INVESTIGATION OF ENGINE OIL LEAKAGE EVENTS IN AN AERONAUTICAL COMPANY AIMING AT REDUCING THE RISK OF OPERATIONAL FAILURE – A CASE STUDY

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ABSTRACT

Competitive and high-performance companies consider customer satisfaction the primary index to measure the quality of products and services. The management of customer complaints is essential for these companies to attain continuous improvement in quality and safety. Every complaint needs to be analyzed, treated, and monitored to avoid major operational problems. The risk of operational failure and, consequently, an accident or incident is severe when root causes of complaints are not addressed. The purpose of this paper is to conduct an in-depth analysis and investigate customer complaints related to engine oil leaks in an aeronautical maintenance company. The objective is to decrease the number of such complaints and maintaining high performance in quality and safety. The authors conducted a case study and a literature review to identify state-of-the-art literature about the subject as a methodological approach. They also used the DMAIC cycle and the Lean Six Sigma tools to determine the factors that caused oil leaks and treat the root cause. As a result, a specific engine family was identified as having frequent occurrences of oil leaks. Corrective actions have been implemented on the root causes to monitor and control such problems and avoid reoccurrence—the results obtained with this work positively impacted the studied company. The number of nonconformities experienced by customers decreased, and opportunities for improvement in another engine family have been identified. The study is essential for professionals and specialists in quality and safety and companies working with aeronautical maintenance.

1. INTRODUCTION

In the engine maintenance process, the engines are divided into modules, and all parts are disassembled, resulting in thousands of components that must be cleaned, inspected, repaired, and reassembled in the original engine. Since different engines, models, and configurations are processed simultaneously, there are risks of possible problems at assembly. The concern about these risks in engine maintenance is not something new. According to Pereira [1], operational risk factors must be identified and evaluated to remain competitive in the national and international markets. Oliveira [2] ensures that approved companies are constantly monitored by regulatory agencies so that the services provided are carried out to the highest standards of quality and technology. The cases of engine oil leakage observed in company records show that it generates complaints and a possible lack of trust of its customers. In order to address this problem, this study proposes the use of quality tools to define actions aligned with the root cause of the problem. The case study used the DMAIC methodology from Six Sigma to treat the root cause of the deviations. This study aims to investigate the events of oil leakage in helicopter engines and the associated operational risks, given the relevance of this subject in the aeronautical field.

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None of the researched previous studies presented information related to oil leakage investigation in jet engines. Some of these researched papers are listed herein in section 2. The study responds to the following important research questions:

Research Question 1: Is the DMAIC methodology effective for treating non-conformities related to oil leakage and reducing risks?

Research Question 2: What benefits has this study provided to the company where the case study was carried out?

Research Question 3: What is the relation between quality and the reduction of operational risks related to oil leakage?

The paper is structured as follows: Section 2 describes the methodology and presents previous studies on oil leakage and Six Sigma. Section 3 presents the discussion, and section 4 the conclusion. In the end, the list of references used in this paper is provided.

2. DESCRIPTION

2.1 Methodology

This study combined the application of the Six Sigma and DMAIC cycle concepts, supported by quality tools to reduce operational risks in aeronautical maintenance, focusing on handling customer complaints, specifically on cases of oil leakage. The proposed methodology was quantitative and explanatory. It consisted of proof of data through statistical analysis and aimed to identify the causes of the problems related to oil leakage. The information was shared with different engineers, mechanics, and operating personnel who had the opportunity to discuss, clarify the causes of engine leaks, and contribute new perspectives on critical factors. The data were converged in the analysis process. Each data source contributed to the understanding of the root cause of the leaks. This combination of information added strength to the analyses as the various strands of data were combined to promote a better understanding of oil leaks. Fig.1 shows the methodology Flowchart.

