Paper 108

Integration of RFID Technologies in Helicopter Maintenance Processes

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ABSTRACT

Helicopter configuration management is a cornerstone for aircraft industries and operators. The information on helicopter configuration is essential for safety, maintenance and availability reasons. Eurocopter is developing a project for integrating RFID (Radio Frequency IDentification) tags on helicopter parts for maintenance. These technologies will support configuration management and provide maintenance information.
As these RFID tags will be embedded, they have to be adapted to aircraft environment and harsh conditions. This improvement will increase RFID tag costs.
In this paper, we identify and quantify impacts on maintenance processes. Our study focuses on a major maintenance cost indicator: the DMC (Direct Maintenance Cost). We will show that RFID technologies can greatly influence the DMC.

INTRODUCTION

Aircraft maintenance is a huge cost vector for the related industries. For an efficient realization of maintenance actions, configuration management is an important input data. The knowledge of "in flight" configuration helps identifying the right part. RFID technologies can support an improvement of aircraft configuration control. However, these technologies are expensive to implement.

We propose to estimate benefits through an economical analysis on maintenance processes. The indicator vector chosen is a maintenance cost indicator widely used in aircraft industries and operators.

CONFIGURATION MANAGEMENT DURING HELICOPTER LIFECYCLE

Configuration management description

A helicopter is made up of a very large number of parts (several hundreds). Unlike airplanes, helicopters can ensure plenty of missions such as offshore, emergency, VIP, workload transportation, etc. An aircraft can assume all these applications and has to be customized to perform them. The configuration of a helicopter can thus vary in a wide range. Optional components can be added or removed and parts can be changed to support the next mission. The configuration can vary daily and parts can be exchanged between aircrafts.

Configuration management is thus a cornerstone during the life time of an aircraft. Each configuration modification has to be tracked for safety, maintenance and availability reasons. The knowledge of this information is not easy to control but is mandatory for certification organisms and airworthiness issues.

Configuration management in maintenance processes

The customer's CMMS (Computerized Maintenance Management System) allows this tracking by merging all configuration data when a modification occurs. This tool of maintenance management and planning also records usage data (flight hours and flight cycles) for usage follow up of each part.

The MSR (Master Servicing Recommendations) indicates at which time (or usage level) parts have to be replaced or repaired. Customer's CMMS and MSR are compared for determining maintenance expiry date of all parts on board submitted to preventive maintenance. The CMMS also delivers maintenance plans considering the operator missions and constraints.

After a plan has been established, aircraft parts have to be maintained at their due dates. There are three levels of maintenance shops depending on intervention complexity (see [6], [10] and [11])

- O-Level: Operating Level. It corresponds to aircraft preparation, current tasks, quick and simple reparations. They are realized at the customer's premises.
- I-Level: Intermediate Level. It corresponds to maintenance which requires moderate means, specialized shops, tools and employees.
- D-Level: Depot Level. It corresponds to major overhauls with qualified labour.

According to the level(s) involved, the part time unavailability varies. In most cases, parts are changed and the removed ones are sent to the appropriate repair shop. Serial number and sometimes part number changes. All information must be updated in the log card and also in the CMMS.

As the log card is a paper document, it can be lost, partially fulfilled or erroneous.

Configuration management: a challenge during aircraft lifecycle

Nowadays, aircraft configuration tracking, particularly for maintenance aspects, constitutes a major stake. Information traceability through electronic tools will support configuration management and enhance configuration reliability. Data will have a better accuracy than the paper follow up.

The problem identified is to find out a technology which permits the configuration of an aircraft to be automatically managed along its life cycle.

INTRODUCTION TO RFID TECHNOLOGIES

Currently, the best technology identified for assuming such an ambition is RFID (Radio Frequency IDentification).

RFID technologies: general description

RFID components are able to communicate in a wireless way. They can transfer data with radio wave signals. RFID tags are composed of a chip which contains data. This chip is connected to an antenna. It allows information to be exchanged with an interrogator module. The packaging protects the tag from environment damages. Contrary to bar code, RFID tag information can be modified and updated. If the part is ageing, data concerning the usage can be updated. Data inside the tag or in an associated data base can provide real time information on the tracked part.

Adaptation to aircraft use case

In the aim of managing "as flight" configuration, RFID tags will be affixed to the parts that are traced. They contain the same data as the actual log card. The log card is the paper form following the part during the maintenance processes. It contains identification and maintenance data. As they will be embedded, RFID tags must be rugged to withstand harsh environmental conditions. Industries are trying to adapt several RFID technologies to support in flight conditions. A data security level will also be integrated. This will protect from counterfeit or data corruption.

These tags will contain information on the parts (identification and maintenance data) as specified in the aeronautical standard for RFID (ATA Spec 2000 Chap 9.5 [1]). This kind of data will help configuration management and also maintenance processes. The concept of e-maintenance will be supported [5]. The traceability in maintenance processes will increase benefits in addition to logistics aspects.

