Process Capability Analysis – A Case of Automotive Technologies Botswana

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Abstract- The continued ambition of many organizations is to supply products that conform to customer specifications at the right time and in the right quantities. The work undertaken in this study was a step towards assisting the case study organization in achievement of that goal. As one of the quality management activities, the case study organization's release of production equipment is carried out when equipment is new and after relocation from one plant to another. It is only during that time, that the case study organization carried out capability studies on their machines. Hence this study sought to augment the efforts of the case organization in quality management by studying the process capability indices of the cutting machines during normal production. The study results show that the crimping process at the case study company were all adequate to meet the customer specifications, with the calculated CP and CPK values being greater than 1.33. The pull-off force test also confirmed that the process was adequate with CPK values being greater than 2.0, showing that the process is at a six sigma level.
Keywords – Process capability analysis, automotive industry, crimping machines, pull-off force, mini-tab

I. INTRODUCTION

Process capability study is a method of combining the statistical tools developed from the normal curve and control charts with good engineering judgment to interpret and analyse the data representing a process [1]. The purpose of process capability study is to determine the spread of the variation and the effect of time on both the average and the process spread. In any manufacturing operations, there is a variability which is manifested in the product made by the operations. Quantifying the variability with objectives and advantages of reducing it in the manufacturing process is the prime activity of process management. Process Capability refers to the evaluation of how well a process meets specifications, or the ability of the process to produce parts that conform to engineering specifications. Process Control refers to the evaluation of process stability over time, or the ability of the process to maintain a state of good statistical control. These two are separate but vitally important issues that must be addressed when considering the performance of a process, so the assessment of process capability is inappropriate and statistically invalid to assess with respect to conformance to specifications without being reasonably assured of having good statistical control.

A Process is a combination of materials, methods, equipment and people engaged in production of a measurable output [2]. Process Capability Analysis (PCA) involves statistical techniques, which are useful throughout the product cycle. Generally, PCA is used in the development activities prior to manufacturing processes, in quantification of process variability, in analysis of process variability relative to specifications and in elimination or reduction of process variability. As a fundamental technique in any production, quality and process improvement efforts, PCA is used to improve processes, products or services to achieve higher levels of customer satisfaction. PCA has become widely adopted as the measure of performance to evaluate the ability of a process to satisfy customer requirements in terms of specification limits. The output of a process is expected to meet specifications, which can be determined according to customer requirements. PCA is a prominent technique that is used to determine how well a process meets the specification limits [2].

Sahay [3] defines process capability as the ability of a process to meet specifications. The capability analysis determines how well the product specifications compare with the inherent variability in a process. The inherent variability of the process is the part of the process variation due to common causes. The other type is due to the special causes of variation. It is common practice to take the six-sigma spread of a process's inherent variation as a measure of process capability when the process is stable. Sahay [3] added that PCA is an important part of an overall quality improvement program. The

The purpose of process capability analysis is said to involve assessing and quantifying variability before and after a product is released for production, analyzing the variability relative to product specifications, and improving the product design and manufacturing processes to reduce variability. Variation is the key to product improvement and product consistency. PCA is useful in determining how well the processes will hold tolerances (the difference between specifications). The analysis can also be useful in selecting or modifying the processes during design and development, selecting the process requirements for machines and equipment, and above all, reducing the variability in production processes.

Wooluru [1] described the following steps as a procedure for estimation of process capability analysis:

a) Understanding the basic concepts of process capability analysis and its measures
b) Process data collection
c) Validating critical assumptions, the critical assumptions will include the assumptions that the data is normally distributed and that the process is in statistical control.
d) Estimation of CP, CPU, CPK, CPM and CPMK

If the process is not capable of meeting specifications, predominant factors that affect the process capability should be sought, action to improve process performance taken, and estimates of confidence intervals and hypothesis testing established. With process capability studies, it is possible to establish quality standards for the process and further improvement will also be possible.

