CONTROLLING DEFECTIVENESS
IN A
COMPLEX PRODUCT

C. L. Harris

Quality Division

Quality Control Department

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MASTER

Mason & Hanger-Silas Mason Co., Inc.
Pantex Plant
P. O. BOX 647
AMARILLO, TEXAS 79177
806-335-1581

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ABSTRACT

A common practice when measuring defectiveness in a complicated product is to assign 'demerit' points to each defect in proportion to the seriousness of the fault. This paper sets forth a plan for monitoring defectives by using a modified demerit per unit control chart. The statistics presented are basic to control charts for demerits. What is different is the chart format which has the advantage of minimum effort for daily updates and independence from required sample sizes. Basically, the charts were designed for simplicity of use where product quantities are not large. Emphasis is placed on maintaining perspective between plotting data and completing the circle of defect reporting, analysis and corrective action feedback.

INTRODUCTION

Recent changes to the quality rating program at Mason & Hanger-Silas Mason Co., Inc., Pantex Plant, prompted a review by the Company to see if current defect reporting and analysis procedures were adequate and to suggest modifications where necessary.

The manufacturing process for each completed assembly is partitioned into stages of production and inspection is made at each stage by Mason & Hanger Inspectors. In addition, the Energy Research and Development Administration (ERDA) inspects on a sampling basis; therefore, defects may be reported by either Mason & Hanger or ERDA inspectors. Under the new quality rating system three defect categories are defined: major, minor, and incidental. As a result, each defect is assigned a particular demerit value depending into which category the defect falls.

Under the old analysis system, primary responsibility for monitoring defects lay with the assembly area quality analyst. Using a type of cumulative sum chart which typically spanned three months, the analyst updated charts weekly and monthly and checked graphs for significant trends. Two shortcomings were noted in this system: (1) Monthly/weekly analyses were not always adequate for timely detection of problem areas; (2) The control charts were difficult to interpret, and hence, could not be used effectively to argue for investigations of problem areas.

The conclusion was to develop a new control chart system and gear towards early detection of persistent problems. The quality analyst would become the hub of the analysis system, constructing charts, establishing realistic control parameters, and insuring proper distribution of defect data. Quality control engineering would be responsible for monitoring activity on individual items, prompting investigations, and insuring as before that adequate corrective action is taken. Finally, a new control chart was chosen that would be easy to use and applicable to all products, regardless of production quantities.

DEMERITS PER STAGE CONTROL CHARTS

Where assemblies take weeks to complete, reporting demerits per unit yields past history rather than current. It therefore seems reasonable to quote defect rates in terms of demerits per stage where "stage" represents an inspection level. Daily statistics are compiled on total stages presented and total demerits received, providing timely data on process/material behavior. The typical demerits per unit control chart records the average number of demerits per unit computed for distinct samples. Sample sizes may or may not differ from plot to plot. If they do vary then the control limits fluctuate also. (See Figure 1 for an example of a demerits per stage control chart with varying sample size.) If samples are very small or show excessive fluctuations then interpretation of the charts, trend analysis in particular, becomes difficult.

To avoid the charting problems inherent to low production schedules a modified demerits per stage control chart was developed (See Figure 2.) Daily plots are of average demerits per stage; however, unlike the chart in Figure 1 the daily plots are computed as the cumulative demerits received to date divided by the cumulative stages presented. The upper control line does change from point to point, but in a very predictable fashion. What follows is a detailed review of the statistics pertaining to the chart parameters: centerline ($\bar{d}$), upper control limit (UCL), and two sigma (2σ) caution line. The statistics derived shall be specifically computed for the case of three defect categories (major, minor, and incidental) receiving 50, 10 and one demerits, respectively. Generalization to more defect classifications with different demerit values should be apparent.

Historical data are used to calculate chart control lines for the product/process of interest. In collecting data it is important to eliminate data from periods where processing was sporadic or where known problems existed. The resulting time period from which data are collected shall be designated as the 'base period'. (If historical data are not available, control values must be generated as defect information becomes available. In this case it will be necessary to change limits periodically as the process continues to demonstrate better stability.)

Figure 1. Demerits per Stage Control Chart with Varying Sample Size.

The expected demerits per stage, d' , is computed, using data obtained from the base period, as follow:

$$d' = \frac{\text{Total Demerits Received}}{\text{Total Stages Presented}}$$

This is the centerline value for the control chart. Comparison of daily plots to the centerline are meaningless, however, without knowledge of the variability of the defect rate. A statistic, σ_d^2 , for measuring this variability is derived in the succeeding paragraphs. Control limits are then defined as a function of d' and σ_d^2 .

