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The Use of Control Charts to Monitor Raw Milk Quality and Udder Health at the Farm Level

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Abstract. Statistical Process Control (SPC) is a very well known tool used for years in different industries to measure variability of different parameters in order to take actions. Despite the fact that these methods are known, the use of them is not popular especially in food industry. Taking into account the fact that the use of these tools was not sufficient studied in literature it was decided to find out if these kinds of instruments can be also used in small farms. It was decided to use data from a small farm from three consecutive years and to apply a statistical process control tool in order to monitor raw milk quality and udder health. It was taking into account data from 2010, 2011 and 2012 like, milk quantity, quantity, fat and protein content but also the somatic cell count (SCC) and total number of germs (TNG). For the variability analysis was used a control chart called Exponentially Weighted Moving Average, which is typically for observation done individually at different time intervals. The used control chart provided insight into sampled data by displaying the level of normal and random variation by revealing the observations that indicate the real change. Control limits were calculated based on the data collected in a time frame called the "control period". The control limits in our study were based on data from January 2010 and December 2012, since there was no indication of special variation in that period and so the process appeared to be "in control". The variation in different quality parameters like fat was between 4,2%-4,5% in winter and 3,9%-4,1% in summer. The same was in case of milk protein who varied between 3,2% and 3,8%. The control charts upper limit was restricted due to legislation en force at 400.000 / ml for SCC and 100.000 / ml in the case of TNG. It can be concluded that monitoring individual raw milk using SPC charts will help dairy managers to identify changes, out of control situations and to take actions in order to keep the process between the established control limits.

Keywords: Statistical Process Control, control charts, dairy, milk, udder health

INTRODUCTION

Statistical process control (SPC) is a collection of tools useful in achieving process stability through the reduction of variability (Montgomery, 1997), being used for years in different industries to measure variability of different parameters in order to take corrective actions. Being tools used in quality control, their results can be viewed also from a quality assurance perspective in companies. Despite the fact that these methods are known, their use in food industry or animal production is not very popular.

The major tools in SPC are control charts (CC). The first quality charts were developed by Walter Shewhart (Shewart, 1931) in the 1920's for the telephone industry. These charts are built on the principle of allocating the observed variation in performance to categories their sources: common causes or special causes (Shewhart, 1931; Deming, 1986; Montgomery, 1997). Control charts have been shown useful in the analysis of performance data in many industries but have not been widely applied in livestock production, but their use has been mentioned in literature (Sard, 1979; Wrathall and Hebert, 1982; Quesenberry, 1997; Polson *et al.*, 1999).

More recently these tools were used to provide capability indices for udder health in dairy cows (Niza-Ribeiro *et al.,* 2004; Lukas *et al.,* 2005, 2008), to monitor raw milk quality in processing dairies using charts and process capability (Pentelescu and Muresan, 2008 a, b) and to monitor milking parlours by the use of control charts (Wallace, 2009).

Control charts may also be used to estimate the parameters of a production process, and, through this information, to determine process capability, which is directly related to process variability (Montgomery, 2009).

The use of SPC tools to monitor milk quality at the farm level was not found in literature and to our knowledge. We consider that the use of some models to relate the influential inputs to process outputs will help to determine the nature and variability in order to take corrective actions, being known that natural variation in raw foods can be about 10% (Luning and Willem, 2009). “In many processes, once the dynamic nature of the relationships between the inputs and the outputs are understood, it may be possible to routinely adjust the process so that future values of the product characteristics will be approximately on target” (Montgomery, 2009).

MATERIALS AND METHODS

Taking into account the fact that the use of these tools was not sufficient studied in literature it was decided to find out if these kinds of instruments can also be used in small farms. It was decided to use data from a small farm from three consecutive years and to apply a statistical process control tool in order to monitor raw milk quality and udder health. It was considered data from 2010, 2011 and 2012 following next parameters: milk quantity, fat and protein content, somatic cell count (SCC) and total number of germs (TNG).

