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Analysis of the use of ratios for process management and decision-making

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Ratios are commonly used in business for various applications, such as quality control, finance, sales, etc. The objective of this paper is to call attention to the possibility of the misuse of ratios used in monitoring processes and offer ways to avoid such misuse.

Keywords: ratios; process management; decision-making

Introduction

Ratios of two quantities are often used to provide insight into the process of making management decisions. The idea behind the use of ratios is described as removing the effect of the changes in the magnitude of the denominator variable upon the magnitude of the numerator variable. For example, one finds ratios such as the following:

Case 1. Number of defective items encountered in samples of various sizes from a production process. A reasonable management goal for such an activity is to decrease the ratio of the number of defective units to the number of units in the sample.
Case 2. Number of square feet of drawings produced each week per employee in the drafting department of a firm. A reasonable management goal for such an activity is to increase the number of square feet of drawings produced (numerator of the ratio) to the number of people in the department (denominator of the ratio).
Case 3. Number of lost-time hours due to accidents in plants with varying numbers of employees. A reasonable management goal for such an activity is to decrease the ratio of the number of lost-time hours to the number of employees in the plants.

The success of the management process in these examples is thought to be indicated by how closely the performance ratio agreed with the targeted value of the ratio. The targeted value of the ratio might be some arbitrarily selected constant value or the value of the ratio at some previous point in time.

Many researchers, both from academia and industry, have studied the use and misuse of various ratios in their respective disciplines. For example, Ankenman and McDaniel (2000) propose the use of the ‘p’ chart (i.e. the ratio of number of defectives to sample size) for monitoring the capability of a process when sensitivity data are all that are available on a particular measure of interest. Spisak (1990) talks about building a control chart for the ratio of two variables and estimating the bias in a ratio estimator. Bottorff (1997) discusses the ratios between the four cost components (i.e. internal failure, external failure, appraisal, and prevention costs), total quality cost, and total sales and how they provide

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valuable information for management. Nelson (1998) talks about what type of average (arithmetic or harmonic) should be used when we deal with the ratios. He states that in the case of a constant denominator, arithmetic mean is the one to use; and in the case of a constant numerator, harmonic mean would be the right one. Faltin and Faltin (2003), in their article, discuss the use of Six Sigma metrics in tracking financial results (some being ratios) and corporate governance metrics. Kontoghiorghes and Gudgel (2004) talk about the impact of quality on the productivity ratio in a manufacturing setting.

Also, process capability indices (e.g. Cp, Cpk, Cpm, etc.), which are commonly used for judging the capability of the process, are basically ratios. Which standard deviation estimate is used in the denominator of these ratios can make a significant difference in concluding what the process capability is (see, e.g. Spring, 1997). These and many others are some examples of the use of ratios in quality.

In the field of forecasting, for example, Hoover (2006) points to the misuse of mean absolute percent error (MAPE), a forecast accuracy measure (ratio) which is defined as the average of the sum of the ratio of absolute forecast error to the actual value of the variable being forecasted. He states that in some forecasting software packages for intermittent data, the time periods when the actual demand is zero are ignored when computing MAPE. He claims that if there are many periods with zero demand, the MAPE calculation on nonzero values will probably understate the amount of the true forecast error, that is, it provides only a partial picture of forecast accuracy. Hyndman (2006) says that even the MAPE calculation for periods of small but nonzero demand is problematic since small absolute errors translate into large percentage errors when the denominator is small. Willemain (2006) also discusses this particular issue and shows that MAPE is not a proper measure of forecast accuracy for intermittent demand data, since MAPE cannot be calculated when demands are zero.

Ratios are also extensively used in the fields of finance and economics. Eisemann (1992), in his article, talks about the use and misuse of industry financial ratios and claims that analysts often misuse these ratios, which often lead to confusing and misleading conclusions. He further states that the assumption that an individual firm's ratio is comparable with its counterpart industry ratio is the source of the problem for many applications of industry ratios. Boone (2008) worked on developing a new ratio called relative profit differences as an alternative to price cost margin (PCM) to measure competition. He argues that, from a theoretical point of view, it is not clear what the relationship between PCM and competition actually is, even though PCM is being used extensively as a measure of competition in empirical research. Choi et al. (1983) state that, due to partly explainable differences in international accounting principles, financial ratios are often misused when applied to foreign companies. Fisher (1987) claims that, even with the assumption of constant returns, the common use of the profits–sales ratio as a measure of the Lerner index of monopoly power is flawed. In his conclusion, he states that use of the profits–sales ratio is an unreliable estimate of the Lerner index. His simulation shows that errors involved in using it may be large in practice, and even the direction of error cannot be easily determined. Liebowitz (1987) talks about similar issues in his article entitled 'The measurement and mis-measurement of monopoly power.' In another study, Attfield (2010) examines the stability of the 'great ratios' of consumption to output and investment to output for the USA and UK. Bierman and Hass (1970), on the other hand, talk about the use and misuse of the price to earning ratio in acquisition and merger decisions. Studies done by Hughson, Stutzer, and Yung (2006) on the misuse of expected returns and Giannetti (2011) on the analysis of stock price ratios are other examples, among many, of the use of ratios in finance and economics.

