



STUDY OF OIL PRESSURE PARAMETER IN OTTO CYCLE ENGINE FOR THE DEFINITION OF QUALITY CONTROL METHOD

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ABSTRACT

In a test process for Otto cycle engines, parameter analysis is essential for reliability, defect detection, and reduction of rework. For this reason, it is important to use quality management. The development of a computational model using the Visual Basic for Applications (VBA) language facilitated the acquisition and modeling of data for assertive and fast analysis. In this way, the analytical process became faster and more cost-effective. The Fire Test Bench (FTB) is a step in the production line where there was a lot of spending on rework. In addition, it was considered a limiting factor in increasing production because of its long operation time. Thus, there was the need to analyze the parameter related to oil pressure to reduce rework. As a result, it was possible to decrease the cost of fuel, increase the production capacity of 12 engines, and reduce cost.

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1. INTRODUCTION

Large companies have methods and tools designed to improve their products and exploit opportunities that will result in tangible financial gains. Other companies, in their struggle to meet market demands, fail to choose different strategies (Barbosa et al., 2020; Cardoso et al., 2022; Santos & Hart, 2020; Sharma et al., 2022). They try total quality, business process reengineering, elimination of boundaries, strategic alliances, planning

by scenarios that reduce waste, thus mitigating the generation of waste, contributing to sustainable industrial development (César et al., 2017; Espuny et al., 2021; Lokanadham & Subbaiah, 2020; Shah et al., 2020). Quality has played a key role in the conquest of new markets. Thus, regardless of the sector or size of the organization, it is necessary to meet customer requirements through new management methods that provide greater quality, satisfaction, and improved

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economic results (Arsovski, 2023; Barbosa et al., 2022; Maftei et al., 2020; Zhu et al., 2008).

Consumers increasingly demand products and services that meet or exceed their expectations, in addition to having better cost and benefit. In this sense, companies seek greater availability, flexibility and precision through resources that contribute to the development of products (Ivanov et al., 2016; Popkova, 2020; Werderits Silva et al., 2021). Six Sigma takes a rigorous statistical approach, and various tools are employed, with the intention of characterizing the sources of variability to demonstrate how this knowledge can control and improve process results. Thus, adopting the Six Sigma methodology means reducing defects, errors, and failures. Another tool used is Lean Manufacturing (Klochkov et al., 2019; Sales et al., 2022; Trung et al., 2021).

An operational philosophy seeks to eliminate waste. We intent optimizing the production line and continuous improvement with the application of quality tools. With this, there is a significant reduction in the time from customer order to delivery, in addition to reducing costs. Considering the eight wastes of the Lean philosophy, a great potential for improvement was noted at the assembler (Matytsin & Rusakova, 2021; Muraliraj et al., 2018; Silva et al., 2021). The work was developed in an assembling company in the south Fluminense State of Rio de Janeiro in the engine manufacturing process. The Fire Test Bench (FTB) is a hot test bench used to verify the final quality of the engines. The equipment can evaluate engine performance and detecting possible faults before it reaches the end customer. The FTB is an important stage for product quality assurance because it detects engine non-conformities, which are identified and segregated until they are reworked. In this stage the engine operation is verified, and its performance is measured.

It is a delicate, high-cost process because it requires the use of fossil fuel. With the increase in the production pace and the need to reduce waste and optimize the process, it is necessary to reduce the stages that do not add value. Due to all these factors and the need to stock semi-finished products, it was necessary to develop a study of time and motion to reduce operations that do not add value to the customer, as well a statistical study to define new limits, thus reducing the range. To meet this need, this work aims to reduce costs related to rework when the engine is tested more than once

2. THEORETICAL FRAMEWORK

The Six Sigma method can be defined as a flexible system for leadership and business performance and enables the achievement of benefits after implementation. A management tool has emerged in large companies and corporations. It is applied to operational processes with the objective of eliminating

defects by attacking the root cause and thus achieving the level of quality required by customers. The Six Sigma methodology uses mathematical and statistical tools to improve process quality (Cardoso et al., 2022; Kaswan & Rathi, 2019; Krstovski & Alwerfalli, 2022; Muthukannan & Chithambar Ganesh, 2019).

While other quality systems were developed to measure performance, the Six Sigma method was different. The procedures were aimed at changing methods so that overall performance could change permanently, and at all levels of the company (Gupta et al., 2020; Kaswan & Rathi, 2019; Muraliraj et al., 2018). Among the main objectives of the Six Sigma program is to reduce the number of defects, failures, and errors, and to reduce process variability. In addition, it aims to improve products and quality, shorten cycle times, improve inventories, and achieve lower costs. It is a methodology for improving business processes, whether operational or transactional, that will result in strong financial impacts for the company, increasing customer satisfaction and expanding market share (Alexander et al., 2019; Arafeh et al., 2018; Improta et al., 2020; Sunder M. & Antony, 2018).

The Lean Manufacturing methodology is based on continuous process improvement for waste reduction and customer focus (Murmura et al., 2021; Teixeira et al., 2022). The basic principle of the Lean system is to focus on the customer, engage the customer, reduce stages that do not add value, and seek perfection (Santos & Millán, 2013; Doiro et al., 2017). Thus, increasing the waste and increasing the quality of the factory (Santos & Barbosa, 2006; Bellisario & Pavlov, 2018; Vieira et al., 2019; Iranmanesh et al., 2019; Paunović et al., 2023; Psomas & Antony, 2019). It uses its concepts to reduce cycle times and waste-related costs, thus increasing the company's competitiveness. The lean waste reduction must be done continuously, eliminating it along the process (Santos et al., 2014; Antony et al., 2018; Arcidiacono & Pieroni, 2018; Silva et al., 2020). With the elimination, the company can remain more sustainable in the market, thus increasing competitiveness (Gupta et al., 2020; Kaswan & Rathi, 2019; Muraliraj et al., 2018; Silva et al., 2022).

