Gage R&R SnapStat

Summary

The *Gage R&R SnapStat* estimates the repeatability and reproducibility of a measurement system based on a study in which *m* appraisers measure *n* items *r* times. It also estimates important quantities such as the total variation, the precision-to-tolerance ratio, the standard deviation of the measurement error, and the percent of study contribution from various error components. It creates a single page of output with a selection of tables and graphs illustrating the results of the analysis.

Depending on the setting on the *Gage Studies* tab of the *Preferences* dialog box, accessible from the *Edit* menu, the method used to estimate the measurement error will be one of the following:

1. *Average and Range Method*.
2. *Crossed ANOVA Method* including Operator by Part interaction.
3. *Crossed ANOVA Method* without Operator by Part interaction.
4. *Nested ANOVA Method*

The *Average and Range Method* and the *ANOVA Method* procedures perform the same calculations in the standard multiple-pane format.

Sample StatFolio: *gagesnapstat.sgp*

Sample Data:

The file *gage1.sgd* contains data from a typical variables gage study, taken from the third edition of the Automotive Industry Action Group's (AIAG) reference manual on Measurement Systems Analysis, MSA (2002). A partial list of the data in that file is shown below:

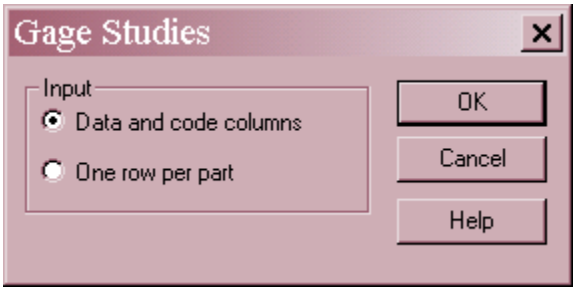
Appraiser	*Part*	*Trial*	*Measurement*
A	1	1	0.29
A	2	1	-0.56
A	3	1	1.34
A	4	1	0.47
A	5	1	-0.80
A	6	1	0.02
A	7	1	0.59
A	8	1	-0.31
A	9	1	2.26
A	10	1	-1.36
A	1	2	0.41
A	2	2	-0.68
A	3	2	1.17
A	4	2	0.50
A	5	2	-0.92

The file contains a total of 90 rows, one for each of $r = 3$ measurements made by each of $m = 3$ operators on $n = 10$ parts.

Note: Data reprinted from the Measurement Systems Analysis (MSA) Manual with permission of DaimlerChrysler, Ford and GM Supplier Quality Requirements Task Force.

Data Input

The first dialog box displayed by this procedure is used to indicate the structure of the data to be analyzed.



Input: The datasheet may be organized into either of two formats:

- *Data and Code Columns*: indicates that the datasheet contains a single column holding all the measurements. In this format, additional columns must be provided to identify which measurements correspond to which part and which appraiser. This is the type of data structure illustrated above.
- *One Row for Each Part*: indicates that the datasheet contains a single row for all measurements on a specific part. In this format, the column names are used to identify which measurements were made by which appraiser. An example of this data structure is shown below:

