STATISTICAL QUALITY CONTROL OF SUPPLIERS' MANUFACTURING PROCESSES

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ABSTRACT: *ISO 9001, the leading industry standard to improve productivity and efficiency of an organization, defines the requirements of a quality management system to produce quality products and services so to meet customer needs. One of requirements refers to control of externally provided processes, products and services so that these do not negatively influence the ability of an organization to achieve its quality objectives. That is why external providers are very important for every organization. In this context, the main objective of this paper is the quality control of suppliers'manufacturing processes of an organization operating in the automotive industry, because it has appeared a chronic problem on the engine assembly line related to one of the parts – a camshaft. The key elements used in this analysis were capability indices in combination with control charts. Minitab software was utilized to process the output data.*

KEY WORDS: *suppliers, statistical quality control, control charts, capability indices.*

1 INTRODUCTION

One of the seven quality management principles - the basis of the ISO 9000 family of quality standards is relationship management (ISO 9000, 2015).

This principle states that for a sustained success, organizations manage their relationships with interested parties, such as suppliers (providers).

Relationship management with the suppliers of an organization is of particular importance because the providers influence the performance of an organization, too. So, this principle of quality refers to the mutually beneficial relationship between the organization and its suppliers, which will increase the ability of both to create value.

ISO 9001, one of the ISO quality family standards that become the leading industry standard to improve productivity and efficiency, defines the requirements of a Quality Management System (QMS) to produce quality products and services so to meet customer needs and expectations (ISO 9001, 2015).

These requirements are designed to be applicable to any kind of organization and describe a set of elements that will guide an organization in QMS implementation, maintenance and improvement. The ISO 9001 requirements are broadly separated into 11 clauses (sections).

One of the requirements ruled in this standard, under clause 8.4, refers to „Control of externally provided processes, products and services".

Every organization must:

- determine and apply criteria for evaluation, selection, monitoring of performance and re-evaluation of external providers;
- determine the controls to be applied to externally provided processes, products and services;
- ensure that externally provided processes, products and services are in concordance with the requirements of organizations.

In the automotive industry, because about 60% of finished price of products are allocated to raw material and purchased parts from the providers, the importance of suppliers' management and their performance must be a continual process (Darestani & Ismail & Ismail & Yusuff, 2010).

There are a number of criteria which can be used to analyse suppliers, one of the main being quality, as shown in figure 1 (Suraraksa & Shin, 2019), (Abdolshah, 2013).

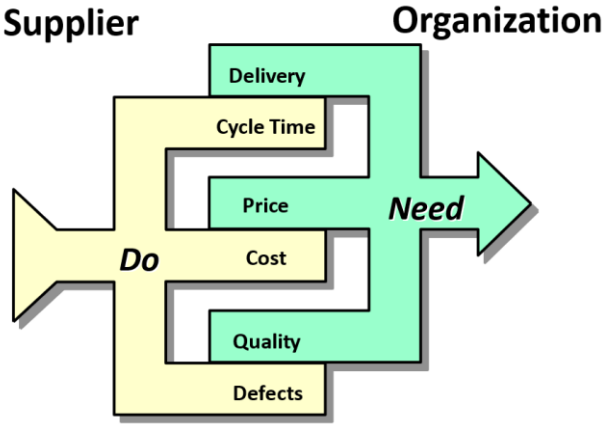

Fig. 1 Organization – supplier interaction

ISO 9000 standard defines quality as "the degree to which a set of inherent characteristics of an object (entity, unit) fulfils requirements".

The same standard defines quality control as a "part of quality management focused on fulfilling quality requirements". Quality control represents the actions (the techniques and activities with operational character) that allow monitoring the process and the realized products, as well as elimination of non-conforming objects or deviations from what was foreseen.

Statistical quality control refers to that part of quality control in wich statistical techniques are used. It can be classified into 2 types: statistical process control and statistical product control.