3. RESEARCH METHOD

A time and motion study was conducted to make improvements and eliminate stages that did not add value to the product. Thus, the production cost was reduced and the equipment availability and, consequently, its productivity was increased. The study of time and motion together with the statistical analysis to define a new limit for the oil pressure parameter is a project for process improvement with the purpose of reducing cost and operation time.

The mapping of operations was performed to identify which operations are performed at the workstation and what their purposes are. For this step, official

documentation was used that establishes each step and operation flow. The goal is to identify each step of the process and whether it is being performed as planned. Next, a step-by-step flowchart mapping of the operation was prepared on the main operations for an accurate analysis of what normally occurs. For the calculation of the number of cycles, the normal operator rhythm and a previous data collection during ten cycles with a relative error of 3% were considered. The company recommends that the relative error be less than 3%. Thus, the degree of reliability is 95%. The previous average of these ten cycles was four hundred and sixty-nine seconds with a range of ninety-six seconds (1).

$$N = \left(\frac{Z \cdot R}{D_2 \cdot \mu \cdot E_r} \right)^2 \quad (1)$$

N = "number of cycles to be timed"; Z = "normal distribution coefficient for a given probability"; R = "sample size"; D₂ = "coefficient as a function of the number of preliminary timings performed"; μ = "average of the values of the observations "; and r = "relative error of the measurement". With the sample calculation performed, the Chrono analysis was then performed. By filming the operation during three shifts, the widest possible variety of models was observed, with the operator's consent to the use of the image. After the Chrono analysis, the footage was analyzed, and the cycle time was calculated according to equation 16 for each activity and the average time for the operation. Thus, some improvements were defined so that the process could reach the desired production capacity (2).

$$TC = \frac{1}{N} \sum_{i=1}^N T_i \quad (2)$$

Then the Takt Time (TT), which is the ratio between the available time of the production line and the requested demand (3).

$$TT = \frac{\text{Available time}}{\text{Demand}} \quad (3)$$

As the cycle time was longer than the TT, it was necessary to adjust the parameter for the decrease of the cycle time. This adjustment was performed to have a process in which the CP and CPK were close to the reference value (1.33). It was also possible to develop the ability to detect faults in the process. It was identified during the time and motion study that the specified parameter for oil pressure was the main cause for the engine being tested more than once, even though it was compliant. According to the variation of temperature and pressure, the specified parameter for oil pressure was measured during the test. Then, a sample of one hundred engines was used and the results were compliant. Next, a schedule to gain agility in the process of file data analysis was developed. The file, which is, automatically saved by the FTB, contains detailed information about each step of

the test and allows the traceability of the engine performance on the FTB.

The program consists of opening files from a selected folder. Then, it searches through the entire file for the selected parameter and which test block this parameter refers to, and finds the equivalent result. Once this is done, the program copies the test result to a list with the engine corresponding number to the test, for traceability of the result. After collecting the results for the selected parameter, the program delivers a result for a visual analysis of the histogram chart and the control chart and for a statistical analysis. The arithmetic mean of the analyzed results, the standard deviation, the calculated upper limit, calculated lower limit, upper specification limit, lower specification limit, sample number, Cp and Cpk are also calculated. After getting the result from the program, the analysis was performed according to the PDCA cycle. The parameter on the test bench was changed to the value set by the Six Sigma analysis, so the results are monitored to observe the decrease in the amount of engines tested more than once.

4. RESULTS

The project was carried out in an automotive company X, located in the southern region of Rio de Janeiro. The company adopts Lean Six Sigma methodology for its process. The FTB is the sector of the production line where 100% of the engines are tested. Because the engine is running, the combustion of the active fluid inside the engine occurs, and that is why the performed test in the FTB is known as the hot test. This test is performed with the engine running, simulating its operation. When simulating the operation, the FTB measures parameters broken down into steps to detect defects.

The test is performed at the end of the engine assembly process with the goal of hot testing 100% of the product before it is transported to the final vehicle assembly line. Initially, the workstation's official documentation is analyzed. This documentation is an important means of control for the factory because all the operation of the workstation is registered in it, and there is the need to have it in each one. After the documentation is analyzed, the mapping of all the activity that is performed is carried out, and the monitoring of the operation at the workstation, to verify if what is in the documentation is being performed.

After this verification, if the result is positive, the operations are grouped according to their order and characteristics. It was necessary to define which would be the elements of analysis: engine entry to the test bench, sensors connection, final coupling, cables connection, test, time spent when the engine needs to be tested more than once, connections removal, visual check, coolant drain, start of engine exit from the test bench, sensors removal, and transport time (exit). With the definition of the analysis elements, a flowchart was prepared for visual

aid. After the definition of the operation flow, the calculation was performed to determine the sample of time and motion study. The normal distribution coefficient as a function of reliability (Z) for 95% reliability is 1.96.

The acceptable relative error varies between 5% and 10%. According to company recommendations, the relative error must be 3%, which caused the number of cycles to increase. The larger the initial sample size, the more accurate the sample number measurement. The coefficient of distribution by sample number (D₂) increases as the number of initial timings increases. Since D₂ is inversely proportional to the sample number (N), the larger the initial sampling, the smaller the value of N. The chosen preliminary sample was seven cycles because, although it is close to the mean, it is not an upper end number.

