management process. The control charts help in differentiating between process variation due to the special and common causes. The causes needed to be identified separately, and each of them requires a different management response in the supply chain sector. This study can help the companies involved in the supply chain to have an approach to monitor the performance and be alerted of out-of-control conditions due to assignable causes or special causes. Once the out-of-control condition is detected, it should prompt further investigation into the operation to determine what the root causes are and then take action to eliminate it. It can also prevent the supply chain management from investing resources to implement ineffective change, leading to poor decision-making across the company. Control charts also help identify the source of error in the supply chain process. With control charts, supply chain management will become better in the future.

1.3. Problem Statement

The biggest challenge in the supply chain will always be the variation in the supply chain process. Once the variation in the supply chain gets decreases, the supply chain's performance will improve. The most important key to improving the supply chain system and supply chain performance is reducing statistical variance. Therefore, understanding and controlling process variation are essential to improve the quality of supply chain systems. Understanding the variation in data allows us to identify the potential problem in an organization, and thus we can tackle it with possible changes or improvements.

2. LITERATURE REVIEW

2.1. Introduction

A supply chain (SC) is the activity concerned with planning and controlling raw materials, components, and finished products from suppliers to the final customers [2]. Several studies demonstrated that a control chart is one of the SPC tools that are not yet applied as much in the supply chain performance that has few of the studies are using the control charts to monitor the supply chain performance. Researchers apply control charts to observe the customer's waiting time, delivery time, and inventory control. Some articles also show how the control charts can help companies decide and improve the supply chain system. They are using the control charts to monitor the delivery time [3], supplier delivery performance [4], and customer satisfaction [5]. The investigators all stated that the control charts could help monitor the supply chain performance and prevent unnecessary costs. This section will discuss the concept of the Statistical Process Control theory and the control charts. Next, it will examine the test rule of the control chart and the interpretation. Lastly, it will discuss how to select a suitable control chart for the dataset.

2.2. Concept of Control Chart

The concept of the Statistical Process Control (SPC) and associated SPC tools was published by Dr. Walter Shewhart, a well-known physicist, in early 1920 [6]. The SPC tools can help monitor the process behaviour and identify the source of the process problem. According to Montgomery (2009), the control chart is one of the powerful SPC tools that can illustrate how the process or production changes over time [7]. Domicic and Zmuk (2011) stated that the primary objective of control charts is to explain the variation of significant quality characteristics and help reduce the variation, leading to process improvements [3]. The integration of statistical process control is one solution that can help minimize defective production [8]. According to Zhong et al. (2019), the control chart can be practical and useful to monitor the supply chain network system, and the effect of monitoring by control chart was stable and consistent [9].

The variation in the process comes from two different sources, common and special causes [10]. The common cause variation is a natural part of the process that exists in every process; it can be decreased by process improvement activities or making a fundamental change, but not eliminated [11]. On the other hand, special causes variation is an unexpected variation in the process; it should be identified, addressed, and eliminated [12]. To deal with special cause or assignable cause variation, people need to find the exact root cause and take corrective action to eliminate it [13]. The control chart helps distinguish the variation caused by common causes (the process is in the state of control) from the variation caused by special causes (the process is out of control). When the control chart contains only common causes of variation and does not show any out-of-control conditions, the process is said to be in the state of control. When the control chart shows the out-of-control condition, for example, a point beyond the control limits or satisfying one or more of the test rules below, the special cause variation must be recognized and removed [10].

According to Montgomery (2009), the SPC regime is implemented in two stages or phases: Phase I and Phase II [7]. Phase I is the process of constructing a control chart with baseline or trial control limits based on the historical data. If the process is in control state, the control chart developed in Phase I will be used in Phase II to monitor the current process state by plotting the values of incoming data and sound the alarm if a plotted point beyond the chart's control limits. Thus, the control charts will be effective in monitoring the delivery performance. It can help companies enhance supplier performance monitoring by implementing corrective actions and improving the caused signal patterns [4].

