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Evaluation of operation and death statistics at surgical procedures by using attribute control charts

Leman Tomak*, **Yuksel Bek**

[a] *Department of Biostatistics and Medical Informatics, Faculty of Medicine, Ondokuz Mayis University, Samsun, Turkey*

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*** Correspondence to:**
Leman Tomak
Department of Biostatistics and Medical Informatics,
Faculty of Medicine,
Ondokuz Mayis University,
Samsun, Turkey
e-mail: lemant@omu.edu.tr

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ABSTRACT

Statistical Process Control (SPC) is a technique that enables the quality controller to monitor, analyze, predict, control, and improve a production process through control charts. So to use of SPC in medical field is very important. The cases were obtained at the Ondokuz Mayis University Faculty of medicine departments of surgical sciences within two year were evaluated. The outcomes of the operations in these departments were followed throughout twenty-four months. For a surgical procedure has two possible outcomes; a nonconforming product (the patient dies) or a conforming one (the patient survives), the both the death and the alive were accepted as attribute data. The four type of attribute charts were applied to this data. These were *p*-chart, *np*-chart, *c*-chart and *u*-chart. If the statistical process was an “in-control” or not was tried to determine by the attribute charts. As a result of the statistical processes of these departments were evaluated, this provided easily be viewed the pattern of process. The aim of this research is to use the attribute control charts in medical field (especially hospital performance evaluation) and to show availability of the attribute control charts in medical field.

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1. Introduction

Statistical Process Control (SPC) is a technique that enables the quality controller to monitor, analyze, predict, control, and improve a production process through control charts (Bass, 2007). The aim of SPC is to reach the intended quality that has minimum cost (Westgard, 2002).

Walter A. Shewhart is the famous scientist who is establish the theorical basis of SPC (Westgard, 2002). Control charts were developed as a monitoring tool for SPC by Shewhart (Bass, 2007; Winkel and Zhang, 2007). These are among the most important tools in the analysis of production process variations (Westgard et al., 1977; Westgard et al., 1981; Westgard and Groth, 1981; Lenz and Wilrich, 2006). After about twenty years from the researches of Shewhart, Levey and Jennings used SPC to apply some differences in clinical laboratory in 1950 (Westgard, 2002). The chart of Levey Jennings is a chart that uses individual value or single value and it is plotted according to reference value. Henry ve Segalove developed a new procedure that a stable reference-example is analyzed to repeat and the individual measurements are plotted on the control charts (Westgard, 2002).

A control chart shows sample statistics and is consist of at least four lines; a vertical line that measures the levels of the samples means, the two out most horizontal lines that represent the upper center line (UCL), the lower center line (LCL) and the center line (CL), which represents the mean of the process. If all of the points take place between the UCL and the LCL in a random manner, the process is considered to be "in control" (Bass, 2007; Montgomery, 2012).

If a statistical process is an "in control", this doesn't mean there isn't variation but instead, when the variations are present, they display a random pattern. They are not outside the control limits and based on their pattern, the process trends can be predicted because the variations are strictly due to common causes (Yücel, 2007). If statistical process is an "in control" process, the test result of ill is reported but statistical process is an "out control" process, the test result of ill isn't reported (Bass, 2007).

The different charts are used for the several types of characteristics. While some charts are prepared for continuous data, others are generated for discrete (attribute) data. The most common charts for continuous data are, S, R, -S and -R (Chandra, 2001; Oakland, 2003; Montgomery, 2012).

There are four types of charts for discrete data. These are *p*-chart, *np*-chart, *c*-chart and *u*-chart. The all of these are referred to attribute charts but they have different characteristics from each other (Chandra, 2001; Wadsworth et al., 2001). Attribute characteristics seem binary data. The most common attribute characteristics are "conforming-not conforming", "good-bad" or "defective-nondefective" in quality control (Oakland, 2003; Montgomery, 2012).

The aim of this research is to use the attribute control charts in medical field (mostly they are preferred to use in industry); to determine the level of their activity in terms of visual and quick decision-making and to exhibit availability of the attribute control charts in medical area, especially hospital performance evaluation.

