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THE ROLE OF 1.5σ SHIFT IN PROVIDING PROCESS EXCELLENCE

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Abstract: The objective of this paper is to point out the difference between 3σ and 6σ distance from the mean to specification limits, since the hypothesis is that this difference is one of the reasons way many quality improvement initiatives have failed. Mentioned difference is explained through prescribed (required) tolerance as „the voice of the consumers" and natural tolerance as „the voice of the process". The paper also gives the statistical explanation of 1.5σ shift, which confirms the importance of change from 3σ to 6σ sigma.

1. INTRODUCTION

A program called Six Sigma was launched in Motorola, in the mid 1980's. This program set an objective for all processes to statistically perform at an error rate no greater than 3.4 errors per million items. Very important thing for this program success is the fact that it should be applied to all processes (not just to the production processes).
The Six Sigma concept methodology includes statistical measures and tool and therefore helps managers to describe process performance in terms of its variability. In this concept, sigma level, as a measure of process quality, is based on the standardized normal distribution. The greater the distance between the mean and specification limits, expressed in standard deviations, implies the higher the Z-score and sigma level. Quality level expressed as 6σ means that, between mean and specification limit (upper or lower) there are 6 standard deviations [8].
Concerning previously mentioned, it can be said that a significant segment of the Six Sigma methodology is a process capability. Process capability shows how the variation, immanent to particular process, fit within the scope of specifications, identified according to the "voice of consumers". The capable process is the one whose variability fits into the established framework. The process that is characterized as a Six Sigma process has less variability than the established, specification limits. It is important to emphasize that the process capability binds to its stability, which means that the process capability can be increased only after providing its stability.

2. NORMAL DISTRIBUTION AS KEY ASSUMPTION OF STATISTICAL PROCESS CONTROL

Statistical Process Control (SPC) is a system for processes monitoring and control. It assumes statistical analysis with purpose of process improvement. SPC includes many instruments and tools, like: histogram, scatter plot, Ishikawa diagram, Pareto diagram, regression analysis, flow chart, control chart, process capability etc.
Nonetheless, the over-all SPC system of a company may be broken down into four basic steps [13]:

- Measuring the process;
- Eliminating variances within the process to make it consistent;
- Monitoring the process; and
- Improving the process.

This four-step cycle should be implemented over and over again for continuous improvement. Two key assumptions of SPC are [7]:

- The data are normally distributed and
- There is no correlation between the data.

When the data are collected, these assumptions should be tested. Before implementation of SPC one should test the measured characteristics to confirm that the data are normally distributed.
The main of physical, biological, and social data, as well as business process data are normally distributed. For that reason normal distribution is the most recognized and the most widely-used statistical distribution.
In SPC "only two parameters are needed to describe a normal distribution, namely, the mean or its centre, and the standard deviation (also known as sigma) or its variability. Knowing both parameters is equivalent to knowing how the distribution looks like. The normal distribution is bell-shaped, i.e., it peaks at the centre and tapers off outwardly while remaining symmetrical with respect to the centre" [13].

3. 6 SIGMA VS. 3 SIGMA

Total Quality Management (TQM) has introduced the usage of SPC. The purpose of SPC has been to monitor and control processes in order to discover variations and defects. Identification of variations and defects represents only first step in processes improvement. The second and significantly important step is reduction of process variation. Process variation has to be reduced so that all of the measured characteristics fall into the specification limits. In this case upper and lower specification limits were identified according to the "voice of customers". There was no difference between *prescribed (required) tolerance* and *natural tolerance* (they were both equal ±3σ).
In TQM there is no difference between defects and defectives. While, defects represent any observation outside of the more restrictive of the control or specification limits, defectives included any observation outside of the specification limits. Because many TQM change initiatives designed processes that would achieve customer tolerance, the control limits were usually the same as the customer's specification limits. The relatively few defect observations that would fall outside of the control limits would be defectives by definition [2].
As a consequence of usage of customer tolerance as specification limits, in TQM there was a problem of process stability. During some period of time the mean of measured characteristics has changed for about ±1.5σ. This change of the mean is known as 1.5σ shift.
The mean shift in TQM has been explained as improvement initiative failure. However, it was not considered that the specification limits should be set up at values inside customers' specifications.
Considering problems that TQM supporters were faced with, the Six Sigma concept has introduced new measure of quality level. The aim of Six Sigma improvement project is to provide 6σ quality level in the short-term, because this means that in the long-term, assuming 1.5σ shift, quality level will be equal 4.5σ. With this quality level there will be only 2 defects in short-term or 3-4 defects in long-term, if there is 1.5σ shift [2].
In the case of natural tolerance of ± 3σ, standard deviation (maximum allowed) can be determined in the following way [5]:

