# MODELING THE RELATIONSHIP BETWEEN AVIATION ORIGINAL EQUIPMENT MANUFACTURERS AND MAINTENANCE, REPAIR AND OVERHAUL ENTERPRISES FROM A PRODUCT-SERVICE SYSTEM PERSPECTIVE

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## Abstract

In this paper, we provide the main arguments for developing a collaborative product-service system business model between aviation original equipment manufacturers (OEMs) and maintenance, repair and overhaul (MRO) companies. The premise of this work is that such cooperation should benefit not only the OEMs and the MRO companies, but also other stakeholders such as operators and end-users. We also present the basic components of the model. It should be noted that the mathematical model has been built; however, page limitations do not allow us to present it in detail here. The model is currently utilized to conduct a large-scale case study that will be submitted for publication in the near future.

**Keywords**: Product-Service Systems (PSS), Product modelling / models, Decision making

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# 1 INTRODUCTION

Airframe original equipment manufacturers (OEMs) are constantly under market pressure for providing outstanding quality in-service support. As their world fleet quickly grows, the worldwide service infrastructure is also expected to be developed at similar rates, however it can be observed that service strategies are not always properly designed, leading these OEMs to deliver unsatisfactory levels of customer support.

Aviation market has witnessed different business models proposals of service offerings, such as few airframe OEMs owned service centers to serve operators with maintenance services. With this model, OEMs can usually offer good maintenance support to the local market where the maintenance center is situated, however there are some inherent challenges that prevent this model of providing adequate worldwide coverage to customers, as for example the high investments required to build service facilities and maintain a heavy organizational structure to operate them in many countries, also dealing with cultural, legal and political barriers. This would lead OEMs to lose focus on their core business, which is primarily product design and manufacturing. A second business model appeared as a result of the OEMs' inability to provide acceptable global service levels, where some operators, such as big airlines and air forces have developed their own maintenance centers, reducing their dependency from manufacturers and increasing maintenance service levels to their fleet. Notwithstanding, that solution also presented some challenges as many operators realized they were steering their operational effort to a direction different from their main business. Then, a third business model was observed when independent maintenance, repair and overhaul (MRO) companies (for simplicity MROs) emerged in the aviation market. Quickly, operators noticed that these companies had advantages over them: due to greater volume of work in those specialized enterprises the efficiency is higher, meaning lower maintenance cost to operators, especially in lower-wage countries such as those in South America, Asia or Eastern Europe. In addition, operators realized that outsourcing MRO activities could be a solution when their in-house capacity cannot absorb demand (FAA, 2013). Consequently, the market witnessed an increasing trend towards outsourced MRO activities (Rosenberg, 2004).

In light of this development, OEMs reacted by creating partnerships with service providers in emerging countries with the objective of benefitting from lower labour costs. Examples include Pratt Whitney and China Eastern, General Electric and Singapore Technologies Aerospace, Boeing and Shanghai Aviation Services Co., and Bombardier and Digex MRO (Vieira and Loures, 2016). The main issue with that business model resides in the fact that in many cases this partnership is not well designed to promote delivery of high service levels. For example, some MRO companies are recognized as Authorized Service Providers by the OEMs and receive few advantages from OEMs such as limited technical training, parts ordering support and limited engineering support. Nonetheless, these small benefits do not really add significant value to MRO operations, nor compensate the investment required for MRO companies to develop maintenance capacity to attend the new aircraft model. This issue becomes even more evident in cases when the MRO company does not enjoy economies of scale that are sufficient to promote the adequate return over those investments. According to a study of the French government, eighty per cent of MRO providers are small or medium enterprises.

The analysis of different strategies of MRO business models in a recent literature survey (Vieira and Loures, 2016) reveals a strong competition between the OEMs, MROs and airlines. Corroborating with this conclusion, this paper proposes a different approach under which airframe OEMs and MROs should align their business interests to foster a collaborative environment that will benefit them both ("win-win" scenario). Given that the operational life of an aircraft can last for more than 50 years, there is a signficant opportunity for aviation original equipment manufacturers (OEMs) and maintenance, repair and overhaul (MRO) companies (for simplicity MROs) to profit from a collaborative product-service system (PSS) business model that can provide operational excellence in supporting the product during its in-service life (Goncalves and Kokkolaras, 2015).