Sampling is a very important element in carrying out Process Capability Studies, as it is often not feasible, due to lack of time and resources to obtain data regarding a certain quality characteristic for each item in the population [4]. In cases where data collection involves destructive testing, manual methods or high production rates, inspector fatigue might kick in which would yield inaccurate data. Mitra [4] described the major objective of a sampling design or scheme as being able to select sample size in such a way that it portrays the population from which it is drawn.

II. METHODOLOGY

To determine the process capability indices of the crimping process machines fifty samples of crimp heights of 1.15 mm with a tolerance of 0.05 mm and 1.08 mm with a tolerance of 0.03 mm were collected from different machines, some fully automated and some semi-automatic. These samples were collected from populations ranging from 1550 to 6550 units. The samples were made of five different readings each, and they were collected at set intervals. The other capability study conducted was for a pull off force test where the sample size was restricted to 17 since the test was a destructive test.

As both the capability indices assume that the data is approximately normally distributed, a probability plot was used to check if the data is approximately normal. Based on the p-value obtained, the null hypothesis (data is normally distributed) would be accepted or rejected. The default normality test was used on mini-tab (AD test), this test (AD test), together with histograms and the Ryan-Joiner normality test were used to verify normality or non-normality of the data. The samples were then plotted into control charts (X-bar and R-chart) to see stability of the process and investigate for the special causes of variation if any. The estimates of the process average and dispersion were obtained from the probability plots and control charts which were constructed using mini-tab, obtained from the process data.

The stability of the process and out of control processes were established using the following rules

Rule 1: A process is assumed to be out of control if a single point plots outside the control limits.

Rule 2: A process is assumed to be out of control if two out of three consecutive points fall outside the 2σ warning limits on the same side of the center line.

Rule 3: A process is said to be out of control if four out of five consecutive points fall beyond the 1σ limit on the same side of the center line

Rule 4: A process is assumed to be out of control if nine or more consecutive points fall to one side of the center line.

Rule 5: A process is assumed to be out of control if there is a run of six or more consecutive points steadily increasing or decreasing.

The five rules for determining out-of-control conditions are however not all simultaneously used. Rule 1 is used routinely along with a couple of the other rules (say, Rule 2 and 3). The reason for not using all of them simultaneously is that doing so increases the chance of type 1 error, [4]. In other words, the probability of a false alarm increases as more rules are used to determine an out of control state.

To collect data interviews were conducted with the quality manager and employees working in the crimping processes. Observations by the researchers were also used, and this involved writing down what is being observed.

III. RESULTS

3.1. To Study The Crimping Processes –

The crimping processes at the case study company involve a process of joining a terminal to the wire to create a circuit through compression. The processes are done at two types of workstation, the fully automated workstation and a manual workstation. At the fully automated workstation the primary task of the operator is to input the necessary parameters on the computer (quantity, batch sizes, wire length, terminal type, and strip length, etc.) all of which are provided on the job-card. The other task involves loading the raw materials onto the machines; these raw

materials include terminals, seals, wire. They also pick up batches as they come out and do visual inspections on the batches. This process incorporates the concept of poke yoke to make the job of operators much easier, the computer prompts the operator to insert the necessary data and raw materials and production will not go on until all the necessary inputs are in place.
The manual workstation includes crimping using a sit down press; the operator has to sit down to manually operate the sit down press. The wires come to the workstation already cut into the desired length and the operator does the crimping with the sit down press. The workstation is less sophisticated as there is no modern technology involved (computers). It is important to note that the workstation is very slow due to it being manually operated.
Before serial production of any job at the cutting and crimping processes re-qualification must be done, that is the machines/workstations must be authorized to do that job. This is done by visual inspections and cross sectioning test and only allowing serial production if the samples pass the test. This is only done on wire of cross section 0.35 mm2 and 0.5 mm2 while other wires random sampling is done on process monitoring. The following figure shows a flow chart for the re-qualification:

