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ROLE OF GAGE R&R IN ESTIMATION OF PROCESS CAPABILITY

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ABSTRACT
Capable process is a process that is able to produce items within the specification limits. The ability of a process to meet specifications can be expressed by using process capability indices. In order to have an accurate estimation of process capability quality management system is required. Gage repeatability and reproducibility analysis (gage R&R) addresses the issue of measurement system precision. If measurement system is not repeatable or reproducible relatively to the variability between items, then that measurement system is not sufficiently precise to be used in product capability analyses. In the ideal case, all variability's in measurements are results of item variation, and only a negligible proportion of the variability's will be due to gage R&R. In this paper an analysis of the influence of quality measurement system on process capability has been carried out.
Keywords: process capability, process capability indices, gage R&R

1. ESTIMATION OF PROCESS CAPABILITY

Estimation of process capability together with statistical control and design of experiments are statistical methods that have been used for years in an attempt to reduce variability of production process and their final products. Process capability refers to the normal behavior of a process not affected by any significant factors and it is customary expressed as a percentage of process under given tolerances. Fundamental requirement of process capability is $T \geq 6\sigma$. Process is capable if requirement range *T* is greater or equal to process range 6σ. Process range means area within ± 3 standard deviations σ in relation to process mean $\bar{x}$, which represents 99,73% of surface below the normal distribution curve used to approximate the process. Process capability is estimated by calculating, the so called process capability indices. Calculation and proper interpretation of process capability indices is based on following suppositions:

- data distribution can be approximated by the normal distribution
- reliable estimation of process capability can be made only based on process monitoring using appropriate control chart and after bringing the process in the condition of statistical control (status under control).

It makes sense to estimate process capability only when special causes affecting process variations are removed and medium process brought to the environment of target value.

1.1. Process capability indices

By taking into consideration time when process is taking place, in accordance to interpretation of the Ford company, process capability indices may be estimated in a longer time period, as *Preliminary Process Capability* and in a shorter time period as *Short-Term Capability.*

Process capability indices in a longer time period are calculated after process took place over some period of time, during which all possible effects of process variations could appear. The most common indices used are those for calculating potential process capability C_p and demonstrated excellence index C_{PK} . C_p index describes tolerance field range in reference to actual data dispersion, while C_{PK} index defines the process position in reference to requirement limits. Process capability indices are provided in the expressions (1) i (2).

$$C_p = (USL - LSL)/6\sigma = T/6\sigma \tag{1}$$

$$C_{pK} = min((USL - \bar{x})/3\sigma; (\bar{x} - LSL)/3\sigma) \tag{2}$$

where::

USL	-	upper specification limit
LSL	-	lower specification limit
T	-	tolerance area
$\bar{x}$	-	arithmetic mean (central line of the control chart)
6σ	-	observed process range

In the expressions (1) and (2) standard deviation has been estimated on the basis of data from control chart. Various control charts are used for detection of variations in the process and determining amount of process standard deviation.

Preliminary estimation of process capability is conducted in the beginning of process or after short process monitoring. In the name of indices the term performance is used instead of capability. Therefore indices are labeled as P_p i P_{pk}. They are calculated in the same manner as C_p i C_{pk}, with the exception that standard deviation, the so called overall standard deviation, is estimated from all data based on expression 3.

$$\sigma = s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \tag{3}$$

2. ANALYSIS OF MEASUREMENT SYSTEM IN PRODUCTION ENVIRONMENT

In order to estimate quality of the measurement system it is necessary to identify and quantify sources of variability, define stability and determine measurement system capability. Measurement system needs to be analyzed upon receiving new measuring equipment, when comparing measuring characteristics of various measuring equipment, when establishing system errors, when comparing measurement characteristics before and after repair of measuring equipment, and in identifying components for calculating measurement process variations and estimating acceptability for production process control. In the event that measurement system variation is significant in comparison to established variation of the item that is measured in a production process, system may not provide valid information on process control. For this reason, prior to establishing process stability and capability, it is necessary to analyze measuring system and determine whether measuring system will be able to consistently, accurately, and precisely differentiate between parts of the process.

2.1. Estimation of measurement system capability

Requirement for estimating quality of measurement systems stems from a very simple fact that measurements are in no way perfect. Variations in the measurement system result from random and systematic effects. Main sources of measurement system variability are the item that is measured, equipment, operator and environment. Significance of elements in the measurement system is expressed by the amount of dispersion of measuring results obtained in defined measurement conditions. Impacts of individual elements of measurement system can be classified in three main categories:

- Repeatability – *EV*

Repeatability is defined as the impact of measuring equipment in the measurement system variation. Repeatability represents dispersion of measurement results obtained by one operator during multiple measurements of identical characteristics on the same parts (samples), while using the same instrument.

- Reproducibility - *AV*

Reproducibility is defined as the impact of operators conducting in the measurement system variation. Reproducibility represents dispersion of measurement results obtained by several operators during multiple measurements of identical characteristics on the same parts (samples), while using the same or different instrument.

