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Process Improvement in Aviation Maintenance Repair and Overhaul

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Six Sigma implementation in an airframe component maintenance shop

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Salzburg, im November 2015

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Kurzfassung

Die Instandhaltung, Wartung und Überholung von Luftfahrzeugkomponenten befindet sich im Wandel. Noch vor wenigen Jahrzehnten waren nationale europäische Fluggesellschaften die weltweit führenden Anbieter von MRO-Dienstleistungen. Durch eine strengere Gesetzgebung und weitere erschwerende Rahmenbedingungen wurde dieser Vorsprung gegenüber der produzierenden Luftfahrtindustrie stark eingebüßt. Um Ihre Marktanteile zu verteidigen, sind die Instandhaltungsbetriebe der Fluggesellschaften bemüht auch zukünftig ein umfangreiches Programm an Wartungsdienstleistungen anzubieten.

Air France Industries ist es als einer der historischen europäischen Luftfahrtgesellschaften gelungen eine führende Position auf dem Instandhaltungsmarkt beizubehalten. In den vergangenen Jahrzehnten sind jedoch wiederholt Schwierigkeiten bei der Instandhaltung von Kundenteilen aufgetreten. So kann auch in der Strukturinstandhaltung beobachtet werden, dass es schwieriger wird Durchlaufzeit und Kosten, bei gleichbleibend hohen technischen Standards, niedrig zu halten.

Das Ziel dieser Arbeit ist es, den aktuellen Instandhaltungsprozess bei AFI zu analysieren und auf etwaige Fehlfunktionen zu prüfen. Im Zuge dessen sollen potentielle Verbesserungsvektoren definiert und ausgearbeitet werden. Aufgrund des Fehlens jeglicher Produktivitätsindikatoren wurde beschlossen, den Instandhaltungsprozess anhand eines Six Sigma Projekts nach der DMAIC Methode zu analysieren. Diese beinhaltet eine strukturierte Herangehensweise an ein Verbesserungsprojekt, mit dem Ziel eine langfristige und anhaltende Verbesserung des dabei analysierten Prozesses herbeizuführen.

Im Zuge des Verbesserungsprojekts wird der aktuelle Prozess definiert und Indikatoren zur Messung der Prozessleistung vorgeschlagen. Die anschließende Analyse dient der Ausarbeitung von Verbesserungsmaßnahmen um die interne Kommunikation, den Inspektionsprozess und die Definition von Reparaturmaßnahmen zu verbessern. Außerdem wurde im Zuge des Six Sigma Projekts die Notwendigkeit von maßgeschneiderten Instandhaltungsprogrammen für Kunden festgestellt und deren Implementierung vorbereitet.

Die Haupterrungenschaft dieses Projektes für Air France Industries ist das gewonnene Bewusstsein über die Schwächen des aktuellen Instandhaltungs-prozesses. Die Verbesserungsmaßnahmen sprechen viele zuvor unbekannte Problemfelder an und geben Anregungen für einen, noch viele Jahre andauernden, kontinuierlichen Verbesserungsprozess bei AFI.

Abstract

The maintenance repair and overhaul of aircraft parts and components business has become increasingly fast paced. Two decades ago, the major European airlines securely held the major market share in MRO services worldwide. The tightened regulatory framework, however, has caused a significant share of maintenance work to shift back towards the manufacturing organisations. The airlines are therefore hard pressed to keep their leading market position as a provider of a wide bandwidth of maintenance services.

Air France Industries, being one of the historical European carriers, today remains one of the world’s leading MRO corporations. It has however, over the last decades, run into substantial difficulties in providing maintenance services for its customers. This problem is generally applicable to the airframe maintenance shop which is currently struggling to keep prices and turnaround time for customers as low as possible, while maintaining high technical expertise.

The purpose of this report remains with the analysis of the current maintenance process, as suggested by management of AFI maintenance shop for airframe structures. The scope of this project is the suggestion of performance measurement indicators as well as improvement vectors for the maintenance process. Since many variables of the process had never been mapped, it had been decided to implement a six sigma process improvement project following the DMAIC method. The DMAIC method is a structured approach on process improvement in order to achieve long term improvement in organisations.

The improvement project defines the current process and proposes indicators that help measure the process performance. It brings forth a set of measures to improve internal communication, inspections and the definition of repair procedures. The project also uncovers the need for custom-made maintenance programs for all customers and highlights the first steps of their implementation. Additionally, it provides an innovative approach on how a state of the art maintenance process could look like in the future.

The main achievement of this improvement project lies in the knowledge gain for AFI Aérostructures on their current maintenance process. Many previously unknown problems have been unveiled and addressed within improvement measures which evolved from the DMAIC project. These problems and irregularities at AFI will be subject to improvement projects for years to come.

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Part I – Literature Review

1. Introduction and Overview

The purpose of this literature review is to introduce the stranger into the world of aviation maintenance. The market where so-called MRO (maintenance, repair and overhaul) organisations evolve in, is a very fast paced environment that has been subject to great changes within the last two decades. The world's leading MRO organisations are the maintenance and engineering divisions of the major European airlines (e.g. Air France) who were able to position themselves in this role in the late eighties and early nineties when competition was scarce and they discovered the gigantic revenue opportunities. Thirty to twenty years ago these aircraft operators were allowed to manufacture spare parts and implement self-designed repairs on their own aircraft which helped them gain a significant expertise in the exploitation of airline fleet maintenance. For the past ten years significant changes to the world of flying have helped smaller MROs and aircraft parts manufacturers close the gap they had on this disputed market. First, the drop of ticket fares and increase of the crude oil price have forced airlines to offer more competitive prices for maintenance. Second, new and tighter regulations which were introduced for safety reasons make it a lot harder for airlines to manufacture spare parts on their own and almost impossible to repair parts without turning to the original equipment manufacturer (OEM) for approval. These OEMs have today entered the market of aircraft maintenance on their own being able to provide maintenance with a lot less regulatory constraints.

The first two chapters of this literature review describe the typical organisational structure of MRO providers, taking up the example of a mid-sized airline, and introduce into the system of European aviation regulations. The following chapters on Process improvement and six sigma methodologies describe the techniques and tools that were applied in the second part of this report which describes the improvement of an overhaul shop of one of the world's leading MROs. The aim is to apply production improvement techniques that have evolved in an environment of mass production to the domain of aircraft component maintenance. Therefore the main challenge was the applicability of these tools and techniques to an industrial sector were turnaround time is longer and every product is unique and subject to great uncertainty during its production process.

2. The MRO Organisation

In order to understand the functions of a maintenance, repair and overhaul organisation it is important to get an overview on how aircraft maintenance is generally organised. Generally speaking, the "organisational structure will vary with the size and type of the organisation"[1] but single branches and departments can be found in every one of these organisations.

2.1. Aircraft Maintenance Divisions

The maintenance of aircraft and aircraft components is, depending on the chosen definition, divided into two to three groups:

Line maintenance activities regroup all daily and weekly routine checks, as well as all checks between flights while the aircraft is in active service. The term line maintenance comes from the fact that the aircraft stays "on-line" during these checks and is not pulled out of service, and into a hangar. Line maintenance includes "A" (daily) and "B" (weekly) checks. They are executed by the pilots, the flight engineers or line maintenance mechanics and engineers.

The base maintenance divisions are responsible for all activities that are performed in hangar. All base maintenance operations call for the aircraft to be pulled out of service and are terminated by a release certificate issued by quality control. Base maintenance contains all major overhaul checks ("C" and "D" checks). During these checks, which are scheduled after a certain amount of flight hours, the aircraft is stripped to its bones: landing gear, engines and the complete interior is removed and sent to the overhaul shops while the main frame is closely inspected. A "C" check pulls the aircraft out of services for several weeks. Some sources include the activities of overhaul shops into the base maintenance divisions, others count them out as a third type of aircraft maintenance.

The organisational structure shown in figure 1 is typical for the maintenance and engineering branch of a mid-sized airline.[2] Hinsch confirms this organisational model and points out that even though the EASA Part 145[3] that regulates maintenance organisations in Europe does not give any specifications on how a maintenance firm should be organised, all MROs show striking similarities in their internal organisational structure.[4] In comparisons to other industries it can be pointed out that "the concept of

[1] Kinnison, Siddiqui, 2012, p.91
[2] Kinnison, Siddiqui, 2012, pp.91-92
[3] For closer descriptions of EASA regulations refer to chapter 3.1. of this report
[4] Hinsch, 2013, p. 202

separating production activities (maintenance and engineering) from oversight functions (quality assurance and control, reliability, etc.) is somewhat unique to aviation"[5].

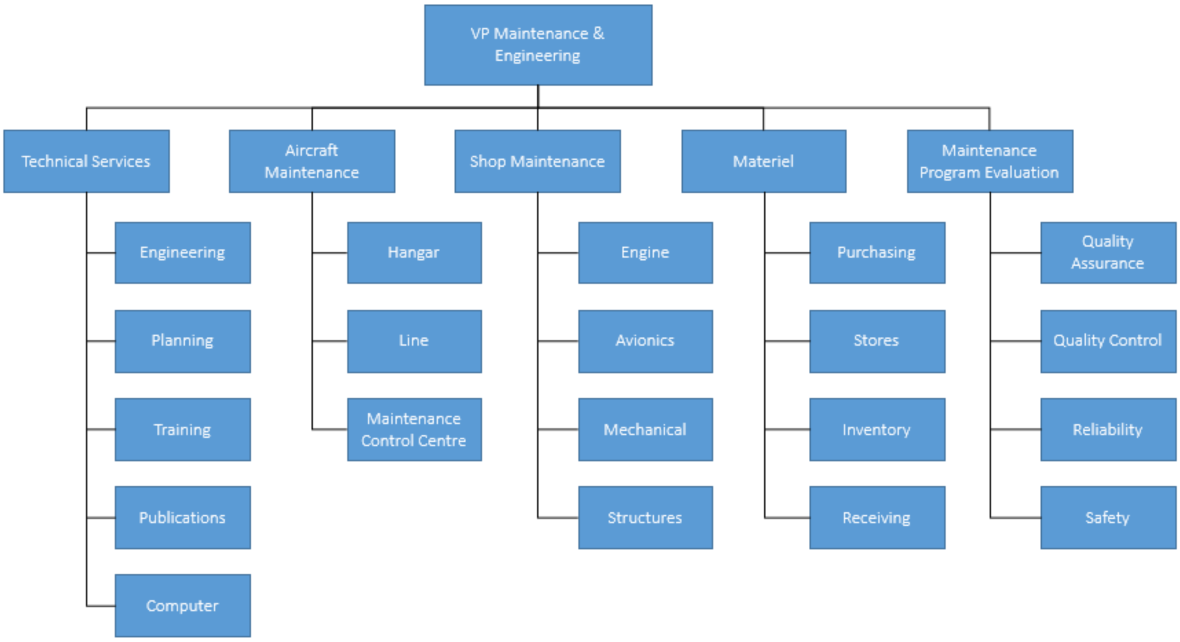

Figure 1: Maintenance organisation in a mid-sized airline

2.2. Overhaul shops

In order to focus on the case studied in the second part of this report, special attention is given to the organisation of overhaul shops. Divided under technical specialities, they provide maintenance on a special group of parts and components removed from the aircraft.[6] While the most common shops are the one for airframe components, engines and landing gear, some sources include the NDT (non-destructive testing) division to the overhaul shops in the organigram.[7] Overhaul shops historically were the first entity of an airline's maintenance and engineering division to perform contract work for other airlines and customers.[8] Today entire fleet maintenance programs are sold to third party airlines. Overhaul shops were initially designed to help and support heavy maintenance (hangar or base maintenance) checks such as "C" and "D" checks. The work performed by these shops can be very complex and time consuming and is therefore not a part of the scheduled maintenance program.[9]

[5] Kinnison, Siddiqui, 2012, p.91
[6] Kinnison, Siddiqui, 2012, p.97
[7] Hinsch, 2013, p.203
[8] Kinnison, Siddiqui, 2012, p.97
[9] Kinnison, Siddiqui, 2012, p.170

Every maintenance shop is responsible for overall management and administration of the shop activity. The shop organisations resembles to the organisation of the entire maintenance and engineering activity shown in figure 1. The time constraints for shop maintenance are different to those in line or hangar maintenance since all work is "done on an out-of-service basis; equipment is removed from the aircraft and replaced with a serviceable unit […]. The removed unit, properly tagged as to maintenance status, is then sent to the stores"[10]. "The maintenance performed in these shops can be anything from simple cleaning and adjustment to complete overhaul"[11].

Kinnison et al. states that data collection is a very important and value adding aspect of maintenance shops. The airline's reliability programs and outsourced maintenance programs are in constant need for data in order to sell the experience they gain on their own fleet. The "shop data collection efforts are submitted through shop tear-down reports that identify servicing, repair and overhaul actions taken, as well as the parts and supplies used in that maintenance work"[12].

2.3. Close Loop and Pool Customers

Another important aspect is the spare parts rotation during aircraft maintenance processes. Every airline keeps an inventory of spare engines, landing gear and other equipment in order to be able to replace damaged or worn elements within a minimal time frame. The removed parts are repaired at the responsible overhaul shop and returned to the inventory as serviceable part. For customers this procedure is not always the same. While some have signed a "pool" contract, which gives them access to the spare parts pool of the MRO provider, others are so called "close loop" customers. If the equipment is treated in a close loop process it needs to be reequipped with the exact same parts (same serial numbers) at the end of the maintenance process. The customer does not have access to the spare parts pool of the MRO provider. Being in a close loop process makes the maintenance procedure longer and more difficult to manage. If the customer doesn't have pool access, he leases a spare equipment on a per-day basis in order to keep his aircraft operational during the maintenance process. Close loop customers therefore demand faster turnaround times and create high time pressure in the overhaul shop's processes.

[10] Kinnison, Siddiqui, 2012, p.171
[11] Kinnison, Siddiqui, 2012, p.170
[12] Kinnison, Siddiqui, 2012, p.179

3. Aircraft Maintenance Regulations

3.1. EASA Regulation

The European Aviation Safety Agency (EASA) has set up rules, to coordinate the development, production, maintenance and operation of aircraft in a standardized and secured manner.[13] These guidelines are binding laws and must be met by all organisations producing, maintaining or operating aircraft in Europe. Alongside the North American FAA (Federal Aviation Administration, USA), the EASA is one of the two major legal bodies worldwide which set up rules for producing and operating aircraft. The EASA regulation consists of two main parts (figure 2). One for all rules on aircraft certification and another one for the continuing airworthiness of all airborne vehicles. While the first is applicable to all developing and producing organisations, the second contains all rules for safe operation and maintenance of aircraft.

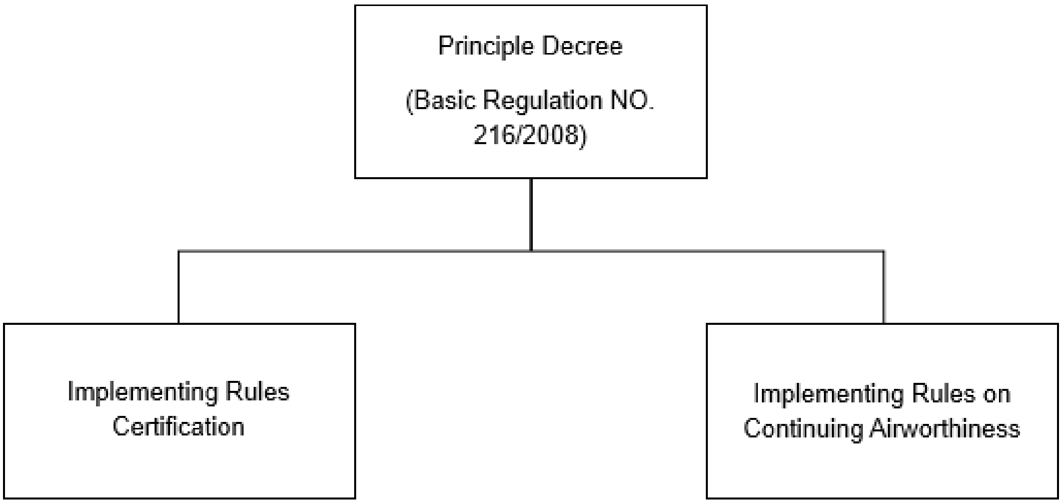

Figure 2: Basic EASA Regulation Structure[14]

The implementing rules (part 21) for certification of aircraft have two distinctive parts: One for manufacturing operations (EASA part 21J) and the development of aircraft and aircraft parts (EASA part 21 G). Companies certified as part 21J only, are restricted to the production of aircraft and aircraft parts, they are not allowed to develop them or implement design changes during the manufacturing or maintenance processes. Aircraft manufacturers like Airbus and Boeing are certified with both part 21J and 21G organisations. The implementing rules for continuing airworthiness however contain 4

[13] Hinsch, 2013, p.12
[14] Hinsch, 2013, p.13

sub-parts all shown in figure 3. It contains distinctive chapters on training of maintenance personnel (part 147), on certification of release personnel (part 66) as well as regulations for continuing aiworthiness (part M) and maintenance programs (part 145).

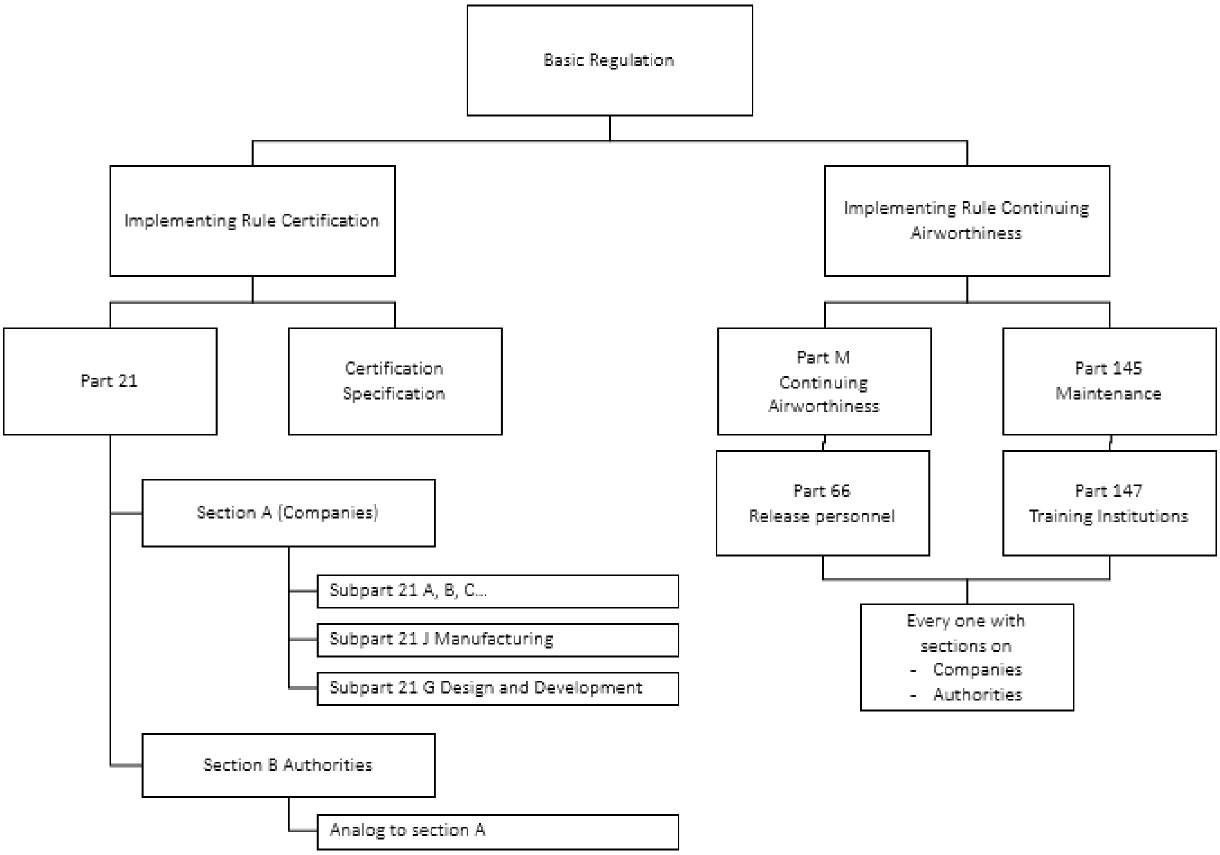

Figure 3: EASA Basic Regulation[15]

3.1.1. PART 21 J

Development and design organisations are, as defined by the EASA Subpart 21 J, all organisations which develop aircraft, parts and equipment and are allowed to implement permanent changes and repair procedures to the original design of the aircraft.[16] Maintenance organisations who need to repair aircraft or parts involving a change to the original design have to apply for a DOA (Design Organisation Approval) at the according 21 J (usually the OEM) organisation. The core activities of design organisations are:

[15] Hinsch, 2013, p.14
[16] Hinsch, 2013, p.17

1. The preparation of design drawings for a product as well as changes to the design of a product,
2. The identification, classification and publication of the manufacturing handbooks and environmental guidelines,
3. Providing evidence that construction and designs are safe and in line with airworthiness and design regulations,
4. Preparation of operation and maintenance manuals (operation handbooks, AMM, CMM),
5. Preparation of regulatory design certification applications.[17]

Many MRO organisations are not accredited design organisations and have to validate design changing repairs with the design organisation. Since DOA procedures can be very time consuming and costly most small MROs limit themselves to repairs within the standard procedures manual (SPM). The market leading MROs however are certified as Part 21 J organisations themselves, in order to be able to validate design changing repairs with their own team of engineers. The high experience, built over many years of aircraft operation, sometimes puts them into a better position to design repairs for aircraft and aircraft parts than the initial OEM.

3.1.2. PART 21 G

Aeronautical manufacturing includes all activities that are directly related to building aircraft, aeronautical engines and aircraft equipment. Only accredited organisations are allowed to manufacture aeronautical parts and products.[18] An organisation declared as part 21 G only, is limited to manufacturing aeronautical goods. It is prohibited from making changes to the design of the goods they produce.[19] The collaboration between developing and manufacturing organisations has to evolve in a highly controlled and coordinated environment and has to be defined and signed by both organisations in a mutual agreement.[20] The major MRO organisations are usually certified EASA part 21 G in order to be able to manufacture spare parts on their own. In earlier years (during the 80s and 90s) the manufacturing activity was substantially bigger among MRO organisations. New limitations and increased spare part pricing pressure from the OEMs have significantly decreased this activity. Today most spare

[17] Hinsch, 2013, p.17
[18] Hinsch, 2013, p.23
[19] Hinsch, 2013, p.23
[20] Hinsch, 2013, p.24

parts are bought directly from the original equipment manufacturer or specific spare parts trading companies.

3.1.3. PART 145

According to the EASA part 145, maintenance organisations are firms that maintain, repair and overhaul aeronautical parts and products in accordance with legally acknowledged documentation. This activity can imply the overhaul, replacement, repair, inspection and permanent change (modification) to aircraft, engines and all other aeronautical parts and products.[21]

The most common documents issued by the design organisation are the aircraft maintenance manual (AMM), component maintenance manual (CMM), engine manual (EM) or the structural repair manual (SRM). On top of that the design organisation provides dozens of maintenance handbooks and standard procedure manuals (SPM). All documents describe how, when, where and by whom maintenance work is to be performed. All maintenance manuals are applicable to one and one aircraft type only and are most of the time only available in English language.[22]

The scope of a maintenance organisations can vary and is therefore divided into four different ratings of EASA part 145 organisations.

- **A-Rating** (Aircraft-Rating): Allows for maintenance, overhaul and repair directly on aircraft. This scope also includes aircraft parts such as engines and APUs (auxiliary power units) as long as they are mounted on the aircraft.

- **B-Rating** (Engine-Rating): Allows for maintenance, repair and overhaul activities on engines and auxiliary power units dismantled from the aircraft alongside all equipment directly affiliated to the engine also dismantled from the aircraft.

- **C-Rating** (Component-Rating): Allows for maintenance, repair and overhaul activities on dismantled aircraft parts and products with the exception of engines and APUs.[23]

The less mentioned D-Rating certifies an organisation to perform non-destructive testing (NDT) which consists of a set of non-destructive material testing methods such as ultrasounds and Foucault currents.[24]

[21] Hinsch, 2013, p.28
[22] Hinsch, 2013, p.29
[23] Hinsch, 2013, p.29
[24] Hinsch, 2013, p.29

Big maintenance and engineering divisions of airlines like Air France Industries are accredited with all of the above ratings. At the same time they are usually accredited training institutions for aircraft mechanics (part 147), accredited release certification organisations (part 66) and accredited to guarantee continued airworthiness of all aircraft they provide a maintenance policy for (part M). Part M is an accreditation standard for all aircraft operators (mostly airlines). Every airline or aircraft owner is legally obliged to set up a program in order to insure continued airworthiness on their aircraft and report it directly to the EASA. The part M obligations of smaller airlines are today often outsourced to bigger maintenance organisations. Only big airlines with considerable fleet sizes have their own part 145 accredited maintenance departments (In Europe e.g. Air France, Lufthansa, Iberia and British Airways).

4. Process Improvement

Business process improvement is a systematic approach that aims to optimize business processes and turn them more efficient. Improvement project focus on the restructuring and redesign of the process sequence while holding on to the existing organisational structure.[25] A process needs to be both effective and efficient. The terms of effectivity and efficiency are often misused. While an effective process simply achieves the correct result, an efficient process is executed with the least necessary input and in the fastest possible manner. Efficient processes are often associated with the catch-phrase of "doing things right" which does not imply that the process is delivering the right result.[26] Therefore a process can be efficient but still unable to achieve the goal it has been set up to. The matrix in figure 4 illustrates the difference between effective and efficient processes.

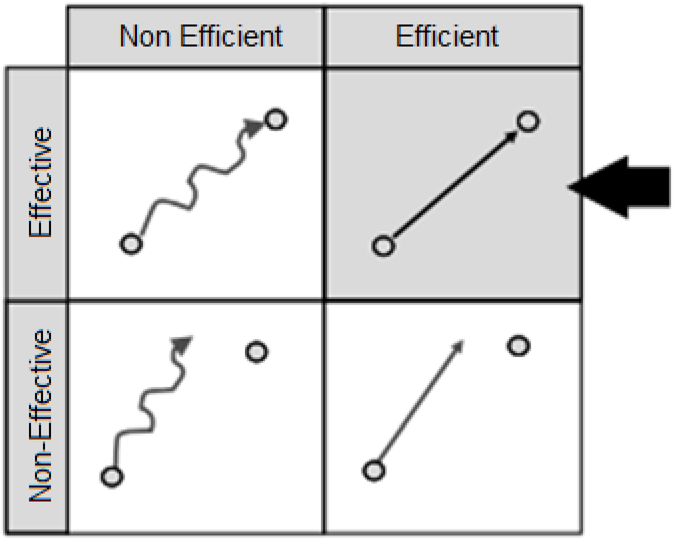

Figure 4: Efficiency and Effectivity[27]

Moreover there is a set of principles good processes need to fulfil. The 10 principles of a good process are:

1. **Effective:** The process does what it is designed to do and delivers the correct result.
2. **Efficient:** The process runs with the least necessary input.

[25] Becker, 2005, p.28
[26] Becker, 2005, p.12
[27] Becker, 2005, p.12

3. **Controlled:** The process is controllable and delivers the same result on every execution with a low fluctuation margin.
4. **Deterministic:** The process does not cause an avalanche of processes. One processes hands its result over to one subsequent process. The result of the process is predictable.
5. **Atomic:** The process needs only one or few input values (material or manpower) to be operative. Input values do not cause significant waiting times when unavailable.
6. **Flexible:** If market, product or customer requirement changes impact the process, the latter remains adaptable and can continue to create its value even under the changed circumstances.
7. **Robust:** No disturbances or quality impact from smaller errors in adjacent processes.
8. **Side effect free:** Processes are closed loop and do not cause side effects on other processes. The processes does not disturb other processes running in parallel.
9. **Documented:** The process is documented while it is executed from the first to the last step. Processes are executed exactly as they are documented. The documentation of the process isn't time consuming and can be consulted at any time.
10. **Continuously improvable:** The process owner is never satisfied with his process and aims to improve the process capabilities and performances.[28]

Once the process is evaluated with the characteristics stated above it leaves a first impression for potential improvement. Furthermore the process improvement team can ask itself the following questions, in order to detect possible process malfunctions.[29]

1. Design and Optimization of the processes:
    - Are the customer requirements fulfilled to 100%?
    - Are the reaction times at the process interfaces too long?
    - Is the process too complex?
    - Are there gaps in the process deployment?
2. Process planning
    - Are the process capacities too low (too big)?
    - Are the reaction time too long?
    - Are the order times before and during processes too long?
3. Process control
    - Is the business backlog high?
    - Are the priorities clearly defined?

[28] All 10 process characteristics from Becker, 2005, pp. 15-17
[29] Questions from Becker, 2005, p.18

- High workloads due to disturbances and interferences?

4. Process application and execution
    - Do the employees have different ways of working?
    - Does the process execution coincide with the process documentation?
    - Are there fluctuation in the project performance

In the study presented in Part II the process improvement approach has been used to determine the characteristics of a good process and ask the right key questions for continuous and sustainable process improvement. For the general systematic approach to the process improvement the six sigma DMAIC method described in chapter 6 has been employed.

5. Lean Production

„Use half of everything“, was the key word[30] at Toyota for Taguchi Ohno (1988) and Shigeo Shingo who first defined the technique later renamed “lean production” in the United States.[31] The three core competences and goals of lean production are:

1. **Pull system:** Using a pull concept rather than a pushed flow in production targets low storage volumes and costs. Production only responds to orders and does not produce more than the market demands.[32] The production in an aircraft maintenance overhaul shop in theory should work with a pulled production processes but is often pushed when it comes to maintenance of parts reintegrating the airlines spare parts pool.

2. **Assembly lines:** Although the assembly line itself is a lot older than the concept of lean production it has been refined and redefined with this new concept. The assembly steps have been broken down into very small and simple steps and are executed by a greater number of small machines each performing one single tasks.[33] The production process in an overhaul shop cannot really be compared to this very advanced type of an assembly line built and designed for mass production due to very individual work scopes.

3. **Waste avoidance:** Is divided into three “MU” (japanese) subparts:

   Muda (Waste)
   Muri (Capacity Overload)
   Mura (Imbalance, Deviation)

   Especially the first part often yields a high potential for process improvement and cost savings since it aims to reduce redundant tasks and movements as well as useless stock and material waste.[34]

Although not unconditionally applicable to MRO organisations, these three principles of lean production have been taken into account in the analysis developed in Part II. Stable, efficient and effective processes along with high quality within short reaction times and little variance are a prerequisite for the deployment of lean production.[35] Therefore both process improvement and six sigma are steps to be executed before

[30] Becker, 2005, p. 38
[31] Becker, 2005, p.39
[32] Becker, 2005, p.40
[33] Becker, 2005, p.39
[34] Becker, 2005, p.41
[35] Becker, 2005, p.41

handling the implementation of lean production even though the ground ideas have been considered at all times during the improvement process.

6. Six Sigma

6.1. Definitions and Description

There are many definitions that describe the aim of the Six Sigma method. Some definitions focus on the six sigma method being a „project driven management approach to improve the organisations products, service, and processes by continually reducing defects in the organisation”[36]. Others describe it as the clarification, minimization and elimination of error causes in the processes of an organisation.[37] Both descriptions put it into direct relation with Lean Production and Lean Management principles. Other definitions try to widen the scope of Six Sigma by adding objectives like optimum cycle time, operations cost reduction, improved productivity and the achievement of high asset utilisation and returns.[38] The key objective most associated with Six Sigma is the aim for improved responsiveness to customer requirements. While some restrain it to the improvement of the sole understanding of customer requirements[39] others illustrate it as the creation of a higher perceived value of the company's products and services in the eyes of the customer.[40] In fact all of the objectives stated above are somewhat true in the measure that Six Sigma is a step by step business improvement strategy that can be focused on different objectives. Whether the improvement should target financial performance, productivity or improving customer satisfaction, needs to be defined in the first steps of the improvement plan. In order to pass Six Sigma implementation with the executive management of the organisation, it has become common use to emphasize the benefits of six sigma in financial returns by linking process improvement with cost savings.[41]

The Name Six Sigma has its roots in mathematics. In statistics, sigma (σ) represents the standard deviation (variance around the average μ). The standard deviation defines the shape of a normal distributed probability density function. Following this mathematical principle, Six Sigma represents six times the standard deviation that lies between the expected value and the specification limitation of a process.[42] Therein sigma measures the quality level of a product or a process. A process that has a 99.99966% probability of being fault-free, has reached Six Sigma standard.[43] The probability of being fault free can also be translated into producing 3 faulty products

[36] Kwak, Anbari, 2006, p.708
[37] Brue and Howes in Koch, 2015, p.166
[38] Evans and Lindsay in Parast, 2009, p.45
[39] Kwak, Anbari, 2006, p.708
[40] Schonberger in Chakravorty, 2009, p.3
[41] Kwak, Anbari, 2006, p.709
[42] Bergbauer in Koch, 2015, p.166
[43] Koch, 2015, p.166

out of 1 million units produced. In the same matter other sigma levels are defined: An organisation that is operating at three sigma level for quality control can be interpreted as achieving a success rate of 93% or 66,800 defects per million opportunities or units.[44] In order to measure this fault occurrence a new measure has been introduced that counts every error in a million opportunities. Defects per million opportunities (DPMO) have since become a new quality standard unit.[45] On this same topic Philipp B. Crosby argued that it isn't the production of quality that generates additional costs but much rather the non-conformity to customer and market requirements. He therefore created the concept of zero-defect production in 1961.[46] In addition the application of Six Sigma in organisations not only shows the inhibition of additional costs through increased quality but often results in a significant cost reduction if it is implemented correctly.[47]

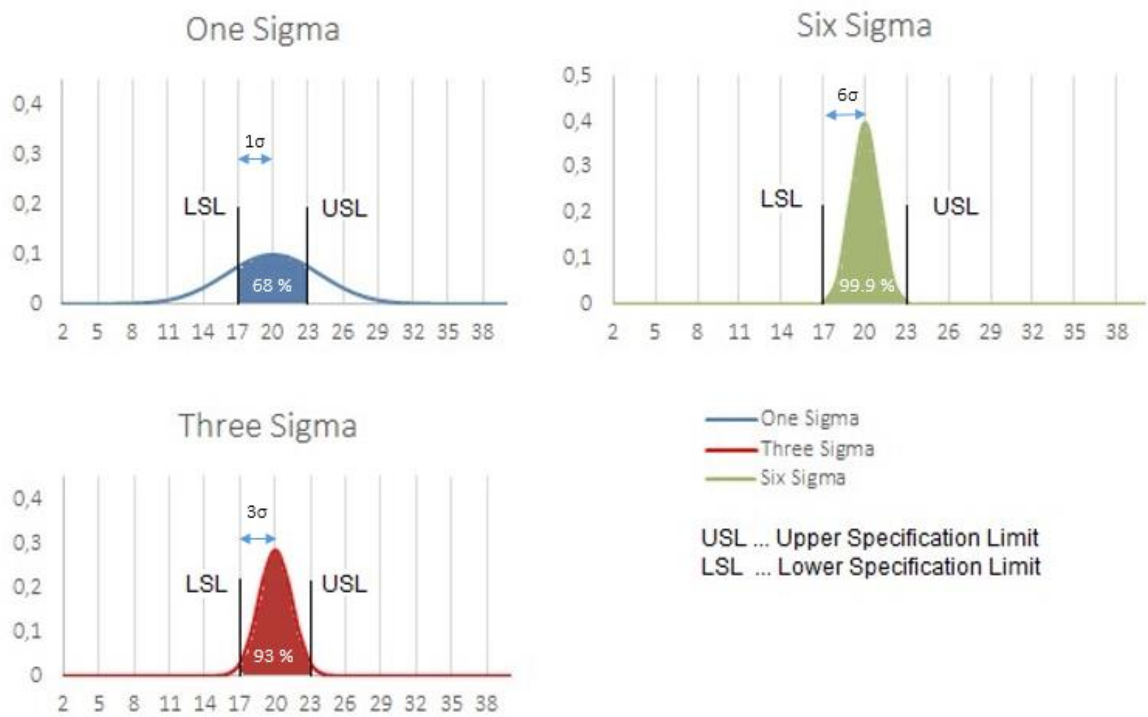

Figure 5: Visualisation of the statistical approach to Six Sigma

The aim of Six Sigma, as it is visualised in figure 5, is to design processes in a way that the process results scatter as little as possible and the probability to obtain the expectancy value is improved.[48] The reduction of the scattering ideally causes an improvement in turnaround time and degree of utilisation.[49] This additionally results in improved process reliability and creates more projectable processes. The reduced

[44] Kwak, Anbari, 2006, p.709
[45] Gundlach und Jochem in Koch, 2015, p.167
[46] Kamiske 6 Brauer in Koch, 2015, p. 166
[47] Koch, 2015, p. 167
[48] Töpfer und Günther in Koch, 2015, p. 169
[49] Magnusson et al. in Koch, 2015, p.169

variation of process results also helps to improve customer satisfaction and process efficiency.[50]

The improvement through Six Sigma is monitored project-oriented across a detailed mapping of processes.[51] In order to achieve Six Sigma level, the concerned process needs to be predictable and controllable. A process is controllable when all non-predictable reasons for scattering are eliminated an only predictable and controllable reasons remain.[52] It is therefore indispensable to do a detailed analyses on the controllability and predictability of the concerned processes. This circumstance gives organizations with a well organised quality control and quality management structure and organisations with a carefully monitored historical process database a head start in Six Sigma implementation.