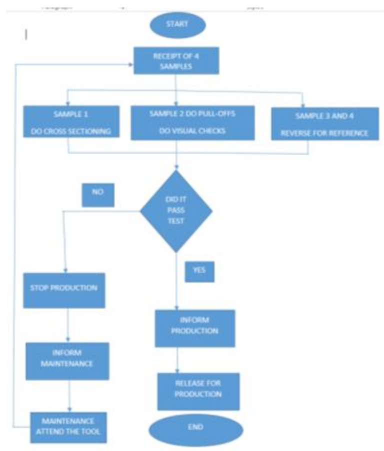

Figure 1 Re-qualification flow chart

After To be able to meet its objectives, that is to be able to produce the harnesses that satisfies the customer in any environment, the company devised a process manual which describes the tests involved in cutting cable harness components for release of machines and tools for serial production. The release of production equipment is carried out when the machines are new (before use) and after relocation from one plant to another. The requirements for release of crimping machines/tools are described below.

3.2 Crimp Machines Release Requirement

For new crimp machines, an MFU (Machine Ability Proof) must be carried out using a crimp press analyzer. Up to 250 crimps should be made per press and test. In doing so, a CPK of greater or equal to 1.67 is required; this value of 1.67 is also given by the customer as a requirement before the process is released for serial production. This analyzer checks the sensor in the base plate for the crimp force analysis, the crimp machine, as well as the top and bottom dead center of the machine.

3.3 The process capability indices of the crimping process machines / tools)

Fifty (50) samples of crimp height 1.15 with a tolerance of 0.05 were collected from the fist automatic machine. The samples were taken from a population of 2000 units and they were randomly picked. The results analyzed here are based on a sample of 50 observations which were collected from the process.
As stated in the methodology we used a probability plot to determine if our data followed a normal distribution. This was vital as the process capability index to be calculated later on takes the assumption that the data is normally distributed. The following figure shows a probability plot which was constructed using mini-tab.
Where the parameter α is called embedding intensity and their effect of validity of the algorithm directly is apply after this process, after that apply the inverse wavelet transform to the image for find out watermark image.

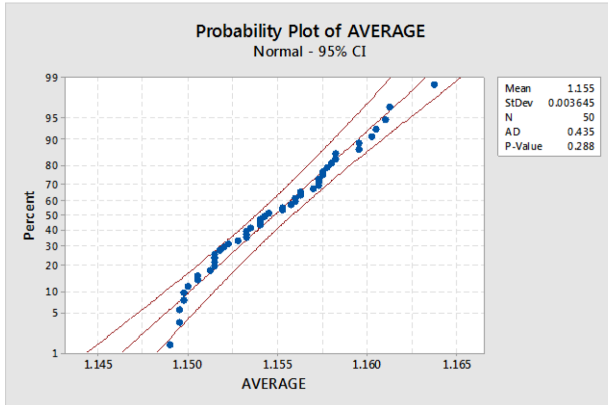

Figure 2 Probability Plot

As we can see from the legend in the probability plot above, we have a p-value of 0.288 which is greater than 0.10, we can now assume that our data is normal. This value of 0.288 tells us that there is not sufficient evidence to reject the normality assumption. Thus we can use the process capability indices for this data.

The following figure shows an X-bar and R-chart for our samples, using rules 1, 4 and 5 for determining out of control points in control charts we can conclude that our process is stable, that is it is in statistical control. There are no special causes of variation in the process and thus the data can now be used to determine the capability of the process.