For the variability analysis was used a control chart called Exponentially Weighted Moving Average modified, which is typically for observation done individually at different time intervals. We modified the formula using not individual observations but instead monthly means of every parameter.

First introduced by Roberts (1959), EWMA charts have a fairly long history, but only recently have its properties been evaluated analytically (Crowder, 1987; Lucas and Saccucci, 1990).

The statistic was done considering the formula:

$$EWMA_t = \lambda Y_t + (1- \lambda) EWMA_{t-1} \quad \text{for } t = 1, 2, ..., n.$$

where:

- $EWMA_0$ is the mean of historical data (target)
- Y_t is the observation at time t
- n is the number of observations to be monitored including $EWMA_0$
- $0 < \lambda \leq 1$ is a constant that determines the depth of memory of the EWMA.

The center line for the control chart is the target value or EWMAo. The control limits are:

$$\text{Upper Control Limit (UCL)} = EWMA_0 + ks_{ewma}$$
$$\text{Lower Control Limit (LCL)} = EWMA_0 - ks_{ewma}$$

where the factor k is either set equal 3 or chosen using the Lucas and Saccucci (1990) tables.

Process capability compares the output of an in-control process to the specification limits by using capability indices. The comparison is made by forming the ration of the spread between process specifications to the spread of the process values, as measured 6 process standard deviation units.

For statistical representation and interpretation, it was used Statgraphics and Minitab 15 statistical software.

RESULTS AND DISCUSSIONS

The used control chart provided insight into sampled data by displaying the level of normal and random variation by revealing the observations that indicate the real change. Control limits were calculated based on the data collected in a time frame called the "control period". The control limits in our study were based on data from January 2010 and December 2012, since there was no indication of special variation in that period and so the process appeared to be "in control". The number of cows under investigation was by yearly means 18.5 heads for 2010, 18.6 for 2011 and 20.33 for 2012. After changes in breeding technology and animal population the milk quantity, it almost doubled over the three years (*Fig. 1*).

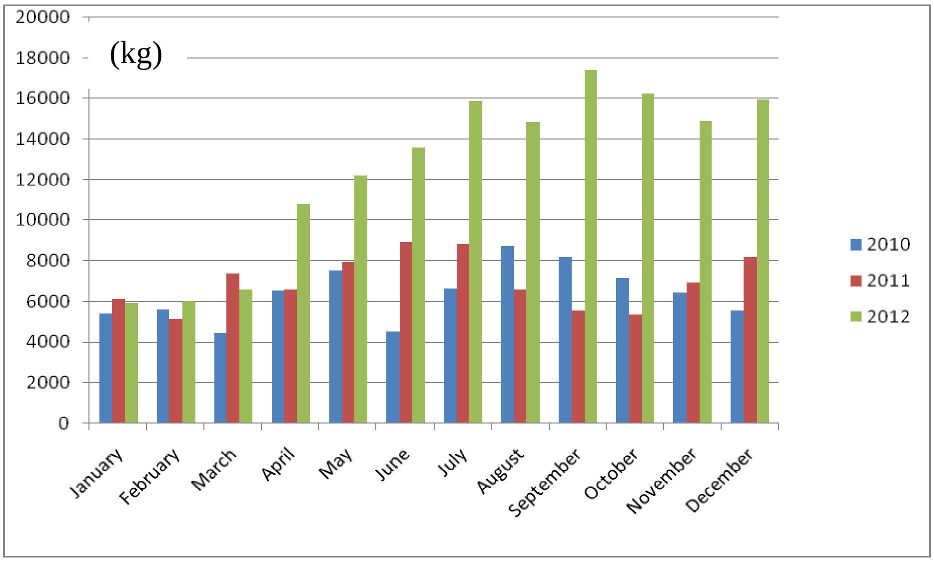


Fig. 1. Milk quantity for the three consecutive years

The variation in different quality parameters like fat was between 3.86% and 4.88% in winter and between 3.9% and 4.1% in summer. The calculated limits in the case of fat were between 4.00 and 4.39 (*Fig. 2*). As already expected increases in fat content were observed in winter for the whole 3 years with some out of control points.