“The key elements for the effective introduction and implementation of six sigma in manufacturing and services organisations have been stated as the following:

- Management commitment and involvement.
- Understanding of six sigma methodology, tools, and techniques.
- Linking six sigma to business strategy.
- Linking six sigma to customers.
- Project selection, reviews and tracking.
- Organisational infrastructure.
- Cultural change.
- Project management skills.
- Liking six sigma to suppliers.
- Training
- Linking six sigma to human resources”[53]

Chakravorty has structured the Six Sigma approach into six major steps:

The model points out the first step as the implementation of an improvement plan through a customer and market driven strategic analysis.[54] Well known tools like the SIPOC analysis or a CTQ analysis are frequently used to describe the customer’s point of view on, and his requirements of the process. The second step is all about the creation of a cross-functional team that is necessary to implement Six Sigma programs. The “purpose of the team is to provide an on-going involvement of management in the implementation process”[55]. The third step contains the establishment of the

[50] Schmelzer und Sesselmann in Koch, 2015, p.169
[51] Koch, 2015, p. 169
[52] Koch, 2015, p.174
[53] Antony and Banuelas in Kwak, Anbari, 2006, p.712
.[54] Chakravorty, 2009, p.3
[55] Pande et al. In Chakravorty, 2009, p.3

improvement tools that are used to tackle the project. This is followed by a process mapping step that prioritizes improvement opportunities. The results of this fourth step is a detailed implementation plan. Steps five and six wrap up the project by implementing and reviewing the improvement measures. This last steps are loop processes that will generally have a few iterations within them.[56] This method described by Chakravorty is a slightly different approach than the DMAIC and DMADV approach usually taught in textbooks and Six Sigma courses today. For the project described in the second part of this report the classical DMAIC model described below has been used. Six Sigma is commonly implemented on four different levels:

- Stand Alone Tool
- Quick Hit
- DMAIC Method
- DMADV Method.

Every single one of those implementation levels represents a different depth of process or product improvement. Every single one of those methods contains one or more tools from what is commonly known as the Six Sigma tool box. Before describing the four implementation methods this tool box has to be listed.

6.2. The Six Sigma Toolbox

The Six Sigma tool box is divided under seven improvement fields. Each contains seven analysis and improvement tools. This results in a total of 49 tools that, although not always affiliated with Six Sigma, have a great impact on the outcome of a Six Sigma improvement project.

The Six Sigma Toolbox		
7 Design Tools	1	Robust Design
	2	QFD
	3	TRIZ
	4	Decision Matrix
	5	FMEA
	6	Fault-Tree-Analysis
	7	Taguchi Method
7 Statistical Tools	1	Factorial Tests
	2	Process Capability
	3	Regression Analysis
	4	Multivariate Statistics
	5	Statistical Tests

[56] Chakravorty, 2009, pp. 4-9

	6	Probability Plot
	7	R&R Study
7 Project Management Tools	1	Precedence Diagram Method
	2	Project and Team Description
	3	CTQ Analysis
	4	Tree Structure
	5	Measurement systems analysis
	6	Cost-Benefit Analysis
	7	Control Charts
7 Lean Management Tools	1	Standardisation
	2	Waste analysis
	3	Bottleneck Analysis
	4	Flow Chart
	5	Supply Chain Matrix
	6	Optimisation of Setup Time
	7	Red-Tag Analysis
7 Customer Tools	1	Kano-Model
	2	Requirements Structure
	3	House of Quality
	4	Loss Function following Taguchi
	5	Customer Interviews
	6	Customer Questionnaires
	7	Conjoint-Analysis
7 Quality Control Tools (7QM)	1	Measuring Plan
	2	Histogram
	3	Pareto Analysis
	4	Ishikawa Chart
	5	Graphic Comparison
	6	Relation Matrix
	7	Control Charts
7 Management Tools	1	Decision Tree
	2	Affinity Diagram
	3	Relation Matrix
	4	Tree Chart
	5	Matrix Chart
	6	Matrix Data Analysis
	7	Utility Network Plan

Figure 6: Six Sigma Toolbox[57]

Many organisations focus too much on selective implementation of six sigma tools from the above tool box rather than following an overall structured six sigma implementation plan (e.g. DMAIC method). Critics point out that the tool box is given too much attention within process optimisation and many users have a tendency towards misinterpretation of the results obtained from the tools.[58]

6.3. Stand-Alone-Tool (SAT) and Quick Hit

The first two Six Sigma implementation levels are superficial improvement methods that aim for a quick improvement of a process or product. While the Stand-Alone-Tool method only uses a single tool out of the six sigma tool box for an individual analysis of a process step or product feature the quick hit method follows a more thoughtful approach with definition of the aim, measurements of the current problem and a structured solution to the problem. Both SAT and Quick Hit aim for a very punctual improvement of a process step or a product feature.[59] While SAT implementation durations can stretch from a couple of minutes (data analysis with a six sigma toolbox tool) up to one day (e.g. FMEA implementation with a selected working group), the Quick Hit implementation can last up to a couple of days when structured improvement workshops are scheduled in the organisation.

6.4. DMAIC

In contrary to the SAT and Quick Hit implementation projects the DMAIC and the DMADV methods are structured approaches that call for long term improvement on processes in organisations. The DMAIC project has been described as a “closed-loop process that eliminates unproductive steps, often focuses on new measurements, and applies technology for continuous improvement”[60]. The operating level of DMAIC can be described as “a metaroutine: A routine for changing established routines or for designing new routines”[61]. The name DMAIC is an acronym for the 5 steps followed during the implementation:

[57] Translated from Magnusson et al. in Koch, 2015, p. 173
[58] Koch, 2015, p.174
[59] Koch, 2015, p. 172
[60] Kwak, Anbari, 2006, p.709
[61] Schroeder et al. in de Mast et al. 2012, p.604

- Define
- Measure
- Analyse
- Improve
- Control

This set of structured steps help the team charged with the implementation "to identify the root causes of the problem, look for solutions, and improve the process"[62]. Originally described as a "method for variation reduction, DMAIC is applied in practice as a generic problem solving and improvement approach"[63]. The set timeframe for a DMAIC process is estimated to about 90 days (or 3 months). It is applied to existing processes that do not yet comply with the critical quality standards that are set by the customer requirements.[64]

A verification of the gap between the process requirement and the process performance is necessary before launching the DMAIC method in order to determine if the gap isn't too big. Problems with a large gap call for a complete redesign following a DMADV process. In an equal matter a DMAIC implementation might not result in a significant improvement, if the process is not structured, developed or controllable enough. In that case measures for improved process tracking and measurement databases might be more adapted as a first step towards sustainable improvement.[65]

The DMAIC method tackles problems with a fixed organisational structure. "This fixed structure […] is one of its main strengths. DMAIC is essentially a problem structuring device that breaks down a problem solving task into a series of generic subtasks. It helps the user to find a strategy for analysing and solving the problem"[66]. In order to evaluate the success, impact and quality of a DMAIC project two measures have been created: The first is described as the "*quantum gain in process knowledge*". "The process knowledge gained during an improvement cycle and the stability of the current process provides an appropriate foundation for the next improvement cycle. […] The knowledge gained from a process improvement study will be particularly valuable, if it is portable"[67]. The second measure is the "*ease of control*" that describes the fluidity with which the carryover between the five steps can be performed.[68] It essentially

[62] Parast, 2011, p.50
[63] McAdam and Lafferty in De Mast et al. 2012, p.604
[64] Koch, 2015, p. 172
[65] Koch, 2015, p.174
[66] De Mast et al. 2012, p.613
[67] Mandal, 2012, p.233
[68] Mandal, 2012, p.233

describes the “ability to hold on to the gains”[69] Both measures have to be considered at any given time in the project and are very important in order to assess the quality of the DMAIC project.

6.4.1. Define

Being the first step of the project its scope is to create an overall project definition. Several different tasks are cited in the literature. One of the most complete definitions of tasks to be performed during the define phase is:

- Identify and map relevant processes
- Identify stakeholders
- Determine and prioritize customer needs and requirements
- Make a business case for the project.[70]

The same approach is supported by other sources who define customer identification, requirement elaboration and the definition of project objectives as the main pillars of the define phase.[71] Therefore it can be very useful to do a so-called “project charter” which includes the elaboration of the following points that round up the project definition:

- name
- definition
- problem situation
- scope
- goals and objectives
- team and participants
- milestones
- official assignment
- current process performance

[69] Mandal, 2012, p.233
[70] De Mast et al. 2012, p.605
[71] Becker, 2008, p.62

In order to gain an optimal view on the company's profile and current performance and to get a first idea on the organisation's strengths and weaknesses, some sources recommend to perform a SWOT (strengths, weaknesses, opportunities and threats) analysis for the organisation. Sources claim, that "performing organisation assessment or SWOT analysis, companies can assess their current situation and develop a strategy for Six Sigma implementation"[72]. Once the SWOT table is established the six sigma team must identify all customers that are implicated in the process that needs to be improved. No matter whether customers are actual external customers or organisation internal customers such as related departments, the define phase is designated to define the customers and identify their critical quality characteristics (CTQs).[73] One of the best adapted tools for gaining an adequate understanding of the process is the SIPOC analysis. SIPOC stands for Supplier, Input, Process, Output and Customer and helps to map and understand the value creation process from the supplier to the customer.[74] Figure 7 shows an exemplary structure for a SIPOC analysis and wraps up all information it has to contain. Once the SIPOC analysis is performed it is important to establish a listing of all customer requirements that are critical to quality (CTQ). This so-called CTQ analysis is another tool that is often recommended for the define step. Since the CTQ analysis also suggests measures for evaluating the different requirements it is a good transition towards the second step of the DMAIC project.

[72] Cheng in Chakravorty, 2009, pp 8-9
[73] Koch, 2015, p.175
[74] Töpfer in Koch, 2015, p.175

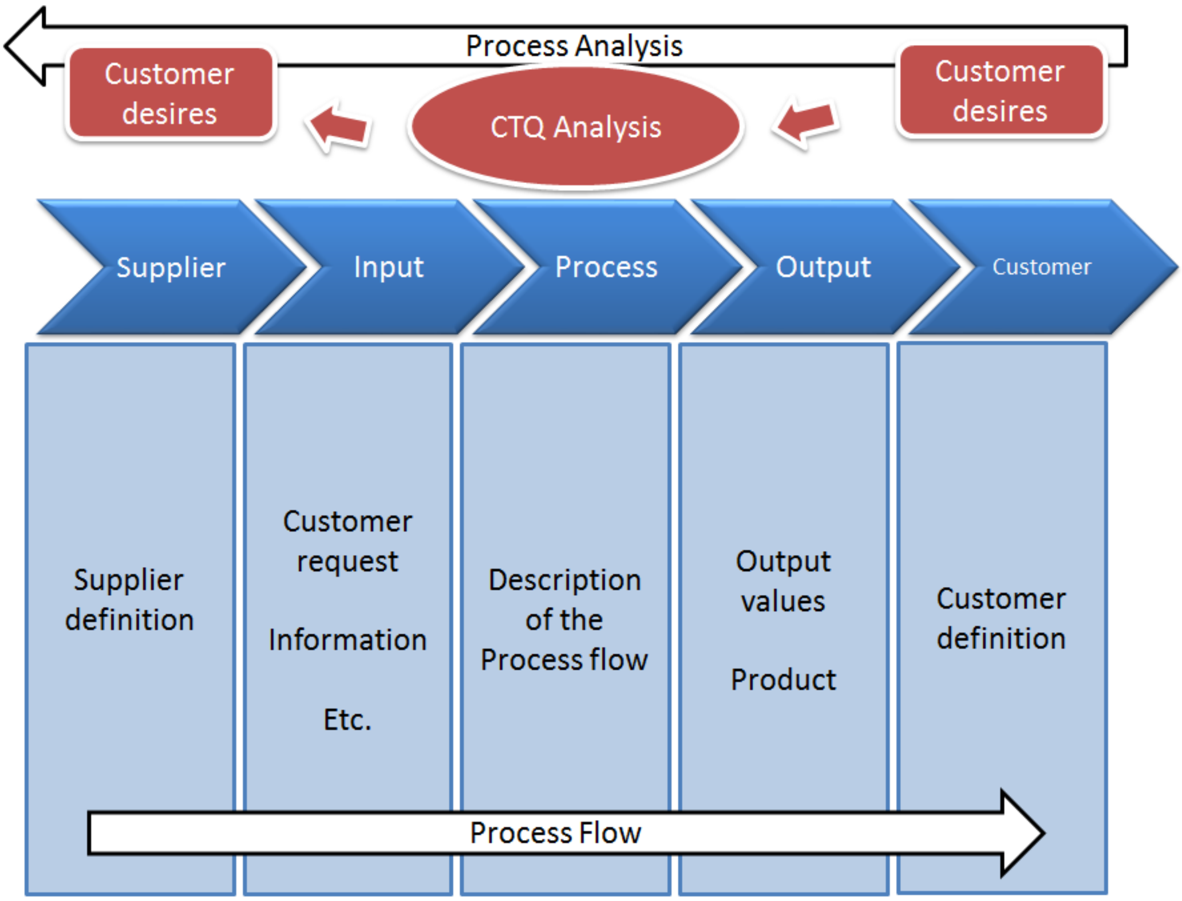

Figure 7: Generalized SIPOC Chart

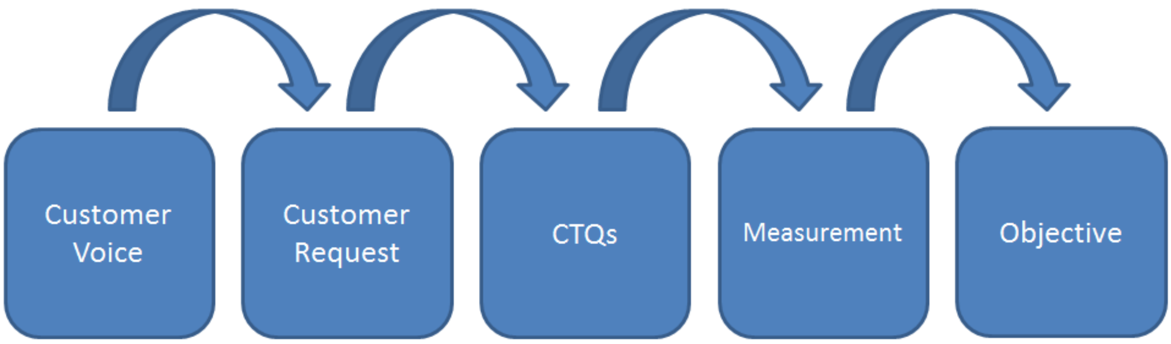

Figure 8: Generalized CTQ Evaluation

6.4.2. Measure

The measure phase of the DMAIC project assesses all so-called "critical to quality" factors. Its main steps contain:

- selection of one or more CTQs
- operational definition for CTQs and requirements
- validation measurement systems of the CTQs
- assessment the current process capability
- definition of the objectives[75]

The main task of the measure-step is to determine the factors that have negative influence on the critical to quality measurements and therefore on the quality of the entire process.[76] Output-, process- and input values have to be defined and mapped. They help to quantify the process capabilities and the current process performance.[77] In order to determine these factors the best practice is to apply a set of tools from the Six Sigma toolbox that will help shed light on the irregularities and malfunctions of the processes in the organisation. Some of these tools are:

Swim Lane Diagram:

The Swim lane diagram characterizes and displays the information and material flow path through an organisational process. Once it is properly established it can be of great use to determine unnecessary steps or show why there are communication problems at the process interfaces. During the analysis of the current state of a process it is advisable to establish a swim lane diagram together with the six sigma team in order to determine the inefficiencies of the process and clarify the process structure and process task sequence for further investigation.[78] At the same time, different steps in the process can be measured in average time and manpower effort in order to gain a better view on inefficiencies and malfunctions.[79]

CTQ Matrix:

While the CTQ analysis has already been introduced during the define phase of the project it has to be completed and evaluated during the measure phase. For every determined CTQ requirement, a detailed measurement of the current status should be performed. While examining the distribution and thus the sigma level of the measure an objective has to be set for the future development of the DMAIC project. The improvement of the sigma level of a measure cannot always be the objective of the project. Some improvement measures might not follow a normal distribution or might only appear to be normally distributed in a bell curve shaped manner. It is

[75] De Mast et al. 2012, p.605
[76] Koch, 2015, p.178
[77] Koch, 2015, p. 178
[78] Becker, 2005, p.131
[79] Chakravorty, 2009, p. 4

recommended to analyse the core problem with an Ishikawa diagram in order to establish a CTQ Matrix.[80] This cause and effect matrix consists of a set number of input values in rows and output values in columns. Every input receives a mark from 0 to 10 of correlation strength to a specific output. Additionally every output receives an importance ponderation mark from 1 to 5. In every row the correlation mark is multiplied with the importance mark and summed up to a final value for every input. To visualize the crucial input values of the process a Pareto chart is drawn to point out the 20% of the input values that are considered most critical to process quality.[81]

It is very important to keep the right balance between quantitative and qualitative data. While quantitative data is numerical and written data from databases, process records, measurements and process archives, qualitative data is collected by reading about former improvement projects, conducting interviews with staff involved in the process that needs to be improved and discussion meetings on the improvement topic. Both quantitative and qualitative data are collected in several alternating steps in order to continuously improve the depth of the analysis.[82]

6.4.3. Analyse

The “analyse phase of the DMAIC process can be seen as the root cause analysis”[83] for all problems emerging during the process that has been defined and measured in the previous steps. The analysis phase often contains an interpretation of the problems and tries to depict the influence factors why the problem reason. Due to its profound examinations it is often considered being the core phase of a DMAIC cycle[84] and said to be one of “the most critical phases for the success of the six sigma implementation”[85]. The main tasks of the phase are:

- Identification of potential influence factors
- Selection of the vital influence factors[86]
- Identification of current process malfunctions

The analysis starts with a breakdown of the process described in the SIPOC analysis during the define phase into several sub processes.[87] Every one of these sub processes is then analysed on its contribution to input and output values, its added

[80] Koch, 2015, p.178
[81] Koch, 2015, p.178
[82] Yin in Chakravorty, 2009, p.3
[83] Mandal, 2012, pp. 235-239
[84] Töpfer in Koch, 2015, p.179
[85] Mandal, 2012, p.232
[86] De Mast, 2012, p.605
[87] Koch, 2015, p. 180

value to customer requirements and is evaluated on possible malfunctions. Additionally every sub process should be examined for his controllability (noise, constant, variable) in the entire process. This phase helps to guide the improvement measures suggested in the following steps of the DMAIC process onto the right improvement vectors which are controllable and variable sub processes that have a high impact on output values and customer satisfaction. Non-controllable sub processes need a significantly higher amount of work and sustainable long term change to be improved.[88]

The analysis phase can be strongly supported by the use of tools from the six sigma toolbox. The tools usually provide a great deal of help for analysing and presenting the problems detected during this phase of the six sigma project.

Generally speaking the analysis phase is the most intuitive and individually designable but also one of the most important phases of the six sigma process. To sum it all up the analysis phase demands for detailed process and data analysis (qualitative and quantitative), a root cause analysis of the process in order to determine where and why it fails and, as a last step, a first approach to possible improvement measures.[89]

6.4.4. Improve

The improve phase is the fourth phase of the six sigma process. It is used to identify the improvement measures, evaluate them and choose a selection of the measures that are most likely to have a positive economic impact on the project.[90] The best measures will be implemented at the end of the improve step. The main aims of the phase are:

- Quantification of relationships between problems and CTQs
- Design of measures to modify the process or setting of influence factors in such a way that the CTQs are optimized
- Conduct pilot test of improvement measures.[91]

Especially the aspect of “selection and prioritization is an important element of Six Sigma Programs”[92]. In order to evaluate the measures against each other a set of tools is used in order to filter the ones yielding the highest improvement potential. The most

[88] Töpfer,in Koch, 2015, p.182
[89] Toutenburg and Knöfel in Koch, 2015, p. 180
[90] Koch, 2015, p.183
[91] De Mast et al. 2012, p.605
[92] Chakravorty, 2009, p.2

commonly used tools are the quality function deployment and the failure mode and effects analysis. Both are described more closely in chapter 7.

In the next step, improvement measures are examined by means of must-criteria set up in the definition phase and a cost-benefit-analysis. Examples for must-criteria are legal regulations (e.g. EASA and FAA certification rules), financial targets and customer criteria.[93] Direct project costs and direct project benefits linked to the improvement measure are evaluated in a cost-benefit-analysis. It is useful to be conservative when estimating and to work with a fluctuation margin for costs and benefits in order to minimise the misjudgement risks.[94] The results of this analysis have to be presented to the project leader or the executive management. It is thereby very important to highlight the “quick wins”, which are improvement methods with low implementation costs and durations as well as significant improvement potential. For all other initiatives retained after the presentation a detailed roll-out plan has to be created in order to structure the implementation of these measures.[95]

6.4.5. Control

The aim of the final phase of a DMAIC project is the examination, whether the implemented measures have realised the announced improvement objectives.[96] The main tasks of the control phase are therefore:

- Determination of the new process capability
- Implementation control measures[97]
- Focus on the quantum gain in process knowledge

The created process with all implemented improvement measures up and running has to be stabilised and evaluated against the originally set objective.[98] It is very important to focus on the quantum gain in process knowledge described above. Even if the improvement measures might not have the impact they were originally designed for, the six sigma project can be considered positive if there is a clear gain in process knowledge. For every new sub-process implemented a database monitoring system should be put into place in order to document the process development and the

[93] Grewatsch and Uremovic, in Koch, 2015, p. 184
[94] Magnusson in Koch, 2015 p.184
[95] Koch, 2015, p. 184
[96] Schmelzer and Sesselmann in Koch, 2015, p.184
[97] De Mast et al. 2012, p.605
[98] Töpfer in Koch, 2015, p. 185

process performance.[99] If the process has at least partially attained the desired improvement it is advisable to search further improvement with lean production (lean management) and continuous improvement projects. These process management approaches can help to stabilise the process on a very high level. The reference for the objective process level should be the best operating organisation operating in the same sector.[100]

6.5. DMADV

If the process that calls for improvement is not controllable and has experienced ground-breaking problems an even deeper improvement project than the DMAIC approach is needed. The DMADV method, which is also known as ”design for six sigma” (DFSS) or PIDOV (Plan Identify Design Optimize Validate), is used to develop new products and processes. In comparison to the above DMAIC method a project following DMADV replaces the improvement and control phases with a design and validation phase. The scope of such a project is a complete renewal of the process and the duration can be of up to 9 months.[101] One of the major aim of a DMADV project is to achieve a better controllable and more structured process in order to be able to apply DMAIC project and continuous improvement measures more easily. In terms of tools used in this type of project the focus lies a lot more on risk prevention since the significant change for the organisation yields a high potential for implementation difficulties. The QFD and FMEA tools used only to assess improvement measures in a DMAIC project are much more important and indispensable in a process redesign project. The validation phase of the DMADV calls for a very well structured implementation plan with a pilot phase, control tools and control milestones with detailed evaluation and predefined points in time after the launch of the project.[102]

6.6. Limitations to Six Sigma

Even if Six Sigma is used all over the world in many different industrial sectors its projects do not always show the originally intended results. In fact some sectors complain that more than half of all six sigma projects are time consuming and do not bring positive effects on productivity and customer satisfaction. “A survey of aerospace companies for example concluded that less than 50% of the respondents were

[99] Koch, 2015, p. 184
[100] Töpfer in Koch, 2015, p. 186
[101] Koch, 2015, p. 172
[102] Koch, 2015, p. 188

satisfied with their six sigma programs"[103]. The next paragraphs describe some of the limitations the six sigma methods usually show.

The mathematical definition of six sigma contains the reduction of process fluctuation and process variance. While this might be a constructive idea in stable environments with well-defined long term customers it is "not very effective in dynamic environments, where the rate of technological change is dramatic"[104]. If the organisation is operating in a variant and dynamic market the stabilisation of processes might not be the right approach for general productivity improvement. While "Six Sigma only enhances innovation for stable, existing customers, and improves their satisfaction level, […] it has a moderate effect on innovation for new customers or on firm performance in an unstable environment"[105].

As second limitation, it has been observed that six sigma is very often implemented as a process and product improvement process. While it addresses the existing processes very well it "moderates the output of radical innovation"[106] The firm that places all its development funds on six sigma improvement projects might miss the leap towards new technologies and new process tendencies. Some sources even go as far as stating that "radical and sustainable process improvement cannot be achieved from Six Sigma projects due to their lack of attention to behavioral and change processes"[107].

Six Sigma has initially been defined as a project in order to improve quality and customer satisfaction. Unfortunately it can be observed regularly that cost reducing measures are rather implemented, than the measures improving customer satisfaction. "In reality, a majority of the improvement projects are selected based on cost minimization and, therefore, the approach becomes suboptimal"[108]. The two goals mentioned in the definitions of the six sigma chapter are:

- quantum gain in process knowledge
- ease of control of the improved process

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[103] Zimmermann and Weiss in Chakravorty, 2009, p.2
[104] Parast, 2011, p.45
[105] Parast, 2011, p.45
[106] Parast, 2011, p.52
[107] Parast, 2011, p.52
[108] Bendell in Chakravorty, 2009, p.8

Those goals are not addressed in a large majority of cases.[109] While the amount of savings generated can't be used to judge the quality of the six sigma project the initial quality and customer satisfaction objectives become less and less important.[110]

Another reason why many six sigma projects fail is because the implementation model (e.g. DMAIC) detailing the sequence of steps and phases to follow is too general. Since every industry needs an individual approach six sigma project leaders often have difficulties to guide the project which then becomes long and costly to the firm. “This generality limits the methodological support it provides, and fails to exploit task-domain specific knowledge. Domain-specific adaptations of the method partly overcome these weaknesses”[111].

The last limitation is the ambiguous and subjective nature of problems six sigma has to deal with. “DMAIC forces project leaders to capture problems in terms of facts and measurable variables”[112]. While “DMAIC is applicable to empirical problems ranging from well-structured to semi-structured problems, it is not applicable to ill-structured problems or pluralistic messes of subjective problems”[113]. Examples for such subjective problems are general motivational problems or social problems within the organisation's staff.

[109] Mandal, 2012, p.232
[110] Mandal, 2012, p.233
[111] De Mast et al. 2012, p.604
[112] De Mast et al. 2012, pp. 608-609
[113] De Mast et al. 2012, p.613

7. Tools

The implementation of a six sigma project calls for many data analysis tools. All of them are listed in the six sigma tool box shown in the previous chapter. A few of them are described more closely since they have been of great use in the project described in the second part of this report.

7.1. Interview

Interviews are an information and opinion gathering tool that helps to gain process knowledge through the operator's point of view. They help to understand backgrounds and historic changes as well as personal decisions during process execution. The starting point to every constructive and informative interview is a clear interview outline in which the key questions are put on record.[114] All interviews should be conducted in a calm and undisturbed environment.

There are three main forms of interviews: by telephone, head to head and paper based with a questionnaire. Both telephonic and head to head interviews create room for emotional answers of the interviewed person. Meanwhile telephonic interviews make it difficult to judge answers since mimics cannot be seen over the telephone. Nevertheless telephone interviews do make the questioned person feel safer and more comfortable sometimes due to the physical distance that is kept while interviewing. Paper based questionnaires are easier and quicker to deal with and represent a good tool for quick surveys.

When creating the questionnaire it is very important to focus on the informative goals of the interview. If the definition of the questions is too vague the interview itself might derive from the topic, become time-consuming and bring forth a lot of useless information. The creation of the questionnaire is not a one-stop process but a long iterative process which can be subject to adjustments between interviews.[115] The questionnaire should contain open and direct questions.[116] Open questions leave room for opinions and interpretations from the person asked. Direct questions aim for very specific information that is crucial to the person conducting the survey. Sources suggest that the minimum number of 15 interviews or responses from 10% of all questioned people are necessary in order to be able to achieve a relevant statistical evaluation of the interview.[117]

[114] Becker, 2005, p.109
[115] Becker, 2005, p.110
[116] Becker, 2005, p.111
[117] Becker, 2005, p.112

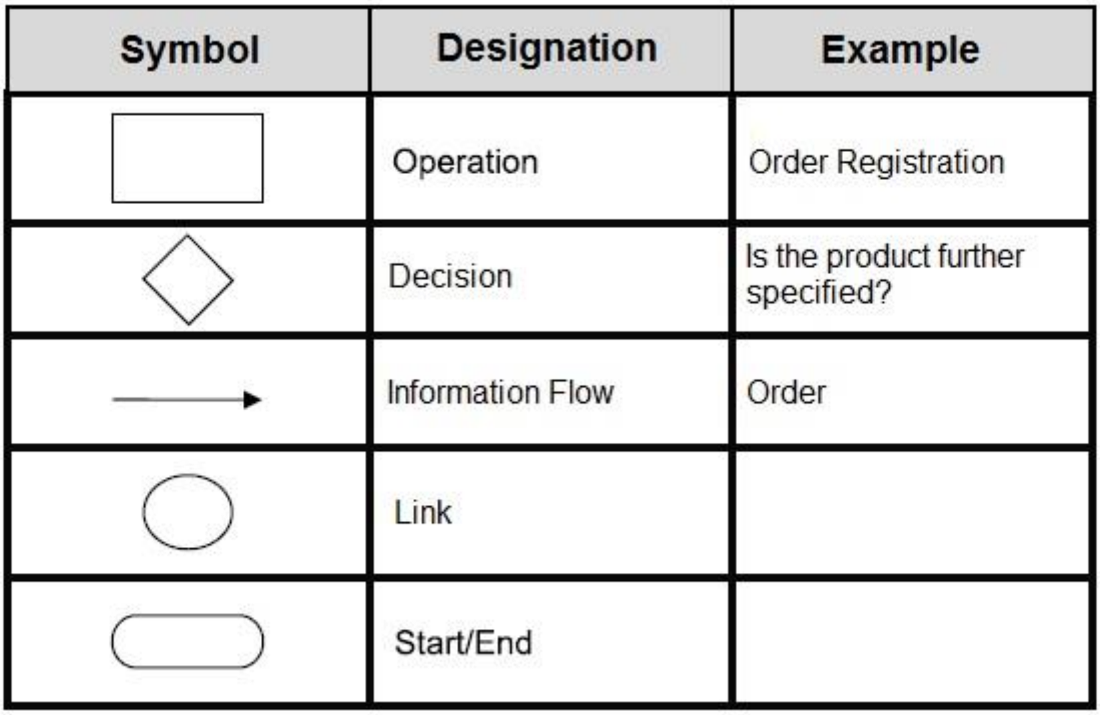
The evaluation of answers after the interview is often neglected but in fact just as important as the interview itself. During the evaluation, the questionnaire can be adapted and complex answers can be put into relation and interpreted in more detail than during the interview itself. If answers remain unclear after the evaluation further enquiry can be conducted with the interviewed person or by adding questions to the questionnaire for future interviews.

For customer interviews the voice of the customer (VoC) method is often used to determine the customer requirements, and to analyse possible discrepancies with the customer image present in the company. VoC consists of four very similar steps to the procedure on how to conduct interviews. Before the interview a questionnaire is created and the order of questions organized in order to create a constructive discussion. After the interview it is post-processed in order to find results or make changes to improve future interviews.

7.2. Flow Chart

Flow charts are a representation form for organisational processes. They are designed to clarify and display simple and easy value creating processes with no more than two process participants. Processes with more participants have a tendency to become confusing and unclear when displayed in a simple flow chart.[118] In order to create flow charts for the value creation process in an organisation the main process needs to be divided into sub-processes. Every process has an input value, a logical information or material flow and an output value. For example, the interaction of any staff member during the value creation process can be used as a sub-process and represented with a flow chart. The flow chart is built out of 4 important symbols that are connected by arrows representing an information flow as shown in figure 9 below.

[118] Becker, 2005, p.128



Symbol	Designation	Example
	Operation	Order Registration
	Decision	Is the product further specified?
	Information Flow	Order
	Link	
	Start/End	

Figure 9: Flowchart Symbols[119]

Every tasks is represented by a square. The different tasks are linked to each other with information flow arrows. If the information is relevant to another sub-process it is linked to a circle which stands for the interface and the knowledge transfer to another process. It is recommended to create flow chats with a minimum of interfaces. Too many circles can make the process unclear and confusing.[120] The diamond shaped symbol represents a decision and splits up the flow chart into various possible paths.

Flow charts are useful for analysis and optimisation of small sub-processes in organisations. Creating a general overview and therefore a better level of process understanding through the limitation to simple tasks is one of the main strengths of the flow chart. The flow chart loses these strengths if the process chosen is too complex and has many parallel running tasks.

[119] Becker, 2005, p.127
[120] Becker, 2005, o.128

7.3. Process Flow Diagram

In order to describe more complex processes with more than two participants the flow chart has been expanded to the process flow diagram. Just like the flow chart it is easy to understand and quickly to create. Compared to the flow chart it has the advantage of not only showing the logic succession of tasks but also their chronological sequence in accordance with the different participants of the process.[121] The process flow diagram allows a representation of more complex processes that run simultaneously with different participants actively working on the process.

The process flow diagram displays the role allocation in an organisational process and shows unnecessary sub tasks performed twice by two distinctive participants. Process flow diagrams still need to be restricted to a maximum number of departments participating in the value creation. Adding more participants can turn the chart unclear and confusing. When optimizing processes the process flow diagram often shows improvement possibilities through change within the organisational structure of the firm.[122]

7.4. Pareto chart

The Pareto analysis chart is a bar chart, named after the Italian economist Vilfredo Pareto, used as a quality management tool for failure analysis. It underlies the Pareto principle that states that most problems (e.g. 80%) can be traced back to a small number of reasons (e.g. 20%). The bar charts displays the reasons downward from the most relevant to the least relevant. A cumulative curve helps to identify all reasons that lead to a set number (often 80%) of problems.

The creation of a Pareto chart starts with the selection of a data source (e.g. number of faulty parts that need to be replaced). This data is divided into categories (e.g. parts categories such as seals, bushings, rivets, structural elements etc.). The occurrence of every category is represented through the sum of its appearances in the set data range. The categories are then displayed as percentages of the total in a bar chart with decreasing values, starting with the highest (e.g. the part categories with the most occurrences) from left to right. In order to add an additional dimension to the chart the different categories can be weighed with another variable (e.g. cost per part in a category). The Pareto curve is the cumulative percentage of all categories that rises from 0 to 100% from left to right.

[121] Becker, 2005, p.129
[122] Becker, 2005, p.128

Pareto analyses are often used to grade data into categories (A-B-C Parts), pointing out the data with the highest impact on a customer requirements (e.g. identification of parts that generate the highest cost or biggest delay in TAT).

7.5. Histogram

A histogram is a graphical visualisation of the frequency (occurrence) distribution of a certain scaled event. It is represented as a bar chart in which every bar represents the occurrence and the probability density of the event occurring in the specific value range (class).

A histogram is created in four main steps:

1. Division of the expected value range in classes. The classes do not necessarily need to be the same size but for better visualisation it is advisable to keep the class sizes roughly the same. Every class later receives a bar that is proportional to the number of occurrences in this specific class range.
2. Every class can reflect a relative or an absolute value. The absolute value of a class is its simple count of occurrences n_j during the sampling process. The relative value is the percentage value of the number of occurrences compared to the total number of samples drawn.
3. Calculation of the probability density of each bar. Since the class occurrence represents the area of the bar, the height of each bar is the quotient of the occurrence n_j and the width of the class d_j.
4. Graphical representation of the analysis and approximation through an adapted distribution if necessary.

7.6. QFD

Quality Function Deployment is a literal translation of the Japanese words *hinshitsu kino tenkai* […] although the word *tenkai* can also be translated as “evolution” instead of deployment. Mizuno narrowly defined QFD as a “step-by-step deployment of a job function or operation that embodies quality, into their details through systematization of targets and means”[123]. It has first been defined by Yoji Akao in 1972 by merging aspects of different quality related processes emerged in the Japanese industry in the early 1970s. It emerged from the Bridgestone Tire Corp. and Mitsubishi Heavy Industries ship building yards.

[123] Akao et al., 2003, p.22

QFD is a teamwork based method that supports systematic and integrated product and quality planning. It is customer requirement oriented and aims to integrate these requirements into all product planning phases rather than the perception of the development engineers who would focus on the best technically feasible product. Dr Kaoru Ishikawa insisted on the importance of having every employee, and not only top management and engineers, take part in the quality control process.[124] The originator himself, Yoji Akao, states that “its purpose is to assure that true customer needs are properly deployed throughout the design, build and delivery of a new product […] and to improve the product development process itself”[125]. The main objective of QFD is to develop economical optimized products and processes which excel through optimal serviceability. In other words it aims for competitive products and processes.[126] Being first implemented in Japan, QFD is still conquering industry sectors in Europe. While Germany and Austria are at the forefront of QFD dissemination in Europe, France has only few reported QFD activities.[127] The implementation of QFD through a method called the “House of Quality” is the most common methodology used today. It is however very important to add that the house-of-quality is only the methodological guideline and documentation of the method and its simple application isn’t enough to successfully run a QFD process.[128]

The original QFD analysis was created in order to point out complex connections between requirements and functions when developing products or processes. In this specific case only a part of the QFD method was extracted in order to correlate the impact of the measures with the customer requirements. The QFD model following the House of Quality (HoQ) method by Yoji Akao (see chapter 14.2) has been used for this analysis. Its implementation served as a decision aid to delimit the measures are most likely to respond to the set customer requirements.