Aircraft implementation

Embedding RFID tags and reading systems (in a meshed network [3]) requires to optimally locate the various components. A global RFID system positioning is complex because each tag has to be read (whatever distance or space restrictions), global weight has to be constrained and cost has to be minimized. There are other constraints which will not be detailed here but taken into account for aeronautical integration (*e.g.*: limitation of reading modules due to aircraft architecture). Each RFID component exists in various technological performances (and prices) which represents a big challenge for decision makers.

In a first part of our work, we have developed an optimization model to support these decisions. Decision makers will select best solution candidates in terms of technologies and cost impacts. This program is based on an ILP (Integer Linear Programming) model and optimises technological choices and location of RFID components into the aircraft. This program is easily exportable to any kind of aircraft or similar systems with few adaptations in the constraints and input parameters.

An overview of the results is shown in Figure 1. It represents the global cost of the entire embedded RFID system according to technological performances and prices.

"A" performances represent the worst read/write distances we have considered in our hypothesis (0.3 meter for passive tags, 0.8 meter for semi-passive tags and 5.2 meters for active tags). "D" performances correspond to the best performances. Similarly, two kinds of technological costs are studied. Low cost corresponds to 0.5 € for passive tags, 5 € for semi-passive tags and 20 € for active tags. High cost tags are also considered. Thus, we varied the parameters for an overview of the global cost trend (sensitivity study).
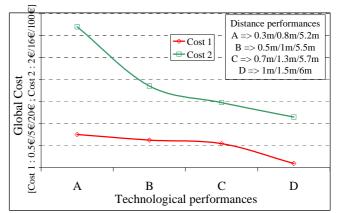

Figure 1 Global RFID system cost *vs.* technological performances

The model provides an overall minimum global cost. It selects the best technology candidate (passive, semi-passive or active tag) for each tracked part, the position of each tag, but also the technology and position of each reading module (full power or medium power).

The main intention of this work is to help decision makers when they are confronted with several possibilities which influence costs, weights and impacts on processes. For instance, in Figure 1, the green chart (Cost 2 = High cost per technology) is drastically decreasing from A to B performances. It could be interesting to choose B performance for high cost per tag. On the contrary, in the case of Cost 1, the global cost is not so much impacted by the same performance improvement.

INTEGRATION OF RFID TECHNOLOGIES IN INDUSTRIAL PROCESSES

RFID generated costs

RFID technologies are expensive compared to other means of traceability. For instance, bar code is only printed and does not imply a big investment. RFID technologies, by themselves, induce additional investment costs when they are introduced in industrial processes. In the aeronautical context, RFID technologies have to be adapted to meet airworthiness conditions. This hardening will considerably increase the cost. Before integrating such technologies, the industry has to consider the associated return on investment.

3

As RFID tags will be on board, the impacts will not only be on logistics aspects (a common use of RFID) but also on maintenance processes. According to ATA Spec 2000, maintenance information will be delivered thanks to the ship memory. This information will considerably help from aircraft delivery by the OEM (Original Equipment Manufacturer) through the entire lifecycle of each aircraft component.

RFID generated benefits

For a better illustration, we have focused our work on the maintenance process at D-Level. A simple description of the process can be found in Figure 2.
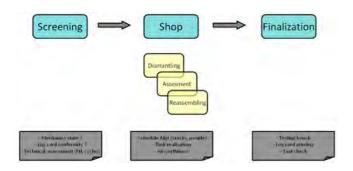

Figure 2 Mechanics D-Level process at helicopter manufacturer

At this level of maintenance, several steps can take advantages of RFID integration:

At the first step, when screening the mechanics, the identification of non-conformities is done. Conformity with log card information is established and update of usage data is checked (flight hours and/or cycles). If there is any lack of data, the mechanics is waiting until the data is updated (e.g.: waiting for data coming from the customer's CMMS).

First benefit ➔ RFID technologies will decrease the lack of information due to paper log card. The handwritten update is obviously associated to human errors which are difficult to avoid. Due to wrong or partial data, a part can wait a long time for data collection at shop level. The waiting time can strongly be reduced or even cancelled thanks to RFID implementation (a part can stay several months at the screening stage).

At the second step, the mechanics is entering into the repair shop. It is dismantled for expertise. The assessment reveals parts to be repaired, to be discarded or to be kept because they can ensure a new service life. Replenishment of spares from Eurocopter stocks allows complete part overhaul. After that, the appropriate parts are reassembled for the overhaul execution.

Second benefit ➔ RFID technologies will anticipate the workload in the repair shop. They will provide accurate statistics about parts repaired or changed for new ones. This will provide more precision and help to better forecast changes in the stock levels. Stock levels will be estimated according to aircraft configurations and versions of parts. Human resources will also be calculated with a real experience feedback. This will avoid workload peaks that are difficult to manage.

