Simplification and Normalization of a Landing Gear's Expertise Procedure

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Abstract

Maintenance, repair and overhaul of aircraft's components is a growing competitive market, thus it is key to increase the company's profitability by improving processes, reduce waste and the Turnaround time (TAT). Lean Thinking tools and principles are essential to achieve such goals in the current production markets, especially in the automotive industry. Their implementation in maintenance is challenging since the component maintained condition plays a massive role, nevertheless they are successfully applied to the maintenance industry and Lean maintenance concept emerged. The present work implements such tools and principles in order to improve OGMA's landing gear maintenance processes, reduce waste and increase its profit margin. The company in question requested the simplification and normalization of the expertise procedure of the Embraer aircraft's E190 landing gear. A program was conceived in order to meet the objectives established, using poka-yoke mechanisms to avoid errors. This program, when implemented, will increase the value-adding time of this activity from the current 40% to 93%. In addition, the global maintenance procedure was analysed and a value stream map styled flowchart constructed, which enabled to identify sources of waste and propose solutions that improve such processes that go beyond the elaboration of the expertise report. Such changes when put into practice could produce gains in the order of 20% in the TAT.
Keywords: Lean Thinking, Lean Maintenance, Value Stream Map, Poka-yoke

1. Introduction

In the aeronautical industry, Maintenance, repair and overhaul (MRO) is a complex process that has precise and strict requirements imposed by airworthiness authorities to guarantee the safety of passengers and aircrew. This sector is responsible for "all actions that have the objective of retaining or restoring an item in or to a state in which it can perform its required function" [8].

Global MRO spend, excluding overhead, in 2014 was valued at 62.1$ billion (22% of which was component's maintenance), which represented around 9% of total operational costs [6]. In 2017, it was 75.6 billion $ and is estimated to reach 109 billion $ in 2027 [3].

Therefore, airlines are always looking for quality service, cost-effective methodologies and innovative solutions to address process efficiency without compromising safety and quality, for this purpose Lean thinking principles are applicable, because they provide a way to do more with less effort, time, equipment and space, whilst creating value to the customer [12].

A MIT study [7] revealed that the application of Lean philosophy in the production of the Boeing 737 Fuselage (1996-2001) lead to a 25% decrease in unit cost, 50% decrease in labour hours/unit (1998-2000) and reduced flow time by 21%. In the company Rockwell Collins (2000-2002), responsible for supplying commercial aviation electronics, it resulted in 37% increase in labour productivity.

This trend is followed my major players within the MRO aerospace industry [4], which shows that the introduction of Lean can have benefits in other areas than production alone.

Thus, it is key to eliminate inefficiency, improve customer satisfaction, improve the quality of the service performed, reduce scrap and rework, diminish the cost and time of production. All of this could be achieved with Lean maintenance, which translates the application of lean principles to the maintenance area, its use enables a MRO company to distinguish themselves from their competitors, because they can provide a higher quality service at a lower cost, giving them a market advantage.

The subject of this paper is the implementation of Lean principles and tools as way to simplify and normalize the expertise procedure of landing gear

components of the Embraer twin engine jet 190 at OGMA-Indústria Aeronáutica de Portugal S.A.

The outcome is a computer tool that allows to collect the information of all the materials applied in the repair, ranges of work associated to standard repairs that are created in library and application of Service Bulletins (SB), in a way that no part is forgotten to be added to the expertise report, thus avoiding the current remake of the expertise report, re-budgeting and profit margin's reduction.

In addition, it is analysed the global maintenance procedure of this landing gear and changes are proposed for its improvement and waste reduction.

In order to do so, a process activity map and value stream map styled flowchart of the global maintenance procedure is constructed, which allows the visualization of the information and material flow, the identification and further reduction of wasteful activities. Additionally, poka-yoke mechanisms, the 5 S's, Just-In-Time and 7 wastes concepts are key to achieve it.

2. Background

Lean involves the distinction of value-adding and non-value adding activities, so that the sources of waste are identified and eliminated, and all steps add value to the process. This way, the flow and efficiency of the processes is improved.

2.1. The seven wastes

The core of Lean is the elimination of waste (*muda*, any human activity which consumes resources but does not create value) in order to enhance productivity and increase customer value. Taiichi Ohno identified the first seven types of waste [5]: Overproduction, Defects, Waiting, Unnecessary motion, Inappropriate processing, Unnecessary inventory and Transport.

2.2. Lean Principles

Womack and Jones [12] defined the following Lean Principles:

- Specify Value: The customer defines the value and the producer creates it.
- Identify the Value Stream: it allows to discover the amount of waste involved.
- Flow: After the avoidable wasteful steps are eliminated the next step is to make the value-creating steps flow.
- Pull: means that no one upstream should produce a good or service until the customer downstream asks for it. [12].
- Perfection must be sought by every single one of the employees involved. This is achieved by *kaizen*, continuous incremental improvement, or by *kaikaku*,a radical improvement.