2 STATISTICAL PROCESS CONTROL AND PROCESS CAPABILITY

The aspects regarding statistical proces control, SPC in combination with process capability analysis were been analyzed by a lot of practitioners for decades.

SPC is a well-establish quality management tool, applied during the manufacturing process of products/providing process of services, used to control how a process works and if corrective actions must be performed to avoid the occurrence of non-conforming units.

Statistical proces control refers to the evaluation of process stability over time. In order to judge the stability of a process or in other words the statistical control state of a process, Shewhart control charts are often used. They are considered one basic tool of SPC and their role is to distinguish between the variation in the plotted measure due to random causes and that due to special causes. Random/common sources of process variation are inherent in every process over time. Special sources of process variation are other than those inherent process variation (ISO 11462-1, 2001).

A process found not to be in the state of statistical control is said to be "out of control" because it is affected by special causes and requires intervention to bring it "in (statistical) control".

Proces capability represents its ability to realize a characteristic that fulfill the requirements for that characteristic (ISO 22514-4, 2016).

Process capability analysis refers to the evaluation of how well a process meets design specifications. It provides an assessment of the natural variation of a process and an estimation of the amount of nonconforming items that can be expected. This can help an organization guide decisions regarding process improvement.

For continuous data, the process capability analysis estimates the process spread (natural variation of a process) and compares it with the design specifications.

2.1 Shewhart control charts

A control chart or a SPC chart represents a visual assessment of the process variability by graphically plotting of the results (appropriate statistics) obtained for a succesion of samples (subgroups of items of a specified size) periodically collected from the process (ISO 7870-1, 2019).

A control chart containts also a centre line that reflects the level around which the plotted statistic may be expected to vary. In addition, there are two lines, called control limits, placed one on each side of the centre line that define a band within which the calculated statistic can be expected to lie randomly when the process is stable. The two control limits are used as a criterion for judging the state of process control (ISO 7870-2, 2013).

There are eight generally accepted tests to check for special causes of variation. Typical signals for an out of control process are points outside the control limits or violations of any of the within-limit rules like as cycles, trends, shifts, runs above or below the center line, hugging the center line or control limits. When any of the above patterns is presents, an investigation shall be initiated to identify the special cause and it is a need for action on the process.

There are mainly two types of Shewhart control charts: variables control charts for quantitative data and attributes control charts for qualitative data.

2.2 Process capability indices

Over the years, practitioners have asserted that process capability is a vital part of any quality-improvement process program (Montgomery, 2013), (Mitra, 2016), (Puspita & Fazri & Pasaribu, 2017), (McCormack & Harris & Hurwitz & Spagon, 2000)

Process capability has three important components: the design specifications, the centering and the spread of natural process variation.

To determine a process capability respectively whether the process has the ability to produce units whose characteristics fulfil the technical requirements (specified tolerance interval) different statistical measures are used (ISO 21747, 2006):

- process capability indices, Cp and Cpk: statistical estimates of the outcome of a characteristic from a process which has been demonstrated to be in a state of statistical control;

These indices are calculated taking into account within subgroups'variation, so they measure only

inherent variation of the process, generated by common causes.

- process performance indices, Pp and Ppk: statistical measure of the outcome of a characteristic from a process which may not have been demonstrated to be in statistical control.

These indices are calculated considering within and between subgroups'variation, so total process variation including special causes, too. That's why these indices are typically considered to be more realistic measure of long-term process capability.

So, the difference between these two categories of indices lies only in the calculation of the standard deviation: Cp and Cpk utilizes the standard deviation as calculated from collected samples whereas Pp and Ppk utilizes the standard deviation as calculated from the overall data set.

The goal is to have a high Cp, and get the process centered so the Cpk increases and approaches Cp. The same applies for Pp and Ppk.

Commonly used measures of proces's capability are capability index Cpk and performance index Ppk; these indices take into account the centering/location of the process among the midpoint of the specifications, and thus they can be used to determine if a process is acceptable not only capable.

