13

MEASUREMENT SYSTEM ANALYSIS OF ATTRIBUTE OR CONTINUOUS DATA, AS A ONE OF THE FIRST STEPS IN LEAN SIX SIGMA PROJECTS

13.1 INTRODUCTION

Lean management as well as Six Sigma, have become one of the main improvement trends of production in factories specializing not only in the automotive market, but covering all sectors of industry. Lean and Six Sigma methodology are no longer separated, because combining them, gives a very measurable and significant impact for projects. The success of each project is derived strictly from the structured DMAIC path, whose letters are the steps: Define, Measure, Analyze, Improve and Control. In this work has been presented one of the Measure phase step, which includes an measurement system analysis and the common errors, as well as explanation how important and significant it may be to check that system before attempting to improve of our manufacturing process. The importance of this analysis is significant because it often can finish or change Lean Six Sigma projects in the early phase of the project. All data and examples come from an extrusion process, and an inspection (length control) area. Extrusion is the first step of preparation in compression molding production – raw material (rubber strips or sheets) is milled and extruded on screw or ram extruder. Extruded blanks (with required shape and cross section) have very big impact on molding process and finished product – therefore controlling of their main parameters is a significant step in production. Whenever gasket is molded and post-cured – length has to be check. Not in all cases are required sophisticated measurements equipment or methods – very often we can use simple Go/No-go gauge to assess required level of information, which in this case is overall gasket length (fit check). If gasket would be to long there is a high risk that it will not fit to the plate heat exchanger unit – which can seriously affect on production timing.

13.2 DATA TYPES

The data we collect during the manufacturing process can be divided into two types [3, 4, 5]:

1. attribute data,
2. continuous data.

Attribute date – the terms applied to „Categorical" data where are distinct boundaries between adjoining values.

Continuous data – the terms applied to „Measurement" data where there are no barriers between adjoining values.

Attribute data can be divided further into:

- Defectives data (the unit is good or bad (defective)) – those data uses Binominal Distribution;
- Defects data – the unit contains x number of defects – those data uses Poisson Distribution.

When we measure continuous characteristics such as length, weight, thickness, etc., there are two metrics to describe the sample:

- Position – usually describe by the mean;
- Spread – usually describe by the standard deviation.

13.3 COMPONENTS OF MEASUREMENT ERROR

Each component of measurement error can contribute to variation, causing wrong decisions to be made. The error components can be divided into six types [3, 4, 5]:

13.3.1 Resolution – the capability to detect the smallest acceptable change – increments in the measurement system should be one-tenth the product specification or process variation,

Resolution is a simplest measurement system problem, where the impact is often recognized but not addressed. It is easily detected and no special studies/"known standards" are necessary.

As an actions for poor resolution we can:

- o Use a device that can measure to a greater resolution,
- o Move to a sample and record an average,
- o Live with it, but understand the repercussions – which may be:
  - Cannot tell one component from another,
  - Cannot tell where component lies within upper and lower specification limits,
  - Cannot accurately Centre Process,
  - Cannot Improve the Process

13.3.2 Accuracy/Bias – difference between observed average value of measurement and the master value.

As an actions for poor Accuracy we have to:

- o Calibrate regularly,
- o Use operations instructions,
- o Review specifications to check for '10 bucket' rule,
- o Validate Data Systems input accuracy,
- o Create Operational Definitions.

13.3.3 Linearity – measurement is not "true" and/or consistent across the range of the "gauge".

If a linearity problem appears we have to:

- o Rebuild/Replace Gauge,
- o Use only in restricted range,

- Use with correction factor/table/curve.

13.3.4 Stability – measurements remain constant and predictable over time.
When stability problem occurred:
- Ensure equipment is properly,
- cleaned and maintained,
- Use control charts,
- Use/update current SOP,
- Ensure adequate training,
- Regular audit.

13.3.5 Repeatability – variation that occurs when repeated measurements are made of the same item under absolutely identical conditions.
Main actions to improve problems with repeatability:
- Repair, replace, adjust equipment,
- SOP.

13.3.6 Reproducibility – the variation that results when different conditions are used to make the measurements.
Main actions to improve problems with reproducibility:
- Training,
- SOP.

13.4 MSA – MEASUREMENT SYSTEM ANALYSIS

At the beginning of measurement system analysis, we have to answer the question, of with which type of data we are going to work – attribute or continuous [2, 3, 4, 5]. The results for the attribute are described by acceptance criteria or lack of them, e.g. Pass, Fail, OK., NOK, etc. Results for continuous data, measure value of the sample and can be given, for example, in grams, millimeters, etc.

For measurement system analysis, will be used Minitab software, which includes a set of tools to carry out a comprehensive statistical analysis. If we consider the analysis of the measurement system for attribute data – use Attribute Agreement Analysis (fig. 13.1), if however, we are dealing with continuous data – we use Gage R&R Study (Crossed) (fig. 13.5) – for non-destructive testing, and Gage R & R Study (Nested) – for destructive testing.

Before starting of MSA, we also have to be sure that the data collected will reflect our actual production process, but also to the process of collection will not take too much time. For an appropriate analysis, it is good to choose three operators and the products that we will examine in relation to the standard. The minimum recommended number of samples (attribute agreement analysis) is 10 – the number of repeats – 3, the last measurement in random order.

13.4.1 Attribute acceptability indicators and Kappa interpretation

- Acceptability Between Appraisers:
  - > 80% – needs improvements,

- 80%-95% – probably adequate,
- 95% > – good for most purposes,
- Approaching 100% may be necessary where there is a risk to safety or of litigation,

- Acceptability All Appraisers Vs Standard:
  - > 80% – needs improvements,
  - 80%-90% – probably adequate,
  - 90% > – good for most purposes,
  - Approaching 100% may be necessary where there is a risk to safety or of litigation,
- Kappa statistics – kappa measure the level of agreement among multiple appraisers when evaluating the same samples:
  - If kappa = 1, then perfect agreement exist,
  - If kappa = 0, then agreement is the same, as would be expected by chance,
  - Negative values occur when appraisers are consistently working against the standard,
  - Kappa less than 0.7 indicates that the measurement system is inadequate,
  - Kappa above 0.9 is to be preferred but required level depends very much on the nature and purpose of the attribute assessment,

13.4.2 Continuous acceptability indicators

- % Contribution – which is measurement system variation (R&R) as a percentage of total observed variation and includes both repeatability and reproducibility,
  - > 9% – needs improvements,
  - 1%-9% – marginal but acceptable,
  - < 1% – good for most purposes,
- % Tolerance – which is measurement error as a percent of tolerance, includes both repeatability and reproducibility, can use 5.15 sigma's to represent 99% of variation,
  - > 30% – needs improvements,
  - 10%-30% – marginal but acceptable,
  - < 10% – good for most purposes,
- Distinct Categories – it is number of divisions that the measurement system can accurately measure across the process variation and it can show how well a measurement process can detect process output variation – process shifts and improvements
  - < 5 – needs improvements or indicates Attribute conditions,
  - 5-10 – marginal but acceptable,
  - > 10 – good for most purposes.

