Improvement of the Quality Control Process in the Central Fuselage of KC390 Program

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Abstract

The quality department is responsible for establishing communication between the company and the customer throughout product design, so as to ensure that all products specifications are met, at the lowest possible cost. The continuous improvement was applied to the assembly quality process of a military aircraft, this being an aircraft that the company receives in the industrialization stage.

Focus on aeronautical industry where the tolerances are very tight and the requirements quite high, it is necessary to ensure that regardless of the operator / inspector involved in the manufacture, the product will be carried out with the utmost rigor and will have the same results. Therefore, were developed work procedures in order to develop the standardized work, contributing for anomalies and corrections reduction, thus increasing the efficiency and effectiveness of inspection, geometric measurement and production processes.

In order to provide tools which allow to easily reach the root cause and in turn decrease the occurrence of nonconformities, it was developed a digital system which track the anomalies throughout the assembly inspection process. Also was implemented a statistical process control with one perspective of control and prevention of nonconformities, having been tested for the process with the most occurrence of nonconformities, incorrect drilling.

Using methodologies such as Lean and Six Sigma, it was possible to successfully implement these practices, adding more value not only to the inspection and production processes, but also to the product and to the company itself.

Keywords: Quality, Aeronautical Industry, Nonconformities, Track and Statistical Process Control.

1. Introduction

The quality is the voice of the customer within a company. Focusing on all client’s requirements and ensure that these are performed in the best way with the lowest possible cost.

The Lean Six Sigma (LSS) methodology focuses on driving business process improvements as a result of merging the key principles of both management philosophies, Lean and Six Sigma [1]. While Lean’s goals consists on adding value with minimum impact work, the Six Sigma system aim is to identify and reduce nonconformities (NC) [2]. Lean Six Sigma has been applied in the manufacturing of aerospace and aeronautic system since 1990 [2][3]. Gradually this methodology has been being implemented and adapted to aeronautical and aerospace industry. Some companies got achieve excellent results applying LSS, reflecting in increase quality product and reduction of process costs [2].

This paper will provide the application and implementation of Lean Six Sigma in an aeronautical company, aiming to achieve the NC reduction and traceability on fuselage assemblies process. This work proposes methodologies to improve the identification of NC in product inspections. Once identified it is important to register and characterize them in a database. Consequently, it is possible to track all NC. Therefore, the relevant NC has been identified it is possible to determine the processes that originated them, finding out the root cause of each NC more quickly. Also a Statistical Process Control (SPC) has been developed so that it is possible to control NC caused by certain production processes.

The results obtained are of interest to both academia and industry. Practitioners, such as quality engineers, may integrate the approach into their set of quality tools in their search for improving quality in manufacturing. Distinct courses such as quality control, (Information Technologies) IT and SPC are bought together. This paper will therefore initially and briefly discusses the nature and structure of existing LSS practices and approaches before describing through a case study, the design
and application of LSS on an aircraft assembly process.

2. Background

This section frames the theoretical background on LSS, standardized work, visual inspection, SPC and quality tools as its relation with the approach proposed. Furthermore, the research goals and scope are discussed.

2.1. Quality in Aeronautical Industry

Quality in the aeronautical industry was developed later than most other industries. Only in 1996 the Lean Aerospace Initiative group was formed to explore the Lean methodology in military aircraft [4][5]. In 1999 American Aerospace Quality Group made the decision of ISO 9001:1994 to be adapted to the aerospace industry by the aeronautical association or standardization department of each country. In Europe, EN 9100 was created by the European Association of Aerospace Industries [6]. The development of these standards is fundamental to standardize quality, production and safety requirements among the various companies.

2.2. Research aims and scope

For a fixed choice of manufacturing process, the key level controlling the subsequent outgoing quality of conformance is inspection. The goal of inspection is to identify produced defects before the components are delivered to the customer [7].

The aeronautics industry has the particularity not only of being a unitary production, but also of the large size of the product and jigs which makes it difficult to introduce automated systems for the detection of NC. Also this industry has the highest production requirements. It is not enough to inspect the product only in the final stage, not even to check only certain characteristics. To guarantee that all the demandings were accomplished it is necessary that the product’s inspections are carried out a 100% by several stages for that some of NC still can be repaired. Like this industry, also in textile and apparel industry, fabric inspection has been done by trained inspections. With any process that is conducted primarily by humans, error is inevitable. Physically inspecting fabric can become tedious and is repetitive in nature, which causes eye fatigue [8]. Besides, mainly inspections include a lot of clamping elements measurement parameters, where inspectors and tools influence the data variability. There are methodologies that can be applied to the inspections in order to reduce this variability, so that the product is delivered with zero defects.