Capability and performance indices can be converted into PPM: Parts Per Million defective respectively the number of units expected to be found defective in a lot size of 1 million.

Table 1. Relation between Cpk and PPM

Cpk	Sigma level	Within specification	PPM
1,33	+/- 4	999.937	63
1,5	+/- 4,5	999.993,2	6,8
1,67	+/- 5	999.999,4	0,6
2,00	+/- 6	999.999,998	0,002

Considering the recommendations given in quality standards and by different practioners, the following guideline could be drawn:

- Cpk index is recommended to be used for in statistical control/stable processes and normally distributed data; Cpk>1,33 should be achieved;
- Ppk index is recommended to be used for out of control/unstable processes with output meeting specifications (for non normally distribution data, only performance indices can be calculated); Ppk>1,67 should be achieved;
- Cpk=Ppk when a process is in control/stable;
- According to Six Sigma philosophy, minimum default capability requirement for most characteristics must be 1,50. Technically speaking, Six Sigma considers a process being acceptable only after achieving a maximum PPM of 3,4. There is a direct correlation between Cpk or Ppk and PPM, because only indices that are greater than 1,50 are achieving this goal. (Montgomery, 2013), (Kotz, 1993) (Steiner & Abraham & MacKay, 1998), (AIAG, 1995).

A process that is operating within control limits is said to be in control. An in control process that is operating within specification is said to be capable.

A capable process that is in control will produce a predictable amount of good products.

3 PRACTICAL WORK

The following situation was considered in an automotive organization: there has been a chronic problem on the engine assembly line related with one of the subansamblies respectively a shaft. This problem had caused poor-fitting assemblies which had led to scrap and rework.

The problem was related to a key (special) characteristic, the lenght of the shaft that has to be 600 mm±3 mm to meet design specifications.

For this product, organization has 3 suppliers (A, B and C).

Because of this unsatisfactory delivery performance, a total of 100 observations (20 samples of 5 shafts each) have been collected from each of the suppliers.

Then a Xbar-R chart was run and process capability study has been carried out for this special characteristic.

3.1 Methodology

In order to monitor a process and its output by using statistical process control and process capability analysis, it is considered that the following steps should be taken (Kotz & Johnson, 1993), (Wooluru & Swamy & Nagesh, 2014):

- checking the stability of the process by using Shewhart control charts;
- testing the concordance of the measured data with the normal distribution;
- identifying another distribution to model the data if they are not normally distributed;
- transforming data (applying a function) to make them fit a normal distribution; different type of transformations may be used, the usual ones being Box-Cox and Johnson.

Box-Cox transformation is a simple (power) function that is easy to understand, but it cannot be used if the data contains negative numbers or zeros.

Johnson transformation uses a complex function, but transforms a wider variety of nonnormal data than the Box-Cox transformation.

If both Johnson and Box-Cox transformation are effective for the data, only Box-Cox transformation provides within-subgroup analysis (so Cpk and Cp values may be calculated).

If non-normal distributions or no transformations are appropriate, the following possible reasons can be taken into account: data may not come from a single source, process may not be stable or data may contain outliers, that shall be removed.

If an appropriate distribution or transformation cannot be find it is recomended to use the distribution with the lowest statistic (the more closely the data set follows that distribution); in this situation is required to use a simpler capability measure of capability, such as percentage out of specification.

- calculating capability and performance indices.

3.2 Results and discussion

3.3

All the requirements mentioned in sub-chapter 3.1 have been verified as follows and the results are presented bellow for each supplier, using Minitab statistical software (Minitab, 2010).

The graphs plotted in figures 2, 3 and 4 present the control charts by variables for all three suppliers, respectively X-bar and R chart which plots the mean (average) of samples and the range within subgroups.

