THE UNDERUSED CONTROL CHART: FACTS, MYTHS, AND APPLICATIONS

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SUMMARY

Since 1924, when Dr. Walter A. Shewhart devised the control chart, the control of quality changed dramatically. With time, the emphasis has shifted from statistical thinking, as represented by the control chart, to procedures and problem solving. This paper reviews some issues related to control charts. Using service and manufacturing examples we will show the power of this tool.

Control charts are one method that started the modern quality control profession. Their use is still valid today. This article shows, by example, how the control chart can be used in areas other than manufacturing. Unfortunately, few uses are made of control charts in service applications. The text argues that particularly those ASQ members engaged in service activities can gain great insights by making more use of this tool.

This thesis also argues that part of the reason for the low use of control charts lies in the misconceptions surrounding the methods. Some of these misconceptions are examined and discussed.

KEY WORDS

management, statistical process control, statistical thinking

INTRODUCTION

When the American Society for Quality Control (ASQC) was founded in 1946, they chose a logo that represented the state of the art at the time: A sigma (the Greek lower case letter "s") and a control chart. The sigma stood for the variation that exists in processes. The control chart was the main tool of modern quality methods at the time. As time went along, the introduction of problem-solving tools such as cause and effect charts, Pareto charts, and other problem-solving methods became so popular that the more technical methods such as control charts, sample theory, and design of experiments were used proportionally less and less. A form of technological Gresham's law appears to be operative, "New methods replace old."

These phenomena were observed and reflected in the society's actions. By 1990, the use of the seal with the sigma and control chart was discontinued as the society's signature. The squared 'Q' with the letters "ASQ" replaced the seal as the society's signature. By 1997, the word "control" was dropped from the society's name. These actions can be interpreted as a shift in interest of the membership. I thought that the change in the society's name was useful since few members realized that the word control meant predictability of a process, and not to "exercise restraint or direction" over an activity (*The Random House College Dictionary* 1975). Other long-term members felt that it was a retreat from the engineering function of the society.

SOME BACKGROUND

The inventor of the control chart, Dr. Walter A. Shewhart (1939), stated that on the time line of "quality control tools," the quality control chart was the newest tool since the invention of the go, no-go gauge, which appeared around 1870. The control chart, introduced in 1924, allows management to look at processes rather than just at products. Shewhart discusses the concept of statistical control. He carefully defines that a control chart is *not* a test of statistical significance. Shewhart describes the test of statistical significance when discussing assignable or, as we say today, special causes of variation. Thus he states: "Such a process [a test of statistical significance] is deductive. In contrast, when an observed statistic falls outside its control limits, the inductive inference is implied that an assignable cause is present" (Shewhart 1939, 31).

Since the early days of the society, a number of advances were made. Dr. Joseph M. Juran studied how problems can be solved successfully. In a major work, "Managerial Breakthrough," Juran (1964) explains the essential elements required for problem solving and improvement. It is interesting to note that Juran's teaching was picked up by the Japanese and returned to the United States as Quality Control Circles. As far as this writer can tell, Dr. Kaoru Ishikawa, known as the father of Quality Control Circles, added the cause-and-effect chart as an aid to brainstorming, but all the rest of the methods were the same as those recommended by Juran.

The popularity of these problem-solving tools and the ease of their use caused many to adopt them and neglect tools such as the quality control chart, which had the stigma of the word "statistics." The nonmanufacturing sectors such as academe, government, and service seemed especially to shy away from quality control charts. This was not the intent of Dr. Ishikawa. He looked at three levels of what he called "Utilization of Statistical Methods" (Ishikawa 1985). In order of difficulty, these are

1. "Elementary Statistical Method" (also known as the "Seven Tools of Quality")
2. "Intermediate Statistical Tools"
3. "Advanced Statistical Methods" (using computers concurrently) (Ishikawa 1985, 198–199)

The elementary tools are the well-known tools used by Quality Control Circles. They are

1. Pareto Chart
2. Cause-and-effect diagram
3. Stratification
4. Check sheet
5. Histogram
6. Scatter diagram
7. Graph and control chart

Ishikawa (1985, 198) has some commentary on these methods. For instance, for the cause and effect method, Ishikawa added parenthetically, "This is not precisely a statistical technique." I feel that this also might be applied to the Pareto chart, stratification, and check sheet. For the graph and control chart method, Ishikawa added, again parenthetically, the "Shewhart control chart."