Collaboration between these two aerospace industry segments can be achieved through the exchange of resources which are of interest for both companies (see Figure 1). For example, technical data is a valuable asset: aviation MROs depend on product data, owned by manufacturers, to provide maintenance services to end-customers (e.g., airlines, private or military operators). On the other hand, OEMs need in-service data to improve product design, reliability, parts consumption forecast, etc. The more product data an MRO company has promptly access to, the faster it will perform maintenance services, reducing thus downtime of their customers' aircraft. At the same time, the more in-service data an OEM possesses, the higher product reliability and operational efficiency it will be able to deliver (Ali and McLoughlin, 2012). Along the years, MRO companies accumulate vast amounts of in-service data through maintenance reports such as components reliability data, failures modes information, troubleshooting results, maintenance access problems, tooling problems, maintenance program improvement opportunities, critical aircraft corrosion areas, most demanded parts, parts consumption history, etc. And, as mentioned, OEMs possess all the product design data. Thus, a win-win partnership can be created between MROs and OEMs so they can share information that will improve quality of their deliverables (maintenance services and product reliability, respectively) and hence, it will increase value-added to customers by delivering higher aircraft availability.

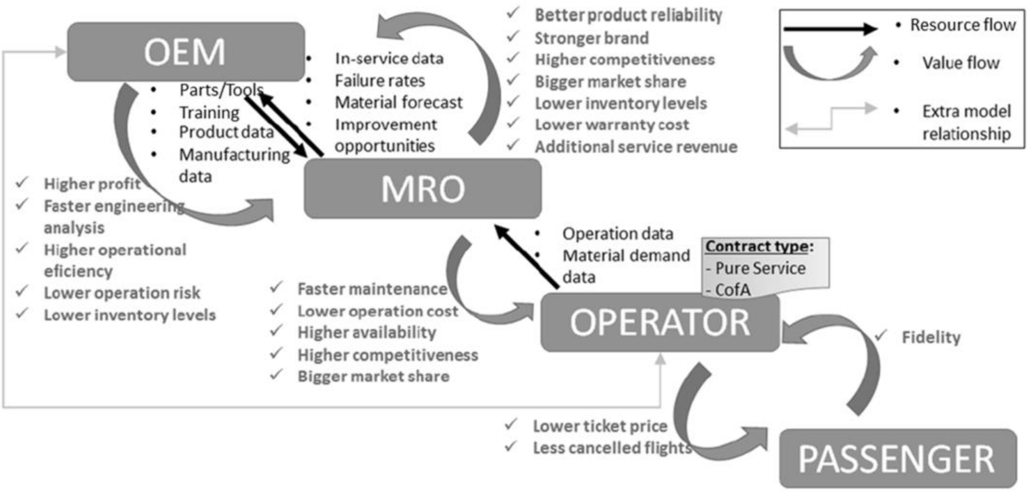


*Figure 1. Proposed value and resources flow in OEM-MRO collaboration*

Therefore, this paper outlines the opportunities and rationale for promoting enhanced collaboration between aerospace OEMs and aviation independent MROs. The development of an associated quantitative model that maps the business relationships between these stakeholders under a PSS perspective has been completed, and the authors are currently conducting case studies in order to publish relevant results.

## 2 COLLABORATION OPPORTUNITIES

### 2.1 How can MROs benefit from a collaboration with OEMS

MRO companies rely on some essential resources availability to deliver high-level services to operators. The higher the availability of these resources, the higher the value delivered by MRO. Based on several interviews conducted with MROs, airframe OEMs and airlines professionals in Brazil, Chile, Argentina and Spain (including an Engineering/Planning Manager, a Quality and Regulations Manager with more than 30 years experience in the international MRO sector, a Maintenance Manager, an experienced MRO Specialist, and a Maintenance Supervisor with more than 30 years of MRO experience), the most relevant resources are 1) product data; 2) spare parts; 3) tooling and equipment; and 4) technical labour qualification.