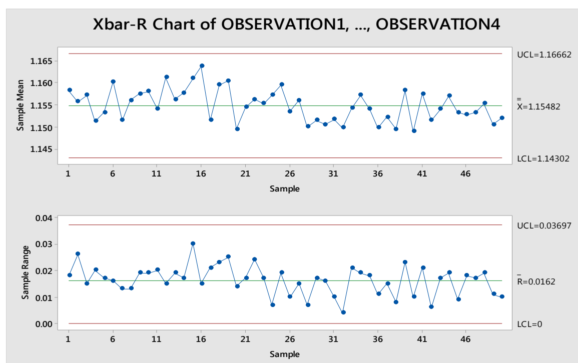

Figure 3 Shows X-Bar Chart and R-Chart

The table below shows the estimated process capability indices for existing process conditions and all the necessary data needed for calculating the PCI’s.

Table -1 The Calculated PCI’S And The Data Used To Calculate Them

PARAMETER	VALUE
USL	1.20000
LSL	1.10000
MEAN	1.15500
STD	0.00365
TARGET	1.15000
CP	4.56621
CPL	5.02283
CPU	4.10959
CPK	4.10959
CPM	2.69229
CPMK	2.49182

Another fifty (50) samples of crimp height 1.08 with a tolerance of 0.03 were collected from a semi-automatic machine. The samples were taken from a population of 6550 units and they were randomly picked. The results analyzed here are based on a sample of 50 observations which collected from the process.

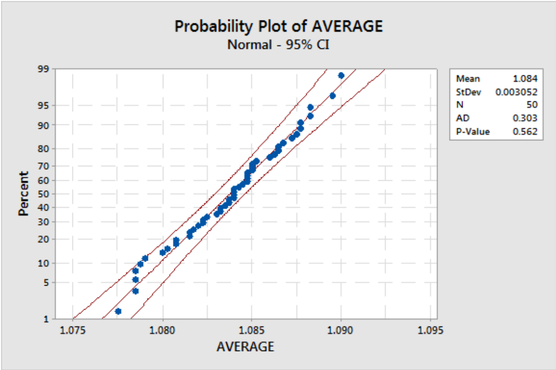

Figure 4 Probability Plot

As we can see from the legend in the probability plot above, we have a p-value of 0.288 which is greater than 0.10, we can now assume that our data is normal. This value of 0.562 tells us that there is not sufficient evidence to reject the normality assumption. Thus we can use the process capability indices for this data.

The figure below shows an X bar chart and R chart which were to check if our process is in statistical control, that is if no special causes of variation exists. If we only apply rules 1, 4, and 5 of control charts stated in the methodology we can say our process is stable, thus we can go ahead and do process capability analysis of the process.

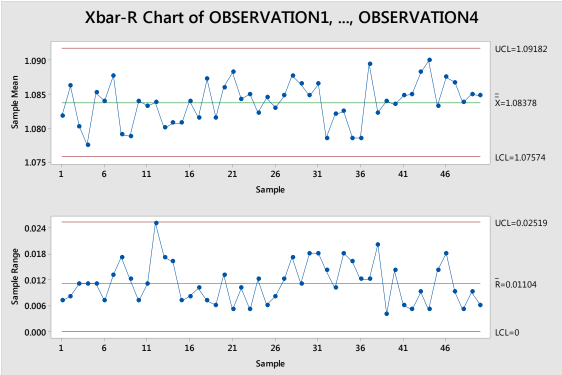

Figure 5 Shows X-Bar Chart and R-Chart

The table below shows the estimated process capability indices for existing process conditions and all the necessary data needed for calculating the PCI's.

Table -2 Shows The Calculated PCI'S And The Data Used To Calculate Them

PARAMETER	VALUE
USL	1.11000
LSL	1.05000
MEAN	1.08400
STD	0.00305
TARGET	1.08000
CP	3.27869
CPL	3.71585
CPU	2.84153
CPK	2.84153
CPM	1.98800
CPMK	1.72294

Seventeen samples (17) samples of pull-off force were collected at from one of the machines, which produced terminals which were meant to satisfy a 50N pull off force. This test variable only had the lower which meant that everything above 50N was acceptable. Although [4] and other authors suggest that a sample size of 4-12 is desirable and [5] says as a thumb rule a minimum of 50 samples must be taken for a process capability study, sometimes it is not possible to get that many samples and the desired sample size due to the nature of the test. This is normally more common in tests involving destructive forces like in this case. Hence this test only limited to 17 samples and a sample size of 3.The samples were randomly picked. The results analyzed here are based on a sample of 17 observations which were collected from the process.
The following figure shows a probability plot which was constructed using mini-tab.