2.3. Interpretation of Control Chart

According to Montgomery (2009), a completed control chart will contain two parts. The first part is the control chart has three horizontal lines, which include the upper control limit (UCL), lower control limit (LCL), and center line (CL) [7]. The UCL and LCL are set at +/- three standard deviations from the mean. When the data points fall within the range of the UCL and the LCL, the process is in the state of control and contains the only common cause of variations. According to Shewhart (2015), when the data point falls outside the range of the UCL and LCL, the process is said to be out of control [14]. Supplementary test rules in Section 2.4 have been added to better characterize the out-of-control process [15].

2.4. Test Rule of Control Chart

Several tests can be applied to detect the special cause variations and identify whether the process is out of control or in control [8]:

1. Any points fall above the UCL or below the LCL
2. Two out of three consecutive points fall between 2σ and 3σ from the mean.
3. Four out of five consecutive points fall between 1σ and 3σ from the mean.
4. A row of eight consecutive points falls on either side of the mean.
5. Six or more consecutive points constantly increasing or decreasing.
6. A row of fourteen consecutive points alternating up and down.

2.5. Types of Control Chart

According to Dumicic and Zmuk (2011), two types of data are used in a quality characteristics study: attribute and variable data [3]. Finison et al. (1993) stated that there are three common types of control chart for variable data, which include X and R, $\bar{X}$ and S, and XmR control chart, four common types for attribute data, which include NP, P, U, and C chart [16]. In this research, P chart and XmR chart will be used to monitor the supply chain process.

3. METHODOLOGY

The examples in this research used secondary dataset collected from the non-manufacturing industry. The variable of interest will be delivery lead time and customer satisfaction rate. Generally, a control chart is constructed by plotting the summary statistics from the subgroup data (delivery lead time and customer satisfaction rate) against time, in chronological order with three horizontal lines: UCL, LCL and CL. This research will look at the two different control charts (P chart and XmRchart) to expand the usage of the control charts in the context of supply chain performance.

3.1. The *P* Chart

The P chart is one of the types of attribute charts. Usually, the P chart is applied to monitor the process of the discrete distributed data. P chart can be created by plotting the non-conforming (defective) units with the sample when the sample size of the dataset is variable. The feature of the attribute data can always be considered only two possibilities in the attribute dataset; either the data pass or fail with some of the standards given. Each data is either defective (passes by the given standard) or non-defective (fails by the given standard). The defective and non-defective forms can also describe as yes or no, good or bad; in other words, the inspected item has only two possibilities.

The total delivery and late delivery of an e-commerce company, DataCo Global, between 1 January 2015 to 31 January 2018, was extracted from Kaggle, using Microsoft Excel [17]. All the data will be analyzed using the software Minitab 18.

Assume there consists of m months. Let $\hat{p}_i$ be the late delivery rate in i^{th} month; D_i be the number of late delivery in i^{th} month;and n_i be the total number of delivery in i^{th} month. Then, $\hat{p}_i = \frac{D_i}{n_i}$.

The first step to produce a P chart is to calculate $\hat{p}_i$, the rate of late delivery, for every subgroup. Then, we calculate the CL, UCL and LCL by using the following formula:

$$CL = \bar{p} = \frac{\sum_{i=1}^{m} D_i}{\sum_{i=1}^{m} n_i} \tag{3.1}$$

$$UCL = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n_i}} \tag{3.2}$$

$$LCL = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n_i}} \tag{3.3}$$

The last step is to plot $\hat{p}_i$, CL, UCL and LCL values on the same graph.

3.2. The Individual and Moving Range (*XmR*) Chart

The total number of reviews and customers' rating score for the iPhone XR is measured monthly from November 2018 to July 2020. The average customers rating is calculated by dividing the total customers rating by the total number of reviews. All the data was extracted from the Amazon India website using Microsoft Excel and analyzed using the software Minitab 18.

Assume there consists of m months. Firstly, to plot the moving range (MR) chart, we have to calculate the moving range between two data points, the difference between each data point by using the formula $MR_i = |x_i - x_{i-1}|$, the x_i is the average customers rating for each i^{th} month, and x_{i-1} is the $(i-1)^{th}$ data points. Then, we can calculate the CL, UCL and LCL by using the following formula:

$$CL = \overline{MR} = \frac{\sum_{i=2}^{m} MR_i}{m-1} \tag{3.4}$$

$$UCL = 3.267 * \overline{MR} \tag{3.5}$$

$$LCL = 0 * \overline{MR} \tag{3.6}$$

The last step is plotting the value of MR_i, CL,UCL and LCL on the same graph.