The QFD analysis following Yoji Akao’s model contains the following steps:

1. Customer group (internal – external)
2. Definition of customer requirements
3. Weighting of customer requirements
4. Competitor analysis (skipped)
5. Technical requirements (listing of improvement measures)

[124] Akao, Mazur, 2003, p.21
[125] Akao, Mazur, 2003, p.20
[126] Brüggemann, Bremer, 2015 p.31
[127] Akao, Mazur, 2003, p.29
[128] Brüggemann, Bremer, 2015, p.31

6. Cross table analysis of the correlation between customer requirements and improvement measures
7. Evaluation of the improvement measures
8. Correlation and conflicts between improvement measures

These steps complete the following matrix commonly known as the “House of Quality”. Although this analysis is not a classical product improvement QFD, all steps of the process have been applied to the underlying case study described in part II of this report.

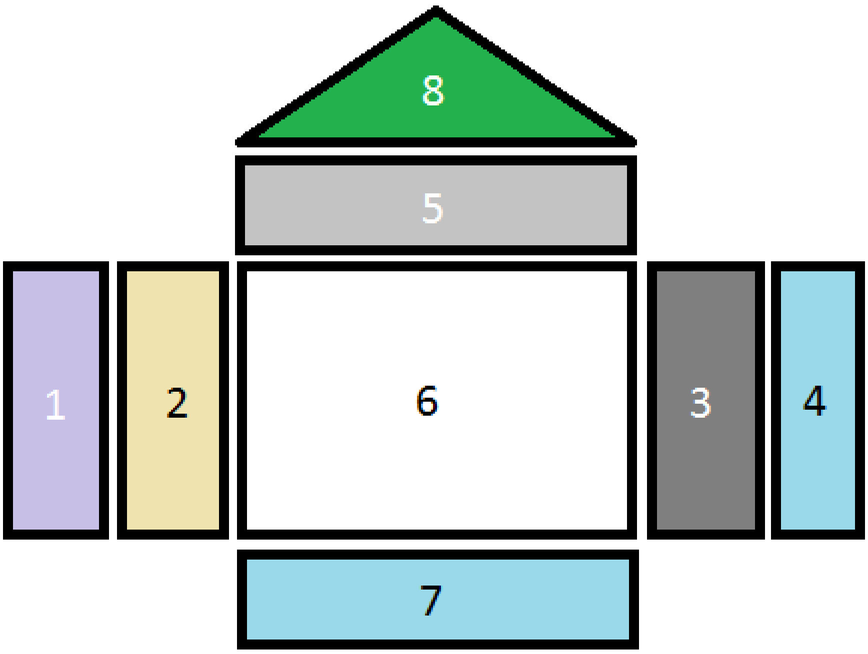


Figure 10: House of Quality General Structure

Even though most companies around the world use QFD solely as a product development tool the originator, Yoji Akao, points out that “the use of the word function in QFD is generally misinterpreted. It refers to a function analysis of the business process phases in order to improve the quality of the product development process itself. It doesn’t however refer to a product function in this context”[129]. He states that it is “regrettable that this part of QFD which is essential to gaining long-term buy-in, implementation and compliance, has been completely overlooked by most QFD practitioners outside Japan”[130].

[129] Akao, Mazur, 2003, p.25
[130] Akao, Mazur, 2003, p.25

7.7. FMEA

The FMEA (failure mode and effects analysis, DIN EN 60182) is a standardized, analytical early failure mode detection tool. It is designed to detect all potential failures during design, construction design and production of a new product.[131] The main aim of a FMEA is the prevention of failures at the earliest possible time during the product or process development.[132] As shown in figure 11 an FMEA can be time consuming in early phases of the product development and therefore often earns sceptical for being too time consuming.[133] The FMEA almost always proves its critics wrong, mainly due to the late but significant payoff of the FMEA during roll-out and mass-production phases were a carefully planned FMEA can reduce rework and corrective tasks.

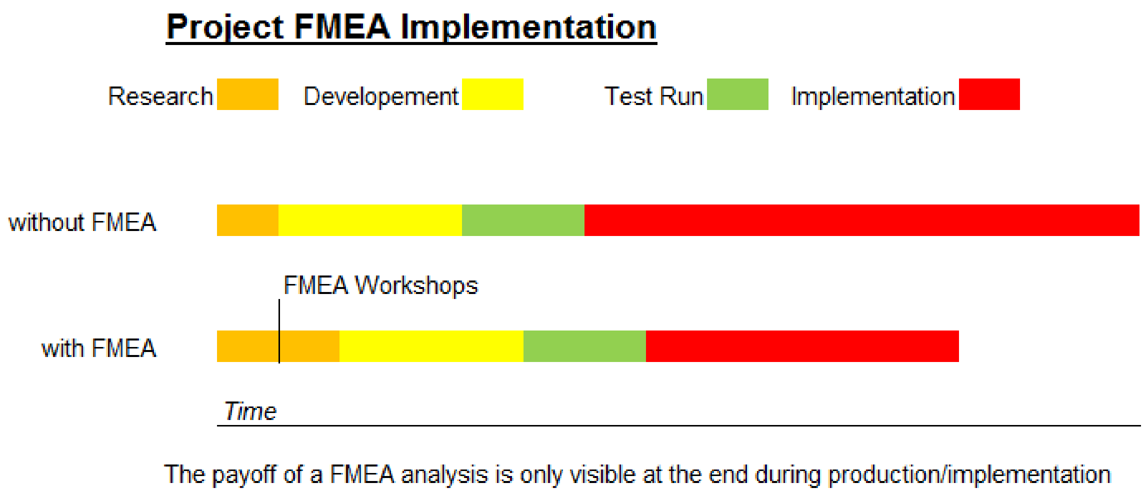


Figure 11: FMEA time investment payoff

An FMEA analysis begins by stating the function of the process that needs to be evaluated. Keeping in mind the aim of the project or the superordinate function that the process needs to fulfil, a list of possible failures and problems can be determined. Every one of these failures is evaluated and graded in order to give answers to the following questions:

- What is the reason of the failure or why did this type of failure occur?

Once the reason is known, an indicating number from 1 to 10 is attributed to the probability (P) of the failure in order to quantify it. The number ranges from 1 if the

[131] Brüggemann, Bremer, 2015, p.44
[132] Brüggemann, Bremer, 2015, p.45
[133] Dale et al. In Brüggemann, Bremer, 2015, p.51

failure is very unlikely to occur to 10 if the failure mode is to take place with almost certainty.

- What are the direct effects of the failure?

Another number is attributed to quantify the severity (S) of the failure. Failures with effects that do not have a serious impact on quality would be attributed a low number (again from ranging from 1-10) whilst failures with negative effects on customer satisfaction would be rated closer to 10 and failures that would have a direct impact on human lives would be rated with a 10.

- Is the failure likely to go undetected? (D)

If the failure is very likely to be detected by another person of the staff along the process or by a routine check of quality control, it would be given a low rating between 1 and 4. If however the failure is likely to go unnoticed it would be given a higher rating up to 10.

In addition to the numerical evaluation of the failure it is very important to give a verbal description of the probability, severity and detection risk. In order to get a valuable assessment of the failure mode potential the three numbers are multiplied (P*S*D=RPN) and form the risk priority number (RPN). The working group should then determine a maximum RPN that mustn't be exceeded. Every failure mode that shows a RPN over and above the maximum allowable limit has to be treated with improvement measures. In a complete FMEA this kind of decision should be handled with the utmost care since the RPN "neither evolves along a linear axis, nor is capable of showing different risk types"[134]. A P-S-D configuration of 2-10-3 for example hasn't a critically high RPN but a critical safety issue in the severity column and not a 100% discovery probability. It is therefore a critical safety issue even if its RPN does not exceed the critical limit chosen. Additionally all failure modes showing 8 or above in the severity (S) rating have to be handled with special care.

In the last step every measure that exceeds the maximum RPN set by the working group and/or have a rating of 8 and above in the severity (S) column will be given specific improvement measures.

An exemplary FMEA can be found in chapter 14 and appendix D.

The objective of the FMEA is to detect potential critical failures and errors early during the development and planning of new products and processes and to consequently avoid the source of the failure[135]. The same source also indicates that another aim of

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[134] Werdich, 2012, p. 52
[135] VDI – Gesellschaft Produkt- und Prozessgestaltung, 2011, p. 89

the analysis is to raise customer satisfaction[136]. Even due to supplement development times a correctly executed and up to date FMEA almost always pays off on the long run.

[136] VDI, 2011, p.91

8. Conclusion and Transition

The purpose of the first part of this literature review is to describe the setting and the background of the study developed in the second part and to introduce the reader to the tools used for this study. It introduces the aircraft maintenance organisation and presents the basic rules and laws every one of these organisations has to comply with. Even if management had been given the freedom to do so, the study developed in part II does not suggest a reorganisation of the maintenance organisation's structure, and does not cross the lines of maintenance certification.

The second part of the literature review describes some basic principles of lean production, six sigma, process improvement and some of its most important tools. In this study a DMAIC process has been applied to the maintenance process of an overhaul shop in order to find a wide range of improvement vectors. Additionally some basic ideas and principles of the lean production and process improvement strategies have been integrated in order to support the problem solving capability of the DMAIC cycle. Some deviations from the classical DMAIC cycle had to be made during the improve and control phases due to organisational problems of the improvement process and the lack of support from the executive management of the maintenance facility.

Within the DMAIC project, a set of tools from the six sigma toolbox have been used. While some tools like the Pareto analysis and the Histogram were implemented in the conventional way, others like QFD and FMEA where not used to their full extent and only partially implemented. Usually described as risk prevention and quality assuring product development tools only single aspects of QFD and FMEA have been implemented. QFD has been used to compare improvement measures rather than product features for their fulfilment of customer requirements. The literature study however has shown that the project improvement aspect of QFD was initially intended by its originator Yoji Akao and is according to him often neglected in product development projects. The FMEA on the other hand has been implemented to see the potential threats and their severity of every possible improvement measure. It has been implemented as an evaluation tool towards the end of the improvement process rather than a preventive product and process improvement tool at the start of the process.

At last, the six month timeframe given was not enough to successfully walk through all stages of the DMAIC cycle. Especially the control phase has been too short to fulfil its initial purpose. Therefore the improvement of the CTQ measures defined in the measure phase remain unknown and can only be estimated. The project and with it a detailed roll out plan for improvement measures and a new control phase has been handed to a following project taskforce in order to assure continued and sustainable improvement.

Part II – Improvement Project

9. Project Charter

9.1. Company Presentation

9.1.1. Air France Industries

Air France Industries (AFI) builds its experience in aircraft maintenance repair and overhaul (MRO) on a long history. Being a historic European airline, Air France has started its maintenance activity in 1952 and since then overhauled almost every medium and long-haul airliner in its shops. Decades of servicing and repairing its own fleet and a wide range of customer aircraft Air France Industries has grown to be a worldwide recognized maintenance, repair and overhaul organisation recognized for its outstanding technical expertise. In 1992 Air France merged with the French airline UTA, taking over its fleet and, most important, its MRO activity including the structural repair shop in Le Bourget. Even though being a rather small airline, UTA had a significant MRO market share and used to provide maintenance services to a large group of international airline customers. After the merger the performance of the former UTA maintenance shops significantly dropped resulting in a loss of many customers across the past two decades. Today, after several restructuring initiatives, most of the former structures and practices are gone. The performance of the shops however never achieved the high level it had in the late 80s or early 90s.

In 2002 Air France went public on the Paris Stock Exchange and by 2003 the French government sold the last shares giving up the last intentions of governing the historically state owned company. The privatization of the carrier had a great impact on the organisational structure and its former state-owned culture can still be seen today.

The last milestone of the company was the merger with the Dutch national carrier KLM in 2005. During the merger of these two major European Air Transport companies the Dutch MRO section KLM Engineering and Maintenance was partially integrated into Air France Industries. For the purpose of customer management the maintenance of KLM equipment has a special status and causes complicated negotiations due to the lack of clear maintenance policy established between the two companies.

9.1.2. The Aérostructures Maintenance Shop

The "Aérostructures" activity provides maintenance repair and overhaul services for flight control panels, radomes, structural on wing repairs and engine housing components. While teams are present on all line and base maintenance stations of AFI, the main activity consists of providing shop repair and overhaul services at three sites in around Paris: Two smaller sites in Roissy (Charles de Gaulle Airport) and Orly and the main site in Le Bourget. The activity in Le Bourget is concentrated on the repair and overhaul of engine nacelle components such as inlet cowls, fan cowl doors and fan thrust reversers. Being spread out over three different sites and facilities AFI has recently decided to move all activities together to a newly built maintenance shop in Roissy. The main aim of the new facility is to simplify operations and increase productivity. The new plant will be located next to all major AFI maintenance hangars at Charles de Gaulle Airport and is designed to cope with the growing MRO market. It will also host the repair and overhaul of several new products, such as the twin engine wide body jet nacelles which slowly replace the four engine jets on the international market. Today such nacelles (mainly GE90 nacelles for Boeing 777) are repaired by subcontractors since their transport by heavy duty transport is expensive and the facility in Le Bourget is not equipped to receive equipment of this size.

Being the most complex equipment treated in Le Bourget, this report focuses on the overhaul of fan thrust reversers. Air France Industries currently provides maintenance services for the following thrust reversers (designated by engine type):

- CFM56-5A (Airbus A320 Family)
- CFM56-5B (Airbus A320 Family)
- CFM56-5C (Airbus A340)
- CFM56-7B (Boeing 737)
- CF6-80C2A (Airbus Beluga Transporter)
- CF6-80C2B (Boeing 747-400 and Boeing 767)
- CF6-80E1 (Airbus A330)
- GE90 (Boeing 777-200 and -300)
- V2500 (Airbus A321)

The following products are currently being integrated in the portfolio:

- GP7200 (Airbus A380)
- RR Trent 1000 (Boeing 787-8)
- GEnx (Boeing 787-8 and -9)
- Trent XWB (Airbus A350)

In this report, mostly CF6-80 FTRs were examined. This type of equipment was chosen on the one hand due to the great technical expertise that exists among AFI personnel on -C2B (B747) FTRs and the great number of -E1 (A330) FTRs that are currently flying and frequently overhauled at the AFI structures shop.

9.2. The Product: CF6-80 Series Fan Thrust Reverser

The fan thrust reverser is a device that diverts the cold air flow of a turbofan engine in order to prevent it from creating forward thrust. It is used as deceleration device upon landing in order to prevent wear on brakes and tires through excessive braking at high touch down speeds. There are two general principles of thrust reverse systems:

- Pivoting doors that open on four sides of the nacelle upon landing
- Translating cowl which travels back and forces blocker doors to stop the air flow

The translating cowl FTR is mounted onto the CF6-80 series turbofan and is therefore described more closely.

Figure 12: Air France Airbus A330 with deployed CF6-80E1 Fan Thrust Reversers

Every engine with a translating cowl system has two thrust reverser halves mounted on each side of the engine pylon which attaches the engine to the wing. Whenever technical documentation speaks of the left-handed (LH) or right-handed (RH) side of a thrust reverser the forward looking view of the pilot is being considered. The translating cowl fan thrust reverser is a duct and nozzle to the cold air flow of the fan which creates up to 85% of the CF6-80 forward thrust.

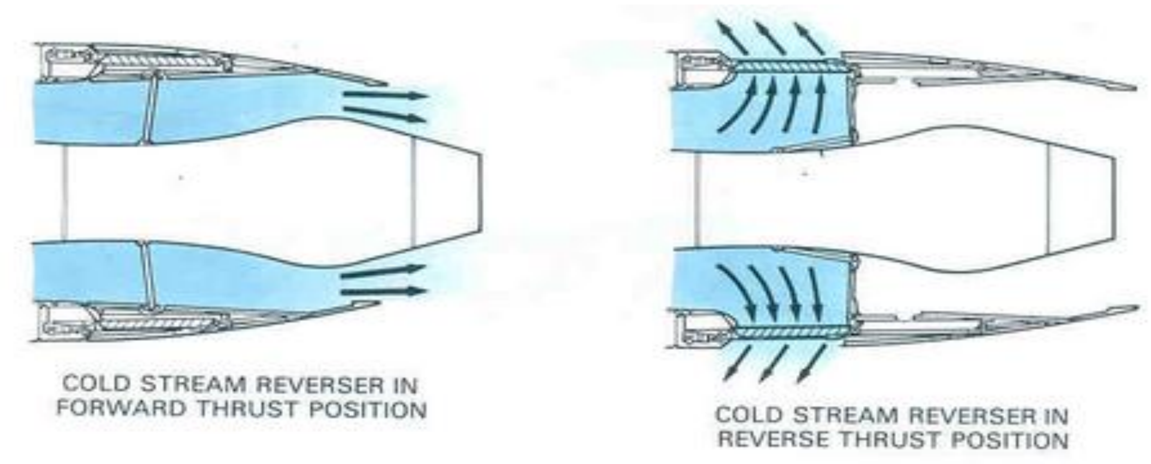

Figure 13: Air Flow through thrust reverser system[137]

When activated by the pilot upon touchdown the outer cowl moves backwards and pulls the hinged blocker doors into position. The Blocker Doors divert the fan air flow outboard and forward through vaned deflectors. These deflectors are only exposed when the outer cowl is moved backwards (deployed). The two fan reverser halves are hinged to the engine pylon at the top, clamped to the engine fan frame at the front and latched together at the bottom split line. The translating cowl is moved pneumatically and is driven by ball screw actuators.

The translating cowl thrust reverser consists of three main parts. The first is called the inner cowl or fixed structure and consists of the core cowl which is attached to the two sidewalls, the beams (hinge beam and latch beam) and the torque box. The torque box is the forward ring that is clamped onto the fan frame and thus part of the outer cowl of the nacelle. It is a support to most of the so called accessories of the thrust reverser. The latch and hinge beam attach the thrust reverser to each other at the bottom (latches) and the engine pylon at the top (hinges). The upper and lower sidewalls hold the core cowl in place which houses the combustion chamber of the engine. The inner core cowl side is thus exposed to very high temperatures. The second vital subassembly of the FTR is the translating cowl (TC). The TC provides the outer nacelle surface and the outer fan flow path. It covers the vaned deflectors in the stowed position and contains housings for the six blocker doors that are attached to it. Together, they form the third major part of the thrust reverser. The blocker doors are hinged to the translating cowl at the forward end and are attached by links to the fixed

[137] https://engineering.purdue.edu/~propulsi/propulsion/images/jets/basics/Frevers1.jpg [07/09/2015]

structure. When the translating cowl moves backwards, the blocker doors are pushed into the air flow of the fan and divert it outboard. The inner surface of the translating cowl, core cowl and blocker doors is made out of acoustically treated composite structure that swallows some of the engine noise. The blocker doors are spring loaded and thereby pushed down in stowed position in order to keep them from fluttering in the fan air flow.

For general functional understanding it is necessary to point out some accessories of the CF6-80 series thrust reverser:

- While performing on-wing repairs the **Hydraulic Power Door Opening Device** allows the mechanic, by connecting a hydraulic line, to lift and lower the FTR door. Lifting and lowering the door allows the mechanic to obtain access to the rear engine assembly and to perform a visual inspection of the core cowl inner surface.

- The **Hold Open Rod** is positioned by the mechanic in order to secure the FTR from closing when it is opened on wing.

- The **Forward Latch** clamps the FTR to the engine fan frame and is activated and secured by a latch handle at the bottom of the FTR halves.

- The **electromechanical (electro-magnetic) disk brake** stows the thrust reverser by using electromagnetic force by applying a mechanical force (friction).

- When the thrust reverser pressuring valve (TRPV) is energized by pushing the thrust lever in the cockpit forward it sends pressurized air through to the **Directional Pilot Valve or DPV** which is located at the 10 o'clock[138] position (looking FWD) of the LH FTR. When pressurized it sets the directional valves in the **centre drive unit or CDU** into deploy position. This mechanism causes the actuators to turn and deploy the translating cowl. Once fully deployed, position switches sends back a signal that terminates the electric current to the TRPV and stop the air supply to the CDU.

- The **Centre Drive Unit** is located at the 3 and 9 o'clock position and provides rotational torque to deploy and stow the translating cowl. They are assisted by the **gearboxes** and **ballscrew actuators** to drive the translating cowl backwards and forward. The gearboxes and actuators are located at the 2 and 10 o' clock positions and at 4 and 8 o'clock positions.

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[138] Clockwise description of equipment locations is always done facing forward looking in the direction of flight.

- **Cowl Guides** and Teflon coated **tee track rails** guide the translating cowl backwards. They are a typical wear and tear item that needs to be replaced at every shop visit.

The CF6-80 series thrust reverser is mainly manufactured in the United States. While UTC-Goodrich (UTAS) is the overall manufacturer of the nacelle, the manufacturer for the fan thrust reverser is Middle River Aircraft Systems (MRAS). MRAS is in charge of the assembly of the main components except for the translating cowl which is manufactured and assembled by one of two US companies: formerly provided by the Martin Marietta Corporation the job has been taken over by the Grumman Aircraft Engineering Corporation after Martin Marietta declared bankruptcy and was taken over by Lockheed Martin in 1995. Today almost all thrust reversers who come to the maintenance shop are mounted with Grumman translating cowls. The entire nacelle is manufactured in accordance with General Electric Aviation which is the engine manufacturer for the CF6-80 series mounted on either Boeing 747 and 767 (CF6-80C2) or Airbus A330 (CF6-80E1) aircraft.

9.3. The Customer

9.3.1. Definition of the Customers

Customers of AFI Aérostructures are mostly airlines and aircraft component brokerage firms. Both airlines and brokers can be either in a long term agreement on the overhaul of their entire fleet or ask for a one-shot action on one of their components. Long term agreements include the entire engineering processes for some airlines. In that case Air France Industries services can go as far as providing a maintenance policy to the airline that is submitted to the EASA for airline certification. Some contracts give the customer access to the AF spare parts pool, others are on “close loop” contracts. This implies that the element must be equipped with the exact same sub components (identical serial numbers) when leaving the shop.

In the case of a taxiway incident to an airframe element at Paris Charles de Gaulle airport, AFI is generally chosen as MRO for the immediate repair process due to the proximity of their shop. Since AFI also leases parts to airlines and aircraft brokers some elements come to the shop after lease return in order to be recertified with the Air France standard. This reintegration into the AF pool is also be considered as a customer maintenance process. The maintenance task necessary upon lease return are billed to the last lessee of the element.

9.3.2. Customer Requirements

The next step of the project charter is the identification of the crucial customer requirements. Therefore a critical to quality analysis (CTQ) has been performed. In order to obtain improvement objectives and critical customer requirements all general requirements were listed. For every general requirement specifications that are critical for its achievement are defined. These specific requirement are so-called critical to quality indexes. As a next step a measure is implemented for every critical to quality requirement. These measures are often considered as key performance indicators (KPI) and should be tracked throughout the organisations activity. Ideally the success of the six sigma project can be determined by looking at the improvement of these KPIs. Figure 23 shows the CTQ tree analysis for the AFI airframe maintenance shop.

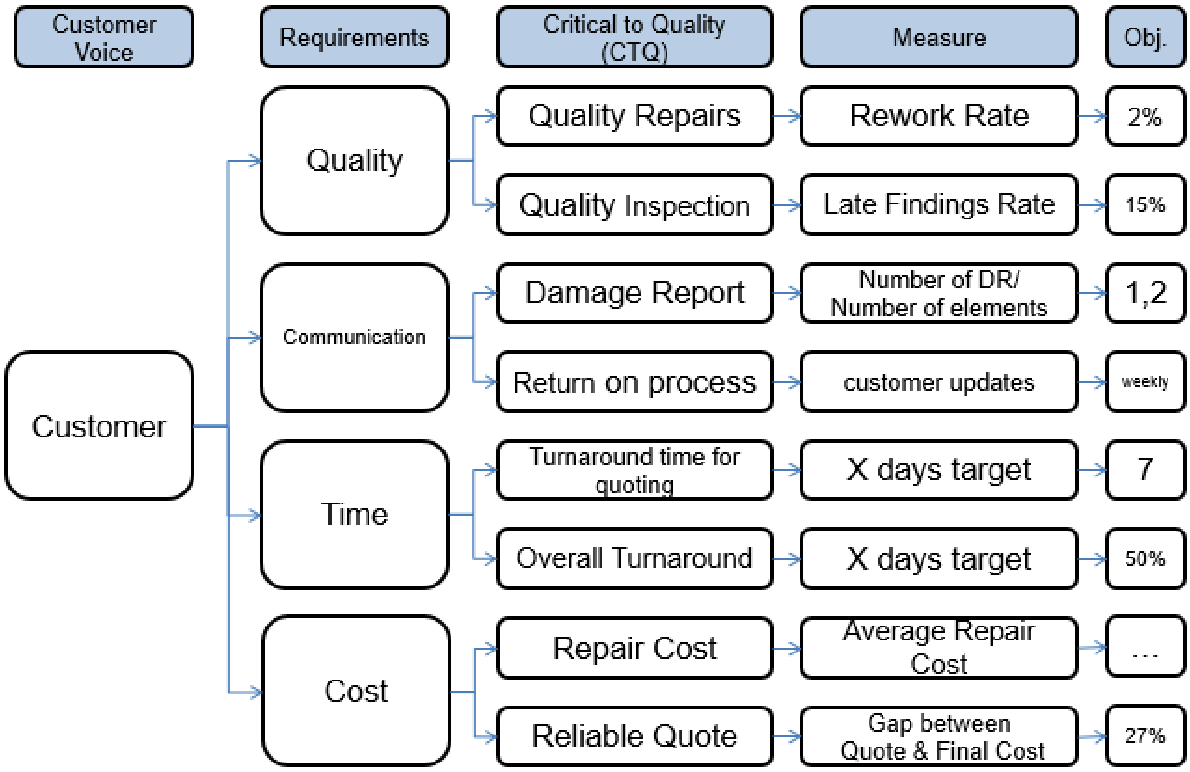


Figure 14: CTQ Analysis

The six general customer requirements are:

1) Turnaround Time

On the one hand the turnaround time for the entire maintenance process but also the turnaround for the inspection and quoting process

2) Reliability

Reliability compared to the promises and expectations declared by AFI. This contains the reliability of the quote compared to the final cost on the hand and the reliability of the workload and turnaround time defined at the beginning of the process.

3) Cost

Customer want the best maintenance for the lowest price. It is the task of AFI to work as efficient as possible in order to be able to suggest a competitive market price to its customers.

4) Expertise

Customers come to AFI for decades of experience in the maintenance of airframe components and a worldwide reknown technical expertise

5) Documentation Quality

Treating every subsequent process owner as an “internal” customer helps to hold up the quality of the entiry process. Poor documentation at process interfaces can cause excessive turnaround time through corrections and rework.

6) Process Monitoring

Keeping a structured oversight of the process at any given time is essential for a good analysis and the process knowledge that help to continiously improve the process in the future.

These six key requirements appear many times along this DMAIC project. Even though they might be named differently here and then everything comes down to the key requirements mentioned above. The measure phase (chapter 11) picks up these requirements and suggest ways to measure the current achievement. It also defines an improvement objective against which the DMAIC project is later evaluated.

9.4. Core Question and Aims of this Project

In the context of the relocation to Roissy the AFI structures shop management has declared an ambitious objective for improved turnaround time for the overhaul process of fan thrust reversers in its maintenance shop. In order to achieve this overall target, every sub step of the maintenance process has been given its own objective. At first the scope of the improvement project was to reduce the turnaround time for inspections, defect analysis and a repair proposal by at least 50% down to 7 days. At the end of this 7 day period, a damage report and reliable quote are sent to customer support management, who communicates the information to the customer. Based on the condition of the equipment and the suggested repair cost, the customer approves or denies the actions suggested by customer support management. Alongside with the reduction of turnaround time the reliability of this first quote and its discrepancy with the final repair price is to be addressed in the improvement project. In order to preserve confidentiality at AFI this report works with invented numbers or ratios.

While the initial goal of the project was to find improvement measure to achieve this 7 day target, executive management soon asked for a complete evaluation of the maintenance process. No limit was given on the extent of possible changes which could go as far as rethinking the organisational structure. The focus of the mission however remained on the inspection process and the internal and external communication between departments, customers and suppliers. In order to keep a structured approach to the topic a six sigma process improvement project following the DMAIC method was implemented.

Due to manpower shortage, no specific task force was defined for the process but the availability of all staff for meetings, interviews and workshops was guaranteed. A two month time span was given to evaluate the current process and find improvement measure for the AFI structure shop. After these two months the results were presented to the executive management of the facility and a meeting with all division leaders was organised in order to decide on possible implementation plans for the suggested measures.

10. Define – Process Description

After a brief definition of the company, the product and the customer a SWOT analysis has been used to describe the situation in which the AFI aero structures shop currently is. The points made in this SWOT chart are based on a preliminary analysis. The chart shows the problems that became apparent within the first weeks of the project and give an idea for possible directions for the improvement project. Especially the square, in which current weaknesses, but still opportunities, are described has raised special attention for the following development of the project.

S	W	Internal Analysis	
O	T	Strengths	Weaknesses
External Analysis	Opportunities	(1) Strong market development (2) High technical expertise and experience (3) Trusted Network of Customers (4) Major new contracts and certification (B787, A380, etc.) (5) Future operator of all modern aircraft (B787, A350)	(1) Poor reporting of business performance (2) Poor tracking of historical maintenance data (3) Huge improvement potential with modernized production technology and processes
	Threats	(1) Relying too much on diplomatic relations for contracts (Algeria, Morocco, etc.) (2) As of today the technical expertise is not "sold" (3) Too little involvement of the small staff member in improvement and change questions	(1) English skills among staff (2) Flight safety question and loss of customer trust (3) Organisational structure and plant history (too much useless management positions for too little operational staff)

Figure 15 : SWOT Analysis

The following sub-chapters introduce into the maintenance process for fan thrust reversers.

10.1. Organizational Structure of the Maintenance Shop

In order to understand the detailed analysis of the maintenance and overhaul process it is useful to take a closer look at the organizational structure of the facility. The aero-structures shop is led by a plant manager that is the manager of 6 sub divisions. Most of these divisions are separated into more than one department, others stand alone as one-department divisions and report directly to the plant manager. Figure 16 shows the initial organisational structure at the beginning of the project.

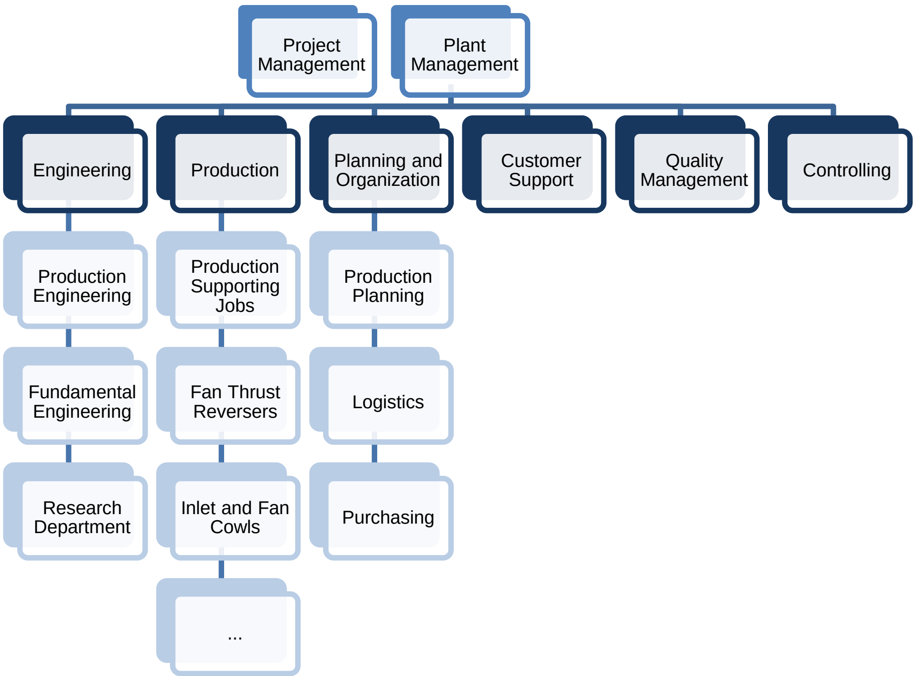


Figure 16: Organisational Structure of AFI Aérostructures

10.1.1. Operations (Production)

The Production division regroups all activities linked to the hands-on work on the products overhauled and repaired in the aero-structures shop. Alongside the mechanics, the division includes shift supervisors and all staff in charge of productivity evaluations. Almost everyone in the production division reports directly to the division manager. The Operations divisions can be considered the core and value creating division of the AFI aero-structures maintenance shop. Production planning and control (PP&C) however, reports to the logistics manager and not to the manager of operations. Mechanics are divided according to the different product lines they are associated with. There are separate groups for Fan Thrust Reverses, FTR Translating Cowls, Pivoting Doors, Fan Cowl Doors, Radomes, Inlet Cowls and Flight Controls. Within the product lines there are mechanics of different professions like expert mechanics for sheet metal repairs or experts for repairs on composite materials. All mechanics being trained aircraft technicians, they are supposed to act on every step of the maintenance process from dismantling to reassembly including inspections and repairs. If required due to his specificity, every mechanic can be sent on on-wing repair missions.

10.1.2. Engineering

The engineering division is made out of three departments: Production Engineering, Fundamental Engineering and the Research and Development department. The term “engineering” is somehow delusive since there are few persons with an actual engineering diploma working in these departments. Many engineering staff are former mechanics that have been promoted for their above average English speaking skills. These skills are needed since the task to communicate with the original equipment manufacturers on the validation of exceptional repairs remains with the engineering departments.

10.1.2.1. Production Engineering

Production Engineering provides direct technical support to the production teams. When a new equipment enters the repair shop, Production Engineering decides on the “initial work package” of actions that need to be performed. This initial work package provides all necessary procedures to the mechanics in order to dismantle, clean and inspect the element. After inspections, Production Engineering jumps back into action to analyse the shop findings and give technical recommendations on the repair actions for the upcoming repair process. They provide the information for the standard procedures during the repair process, an estimation on working hours required for the repair and the bill of materials and spare parts that are needed for the process. Any findings that are not covered by the standard maintenance manuals (CMM and SRM) are sent to R&D Engineering. As a result of this work, that is generally called “defect analysis”, the department issues a damage report and a quote to customer support management that allows them to communicate the approximate maintenance cost and a display of all damages to the customer.

10.1.2.2. Research and Development Engineering

All damages that are not covered by the standard maintenance and repair manuals have to be notified on an exceptional repair voucher (called *“bon éxceptionnel”* or BX at AFI). Research Engineering processes all of the vouchers, generally by asking the OEM for an applicable repair procedure. Alternatively they can create a procedure on their own which has to be validated by the OEM. R & D also translates the standard procedures from the Aircraft and Component Maintenance Manuals (AMM and CMM) and Structural Repair Manual (SRM) into standard procedures applicable in shop and display them on job cards. Additionally, R&D Engineering issues the so-called component structural damage reports (CSDR), for every repair that results in a permanent change to the initial design of the component. The CSDR is an official EASA document that needs to be backed by the design organisation and can be consulted in the aircraft’s log book at any time.

10.1.2.3. Fundamental Engineering

Starting from the aircraft maintenance manual, Fundamental Engineering issues a maintenance policy for every product in the portfolio. This maintenance policy is applicable to all Air France equipment. Maintenance policies for customers which have outsourced their engineering tasks to AFI are issued by Fundamental Engineering. The department is also responsible for the integration of new equipment into the Air France product portfolio.

10.1.3. Production Planning & Control

Production Planning is responsible for forecasting and planning the maintenance processes. A maintenance planner typically has the “task to develop all scheduled work and/ or work scope needed”[139] to perform an efficient maintenance shop visit in respects to labour cost and turnaround time. They have to be aware of the task distribution in shop and handle waiting times due to spare parts orders. While Production Planning and Control usually has a forecasting role, the planning department at AFI aero-structures only has a reporting role. Planning also chairs the daily production meeting that takes place every morning at 9.00 am and helps to communicate an overview of all ongoing progress made during the last day. The actual planning of the process is performed by Production Engineering who issues the work packages on the one hand and production management who distributes the tasks of the work packages to the mechanics. Production planning is responsible for the prioritisation of the different elements and the communication of these priorities.

10.1.4. Logistics

Logistics handles the reception and handling of the elements in the beginning and at the end of the maintenance process, and places orders for spare parts and consumable material needed for the repairs. Material and spare parts that are not in storage have to be ordered and bought by the purchasing department who acts upon request of the logistics department. Logistics equally handles the traceability of the element in Air Frances internal tracking database.

10.1.5. Customer Support

Customer Support Management hold responsibility for customer communication during the entire visit of customer equipment in the maintenance shop. Therefore they inform

[139] Kinnison, 2013, p.118

production planning of the imminent arrival of customer parts, they arrange a meeting with Production Engineering and fundamental engineering in order to define the work scope of all actions to be performed during the shop visit. After Inspections they report the damages to the customer and negotiate the repair procedures that need to be applied. Customer Support also communicates a quote for the total price of the works to be performed. The department also holds several non-operational tasks like aftersales management and negotiation with potential new customers.

10.1.6. Quality Management

The Quality Management department is made of four inspectors whose work consists of checking and verifying all tasks performed during the maintenance process. “The basic qualification to become an inspector is to have a valid mechanic’s license and 2 years working experience under that license without violations”[140]. Additionally they have to “[…] have knowledge of the airline’s regulations and policies […] and they should have completed the quality control inspector’s course and successfully passed the quality control exam conducted by the airlines quality control organisation”[141]. These double- and cross-checks are done with the help of the job cards that are initially issued to guide the mechanic step by step through maintenance tasks. The Inspector verifies if the mechanic has signed off on every task he had to perform. With each signature the mechanic takes the responsibility for the work he did. The inspector has the task of verifying that all works have been correctly signed off. The verification and control work of the inspectors consists of paperwork checks only. On rare occasions the inspectors check the actual technical and practical quality of the works performed. Inspectors are the only staff of the maintenance shop holding the permit to validate a maintenance process folder of an element and thereby turning it back to a serviceable state. By giving an element a “serviceable” tag at the end of the repair process the inspector holds a part of the responsibility for the reliability and operational capability of the element.

