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Quality Improvement With Statistical Process Control in the Automotive Industry

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Abstract

In this context of a worldwide market opening, the economy defies firms with numerous challenges, is no longer enough to produce, the current principles are based on quality as a condition for achieving productivity and competitiveness. And given that the quality is not static, it is constantly being changed, and because customers are increasingly demanding, any business organization that aims to be competitive it has to innovate. In the competitive environment in which we live organizations increasingly seek to produce quality at the lowest possible cost, to ensure their own survival. One response to this claim is the Statistical Process Control (SPC) - a powerful management method which enables quality improvement and waste elimination. This paper suggests the improvement of the quality of a process through the use of SPC in an enterprise of the automotive industry makes a brief review of concepts related with the methodology and aims to demonstrate all the advantages associated with its use as a method for improving quality and reducing waste. To accomplish this, after being completed the sample collection, the interpretations of control charts and its analysis, it was made a study of the existing methodology of implementation of SPC in the same process, and it was sought a way to adapt it to the reality of the company.

Key words: *Quality Control, Statistical Process Control, Decision Analysis, Automotive Industry, Quality improvement.*

1. INTRODUCTION

The control and quality improvement has become one of the core strategies of business for countless organizations, fabricants, distributors, transporters, financial, health and state service organizations [1]. Quality is a competitive advantage [2] and any given organization that satisfies its clients through quality improvement and control can prevail over the competition [3] [4] [5].

The increasing globalization and the increment of automotive production capacity stimulate the competitiveness of automotive plants [6] [7]. For the automotive industry the quality is expressed through the customers' satisfaction in relation to the products and offered services [8]. An answer to this increasing demand is the Statistical Process Control (SPC) – a set of tools for process management and for determination and monitoring of the quality of an organization outputs [9]. It's also a strategy for improving capability through the reduction of variability of products, deliveries, processes, materials, attitudes and equipment [10] [11] [12]. The correct implementation and use of the SPC can lead to decisions based on facts, to a growing perception about quality at all levels, to a systematic methodology concerning problem resolution, to a gathering of experience and to all kind of improvement, even in communication. Predominantly in manufacturing and concerning quality, SPC is the most widely used technique [13] and once appropriately applied, can improve operational and financial benefits [14].

Control charts are used to check for process stability [15]. In this context, a process is said to be "in statistical control" if the probability distribution representing the quality characteristic is constant over time. If there is some change over time in this distribution, the process is said to be "out of control." [16] [17]. In contrast, an out of control condition signals the presence of assignable or special cause variation of the distribution [18]. This type of variation has to be identified and eliminated in

