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EVALUATION OF THE QUALITY OF THE PROCESS BY MEASURING THE INDEX OF OPPORTUNITIES

Abstract: *Effective production process management contributes to the competitiveness of a company. If a manufacturer knows customer requirements to produced goods he can define specification levels for a product at each production process. Therefore, a complex index is required which allows to evaluate process quality quantitatively depending on the extent of its shift and dispersion. The tool widely used for assessing process quality is capability index. The analysis presented in the paper shows that this index has two drawbacks: it does not consider costs level and process change dynamics. To solve this problem we introduced two additional indices. One index based on the calculation of economic losses, and the second one considers process change dynamics. Developed quality indices can be applied for the cases when a production process follows the Gaussian law. Moreover, Q index should be used in the cases when the probability of nondefective units production is high.*

Keywords: *quality in engineering, capability index, tolerance limits*

1. Introduction

For many enterprises competing for a customer the problem of managing production processes play a crucial role (Stefanović, 2015). If a manufacturer knows customer requirements to produced goods he can define specification levels for a product at each production process. Therefore, he needs a complex index which allows evaluating process quality quantitatively depending on the extent of its shift and dispersion. Calculation of this index requires selecting such functions which would fulfil the following conditions: evaluation should be based on several independent parameters measurements which specify current process state; the index being developed should be easy to apply in practice and should not require special training. The most common index that meets these requirements is capability index (Arif et al., 2017; Aslam et al. 2017; Balamurali et al., 2017). Let us discuss it in detail.

If there are established upper and lower tolerance limits (UTL and LTL) for parameter X, we must assess its quality at certain production stages. This quality depends on the percentage of product items within upper and lower tolerance limits. Practically, process quality is often assessed using one of capability indices (Mittag and Rinne, 1999). Let us assume that a process proceeds normally, i.e. we obtain product

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items with a quality parameter having allocation with ($\overline{X}$;σ^2) (Carrión et al., 2017; Chen and Chou, 2017). Lack of quality in this process is a result of, at least, one of the following causes:

- process dispersion σ^2 is too large comparing with tolerance limits (UTL and LTL);
- process customization level $\overline{X}$ is too far from the middle of a tolerance interval.

Capability index is calculated as follows:

$$Cp=\frac{UTL-LTL}{6\sigma} \quad (1)$$

The greater capability index value is, the larger is the established tolerance limits compared with the natural process dispersion, i.e. with the extent of 6σ interval (UTL and LTL) that covers 99,73% of parameter X values having dispersion with ($\overline{X}$;σ^2). Capability index does not depend on the process customization level; it can be interpreted as a potential quality parameter of a process if its balance is optimal (Chen et al., 2017; De-Felipe and Benedito, 2017). Capability index is a real parameter of technological process quality level; to calculate it we use the following formula:

Cpk = (1-K)Cp, where (2)

$$K=\frac{\left|\frac{UTL+LTL}{2}-\overline{X}\right|}{\frac{(UTL-LTL)}{2}} \quad (3)$$

K is a dimensionless value which characterizes the difference between real and optimal levels of process customization. Non-negative value of K characterizes customization level: it is zero if $\overline{X}$ is equal to the tolerance interval mean and it is 1 at the tolerance interval boundaries. Smaller value of K represents optimal customization level. If *K* is greater than 1, $\overline{X}$ does not fall in the tolerance interval. One of the drawbacks of this index is the absence of its upper limits and can vary within the interval (0; $+\infty$) (Papic, 2011).