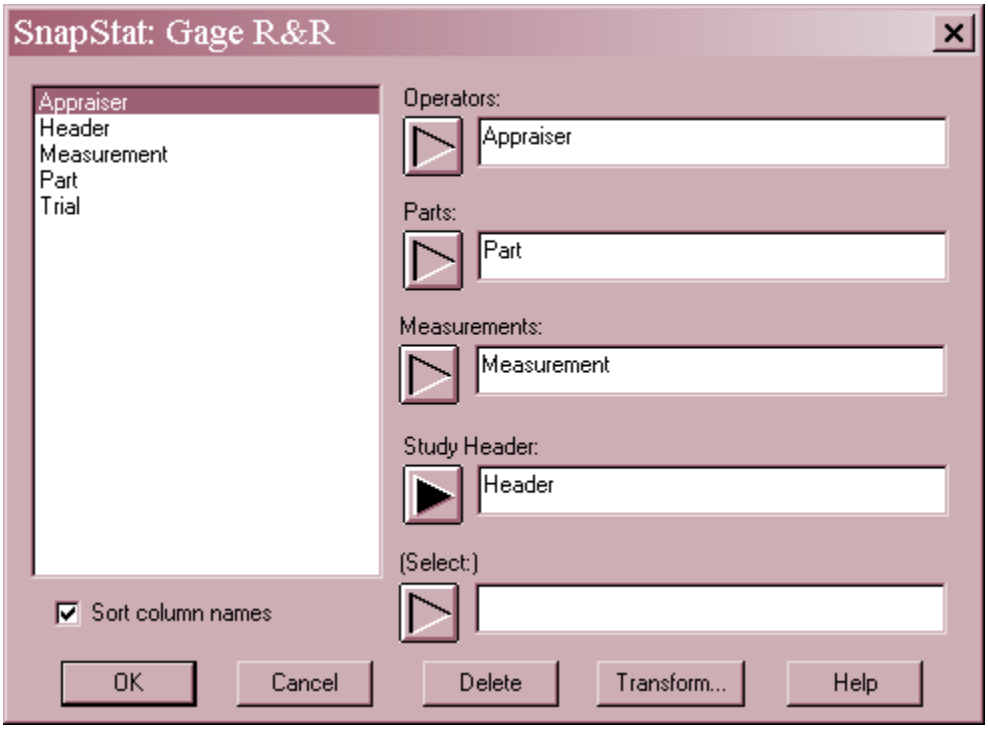
Part	A_1	A_2	A_3	B_1	B_2	B_3	C_1	C_2	C_3
1	0.29	0.41	0.64	0.08	0.25	0.07	0.04	-0.11	-0.15
2	-0.56	-0.68	-0.58	-0.47	-1.22	-0.68	-1.38	-1.13	-0.96
3	1.34	1.17	1.27	1.19	0.94	1.34	0.88	1.09	0.67
4	0.47	0.50	0.64	0.01	1.03	0.20	0.14	0.20	0.11
5	-0.80	-0.92	-0.84	-0.56	-1.20	-1.28	-1.46	-1.07	-1.45
6	0.02	-0.11	-0.21	-0.20	0.22	0.06	-0.29	-0.67	-0.49
7	0.59	0.75	0.66	0.47	0.55	0.83	0.02	0.01	0.21
8	-0.31	-0.20	0.17	-.63	0.08	-0.34	-0.46	-0.56	-0.49
9	2.26	1.99	2.01	1.80	2.12	2.19	1.77	1.45	1.87
10	-1.36	-1.25	-1.31	-1.68	-1.62	-1.50	-1.49	-1.77	-2.16

If the data will be analyzed by other STATGRAPHICS procedures, *Data and Code Columns* is the preferred format since it follows the structure expected by most other procedures.

The second dialog box displayed depends on the setting in the first dialog box.

Data and Code Columns

If you select *Data and Code Columns* on the first dialog box, the second dialog box requests the name of the column containing the measurements and the columns containing appraiser and part indicators.

