SPECIAL NOTES FOR NEW USERS OF EZZE GAGE

WARRANTY

The author is not liable for errors contained herein or for incidental or consequential damages in connection with the furnishing, performance or use of this material. **All technical application software is inherently complex and users are cautioned to verify the results.**

TERMINOLOGY

In the EZZE GAGE program there is some terminology used which may not be familiar to you. Definitions and significance of calculated parameters can be found in the references listed below or the tutorial.

TECHNOLOGY

This module does Measurement System Analysis (I.e. Gage Study) of measurement devices used in your process. The methods used are the "Range Method" and the ANOVA (Analysis Of Variance) two-way, fixed effect model with replications. Whereas range IS statistically acceptable for short term, quick studies when zeroing in on changes to a measurement system. The ANOVA is the most accurate method for quantifying repeatability and reproducibility and allows for variability of interactions between appraisers and parts. Ultimately, that which is acceptable to the customer governs in most cases. The user should refer to to the MSA manual (MSA3), your customer's or your Quality Assurance Manual or internet(ref below) for more information.

REFERENCES

BOOKS OR MANUALS (FREE)

http://www.itl.nist.gov/div898/handbook/index.htm

AND

DataMyte Handbook, A practical guide to computerized data collection for Statistical Process Control.
http://www.ab.com/events/pressrel/9603/960319.html

INTERNET SITES

www.isixsigma.com	good reference & forum
http://yeivier.20m.com/statistics/MSA/MSA.html	Excellent and complete article covers theory that you need
http://www.aiqusa.com/index.asp	organization + excellent reference material

PLEASE NOTE:

NOTE: THE PROGRAM DOES NOT REQUIRE THE STATISTICS "TOOLPAK" ADD-IN
IT REQUIRES ONLY THE STANDARD EXCEL FUNCTIONS, EZZE GAGE DOES THE "MATH"

1 USERS NOT FAMILIAR WITH SPC SHOULD REFER TO OTHER SOURCES FOR MORE DETAILED INFORMATION TO ENSURE THE PROPER INTERPRETATION OF DATA PROVIDED BY THE EZZE GAGE TEMPLATE

2 **READ "TUTORIAL" BEFORE USING THE EZZE GAGE PROGRAM**

4 **DATA ENTRY CELLS ARE HIGHLIGHTED**

CALCULATED DATA IS HIGHLIGHTED

PLEASE ENTER DATA THROUGH THE KEYPAD PAGE

SHEETS THIS PROGRAM

READMEFIRST	THIS PAGE
TUTORIAL	THEORY & HOW TO USE THE PROGRAM
KEYPAD	DATA ENTRY AND PROGRAM KEYPAD
GAGER&RSAMPLEDATA(3)	RANGE & AVERAGE WORKSHEET
ANOVASAMPLEDATA(2)	ANOVA WORKSHEET
RANGEAVGREPORT	REPORT FOR RANGE & AVERAGE
ANOVAREPORT	REPORT FOR ANOVA
RANGECHART	GRAPH OF APPRAISER READINGS
RUNCHART	SAME
WHISKER	SAME
STACKEDCHART	SAME
GRAPHDATAFILE	DATA FILE FOR GRAPHS
DATATABFILE	SAMPLE DATA FOR GAGE STUDIES

5 GO TO THE TUTORIAL NEXT -IT'LL GIVE YOU A "QUICK START
BUT BE SURE TO GET REFERENCE BOOKS TO HELP YOU USE THIS PROGRAM

HOW TO USE EZZE GAGE

EZZE GAGE is very simple to use - basically everything you need to do is on the KEYPAD

You have completed your gage study and are ready to analyze your data YOUR 1st STEP

1 IN THE KEYPAD DATA TABLE YOU ENTER DATA IN THE BLUE SQUARES

2 FOR THE PROGRAM TO WORK YOU REQUIRE MEASUREMENT DATA, USL AND LSL - THE BALANCE OF THE INFORMATION TO DOCUMENT IS FOR RECORDS