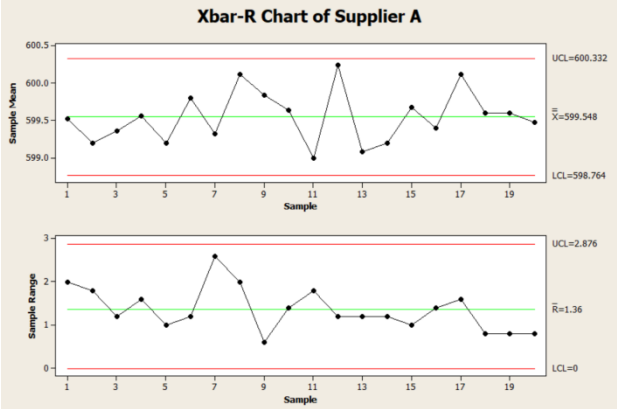

Fig. 2 Checking process stability - supplier A

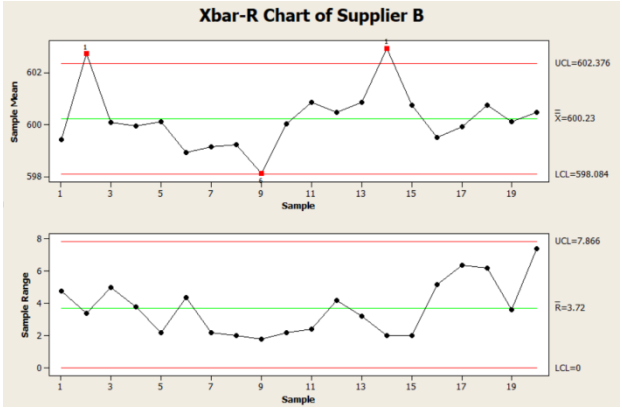

Fig. 3 Checking process stability - supplier B

In figure 2 and 4 it can be seen that all dots (data) are falled within the control limits of both charts and no other patterns are present on the graphs (there are not red flags to indicate violations of any of the eight generally accepted tests).

So it can be stated that the manufacturing processes of supplier A and C are stable, respectively no special causes of variation appear in their processes. As a result, these control limits can be used as a guide in the process of each supplier.

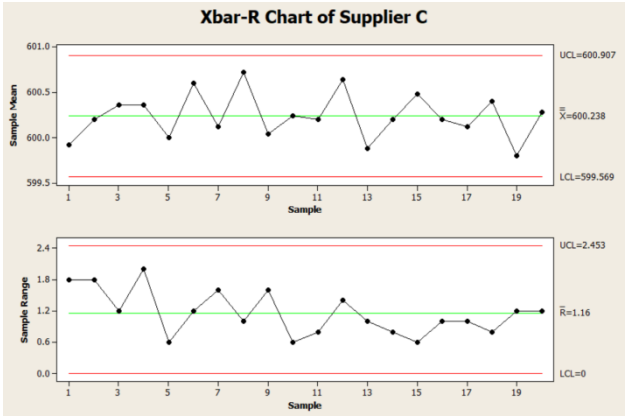

Fig. 4 Checking process stability - supplier C

Regarding the supplier B, it has been observed from figure 3 that there are present typical signals for an out of control process – points highlighted in red and including a number indicating which special cause test has been violated:

- test number 1 (one point more than 3 standard deviations from center line) failed at points (samples) 2 and 14.
- test number 6 (4 out of 5 points more than 1 standard deviation from center line (on one side of center line) failed at point (sample) 9

It can be concluded that the manufacturing process of supplier B is not under statistical control and is operating under the influence of special causes of variation, too.

Testing the concordance of the measured data with the normal distribution is displayed in figures

from 5 to 7, using a graphical method – the normal probability plot.

The general rules when testing the concordance with any type of distribution, if that distribution fit the data are:

- the plotted points will roughly form a straight line and they fall close to the fitted line;
- the characteristical statistic of the used test (by default, Minitab performs an Anderson-Darling test) will be small and the associated probability value, p-value (a number describing how likely it is that the data would have occurred by random chance) will be larger than choosen α-level (level of statistical significance), p-value > α. Common choosen level for α include 0,05 and 0,1.