Once the parameters for calculating the number of samples were defined, the Chrono analysis of the first seven samples was performed. With these samples, the time of each cycle was calculated. Then, the average was calculated and used to determine the value of N. The average of the seven samples was 465 seconds. It can be seen that the "Retest" and "LLC Drain" operations did not occur in all tests. The "Retest" operation occurs when the engine needs to be tested more than once. The LLC Drain occurs when the coolant is drained from the engine and is taken back to the reservoir. The calculation of the sample number depends on the amplitude (R) of the preliminary samples. The amplitude can be described as the difference between the largest and smallest sample value. The results of the seven samples are described, the largest result is 8 minutes and 35 seconds, and the smallest is 6 minutes and 59 seconds. According to the international system, the unit of measurement for time is

seconds, so it was necessary to convert the time from minutes to seconds. The longest time can be written as 515 seconds and the shortest time, 419 seconds. Thus, we have the range of 96 seconds (4).

$$R = T_{\max} - T_{\min} = 515 - 419 = 96 \text{ seconds} \quad (4)$$

Data: Z=1.96 (for 95% reliability); R=96 seconds; D₂=2.704 (for the number of seven samples); $\mu=465$ seconds; and Er=0.03 (3% error). With the set data and using equation 16, the number of cycles was calculated. As a result of equation 19, the determined amount was twenty-five cycles (5).

$$N = \left(\frac{1,96 \cdot 96}{2,704 \cdot 465 \cdot 0,03} \right)^2 = 24,88 = 25 \text{ cycles} \quad (5)$$

With the calculated number of samples, the chronoanalysis of the twenty-five cycles was performed. After analyzing the images, the cycle time for each element of analysis performed was then obtained (5).

$$TC = \frac{1}{25} \sum_{i=1}^{25} T_i \quad (6)$$

The operator's speed is determined subjectively by the chronoanalyst. For the operator's normal operating speed is assigned a rate, or rhythm, of 100%. There are speeds that are above and below normal. After the recording, each of the results was analyzed with their respective notes and observations, and the pace of the standard operation was decided. The cycle time is equal to the average of the accumulated time of the 25 analyzed cycles (7).

$$TC = \frac{1}{25} (07,03 + 06,59 + 08,35 + 07,50 + 09,10 + 07,25 + 07,05 + 07,36 + 07,58 + 07,32 + 07,56 + 07,17 + 08,47 + 08,30 + 07,51 + 08,30 + 07,20 + 07,46 + 07,58 + 07,49 + 07,35 + 07,12 + 10,37 + 07,30) \quad (7)$$

The total operation time was seven minutes and fifty-six seconds. The cycle time was calculated as the average of the results of the analyzed cycles. Cycle time means the time taken to perform an operation. The operating rate, or operating speed, is the rate at which the operator works during the chronoanalysis (8).

$$TC = 7 \text{ minutos e } 56 \text{ secondsos} \quad (8)$$

To calculate TT, we first calculate the number of motors passing through each of the four banks per hour. The requested demand was 31 motors per hour. Since there are four test benches at the FTB, the average number of engines that are tested on each bench per hour is calculated with the ratio 23. This calculation is necessary because the FTB performs the same operation on its benches. For this reason, the FTB tests four engines simultaneously. Therefore, the production demand is divided between the benches (9).

$$\text{Number of Engines per Test Bench} = \frac{\text{Production Demand per Hour}}{\text{Test Bench Quantity}} = \frac{31}{4} \quad (9)$$

The demand per test bench, according to equation 24, is 7.75 motors per hour (10).

$$TT = \frac{60 \text{ Minutes}}{\text{Number of Engines per Test Bench}} = \frac{60 \text{ Minutes}}{7,75} \quad (10)$$

The TT result of FTB was 7 minutes and 44 seconds. With the results of the calculations, it could be seen that the cycle time of the current line - 7 minutes and 56 seconds - did not meet the TT of the FTB. Thus, the FTB is a bottleneck for production. There was theneed for an analysis of the entire process to identify and eliminate steps that did not add value. When analyzing the activities separately, it was observed that the average time used to test the engine more than once (retest) was 26 seconds. The second engine test is considered rework because the same operation is performed without adding value to the product. It was then analyzed that this waste should be eliminated, thus reducing 26 seconds of the total test time, which was 7 minutes and 56 seconds (11).

$$TT = 7 \text{ minutes e } 44 \text{ seconds} \quad (11)$$

Then, there was a need to analyze the test results to identify which parameter was the cause of the engine being tested more than once. The chosen parameter was oil pressure because its limits were off centered in relation to the mean and standard deviation. The lower specification limit was 0.7 bar and the upper specification limit was 4.5 bar. The mean was 4.07 bar, toward the upper limit (Figure 1).

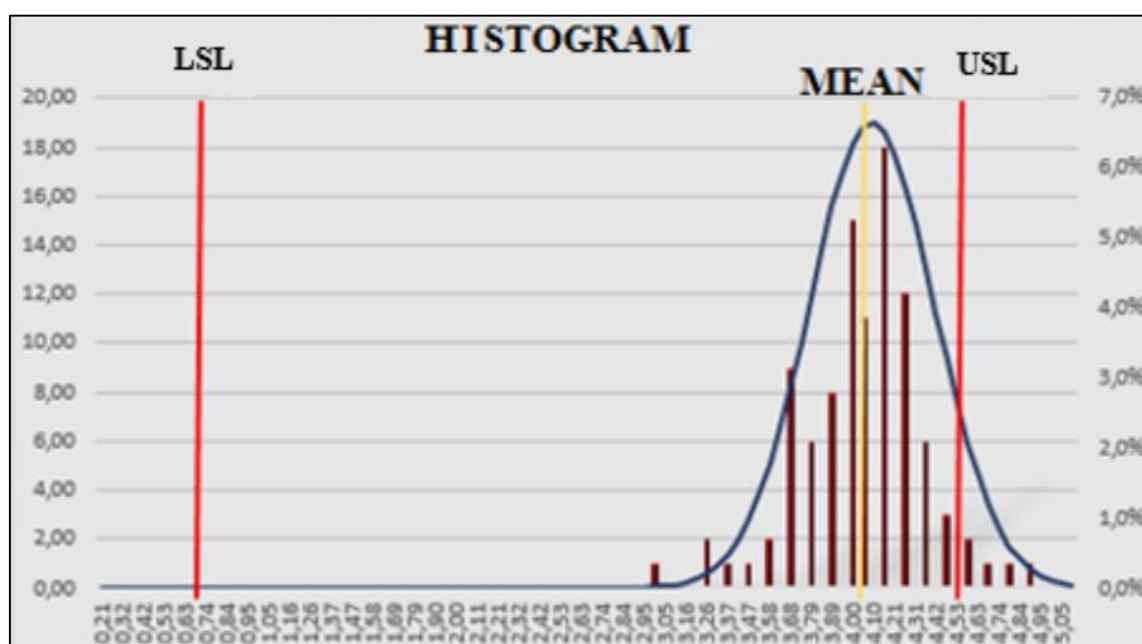


Figure 1. Schematic of the operation of the cabin conveyor on the production line

