A NEW ALTERNATIVE OF IMPROVING WATER QUALITY CONSUMPTION INDICATORS USING CURRENT STATISTICAL APPROACH SIX SIGMA (6σ)

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Abstract: The concern for quality assurance and improvement of water intended for technological and human consumption is a very topical issue at the state level to any organization, regardless of the activity profile and thus guarantees quality compliance (assurance), performance, competitiveness and organizational profitability. This paper addresses the need to improve water quality indicators of consumption through “Six Sigma”, a statistical method which is based on reducing non-conformities in specified limits and to ensure maximum effectiveness, equivalent to yield 3.4 defects per million opportunities.

Keywords: drinking water, six sigma, indicator of quality improvement, effectiveness

1. INTRODUCTION

The concerns in the field of process improvement of the quality of drinking water are of great interest, with a significant impact on all consumers (human and industrial). A scientific research of the processes of improving water quality is necessary, given that on the one hand, the quality of water resources (underground and surface) for drinking water has deteriorated due to increased load of organic materials, and on the other hand of increased requirement of all consumers, reflected in indicators more severe imposed by law. As a result, rehabilitation, upgrading and optimization of processes improving the water quality are an opportunity for scientific research and current technology to increase water quality with reasonable production costs. Looking from social point of view, the opportunity of increasing the produced water quality, with reasonable production costs, is the first priority for a decent living in decent sanitary conditions [1, 2].

Although there is no generally accepted definition in current technical conception quality of the water can be defined by a set of conventional physico-chemical and biological, expressed by values, which is either standards for assessing the possibilities of using water or simple steps comparison.

For more accurate water of quality for the many characteristics that can be determined by laboratory tests, it is used a limited number, namely, only those considered most significant. Global Plan for Water Quality Monitoring, which is part of the global system monitoring environment (GEMS), initiated by the United Nations Environmental Program provides tracking of water quality through three categories of parameters:

a) basic parameters (temperature, pH, resistivity, dissolved oxygen, coli bacilli);

b) indicative parameters of persistent pollution (cadmium, mercury, halogenated organic compounds, organometallic mineral oils);

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c) optional parameters (total organic carbon - COT, biochemical oxygen demand - CBO₅, anionic detergents, heavy metals, arsenic, boron, sodium cyanide, total oil, streptococci).

Given the drinkability requirements that water must meet for domestic needs or for the industries that are using it in its production processes is absolutely necessary and mandatory to have the classification levels of organoleptic analysed properties (smell, taste), physico-chemical (colour, temperature, electrical conductivity, radioactivity, TDS, hardness, pH) and bacteriological (bacteria trivial and scavenge pathogens coli bacilli), on the maximum allowable or acceptable levels set by standards, guidelines and legal norms mentioned.

Given the importance of improving the water quality, the main objective of the research herein presented in this paper is the application of current statistical approach Six Sigma (6 σ) as an alternative method to improve the water quality necessary to carry out production processes in an industrial company specific to processing by preserving of fruits and vegetables.

Thus, it takes into account using the results of assessments carried out for one of the most important indicators of quality of drinking water needed in the industry above mentioned, such as for example, hydrogen ion concentration (pH), which must have a weak alkaline character (pH = 7 to 7.5) and in any case – acid, to prevent corrosion of cans and equipment and process installations. Therefore, the opportunity to apply statistical method Six Sigma in this study is absolutely justified because achieving target function, namely to classify the distribution of pH values measured within set specifications limits and getting a maximum efficiency.

2. DESCRIPTION OF THE STATISTICAL METHOD „SIX SIGMA”

The novelty of this statistical method "Six Sigma", an own engineering quality, is the possibility of its application to many organizations, regardless of their specific activity.

Therefore, starting from the appearance of the “zero defects” concept, which was the starting point in the creation of the “Six Sigma” statistical method for Motorola Company in 1986 by Bill Smith and then continuing with its implementation and for other leading companies (General Electric, Honeywell International, ABB, Lockheed Martin, Polaroid, Sony, Honda, American Express and Solectron), it came to application of this statistic approach in many organizations worldwide, most of which could prove the role of pivoting element method “Six Sigma” to their success [3].