Generally, p-value > 0,05 indicates that a distribution fits the data (or a transformation makes the data normal).

Test results of normal probability plot for supplier A, from figure 5, shows that p-value=0,029 is less than the significance level α= 0,05. Thus, it is concluded that the measured data cannot be regarded as taken from a normal process and prior to perform capability analysis for this data it is required to identify another distribution to model the data.

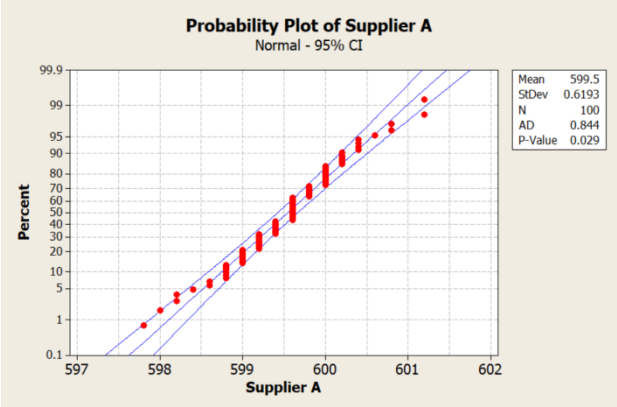

Fig. 5 Testing the normality of data – supplier A

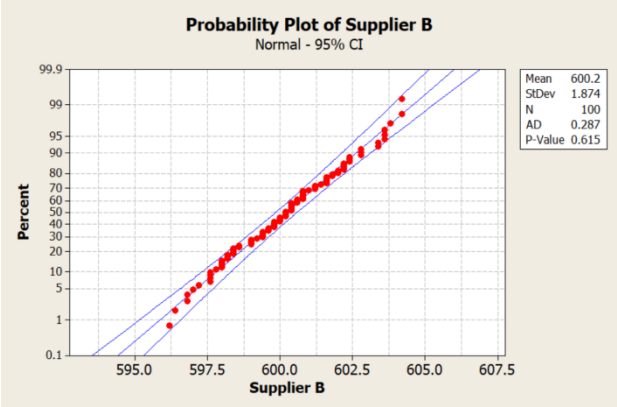

Fig. 6 Testing the normality of data – supplier B

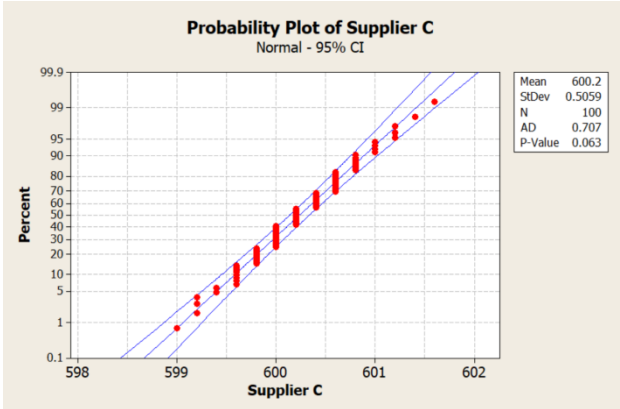

Fig. 7 Testing the normality of data – supplier C

Regarding the suppliers B and C (figure 6 and 7), because p-value for both of them is greater (0,615 and 0,063) than the significance level α=0,05 it can be stated, with 95% confidence level, that data are normally distributed for both.

Figure 8 shows the type of distribution for suplier A. To identify a suitable distribution for measured data of shafts produced by supplier A, Anderson-Darling goodness of fit test was used. It has resulted that the appropriate distribution that fits the data is the logistic distribution; that is because its associated probability value, p-value=0,055 is the highest among all 14 distributions provided by Minitab and is greater than the significance level α=0,05.