13.5 METHODOLOGY AND RESULTS

For both type of data attribute and continuous we used MiniTab statistical software – which contain number of useful statistical tools. Data has been collected from two different steps of rubber gaskets production. Attribute analysis is based on Go/No-go length check for plate heat exchanger gaskets; continuous analysis was prepared in extrusion area, where blanks thickness has to be control to avoid an excessive material usage and potential molding problems in the next process step [5].

13.6 MSA – ATTRIBUTE DATA

The main steps (fig. 13.1) for this analysis ware [1, 4, 5]:

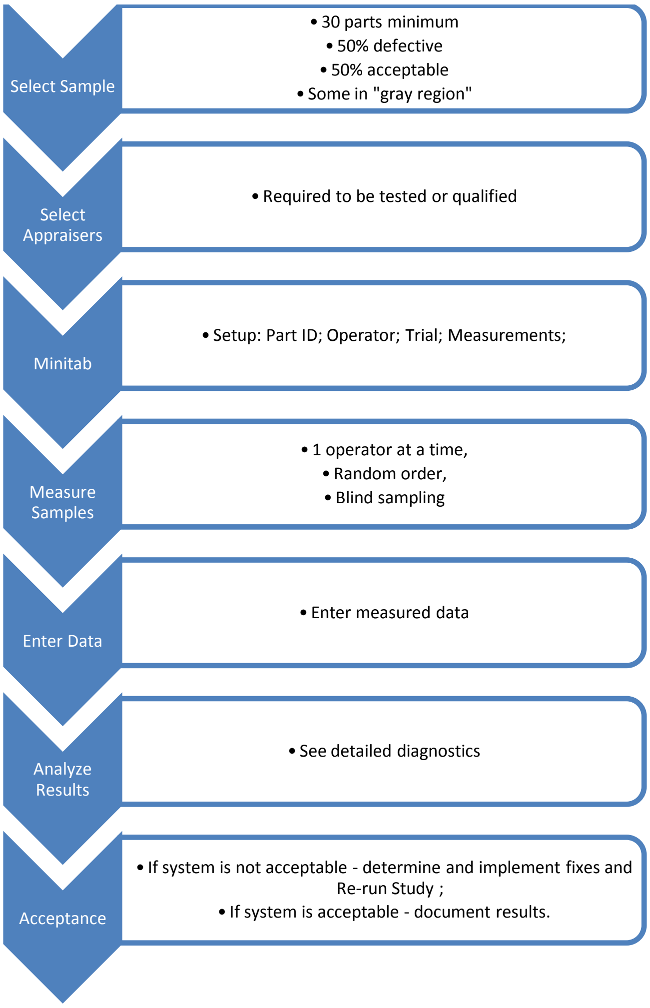

Fig. 13.1 Roadmap to Attribute Assessment Analysis

Source: TSS Black Belt training materials

- Sample selection – 30 pcs minimum; 50% good; 50% bad – some of them can be in "gray region" – difficult to assess whether they are OK or NOK.
- Appraisers selection – required to be tested or qualified,
- Preparation for measurements – parts have to be marked – it is not visible for appraisal,
- Measurements – 1 operator at a time; first measurement from sample number 1 up to 30, second measurement in random order – sampling is blind for appraisers;
- Analysis;
- Assessing that measurement system is acceptable or not; if not we have to determine and implement fixes and re-run the study. If yes we can document data and plan the next control.

In order to perform measurement system analysis for attribute data, we have to chose in "Stat" menu: "Attribute Agreement Analysis" (fig. 13.2),