Capability index is a function of parameters $\overline{X}$ and σ. At the point $\overline{X}=\frac{UTL+LTL}{2}$ is maximal equal to Cp, and at the points $\overline{X}$ =LTL and $\overline{X}$ =UTL it is equal to zero. If $\overline{X} \in [LTL, UTL]$, Cpk is between 0 and Cp; in the opposite case it is negative. Thus, Cpk is limited above by Cp index, and below it varies until $-\infty$. Cp index is not limited above, and below it has a limit equal to zero. If a process runs unsatisfactorily, we cannot explain it using only Cpk index without concerning other factors. We will not be able to determine whether process disturbance is caused by its high dispersion or insufficient customization; detailed explanation is possible if we explore the factors which cause the variation of all Cp indices together. According to H.J. Mittag and H. Rinne, probability characteristics of process quality measure are more evident compared with Cpk index and limited above.

We used Cpk as a main index describing production process quality (Fallah et al., 2017; Hussain et al., 2017; Kahraman Kahraman): all management decisions are taken considering its value. We detected the following drawbacks of this index in some particular cases:

- index insensitivity to defect rate increases;

In case of process change (see Figure 1) Cpk index remains constant because it is monodirectional: defect rate change to the left will not be considered until it exceeds the defect rate to the right (Klochkov et al., 2016; Kozlovsky et al., 2016). With that both $\overline{X}$ and σ change.

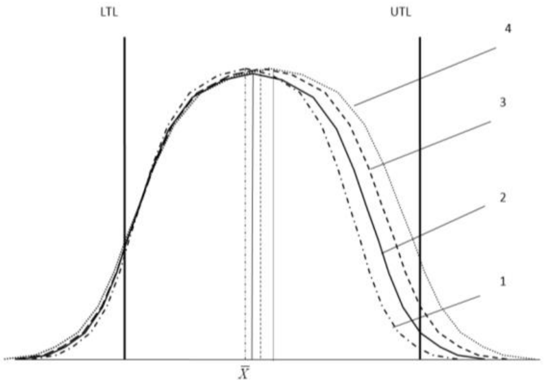


Figure. 1. Curve type describing production process state 1, 2, 3, 4 are production process states

- Cpk index value increases when the rate of irreparable defects grows, though in this case it must decrease.

By process change (see Figure 1) Cpk index increases because defect rate to the left remains less than that to the right, and defect rate to the right decreases (Oprime et al., 2017). But in practice we can often see a situation when exceeding one limit results, for instance, in excessive material consumption, while exceeding the other limit leads to batch rejection or to more substantial economic losses. It should be emphasized that in these cases only $\overline{X}$ value changes. Such index drawbacks result in false management decisions.

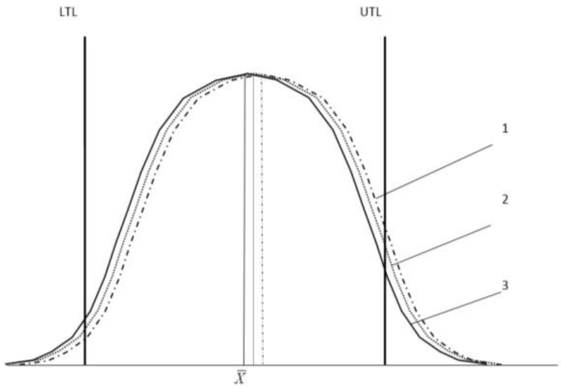


Figure 2. Gauss curves describing a production process 1, 2, 3 are production process states

By process change (see Figure 1) Cpk index increases because defect rate to the left remains less than that to the right, and defect rate to the right decreases. But in practice we can often see a situation when exceeding one limit results, for instance, in excessive material consumption, while exceeding the other limit leads to batch rejection or to more substantial economic losses. It should be emphasized that in these cases only $\overline{X}$ value changes (Klochkov et al., 2016; Papic et al., 1998). Such index drawbacks result in false management decisions.

2. Suggested quality level assessment technique

Quality level assessment technique in the case shown in Figure 1 is based on the calculation of such index which allows tracking production process changes. According to many specialists, it is very convenient to use a complex index because it makes possible to track both separate indices change and integrated index change as a whole.