After identifying the problem, which was the decentralization of the average, the first analysis was developed for a sample of ten engines. However, to obtain a fast and safe analysis for a sample of one hundred engines, there was the need to develop a computer program in the Visual Basic for Application language of Microsoft Excel. Without programming in VBA, the statistical analysis would have to be performed according to the following steps:

1. download the machine data from the operating station;
2. save in a folder of preference;
3. run the files according to the sample size;
4. look for the step and the parameter that you want to analyze
5. copy their respective results into a list;
6. calculate the statistical data, such as mean, standard deviation;
7. make the histogram and the control chart to analyze the chosen parameter; and

8. analyze the results of the previous steps.

With the program, the analysis has become much simpler, faster, and safer. The number of steps was reduced from nine to seven. Others were also simplified, resulting in quantitative and qualitative gain. The new sequence of activities was:

1. download the machine data from the operating station;
2. save in a preferred folder;
3. open the program;
4. select the step and the parameter;
5. click on “generate data”;
6. click on “compile”; and
7. analyze the results.

Figure 2 makes a comparison regarding gained the time running the program using ten motors. Since a lot of time was spent on the ten engines, it would not be possible to analyze the necessary number of engines for the

statistical study. In the case of the study, which aims to change the limits of the oil pressure parameter, a sample of one hundred engines was needed. Therefore, the time

gain will be greater because the greater the number of engines, the greater the difference in time between the manual analysis and the program.

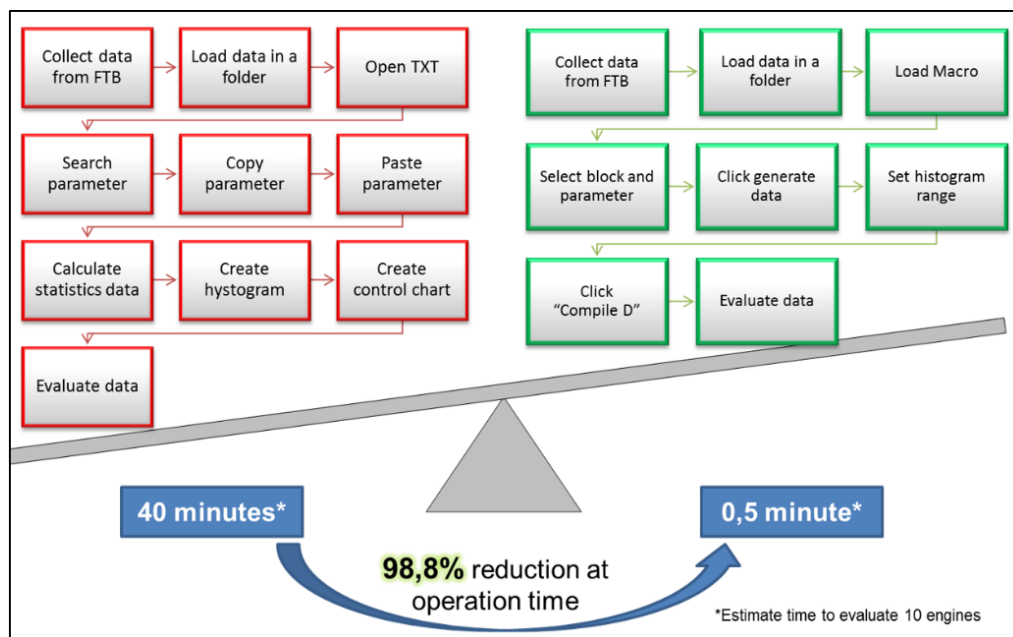


Figure 2. Comparison of steps and process time for 10 engines

With the created program, the programming was run with one hundred motors. The selection of these motors was not random. We tried to select motors from different periods of the year to cover the greatest variation in ambient temperature, which is a factor that directly

influences the oil pressure. If the ambient temperature is above average, the oil becomes less fluid, less viscous and the pressure decreases. On the other hand, if the temperature is below average, the oil becomes more viscous and the pressure increases (Figure 3).

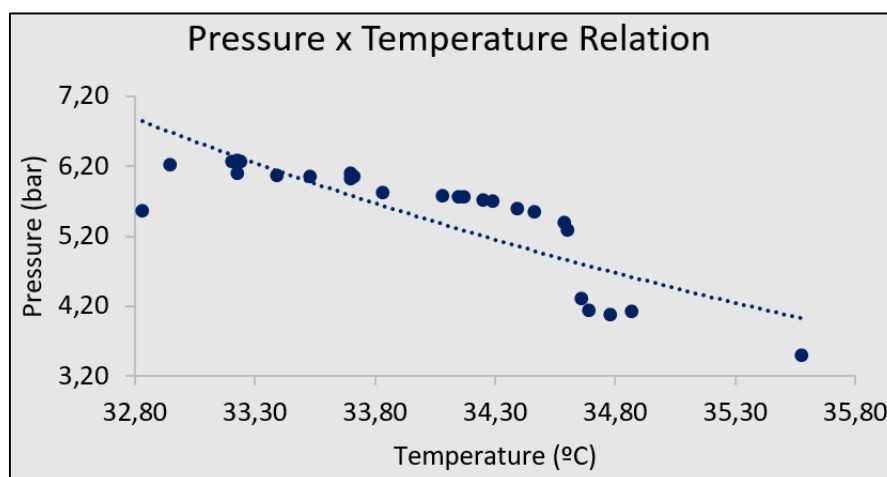


Figure 3. Pressure x Temperature relationship throughout the test

After the selection, the test results were separated in a data folder on the computer. The programming, when run, selects the data for the specific parameter thus generating the control chart and histogram for analysis. The data was filed in the data folder. The first result was studied and analyzed so that the compliant motors were not mistakenly considered in the test as non-compliant motors. With this analysis of the first result, it was detected that the limits were not adequate to judge the parameter. The lower limit in this step of the analysis was