10.1.7. Observations and Analysis

The organisational structure of the AFI aero-structures maintenance shop resembles to the one described in the literature review. The only difference is the location of the production planning department that reports to the logistics division manager and not to the operations division. At the AFI structures shop PP&C does not hold the key role at the heart of maintenance and engineering organisation[142] in which many experts

140 Kinnison Siddiqui, 2013, p.209
141 Kinnison, Siddiqui, 2013, p.209
142 Kinnison, Siddiqui, 2013, p.117

see it. The position it executes is merely an observing and reporting role. On further notice, the demographic distribution of age classes can also be reported as unusual. The positions that call for extensive experience in the maintenance of aircraft equipment are mostly occupied by very young personnel. Mechanics on the other hand have a huge generation gap, with one half of the staff being two to three years from retirement and the other half having less than 2 years of experience in the company. This significant age split among the shop floor staff has already caused many difficulties in social interactions in the past.

10.2. The Current Maintenance Process

In order to understand the process of value creation in the maintenance shop the material and information flow paths of a fan thrust reverser have to be detailed. For the purpose of this study material and information flow are projected onto the overhaul process of a customer equipment.

10.2.1. Standard Overhaul Process

The flow of a customer element starts with the contact between customer support management and the customer. The latter announces the arrival of one of his parts as well as the reason of its removal from the aircraft. Customer support notifies the planning department of the exact arrival date and time of the element. Upon arrival four departments hold a meeting in order to decide what operations need to be performed on the element. The so-called work scope meeting is followed by the creation of an initial work package of job cards by Production Engineering. The initial work package is then transmitted to production, starting the maintenance or overhaul process. The repair or overhaul process always follows the same main steps: Starting with an inventory in order to determine whether any parts of the element are missing it is disassembled in accordance with the initial work package. Further, all dismantled and remaining sub-assemblies are cleaned and inspected. After the inspection Production Engineering analyses the found defects and decides on the repair actions to be undertaken. After production has finished repairing the element and has reassembled all sub-assemblies, the element is send to the paint shop. At the very end of the process, the documentation folder containing all job cards is inspected by quality management in order to be recertified with an EASA “serviceable” tag. Once the element has its “serviceable” tag it is sent back to the customer.

10.2.2. SIPOC Analysis

The SIPOC analysis shows a global view of the process and helps to determine the critical input and output values as well as the customer groups. The SIPOC analysis works through the process by determining:

- Suppliers
- Input
- Process
- Output
- Customers

Furthermore it suggests to evaluate the process from back to front in order to determine the values that are critical to a high quality result (CTQs). The following analysis shows a very general view of the process. It has been completed within the first days of the DMAIC project in order to get a first glimpse at the entire problem. The amount of detail has been kept to a minimum since every one of the five columns has been evaluated one by one in further along the project.

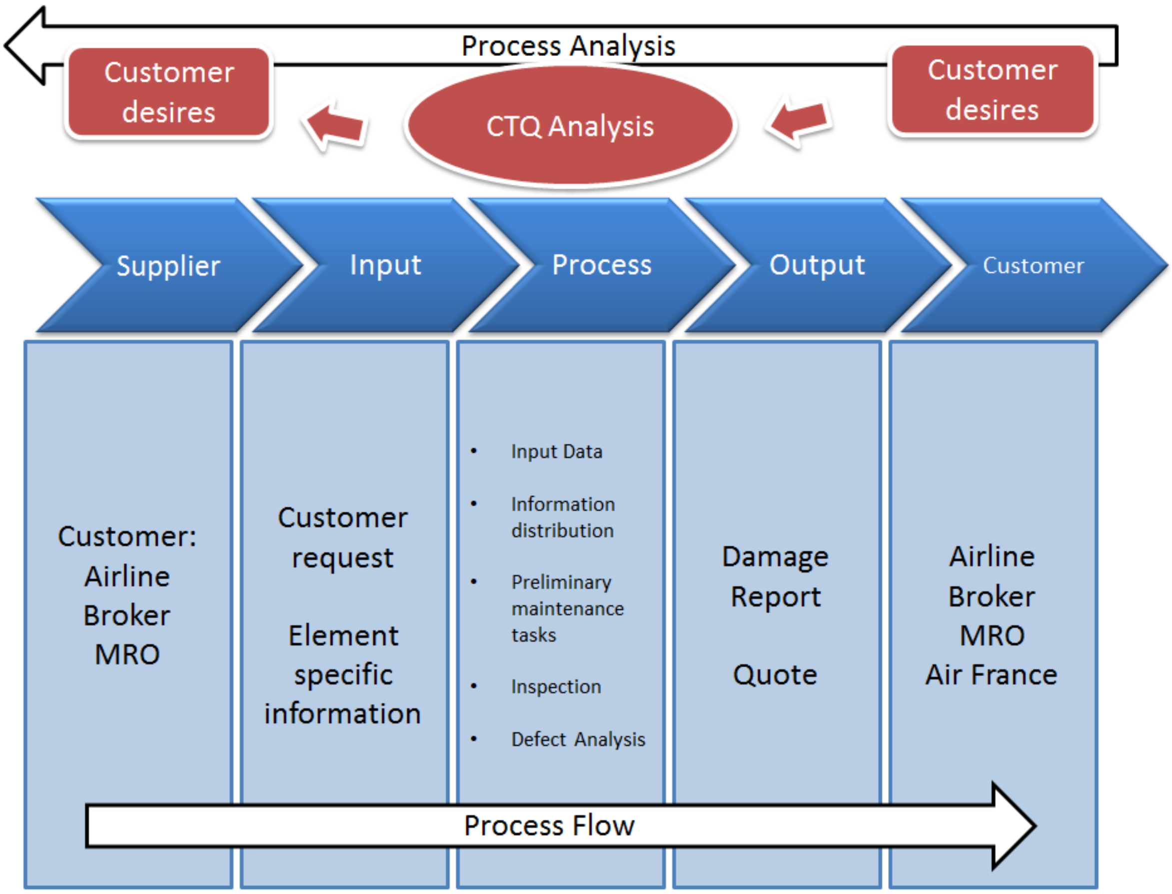


Figure 17: Preliminary SIPOC Analysis

10.2.3. Important Documents

In order to understand the overhaul process of a customer element some documents that are crucial to the information transfer between the maintenance steps have to be introduced. This part helps to understand how information circulates at the AFI structures shop. Some of the names can be found in other MRO organisations, some are purely “Air France slang”.

10.2.3.1. Customer Work Scope

The Work scope is a document initialized by customer support management upon arrival of the element in the repair shop and prepared in a meeting together with fundamental engineering, Production Engineering, purchasing and quality management. The aim of the meeting is to clarify all customer relevant informations that are important to the maintenance process. It contains flight hours (or cycles) since the last overhaul, whether the client accepts DOA procedures and, most importantly, the reason for the elements shop visit. Once all customer information is summarized, the team members agree on the initial actions to be performed on the element. This usually contains the dismantling level and the necessary inspections in order to issue a reliable repair cost and TAT quote to the customer. The document in which all this information is collected is called the customer work scope.

10.2.3.2. Repair Order

The customer provides a repair order to AFI with all information he thinks is necessary to turn his element back to serviceable state. Since the repair order might contain vital information that won’t be transcribed into the work scope it has to be joined to the work scope and handed to the person who edits the initial work package of job cards.

10.2.3.3. Job cards

All works that are performed during a shop visit of an element have to be described step by step in an official procedure. Usually these procedures are transcribed from the component maintenance manual and structural repair manual. Both are documents issued by the design organisation and describe all steps from dismantling to reassembly as well as all standard repair procedures. At Air France – KLM these standard procedures are called job cards. Many job cards form a work package. Job cards also help the different departments to check on the ongoing repair process. The production planning department receives every job card when it is finished and redistribute it to the next person in the process. This allows them to precisely monitor the time that is left to complete the repair process. Job cards are being used in almost every MRO organisation on the planet. The literature describes them as documentation that settle and clarify standard procedures and insure that all actions are performed in a controlled and restrained environment.[143]

10.2.3.4. Damage Report

After inspections, Production Engineering issues a damage report containing all defects found on the element during inspections. All of these damage reports are saved and archived in a database in order to keep a traceability of all elements treated in the maintenance shop. The damage report is used as a communication document in order to inform the customer on the status of his element and negotiate repairs. It contains pictures of the defect, part numbers to be exchanged, and the repair action that is recommended for every damage found during inspections.

10.2.3.5. Diffusion 1 and 2

Once Production Engineering has decided on the repair procedures that need to be applied, it evaluates every action by estimating how many labour hours, which spare parts and how much consumable material will be used to complete the repair procedure. The sum of all this estimates make up the initial repair cost quote. At Air France Industries this quote is called diffusion 1. If a revisions or corrections are needed, the following quote is called diffusion 2. One of the scopes of the improvement project was to reduce the discrepancy between the initial quote and the final repair cost issued by controlling.

10.2.3.6. CSDR

The Component Structural Damage Report (CSDR) is an extension to the damage report. Every repair that generates a permanent change to the elements geometry necessarily needs to have its own CSDR. In extension to the information displayed in the damage report the CSDR contains a picture of the finished repair as well as the signature of the mechanic who performed and the engineer who approved the repair. The CSDR insures the traceability of this repair and can be consulted by anyone working with the plane it is placed on from the pilot to any mechanic performing maintenance on the element in the future.

10.2.4. Material Flow

The maintenance facility at Le Bourget is divided into 5 main treatment sites:

1. Hangar 1 (H1)

[143] Hinsch, Olthoff, 2013, p.3

Hangar 1 is dedicated to fan thrust reverser and radome maintenance. Thrust reversers are almost entirely repaired in this section of the aero-structures facility. It contains arrival bays, bays for disassembly, inspection and repairs, equipment for functional bench tests and a repair shop for all wear and tear kits such as screws, bolts and smaller accessories. Hangar 1 also contains the offices of all three engineering departments, logistics, production-planning and quality management.

2. Hangar 2 (H2)

Hangar 2 is home to the repair shop for fan cowl doors, inlet cowls and flight control panels. Since there is a need for composite repairs in these fields it houses an autoclave for repairs and research in the field of composite materials. The plant manager, purchasing and customer support management have offices in hangar 2.

3. Bâtiment St. Exupéry or “Building” (BLD)

This Building is located next to Hangar 1 and is the home of the composite parts of the fan thrust reversers such as Translating Cowls, Blocker Doors and Pivoting Doors.

4. Repair Shop A3

Repair Shop 3 is responsible for the repair for major thrust reverser sub-assemblies such as latches and access doors.

5. Repair Shop A4

Home to AERTEC, an Air France subcontractor, the A4 shop is the place where all elements are cleaned, sanded and repainted after the repair or overhaul process.

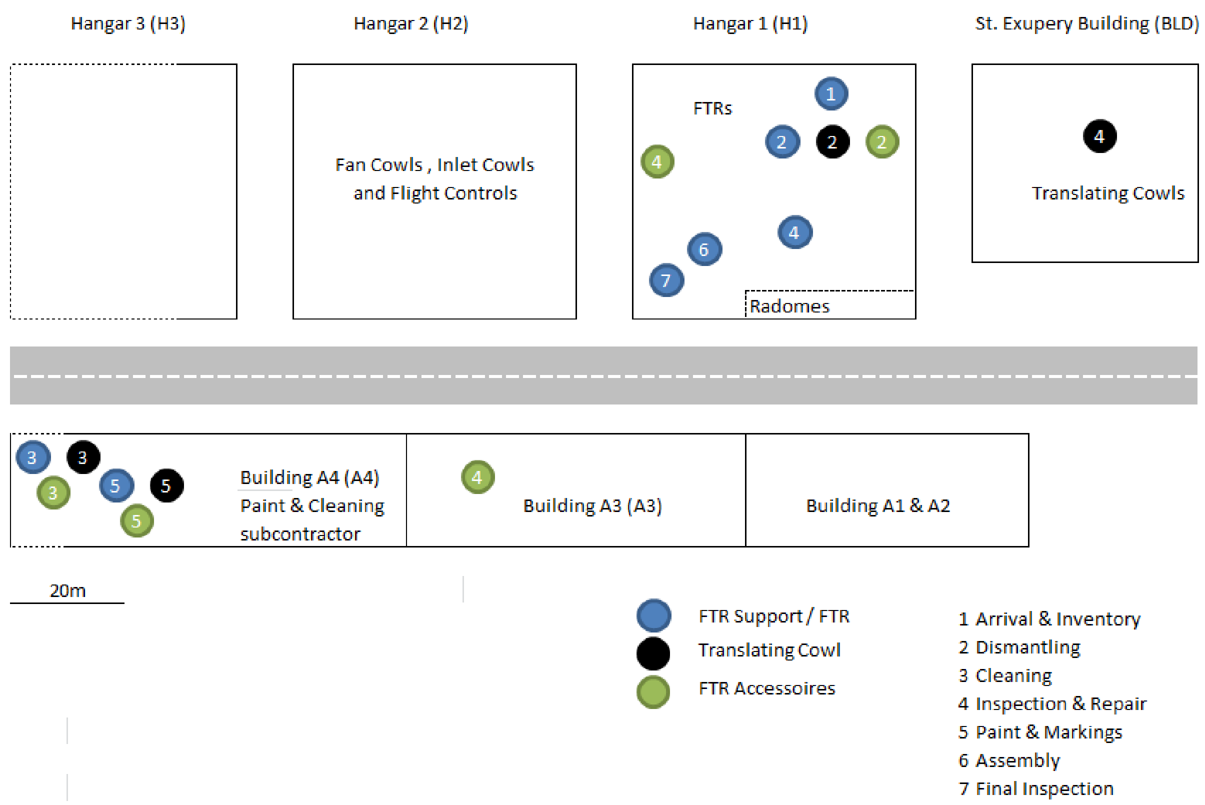


Figure 18: Material Flow at the Le Bourget site

This scattered material flow and the changes between many separate repair shops for different elements was one of the major reasons to move under one roof at a new facility. The distance between the different repair shops is considered being one of the biggest inhibiting factors for a better turnaround time.

10.2.5. Information Flow

The purpose of this chapter is to understand the different stages of the maintenance process of a customer element through the aero-structures shop and give an overview, which tasks are executed by which department and where the information is handed on in the process.

Every repair or overhaul process starts with the arrival of the element and its unpacking from the shipping crate. After logistics has opened up a new repair folder and created an official dismantling record in the Air France tracking system ASTRE, they send out an arrival message to customer support management. Customer support is in charge of organizing a meeting with several departments in order to generate a customer work scope based on the information they have previously received from the customer in the repair order. Once they have received the signed work scope Production Engineering starts to issue the initial work package which contains all job card procedures for dismantling, cleaning and inspections. The initial work package has to be created in accordance with the work scope.

Every procedure issued during any moment of the maintenance process is sent through the production planning. The job cards are the lifeline of production planning department. They allow them to follow the process and plan the work distribution of the entire shop.

The actual treatment of the element starts with a major parts inventory (MPI). This procedure detects missing parts of the thrust reverser upon arrival at the shop. While missing parts are reported to customer support management production proceeds with an incoming visual inspection. This type of inspection is intended to detect major structural flaws and defects that require elaborate repair procedures. This step is crucial for CF6-80 series thrust reversers because extensive damage enhances additional cleaning processes such as the removal of corrosion inhibiting compounds. These compounds do not withstand high temperature and pressure levels and have therefore to be removed before every repair using the autoclave.

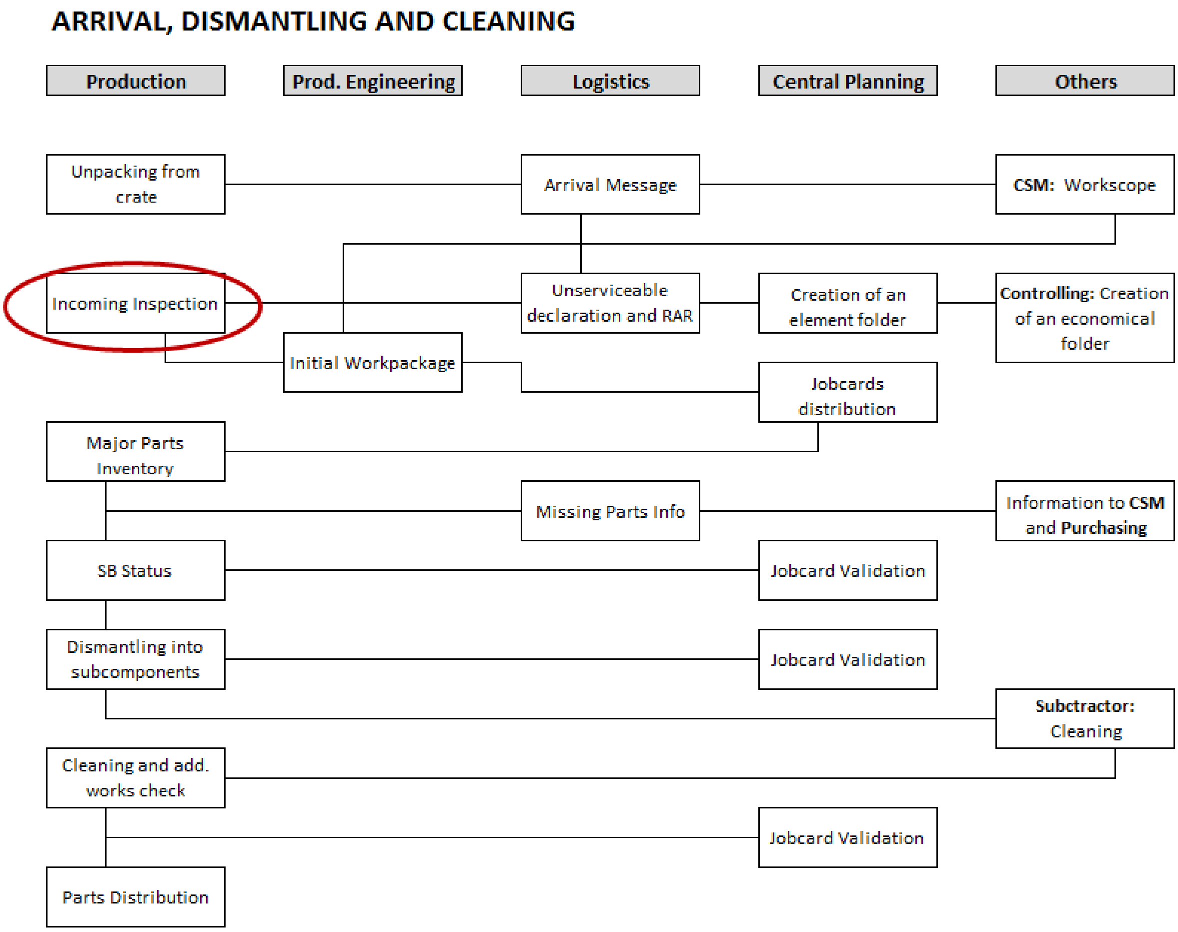


Figure 19: Information Flow from Arrival to Inspection

After the incoming inspection, a mechanic analyses the service bulletin (SB) status of the element. Customer support management discusses with the customer which SBs are applicable during the upcoming maintenance process. Once the SB status is finished the element is be dismantled into sub-components.

All sub-components are cleaned by a subcontractor and sent to their respective repair shops. Today the elements are dispatched into 5 different repair shops. While the support structure and the torque box stay at hangar 1 (see figure 19: description of Le Bourget repair shops) there are separate repair shops for all sub-assemblies with composite materials like the translating cowl and blocker doors. Wear and tear kits and large accessories like the forward latch or the access doors also have separate repair shops. No matter the shop, every finished job card is sent to production planning in order to keep track of the progress that has been made on the element.

Upon return from cleaning all sub-assemblies are inspected in their respective shop for defects following the procedure of the inspection job cards.

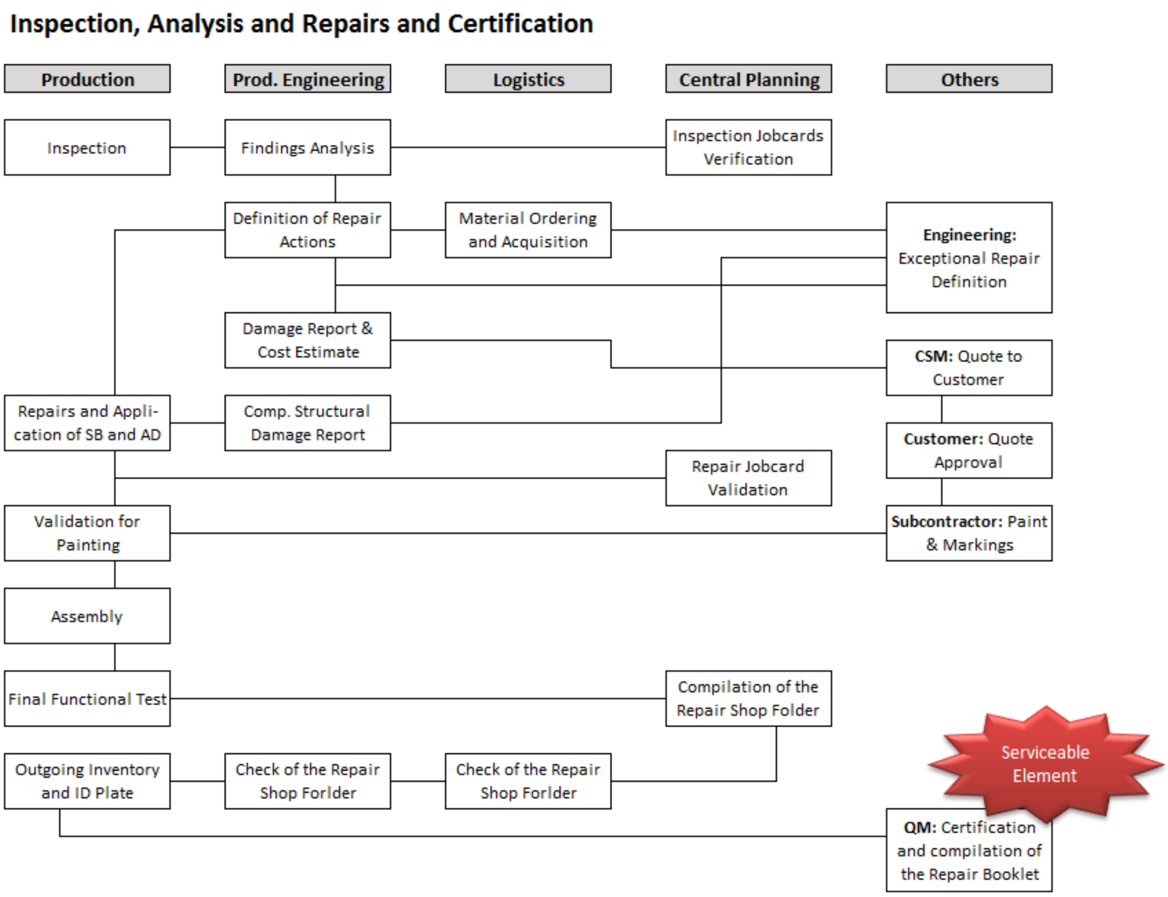


Figure 20: Information Flow from Inspections to Release

After inspections Production Engineering analyses the defects and defines a repair procedure for every defect. For unusual damages that are not covered or surpass the repairable limits given by the CMM, Production Engineering hands on the task to R&D engineering. R&D engineering is in charge of communicating the defect to the original equipment manufacturer and finding a suitable repair procedure. Moreover Production Engineering issues a damage report and a first quote (diffusion 1) which are both sent to customer support management. Once the customer has approved all repair actions on the element the repair process starts.

The repair process itself is executed by the mechanics and organised by the shift and shop floor supervisors. Production at the AFI structures shop runs in two 8 hour shifts from Monday to Friday.

At the end of the repair process Production Engineering creates a component structural damage report (CSDR) for every repair that permanently changes the geometry of the initial design. Additionally all documentation on repair procedures have to be verified before the element can be sent to the paint shop, where it is coated and painted in the airlines colours by a subcontractor. Only after all sub-assemblies are painted the element is assembled and ready to be certified as serviceable. Some certification guidelines require a functional test before the release of the element. Central Planning and Quality Management create a repair booklet that traces all works performed on the element and Quality Management signs off the FAA or EASA certification that turns the element back to a serviceable state. The booklet is sent to the costumer and follows the element in order to provide a reliable traceability of previous maintenance work to future maintenance organisations or anyone operating the aircraft the element is mounted on.

10.2.6. Timeline for a Shop Visit

The following Gantt chart shows an example timeline of the treatment of a Fan Thrust Reverser. To help Air France keep its work confidential the number of days spent on each tasks has been invented. This chart merely gives an idea of the time ratios spent on each task. Within the current state analysis it became apparent that more tasks, other than inspections and findings analysis directly impact the quoting process. Especially the first steps after the arrival and unpacking of the fan thrust reverser from the crate can be considered as crucial. The split of tasks in the chart upon return from cleaning is due to the dismantling and henceforth separate treatment of the three main sub-assemblies in three physically separated shops. While the supporting structures (torque box and core cowl) stay at Hangar 1, translating cowls are sent to H2 and disassembled accessories are sent to repair shop A3. In this analysis mainly the support structure was looked at since it is considered being the most time-consuming sub assembly to treat within the entire maintenance process.

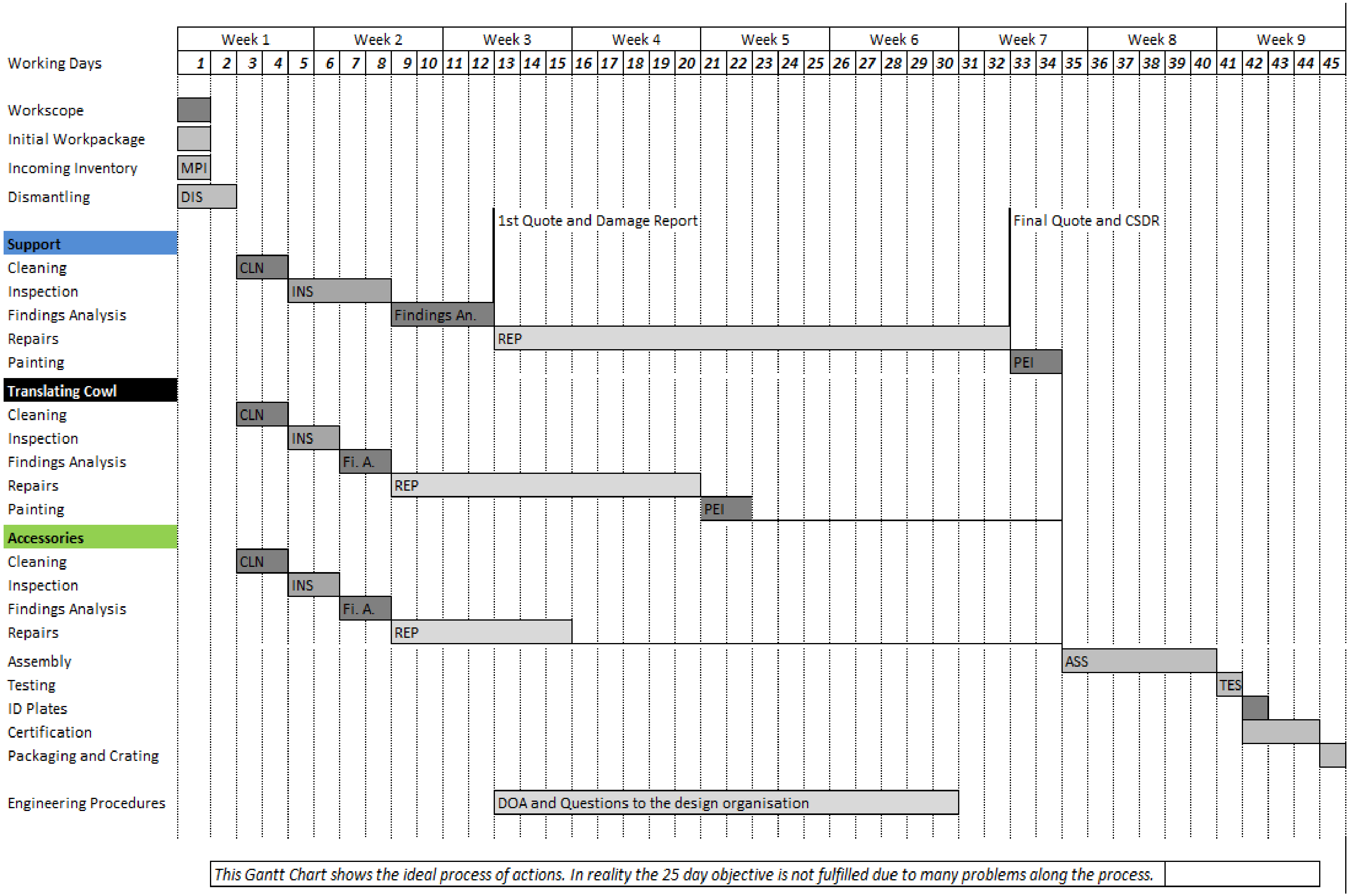


Figure 21: Gantt chart showing the maintenance process

10.2.7. The “Helios” Project

The new plant at Charles-de-Gaulle Airport has been named “Helios” and is generally considered as the “tool for improvement” by Air France Industries. Project management has declared two major improvement objectives for the new maintenance facility:

1) Join the maintenance shops of Orly, Le Bourget and Roissy together to one maintenance plant close to Air France Industries main maintenance hub with its aircraft maintenance hangar.
2) Reduce the overall turnaround time of all major airframe equipment treated by the structures-shop through a new state of the art maintenance plant.

While the first objective seems perfectly achievable this is not so likely for the second one. A large part of the AFI aero-structures staff asks itself the justified question how a new plant that involves huge organisational change can reduce turnaround time. At the same time a lot of people are sceptical towards the non-observance of obvious organisational problems that remain without a solution today. Organisational changes and changes in work attitude are still be necessary to achieve the ambitious turnaround time objectives. At the same time the new plant is very likely to create new problems that are not accounted for neither. Specifically the localisation of the supporting departments like engineering, quality control or production planning could cause serious troubles. All of them locally move away from the bays where the elements are repaired. While the operating mode is today based on verbal communication and a strong “go-and-see” attitude the newly long walking distances between offices and bays might be an inhibiting factor to the day-to-day work routines.

The main organisational change in new plant will be that every mechanic has to perform and manage the maintenance process of his element from inspection to reassembly. Today the tasks are distributed randomly and no mechanic ever sees the end to the work he is currently performing. By changing the shop floor organisation project management want to increase motivation of the shop floor workers, giving them the feeling of accomplishment in their day-to-day work.

Listening to the voices on the shop floor and in the offices a lot of people are very sceptical towards the new plant and the organisational change that comes with it. However project management does not seem to communicate enough about the potential risks they have detected and the way they are being addressed.

10.3.Ishikawa Diagram

The following Ishikawa (fishbone) diagram is the result of a brainstorming meeting conducted with participants from customer support management and production. It shows a selection of possible failure modes and problems according to the five problem sources (5M):

- Material
- Machine
- Method
- Measurements
- Manpower

The meeting has been called before the measure phase of the DMAIC project during the define phase. Its purpose was to get a first impression of the possible problems and determine the fields that need to be observed and analysed with special attention.

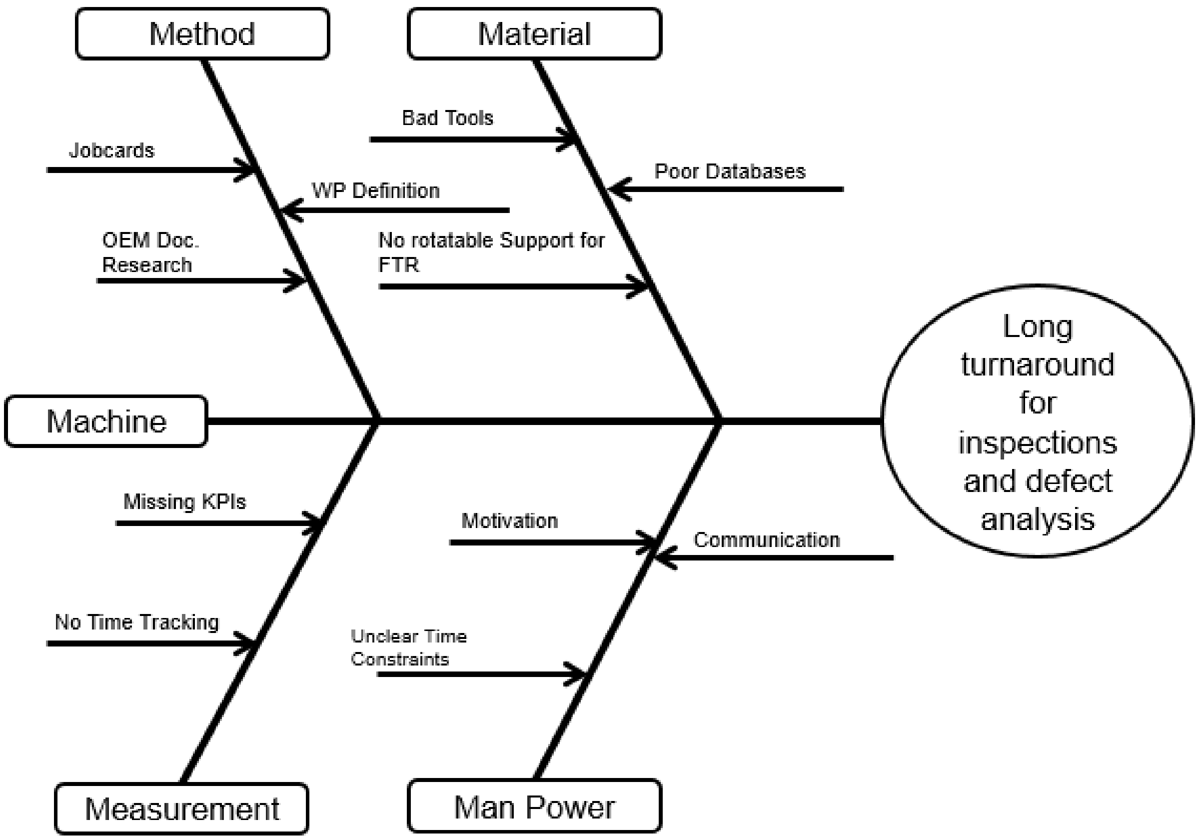


Figure 22: Preliminary Ishikawa Diagram for the entire maintenance process

11. Measure – Process Performance

11.1. Rework Rate

The rework rate responds to the customer requirements of quality and time. One the hand, a high rework rate shows the probability of running into errors and flaws in the process that might not always be detected. On the other hand, a high rework rate causes excessive and unnecessary turnaround time. “The rework metric is a fundamental metric used across all industries. It is used to measure the amount of rework generated by a given process. It can be measured in dollar amount, hours of rework, or by percentages”[144]. The rework rate at AFI was determined by creating a percentage of all repair job cards that needed supplement treatment. A faulty job card means that the procedure, the job card describes, has not correctly been executed.

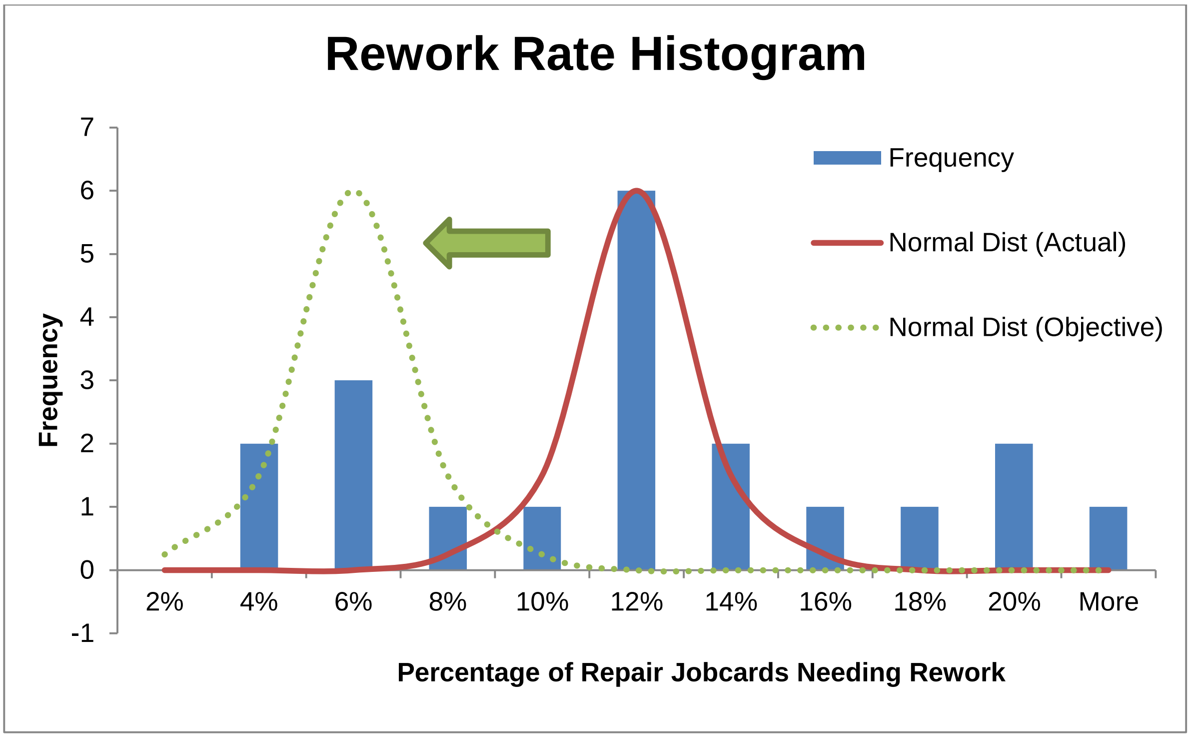


Figure 23: Rework Rate Histogram

Figure 25 shows a histogram of the percentage of repair job cards of an element that needed rework. The declared objective for this measure is to decrease the rework average (currently around 12%) as shown by the dotted line. Unfortunately the rework rate is a newly introduced KPI and is not yet traced in the AFI airframe shop’s databases. For this analysis only a small number (20) of recent maintenance process

[144] Taaffe et al., 2014, p.124

have been examined. In order to achieve a more reliable rework rate measurement the metric needs to be monitored closely throughout the facility for a longer period. For future maintenance processes it is recommended to include the rework rate into the analysis both as a percentage of job cards and a distinctive number of labour hours.