The suggested assessment technique implies repetitive use of developed indices to assess the dynamics of production process change. To calculate such index we should find a function, which meets the following requirements: the assessment should be based on the measurement of several independent factors describing current process parameters; the suggested index should be easy to use in practice without requiring special training of staff (Papic et al., 2011; Seifi and Nezhad, 2017).

To correct the first drawback mentioned above (index insensitivity to defect rate increase) we shall introduce a new index. As a process dispersion quality index Qp we consider the difference between the real fraction of nondefective units (RF) and the same fraction, but in the case of a centred process (RCF) (i.e. if a mathematical expectation coincides with the tolerance interval mean). The real fraction of nondefective units is calculated using the formula:

$$\text{RF} = f\left(\frac{UTL-\overline{X}}{\sigma}\right) - f\left(\frac{LTL-\overline{X}}{\sigma}\right) \qquad (4)$$

To calculate the real fraction for a centered process we calculate mathematical expectation change Δ in relation to the tolerance interval mean:

$$\Delta = \overline{X} - \frac{UTL+LTL}{2} \qquad (5)$$

After we have introduced Δ, the probability of producing a nondefective item is as follows:

$$\alpha = f\left(\frac{\frac{UTL-LTL}{2}-\Delta}{\sigma}\right) - f\left(\frac{-\frac{UTL-LTL}{2}-\Delta}{\sigma}\right) = f\left(\frac{1-\Delta'}{\sigma'}\right) - f\left(\frac{-1-\Delta'}{\sigma'}\right),$$

where $\Delta' = \frac{\Delta}{\frac{UTL-LTL}{2}}$ and

$$\sigma' = \frac{\sigma}{\frac{UTL-LTL}{2}}$$

If a process is perfectly adjusted to the tolerance interval mean Δ= Δ' =0, then:

$$\alpha = f\left(\frac{1}{\sigma'}\right) - f\left(\frac{-1}{\sigma'}\right) = 2f\left(\frac{1}{\sigma'}\right)$$

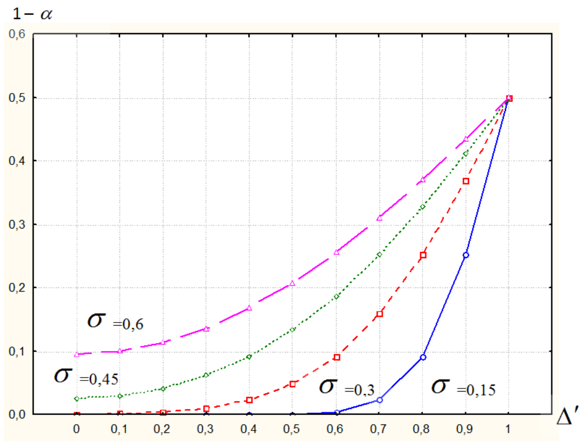


Figure 3. σ and Δ' effect on the defective items fraction $(1-\alpha)$

We can see that the probability of producing a nondefective item depends only on σ'. Now it is possible to analyse how σ and Δ value (tolerance interval mean deviation of $\overline{X}$) affect the probability of producing a nondefective item or the level of production defects. Figure shows the dependence of value $(1-\alpha)$ on Δ' at various σ'.

Having plotted a chart (Figure 1) we can find out when a change $\overline{X}$ or σ is profitable for an enterprise. Obviously, the capability index Cpк is not able to provide such information. Nevertheless, it remains important for enterprises to use an index, which demonstrates a production process change and does not depend on economic losses (Dianda et al., 2017; Yury et al., 2016).

We shall find UTL' and LTL' for a centred process:

$$UTL' = \text{UTL}+\Delta, \tag{6}$$

$$LTL' = \text{LTL}+\Delta \tag{7}$$

Then we calculate RCF as:

$$\text{RCF} = f\left(\frac{UTL'-\overline{X}}{\sigma}\right) - f\left(\frac{LTL'-\overline{X}}{\sigma}\right) \tag{8}$$

Indeed, in this case the RCF value will be as in the situation when mathematical expectation coincides with the tolerance interval mean. Then the index is as follows:

$$\text{Qp} = [1-(\text{RCF}-\text{RF})]. \tag{9}$$

Obviously, in practice RCF will be always greater than RF.