#### *2.1.1 Product data availability*

Product data such as engineering reports, installation and fabrication drawings, detailed aircraft systems descriptions, Root Cause Analysis data, if not promptly available to MROs, they can increase the cycle time of troubleshooting and engineering analysis during maintenance services execution, causing delays, thus resulting in significant financial losses to operators.

As per regulatory requirements, OEMs produce and sell standard sets of maintenance manuals to MROs, containing extensive technical instructions and procedures to properly maintain their aircrafts. However, eventually MROs need some specifics that are not covered by these standard manuals, so they have to request special technical dispositions to the manufacturer. Depending on the elapsed time to receive the

answer, service schedule delays may occur. Thus, the more technical data OEMs can make available to MROs, the lower will be the risk of delays caused by lack of that resource.
Nowadays, product data are generally sold to MROs by OEMs through customer support channels such as annual subscriptions to maintenance manuals, service bulletins, service letters, call centers, field support services, etc. (Ibekwe, 2014).

#### 2.1.2 Spare parts availability (inventory size and location)

One of the biggest challenges faced by an MRO is that spare parts are not always available when required. The challenge is: since an aircraft has thousands of parts, and many of those can be rejected after inspection during a shop visit, how can an MRO keep a low inventory level (not to inflate operational cost) and at the same time be ready to replace a damaged part during execution of a maintenance service (SAS, 2012)?
This research suggests that the answer to that question could be in a partnership created between MROs and OEMs where these two players could split and rationalize their investments in spare parts. In that model, MRO could keep a minimum inventory of basic parts and would have the OEM as its main spare parts supplier. On the other hand, OEM could use MRO's consumption data to better forecast regional demand for parts, thus reducing risk of over production.
By considering that conceptual model, a second question would arise: how much would each company have to invest in spare parts so to enable MRO to provide maintenance services without significant disruptions resulted from lack of spare parts? In order to answer that second question, this research proposes to design a PSS model by mapping relationships between OEM and MRO in order to identify new collaboration means between the two companies. To properly design that collaboration, some parameters need to be defined as well as some aspects ought to be understood, as for example:

- MRO's production capacity (types and number of maintenance checks): so size of the required inventory can be determined;
- Types of spare parts to be stored: to determine classes of materials and enable inventory cost as well as lead time estimation;
- MRO's location: to determine the warehouse location, since some countries face huge challenges with customs to import parts and components, causing excessively long lead times (Cohen and Wille 2006). In that case, a local warehouse would be ideal;
- Inventory ownership would need to be defined between MRO and OEM;

#### 2.1.3 Tooling and equipment availability

Similarly to the case of spare parts, tooling and ground support equipment (GSE) availability is of vital importance to MROs' operation. Certain maintenance tasks require special tooling to be performed, thus lacking one of these required equipment during maintenance activities may represent production interruption and longer stay of the aircraft on the ground.
To reach full capacity of providing maintenance services, MROs must acquire a wide range of tools and GSEs which can vary from a simple torque wrench to complex and expensive electronic test sets, or aircraft jacks, jigs and stands. In addition, many of this equipment are specific to a particular aircraft model. As MROs typically deal with several models of aircrafts, the number of GSE required to support all types of aircrafts rapidly becomes very high, forcing MROs to heavily investment in equipment, which sometimes can even be underutilized.
The main challenge here is to avoid high investments, while keeping high service levels. The second question raised in Section 2.1.2 is also applicable for the tooling issue: how much would each company have to invest in tooling and GSE so to enable MRO to provide maintenance services without significant disruptions resulted from lack of these resources?
The collaboration model proposed by this research could also be the solution for the tooling issue, aiding to define the right levels of investments to be made by MROs and the adequate level of support that OEMs should provide to help MRO with that issue.