3 ONCE THE DATA IS ENTERED LEFT CLICK THE "GO" BUTTON , GRAPHS, REPORTS ARE COMPLETED READY TO FORMAT &/OR PRINT

YOU WLL NOTICE ONE NON TYPICAL GRAPH (IE STACKED) I PREFER TO LOOK AT ONE STACKED CHART TOSEE IF THERE IS DATA CORRELATION FOR APPRAISERS RATHER THEN LOOK AT SEVERAL CHARTS IF CORRRELATION GOOD LINES TRACK CLOSELY

4 TO PRINT YOUR REPORT LEFT CLICK THE BUTTON FOR THE REPORT YOU REQUIRE

5 GRAPHS ARE IN THE REPORTSAND CAN BE PRINTED INDIVIDUALLY USING EXCEL

SUPPORT

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TUTORIAL

We must determine the uncertainty of our measurement systems before we can compare, control or optimize our manufacturing processes.

Gages must be accurate (calibrated) and precise (capable) if they are to provide useful information An accurate gage will, on average, report the specimen's actual dimension. The words "on average" are unsettling, and they should be. A non-capable (imprecise) gage will return widely differing measurements from the same specimen. If the piece's dimension is slightly out of specification, the gage may pass it. If the piece is slightly within specification, the gage may reject it. Hence the need for a means of determining gage capability. Two methods are presented in this program.

BEFORE WE GET INTO THE PROGRAM WE SHOULD DISCUSS THE "WHAT", "WHY" AND "WHEN" OF GAGE VARIATION STUDIES.

WHAT IS IT?

A study to determine the capability of the measurement process and how much variation is introduced into the product by the measurement process itself. In essence, we will be calculating the percentage of the engineering (product) specification that is consumed by measurement variability. As strange as it may seem, the measurement process is one of the major contributers to process variability!

It is often assumed that measurements are exact. However, every part of the measurement process (instruments (gage), operators, methods, environment) introduces variation into the measurement. In some cases there is more variation in the measurement process then in the parts (process) being measured. This is why in determing gage accuracy we are looking at "REPEATABILITY" (variation due to the gage itself - operator's ability to repeat measurements on the same part using the same gage) and "REPRODUCIBILITY" (the variation due to different operators taking measurements I.e. the ability of different operators to produce the same measurement results on the same part using the same gage).

WHY DO IT?

1. To determine the amount of variation due to the measurement process (gage and operator)
2. To compare measurement variation with engineering tolerance (is there a problem)
3. To compare amount of measurement variation between different gages.
4. To determine if measurement variation is a problem and if so find a solution (is more training required for operators, do instruments require maintenance or replacement,are procedures correct, environmental changes required (lab hot?))
5. To use as justification for gage purchasing and planning decisions.
6. Reduce variation and improve Cpk by improving the measurement process.

WHEN?

a key parameter or process is not capable
a key parameter is out of control and no special cause can be found
A gage needs to be evaluated to determine if it is suitable for use in the process
The measurement process is thought to be a major contributor to overall process variation. Through the use of the methods contained herein one can determine if it is or not and how much it is contributing

There are many methods cited in literature that can be used to perform Gage R&R :-

1. ANalysis Of Variance (ANOVA) method
2. Average and range method.
3. Within part variation (WIV) method

4. Automotive Industry Action Group (AIAG, Southfield, MI) method
5. Short Range method for non-destructive testing
6. Short range method for destructive testing
7. Long range method for non-destructive testing
8. Long range method for destructive testing
9. The instantaneous method (one appraiser for equipment variation only)

The most common methods used are the two used in this program - ANOVA and the range and average methods.

RANGE & AVERAGE METHOD

The Range and Average Method computes the total measurement variability, and allows the total measurement system varability to be separated into repeatability, reproducibility and part variation,

Repeatability:
Variation in measurements when an operator measures identical characteristics on the same part using the same measuring instrument.

Reproducibility:
Variation in measurements when different operators measure identical characteristics on the same part using the same measuring instument.

To quantify repeatability and reproducibility using the average and range method, multiple parts, appraisers (operators), and trials are required. The recommended method is to use 10 parts, 3 appraisers and a minimum of 2 trials, for a total of 60 measurements.