3.1 bar and the upper limit was 5.1 bar. It could be seen that if the lower limit of 3.1 bar was considered, there would be compliant motors in the sample below this limit. It was then decided to adopt the lowest value of the sample as the lower limit, which corresponded to 3.0 bar. The upper limit was also changed to 5.0 bar, to maintain the amplitude of the first result. With these limits, there were engines that showed no defects, although their oil pressure was below the lower limit due to temperature variation. Therefore, they would be compliant engines

judged as non-compliant. After defining the limits, the values were changed in the system used to perform the test. When performing the test, it was detected that in some specific cases, the second limit change did not absorb the pressure variation. It was then necessary to use the PDCA cycle again to analyze the parameter. Thus, the results of these engines were observed to be compliant even with low pressure and the temperature of this engine was at specification limit. Then, it was necessary to readjust the lower limit.

The lower limit was set to 2.0 bar. This value was chosen as the lowest oil pressure value was observed after the engine was tested more than once, thus absorbing the temperature variation and covering compliant engines. For these changes, the PDCA cycle was used, seeking

process improvement. Once the limits were defined, the practical test was performed. The parameter limits were changed again in the system that performs the test on the test bench computers. The FTB is composed of four test benches in sequence performing the same operation. Then, bench number four was chosen for the test because it had the lowest production demand, so that if something unexpected happened, the other three benches could absorb the production demand. For this stage of the test, a production time of one day was stipulated. Due to the FTB layout and the scheduling system, when the engine passes through the FTB line it tends to park in the first empty bench (Figure 4). With this scheduling logic of the engine movement on the test bench, the number one bench tends to have a higher production demand than the other benches.

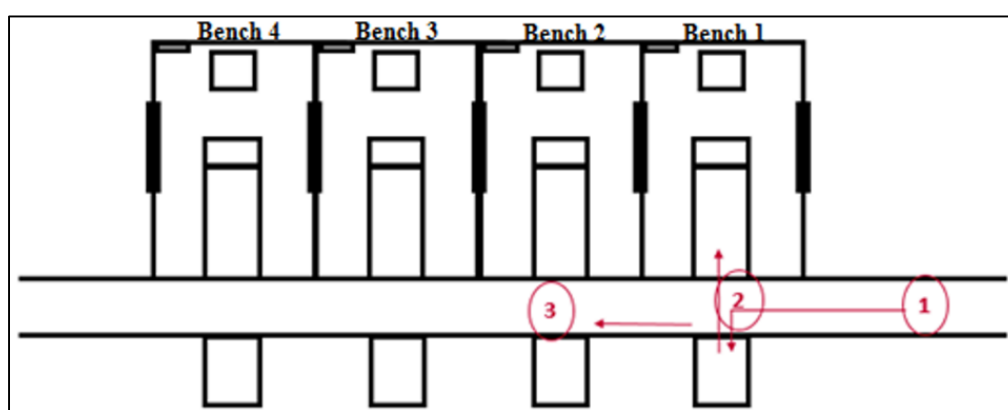


Figure 4. Motor movement on the test stand

The numbering in the figure above indicates the movement of the motor along the bench. The first indicates the motor entering the test stand. In this movement the motor arrives from the production line and is parked in the indentation waiting for the test. On the second movement, it leaves the indentation and heads for the test stand. After the test, the engine is moved to the next station on the production line. The movements are also described in Table 1.

Table 1. Motor movement on test bench frame

Step	Activity
01	Transporting the line to the recoil
02	Transport from recoil to bank
03	Transport from the bank to the next station

After the first day of testing without any nonconformity, the period defined for the test in only one bank was postponed to one month. After this period, the limits of the other banks would be changed. The reason for this decision was out of caution because if any unforeseen event occurred the other benches would be able to absorb the production, not impacting the indicator of line stoppage. During this period, there were no unforeseen

problems in bench four. Thus, it was concluded that the test improved the performance in relation to the other benches. The parameter limit was then changed for all benches. With the application of the new parameter limit, there was also monitoring of all FTB benches for another month because in case of an unexpected event, there would also be a quick detection and reaction.

After the monitoring, there were no unforeseen events, making the test successful. With the execution of the time and motion study, it was possible to observe every movement of the operator, as well as all the steps that were completed during the period of a test. With these mapped steps, the operator's movement during the test was tracked, aiming not only at the reduction of steps but also at the ergonomics of the operator. Figure 5 shows in detail the operator's movement during the test, and Figure 6 shows the operator's movement during the test and after the test.

With this scenario, the FTB would not meet the proposed production volume. Thus, there was the need to increase the availability of the machine to meet the production line by reducing the number of engines tested more than once.