2. Methods

The cases were obtained at the Ondokuz Mayis University Faculty of medicine the departments of surgical sciences within two year were evaluated. The outcomes of the operations in these departments were followed throughout twenty-four months.

The both frequency of operations and frequency of deaths for these deparments were investigated. Because a surgical procedure has two possible outcomes; a nonconforming product (the patient dies) or a conforming one (the patient survives), the both frequency of the death and the alive were accepted as attribute data. The four type of attribute charts were applied to this data. Here, the number of nonconforming items was accepted as the frequency of dead for all of attribute charts. So, if the process was an "in-control" or not was tried to determine. MINITAB Statistical Software 15.0 was used to get attribute charts (Minitab Inc., 2009).

The *p*-chart

A good example for a *p*-chart is the inspection of products on a production line. The products are either conforming or nonconforming. When *p*-chart is used for surgical death, they will be either alive or dead. The probability distribution in this context is the binomial distribution with p representing the ratio of dead and q (which is equal to 1-p) representing the ratio of alive. Because statistical process is only inspected once, the experiments are independent from each other (Bass, 2007; Ryan, 2011).

The first step creating a *p*-chart is to calculate the proportion of dead for each month (Ishikawa, 1986; Chandra, 2001).

$$p_i(\text{the proportion of dead}) = \frac{X_i \text{ (the number of dead in each month)}}{n_i(\text{the number of operated patients in each month})} \quad (2.1)$$

Second step is to determie $\bar{p}$ is the mean proportion (Oakland, 2003; Yücel, 2007).

$$\bar{p}\,(\text{the mean proportion}) = \frac{\text{the total number of dead in "k" months}}{\text{the total number of operated patients in "k" months}} = \frac{\sum_{i=1}^{k} X_i}{\sum_{i=1}^{k} n_i} \quad (2.2)$$

If the proportion of dead is not known, standard deviation is estimated as follows (Wadsworth et al., 2001; Winkel and Zhang, 2007):

$$\blacklozenge_p = \sqrt{\frac{\bar{p}\,(1-\bar{p})}{n_i}} \quad (2.3)$$

According to this, the control limits for *p*-chart are (Chandra, 2001; Ryan, 2011; Montgomery, 2012).

$$\begin{aligned} UCL &= \bar{p} + 3\cdot\sqrt{\frac{\bar{p}\,(1-\bar{p})}{n_i}} \\ CL &= \bar{p} \\ LCL &= \bar{p} - 3\cdot\sqrt{\frac{\bar{p}\,(1-\bar{p})}{n_i}} \end{aligned} \quad (2.4)$$

$\bar{p}$ indicates the center line.

If the proportion of dead is known, standard deviation and control limits are estimated as follows (Wadsworth et al., 2001):

$$\blacklozenge_{p_0} = \sqrt{\frac{p_0\ (1\text{-}p_0)}{n_i}} \tag{2.5}$$

$$\begin{aligned} UCL &= p_0 + 3\cdot\sqrt{\frac{p_0\ (1\text{-}p_0)}{n_i}} \\ CL &= p_0 \\ LCL &= p_0 - 3\cdot\sqrt{\frac{p_0\ (1\text{-}p_0)}{n_i}} \end{aligned} \tag{2.6}$$

The *np*-chart

This chart plots the number of dead per month. The expected outcome is “alive” or “death” and so the mean number of successes is *np* (Chandra, 2001; Wadsworth et al., 2001; Oakland, 2003)

The control limits of *np*-chart are shown as below. In this chart that is define center line is the mean number of dead (Kume, 1992; Montgomery, 2012).

$$p_i = \frac{x_i}{n_i} \quad \text{and} \quad X_i = p_i * n_i \tag{2.7}$$

$$\bar{p} = \frac{\sum_{i=1}^{k} p_i}{k} = \frac{\frac{\sum_{i=1}^{k} X_i}{n}}{k} = \frac{\frac{\sum_{i=1}^{k} X_i}{k}}{n} = \frac{\bar{X}}{n} \quad \text{and} \quad \bar{X} = n\cdot\bar{p} \tag{2.8}$$