CALCULATIONS RANGE ANDAVERAGE
There are two methods used to calculate variation values in the Range and Average (GAGER&RSAMPLEDATA) Sheet . Method 1 uses "D2" values whereas Method 2 use "K" factors which include a 5.15 (90%) multiplier which is removed when required by the program. The main equations for both methods are listed on the Range and Average sheet and both give ~ same answers which should not be a surprise. The Method 1 values are used to check Method 2 values but are not used for the final report. The "new" MSA handbood lists"K" values with the multiplier factor removed but ultimately you arrive at the same results.

Before we look at ANOVA we should look at the following template
It will make the ANOVA discussion more understandable.

GAGE STUDY PROCEDURE TEMPLATE

1.0 Purpose: To describe a step by step process for the evaluation of measurement systems.

2.0 References:

3.0 Definitions:
3.1 Bias-The difference between the observed value and the reference value.
3.2 Repeatability- the variation in measurements obtained with one measurement instrument when used several times by one appraiser while measuring the identical characteristic on the same part.
3.3 Reproducibility- the variation in the average of the measurements made by different appraisers using the same measuring instrument when measuring the identical characteristic on the same part
3.4 Stability-the total variation in the measurements obtained with a measurement system on the same parts when measuring a single characteristic over an extended time period.
3.5 Linearity- the difference in the bias values through the expected operating range of the gage.
3.6 Discrimination(resolution) - the ability of the measurement system to detect and indicate small changes in the characteristic.
3.7 Gage- generic term for all Measuring and Test Equipment

4.0 Responsibility

4.1 Process and Design engineers identify what equipment needs to be evaluated. All gages in the control plan are evaluated using this procedure and the MSA.

4.2 The quality control manager is responsible for choosing trained individuals, evaluation the results, choosing the samples, and providing an environment consistent with MSA requirements. In addition, the quality control manager is responsible for the overall integrity of the study.

5.0 Safety/Environmental Instructions:

5.1 Safety helmets, glasses and shoes must be worn at all times in designated areas

5.2 Obtain MSDS sheet for disposal, storage, and safety instuctions for any chemicals used to perform the MSA

6.0 Equipment/Tooling:

6.1 All reference standards must be NIST Traceable

6.2 Equipment as described in customer control plan

7.0 Procedure:

7.1 There shall be procedures for the use of all gages in the study

7.2 There shall be documented training records to ensure that all appraisers are trained on the proper use of the gages in the study.

7.3 Ensure the gage has the correct discrimination. The resolution must be at least one-tenth of the six sigma value of the tolerance.

7.3.1 For example if the tolerance is .0031ä to .0033ä then the resolution of the gage . must be capable of reading in increments of .000002ä

7.3.2 Use consistent units of measure. Avoid conversions (i.e. Inches to millimeters)

7.4 Ensure the stability of the measurement system, taking into account:

7.4.1 The environment including:

7.4.1.1 Is the measuring system influenced by temperature/humidity fluctuations(i.e. expansion coefficients for gage blocks/calipers)?

7.4.2 Does the system need to be cleaned on a regular basis?

7.4.3 Is the system subject to wear over time?

7.4.4 Does the system need a 'warm-up' period (for electronic gages)?

7.4.5 Consult ownerâs manual or procedure for additional sources that could affect stability.

7.5 Conduct long term stability studies at the discretion of the quality assurance manager.

7.5.1 The QA Manger will consider:

7.5.1.1 Cost of the study

7.5.1.2 Customer requirements

7.5.1.3 Time to perform the study

7.5.1.4 The availability of other gages

7.6 Determine the bias.

7.6.1 Measure one sample on the NIST reference instrument.

7.6.2 Measure the same sample 10 times using the gage being evaluated.

7.6.3 Calculate the average of the 10 readings.

7.6.4 Bias = observed average - Reference Value. This means that the observed measurements will be on the average +/- the bias of the reference value.

7.7 Convert the Bias to a percentage of the tolerance by multiplying 100 and dividing by the tolerance. If the bias is large look for:

7.7.1 Error in the master

7.7.2 Worn Components

7.7.3 Instrument made to the wrong dimension

7.7.4 Instrument measuring the wrong characteristic

7.7.5 Instrument not calibrated

7.7.6 Instrument used improperly

7.7 Determine the linearity

7.7.1 determine the range of use of the measurement system.