order to be able to return the process to a state of statistical control [13] [19] [20].
Depending on the type of data, there are variable and attribute control charts. Variable control charts are intended to control process or product parameters which are measured on a continuous measurement scale such as pounds, inches, miles, etc. rather than quantity defective [21]. For a manufacturing process, the most common control charts in use are mean and variance that must be monitored jointly to ensure high quality yield. Joint Shewhart the $\bar{\bar{X}}$ and R (or s) control charts have been used to control the process mean and variance for more than half a century [22]. The attributes control charts classify processes in terms of good or bad, accept or reject, etc. Amongst all the attributes control charts, the p chart is more suitable for manipulating the variable sample size and have been used widely in industries to control the process fraction nonconforming p, since it is defined as the ratio of the number of nonconforming units in a population to the total number of units in that population [10] [23] [24].
Process capability analysis has become in last two decades a significant and well-defined tool in applications of SPC to a continuous improvement of quality and productivity [25] [26]. Following this, the ability of the process to meet specifications is assessed through calculation of one or more capability indices. The most easily interpreted of these is the proportion of items produced by the process which are within specification [27].
This paper aims to contribute to solve a quality problem, particularly the improvement of a process quality using statistical tools. A qualitative research methodology is used, in order to examine the deployment of the SPC and its impact on company's success. Moreover, according to the reached results, it is considered the possibility to suggest possible improvements regarding the use of SPC.
In this context, this paper intends to study and improve the application of Statistical Process Control philosophy in a stamping process of an automotive plant producing metal components.
This objective is justified since the company has made several unsuccessful attempts, in the past, to use statistical tools for diagnosis and monitoring but they failed due to structural problems such as: lack of capacity, lack of planning and lack of systematic methodology. Currently, the company has grown, and is in a maturity phase having already implemented the quality control system. Therefore, this paper aims to demonstrate, through a case study, how the SPC can assist in quality control and in management decision making.
This paper is organized as follows. After the introduction a literature review on Section 1 gives a general overview of the topic - the state of art, the objectives, the paper organization and the study methodology. Section 2 presents the description of the intended industrial unit and the analysis of the process, data collection and utilized control charts; the results and its details are then presented in section 3. In section 4 is made an analysis of the same results and the discussion of them. The paper concludes in Section 5 with general conclusions and recommendations.
It is widely believed that modern statistical quality control may have begun in the USA in the 1920's, where, in the Bell Telephone company in 1924, Walter Shewhart designed the first control chart and applied it in process monitoring and control. The next major developments took place in post-war Japan when in 1950, made by W.E. Deming, which was influenced by the earlier work of Shewhart. By the seventies, Japan had become a major world economic force. In the 1980's and 1990's, Western industry, started to reimport from Japan the ideas of statistical thinking and quality management [27]. Ever since W.E. Deming reintroduced SPC to corporate America in the 1980s, SPC has been implemented in diverse industries by companies around the world. For example, documented evidence of the deployment of SPC has been reported in such manufacturing industries such as automotive, automotive suppliers, chain saw, chemical, consumer electronics [14], food industry [28] and food safety [29], and environmental process control and management [16], etc. SPC has even been embraced by service industries, including healthcare, transportation, and fast food chains like Kentucky Fried Chicken and so on, so nowadays, there is a wide range of theories, systems and methodologies, along with gurus to promote them [14].
Since the main objective of this research is to demonstrate how the SPC can assist not only in quality control but also in management decision making a convenient case study from the Portuguese automotive SC was used. This kind of approach is appropriate when the boundaries of a phenomenon are not only unclear, but where there is no control over behavioural events [30]. The case study comprises one automotive supplier company, mainly, one factory unit.

2. METHODOLOGY

The methodology is a general framework used in research work and addresses a more practical perspective, referring to tangible paths used to better understand the involved certainties [31].
A case study can make an important contribution to scientific development and such research is not simplistic [32] at all since requires adequate theoretical basis, expertise, dexterity and time availability. On the other hand, certain situations and processes run the risk of going undetected in studies of larger proportions (and greater academic prestige ...) while analysing cases, even unusual cases, can be illustrative of critical conditions for systems and organizations [30].

3. THE INDUSTRIAL UNIT AND THE PROCESS

The case study is an automotive plant belonging to an industrial group founded in the 80s. This plant produces components for automotive industry, having Investigation and Development centres all over the world. It has a wide customer portfolio, representing an important player in automotive industry. It supplies the main Original Equipment Manufacturer (OEM) of the sector with stamped metallic pieces, subassemblies, welded assemblies, chassis and more recently some precision parts.

This case study has a diversified production launching over 90 different products to the market. This factory is characterized by different processes of fabrication, like manual and automatic welding of structures or small components, surface treatment and a wide range of different dimensions stamping. The production process of each product follows a specific flow, as each stamped piece requires a specific tool.

For such processes and in order to have better quality control at various stages the case study plant has implemented a wide range of SPC tools. . During the production process of metallic pieces the statistical control is required by the customer specifications as a requisite. Therefore, there are features of each conceived piece, almost all dimensional, which must be controlled, as required. Some parts are quite complex because they contain more significant features than the rest which requires to be controlled with the important support of the control charts. Likewise, the most common manufactured products require more attention and monitoring than slow movers.

This case study is confined to the study an analysis of statistical process control applied to one piece reference by analysing variables control charts for the most produced piece by the plant, and also the example of an attribute control chart for of the same piece if so is needed.

Thus, the study is based on these two types of control chart, each corresponding to production process of two references to the same piece, omitting the study of remaining pieces since the references are not very similar between each other and control method varies from one another. Also, the statistical process control of all slow movers is ignored because it is out of the scope of this study.

