METHODICAL APPROACHES TO PROCESS CAPABILITY ANALYSIS IN THE CASES OF NON-NORMAL DISTRIBUTIONS OF MONITORED QUALITY CHARACTERISTIC

NEPRAŠ Karel, PLURA Jiří

VSB - Technical University of Ostrava, Faculty of Metallurgy and Materials Engineering, Ostrava, Czech Republic, EU

Abstract

Evidence of production process capability is one of the basic requirements for automotive industry suppliers including metallurgical companies. From this reason these suppliers must perform process capability analysis. While in the cases of normal distribution of monitored quality characteristic the methodology of process capability analysis is practically uniform, in the cases, when data are not normally distributed, individual producers use different approaches. This fact may cause different results of process capability analysis. This paper deals with analysis of methodical approaches used by selected automotive producers for process capability analysis in the cases of non-normal distributions of monitored quality characteristic. Process capability analysis is performed using selected strategies for data with different skewness. Analysis of different process capability indices is done and achieved results are compared with other possibilities of process capability analysis in the cases of data non-normality.

Keywords: Process capability, methodology, non-normality

1. INTRODUCTION

Process capability analysis is one of the important parts of quality planning, quality assurance and quality improvement. Process capability is defined as process ability to produce products meeting required quality criteria. Evidence about capability of production processes is strictly required in the branch of automotive suppliers, which include most metallurgical companies. In the cases that given production process is not capable, a hundred percent inspection of products is required. It can mean considerable increasing of production costs and loss of competitiveness.

Process capability analysis is based on the theory of probability and mathematical statistics. For its processing they are supposed assumptions like statistical stability of the process, data normality and data independence. If all assumptions are met then capability indices are calculated classically. This way is the best but not often in real practice. Assumptions are not kept and non-standard situations must be solved. Several ways for capability indices calculation in non-standard situations are known, but there is no uniform and complex procedure which exactly specifies what to do in cases of data non-normality, non-stability or data dependence. Then achieved capability indices results can be different [1, 2]. Correct and both parties accepted capability results can be obtained only in case of following correct assessment methodology.

Especially in real practice of metallurgical or machinery companies there are many quality characteristics, whose natural distribution is not normal. They include taper ration, flatness, roughness, concentricity, eccentricity, perpendicularity, roundness, angularity, weld strength, tensile strength, hardness of castings, hole location or parallelism. Data non-normality was also solved in process capability studies in case of wire diameter in wire drawing process or in case of rod diameter in rod peeling process [3].

In metallurgy brand they are often used only simple and classical approaches for process capability analysis but quality characteristics character (normality is not often achieved) needs special approaches. This paper introduces and compares possibilities of capability assessment which are in accordance with customer evaluation methodologies.

2. PROCESS CAPABILITY ANALYSIS BY METHODOLOGIES OF SELECTED CUSTOMERS

General methodology for process capability analysis does not provide uniform procedure for non-standard situation solving. Standards in automotive industry (e.g. QS 9000 or VDA) deals with process capability assessment but situations when assumptions are not met are described insufficiently.

A specific customer requirement for process capability assessment comes from superior standards used in automotive industry which usually provides basic information. For example VDA 4 in chapter "Process capability investigation" provides main principle which tries to find adequate time model of process behaviour. This standard prescribes eight process time models [4]. Originally American standard QS 9000: "Statistical process control" describes in chapter concerning on clarification of terms of process capability and process performance for measurable quality characteristic recommended procedure. This procedure is similar like general methodology for process capability assessment [5].

From standards which are used in automotive industry individual customers methodologies were specified. These methodologies are usually more detailed. Suppliers in automotive industry must follow methodology accepted by concrete customer for process capability assessment. Very sophisticated option of selected methodologies for process capability assessment is offered in statistical software QS-STAT.

Methodologies for process capability assessment based on requirements of selected customers will be presented in next sections. Methodical approaches were formed especially due to insufficient information mentioned in automotive standards (like VDA or QS 9000). Customers established own methodologies which provides better guideline for process capability assessment.

3. CASE STUDY

Case study is focused on normality testing used in selected methodologies and approaches for process capability analysis in the case of data non-normality. As first, normality tests used by selected methodologies are confronted. Then achieved results of normality testing for data sets with different skewness are compared. Each steps of selected methodologies applied on data with different skewness and achieved results of capability indices C_p a C_{pk} are discussed.

Approaches of different methodologies are compared on simulated data sets with various skewness. In total, 11 data sets with 100 values each were prepared with different skewness in range from 0.19 to 0.86. Data sets had same mean and standard deviation and were considered as data of monitored quality characteristic (25 subgroups, subgroup size 4) collected for process capability analysis. Tolerance limits were prescribed as: LSL=3 and USL=23.