The zero defects has been proposed as the ultimate target for quality control and assurance. According to Crosby “The quality manager must be clear, right from the start, that zero defects is not a motivation program. Its propose is to communicate to all employee the literal meaning of the words zero defect and the though that everyone should do thing right the first time.” [9].

The standardized work is one of the most powerful lean tools, which minimize the variability of processes. By documenting the best practice, the standardized work prevents defects in production and at the same time creates procedures to prevent the occurrence of other errors that could have an impact on production and inspection [10].

However, in order to achieve the zero defects, it is necessary to identify their root cause by tracking and control processes during the production.

The SCP is a statistical technique applied to production that allows the systematic reduction of variability in quality of interest characteristics, contributing to the improvement of individual quality, productivity, reliability and cost. Focused on the prevention and detection of NC, this eliminates wastes [11]. In the 1920s, Dr. Walter Shewhart made the distinction between controlled and uncontrolled process. A process is not controlled when it exceeds the Upper Control Limit (UCL) and Lower Control Limit (LCL), as shown in Fig.1 or when it follows standards, previously studied and analyzed in standard ISO/WD 8258, which characterize an uncontrolled process [12]. Knowing that we are improving a quality system on an aeronautical industry, it would interesting make a SCP for drilling process. The drilling process is the most important operation in this industry because implies a high economic cost. A small or medium size aircraft has more than 250,000 holes to be inspected [13].

![Figure 1: Example of control chart.](image)

The traceability of products depends largely on degree of IT implementation. Additional work might be done for data analysis, interpretation and visualization [14]. There are several studies aimed at the prioritization and traceability of NC in the industry. Donauer presented a methodology to identify specific machines within a manufacturing process as the possible origins of a given NC, where results are visually represented using highlighted color matrices. These matrices identify the source responsible for the NC being investigated. In order to create the matrices, all NC occurrences are analyzed and their concentration is measured on the ma-
chines. Azevedo also presented a novel approach to track and prioritise NC, a multi-attributes weighting engine based on failure mode and effect analysis (FMEA) and Pareto principles [15].

Not only the research on traceability and identification of NC were important, but also the research on visual inspection, so that if it was possible to propose an autonomous system. According to the statistics, around 60% and 70% low-quality fabric (with defects) can be effectively detected by the human visual inspection even with the skilled operator. To improve the overall quality of assemble fabric and increase the detection efficiency, Automated Visual Inspection based fabric quality inspection is urgent for better productivity [16]. Some industries have a automated fabric inspections machines that use light and cameras to look for fabric NC [17]. However, this system is static while the product is moving. With the study of this industry, a portable system that can reach the product has to be analyzed.

3. Implementation

This section presents the proposed methodologies applied and designed to serve as a quality tool. Describe the methodologies implementations and the advantages to apply them.

3.1. Purpose and overview

In an initial phase of monitoring the processes and products, there were gaps in product inspection through the various phases, both in terms of the organization procedures and the level of knowledge of customer specifications, since there were a few but very extensive standards, illustrative of customer requirements. It was also found that although the number of NC was high, they were not quantified, nor even identified according to the product area and the production site where they were committed.

The objective is to reduce complaints and eliminate existing gaps with the introduction of inspection of the product. It was necessary to implement methodologies that fit both the client and company needs, as shown in Fig. 2.

As the case studied is in the industrialization phase, it undergoes configuration modifications in several chipsets. Although these changes are small, it becomes more difficult to standardize procedures and consecutively to improve each iteration. Constant product modifications has a negative impact and leads to an increasing of NC committed, while the process learning curve remains almost constant.

Companies will also define what they assume as crucial, major and minor NC [8]. In this project a major NC results in product deviation which needs an evaluation by production engineering. If it not allowed to continue the process, engineering will have to inform the customer and wait for customer correction demands. All the major NC that are reported to the customer give rise to a Communication of Discrepancy (CD) note. Minor NC do not require any paperwork from both the company or customer side. Like major NC, this minor NC are identified by inspectors, but the minor ones are corrected by the production department immediately.

For the available resources to be allocated where there is a greater need for problem solving, it was essential to understand which NC are most frequent. Figure 3 shows the results of CD notes on the last 5 Central Fuselage (CF) assembled.