By using clear evaluation outcomes to quality characteristics specific of hydrogen ion concentration (pH) of water samples taken at the organizational level of the processing industry by preserving fruit and vegetables, this work aims to own a methodology to the statistical methods „6σ”, to identify with a guide application, thus to lead to improvements in performance, efficiency and quality of drinking water at the organizational level and reduce defects / nonconformities corresponding measured values of pH within the specified limits (LIS = 7 and LSS = 7.5), ensuring maximum effectiveness. In Figure 1, it is highlighted the performance of Six Sigma methodology (“6σ”) compared to method „3σ”, taking into account the standard deviation “σ”, that represents the basic metric in statistical analysis of evaluated data / measured characteristics, respectively the variable that shows the distribution of process output feature. A higher value for sigma (σ) is indicating a more stable process, with less risk for faulty events (pcs / major nonconformities) and respectively lower cost.

![Fig. 1. Performances of the ”Six Sigma” method](image)
For any type of industrial organization that applies the "Six Sigma" strategy, the specific phases of this method are presented in order of application (DMAIC) in Figure 2.

Fig. 2. Phases of “Six Sigma” method [3, 4].

3. EXPERIMENTAL SETUP. THE APPLICATION OF STATISTICAL METHOD "SIX SIGMA"

The paper takes into account the specific step by step phases approach using the "Six Sigma" (DMAIC) as shown above in Figure 2, beginning from determining opportunities (problems, nonconformities, etc.) and as well the assessed data quality characteristics (measured, quantified) of pH values that characterize the current performance level and then continuing with other specific steps of this method.

3.1. Defining quality improvement opportunities (D)

Primarily we use the brainstorming technique for identifying defective opportunities (DOi) / drawbacks, nonconformities, obstacles, etc., theoretically, culturally and materially on ensuring water quality indicator (pH), namely:
- ensuring quality indicator classification - pH within specifications – LIS/LSS (DOi);
- current delivery term (DOi);
- the amount of delivered water (DOi).

In order to achieve and sustain the success of such „Six Sigma” project it is necessary to ensure a comprehensive and flexible system, heavily focused on deep knowledge of opportunities for improving water quality indicator - pH, leading to the elimination of inconsistencies in the system and poor quality costs needed for implementing a quality management.

Therefore, selection matrix of quality improvement project alternatives are presented in Table 1, regardless of the 9 criterias (Ci), according to which the project team will give marks from 1 to 5 corresponding to the 5 defective opportunities (DOi) referred to above. These criteria are as follows [3-5]:
- chronicity (C1): to correct a problem that occurs frequently;
- importance (C2): to characterize the appearance of the final results vs. the effort made;
- duration (C3): in order to provide a period of less than one year;
- potential impact (C4): that must be quantified;
- urgency (C5): requires addressing the vulnerabilities of the organization / company;
- potential risk (C6): may lead to failure of expected results;
- possible resistance to change (C7): it has a major impact on the selection of the project;
- success of the project (C8): proof of positive results;
- quantification / measurement (C9): it is required to start any project to ensure the necessary evaluation data.

<table>
<thead>
<tr>
<th>Defective opportunities (DOi) seen</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
<th>C8</th>
<th>C9</th>
<th>Total</th>
<th>Percentage from Total [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>DO1</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>41</td>
<td>0.406</td>
<td></td>
</tr>
<tr>
<td>DO2</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>31</td>
<td>0.307</td>
<td></td>
</tr>
<tr>
<td>DO3</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>29</td>
<td>0.287</td>
<td></td>
</tr>
<tr>
<td></td>
<td>101</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.000</td>
<td></td>
</tr>
</tbody>
</table>
Further, the project is developed in order to improve drinking water quality indicator - pH, on the opportunity side that ensures its classification within the specifications LIS / LSS (DO1) and also strategy of detecting, quantifying and eliminating non-conformities in order to obtain a high level of qualitative performance.

3.2. Measurement of current performance levels (M)
Current performance level on ensuring water quality classification indicator of consumption – pH, within specifications (LIS = 7 and LSS = 7.5) is based on the situation of nonconformities results (Xi) from the review of the quality analysis report of appropriate drinking water quality characteristics for a representative sample consisting of 30 water samples taken from different sources on the same site, the values of which are presented in a statistically unsorted string, as follows: 7.0; 6.4; 6.6; 7.2; 6.6; 6.7; 7.9; 7.1; 7.2; 7.3; 6.4; 6.5; 8.0; 8.1; 7.5; 7.6; 7.7; 7.0; 7.8; 6.7; 7.3; 7.4; 6.5; 7.1; 7.9; 6.9; 7.1; 7.6; 7.0; 7.5; 7.2.