$$\sigma_{max,3} = \frac{GGS - DGS}{6} \tag{1}$$

According to the Six Sigma concept, the process is „capable", if standard deviation is not more than one twelfth of the prescribed tolerance. In the case of natural tolerance of ± 6σ, standard deviation (maximum allowed), can be calculated in the following way:

$$\sigma_{max,6} = \frac{USL - LSL}{12} \tag{2}$$

For example, if the mean is 100 and the upper and lower specification limits 106 and 94, respectively, based on previous relations (1) and (2) it can be determined that the standard deviation in the case of 3σ process is 2, which is twice more, compared to the standard deviation in the case of 6σ process, which is equal 1. Change from 3σ to 6σ involves the reduction of defects [5]. Defects' reduction assumes reduction of observed phenomena variability or reduction of deviations from the mean. For that reason it is usually said that in the case of 6σ quality level 12 standard deviations can feet between specification limits, while in the case of 3σ quality level only 6 standard deviation can feet between specification limits, assuming that specification limits are not changed.

4. ANALYSIS OF 1.5 SIGMA SHIFT

According to the Six Sigma concept accuracy rate for key processes has to be 99.9999998%. This means that the prescribed tolerance, „the voice of the consumers“, must be twice large then the natural tolerance (± 3σ), as „the voice of the process“. In that case the value of Cp, and when the process is centred the value of Cpk, will be 2 [1].

Variations are more pronounced in the long run than in the short, because there is a deviation within samples as well as between the samples. Protagonists of the Six Sigma concept emphasize that, as a result of variations in the long run, mean can shift for 1.5σ. Therefore, they suggest that the sigma level, as a measure of process quality, should be calculated by adding 1.5σ to Z scores. Without taking into account the sigma shift in the previous example, with standard deviation 1, Z score is 6 ((106 to 100) / 1). If, however, 1.5σ shifts is considered, Z score in the long term will amount to 4.5 ((106-101.5) / 1). In this case, Cp remains 2 ((106-94) / 6 * 1), but CPC is now equal 1.5 ((106-101.5) / 3 * 1), because the difference between specification limit and mean decreased for 1.5 σ [1].

Although Motorola's concept was named Six Sigma, quality level marked as 6σ should be reached in short period of time and it is allowed for the process to perform at lower levels when the process shift is considered [4]. Table No. 1. relates the various levels of sigma to defects per million opportunities with and without considering 1.5σ shift.

Table No. 1. Sigma levels and number of defects per opportunities (DPO) [5]

with considering 1.5σ shift		without considering 1.5σ shift	
sigma levels	DPO	sigma levels	DPO
1	697672	1	317300
2	308770	2	45500
3	66811	3	2700
4	6210	4	63
5	233	5	0,57
6	3,4	6	0,002

Sigma shift is justified by the fact that the traditional model of normal distribution curve based on the natural tolerance of ± 3σ overestimates the reality and contributes that „the things look better than they are“. The first, when measuring the quality of the observed characteristics, there is a certain error risk. The second, the measurement is performed in production, while possible effects of some factors during the usage of product, whose characteristics are considered, are neglected. In this regard, it is considered that such measures which are internally used (to measure process quality) underestimate problems the users of products are faced with during their usage [6].