To construct X chart, the first step is to calculate CL, UCL and LCL by using the following formula:

$$CL = \overline{x} = \frac{\sum_{i=1}^{m} x_i}{m} \tag{3.7}$$

$$UCL = \overline{x} + 2.66\overline{MR} \tag{3.8}$$

$$LCL = \overline{x} - 2.66\overline{MR} \tag{3.9}$$

The last step is plotting the value of x_i, CL, UCL and LCL on the same graph and placed the graph on top of the MR chart.

4. Results

This part is to determine the use of a control chart in supply chain performance by applying the following examples. It will show how the control chart monitors the supply chain process and identifies the special cause variations.

4.1. The *P* chart for the rate of late delivery

Data Co Global is an e-commerce company that sells electronics, clothing, and sports goods. From January 2015 until January 2018, there were a total number of 103400 late delivery, with a total number of 180519 deliveries. P chart is selected to monitor the rate of late delivery. The average rate of late delivery was around 0.5728. Figure 1 shows the chart with the CL = 0.57279, the LCL = 0.54058 and the UCL = 0.60500. The control chart shows sample 19 (July 2016) falls below the LCL. Thus, the process is unstable and said to be out of control. The control chart indicates sample 19 (July 2016) falls below the LCL, which means the delivery for this month has a shorter delivery lead time. The company should investigate this point to figure out the root of the special causes. The process can be enhanced by first taking corrective action to eliminate it, then shifting the process into a state of control. After investigation, the company has offered four different shipping modes: Same Day, First Class, Second Class, and Standard Class. The Same Day shipping mode means the consumers should receive their packages in less than 24 hours, ideally within the same day. The First Class, Second Class, and Standard Class shipping modes mean the delivery of products in less than 1, 2, and 4 days respectively. Analysis of the data from sample 19, July 2016, indicates that 4%, 23%, 29%, and 44% of the total deliveries are shipped with Same Day, First Class, Second Class, and Standard Class, respectively. The Same Day deliveries for July 2016 are lower than in other months. Thus, the Same Day delivery might not be a reliable shipping mode. Then, Data Co Global can take corrective action by shifting most deliveries to other modes such as First Class, Second Class, and Standard Class. Once the company act to eliminate the special cause variation, we can eliminate sample 19 to shift the process into the state of control.

The newly revised control limits will be defined as the CL = 0.57342, the LCL = 0.54122 ,and the UCL = 0.60563, as shown in Figure 2. The CL of 0.57342 indicates