We can list studies done by Cushing (1989) and Manuele (2011) as additional examples of the use of ratios in other fields. Cushing talks about the use and misuse of the ratio of allocation rate in modelling population migration. Manuele questions the use of the ratio of the indirect to direct costs of accidents to inform management on total accident costs. He claims that these published ratios are currently not valid because the increase in direct costs in the past 15 years has been much bigger than the increase in indirect costs.

It is the purpose of this paper to examine the abuse, misuse and use of ratios, using the examples such as the ones described above.

Abuse

The abuse will be addressed first simply to eliminate that matter from further consideration.

Case 1. Number of defective items encountered in samples of various sizes from a production process. This ratio (known as the 'fraction defective') may be abused by simply changing the definition of the number of defects allowed to consider an item to be defective. That is, artificially decrease the numerator in a questionable fashion so as to meet the goal of decreasing the ratio.

Case 2. Number of square feet of drawings produced per week in the drafting department of a firm. A reasonable management goal of such an activity is to improve the output of the people producing drawings.

This ratio may be abused by putting what is actually a small-sized drawing on a sheet whose size is ordinarily used for larger drawings so as to make the productivity ratio artificially larger (i.e. artificially increase the numerator).

Case 3. Number of lost-time hours due to accidents in plants with varying numbers of employees. A reasonable management goal for such an activity is to decrease the ratio of the number of lost-time hours to the total number of hours worked.

An example of this type of abuse has recently been in the news, because firms were forcing seriously injured personnel (normally leading to lost-time hours) to return very prematurely to work (or be fired), even if they could not perform any useful activity. This action would avoid an increase in the numerator of the ratio and thus paint a false sense of this ratio not getting worse in the face of an increasing occurrence of accidents.

At this point, we will proceed to discuss the issues of use and misuse with the assumption that there has been no attempt to perform advantageous manipulation of numerators or denominators of the ratios to influence management decisions. Case 3 will be dropped from further consideration in this paper (though it remains as a serious issue for the government agencies involved with employee safety).

Use: the case where ratios may be a useful tool

Case #1. Number of defective items encountered in samples of various sizes from a production process. A reasonable management goal for such an activity is to decrease the number of defective units produced.

This case is an example of a ratio defined as the number of defective items (D) divided by the number of items (N) in the denominator. The ratio is thus defined algebraically as

$$p = \frac{D}{N}. \tag{1}$$

It should be noted that $0 \leq p \leq 1$.

The value of this ratio is improved by taking managerial actions which lead to decreased values of p. Another form of Equation (1) is shown below:

$$\mathrm{D} = p * N. \tag{2}$$

Equation (2) represents the equation of a straight line which passes through the origin (i.e. the point (0,0)). Given a number of observations of the pairs (D, N), the best-fitting equation for this line (using the method of least squares) results in the value of p being determined as

$$p = \frac{\overline{D}}{\overline{\overline{N}}}, \tag{3}$$

where $\overline{D}$ is the average of all of the D values, $\overline{N}$ is the average of all the N values and p is, in effect, the average fraction of defective ratios occurring in the data set.

The implication of using the concept that a ratio should remain constant is that, if a variety of pairs of (D, N) were to be plotted on a graph paper, the result would be approximately a straight line passing through the origin where both N and D are zero. In addition, the slope of the line would be the value p in Equation (3). Given that a number of pairs of (D, N) have been gathered from real processes, the values of D would be expected to vary somewhat at random around the line determined using Equation (3).

In this case, it might be appropriate for management decisions to be based on the values of p determined for each sample (D, N) combination by simply comparing the observed ratio to the value for p obtained in Equation (3). If the observed ratio is sufficiently greater than p, the process may be assumed to have gotten worse. Should the value of the observed ratio be sufficiently smaller than p, the process may be assumed to have improved. Statistical tests exist which are useful in determining how large the difference (i.e. observed ratio $-$ p) should be to suggest that a real difference has been made (see, e.g. Duncan, 1986; Montgomery, 2001; Holmes, 2003). Should the test prove to be inconclusive, there is no reason to act as if a change in process performance has occurred. That is to say, do not over-manage a random process. Such actions simply have a tendency to increase the degree of process variation (and the amount of money spent beating a dead horse).

