The Control Chart as a Diagnostic Tool

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ABSTRACT

Many people know that the control chart is a tool that distinguishes special causes from common causes of variation. In essence, that is all that it does. The use of this tool is not as frequent as one might expect (Latzko, 2000). In most instances it seems to be used to maintain a process at a reasonable level. This paper discusses the use of the control chart as a test instrument. Five examples are presented as well as some background from the theory of control charts.

INTRODUCTION

Since the introduction of the control chart by Shewhart (1939) in 1924 the control chart has been most widely used as a tool to determine that processes have remained constant and predictable. It is, as Shewhart (1931) stated, "[A] constant system of chance causes." Today, we would call it a stable system or a system with only "common causes of variation" present. Such a constant cause system has variation that arises from factors inherent in the process. Indeed, the only way to change the common cause system is by making a fundamental change in the process.

Shewhart (1931) went on to say, "… there are unknown causes of variability in the quality of a product which do not belong to a constant system … these causes were called *assignable*" [p. 14, italics in the original]. Today we tend to call these "special causes of variation." The control chart is a tool that makes the economic distinction between special and common causes of variation. When the control chart indicates that assignable or special causes of variation exist in the process, the proper management action is to concentrate on these causes to eliminate them and avoid their recurrence. When only chance or common causes exist in the process, and we wish to improve the process, we must work on the process as a whole rather than picking any one or more data points and work only on these. To select a given data point — perhaps a data point very close to a control limit — is to tamper with the system. In general, tampering makes the system worse than leaving it alone (Deming, 1994, see Chapter 9). In process control it is vital to distinguish between special and common causes to avoid tampering with the system.

In an attempt to improve systems, the basic theory of the control chart appears to have been forgotten. Latzko (2000) indicated that the absence of papers applying the control chart, both in the Annual Quality Congress and the general media, implies the absence of the use of control charts. The emphasis appears to be on quality systems — which seem to place a heavy reliance on inspection — and problem solving. While both of these quality methods are great contributors to the improvement of quality of products and service, they can act in a manner exactly opposite from what was intended if the nature of the process problem is misread. It requires the use of a control chart to determine the proper approach to quality improvement.

Mr. W. A. J. Golomski wrote to the writer that

> Shewhart said that to help him conceptualize and abstract what went on in the factory he didn’t see people or machines or work stations, but blocks in a flow chart with inputs and outputs that were statistical distributions. The factory spoke to him through the measurements and analyses that he made. (Personal communication, July 15, 2000)

While the control chart is a powerful management tool for the detections of special causes, for the determination of the proper approach to problem solving, and for learning about what is happening with a process, it is also a powerful tool for evaluating the efficacy of a variety of solutions. It is, in effect, the essential ingredient in the Plan-Do-Study-Act cycle that can distinguish the results that are meaningful. In short, the control chart is a diagnostic tool as well as a form of management by exception.

To see how this works, we will look at some basic concepts concerning the control chart and how it lets the process speak to us. This paper goes on to illustrate, with some examples, the application of the control chart as a diagnostic tool.

THE CONTROL CHART AND CHAOS THEORY

Wheeler (1995, Section 1.8) makes a convincing case that Shewhart’s theory of a control chart is similar to chaos theory. Using Ditto and Pecora’s (1993) paper and their description on page 80, Wheeler (1995) examines a period one, a period two, and a chaotic attractor using both a position-time and a state-space chart. Wheeler comes up with the following relationship:

> If a process displays chaotic variation, it will be a waste of time to try and find assignable [special] causes. If a process does not display chaotic variation, it will be profitable to look for assignable [special] causes. (p. 28)

Wheeler is basing these conclusions on the statement by Ditto and Pecora (1993) that

> Although chaos is unpredictable, it is deterministic. If two nearly identical chaotic systems of the appropriate type are impelled, or driven by the same signal, they will produce the same output, even though no one can say what that output might be (p. 78)

In short what this says is that as long as the random or common causes of variation are from the same chaotic system, the process is predictable and stable. Change the chaotic system or its driver and the process changes. If a period-one attractor drives the process, it is no longer random and so that a control chart will signal that an assignable or special cause present.