11.2. Late Findings Rate

Unfortunately even the best mechanic cannot always spot all defects during inspections. If defects are found after the first quote is issued, they raise the initially suggested repair price and the predicted turnaround time of the element. The late findings rate, a metric that counts the number of defects discovered on the element after inspection and defect analysis, responds to the customer requirements of time and cost. As shown in figure 26, the declared objective is to reduce the total number of late defect findings. Figure 26 shows the current trend and an approximate target through the dotted line.

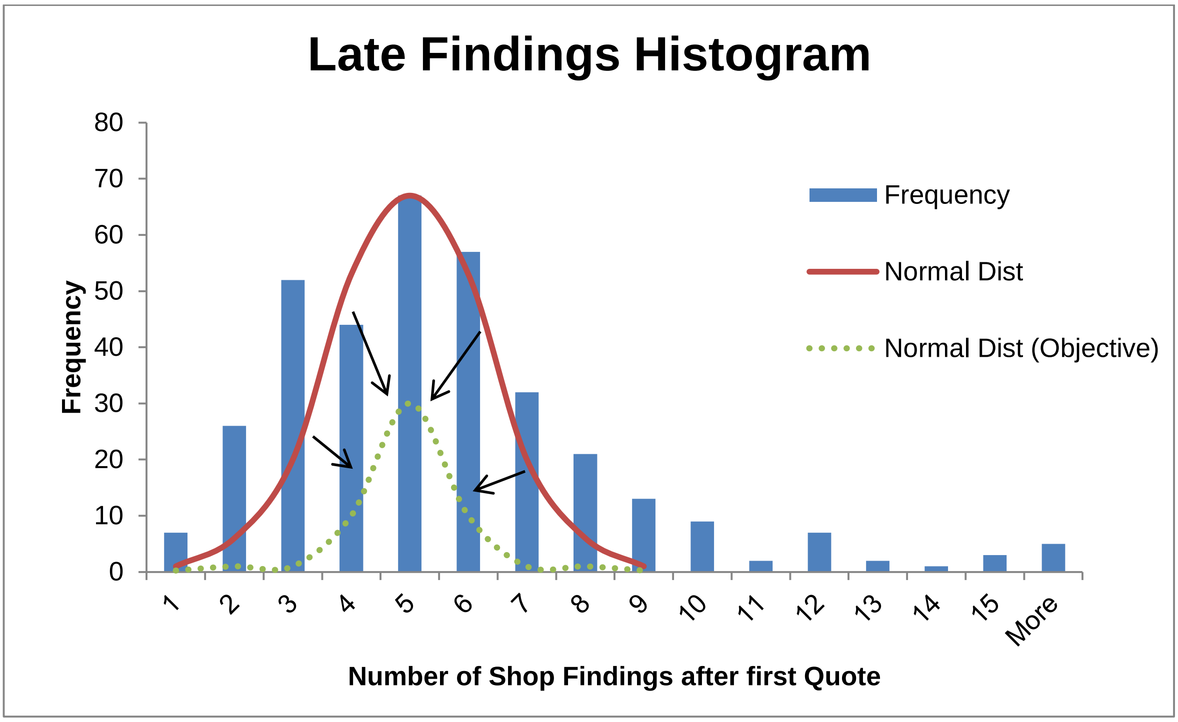


Figure 24: Number of shop findings after inspections and defect analysis

11.3. Turnaround Time

Turnaround time values are not published due to confidentiality reasons. All that is revealed here is that AFI aero-structures tries to cut in half its turnaround for the quoting process and has set the objective to reduce the currently achieved turnaround for the entire maintenance process by 60 percent. The reduction in turnaround time is AFI's major objective for the new production facility at Charles de Gaulle Airport.

11.4. Repair Price

The histogram on repair prices shown in figure 27 shows the overall maintenance price distribution for all CF6-80 thrust reverser programs over the past 5 years. The measure responds to the customer requirement of low maintenance cost. One of the major objectives for AFI is to be able to suggest a strong market price by reducing their overall operating cost and keeping technical quality at a high level.

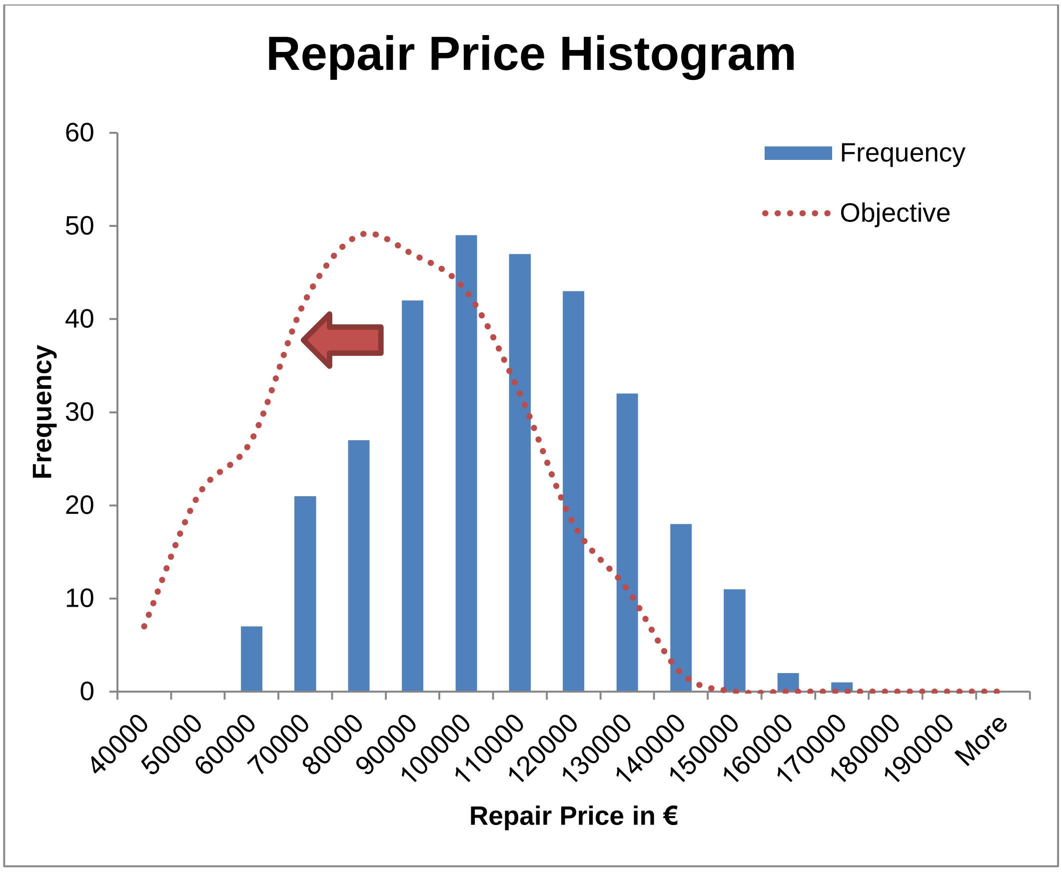


Figure 25: Average repair price for the overhaul of CF6-80E1 FTR

11.5. Quote Gap

The quote gap shows the difference between the quote and the final price as a percentage of the total maintenance price billed to the customer at the end of the maintenance process. A small gap responds to the customer requirement of reliability. Today the first quote represents on average only about 65% of the final price. Figure 28 shows a histogram on the quote gaps that occurred for CF6-80 fan thrust reversers over the past 5 years. The reasons for this gap are bad manpower cost estimations and late findings that call for complicated and long repair procedures. A detailed analysis on the reasons that lead to big difference between the first quote and the final price can be found in the analyse phase of the DMAIC process. The objective is to push the gap down to a lower average quote gap.

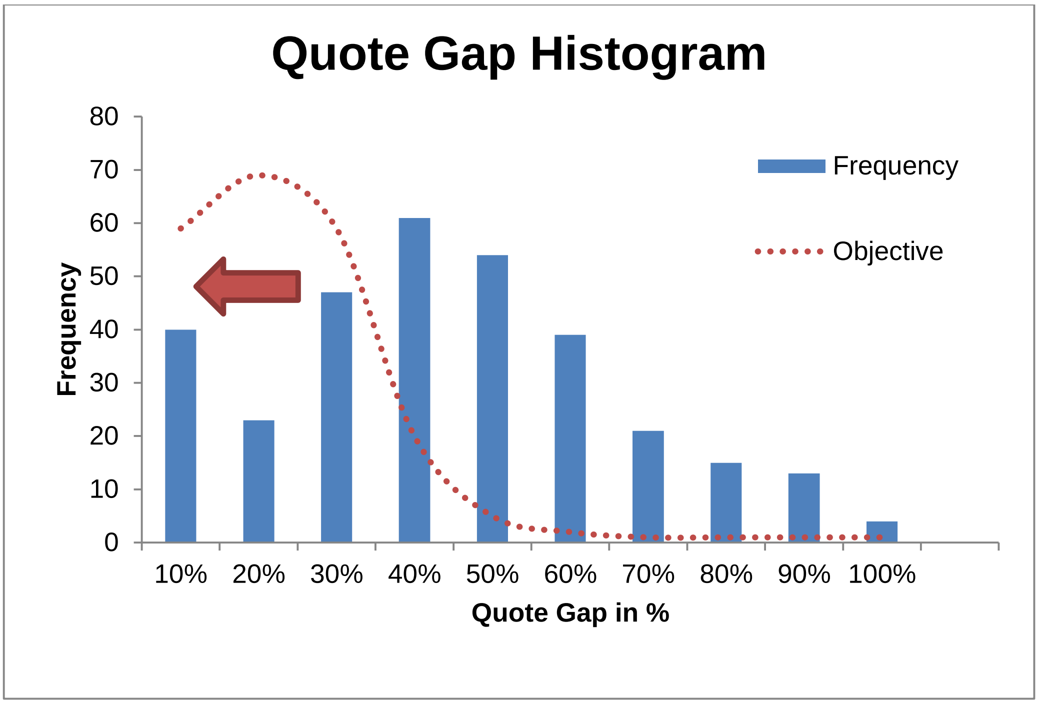


Figure 26: Quote Gap

11.6. Other Indicators

Other performance indicators were identified but not numerically tracked. A well informed customer is more satisfied and more likely to accept a price raise or excessive TAT. Therefore, the number of customer interactions during a maintenance process can be seen as a quality indicator. While the number of exchanges between the customer and the customer support team should be regular and informative, the number of price updates should be kept at a minimum.

11.7. CTQ Matrix

The CTQ matrix shows the correlation of the performance measures with the customer requirements that are critical to a quality process. Since it would represent a very high workload to track all measures during the improvement process this matrix allows the improvement team to select a small number of performance indicators and still cover a high number of customer requirements.

CTQ / Output	Rework Rate	Late Findings Rate	N° of DR updates	Customer updates	Turnaround (total)	Turnaround (Quote)	Repair Cost for IWP	Quote Gap
Quality Repairs	●				○			
Quality Inspection		●						●
Correct Damage Report	○		●					◉
Regular return on process				◉				
Low TAT	●	○			●		○	
Low TAT for quote			◉		◉	●	○	
Minimal Repair Cost	◉						●	
Reliable Quote			◉					●

● Strong correlation ◉ Medium Correlation ○ Weak Correlation

Figure 27: CTQ correlation matrix

11.8.Conclusions and Outlook

The measure phase has helped to confirm the problems that were stated at the beginning of the improvement project and has helped to identify new problem sources. The focus of this DMAIC process has been placed on the analysis phase and the suggestion of improvement measures. Due to this target and also due to the slow business environment at AFI it was clarified at a very early stage that the evaluation of the project with the above measures would not be seen by the project team. Most of the above performance measure are not monitored at AFI today. When beginning a new project in a new environment it is not recommended to work with completely new measures as they can be misleading. A lot of further performance measures came up in the current state analysis described in the following chapter which suggest that it would be more appropriate to measure the process performance only after the analyse phase. As a result to the wide scope of the project all performance measures above have been considered during the analyse and improve phases.

12. Analyse - Problem Analysis

In order to analyse the current state of the process a series of inspections and findings analysis processes have been closely followed. To begin with, three complete overhaul inspections were followed in order to develop hypotheses on the problems that could lead to the high TAT. Once these hypotheses were set up, 15 further inspections were actively followed. 13 out of 15 inspections were followed on customer elements but not necessarily on CF6 thrust reversers. Before assisting to the inspection the work scope meeting was attended for all 13 customer elements. Additionally, the mechanic performing the inspection was interviewed (The complete questionnaire for the interview can be found in appendix F). Additionally, all sub-tasks of the job cards were timed in order to identify critical tasks and analyse potential time savings though elimination of redundancies. The following chapters describe the problems that the current process yields and the several inefficiencies that were detected.

12.1. Customer Maintenance Programs

Every customer that sends an element to the AFI airframe maintenance shop basically has the same requirements: Bringing the element back to a serviceable state in minimal turnaround time (TAT) at a minimum repair price. In order to achieve this customer request Air France has to decide on the composition of maintenance tasks that has to be performed on the element. The difficulty lies within issuing a set of maintenance tasks that is not too detailed, but still enough to satisfy the customer. Based on the recent history of FTR treatments in the airframe shop, AFI is at this date not capable of issuing a maintenance program that is tailored to the customer's needs. This causes excessive turnaround time and time consuming supplementary tasks. The reasons to this situation are explained in the following sub-chapters.

12.1.1. Communication of Customer Requests

Since every customer request is unique, the communication about them is currently very difficult. There are a great number of reasons why a fan thrust reverser is dismantled from the aircraft. These reasons can range from incidents to scheduled overhauls due to the culmination of a certain number of flight hours or cycles of the element. Incidents can range from bird-strikes, collisions on the taxiway, apparent cracks and dents to corrosion due to the operation in humid and salty environment. Others come to the shop after being leased to a customer while his element was being repaired. In the last case AFI used the wording “loan return” on the customer work scope. This means that the element is reintegrated in the Air France parts pool and has to be recertified according to Air France standard. Every removal reason enhances a different treatment and therefore a different work package of job cards. As of today the customer requests and the removal reasons are not sufficiently communicated from customer support to production.

A survey among production and Production Engineering staff has shown that less than 15% of the questioned agents actually knew why the element had come to the shop or what work package the customer demanded. Especially during inspections this can cause a lot of additional work that hasn't been scheduled and requested in the first place. If the element comes to the shop for dents in the outer skin but is then thoroughly inspected all over with a detailed visual inspection and dismantled into all sub-components the shop findings report will be a lot longer. This results in a higher price for the customer and longer turnaround time (TAT). Not being part of the initial shop visit reason and therefore the initial maintenance agreement, these supplement tasks are difficult to justify to the customer.

In order to overcome this lack of information and communication the AFI airframe shop management has decided to hold a meeting upon arrival of every customer element in order to discuss what works are to be performed. The meeting is organised by customer support and is attended by experts from Fundamental Engineering, Production Engineering and quality management. As of today production, who is in charge of treating the element and has to sign off on the repairs, isn't invited to the work scope meeting. Additionally the meeting is often held without taking a first look at the element. This first visual inspection could show an experienced agent what works need to be performed to turn the element back into a serviceable state.

The "repair order", a form the customer has to fill in for AFI in order to get his element repaired, rarely contains suitable information about the removal reasons. For instance, a removal due to corrosion found during a routine check on wing is often notified with no more information than "corrosion". While the Air France inspection agent tries to find the corroded area he might also find a lot of minor defects that inflate the repair price and need to be justified to the customer while they had, again, nothing to do with the initial removal reason.

In order to illustrate the lack of information on removal reasons among the mechanics, 15 interviews were conducted. While the complete questionnaire can be found in appendix F, the following listing shows a summary of the results.

1. 13 out of 15 mechanics interviewed, knew who the customer was. This shows that the mechanics are generally rather well informed. However this information is not transmitted across the customer work scope but across the job card, on

which the customer code is notified. One of the two wrong answers was due to wrong information on the job card, the other one was due to ignorance of the mechanic who stated: “I don’t care who the customer is, for me every element is treated the same way”.

2. The second question concerned the repair status (incident, light repair, overhaul, etc.) the element is in. 10 out of 15 mechanics had an answer to the question about the element status. Only 6 mechanics however, knew about the true status of the element. Again, they all could tell the status from the information on the job card. The information on the job card however doesn’t reflect the status of the element but is a name given to the job card years ago for the overhaul of Air France elements and is therefore no reference to the customer element currently treated. None of them was actively informed about the status of the element by the shift supervisor or someone who attended the work scope meeting.
3. Most questioned personnel (13 out of 15) stated, they were aware about the reason for the shop visit. Again they weren’t informed by a supervisor but could tell the reason from a major defect found on the element. The two wrong answers were due to two elements that came for overhaul and didn’t have any major defects.
4. Only 2 out of 15 interviewed mechanics had an answer about the question on customer demands. This vital information never reaches them. The only two answers were due to mechanics guessing correctly, that the customer wanted a short turnaround with minimal cost.
5. Concerning the degree of information, transmitted by their supervisor, some mechanics were neutral about the fact they didn’t receive any information and said as long as they received a job card they would do their job and were happy with the fact that they didn’t have to think any further than that. Others suggested that they would like to have more information in order to work more efficiently.
6. None of the 15 mechanics interviewed had ever seen a work scope or even heard about it.
7. None of the mechanics knew how an overhaul of fan thrust reverser is defined by Air France standards. Even if no customer element is actually treated by the AF standard, it could be useful to production staff, to know about the tasks to be performed in a standard overhaul procedure.

The result of the questionnaire presented to the mechanics shows that they know the corner stones of the repair process like the customer name or the status of the element. While the first information is not of much use to them the second one would be, if they knew how an overhaul or an incident repair is defined. Furthermore the mechanic is kept in the dark about all information in the work scope and the repair order. This circumstance is very concerning. The level of information the mechanic is trusted with is very low and shows the distrust with which he is treated. Most mechanics however would like to be better informed and constantly complain about not knowing what the customer initially asked for. These circumstance call for an awareness campaign on how to perform quality work to the customer's full satisfaction and an evaluation of the human factors between the mechanics and their superiors.

12.1.2. Internal Decision-Making on Works to be performed

Once the works to be performed have been notified correctly on the work scope that is currently issued at the kick-off meeting, Production Engineering is in charge of issuing an accurate initial work package. This package of job cards defines all disassembly, cleaning and inspection tasks. Currently the existing job card library makes it impossible to create an accurate work package that coincides with the works defined in the work scope.

All job cards are defined and created according to Air France standards. Due to their structure it is very difficult to define a specific dismantling level other than the standard dismantling level applied to Air France elements. One of the reasons is the integral treatment of a job card once it is issued. Therefore a lot of customer elements end up being treated following the same high standard than Air France equipment. Most customer items are dismantled further than initially agreed on, inspected in more detail than requested by the customer and end up with a lot more findings which raise the price and increase turnaround time.

In order to show how much the excessive tasks account for, 24 FTR repair processes have been analysed during their dismantling and inspection stops. It can be noted that during dismantling only 5 of 24 FTR ended up with the exact dismantling level defined in the customer work scope. Out of the five correct procedures three were scheduled to get a full Air France standard overhaul and the other two an Air France standard repair process. On the other 19 processes too many tasks were issued on job cards and excessive work was performed. An average of seven excessive tasks were performed, which can be translated to seven sub-assemblies that were removed and inspected. Seven tasks the customer never asked for. In the most extreme case an FTR came to shop in a close loop treatment for a standard exchange on the centre drive unit. While this task could be performed within two days, the discovery of a small defect during the pre-inspection created additional inspection tasks sending it into a complete standard overhaul. It stayed in the shop for several months, much to the customer's frustration who was operating on a FTR leased at a high daily rate during the whole time.

Taking a closer look at the analysis it can also been seen that Air France is only capable, due to its job card structure to perform either a complete disassembly (51 tasks), disassembly of all accessories and the translating cowl (29 tasks) or a disassembly of all accessories (18 tasks). The only case were this was avoided was an FTR who came to shop for a repair on the upper sidewall forward fairings who sent the job card into action to dismantle all fairings (11 tasks for upper and lower sidewall fairings). This shows that the company is only capable of adapting the dismantling level in function of its job cards. A solution that allows to define tailored fit dismantling levels for a customer seems absolutely essential.

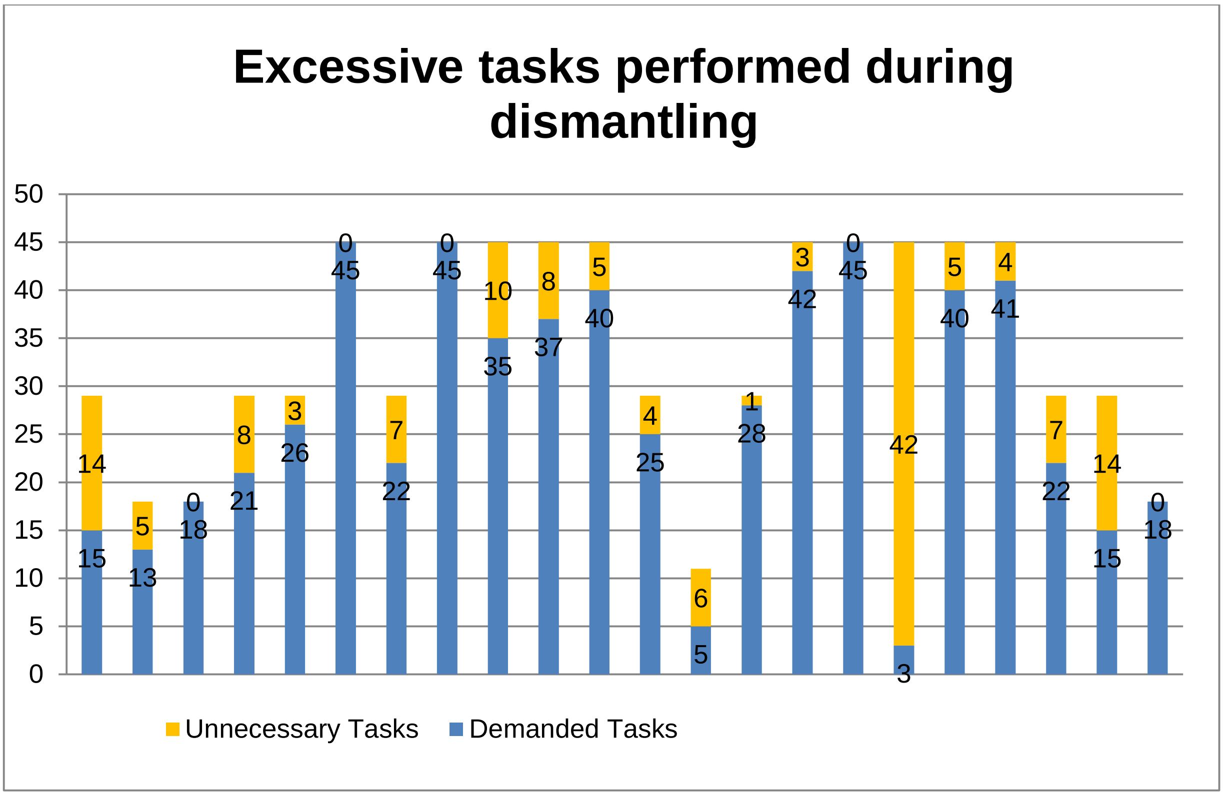


Figure 28: Excessive Tasks

An even amplified phenomenon comes into play when looking at inspections. For every excessive sub-assembly dismantled from the element, several inspection tasks follow. Every supplement inspection task creates the possibility for defect findings.

12.2. Lack of an initial cost estimation

Estimations essentially yield two major problems: first, the time needed to issue it and second, the reliability of the cost estimation. Even if it is perfectly clear that a reliable estimation is impossible upon arrival of the element, a cost estimate based on experience does not exist today at AFI, even though the company claims to be one of the oldest MRO organisations with an unbeatable experience when it comes to overhauling airframe components. Interviews with production and engineering staff suggest that the same defects keep appearing on thrust reversers over and over again. If this is the case, it shouldn't be that difficult to create an accurate cost estimation before the inspection of the element. Customer support management has been asking for repair rates giving the customer a choice of light, medium or full overhaul (heavy) repair programs. The dismantling level is then defined according to this choice and an approximate repair price is calculated based on defect occurrence levels. In order to determine the applicability of this idea Pareto charts have been created to evaluate the shop findings on all CF6-80E1 thrust reversers over the past 5 years (126 shop visits). The results show that up to 60% of all findings are accounted for by 17 of 101 known repair procedures and service bulletins. The following 30% by a further 35 repair procedures and the remaining 10% by 46 job cards that occurred only once or twice among 126 repairs.

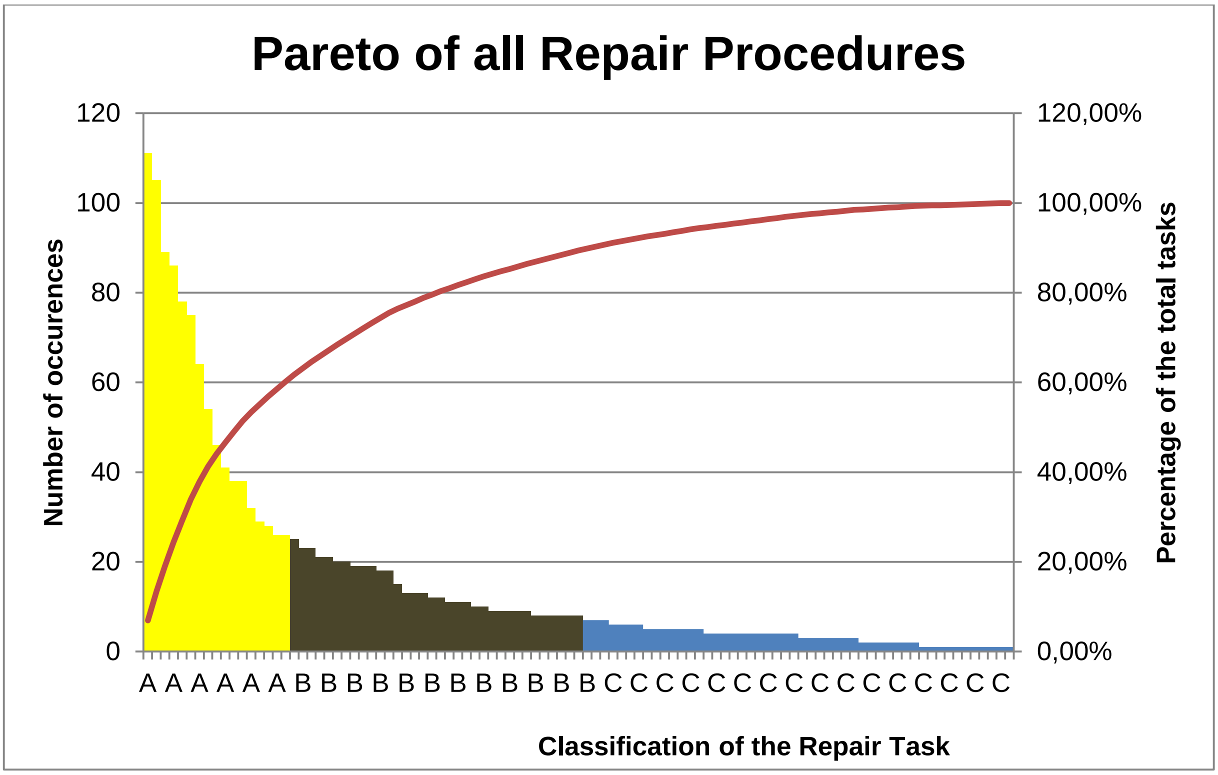


Figure 29: Pareto Chart (60-90-100) for all repair procedures applied since 2010

This shows that a big part of the repair price could be estimated on day one by looking at reoccurring defects and general weaknesses of the element. For example, the procedure for changing the fire seals on an this type of FTR has been issued 103 times over the past five years compared to the 126 FTRs treated at the Le Bourget airframe maintenance shop over the same period.

Figure 31 shows a classification of all repair procedures, service bulletins or procedures validated by the OEMs. The 17 job cards that keep reoccurring and make up for 60% of all repairs performed since 2010 are general wear and tear item replacement procedures for bushings and seals. Unfortunately the awareness about the occurrence of a defect is not enough to issue a reliable quote since the most expensive repair procedures figure among the ones classified as C. They only make up for 10% of all procedures. Among them are repairs on hinge or latch beams which are rarely necessary but can cost over $75.000 if the whole beam has to be replaced.

In summary it is on the one hand good to know with which occurrences wear and tear items have to be replaced in order to issue reliable quotes. On the other hand a quote created only with the use of historic data has to be handled with care due to hidden costs through expensive but unlikely repairs. A first step towards quotes for wear and tear replacement would be reliable historic data which is not directly available today and time consuming to gather.

12.3.Inspections

12.3.1. Task Sequence

Inspection tasks can be tedious and are not optimised in an ergonomic way. The mechanic who inspects the element receives a stack of job cards which guide him through the inspection. They point out every area he needs to take a look at, inform him about places on the element where defects frequently occur and show him the serviceable measure limits of the defected areas. An experienced airframe mechanic develops his own way of performing an inspection and while the job card tasks remain important he usually performs the inspection in his own way. The job cards currently used at Air France are not created by the mechanics inspecting but by other departments that create them using only the component maintenance manual as a reference. Therefore the sequence of job cards isn’t ergonomically suited to the natural way of inspecting the element. In the case of a thrust reverser this leads the inspecting agent to flip over the element a number of times which can be very tiring considering the size and weight of the element. Only on rare occasion fan thrust reversers are locked onto rotatable supports for inspections (see Figure 32).

Figure 30: Rotatable FTR support structure

The left hand side of figure 33 shows the current sequence of tasks for the job card: “CF6-80E1 General Detailed Inspection”. The tasks (numbers 1-7) are:

1) Inspection for cracks and wear on power opening device attachment bushing
2) Visual Inspection for wear on the FWD cascade support ring
3) Inspection of the lower latch beam bushings and bolts
4) Inspection for cracks and wear on the torque box
5) Inspection for wear on the hinge beam bushings and bolts
6) Inspection for wear on the bumper pads
7) Inspection of the hold open rod brackets

If the thrust reverser is placed on a crate and not on a rotatable station as shown in figure 32 it must be flipped over manually five times (between steps 1 and 2, 2 and 3, 3 and 4, 4 and 5 as well as 6 and 7) in order to perform the tasks in the presented order. On a rotatable station this tasks gets easier due to the mechanical aid of the support station. But even on this more sophisticated support the sequence of tasks calls for 3-4 turning actions.

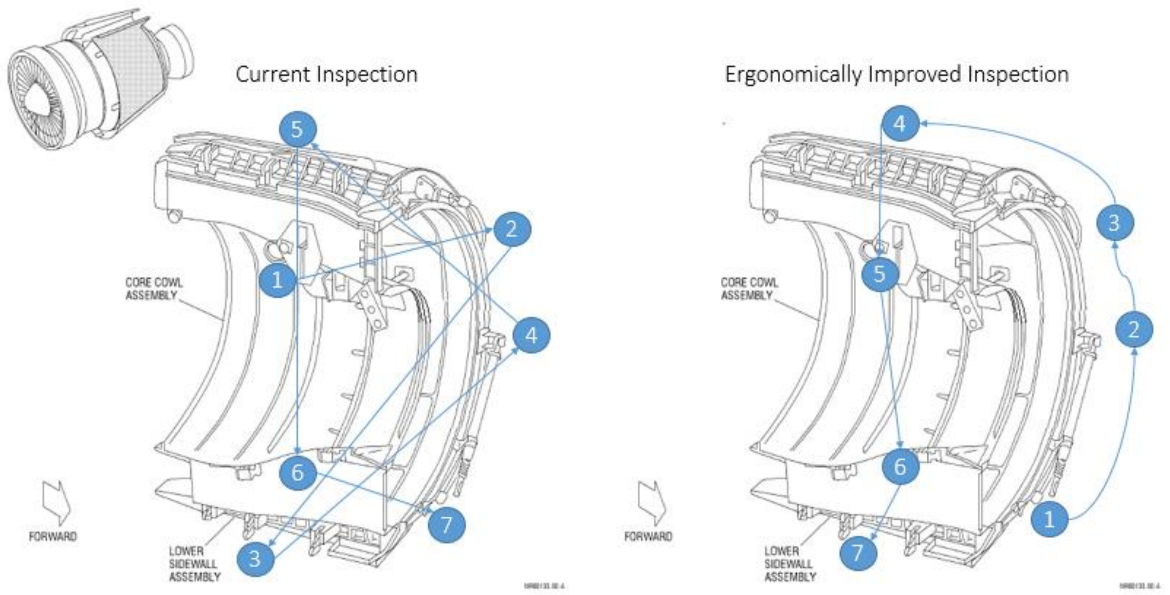


Figure 31: Sequence of tasks for the CF6-80E1 General Detailed Inspection

If the sequence of tasks however would be changed to the way it is shown on the right hand side of figure 33, the FTR, even if it is only placed on a simple crate, has to be turned only once between steps 3 and 4. The mechanic would first inspect all elements on the forward torque box structure, then flip over the FTR on his front side in order to gain visual access to the inner cowl structure and perform tasks 4-7.

Following the natural order of inspecting an element could help to speed up the process significantly and wouldn't interrupt the mechanic so often during his inspection. Additionally the process would be a lot easier for older mechanics who would have to perform less heavy lifting during inspections.

12.3.2. Research Interruptions

Additionally to interruptions due to the unnatural way of looking at the element, the inspection agent has to look up information in the AFI online maintenance database. This information can be serviceable limits for parts, part numbers and repair procedures which can be found in the aircraft and component maintenance manual. The mechanic has access to all data through the internet-based AFI maintenance information system. These manuals can be very tiring to work with, needing significant loading times and automatically closing down when remaining untouched for more than 90 seconds. According to some mechanics the research in the maintenance manuals take up to 75% of the whole inspection time. The following example illustrates the time loss through documentary research:

The mechanic who is performing the inspection discovers that one of the bushings on the hinge beam where the fan thrust revers is attached to the engine pylon is worn down significantly. Since this is a major flight safety issue he will measure the wear on the bushing and open up the component maintenance manual on his computer in order to check the serviceable limit. If he has a computer in the bay where his element is situated the manual will be open after about two minutes (maintenance manuals are several thousand pages long and need significant time to download). In many cases he has to go and find a computer in another FTR bay since there are only five stations available for 32 FTR bays. Once he has found a computer and the manual is open he has to look up the serviceable limits in the component maintenance manual. The research can again be time consuming in a document that is over one thousand pages long. If he finds out the wear on the bushings is too high they have to be replaced. The job card indicates that he has to notify the exact part number (P/N) on the inspection job card in order to ease the work of Production Engineering who analyses the defect. In order to find the P/N he has to close the CMM and start looking in the illustrated parts catalogue (IPL). Again this document is over a thousand pages long and not easy to work with.

The procedure described above is repeated every time the mechanic finds a defect on the element. In order to determine the average duration, the research has been timed during the 15 inspections followed. The histogram in figure 34 shows that the average research time in the technical documents is about 25 minutes.

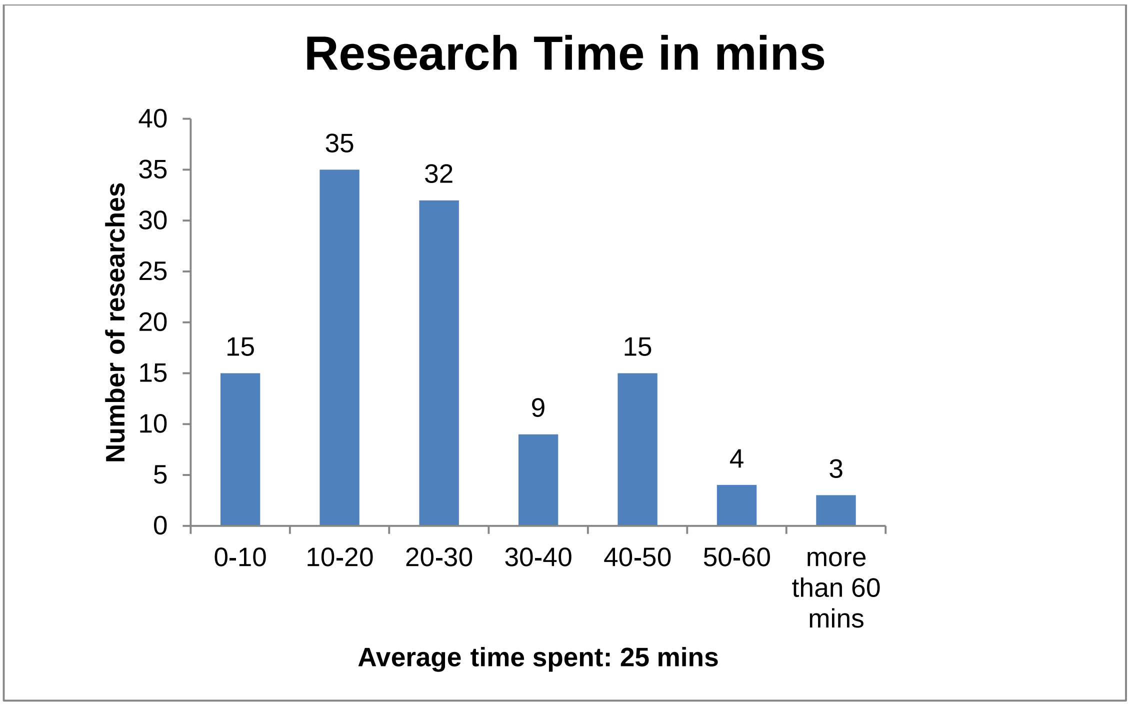


Figure 32: Histogram for time spent on CMM and IPC research.