The intermediate methods use sample theory and design of experiments. The advanced methods apply "Advanced methods of design of experiments" (EVOP? Fractional Designs? Ishikawa does not say), "Multivariate analysis," and "Various methods of operations research" (again unspecified) (Ishikawa 1985, 199).

Although Ishikawa includes the Shewhart control chart as part of the elementary tool kit, I have seen few applications of their use in problem solving or monitoring processes. Most of these applications were in the manufacturing sectors; only a few in service applications.

LITERATURE SEARCH

I searched the transaction of the 53rd Annual Quality Congress (AQC) and the files of ABI/Inform Global in ProQuest Direct abstracting service. The AQC transactions tend to reflect the thinking about current issues of quality while the ABI/Inform Global covers a vast array of journals, such as academic, professional, trade journals, and similar publications. The ABI/Inform file extended from January 1997 to the time of writing this paper, July 1999. On the theory that publications reflect the interest in topics and that this, in turn, reflects the utilization of tools, I researched how many articles contained the subject quality control and of those how many also contained the subject of control chart.

PAPERS FROM THE 53rd ANNUAL QUALITY CONGRESS (AQC)

The CD Rom search of the 53rd AQC showed that there were 141 papers presented. Of these, 4 used the term control charts. Of the four, I was particularly impressed by Tom Pohlen's (1999) paper relating the use of a control chart to a personal application. This paper was the only one that truly used a control chart. While Audrey Prosser's (1999) paper contained a sample control chart in her slides, as an example of what might be done, her main thrust did not deal with control charts. One paper merely mentioned, in the conclusion section, the possibility of using control charts for the measures developed (Peña 1999, 557). Jones (1999) listed the control chart among the many elements in his matrix of management review meetings.

In searching for the words, "Statistical Process Control" or "SPC," several more papers were found. A few of these dealt with control charts. One abstract by Dr. Donald J. Wheeler (1999) discusses the use of "Process Behavior Charts." By avoiding the term "control charts" Wheeler gains some independence from the entire mystique, much of it false, attached to the latter term. However, he loses Shewhart's basic concept of prediction given a series of events. Anita Carleton's (1999) brief discussion was based on her book. The diagram included in her paper indicates that somehow, a control chart is used to detect special causes and is used to remove these. The diagram further implies that chart data can be used to determine process capability. Klenz (1999) discusses the method of "data warehousing" to give "data marts" and "info marts" that can be used for decision making by yielding meaningful information. Control charts are part of his database. Hutton and Topp (1999) in discussing the use of Baldrige assessment to improve quality, discuss a management review process in which all managers are trained in SPC and can interpret control charts adequately. They call them "result charts" in their paper. This change of name has the benefit and drawbacks mentioned above.

In summary, the 53rd Annual Quality Conference featured one paper that detailed the use of a control chart. In addition, Dr. Wheeler's (1999) talk also dealt with the application of control charts although the paper was brief. Six other papers mentioned control charts in passing. Less than two percent of the papers dealt directly with control charts and less than six percent mentioned the method at all.

ABI/INFORM

The volume of articles from the ABI/INFORM citations made it impossible to review the material in as much detail as was possible with the material from the 53rd AQC. The search was conducted on subjects coded as "Quality Control" and then with the additional source code of "Control Chart." There were 1485 articles dealing with the topic of quality control. Of these, 11 dealt with control charts. Another 20 papers had the subject, "SPC." A total of 31 papers out of the 1485 or a little over two percent dealt with these topics. The numbers are much the same as those observed in analyzing the 53rd ASQ. It seems that control charts are not much used in general and very little use is made of them in service applications.