Let p_1 , p_2 , and p_3 denote the fraction defective, obtained from base period data, expected for the three defect classes (major, minor, and incidental). For example, p_1 is the total number of major defects reported divided by the total number of stages presented. Then, for a sample of n stages:

$$np_i = \text{expected number of defects for the } i\text{th class,}$$

and

$$\frac{(np_1)50}{n} = \text{expected number of demerits per stage due to major defects.}$$

$$\frac{(np_2)10}{n} = \text{expected number of demerits per stage due to minor defects.}$$

$$\frac{(np_3)1}{n} = \text{expected number of demerits per stage due to incidental defects.}$$

For large samples ($n > 16$) and small fraction defective ($p < 0.10$), the number of observed defects is approximately distributed as a Poisson variable with mean np and variance np . Hence, if w refers to the demerit weight, a constant, the number of weighted defects, per unit, has variance.

$$\frac{(np)w^2}{n^2} = \frac{w^2 p}{n}$$

(This results from the fact that if a variable X has variance σ_x^2 , then a variable bX has variance $b^2\sigma_x^2$) Applying this result to the three defect classes, their respective variances become $(50^2p_1)/n$, $(10^2p_2)/n$, and $(1^2p_3)/n$. Assuming that the defect classes are independent of one another, the variance for the total demerits per stage is

$$\begin{aligned}\sigma_d^2(n) &= \frac{50^2p_1}{n} + \frac{10^2p_2}{n} + \frac{1^2p_3}{n} \\ &= \frac{1}{n} (50^2p_1 + 10^2p_2 + 1^2p_3).\end{aligned}$$

The gage for measuring acceptable process performance is $\sigma_d(n)$ in conjunction with the expected demerit rate, d' . Thus, the upper control limit becomes the usual three sigma limit

$$UCL(n) = d' + 3\sigma_d(n),$$

and the caution limit becomes

$$2-\sigma(n) = d' + 2\sigma_d(n).$$

CONTROL CHARTS WITHIN THE DEFECT REPORTING SYSTEM

Using the results of the preceding section, the quality analyst can compute control limits and centerline values for individual control charts. These chart parameters are quantitative measures used for product evaluation and are established with the concurrence of the division manager, Quality, and the quality control department head. At the discretion of management, control limits and centerline values may be modified. While indiscriminate changes should be shunned, intelligent management decisions can prompt improvement from processing areas and establish realistic limits for new production operations.

Once d' , UCL, and 2σ have been computed, the control chart is ready to be constructed. The total number of stages, n , to be accommodated along the x-axis is variable. We have found it convenient to plan the chart so that one month's data can be plotted. In cases where work is slow but consistent, charts may cover several months of activity. As n gets large the upper control lines converge towards the centerline; consequently, from a practical standpoint the chart's effectiveness terminates when it is impossible to distinguish between d' , 2σ , and UCL, given a reasonable scale on the vertical axis.

Control charts are updated and reviewed by quality engineering on a daily basis or as data become available. To compute each new plot, the cumulative demerits are divided by the cumulative stages reported. For a controlled process, the probability of a point falling outside the UCL is small, generally less than 0.01. Consequently, any plot exceeding the UCL is a flag to the quality engineer that immediate action is required in the area. Because of the critical nature of the product the division manager of quality is notified, and he coordinates the formal investigation. If deemed necessary, inspection may be withheld on the product until satisfactory corrective measures are taken.

When a point exceeds the UCL an unsatisfactory state exists which quality, process engineering and manufacturing personnel work to correct. However, in terms of maintaining control over defectiveness the 2σ line can be the most important feature

of the control chart. By carefully monitoring the $2\text{-}\sigma$ band, it is possible to prevent an out-of-control state or at least mollify it. Normally a run of several consecutive points above a $2\text{-}\sigma$ line is indicative of change in the process. Since the plots on the demerits per stage control chart are not independent, it is difficult to develop criteria which define a 'run'. Bowing to the adage 'an ounce of prevention is worth a pound of cure', the quality engineer investigates any process whose chart exhibits one or more points above the $2\text{-}\sigma$ line. If preliminary information indicates that a serious problem is developing, inspection may be withheld at the discretion of the quality assurance department head.

Figures 3 and 4 provide examples of the demerits per stage control chart in use. Data plotted in Figure 3 indicate a controlled process; the reported defect rate is holding close to established limits. Figure 4 contains the same data reported in Figure 1. Because of the variation in the small daily sample sizes, the upper control limits fluctuate widely in Figure 1 making interpretation difficult. In fact, in Figure 1, the first indication of a problem is at sample No. 16 whereas Figure 4 suggests an area of concern as early as sample No. 9. If $2\text{-}\sigma$ lines are plotted in Figure 1, only one point (No. 8) exceeds the limit besides sample No. 16. Because of the small sample size, plot No. 8 does not carry sufficient weight to instigate a process investigation. Figure 4, on the other hand, identifies the assembly problem at an early stage. The out of control condition may not be avoided; nonetheless, adequate forewarning is provided.

Details of all incidents should be recorded on the control chart for ready reference. In this manner, a file of old charts can be used to quickly identify periodic problems. It should be noted that recovery from out-of-control conditions will often appear as a gradual trend on the chart because of lack of independence between plots. Current charts are displayed so that management and other responsible people can assess area activities.

Figure 3. Demerits per Stage Control Chart Illustrating Process Performance.
Example No. 1.

Figure 4. Demerits per Stage Control Chart Illustrating Process Performance.
 Example No. 2.

CONCLUSION

It is felt that a realistic assignment of responsibilities along with effective control charts improve response to process problems. Early usage indicates that the demerits per stage control charts, as presented in this paper, mirror manufacturing activity. Furthermore, they are adaptable to processes where activity is low. Problem areas are easily identified. In addition, the simple format and charting requirements make day-to-day updates painless. The charts are not a panacea for excessive product defectiveness; they merely quantize product quality. Timely evaluation of problems along with adequate follow-up are essential for an effective defect reporting and analysis system.

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