3.1. Data normality testing

One of the most important step of process capability analysis is data normality testing. Standard calculation for process capability indices can be used in the cases of data normality. When data do not meet normality then other way of calculation must be found. Different normality tests can be used for normality testing, so different results can be expected. Normality testing is very important part of process capability analysis.

Statistical software QS-Stat provides seven possible tests for data normality verification: Symmetry test, Kurtosis test, D´Agostino test, Shapiro-Wilk test, Epps-Pulley test, Chi-square test and Anderson-Darling test. Each evaluation strategy has predefined preferred normality tests in advance. **Table 1** summarizes available normality tests predefined for seven evaluation strategies used by selected customers. **Table 1** shows that evaluation strategies use different normality tests. Some strategies use only one normality test while other ones apply several tests. If more normality tests are used then at least one test must be successful for normality confirmation.

Applied tests mentioned in **Table 1** are selected in dependence of number of values, but defined range of values for each test is not uniform in various methodologies. Underlined tests in **Table 1** were applied in situation when data set have 100 values of monitored quality characteristic. These tests were used in this case study.

Table 1 Normality tests used by selected evaluation strategies. Source: own.

		Used normality tests
Selected evaluation strategy	Audi AG	Epps-Pulley
	BMW Cp	Symmetry test, Kurtosis test
	Bosch 2012	Symmetry test, Kurtosis test, Shapiro-Wilk test
	Q-Das	Symmetry test, Kurtosis test, Shapiro-Wilk, Epps-Pulley, Anderson-Darling
	Ford short term	Symmetry test, Kurtosis test
	Ford on going	Symmetry test, Kurtosis test
	VW 101 31	Epps-Pulley, Chi-square

The results of normality testing for eleven data sets with various skewness are given in **Table 2**. It can be seen that some tests indicate non-normality already at low skewness and other ones indicate non-normality until at higher skewness. This fact has the greatest impact on the next step which is process capability assessment.

Table 2 Used evaluation strategies for capability indices calculation. Source: own.

		Data set (skewness)										
		D1 (0.19)	D2 (0.25)	D3 (0.31)	D4 (0.38)	D5 (0.44)	D6 (0.51)	D7 (0.57)	D8 (0.64)	D9 (0.71)	D10 (0.79)	D11 (0.86)
Used distribution model for capability assessment	Audi AG	N	N	N	N	N	N	No dist.	No dist.	No dist.	No dist.	No dist.
	BMW Cp	N	N	N	N	Rayleigh	Rayleigh	N	N	N	N	Mixed
	Bosch 2012	N	N	N	N	JT	JT	JT	JT	JT	JT	JT
	Q-Das	N	N	N	N	N	N	Log-N	Log-N	Log-N	Log-N	Mixed
	Ford short term	N	N	N	N	Log-N	Log-N	Log-N	Log-N	Log-N	Log-N	Log-N
	Ford on going	N	N	N	N	Log-N	Log-N	Log-N	Log-N	Log-N	Log-N	Mixed
	VW 101 31	N	N	N	N	N	N	No dist.	No dist.	No dist.	No dist.	No dist.

Legend: N (normal distribution). Log-N (Lognormal distribution). Rayleigh (Rayleigh distribution (folded <>0)). No dist (No dsitribution, QS-Stat do not found any distribution based on selected evaluation strategy). Mixed (Mixed distribution). JT (Johnson transformation)

Process models (distribution models) used by software QS-Stat are in detail described in standard ISO 21747, standard VW 10131 or software QS-Stat help [6, 7, 8]. From **Table 2** it is visible conformity in distribution model for data sets till skewness 0.38. All evaluation strategies indicated normal distribution and process capability indices were calculated by classical equations based on normality assumption of monitored quality characteristic.

In the cases of higher skewnesses than 0.44 each evaluation strategies used different process models. For example for data set D5 (skewness 0.44) evaluation strategies Audi AG, Q-DAS a VW101 31 applied approach valid for normal distribution of monitored quality characteristic. Other evaluation strategies applied approaches for non-normal distribution of data. The reason is that applied normality tests already indicated non-normal data distribution.

Specific behavior was found in strategy BMW C_p, where first four data sets were indicated as normal distribution, next two data sets were indicated as Rayleigh distribution (folded <>0) and then next four data sets with higher skewnesses were again indicated as normal distribution. The last one data set D11 with a maximum skewness was indicated as mixed distribution. Only evaluation strategy according to Bosch 2012 used data transformation (concretely Johnson transformation) which was applied from 5th data set. Other ones prefer finding the best distribution model (quantile method).

3.2. Process capability analysis

After verifying data normality and evaluation of statistical stability process capability assessment based on selected evaluation strategy was the next step. In this case study all 11 data sets were corresponding to statistically stable process and then process capability indices C_p and C_{pk} could be calculated. **Table 3** summarizes calculated values of process capability indices using selected evaluation strategies. Dependences of calculated capability indices on skewness of individual data sets are shown in **Figure 1** and **Figure 2**.