Quality magazine ran a reader survey on their web site asking a number of questions about SPC. Nancy Chase (1999) reported the results in an article. Some 90% of the respondents used SPC, but only 87% of those felt that it was helpful, and less than a quarter felt that they were using it to full advantage. In the article, Dr. Wheeler deals with questions such as convincing management to use SPC, too many false alarms, application to complex processes, SPC software packages, finding SPC cumbersome, Cpk and control charts, tool wear and charts, and suppliers using SPC as a sales tool. On being asked, Ms. Chase felt that given the focus of the magazine, that it would be surprising if the respondents were not associated with some phase of manufacturing (personal communication July 8, 1999).

Many of the questions raised by *Quality*'s readers and others come from a misunderstanding of what a control chart is and what it is not. A number of the myths about control charts have found their way into books and are copied by other authors who do not go back to the original source, Shewhart's (1939; 1931) writing. Since myths seem to be responsible for the lack of use of control charts, I examine some common myths.

MYTHS AND FACTS

Shewhart explained it this way, "The principal function of the [control] chart is to detect the presence of assignable causes" (1939, 30). He goes on to define, "An assignable cause of variation as this term is used in quality control work is one that can be found by experiment without costing more than it is worth to find it." To accomplish this one needs a criterion that indicates an assignable cause.

Some writers talk about an underlying distribution for a control chart. Shewhart never depended on this nor on the Central Limit Theorem. The setting of the control limits (or criterion as Shewhart calls them) was the result of extensive experimentation. As he states

> Obviously, there is no a priori, formal, nor mathematical method of setting up a criterion that will indicate an assignable cause in any given case. Instead the only way one can justify the use of any criterion is through extensive experience. The fact that the use of a given criterion must be justified on empirical grounds is emphasized here in order to avoid the confusion of such a criterion with a test of statistical significance (30).

In his first book on quality control, Shewhart (1931) describes in Chapter XX the experiments he used to select the criterion (the three sigma limits) that we use today. The reader is referred to this chapter for the details.

A control chart predicts that, in the absence of assignable causes, the process will operate as a random system and produce the present level of quality in the future. If that level of quality is not satisfactory, a fundamental change in the process is required. In his book, *The Deming Route to Quality and Productivity*, Mr. W. W. Scherkenbach (1998, 25), cites five inputs of the process to be the following:

1. Material
2. Method
3. Equipment
4. Environment
5. People

One needs to make a fundamental change in one or more of these components to change the level of quality of a stable system. A stable system is one without any assignable causes of variation.

In their book, *Understanding Statistical Process Control*, Wheeler and Chambers (1992, 76ff) deal with four myths that have held back people from using these tools. The four myths cover:

1. The need for normal distribution
2. The use of the Central Limit Theorem
3. Independence of observations
4. Data must be in control before one can plot them on a control chart

Wheeler and Chambers show that these are not conditions for a control chart. Belief in these conditions being necessary leads one into mistaken application of the chart that can result in both tampering and costly false decisions. Again, I refer the reader to the book by Dr. Wheeler and Dr. Chambers for the detailed arguments.

The control chart is a management tool used for decision making. I discussed this point in the 43rd AQC, in my paper on "Quality in the Board Room" (1989). All activities in a corporation are processes, whether they be the collection process as evidenced by the accounts receivable, or weekly sales as shown in the "Quality in the Boardroom" (1989, see figure 4 and 5) or other accounting process. Since control charts deal with processes, we need to examine this aspect of the chart.