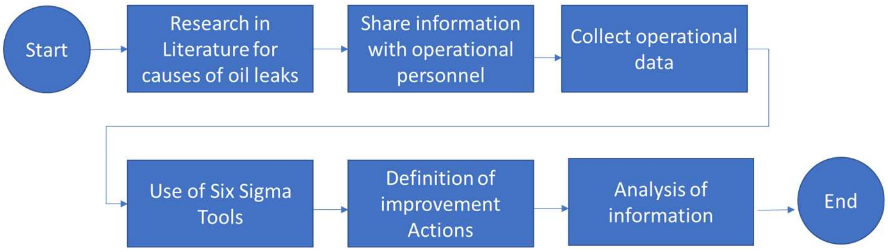

Figure 1 – Methodology Flowchart

2.2 Quality in Aeronautical Maintenance

Within the diversity of industrial sectors where quality is essential, Costa [3] ensures that the aeronautical sector has the most significant concern in maintaining efficient Quality Management. According to Marcuzzo [4], aircraft maintenance should be a systematic and consistent process, requiring a list of records controls to ensure aircraft ability. The control of each maintenance stage records is an essential requirement for the adequacy of a quality management system to provide evidence of compliance and ensure the traceability of information.
In order to perform maintenance on aeronautical engines, it is necessary to have trained maintenance personnel and the appropriate facilities, equipment, tools, and parts. Therefore, any maintenance service must be following the manufacturer's maintenance manual and the workshop. Moreover, to ensure the quality of the

service, it is recommended that the organization has professionals trained in operational safety, of which they will be responsible for internal audits. Audits are inspection processes that aim to evaluate the system and procedures described therein, making them remain effective and achieve the proposed purposes. The mechanic's service depends on the proper functioning of his tools; these must be measured and calibrated frequently to ensure the quality of service. In addition, the parts applied to the engine must be airworthy with traceability of its life. It avoids the inadvertent use of parts with their limits exceeded, putting at risk the airworthiness of the engine. According to data published by CENIPA [5], for every 4 (four) aircraft accidents, 1 (one) is fatal. Therefore, the control and investigation of customer complaints are essential to quality in aviation maintenance processes.

2.3 Six Sigma and DMAIC Methodology

Six Sigma is a profit maximization technique achieved through customer satisfaction. It was first successfully implemented by Motorola and has since been adopted by other companies. Pande [6] stated that Six Sigma focuses on three main areas: increased customer satisfaction, reduced cycle time, and reduced defects. Still, according to Pande [7], "Six Sigma is the smartest way to manage a business or a department. Six Sigma puts customers first, using facts and data to drive the best solutions." Therefore, the Six Sigma methodology goes beyond quality strategies and can also be understood as business strategies. The main objectives of Six Sigma are to increase profitability and customer satisfaction, keep current customers, and create relationships with new ones. The Six Sigma methodology is composed of a broad set of tools and techniques to improve quality. In the present work, the application structure to be developed is the DMAIC cycle. DMAIC is a method of change management and problem-solving that emphasizes applying the Six Sigma system in the production of goods or services. Werkema [8] cites DMAIC as a roadmap that can be widely applied in process improvement. Also, according to Werkema [9], the DMAIC method is a quality tool that aims to form teams to carry out activities of strategic objectives. In the case of this work, it was used to reduce the number of customer complaints. According to Brady [10], each letter has a defined meaning. The DMAIC is structured as follows, Define, Measure, Analyze, Improve, and control. According to Santos [11], this model supports keeping the focus on activities in a structured direction. The DMAIC methodology is used when an existing process does not meet the customer's needs or objectives or underperform [12]. The initial phase of the methodology consists of the definition of the problem and operational impact to facilitate the project's development in the following steps. The definition of the problem constitutes the backbone of any Six Sigma project [13]. The Measurement phase is the time to determine the problem. According to Moreira [14], the objective of this phase is to dismember the more significant problem in problems of smaller scope or, more specifically, to identify the focus of the critical problems to be investigated. When dismembering into more specific problems, it is necessary to use some quality tools that were used in the Measurement phase of this case study. For Werkema [15], it is oriented to use statistical tools for data collection. Establishing that Pareto Diagram, Histogram, among other tools, are of great use in this step. In the third second phase [16], the data collected in the previous phase are analyzed to identify the fundamental causes and their quantification of the problem in question. Still, it is essential to determine the causes of each priority problem at this stage, analyze the process that generates the priority problem, and identify and prioritize potential causes [17].