3.1 The Process

Being in mind the main objective of this study, a process that justifies the use of both, variables and attribute control charts is analysed. Firstly a detailed analysis of the process of a specific produced piece named "X" is performed.

Before the process analysis, it is important to describe the selected piece of measurement and study - a concave piece resembling an asymmetric cooking pot with some complexity in stamped form. In the interior, at the base, a welded element is founded, consisting of a tube and platen. To a better understanding the process flow chart of the chosen piece is described in Figure 1.

As can be seen in Figure 1 several steps are involved in the production process of piece "X". These steps are described below:

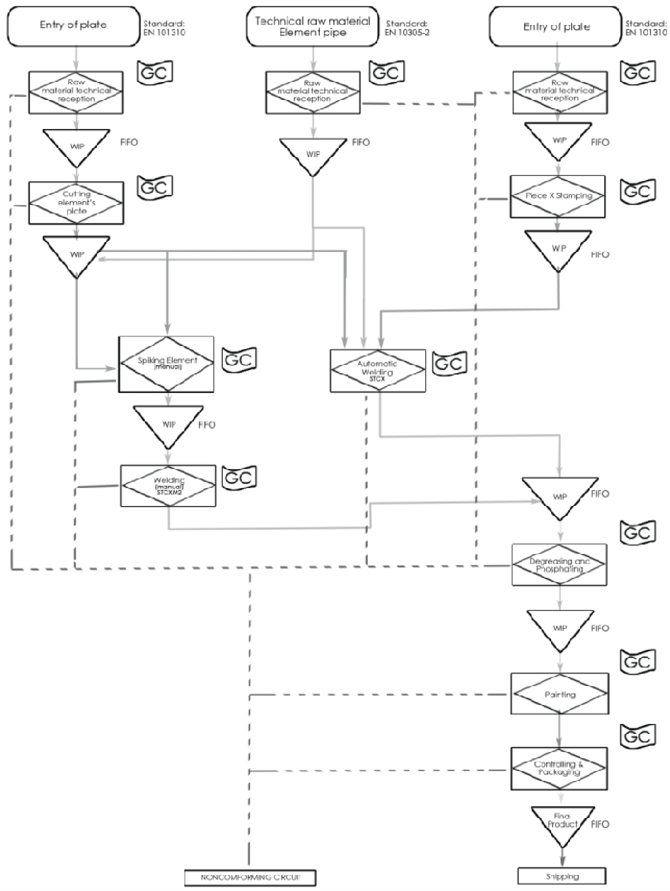

Figure 1. Piece X process flow chart.

• Step 1 –Raw material entrance is given to the rolled steel coil warehouse which is provided by cutting centres in the form of rolls, which are unloaded, the total weight and the width are measured and the certificate of raw material inspected, that contains the mechanical and chemical characteristics of the provided steel. It also occurs the input of a small tube – named Element pipe, being also inspected, and the certificate of the raw material verified and several important dimensional features measured.

• Step 2 – After the introduction of the rolled steel coils in hydraulic presses, the "X" piece ant the element’s plate are stamped. The "X" piece suffers a profound stamping which is made in a powerful hydraulic press. On the contrary, the element’s plate is stamped in a press with inferior capacity but with a significantly higher unit per minute production frequency.

• Step 3 – This step covers only the spiking of an element pipe in a plate, resulting a piece known as “The Element”

• Step 4 – At this stage of the process two welding productive means of the element on the "X" piece are present, one manual and the other automatic. At the automatic welding station lie, on a spinning dish, 6 equally distributed bases and where the pipe is automatically spiked and the element welded to the "X" piece. At the manual welding station the element already containing the spiked pipe and the plate from Step 3 is welded one by one by an operator.

• Step 5 – The welded "X" pieces pass through a degreasing and phosphating process. The degreasing is required to remove [33]the oil originated from the rolled steel coils and other oils acquired in press during the stamping process. The phosphating process is used in metalworking industry for surface protection of metals, which consists in coating the metal parts with zinc phosphate, iron and manganese in order to protect produced pieces from corrosion [34].