Observing the distribution of defects nature through the CF1 till CF5, it is possible to see the increase of CD notes related to the NC4 in the last CF. This increase was due to the introduction of a new automated machine on the assembly line. The NC4 refers to surface scratches and marks in the product, which occurred during the process of automatic drilling and riveting. Because it is a main and new tool in the company, it needed to be ad-
justed, mainly at the programming level, at each iterate. The NC due to the material were decreasing with the production of new CF, demonstrating that somehow they were controlled, not being the main focus in the current work. It is intuitive that the NCI (drilling process) has to be reviewed due to the most CD occurred. Regardless of the CF or the entry of the automatic riveting machine, incorrect drilling always stands out as the predominant NC. It should be noted that there are only two CF with the same configuration, CF2 and CF3, where there is a similarity in the number of CD notes. The CF3, CF4 and CF5 were assembled fuselages for several tests, and it was not necessary to completely assemble the aircraft. On CF4 only one of the largest panels was set up for a specific test, this is one of the reasons for the lowest CD collected.

3.2. Standardized Work

In the development of work procedures were considered more specific requirements from the client part such as, visual alerts, tool handling and comparative images of what is right and wrong. When creating the document, emphasis was placed on ambiguous situations, that is, if there were doubts about a certain NC, it should be included in the document. The work procedures should only contain basic information in a simple and concise form. Should be easy to understand, consult and change [10].

The inspection is the process that ensures continuous improvement during manufacturing. The inspector has the function of checking the work done on the panels, based on the standards and requirements outlined by the client [8]. Therefore, most of the inspections were followed in order to visualize the most common NC, the actual inspection times and the possible difficulties that the inspector deals in his daily work. This being a project aimed to detect the NC, it was fundamental to understand what were the adversities found by an inspector on detecting NC, in order to reduce or even eliminate these difficulties. During the execution of the project the work procedures were constantly updated. After the delivery of the CF5, the work procedures were checked by the quality and production engineers to discuss which are the ones that need improvements.

3.3. Tracking Minor NC

These NC are identified and marked in the product with a red pencil or writing the NC on paper tapes, when it is not possible to write on the surface, as Fig.4 illustrates. Therefore, the information stays on the product until the production performs its repair. Once this is repaired, a check is issued on the NC identification, so that the inspector can then confirm the repair and remove the NC identification. Identification with the pencil has the advantage of being faster, but on oily surfaces the pigment of the pencil does not adhere easily, and the identification is subject to disappear. The paper tapes have the advantage of not having to clean the surface later, however, they can fall and then the identification process requires much more time. The ideal would be to have a digital platform with the NC registers (a database) in order to not lose their traceability. Notwithstanding the registration with the pencil and paper tapes, an online page was created with connection to the company’s computer system. The amount of Minor NC can be introduced, the nature of the defect, the NC product location, and so on. This page has a database with all the location matrices where the only input needed is the quantity and defects nature in each region. A simple but time consuming process of inspection.

In a first phase the inspector identifies the NC in the product and later registers them in the tablet. When a defect is registered in the tablet, a Minor NC process is opened and automatically directed to the production in real time. Production has access to the NC by the quantity and defects nature, as well as the location code in the respective product. For production to complete its part of the process, it needs to repair the NC and give entry in the system the time for this reparation, only after this registration the flow returns again to the inspector. Finally, the inspector closes the flow of the process with the verification of the NC correction.

![Figure 4: Identification of NC in the product during an inspection.](image)

Therefore, this project allowed to register Minor NC during the assembly of the CF6 by using the digital platform. There were 1366 Minor NC’s divided by 7 panels and 3 inspection phases (before going to automatic riveting machine, after going to automatic riveting machine and the final inspection).

3.3.1 Localization Matrices

One of the processes studied and developed in this work was the register of Minor NC. Based on Donauer research, where a methodology designed was proposed to help identify the root causes of NC by constructing tables which provides a visual depiction of the problem areas, a locations matrices
were developed for each panel [14].