The control charts were designed under the assumption that the data come from a normal distribution with a mean equal to 4.24% and a standard deviation equal to 0.14. These parameters were estimated from the data. Of the 36 non-excluded points shown on the chart, 5 are beyond the control limits. If in the case of upper out of control points it is not a problem, unfortunately the out of control point in the lower side must be investigated. The causes must be established and corrective plan must be used, due to the fact that the graphic was following same trajectories for the next years. August and September are months in which the feed at the farm level can be proper adjusted to have the whole process under control being better managed in the second year.

The same was in case of milk protein, which varied between 3.2% and 3.8%. The control charts upper limit was restricted to 3.51% and the lower limit was 3.31% (*Fig. 3*). The control charts are constructed under the assumption that the data come from a normal distribution with a mean equal to 3.41% and a standard deviation equal to 0.09. These parameters were estimated from the data. Of the 36 non-excluded points shown on the charts, 3 are beyond the control limits. An out of control point, which is problematic was measured for the summer of 2012. Again, for this period of the year a plan of corrective actions must be established at the farm level to keep the process between control limits.

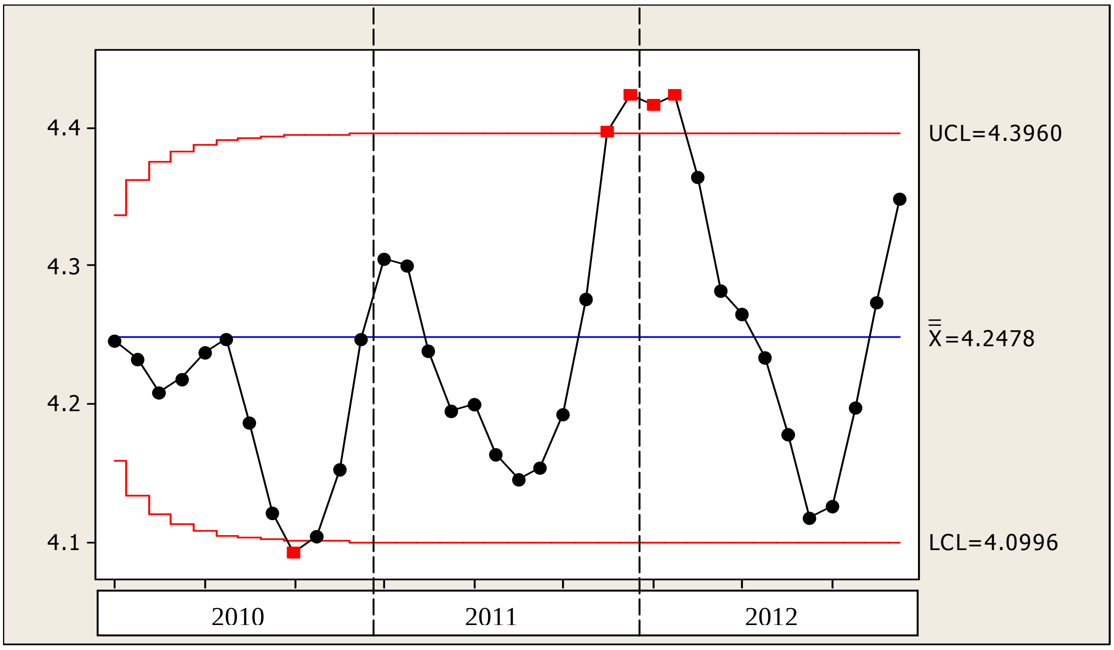


Fig. 2. Modified EWMA chart for fat

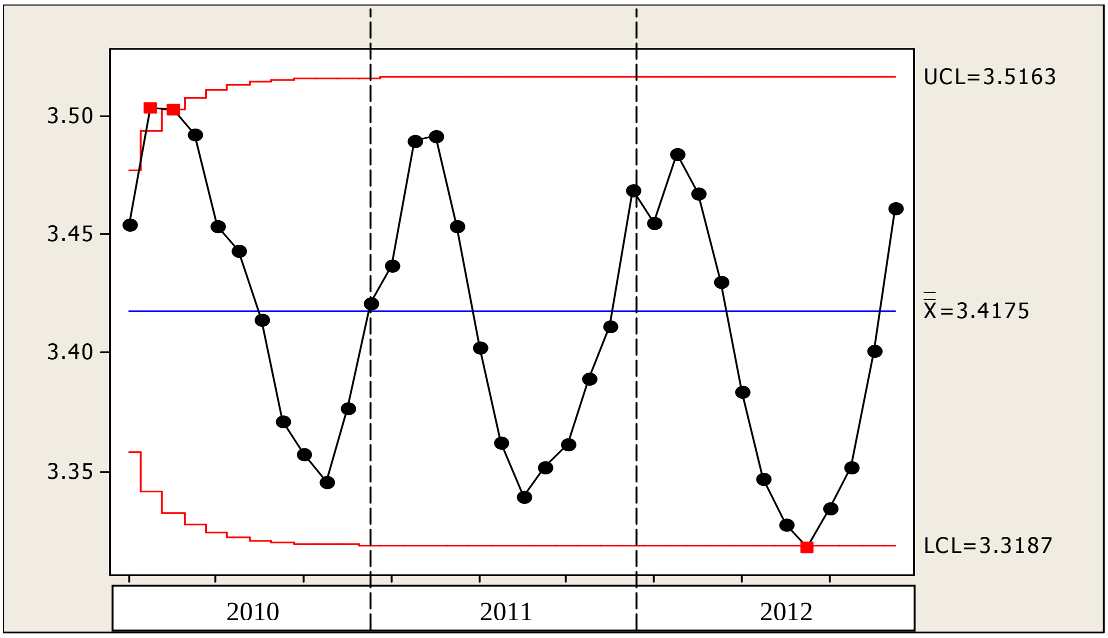


Fig. 3. Modified EWMA chart for protein

Considering the somatic cell count (SCC) which is related to udder health, the upper limit must be restricted due to legislation en force at 400.000/ml. Anyway using our calculation method the upper control limit was 144183 SCC/ml and for the LCL 130150 SCC/ml (*Fig. 4*). The control charts are constructed under the assumption that the data come from a normal distribution with a mean equal to 137167 SCC/ ml, and a standard deviation equal to 7016.21. These parameters were estimated from the data. Of the 36 non-excluded points shown on the charts, 3 are beyond the control limits. Even if not all the points plot are not inside the control limits they behave in a systematic or nonrandom manner, the out of control points below 130150 SCC /ml could not be considered for corrective actions.