• Step 6 – During this step all pieces are painted black by electrostatic painting method, after which all go in the oven.

• Step 7 - By means of a handler, the pieces are removed from the paint line and automatically reach at the checkpoint and packaging. The visual control, at the end of the paint line and before the packaging, is carried out by operators to 100 %. The quality of the paint is verified in order to find marks, scratches, pores and peeling of paint. Also leaktightness of the piece at the end of the line is tested to 100 %.

• Step 8 – By means of coordinated movement, the pallets/containers are placed in a warehouse area (waiting for dispatch).

In addition to these eight steps, there is also a segregation circuit for parts and/or pieces that do not conform which is the same for all stages. That is, if one part and/or piece is not as in each step of the process, it is isolated and identified in an area specifically designated for that purpose.

3.2 Collection of data

The collection of data related to piece "X" necessary to perform the qualitative analysis and measurement it is made in two steps of the described process, after Step 2 – the element's plate stamping and after Step 4 – the welding of the element on the "X" piece. According to the technical drawing given by the customer, there are nine critical dimensional characteristics after Step 2 and four after Step 4. The other dimensions are not significant and do not require constant monitoring, however are also important. The statistical process control is made for all 13 critical dimensional characteristics as required by the customer, of which 12 are by variable control charts and one is by an attribute chart. In this paper the analysis will be made for each kind of control chart – one by attributes and one by variables.
The collection frequency for measurement and inspection is established on a sample of 5 parts per shift and there is one shift daily, resulting in one sample for measurement. The variables measurement of the dimensions is carried out by a CMM machine when data are required for a sample of 5 parts to complete variables control charts. The fixture is used after Step 7 for data collection to detect a fraction of defective products or non-conforming products with a variable sample of pieces per shift, this requires attribute control charts.

The non-conformities identified are recorded, and follow a pattern identified with the problem as well as the nomenclature of the problem or defect. This standardization allows doing a query of the data collected and the analysis of the main production line problems, epidemic problem identification and the prioritization of corrective actions for further elimination.

3.3 Control Charts

As mentioned previously, the sampling frequency is 5 pieces per shift and since there is only one per day, one point in the control chart is daily recorded. There are two types of control charts used for the existing process, one by variables and one by attributes and along this paper will be studied a control chart of each type.
In the Figure 2, it is possible to see an illustrative image of a variable control chart ($\bar{X}$, R). This chart is divided in two big parts, with 25 samples each. The variables control chart is composed by the following sections: 1) Identifying data of the chart and of the process; 2) Statistical control chart; 3) Data table in which all measurements are introduced; 4) Result section, one being the Capability Index; 5) Histogram; 6) Normal Probability chart; 7) Kolmogorov-Smirnov Test; 8) PPM (Parts per million).

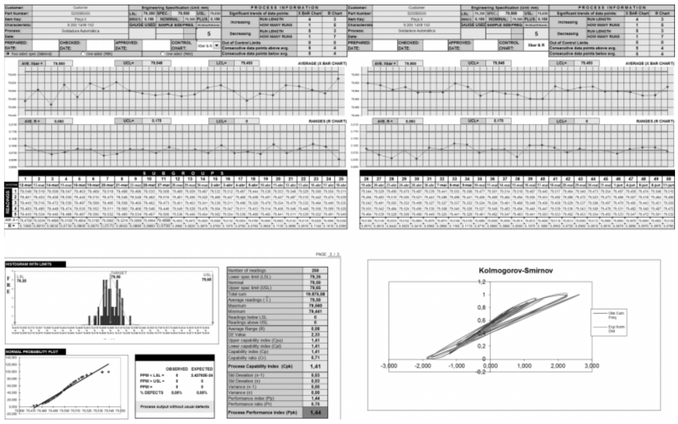

Figure 2. Variables control chart.

The next figure shows one p attribute control chart. The p attribute control chart it is made by less sections, which are: 1) Identifying data of the chart and of the process; 2) Statistical control chart; 3) Data table in which all measurements are introduced; 4) Result section, one being the Capability Index; 5) Note that this control chart has a lack of several statistical tools present in variable control charts such as normality test and histogram.