As a quality parameter describing the ability of a process to meet certain requirements we suggest to use the following ratio where RF is a target (standard) value used inside an enterprise.

$$\text{Qs} = \text{RCF}/\text{RF}. \tag{10}$$

Besides the indices mentioned above, we also suggest using an index showing process entropy and probable process results number increase. Using degree of uncertainty allows – in case of long-term observation – describing process maladjustment related to the ageing of production equipment.

where H is process entropy.
Complex index is calculated by the formula:

$$\text{Q} = \text{QpQsQh} \tag{12}$$

3. Quality level assessment method considering economic risks (related to parameters exceeding tolerance limits)

Quality level assessment method considering economic losses must be based on such index which comprises on factors such as volume of production, defects probability and degree of potential economic losses.

Such method provides an essentially new perspective on quality expenses. Using some simple calculations we can determine, for instance, when it is efficient to correct defects and when it is more cost-effective to refuse a produced defective item, as well as solve other particular problems related to economically feasible production management.

The developed index will be used along with conventional capability indices and other quality factors and should be calculated periodically.

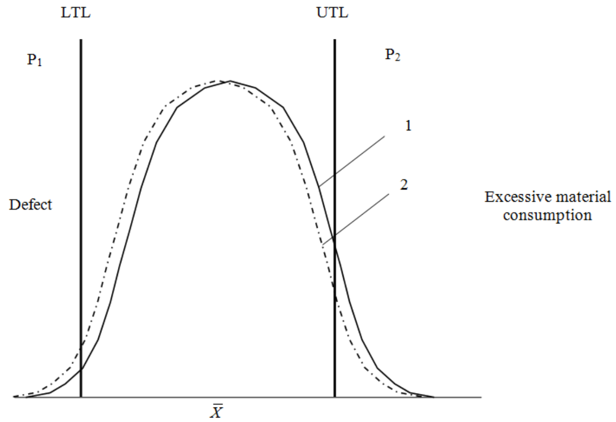


Figure 4. Change of a production process state with time 1, 2 are production process states

In case of production process change (Figure 2) we suggest calculating quality index Qec as follows:

$$Qec=P_1E_1+P_2E_2, \quad (13)$$

where

P_1 is the probability of LTL exceed,
P_2 - the probability of LTL exceed
E_1 - economic losses related to LTL exceed,
E_2 - economic losses related to UTL exceed,

While the first summand in the Qec formula is easy to calculate because economic losses do not depend on LTL exceed, the other case is quite complicated.

Therefore, P_1E_1 is calculated as follows:

$$P_1E_1=\sum p_i e_i, \quad (14)$$

where

p_i is the probability of exceeding material consumption, and

$э_i$ is economic losses related to the particular exceeding material consumption level (per a production unit).

Besides, we shall consider volume of production V. Then,

$$Qec=V(\sum p_i e_i+ P_2E_2). \quad (15)$$

4. Major advantages of using suggested quality level assessment methods and recommended practice

Obviously, Qp index is similar to (1-K) index calculated for Cpk. It differs from (1-K) only in the fact that Qp is limited above and below and varies within the interval from 0 to 1, while (1-K) varies within the interval from -∞ to 1.

Let us show the difference between these indices with the help of an example, where Cpк remains constant and is equal to 0,33, UTL=50, LTL=10, and $\overline{X}$ varies from 11 to 49 in increments of 1.

The data for the index (1-K) are shown in Figure 5. We can see that the index variation is linear. The index variation is plotted in Figure 6. (1-K) can be plotted as (1-$a/в$), therefore in our example it varies linearly. According to the calculations, Qp index varies as follows (Figure 7).