If there are no unforeseen factors and the mean is centred, the process, that has 6σ quality level in the short term, will also have only 2 defects in a billion opportunities in the long term. If, however, there are unforeseen factors and it consequently the mean is off-centre by ± 1.5σ, this process will have 3 to 4 defects in a million opportunities (units). In this way, the sigma quality level in the long run represents the sigma quality level in the short term reduced by 1.5 σ. [11]

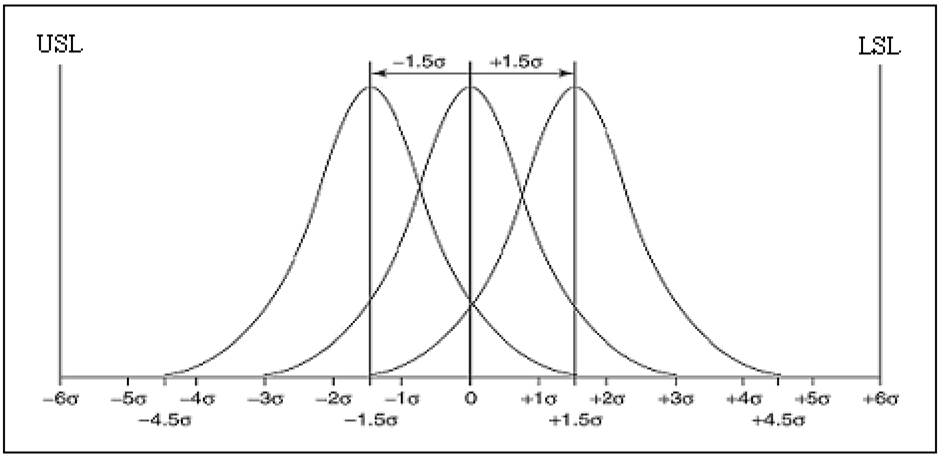

Figure No. 1. 1.5 sigma shift [3]

When it comes to the shift value, it should be noted that it was assigned in Motorola, based on long-term monitoring of the key processes. The shift value is determined based on monitoring of the mean values variation, which were usually in the range of 1.4σ to 1.6σ, and, therefore, it was accepted that the shift value is 1.5 σ. However, this does not mean that the mean of every process in each enterprise will be shifted for 1.5σ. For some processes this shift may be lower or higher [5]. Bearing in mind that the sigma shift is not constant, it should be viewed as heuristics, which emphasizes that the products and services should be viewed with „the eyes of consumers“ and that customers problems should not be underestimated [6]. Table No. 2. shows number of defectives for different sigma quality levels and for different mean shift (off-centring).

Table No. 2. The effects of mean shift size and process quality level on number of defects per million opportunities [4]

	process quality level						
mean shift	3σ	3.5σ	4σ	4.5σ	5σ	5.5σ	6σ
0	2,700	465	63	6.8	0.57	0.034	**0.002**
0.25σ	3,577	666	99	12.8	1.02	0.1056	0.0063
0.5σ	6,440	1,382	236	32	3.4	0.71	0.019
0.75σ	12,228	3,011	665	88.5	11	1.02	0.1
1σ	22,832	6,433	1,350	233	32	3.4	0.39
1.25σ	40,111	12,201	3,000	577	88.8	10.7	1
1.5σ	66,803	22,800	3,200	1,350	233	32	**3.4**
1.75σ	105,601	40,100	12,200	3,000	577	88.4	11
2σ	158,700	66,800	22,800	6,200	1,300	233	32

However, after several years of the Six Sigma concept implementation, some authors have tried to give a statistical explanation for a 1.5σ shift. The explanation is based on the analysis of variance (Table No. 3.), and assumes that the difference between the Z result in the short term (Z st) and Z result in a long time (Z lt) is equal 1.5σ [9]. Assumption about 1.5σ mean shift is the subject of criticism by many authors. Some of them even believe that this is a ridiculous premise. However, supporters of the Six Sigma concept say that perhaps a shift value is slightly greater than the real situation, but that the criticism of this assumption is unjustified, because it is hard to imagine that the arithmetic mean may be held at the same level in the long term.