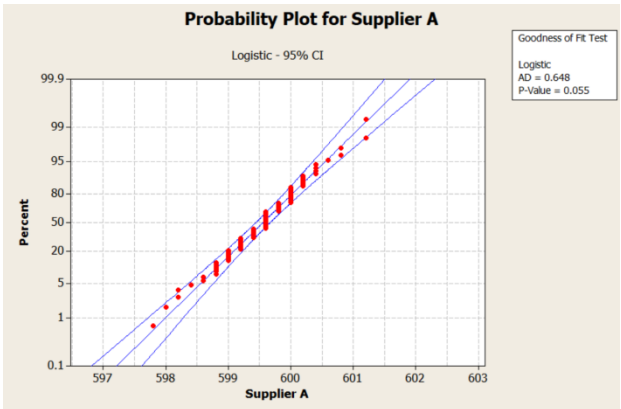

Fig. 8 Identifying distribution of data – supplier A

After validating all mentioned critical aspects, process capability analysis was performed, and the results are present from figure 9 to 11.

Based on the results shown in these figures and considering the recommendations given in literature regarding the values of capability and performance indices for automotive industry (table 2), the conclusions that can be drawn regarding the manufacturing processes of suppliers are presented below.

Table 2. Relation between indices and capability

	Cpk	Ppk	Sigma
Not capable	<1,00	<1,33	<4,5
Barely capable	1,00-1,33	1,33-1,67	4,5-5,5
Capable	>1,33	>1,67	>5,5

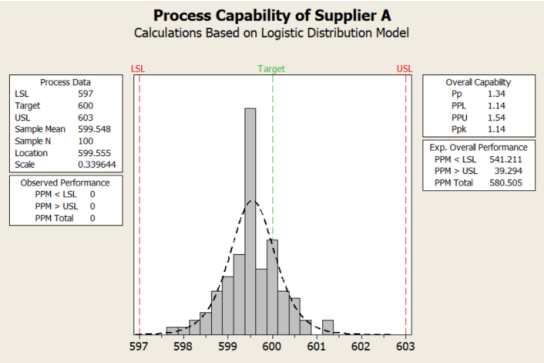

Fig. 9 Process capability analysis – supplier A

Analysis of the results presented in figure 9 leads to the following remarks regarding the supplier A:

- the histogram does not indicate evidence of any serious discrepancies between the assumed model (the logistic distribution) and the data, but shows that the process location is not on the target;
- Pp and Ppk values not close indicate that the process is not centered; it is moved toward the lower specification limit;
- the process is not capable because Ppk=1,14<1,33;
- the observed performance (the percent that was outside of the upper and lower specification limits in this data set) is 0 PPM;
- the expected overall performance (shows the percent that is expected to be outside of the upper and lower specification limits on an long term basis; this projection is based on the overall standard deviation and the process mean) is approximately 580 PPM from which, the most of them, 541 PPM under the lower specification.

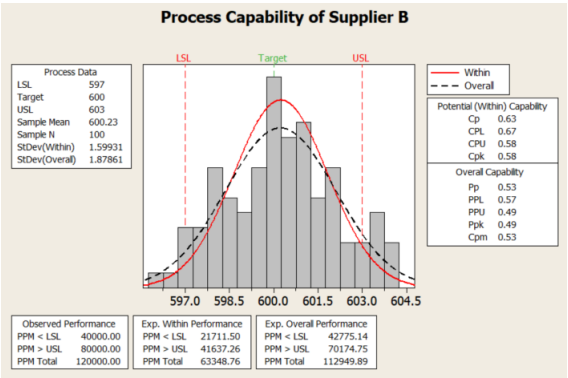

Fig. 10 Process capability analysis – supplier B

Analysis of the results presented in figure 10 leads to the following remarks regarding the supplier B:

- the histogram does not indicate evidence of any serious discrepancies between the assumed model (the normal distribution) and the data, but shows that the process location is not on the target;
- Cp and Cpk values, respectively Pp and Ppk not very close indicate that the process is not centered; and it is moved slighty toward the upper specification limit;
- the process is not stable and it is changing over time as indicated by the difference between the within (red) and between (black dashed) lines; this aspect was observed on Xbar -R control chart;
- the process is not capable because Cpk=0,58<1,00 and Ppk=0,49<1,33;
- the observed performance is approximately 120.000 PPM from which 40.000 PPM are under the lower specification limit and 80.000 PPM are above the upper specification limit;
- the expected within performance (the percent that is expected to be outside of the upper and lower specification limits on a short term basis; this projection is based on the within standard deviation and the process mean) is approximately 63.348 PPM from which 21.711 PPM under the lower specification limit and 41.637 PPM above the upper specification limit;
- the expected overall performance is approximately 112.949 PPM from which from which 42.775 PPM under the lower specification limit and 70.174 PPM above the upper specification limit.

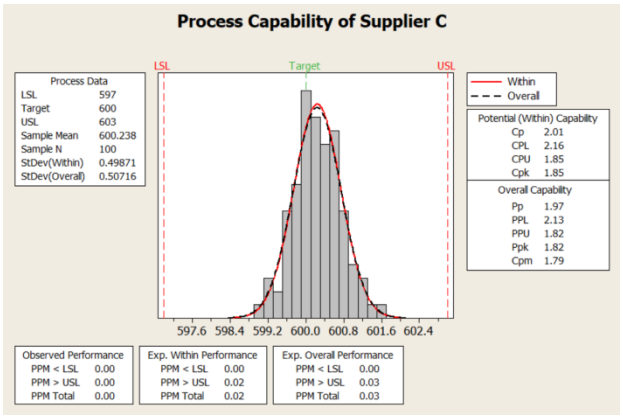

Fig. 11 Process capability analysis – supplier C

Analysis of the results presented in figure 11 leads to the following remarks regarding the supplier C:

- the histogram does not indicate evidence of any serious discrepancies between the assumed

- model (the normal distribution) and the data, but shows that the process location is not on the target;
- Cp and Cpk values, respectively Pp and Ppk not very close indicate that the process is not centered; and it is moved slighty toward the lower specification limit;
- the process is very stable as indicated by the the within (red) and between (black dashed) lines being very close together;
- Cpk and Ppk values almost identical, show that process variation is due only to the random causes and no systematic variation occur, so the process is stable;
- the process is capable because Cpk=1,85>1,33 and Ppk=1,82>1,67;
- the observed performance 0 PPM;
- the expected within performance is approximately 0 PPM (0,02 PPM);
- the expected overall performance is approximately 0 PPM (0,03 PPM)

Based on the results of supplier process capability analysis, the organization decision was as follow:

- the problem encountered on the assembly line was generated by supplier B and consequently, supplier B has been blocked for future transactions;
- supplier A was requested to initiate immediate actions, analyze its entire manufacturing process, implement corrective actions and monitor the implementation as well as it must provide the proof of process capability improvement: minimum capability requirements that must be obtained are Cpk=1,33 and Ppk=1,67;
- supplier C is considered a strategic provider for organization.

4 CONCLUSIONS

The quality of the raw material and supplied product from providers plays a critical role in the quality of the final product of an organization.

For a number of industries, control charts and capability analysis are critical activity to effectively operating a quality management system and to fulfill customer requirements regarding product quality.

Organizations operating in automotive, electronics, aerospace, food and other sectors routinely utilize control charts (for special characteristics) and process capability analysis as a major criterion to assess suppliers manufacturing processes. This allows the manufacturer to minimize direct inspection of purchased products and materials.

Only with suppliers which are capable and bring in all their product and process specific know-how for mutual benefit, an organization will be in a position to achieve the quality objectives.

Sustained success is more likely to be achieved when the organization manages relationships with its suppliers to optimize their impact on its performance.

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