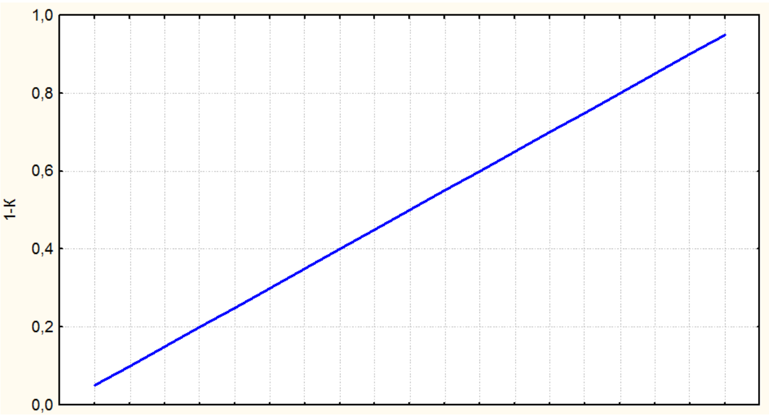


Figure 5. Index (1-K) variation

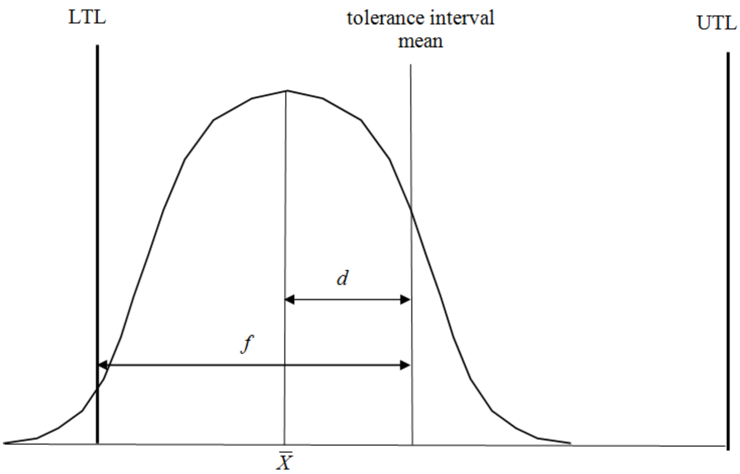


Figure 6. (1-K) index calculation

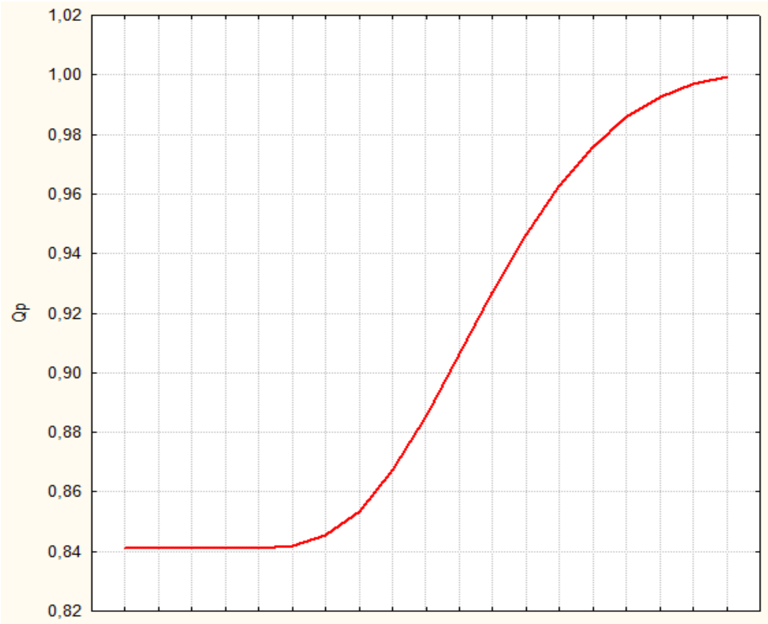


Figure 7. Qp index variation

Such variation as shown in Fig.7 can be explained by the fact that Qp considers not linear distance variation *d* related to *f* (Fig. 4), but areas under curve (Fig. 8). According to correlation analysis carried out using software package Statistica 6.0, (1-K) and Qp indices have correlation degree equal to 0,96. The analysis shows that σ and $\overline{X}$ vary linearly (Figure 9 and 10).