The purpose of the Improve phase is to create an action plan with the activities carried out to eliminate defects, waste, and costs. The proposed actions need to be linked to the identifications of the previous phases. Through the results obtained in the previous phases, one should produce enough arguments to propose changes and always with the thought of continuous improvement. [18]. In the last phase of the DMAIC methodology, Carpinetti [19] declares that the goal is to ensure the continuity of the improvements built and not forgotten or lost in the company, performing rigorous monitoring. Werkema [20] Comments that it is possible to maintain a stable process in the control step when improving procedures and work instructions. Moreover, it is of great importance to record and not lose traceability of changes. Finally, DMAIC is considered a consistent and good-result method because it is monitored and planned in all phases, avoiding unnecessary actions. The existence of a predefined roadmap for the actions of a project is of paramount importance to increase the chances of success.

3. DISCUSSION

The case study was conducted at an aeronautical maintenance company focused on investigating the root cause of customer complaint events related to oil leaks. The production process is divided into two main steps, as shown in the flowchart below. Pre Quote is the step that precedes the approval of the budget by the client. The Order Completion is the step after the approval of the budget by the customer.

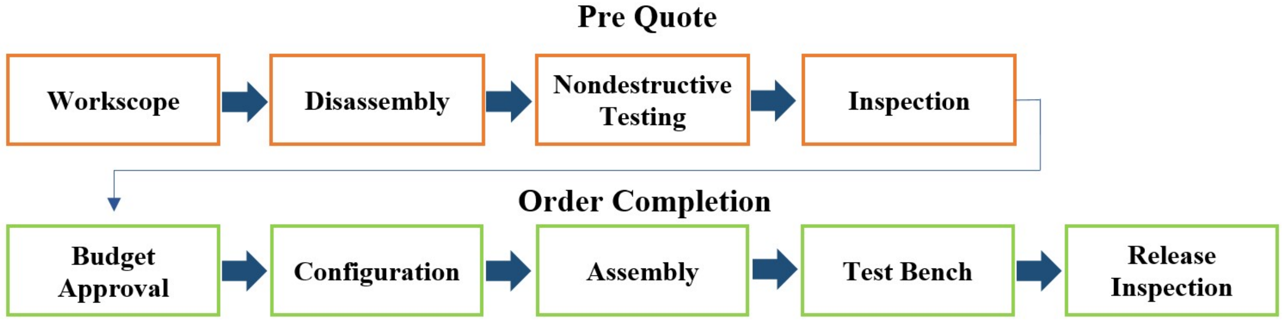

Figure 2 – Production Process Flowchart

The Pre Quote phase begins in the Workscope sector to define the scope and level of service to be performed. Then the engine is disassembled, and the parts are submitted to the cleaning process and NDT (Non-destructive tests). After cleaning, the parts are inspected visually and dimensionally so that the conditions for a service return are defined, whether they require repair or whether they will be rejected and scrapped. Once the conditions of each part have been defined, the inspector prepares the Technical Report. The Commercial sector will use this to display the services necessary for delivering the engine in perfect condition. If the customer accepts the budget, the Pre Quote phase ends, and the Order Completion phase begins.
The Order Completion phase begins in Accumulation and Configuration. The parts inspected, new or reparated in these sectors are located in carts with foams suitable not to be damaged. Later, these carts are forwarded to the assembly, where the assemblies of the modules are performed. Then the final assembly or modulation process starts, which is the union of the modules. Soon after assembling the modules, the complete engine is taken to perform the performance test at the Test Bench. Once approved in the parameters established by the admissibility criteria, the engines are forwarded to the last phase. This is the final inspection, also known as finalization. The final inspection consists of the conference of torques in screws, checks of air leakage, fuel, oil, filling of holes, and other inspections. The engine is subsequently routed to the final inspection phase of the shipment.
All tasks are essential in engine overhaul and repair, but those that have relevant prominence in this case study are assembly, inspection, and testing.