The change in a process impacts the attractor and causes a change that has an effect upon both the position-time and state-space charts. The control chart has the ability to detect such changes. When used in a diagnostic sense, when a supposed change in the process does not result in a change in the control chart the change had no impact. Since there is noise in any process, a change needs to be greater than the noise to be considered as a signal. A control chart differentiates noise from signal in an economic way.

There are, of course, other methods of experimentation based on statistical principles (see, for instance, Moen, Nolan, & Provost, 1991). In complicated cases these methods can be used. However, most continual improvement methods such as the Plan-Do-Study-Act method, Managerial Breakthrough, etc. can use the control chart to evaluate their experiments.

ANALYTICAL AND ENUMERATIVE STUDIES

As long ago as 1942, Dr. Deming (1942) discussed the difference between studies designed to determine what conditions exist and studies to learn why those conditions exist. Early on he termed these as Type A and Type B actions respectively. Later, he renamed them Enumerative and Analytic Studies (Deming, 1950). In experimentation for continual improvement one is interested in the analytical aspects of prediction. Many of the excellent tools that are used today are great for estimation but not for prediction. As Deming (1992, p. 132) put it,

> The teaching of pure statistical theory in universities, including the theory of probability and related subjects, is almost everywhere excellent. Application to enumerative studies is mostly correct, but application to analytic problems—planning for improvement of tomorrow's run, next year's crop—is unfortunately, however, in many textbooks deceptive and misleading (Deming, 1950).
>
> Analysis of variance, t-test, confidence intervals, and other statistical techniques taught in the books, however interesting, are inappropriate because they provide no basis for prediction and because they bury the information contained in the order of production.

Wheeler treats this topic in Chapter 19 of his book on *Advanced Topics in Statistical Process Control*. In this book, he points out (Wheeler, 1995, p. 409), "Shewhart's control charts are tools for inductive inference. They are intended for the problems of Analytic studies." Continual improvement requires that one make changes and predict, based on the Plan-Do-Study-Act cycle that the changes will improve the process. The control chart is one of the best, if not the best, tools to accomplish the aim of continual improvement.

EXAMPLE 1: INSTALLATION OF NEW FURNACE

In dealing with continual improvement changes are made to the process. These changes are meant to better the outcomes of the process. In most cases, simple changes are the order of the day although at times, several changes are made simultaneously. Whatever the nature of the changes that are made, the impact of such changes are best measure by the use of a control chart. The control chart takes a number of readings over time and evaluates the impact of the change. In this way the variance of the process is considered over time and several measurements are made before a conclusion is drawn.

Unless the change or changes in the process result in a special cause of variation as evidenced by a control chart, it is questionable whether the proposed change was of sufficient magnitude to create a belief that the change had an impact and *will continue to have an impact on the process in the future*. It is the other side of the coin from saying that a special cause exists.

A simple example came about when the writer's furnace caught fire and was destroyed. It was an old furnace that came with the house when the writer bought it many years before. The Oil Company had maintained it regularly but nothing lasts forever. A new furnace was installed. The oil company claimed that it was more efficient and that the efficiency would pay for itself. That is often the reason for replacing depreciated equipment.

Fortunately, a record of oil usage was available for the two years preceding the installation was available. The furnace is only used to heat the house. A gas-fired heater provides hot water. Therefore it was possible to prepare a control chart of the before and after installation period. On interesting problem existed with the control chart in that the use of the furnace was dependent on the weather. In the New York Area where the writer lives, that means heavy usage from late fall until early spring, with the usage varying month by month. Figure 1 shows what happens when the raw data is plotted. The oil usage goes from the maximum point to zero and back in a sine like curve.