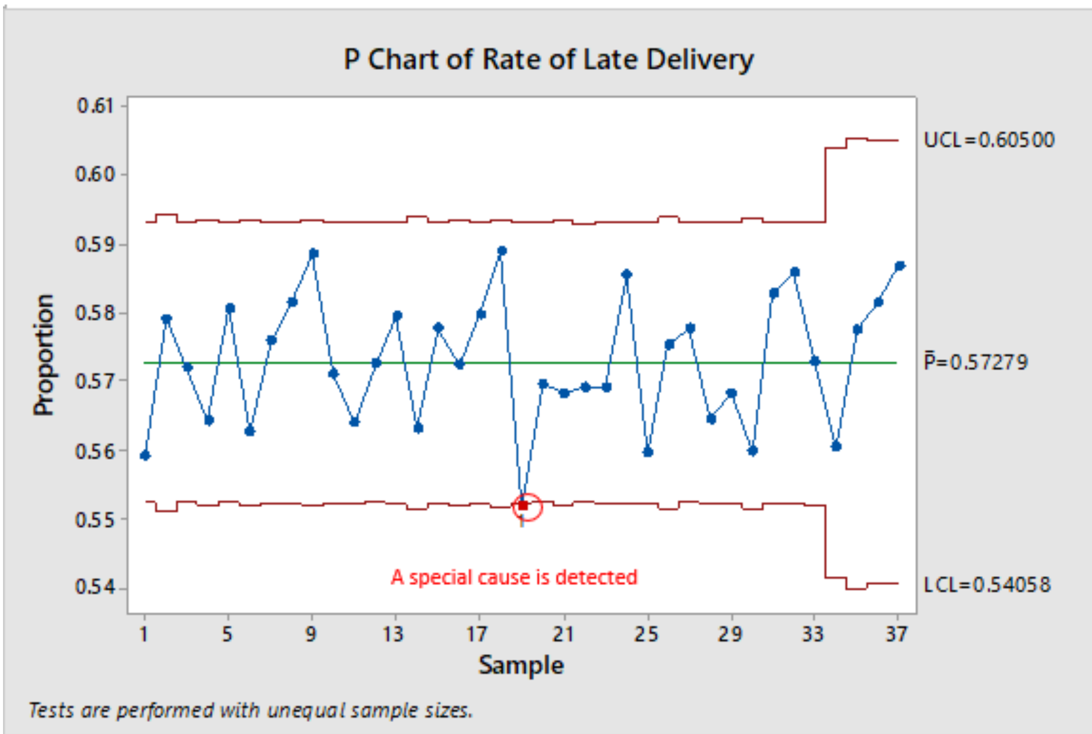

FIGURE 1. P chart for the rate of late delivery

that more than half of the deliveries of Data Co Global did not ship on the requested ship date. E-commerce businesses are well-established in todays world. People have become accustomed to ordering most of their purchases online. On-time delivery is one of the critical elements in determining whether an e-commerce business succeeds or fails. According to Howen (2014), 70% of customers are less likely to shop with the store or retailer in the future after one late delivery, and 14% of customers will abandon the retailer after one late delivery [18]. Thus, this might lead to lower customer satisfaction and sales. To reduce late deliveries and increase customer loyalty, the company needs to implement a change. However, the process in Figure 2 is stable and contains only common cause variations. Unless the company has restructured the system; otherwise, the process with only common cause variations will continue to generate the identical outcome within the statistical limits. Thus, if the company wants to improve its performance, it needs to implement a change to restructure their delivery system in a desirable direction. Further investigation should be carried out on the delivery process to analyze the reliability of the operational efficiency, such as if internal factors or external factors cause the late deliveries. If no internal factors are causing late deliveries, Data Co Global should seek a more reliable shipping company or partner. After the company implements the change, it should continue to use the control chart to monitor the new process against current measures, determine whether there is an improvement, and track the sustainability of process improvements by detecting any future special cause variations.