PROCESS

I believe that it was Irving Burr who first stated that the control chart is the process speaking to us. If only we could or would listen. Campbell defines a process as "any activity or series of activities that is repeated within limits" (1998, 59). In manufacturing, a process is the activity of converting raw material into work in process or finished goods. In job shops, a process is the activity that is used to achieve a result. For instance, in a tool and die shop it is the use of a particular grinder to work a part. The parts that are produced may differ materially, but the process is grinding. In an ad agency, the activity may be copy writing. In a bank, the activity may be preparing a loan application, or filing, or deciding to give the loan, etc. Just about every human endeavor is an activity designed to achieve some outcome.

One factor often overlooked in using a control chart is the order of events. Unless the chart reflects the sequence of events, it can give misleading information. I, therefore, examine next the importance of the order of events.

ORDER

The control chart can give us a great deal of information if we examine or measure the outcome *in the order in which they were created*. Change the order and the result can be very different and *may give no information at all*. To illustrate this effect we look at the first 100 drawings from a bowl as reported by Shewhart (1931). The chips in the bowl were numbered to represent a normal distribution. The process is drawing chips with replacement.

Figure 1 shows a stable system. The original order of drawing the chips was maintained. Figure 2 shows a very different picture. Sorting them in ascending order reordered the readings of the 100 chips. In reordering the readings in this way, the random aspect of the sequence was lost and the same data gives meaningless results. *Order is important*!

To see how control charts are used in practice, I examine some applications from home, government, and service industry.

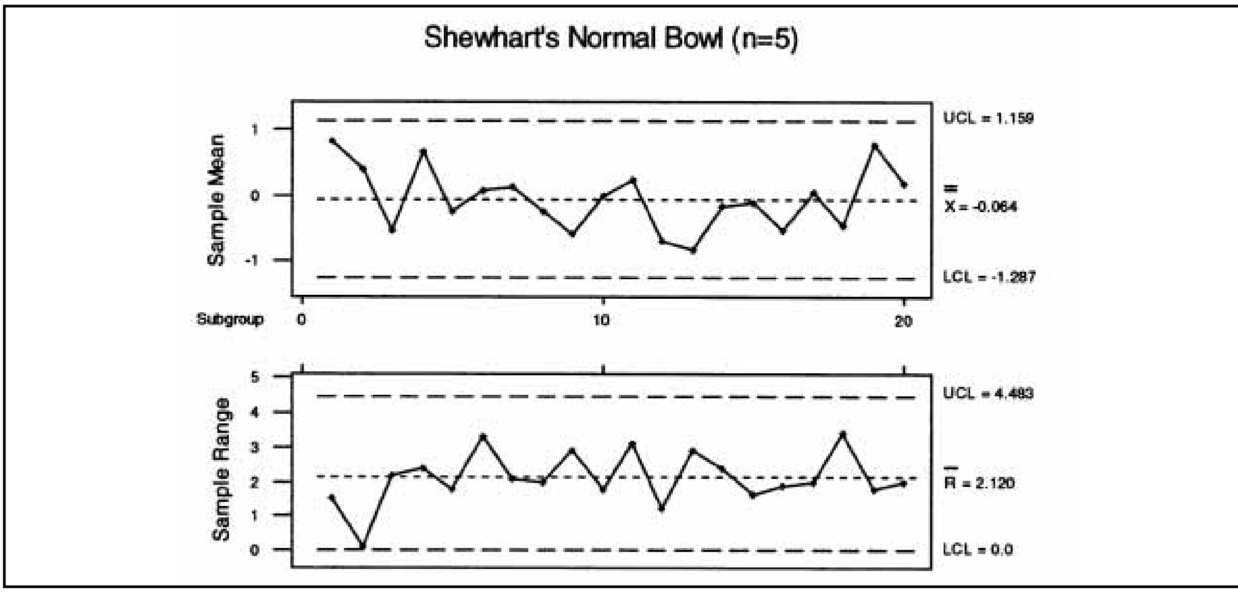

Figure 1. Drawings in original order.