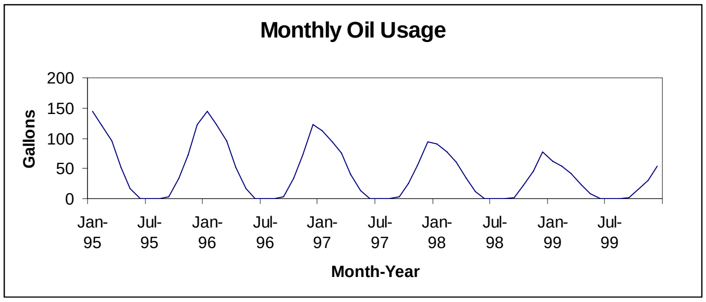

Figure 1. Plot of Raw Data

Removing the summer months does not impact the up and down nature of the data to any great extent. The reason for the curvature is the seasonality of the data. The way to eliminate the change with every month is to remove the seasonal effect. Using Degree Days For the area from the Weather Bureau, the data was adjusted for the seasonality factor. Thus January 1995 used 144 gallons of oil. The Degree Days indicated that January was 260 percent of the heating units. By dividing the gallon usage by 260% or 2.6, the seasonal effect is removed. Thus the January 1995 value without the seasonal impact was 144/2.6 =55 gallons (rounded off). Doing this for all the values that had Degree Days, it was possible to measure the impact of the new furnace by using a control chart for individual values. Figure 2 illustrates the impact.

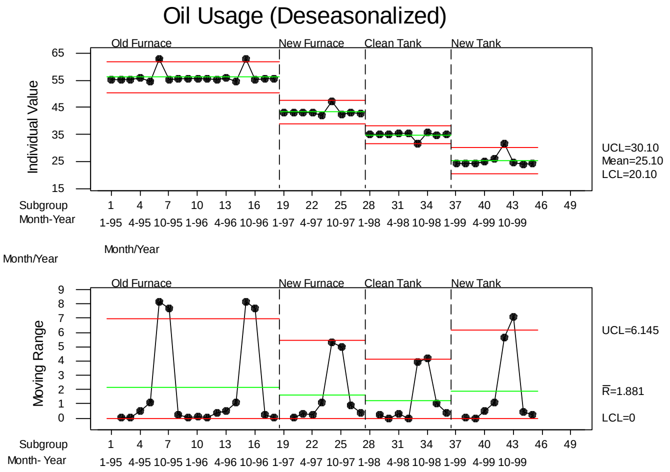

Figure 2. Control Chart for Furnace

There are a few points to note about the chart. First of all, the new furnace saves approximately 20% of the oil used in the past. However, the new furnace also showed up a problem not noted before. That problem turned out to be water in the Oil Tank. On cleaning the tank, the system operated well for a year after which a new tank was installed. The combination of effects saves about half the oil usage from before, which in days when the price of oil is going up, is much appreciated. In addition, special cause points seem to occur each September. That is the time when the furnace is first used after the summer down time. There is no explanation for this effect as yet.

EXAMPLE 2: IMPACT OF CHANGE OF MEDICATION ON BLOOD PRESSURE

When the writer’s annual physical disclosed that his heart had a leaky valve as well as high triglycerides, the blood pressure became of concern. Initially a generic drug was tried without a great deal of effect. Then the doctor switched to a new brand name drug. The question of whether that switch was effective in the writer’s case is shown dramatically in figure 3.

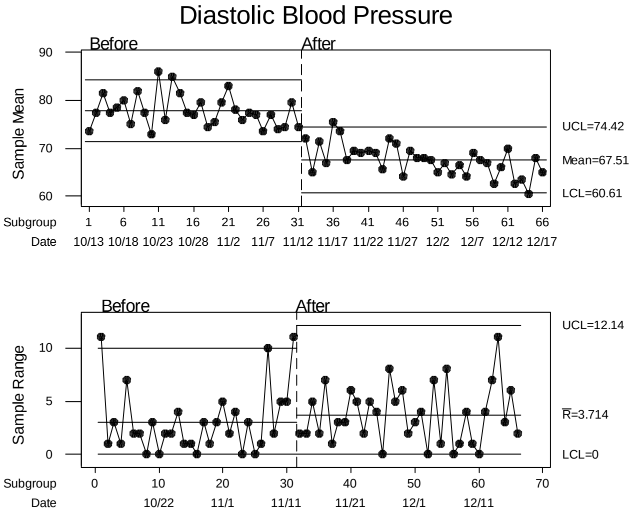

Figure 3. Impact on Blood Pressure

Figure 3 shows an $\overline{X}$, R-chart and, as can be seen, the switch showed a dramatic decline in blood pressure. The generic drug is shown by the “before” section, while the impact of the brand name drug is clear in the “after” section of the chart. The change resulted in a special cause -- for the better. Health care providers tend to measure outcomes on a few observations. It may pay them to use the control chart as a means of determining the efficacy of their prescriptions.