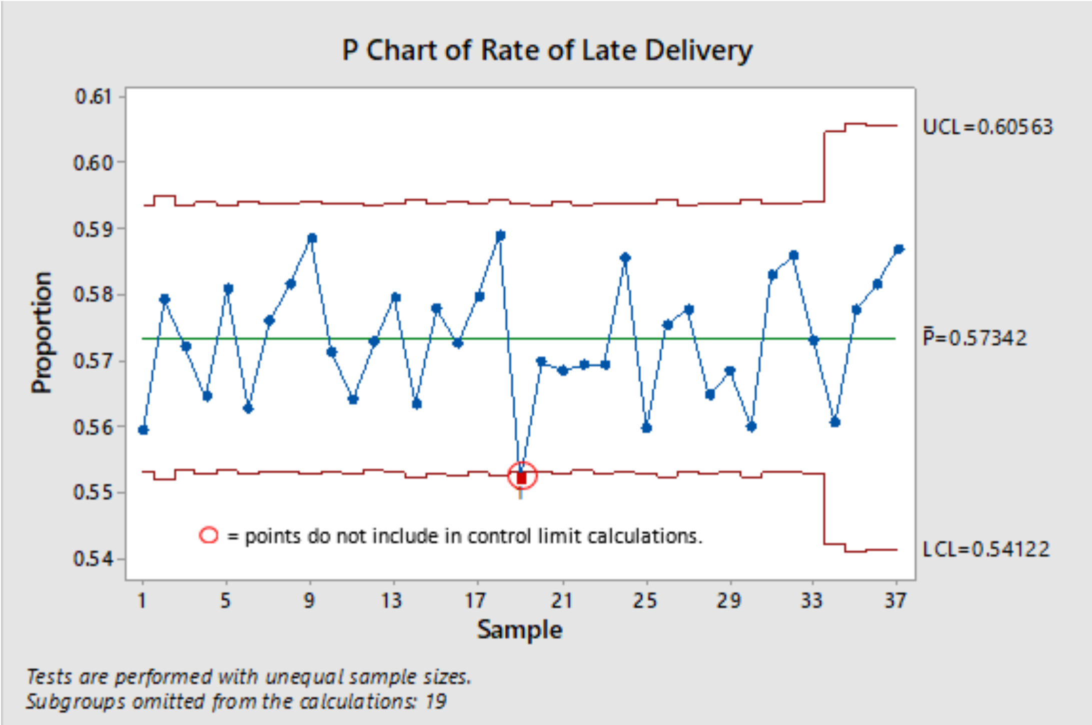

FIGURE 2. Revised control limits on the rate of late delivery P chart

4.2. The *XmR* Chart for the average customers rating of iPhone XR

Amazon is one of the leading e-commerce companies, and it has been operating in India since February 2012 [19]. The key to the success of Amazon India is its efficient supply chain and logistics system. Amazon India employs a centralized shipping network called Fulfillment by Amazon (FBA) to store and ship the products it sells [20]. Sellers will add the barcodes to their products and send them to Amazon fulfillment centers; then, Amazon will store, packs, and ship the products on the seller's behalf for a fee. To date, Amazon has built nearly 60 fulfillment centers in 15 Indian states, covering an area larger than 100 football fields [21]. Every year, Amazon India will be hosting a month-long event called the Great Indian Festival Sale to entice shoppers looking for discounts and deals throughout the festival season. This festive sale will have a variety of discounts on electronic products such as smartphones, consumer electronics, televisions, and other items. In preparation for the Great Indian Festival Sale in 2019, Amazon India launched a massive expansion across its fulfillment center and delivery network since May 2019 [22, 23]. It has opened close to 90,000 seasonal employment opportunities across its fulfillment centers, delivery stations, sorting centers, and customer support sites. The change of enhanced capacity in the supply chain network will allow Amazon India to improve customer experience and strengthen its delivery capabilities, especially during a festive season when the volume of customer's order is expected to rise [23]. An *XmR* chart can be applied to monitor customer satisfaction of iPhone XR on the Amazon India website and see how the process has evolved as the supply chain networks capacity has grown.

Before enhancing capacity in the supply chain network, the total customer rating score was 447, with 105 customers reviews during the baseline period, from November 2018 to

April 2019. The average customers rating was approximately 4.293. Figure 3 indicates the *XmR* chart with the CL = 4.293, the LCL = 3.144, the UCL = 5.442, and the process is in a state of control (Phase I study). Then, the company can use these baseline limits to determine if the change has improved the existing process state (Phase II study). Figure 3 illustrates the continuation of data after the change of an increased capacity in the supply chain network; from May 2019 to July 2020. Any adjustments or changes in a process are deliberate attempts to introduce a special cause variation. A special cause variation due to the Rule 4 is detected, which is most likely indicates that the process has changed considerably. After implementing the change, it shows the process improved to an average customer rating of 4.379. Since there is an improvement, the control limits will be recalculated based on the data after the change implementation. The recalculated control limits for X chart is CL = 4.379, LCL = 3.765, and UCL = 4.992 and for MR chart is CL = 0.231, LCL = 0, and UCL = 0.754, as shown in Figure 4.

Figure 4 indicates one point, April 2020, that falls below the LCL, and more than eight consecutive data points fall on one side of the mean, May 2019 to March 2020; thus, the process is out of control. Examination of these data reveals that some customers complained in April 2020 that they received a defective and damaged phone. Thus, Amazon India should further inspect the inventory, take a comprehensive look at its fulfillment centers, as moisture, temperature, and other environmental factors can damage a wide range of products. In addition, the company also can implement a pre-shipment inspection to examine the products before they are shipped out. Once Amazon India takes corrective action to reduce or prevent such defects in the future, the out-of-control data points (April 2020) can be removed from the *XmR* chart, as shown in Figure 5. Then, the company can continually apply the control chart to monitor the performance.