A defect like the wear of the hinge beam bushings appears on every second fan thrust reverser inspected in shop. Every time the defect is found the agent spends 25 minutes researching the exact same information. This translates to significant savings potential if serviceable limits and part numbers were notified directly on the inspection job cards. Additionally, the research in the online databases lasts that long, that it can be considered as a task interruption to the inspection. Task interruptions are a very serious flight safety and quality management issue in aviation maintenance.

Additionally, the work attitude of many mechanics takes up a significant role. Many mechanics are fed up with the way they have to do the inspection and especially with the research in the technical documentation that they will gladly pause their task and take excessive breaks, complain to other mechanics (and thus interrupt their tasks) and sluggishly complete the information needed for the steps following the inspection.

The interviews already described in the previous chapter contain a couple of questions about the mechanics satisfaction with the inspection job cards. The interview showed that all 15 questioned mechanics were unhappy with the way the inspection job cards were structured and complained about a lack of CMM and IPC research training. More than half of the mechanics said they would be happy to do the research, but they never received appropriate training on how to work with the documentation. More experienced mechanics also commented that a couple of key elements, they always inspected in the past and often found defects on, had disappeared from the job cards without further notice. All 15 questioned mechanics confirmed, that they hadn't been involved in the creation process of the job cards even if they have decades of hands on experience on the products. They also insisted, that they would be happy to work more closely with engineering on the creation process of better adapted job cards.

12.4. Problems within Production Engineering

12.4.1. Information Exchange

Taking a closer look at the turnaround time of inspections and the so-called "shop findings analysis" often referred to as defect analysis in this report, it can be observed that many inspection tasks are performed twice, leading to a significant time loss. This inefficiency is due to bad communication between the inspecting mechanic and the Production Engineering agent that analyses the shop findings.

Once finished with the stack of inspection job cards and having signed off on every inspection item, the production agent hands back all cards to production planning. The job cards are then sent to Production Engineering who is in charge of the assessment of the defects found during inspections. While the process of handing on the cards from production through planning to Production Engineering can take up to one day, the inspecting production agent and the Production Engineering agent never actually physically meet. All the information gathered during inspections is shared and notified on the job cards. In order to make a good assessment of the defects found, the Production Engineering agent needs to physically see the defect (the production agent leaves him a folder with pictures of the defects on the AFI share drive), know where the defect is situated and have exact information about the size[145] of the defect. This information is today rarely available to Production Engineering. In order to get a qualitatively acceptable starting point for the assessment of the found defects the Production Engineering agent has to go out onto the shop floor and "re-inspect" the element a second time: He searches for the exact location of the defect, takes clear pictures for the damage report on which the customer is able to see the location and the extent of the defect and measures the defects in order to know which repair procedure he can apply within the manufacturers regulation. The following examples describes a common situation during the beginning of the defect analysis.

The inspection job card indicates that there is a "crack" on the aft deflector ring. With this information the Production Engineering agent does not know where the crack is located or what the dimensions of the cracks are. Additionally the picture of the crack has been taken so close to the part, that one can see the crack but doesn't give any hints on the exact location. If this picture would be sent to the customer in the damage report he is able to take a decision on whether the crack needs to be repaired, or whether he might be looking at a minor issue that doesn't impact flight safety. To be able to continue his work, the Production Engineering agent has to find the element on the shop floor, look for the location of the crack, measure it and take two new pictures: one of the AFT deflector ring on which you can see the crack and a close-up view which references the dimension of the crack. The correct info on the job card should have been: *"Crack at 8 o'clock on outer AFT deflector ring, ##mm wide, ##mm deep, referencing pictures IMG### (global view) and IMG### (detailed view) in Folder ####."*

In aviation maintenance the defects of an element and the repair measures are discovered only time after time along the disassembly, inspection and analysis of the element. A general problem in the maintenance, repair and overhaul industry is the lack of early and reliable information about the regeneration procedures that need to be performed. Literature on engine maintenance states that "the unknown workloads of the engines in combination with strict deadlines from the customer and the need for efficient capacity usage represent the main challenges for capacity planning in an MRO company"[146]. The same logic is applicable to thrust reverser systems. The usual

[145] Every defect in aviation maintenance has a maximum serviceable limit that is notified in the CMM. Any wear and tear above and beyond these serviceable limits results in the repair or replacement of that part.
[146] Eickemeyer et al., 2014, p.254

workload information known to the staff of an MRO organisation usually starts out very low (almost at 0%) and gains slowly across the disassembly, inspection and defect analysis processes. In today's ideal process knowledge of 100% of the repair actions necessary is achieved after the defect analysis. Even if the real issue that the aviation maintenance industry faces today is to get a steeper and therefore quicker knowledge gain and a lot of possible solutions exist, Air France Industries faces another problem: the loss of information after inspection due to the knowledge transfer at the process interface between inspection and defect analysis.

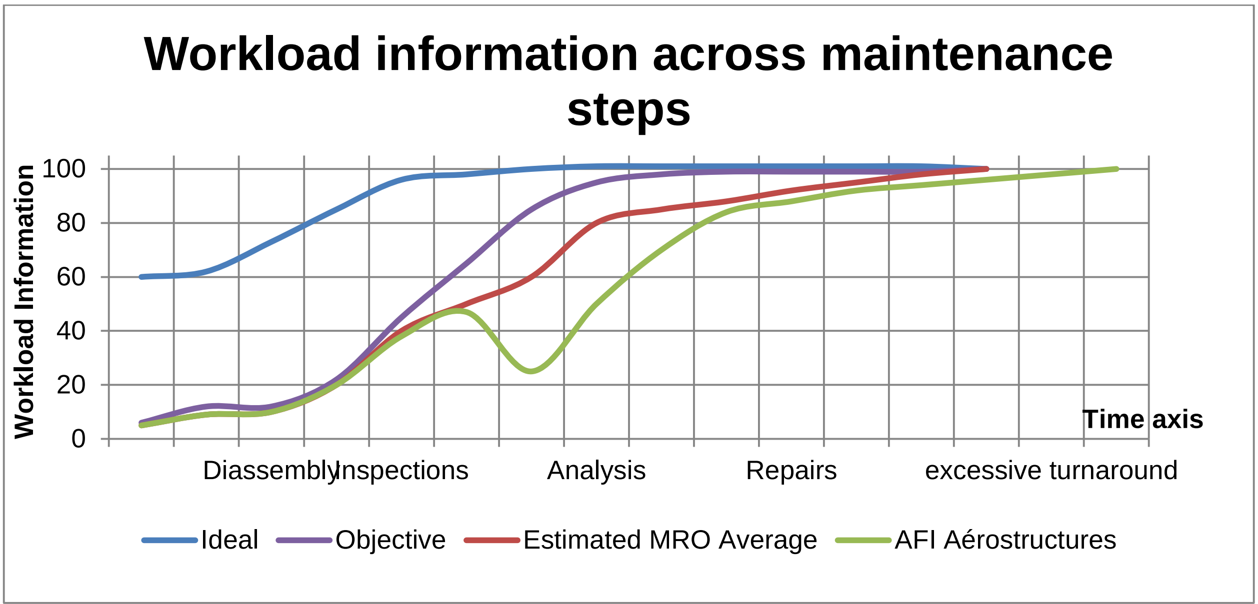


Figure 33: Accuracy of information during the regeneration process[147]

Due to this information loss AFI loses days of turnaround time in comparison with its competitors. A visualisation about the learning curves is depicted in figure 35 where 4 curves have been traced to evaluate workload information gains over time. The gap between the ideal curve and the three others in the beginning is due to previous database powered models to predict aircraft maintenance processes. These database tools are currently being developed. The gap between the objective curve and the current MRO average can be closed by implementing leaner and more efficient processes. Meanwhile measures to avoid the information dip after inspections at AFI have to be evaluated in order to catch up to the competition and reduce turnaround time.

[147] Eickemeyer et al., 2014, p.254

12.4.2. Databases

In order to perform a defect analysis, the Production Engineering agent has to work through 5 databases. Starting from an online job card database he has to work with three MS Access databases in parallel in order to generate exceptional repair procedures, quotes and damage reports. Additionally he uses Air France's internal parts tracking system ASTRE and needs to work with SAP extractions in order to compare the quote to the final numbers issued by controlling. Transferring data from one database to the next and reopening them for corrective actions on numerous occasions eats up a lot of working time and can be psychologically tiring. The loading and compilation times of these databases can also be considered as task interruptions. All Access databases have been installed 5 to 7 years ago as a temporary tool before switching all operations onto an SAP based platform. The change to SAP has still not occurred today and is not to be expected any time soon.

In order to quote a repair procedure, Production Engineering has to enter the amount of labour hours and the material cost into an MS Access database. Material cost consists of consumable material on the one hand, and replacement parts on the other. The price catalogue Production Engineering uses for spare parts in MS Access is not up to date, which leads them to look up the prices in different sources. Some of them can be found in the Air France tracking and logistics database ASTRE, others come from the manufacturers catalogues such as *"My Boeing Fleet"* or need to be enquired by email from manufacturers like UTAS or MRAS.

12.4.3. Damage Reports

The Damage Report currently issued by Production Engineering should be a reference document that can be sent to the customer. Today the damage report does not correctly value the amount of work put into inspection and defect analysis. Additionally it doesn't inform the customer with enough qualitative details about the defects found on his element.

The AFI airframe shop damage report consists of one small picture (30mm x 40mm) and a very short description of the damage. Sometimes it states the corrective action that is used to repair the damage by referencing a chapter of the CMM. All in all it doesn't reflect the working quality Air France has put into the Inspection of the part and does not show the information that is important to the customer. On the current damage report the customer isn't able to see the damage due to small, not informative pictures. In many cases the defect is visible but the picture does not hold any information about the location of the damage. On top of that, stating a corrective action by referencing a chapter from the CMM doesn't really help to understand what amount of labour hours and the material cost the repair procedure yields. Last but not least the damage report, published in English, has many spelling mistakes and thereby transmits an unprofessional image. A little benchmarking and comparing to damage reports issued by the competition and other Air France Industries subsidiaries such as AMES in Dubai show the big backlog the AFI airframe shop has in this field. The current damage report confuses the customer more than it informs him and doesn't reflect the quality Air France sells to its customers.

12.4.4. Quote Reliability

In theory the first quote, issued by Production Engineering after the analysis of the defects and the decision on all repair actions, should be sent to customer support as a reliable price estimation. Customer support uses the quote to communicate an approximate repair price to the customer. Today the repair price on the first quote (called diffusion 1 at Air France) is too far off the final price which is billed to the customer at the end of the maintenance process.

This quote gap is created by various factors:

1) The prices in the MS Access databases do not coincide with the actual market price of the spare parts that appear on the quote. While controlling bills the correct price at the end of the maintenance process, Production Engineering is working with false prices while putting together the initial quote.
2) The material usage and labour hours estimated to perform the repair and maintenance tasks are nowhere near the hours actually spent on the repair task. Since two different organisms issue the estimation and perform the tasks there is no adjustment between estimation and reality. On top of that a lot of material and consumables are used by production during the repair process that weren't initially accounted for when Production Engineering issued its quote. While production can freely order additional parts and materials at the logistics department, they create a material output that Production Engineering never is informed about.
3) The repair procedures suggested by Production Engineering are not always followed by the mechanics. While for routine repairs everything goes according to plan the actions taken by the mechanics may often differ significantly for minor and major repair procedures. Production often refuses to act on minor (routine) repairs without a designated procedure on a job card and hand major repairs, with exceptional procedures on to R&D engineering. No aviation guidelines impose a job card but the fear it could legally be used against them

in case of an accident prevents mechanics from working without a standard procedure. The trust level production brings to the scene is not high enough to perform a major repair defined and designed only by Production Engineering.

The average gap between the first and the final issued repair price has already been measured during the measure phase in chapter 11 (see figure 28). According to customer support the non-reliable quote has had a highly negative influence on customer satisfaction for the past years. Due to non-reliable quotes AFI has earned a high level of distrust among some of its oldest customers and partner airlines.

Figure 36 shows the apparent correlation between the repair price gap and the number of shop findings. It can be concluded, that more defects found on the thrust reverser result in a higher the price volatility after the initial quote. Due to various reasons that contribute to the changes between the two quotes this analysis seems logical. This is not caused by the sum of all defects found but by the likelihood of having a big cost gap on one of them that significantly increases with a higher number of shop findings.

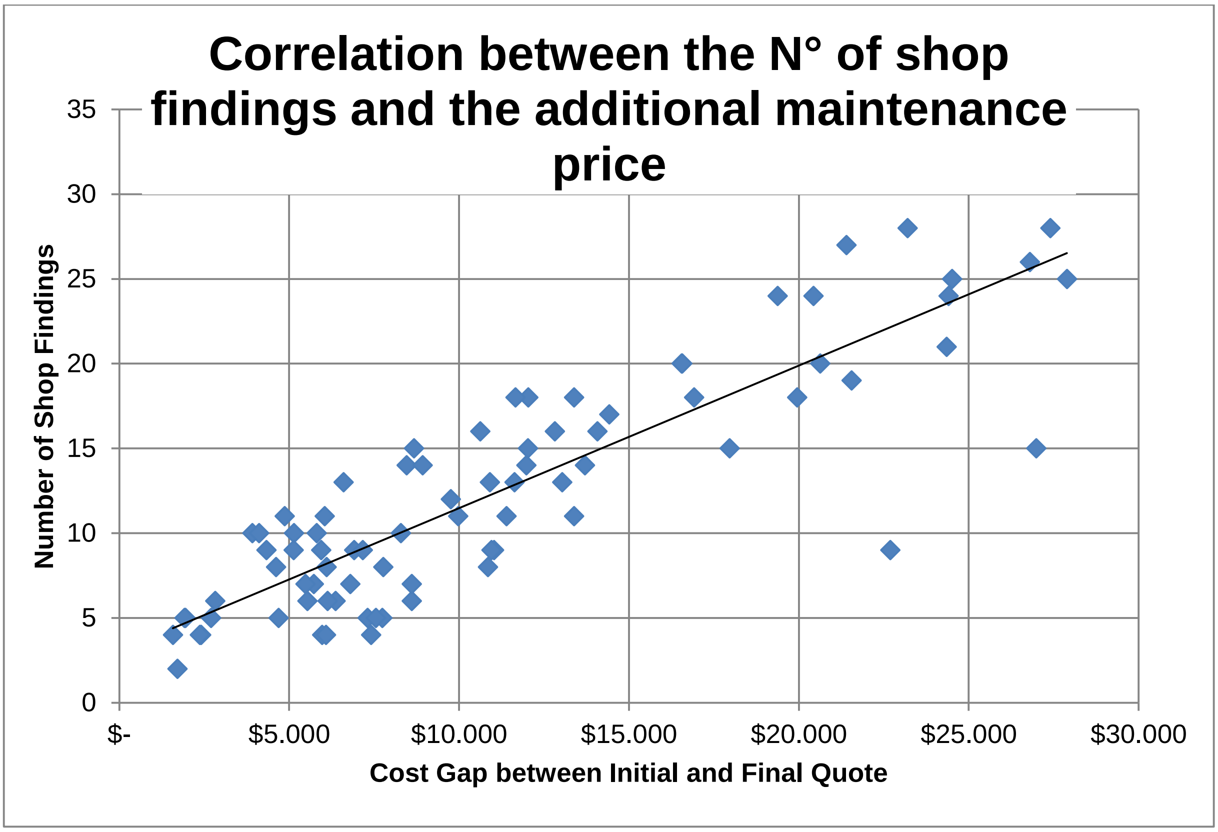


Figure 34: Correlation - number of repair actions vs price gap

12.4.5. Rework

A full defect analysis has four main parts: Preparing the shop findings analysis, finding the appropriate repair procedures, issuing an informative damage report as well as reliable quote for all repairs that need to be performed. These four tasks make up a full time job for the Production Engineering agent. Currently, all of these tasks suffer through the fact that the agent has to perform a lot of corrective actions during the repair process for other departments. Employing mostly highly experienced, former mechanics, Production Engineering is the department most departments turn to when running into a problem along the maintenance process. Some of these corrective actions are:

Lost Job Cards:

Since Job Cards need to be saved into a database when issued, signed when executed and checked by quality management at the end of the maintenance process it is a big deal if they are lost. Due to the high number of job cards circulating and the lack of a tracking system for job cards this happens regularly. In general AFI staff turns to Production Engineering to issue a new job card. They need to log onto the database, cancel the old job card and issue a new one. Both still appear on the final maintenance report booklet issued by quality management and can therefore cause confusion.

Consumables and Parts that weren't on the initial quote:

Since production has the right to ask for consumable material and spare parts directly at the logistics department, those parts do not appear on the quote and remain an unknown expenditure until the final bill is published. This can impact small wear and tear items as well as big replacement parts with a significant price. Frequently, production has to reorder parts that already were ordered once, but lost or damaged during the repair process. This causes double appearances of the same part number on the final bill. Cost due to faulty or damaged spare parts should never be billed to the customer but should be declared as waste and written off in value. Currently the task of correcting these anomalies is given to Production Engineering.

Additional Shop Findings:

Repair procedures may, for practical reasons, cause further disassembly of sub-parts than initially agreed on during the work scope meeting. Further disassembly always yields the risk of discovering further damage, such as cracks, dents or wear, on the element. The mechanic is legally obliged to notify every damage he finds on the element and does so by informing Production Engineering. As a result of this new shop finding, engineering production has to add a new repair procedure to the initial quote. The new procedure has to be presented to the customer, for him to decide whether it shall be executed or not. Delivering late findings to the customer is somewhat considered unprofessional in the French culture and thereby becomes a delicate subject. This goes as far as adding the repair on own account, but thereby delaying the customers delivery date without keeping him informed on the reasons.

Changes to Damage Reports:

Every spare part with a value over and above a material threshold has to appear on the damage report while all spare parts below this threshold are considered wear and tear and are billed through a flat rate. This material threshold, which is usually negotiated between the customer and customer support management, can vary from customer to customer and is confidential information. If the material threshold is unusually low, customer support should inform Production Engineering that there might be more items to be included in the damage report. If the threshold isn't properly communicated it can be very difficult to integrate parts into the damage report weeks after the defect analysis, since they often have already been scrapped by then.

All these actions take the focus off of the four main tasks stated at the beginning of this paragraph, the quality of these suffers and the output is deteriorated. Additionally all rework tasks delay the release of the final quote.

12.5. Non-linear information flow between production and logistics

As pointed out before, the information flow on consumable material and spare parts is not linear but rather triangular. On the one side Production Engineering hands out an estimation of consumables and spare parts to be used to logistics. They order the estimated amount and send it to production alongside the job card it concerns. If the mechanic has not been provided with all supplies and parts needed to perform the repair he has the possibility to order them himself by contacting the logistics. In this scenario Production Engineering is not informed of the supplement part or supply needed for the repair and has no chance of adding it to the customer quote. The expenditure therefore appears on the final bill, since logistics have taken it out of their ordering system, but not on the customer quote. There are two main reasons why the production agent has to order supplement supplies and spare parts:

1) The Production Engineering agent forgot to notify a parts that is vital to the repair. In this case the production agent can go see Production Engineering and the agent who prepared the shop findings analysis will correct his mistake. He adds it to the quote and order the missing part with logistics.

2) The mechanic breaks or loses a part in the repair process. While this can happen at any time there is a standard scrap procedure to write off the broken part and a new one is ordered. Since the production agent does not want his name to show up on the write-off list he will rather order a new part at the logistics department. At controlling this creates a double appearance of the part on the customer’s bill, but nobody is able to trace it back to the mechanic who committed the error.

Logistics has no tool to control material or spare parts orders and do not have the technical knowledge to check the amount of parts per element ordered themselves. This circumstance makes it very difficult for them to assess whether the part has already been ordered, or is really needed.

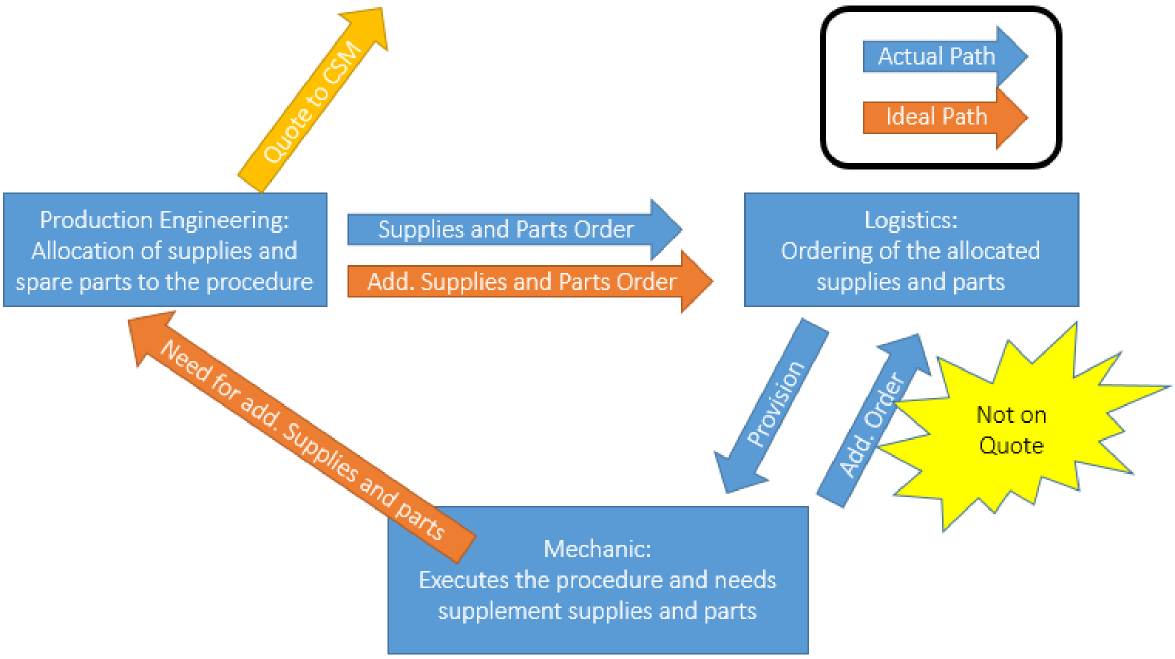


Figure 35: Triangular order process.

12.6. Process Overview

The repair process of a fan thrust reverser can contain a high number of different repair procedures. On average, 21 defects are found on a thrust reverser, during a complete overhaul. Every one of these repairs is assigned to a mechanic by the shift supervisor. The mechanic executes the process according to the procedure given to him on the job card. If he hasn’t finished by the end of his shift, the task is completed by another mechanic on the next shift. Due to the specification of the mechanics it happens, that a mechanic is reassigned to another task in the middle of his repair procedure. In that case, the abandoned task is taken over by someone else, sometimes days later. The mechanic, who is capable of planning the repair of an element with several defects on his own through of his experience, is never consulted during the assignment of tasks.

While interviewing the mechanics it appeared that almost all of them had lost the overview on how far the repair process on the element they were working on actually is. Even the shift leaders rarely could provide valuable information about the progress on a particular element. The global view of the element and the status of its shop visit is currently completely missing at AFI airframe maintenance shop. Additionally, the situation in which a mechanic starts a procedures, but cannot finish it creates a noticeable motivational downturn among the mechanics.

12.7.Historic Data

During the measure and analyse phases of the DMAIC project, there has been a constant lack of accurate historic data. The AFI databases do not provide qualitative information on historic maintenance processes. For the purposes of this project this lack of data was overcome through extensive research in the paper based archived maintenance records. Experts from engine maintenance departments underline that “the available information about an engine has to be used in the best possible way and merged into an estimate of the total workload.”[148] Even though engine maintenance has to deal with a higher level of complexity this logic can also be applied to thrust reversers and other airframe components. Looking into the future, it would be very helpful if AFI started to record maintenance data in order to use them for maintenance planning models. Even the literature on aircraft maintenance point out that “shop data collection efforts […] that identify servicing, repair and overhaul actions taken, as well as parts and supplies used for maintenance work, provide useful information on internal systems”[149] and processes. Data analysis and therefore the knowledge gain on the repair and maintenance process is currently not performed in the AFI airframe maintenance shop.

[148] Eickemeyer et al., 2014, p.254
[149] Kinnison, Siddiqui, 2013, p.179

13. Improve – Improvement Measures

After having analysed the current situation and discovered multiple problems the next step of the project was to find improvement measures. Every one of these measures bears a potential for improvement, an estimated implementation work and implementation risks. All three domains are analysed alongside a detailed description of each measure in the following part. An overall quality analysis, a risk evaluation and an evaluation of which measures to implement is performed in chapter 14.

13.1. Measures for Improved Communication

The first five measures respond the lack of effective and precise information exchange and communication within the airframe maintenance shop. Taking into account that a lot of software, paper-based information sheets and databases already exist, the measures are designed not to hinder the processes by creating another paper-based information sheet. At the same time they shouldn’t introduce new software or databases that would call for training of the current staff but aim to bring immediate and continuous improvement. Long and frequent meetings are also considered an inhibiting factor for speeding up the process. An improved information flow and fewer meetings are among the main objectives for this set of measures on improved communication.

13.1.1. New Generation Work Scope

Since every element treated in the airframe maintenance shop has a unique operation history, flight hours and previous maintenance processes the idea to meet upon arrival of an element in order to determine the scope of all actions to be performed is not new at all. In fact the so-called work scope meeting has appeared again and again over time and has failed again and again due to poor management of the meeting itself or bad layout and insufficient diffusion of the information. The work scope meeting that is currently held is no different. The work scope document does not contain enough added value to the people who weren’t able to attend or invited to the meeting. The first improvement measure is therefore to create a work scope document that improves its informative value for the departments using it. The suggestion splits the work scope process into four stages:

Work Scope Phase 1 – Removal Reason:

Customer Support Management informs about the reason why the element has been removed from the aircraft. If the element comes to shop from a lease return and has to be recertified to Air France standard or comes to shop for an overhaul this is easy to notify. If however the removal reason is due to a defect found during line maintenance, a foreign object damage (FOD) or another technical incident (e.g. corrosion) customer support needs to clarify where on the element the damage is situated. If the location of the damage is not notified correctly the element will undergo a full inspection and might end up in full standard overhaul process. Customer support also has to clarify if an incoming functional test of the element is demanded by the customer.

Work Scope Phase 2 – Preliminary Inspection:

Fundamental engineering performs a short visual inspection of the element together with the mechanic who is in charge of the repair process. Together they check if the element has major damages such as delamination of the composite structure, dents, cracks and other visible defects. In case of a shop visit due to an incident they have to check the extent of the damage in order to make a first estimate about the time and repair actions that will be necessary. The preliminary inspection helps to determine major repair actions at an early stage and help to create a more realistic turnaround time target. The time frame given for the preliminary inspection shouldn't be more than 20 minutes.

Work Scope Phase 3 – Work Scope Definition Meeting:

After the preliminary inspection follows the actual work scope meeting. The first thing to determine about this meeting is who to include. The meeting should be on the one hand restricted to a small group, but still include all important departments who are involved in the maintenance process. The meeting should therefore include:

- 2 persons from Production Engineering: the agent who will analyse the findings and the one who will define the initial work package of job cards.
- 1 production planning agent
- The 2 mechanics that will work on the element during the morning and afternoon shifts
- The customer support manager who is in charge of customer communication
- The quality control agent that will sign the element off as "serviceable" at the end of the process
- The agent from fundamental engineering who performed the preliminary inspection

In order to create a dynamic meeting the 8 agents should meet on the shop floor around the element. The work scope document is filled out during this meeting by customer support who called the meeting and send out the results in form of a PDF document after the meeting.

The "Work Scope" PDF created from an Excel file is also subject to significant changes. While today the tasks to be performed are filled in individually every time a new work scope is generated the new document should be a lot more restricted and contain only check-box options:

- Is an incoming functional test necessary? Yes/No
- Is the element to be cleaned? Yes/No
- Is the wiremesh to be removed? Yes/No
- Which major sub-assemblies are to be removed? A full list with check-boxes is provided on the document.

In order to work with the correct list of sub-assemblies and cleaning options every product has to have its own generic form. That way there will be no confusion while having to complete the same form for thrust reverser with translating cowls and thrust reversers with pivoting doors or even fan cowl doors and inlet cowls.

Work Scope Phase 4 – "Wrap-up" Meeting:

After the element has gone through dismantling, cleaning and inspections the mechanics and Production Engineering meet once more around the element in order to discuss which defects have been found and what repair procedures are to be launched. The meeting helps Production Engineering to get an overview of the defects found while and include the mechanic who can actively participate in the decision about an adequate repair procedure. This exchange can help handing experience from older (Production Engineering) to younger (production) staff and conserves the high technical knowledge level at Air France Industries.

In addition to the verbal exchange about the works to be performed all defects (findings) will be listed onto the last page of the work scope. This list gives a first impression to the customer support manager of the extent of maintenance work necessary. On some occasion he will be able to communicate some of the defects a lot earlier to the customer than today.

This new work scope definition procedure implicates, when executed correctly, more departments and eliminates a lot of unclear communication about what tasks to be performed on the element. Even if the new work scope document is longer it should ideally result in the disappearance of many smaller documents that are supposed to help communication between departments today. Even with the two supplement tasks, its implementation will shorten turnaround time on the long run.

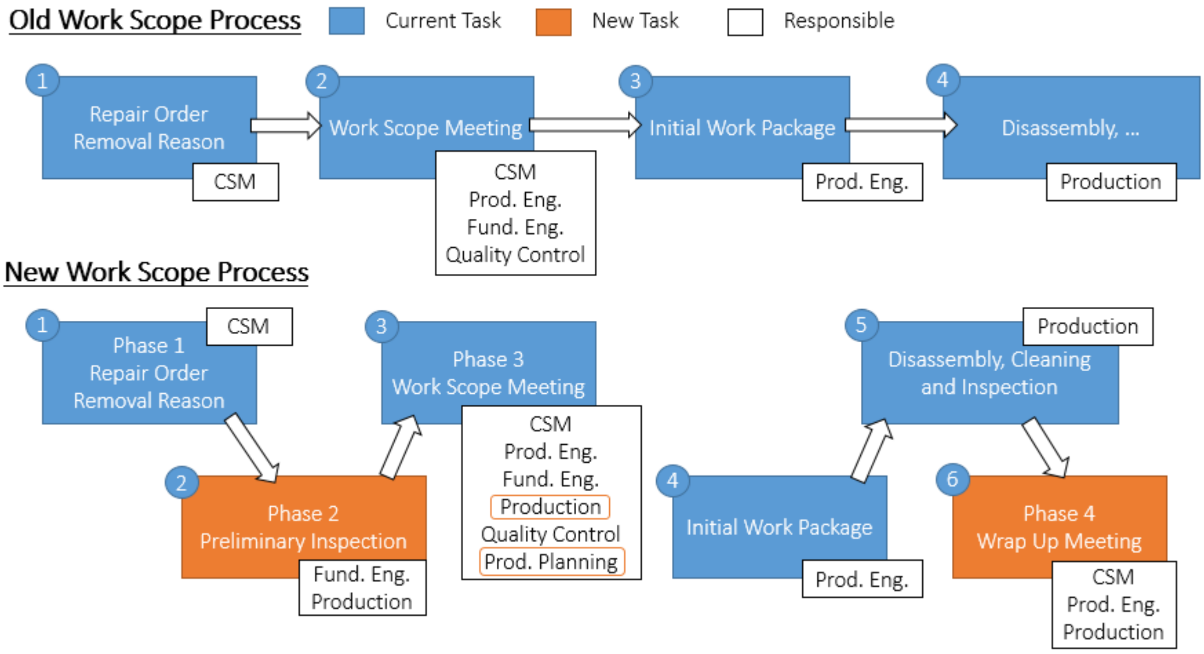


Figure 36: Summary of the new work scope process

The creation of this new MS Excel document calls for an agent who has on the one hand good knowledge of the products treated at aero-structures and some MS Excel skills on the other. He has to define the extent of works that might occur on every different product. An idea for a new generation work scope is shown in appendix A. The new work scope document has to be validated by all division managers, who are involved in the creation process. The same division manager has to assure that the new procedure is properly introduced among his staff and that older, now outdated processes are no longer executed.

13.1.2. Repair Summary

In order to create competitive turnaround cycles, the mechanic has to be aware of the turnaround time target and implicated in the process improvement projects. The interviews and surveys have shown that most of the mechanics do not have an overview of the progress of the element they are currently working on. Upon questioning, none of them was able to tell how many tasks had been executed, or how many days the element had spent in the repair shop. Today, mechanics only receive one job card at the beginning of their shift. Once this job card is properly executed they either wait for the rest of the shift to pass or might ask for the next job card which might not concern the same element. The main question that arises is: How can the mechanics respond to the turnaround time they are asked to perform if they don’t even know how far along the process they currently are? A higher awareness of the maintenance progress made on an element could be achieved through the creation of an overview document. This overview will be displayed in the bay the thrust reverser is treated at all times and has to be updated every time a subtask is finished. The document should inform about:

- **Number of the task:** Gives an overview about the number of tasks there are to be performed on the element and can be a reference to the defect or task. This reference can then be used on other documents such as the defect mapping that is described below.
- **Task description:** Gives a clear description of the task to be performed in a few words. Ideally it contains a verb or a noun that describes the action, the location and the part of the element concerned. Example for an adequate description: **“***Weld repair on the upper sidewall hinge beam fillet fairing.”*
- **Working time:** Number of labour hours advised to finish the entire procedure. This helps the mechanic gain independence as he is capable of finding tasks that can still fit into his shift and choose them accordingly.
- **Localisation of the repair:** This field is optional but can clarify the localisation of the concerned part.
- **Job card reference:** Gives the reference of the job card procedure that needs to be followed in order to complete the task. Especially this field will help the mechanic gain independence since he is able to look or ask for the job card he needs to continue the maintenance process.
- **Documentary reference:** Gives reference to the concerned CMM chapter. This field is optional since it is notified on the job card.
- **Material supply complete:** Shows whether all spare parts and supplies ordered for the repair have arrived. The mechanic knows whether he can start the repair or still has to wait on necessary parts and supplies. This field needs to be filled in by logistics by checking a box if they have received all ordered parts.
- **Task Begun:** The mechanic can check this box when he begins the demanded repair procedure. Along with the next step that shows the completion date of the task everyone how consults the repair summary will now whether the task is still open, has been begun or is already finished.
- **Task Finished:** This field lets the mechanic fill in the date (and time) he finished his work.
- **Name:** The mechanic will fill in his name once he has executed and finished the repair procedure.

Additionally to the repair summary signoff sheet a **mapping of all defects** on a five-view technical drawing could be joined to the document. Since a lot of tasks demand redundant subtasks, the mapping warns the mechanic about other repairs in the same area and prevents redundant work. A suggestion of how the repair summary signoff sheet and the defect mapping could look like is shown in appendix B.

These new documents create a supplementary work load for the department who is in charge of issuing it. Ideally it would be generated automatically from one of the databases used by Production Engineering when they summarize and analyse the shop findings. Independent mechanics, who drive the maintenance process on the element they are assigned to from dismantling to serviceability has been declared as one of the major objectives for the new plant "*Helios*". While a document like the repair summary would strongly support the mechanic, his determination to proactively drive the process remains a prerequisite for its success.

13.1.3. Quality Gate Checks and proactive PP&C

Currently, quality control only checks the documentation of the maintenance tasks performed at the very end of the process. In order to keep their work from being purely reactive, the implementation of quality checks along the process has been suggested. It would diminish the workload of quality control before the final release and make necessary rework procedures appear at an earlier stage. A possible approach to this could be the implementation of quality gates. Usually implemented on mass production lines in the automotive industry this method could be applicable, with a few changes, to the shop maintenance process of aircraft equipment.

Maintenance Quality Gates are intentionally chosen points in the maintenance process that check the quality of the performed actions and the documentation to these actions according to predefined checklists. Only the positive validation of these quality gate steps allows the element to proceed to the next stage in the maintenance process.

The Q-Gate 1 checklist after inspections and defect analysis could contain the following elements:

- All disassembly job cards have been filled in accordingly and signed off
- The total work package of disassembly (according to the customer work scope) tasks has been:
    - Exactly achieved
    - Some sub-assemblies have not been disassembled -> Rework
    - Too many sub-assemblies have been disassembled -> KPI for excessive tasks

- All cleaning job cards have been filled in accordingly and signed off
- All inspection job cards have been filled in accordingly and signed off
- A repair procedure for every found defect has been defined
- All necessary airworthiness directives and service bulletins implementation procedures have been put into action
- A listing of all repair actions is issued and will be used as checklist for the next quality gate
- All checked job cards are compiled to a folder
- Necessary rework, re-inspection, further disassembly, etc. is put into action

The Q-Gate 2 checklist after repairs could contain the following items:

- All repairs on the checklist issued at Q-Gate 1 have been performed
- All repair job cards and additional works sheets have been filled in accordingly and signed off
- All necessary airworthiness directives and service bulletins have been implemented
- The correct painting procedures have been issued
- The checked repair and AD/SB job cards are added to the folder that has been created at the end of Q-Gate 1
- Necessary rework is put into action

The remaining final quality control check to get the element certified according to EASA and FAA standards would be a lot smaller. The folder that has already been created at Q-Gates 1 and 2 is now topped off with the EASA and/or FAA release certificates and the final assembly, test and outgoing inventory job cards. The main intention of this measure is to reduce the rework rate and thereby reduce overall turnaround time.