3.4 Results ob tained from ($\bar{X}$,R) Control Chart

For "studying the dimensional feature of the "X" piece a control chart ($\bar{X}$,R) is used being defined as target the dimensional feature of 79,5 mm with a tolerance of 0,15 mm. The daily collected sample of 5 pieces comes from Step 4 of the process, from automatic welding station and all pieces come from spinning dish' 6th base. The control chart samples for process analysis started at March, 12, 2013 and finished at June 11, of 2013. It is

important to note that weekends and holydays are not considered in control chart.
In the Figure 2, it is shown the sample data. Also is to be noted that this table is divided in 5 readings and gives info on dates, average and range.
After filling the data slots with collected measurements, the graphic marks start to appear. In the Figure 2, the result of the collected data is revealed. It is possible to observe the behaviour of the graphic by following the dots connected line and it is possible to see the control limits and also the average as well as the small boxes above the charts containing the value of the average, range and control limits.

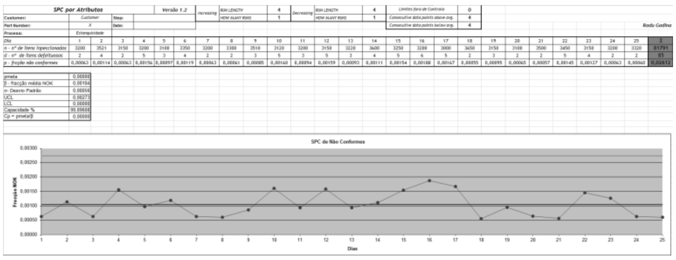

Figure 3. *p* attribute control chart.

The interpretation and the obtained results from this control chart are discussed further in the paper.
For the study of the behaviour of a p control chart of one "X" piece feature the leaktightness test is used.
The numbers of inspected items are the numbers of pieces that are tested by the control fixture.
In Figure3 the sample data is presented, which is divided into 25 subgroups and it can be seen the inspected items row, the number of defective items and non-conforming fraction. It's also to be noted that the last column is the sum of all the others.
After filling the data slots with collected measurements, the graphic marks start to appear. It is possible to observe that the behaviour of the graphic by following the dots and the connecting line, also the vertical lines, the control limits and the average are shown.
The interpretation and the obtained results from this control chart are going to be discussed further in the paper.

4. RESULT ANALYSIS

After the data insertion in control charts and after making the observation of graphs' shape it is possible to deduce some indices, like capability index, in order to better understand the obtained results. The capability calculation was made by Excel®™ software that analyses the tendencies and the process' Capacity index.
Also with other statistical tools in case of variable control chart, for instance the normality test a better understanding of the acquired results can be reached.

4.1 ($\bar{X}$, *R*) Control Chart obtained results analysis

Before beginning the chart results analysis there is a need to verify if collected data are trustworthy or not, therefore a normality test has to be performed in order to verify if the analysed data set is derived from a normal population or not.
By observing this histogram, it is possible to state that the distribution of the collected data is within the specified limits and there is a tendency to create a graphical representation of a smooth curve - the normal curve distribution.
Another graph shown in Figure 2 that contributes to a better understanding of the collected data is the normal probability plot which provides evidence on the set of analysed data that comes from a normal population.
The analysis made to the normal probability plot of this control chart proves that collected data is assumed to be normally distributed. Turn the Kolmogorov-Smirnov test is part of this work because the control charts require normality. The observation of this graph shows that the data follow a normal distribution.
Since previous results obtained ensure the viability of the collected data, this work begins with the analysis of the graphs behaviour of obtained data.
One interpretation of control charts is done through the study of the occurrence (or not) of non-random patterns. By examining the obtained graphs for patterns and by counting the obtained points it has come to the results present in Table 1.

Table 1. Information on non-random patterns.