For the graphic representation of the density of probability for a normal distribution (Gauss) of results corresponding to the strategy of accurately detection of irregular pH values, measure and dispose them, is to necessary to follow the following procedure [4, 5]:
a) it is sorted from low to high, the string of measured values of quality characteristic, so that: 6.4; 6.4; 6.5; 6.5; 6.6; 6.7; 6.7; 6.9; 7.0; 7.0; 7.1; 7.1; 7.1; 7.2; 7.2; 7.2; 7.3; 7.3; 7.4; 7.5; 7.5; 7.5; 7.5; 7.6; 7.6; 7.7; 7.8; 7.9; 7.9; 8.0; 8.1.
b) there are noted the minimum values $X_{min}$ as well as, the maximum $X_{max}$ of the above string:

$$X_{min} = 6.4; \quad X_{max} = 8.1$$

(1)

c) it is determined the amplitude of the string:

$$R = X_{max} - X_{min} = 1.7$$

(2)
d) it is determined the number of classes, $K$ from the row of sorted values with Sturges formula:

$$K = 1 + 3.22 \cdot \lg n = 1 + 3.22 \cdot \lg 30 = 5.75 \approx 6$$

(3)
e) it is filled below in Table 2, the corresponding sorted values of the previously determined classes, as follows:

Table 2. The corresponding sorted values of the previously determined classes.

<table>
<thead>
<tr>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.4</td>
<td>6.7</td>
<td>7.0</td>
<td>7.2</td>
<td>7.5</td>
<td>7.8</td>
</tr>
<tr>
<td>6.4</td>
<td>6.7</td>
<td>7.1</td>
<td>7.2</td>
<td>7.5</td>
<td>7.9</td>
</tr>
<tr>
<td>6.5</td>
<td>6.9</td>
<td>7.1</td>
<td>7.3</td>
<td>7.6</td>
<td>7.9</td>
</tr>
<tr>
<td>6.5</td>
<td>7.0</td>
<td>7.1</td>
<td>7.3</td>
<td>7.6</td>
<td>8.0</td>
</tr>
<tr>
<td>6.6</td>
<td>7.0</td>
<td>7.2</td>
<td>7.4</td>
<td>7.7</td>
<td>8.1</td>
</tr>
</tbody>
</table>

f) it is determined the amplitude of the class $\delta$, with the formula:

$$\delta = R/K = 0.283$$

(4)
g) it is determined the grouping ranges for the class values and for the mean value $\bar{X}$ (see Table 3):

Table 3. The grouping ranges for the class values.

<table>
<thead>
<tr>
<th>Item no.</th>
<th>Grouping Interval $x_i \pm x_{i+1}$</th>
<th>Centered value $x_{ic}$</th>
<th>Simple Frequency $a_i$</th>
<th>Cumulated Frequency $f_i$</th>
<th>$A_i$</th>
<th>$F_i$</th>
<th>$\bar{X} = f_i \cdot x_{ic}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.0 \pm 6.7</td>
<td>6.35</td>
<td>7</td>
<td>0.233</td>
<td>7</td>
<td>0.233</td>
<td>1.479</td>
</tr>
<tr>
<td>2</td>
<td>6.9 \pm 7.1</td>
<td>7.0</td>
<td>7</td>
<td>0.233</td>
<td>14</td>
<td>0.466</td>
<td>1.631</td>
</tr>
<tr>
<td>3</td>
<td>7.2 \pm 7.4</td>
<td>7.1</td>
<td>6</td>
<td>0.200</td>
<td>20</td>
<td>0.666</td>
<td>1.420</td>
</tr>
<tr>
<td>4</td>
<td>7.5 \pm 7.7</td>
<td>7.6</td>
<td>5</td>
<td>0.167</td>
<td>25</td>
<td>0.833</td>
<td>1.269</td>
</tr>
</tbody>
</table>
h) it is determined the mean square error $\sigma$, with the formula:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}} = \sqrt{\frac{\sum_{i=1}^{20} (x_i - \bar{x})^2}{29}} = 0.497$$  \hspace{1cm} (5)$$

i) there are determined the specifications limits (lower $LIS^*$ and upper $LSS^*$) for the actual level of performance $6\sigma = 2.982$:

$$LIS^* = \bar{X} - 3\sigma = 5.632$$  \hspace{1cm} (6)$$

$$LSS^* = \bar{X} + 3\sigma = 8.614$$  \hspace{1cm} (7)$$

j) using the "Six Sigma" architecture it is represented the normal distribution curve as shown in Figure 3, related to the specific quantification of maximum performance values (appropriate $6\sigma$ level, equivalent to 3,4 defects per one million opportunities), using the normal Gaussian distribution function, $f(x)$ and also with the help of Mathcad software:

$$f(x) = \frac{1}{\sigma \sqrt{2\pi}} \cdot e^{\frac{1}{2} \left( \frac{x - \bar{x}}{\sigma} \right)^2}$$  \hspace{1cm} (8)$$