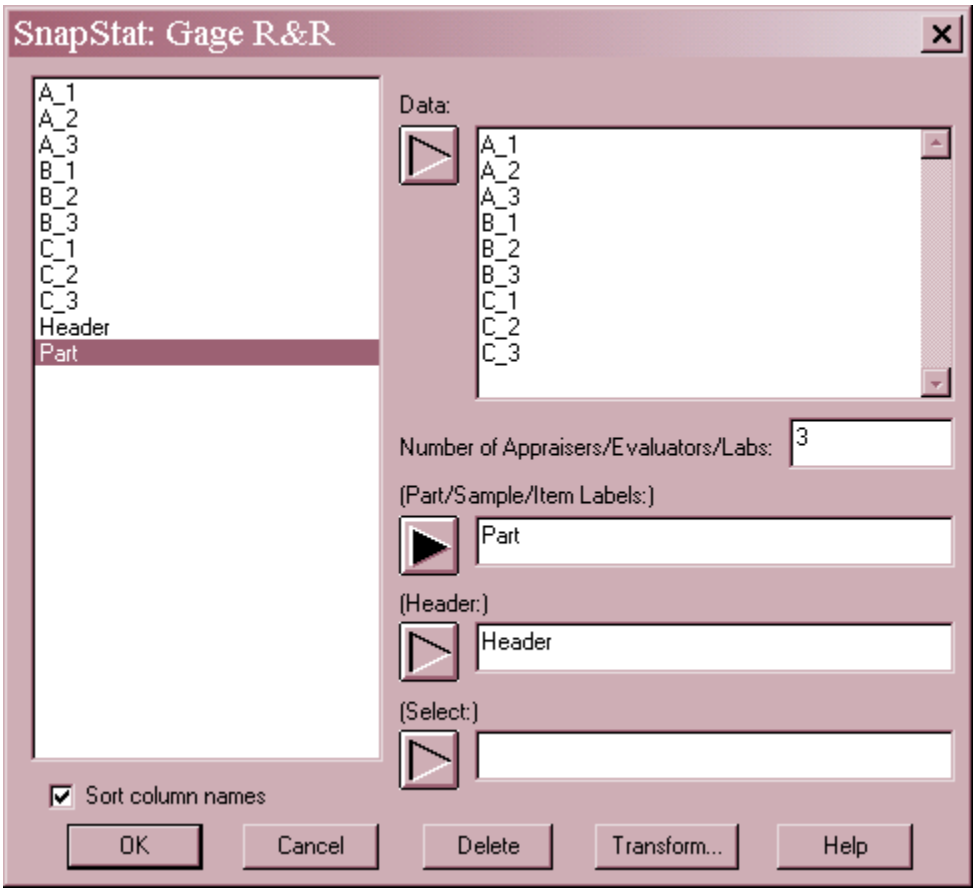


- **Operators**: numeric or non-numeric column indicating the appraiser corresponding to the measurements in each row.
- **Parts**: numeric or non-numeric column indicating the item corresponding to the measurements in each row.
- **Measurements**: numeric column containing the measurements.
- **Study Header**: optional header to be printed at the top of each output table.
- **Select**: subset selection.

If the study has *m* appraisers, *n* items, and *r* trials, there must be exactly *mnr* rows with non-missing data. Each operator-part combination must also have exactly *r* measurements (i.e., the study must be balanced).

One Row for Each Part

If you select *One Row for Each Part* on the first dialog box, the second dialog box requests the names of the columns containing the measurements and the number of appraisers.



- **Data**: numeric columns containing the measurements. Each group of *m* columns is assumed to correspond to the same appraiser.
- **Number of Appraisers/Evaluators/Labs**: *m*, the number of appraisers. This number must be between 2 and 18 and divide evenly into the number of data columns.
- **Part/Sample/Item Labels**: optional labels for each item in the study. In no entry is made, the items will be numbered from 1 to *n*.
- **Study Header**: optional header to be printed at the top of each output table.
- **Select**: subset selection.

Output

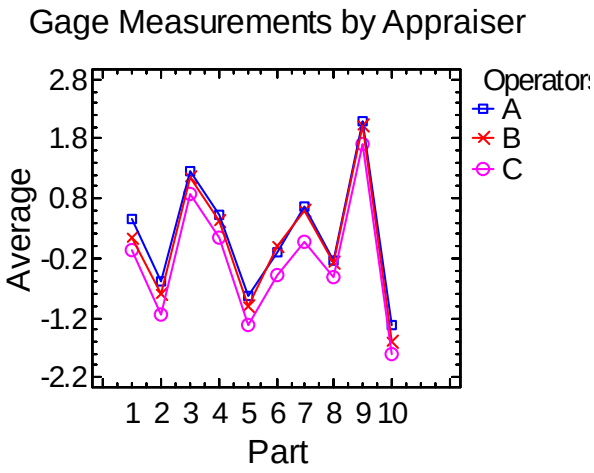
The output from the SnapStat consists of a page of graphs and numerical statistics.

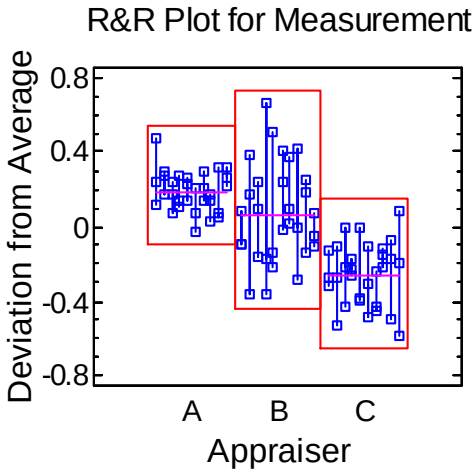
SnapStat: Gage R&R - Average and Range Method
Data variable: Measurement

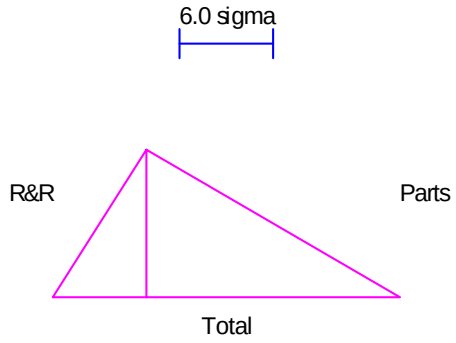
	Est. Sigma	% TV	% Contrib.
Repeat	0.200894	17.5269	3.07193
Reprod	0.229711	20.0411	4.01646
R&R	0.305165	26.624	7.08839
Parts	1.10483	96.3907	92.9116
Total	1.1462	100	