Table 3 Values of capability indices C_p and C_{pk} based on selected evaluation strategy. Source: own.

		Capability index	Data set (skewness)										
			D1 (0.19)	D2 (0.25)	D3 (0.31)	D4 (0.38)	D5 (0.44)	D6 (0.51)	D7 (0.57)	D8 (0.64)	D9 (0.71)	D10 (0.79)	D11 (0.86)
Values of capability index	Audi AG	C_p	1.11	1.11	1.11	1.11	1.11	1.11	1.15	1.14	1.14	1.13	1.13
		C_{pk}	0.78	0.78	0.78	0.78	0.78	0.78	0.94	0.94	0.95	0.95	0.95
	BMW Cp	C_p	1.11	1.11	1.11	1.11	1.14	1.14	1.11	1.11	1.11	1.11	1.18
		C_{pk}	0.78	0.78	0.78	0.78	0.82	0.82	0.78	0.78	0.78	0.78	1.05
	Bosch 2012	C_p	1.11	1.11	1.11	1.11	1.21	1.20	1.19	1.18	1.18	1.18	1.17
		C_{pk}	0.78	0.78	0.78	0.78	1.06	1.09	1.13	1.17	1.16	1.14	1.11
	Q-Das	C_p	1.11	1.11	1.11	1.11	1.11	1.11	1.08	1.07	1.07	1.06	1.18
		C_{pk}	0.78	0.78	0.78	0.78	0.78	0.78	1.03	1.05	1.06	1.04	1.06
	Ford short term	C_p	1.11	1.11	1.11	1.11	1.09	1.08	1.08	1.07	1.07	1.06	N/A
		C_{pk}	0.78	0.78	0.78	0.78	0.97	1.00	1.03	1.05	1.06	1.05	N/A
	Ford on going	C_p	1.11	1.11	1.11	1.11	1.09	1.08	1.08	1.07	1.07	1.06	N/A
		C_{pk}	0.78	0.78	0.78	0.78	0.97	1.00	1.03	1.05	1.06	1.05	N/A
	VW 101 31	C_p	1.11	1.11	1.11	1.11	1.11	1.11	1.15	1.14	1.14	1.13	1.13
		C_{pk}	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.94	0.95	0.95	0.95

From **Table 3** and **Figures 1 and 2** they are visible differences between calculated capability indices C_p and C_{pk} for data sets with higher skewnesses.

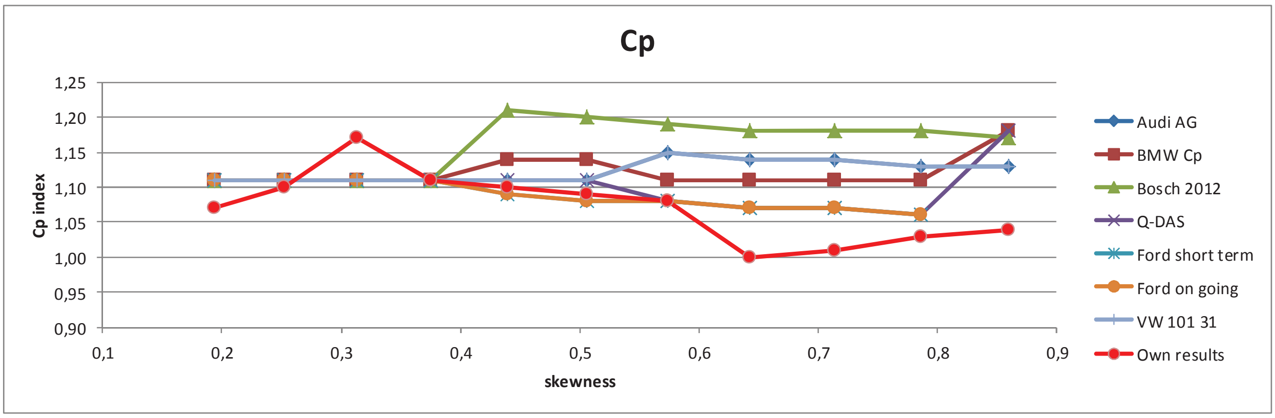

Figure 1 C_p index values calculated on the base of selected assessment strategy for data sets with different skewness. Source: own.

For data sets D1 to D4, where data normality was confirmed, all evaluation strategies provided same values of capability indices. But for data sets with higher skewnesses various strategies provided results with significant variability between calculated indices. These differences are caused by different approaches of selected evaluation strategies used for capability indices calculation (see **Table 2**).