According to the graphical representation of the function $f(x)$ in Figure 3, above, for the distribution of the measured values of the characteristic quality - $pH$, relative to their average value $\bar{X}$, it results that the form "Gaussian" type distribution is within the limits of the specifications ($LIS^*$ and $LSS^*$) previously determined equations (6) and (7). Such distribution characterizes a real level of maximum $6\sigma$ performance, equivalent to 3.4 defects per one million opportunities.

3.3. Analysis quality improvement opportunities ($A$)

This study calls for undertaking measures regarding the removal or reduction of the cause / causes related to the quality problem or detect / identify precisely the lack of conformity, quantification and respectively their disposal. This stage covers the following activities: evaluation of alternatives, design improvements, culture change, proving the effectiveness and implementation [3, 4].
3.4. Improving the performances (I)
At the level of organization for which this study is done, it must be rigorously enforced the implementation of an algorithm that includes the following steps to improve performance [3, 4]:

a) continuously involvement of the organization in a number of activities that are to be implemented;

b) initiating quality improvement activities by drawing up a program of activities and allocation of necessary resources;

c) investigating the possible causes of non-conformities detected in order to increase understanding the nature of the process that are to be improved;

d) establishing cause-effect relations to identify the nature of the process towards what is to be improved;

e) initiating preventive or corrective actions on the processes in order to achieve satisfactory results and / or reduce the frequency of unsatisfactory results;

f) confirmation of improvement after implementing preventive or corrective actions;

g) maintaining over time the improvements involving changes in the specifications and / or operational procedures and necessary practices;

h) further improvement with the possibility of repeating based on new options.

3.5. Performances control (C)
Identification of actual performance measuring process (including, comparing them to the desired performance) with their actual control should prevent the recurrence of nonconformities and maintain the achievements through improvement. To maintain these results, there should be implemented four types of activities: designing effective control elements, perfecting improvements, audit controls, and developing an effective quality control [3, 4].

4. RESULTS AND DISCUSSIONS
Given that the basic requirement of measured values for hydrogen ion concentration (pH) that characterize the quality of drinking water needed in aforementioned industry, is represented by the need for a weakly alkaline nature, so that all pH values should lie strictly within the imposed specifications limits (LIS = 7.0 and LSS = 7.5). This would mean that all pH values outside these limits to be excluded, but by implementing the statistical method „Six Sigma”, those specifications limits calculated (LIS* and LSS*) are more permissible, thereby allowing extension of preliminary (imposed) specifications limits to the calculated values. It should also be noted and the desired effect of achieving a sustained maximum performance level “6σ”, equivalent to 3.4 defects per one million opportunities.

Implementing the project to improve the water quality indicator of consumption - pH, where fall within the normal range of specifications calculated as illustrated in Figure 3 above, can be an example to be followed and to improve other quality indicators, as well, while identifying new projects and improvements that can be approached and started.

Situating the distribution of values within the real specifications limits (LIS* and LSS*) ensures obtaining an efficacy index of 3.4 defective parts per million opportunities (DPMO), which corresponds to an efficiency of 99.9997%, synonymous with successful completion quality improvement project [6-10].

5. CONCLUSIONS AND REMARKS
Through the presented study on the application of statistical methods "Six Sigma" in an organization / industrial companies, it can be met the target function defined by the characteristic of improving the drinking water quality - pH. Although it is a method that is based on mathematical statistics, "Six Sigma" does not provide a toolbox difficult to use and, thus guarantees success for organizations that targets to achieve remarkable results and provide higher performance levels.

Therefore, the "Six Sigma" statistical method is addressed equally to all industrial companies which are aiming to improve performance, efficiency and quality manufacturing processes, manufactures and utilities (water, steam engines, gas, compressed air, etc.) and to reduce non-conformities within the specified limits by ensuring stability and maximum effectiveness.
REFERENCES