$$Qp=1-(S_1-S_2) \tag{16}$$

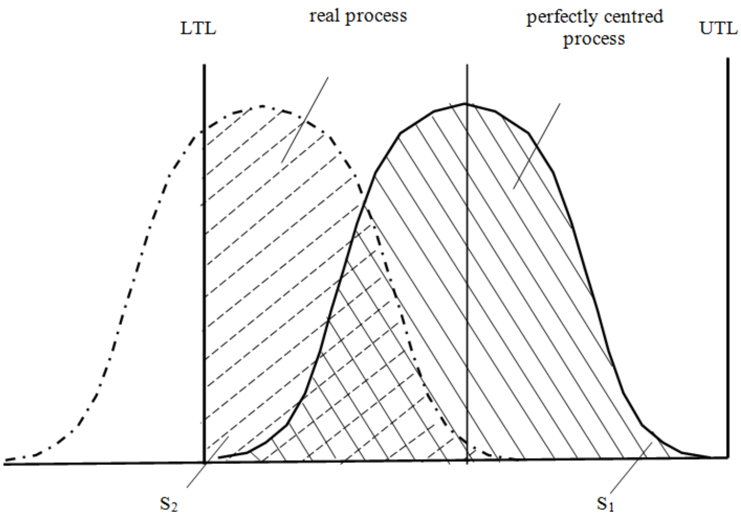


Figure 8. Method of Qp index calculation

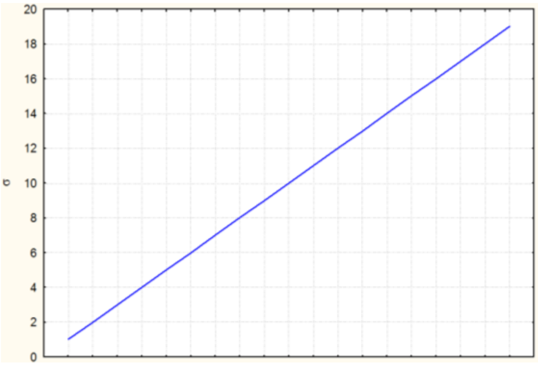


Figure 9. σ variation

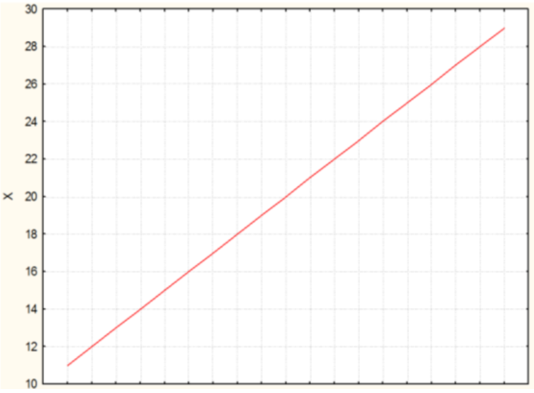
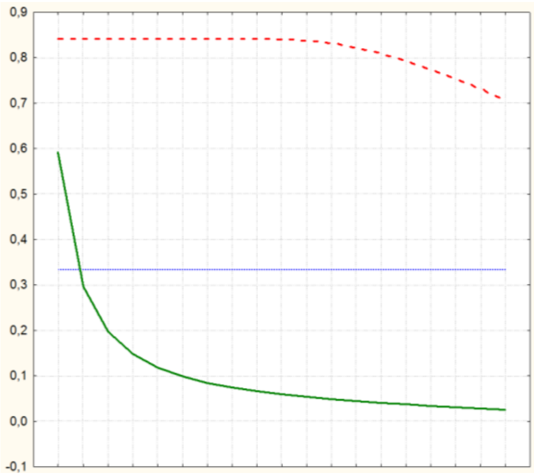


Figure 10. Variation $\overline{X}$



...... Cpk; - - - - RF; —— Q.