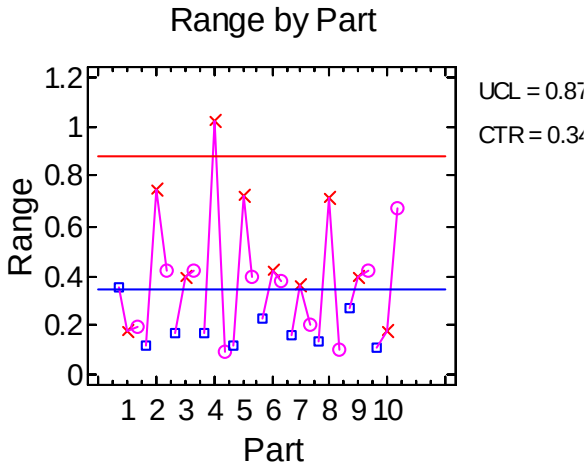
	% R&R	6.0 Sigma	% Tolerance
Repeat	43.34	1.20536	
Reprod	56.66	1.37827	
R&R	100.00	1.83099	
Parts		6.62898	
Total		6.8772	

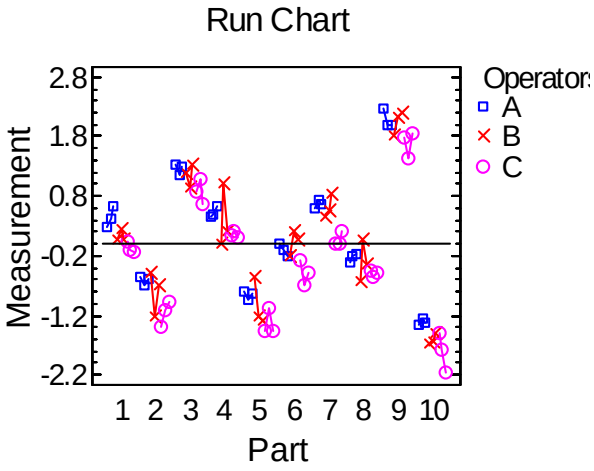
Number of distinct categories (ndc): 5











Tabular Summary (top left)

This summary displays:

- **Repeatability** - estimate of the variation between measurements made by the same appraiser on the same part, usually attributed to the instrument.
- **Reproducibility** - estimate of the variation between measurements made by different appraisers on the same part, usually attributed to the appraiser.
- **Interaction** – if using the ANOVA method with Interaction, an estimate of the variation due to an interaction between appraisers and parts. An interaction would occur if the differences between operators varied from one part to another.
- **R & R** - estimate of the total measurement error, calculated by adding the variances due to repeatability and reproducibility.
- **Parts** – estimate of the actual variability among the items measured. If the measurement process is capable of separating good items from bad items, this should be large compared to the variability of the measurement process.
- **Total** – sum of the variability due to the measurement process and the actual variability amongst the items.

For each measurement unit (component), the columns of the table show:

- **Estimated Sigma** – the estimated standard deviation $\hat{\sigma}_{component}$.
- **Percent Total Variation** – the percentage of the total standard deviation:

$$100\frac{\hat{\sigma}_{component}}{\hat{\sigma}_{total}}\% \qquad (1)$$

where

$$\hat{\sigma}_{total} = \sqrt{\hat{\sigma}^2_{repeat} + \hat{\sigma}^2_{repro} + \hat{\sigma}^2_{\text{int}eractions} + \hat{\sigma}^2_{parts}} \qquad (2)$$

- **Percent Contribution** – the percentage of the total variance:

$$100\frac{\hat{\sigma}^2_{component}}{\hat{\sigma}^2_{total}}\% \qquad (3)$$

- **Percent of R&R** – the percentage of the overall measurement variance:

$$100\frac{\hat{\sigma}^2_{repeat}}{\hat{\sigma}^2_{R\&R}}\%,\ 100\frac{\hat{\sigma}^2_{repro}}{\hat{\sigma}^2_{R\&R}}\%, \text{ and } 100\frac{\hat{\sigma}^2_{\text{int}eractions}}{\hat{\sigma}^2_{R\&R}}\% \quad (4)$$

- **6.0 Std. Dev.** – the multiple $K\hat{\sigma}$ for each of the error components. If *K* equals 6.0, this estimates the interval within which the associated error component will lie 99.73% of the time. The value of *K* is set on the *Gage Studies* tab of the *Preferences* dialog box, accessible from the *Edit* menu.

- **% tolerance** – the percentage of the tolerance represented by $K\hat{\sigma}$:

$$100\frac{K\hat{\sigma}_{component}}{tolerance}\% \quad (5)$$

Of particular interest is the percentage for R&R, which equals 26.6% in the table above. The rule of thumb cited by the AIAG is that if this value is less than 10%, then the measurement system is usually deemed to be acceptable. In certain cases, values between 10% and 30% may also be acceptable, depending on the circumstances. The relative percentages of repeatability and reproducibility can also be helpful in isolating the largest source of variability in the measurement process.