3.1 Application of DMAIC Methodology

The first phase of applying the DMAIC Methodology was defined through the Six Pack tool. It helped identify the most critical information such as operational impacts, objectives, schedule, description of the problem, scope, and the team involved. Historical data about leakage cases were collected in the studied company. Tab 1. shows an increase of 66.66% in oil leakage cases in 2019 compared to the number of cases in 2018. Moreover, the fuel leak has decreased by about 50%.

Table 1 – Non-Quality Exported Issues

Non-Quality Exported (Quality Roadmap)			
Issue (Axis)	2018	2019	(%)
OIL LEAK	3	5	66,66% ⬆
FUEL LEAK	2	1	50% ⬇
CHIP LIGHT	3	1	66,66% ⬇
DOCUMENTATION	10	0	100% ⬇

The second phase aimed to raise more detailed information about the leakage cases to identify the specific critical problems to be investigated. For this, some data analyses were performed from 2017 to 2019 using histograms.

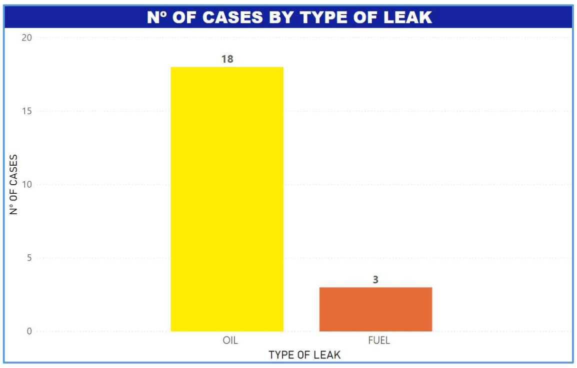

Figure 3 – Number of Cases per Type of Leak

Fig.3 was prepared based on historical data on customer complaints. Twenty twenty-one cases of leakage were observed from 2017 to 2019, and 18 (eighteen) cases representing 86% of the total are related to oil leakage. The other 3 (three) cases are related to fuel leakage. Of the 21 cases of leakage, 43% are from the A1, M1, and M2 engines; the other 57% are from the A2 engine. Before sending the engine to the customer, tests were performed. A total of 1226 (one thousand two hundred and twenty-six) engine test records were reviewed from July 2017 to November 2019, and 75 occurrences of leakage were observed. The analysis revealed that the M1 engine family had more cases of leaks in the test cell and fewer recorded cases of nonconformities reported by customers. Fig. 4 shows that A2 engine family had 27 (twenty-seven) occurrences of oil leakage, thus representing 36% of the total cases per detection in the test cell.

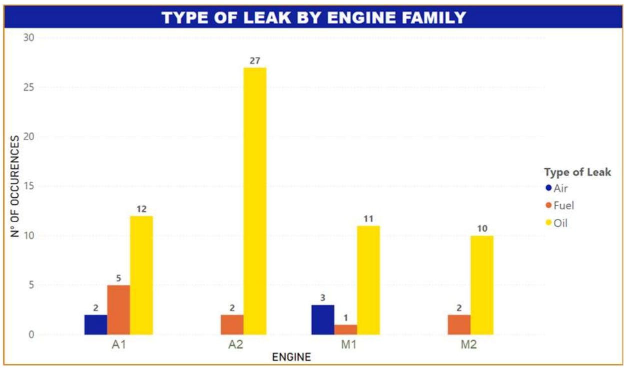

Figure 4 – Leak Types: Engine Family

The analysis of cases of leakage reported in the field during 2019 around the world revealed a total of 387 (three hundred and eighty-seven) occurrences. From these, 161 (one hundred and sixty-one) records are related to A2 engine, and 76% are oil leakage. Data shows leakage problems in A2 engines. The next phase of analysis was identifying the fundamental causes that led to non-conformities in this engine. The third phase was oriented to analyzing the data collected in the previous phase to identify the fundamental causes. Problems identified by customers and the ones detected in the test cell were reviewed. Fig. 5 shows recurrent deviations in the Magnetic Seal and Oil Return Line G3.