Figure 11. Indices comparison

To analyse Q and Cpk indices we plot variation curves for them (Figure 11). According to the plot, Cpк index does not change, while Q index tends to decrease. Such variation of Q index is caused by the fact that the probability of defects increases, so σ increases, too. That indicates not only that $\overline{X}$ shifts in relation to the tolerance interval mean, but also that equipment wears out. If the equipment did not wear (i.e. σ and entropy did not increase), the curve Q would coincide with the curve RF.

5. Conclusions

Developed quality indices can be applied for the cases when a production process follows the Gaussian law. Moreover, Q index should be used in the cases when the probability of nondefective units production is high, i.e. when Cpk=0,5. In other cases it is more convenient to use conventional Cp indices. Qec index can be applied when losses caused by one tolerance limit exceed are not equal to the losses caused by another tolerance limit exceed. In particular, such index can be used in the cable production where cable diameter reduction results in rejecting the whole batch while its expansion leads to the excessive material consumption (electrical conductor as well as isolation material consumption). Thus, quality level analysis of a production process is a complex problem; its solution depends on an adequate application of certain indices.

References:

Arif, O. H., Aslam, M., & Jun, C.-H. (2017). Acceptance sampling plan for multiple manufacturing lines using EWMA process capability index. *Journal of Advanced Mechanical Design, Systems and Manufacturing*, *11*(1). DOI: 10.1299/ jamdsm.2017jamdsm0004

Aslam, M., Wu, C.-W., Azam, M., & Jun, C.-H. (2017). A proposed procedure for variable sampling plans design based on process capability index. *Journal of Engineering Research*, *4*(4), 113-129.

Balamurali, S., & Usha, M. (2017). Developing and designing of an efficient variables sampling system based on the process capability index. *Journal of Statistical Computation and Simulation*, *87*(7), 1401-1415. http://www.tandfonline.com/doi/pdf/10.1080/ 00949655.2016.1267735

Carrión Garcia, A., Grisales del Río, A., & Papic, L. (2017). Deming's Chain Reaction. International Journal of Productivity and Quality Management, *21*(2), 264-271.

Chen, C.-H., & Chou, C.-Y. (2017). The joint determination of specification limits, process mean, and economic manufacturing quantity. *Journal of Industrial and Production Engineering*, 1-6. http://www.tandfonline.com/doi/abs/10.1080/21681015.2017.1292962.

Chen, K.-S., Huang, C.-F., & Chang, T.-C. (2017). A mathematical programming model for constructing the confidence interval of process capability index Cpm in evaluating process performance: an example of five-way pipe. *Journal of the Chinese Institute of Engineers, Transactions of the Chinese Institute of Engineers,Series A/Chung-kuo Kung Ch'eng Hsuch K'an*, *40*(2), 126-133.

Chen, K.-S., Wang, K.-J., & Chang, T.-C. (2017). A novel approach to deriving the lower confidence limit of indices Cpu, Cpl, and Cpk in assessing process capability. *International Journal of Production Research*, 1-19. http://www.tandfonline.com/doi/abs/ 10.1080/00207543.2017.1282644

De-Felipe, D., & Benedito, E. (2017). A review of univariate and multivariate process capability indices. *International Journal of Advanced Manufacturing Technology*, 1-19. https://link.springer.com/article/10.1007/s00170-017-0273-6

Dianda, D. F., Quaglino, M. B., & Pagura, J. A. (2017). Distributional Properties of Multivariate Process Capability Indices under Normal and Non-normal Distributions. *Quality and Reliability Engineering International*, *33*(2), 275-295. DOI: 10.1002/qre.2003

Fallah Nezhad, M. S., & Seifi, S. (2017). Repetitive group sampling plan based on the process capability index for the lot acceptance problem. *Journal of Statistical Computation and Simulation*, *87*(1), 29-41.