7.7.1.2 For example a scale may have the capability of taking measurements from 0 to 100 pounds, but IS USED from 50 to 70 pounds. Linearity must be determined in the range of 50 to 70 pounds.

7.7.2 perform 7.6.1 - 7.6.2 exempt repeat the process at the low end of the range, mid range and upper range.

7.7.3 Use formula in 7.6.4 but substitute Linearity for bias and repeat for all three measurements.

7.8 If using an automated gage, or user influence is not a factor the reproducibility does

not need to be performed.
7.9 Samples are chosen that represent the entire operating rage of the gage in the study.
7.9.1 Each appraiser measures the same part of the same sample. Where the measurement is supposed to be taking place is indicated on the sample to ensure all operators are measuring the same part.
7.9 Determine gage repeatability and reproducibility using three appraisers and record information on gage R&R worksheet.
7.9.1 If Gage R&R greater than 30% the fill out an NCR ir (NON COMPLIANCE REPORT) AND TAKE ACTION.
7.9.2 If Gage R&R is between 11-30% fill out NCR (MARGINAL SHOULD MONITOR & CONSIDER ACTION)
7.9.3 If Gage R&R is 10% or less the gage is acceptable
7.10 If repeatability is large compared to reproducibility look for:
7.10.1 The gage may need maintenance
7.10.2 The gage may be redesigned to be more rigid
7.10.3 The clamping or location of the gage needs to be improved
7.11 If reproducibility is large as compared to repeatability look for:
7.11.1 Operator training
7.11.2 Accuracy of procedures
7.11.3 Calibrations on the gage are not clear

8.0 Statistical Techniques/calculations:
8.1 See procedure (ONE SHOULD BE AVAILABLE)for selection and interpretation of control charts
8.2 Acceptance criteria for gage R&R is taken from ASQ Automotive Statistical Process Control Manual,

9.0 Records

ANOVA METHOD

The analysis of variance method (ANOVA) is the most accurate method for quantifying repeatability and reproducibility. In addition, the ANOVA method allows the variability of the interaction between the appraisers and the parts to be determined.

The ANOVA method for measurement assurance is the same statistical technique used to analyze the effects of different factors in designed experiments. The ANOVA design used is a two-way, fixed effects model with replications.

Table 5. Two-Way ANOVA Table.

Source of Variation	Sum of Square s	Degrees of Freedom	Mean Square	F Statistic
Appraiser	SSA	a-1	$MSA = \frac{SSA}{a-1}$	$F = \frac{MSA}{MSE}$
Parts	SSB	b-1	$MSB = \frac{SSB}{b-1}$	$F = \frac{MSB}{MSE}$
Interaction (Appraiser, Parts)	SSAB	(a-1)(b-1)	$MSAB = \frac{SSAB}{(a-1)(b-1)}$	$F = \frac{MSAB}{MSE}$
Gage (Error)	SSE	ab(n-1)	$MSE = \frac{SSE}{ab(n-1)}$	
Total	TSS	N-1		

$$SSA = \sum_{i=1}^{a} \frac{(Y_{i..})^2}{bn} - \frac{Y_{\bullet\bullet}^2}{N}$$

$$SSB = \sum_{j=1}^{b} \frac{(Y_{.j.})^2}{an} - \frac{Y_{\bullet\bullet}^2}{N}$$

$$SSAB = \sum_{i=1}^{a} \sum_{j=1}^{b} \frac{(Y_{ij.})^2}{n} - \frac{Y_{\bullet\bullet}^2}{N} - SSA - SSB$$

$$TSS = \sum_{i=1}^{a} \sum_{j=1}^{b} \sum_{k=1}^{n} Y_{ijk}^2 - \frac{Y_{\bullet\bullet}^2}{N}$$

$$SSE = TSS - SSA - SSB - SSAB$$

a = number of appraisers

a = number of appraisers,
b = number parts,
n = the number of trials, and
N = total number of readings (abn)

The table and equations above form the basis of this part of EZZE GAGE. The important key to ANOVA is the fact that variances can be divided up, that is, partitioned. Remember that the variance is computed as the sum of squared deviations from the overall mean, divided by n-1 (sample size minus one). Thus, given a certain n, the variance is a function of the sums of (deviation) squares, or SS for short. Partitioning of variance tables are prepared by this program. The tables ARE NOT LOCKED - becareful in this area

When conducting a study, the recommended procedure is to use 10 parts, 3 appraisers and two trials.