- Part variation – *PV*

Part variation is defined as the impact of parts (items) in the total variation of measurement system *TV*.

- Measurement system variation *R&R*

Measurement system variation depends on the total dispersion of measurement results due to mutual effect of repeatability and reproducibility *R&R*. Calculation of the measurement system variation *R&R* is provided in the expression 4.

$$R\,\&\,R = \sqrt{EV^2 + AV^2} \tag{4}$$

- Total variation *TV*

Total variability *TV* (expression 5) depends on the variation of measurement system *R&R* and parts variation *PV*.

$$TV = \sqrt{(R\,\&\,R)^2 + PV^2} \tag{5}$$

- Measurement system capability

Measurement system capability represents share of measurement system variability *R&R* expressed as percentage of total variation *TV* or tolerance field *T*, i.e. share of measurement system variance in the total variance. Expressions for calculating measurement system capability are as follows:

$$Measurement\ system\ capability = R\,\&\,R / TV \cdot 100\% \tag{6}$$

$$Measurement\ system\ capability = R\,\&\,R / T \cdot 100\% \tag{7}$$

$$Contribution = \sigma^2_{R\&R} / \sigma^2_{TV} \cdot 100\% \tag{8}$$

Criteria for assessing quality of measurement system *R&R* in the tolerance field *T* or total variation *TV* are provided in table 1, and criteria for assessing quality of measurement system *R&R* for contribution percentage are provided in the table 2.

Table 1. Criteria for assessing quality of gage R&R in the tolerance field T or total variation TV.

% *T*, %*TV*	Gage *R&R* is
< 10	Acceptable
10 – 30	Borderline
> 30	Unacceptable

Table 2. Criteria for assessing quality of gage R&R for contribution percentage.

Contribution %	*Gage R&R is*
< 1	*Acceptable*
1 – 9	*Borderline*
> 9	*Unacceptable*

3. EFFECT OF GAGE R&R VARIATION ON PROCESS CAPABILITY INDEX C_p

When analyzing process capability the most significant is C_p index based on process dispersion. In order to be able to provide notion on actual process capability, gage R&R must be able to detect any deviation in monitored process or product. Further analysis shows the relationship of the observed process capability index C_{pTV} that results from total variability *TV* and actual index C_p, based on variation of parts in *PV* process.

$$C_{pTV} = C_p \times \sqrt{1 - (R\,\&\,R)^2} \tag{9}$$

Relationship between process capability indices C_{pTV} i C_p that depends on quality of gage *R&R* are illustrated on Figure 1, and in Table 3.

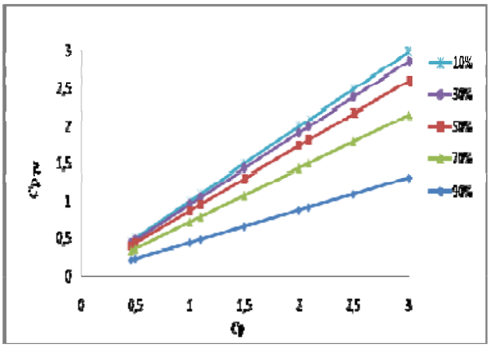

Figure 1. Relationship between process capability indices C_{pTV} and C_p

Table 3. Relationship between process capability indices C_{pTV} and C_p

C_p	Gage *R&R*, %				
	90%	70%	50%	30%	10%
	C_{pTV}				
0,5	0,22	0,36	0,43	0,48	0,50
1	0,44	0,71	0,87	0,95	0,99
1,5	0,65	1,07	1,30	1,43	1,49
2	0,87	1,43	1,73	1,91	1,99
2,5	1,09	1,79	2,17	2,38	2,49
3	1,31	2,14	2,60	2,86	2,98

From the presented results it may be concluded that quality of measurement system significantly affects process capability index C_p. If the observed process capability index $C_{pTV} = 1{,}73$, and gage *R&R* spends 50 % of total variation or tolerance field, actual process capability index will be as follows: $C_p = 2{,}0$. However, if gage *R&R* spends 10 % of total variation or tolerance field, the observed process capability index will be $C_{pTV} = 1{,}99$, meaning that process capability estimation is significantly better. Also, it needs to be emphasized that in case that gage *R&R* variation is significant in comparison to the established variation of the parts *PV*, measurement system will not be able to give an accurate estimate of process capability.

4. CONCLUSION

Based on conducted analysis it may be concluded that high quality measurement system is essential for detection and monitoring of process variations. Greater % *R&R* means greater error in estimating process capability index C_p. Error in estimation increases as the index C_p increases. Only high quality measurement system will be able to provide accurate and precise estimation of process capability.

5. REFERENCES

[1] Forrest W. Breyfolge III: Implementing Six Sigma, Awiley-Interscience Publication, 1999.
[2] Mudronja V., Lectures in Quality Management, FSB, 2008.
[3] Bass I., Lawton B., Lean Six Sigma, eBook, 2009.