Variables Control Charts: A Measurement Tool to Detect Process Problems Within Housing

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INTRODUCTION

When housing administrators discovered that female residents were unsatisfied with the equality of hot water coming from the community showers in a high-rise residence hall, they relied on the concepts of Total Quality Management (TQM) to help them identify both the causes of and possible remedies for the problem. TQM is a method of achieving quality using scientific and teamwork approaches. By utilizing quantitative measurement, administrators believed they could pinpoint the underlying causes of the hot water problem—something previous focus groups could not. After identifying the problem, they relied on various teamwork methods to discuss and implement changes to improve the process of hot water distribution.

Current literature concerning TQM in higher education places heavy emphasis on nonempirical methods of achieving quality. Although teamwork, customer satisfaction, and ownership are all important factors in TQM, authors who have written about these concepts have failed to address the significance of statistical methods in quality control.

According to some (Luna, 1996; Teeter & Lozier, 1993), Statistical Process Control (SPC) is the one component separating TQM from other improvement methods. In fact, quality is defined in TQM as a measurable characteristic of a product, process, or service (Montgomery, 1985). By using quantifiable measurement techniques, it is possible to synthesize and evaluate quality in relationship to operational variables. Furthermore, one may examine the effects of these variables to any changes within a particular process under study.

Although examples of quantitative methods of achieving quality are limited in the literature, some articles do exist. Grace and Templin (1994) used a simple form of statistical measurement to help them improve the quality of their student services departments. Macchia (1993) used SPC to measure the enhancement of student learning, and Koberna and Walter (1993) explained how a community college used many TQM tools to achieve quality. This study offers another example of how a traditional TQM tool can be used in higher education, specifically in a residence hall.

More often than not, higher education professionals tend to use only the process definition tools available in TQM, and avoid important data generation and analysis tools. Koberna and Walter (1993) attribute this aversion to statistical methods to the newness of TQM in the higher education community. By not utilizing Statistical Process Control tools, higher education professionals may be creating barriers in achieving a better understanding of TQM in the future (Seymour & Collett, 1991). Before they fully understood TQM, some professionals stated that SPC tools may not be needed for achieving better quality in higher education (Vance & Schipani, 1993), and some have even criticized TQM for its ambiguity and simplicity (Fisher, 1993). Clearly, statistical tools can provide a reliable solution for turning the enigmatic into the exact (Seymour & Collett, 1991).

This article focuses on one of the more intricate statistical process control tools in TQM. The Control Chart is one of the most widely used SPC tools in business and industry and probably one of the least understood among those in higher education.

THE CONTROL CHART

The underlying principle behind the Control Chart is that every process, no matter how well executed is imperfect. Because many variables are involved in all processes, deviations can occur in one or more of these variables, creating a less than perfect process. According to Tague (1995), the variables involved in a process can usually be placed into the four distinct categories of personnel, machines, materials, and methods.

According to Shewhart (1986), variations that occur among these elements can produce deviations in central tendency which can lead to output variations in the process. Detecting changes and controlling input variations from either of these categories requires a well-identified system for evaluating process output (Demming, 1986).

The Control Chart is a tool for determining the type of variation in a process. When a process is in control, it is subject only to a stable system of random causes. When a process is out of control, it is subject to an assignable cause or cause of variation (Montgomery, 1985).

Stated another way, TQM philosophy assumes all processes have internal and external factors effecting efficiency and reliability. When these factors occur randomly, they are assumed to be caused by chance circumstances outside the control of the worker or the institution. However, if these factors occur in a nonrandom fashion, or if they exceed required specified limits, it is assumed that there is an underlying cause which can be pinpointed and corrected. These underlying causes are called "assignable" because they are identified as an assessable variable which can be manipulated and controlled (Luna, 1996).

