**Gage R&R Study**

Measurement systems analysis assesses the adequacy of a measurement system for a given application. When measuring the output from a process, consider two sources of variation:

* Part-to-part variation
* Measurement system

If measurement system variation is large compared to part-to-part variation, the measurements may not provide useful information. Therefore before experimental design and Process Design, Control and Capability, it is important that the measurement system measures consistently and accurately and adequately discriminates between parts. To check this system, Gage R&R study is done in this experiment to see if the measurement system is adequate or not. Three operators were chosen to perform this study with 10 different parts. To reduce any unexplained variability, 3 replications were performed by each helicopter by every operator, making total of 90 readings. Randomization is also done to overcome the effect of any nuisance variable. Videos of the helicopters were not named by the number and operators didn’t have any clue of the flight/helicopter number before taking the reading. This helped us eliminating in bias in the experiment.

Example of one such video/flight is given below:

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**Initial Study Results:**

Source DF SS MS F P

Helicopter 9 0.437996 0.0486662 25.7056 0.000

Operators 2 0.001167 0.0005833 0.3081 0.739

Helicopter \* Operators 18 0.034078 0.0018932 8.3524 0.000

Repeatability 60 0.013600 0.0002267

Total 89 0.486840

α to remove interaction term = 0.25

**Gage R&R**

%Contribution

Source VarComp (of VarComp)

Total Gage R&R 0.0007822 13.08

Repeatability 0.0002267 3.79

Reproducibility 0.0005555 9.29

Operators 0.0000000 0.00

Operators\*Helicopter 0.0005555 9.29

Part-To-Part 0.0051970 86.92

Total Variation 0.0059792 100.00

Process tolerance = 0.45

Study Var %Study Var %Tolerance

Source StdDev (SD) (6 × SD) (%SV) (SV/Toler)

Total Gage R&R 0.0279675 0.167805 36.17 37.29

Repeatability 0.0150555 0.090333 19.47 20.07

Reproducibility 0.0235694 0.141416 30.48 31.43

Operators 0.0000000 0.000000 0.00 0.00

Operators\*Helicopter 0.0235694 0.141416 30.48 31.43

Part-To-Part 0.0720902 0.432541 93.23 96.12

Total Variation 0.0773251 0.463951 100.00 103.10

Number of Distinct Categories = 3

Based on the results above, we can see that the Helicopter\*Operator interaction is statistically significant. We can also see that for operators the P Value is less than 0.05 and therefore we fail to reject the null hypothesis and therefore different operators are not the reason behind this variation in the process. That means this variation is the flight time is because of the different helicopters i.e. part to part variation.

It is also important to evaluate the ANOVA table for the number of degrees of freedom (an indicator of the number of repeat measurements) available to estimate the repeatability of the gage. Here we see 60 degrees of freedom, well above the recommended 30 to 45 and therefore, the reduced number of Parts in the study has not hindered our ability to estimate the contribution of the gage repeatability to the overall variation of the measurement system. And hence we can now focus on the Gage R&R Table:

Ideally, differences between parts should account for most of the variability; variability from repeatability and reproducibility should be very small. And that is the case here in our studies. We can that 87% of the variability contribution is because of different helicopters. Even though the R&R is low but it is still not acceptable as the % contribution of 13% is greater than the acceptable threshold of 9%.

Similar is the case with % Study Variation, 36.17% variation for Gage R&R which is the greater than the threshold of 30% makes the measurement system unacceptable.

**Note:** *Upper and lower specification limit in the system is based on the 6 sigma. Average and standard deviation of the data set was taken every time the experiment was performed and USL and LSL was established by using the formula Mean (+-) 3\* Std Dev.*

**Steps to Improve the Measurement System:**

Based on the initial experiment, we can see that the variability in repeated measurements by the same operator is much less than the variability when the same part is measured by different operators. This means repeatability is much better than the reproducibility in our measuring system. That means 3 operators lack in the common technique that should be used to measure the flight times.

To overcome this variation, discussions were made on dropping and ending points of the helicopters. It showed that the operators have different idea for these points. Because of the variation in the height of operators itself, dropping the helicopter from the height of 6 feet every time will bound to introduce some explained variability in the process. To overcome this, a thread at height of 6 was tied horizontally along the wall to improve the variation in dropping height. Every time the helicopter’s base was kept of the top of the thread and dropped to measure the flight time.

All the end time of the flight was calibrated so that each operator has the same understanding of the end time of flight i.e. when the base of the helicopter hits the floor. After these adjustments, videos were recorded again and measurement studies were performed to validate these improvements.