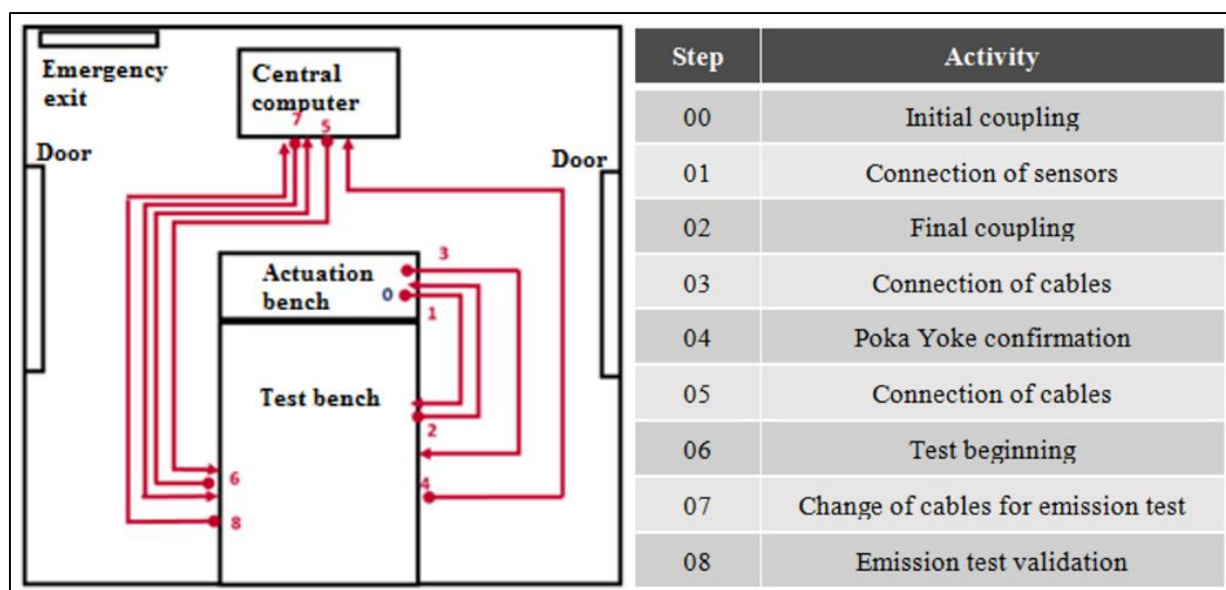


Figure 5. Operator movement during the test and legend

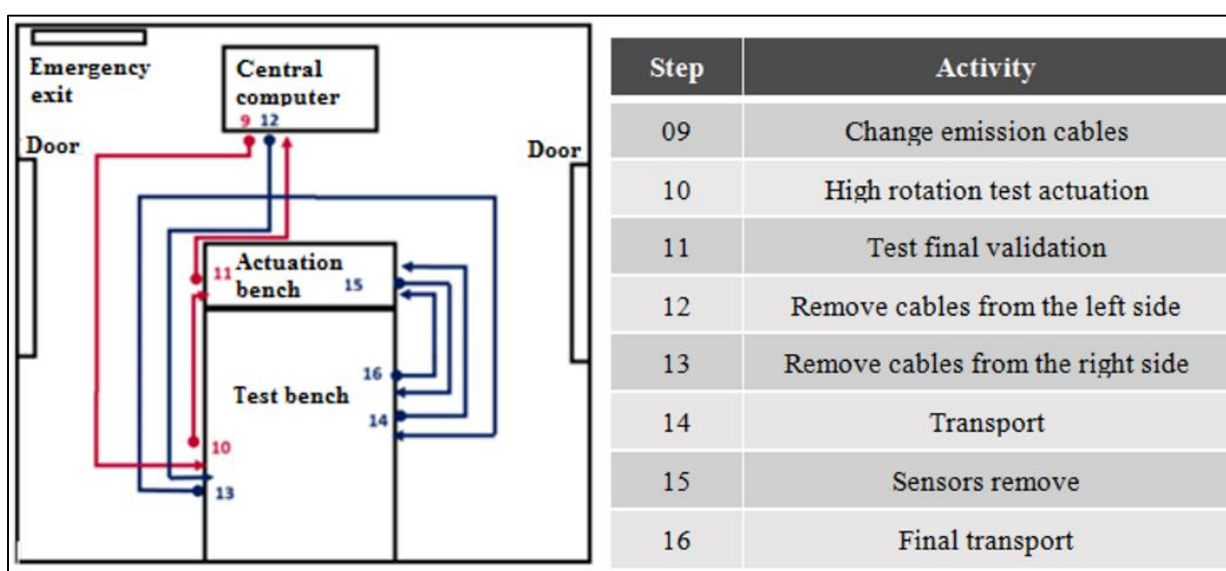


Figure 6. Movement during the test (red) and after the test (blue)

As an opportunity for improvement, it was decided to perform a statistical study to change the oil pressure parameter based on the Six Sigma process. In this study, one can analyze the old scenario through the histogram and the control chart, where one can see a large difference between the limits: lower specification limit 0.7 bar and upper specification limit 4.5 bar. So, there was a large range, with the possibility of defects not being detected. On the other hand, there were many compliant motors that were tested more than once. This was a waste of time and fuel that did not add value to the product and prevented the workstation from reaching its maximum capacity. With the above limits, the Cp value, given by equation 12, was calculated, and the standard deviation calculated by the program was 0.32. With Equation 12,

we obtained the value of Cp 2.01, higher than the reference value (12).

$$CP = \frac{LSE - LIE}{6\sigma} = \frac{4,5 - 0,7}{6(0,32)} = 2,01 \quad (12)$$

The Cpk was also calculated with the above limit, using the standard deviation the average found which was 4.07. The result of Cpk was found with Equation 13, which showed how decentralized the process was because the value found was 0.45, which is below the reference value. Figures 7 and 8 show the state of the process in this condition.

$$CPk = \min \left\{ \frac{(LSE - \bar{X})}{3\sigma} \left| \frac{(\bar{X} - LSI)}{3\sigma} \right. \right\} = \min \left\{ \frac{(4,5 - 4,07)}{3(0,32)} \left| \frac{(4,07 - 0,7)}{3(0,32)} \right. \right\} = \min \{0,45 | 3,51\} = 0,45 \quad (13)$$

