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Assessment of Quality Levels in PPM Using Variables Test Data

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### Assessment of Quality Levels in PPM Using Variables Test Data

#### EIA-591

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# ASSESSMENT OF QUALITY LEVELS IN PPM USING VARIABLES TEST DATA

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## ASSESSMENT OF QUALITY LEVELS IN PPM USING VARIABLES TEST DATA

(SP-2438-A was formulated under the cognizance of the EIA Quality and Reliability Engineering (QRE) Committee)

### 1. INTRODUCTION

The traditional approach to measuring levels of nonconformance using attribute data, whether the results are stated in percent or Parts Per Million (PPM), becomes more burdensome as the nonconformance levels approach zero. The quantities required to establish a data base for an acceptable confidence level may be in the hundreds of thousands, which also makes it impracticable for a user to verify these quality levels at an Incoming Inspection facility.

The use of variables test data offers a solution to these problems. Oftentimes, sample sizes of 100 or fewer can be used to generate acceptable confidence levels for selected parameters, either by the manufacturer or the user. Such characterizations can be statistically meaningful only if the product represented can be considered to have come from a statistically stable (uniform) manufacturing process. The procedure described here further requires that the measured characteristic (or some transformation of it) follow a normal distribution.

The procedure described in this document is a useful approach to estimating PPM nonconforming using variables data if, but only if, the data are consistent with the assumption of an underlying population distribution that is normal (Gaussian). If this requirement is not satisfied, then the procedure described here should not be used, because it may yield greatly erroneous estimates of PPM nonconforming. One method for testing the assumption of normality, and a brief suggestion of some possible alternative approaches when the data do not appear to be normally distributed, are also included (see section 6., and sections 1.1.2 and 1.1.3, respectively).

### 1.1 APPLICABILITY

#### 1.1.1 Nonconforming or Unmeasurable Samples

If the tested samples yield any measured values of the quality characteristic that do not conform to the product specification(s), or if any of the tested samples fail to yield a measurement of the quality characteristic, (e.g., because a short circuit or an open circuit results in no measured value from an electrical test on the affected sample item), then the procedure described in this document should not be applied to that set of

data unless it can be clearly determined that the exceptional sample items resulted from cause(s) specifically restricted to those exceptional items. Such causes could include, e.g., that the exceptional items (and only the exceptional items) had been improperly tested or measured, or had been dropped, etc.

If, and only if, such restricted cause(s) can be determined, then the procedure described in this document (including, of course, the test for normality) may be applied to the remaining (measured and conforming) data values.

If no such restricted cause(s) can be determined, then the process of producing and testing the product should be studied for general cause(s) of such nonconforming or unmeasurable items. These causes should be eliminated from the process, and then an entirely new sample should be taken from the modified process and tested.

This restriction is specifically intended to preclude any possibility of simply "explaining away" nonconforming or unmeasurable sample items and then estimating PPM nonconforming based only on the remaining conforming items

#### **1.1.2 Statistical Outliers Conforming to Product Specifications**

If the sample data values fail the test for normality described in Section 6., then the underlying population cannot reasonably be assumed to be normal (Gaussian). In this case, the procedure for estimating PPM described in this document is not directly applicable, and the procedure can be used with such data only under specific, limited circumstances described here and in Section 1.1.3.

One way the sample data values can fail the test for normality is through the presence of "statistical outliers" among otherwise normally-distributed data. It is assumed in this section that any such outlying value(s) of the measured quality characteristic still conform to the product specification and represent otherwise acceptable product. Their only exceptional feature is that they do not appear to come from the same underlying statistical distribution as the bulk of the data. There are several statistical tests for outliers that may be applied when a histogram and/or normal probability plot of the data suggest that one or more extreme data values may not be from the same distribution as the remaining bulk of data. See Dixon and Massey (1983, pages 377-380) and David (1981, chapter 8).\*

\*Dixon, W.J. and Massey, F.J., Jr., Introduction to Statistical Analysis; McGraw-Hill, New York, 1983.

David, H.A., Order Statistics; John Wiley & Sons, New York, 1981.

When such extreme data values are identified as "outliers" on the basis of one or more statistical tests, then an investigation should be undertaken to determine the cause of these aberrant values. If such cause can be determined, and if it can be determined that this cause in no way affected the remaining data values, and if this cause is not an inherent part of the process, (for example, the aberrant values resulted from an improperly conducted test or measurement on those specific items only), then the remaining data may be used in the analysis described in this document, (including a new test of normality). Alternatively, and preferably, an entirely new sample may be drawn and the analysis begun anew with the new sample data values.