**2nd Study Results:**

Source DF SS MS F P

Helicopter 9 0.453290 0.0503656 43.3218 0.000

Operators 2 0.000762 0.0003811 0.3278 0.725

Helicopter \* Operators 18 0.020927 0.0011626 5.2845 0.000

Repeatability 60 0.013200 0.0002200

Total 89 0.488179

α to remove interaction term = 0.25

**Gage R&R**

%Contribution

Source VarComp (of VarComp)

Total Gage R&R 0.0005342 8.90

Repeatability 0.0002200 3.67

Reproducibility 0.0003142 5.24

Operators 0.0000000 0.00

Operators\*Helicopter 0.0003142 5.24

Part-To-Part 0.0054670 91.10

Total Variation 0.0060012 100.00

Process tolerance = 0.45

Study Var %Study Var %Tolerance

Source StdDev (SD) (6 × SD) (%SV) (SV/Toler)

Total Gage R&R 0.0231127 0.138676 29.84 30.82

Repeatability 0.0148324 0.088994 19.15 19.78

Reproducibility 0.0177256 0.106354 22.88 23.63

Operators 0.0000000 0.000000 0.00 0.00

Operators\*Helicopter 0.0177256 0.106354 22.88 23.63

Part-To-Part 0.0739391 0.443635 95.45 98.59

Total Variation 0.0774674 0.464804 100.00 103.29

Number of Distinct Categories = 4

Based on the results, we can see the improvement in the measurement system and we can conclude that maximum variation is the process is due to the part to part variability and not the actual measuring system. Even though the improvements made have shown some results geometric sum of repeatability and reproducibility (R&R) has been reduced from 36.17 to 29.84, which is marginally acceptable. Also the % contribution has been reduced 8.9% i.e. also below the threshold.

**Steps to further Improve the Measurement System:**

We can see that maximum % study variation is due to reproducibility but this again can been viewed in two different components. All of this % contrition is due to the operator\*helicopter interaction. We have already established that there is a variation in the process these helicopters have been made and this variation is hampering the different operator ability to measure the flight time for different helicopters accurately. As part to part variability is not the focus of this study, we will except this variation and try to reduce the repeatability in the system.

Individual operator readings were analysed to see which operators has the best accuracy. All the analysis, it was established that operator 1 is most efficient out of the three and he/she was used to train the other operators on the use of stop watch and other parameters like dropping height, flight end time and position to hold the helicopter while dropping. After this small training session, final experiment was performed and videos were made and analysed again. Shown below are the Minitab results:

**3nd Study Results:**

Source DF SS MS F P

Helicopter 9 0.504739 0.0560821 113.794 0.000

Operators 2 0.000862 0.0004311 0.875 0.434

Helicopter \* Operators 18 0.008871 0.0004928 4.265 0.000

Repeatability 60 0.006933 0.0001156

Total 89 0.521406

α to remove interaction term = 0.25

**Gage R&R**

%Contribution

Source VarComp (of VarComp)

Total Gage R&R 0.0002413 3.76

Repeatability 0.0001156 1.80

Reproducibility 0.0001258 1.96

Operators 0.0000000 0.00

Operators\*Helicopter 0.0001258 1.96

Part-To-Part 0.0061766 96.24

Total Variation 0.0064179 100.00

Process tolerance = 0.46

Study Var %Study Var %Tolerance

Source StdDev (SD) (6 × SD) (%SV) (SV/Toler)

Total Gage R&R 0.0155344 0.093206 19.39 20.26

Repeatability 0.0107497 0.064498 13.42 14.02

Reproducibility 0.0112143 0.067286 14.00 14.63

Operators 0.0000000 0.000000 0.00 0.00

Operators\*Helicopter 0.0112143 0.067286 14.00 14.63

Part-To-Part 0.0785912 0.471547 98.10 102.51

Total Variation 0.0801118 0.480671 100.00 104.49

Number of Distinct Categories = 7

We can see that % study variable for gage R&R is reduced to 19.39 which is now in marginally acceptable range i.e. between 10-30% and same is the case with %Contribution which is between the marginally acceptable ranges of 1-9%. The %Tolerance results indicate that the measurement system variation is less than 20.26% of the tolerance width. Shown below are some graphs which depict the same results i.e. the operators between themselves are accurate and system doesn’t lack repeatability also the most of the variability in the system is due to the variability in the helicopters and not due to the measurement system.



Therefore we can conclude that out measurement system is acceptable given that manufacturing process is improved to make identical helicopters with greater flight time in next phase of the project.