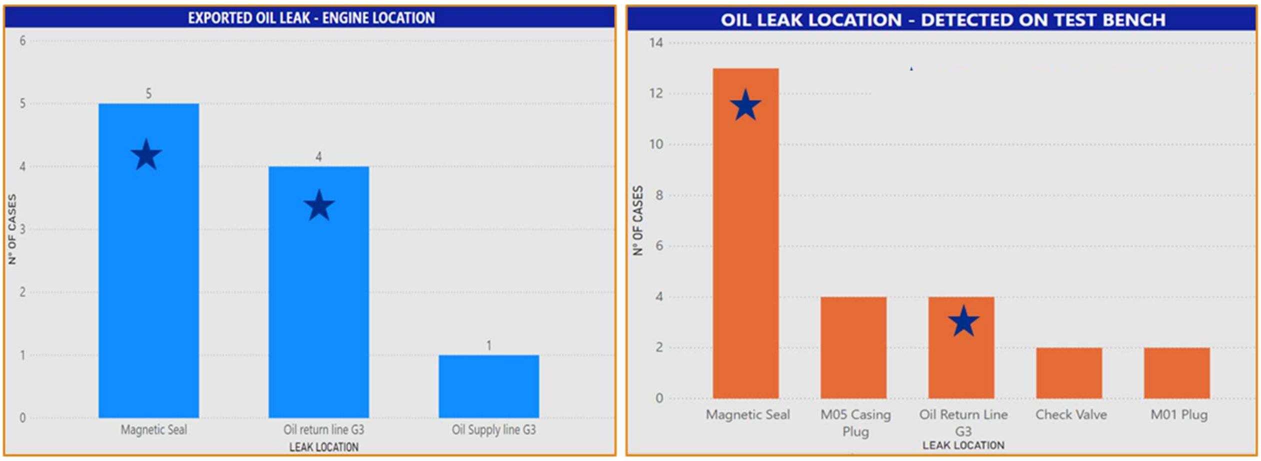

Figure 5 – Oil Leaks Identified by Customers and in the Test Cell

The problems of oil leaks in the magnetic seal are known globally and are being treated accordingly. For this reason, they would not be the object of analysis of this study. These problems occurred due to the low quality of the manufacturer of the magnetic seal, which contained scratches and porosity. Another problem was identified in the assembly process; the graphite ring of the magnetic seal is sensitive to shock, causing cracks. Through Brainstorming with mechanics and engineers, it was possible to identify that leaks through the Return Line happen due to internal leaks that flow to the bottom of the module by gravity. Three different places of leaks have been identified. The first occurred in the Rear Bearing Housing Seal, the second was the incorrect installation of duct seal, and the third was the incorrect installation of another seal. Although the seals were in different locations for the three (3) cases, the problem's solution was their replacement. Analyses were made on the other deviations found with lower incidence. It was observed that in the Rear Casing Plug of module 5 and Casing Plug of module 1, leaks were detected during tests in the test bench. For the solution of these cases, the modules were reworked to reinsert plugs correctly. The contributing factors for the deviation in check valve was caused by incorrect installation of the O'ring during modulation; this is because different variants of the A2 engine have different sizes and quantities. Fig. 7 shows a cause and effect diagram, which was prepared to allow the definition of the solution to the deviations found and an analysis of the influence factors on the problem of A2 engine oil leakage.