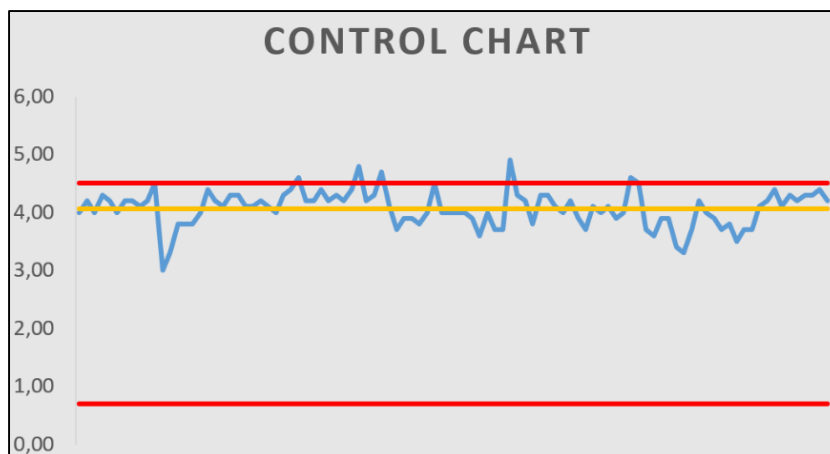


Figure 7. Old Scenario Control Chart

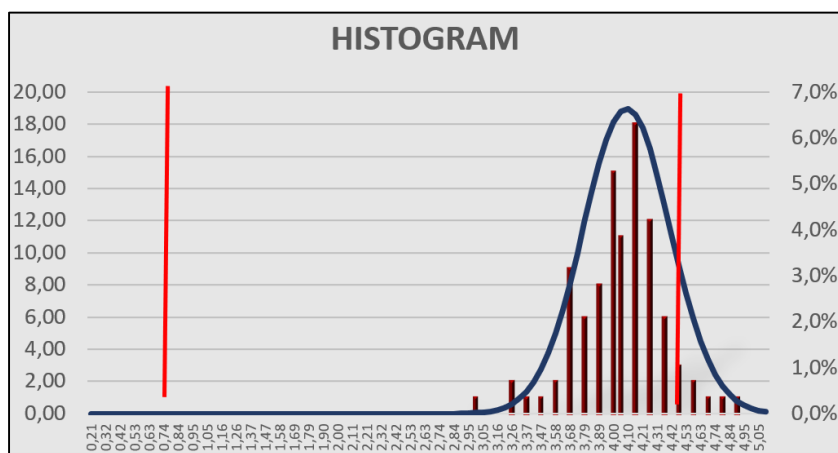


Figure 8. Histogram of the old scenario

With the analysis of the parameter and the need to change the lower and upper limits, a smaller range was proposed for testing. Based on equation 14, the program calculates the upper specification limit, which is 5.01 bar, and based on equation 15 the program calculates the lower specification limit, which is 3.1 bar (14 and 15).

$$LSE = \mu + 3 * \sigma = 4,07 + 3 * 0,32 = 5,01 \quad (14)$$

$$LIE = \mu - 3 * \sigma = 4,07 - 3 * 0,32 = 3,1 \quad (15)$$

Figures 9 and 10 show the process with the changes proposed above. From Figure 9, it is possible to observe that the proposed limits cannot absorb process variations. These variations occur because the process is influenced by several factors, the main one being temperature, which can be the engine's oil temperature or even the ambient temperature. Even so, there were compliant engines tested more than once.

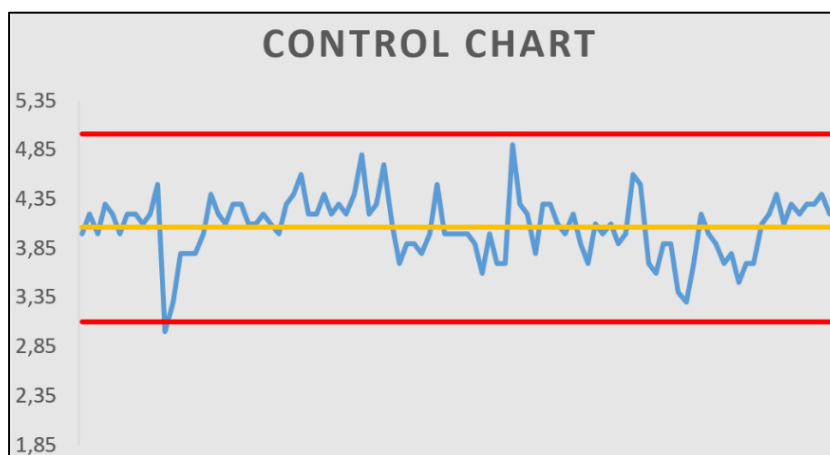


Figure 9. Control Chart with the proposed Limit (3.0 to 5.0 bar)

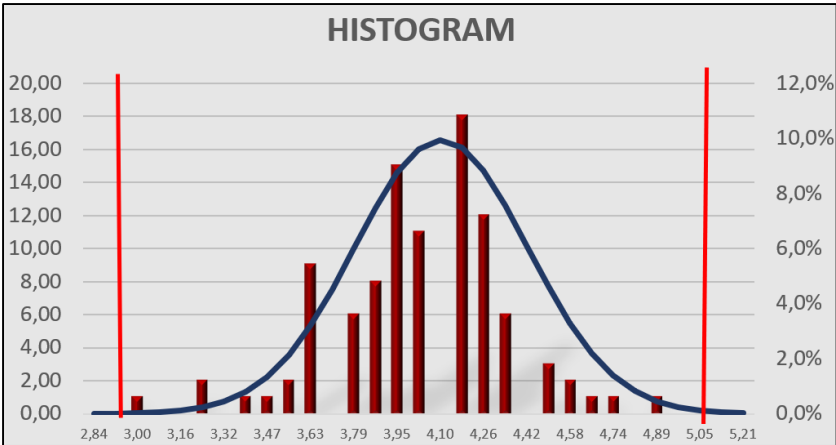


Figure 10. Histogram of the Proposed Scenario (3.0 to 5.0 bar)

For this reason, there was the need to run the PDCA cycle again for the adequacy of a limit that would reach the production need. A study was then conducted where defects related to the parameter and its test result were observed. With this result, the process variations and limits that could absorb this change were observed. Thus, the value of the lower limit was considered equal to 2.0

bar because it was the lowest value obtained in the test. The determined lower limit was 3.0 bar and the upper limit was maintained at 5.0 bar. According to the changes introduced in the process, a new control chart and a new histogram were obtained which are represented in images 11 e 12.