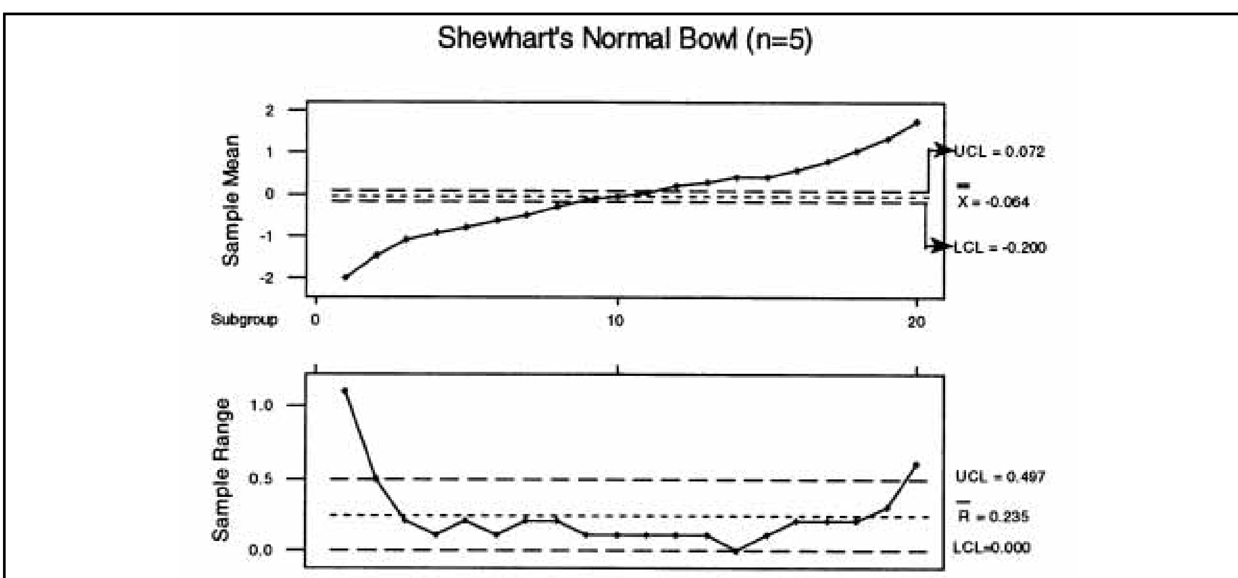

Figure 2. Drawings sorted in ascending order.

APPLICATIONS

Pohlen's (1999) paper in the 53rd AQC was a fine example of the use of statistical thinking in a situation that was at once medical and an application at home. There are many applications where this type of thinking can be useful at home. There are all sorts of processes in the home. Things such as heat, water usage, telephone usage, in fact any utility usage is a process subject to measurement. I keep track of my mileage and the amount of gasoline used for that mileage. Converting this data into miles per gallon (MPG), I chart the data on a chart for individuals. In theory when the MPG falls below, the lower control limit, the car should be tuned up. Alas, at home, theory is not always strictly followed. My dear wife believes in regular maintenance and so, has the car tuned up on a regular schedule. After the tune-up it takes the engine a while to get back into a stable state. A stable state is one where no special or assignable causes exist.