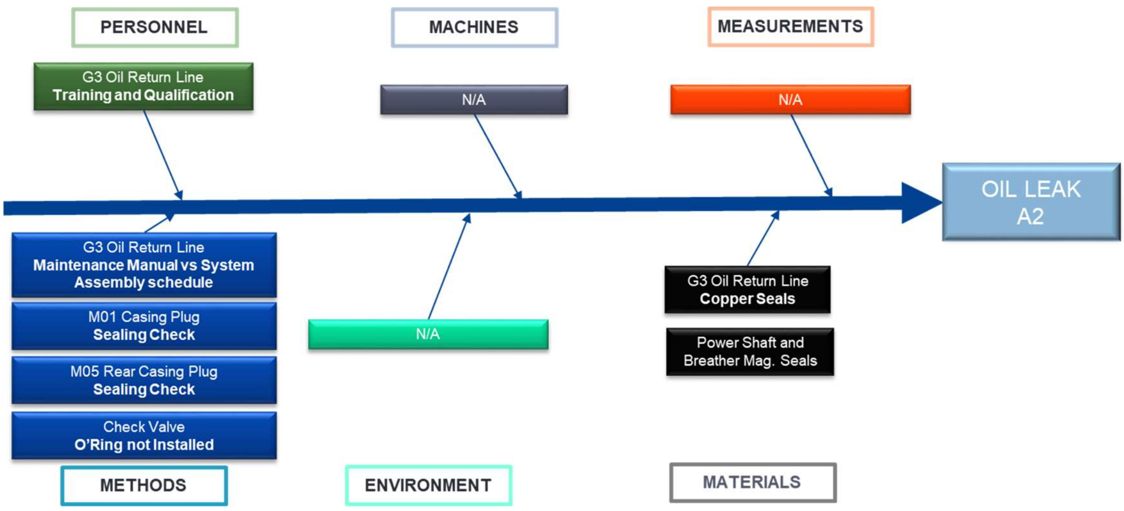

Figure 6 – Cause and effect diagram

By using the 5 Whys tool, it was possible to determine the root cause of each deviation found. It helped the preparation of the action plan. This plan has the actions and expected results to reduce the number of oil leakages.

Table 2 – Actions Plan

#	Subject	Action	Expected Result
1	Copper Seals	To **include** a dedicated line for Copper Seal installation in the A2 **On-The-Job training program and technical check**	To ensure that new assembly line mechanics are well trained for this task application
2	Check Valve O'rings	To **review and update** the **installation kits** of A2 engines with the correct quantity of O'rings	To ensure that there are no spare O'rings in the installation kits as a way to avoid forgetfullness
3	Module 1 Casing	To **develop** a **sealing check** for A2 Mod 1 casing	To reduce cost of reworks due to engine rejection on test bench
4	Module 5 Casing	To **implement** the RP-10 for sealing check of the A2 Mod 5 casing	To reduce cost of reworks due to engine rejection on test bench

In order to maintain corrective actions, strategic issues were added to the list of questions of internal audits to investigate whether the actions performed are being carried out.

4. CONCLUSION

As initially proposed, the results show, through a case study, the application of Six Sigma to reduce events of oil leakage. The result is significant compared to previously published studies, as it contributes to eliminating oil leak events and reducing risks. The study also shows the benefits to the company. According to the analyses and results presented in chapter 3, considering the methodological guidelines and literature researched, it was possible to confirm that good management aligned with an efficient team and the help of quality tools is essential to obtain the expected results.

In response to the first research question, "*Is the DMAIC methodology effective for treating non-conformities related to oil leakage and reducing risks? "*. It was possible to apply the DMAIC methodology to analyze and treat the root cause, and it assisted in reducing operational risks.

In response to the second research question: *What benefits has this study provided to the company where the case study was carried out?*" it could be shown that the benefits granted to the company were: risk mitigation, customer satisfaction, reduced maintenance repair costs, and fewer hours of rework.

In response to the third question: "*What is the relation between quality and the reduction of operational risks related to oil leakage?* This case study made it possible to understand that sound quality is thoroughly intertwined with reducing operational risks. It could also be understood that the ultimate goal was delivering the engine to the customer without fail in the production process.