The Control Chart is a graph representing the variability of a process variable with respect to time (see Figure 1). The horizontal axis on the graph represents rational subgroups over a period of time. Each point on the horizontal axis coincides with observations made on a subgroup

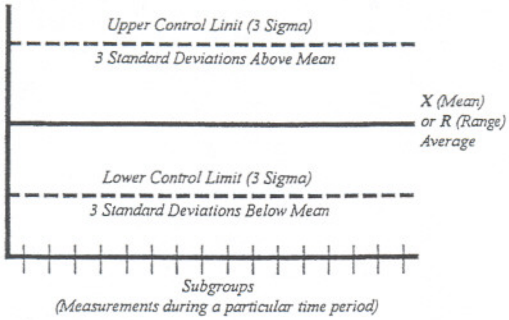

Figure 1. **Example of a Control Chart**

drawn from the process at a particular point in time. Stated another way, a subgroup is a point in time when a series of measurements are gathered during a particular time within the process. The subgroup then becomes the mean of each of the observations within that time period.

The center line is drawn horizontally across the chart to represent an average value. This value can be obtained from the subgroup data, or it can be in the form of a specification mean evolving from longer-term historical data. For a means chart, the center line is derived from the sample observation averages within each subgroup. For a range chart, the center line is the average range of samples within each observation. Lines above and below the center line represent the upper control limits (UCL) and the lower control limits (LCL) of the average respectively. The upper and lower control limits are based on three standard deviations above and below the mean (referred to as "3 sigma" in TQM terminology). The control chart may indicate an out-of-control condition either when a point falls beyond the control limits, or when the plotted points exhibit some nonrandom pattern of behavior. Ishikawa (1990) defined nonrandom causes of variation as follows:

1. Runs – when several points line up consecutively on one side of the central line.
2. Trends – when there is a continued direction of a series of points.
3. Periodicity – when the points show the same pattern of change over equal intervals.
4. Hugging of the control line – when the points on the control chart fall close to the central line or to the control limit line.

If there is no reason to suspect an out-of-control condition, changes should be made to the system and further measurements conducted. If the change positively effects the process, the data in the control chart will move toward a controlled state. If the change brings a negative effect, the control chart will indicate that the process is more out of control than before the change.

Many control charts are available for the study of a process. The major factor in determining which chart to use is the type of data generated from the study. Again, the most fundamental concept of TQM is the ability to count or measure a particular characteristic. However, counting and measuring are two different functions in statistics and should be treated differently in TQM. The process of counting involves a finite scale and scores generated are based on the binomial distribution. The tool for this type of data is the Attributes Control Chart. The process of measuring involves an infinite scale and scores generated are based on the normal distribution. The tool for this type of data is the Variables Control Chart. To understand fully how distributions and Control Charts are related and used, refer to Montgomery (1985).

METHOD

The purpose of this study was to determine if the current process of supplying hot water to a high-rise residence hall for women at a Southeastern Doctoral I granting institution was in control. After a series of focus groups among the residents in that hall, it was determined that they were mostly concerned about the consistency and availability of hot water in the building.

One resident assistant (RA) from the fourth, ninth, and twelfth floors was involved with the study. These floors were predetermined so that the building was separated into lower, middle, and upper areas. Each RA measured the temperature of hot water (in Fahrenheit) coming from a common area bathroom faucet on their floor. This was done during the morning, noon, and evening at specified times during the day for 14 days. Therefore, each RA recorded 42 observations for a total of 126 observations. Because the data measurement was based on a continuous scale, the x (pronounced x-bar) R Control Chart was used which shows changes in the mean of the process (x) and changes of the dispersion of observations (x and R).

If the subgroup observations tended to hug around the mean, it was inferred that multiple factors were mixed into a subgroup and that the process of supplying hot water was not consistent throughout the building. Therefore, the same individual temperature observations were stratified by floor and each floor was re-examined. If each floor were treated individually, subgroups then contained observations from each of the three time periods per day for 14 observations per floor. Stated another way, for a given floor, each subgroup represented the average of a particular day's three temperature readings.

RESULTS

The results of the initial test indicated a problem with hugging of the mean within the central line of the x or means chart (see Figure 2). This showed that the majority of observations fell within a close proximity of the mean, indicating that more than one factor was being measured. Observations within the R or Range Chart, however, indicated an out-of-control state because of a possible run problem for the first six observations, a possible trend problem, for observations 19 through 27, and two observations, 26 and 32, which exceeded the lower and upper control limits respectively. The R chart in this example exhibits an out-of-control state because observations either exceeded the control limits of 3 sigma or groups fell into patterns of nonrandom behavior.