#### 2.1.4 Technical labour qualification

The main stream of revenue in MRO companies comes from selling production man-hours, so production efficiency has a direct and significant impact on those companies' financial results. For that reason, investments in training are constantly required for MROs to nurture their high skilled labour

force, maintaining adequate productivity rates and hence their competitiveness. An aerospace study involving Northrop Aircraft Inc. showed results of production increase in the order of 17% after consistent training of 1241 employees (Dinero, 2005).
Different types of training are needed to keep maintenance personnel at required qualification levels, for example: standard industry maintenance practices, aircraft familiarization and ground operation, regulatory training, training on particular operators procedures, etc. Due to the wide range of training required along the year, this investment represents another burden on the MRO's budget.
The question here is similar to the ones for spare parts and tooling: how to reduce MRO investments in training, but keep maintenance personnel at high qualification levels? The answer in this case could come from a partnership where OEMs would share their training structure with MROs. Manufacturers have either an in-house training organization or an outsourced solution, so in any of these cases, their training solution could be used by MROs, so operational cost of those training centers could also be shared between the two companies.

## 2.2 How can OEMs benefit from a collaboration with MROs

MROs can deliver value back to OEMs by sharing in-service data and in-service revenue.

### 2.2.1 In-service data

#### 2.2.1.1 Historical data of failures

By providing maintenance services, MROs naturally collect significant amounts of aircraft failures data from many different fleets around the world. This data is accumulated along the years and quickly becomes a precious raw material for statistical analysis that could be shared with OEMs to improve their understanding of their product`s operation (Broderick, 2015). This type of statistical analysis usually reveals important results for manufacturers such as fleet (model of aircraft) behaviour data, where a certain aircraft model can present a particular failure when operated in a certain region (desert, or tropical climate, or extreme cold, etc.), but not in others. This only becomes evident when you compare historical data from similar aircrafts operating in different regions.
The same sort of findings can come from comparison of data coming from airlines that fly the same feet (model), but in a different type of operation (short or long flights, with or without fuel/brakes savings policy, short or long run ways, etc.). Historical data will also point out components with low MTBF (Mean Time Between Failures) as well as will reveal that for a certain fleet, some failures will correlate with the age of the aircraft.
In summary, all of that information gathered by MROs becomes an asset and could be used as a resource by OEMs to identify weaknesses in their products and improvement opportunities in their maintenance programs in order to continuously increase product reliability and consequently competitiveness (Canaday, 2016).

#### 2.2.1.2 Material demand forecast

Supply spare parts in a timely manner to the world fleet is a big challenge for aerospace OEMs. The paradox is like the one faced by MROs: how to meet world demand for spare parts in a timely fashion without having to keep huge inventory levels?
The answer for that question could reside on a better collaboration relationship between OEMs and MROs. There is in the literature, a real case involving Procter & Gamble (P&G) and Walmart, where these two companies dealt with a similar issue and obtained successful results (Grean and Shaw, 2002). In summary, they decided to join forces to reduce their inventory levels. As Walmart is closer to the end customer, it has the privilege of having advanced customer demand information. So Walmart agreed to share retail demand data with P&G, so the last one could use this information to adjust production rates of many product lines accordingly, thus avoiding high inventory levels. On the other hand, P&G created an open channel for Walmart to put manufacturing orders directly to P&G`s production lines via an integrated IT system. This solution brought more flexibility and agility for Walmart to replenish the shelves in the stores, also eliminating the need for high inventories.
Although the relationship between aerospace OEMs and aviation MROs has no direct relation with the retail market, this research study sees the opportunity of applying the collaboration approach adopted by P&G and Walmart to improve supply chain efficiency between aerospace OEMs and MROs. In the opportunity discussed herein, the OEM would play P&G`s role and MROs would act as Walmart since

this last one has a growing amount of historical data on parts consumption. As a result, OEMs would be able to adjust their spare parts manufacturing rates in order to avoid high inventory levels and at the same time, MROs would have faster response to operators` spare parts demands.