This study brought significant benefits to the company where the case study was carried out. The solution of occurrences of oil leaks brings credibility and reliability of current and possibly new customers, and a significant risk reduction, thus allowing to continue to be competitive in the national and international market.

Finally, another significant highlight of this study was recorded in the Measure and Control Phases, where it is clear the importance of having good data collection, traceability, and monitoring of actions. So that the improvements found during the project are not only corrective actions but also serve as maintenance of the results obtained and opportunities for future improvements in other engine families.

5. REFERENCES:

[1] PEREIRA, JOSÉ CRISTIANO ET AL. Fatores de Risco Operacionais Críticos na Indústria de Manutenção Aeronáutica. (2012)

[2] OLIVEIRA, KIM CARVALHO DE. "Análise de risco no processo de manutenção de componentes aeronáuticos." (2019).

[3] COSTA VIVIEN., Aeronautical Maintenance and Quality Control to Improve Flight Safety. , ASME, US (2014);

[4] MARCUZZO JUNIOR, ADILIO., *Legislação Aeronáutica Comentada: ênfase em manutenção*. Asa. São Paulo, Brasil (2008).

[5] CENIPA., A Manutenção na Prevenção de Acidentes Aeronáuticos.

[6,7] PANDE, P. HOLPP L., What is six sigma?. Milwaukee, ASQ Quality Press, US (2001).

[8,9] WERKEMA, Cristina., *Métodos PDCA e DMAIC e suas ferramentas analíticas*. Elsevier, Rio de Janeiro, Brasil, (2013).

[10] BRADY, J.E., & ALLEN, T.T., "Six Sigma Literature: A Review and Agenda for Future Research". *Quality and Reliability Engineering,* 22(3): p. 335-367, (2006).

[11] SANTOS, B. ADRIANA; MARTINS F. MANOEL., "A Implementação dos Projetos Seis Sigma Contribuindo para o Direcionamento Estratégico e para o Aprimoramento do Sistema de Medição de Desempenho", *Revista Pesquisa e Desenvolvimento Engenharia de Produção*, n.1, p. 1-14, (2003)

[12] OLIVEIRA, M. L. P. Aplicação do Método DMAIC para Redução de Erros de Separação de Pedidos em um Centro de Distribuição no Ceará. 105 f. Monografia (Graduação em Engenharia de Produção Mecânica) – Universidade Federal do Ceará, Fortaleza, Brasil, (2018).

[13] KAUSHIK, A. *Web Analytics 2.0: The Art of Online Accountability and Science of Customer Centricity.* Sybex, New Jersey, USA, (2010).

[14] MOREIRA, A.C.V.B., DARÉ, C.T., RODRIGUES, M.D.F. et al. Green Belts Industrial. v. 6. Fundação de Desenvolvimento Gerencial, 2004

[15] WERKEMA, Cristina., *Métodos PDCA e DMAIC e suas ferramentas analíticas*. Elsevier, Rio de Janeiro, Brasil, (2013).

[16] CARPINETTI, LUIZ CESAR RIBEIRO. *Gestão da Qualidade: Conceitos e Técnicas, 2. Ed.* Atlas, São Paulo, Brasil, (2012)

[17] SILVA, L. C., OLIVEIRA, M C., SILVA, F. A. "Implementação da Metodologia Seis Sigma para Melhoria de Processos Utilizando o Ciclo DMAIC: Um Estudo de Caso em uma Indústria Automotiva. " *Exacta*. Vol. 15, Núm. 2, pp. 223-232 (2017).

[18] WERKEMA, Cristina., *Métodos PDCA e DMAIC e suas ferramentas analíticas*. Elsevier, Rio de Janeiro, Brasil, (2013).

[19] CARPINETTI, LUIZ CESAR RIBEIRO. *Gestão da Qualidade: Conceitos e Técnicas, 2. Ed.* Atlas, São Paulo, Brasil, (2012)

[20] WERKEMA, Cristina., *Métodos PDCA e DMAIC e suas ferramentas analíticas*. Elsevier, Rio de Janeiro, Brasil, (2013).