The results of the initial test also indicated that because of the high variance of observations in the R or Range Chart, water temperature variance problems may exist between the three

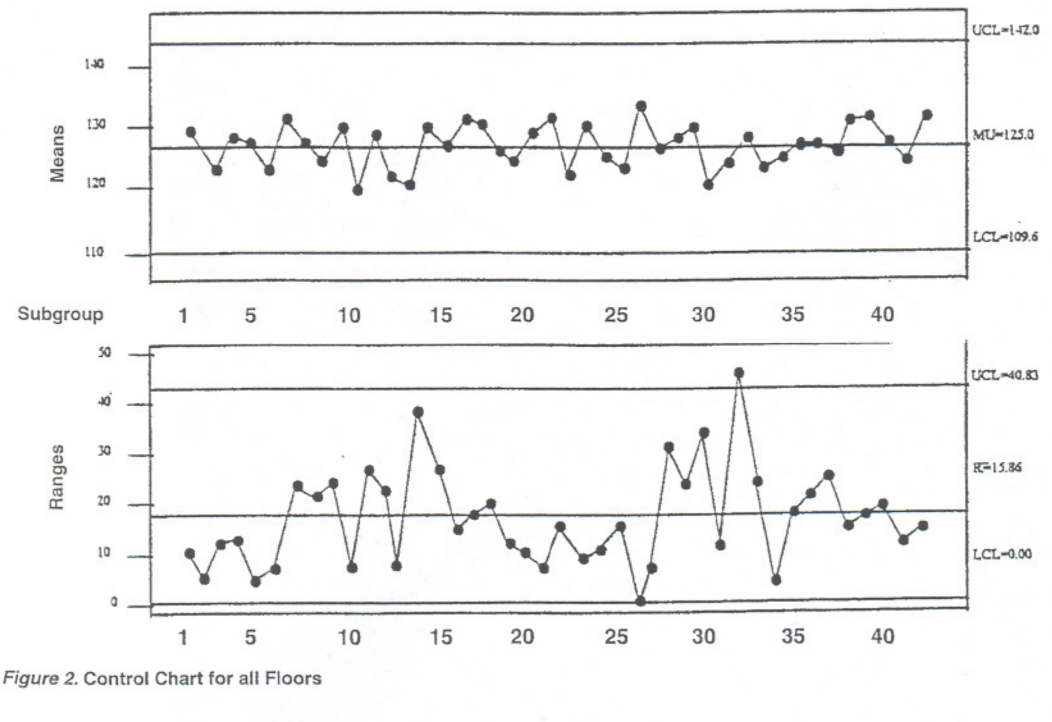

Figure 2. Control Chart for all Floors

floors. This assumption was later supported by independent floor tests. One of the major keys in reading this chart was looking at observations 26 and 32 in the range chart. Observation 26 indicated that no variance existed within this subgroup while observation 32 exceeded a range of more than 40 degrees. Because the results of this test indicated high variance among subgroups within the R chart and hugging of the mean within the *x* chart, the test was rerun after separating the floors and redesigning the subgroup to contain observations from each of the three time periods for each day.

The observations for the fourth floor (see Figure 3) indicated that the Range Chart was in control because observations did not fall outside of the 3 sigma control limits and because no patterns existed among groups of observations. The means chart, however, was out of control. Observations 5 through 10 on the means chart indicated a possible trend problem and observation 10 exceeded the upper control limits. Although most of the observations from the means chart tended to hug the center line, the range chart indicated that the variance was within acceptable limits. It was clear to see that the fourth floor experienced higher water temperatures than the other two floors and that, in some cases, these higher temperatures far exceeded the 125 degree mean. Additionally, observations 3 and 10 on the means chart indicated that the higher temperatures occurred on Wednesdays and, according to the Range Chart, little temperature variation occurred among the three time periods in these days.

The observations for the ninth floor (see Figure 3) also indicated that the Range Chart was in a controlled state. However, the means chart for the ninth floor indicated a possible periodicity problem. This type of problem is harder to detect than other out-of-control states and is usually based upon experience and a greater understanding of the process (Ishikawa, 1990). The periodicity problem was apparent after every 3rd observation and continued over equal intervals during the entire length of time measured. According to the means chart, water temperature for both weeks increased on Thursday through Saturday and decreased on Monday through Wednesday.