13.1.4. Damage Report

In order that companies can to use their competitive advantage, they have to present this advantage in a way their customers will not only understand, but also believe it.[150] Since the current damage report is unsatisfactory compared to the ones issued by the competition on the MRO market, customer support has asked for a review and rework of the document. The core question that arises from this topic is the one for the information need of the customer. The information need derives itself from the phase of the purchase decision.[151] The decision whether to repair the element or not, is based

[150] Kleinaltenkamp, 2009, p.115
[151] Kleinaltenkamp, 2009, p.119

on the damage report, and therefore makes it one of the key documents for the purchase decision.

The current damage reports are unclear and give a wrong impression about the work quality put into the inspection and defect analysis and therefore communicates a false value of the *"maintenance product"* AFI airframe structures is selling. Since the actual damage report confuses and upsets the customer with unclear descriptions, small thumbnail pictures and spelling mistakes, customer support has asked for a report that impresses the customer and gives the immediate impression of quality and high technical expertise behind the works preformed at AFI.

Due to high competition on the MRO market customers have to deal with an information overload that makes it more and more difficult to take a clear and well evaluated decision.[152] The customer has the tendency to choose the offer that shows the clearest presentation of the defects found.

In order to be able to sell the maintenance of an element, the customer needs to be informed about the extent and the severity of the damage in terms of flight safety. Therefore a thumbnail picture where the damages can't be seen properly isn't enough. What the damage report needs, are a big, clear pictures of the defect that ideally come with a global view of the element in order to describe the precise location of the defect. Furthermore the actual damage reports have a lot of spelling mistakes and insufficient damage descriptions and repair suggestions in them. In order to overcome these problems the following suggestions have been made:

- The layout of the damage report needs to be changed in order to enlarge the picture and print every defect onto a whole page. This layout change has no impact on the creation process of the damage report and won't cause any supplement tasks to Production Engineering.
- A training will be given to Production Engineering for the new picture format and how to incorporate different views of the defect into one .JPEG file that can be loaded into the MS Access database for damage reports. Several software solutions have already been suggested to create this picture the best one so far being MS Publisher.
- The damage reports will be editable by customer support for the correction of potential spelling mistakes.
- The damage report should include a conclusion page where the customer can check boxes for the repairs he wants to be done.
- Another page at the end will leave the room for Service Bulletins and Airworthiness Directives that need to be implemented.

[152] Kleinaltenkamp, 2009, p.115

- All parts that have been identified as missing during the incoming inventory will be notified in the beginning of the damage report after the cover page

The detailed damage report is now an entire booklet and contains clear information about the defects found. The customer should feel he got his money's worth holding in his hand a detailed booklet that mirrors the quality work performed at Air France Industries rather than the usual 2-4 page defect listing where he couldn't clearly identify what was wrong with his element.

13.2. Measures for improved Turnaround Time

13.2.1. Inspection Job Cards

High level inspections, performed by technically experienced aircraft mechanics are one of the core competences of a well-functioning maintenance repair and overhaul organisation. In order to be able to feed the customer the vital information about the defects on his element as quickly and as completely as possible, a quick and technically accurate inspection process is indispensable.

Today inspections are done according to a package of job card procedures. Every one of these procedures is based on the inspection chapters in the component maintenance manual provided by the OEM. The mechanic has to perform and sign off on every single item on the job card in order to validate the procedure. The sequence of tasks is often not adapted to an ergonomically fluent inspection and rather randomly aligned. When questioned about their opinion on the inspection procedures mechanics did complain about the process being tiring and tedious to execute. An additional field of complaint were the long and extensive research times in the technical documentation. The research for part numbers usually consists of a combined research in the CMM and IPC but can sometimes go as far as looking into the aircraft maintenance manual. Every one of these documents is over 1000 pages long and not easy to work with.

In order to optimize the work flow during inspections the items on the inspection job card have been rearranged (as suggested in figure 33). This rearrangement of items minimizes task interruptions and helps keeping the eyes of the inspector on the element a maximum amount of time. Additionally the tasks have been arranged in a way the element doesn't have to be turned around between every other task. The Gantt chart in figures 39 and 40 shows the reduction in FTR flipping movements (white) and the hereby achieved time reduction of 20 minutes. If an improvement of 20 mins can be achieved on every inspection job card, the total improvement potential could up to four hours (13 job cards) for a complete overhaul inspection only by reducing the number of FTR turn movements.

The second efficiency improvement measure for the inspection process concerns the research in the manufacturer documentation. The mechanic, who is not trained to work with the documentation, currently has the task of researching the necessary information and thereby loses a lot of time. Mechanics face the same defects and are therefore looking up the same information over and over again. It would be a lot easier if the necessary information was looked up once and notified directly on the job card. The only supplement work this change would demand is the verification and the possible update of the job card with every revision of the CMM (bi-annually).

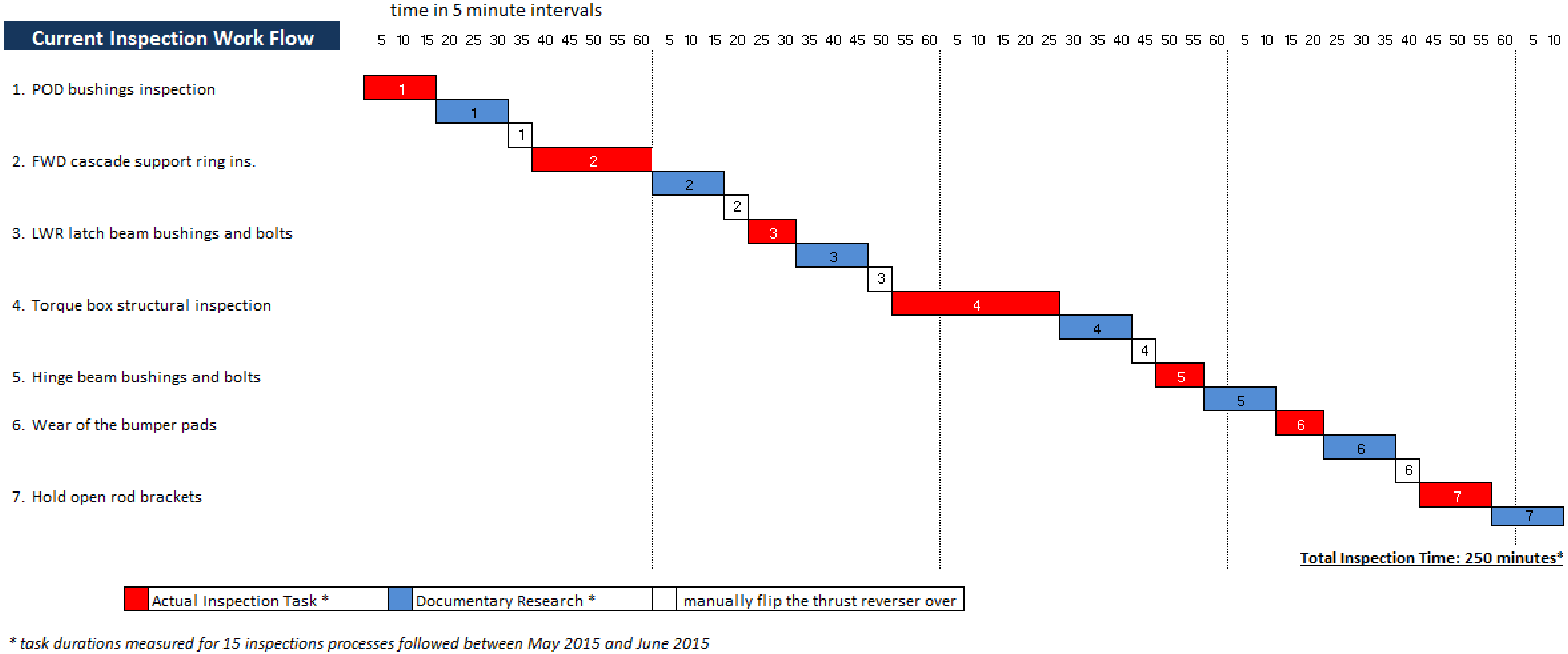


Figure 37: Gantt chart for the current work flow

Figure 39 shows five breaks to turn over the thrust reverser between tasks 1-2, 2-3, 3-4, 4-5 and 6-7. Every time the thrust reverser has to be flipped over a second mechanic has to be called to help perform the physically demanding task of turning the FTR. Additionally every moving break forces the mechanic to put his inspection papers aside and thereby creates a task interruption. Task interruptions are a significant quality management issue and are addressed just about everywhere in the maintenance hangar. Additionally, the blue steps show the research time in the technical documents. They represent a significant time loss since these tasks are highly redundant and appear frequently on inspections performed on this type of fan thrust reverser.

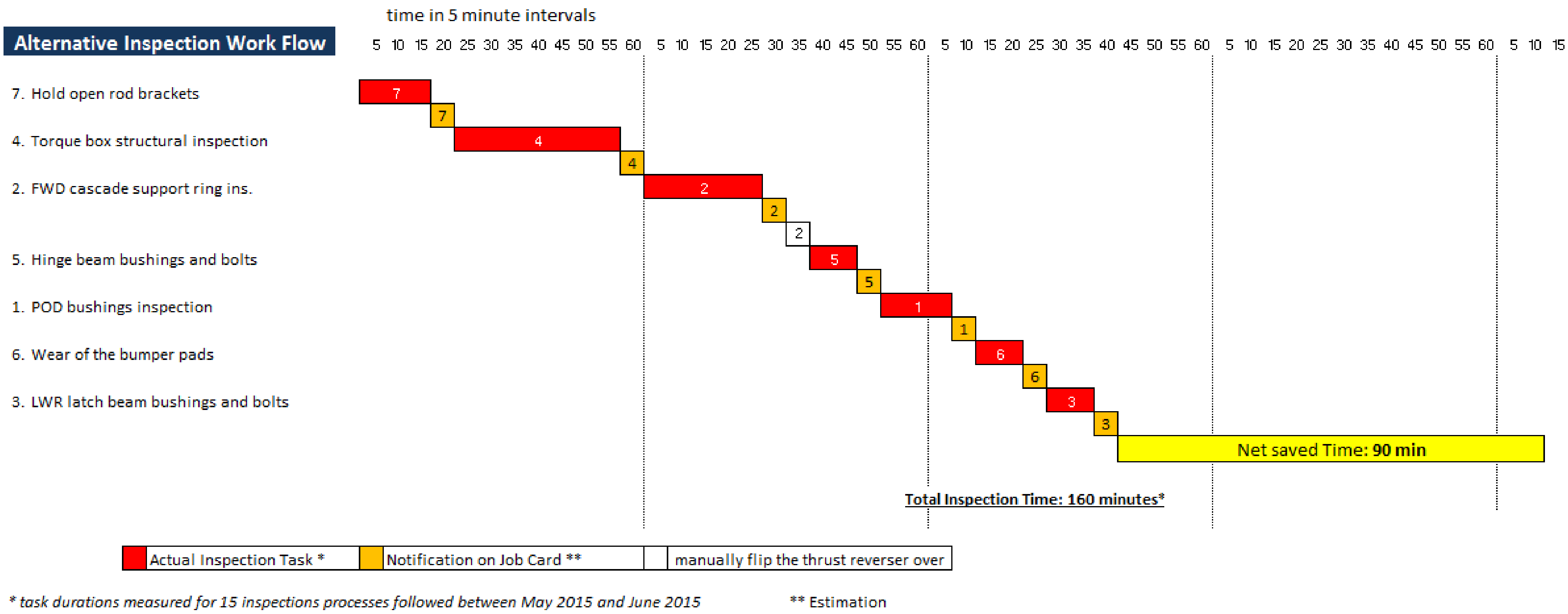


Figure 38: Gantt chart of the improved work flow

When creating an alternative inspection sequence by rearranging the tasks and notifying all necessary information for serviceable and repairable limits as well as part numbers and figures on the job cards, the inspection process gets significantly shorter (Figure 40). Turning the thrust reverser is over only once between steps 2 and 5 (Note that while the tasks where rearranged, the numbering was kept the same) saves approximately 20 minutes. In addition to that, part numbers and limits notified on the job card save up to 10 minutes per task, resulting in potential time savings of up to 70 minutes on the whole job card. The 10 minutes savings are calculated from an estimated 15 minutes research time in the old scenario which are replaced by 5 minutes notification time for checking the correct box on the job card.

The 15 minutes research time is a very conservative number since the average research time has been measured to 25 minutes (see chapter 12.3.2.). Even with this conservative view the potential time savings is up to 90 minutes for 7 job card items. Even though it is not likely to find defects on all 7 items (only if a defect is found the technical documentation has to be consulted) it is very likely to get huge time saving from rearranging the tasks in a more linear and ergonomic way considering that an inspection usually represents at least 5 job cards (13 for a complete overhaul) and the above time savings can be applied to each one of them.

A rearrangement of the items on the job cards calls for a complete renewal of all inspection job cards. This being an unpopular task among engineering staff it will not be welcomed when suggested. In fact the actual task of reviewing all inspection job cards would take no longer than two weeks including the research on how to arrange the items in order to make an ergonomically better adapted work flow.

Please note that this example again uses false time data in order to preserve confidentiality at Air France Industries. It also only shows the example of one out of 33 inspection job cards used. A detailed study of all job cards however showed that the above mentioned problems arise in almost every inspection procedure.

13.2.2. Inspections by Engineering

As soon as the mechanic has finished filling out his last inspection job card, he passes on the stack of job cards to production planning. From there, the package of job cards is redistributed to Production Engineering. The analysis of the defects found during the inspection currently yields a lot of problems described in chapter 12. One of the major problems, the knowledge transfer from production to Production Engineering is causing what can be called a “re-inspection” of the element. Defects have to be localized, measurements are missing and pictures have to be retaken. In total the Production Engineering agent can spend up to one eight hour day “cleaning up” the data given to him in order to proceed with his actual task of defining and quoting maintenance procedures.

A possible approach to this problem dates back some time. In the old days, when the airframe maintenance shop was part of UTA Maintenance, inspection and defect analysis were performed by the same agent. This procedure changed in the last 10 years when the executive management of the company opted for the idea to homogenize the organisational structures with the ones in line and hangar maintenance. This meant that now mechanics would execute a job card procedure and engineering would only control the process from the outside. These restructuring efforts have significantly deteriorated the process and created multiple process interfaces which hinder knowledge and information transfer. The basic idea behind this improvement measure is to go back to the old structure. This would see Production Engineering go back onto the shop floor and perform inspections. Experienced staff helped to set the hypothesis, that a Production Engineering agent could, with his many years of experience, inspect the product in half of the time a mechanic currently needs and would subsequently be more efficient on the defect analysis.

The hypothesis that Production Engineering would get through inspections quicker, is supported by time estimations given by production management itself. Based on some historic data from UTA days and the opinion of some senior Production Engineering agents the inspection time spent on an inspection could be reduced by 40-50%. Additionally the rework time spent in the department today would disappear entirely causing another 25% reduction to the overall processing time for defect analysis. These two reductions would result in an overall 30-35% reduction of the turnaround time for inspections and defect analysis. On top of the net reduction in turnaround time this measure frees one mechanic of his inspection tasks and increase availability of staff for repairs and other supporting procedures. Figure 41 shows the potential of the improvement measure. Considering eight hour shifts the measure can save between one and two days of turnaround time.

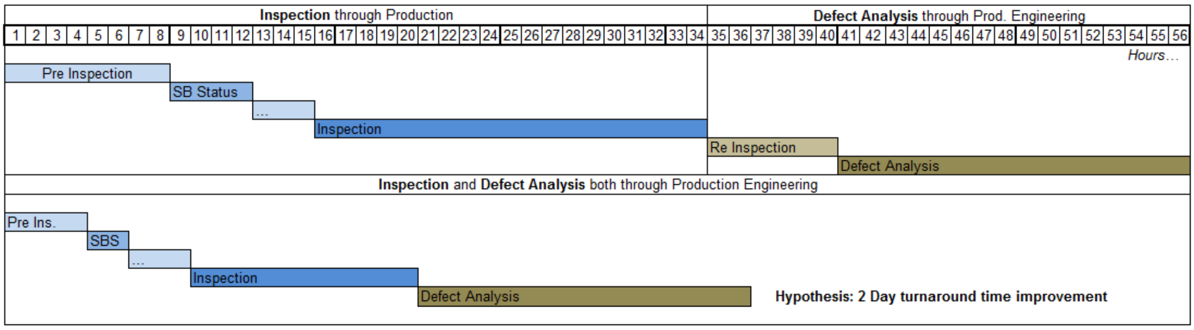


Figure 39: Improvement potential through Prod. Engineering inspection

It remains important to mention that a complete shift of the inspection tasks from production to engineering represents an increased workload for the latter and needs to be compensated by removing other duties from their task list. While the implementation of this measure seems fairly easy the most difficult task would be to convince mechanics, which follow training in order to be able to do inspections, and Production Engineering, who usually are former mechanics which have been promoted *“off the shop floor and into an engineering position”,* that this measure will in fact help the company and doesn’t undermine their well-earned position in the company’s hierarchy.

13.3. Global Improvement Measures

13.3.1. "Tablet Inspection"

Looking at the overall process of inspections and defect analysis with paper based communication and MS Access databases with no utilisable historic data collection system, it became apparent that the aero-structures shop would sooner or later need a big innovative step in order to defend their leading technological position on the MRO market. An example for such an innovation could be the incorporation of the whole process into a "*21st century*" communication and data processing device. The brainstorming with a few members of production and engineering brought forth computer tablets and reality augmented goggles. While augmented reality might go a little too far the idea of incorporating the entire inspection process onto a tablet device seems feasible.

The idea of the project is simple: Create a computer tablet based application that handles the entire inspection and defect analysis process and has as output values the damage report and a reliable quote for the repair price. With this application the person performing an inspection on a customer element would step up to the element, tablet in hand, and follow the tasks of the application one by one:

1) Select a product type (e.g. CF6-80E1 FTR) and open the element you want to inspect from the database by entering a distinctive reference (work order, part or serial number or other newly created reference).
2) Once opened the application displays the FTR with all zones to be inspected lit up into distinctive colours. Additionally a side bar could show information about removal reasons from the aircraft, due dates and other relevant customer related information loaded into the database from the work scope.
3) By tapping on the highlighted zones of the FTR on the screen the procedures appear step by step which then need to be inspected on the actual FTR.
    a. If no defect is found the inspecting agent can check a box and sign off the task with his electronic signature (e.g. fingerprint scan)
    b. If a defect is found the procedure goes on to step 4)
4) If a defect is found the inspecting agent is given a direct link in order to take a picture of the defect. The device imperatively asks the agent to take two pictures: A major view of the element with the visible zone of the defect and a detailed view. By touch, arrows, circles and measurement indicators can be added to the two pictures.
5) Once both pictures are taken the application automatically recognizes the area on the FTR where the defect lies and opens the according chapter of the CMM. The integrated CMM informs about the serviceable and repairable limits of the

specific area and suggest repair procedures. If however the inspecting agent does not agree with the suggested procedures he can select a different one from the list or send the pictures alongside with a description of the defect and the dimensions directly to R&D engineering for a DOA procedure.

6) If the repair procedure is known (standard procedures, SRM or CMM procedures, etc.) the next step is to select from a list the spare parts and consumable materials needed to perform the repair. Concerning consumables the application would ideally be able to calculate the amount needed to perform the repair from the dimensions of the defect. While the information about parts and materials is handed on to logistics for ordering, the repair procedure is directly sent to production planning in order to launch the job card.
7) Once the application has all necessary information about material, repair procedures or information for the launch of a DOA procedure it automatically carries on with the following inspection task. Every one of these tasks has an electronic signature, just like they have today on the job cards.
8) At the end of the inspection when all tasks have been executed, the application should have all the necessary information to compile the damage report and the first reliable quote. By signing off on the entire inspection process the inspecting agent sends the documents to customer support management for further review. The documents isn't available before the final sign off on the inspection but can be downloaded from a computer based sister-database by a group of authorized personnel.

It is absolutely necessary that changes can be made to the different inspection tasks and defect descriptions given in the first place if they are found to be incorrect or inaccurate later during the process. However every subsequent change has to be signed off on in order to keep a traceability of changes. The application could help with predictions on turnaround time and keep track of defect or repair probabilities. It helps to keep an exploitable and reliable history and reveals information on occurrences of repair procedures, occurrences of consumable materials in repair procedures and information for other performance measuring indicators.

The implementation of such a modern inspection method seems like a huge, time consuming project but is in fact closely related to the development time of the application. The cost of implementation would just likewise be closely linked to the development cost of the application. The support (any tablet PC with an integrated camera) can be leased from a subcontractor who provides maintenance on the tablets and insures that they remain operational at all times. The staff using the tablets in the maintenance shop has to borrow it from a central electronic tracking station which monitors the time intervals it has been used and the person who used it in order to prevent theft or destruction of the tablets. Generally speaking the implementation and acceptance among the mechanics and shop floor staff is estimated to be rather easy since they all are enthusiastic about new technologies and modern “toys” like tablet PCs.

13.3.2. Tailored Fit Work Package Creator

Currently the number of job cards for every thrust reverser type is so high, that barely anyone is capable of keeping an overview over the architecture of these procedures. In fact, there is no existing documentation of the job card structure, showing the links between job cards and explaining the different levels of maintenance that can be applied by launching specific work packages. As a direct, result only a few paths are known (commonly the ones followed for AF repairs and overhauls) which prevents the company to create on demand and tailored fit work packages for customers. Every time the customer demand aims beyond a general visual inspection without dismantling the element is in danger of being completely disassembled and overhauled per Air France standard. Customer support confirms, that they are currently unable to quote individual maintenance levels (dismantling and inspection levels) due to the unknown job card landscape. On occasion CSM ends up offering work packages to customers without knowing whether they can actually be delivered.

In order to start working on the documentation of the job card structures and determine restructuration of job card fields (inspection, assembly, disassembly, etc.) the first part of the measure is to create an overall architecture for every product line, showing not only every available job card, but also the existing links between the cards.

Since Air France is not selling its own maintenance policy to its customers, but distinctive CMM tasks, Service Bulletins and Airworthiness Directives, the second measure would be to compare the job cards to the component maintenance manual and see which CMM task coincides with which job card item. This involves the creation of a database that contains a list of all CMM tasks and the job card items covering it. The input value of the database is a form with the main sub-assemblies that can be checked by customer support if they want them to be dismantled and inspected. From a known job card structure and its coverage of CMM tasks, it is possible to create a work package from single job card items that is able to respond to a specific “tailored fit” maintenance work package. Once these work package have been tried out on AF material and succeeded in displaying the correct tasks customer support management can starting to sell individual work packages to its customers. A first iteration for the form, the job card structure and the CMM compliance has been created in an MS Excel worksheet and is partially displayed in Appendix E.

Once this analysis is completed a second step has to be launched that re-analyses the labour and material cost of every CMM task (job card item). The same analysis has to be done for every Service Bulletin that customer support management sells to its clients. This quoting of single repairs and CMM tasks allows AFI to attach a direct cost, split up into labour and material cost, to every task issued on the work package. The values compiled by this program should show a reliable estimation after a few iterations. Customer support management could use this tool in order to answer to individual work orders and use it to sound the market and compare their estimation to the offers from competing MRO organisations.

To go one step further, the work package creator could be equipped with an early warning system for frequently occurring repairs. Looking at the history of repairs on CF6-80E1 thrust reversers the Pareto analysis discussed in the previous chapter shows that 17% of all known repair procedures account for 60% of all defects found over the last five years. This information could, together with the knowledge about the demanded work package and some data about the operating history of the aircraft[153], provide an accurate prediction of what repairs to expect on the element.

A first approach to this measure has been created and is displayed in Appendix E.

[153] Information about the aircraft's operating hours and cycles as well as the environment the aircraft was flying can give vital information about likely defects to be found. Aircraft with many cycles actuate their thrust reverser more frequently and have therefore more wear on all moving elements like actuators and translating cowl guides and hinges. Aircraft that operate in a cold and icy environment are more likely to metal fatigue defects while aircraft operating in humid marine environments are more likely to be exposed to corrosion.

14. Evaluation of improvement measures

In order to assess the eight improvement measures presented in the previous chapter, two management tools have been applied to identify the most suitable measures for immediate improvement. The aim of the analysis was to underline the feasibility of the measures and to ease the choice for plant management and the five division managers, to whom the measures were suggested in a presentation. Both management tools have previously been described in the literature review.

14.1.FMEA Failure Mode and Effect Analysis

Before presenting the set of improvement measures to the plant management, it was decided that a risk analysis tool was to be presented. Since the tool was at that point unknown to them, a few application examples for the presented measure were presented alongside the tool. The process FMEA analysis was chosen to be most suitable for this study. The application theory of the process FMEA has previously been described in chapter 7 of the literature review.

Every risk has been quoted in 3 categories: Probability of incidence, severity and probability of detection. These three category marks result in the risk priority number (RPN). A high RPN is the major indicator for a high failure risk. However single category marks can also be enough reason to react immediately on the potential failure. When the severity rating for instance indicates a flight safety issue the failure mode has to be handled with absolute priority and utmost care. For this project, the deterioration of customer satisfaction has also been considered an event of high severity alongside the flight safety.

The results of the FMEA for the eight suggested improvement methods showed different problems. Often, the main risk of the improved process was the acceptance of the new process through the operational or supporting staff (mechanics and supervisors). For every one of these possible failure modes the determined RPN was not significantly high since the refusal of a new process would not endanger flight safety or cause an immediate deterioration of the customer satisfaction.

During meetings on the issue, many solutions came up on how to overcome acceptance difficulties. The key element herein is the demonstration of improvement potential through improved working conditions once the measure is implemented. The usage of new documents can be achieved through creation of work evaluation incentives. If a mechanic is evaluated on the completion rate of his tasks, and the only document displaying this rate is the repair summary suggested in chapter 13, he has a strong incentive of tracking his work with the help of this new tool.

Improvement measures that call for radical organizational change or a change to the main working documents of the operational shop floor staff have shown higher RPN ratings. This higher RPN are mostly due to the high severity if the changed documents result in forgotten maintenance tasks and thereby become a flight safety issue. If the probability and severity of the failure modes are too high, the standard preventive measure would be to include regular quality checks in the ramp up process of the improvement measure and increase the frequency of quality control checks during the time of implementation. Especially the changes to the inspection job cards and the new “tailored fit” work packages are very likely to call for such supportive measures like an increased frequency of quality control, re-checks and double checks.

A complete FMEA usually contains steps that designate a responsible for every detected failure mode. Since none of the eight improvement measures has officially been approved when the FMEA was created this step was not implemented yet. A more accurate and detailed FMEA (e.g. one for every improvement measure that is implemented) is necessary once the implementation of the measure is approved. Especially big projects like the tablet PC inspection should have designated work groups that work on a detailed FMEA before launching the product. Many failures and potential rework can be prevented by using a FMEA before launching the development of the new inspection application. Finally it has to be pointed out, that the RPN rating shouldn’t be the only criteria the FMEA analysis is evaluated on. Whatever the RPN is, all risks and their possible impacts have to be evaluated by themselves.

The FMEA implemented for this project is displayed in Appendix D.

14.2. QFD – Quality Function Deployment

The original QFD analysis was created in order to point out complex connections between requirements and functions when developing products or processes. In this specific case only a part of the QFD method was extracted in order to correlate the impact of the measures with the customer requirements. The QFD model following the House of Quality (HoQ) method has been used for this analysis. Its implementation served as a decision aid to delimit the measures that are most likely to respond to the selected customer requirements.

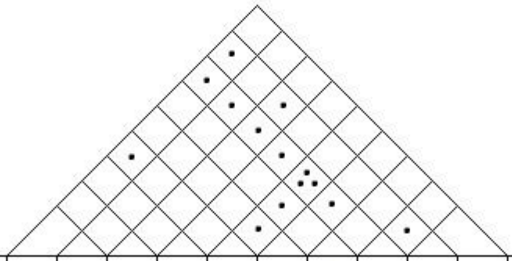
Every customer requirement is accompanied by the specification that points out whether it responds to an internal or an external customer requirement. In order to improve quality at AFI, a recent development in the company’s corporate philosophy states that every internal department has to be treated like a “customer” in terms of process quality.

As customer requirements, the set already defined in chapter 9 has been used to evaluate the merit of each measure (step 2 of the HoQ). Since promptness and reliability of the quote are considered being a trade-off that can hardly be achieved at the same time a weighting of the requirements has been established for both cases. The first evaluation weighs the requirements that have a high impact on a quick quoting process, the second one leaves the time constraint aside and concentrates on the reliability of the quote.

In order to find a correlation (step 6 of the HoQ) a grading key has been defined grading every improvement measure on its performance on every customer requirements. If the measure negatively impacts the requirement, it has been given a negative mark (-1), if it doesn’t impact the requirement the grade has been left at zero whereas all improvement has been graded with 1 for small improvements and 3 for significant improvements.

The correlation and conflict (step 8 of the HoQ) has been evaluated showing one dot for supportive correlation between two improvement measures. Three dots show that one improvement measure makes the other one obsolete. Except for one interference between tablet PC inspection and improved inspection job cards (the first making the second obsolete) the improvement measures do not inhibit each other and show rather positive correlations.

Correlation	Mark
worse	-1
unchanged	0
small improvement	1
big Improvement	3



Customer Group	Improvements methods / Improvement measures	modified workscope	repair summary	Quality Gates (INS et ASS)	Damage Report	Inspection job cards	Inspections by engineering (alone)	Inspections by engineering (couples)	Tablet Inspection	Work Package Catalogue		Importance (1 to 5) **Promptness**	Importance (1 to 5) **Reliable**
both	TAT Diffusion 1	0	0	0	0	1	3	1	3	0	-	5	2
both	TAT Diffusion 2	1	1	0	0	0	1	1	3	0	-	2	1
both	TAT Total (reliability)	3	1	1	0	0	1	1	3	0	-	1	1
both	Reliable Diffusion 1	1	0	0	1	1	1	1	1	3	-	3	5
both	Minimal Quote Gap	0	1	0	0	1	0	0	0	1	-	2	5
customer	Defect Findings Quality	1	0	1	3	1	3	3	3	0	-	3	4
internal	Knowledge Transfer	0	1	0	0	0	0	3	0	0	-	4	3
internal	Documentation Quality (CSM)	3	3	0	3	0	0	0	3	3	-	3	3
internal	Global Process View	3	3	1	1	0	1	1	1	1	-	3	3

Evaluation **Promptness**	1,1	1,0	0,3	0,9	0,5	1,3	1,3	1,8	0,9	0,0
Evaluation **Reliability**	1,1	1,0	0,3	1,1	0,6	1,0	1,2	1,5	1,2	0,0

Figure 40: QFD - House of Quality

The results of the QFD analysis show that the tablet PC inspection has the biggest improvement potential on the selected requirements. Inspections and defect analysis done by the engineering department also show good results. While the tablet PC inspection project comes first in both evaluation criteria (promptness and reliability) the inspections by engineering mainly improve the turnaround time aspect of the process. The analysis shows that the reliability of quotes can also be improved by “tailored-fit” work packages and the modified customer work scopes. The QFD shows that both scored very well on the internal customer requirements meaning they might be good immediate measure to improve internal communication at AFI.

15. Control - Implementation Instructions

All improvement measure their evaluations where presented to a committee consisting of the executive management of the aero-structures facility. Alongside the plant manager the engineering division, operations division, manager of the "*Helios*" plant project, quality control division and customer support division managers were present at the presentation. The improvement measures were met with general approval by all members of the committee. The following chapter discusses the implementation of measures decided during the debate following the presentation and the next steps to be taken.

15.1. Cost Estimates

The absence of initial cost estimates and the incapability to quote customer offers accordingly was considered a do or die project very early in the improvement process. In order to find a quick solution and a working tool for customer support management, maintenance rates in USD for all products were created for three different maintenance levels.

Maintenance Level	Included in Quotation
Single Repair	Quotation of labour hours for incoming tasks, visual inspections and outgoing testing. No elements are disassembled from the element in the first place. Cleaning and Painting of the element are NOT included.
Intermediate Repair Program	Quotation of labour hours and materials used for incoming tasks, intermediate dismantling, inspections, wear and tear repairs (everything below a predefined material cost threshold), assembly and final testing. Additionally cleaning of the element and outer surface painting are included in the rate whereas surface treatments and complete painting not included.
Standard Overhaul Program	Quotation of labour hours and materials used for incoming tasks, complete dismantling, inspections, wear and tear repairs (everything

	below a predefined material cost threshold), assembly and final testing. Additionally complete cleaning and painting of the element are included in the rate. Surface treatments are partially included.
Major Parts Price Catalogue	A Catalogue for labour hours and material cost for major repairs. This catalogue gives the ability to add specific repairs to the chosen repair program if the demanded by the customer.

Figure 41: Quoted maintenance programs

All quotes are based on historic maintenance data and on job cards indications combined with a return on mechanic experience. The quotes include both complete CF6-80 series nacelles, GE90 fan cowls and thrust reversers, complete CFM56-5B nacelles as well as CFM56-5C and -7 thrust reversers. A first approach to V2500 nacelles was tried but cancelled due to unreliable and scarce historic data. These quotes will significantly help customer support management to respond to offers in a quick and detailed manner. Additionally CSM is now able to compare its repair price to the one declared by the competition in an online competition comparison database.

15.2. Damage Report

In order to improve the knowledge transfer and the communication interface between engineering, customer support management and the customer itself, a new damage report layout has been implemented. It now contains two images of the defect: A global view of the element and a detailed view of the damage. This new image layout has been asked for due to many localisation problems that frequently appeared in the past. Additionally the damage report contains a list of parts that were missing upon arrival and a list of Service Bulletins that are recommended for the upcoming shop visit. The customer is now able respond and choose the SB he wants by checking the boxes on the damage report and returning it to customer support.

In order to provoke a smooth change between the old and the new damage report the creation interface has been left unchanged. The new pictures have to be created with MS Publisher, a very intuitive tool that has common functions to MS Word and MS PowerPoint and are commonly known to Production Engineering staff. On top of that a standard work instruction presentation has been created and small learning courses have been provided to the workers to help the smooth transition.

15.3.Rework of Inspection Job Cards

The suggested renewal of inspection job cards has not been adopted completely. The engineering division manager feared that the workload his agents had taken up in order to create complete part number listings and serviceable limit information on job cards would be too high. He also added that numerous revisions of the job cards had been undertaken in the previous years. He did not show any insight in the dissatisfaction of the mechanics that, according to him, were implicated in the revision and creation process over the last years. After some convincing and insistence from operations management he agreed on the fact that the current situation does not favour a good and ergonomic inspection. As a direct result from the meeting a "Task Force" will be charged with the project of improving the job card structure in general. Later it has been decided that the "Task Force" will be a new department named "documentation engineering" and will be permanently charged with the creation, revision and improvement of job cards from now on. They will have to conduct a survey among the mechanics on what expectations they hold towards the documentation they are working with. The suggested improvement measures for job cards have been communicated in a summary paper and are to be implemented by this new department.

15.4.Rework of Work Scopes

The initiative of improving and expanding the work scope process has been fully adopted and validated by all parties during the presentation. The implementation will be completed in accordance with the four steps defined in chapter 13. Customer Support Management was selected to be in charge of the implementation process while the quality control will correct the new working document since it will be the basis for their final check before issuing the release certification. The first step of the work scope will mostly stay unchanged. In order to put into place the second step a job card has been created (for CF6-80 series FTRs only, others are in progress) to give an official procedure for the preliminary inspection. The third work scope step which will detail on a summary page all tasks of the initial work package and define a dismantling level has also been created together with an experienced mechanic, a Production Engineering agent and a customer support manager. The validation has currently been put on hold due to its strong interference with the newly defined "tailored fit" maintenance programs. It is very likely that the implementation of these programs will contain a document describing the dismantling level and the preliminary works performed upon arrival of the element and thus, the content looked for in the work scope step 3. The last work scope chapter, which suggested a meeting around the element on the shop floor after the defect analysis has not yet been implemented. Nevertheless the idea has been embraced by mechanics and Production Engineering and currently and already exists in form of an unofficial meeting held to go through the defects found during inspection.

15.5.Inspections

Instead of changing the organisation of inspections, as initially suggested, the executive improvement meeting has only resulted in informative measures that are supposed to raise quality aspects between operations (mechanics) and engineering. The reason why the radical changes initially suggested were not approved are extensive inspection training courses paid to the mechanics within the last few years.

15.5.1. Expectations of Mechanics towards Management

In response to the numerous disappointed voices and complaints about poor working conditions and tools coming from “producing staff” on the shop floor, the executive management has decided to implement yet another survey among the mechanics in order to define all areas in which working conditions have to be improved. In terms of job card ergonomics this task will fall to the newly created documentation engineering department who will be in charge of defining the needs of the mechanics and implement them into new and reviewed job cards accordingly. Additionally a training course will be offered for mechanics to improve their skills while working and researching in the technical documentation. In general it appears that this decision sees once more the needs of the mechanics pushed aside since the documentation engineering department seems to be radically understaffed and not capable of coping with the new work load. It is therefore very unlikely that significant improvement for the mechanics will be seen on the short term. Only the rearrangement of inspection items in order to create a quicker, more ergonomic work flow will be a priority for the new department since it has been proven to bring significant reductions in turnaround time.