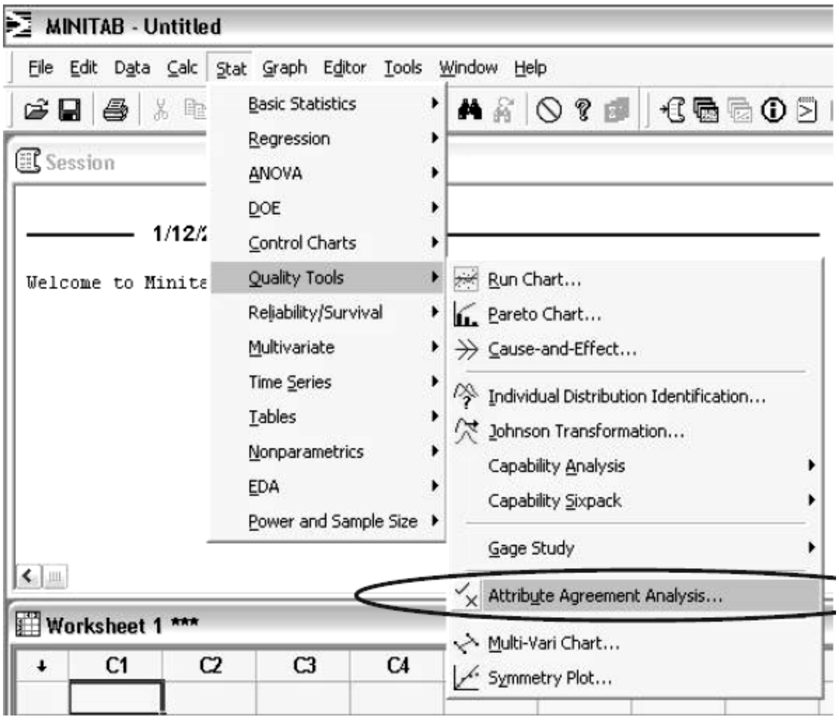

Fig. 13.2 Attribute Assessment Analysis path in Minitab menu

Source: Minitab print screen

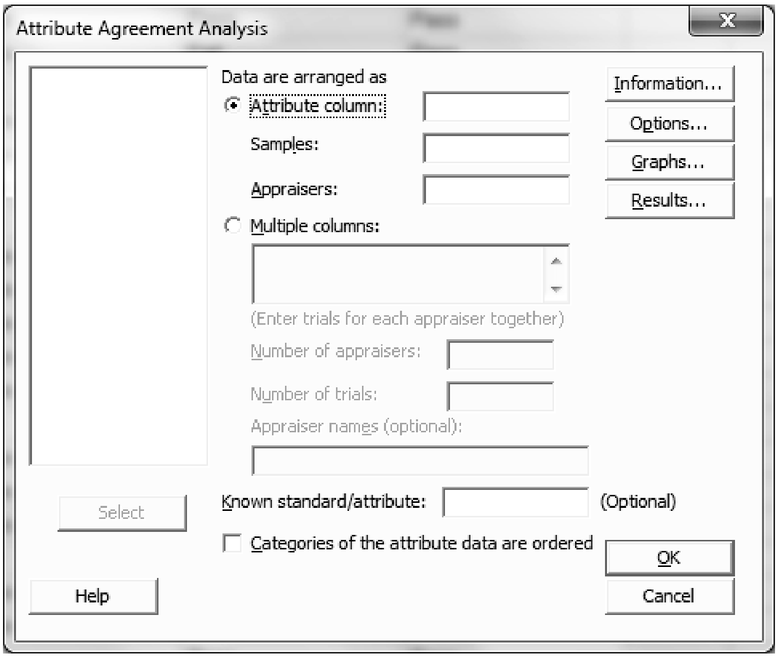

Fig. 13.3 Attribute Assessment Analysis session window

Source: Minitab print screen

In attribute agreement window we have two options for data which are stack and unstuck (fig. 13.3). For stack type of data, we have to use: Attribute column; Samples and Appraisers cells. For unstuck data we have to use Multiple columns; Number of appraisers and Number of trials cells. As an option we can add appraisers names and known standard.

As a result we will receive graph (fig. 13.4) and session window with data analysis.

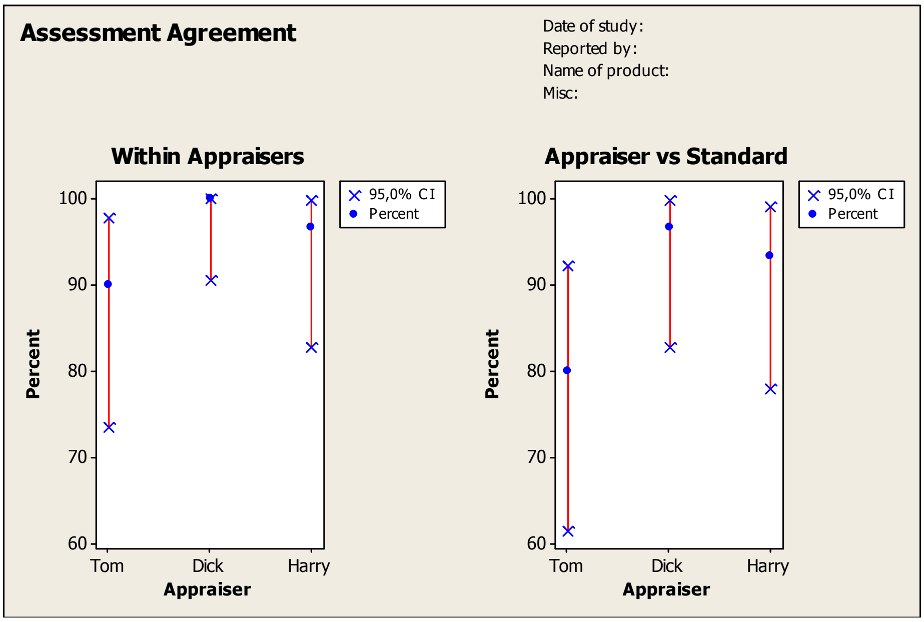

Fig. 13.4 Attribute Assessment Agreement

Source: Minitab print screen

13.6.1 Graphical analysis

"Within Appraisers" – Repeatability: Appraiser's ability to agree with himself; data show that operator Tom has the biggest problem to agree with himself.

"Appraiser vs. Standard" – Appraiser's ability to agree with himself and the standard, data show that Tom and Harry have problems to agree with standard.

13.6.2 Data analysis

Within Appraisers

Assessment agreement within appraisers show, how Appraiser agrees with him/herself across trials.

Appraiser	# Inspected	# Matched	Percent	95 % CI
Tom	30	27	90,00	(73,47; 97,89)
Dick	30	30	100,00	(90,50; 100,00)
Harry	30	29	96,67	(82,78; 99,92)

Kappa statistics - measure the level of agreement among multiple appraisers when evaluating the same samples.

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
Tom	Accept	0,86560	0,105409	8,21185	0,0000
	Reject	0,86560	0,105409	8,21185	0,0000
Dick	Accept	1,00000	0,105409	9,48683	0,0000
	Reject	1,00000	0,105409	9,48683	0,0000
Harry	Accept	0,95151	0,105409	9,02680	0,0000
	Reject	0,95151	0,105409	9,02680	0,0000

Each Appraiser vs Standard

Assessment agreement for each appraisers vs. standard, show how Appraiser's agrees with the known standard. Dick agreed with known standard 29 times out of 30.

Appraiser	# Inspected	# Matched	Percent	95 % CI
Tom	30	24	80,00	(61,43; 92,29)

```
Dick                 30         29    96,67  (82,78; 99,92)
Harry                30         28    93,33  (77,93; 99,18)
```

Assessment Disagreement
Reject / Accept: Assessments across trials = Reject / standard = Accept.
Accept / Reject: Assessments across trials = Accept / standard = Reject.
Mixed: Assessments across trials are not identical.

Appraiser	# Reject / Accept	Percent	# Accept / Reject	Percent	# Mixed	Percent
Tom	3	14,29	0	0,00	3	10,00
Dick	1	4,76	0	0,00	0	0,00
Harry	1	4,76	0	0,00	1	3,33

Kappa statistics - measure the level of agreement among multiple appraisers when evaluating the same samples and considering acceptance and rejection.

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
Tom	Accept	0,669289	0,105409	6,34943	0,0000
	Reject	0,669289	0,105409	6,34943	0,0000
Dick	Accept	0,922978	0,105409	8,75614	0,0000
	Reject	0,922978	0,105409	8,75614	0,0000
Harry	Accept	0,874326	0,105409	8,29459	0,0000
	Reject	0,874326	0,105409	8,29459	0,0000

Between Appraisers

Assessment agreement between appraisers show, how Appraiser agrees with him/herself across trials. Data below show 83,33% of agreement, which means that is probably adequate.