Hussain, J., Balamurali, S., Aslam, M., & Jun, C.-H. (2017). SkSP-R sampling plan based on process capability index. *Communications in Statistics - Theory and Methods*, *46*(6), 2955-2966. http://www.tandfonline.com/doi/abs/10.1080/03610926.2015.1053939

Kahraman, C., Parchami, A., Cevik Onar, S., & Oztaysi, B. (2017). Process capability analysis using intuitionistic fuzzy sets. *Journal of Intelligent and Fuzzy Systems*, *32*(3), 1659-1671. DOI: 10.3233/JIFS-141877.

Klochkov, Y., Gazizulina, A., & Golovin, N. (2016) Assessment of organization development speed based on the analysis of standards efficiency. *Proceedings - 2nd International Symposium on Stochastic Models in Reliability Engineering, Life Science, and Operations Management, SMRLO 2016*, 530-532 DOI: 10.1109/SMRLO.2016.93

Klochkov, Y., Klochkova, E., Antipova, O., Kiyatkina, E., Vasilieva, I., & Knyazkina, E. (2016). Model of database design in the conditions of limited resources. *5th International Conference on Reliability, Infocom Technologies and Optimization, ICRITO 2016*, 64-66. DOI: 10.1109/ICRITO.2016.7784927

Kozlovsky, V., Klochkov, Y., Ostapenko, M., Ushanova, N., & Antipov, D. (2016). Conformity assessment of car quality databases exemplified on the case of the Russian car manufacturer 'Auto VAZ'. *5th International Conference on Reliability, Infocom Technologies and Optimization, ICRITO 2016*, 57-60. DOI: 10.1109/ICRITO.2016.7784925

Mittag, H, & Rinne, H. (1999*). Prozessfähigkeitsmessung für die industrielle Praxis*. München, Hanser.

Oprime, P. C., & Mendes, G. H. S. (2017). The X-bar control chart with restriction of the capability indices. International *Journal of Quality and Reliability Management*, *34*(1), 38-52. http://www.emeraldinsight.com/doi/abs/10.1108/IJQRM-08-2014-0103?af=R

Papic, L., & Khan, M. (1998). Quality Assuranace on the Basis of Failure Modes. Effects and Criticality Analysis: Review, Communications in Dependability and Quality Management, *An International Journal*, *1*(1), 101-113.

Papic, L., & Pantelic, M. (2014). Maintenance-Oriented Safety Control Charts. International Journal of Systems Assurance Engineering and Management, *5*(2), 149-154. https://link.springer.com/article/10.1007/s13198-014-0224-7

Papic, Lj. (2011). Quality Management (In Serbian). DQM Research Center, Prijevor, 288.

Seifi, S., & Nezhad, M. S. F. (2017), Variable sampling plan for resubmitted lots based on process capability index and Bayesian approach. *International Journal of Advanced Manufacturing Technology*, *88*(9-12), 2547-2555. https://link.springer.com/article/10.1007/s00170-016-8958-9

Stefanović, M., Tadic, D., Arsovski, S., Pravdic, P., Abadić, N., & Stefanović, N. (2015). Determination of the effectiveness of the realization of enterprise business objectives and improvement strategies in an uncertain environment. *Expert Systems*, *32*(4), 494-506. http://dx.doi.org/10.1111/exsy.12102

Yury, K., Lera, G., Elena, K., Irina, V., & Sergey, D. (2016), Consideration of Uncertainties and Risks in the Building Process of Multifunctional Harbor Transshipment Complex. *International Journal of Reliability, Quality and Safety Engineering*, *23*(6). http://www.worldscientific.com/doi/abs/10.1142/S0218539316400118?af=R&

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