One more statistic is also displayed:

- **Number of distinct categories (ndc)** – According to the AIAG (2002), *ndc* represents "the number of distinct categories that can be reliably distinguished by the measurement system." It is basically a measure of how many 97% confidence intervals for the true value being measured can fit within the range of expected part-to-part variation. Values greater than or equal to 5 are desirable.

Operator and Part Plot (top right)

In estimating repeatability and reproducibility, the first step is to calculate statistics for each combination of operator and part:

$\bar{x}_{ij}$ = average measurement made by operator *i* on part *j*

R_{ij} = range of measurements made by operator *i* on part *j*

$\bar{x}_i$ = average measurement made by operator *i*

The *Operator and Part* plot displays $\bar{x}_{ij}$, the operator by part averages. This plot is useful for showing any consistent differences between the appraisers. For example, Appraiser C appears to be consistently lower than Appraiser A.

R&R Plot (left center)

Another useful plot is the *R&R Plot*, which contains a single point for each measurement in the study. The vertical axis is scaled to show the difference between each measurement and the overall mean of all the measurements. The points are grouped by appraiser, and a horizontal line is drawn at the average measurement $\bar{x}_i$ for each appraiser. Vertical lines connect measurements made by the same appraiser on the same item.

It can be seen from the above plot that Appraiser C's measurements are smaller on average than those of the other two appraisers. On the other hand, Appraiser B shows considerably more variability. In fact, the repeatability of Appraiser B is poor, since there are several large discrepancies between repeated measurements on the same item.

Tolerance Diagram (right center)

This diagram illustrates the size of the measurement error relative to the tolerance, if a tolerance has been entered. It also shows the relative size of the measurement and part-to-part variation.

Information that may be displayed includes:

1. **P/T Ratio** – The precision-to-tolerance ratio, defined by

$$100\frac{K\hat{\sigma}_{component}}{tolerance}\% \qquad (6)$$

   P/T is a measure of how wide the measurement error distribution is compared to the specifications for the item being measured. Values of P/T less than 10% usually imply an acceptably small measurement error, although P/T may be as high as 30% in some cases and still be acceptable.

2. ***K* sigma** – a horizontal line illustrating the error of the measurement process. If $K = 6$, the length of the line covers 99.73% of the errors, assuming a normal distribution.

3. **Tolerance** – a horizontal line illustrating the size of the tolerance. The diagram is designed to allow you to compare the *K sigma* spread to the distance between the specification limits.

4. ***R&R*** – a triangular diagram illustrating the decomposition of the total variation into components due to the measurement error and the variation amongst the parts. The horizontal base of the triangle is scaled according to the magnitude of the total variation $\hat{\sigma}_{total}$. It is subdivided relative to the magnitude of the standard deviations due to R&R and parts. The labels indicate the percentage of the tolerance covered by each component, defined by:

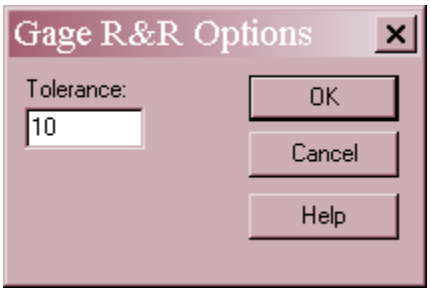
$$100\frac{K\hat{\sigma}_{component}}{tolerance}\% \qquad (7)$$

Range Charts (bottom left & bottom right)

The operator by part ranges, R_{ij}, are displayed on two plots: the *Range Chart by Operator* and the *Range Chart by Plot*. The *Range Chart by Operator* may be used to determine whether there are any instances of usual discrepancies between repeated measurements on the same item. Included on the chart is a 3-sigma upper control limit. Any ranges beyond this limit, of which Appraiser B has one, indicate unusual events. In fact, Appraiser B shows consistently larger ranges than the other two appraisers.

The *Range Chart by Part* is used to detect items that are unusually difficult to measure. In this case, no single part seems to have a large range for more than one appraiser.

Analysis Options



- **Tolerance**: the distance between the specification limits, USL - LSL. The value entered in this field is used by the *Tolerance Analysis*, described below, to compute a *precision-to-tolerance* (P/T) ratio.

Calculations

The mathematical details of this analysis can be found in the documentation for the *Average and Range Method* and the *ANOVA Method* procedures.