Table No. 3. Statistical explanation of 1.5σ shift [9]

Z st - Z lt = 1,5σ	
Z st = (SL – TV) / SDst	Z lt = (SL – AV) / SDlt
SDk = $[SS_R / rn - r]^{1/2}$	SDlt = $[SS_T / rn - 1]^{1/2}$
TV – target value	AV – average value
SL – specification limit (closer to TV)	SL – specification limit (closer to AV)
SDst – short-term standard deviation	SDlt – long-term standard deviation
SS_R – sum of squares within samples (residual)	SS_T – total sum of squares
r – number of samples	r – number of samples
n – sample size	n – sample size

1.5σ shift can be approved through the „learning effect“, as well as through the „usage effect“. Considering learning curve, the authors that advocate sigma shift believe that mean shift may occur as a result of learning. For example, as a consequence of the production process improvement fuel consumption per kilometre can be reduced. However, on the other hand, the consumption per kilometre can be increased during the car usage, due to physical deterioration [1].
The model based on 1,5σ shift certainly can not be regarded as absolutely correct, but many companies considered it more useful than the traditional model. The reason for this is the fact that it provides „the reserve“, which allows that customers' satisfaction can be provided even when unpredicted factors occur.

5. SHORT TERM VS. LONG TERM

There is no specific timeframe to make the difference between a short-term and a long-term is. The qualification short-term and long-term varies from process to process. If a process has only common cause variation for one month, but special causes can influence this process month over month then one month could be considered short-term. If another process has common cause variation for one week but special causes influence it week after week, then one week could be considered short-term. Therefore what can be considered short term for one process, may represent long-term for another. Ideally, all trends, seasonality, and all types of special causes should be accounted for in the long-term so that long-term number of defects per million opportunities is accurate. Generally, it can be accepted that 6 months to 1 year can be considered long-term period [10].
When calculating sigma level one should have in mind the difference between short-term sample and long-term sample. These differences are shown in the following table.

Table No. 4. The differences between short-term and long-term [12]

SHORT term sample	LONG term sample
Free from assignable or special cause	Consists of random and assignable causes
Represents random causes only	Collected across a broad inference space
Group of similar things	The long term distribution includes all the short term distributions
Collected across a narrow inference space	
Data from one lot of material, on one shift, one part, on one machine with one operator	Data from several lots of materials, many shifts, many parts, many machines and operators

6. CONCLUSIONS

There are a lot of comments concerning 1.5 sigma shift. Some of them are positive, but some are negative. Regardless these comments, managers must have one thing in mind:

they have to use Six Sigma methodology and 1.5 sigma shift in order to reduce defects and to save money. The money refers to increased revenue and reduced costs.
The sigma shift emphasizes customers' satisfaction. Therefore, it assumes that "the voice of the customers" should be listened before making decisions about products' characteristics. Many companies had some of the best efficiencies in the industry, but soon after that they went bankrupt. It shows that focus on process efficiencies is not a guarantee of success.
Therefore it can be said that it is easy to cut costs, but if one wants to increase ability to provide the products and services customers expect, he confronts with risk of losing those customers and the revenue. For that reason, it is not important just to cut costs, but to cut the non-value added activities that cause non-necessary costs.
Concerning previously mentioned it can be concluded that centring the process mean and reducing the process breadth represent very important task for successful implementation of the Six Sigma concept. However, the realization of this task assumes some actions that should proceed. First, identify the product characteristics according to the "voice of the customers". Second, determine how product's elements contribute to characteristics that customers have marked as critical for their satisfaction. Third, determine target value and allowable tolerance for the critical characteristics. Fourth, determine the capability for process elements that control critical characteristics. Fifth, provide that Cp is equal 2, and Cpk 1,5 by using the Six Sigma improvement methodology (including DMAIC and DMADV methodology).

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