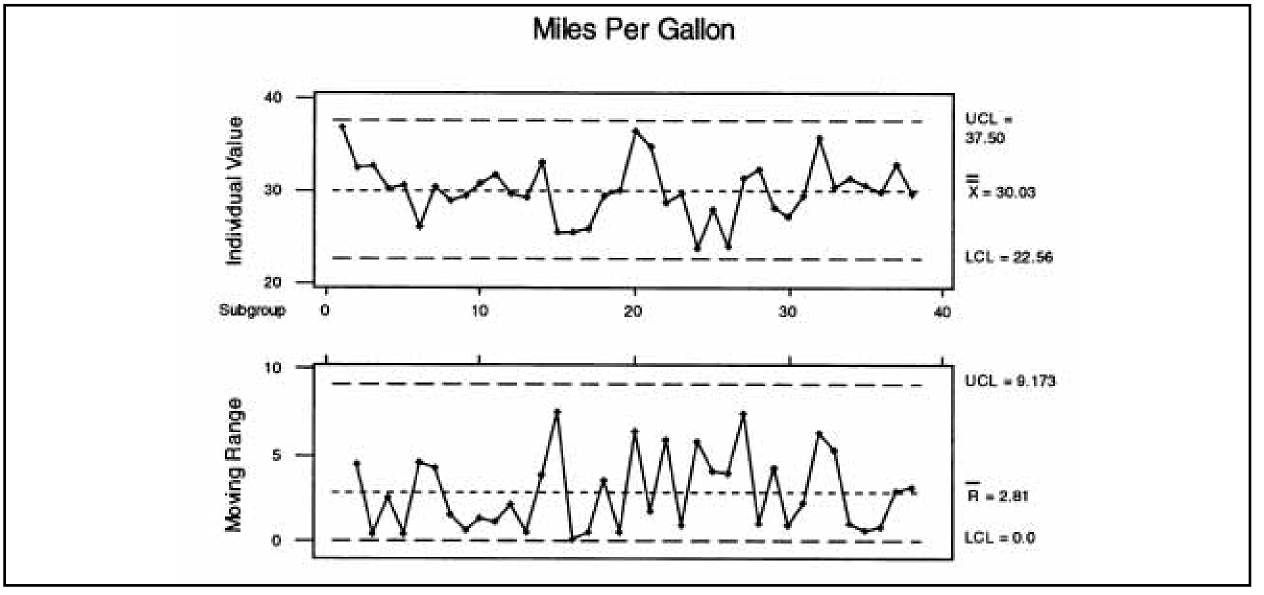

Figure 3. When to tune-up.

Pohlen's (1999) paper was also a fine example of how control charts could be used in health care. Dr. W. E. Deming (1992, 252) cited the work of Dr. Shunji and Dr. Sugiyama in using a control chart to determine when additional training will not help a patient to walk any better. Dr. Sugiyama measured the time it took the patient to take a series of steps. At first, the patient was wildly out of control. As training progressed, the patient's time to take steps became stable indicating that additional training would not help the patient.

Deming, in his last book, *The New Economics* (1994) discussed how people can understand and work with variation. He illustrated what he called, "Shocks from common causes of variation of trade deficit" (214). He showed a run chart of the Balance of Trade Figures from 1988 through mid 1990. This chart showed, "The United States trade deficit was stable over a long period of time though with a possible slight downward trend" (215). He then cited headlines which gave hurrahs for every narrowing or improvement of the gap compared to the prior month's gap and boo's for every widening compared to the month before. In fact, these variations were random. By failing to look at the long term process, we fail to understand what the process is telling us. Today, we still cheer when the trade deficit is less than the month prior and become concerned when the deficit increases. In Figure 4, I show the monthly Balance of Trade for 1994 through 1996.

Again, each point higher than its predecessor was deemed good while each point lower than its predecessor was deemed bad. In reality, the seven points in a row below the average in 1995 should have alerted us to coming problems. Indeed, the period from 1997 to present shows a dramatic slide into larger and larger trade gaps. Sure, there were some points higher than their predecessors, but these were just random fluctuations. Failure to recognize random fluctuations causes erroneous market and policy decisions.

In chapter 7 on "Service Organizations" of his book, *Out of the Crisis*, Deming (1992) gives well over 100 suggestions for applications of control charts. These cover such diverse areas as sales personnel, motor freight, administrative applications of a manufacturer, health care including hospitals, airlines, Bureau of the Census, hotels, restaurants, city transit system, railways, telephone companies, department stores, banks, electric utilities, and municipal services.