2.3. 5 S's

The 5 S's are a Lean tool that establish the five practices that lead to a clean and manageable work area, which allows the elimination of waste and the creation of value. These are: *seiri* (organization), *seiton* (orderliness), *seiso* (cleaningless), *seiketsu* (standardized cleanup), and *shitsuke* (discipline).

2.4. Just-In-Time

The Just-In-Time (JIT) flow management system reduces costs by eliminating warehouse storage needs and reduces inventory costs, only the right amount of raw material needed to produce the scheduled products is ordered and delivered at the right time.

2.5. Poka-yoke

Its key to avoid mistakes that result in defects in the production processes, this is done through poka-yoke (mistake-proofing) techniques [11].

Shigeo Shingo identified, among others, the following types of inspection. Informative inspection informs when a defect is discovered. In successive inspection, the workers inspect products of the previous operation, whilst in self inspection the workers inspect their own work. On the other hand, source inspection prevents defects through the control of the conditions that impact on the quality at their source.

Both can be accomplished through the use of poka-yoke methods of warning type, when a mistake is made an alarm or light is activated; and of control type, the poka-yoke device triggers physical actions that prevent the defect from happening.

2.6. Value Stream Mapping

Value Stream Mapping (VSM) illustrates the process activities using symbols in a graphical manner [12]. To construct it, it is required to follow a product's production path from client to supplier and elaborate a visual representation of the processes, material and information flow. This allows the identification of waste and its sources and the elimination of non-value adding activities [10]. The activities performed can be classified as:

- Value-adding activities (VAA): activities the customer considers valuable.
- Non-value-adding activities (NVAA): all of the activities the customer considers not valuable, thus constitute as a waste.
- Necessary but non-value-adding activities (NNVAA): activities that are unavoidable in the current working conditions, but are considered not valuable by the customer.

To draw it is required to select a product family, that is a group of products that go through similar processing steps and throughout common equipment; assign a value stream manager, whose respon-

sibility is to understand a product's family value stream and improve it, this is called flow *kaizen* and leads to profound changes, whereas process-level *kaizen* focus on the elimination of waste, people and process flow; draw the current state; draw the future state; and finally make a value stream plan containing the steps required to achieve it.

2.7. Process Activity Mapping

Process activity mapping is one of the many VSM tools and it was chosen because it allows the better understanding of the value stream, especially when it comes to the information flow, enables the identification of all wastes within the value stream and the role of each element of the organization more easily than the other tools [5].

2.8. Lean Maintenance

Nowadays, Lean has a well-established base in the manufacturing sector and is taking hold of the maintenance sector. To capture its application into the maintenance industry the term "Lean Maintenance" was created [2].

The challenges in the application of Lean principles to the maintenance industry lie with the extremely broad work scope, changing demand and the inability to predict the jobs steps required for the aircraft to be again fully operational as well as the time required to accomplish them.

Moreover, maintenance is an activity prone to error [9]. The ADAMS project confirmed that, in one third of the tasks surveyed, the aircraft maintenance engineer or inspector did not carried out their work in compliance with the procedure or manuals provided by the company or the Original equipment manufacturer (OEM).

Despite the hardships of Lean implementation into the MRO business, its implementation is key to eliminate waste and create value.

3. Current State

Currently, OGMA does the maintenance of the main landing gear of the Embraer's ERJ145, E170, E175 and E190, Lockheed's P-3, C-130 and L100.

In the MRO of a landing gear several departments are involved, namely: Commercial obtains the information necessary for the MRO from the client; Reception is responsible for the medium to long term planning of the Production schedule; Quality is responsible for ensuring compliance with the technical specifications and contractual quality requirements; Production Planning plans the short term production schedule; Programming programs the different phases on Sigma (the company's Enterprise Resource Planning system), prints the work-cards (document with work instructions) and delivers them to the Production; Production Control does the shop floor planning; Production is constituted by the landing gear's mechanics, which analyse and evaluate the parts, disassemble, test and assemble the landing gear; Engineering analyses the requirements in terms of Airworthiness Directives (AD) and SBs, defines the work to be carried out, verifies whether the expertise report and the List of material to order obey the Component Maintenance Manual (CMM); Shared Centres is where non destructive inspection techniques, milling, electrolytic treatments, painting, surface and thermal treatments take place; Material Planning programs and requests on Sigma the material required; Purchases; Warehouse; Logistics; Financial Area.

A process activity map was done in order to help visualize the informational and material flow more easily, to facilitate the construction of the Value Stream Map styled flowchart. The product family selected was the Embraer's E190 Landing Gear.

The Turnaround time (TAT) of the first landing gear maintained was 163 calendar days and for the second one 114, whilst the target is 45 calendar days, which is a tremendous difference. In addition, there are enormous differences between the scheduled and the time actually taken to perform the maintenance tasks.