EXAMPLE 3: IMPACT OF MEDICINE INTERACTION

Another clinical example of the use of the control chart is the usefulness of medications and their interaction. After medical treatment changes are expected that eventually revert to normal functioning. The adverse effects in the early stages can be controlled with medication. From time to time, the

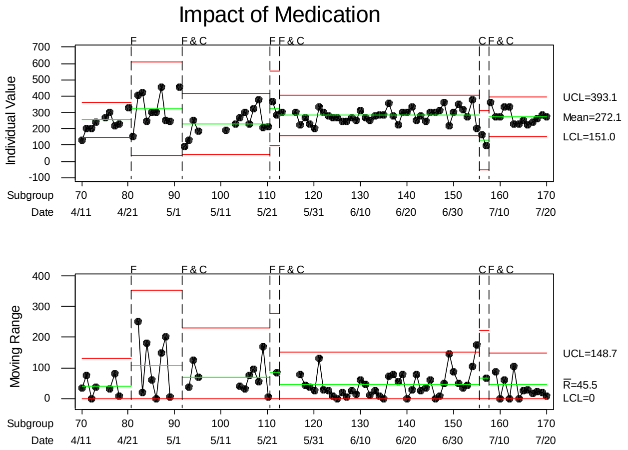

Figure 4. Impact of Medication

medication is stopped to see if the system has reverted to normal conditions. It is also known that Antihistamines can aggravate the effect.

Figure 4, a chart for individual values, shows the impact experienced by the writer. The initial phase was the use only of antihistamine. The surgeon found the impact to be dangerously close to affecting the kidneys and prescribed a medication to alleviate the condition and recommended discontinuing the use of the antihistamine. The second segment of the chart shows that this resulted in improvement but also increased variation. In addition, the antihistamines proved necessary. Apparently, the impact of the antihistamine caused the mean to get a little less but also reduced the variation. From time to time, as the chart shows, the medication is stopped to see if the system has healed. When the chart shows no shift in the process on discontinuing the medication, it means that the system has completely healed and the medication is no longer required.

EXAMPLE 4: RECORD MAKING

While working with the Columbia Record Club, the writer had the opportunity to compare the record return rate with the production of the vinyl batches used in making the record. Using monthly data as cited in Latzko (1969) using a u-chart, a special cause point was apparent. On investigation, it turned out that a change in the formulation of the plastic in April, just at the point were the returns decreased. In this case it was necessary to relate the returns to the time of production. Figure 5 shows the control chart involved.

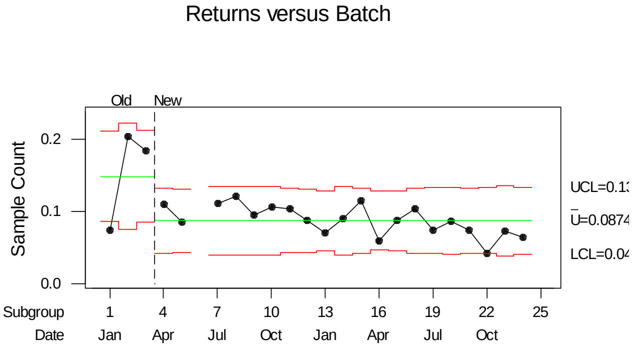

Figure 5. Record Production

It is interesting to note that a u-chart was appropriate since the returns and batch weights were different units. The fluctuation of the control limits is due to the variation in the batch sizes. Also, as with a lot of historical data, the information for June was missing. Again, if this had been a test to determine which formulation gave better results, a before and after control chart will show this.

CONCLUSION

The control chart is a powerful tool that can show changes in the process. We often use this fact in monitoring processes. It can also be used to see if the changes mad to better the process actually result in a meaningful improvement.

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