Firstly, as shown on scheme in Fig.5 the drawings of each panel were transformed in Two Dimensions (2D). The fact that the distance between stringer-stringer and frame-frame is approximately constant facilitates the construction of the matrices, with planning of the panels represented in a flat configuration and not in their original configuration (concave). The location matrices were constructed and organized, assigning letters to the columns, where each letter represents a frame and numbers to each line, corresponding to each stringer. NC typically occur at the intersection between frame-stringer, so each cell must contain a union of these elements. This rule was not always conceived due to the panel configuration, there was a reduced number of matrix cells that had no stringer attached. Note that before starting to draw individually the matrix of each panel, it was designed a global matrix of the top and bottom view, so that it was possible to establish the correspondence between all frames and stringers. Since the frame can be represented as a circle of the fuselage, it covers different panels and it was necessary to assign the same letter to all the cells that have the same frame. The designations of Right Hand (RH) and Left Hand (LH) were given by the client due to the near symmetry of the CF, having been assigned the green and blue color to the matrix lines, to distinguish the RH and LH, respectively. There is at least one matrix per panel. In the case of panels with more details it was necessary to implement a matrix for the interior and another for the exterior and also, for the exterior and also, in panels that contemplate the landing gear, were specifically constructed matrices for that zone.

3.4. Statistical Process Control

Knowing that the Major NC registered was incorrect drilling, it was necessary to apply a SPC to understand the behavior of the process itself and, how it varies with the different characteristics. As the drilling process is performed by the automatic riveting machine as well as by the worker, it was necessary to separate the data from each process, since each one has intrinsically different characteristics. Therefore, the attribute $p$ control charts for manual drilling and the variables $\bar{X}/S$ control charts for automatic drilling were selected. A flowchart with the different types of control chart is shown in Fig.6, one can follow the reasoning that was taken into account in the choice of charts. An Excel spreadsheet has been developed where the user only has to enter the attributes or variables of each record. Automatically control charts are created on an excel sheet. The program has the ability for an Excel sheet to create 5 control charts, always using as reference the previously calculated control limits chart. Both the production and the inspections were followed up in several work shifts, in order to understand the existing difficulties and to create complicity with the workers. Thus, it was easier to introduce the procedure of how to make the records, as well as the importance that they entail.

3.4.1 Attributes control charts

As manual drilling could not be controlled by variables, as it would imply a significant increase in the production time, the measurement system was chosen using the "go no go" tool. However, the diameter of the hole is not the only requirement to verify, since the existence of burr and the finishing of the inside of the hole itself (scratches) are also NC to be considered when registering, that is, to guarantee an OK in the evaluation of the hole,
and that all three requirements must be met. The $p$ control chart controls the proportion of nonconforming units in the process, based on the sample ratio [18]. In these letters each result can be classified as success or failure and the probability of success is constant, that is, the probability of a unit being classified as NC is equal and constant to $p$.

3.4.2 Variables control charts

Variable control charts were applied to the drilling process of the automatic riveting machine, as it is a new automated tool in the company, and it is necessary to prove its correct operation. As the certification requires a rigorous measurement, the "go no go" tool is not enough, because it was necessary to measure all the holes with a micrometer. Since there were very small measurement variations, it was needed to create a Measurement System Analysis (MSA) to evaluate the variability of the measurement system. The system was implemented by following the methods already used in the automotive industry, ensuring the principles of Six Sigma [19]. Considering the scheme in Fig.7, all phases were calculated, except the stability. To verify the normality of the sample, each variable chart has associated a histogram, as well as the normal distribution referring to those data. Although some of the distributions did not exactly follow a normal distribution, since the sample on each chart is $N = 125$, it can be stated by the Central Limit Theorem that regardless of population distribution, samples tend to be normally distributed [12]. If the population distribution is not extremely non-normal, it is assumed that mean, $\mu$, and variance, $\sigma^2$, of the distribution follow a Normal distribution, even for small sample sizes. This is the reason why mean sample of control chart, $\bar{X}$, based statistical methods are known to be robust in relation to the assumption of normality for the population [12]. Finally, all indices of capability were calculated. Although at an early stage the minimum requirements to be taken into account are those relating to the preliminary process capability, $P_{pk}$, and preliminary process performance, $P_p$, when the control is carried out continuously, the other two indices are to be evaluated.

In spite of the longer statistical control process at an early stage, because it is necessary to find quantities for the number of samples, limits of control, among other fundamental characteristics to the process, this practice Six Sigma is an added value for all industries, calculating the NC variability through the all process. If the capability of the process is high and the process is fully controllable, then the resources allocated in that process can be diverted, because the control frequency or sample may be reduced, not requiring the same amount of resources. In this project, such as in an aeronautical industry where inspection and control must be 100% accurate it can be shown that the process is controllable and its capability goes beyond Six Sigma, that is, if a process has 0.0019 defects per million opportunities. This result can satisfy most safety departments, since the risk of accident due to a defect is less than $1 \times 10^{-7}$ [3]. In this way, control would no longer have to be carried out at 100%, thus increasing the efficiency and effectiveness of the processes.