The scheduled time is the time an operator should take to complete the task and it is based on measured times, with it the initial Sale's Budget, which was given to the Client at the beginning, is calculated. The client only pays the "Scheduled Man Hours", the difference is supported by the MRO service provider.

In Figure 1 is shown the global deviation between the scheduled and the actual time it took to accomplish the tasks by resource used for the first and second landing gear maintained. Analysing it, it is possible to conclude that the landing gear mechanics are the resource with the most discrepancies in man-hours, thus they represent the primary source of NVAA, since the extra time they take to accomplish the tasks is not paid for the client.

Additionally, there was a decrease in the deviation in man-hours in this resource from the first to the second landing gear maintained due to the experience attained. However, this is clearly insufficient and contributes to the large deviation in the TAT.

Unfortunately, the waiting times between the process phases were not included in the VSM styled flowchart, because they currently are not measured. Consequently, the overall vision of the flow has missing pieces, not allowing for the clear identification of problems and solutions that improve the flow of materials. Therefore, the analysis will be centred in improvements of the process itself, that is the focus is concentrated in process-level *kaizen*.

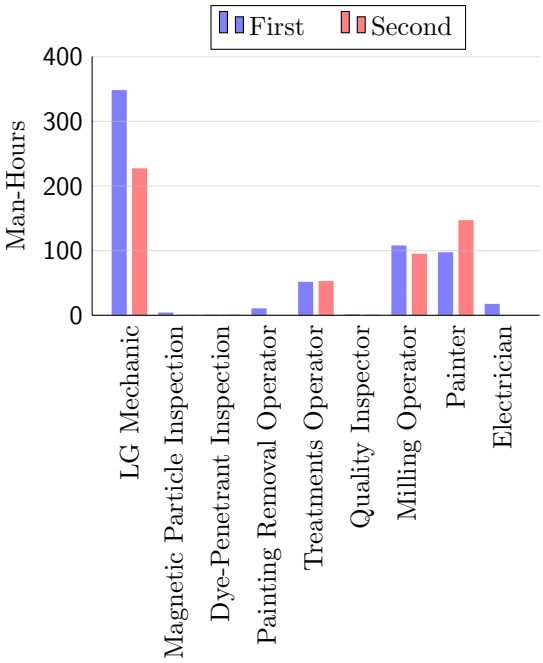

Figure 1: Global Deviation between the Scheduled and the time taken to perform the task in man-hours by resource used in the 1st and 2nd LG maintained

3.1. In depth analysis of the Expertise Procedure

At the end of the inspection, the final decision regarding the part is made and recorded in the work-card, it could be good for use, repairable or rejected.

To each work-card is associated in Sigma the material required to be ordered. The List of Material to Order encompasses all these materials and is used to do the Cost's Budget and to request the material. Usually, the technician prints this list and uses it as a "cheat sheet" to fill out the Expertise Report.

In Sigma's Expertise Report interface, the technician copies, one by one, the part's nomenclature, Part Number (P/N), quantity, description of the anomaly and whether that part was missing or rejected. It is clear that there is a re-done of work and a source of errors such as: mistakes in writing the P/N and Nomenclature; unstandardised descriptions; no control on the quantity ordered; forgetfulness of material.

Th systematic parts, whose substitution is compulsory regardless of its state, are grouped in Sigma and associated with work-cards which when selected triggers their import to the expertise report.

Furthermore, multiple authorized technicians can add parts to the expertise report, however the last one who accessed it is held responsible for its entire elaboration.

In Figure 2 are illustrated the relative percentages of the time each activity takes during the elaboration of the expertise report for sub-assemblies of the second landing gear maintained. The scheduled time for the elaboration of the expertise report was 45min.

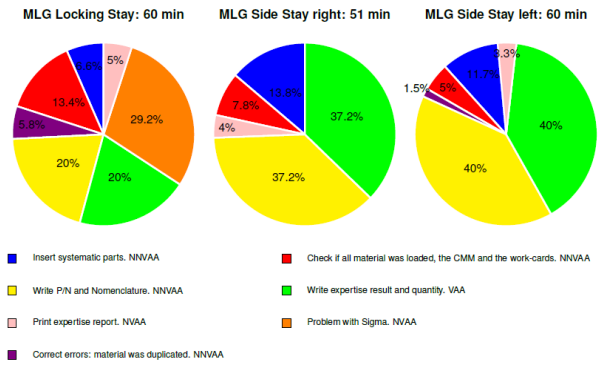

Figure 2: Classification of the different activities involving the Expertise Report elaboration

In the Main Landing Gear (MLG) Locking Stay and MLG Side Stay left this time was exceeded by 33.3%, whereas in the MLG Side Stay right it was only by 13.3%. This is consistent with the 23.78% deviation for the second landing gear maintained, which was an improvement from the 88.68% of the first one. This difference is due to the know-how attained and on the second one Sigma allowed the addition of material to the expertise report as the final inspection decision is being taken.