PROCESS INFORMATION			
Significant trends of data points:		X BAR Chart	R Chart
Increasing	RUN LENGTH	4	3
	HOW MANY RUNS	1	5
Decreasing	RUN LENGTH	5	3
	HOW MANY RUNS	1	7
Out of Control Limits		0	0
Consecutive data points above avg.		5	4
Consecutive data points below avg.		5	4

Table 1 shows that there is no non-random pattern, since it is not verified the occurrence of seven or more consecutive points to follow a trend or consecutive data points above or below average. This is verified in both cases: graph of the mean ($\bar{X}$) and the amplitude (*R*).
Other table that makes a part of this control chart is the PPM table (Table 2):

Table 2. PPM Table.

NORMALITY TEST		
	OBSERVED	EXPECTED
PPM < LSL =	0	2,42792E-24
PPM > USL =	0	0
PPM =	0	0
% DEFECTS =	0,00%	0,00%
Process output without usual defects		

By examining Table 2, it can be observed that the PPM is 0 which represents much less than expected, making possible to conclude that the process output produces no defective items. Finally it is necessary to perform the analysis of the process ability to confirm that the process is capable or not. The Table 3 provides all the data necessary to perform this kind of analysis.

Table 3. Process capability analysis.

Number of readings	**250**
Lower spec limit (LSL)	**79,35**
Nominal	**79,50**
Upper spec limit (USL)	**79,65**
Total sum	**19.875,08**
Average readings (X)	**79,50**
Maximum	**79,560**
Minimum	**79,441**
Readings below LSL	**0**
Readings above USL	**0**
Average Range (R)	**0,08**
D2 Value	**2,33**
Upper capability index (Cpu)	**1,41**
Lower capability index (Cpl)	**1,41**
Capability index (Cp)	**1,41**
Capability ratio (Cr)	**0,71**
Process Capability Index (Cpk)	**1,41**

The collected data from the Table 3 can give some conclusions. After computing all data the process capability index *Cpk* is 1,41. This plant as many others uses as a standard of quality goal of *Cpk* > 1,33 ensuring that the specification contemplates 8σ of the process. However as 1.41> 1.33 it can be concluded that the process is capable. Also the potential capacity of the process is calculated and the *Cp* index assessed, reaching a value of 1.41, which is greater than 1.33, so the process is potentially capable.

4.2 *p* Control Chart obtained results analysis

By placing the data into the control charts and after viewing the shape reached by the control chart it is possible to deduce the capacity rate, to better understand the results. By examining the p control chart and by searching for pattern recognition and counting the obtained points it was filled up the Table 4:

Table 4. Information on non-random patterns.

Increasing	*RUN LENGTH*	4	*Decreasing*	*RUN LENGTH*	4	*Limites fora de Controlo*	0
	HOW MANY RUNS	1		*HOW MANY RUNS*	1	*Consecutive data points above avg.*	4
						Consecutive data points below avg.	4

Table 4 shows that there is no non-random pattern since it is not verified the occurrence of seven or more consecutive points to follow a trend or consecutive data points above or below average. The data required to obtain the capability of the process from the p control chart is in Table 5:

Table 5. Process capability analysis

p_ goal	0,00000
p - Average Fraction NOK	0,00104
σ- Standard Desviation	0,00056
UCL	0,00273
LCL	0,00000
Capacity %	99,89608
Cp = p_goal/p	0,00000

Table 5 provides information on the capacity percentage which is related to the expectations and goals of the management. With this data the capacity index (*Cp*) is computed. When *Cp* = 0 and since *Cp* < 1, this means that the management must act on the process.
Attending to the analysis of p control chart this process does not present satisfactory results of stability and capability. However, due to customer requirements, the use of this type of control chart was abandoned. As the customer demanded 0% of non-conforming leaktightness pieces, management decided to give up of this method of control and implemented a 100% control, i.e., a unitary control at the end of Step 7.