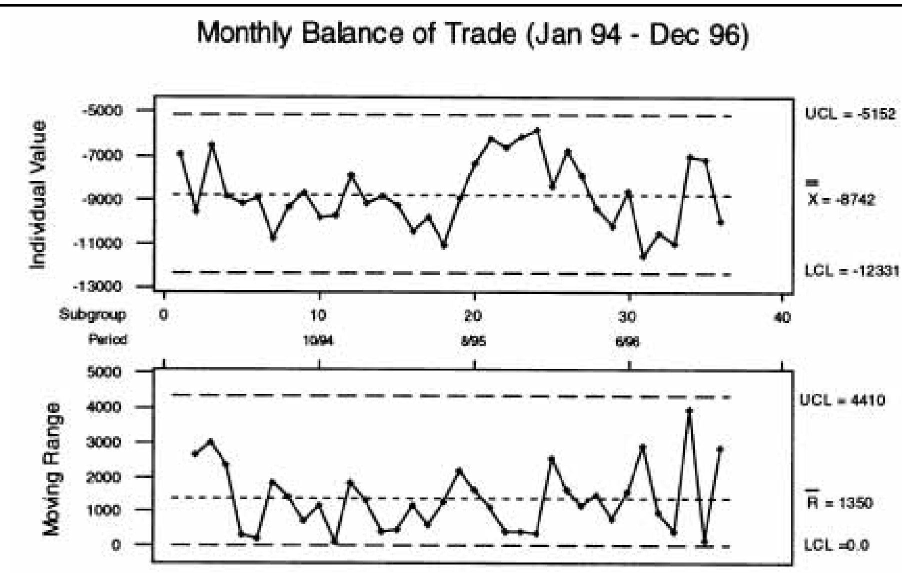

Figure 4. Balance of trade 1994–1996.

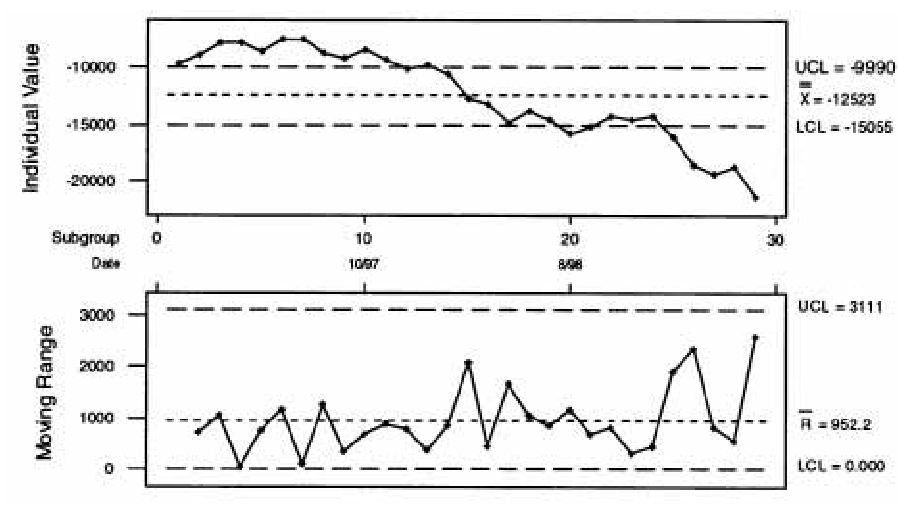

Figure 5. Balance of trade 1997 through 1999.

Table 1. Complaints.