Furthermore, in the best case measured the VAA corresponded only to 40% of the time taken to perform the task.

It should be noted that the times presented do not include the elaboration of the List of Material to Order. Since this list is being elaborated as the parts are being inspected, this time was difficult to estimate and thus was omitted.

A Product Engineer reviews and corrects the Expertise Report and List of Material to order to comply with the manual, in terms of P/N, nomenclatures and quantities, this task usually takes 2 hours.

On the expertise report of the MLG Side Stay right the technician inserted 5.6% more parts than there were in the manual, 8 of them were systematic and 3 were not; later on some were removed by the Engineer, thus reducing this share to 1.5%, 2 of them were systematic and 1 was not.

This poka-yoke mechanism, classified as Successive Inspection, clearly is insufficient, since, after the Sale's Budget is approved by the client, material not included in the expertise report is ordered, for example it was found that 11.3% of the parts of the MLG Side Stay right were rejected after the Sale's Budget was sent to the client, 4 of them were systematic, and 18 were not. Typically, there is a 20% difference between the Sale's Budget and what the actual material cost is, this has a massive impact

on the gross margin of the project and can result in the project's delay due to material waiting.

Additionally, in order to comply with a SB in some cases parts must be replaced, therefore they are added to the List of Material to Order, that same part can also be rejected in the expertise report due to its condition. Thus, that part is ordered twice.

The facts presented comes to show that the current expertise procedure is insufficient, takes longer than expected, longer than the client is willing to pay for, has an intense human factor making it prone to errors and the current poka-yoke methods are insufficient.

3.2. Provisioning of materials

At an early stage it is checked whether there is capacity to perform the MRO, if not it is subcontracted to an outside company and the contact with the client is indirect.

The OEM that sells the replacement parts offers short lead times to their clients, roughly 2 days. When the contact with the client is direct, the MRO provider can give to the client the list of material to order, and he orders it directly to the OEM with a short lead time. However, when the contact is indirect, the MRO provider orders directly to the OEM, this comes with longer lead times, a matter of several weeks sometimes, which can increase greatly the TAT.

To overcame this, usually inventory is build up before the landing gear part's inspection, which clearly constitutes a form of waste and goes against the Just-In-Time philosophy.

Once capacity is confirmed by the Reception, the Material Planning department runs the Material Resource List (MRL), which hold in its database all the materials used in previous projects and calculates the percentage of their usage.

This is a away to overcame the unpredictability inherent to the maintenance business. The bigger this database is, more reliable is the prediction.

Unfortunately, once a MRL is made, another projects can not be added to its database, thus a new MRL must be created, this takes time and is not done often and constitutes a waste of inappropriate processing.

Moreover, the screen does not contain any information regarding the lead times and costs of the parts which is vital. For instance, when the percentages of usage are low, the lead times short and the cost is high the advantage of buying the material beforehand is lost, thus unnecessary inventory is built. This information can be accessed by clicking on the individual parts that are on this list, which is a inappropriate processing given that a landing gear typically has hundreds of parts.

With the MRL database, a suggestion purchase can also be made, by inserting the number of landing gears to be maintained. The result is a list of material recommended to purchase. However, it does not take into account when the landing gear is expected to arrive and the lead times of the materials. As a result, material ordered through the use of this list could arrive much sooner than it needs to be, thus creating unnecessary inventory; or late which causes delays in the production schedules and waiting, another form of waste, occurs .

All the problems stated above cause for some materials to be ordered after the client's approval and, in the case were there is not direct contact with the client, sometimes causes enormous lead times for the provision of material and can even stop the assembly of the landing gear due to the lack of parts.

3.3. Generate and Print the work-cards

The Programming department generates in Sigma the work-cards, using as baseline the templates created by Engineering. In five minutes this process could be complete, however the PDF file generated would have all work-cards aggregated, not giving a blank sheet of paper for odd pages. Therefore, usually the work-cards are generated on by one in Sigma, having its own PDF file associated, and then printed. This is a time consuming process, being classified as a waste of inappropriate processing.

3.4. Lack of information in the work-card and lack of a preparator

The work-cards contains the work's instructions to be accomplished, this is generally the mention to a subtask on the CMM and a place to record the measurements, part's condition and defects. Inevitably, the manual is consulted back and forward as each task is completed, which takes time, time the client is not willing to pay for, given that what adds value to the customer is the part's evaluation. For example, the case where the parts that require measurements to ensure that they are within acceptable limits, is depicted in Figure 3.