# Inspected	# Matched	Percent	95 % CI
30	25	**83,33**	(65,28; 94,36)

Kappa statistics - measure the level of agreement among multiple appraisers when evaluating the same samples and considering acceptance and rejection.

Response	Kappa	SE Kappa	Z	P(vs > 0)
Accept	0,854805	0,0304290	28,0918	0,0000
Reject	0,854805	0,0304290	28,0918	0,0000

All Appraisers vs Standard

Assessment agreement for each appraisers vs. standard, show how all Appraiser's agrees with the known standard. Data below show 80%, which means that it is border values, but system is probably adequate.

# Inspected	# Matched	Percent	95 % CI
30	24	**80,00**	(61,43; 92,29)

Matched: All appraisers' assessments agree with the known standard.

Kappa statistics - measure the level of agreement among multiple appraisers when evaluating the same samples and considering acceptance and rejection. Data below show level 0,82 for both acceptance and rejection, which means that based on acceptance criteria that system is probably adequate.

Response	Kappa	SE Kappa	Z	P(vs > 0)
Accept	**0,822198**	0,0608581	13,5101	0,0000
Reject	**0,822198**	0,0608581	13,5101	0,0000

13.7 MSA – CONTINOUS DATA

Below is presented MSA from extrusion line, which prepare rubber blanks for compression molding production. It was part of the black belt project, so there are two steps, which shows measurement process before and after improvements [1, 2, 3, 4, 5].

Discrepancies in measurement system can be indication for the project in itself, and we cannot to ignore it, because further analysis very often is built on our measurements. Before we start analysis, it is required wider understanding of repeatability and reproducibility for measurement system.

Repeatability – variation that occurs when repeated measurements are made of the same item under absolutely identical conditions:

Same:

- Gauge,
- Operator,
- Set-up,
- Units,
- Environmental conditions.

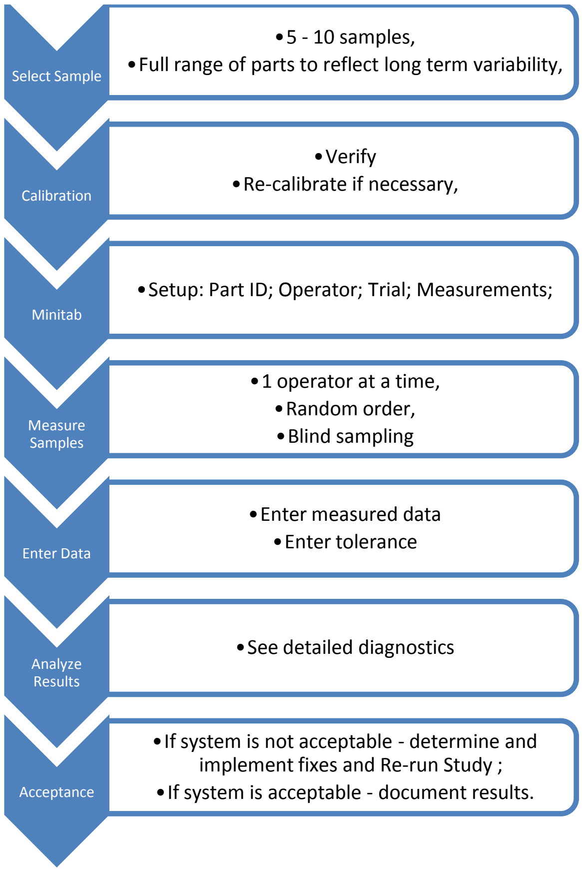

Fig. 13.5 Roadmap to Gage R&R Study

Source: TSS Black Belt training materials

Reproducibility – variation that results when different conditions are used to make the measurements.

Different:

- Operators,
- Set-ups,
- Test units,

- Environmental conditions,
- Locations,
- Companies.

First analysis of measurement system, shown bigger problem with reproducibility. After small adjustments – training for extruder operator and when measurement equipment has been changed/upgraded – we can observe positive results in all measurements.

In order to perform measurement system analysis for continuous data (fig. 13.5), we have to chose in "Stat" menu: "Quality Tools\Gage Study\Gage R&R Study (Crossed)" (fig. 13.6). For not destructive test we have to use Gage R&R Study (Crossed); for destructive test we have to use Gage R&R Study (Nested).

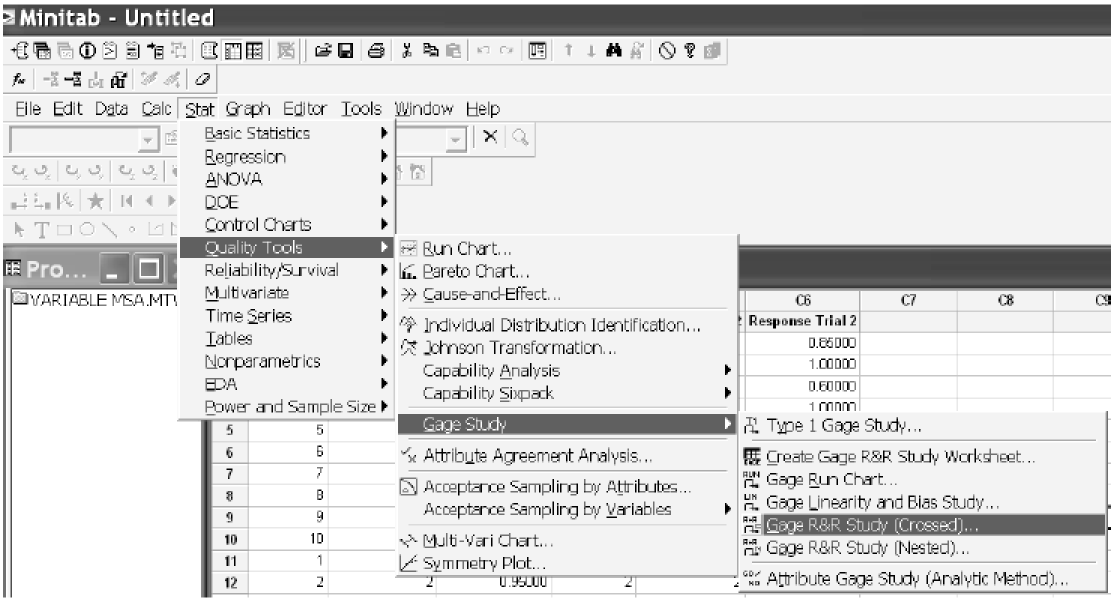

Fig. 13.6 Roadmap to Gage R&R Study

Source: Minitab print screen

In Crossed – Gage R&R Study window we have two options for data analysis: Anova and Xbar (fig. 13.7). For purpose of this analysis we choose Anova one.