5. Conclusion

This study aims to show how a control chart is an effective tool in monitoring the supply chain process to detect out-of-control performance and identify the special cause variation. This study involves the construction of two types of control charts (P chart and X chart) in monitor supply chain performance. It shows that the control chart will enable not only to monitor performance in the supply chain but also to identify whether the change leads to positive impacts on the supply chain performance, like in the case of the average customers rating of the iPhone XR example. Thus, it can help the company from further squandering money and resources on the changes that seem great but do not result in actual progress. Overall, the above examples illustrated, by using the control chart, there are two general approaches to improve the process either (1) eliminating the special cause variations and shifting the process into a state of control if the process is out of control) or (2) allocating more resources to improve the stable process and restructure the supply chain system in a favourable direction if the process is in control. Hence, the control chart can help evaluate the effectiveness of current process performance and ensure the process improvements are consistent over time.

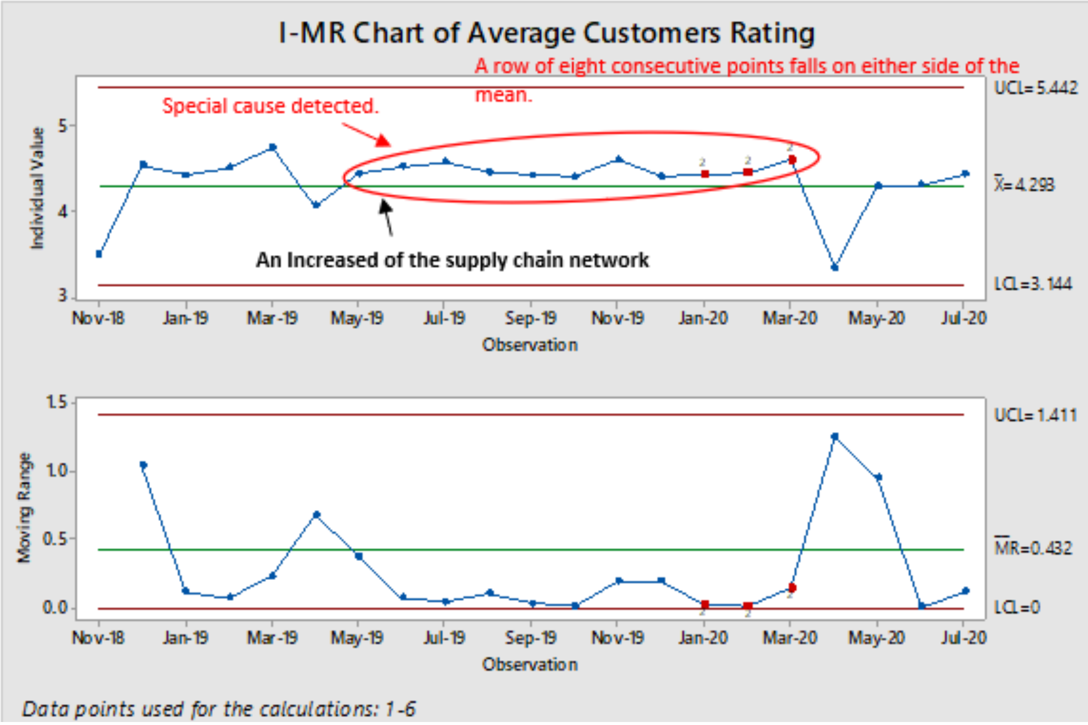

FIGURE 3. *XmR* Control Chart for Average Customers Rating: baseline compared with the period following the change of enhanced capacity in the supply chain network