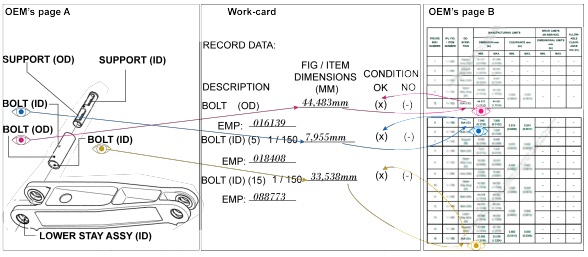

Figure 3: Workflow of the inspection procedure

In a typical measurement process 70% of the time is spent finding the information needed, 18% actually measuring and 12% recording it into the work-card. Thus, only 30% is VAA time, the rest is

NNVAA time.

Furthermore, in all the tasks, except for the expertise report, the technician performing it not only does the task, but it is also in charge of finding the material necessary to complete it, for example, paint, sealants, tools, measuring equipments and so on. This is a NNVAA and is done by a highly skilled worked, the LG mechanic, when it should be done by a undifferentiated preparator.

The scheduled time to do a certain task does not include this time, it only includes the time taken to actually perform the task, that is also the time the client considers valuable and worth paying for.

Both of this problems are coherent with the 88.68% deviation for the inspection of the first landing gear maintained. In the second one, this percentage dropped to 58.37%, mainly because of the experience attained, that is, the technician already knew were to look for the information needed to complete the inspection procedure.

This happens not only in Inspection, but in fact is transversal to all activities performed by the Production and Shared Centres and is the main contributor to the deviation between the scheduled and the time taken to perform the task in the landing gear mechanic resource exhibited in Figure 1.

4. Future State

The TAT for the analysed landing gear is greater than the target one, which is a problem because the client's expectations are not met, who will be reluctant to return and can result in payment of fines. The purchase of material after the client approved the Sale's Budget resulting from the errors committed during the elaboration of the expertise report affects the profit margins, which affects the company's profitability.

Consequently, it is key to reduce the TAT and costs by reducing the non-value-adding activities and sources of waste, improving the processes, material and informational flow.

In order to do so and taking into account the sources of waste identified and analysed in section 3, the proposed Future State VSM styled flowchart was conceived and the process's proposed changes are detailed in the subsequent sections.

4.1. Provisioning of materials

In an ideal world, where the lead times are short and the contact with the client is direct, according to Just-In-Time premisses, only when the client approves the repair, the materials are ordered, however this is not possible for the company in question. Hence, the supply of materials must be made at an early stage of the project.

Thus, a robust database of materials from previous projects must be built and new projects ought to be added easily, contrary to what happens currently, leading to a higher reliability in the forecast of parts that are going to be required later on. In addition, to facilitate the process of analysing the output resulting of running the MRL, the screen must include the material's lead time and cost, and consumptions of the two previous years. Both of them could be implemented fast and easily.

At last, the Suggestion of Purchase algorithm must be revised to preclude in its calculations when the landing gear is expected to arrive and the lead times of the materials. This is a profound change and is expected to take more time and resources to be completed.

This way, the problems presented in section 3.2 are tackled and an accurate material's forecast of demand is attained and all the material necessary to perform the MRO is purchased at an early stage of the project.

4.2. Generate and print the work-cards

The solution for this problem, presented in section 3.3 is simple, it is just add a blank page for odd pages when the work-cards are generated as a single PDF file. This way its generation would be reduced from the current 10h to 5min.

However, a step further could be taken, the work-cards could loose their physical existence and be directly accessed and filled out by the technicians on Sigma. The transportation of the work-cards from Programming Department's offices to the shop floor, would be eliminated, thus reducing a transportation waste and waiting time. For movements between centres, the work-card should be substituted by a bar code and attached to the part's already existent tags. Only at the end of the project, the work-cards and other files would be printed out for archive purposes.

4.3. Lack of information in the work-card and lack of a preparator

The lack of information in the work-card problem presented in section 3.4 and its consequent waste could be solved by putting all of the information needed to complete the task in the work-card as represented on Figure 4. The work-flow in the proposed solution would be much smoother and for the analysed case the 70% NNVAA time of the inspection procedure would be reduced to zero.

The disadvantage is the continuous revise of the information presented in the work-card, as the CMM undergoes updates. At the most this update happens every year, but more commonly every 3 years, thus the solution presented is viable.

In addition, a preparator should be hired to perform the tasks necessary for the LG mechanic fulfil the assignment, which include giving the material necessary, such as tools, sealants, paints, measuring equipment, among others, and do tasks neces-

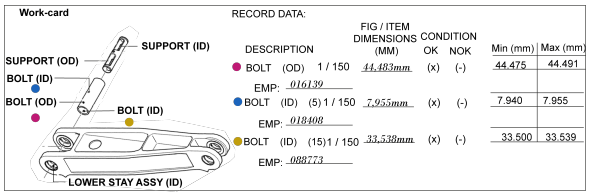

Figure 4: Workflow of the inspection procedure

sary for the movement of the parts between centres, such as labelling and attaching the work-card to the part, which are NNVAA that do not require a highly skilled worker for its completion. This way, the deviation between the Scheduled and the time taken to perform the task, present in Figure 1, for the LG mechanic resource would be reduced to zero.