### 2.2.2 In-service revenue

The collaboration model could represent a new source of revenue for OEMs in various forms. MROs could share a percentage of their profit to compensate all the benefits received from OEMs, representing a tangible monetary benefit to OEMs. Additionally, manufacturers must also consider some intangible gains rendered by offering increased service level to operators, such as better product reliability resulting in stronger brand, increased market share, higher sales and lower warranty costs.

Another source of revenue for OEMs could come from training services provided to MROs. At the same time OEMs would be offering training incentives to MROs, they could gain in economy of scale. Since 80 per cent of the MRO companies are small and medium enterprises, which usually resolve their training needs with local solutions, OEMs could have a stronger participation in the training market niche by offering such incentives.

In essence, cooperation between OEMs and MROs should be much more robust than it is today. A new PSS business model should be designed and tested to strongly promote collaboration between these two aerospace players.

## 3 FOUNDATION FOR THE PSS COLLABORATION MODEL

In Section 2, opportunities of collaboration were raised under the approach of operational resources exchange between OEMs and MROs, with the objective of improving financial results of both companies while bringing added value to aircraft operators by delivering high quality services. In this section, the different types of resources previously mentioned are grouped in three categories: 1) Spare Parts and Tooling; 2) Data; 3) Training, and then each category is broken down into sub-tiers which will be the basic components of the future quantitative model. In the context of this work, the term “resources” refers to any spare part, tools, high skilled personnel and data needed to perform aircraft maintenance activities or created during that process.

In addition, Section 3 also explains how reduced turnaround time (TAT) represents added value to operators. According to FAA (2012), one of the three main reasons that operators outsource maintenance activities to MROs is the reduced TAT to complete the service due to the higher level of specialization of these maintenance providers. In the MRO industry, TAT is the acronym used to specify the planned duration of a maintenance check, thus in the context of this study, when mentioning TAT increase, it refers to the delay on the maintenance service planned schedule. In that sense, if TAT reduction means value to operators, then it can be assumed that reducing the risk of TAT increase is a value-added activity within MRO business.

In fact, the shortage of any of the above resources implies risk of TAT increase, so the proposed model will capture the relation between TAT increase and resources availability. The amount of required investment will usually depend on the MRO's production capacity and can either be estimated by an MRO expert or from MRO's historical data. It needs to be set as a parameter in the mathematical model. The average TAT increase is also a parameter to be set in the model and it can either be obtained as for the parameters related to investment requirements or even calculated by using the PERT/CPM technique (Darci, 2004). Most of MRO companies adopt specific PERT/CPM based software to plan and schedule the maintenance tasks in form of a project with the objective of better managing TAT through the critical path analysis. By doing that, MROs are able to plan TAT for each aircraft shop visit in a more precise manner and also better monitor the progress of the maintenance tasks during the project execution. In addition, this type of technique also enables assessment of impacts on schedule caused by deviations such as lack of resources or any other technical problem encountered during the execution of the maintenance activities. Figure 2 conceptually illustrates the main phases of an aircraft heavy maintenance check. Phase 3 is where all the discrepancies previously identified in Phase 2 are corrected by means of parts replacements or repairs. Therefore, it is exactly in that phase of the project where all the unplanned resources demand occurs, such as demand for specific parts or tools. Consequently, most of the TAT delays are caused in Phase 3.

Within the context of this study, the TAT increase caused by lack of resources is considered to happen in the "Rectification Phase" of the aircraft heavy maintenance. Therefore, the average TAT increase can be calculated as the difference between the time for acquisition of the unplanned resource (including procurement time, importation, transportation and utilization) and the time originally planned for Phase 3. The average acquisition time of the unplanned resource can be estimated by an MRO expert or even obtained from purchasing department's historical data. That type of information (also called lead times) is usually recorded and stored in MRP (Material and Resources Planning) systems. The planned time of each phase is usually estimated by MRO experts and depend on the type of maintenance check as well as on type of aircraft.