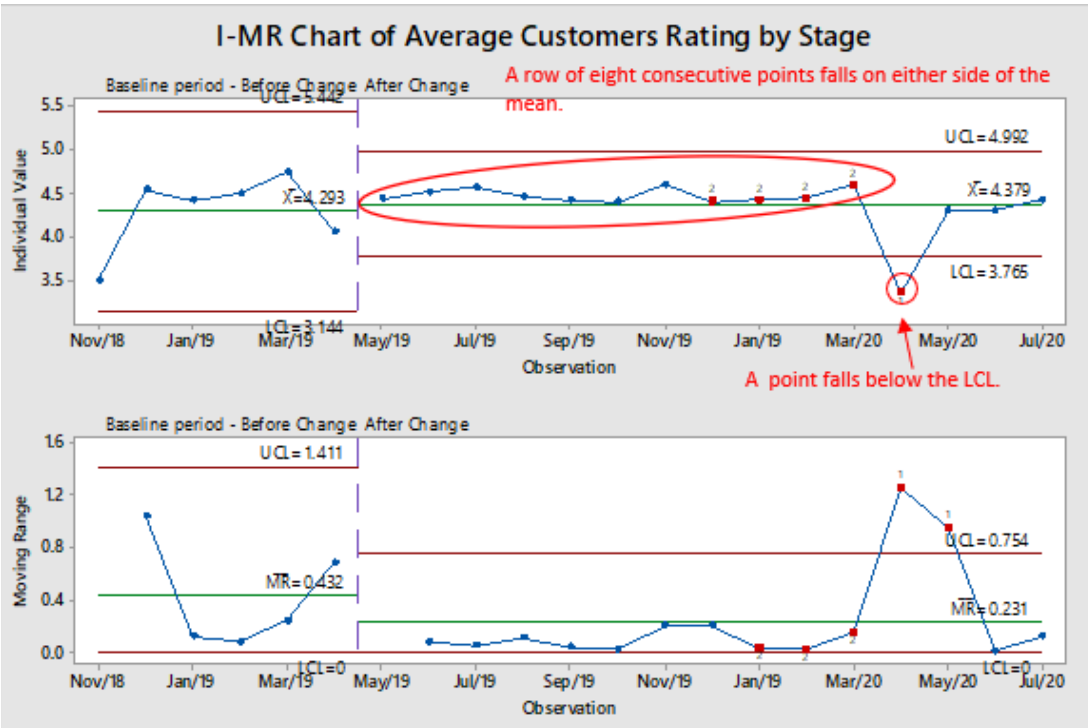

FIGURE 4. Revised control limits on the average customers rating *XmR* chart

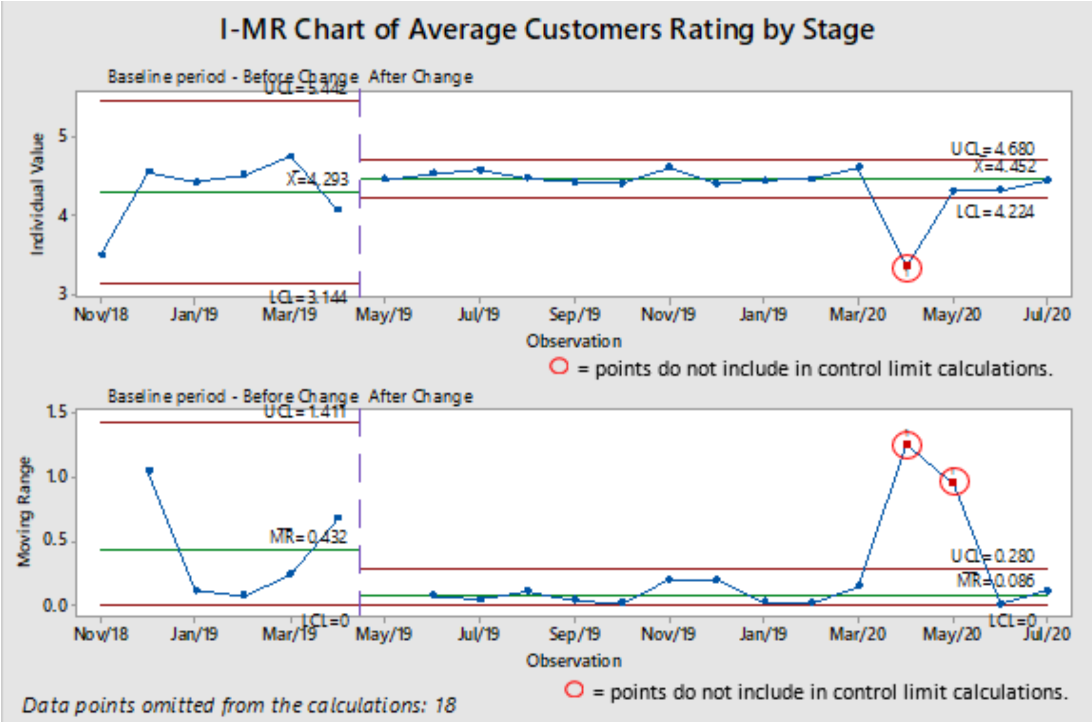

FIGURE 5. Complete XmR chart on the average customers rating

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