The Relationship between Quality and Productivity

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Abstract

Quality improvement can be a vital way of increasing a company's productivity. A more uniform product results in less defective output, less items that are to be scraped and a decreased need for rework of non-conforming items. A more uniform product that conforms to manufacturer specifications represents an improvement in quality of conformance. This improvement in a product's quality of conformance in-turn leads to increased productivity since the same level of production can be achieved at a reduced cost.

Keywords: quality, productivity, control chart, design, conformance

1. Introduction

Traditionally, manufacturing managers have viewed productivity and quality as tradeoffs. Many managers believe that the quality of a product can only be improved at the expense of production efficiency and increased costs (Evans and Lindsay 2011). Managers, who hold this belief, are missing the big picture. Improved quality results in a reduction in defective output, a decrease in unnecessary time and cost spent on rework, less inspection, higher employee morale and increased customer satisfaction. The decrease in cost associated with these activities allows manufactures to have the same level of production at a decreased cost. In turn, this leads to increased productivity. The focus of this article is on the beneficial effects of increased product quality on productivity. In particular, the role of the control chart in improving product quality and in turn increasing productivity is examined.

2. Productivity and Quality

Consumers expect that the products they purchase, to be ready for use or fit for use. In fact, “fitness for use” is a generally accepted definition of quality. For example, purchasers of new cars expect them to conform to their specifications in terms of color, size and features and meet their needs by providing reliable transportation to and from work daily. There are two generally recognized aspects of quality: quality of design and quality of conformance (Montgomery 2013, Besterfield et al. 2006). Quality of design refers to intentional variation in the type or grade of a product that is to be made. For example, a chemical manufacture may produce two grades of sulfur, one that is 90% pure and one that is 95% pure. These grades of sulfur are designed to be of different quality levels by virtue of their purity levels. Improvements in quality of design are infrequent, and can only be achieved by the active intervention of management. Quality of conformance refers to the uniformity of the product and how well it conforms to the specifications of the design. A computer manufacturer that purchases computer chips from a supplier will like batches of the chips to be within specifications and as similar as possible. A more uniform product results in less scrap and rework by production employees. It also results in less inspection cost by the quality control department, lower long-run production costs and increased productivity, since the product can now be produces at a reduced cost.

Greater uniformity of the product that leads to higher levels of quality of conformance is the focus of this article. The quality control chart is the primary tool in achieving greater levels of quality of conformance.

3. Productivity Improvements and Control Charting

Non-uniformity or variation is a fact of life in all manufacturing and service industries. A production employee, who takes reading on the flow pressure produced by an oil pump on an hourly basis, will find that the readings are never the same. This non-uniformity is referred to as variation. Decreases in variation of the level of product or service result in improvements in quality of conformance. A control chart is a plot of observations from a process over time. Pegels (1995) suggests that "control charting involves the charting of statistics on a chart in such a way that deviations from a standard can be quickly observed, and action can be taken to correct the undesirable variation." Typically, a process can be summarized by an average value (Xbar) and a measure of variation, the range (R). If a product is to consistently meet the customers' fitness for use criterion, generally, it should be produced by a stable process. A stable process is better able to meet customers' needs for a uniform, high quality product. The purpose of the control chart is process stability, through the reduction of process variability. This is done by distinguishing between common cause and special cause variation. Common causes are small, uncontrollable influences that are an inherent part of the process. They cannot be removed from the process without basic changes in the process that usually require management action. Special causes are larger, unusual influences that can be removed from the process. A process that is operating with only common cause variation present is said to be in statistical-control. The control chart is used to determine whether a process is in-control.

As an example, consider wafer boards that are used in the construction of storage boxes. Wafer boards are designed to be 20 inches in width as specified by the storage box manufacturer. Minor deviations (common causes) from this width are acceptable, but the manufacturer will like to know when substantial deviations (special causes) exist, so that corrective action can be taken. The manufacturer decides to sample 5 boards from the process every hour. It is assumed that width of wafer boards follows a normal distribution.

3.1 She whart Chart and Range Chart

Table 1 displays mean widths and ranges of wafer board widths for five samples. The range ® is the difference between the largest and smallest observation in each sample. The She whart Xbar control chart is constructed with control limits set at three standard deviations from the overall average. This translates into a 99.7% chance that a sample mean will fall within the control limits. The range chart limits are found using the D3 and D4 factors for sample of size n, in this example n = 5. Multiplication by the factors D3 and D4 results in three standard deviation control limits. Tabled values of D3 and D4 can be found in most quality control textbooks, for example, Montgomery (2013). The control limits for the range chart are:

LCLR = D3 (average R) = 0 (3.4) = 0
UCLR = D4 (average R) =2.1144 (3.4) = 7.189

The Xbar control chart limits for the individual observations can be found by using an A2 factor that results in three standard deviation control limits. The A2 factor for n = 5 is used in the following formula:

UCLXbar =Overall mean + A2 (average R) = 20 + 0.577 (3.4) = 21.96
LCLXbar = Overall mean – A2 (average R) = 20 – 0.577 (3.4) = 18.04

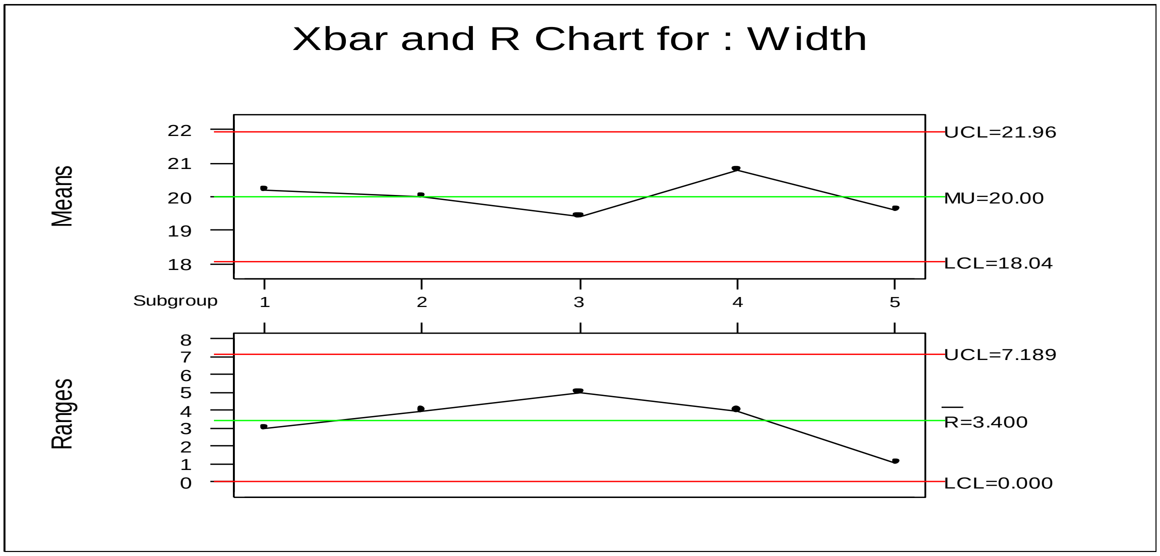
Table 1: Widths of Wafer Boards

Sample Number	**Width of Wafer Boards**	**Mean**	**Range**
1	21 19 22 19 20	20.2	3
2	22 20 18 19 21	20.0	4
3	17 19 22 19 20	19.4	5
4	19 21 22 19 23	20.8	4
5	19 21 22 19 23	19.6	1
Totals		100	17

Figure 1 displays the Xbar control chart and R control chart for the average value and range of the widths of wafer boards respectively. The R control chart shows that the ranges for all five samples fall within the control limits, indicating that the variation of the widths are in-control and not in need of adjustment. The Xbar-control chart reveals that the widths of the wafer boards are also in-control since the averages for all five samples fall within the control limits.

Should an observation exceed the control limit for either chart, the cause of the unusual observation should be found and eliminated, and the control limits recalculated without the unusual observation. Improvements in the quality of conformance are achieved by the elimination of unusual sources of variation that results in a more uniform product, and by the resultant tightening of the control limits.

Figure1. Xbar and Range Charts for Widths of Wafer Boards



3.2 Exponentially Weighted Moving Average (EWMA) Chart

If small changes in the mean of the wafer boards are of interest, Montgomery (2013) suggests the use of the Exponentially Weighted (EWMA) control chart or the Cumulative Sum (CUSUM) control chart for process monitoring. Originally introduced by Roberts (1959), control limits for EWMA charts are constructed using the average moving range, MR, or the sample standard deviation, S, as a measure of dispersion.
deviation, *S*, as a measure of dispersion.

$$X_i + \lambda\ \Sigma(1-\lambda)^j\ X_{i\text{-j}} + (1-\lambda)^n\ W_0, \qquad i = 1, 2,..., n \tag{1}$$

where $0 < \lambda \leq 1$ and $W_0 = \overline{X}$. The constant, λ, is the weight assigned to the present observation. Montgomery[1] suggests values of λ in the interval $0.05 < \lambda \leq 0.25$. Smaller values of λ are used to detect smaller shifts in the process mean. Control limits are set at

$$\overline{X}\ \pm\ k\ (S/c_4)\surd[\ \lambda/(2-\lambda)\ [1-(1-\lambda)^{2i}\ ]\ ] \tag{2}$$

where $k > 0$ (usually $k = 3$) and

$$\overline{X} = \Sigma\ X_i/n,$$

$$S = [\ \Sigma\ (X_i - \overline{X})^2\ /\ (n-1)\ ],$$

or

$$\overline{X}\ \pm\ k\ (MR/d_2)\surd[\ \lambda/(2-\lambda)\ [1-(1-\lambda)^{2i}\ ]\ ] \tag{3}$$

where $\qquad MR = \Sigma\,|X_{i+1} - X_i|\ /\ (n-1) \qquad \text{i} = 2, 3,..., n.$

The values of c_4 and d_2 are chart constants that depend on *n*. The chart signals if a value of W_i crosses the control limits.

