Teaching Measurement Systems Analysis to Engineers Using R

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Introduction

Measurement Systems Analysis (MSA) is based on the reference manual of the Automotive Industry Action Group (AIAG) which was first published in 1990. Based on this reference manual a variety of company guidelines and other texts such as the Band 5 of the Verein Deutscher Automobilbauer[1] (VDA) originated, which in its 2nd edition, is based on the Norm ISO 22514-7 Measurement Process Capability and is to be published at the end of 2011 [7]. In addition, the verification of measuring equipment to ensure valid results is a formal requirement of any ISO 9001 certified corporation [4]. With the ISO 9001 topping one million certifications in 2009 [3], Measurement Systems Analysis should be an important aspect within the statistical education of engineers. Moreover, Measurement System Analysis is a standardized procedure within a 6σ methodology.

Concepts & Terminology

Gages can have three types of impairments which are a lack of linearity, a bias and variation. The latter can be split into system immanent variation of the measurement itself and variation introduced by other factors such as operators using these measurement systems:

bias: difference between the average measurement and the reference value (accuracy)

repeatability: is given by the standard deviation of subsequent measurements under repeatability conditions (inherent precision)

reproducibility: is given by the average of measurements for a change in one factor

repeatability conditions: fixed and defined conditions i.e. identical operator, measurement device, part and quality characteristic

reproducibility conditions: repeatability conditions with one factor subject to change e.g. operator

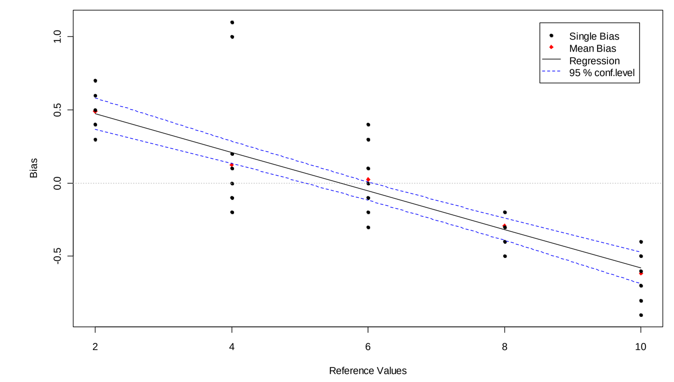
reference interval: the range in which 95.5% or 99.73% of the measurements are to be expected

tolerance interval: upper – lower specification limit

Linearity and Stability

For assessing the linearity of a gage, parts with measurements covering the operating range of the gage are taken. Each reference part is repeatedly measured under repeatability conditions. A graphical and numerical analysis of the measurements is done [1].

```
library(qualityTools)
example(gageLin)
```

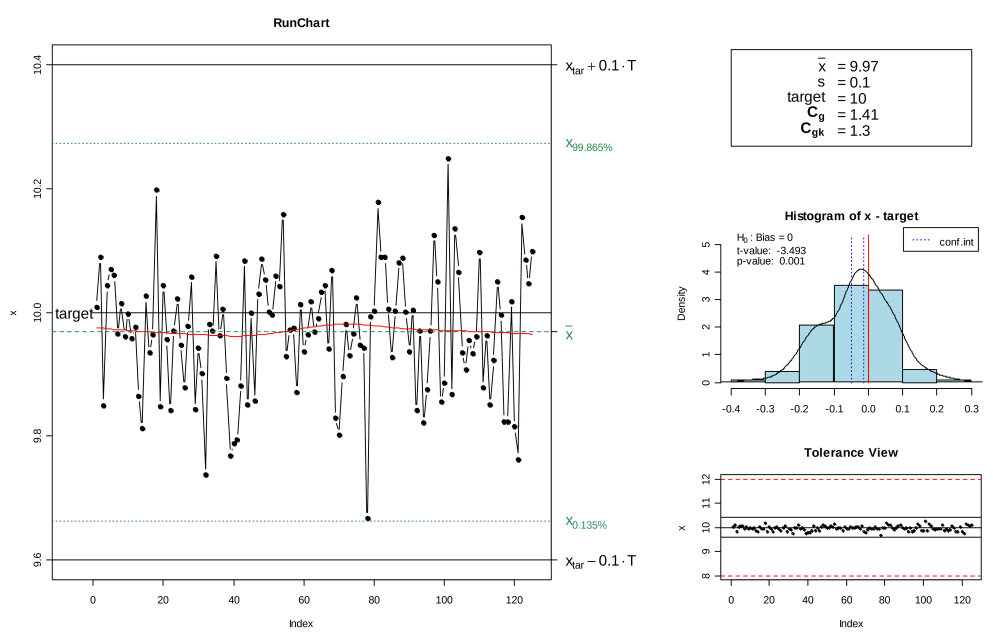


```
------------
LINEARITY:
  13.16667
```

MSA Type I – Bias & Repeatability

The focus of this study is to determine the bias and repeatability of the gage. The quality characteristic of a reference part is measured repeatedly under repeatability conditions and the repeatability and bias is determined. The capability of the gage is then expressed in the gage capability indices c_g and c_{gk} (analogous to the process capability indices c_p and c_{pk}) which relates the reference interval of the measurements to a portion of the tolerance interval of the considered quality characteristic [8]. The portion depends on company guidelines and usually takes on values around 0.2.

```
example(cg)
```



MSA Type II – Gage Repeatability & Reproducibility

The focus of this study is to identify the source and magnitude of the variation for a given gage in a production environment. The quality characteristic of parts is measured under reproducibility conditions and the parts are sampled from the production process. Using a Gage R&R study the repeatability and reproducibility of the gage is determined. Repeatability refers to the inherent precision of a measurement system. Reproducibility is the part of the overall variance that models the effect of different e.g. operators performing measurements on the same unit and a possible interaction between different operators and parts measured within this Gage R&R. The relation between these component is given by [1]:

$$\sigma^2_{Total} = \sigma^2_{Parts} + \sigma^2_{Operator} + \sigma^2_{PartsxOperator} + \sigma^2_{Error}$$

In here σ^2_{Parts} models the variation between different units of the same process. σ^2_{Parts} is thus an estimate of the inherent process variability. Repeatability is modeled by σ^2_{Error} and reproducibility by:

$$\sigma^2_{Operator} + \sigma^2_{PartsxOperator}$$

Suppose 10 randomly chosen units were measured by 3 randomly chosen operators. Each operator measured each unit two times in a randomly chosen order and the units were presented in a way they could not be distinguished by the operators.