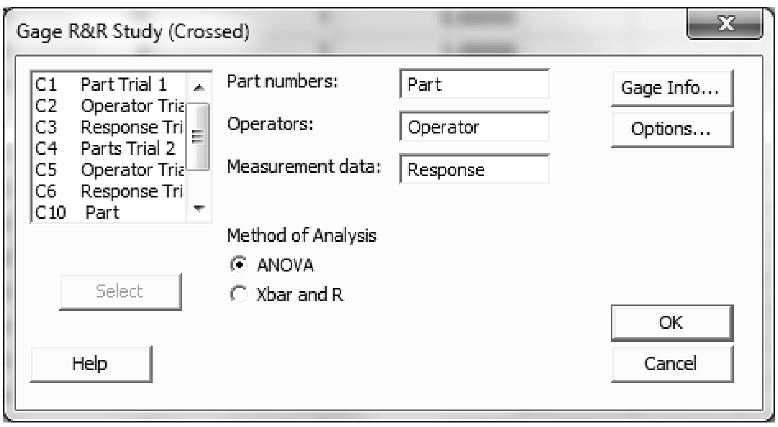

Fig. 13.7 Gage R&R Study session window

Source: Minitab print screen

After clicking an option (fig. 13.8) we can choose study variation level (number of standard deviation), specification limits, and historical standard deviation. In most cases we will Check the “Do not display percent study variation” unless analysis specifically required such option. Percent study variation’ is similar to ‘Percent contribution’ but is less statistically sound & adds little to the study.

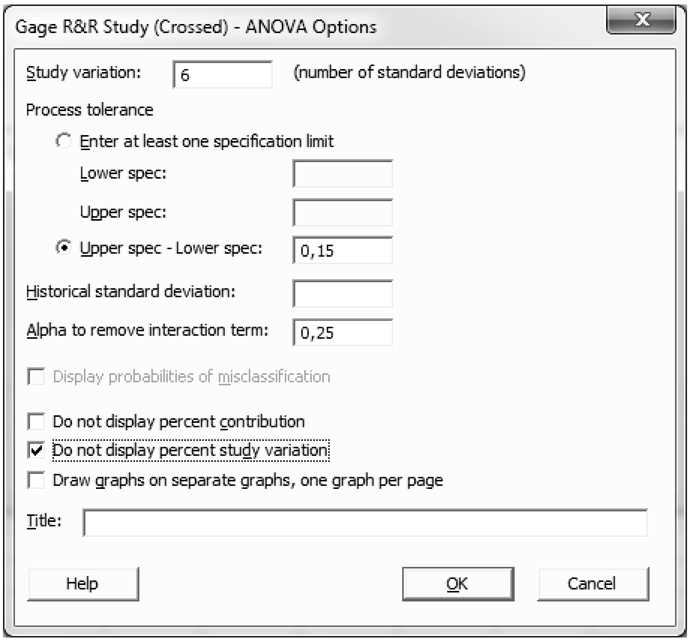

Fig. 13.8 Options in Gage R&R Study session window

Source: Minitab print screen

As a result we will receive graphical (fig. 13.9) and session window with data analysis.

Measurement system before improvements

13.7.1 Graphical analysis:

Going down from the left top diagram

1. Components of variation – show two or three different components of variation:
   - % of Contribution – Measurement System Variation (R&R) as a percentage of Total Observed Process Variation – in this case variation come not only from the part, but also from measurement process,
   - % of Study Variation (total variation),
   - % of Tolerance – measurement error as a percent of tolerance, includes both repeatability and reproducibility,
2. R chart by operator – Difference between 1st and 2nd measurement for each Operator – Exposes gauge repeatability & resolution issues – In Control Required. Each point is the range of the measurements for a part. In this study, 4.2% of the points are above the upper control limit, indicating parts were measured inconsistently. In such case, we have to try to understand why the measurements are inconsistent and determine whether there were any data entry errors.

3. Xbar chart by operator – Average Measurement for each part – Exposes discrimination issues – Out of Control Required. The control limits are based on Repeatability. Ideally, the variation from repeated measurements is much less than the variation between parts. Guidelines suggest that approximately 50% or more should fall outside the limits. – In this study, 66.7% are outside,
4. Dot plot of all Measurements (Diameter) by part – all results for each part in order, to see if particular part ware difficult to measure – in this case parts 4, 6, 7 and 8 have very variable results
5. Dot plot of all Measurements (Diameter) by operator – chart helps to show reproducibility by showing all the results by appraiser. In this study, one operator measures parts consistently higher or lower than other operators, which might be worth investigating,
6. Interaction plot (Operator * Part interaction) – results for each part in order, but splitted by appraiser – Operator 1 in many cases, measured differently in comparison to the rest of operators.