Higher differences were found for C_{pk} index. For example, for the same data set D8 with skewness 0.64 achieved results of C_{pk} index are in range from 0.78 to 1.17 (see **Figure 2**). These differences can mean big problems in the practice, because C_{pk} index is used as main criterion of process capability. Due to this fact they are possible situations, when the same production process can be for one customer classified as capable and for another customer as incapable.

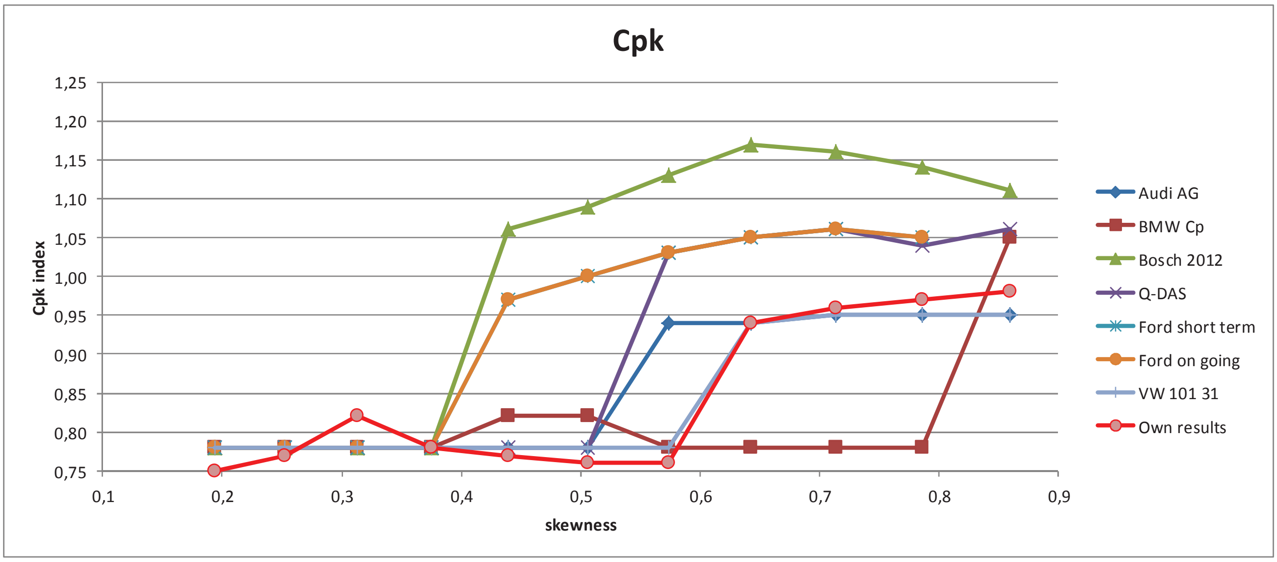

Figure 2 C_{pk} index values calculated on the base of selected assessment strategy for data sets with different skewness. Source: own.

The results achieved by individual evaluation strategies can be compared with results based on Lognormal distribution presented in previous work of authors [9]. It can be seen that results are not same but similar. The differences in the case of normal distribution of data are caused by different way of standard deviation estimation. In authors work it was estimated on the basis of pooled standard deviation, which characterize average variability in subgroups (this way of estimation is preferred in AIAG methodology [5]). Differences determined in the cases of using lognormal distribution, which was used also by Q -DAS, Ford short term and Ford on going evaluation strategies are caused by differences in found quantiles of lognormal distribution.

In spite of found differences in results, evaluation strategies determined by individual customers represent easier and more explicit approach to process capability analysis. The ways of process capability analysis are predefined and especially process capability is assessed exactly in accordance with customer requirements.

CONCLUSION

This article was focused on process capability analysis according to selected assessment strategies of various customers from automotive industry, which should use suppliers to this area, including metallurgical companies. Comparative study for seven selected assessment strategies was performed for data sets with various skewness. While in the cases of normal distribution of monitored quality characteristic the results of process capability analysis was practically uniform, in the cases, when data are not normally distributed, individual assessment strategies provided very different results. These differences can cause that the same production process can be for one customer classified as capable and for another customer as incapable. It was found that big influence on results variability has normality testing (type of used normality test). Some assessment strategies for the same data set used procedure for normal distribution and another used procedures for non-normal distribution. Another causes of results variability in the cases of non-normal distribution are connected with various ways of process capability evaluation.

Metallurgical companies should take increased attention to the ways of process capability analysis in the case of non-normal distribution, because natural distribution of many monitored quality characteristics is not normal distribution (e.g. taper ration, flatness, roughness, concentricity, eccentricity, perpendicularity, roundness, angularity, weld strength, tensile strength, hardness of castings, hole location or parallelism). The best strategy is to follow customer requirements on process capability analysis (if some are prescribed) to avoid any discussions and ambiguities. If no customer assessment strategy exists, it is possible to use some of defined strategies.

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