Although the observations for the twelfth floor indicated that the Range Chart was in a controlled state, the means chart for this floor showed an out-of-control state more severe that the other two floors (see Figure 3). Observations 3 through 7 and 10 through 14 indicated possible run problems and observations 5 through 10 exceeded the lower control limits. Additionally, these observations indicated periodicity problems starting after the 5th subgroup. By looking at this chart, it was apparent that water temperatures were significantly lower for this floor during Thursdays and Fridays and that, on average, the water temperatures were lower than on the other two floors. Furthermore, observations 5 and 10 on the means chart also indicated wide variation within the subgroups. Specifically, the control chart indicated that a wide variation existed between the observations within these subgroups. After observing the raw water temperature data, it was determined that the water temperatures for the afternoon and evening hours were significantly lower than during the morning hours.

Each of the three floors indicated that the Range Chart was in a controlled state. This showed that the source of variation in the water temperature on any floor during the morning, noon, and evening hours was not attributed to patterns of change on that floor. The *x* or means chart for each floor, however, indicated an out-of-control state because observations exceeded the control limits or formed patterns of behavior over a day-to-day period.

DISCUSSION

This study demonstrated the use of the Variables Control Chart for detecting problems with a residence hall hot water supply. Through this study, a better understanding of the hot water supply was achieved and recommendations for the improvement of the system were made.

The Variables Control Chart indicated three problems: (a) high variation of water temperatures from floor to floor, (b) much higher water temperatures on the 4th floor than on the 12th floor, and (c) lower temperatures or higher demands for hot water during the afternoon and evening hours on Wednesdays, Thursdays, and Fridays.

The first recommendation concerned the first two problems. High variation of water temperatures from floor to floor and higher temperatures on lower floors indicated potential water flow problems. Increasing the overall water temperature piped into the building will increase the temperature for the higher floors, however it will not address the variation problems between floors and will lead to even hotter water on the lower floors. Remedies for these variation