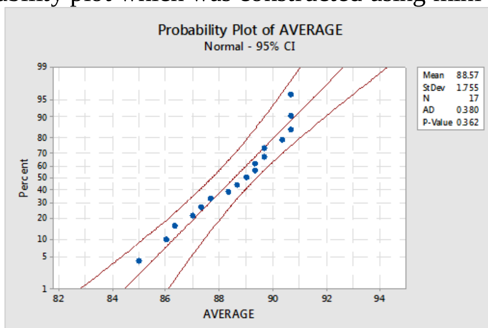

Figure 6 Shows Probaility Plot

As we can see from the legend in the probability plot above, we have a p-value of 0.362 which is greater than 0.10, we can now assume that our data is normal. This value of 0.362 tells us that there is not sufficient evidence to reject the normality assumption. Thus we can use the process capability indices for this data.

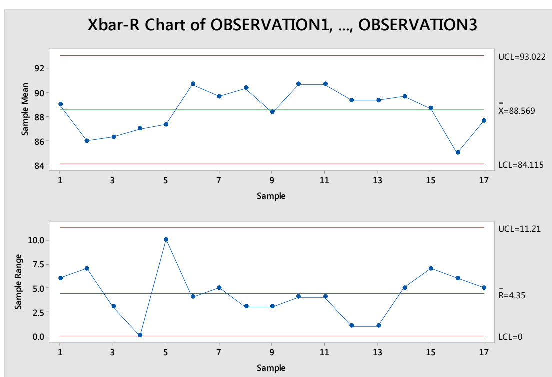

Figure 7 Shows X-Bar Chart and R-Chart

The table below shows the estimated process capability indices for existing process conditions and all the necessary data needed for calculating the PCI's,

Table -3 Shows The Calculated PCI'S And The Data Used To Calculate Them

PARAMETER	VALUE
USL	
LSL	50.00000
MEAN	88.57000
STD	1.75500
TARGET	
CP	
CPL	7.32574
CPU	
CPK	7.32574
CPM	
CPMK	

IV. DISCUSSION OF RESULTS

The table below shows the summary of the process capability indices calculated for the crimping process (crimp height).

Table -4 Shows a Summary of the PCI'S Calculated Across Two Terminals Studied (Crimp Height)

TERMINAL TYPE	CP	CPK	CPM	CPMK
BN10335802(A)	4.56621	4.10959	2.69229	2.49182
BN10335704(A)	3.27809	2.84153	1.98800	1.72294

The CP and CPK values obtained for the crimping process are very impressive, they are both over 1.33 which indicates that the process is adequate to meet specifications and that the process is capable in the short term. Is it is said that CP = CPK when the process is perfectly centered, [1]. It can be seen from comparisons of both the indices obtained for each terminal that it shows that our process is centered, even if it is not perfectly centered. The CPM and CPMK also back the argument that the process is centered as the difference in their magnitudes is not very high. As it can be seen from the table above we have terminals of the same type produced from different workstations (automatic workstation and sit down press), from the process capability indices calculated we can say both the workstations are well capable of meeting the customer specifications.

Table 5 shows the summary of the CPK values calculated for the crimping process (pull-off force). The table also shows several other pull off force test results which were performed using different forces in addition to the one reported here. The table shows all pull off force CPK values to be far greater than 2, which means the process is operating at more than six sigma level.