15.5.2. Expectations of Management towards Mechanics

In return to the work improvement for the shop floor staff these will be evaluated among a quality standard when delivering job cards to Production Engineering after inspection. Detailed information and workshops will be implemented, in order to teach the mechanics what kind of information is needed on job cards. Therein the mechanic will be informed about:

- How to take informative pictures of the element
- How to save this pictures in order to be found quickly on the share drive
- What kind of defect description is informative and what elements are necessarily to be notified
- How to describe the location of the defect on the element correctly
- Etc.

A survey in Production Engineering will be held beforehand in order to complete the list above and quality audits will randomly be performed. To go even further a performance indicator for the number of defects that needed rework (re-inspection) was suggested. The implementation of this performance indicator has since then not been further discussed.

15.6.“Tailored Fit” Maintenance Programs

The suggestion of a working tool that helps define “tailored fit” work packages for customers based on the currently existing job cards will be implemented. For the moment a prototype for the CF6-80E1 thrust reverser has been created. In order to create this new tool the first step was to develop a hierarchy of all existing job card. In parallel the definition of sub-assemblies that are likely to be disassembled has been created. This disassembly list is formatted as a MS Excel form that is filled out during the work scope step 3. From this form MS Excel automatically creates a set of job card items that need to be launched in order to fulfil the defined dismantling level. A prototype for this automated program has already been created for CF6-80 series thrust reversers. Talks with quality control are currently been held in order to adapt the work package creation tool to their needs. Their validation is necessary since the EASA or FAA release certificate is based on the repair action the customer initially asked for. The initial work package defined by the program will contain tasks to launch SB status inspections, incoming inventory checks, dismantling, inspections and assembly as well as final testing. While the first steps stay the same in every configuration the dismantling, inspection and assembly tasks are different in accordance with the dismantling level defined on the disassembly form.

The work package definition tool will soon be used to launch its first maintenance processes. Once it is operational it will need to be improved continuously over the next few months and years. Therefore a strict implementation and review plan will be defined with experience return meetings and reiterations of the program.

The program could be expanded to the definition of repair actions linked to the inspection tasks. These will have to be quoted in labour hours, material and overhead costs for the tool to be fully operational for customer support management. If this last step is done with the necessary precaution, CSM will be able to sell repairs, being able to choose an initial work scope with a predefined work package. The main purpose for customer support management is to be able to quote specific repair processes and increase the transparency of how maintenance work packages are built at the AFI airframe shop.

15.7. Tablet Inspection

The idea of the tablet inspection was adopted with great enthusiasm by the plant manager due to its innovative character and huge improvement potential. It serves Air France well in achieving one of their major, company-wide goals: Using state of the art technologies to secure their worldwide position as one of the most technologically cutting-edge MRO organisations. Due to the upcoming move to the new plant at Charles de Gaulle Airport the project has been put on hold. For now only an implementation plan is being worked out and sent to the central improvement-project evaluation office at the Air France Group's head office. By the end of this project, the evaluation office confirmed the project and added, that it had recently been envisioned for the line and hangar maintenance division but implementation was still pending. The evaluation office suggested to conduct the tablet PC inspection project as a pilot for the whole of AFI in the airframe maintenance shop. If the pilot project is approved by the strategic group management it is likely to become the next big improvement measure to be implemented after the move to the new plant.

16. Benefits of the Project

Although the project was specifically defined at the beginning, the initial specifications were quickly overthrown by the executive shop management. While the initial aim was a turnaround time reduction of the quoting process, it turned into a general process analysis and the suggestion of improvement vectors for the illnesses detected within the maintenance process. In order to keep a structured approach, it has been decided to perform a six sigma DMAIC process improvement project.

Since it was quickly clear that the project would not contain all the conventional steps of a DMAIC project and would, due to the slow project pace at AFI, not go as far as implementing improvement measures, two evaluation measures for DMAIC projects were introduced during the literature review. In the aftermath of the project both measures can be seen as successfully achieved.

First, the quantum gain of process knowledge can be seen as the major added value achieved through the DMAIC project. AFI asked for a global assessment of their maintenance process and their customer communication and has been provided with extensive information about process illnesses, malfunctions and potential improvement vectors. Second, the ease of control between the evaluation and improvement steps has been achieved as far as possible. The definition of the processes and the customer requirements had never been documented in this detail and has helped define the performance measures illustrated during the measure phase. Having defined these performance indicators has helped o underline the problems defined in the analyse phase of the project. Not being finished to a full extent, the ease of control over steps four and five of the DMAIC process have yet to be observed and evaluated.

Usually the last two steps of the DMAIC process include the implementation of improvement measure and the control of their actual improvement potential. On the last steps, the DMAIC project applied at AFI derives from the classical method. In the underlying case study the improve phase reflects a simple proposal of improvement measures and their improvement potential. The control phase gives a short overview on the projects launched after the executive management meeting and the first steps that will help AFI staff pursue the implementation of the said measures. Globally speaking there are four improvement vectors AFI will subsequently work on in order to improve the maintenance process of customer elements:

1) In order to gain efficiency in the maintenance process, the AFI airframe maintenance shop has to improve its internal communication. The improvement the maintenance shop has achieved within the six months of this project can already be counted as a success. In the past six months AFI started to hold

work scope meetings in order to agree on all works to be performed on customer elements. This helps keeping everyone on the same information level about the customer's needs and requirements and helps to communicate about the defects found and the maintenance status of the element. Additionally, operations and engineering have improved their communication. The exchange meeting held at the end of inspections and before the defect analysis has helped to get a clear picture of the upcoming repair process. The meeting has already helped to significantly decrease turnaround time in this phase of the maintenance process.

2) Inspections, which have become tedious and difficult for mechanics and do not provide the desired results, have been mentioned a few times in this report. The aim for a high quality inspection that can be performed quickly and accurate while delivering excellent defect documentation has to be one of AFI's top priority objectives once the move to the new facility is performed. Although a number of improvement ideas have been provided, the implementation is still very slow and has to be observed and continued very attentively.
3) Through the study of the job card structure and historic maintenance data it has become apparent that the AFI maintenance shop is incapable of issuing custom made maintenance programs. Being able to provide to the customer a "tailored-fit" work package is a critical quality measure in today's MRO market. The information has raised great interest with customer support management and caused the launch of several ongoing improvement projects that will help to tackle this problem. The work package catalogue created within the last months of this project will be the first step to individually tailored maintenance programs for customers.
4) With the proposal of a highly innovative, state of the art method like the tablet PC inspection AFI can underline its role as one of the worldwide most technically advanced MRO organisations. The measure has shown great acceptance by the plant manager and is already being suggested as next big improvement project to AFI general management. Even if it had been suggested before, the new proposal seems to have given the idea a new push and led to the discussion, whether it should be implemented throughout the airline on line and hangar maintenance operations. The airframe maintenance shop has applied as pilot for the project.

Finally, the project has helped to raise awareness about the improvement potential that six sigma and continuous improvement projects yield in the MRO industry. Moreover it has brought new knowledge to the AFI staff about, evaluation techniques such as FMEA and QFD analysis. The project has helped to get a clear overview over the MRO market and has provided a lot of interesting insights on the subject.

17. Conclusion

This report addresses many illnesses, disturbances and malfunctions in the current maintenance process for fan thrust reversers and other airframe components. It has helped Air France to get a better knowledge of the process within its facility and has brought forth a significant number of potential improvement vectors. Unfortunately most of the staff has currently been preoccupied with the move to the new facility at Charles-de-Gaulle airport. One of the main efforts during the last weeks of presence was not to let the results of the project fall into oblivion. This has been achieved through the mobilisation of a new improvement team out of three young and dynamic engineers. After a detailed project transition the new team is determined to continue to shed light on the problems at AFI airframe components.

Even though the six sigma improvement project has brought forth a lot of improvement vectors and clear measures it will not directly solve the company's problems. At this stage it is important to address a couple of other problems that intentionally haven't been addressed in this report. Especially the human relations within the airframe maintenance shop are deeply deteriorated and have to be slowly recovered through communication and involvement of all divisions in future improvement decisions. The implementation of regular continuous improvement workshops can be one step to bring the parties together around the same table. The newly learned tools and techniques should help AFI to gain back a dynamic workforce by implicating everyone in the changing process. It is strongly recommended to implement ongoing continuous improvement workshops in order to regain a strong team spirit at Air France Industries.

This report can be used as an example on how to approach, tackle and succeed in the forthcoming improvement projects. Especially the FMEA and QFD tools, which have been only quickly introduced during this project weren't known and do not seem to be introduced in the French industry or taught at French engineering schools. The acceptance and implementation of these tools into their improvement projects has been embraced with great enthusiasm. Many aspects of the DMAIC project are not yet fully implemented at AFI. In the context of an internship based project the influence of the project leader is limited by the scope of trust through managers and full time employees. For future improvement it is recommended to create an official improvement team under supervision of a division manager or even the plant manager.

Appendixes

Appendix A – Customer Work Scope

AIRFRANCE INDUSTRIES AEROSTRUCTURES PRODUCT	CUSTOMER WORKSCOPE	CLIENT

COVER SHEET

Engine Type	CF6-80E1
Nacelle Element	TR
MPN	

Workscope N°	XXX	1
Repair Order		
SN:		

PMA	☐ Yes	☐ No
DER	☐ Yes	☐ No
DOA	☐ Yes	☐ No

Quote	XX days after reception
TAT	XX days from quote acceptance

Removal Reason :

☐ Incident	Type of Incident / Location: ______________________
☐ Corrosion	Location of Corrosion: ______________________
☐ Repair	Type of Repair: ______________________
☐ Overhaul	
☐ Other reason	Description: ______________________

Hours and cycles prior to removal :

TSN : TSO : DAYCA :

CSN : CSO :

LOGO

☐ Standard exchange ☐ Close loop ☐ Loan return

Authorized Release Certificate required :

☑ EASA : ☐ FAA : ☐ EASA/FAA : ☐ Other :

JOIN REPAIR ORDER to this WORKSCOPE

and all other information required to launch workshop

- Electronics messages,
- Customer phone indication summary,
- Customer Minutes of meetings
- ....

Initial workscope approved by customer support :

NAME	DATE	SIGNATURE

Figure 42: Suggested work scope - Page 1

AIRFRANCE INDUSTRIES	CUSTOMER WORKSCOPE	CLIENT

WORKSCOPE PART 1

Engine Type	**CF6-80E1**				
Nacelle Element	**TR**	**Workscope N°**	**XXX**	**1**	**REV**

General Contract Conditions

Material Cost Threshold: **500** ☐ Euro ☐ US Dollar

SB // AD included: ☐ Yes ☑ No

Repairs included: ☑ CMM ☑ SRM

	Subject		Comments	Signature
	Incoming Functional Test	☑ Yes ☐ No		
	Incoming Inventory (MPI)	☐ Yes ☑ No		
		☑ Yes ☐ No		

Before proceeding perform an Incoming Visual Inspection for Disassembly Decisions (AEOA G1-78-0042-0 00571)

Disassembly	Removal of the Translating Cowl	☑ Yes ☐ No		
Disassembly	Removal of the Deflectors	☐ Yes ☐ No		
Disassembly	Removal of Accessories:	☐ DPV ☐ LWR Latches (LH) ☐ IDG Door ☐ LWR Doors (RH) ☑ CDU ☑ Actuators ☑ Hold Open Rod ☑ Lock Brake ☐ FWD Latch ☐ POD ☐ Others:		
Disassembly	Further Structural Disassembly	☐ Fairings ☐ Upper Sidewall ☐ Core Cowl ☐ Lower Sidewall		
	Cleaning	☐ Yes ☐ No		
	Further Action	☐ Wiremesh TC ☐ Wiremesh CC ☐ MA25S Removal		

Inspection accoring to CMM 78-32-00

NAME	DATE	SIGNATURE

Figure 43: Suggested work scope - Page 2

AIRFRANCE INDUSTRIES | **CUSTOMER WORKSCOPE** | **CLIENT**

WORKSCOPE PART 2

Engine Type	**CF6-80E1**				
Nacelle Element	**TR**	**Workscope N°**	**XXX**	**1**	**REV**

Damage report required

Work to be performed (requiring customer's approval) :
(for details see image on following page)

N°	Subject:	Jobcard Number: *(or Document N°)*	CSM approval : *(Signature and date)*	Launched by : *(Signature and date)*
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
	OTHER WORKS ... (requested by work order attached)			
	Paint and markings:			
	Final functional test			
	Outgoing MPI			
	Provide a workshop report "Booklet"			

NAME	DATE	SIGNATURE

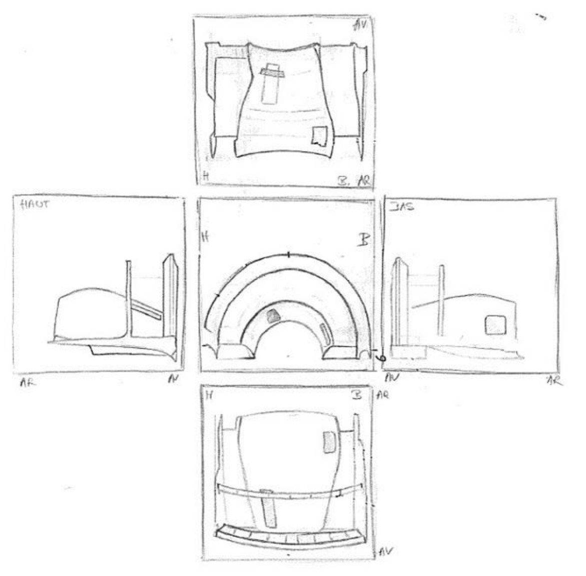
AIRFRANCE INDUSTRIES | **CUSTOMER WORKSCOPE** | **CLIENT**

WORKSCOPE PART 2

Engine Type	**CF6-80E1**				
Nacelle Element	**TR**	**Workscope N°**	**XXX**	**1**	**REV**

Damage report required

Work to be performed (requiring customer's approval) :
(see attached Image)



Please show the placement of all repairs indicated by the Repair Number on sheet 2

Figure 44: Suggested work scope - Pages 3 & 4

Appendix B – Repair Summary Sheet

RAR: xxxxxxxx
Ordre: xxxxxxxx
N° Repair Order: XxxxxxxxXxx
Type Moteur: CF6-80C2

Respo. Logistique: Nom
Respo Technique: Nom
Respo Production: Nom
SN : XXXXXXXXXX
MPN: XXXXXXXXXX

N°	Designation	Carte	Emplacement	Document	Appro	Traité	le	Par
1	4 rivets à remplacer	AW-XX-00-00-00-01792		CMM 78-32-02 Repair 005	☑	☑	/ /2015	
2	Bague à remplacer	REP-G8-78-...	Upper Beam	REP-G8-78...	☑	☐	/ /2015	
3	12 Rivets à remplacer	AW-XX-00-00-00-01792	Fairing 10'	CMM 78-32-02 Repair 005	☐	☐	/ /2015	
4	Access Door Latch Wear	REP-G8-78-...	Access Door		☑	☑	/ /2015	
5	Dents Lower Sidewall	REP-G8-78-...	Lower Sidewall		☑	☐	/ /2015	
6	Ovelized Holes on AFT Ring	REP-G8-78-...	AFT Ring	DOA	☐	☐	/ /2015	
7	Bumpers	REP-G8-78-...	Ring 7' and 8'		☐	☐	/ /2015	
8					☐	☐	/ /2015	
9					☐	☐	/ /2015	
10					☐	☐	/ /2015	
11					☐	☐	/ /2015	
12					☐	☐	/ /2015	
13					☐	☐	/ /2015	
14					☐	☐	/ /2015	
15					☐	☐	/ /2015	
16					☐	☐	/ /2015	
17					☐	☐	/ /2015	
18					☐	☐	/ /2015	
19					☐	☐	/ /2015	
20					☐	☐	/ /2015	
21					☐	☐	/ /2015	
22					☐	☐	/ /2015	
23					☐	☐	/ /2015	

Figure 45: Example for a repair summary document

Appendix C – Job Card Analysis

Table 48 shows a count of all job cards used at the aero-structures repair shop. It can be quickly seen that the number of job cards represents a huge amount of paperwork since every job card has to be printed before stepping into action when it is performed by the mechanic on the actual element. The average job card package for the initial treatment of an 80E1 thrust reverser is up to 500 pages long. Only for CF6-80E1 there are 33 inspection job cards with many redundancies within them.

# of Jobcards	Task Type										
Engine	ASS	CLN	DIS	INS	LCT	PEI	REP	TES	VSB	others	Total
CF6-80C2	23	3	12	42	12	11	188	9	21	149	470
CF6-80C2A		1		2			3			9	15
CF6-80C2B	11		6	16	7	8	49	6	6	38	147
CF6-80C2D										1	1
CF6-80E1	23	3	9	33	16	9	102	9	7	132	343
CFM56-3	12	1	12	22	7	2	15	1	1	28	101
CFM56-5A	16	2	5	27	14	5	116	8	21	200	414
CFM56-5A/B										2	2
CFM56-5B	19	2	10	25	11	7	105	11	13	141	344
CFM56-5C	10	1	8	29	9	6	57		49	74	243
CFM56-7B		1		4					9	26	40
GE90-1		1		8	3	3	2	1	1	22	41
GE90-9	6	2	5	20	10	5	24	5	4	55	136
ALL-GTR							2			13	15
V2500										54	54
Total	120	17	67	229	89	57	663	50	132	980	2404

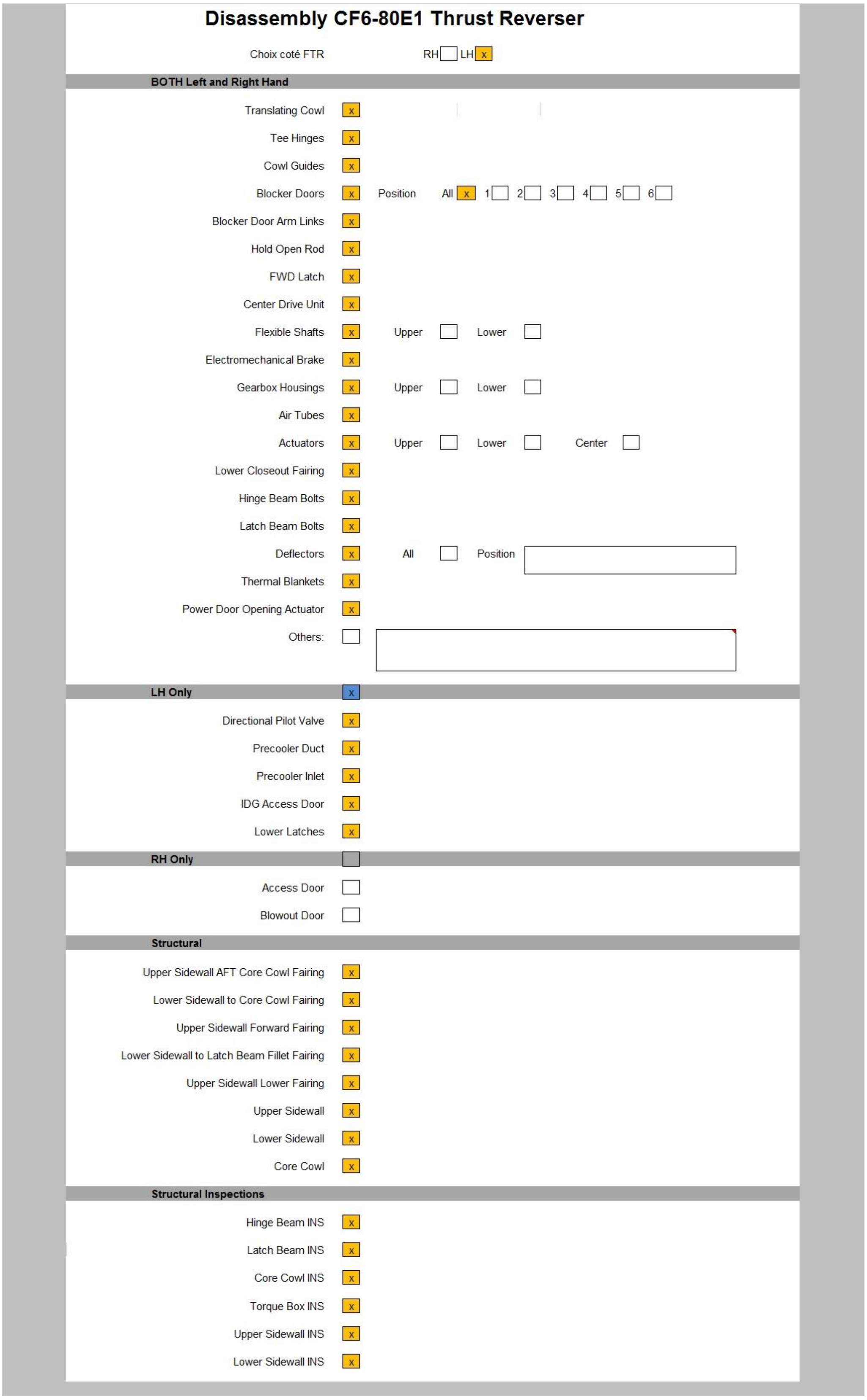
Figure 46: Job Card count

Appendix D – Process FMEA

#	Improvement Measure	Superordinate Function	Failure	Reason	Prob.	Effects and Severity	Severity	Detection	Detection	RPN	Objective	OK	Preventive Measures	P	S	D	RPN (improved)
1.1.	New Generation Work scope	Improved Communication	non-acceptance of the new document	resistance to change	5	non attendance to the work-scope meeting, no communication via the workscope	5	Immediate	2	50	80	ok	making the work scope compulsory and an official working document	5	5	2	50
1.2.	New Generation Work scope	Improved Communication	work scope not informative	not enough communication during creation of the document	6	no communication via the work scope - non usage	5	Immediate	2	60	80	ok	Working group to determine what the work scope should look like, elimination of the some old paper based communcation methods	4	5	2	40
2.1.	Repair Summary	Overview over repair process	incomplete listing	bad creation process	5	forgotten repair if the mechanic starts to rely only on the repair listing, flight safety issue	10	At the end of the process through QC	5	250	80	Improve!	List should only be informative and not be declared an offcial document. "For Information Only" Stamp. Repairs are still fed to the mechanic through job cards	5	10	1	50
2.2.	Repair Summary	Overview over repair process	unreliable information on duration but consultation	parallel process to job cards makes it look less important	9	wrong client information, wrong planning	4	Along the first execution of every task	2	72	80	ok	during the first months of utilization, expected and real duration should be compared. Creation of a tracking KPI and adaption of the inital expected duration value	3	4	2	24
2.3.	Repair Summary	Overview over repair process	reliable information but non consultation	new process that staff doesn't rely on	7	no improvement	2	late or no detection, no change, no improvement	8	112	80	Improve!	Evaluation of the staff and objective achievement in accordance with the document. If the staff is evaluated on this basis he will consult it.	4	2	8	64
3.1.	Quality Gate Checks	More quality checks, easier quality checks	chaos in the new process	new procedures	2	forgotten checks can have effects on flight safety	8	no detection mechanism since QC is not re-checked by anyone	10	160	80	Improve!	Creation of checklists for every procedure	2	8	3	48
3.2.	Quality Gate Checks	More quality checks, easier quality checks	inacceptance of the new process through mechanics	mechanics feel "controlled"	9	slower process, worse human relations	2	immediate reactions from mechanics	2	36	80	ok	Commuication about the new procedure, new procedure should be a help and not a punishment	4	2	2	16
4.1.	Consolidated Databases	Easier handling by production engineering staff	slower, even more tedious process	more information in one MS Access Database	5	slower process	2	almost immediate detection	4	40	80	ok	probably no use to even redefine once more the MS Access database but plan a switch to a more powerful tool (SAP)	complete change measure			
5.1.	Damage Report	Better customer communication	non acceptance due to longer and unknown process	unkown MS Publisher skills for pictures and averse to change	4	still bad communication, unsatisfied customers	6	immediate detection	1	24	80	ok	MS Publisher standard work instruction and individual courses	2	6	1	12
6.1.	Inspection Job Cards	faster more ergonomic inspection	inspection cards not followed step by step anyway	experienced mechanics follow their own way of doing things	4	no turnaround improvement	2	no or unlikely detection	7	56	80	ok	Autoregulated through legal inspection responsibility of the mechanic	4	2	7	56
6.2.	Inspection Job Cards	faster more ergonomic inspection	change without consulation of the mechanic	communication barriers, wanting to change things too quickly	6	another bad procedure	4	no change, but immediate detection	2	48	80	ok	Task force for job card improvement including the mechanic, involve the mechanic in the final layout	2	4	2	16
7.1.	Inspection by Engineering	less information loss	information loss later at the next process interface	bad communication between defect analysis and repairs	3	no effect due to no communication today, no improvement but not worse	4	nothing to detect	1	12	80	ok	talks about a problem that is not resolved by this measure but exists anyway	no change			
7.2.	Inspection by Engineering	less information loss	bad knowledge transfer	expertise fades among mechanics who do not analyse but only execute procedures	2	bad for technical expertise creation	3	detection only after years	10	60	80	ok	no change to knowledge transfer, promotion of good mechanics	2	3	5	30
8.1.	Tablet Inspection	faster, modernised inspection	incomplete CMM coverage	non adapted application	4	forgotten tasks, flight safety issue	8	detection through QC	3	96	80	Improve!	plan numerous reiterations of the application 2,4,6 and 12 months after the launch of the tablet inspection	2	7	3	42
8.2.	Tablet Inspection	faster, modernised inspection	difficulty to work with the new application	too radical change	4	slow turnaround time, tedious procedure	4	immediate detection	2	32	80	ok	learning groups and courses	4	4	3	48
8.3.	Tablet Inspection	faster, modernised inspection	eyes off the element procedure	too much visual contact with the tablet PC	5	forgotten tasks, flight safety issue	8	detection through QC	3	120	80	Improve!	how to force the mechanic to keep the eyes on the inspection???	no result yet, TBD			
9.1.	Tailored Fit Maintenance Work Packages	Improved turn around and customer satisfaction	incomplete workpackage through incomplete job card coverage	non adapted job cards	6	forgotten repairs cause rework or cause a flight safety issue if undetected	8	should be seen at the end of the process through QC	2	96	80	Improve!	Rework of the job card structure, adaption to the new way of launching work packages. For example detached items in a new database	complete change measure			
9.2.	Tailored Fit Maintenance Work Packages	Improved turn around and customer satisfaction	forgotten tasks due to errors in the application	non adapted MS Excel application	3	forgotten repairs cause rework or cause a flight safety issue if undetected	8	might never be seen	6	144	81	Improve!	reiteration of the application 2,4,6 and 12 months after the launch	3	5	4	60

Figure 47: Process FMEA

Appendix E – Launch Form & Output



Disassembly CF6-80E1 Thrust Reverser

Choix coté FTR — RH [ ] LH [x]

BOTH Left and Right Hand		
Translating Cowl	x	
Tee Hinges	x	
Cowl Guides	x	
Blocker Doors	x	Position All [x] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 [ ] 6 [ ]
Blocker Door Arm Links	x	
Hold Open Rod	x	
FWD Latch	x	
Center Drive Unit	x	
Flexible Shafts	x	Upper [ ] Lower [ ]
Electromechanical Brake	x	
Gearbox Housings	x	Upper [ ] Lower [ ]
Air Tubes	x	
Actuators	x	Upper [ ] Lower [ ] Center [ ]
Lower Closeout Fairing	x	
Hinge Beam Bolts	x	
Latch Beam Bolts	x	
Deflectors	x	All [ ] Position [ ]
Thermal Blankets	x	
Power Door Opening Actuator	x	
Others:	[ ]	[ ]
LH Only	x	
Directional Pilot Valve	x	
Precooler Duct	x	
Precooler Inlet	x	
IDG Access Door	x	
Lower Latches	x	
RH Only	[ ]	
Access Door	[ ]	
Blowout Door	[ ]	
Structural		
Upper Sidewall AFT Core Cowl Fairing	x	
Lower Sidewall to Core Cowl Fairing	x	
Upper Sidewall Forward Fairing	x	
Lower Sidewall to Latch Beam Fillet Fairing	x	
Upper Sidewall Lower Fairing	x	
Upper Sidewall	x	
Lower Sidewall	x	
Core Cowl	x	
Structural Inspections		
Hinge Beam INS	x	
Latch Beam INS	x	
Core Cowl INS	x	
Torque Box INS	x	
Upper Sidewall INS	x	
Lower Sidewall INS	x	

Figure 48: Thrust Reverser Maintenance Program Launch Form

Workpackage Initial CF6-80E1			afficher les cartes de travail
Lancement		G1-78-0042-LVL 00570	Decision Level FTR
		G1-78-0042-0 00571	Gamme Pré Workscope
Taches MS	SU	G1-78-0040-1 SU 00569	
	LUB	G1-78-0040-1 LUB 00808	
	TC	G1-78-0040-1 TC 00569	
Vérification AD/CN		EQ-78-0112-1 IN 00308	
Etat SB	SU	EQ-78-0113-1 SU 00559	
	TC	EQ-78-0113-1 TC 00560	
Incoming MPI	SU	MPI-G1-78-32-00-01913	
	TC	MPI-G1-78-32-00-01917	
Pré Inspection		INS-G1-78-32-02-02993	
Inspection Generale	SU	INS-G1-78-32-02-02992	
Inspection Generale	TC	INS-G1-78-32-31-02142	
Outgoing MPI	SU	MPI-G1-78-32-00-01915	
	TC	MPI-G1-78-32-00-01918	

Workpackage for Selection		Desassemblage		Inspection		Assemblage	
Clé item	-	Gamme DIS	Item DIS	Gamme INS	Item INS	Gamme ASS	Item ASS
Flexible Shafts		DIS-G1-78-32-00-00932	050	RPEX	-	ASS-G1-78-32-00-02108	MULTIPLE
Center Drive Unit		DIS-G1-78-32-00-00932	060	RPEX	-	ASS-G1-78-32-00-02108	130
Center Drive Unit		DIS-G1-78-32-00-00932	070	RPEX	-	ASS-G1-78-32-00-02108	140
Hold Open Rod		DIS-G1-78-32-00-00932	080	INS-G1-78-32-11-00769	ALL	ASS-G1-78-32-00-02108	040
Electromechanical Brake		DIS-G1-78-32-00-00932	090	RPEX	-	ASS-G1-78-32-00-02108	180-190
FWD Latch		-		-		-	
FWD Latch		DIS-G1-78-32-00-00932	110	INS-G1-78-32-07-00636	ALL	ASS-G1-78-32-00-02108	020
Translating Cowl		DIS-G1-78-32-00-00932	030	INS-G1-78-32-31-00858	ALL	ASS-G1-78-32-00-02108	250-290
Translating Cowl		DIS-G1-78-32-00-00932	040				
Blocker Doors		DIS-G1-78-32-00-00933	010	INS-G1-78-32-03-00859		ASS-G1-78-32-00-00568	ALL
Air Tubes		DIS-G1-78-32-00-00932	120	INS-G1-78-32-00-00767	080-120	ASS-G1-78-32-00-02108	100
Air Tubes		-		-		-	
Directional Pilot Valve		DIS-G1-78-32-00-00932	140	RPEX	-	ASS-G1-78-32-00-02108	090
Actuators		DIS-G1-78-32-00-00932	150	RPEX	-	ASS-G1-78-32-00-02108	070
Gearbox Housings		DIS-G1-78-32-00-00932	170	RPEX	-	ASS-G1-78-32-00-02108	060
Deflectors		DIS-G1-78-32-00-00932	175	INS-G1-78-32-00-00767	030	ASS-G1-78-32-00-00938	050
Blocker Door Arm Links		DIS-G1-78-32-00-00932	270	INS-G1-78-32-08-00599	ALL	ASS-G1-78-32-02-02159	040
Precooler Duct		DIS-G1-78-32-00-00932	300	INS-G1-78-32-02-00635	ALL	ASS-G1-78-32-00-00938	040
Precooler Inlet		DIS-G1-78-32-00-00932	310	INS-G1-78-32-02-02997	060	ASS-G1-78-32-02-02159	050
Lower Latches		DIS-G1-78-32-00-00932	260	INS-G1-78-32-11-02640	ALL	ASS-G1-78-32-00-00938	060
Core Cowl		DIS-G1-78-32-02-02156	ALL	INS-G1-78-32-02-02997	ALL	ASS-G1-78-32-02-02159	ALL
Upper Sidewall AFT Core Cowl Fairing		DIS-G1-78-32-02-01113	020	INS-G1-78-32-02-02997	120-1	ASS-G1-78-32-02-02197	080
Lower Sidewall to Core Cowl Fairing		DIS-G1-78-32-02-01113	060	INS-G1-78-32-02-02997	120-2	ASS-G1-78-32-02-02197	070
Upper Sidewall Forward Fairing		DIS-G1-78-32-02-01113	030	-		ASS-G1-78-32-02-02197	060
Lower Sidewall to Latch Beam Fillet Fairing		DIS-G1-78-32-02-01113	070	-		ASS-G1-78-32-02-02197	020
Upper Sidewall Lower Fairing		DIS-G1-78-32-02-01113	040	-		ASS-G1-78-32-02-02197	010
Upper Sidewall		DIS-G1-78-32-02-02154	050	INS-G1-78-32-02-02996	ALL	ASS-G1-78-32-02-02157	ALL
Upper Sidewall		DIS-G1-78-32-02-02154	060	-		ASS-G1-78-32-02-02157	ALL
Lower Sidewall		DIS-G1-78-32-02-02155	040	INS-G1-78-32-02-02998	ALL	ASS-G1-78-32-02-02158	ALL
Lower Sidewall		DIS-G1-78-32-02-02155	050	-		ASS-G1-78-32-02-02158	ALL
Tee Hinges		REP-G1-78-32-31-01597	020	INS-G1-78-32-31-01983	ALL	INS-G1-78-32-31-01983	ALL
Cowl Guides		REP-G1-78-32-31-01593	010	INS-G1-78-32-31-01982	ALL	INS-G1-78-32-31-01982	ALL
Hinge Beam Bolts		DIS-G1-78-32-00-00932	020	INS-G1-78-32-00-00767	170-180	ASS-G1-78-32-00-02110	030
IDG Access Door		DIS-G1-78-32-00-00932	015	INS-G1-78-32-09-00601	ALL	ASS-G1-78-32-02-02159	060
Thermal Blankets		DIS-G1-78-32-00-00932	240	INS-G1-78-32-00-00767	260-280	ASS-G1-78-32-00-00938	090
Thermal Blankets		DIS-G1-78-32-00-00932	250	INS-G1-78-32-00-00767	260-280	ASS-G1-78-32-00-00938	080
Latch Beam Bolts		-		INS-G1-78-32-00-00767	150-160	-	
Power Door Opening Actuator		DIS-G1-78-32-00-00932	280	RPEX	-	ASS-G1-78-32-00-02110	020
Lower Closeout Fairing		DIS-G1-78-32-00-00932	330	INS-G1-78-32-02-02999	040	-	
Hinge Beam INS		-		INS-G1-78-32-02-03001	ALL	-	
Latch Beam INS		-		INS-G1-78-32-02-02998	ALL	-	
Upper Sidewall INS		-		INS-G1-78-32-02-02999	ALL	-	
Lower Sidewall INS		-		INS-G1-78-32-02-02996	ALL	-	
Core Cowl INS		-		INS-G1-78-32-02-02997	ALL	-	
Torque Box INS		-		INS-G1-78-32-02-03000	ALL	-	

Figure 49: Maintenance Program Launch Output

Appendix F – Questionnaire

MECHANIC MAINTENANCE PROGRAM INFORMATION QUESTIONNAIRE

Name:____________________ Specification:__________________ In the company since:_______

1 Do you know who the customer is?

2 Do you know what maintenance status this element has?

3 Do you generally get information about the maintenance status?

4 Do you know the reason why this element came to the shop?

5 Do you know why this element was removed from the aircraft?

6 What did the customer ask for in this specific case?

7 Can you say that you have been sufficiently informed by your supervisor on the works to be done on this specific element?

8 Are you generally well informed? What information do you get?

9 Would you like more precisions about the inspections?

10 Did your supervisor make any precisions about inspections?

11 Do you what a "workscope" is?

12 If yes, do you ever get to see it?

13 Do you know what tasks an overhaul contains?

14 According to you, do the job cards cover a complete inspection?

15 Are you satisfied with the way the job card procedures are written?

16 What takes up most time during inspection?

17 How do you like working with the technical documentation?

Figure 50: Questionnaire

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Table of Figures

List of Acronyms

AD	Airworthiness Directive
AF	Air France
AFI	Air France Industries
AFT	After (Meaning “rear” in aviation slang)
AMM	Aircraft Maintenance Manual
CDU	Centre Drive Unit
CMM	Component Maintenance Manual
CSDR	Component Structural Damage Report
CSM	Customer Support Management
DMADV	Design Measure Analyse Design Validate (Six Sigma Procedure)
DMAIC	Design Measure Analyse Improve Control (Six Sigma Procedure)
DOA	Design Organisation Approval
DPV	Directional Pressure Valve
DR	Damage Report
EASA	European Aviation Safety Agency
FAA	Federal Aviation Authority
FC	Fan Cowl
FMEA	Failure Mode and Effect Analysis
FTR	Fan Thrust Reverser
FWD	Forward
ETC	et cetera (and so forth)
IPL/IPC	Illustrated Parts List (Catalog)
KLM	KLM Royal Dutch Airlines
LH	Left Hand
LWR	Lower
MRO	Maintenance Repair and Overhaul
MS	Maintenance Schedule Task - Generally on wing (line) maintenance
OEM	Original Equipment Manufacturer
QFD	Quality Function Deployment
RH	Right Hand
RPN	Risk Priority Number
SB	Service Bulletin
SRM	Structural Repair Manual
TAT	Turnaround Time
TC	Translating Cowl
UPR	Upper
UTA	Union des Transports Aériens (Former French Airline)