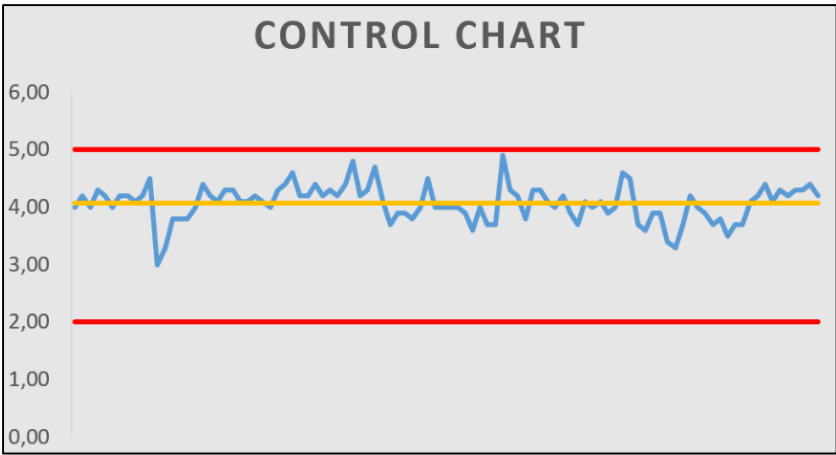


Figure 11. Control Chart with the proposed Limit (2.0 to 5.0 bar)

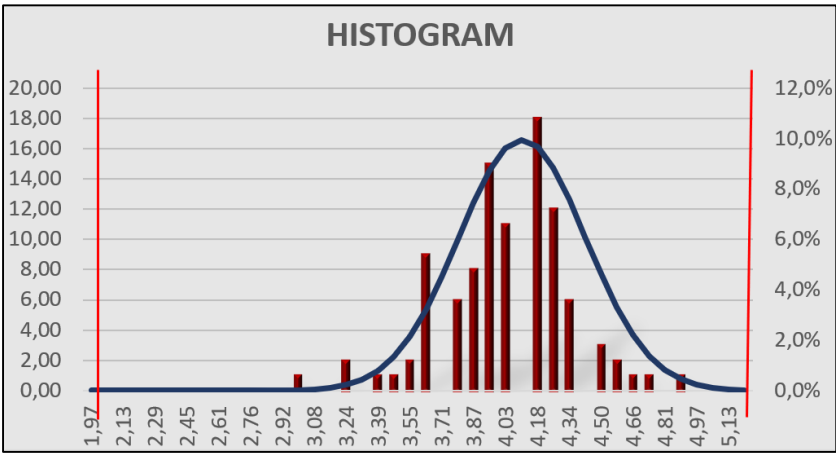


Figure 12. Histogram of the Proposed Scenario (2.0 to 5.0 bar)

With these limits, the C_p was then calculated by Equation 16 to analyze the amplitude of the process.

With the value of 1.56 C_p was close to the reference value, which is 1.33.

This way, the process capability reaches centralized distribution.

$$CP = \frac{LSE - LIE}{6\sigma} = \frac{5,0 - 2,0}{6(0,32)} = 1,56 \quad (16)$$

$$CPk = \min\left\{\frac{(LSE - \mu)}{3\sigma} \mid \frac{(\mu - LIE)}{3\sigma}\right\} = \min\left\{\frac{(5,0 - 4,07)}{3(0,32)} \mid \frac{(4,07 - 2,0)}{3(0,32)}\right\} = \min\{0,97 \mid 2,16\} = 0,97 \quad (17)$$

With this new scenario, it is possible to reduce the cycle time by 26 seconds, from 7 minutes and 56 seconds to 7 minutes and 30 seconds, according to Equation 18. There was also a reduction in fuel expenditure since there were 26 seconds less with the engine running on a test.

$$TC = 7 \text{ minutes and } 30 \text{ seconds} \quad (18)$$

$$\text{Time reduction per bank} = 7,75 * 26 \text{ seconds} \\ = 3 \text{ min and } 22 \text{ sec} \quad (19)$$

$$\text{Production capacity} = \frac{\text{Time available for production}}{\text{Production time per unit}} = \frac{60}{7 \text{ min } 30 \text{ seg}} \quad (21)$$

$$\text{Production capacity per hour} = 8 \text{ engines per seat} \quad (22)$$

$$\text{Total production capacity} = 8 \text{ engines per seat} * 4 = 32 \text{ engines per hour} \quad (23)$$

With the above calculations, it is proven that there was an increase in production capacity from 26 to 32 engines per hour, higher than the capacity of the production line. With this result, the FTB is no longer a bottleneck and starts to meet the production needs.

5. CONCLUSION

This work studied the data behaviors of the oil pressure parameter in the FTB, where the engine was tested at the end of the production line. It had its model developed with the Visual Basic for Application programming language and with the Six Sigma methodology. Concepts of lean manufacturing, statistics, and Otto cycle engines were reviewed to achieve its objectives. A programming code was created to facilitate the analysis of the chosen parameter. This way, the analysis time was reduced. With the execution of the program, it was possible to generate new limits based on the Six Sigma methodology. To apply these limits, the PDCA cycle was used, where all the steps were carried out until the actual

For Cpk, calculated with Equation 17, we have the value of 0.97, below the specified value, but greater than the initial and close to the reference value, thus making the process able.

$$\text{Total time reduction} \\ = 3 \text{ min and } 26 \text{ sec} * 4 \text{ banks} \\ = 13 \text{ min and } 26 \text{ sec} \quad (20)$$

The production capacity was calculated using the available time and the production time, resulting in 8 motors per bench in one hour. Therefore, in every FTB, production capacity was calculated by Equation 21, resulting in 32 engines per hour.

implementation. By changing the parameter limits, it was possible to increase machine efficiency and production availability. The rework costs caused by motors tested more than once were reduced.

The change allowed the test to gain greater accuracy. It was possible to increase defect detection and decrease the judgment of compliant engines as non-compliant ones. Thus, there was an increase in test reliability. With the production gain, the FTB was no longer a bottleneck. Its capacity increased from 26 motors to 32 motors per hour. As the need for the line is 31 motors per hour, there was time to change the station. One can cite changes for ergonomic reasons, organization, and the possibility of putting other operations in the station. A new line balancing is in progress, with a gain in manpower and an increase in the company's profitability.

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