4. Results

This section frames the methodologies applied effects and the discuss about outputs generated by them.

4.1. Standardized Work

The work procedures were updated and improved during the assembly of each CF5 and CF6. They proved to be very useful, not only on quickly learning of the new inspectors, but also on the help they provided to the operators on the assembly lines. Now, the operator is able to do specific process, complying all the customers needs. This is a beginning of a system implementation based on self-inspection during the assembly, where it is emphasized the continuous improvement to reach the zero defects. The work procedures intend to give only the fundamental specifications to the operators and inspectors, making processes Lean. The standardized work has resulted in increased efficiency in the inspection process, and especially in increasing the effectiveness of some production processes.

4.2. Tracking Minor NC

The Minors NC registered on CF6 were divided by their nature of defect. Figure 8 presents the seven prevailing defects nature. Focusing on evaluating the influence of automatic riveting process, the data was divided, separated from before and after the panels go to the automatic riveting. There is
no discrepancy in the distribution of defects natures between the two processes. Nevertheless, this analysis only takes one panel in consideration before the automatic riveting machine, being necessary to reassess this situation in the next iteration with all the panels data. Results indicate that independently of panels, the NC6, NC7 and NC11 were the most NC occurred.

(b) After automatic riveting machine (A, B, C and D panels)
(a) Before automatic riveting machine, A panel
NC9 NC8 NC7 NC6 NC11

Figure 8: Percentual distribution of the main 7 NC.

In spite of the NC quantification to be important to the quality process of an industry, it is also crucial that the NC traceability has characteristics like the location in the panel or the process where it occurred, so that the root cause could be analyzed and identified. In complement to this issue, a system that brought a relevant and compiled information it was implemented, as shown in Fig.9. Only the three most common NC (identified with the same colors in Fig.8) are shown in panel A, after this has gone to the automatic riveting machine. Although there are some NC concentration areas, the root cause could not be identified because not having enough data, on the same conditions.

With the results obtained it was verified that there are some defects nature which do not make sense to be identified in certain inspections. With this in mind, was made a list with all the part numbers and inspections to be performed, and consequently the NC to register on the tablet in each inspection stage, thereby was created the NC registration process without redundancy.

The introduction of IT to the product inspections is something innovative and that can trace NC. Still, this process is time consuming and requires that the inspector has to register each NC in the system, individually, in addition to identifying the NC on the product, as he did before. The purpose of the solution presented is to account NC on the panel through photographs. In order for the image to be able to recognize the defects nature identified in the product, all NC might be identified with labels, shapes or colors representative of that defects nature. With this system, the program

Figure 9: Three main defects nature in panel A after having gone to the automatic riveting machine.
not only counts the NC but also assigns their location code, based on the created matrices. Taking this problem in consideration, some engineering students had projects on a Computational Vision course, whose the objectives was to verify the feasibility of computer programs to recognize the stringers and frames of photographs with different geometries and light conditions. These tasks were successfully carried out and this is a suggested topic to develop in a future master thesis.

4.3. Statistical Process Control

Numerous measurements were taken during the CF6 assembly, mainly the drilling and riveting performed by the automatic machine. The data analysis was performed after the delivery of CF6, because it was necessary to follow the inspections, register the Minor NC and measure the characteristics for SPC.

4.3.1 Attributes Control Charts

Although the attribute charts have a faster measurement process, these also allow the register of more characteristics. Measurements were made on 1322 holes with two different diameters. In the two control charts created for this process, similar results were obtained, in table 1, where $C_p$ is a continuous process capability.

Table 1: Outputs of attributes control charts developed.

<table>
<thead>
<tr>
<th>Diameters</th>
<th>$C_p$</th>
<th>$\bar{p}$</th>
<th>$\sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>97%</td>
<td>0.027</td>
<td>0.043</td>
</tr>
<tr>
<td>D2</td>
<td>96%</td>
<td>0.039</td>
<td>0.040</td>
</tr>
</tbody>
</table>

Analyzing the behavior of the gathered data along the groups in the control charts, there are points out of control in the last groups of charts. Despite the low probability on occurring a NC and guarantee the $3\sigma$ in Six Sigma methodology [20], there are points out of control. Thus, although $C_p$ is high, it can not be concluded that the process is controlled.

Taking into account the results obtained and the monitorization performed during the measurements, it is suggested that new measurements be made in a next iteration to analyze the behavior of the process. The control limits for the next iteration should be those calculated by these charts. It is also proposed to carry out an MSA study for the production, since there can be great variability in the measurements that are not being taken into account.