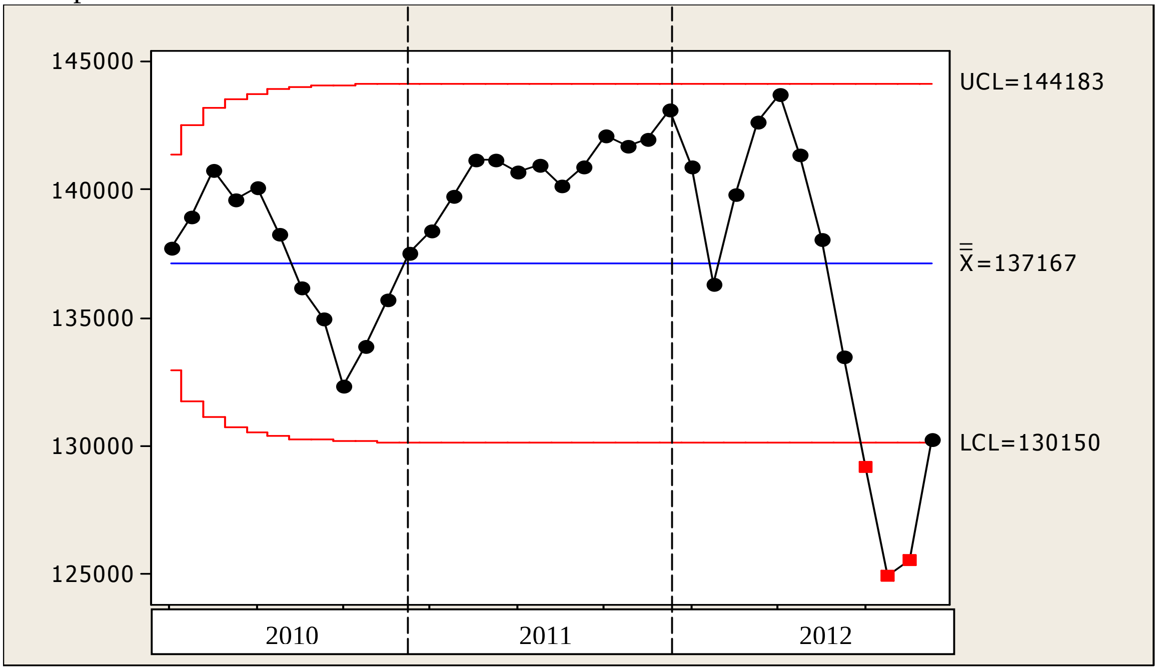


Fig. 4. Modified EWMA chart for somatic cell counts