If no such cause can be determined, then the process of producing and testing the product should be studied for general cause(s) of such outlying data values. These causes should be eliminated from the process, and then an entirely new sample should be taken from the modified process and tested.

This restriction is specifically intended to preclude any possibility of simply "explaining away" outlying data values and then estimating PPM nonconforming based only on the remaining normally distributed data.

#### **1.1.3 Data that are Inherently not Normally Distributed**

Many quality characteristics are inherently not normally distributed. For example, any small (near zero) but intrinsically positive-valued characteristic may not be adequately fitted by a normal distribution simply because the left tail of a normal distribution fitted to the data includes a significant portion corresponding to (impossible) negative values of the quality characteristic.

In such a case, it may be possible to find a transformation of the original data such that the transformed data values are normally distributed. The procedure for estimating PPM may then be applied to the transformed data values, using similarly transformed specification limits. For example, if all the sample data values are positive and if the sample is skewed to the right (i.e., "stretched" more toward high values than would be the case for a normal distribution), then it could be that the logarithms of the data values will be normally distributed. In this case, if the specification limits are also positive, then the procedure for estimating PPM could be applied using the logarithms of the sample data values and the logarithms of the specification limits.

If a suitable transformation cannot be found, then alternative procedures for data analysis (for example, techniques based on the Weibull distribution), may be tried. Such alternative procedures are not discussed in this document.

## **2. OBJECTIVES**

The objectives of this PPM approach are (1) to characterize the quality of shipment-ready lots of products and (2) to verify the quality level of received lots by the customer. For both objectives, this assumes a uniform manufacturing process that yields normally distributed data and has controls for eliminating nonrepresentative lots.

## **3. DEFINITIONS**

### **3.1 SHIPMENT-READY PRODUCT**

Product that has been through the complete manufacturing process of build, inspect, test and final acceptance. It is product that will be shipped to customers without having to meet any further acceptance criteria.

### **3.2 ACCEPTANCE PROCEDURE**

An inspection/test procedure to determine whether the product meets the established requirements. The action resulting from the application of such a procedure is the acceptance or rejection of the product (or lot).

### **3.3 AUDIT**

A measurement procedure intended to gather information that will be used to assess product quality. The action resulting from an audit is taken on the process that produced the product.

## **4. ASSESSMENT**

Assessment of PPM is determined by a test of samples drawn at random from an individual lot or series of lots that are selected to compose a given population. This assessment of PPM is based on test data derived from shipment-ready product. Since the taking of variables data is over and above the normal attribute lot acceptance procedure, all variables data taken shall be used in the PPM determination.

PPM estimates shall be determined separately for those parameters that the users agree are applicable to the product quality. Any measurable variables parameter can be used for this purpose, provided that it, or some transformation of it (e.g., the logarithm or the square root), is normally distributed.

## **5. PROCEDURES**

The procedures that follow include two parts. First, determine if

the data meet the requirement for assumption of an underlying normal (Gaussian) distribution. Second, if the normality requirement is met, calculate the estimated proportion of that normal distribution that is beyond the specification limit(s); that proportion becomes the estimate of proportion nonconforming, and will be expressed in terms of parts per million (PPM) nonconforming.

## 6. TESTING FOR NORMALITY

Appendix A discusses the mathematical details of a test for normality using the correlation coefficient for a normal probability plot of the data. The routine calculations for this test have been done and the results are tabulated in Table 2. This table includes sample sizes from 5 to 100 in increments of five, but for best results, sample sizes of at least thirty are recommended.

The following example using twenty data values will demonstrate the procedure for testing normality of the underlying distribution. These same data values will be used in subsequent sections to demonstrate the estimation of PPM out of specification, when

- (i) the specification includes both an upper limit and a lower limit (Section 7.);
- (ii) the specification includes only a lower limit (Section 8.);
- (iii) the specification includes only an upper limit (Section 9.).

As indicated in Section 1., these procedures are applied to variables data. In the following example, imagine that the data values represent measurements of electrical resistance in ohms on twenty resistors that are intended to have a specification nominal resistance of 1,000 ohms.\* The sample data, in ohms, are as follows:

|      |      |      |      |      |      |      |      |      |      |
|------|------|------|------|------|------|------|------|------|------|
| 1016 | 1047 | 1055 | 1015 | 1028 | 960  | 1009 | 1011 | 1018 | 978  |
| 1021 | 992  | 996  | 978  | 977  | 1047 | 1021 | 1019 | 1040 | 1004 |

Now, using any computer program that calculates correlation coefficient, make two vertical columns. The first column is the sample data above, put in ascending order and labeled Y. The values for column X are found in Table 2. For this example, 20 data values are used, so column X is a copy of the values under "Sample Size 20".