Date	*Complaints*	*Comments*	*Date*	*Complaints*	*Comments*
1/4	0	No complaints	1/18	4	Late delivery
1/5	1	Late delivery	1/19	5	Late delivery
1/6	2	No complaints	1/20	3	Late delivery & billing
1/7	0	Billing	1/21	8	Billing
1/8	1	Billing	1/22	0	No complaints
1/11	7	Billing	1/25	2	Late delivery
1/12	3	Late delivery & billing	1/26	1	Late delivery
1/13	2	Late delivery	1/27	3	Late delivery
1/14	2	Late delivery	1/28	1	Late delivery
1/15	3	Late delivery	1/29	3	Late delivery

An interesting and simple application is that of customer complaints. Table 1 shows the complaint record of one organization.

The total number of complaints in Table 1 is 51 for the month. Using a c-chart, the average number of complaints is = Total complaints / Days = 51/20 = 2.55. The control limits are computed as $\bar{c} \pm 3\sqrt{\bar{c}} = \sqrt{2.55} \pm 3\sqrt{2.55} = 7.34$ for the Upper Control Limit (UCL) and 0 for the lower control limit. In spite of the arithmetic, 2.55 - 4.79 = - 2.24, the lower limit was set to zero because counts cannot be less than zero.

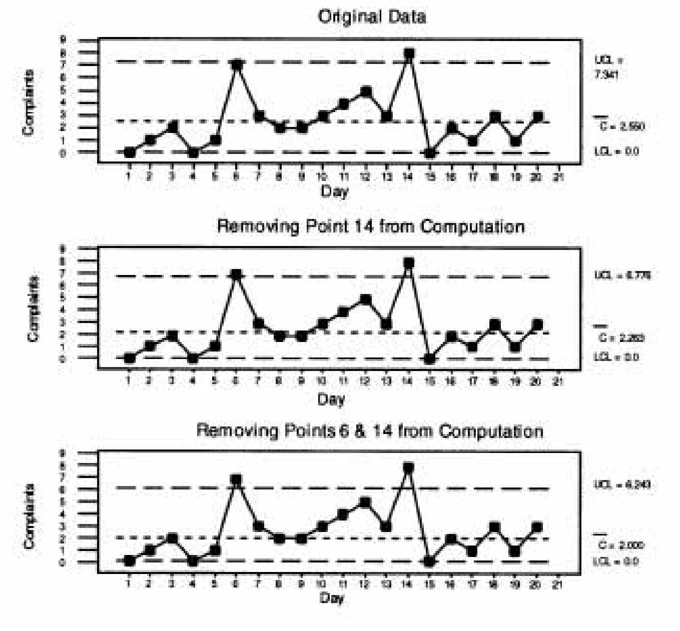

Figure 6. Complaint analysis.

Looking at the upper panel of Figure 6 it is clear that point 14 is above the UCL. Point 14 in Table I is the 21st of January when eight complaints were registered concerning the billing. On investigation, it was found that the computer experienced a problem five days earlier. When the computer problem was corrected, the discount date was not adjusted properly and this caused the billing complaints.

As a special cause, point 14 was removed and the chart re-computed. The center panel shows the re-computed chart. A new special cause point now appears, point 6. Referring to Table 1, one sees that the same situation occurred with this point. It is interesting to note that a particularly large special cause can, under circumstances, mask other special causes.

On removing the special cause points and re-computing, one gets the chart shown as the bottom panel of Figure 6. This is now a stable process averaging 2 complaints per day. To improve this process, one needs to examine what causes this average of two complaints. It will require a fundamental change of the process to reduce the 2 complaints per day.

CONCLUSIONS

The Shewhart control chart is a powerful management tool that allows us to listen to the process under consideration and to understand how variation impacts our process. It saves one from tampering with the process yet make changes where changes are needed.

The current literature rarely mentions the control chart, leading to the assumption that this useful tool is underused. The application to service processes appears to be particularly rare. It may be that the myths that have grown up over the years encourage service function practitioners to shy away from the tool as being too complex or statistical. The experience with the Balance of Trade figures, which influence our standard of living, shows that failing to use the Shewhart charts can result in misleading decisions.

The Shewhart control chart is one of the best tools that managers have to deal with the constant problem of variation.

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