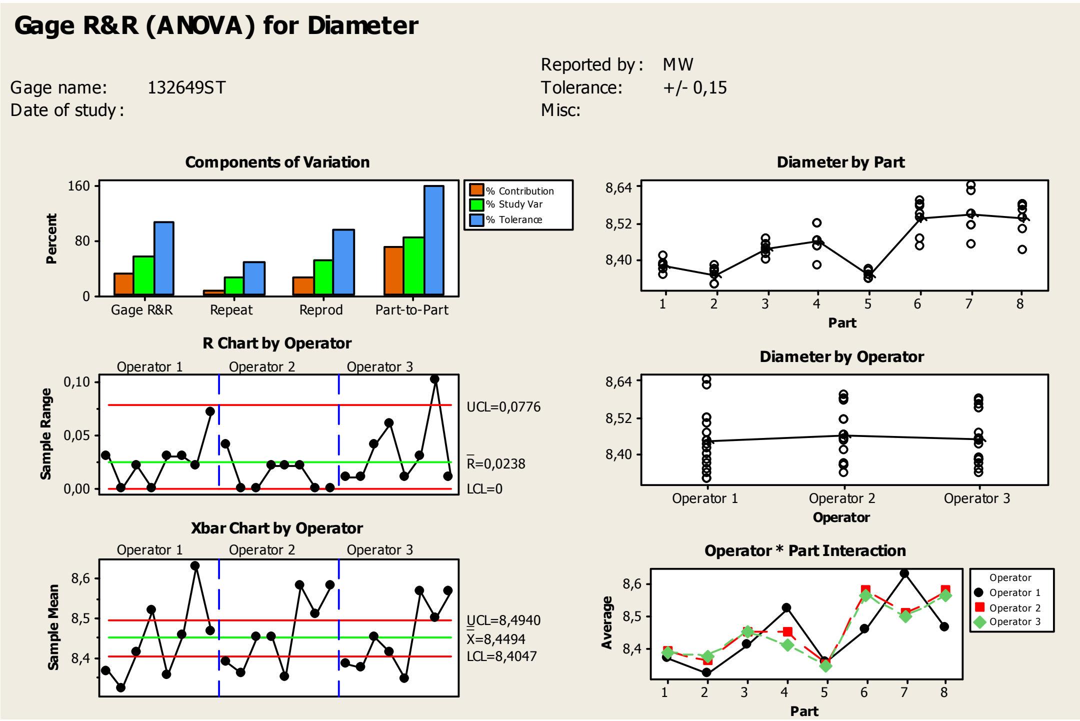

Fig. 13.9 Graphical analysis – Gauge R&R before improvements

Source: Minitab print screen

13.7.2 Data analysis

Minitab uses the analysis of variance (ANOVA) procedure to calculate variance components, and then uses those components to estimate the percent variation due to the measuring system. The percent variation appears in the gage R&R table. The two-way ANOVA table includes terms for the part, operator, and operator-by-part interaction. If the p-value for the operator-by-part interaction is ≥ 0.25, Minitab generates a second ANOVA table that omits the interaction term from the model.

Gage R&R Study – ANOVA Method

```
Gage R&R for Diameter
Gage name:        132649ST
Date of study:
Reported by:      MW
Tolerance:        +/- 0,15
Misc:
```

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part	7	0,291865	0,0416949	8,22685	0,000
Operator	2	0,002813	0,0014063	0,27747	0,762
Part * Operator	14	0,070954	0,0050682	8,78236	0,000
Repeatability	24	0,013850	0,0005771		
Total	47	0,379481			

The ANOVA table show that P value for part is 0.000, indicating that there is a difference between parts. P value for operator is 0.762, indicating that operators haven't significant difference in their mean measurements of the same part.

Minitab calculates a column of variance components (VarComp) and uses the values to calculate % Gage R&R with the ANOVA method. The gage R&R table breaks down the sources of total variability:

- Total Gage R&R consists of:
  - Repeatability – the variability from repeated measurements by the same operator,
  - Reproducibility – the variability when the same part is measured by different operators. (This can be further divided into operator and operator-by-part components.).
- Part-to-Part-the variability in measurements across different parts.

Variance components are used to assess the amount of variation that each source of measurement error and the part-to-part differences contribute to the total variation. Ideally, differences between parts should account for most of the variability; variability from repeatability and reproducibility should be very small.

Percent of contribution is based on the estimates of the variance components. Each value in VarComp is divided by the Total Variation, and then multiplied by 100. Therefore, 68.38% of the total variation in the measurements is due to the differences between parts. This rather low % Contribution is considered bad. When % Contribution for Part-to-Part is high, the system can distinguish between parts.

Because % Contribution is based on the total variance, the column of values adds up to 100%. Minitab also displays columns with percentages based on the standard deviation (or square root of variance) of each term. These columns, labeled %StudyVar and %Tolerance, typically do not add up to 100%. Because the standard deviation uses the same units as the part measurements and the tolerance, it allows for meaningful comparisons.

Contribution indicate 6.46% for repeatability which is marginal value, 25.15% for reproducibility which is bigger than 9% and is not acceptable.

Gage R&R

```
                                  %Contribution
Source                VarComp     (of VarComp)
Total Gage R&R       0,0028226           31,62
  Repeatability      0,0005771            6,46
  Reproducibility    0,0022455           25,15
    Operator         0,0000000            0,00
    Operator*Part    0,0022455           25,15
Part-To-Part         0,0061045           68,38
Total Variation      0,0089271          100,00

Process tolerance = 0.3
```

We can also use percent of study variation % StudyVar to compare the measurement system variation to the total variation. Minitab calculates % StudyVar by dividing each value in StudyVar by Total Variation and then multiplying by 100. % StudyVar for gage R&R is (0.318770/0.566899) 100 ≈ 56.23% – we can't adequately assess process performance because it is more than 30% we can clearly state that system is unacceptable. Minitab calculates StudyVar as 6 times the standard deviation for each source. 6s process variation Typically, process variation is defined as 6s, where s is the standard deviation, as an estimate of σ. When data are normally distributed, approximately 99.73% of the data fall within 6 standard deviations (± 3 standard deviations from the mean), and approximately 99% of the data fall within 5.15 standard deviations (± 2.575 standard deviations from the mean).

Comparing the measurement system variation with the tolerance is often informative. If we enter the tolerance, Minitab calculates % Tolerance, which compares measurement system variation to specifications. % Tolerance is the percentage of the tolerance taken up by the measurement system variability. Minitab divides the measurement system variation (6·SD for Total Gage R&R) by the tolerance. Minitab multiplies the resulting proportion by 100 and reports it as % Tolerance. % Tolerance for gage R&R is ≈ 106.26%.

We can use % Tolerance or % StudyVar to evaluate the measuring system, depending on the measuring system:

- If the measurement system is used for process improvement (reducing part-to-part variation), % StudyVar is a better estimate of measurement precision,
- If the measurement system evaluates parts relative to specifications, % Tolerance is a more appropriate metric.

Because measurement system variation equals 106.26% of the tolerance, so also more than 30%, which means that system is not satisfactory for any of application.

As a major point, where we should put more attention is reproducibility – Operator and Operator by Part components: The variation that occurs when different people measure the same item. This equals 89.2% of the measurement variation and is 50.2% of the total variation in the process.

Number of distinct categories value estimates how many separate groups of parts the system can distinguish. Minitab calculates the number of distinct categories that can be reliably observed by:

$$\frac{S_{part}}{S_{measuring_{system}}} \cdot \sqrt{2}$$

Minitab truncates this value to the integer except when the value calculated is less than 1. In that case, Minitab sets the number of distinct categories equal to 1. Here, the number of distinct categories is 2, so it is less than 5 which mean that measurement process cannot detect process output variation, process shifts and improvements.