4.3.2 Variables Control Charts

Variable control charts were developed, verified with CF6 measurements and validated in Minitab® software. The study of the entire implementation of variable control charts has its focus on the drilling process of panel C, where all the followed steps are presented in section 3.4.2. A MSA was developed to verify the variability of the measurement system. As shown in table 2, the repeatability and reproducibility (R&R) result does not satisfy the Six Sigma requirements. Since this analysis was performed only after all measurements made, it was considered that it met the specifications, so that all processes were created and validated. It is suggested that before the next measurements a new MSA with more repetitions and standard holes is made, in order to analyze the reasons for this great variability in the measurement system. The Number of Distinct Categories (NDC) value, is greater than 5 and meets the Six Sigma specifications. It can validate the program performed, because the results are very similar to those calculated by the Crossed method in Minitab®, as shown in table 2.

Table 2: Outputs of micrometers MSA.

<table>
<thead>
<tr>
<th></th>
<th>Program Improved</th>
<th>Minitab®</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repeatability</td>
<td>22.16</td>
<td>21.97</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>53.19</td>
<td>53.20</td>
</tr>
<tr>
<td>R&amp;R</td>
<td>53.19</td>
<td>53.20</td>
</tr>
<tr>
<td>$NDC$</td>
<td>5.12</td>
<td>5.00</td>
</tr>
</tbody>
</table>

Since stability requires two iterations because it measures the variation of values over time, this study was not performed. It has been found that bias tends to decrease by increasing bore diameter and that most of the registers are oversized (positive bias). Consequently, the inconsistency of the bias between the holes indicates that the measurement system also has linearity problems. After the new R&R analysis, it is suggested that the bias and the linearity also should be recalculated.

With the measurements pertaining to the holes of panel C, were constructed 5 $\bar{X}$/$S$ control charts, each control chart having a sample of $N = 125$, divided by groups, $m = 25$, where each group have set of measurements, $n = 5$. Figure 10 shows control chart $\bar{X}$ relative to the measured hole of one frame, being the Excel chart presented in Fig.10(a) and the Minitab® one in Fig.10(b), by comparing the two control charts. It was found that both measurement records behave in the same way, thus validating the $\bar{X}$ control chart calculations. Also it was possible to conclude that the drilling process is not controlled according to the Six Sigma theory and ISO/WD 8258 standard, it is necessary to analyze what causes these deviation of control points [18].

As for the process capability results, shown in
In Table 3, you can conclude that virtually all meet customer specifications. However, it is necessary to redo the MSA to verify these values. The fact that the drilling process is not controlled, no point is outside the customer’s specific limits, which is not the case in other processes. Using control charts for these characteristics, processes have been identified that need to be quickly rectified, as they have control limits well above specific limits.

Table 3: Capability indices of the control chart present before.

<table>
<thead>
<tr>
<th>Capability indices</th>
<th>$P_{pk}$</th>
<th>$C_{pk}$</th>
<th>$P_p$</th>
<th>$C_p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Results</td>
<td>4.29</td>
<td>5.37</td>
<td>4.46</td>
<td>5.59</td>
</tr>
</tbody>
</table>

5. Conclusions

The main goals of this project were achieved by applying to Lean and Six Sigma methodologies, in order to create tools and practices to improve the identification and registration of NC throughout the CF assembly of this aircraft model.

The 42 work procedures developed have helped to introduce the standardized work, making the processes more efficient and effective. As the work procedures were being introduced, there was a reduction of the NC committed as well as the reworks needed. The standardized work not only improved the identification process of NC, but also eradicated some of them. However, it is really important to quantify this improvement. In this way, location matrices were designed with aim of divide all of the CF in equal areas, where the each area has an assigned code, thus tracking the location of NC. These matrices, coupled with the digital platform allowed to register about 2880 NC and allowed to conclude what is the most frequent process, nature and location NC.

Knowing that the drilling is the most sensible process in aeronautical industry, it was established a SPC for this specific process. However this program could be extended to other characteristics that needed to be analyzed. The SPC is a Six Sigma practice which quantifies the variability and capability of the process. This program templates have been developed to have few inputs, automatically provide control charts and MSA of variable study in mind. The company not only saved at least 1,250 euros [21] (cost of each license of Minitab® software), but also obtained the results of 4655 measurements performed for different processes during CF6 assembly. In conclusion, this project contributes to the development of continuous improvement in the company, adding value in several processes.

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