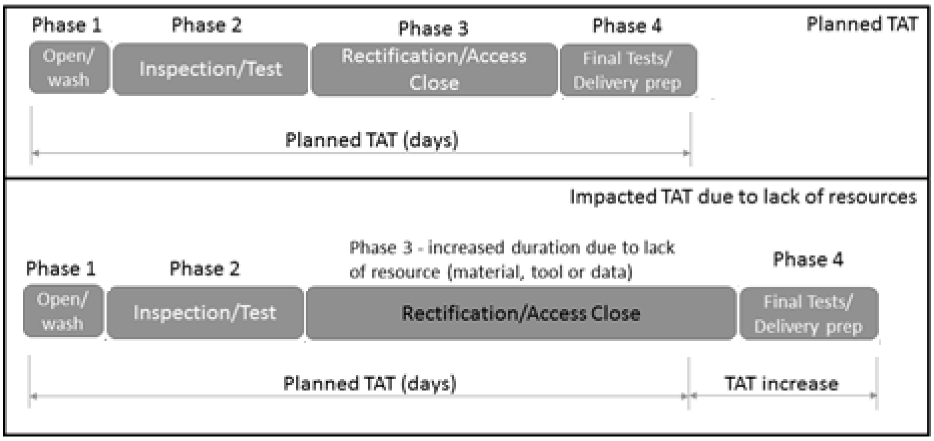


*Figure 2. Conceptual impact on TAT due to lack of resources*

### 3.1 Spare Parts and Tooling

Spare parts and tooling availability is crucial for a smooth MRO operation. The more spare parts and tools MRO has available, the lower is the risk of stopping maintenance activities due to lack of those type of resources. If during maintenance activity, a required spare part or tool is not available, that activity is interrupted while supporting departments such as Purchasing go through the procurement and acquisition process, which sometimes can take up to several days depending on the type of part, importation process, transportation means, etc. Consequently, that interruption then creates a risk of TAT increase. As mentioned, each type of spare parts can affect differently the TAT, depending on its logistics lead times and impacts on production line. According to International Air Transport Association, spare parts can be classified as "rotable", "repairable" and "expendable", depending on criteria such as scrap rate, financial or life-cycle (IATA, 2015). In the scope of this research, an adaptation has been proposed, where "consumable" is introduced, "expendable" is subdivided in two and "repairable" is considered as being the same as "rotable":

- Consumable: those are mostly chemicals such as sealants, lubricants, solvents, cleaners, grease, oil, paint, adhesives, resins, other fluids, etc. This type of material is associated with low cost, and can usually be bought locally, so the procurement and logistics process is relatively short;
- Light expendable: hardware, attaching parts, fasteners, brackets, clamps, clips, nuts, bolts, washers, etc. These parts also are low cost, however procurement and logistics process can be longer than consumables because they are not always found locally, so they must be imported from other countries, what usually is time consuming due to customs processes;
- Heavy expendable: heavy extruded profiles, sheet metal parts, casting, raw material, etc. Those present higher unit cost as well as a more difficult procurement and transportation process, mainly when they must be imported. This type of part is always critical because they are demanded usually for structural repairs which are often time consuming. In addition to the long acquisition time and more complex installation process, there is the part finishing time that may involve one or more of the following fabrication processes: machining, heat treatment, shot peening, adjustments, surface protection, etc. The part finishing process is usually required before the part final installation on the aircraft. Thus, considering all those processes, it is easy to perceive that the lack of this type of part can cause a high risk of maintenance delay.
- Rotable or Line Replaceable Units (LRUs): those are the more expensive parts, such as computers, electronic modules, complex components, however they don't require much effort for installation

as they are designed to be "plug & play". Examples of LRUs are: smoke detectors, main DC power batteries, altimeter, wheels, etc. Most often, procurement is not done locally.

As per the above break down, TAT increase related to each type of spare part will be particularly modelled in accordance with its characteristics.