Standard error for *np*-chart is (Winkel and Zhang, 2007; Montgomery, 2012):

$$\hat{\blacklozenge}_{\bar{x}} = \sqrt{n\cdot\bar{p}\cdot(1-\bar{p})} \tag{2.9}$$

As a result control limits of *np*-chart are (Bass, 2007; Oakland, 2003; Ryan, 2011):

$$\begin{aligned} UCL &= n\bar{p} + 3\sqrt{n\bar{p}\ (1\text{-}\bar{p})} \\ CL &= n\bar{p} \\ LCL &= n\bar{p} - 3\sqrt{n\bar{p}\ (1\text{-}\bar{p})} \end{aligned} \tag{2.10}$$

If *p* value of population is known, control limits of *np*-chart are given as below (Wadsworth et al., 2001; Winkel and Zhang, 2007)

$$\begin{aligned} UCL &= n\cdot p_0 + 3\sqrt{n\cdot\ p_0\ \ (1\text{-}p_0)} \\ CL &= n\cdot p_0 \\ LCL &= n\cdot\ p_0 - 3\sqrt{n\ \cdot p_0\ \ (1\text{-}p_0)} \end{aligned} \tag{2.11}$$

The *c*-chart

The *c*-chart monitors the process variations due to the fluctuations of dead in different surgery departments per month, without taking care to the number of operated patients (Chandra, 2001; Oakland, 2003).

For control limits, average of *c* is (Bass, 2007; Winkel and Zhang, 2007).

$$\bar{c} = \frac{c_1 + c_2 + \ldots.c_k}{k} \tag{2.12}$$

In equaiton, *c* is the number of dead in different surgery departments per month and k is the total number of months.

Because average of Poisson Distribution is equal variance of Poisson Distribution, standard deviation is $\hat{\blacklozenge}_{c} = \sqrt{\bar{c}}$ The both UCL and LCL will be given similar to those for a kσ control chart (Chandra, 2001; Winkel and Zhang, 2007; Montgomery, 2012):

$$\begin{aligned} UCL &= \bar{c} + 3\cdot\sqrt{\bar{c}} \\ CL &= \bar{c} \\ LCL &= \bar{c} - 3\cdot\sqrt{\bar{c}} \end{aligned} \tag{2.13}$$

If c value of population is known, the control limits are obtained as follows (Wadsworth et al., 2001).

$$\begin{aligned} UCL &= c_0 + 3\cdot\sqrt{c_0} \\ CL &= c_0 \\ LCL &= c_0 - 3\cdot\sqrt{c_0} \end{aligned} \tag{2.14}$$

The *u*-chart

u-chart is used, if the number of operated patients in different surgery departments for each month is different from each other and the number of dead in different surgery departments for each month is wanted to be show on the chart (Bass, 2007).

The first step in creating an *u*-chart is to calculate the number of dead per department for each month (Montgomery, 2012).

$$u_i = \frac{\text{the number of dead in different departments per each month}}{\text{the number of operated patients in different departments per each month}} \tag{2.15}$$

Once all of the averages are determined, a distribution of the means is created and the next step is to find the grand mean (the mean of the distribution):

$$\bar{u} = \frac{\sum_{i=1}^{k} u_i}{k} = \frac{u_1 + u_1 + \ldots + u_k}{k} \tag{2.16}$$

where k is the total number of months (Bass, 2007; Yücel, 2007).