One thing to remember in doing your ANOVA TEST - Each mean square is an estimate subject to sampling error. In some cases the estimated variance will be negative or imaginary. In these cases, the estimated variance is zero. IN THESE CASES "EZZE GAGE" AUTOMATICALLY MAKES THIS CHANGE AND TO ENSURE YOU ARE AWARE OF THIS CHANGE THE NUMBER (0) WILL BE BLUE!

Underlying structure of ANOVA: Hypotheses

The *F* Distribution

- Mean is one statistic for hypothesis testing
- Variance is another
- The F test (R.A. Fisher) is the ratio of two independent estimates of the same population variance

$$F_{obt} = \frac{\text{variance estimate 1 of } \sigma^2}{\text{variance estimate 2 of } \sigma^2}$$

Characteristics of the F Distribution

- Can only have positive values
- Positively skewed
- Median is ~1
- Family of curves, one for each combination of two df
- One-tail test, critical value in right tail.

Two sources of variability

1. Variability within each group

Within-groups sum of squares (SS_W)

2. Variability between the groups

Between-groups sum of squares (SS_B)

F Ratio

$$F_{obt} = \frac{s_B^2}{s_W^2} = \frac{\sigma^2 + \text{IV effects}}{\sigma^2}$$

The larger the effect of the independent variable, the larger the value of F.

F **- Test** (REF http://simon.cs.vt.edu/SoSci/working/ANOVA_I/)

The ***F*** **test** statistic is computed by dividing the MS_{within} into the $MS_{between}$ ($MS_{between}$ / MS_{within}). It is a ratio of two estimates of variance. The *F*-test can be used to test the null hypothesis that none of the variance in the dependent variable is due to group effects. In order to do this, there are two assumptions:

(1) The groups are independently drawn from a normal distribution
(2) The population variance is identical to the variances within each group (This assumption is termed homoscedasticity . When population variances differ, they are termed heteroscedastic.)

Research hypotheses often involve inferences from sample data about the equality of means of two populations in which case the t or z distributions are appropriate for testing for significant differences. If comparisons involve assessment of sameness vs. difference in three or more means, the F distribution and ANOVA are instead used. The term "analysis of variance" to evaluate differences of means may seem a little confusing. This seeming misleading term is explained by the fact that the goal of ANOVA is to determine whether there is a difference among a set of means but because there are more than two means under consideration, the way to make this judgment is to evaluate the variance among those means compared with the variance within each subsample. To make these comparisons, it is necessary to compare for differences in the number of cases comprising the variances that are compared. The Between SS is divided by its degrees of freedom (k - 1); similarly, the Within SS is divided by its number of degrees of freedom (N - k). If the F ratio is large so as to warrant rejecting the null hypothesis, then the differences

Use of the F distribution to test for differences among three or more means requires making the assumptions that random, independent samples be drawn from two normal populations that have the same variance. In actual practice, however, the F-test has been found to work well even when these assumptions are not met unless the departures from those assumptions are very large. The *F*-ratio distribution is nonsymmetric (see the figure below).[Q: Do we deliver on this?? XXX] The *F*-distribution's shape depends upon the degrees of freedom associated with the numerator and denominator. If the computed *F* - ratio is larger than the critical value (this critical value is found in an *F*-distribution table in the back of most statistics books) associated with a particular alpha level (e.g., 0.05, 0.01, 0.001), then we can reject the null hypothesis and conclude that there are group effects.

In order to use an F distribution table you must calculate the degrees of freedom for the mean sum of squares (both the MS "between" and "within"). After calculating these values, go to the F distribution table. The degrees of freedom for the numerator (MSbetween) are located across the top of the table. The degrees of freedom for the denominator (MSwithin) are located down, along the left-hand side of the F distribution table. Find the critical value associated with the degrees of freedom for the numerator and denominator by finding the intersection of the two in the F distribution table. If the computed F-ratio is larger than the critical value associated with a particular alpha level, then we can reject the null hypothesis and conclude that there are group effects.