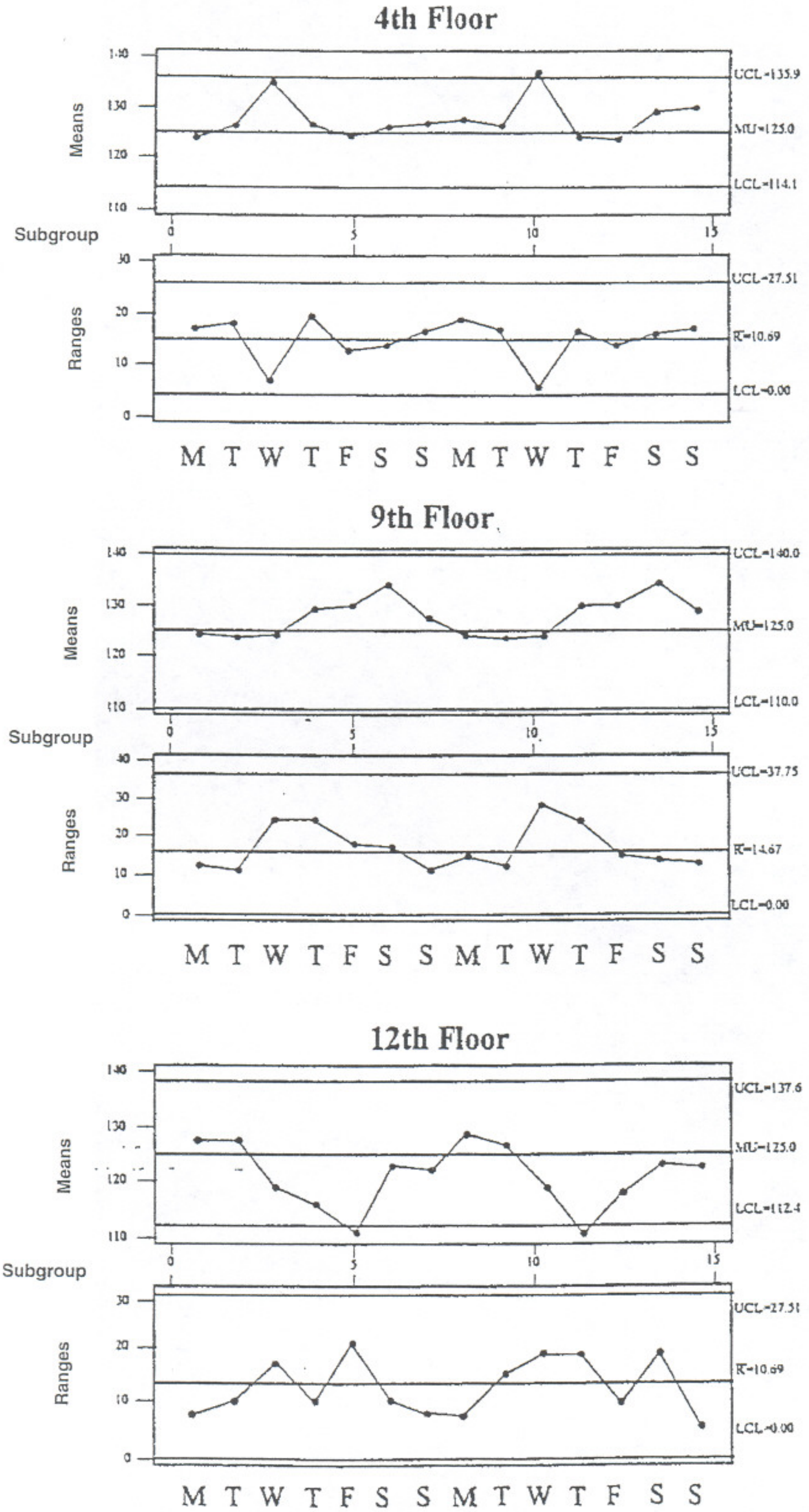

Figure 3. Control Chart By Floors

problems could include, but are not limited to, better pipe insulation, repairing or replacing internal pumping systems, adding booster systems which would reheat water on the higher floors, and redesigning of the hot water supply system.

The quality team charged with the initial investigation of the hot water supply process recommended that Physical Plant staff explore remedies for improving the process. These remedies would be classified according to cost and perceived effectiveness and be introduced into the system one at a time. By including cost as a factor in the order of remedy, lower cost changes would be introduced to the system first. Thus, if the system entered into a controlled state, it would do so at the lowest possible cost.

There was a chance that the third problem of day and time might be controlled by finding a solution to the first two problems, but it was recommended that the same team investigate adjusting the delivery of hot water to the building to increase the temperature when the system is mainly in use, such as Thursdays and Fridays. Likewise, the delivery of hot water could be decreased when demand is less, such as Wednesdays.

The third recommendation concerned future monitoring. For TQM to remain effective, a process must undergo continuous measurement to determine if changes increase quality or if the system falls back into an out-of-control state. For this reason, it was recommended that the water temperature be continually measured for two weeks for both fall and spring semesters.

CONCLUSION

Statistical Process Control is an important application to Total Quality Management. To fully utilize the concepts of TQM, one must define, synthesize, and evaluate quality. The Variables Control Chart is one of many tools for achieving these goals. Because it is used with variables that are measured, this tool can be used for any continuous repeating variable such as money, time, scores on a survey or evaluation, weights, distance, or volume.

For example, housing personnel could use this chart to measure utilities' output within the halls in conjunction with energy saving changes to the buildings. It also could be used to track survey responses of residents each week over a period of time, or to track the completion rate for work orders This chart also has been used to track the difference between predicted and actual values in forecast models to locate patterns which, if detected and changed, could improve the ability of the model to make more accurate predictions.

Although the Variables Control Chart may seem complicated and foreboding at first, with practice it can be a relatively simple tool to use. Many software companies offer packages that make entering data and interpreting Control Charts effortless. As seen in this study, the Control Chart is a powerful tool in measuring the quality of a process and assessing the effects of changes to it. Because the Variables Control Chart works with continuous data, it can be used to evaluate any process for which this type of data can be collected.

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