Gage R&R

```
                              %Contribution
Source               VarComp   (of VarComp)
Total Gage R&R     0,0028226          31,62
  Repeatability    0,0005771           6,46
  Reproducibility  0,0022455          25,15
    Operator       0,0000000           0,00
    Operator*Part  0,0022455          25,15
Part-To-Part       0,0061045          68,38
Total Variation    0,0089271         100,00

Process tolerance = 0,3

                                Study Var  %Study Var  %Tolerance
Source             StdDev (SD)   (6 * SD)       (%SV)  (SV/Toler)
Total Gage R&R       0,0531283   0,318770       56,23      106,26
  Repeatability      0,0240226   0,144135       25,43       48,05
  Reproducibility    0,0473871   0,284323       50,15       94,77
    Operator         0,0000000   0,000000        0,00        0,00
    Operator*Part    0,0473871   0,284323       50,15       94,77
Part-To-Part         0,0781311   0,468786       82,69      156,26
Total Variation      0,0944832   0,566899      100,00      188,97

Number of Distinct Categories = 2
```

Measurement system after improvements

Going down from the left top diagram (fig. 13.10).

13.7.3 Graphical analysis:

1. Components of variation – after system improvements the biggest part of variation come from the measured parts. Total gage R&R variation has been decreased, problem with repeatability and reproducibility significantly reduced.
2. R chart by operator – Each point is the range of the measurements for a part. In this study, 10.0% of the points are above the upper control limit, indicating parts were measured inconsistently. Number of points on the same line can suggest perfect repeatability or poor resolution – in that case good repeatability.
3. Xbar chart by operator – The control limits are based on Repeatability. Ideally, the variation from repeated measurements is much less than the variation between parts. Guidelines suggest that approximately 50% or more should fall outside the limits. In this study, 96.7% are outside.
4. Dot plot of all Measurements (Diameter) by part – all results for each part in order, to see if particular part ware difficult to measure – in this case part 7 have some variability during measurements,
5. Dot plot of all Measurements (Diameter) by operator – after measurement system adjustments it has been observed improvement in measurements,

6. Interaction plot (Operator Part interaction) – results for each part in order, but splitted by appraiser – Operators measure parts on similar level.

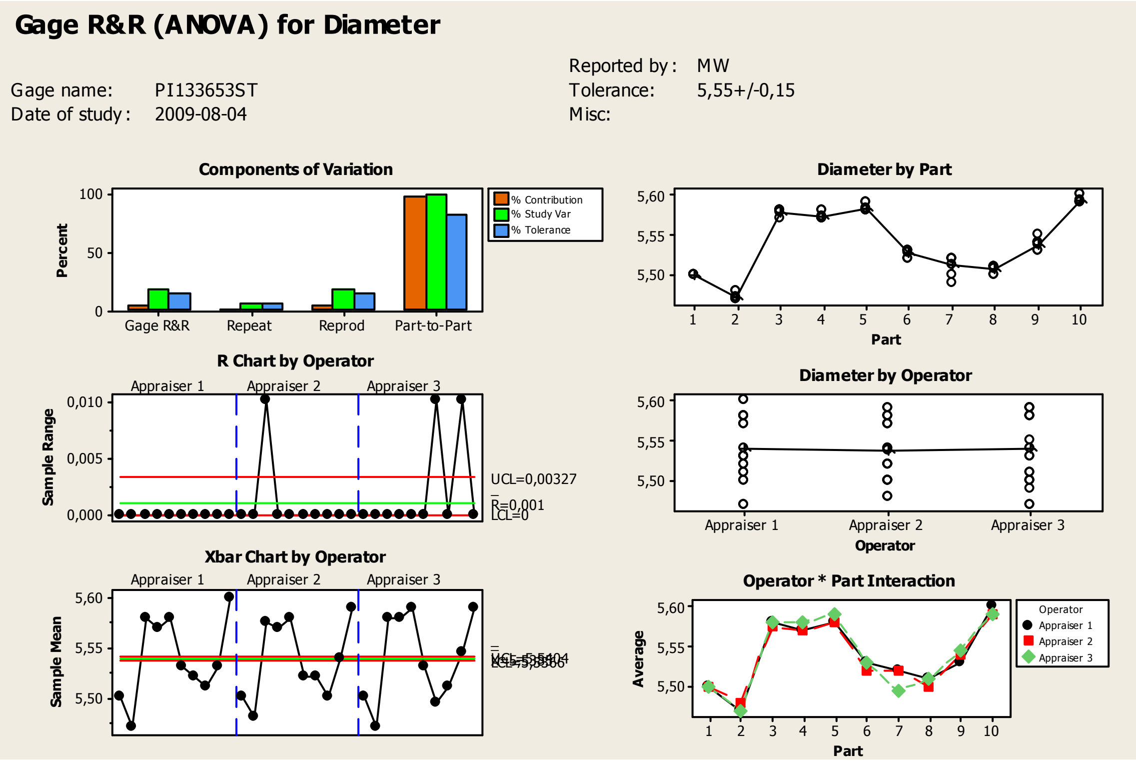

Fig. 13.10 Graphical analysis – Gauge R&R after improvements

Source: Minitab print screen

13.7.4 Data analysis

The ANOVA table show that P value for part is 0.000, indicating that there is a difference between parts. P value for operator is 0.857, indicating that operators haven't significant difference in their mean measurements of the same part.

Gage R&R Study - ANOVA Method

Gage R&R for Diameter

Gage name: PI133653ST
Date of study: 2009-08-04
Reported by: MW
Tolerance: 5,55+/-0,15
Misc:

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part	9	0,092515	0,0102794	98,9465	0,000
Operator	2	0,000030	0,0000150	0,1444	0,867
Part * Operator	18	0,001870	0,0001039	20,7778	0,000
Repeatability	30	0,000150	0,0000050		
Total	59	0,094565			

Alpha to remove interaction term = 0,25

Contribution indicate 0.29% for repeatability which is acceptable value, 2.82% for reproducibility which is also acceptable.