INTERPRETATION OF DATA IN THE REPORT

AIAG guidelines for gage R & R table

% Tolerance % Study Var	%Contribution	System is
10 % or less	1% or less	Acceptable
10% - 30%	1% - 9%	Marginal
30% +	9% +	Unacceptable

Graph patterns with low measuring system variation

Graph	Pattern
R-bar	small average range
X-bar	nattow control limits many parts out of control
By part	very similar individuals across all operators & obvious difference between parts
By operator	straight horizontal line
operator by part	overlaid lines

ANOVA GAGE TEST REPORT

YOUR COMPANY LIMITED

YOUR CITY, STATE

TEST CONDITIONS

INSTRUMENT FINGER | MODEL M MOUSE | ASSET # 999E

SUPPLIER PURCHASED		MAINTENANCE RECORD	

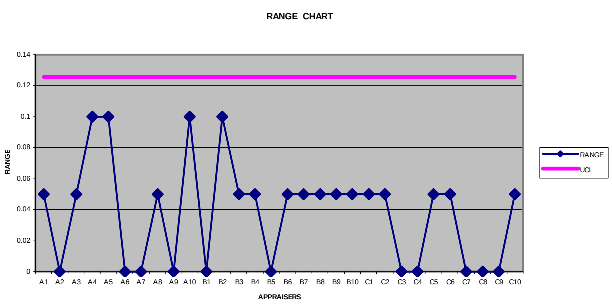
APPAISERS 3 | # OF PARTS 10 | # OF TRIALS 2

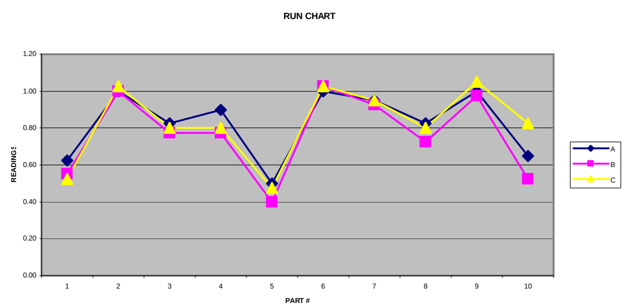
PART DESCRIPTION		TEST PROCEDURE	

ANALYSIS SUMMARY

APPRAISER	AVERAGE READING	POPULATION SIGMA	RANGE	SOURCE	ESTIMATED SIGMA	ESTIMATED VARIANCE	% OF TOTAL
A	0.8275	0.177315508	0.045	REPEATABILITY	0.035939764	0.001291667	12.14495593
B	0.7675	0.214767316	0.045	REPRODUCIBILITY	0.01494589	0.00022338	2.10033736
C	0.8275	0.195660151	0.025	INTERACTION	0.09550063	0.00912037	85.75470671
TOTAL	0.8075	0.340365516	0.038333333	R & R	0.103128157	0.010635417	100

GAGE REPORT - CHARTS





ANOVA REPORT

SOURCE	SUM OF SQUARES	DEGREES FREEDOM	MEAN SQUARE	F RATIO
APPRAISERS	0.048	2	0.024	18.58064516
PARTS	2.058708333	9	0.22874537	177.09319
APPRAISERS - PARTS INTERACTION	0.103666667	18	0.005759259	4.458781362

GAGE REPORT

	VARIATION	%	% CONTRIBUTED	VARIANCE EST	SIGMA EST	% ENG. TOL.
REPEATABILITY	0.185089787	16.43850543	2.702244606	0.001291667	0.035939764	XXXXX
REPRODUCIBILITY	0.076971334	6.836107548	**0.467323664**	0.00022338	0.01494589	XXXXX
INTERACTION	0.491828246	43.6810773	19.08036514	0.00912037	0.09550063	XXXXX
R & R	0.531110006	47.16983508	**22.24993341**	0.010635417	0.103128157	XXXXX
PARTS	0.992819985	88.1759982	77.75006659	0.037164352	0.19278058	XXXXX

DATE 06/09/04 PREPARED BY **Bilbo Baggins**