\* Note that the data values could just as well represent measurements of tensile strength in pascals, or length in millimeters, or capacitance in farads, or measurements of any other variable in appropriate physical units.

| <u>Y</u> | <u>X</u> |
|----------|----------|
| 960      | -1.86866 |
| 977      | -1.40366 |
| 978      | -1.12821 |
| 978      | -0.91904 |
| 992      | -0.74390 |
| 996      | -0.58910 |
| 1004     | -0.44734 |
| 1009     | -0.31413 |
| 1011     | -0.18640 |
| 1015     | -0.06177 |
| 1016     | 0.06177  |
| 1018     | 0.18640  |
| 1019     | 0.31413  |
| 1021     | 0.44734  |
| 1021     | 0.58910  |
| 1028     | 0.74390  |
| 1040     | 0.91904  |
| 1047     | 1.12821  |
| 1047     | 1.40366  |
| 1055     | 1.86866  |

Now let the computer calculate the correlation coefficient and compare the answer to the value for a sample size of 20 in Table 1. If the correlation coefficient is equal to, or greater than, the value in Table 1, then proceed to the next step. EIA-591 should be used only for data that tend toward normality. If the above normality test fails, then an off-line analysis of that situation should be made, which is not a part of EIA-591. (Note that some variables measurements may be inherently nonnormal - i.e., their natural and proper distribution may be something other than a normal distribution. In such cases, the procedure described in this document for estimating PPM nonconforming should not be used.) For the example in question, the correlation coefficient of the sample data equals 0.986. Since this is greater than 0.951 in Table 1, the analysis can proceed. Note will the warning footnote to Table 1.

#### **7. ESTIMATION OF PPM NONCONFORMING TO A TWO-SIDED SPECIFICATION**

The second part of the analysis is an estimate of the area of the population distribution that lies outside the specification limits.

If the specification limits fall at the  $\pm 3$  sigma limits of a normal distribution, then the area between the specification limits includes 99.73% of the total population (95% for  $\pm 2$  sigma), leaving 0.27% or 2700 PPM outside the specification limits, with 1350 PPM above the upper specification limit and 1350 PPM below the lower specification limit. This is the next step in the analysis. Unfortunately, the  $\pm 3$  sigma example just discussed is accurate only when 1) the mean of the normal distribution is

exactly centered between the specification limits, and 2) the sample size is infinite. EIA-591 simply addresses the situation of finite sample sizes up to 100 and a distribution mean that may or may not be centered between the specification limits.

The analysis requires the use of the Table of the Area Under the Normal Distribution Curve, which will be referred to as the Area Table, and which can be found in nearly any statistical text book or handbook of statistical tables. For ease of use, a table having up to 7 decimal places is recommended; such a table is included as part of this document in Appendix B.

The average value of the sample data in question equals 1011.6 ohms and the estimate of standard deviation (using a divisor of N-1) equals 25.730 ohms. (This average and standard deviation will be denoted by  $\bar{X}$  and  $s$  below.) The first step is to calculate  $K1$  and  $K2$ , which are simply:

$$K1 = (\bar{X} - LSL)/s \quad \text{and} \quad K2 = (USL - \bar{X})/s$$

Applying these equations to the example data and using lower and upper specification limits of  $LSL = 900$  ohms and  $USL = 1100$  ohms, respectively, gives:

$$K1 = (1011.6 - 900)/25.730 = 4.337$$

$$K2 = (1100 - 1011.6)/25.730 = 3.436$$

A common, but naive, procedure is to now enter the Area Table with  $K1$  and  $K2$  to find the areas beyond the specification limits. From the Area Table (Appendix B), the area under the normal curve between zero (the mean) and 4.337 (i.e.,  $K1$ ) is found to be 0.4999928, and the area between zero and 3.436 (i.e.,  $K2$ ) is found to be 0.4997048. The resulting areas outside the specification limits, or the fractions nonconforming, expressed in PPM, are:

$$PPM1 = (0.5 - 0.4999928) * 10^6 = 7 \text{ PPM}$$

$$PPM2 = (0.5 - 0.4997048) * 10^6 = 295 \text{ PPM}$$

This results in a total PPM value of:

$$PPM = PPM1 + PPM2 = 7 + 295 = 302 \text{ PPM}$$

This would be the correct answer if the sample size were infinite, so that the sample average,  $\bar{X}$ , and sample standard deviation,  $s$ , were equal to the population mean,  $\mu$ , and population standard deviation,  $\sigma$ , respectively. But this is not the case. As a result, the correct estimate of the PPM level is different and depends upon the sample size and the confidence level desired. It is this real life situation that EIA-591 addresses.