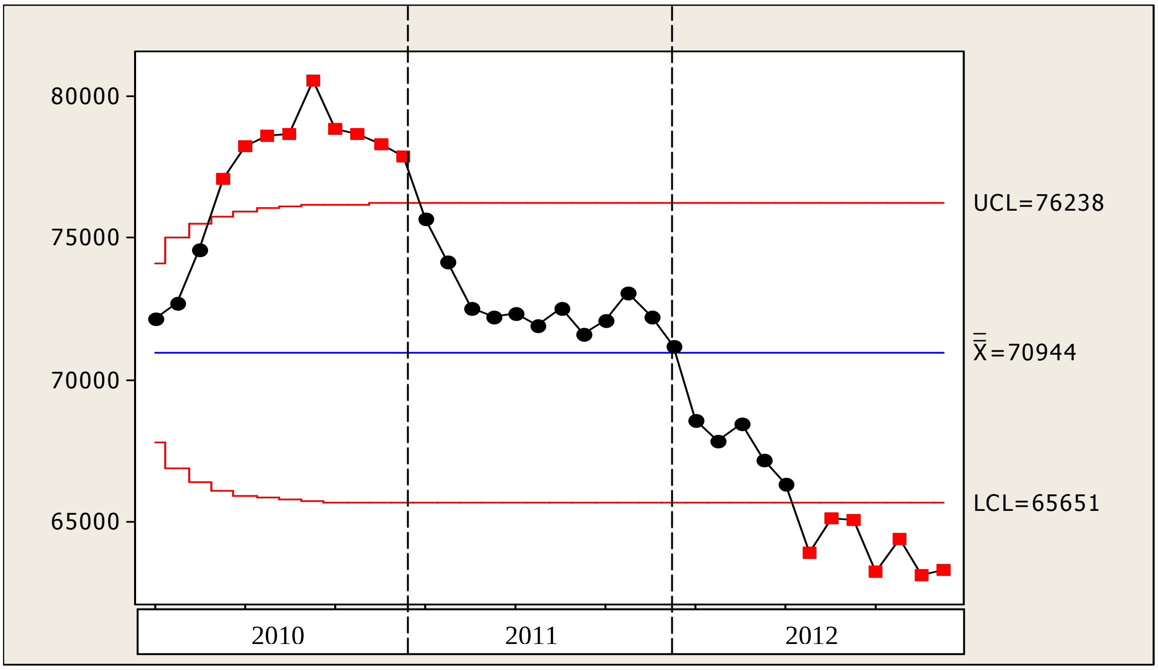
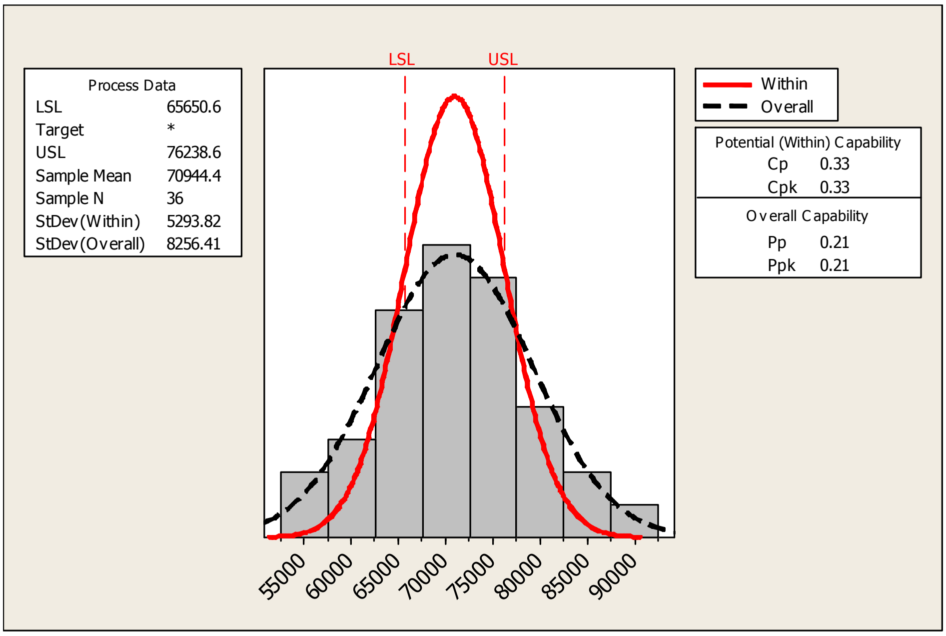