The corresponding Gage R&R design can be created using the `gageRRDesign` method of the qualityTools package.

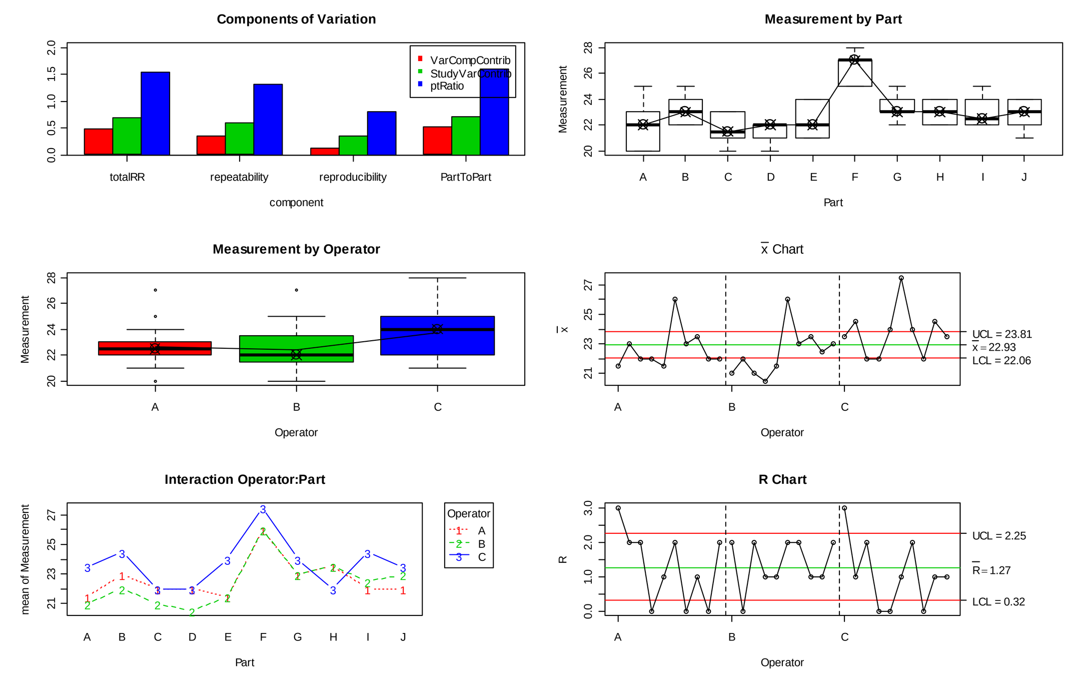
```
design = gageRRDesign(O=3, P=10, M=2)
```

The measurements are assigned to this design using the `response` method.

```
response(design) = c(23,22,22,22,22,25,23,…)
```

Methods for analyzing this design are given by `gageRR` and `plot`.

```
gdo = gageRR(design); plot(gdo)
```




```
Gage R&R
                  VarComp      StudyVarContrib P/T
Ratio
totalRR             1.664  …         0.695     1.55
 repeatability      1.209  …         0.592     1.32
 reproducibility    0.455  …         0.364     0.81
   Operator         0.455  …         0.364     0.81
   Operator:Part    0.000            0.000     0.00
Part to Part        1.781            0.719     1.60
totalVar            3.446            1.000     2.23
```

Summary

MSA is covered in an obligatory introductory statistics course for engineers at the TU Berlin using the `qualityTools` package. Understanding the methodology is enhanced by performing a Gage R&R during class. In this activity the thickness of each of six dice is measured three times by three students in a randomized fashion [5]. This classroom experiment proved to be valuable for understanding the concept of repeatability and reproducibility. The observed variation is assigned easily to particular variance components using the provided methods.

References

[1] A.I.A.G - Chrysler Corp., Ford Motor Co., General Motors Corp.: Measurement Systems Analysis, Reference Manual. 4th ed., Michigan (USA)

[2] ISO (2010) ISO/DIS 22514-7: Statistical methods in process management -- Capability and performance -- Part 7: Capability of measurement processes.

[3] The ISO-Survey of certifications 2009, 18th ed.

[4] ISO (2008). Quality management systems – Requirements (ISO 9001:2008)

[5] Mathews, P.(2004): Design of Experiments with MINITAB. ASQ Quality Press. – ISBN 0-87389-637-8

[6] Roth, T. (2010). qualityTools: Statistical Methods for Quality Science. http://www.r-qualitytools.org

[7] Dietrich, E 2011, 'Wo liegen die Unterschiede', QZ - Qualität und Zuverlässigkeit, no. 6, pp. 30–34

[8] Dietrich, E & Schulze, A 2007, Eignungsnachweis von Prüfprozessen. Prüfmittelfähigkeit und Messunsicherheit im aktuellen Normenumfeld, Hanser, München [u.a.].

[1] Association of German Car Manufacturers