The control limits are determined assistance of the grand mean (Chandra, 2001; Oakland, 2003; Ryan, 2011; Montgomery, 2012):

$$\begin{aligned} UCL &= \bar{u} + 3 \cdot \sqrt{\frac{\bar{u}}{n_i}} \\ CL &= \bar{u} \\ LCL &= \bar{u} - 3 \cdot \sqrt{\frac{\bar{u}}{n_i}} \end{aligned} \tag{2.17}$$

If value of u for population is known, control limits are obtained as followings (Winkel and Zhang, 2007):

$$\begin{aligned} UCL &= u_0 + 3 \cdot \sqrt{\frac{u_0}{n_i}} \\ CL &= u_0 \\ LCL &= u_0 - 3 \cdot \sqrt{\frac{u_0}{n_i}} \end{aligned} \tag{2.18}$$

3. Results

The attribute charts were generated for the data that was collected in the eleven surgery deparments. These data included the both the number of operated patients in each surgery department and the number of dead in each surgery department for twenty-four months.

The both p-chart and np-chart were created for first surgery department. Other attribute charts (c-chart and u-chart) were created for all of surgery departments (eleven departments).

The p-chart of mortality for first department is showed to Fig. 1. All of the points represent death rate per the operated patients in each month. For first surgery department, the process is assumed not to be in statistical control because one point (twelfth month) is located outside the UCL.

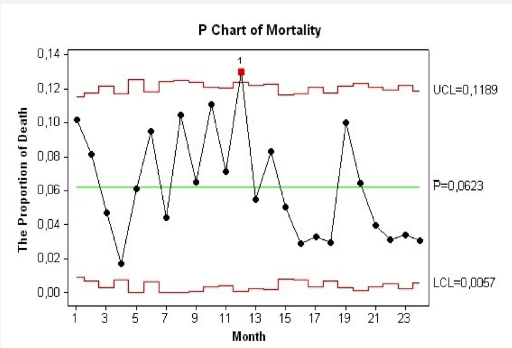

Fig. 1. *p*-chart of mortality

The np-chart of mortality for first surgery department is showed to Fig. 2. The points represent the number of dead per the operated patients in each month. The statistical process is an "out-control" for this department. Only one point exceeded control limits at twelfth month.

The c-chart of mortality for all of departments is represented to Fig. 3. The c-chart shows the frequency of dead in different surgery departments per month.

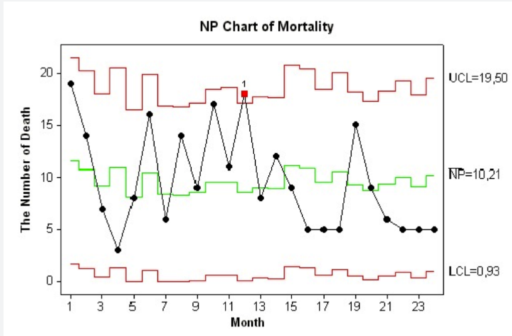

Fig. 2. *np*-chart of mortality

The statistical process is an "out-control" for this chart. The process exceeded the control limits at two point that are seventh month and fifteenth month.

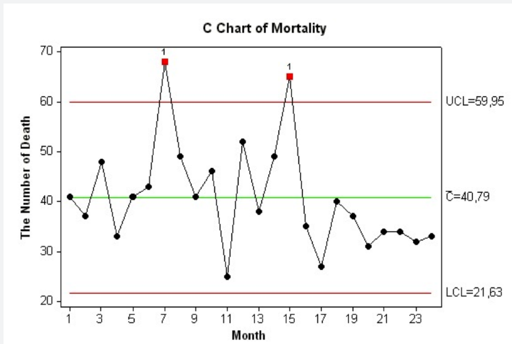

Fig. 3. *c*-chart of mortality

The u-chart of mortality for different departments is showed to Fig. 4. The u-chart shows the average proportion of dead per department for each month. The process is assumed to be out statistical control. Because one point (seventh month) of the process for these departments is located outside the UCL.