In the worst case scenario, assuming that no improvements in the time taken to perform the task were made, all these hours would be performed by an undifferentiated worker. The labour rate for aircraft's mechanics in western Europe, which is the case, is 77$/man-hour [1]. Whilst, in Portugal an undifferentiated worker earning the minimum wage costs 4.02$/man-hours.

Thus, by hiring a preparator only for the landing gear mechanic, considering all the activities performed by him, except for the Expertise Report, SB's check and Certificate of Conformity emission, considering the times of the second landing gear maintained, would result in a saving of 16 296$.

The LG mechanic accounts for 43% of the deviation between the scheduled and the time taken to perform the task. Hence, of the total 51 days the target of the correspondent milestones were exceeded, by implementing the proposed solution the TAT could be reduced in 22 days, thus producing a gain of 19%.

4.4. Computer Tool for application to the Expertise Procedure

The database containing the part's information consists of a product tree where the multiple columns give the information regarding the part's: figure, item number, P/N and nomenclature. In addition, it allows to distinguish systematic, recommend, standard, repair, superseded and non procurable parts, that is it can not be ordered, because it was superseded, or because it is a critical part of a sub-assembly and the sub-assembly must be purchased instead.

The goal is to simplify and normalize the expertise procedure, automatically fill the information associated with a part, identify the technician inserting it, display the repairs available and the SBs. In addition, a poka-yoke method of control type is required, in order to stop the worker from misspelling the P/N or the Nomenclature, inserting a quantity that exceeds the one prescribed in the CMM, forgetting to inspect a part and ordering the wrong part for repair.

To reach it, a prototype program further illustrated in the following sections was created in *Excel* using Visual Basic for Applications (VBA) programming language, because it allows for a good interface with a relative low programming effort, all the databases external to Sigma are in *Excel* and all the workers are familiarized with it.

The following sections illustrate with greater detail the program's operation and results. This program was made for all the *Escora*'s assemblies, which include all the sub-assemblies that constitute the landing gear excluding the Shock Strut, namely: Nose LG Drag Brace and Locking Stay; Main LG (left and right) Side Stay, Locking Stay and Downlocking Spring.

4.4.1 "Start" menu

The interface shown in Figure 5 is the first contact the user has with the program. The "Start" button initializes the expertise procedure and opens the "Start" menu and the "Continue" button opens the "Continue" menu which allows to continue the work were it was left on.

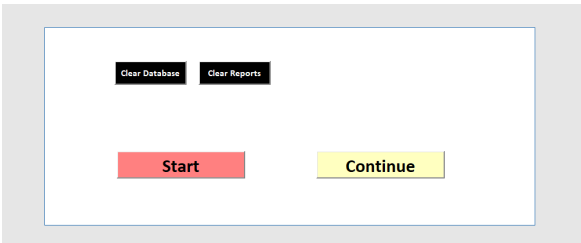

Figure 5: Expertise tool

Here, the main goal was to protect the data from external users, to identify the current user and make him fill out all the required fields present in Figure 6. Once these fields are filled out, this information is saved. After that, "Parts Inspection: Life Limited Parts" menu is opened.

4.4.2 "Continue" menu

This menu, represented in Figure 7, was created in order for the expertise report to be built as part's work-cards are reaching their final inspection steps, this way the technician does not need to go through all of the work-cards and adding the parts to the report all at once at the end.

4.4.3 "Parts Inspection: Life Limited Parts" menu

The life limited parts are controlled by the number of flight cycles they have performed, once the

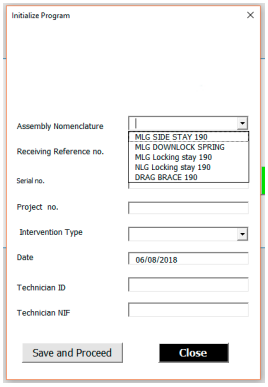

Figure 6: Expertise tool: "Start" menu

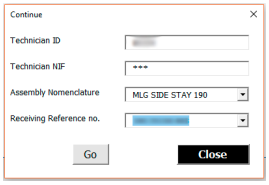

Figure 7: Expertise tool: "Continue" menu

life limit is reached, the part must be replaced and it needs to be added to the expertise report. In the case that part is not procurable, its upper set is added instead automatically.

Once this process is complete, it is opened the "Systematic Parts" menu.

In this menu, depicted in Figure 8, as well on the following ones, it is displayed the technical publication abided by the program. In the case that it does not match with the one on the work-card, because the CMM was updated, the technician ought to notify the engineering department to update the program's database.