The measurement system variation equals 17.64%, (we can marginally assess process performance) because it is less than 30% we can clearly state that system is marginally acceptable. The measurement system variation equals 14.76% of the tolerance, so also less than 30%, which means that system is marginally satisfactory for application. Reproducibility has been improved, but there is steel room to make an improvements – Operator and Operator by Part components: The variation that occurs when different people measure the same item. This equals 95.3% of the measurement variation and is 16.8% of the total variation in the process.

Distinct categories is 7, so it is marginal and mean that measurement process can detect process output variation, process shifts and improvements.

Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0,0000544	3,11
Repeatability	0,0000050	0,29
Reproducibility	0,0000494	2,82
Operator	0,0000000	0,00
Operator*Part	0,0000494	2,82
Part-To-Part	0,0016959	96,89
Total Variation	0,0017504	100,00

Process tolerance = 0,3

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0,0073786	0,044272	17,64	14,76
Repeatability	0,0022361	0,013416	5,34	4,47
Reproducibility	0,0070317	0,042190	16,81	14,06
Operator	0,0000000	0,000000	0,00	0,00
Operator*Part	0,0070317	0,042190	16,81	14,06
Part-To-Part	0,0411816	0,247090	98,43	82,36
Total Variation	0,0418374	0,251025	100,00	83,67

Number of Distinct Categories = 7

SUMMARY

The measurement system analysis is a very important part of Lean Six Sigma Projects. As an important point of Measure phase, makes it easy to understand the potential problems that may significantly affect all measurements. Measurements process cannot be treated as a baseline without this analysis – because only with "true" data we are able to provide that we fully understand the problem. To carry out the measurement system analysis, we can use simple spreadsheet, but the preparation of the data and calculations are time-consuming. Currently on the market there are available number of computer aided engineering statistical software – the most popular is Minitab. This software, when is used skillfully, provides full range analysis of the measurement system, however, does not in itself change the approach to measurements and standards that have been previously introduced. This is the only tool that will show us how our system is good and where we need to improve, and this is particularly important when there is a fluctuation of employees. In many of Green or Black Belt projects, which has been not completed successfully, we can say that one of the common reasons that, is the lack of a clear understanding of the measurement system analysis and ignore it as a potential source of variation. However at the root cause of these problems is, a way of Lean Six Sigma project management and/or lack of support from top management in the organization. Proper Green or Black Belt training has to be relevant and meaningful to provide knowledge of the methodology, but also a structured project management. To lead projects, top management cannot afford to ignore the facts alleged by the DMAIC methodology, as well as the need to generate time for Green/Black Belts, and the project team. Each Green/Black Belt is a person having a set of tools that properly used, fully ensure that the project/issue is fully resolved. If Green/Black Belt, does not receive this support – a set of these tools becomes completely useless. As a Black Belt, later Master Black Belt responsible of leading the projects, the implementation of Lean Six Sigma ideology in the manufacturing plant, as well as training, I encountered the problem of a proper understanding of the basic tools – MSA Capability, SPC, DOE – therefore developed a training program to ensure that these tools will be expertly and properly used. Starting from the analysis of the measurement system, the training program covers all methods of its implementation, the errors that can occur during the analysis, the problems that result from lack of proper understanding of the problem and from the same analysis as well as a detailed explanation of the use of computer-aided engineering statistical software. All presented examples were part of the Lean Six Sigma projects that have been positively completed and brought to the company's high annual profits – problems has been solved implemented solutions are monitored till now. In all these examples, the analysis revealed a significant measurement system process noise that has been removed, before the next step of the project.

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MEASUREMENT SYSTEM ANALYSIS OF ATTRIBUTE OR CONTINUOUS DATA, AS A ONE OF THE FIRST STEPS IN LEAN SIX SIGMA PROJECTS

Abstract: *Measurement System Analysis is a part of "Measure" phase, which is a structured project management approach. This approach consist of the following steps: Define, Measure, Analyze, Improve, Control – "DMAIC" and is a path to resolve production problems based on Lean Six Sigma methodology. This method has been presented by using of computer aided statistical software – Minitab – which is a most common statistical software, used by Green or Black Belts. As a Master Black Belt I faced to the problem of lack an appropriate explanation of using it by the Belts – which contributed by implementation of a proper training program. Measurement system analysis in this program, is divided by Attribute Agreement Analysis, which is analysis of attribute data, and Gage R&R – analysis for continuous data. Therefore it is very important to understand differences between attribute and continuous date and their main metrics. Understanding data types, allowed to explain components of measurement errors. This base knowledge is a foundation of measurement system analysis and going further – base knowledge of each Green or Black Belt.*

Key words: *Measurement system analysis, Lean Management, Six Sigma, Gage R&R, measurement error*

ANALIZA SYSTEMU POMIAROWEGO DANYCH ATRYBUTOWYCH I CIĄGŁYCH, JAKO JEDEN Z PIERWSZYCH KROKÓW PROJEKTÓW LEAN SIX SIGMA

Streszczenie: *Analiza systemu pomiarowego jest częścią fasy "Pomiar", która jest ustrukturyzowanym podejściem do zarządzania projektami. To podejście składa się z następujących kroków: definiowanie, pomiar, analizowanie, poprawa, kontrola/sterowanie – "DMAIC" i jest drogą do rozwiązania problemów produkcyjnych opartych na metodologii Lean Six Sigma. Metoda ta została przedstawiona za pomocą komputerowego wspomagania statystycznych prac inżynierskich – Minitab – jest najczęściej spotykanym oprogramowanie statystyczne, wykorzystane przez Green lub Black Beltów. Jako Master Black Belt zetknąłem sie z problemem braku odpowiedniego wyjaśnienia/zrozumienia I jego wykorzystania przez Beltów – co przyczyniło by wdrożenia odpowiedniego programu szkoleniowego. Analiza systemu pomiarowego w tym programie, jest podzielona na analizę systemu pomiarowego dla danych atrybutowych, oraz Gage R&R – analiza systemu pomiarowego dla danych ciągłych. W związku z tym bardzo ważne jest, aby zrozumieć różnice pomiędzy danymi atrybutowymi, a ciągłymi oraz ich główne współczynniki/metryki. Zrozumienie typu danych pozwoli na wyjaśnienie składników błędów pomiarowych. Ta podstawowa wiedza jest fundamentem analizy systemu pomiarowego, a idąc dalej – podstawową wiedzą każdego Green lub Black Belta.*

Słowa kluczowe: *Analiza systemu pomiarowego, zarządzanie szczupłe, Six Sigma, pomiar powtarzalności i odtwarzalności, błąd pomiarowy*

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