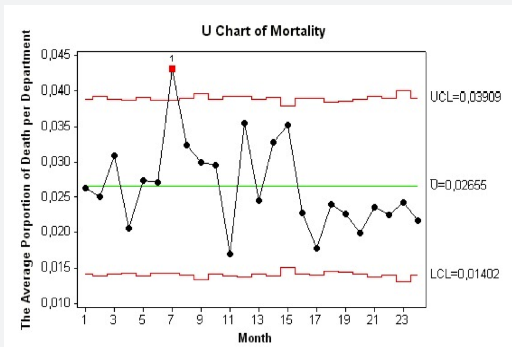

Fig. 4. *u*-chart of Mortality

4. Discussion

The mortality situations of different surgery departments were presented by attribute charts. All of atttribute charts showed mortality situation for these departments but atttribute charts varied from each other due to some characteristics.

When the death cases of surgery departments were evaluated by all of the attribute charts, all of statistical processes were detected to be “out-control”. We did not only find this fact but also we saw the distribution of statistical process and variability of statistical process. So, when we look to the attribute control charts, we can easily determine the pattern of statistical process.

While all of the attribute control charts consider discrete data, there are different points in each chart. They have some specific characteristics. So, some of them are preferred special position.

We were created the both *p*-chart and *np*-chart to show the death that is obtained from just a surgery department throughout twenty-four months. We were created the both *c*-chart and *u*-chart to evaluate the death that is obtained from all of surgery departments in faculty throughout twenty-four months. If there aren’t subgroups, the both *p*-chart and *np*-chart are enough to evaluate the process. When there are more than one subgroups, the both *c*-chart and *u*-chart are preferred as in our study.

The *p*-chart is used when dealing with ratios, proportions, or percentages of conforming (the alive) or nonconforming (the death) parts in a given sample (Chandra, 2001; Bass, 2007; Ryan, 2011). In the condition ni is different for each month, standard deviations of months are different from each other. The both UCL and LCL of each month is computed. So control limits seem as stairs line on the chart. If ni of each month equals, the control limits of all months equal each other. So control limits seem as straight line on the chart (Wadsworth et al., 2001; Bass, 2007).

The number of the operated patients per each month can either be stable or unstable for *np*-chart. If the number of the operated patients per each month equals, the expected number of dead is determined as. This chart is preferred, when the number of months is stable. The np chart that the audit process of the samples has binomial distribution is one of the easiest to build (Wadsworth et al., 2001; Montgomery, 2012).

One of the advantages of using *p*-chart is to see that the variations of the process change with the frequency of operated patients and ratio of dead for each month. The both *p*-chart and *np*-chart are similar except of a few point. While *p*-chart represents the ratio of dead, *np*-chart represents the expected number of dead (Oakland, 2003). When the number of operated patients in each month is different, *p*-chart is preferred. When the number of operated patients in each month is same, np- chart is recommended to use (Bass, 2007). Briefly, if the count of the used subgroup is stable, *np*-chart is used; if it is not, *p*-chart is used (Wadsworth et al., 2001; Winkel and Zhang, 2007).

The both *p*-chart and *np*-chart have same pattern, but there are just a few differences for the upper and lower control limits. If the units sizes are stable, the trends of these charts are same, but the control limits of them are different (Bass, 2007).

When the *c*-chart is useful to know not just how many operated patient are dead but how many dead there are per month (Chandra, 2001; Wadsworth et al., 2001; Ryan, 2011). The probability for the frequency of dead per each month follows a Poisson distribution. When there are “k” months that just have single sample, *n* is equals “k” (Chandra, 2001). If the number of operated patients per each month is stable and the number of dead per month are fairly easy to count, the *c*-chart becomes an effective tool to monitor the quality of the statistical process (Winkel and Zhang, 2007).

When the number of operated patients per each month are not equal and the aim is to determine the number of dead per each month, the *u*-chart is used. The number of dead can not exceed the number of items on a sample for a *p*-chart or an *np*-chart but it is conceivable for a *u*-chart (Chandra, 2001; Wadsworth et al., 2001; Oakland, 2003; Ryan, 2011). The number of operated patients per each month can vary. The u-chart does not require any limit to the number of potential dead (Bass, 2007).

Consequently the attribute control charts can easily used as a monitoring tool for process control in medical area. The most important features of them are that they have simple vision and quick decision-making. So they should be preferred in medicine and to use of them should be increased.

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