The modelling of TAT increase caused by the lack of tooling follows the same rationale as for lack of parts. The main types of tools and equipment considered to be modelled are:

- Non-destructive inspection (NDI) equipment and accessories: such as eddy current, dye penetrant inspection, magnetic particle, x-ray inspection, borescope, etc;
- Hydraulic cart: used to test the hydraulic systems of the aircraft. In many cases, it substitutes the aircraft's hydraulic pumps for a specific test. Usually, different aircraft models require different requirements (pressure, flow rate, type of fluid or even features) for a hydraulic cart, obliging the MRO to have several carts in its facility;
- Special tools: adapters, special pressure units/valves, flight controls tools, Hot Bonder, etc;
- Test sets: as Vaclav, special borescope, vapour seal, Air Data Test, ATC transponder test set, etc;
- Special jigs: for engines removal, landing gear removal, APU, thrust reverser, primary flight control surfaces balancing and many others.

Therefore, following this rationale, the smaller the investment gap, the lower the risk of TAT delay. However, having huge inventories mean high investments for an MRO, what most of the times is not feasible. Therefore, the concept considered for the proposed model is that OEM and MRO should split this investment in spare parts and tooling to promote a financially feasible collaboration. That viability shall be performed by analysing the impact on gross profit of both companies created by the related costs and investments. For instance, if OEM invests in MROs by sharing resources such as spare parts and tooling, this will cause a negative impact on OEM's Gross Profit. On the other hand, that same investment will contribute for a positive impact on MRO's Gross Profit. The opposite effect will occur when MRO shares its resources with OEM. Hence, the model will calculate the final balance of gross profit impact to use it as a financial indicator. In accounting, gross profit is the difference between revenue and the cost of making a product or providing a service, before deducting overhead, payroll, taxation, and interest payments.

## 3.2 Data sharing

As discussed in Section 2, data exchange between OEMs and MROs can represent a competitive advantage for both businesses. In the context of this research, the main types of data that can be exchanged are:

### *3.2.1 Product data*

MROs rely on this type of data to reduce the cycle time of problem resolution analysis of unscheduled maintenance events occurred during services execution. That means shorter aircraft downtime for operators. Product data is usually owned by OEMs. The product data considered in the proposed model are: 1) Installation drawings; 2) Fabrication drawings; 3) Component Maintenance Manuals (CMM); and 4) Service Bulletins.

Usually, OEMs sell these types of data to MROs through annual subscriptions. The more access to data MRO wants to have, the higher the price it will pay to OEMs. However, the more data MRO has, the quicker it is to resolve the problems identified during the aircraft maintenance check.

Therefore, the lack of this type of data during a maintenance event creates a risk of TAT (Turnaround time) increase. By sharing product data with MROs, OEMs would be losing revenue once in usual commercial conditions this type of data would be sold to MROs by means of annual subscriptions.

On the other hand, when OEMs share their product data with MROs, it creates a positive impact on MRO's gross profit since they are reducing expenditures with product data subscriptions.

### *3.2.2 In-service data*

In the context of this research, this is the maintenance data produced when aircrafts stop for a shop visit in an MRO, for example: Maintenance and Pilot reports; Maintenance actions; Troubleshooting reports; or Component shop reports.

As discussed in Section 1, MRO services is a growing market, thus the amount of in-service data annually produced by those maintenance providers is expected to increase by following that market expansion trend. In addition, it is well known that OEMs rely on in-service data so they can identify product improvement opportunities. For example, by having the information on which "no-go" components (the ones that if fail will prevent the aircraft to fly) present the higher failure rates, OEMs can prioritize engineering failure mode and effect analysis of those components aiming at increasing their reliability to reduce the number of AOG (Aircraft on ground) events, which represent huge losses to operators since that type of event means the aircraft is prevented of performing a revenue flight.

Another benefit of improving the product reliability is that the maintenance intervals of the referred component can be increased, meaning less shop visits and consequently less interruption of aircraft operation. For instance, considering a hypothetical case where a manufacturer specifies that the aircraft must stop for a shop visit every five thousand flight-hours for the landing gear to be overhauled. Imagining that after gathering some years of in-service data, the manufacturer is able to improve the product so that maintenance interval can be extended from five thousand flight hours to ten thousand flight hours, this will promote a lower number of aircraft stops along its lifespan, meaning less interruption on revenue generation for operators as well as reduced maintenance cost.