Table -5 Shows The Calculated CPK Across All Terminals Studied (Pull-Off Force)

TERMINAL TYPE	CPK
BN10335705(A)	5.92944
BN19335704(S)	7.32574
BN10225704(A)	6.56713
BN10335802(A)	6.04732

The pull-off force has one limit only, which is the lower limit. As that we could only calculate the CPK for the process and as can be seen from the table above, CPK values are way over the 1.33 value. The process is adequate to meet the customer specifications and we can say the process is operating at a six sigma level. Very few defects will be made by this process. However the results obtained might not be a true definition of what is happening in the process; as a result of the nature of the test only 17 samples were collected with a sample size of 3, so only a fraction of the population was taken for study.

The whole purpose of crimping (joining wire and terminal through compression) to make a circuit with good electrical conductivity, so if all the desired physical attributes of crimps are not met we will end up with a circuit with poor electrical conductivity. This will affect the performance of the circuit later on, it may be by leading to the complete harness failing to pass the inspection at the last stage or by leading to poor performance of the Volkswagen cars. The list of things that may happen due to the presence of bad crimps attributes is endless, some of the possibilities will be discussed in the subsequent paragraphs.

If the terminal is not tight enough, the force required to deform the circuit (separating copper wire and terminal) will be very low, this will mean that the wire and terminal can be easily separated and hence losing our electrical conductivity. This alone can lead to serious car accidents; imagine a circuit for indicators failing when the owner of a car tries to make a turn. If the PVC goes inside the core it will add more stress to the area leading to increased resistance at the core and the terminal can be easily removed. The presence of the bellmouth (a flare that is formed on the edge of a conductor crimp) is very important in a crimp; it indicates that the crimp die is making contact with the terminal material only, and not with the wire surface. If it is absent or at the wrong end it might suggest that the crimp die is hitting the wire strands directly and if that is the case it can cause scratching or breakage that would reduce the force required to pull the wire from the terminal.

Between the conductor crimp and the insulation crimp, there should be a stripped copper wire and an insulated copper wire, preferably at a ratio of 1:1. If the insulated copper wire is not available, it is likely that the retention force of the terminal will be diminished. On the other hand if only the insulated copper wire exists between the conductor crimp and insulation crimp, it will mean the insulation (PVC) will extend into the conductor barrel causing discontinuity.

The selection of the correct wire, terminal and seal is also critical. The correctness of the wire refers to the wire of the right colour and cross section, if a wrong wire or terminal is used it will result in the circuits being unusable leading to a lot of scrap leading to reworks and this will be very costly to the company. The correct combination of wire and terminal is also important because for each combination of wire and a particular terminal, certain ranges of crimp heights and pull-forces are required, so if a proper combination is not selected specifications will not be met. Seals are very important as they protect the circuit from oils, water and other impurities which might affect the ability of the circuit to function, so their absence or a wrong type being used will result in the failure of the harness.
In addition to the physical characteristics that can be observed on crimps, cross sectioning photograph test is equally important. It is used to further evaluate the crimped termination when additional diagnostics are necessary, in the case of Pasdec automotive technologies it is used for documentation purposes and for release of production. In every batch cross sectioning is done in one of the first four samples produced. The following dimensions are observed on the crimp during cross sectioning: Crimp height, Crimp width
Measurable crimp width, Supporting angle, Barrel end clearance, Distance between crimp barrels Burr height, Burr width, Supporting height, Base thickness.

V. CONCLUSION

In this study a process capability analysis of the crimping process was carried out. The process capability analysis showed that the crimping processes are adequate to meet the customer specifications, with all the calculated CP and CPK values being greater than 1.33. The pull-off force also showed that the crimping processes at the company was adequate to meet the customer specifications, all the calculated CPK values were greater than 2.0 which suggested that on the aspect of pull-off force the process was operating at a six sigma level. In summary the study concluded that the process for crimping at the company was able to meet sufficiently the customer specifications.

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