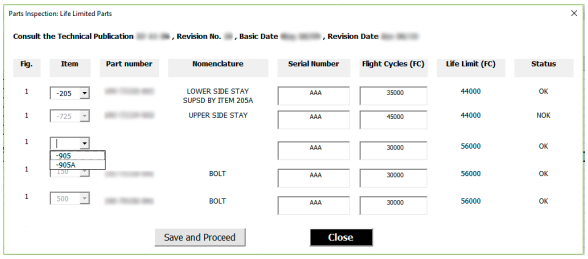

Figure 8: Expertise tool: "Parts Inspection: Life Limited Parts" menu

4.4.4 "Systematic Parts" menu

The systematic parts are added all at once in the menu illustrated in Figure 9, there is no room for error. In the case where the systematic part belongs to a sub-assembly which was already added to the expertise report, the systematic part appears on screen with the Status "Cancelled" and the Description "XXX ASSY was already added, a life limited part has exceeded its life limit and it is not procurable".

Once this step is complete "*Escora*" menu opens.

This constitutes a poka-yoke mechanism of control type and is clearly more efficient and effective than the current successive inspection made by the engineering department.

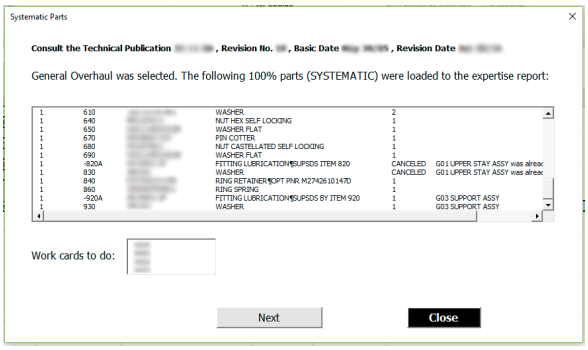

Figure 9: Expertise tool: "Systematic Parts" menu

4.4.5 "*Escora*" menu

This menu, shown in Figure 10, has a central figure taken from the CMM, displaying the part's position in the assembly and identifying it by item number.

A part can have the same P/N and be placed in different parts of the assembly, but its item number is different. Thus, the item number was the variable chosen to distinguish the different parts of the assembly.

In addition, instead of predefining an order of parts to inspection, it was given to the user the liberty to examine the one they want first, because the parts do not arrive all at the same time to the landing gear mechanic for its final inspection.

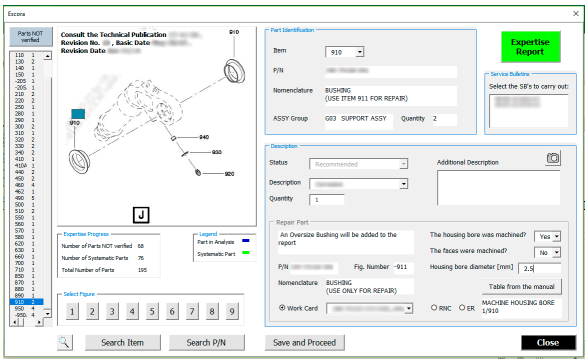

Figure 10: Expertise tool: "*Escora*" menu

In order to help with the identification of the parts yet to be verified the list "Parts NOT verified" at left on the screen displayed in Figure 10 was created, by clicking in the corresponding button more information can be visualized, as displayed in Figure 11. This list is also a way to select the part to inspect, just like the drop-list "Item" on the "Part Identification" frame, which contains all the parts present in the Figure selected.

In order to see in which Figure a certain Item or P/N is, the buttons "Search Item" or "Search P/N" are used, which in turn open the screens on Figures 12 and 13, respectively. The magnifying icon on

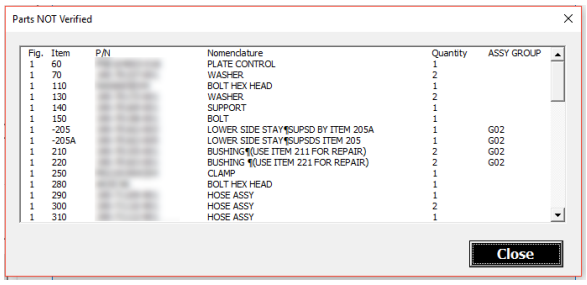

Figure 11: Expertise tool: Parts NOT verified

the bottom left of Figure 10 allows to search a P/N directly on the "Parts NOT verified" list on screen.

The progress of the expertise is displayed in the frame "Expertise Progress", represented in Figure 10, and contains information regarding the total number of parts in the assembly, number of systematic parts and the number of parts who has not yet been verified.