This case is an example of the use of ratios where the numerator is linearly related to the denominator – with the added constraint that the line is the one that is approximately passing through the origin. Figure 1 is a scatter diagram of typical data (e.g. number of defectives versus sample size) from Case #1 situations where the y-intercept is approximately zero.

Figure 2 shows a plot of the ratios from sample to sample for Case #1.

Figure 2 is a statistical process control (SPC) chart (X-chart) which indicates the random variation that might be expected for ratios with some randomness in one or both of the variables. It should be noted that this chart indicates that the ratio is steady

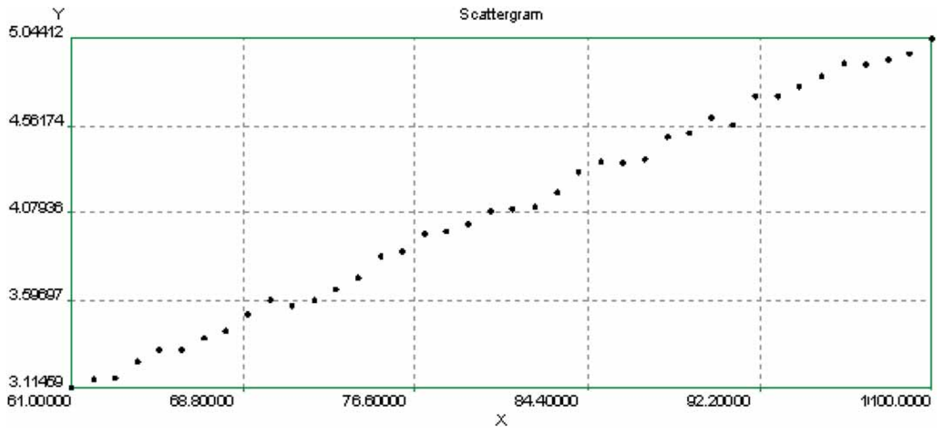

Figure 1. Scatter diagram for Case #1.

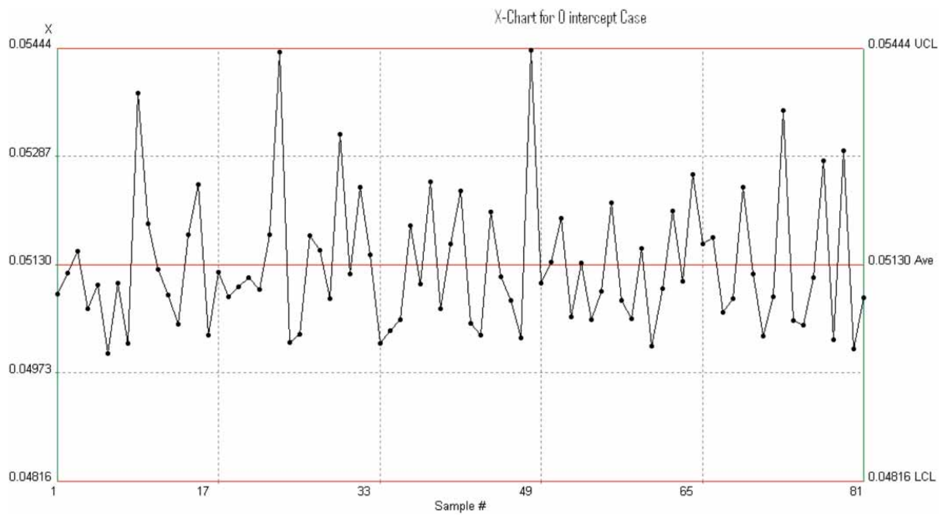

Figure 2. X-chart for the ratios for Case #1.

at about 0.05 (this agrees with the random generation procedure used to produce the data), although there are few points which are right on the upper control limit. Thus, those points may raise concern for the managers and they may think that something is wrong. However, when you check those points against the line that goes through the origin (Figure 1), they are not significantly away from the line, so things are OK. There is no need to take action.

Misuse: the case where use of ratios is not a useful tool

> *Case #2*. Number of square feet of drawings per employee produced each week in the drafting department of a firm. A reasonable management goal for such an activity is to improve the output of the people producing drawings.

Should the approximate straight line NOT pass through the origin, the use of simple numerator/denominator ratios is not appropriate. In Case #2, a ratio of square feet of drawings (S) produced to number of department employees (P) might not be appropriate for the following reason.

Given that the total number of employees in the department includes draftsmen, management and administrative personnel, the best-fitting straight line estimate might well be one which would not pass through the origin but would rather cross the employee axis (the x-axis) at some point significantly to the right of the origin. That is to say, there would be a number of people in the department even if there were no drawings being produced (typically referred to as a 'fixed' component).

The line describing such a situation would be in the form:

$$S = c_1 P - c_2, \tag{4}$$

where c_1 is the slope and c_2 is the constant term.