Therefore, by possessing in-service data OEMs can work more efficiently to improve the aircraft dispatch reliability, which is an important quality indicator as well as a strong selling point. Boeing has been doing significant improvements in maintenance programs by applying statistical analysis on in-service data. From 1997 to 2011 Boeing optimized its B737-NG airplane's maintenance program, being able to increase 1000 FH (flight hours) in hangar scheduled maintenance intervals every four years, what is in average 250 FH per year (McLoughlin et al., 2011).

One of the most interesting opportunities for OEMs by following the collaboration model proposed by this research is that manufacturers would be able to do better spare parts demand forecast, thus promoting significant cost reduction through more efficient inventory management. MROs detain precious information on spare parts consumption. By recording all the parts consumed in each shop visit along the years, they usually have databases populated with parts consumption information, which, if shared with OEMs, can be used to identify the most consumed parts, so they can optimize their inventory levels, what always represent significant monetary savings.

A case study developed by an aerospace manufacturer and published by SAS (2012), has reported that a manufacturer was able to increase significantly the accuracy of forecasting and consequently reduce inventory costs by automating in-service data statistical analysis. The return over investment after one year was estimated to be between $10-15 million.

In order to model the relation between the amount of in-service data and the inventory cost reduction, this research utilizes the findings in the SAS 2012 and Airbus (Canaday, 2016) studies, which report that 240 aircrafts in four years produced reasonable amounts of in-service data to enable conclusive statistical analysis.

## 3.3 Training

As previously discussed, high skilled personnel is one of the key resources required by MRO companies in order to produce good quality and efficient maintenance services. The amount of training given to the MRO's maintenance personnel affects the company's productivity, thus impacting directly the TAT of maintenance services. Therefore, in the scope of this research, the amount of training given to maintenance technicians is defined as a required resource. Additionally, training is also a regulatory requirement, which is recurrently audited by aeronautical agencies such as FAA (Federal Aviation Administration), EASA (European Aviation Safety Agency) and others. Aircraft maintenance personnel require technical and non-technical training. Technical training examples are:

- Aircraft model-specific: the MRO must have all the technicians trained in all the aircraft models for which it is certified to work on;
- Special services: such as NDI (Non-Destructive Inspections), borescope inspections;
- Standard maintenance practices.

Examples of non-technical training are: Aviation Regulations; Lean manufacturing; Language courses; Customer relations; Safety Management System; Human Factors; etc. An aerospace case involving Northrop Aircraft Inc. revealed that many positive results were achieved plant wide after consistent training of 1241 employees (Dinero, 2005). Some of the improvements were: production increased in 17%; rejections reduced 12%; scrap reduced 27% and injuries reduced 45%. The present research intends to use the production increase data above to establish the relation between investment in training and expected TAT gains.

## 4 CONCLUDING SUMMARY

Literature suggests that MRO stakeholders should shift from high competitive to more collaborative business model strategies. In Section 2, we identified opportunities to improve business relations between airframe OEMs and aviation MROs under the approach of increased collaboration to raise operational resources availability at these service centers. Interviews with MRO and OEM professionals from Brazil, Spain, Argentina and Chile, indicated the four types of operational resources that have the highest impact on TAT. Section 3 defined the taxonomy and characteristics related to each type of resources, and outlined the effects caused by the availability variation for these resources on TAT. The relevance of in-service data collection for OEM to improve their product's reliability was also discussed. The success of the proposed collaboration approach depends on the ability of OEMs and MROs to deal with possible challenges such as cultural and language issues, political aspects, customs regulations, etc. The overcoming of these barriers will require a certain level of determination and innovation mindset. In fact, Wallin (2013) states that capabilities for innovation is one of the key requirements for a successful PSS strategy. This paper set the foundation for a quantitative model that maps the business relationships between aerospace OEMs and aviation independent MROs under a PSS perspective, aiming at promoting enhanced collaboration between these two stakeholders to provide global support to operators at higher service levels.

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