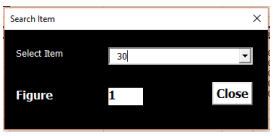

Figure 12: Expertise tool: Search Item

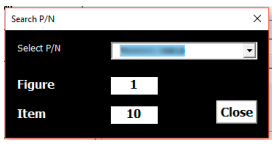

Figure 13: Expertise tool: Search P/N

Once an Item is selected, a green rectangle indicates where it is in the figure if the part is systematic and blue in case it is not, the information regarding its P/N, Nomenclature and Assy group is automatically filled out. In the case the part is systematic, the "Save" button and the remaining fields are disabled, and in the Additional Description is stated "Systematic Part was previously added to the expertise report".

The technician, unlike in the current expertise procedure, has only to state the part's Status, which can be the following:

- OK: part is good for use;
- NOK: part must be repaired and to save it, it is required to add a work-card with the correspondent repair;
- Missing: part was not present and a new one must be purchased;
- Not Repairable: part's condition is not repairable, that is the CMM does not prescribe any repairs for it, nor special Engineering Repairs (ER), Report of Non Conformity (RNC) or Other repairs from the engineering department were issued.

In the cases the part is "NOK" or "Not Repairable", the user also has to describe the anomaly using standardized descriptions, such as: corrosion; excessive corrosion; damaged; fracture; missing traceability; scratched; out of limits; other: free writing field in the "Additional Description" must be filled with the correspondent damage observed.

Additionally, the technician can also upload photos of the damages using the camera icon, the current Sigma's interface does not allow to do this, but the client may require it.

When the part is a bushing, additional fields, depicted in Figure 10, are necessary to be filled, namely the housing bore diameter, if it was machined or if the faces were machined. The button "Table from the manual" opens directly the manual on the page which contains the information regarding the size of the bushing to order. This information can be then written by the technician in the "Additional Description" field.

Furthermore, there is also a Service Bulletins frame which contains the SB's applicable to that specific part. To comply with a SB, the technician just has to select it and the material associated with it is directly added to the expertise report. If a SB was already complied with, the corresponding material is not loaded and the message box "The SB XXX was previously fulfilled" appears.

At last, the green button "Expertise Report" allows to access the expertise report, only when the number of parts not verified is zero, that is, all the parts were inspected, if it is not the message box "You have to make a decision on the following parts:" and the "Parts NOT verified" list appears, represented on Figure 11, not allowing to finalize the expertise procedure. If the number of parts not verified is zero this button erases all the parts with the Status "Cancelled" and opens the Expertise report.

For this program to be successfully implemented and substitute the current expertise interface presented in section 3.1, its logic needs to be integrated in Sigma, all product databases must be in Sigma and updated whenever a CMM is revised.

Moreover, it is required to construct a database with the materials and parts associated to each SB. Once this database is constructed, the repeated material resulting from the fulfilment of the SB will be eliminated.

Despite the challenges of its implementation, this program has the following benefits:

- Allows for the expertise procedure to be standardized, from the standardized descriptions, to the amount of data needed to correctly inspect a part and the actual work-flow. This way the Standardized clean up lean principle is abide by;
- Poka-yoke control type mechanism are put in place, not allowing for the technician to save a part without all the information needed is present. In addition, all the P/N, nomencla-

tures are automatically filled leaving no room for error. A control on the quantity inserted is also performed. Finally, all the assembly parts need to be inspected and saved, even if they are fit for use, which allows to make sure that all material needed is in the Sale's Budget, thus is paid for by the client and not by the company;

- The program's interface is much more user friendly than the current one;
- The visual representation of the part to be inspected allows for any technician, more experienced or not, with the poka-yoke mechanism in place, produce the same results and in the same time;
- The workload is distributed as parts are reaching its final inspection phase;
- Only the tasks "Write expertise result and quantity" and "Print expertise report", represented in Figure 2, will be performed by the technician, thus reducing the NVAA and NNVAA time. In order to validate the program, a technician was put in contact with it and he took 45minutes to complete the expertise procedure. Thus, using this program, the final expertise procedure will be composed by 7% NVAA and 93% VAA time and the estimated time will be met.

5. Conclusions

Even though, the maintenance field does not allow a quick and easy translation of Lean principles, unlike the production area, because the state of the component plays a key role in its flow direction. The construction of the value stream map styled flowchart was key, through the visualization of material and information flow, and analysis of the differences between the scheduled and the actual time it take to perform the task to point out the sources of waste and delays that cause to exceed the TAT target.

The developed program for the elaboration of the expertise report allows to avoid the current errors and subsequent delays in the supply of materials and gross margin's reduction, through the use of control type poka-yoke mechanisms. In addition, it standardizes the process and allowed to increase the value-adding activities from 40% to 93%.

For the other problems encountered, the solutions proposed allows to reduce the TAT by 19%.

For future work the proposed changes ought to be implemented and the value stream styled flowchart completed with the waiting times, in order to discover further opportunities of improvement.

In conclusion, Lean principles and tools can be applied effectively to the aeronautic maintenance industry, thus contributing to its process's improvement, waste reduction and significant gains in terms of TAT.

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