It is also possible to express the EWMA statistic in its standardized form as

$$Z_i = [c_4(W_i - \overline{X})\ /\ S\ ]\ \surd[\ \lambda/(2-\lambda)\ [1-(1-\lambda)^{2i}\ ]\ ] \tag{4}$$

with control limits in (4) replaced by ± *k*. Alternatively, the standardized EWMA statistic can be stated as

$$Z_i = [d_2(W_i - \overline{X})\ /\ MR\ ]\ \surd[\ \lambda/(2-\lambda)\ [1-(1-\lambda)^{2i}\ ]\ ] \tag{5}$$

with control limits in (5) changed to ± *k*.

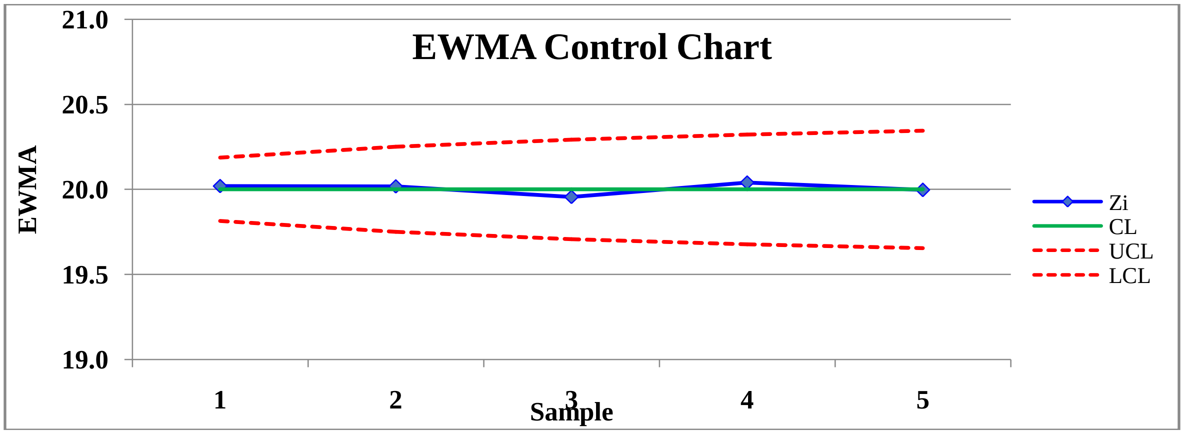
For the widths of the wafer board data in Table 1, the standardized EWMA Statistic on the means are displayed in Table 2 with an initial mean set to 20, estimated standard deviation (mean R/d2(5)= 3.4/4.918= 0.69134) 0.69134 and L set to 2.7 in constructing control limits as suggested by Montgomery (2013).

Table 2: Standardized Mean Widths of Wafer Boards

Observation	$Xbar_i$	Z_i	UCL	CL	LCL
0		20.0000			
1	20.20	20.0200	20.19	20	19.81
2	20.00	20.0180	20.25	20	19.75
3	19.40	19.9562	20.29	20	19.71
4	20.80	20.0406	20.32	20	19.68
5	19.60	19.9965	20.34	20	19.66

Figure 2 displays the standardized mean wafer board widths for the data of Table 2 and the appropriate control limits. Note that all values are within control limits indicating the widths of the wafer boards are in-control and there are no unusual causes of variation present.

Figure 2: EWMA Chart for Mean Widths of Wafer Boards



4. Conclusions

The control chart is the primary tool in improving the quality of conformance of a product or service. It provides a visual display of the uniformity of a company's product over time. Observations that fall within the control charts limits are used to determine whether the process is in statistical control, that is, producing a uniform product. Shewhart and EWMA control charts are two process monitoring schemes that may be used to determine whether a process is in statistical control. The elimination of unusual sources of variation and the resultant tightening of the control limits, represents improvements in the quality of conformance. Improved quality results in a reduction in defective output, a decrease in unnecessary time and cost spent on rework, less inspection, higher employee morale and increased customer satisfaction. The decrease in cost associated with these activities allows manufactures to have the same level of production at a decreased cost. In turn, this leads to increased productivity.

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