5. CONCLUSIONS AND RECOMMENDATIONS

Briefly, the development of this work led to a deepening of knowledge around the management method or set of tools for managing processes - the statistical process control (SPC) with respect to its scope, its embracement and its implementation in the reality.
The main objective of this paper is to present the application of a systematic approach to the use of Statistical Process Control (SPC) across the several stages of production of a specific "X" piece in a plant with the purpose of improving the quality in its manufacturing processes.
Using means of control charts this approach, allows the identification of problems into the company's production process. By applying this model, it was possible to put into practice what has been presented and studied in theory [1] [10] [35], increase knowledge and learning through the difficulties and challenges encountered in each step of application of the statistical process control. Thus, it is possible to show that depending on each case the researcher should develop alternatives to make SPC applicable to different kind of companies since they could have different processes, routines and particularities, requiring specific adaptations.
Although the analysis of the results of attribute control charts have demonstrated that the process is not capable of producing 100% of the specified pieces within required specifications, it can be seen that, through these information it the manufacturing process of the X piece can be better understood and the analysis of the results and the application of corrective actions and improvement are facilitated.
By preparing the case study was possible to apply this solution to the reality of an industrial unit within all its complexity. However, this study had some limitations, since the application of the case study method was made only in a singular factory.
The implementation and use of SPC produced clear satisfactory results in the case of variable data dimensional characteristics as in Montgomery, Oakland and others [1] [10] [35] in face of what had been the objectives set by management. Indeed, it was possible to visualize the production process behaviour and to calculate the capability of it and it is concluded that the process is capable.

Regarding the results of attributes control chart, became unsatisfactory since it cannot guarantee 0% defects and some nonconforming parts eventually reach the customer. The solution chosen by management was the 100% unit control output in Step 7. Although it is a more expensive and requires more hand labour, guarantees 100% leaktightness of the X piece, as requested by the customer.

Choosing the right steps for using this method it is very important since it allows better control of the process in its various stages of production and creates the possibility of identifying some problems at the root and not only detect them at the end of the process.

During this analysis did not arise any special causes, all causes of problems found, especially in the case of leaktightness, which are common and for their correction is required a heavy investment and the plant at the moment is not capable of making it.

By analysing the results obtained in the case study, it is believed that the application of the proposed model, with the necessary adaptations, can help other companies to achieve high levels of quality, resulting in gains and in meeting the expectations of final customer that may contribute in a crucial way to the growth of the company's image, which is its greatest asset.

The approach proposed can be applied at other stages of the process, contributing significantly to the reduction and/or elimination of failures in the production process, allowing the fulfilment of the quality targets set by the management company to other ones. This demonstrates that continuous improvement is a necessity that must be born from the product design or new processes, making it possible to gain time and resources, not forgetting that the company is working preventively and not correctively.

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Unapređenje kvaliteta statističkom kontrolom procesa u automobilskoj industriji

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Apstrakt

U kontekstu otvaranja tržišta globalno, ekonomija prkosi kompanijama sa brojnim izazovima, pa tako više nije dovoljno samo proizvoditi, već integrisati savremene principe osiguravanja kvaliteta kao uslov za postizanje produktivnosti i konkurentnosti. Imajući u vidu da kvalitet ne predstavlja statičnu varijablu, odnosno da je podložan promenama, kao i činjenicu da su kupci sve zahtevniji, svaka poslovna organizacija koja ima za cilj da bude konkurentna mora da inovira. U konkurentnom okruženju u kojem živimo organizacije sve više nastoje da proizvedu kvalitet po najnižoj mogućoj ceni kako bi osigurale sopstveni opstanak. Jedan odgovor na ovu tvrdnju je statistička kontrola procesa (SKP) –moćan metod upravljanja koji omogućava poboljšanje kvaliteta i eliminaciju otpada. Ovaj rad sugeriše poboljšanje kvaliteta procesa kroz korišćenje SKP u automobilskoj industriji uz kratak pregled pojmova u vezi sa metodologijom i ima za cilj da ukaže na sve prednosti upotrebe ovog metoda sa ciljem poboljšanja kvaliteta i smanjenja otpada. Da bi se to postiglo, nakon prikupljanja uzoraka, tumačenja kontrolnih karata i analiza, izrađena je studija o postojećoj metodologiji sprovođenja SKP za posmatrani proces, uz identifikaciju efikasnog načina prilagđavanja trenutnom funkcionisanju kompanije.

Ključne reči: *Kontrola kvaliteta, statistička kontrola procesa, analitičko odlučivanje, automobilska industrija, unapređenje kvaliteta.*