Figure 3 is a scatter diagram of typical data from Case #2 situations where the y-intercept is approximately -2. It should be noted that the negative intercept caused the value for y to be approximately zero at the point where x is 61 (the number of indirect employees in the department).

Figure 4 shows the ratios from Case #2 on an X-chart.

This data set was generated using the same generator as for Figure 2 with the exception that, although the slope of the line was set at 0.05 as for Figure 2, there was a negative intercept on the y-axis to demonstrate the potential problems should the line be described as in Equation (4). In Figure 4, the control chart shows one out-of-control point, which will raise a flag indicating that ratios are out-of-control. Again, if you check this point against the line (in Figure 3) which has an intercept, this point is not far from the line indicating that the ratios are OK. Thus no action is required. However, since management might be working with the model that assumes the line representing ratios is going through the origin, which is not the case, and thinking that the ratios are out-of-control, they will probably take an unnecessary action, where in reality no action is required. In other words, managers would be testing the wrong model, that is, $D = p^*N$, on the control chart,

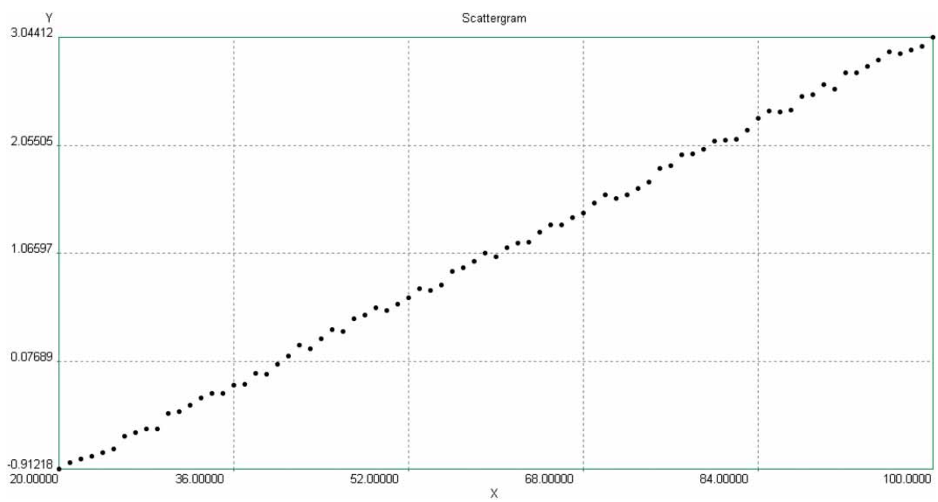

Figure 3. Scatter diagram for Case #2.

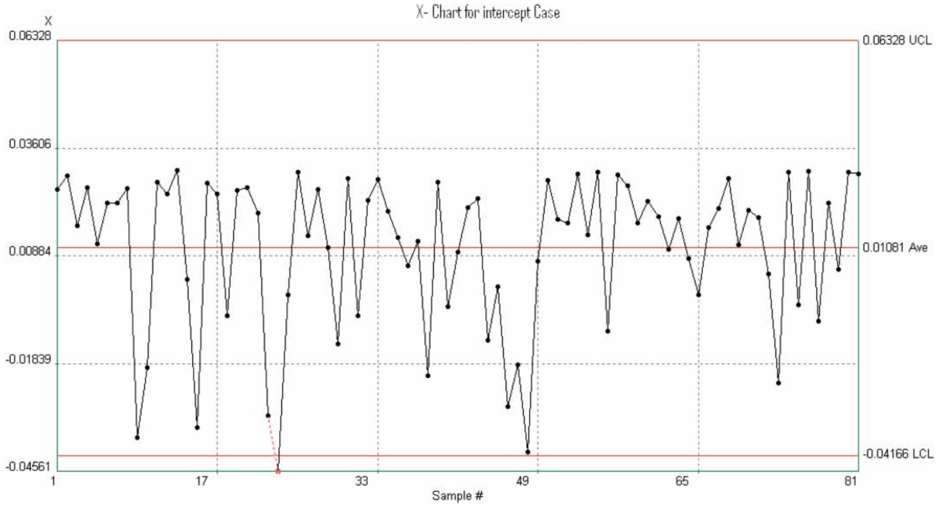

Figure 4. X-chart for the ratios for Case #2.

whereas the correct model should be $S = c_1P - c_2$. Of course, this unnecessary interference may cause more harm to the process.

Summary

When using ratios to provide performance measures, care must be taken to ensure that a scatter diagram of the numerator versus the denominator indicates that the line describing the relationship is approximately a straight line which passes through the origin. If the line does not pass through the origin, erroneous conclusions relative to process performance may result.

Should the relationship between the numerator and denominator not be approximately linear, the effect of using ratios for decision-making is open to misleading conclusions.

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