Fig. 5. Modified EWMA chart for total number of germs.

The Total Number of Germs (TNG) is restricted due to the legislation in force at 100000/ ml. Our control limits are in between 76238/ ml and 65651/ ml (*Fig. 5*). The control charts are constructed under the assumption that the data come from a normal distribution with a mean equal to 70944.4 and a standard deviation equal to 5293.82. Of the 36 non-excluded points shown on the charts, 16 are beyond the control limits. What it was observed was that in the case of the year 2010 were 9 out of control point (from April till December). Evan if these out of control points are not larger then the legislative requirements a corrective action plan is necessary to put in place. That was in fact established at the farm level thru the aim of some special hygienic rules, with positive results starting with the beginning of the year 2011.

The procedure of process capability is designed to compare a set of data against a set of specifications. The goal of the analysis is to estimate the proportion of the population from which that data come which falls outside the specification limits. In our case, a normal distribution was fit to a set of 36 (*Fig. 6*). 52.14% of the fitted distribution lies outside the specification limits. If the normal distribution is appropriate for the data, this estimates the percent of the population, which lies outside the specifications.

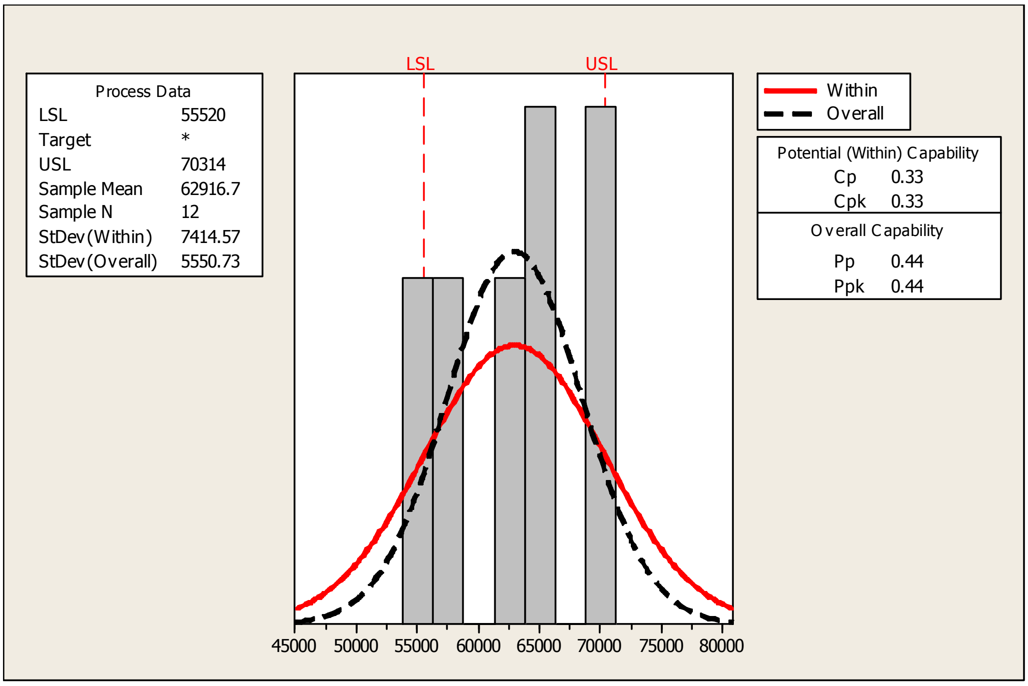


C_p= Process Capability. Value: at least = 1. C_{pk}= Process Capability Index. Value: at least = 1.
P_p= Process Performance. Value: > 1. P_{pk}= Process Performance Index. Value: > 1.
Fig. 6. Process capability 2010-2012

Several capability indices have been computed to summarize the comparison of the fitted distribution to the specifications. One common index is Pp, which in the case of the normal distribution equals the distance between the specifications limits divided by 6 times the standard deviation. In this case, Pp equals 0.21, which is usually considered to be not good. Ppk is a one-sided capability index, which in the case of the normal distribution divides the distance from the mean to the nearer specification limit by 3 times the standard deviation. In this case, Ppk equals 0.21.

Since capability indices are statistics, they will vary from one sample of data to another. The 95.0% confidence intervals show how much these statistics might vary from the true values given the fact that only 36 observations were taken.

To better understand how process capability was performing for the year 2012 we applied the same procedure of a normal distribution, which was fit to a set of 12 observations. 18.16% of the fitted distribution lies outside the specification limits (*Fig. 7*). In this case, Pp equals 0.44, which again is usually considered to be not good. In this case, Ppk equals to 0.44. Even so, we need to consider the fact that the process capability was facing an improvement (aloust doubling from 0.21 to 0.44) which means that the process was following a better milking hygiene procedure in 2012 fact that was confirmed by the farmer too.



C_p= Process Capability. Value: at least = 1. C_{pk}= Process Capability Index. Value: at least = 1.
P_p= Process Performance. Value: > 1. P_{pk}= Process Performance Index. Value: > 1.
Fig. 7. Process capability for 2012

CONCLUSION

Quality control and improvement involve the set of activities used to ensure that the products and services meet requirements and are improved on a continuous basis. Since variability is often a major source of poor quality, statistical techniques, including SPC are the major tools of quality control and improvement starting from the farm level. Raw milk quality cam be monitored with these tools in order to take corrective actions. A very important part of the corrective action process associated with control chart usage is the out-of-control-action plan (OCAP) (Montgomery, 2009). An OCAP is a flow chart or text-based description of the sequence of activities that must take place following the occurrence of an activating event. The use of a OCAP at the farm level is a necessity. It can be successfully used to monitor raw milk quality, but also udder health.

It can be concluded that monitoring bulk tank raw milk using SPC charts will help dairy managers to identify changes, out of control situations and to take actions in order to keep the process between the established control limits.

Further investigations are needed to identify and the nature of the relationship between the important variables and the process output.

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