While the mechanics is under overhaul, the airworthiness service updates log card data (part number, serial number, installation date, removal date, service life, etc.) of all elements involved in the mechanics. It makes sure that the mechanics has followed the right operations and is able to ensure a new overhaul life.

Third benefit ➔ RFID technologies will facilitate the inventory of parts and reassembly [7]. A mechanics can contain up to 150 parts. All of them are not submitted to preventive maintenance but are involved in the repair process.

After being reassembled, the mechanics is tested and evaluated on a testing bench. After this stage, a last part check is performed and the new log card is edited.

Fourth benefit ➔ RFID technologies will facilitate the last inspection and will avoid conformity problems [8]. At this step, if a serial number is wrong, the mechanics has to be dismantled again, the part is changed and new tests are performed. RFID will help to avoid such mistakes.

Managing numerical log cards can considerably improve maintenance processes. That is why we have worked on a D-Level maintenance shop to estimate RFID benefits. To evaluate the impacts of RFID technologies, a significant indicator in an aeronautical context has to be considered. This indicator can be the availability of the aircraft, the return on investment, the customer satisfaction, etc. As aeronautical industry is really concerned by maintenance costs (about half of the lifecycle cost of a helicopter) [9], we decided to consider the Direct Maintenance Cost (DMC).

FIRST RESULTS ON THE DIRECT MAINTENANCE COST (DMC) STUDY: QUANTITATIVE IMPACTS

Brief introduction of DMC

The DMC is used a lot as a statistical figure that varies with the type of mission carried out by the operator. It is the most significant cost driver over the in-service phase and is consequently a competitiveness indicator.

The DMC is taking into consideration both preventive maintenance and corrective maintenance. It includes direct costs allowing the maintenance of a system. It concerns spare parts, consumables, repair and replacement labour and tool depreciation [4] and [2]. For a global view, it can be separated in:
- Technical labour (due to preventive or corrective maintenance)
- And spare parts and consumables costs

The Direct Maintenance Cost is expressed per usage metrics. In the aeronautics domain, the reference unit is the flight hour.

Details on DMC

The DMC is the sum of two parts (Eq. 1). The first part of the expression corresponds to preventive maintenance, and the second part is associated to corrective maintenance.

$$DMC = \frac{Preventive\ maintenance\ Cost}{Expiry\ date} + \frac{Corrective\ maintenance\ Cost}{MTBUR} \quad \text{(Eq. 1) [4]}$$

The preventive maintenance cost per flight hour is defined as the ratio between the maintenance cost and the time between two preventive maintenance actions (replacement, check or overhaul according to the part considered). The corrective maintenance cost per flight hour is defined as the ratio between the maintenance cost and the time between unscheduled maintenance actions (MTBUR = Mean Time Between Unscheduled Removals).

To improve the DMC, maintenance costs (preventive or corrective) have to be managed and reduced. In the same objective, time between maintenance actions should be improved. The study we led is focusing on maintenance costs for both preventive and corrective maintenance actions.

Modelling the gain provided by RFID technologies

As mentioned before, RFID technologies have a great incidence on time savings (see first, second and fourth benefits in the previous section). RFID technologies will impact several aspects of maintenance processes. For a first estimation, we focus on labour reduction and task force optimization.

DMC can be detailed as follows:

$$DMC = \frac{Overhaul\ mtc\ Cost}{Overhaul\ Expiry\ date} + \frac{Replacement\ mtc\ Cost}{Replacement\ Expiry\ date} + \frac{Repair\ mtc\ Cost}{Repair\ MTBUR} + \frac{Replacement\ mtc\ Cost}{Replacement\ MTBUR}$$
$$\text{(Eq.2)}$$

Overhaul and replacement costs (bold font) correspond to preventive maintenance that happens regularly. More spare parts are concerned with overhaul than with replacement. The replacement of a new part is an easy process when workers have the right working card. Overhaul also implies dismantling, inspection and reassembly. More labour time is necessary for this kind of maintenance action. Overhaul maintenance will benefit more from RFID technologies than replacement maintenance.

For corrective maintenance, the same reasoning can be applied. Repair will be more impacted by RFID technologies than replacement. However, for replacement in a corrective maintenance action, additional time is needed. Corrective maintenance may require more man hours around the task itself. For instance, corrective maintenance can claim more labour time because of failure location and No Failure Found Rate (NFFR). Thus, for replacement maintenance cost, RFID technologies have more impact on corrective maintenance.

As previously detailed, Direct Maintenance Cost can be separated into technical labour and spare parts. Thus, we have:

$$\frac{Overhaul\ mtc\ Cost}{Overhaul\ Expiry\ date} = \frac{Overhaul\_Labour\_Cost + Overhaul\_Parts\_Cost}{Overhaul\ Expiry\ date} \quad (Eq.3)$$

$$\frac{Replacement\ mtc\ Cost}{Replacement\ Expiry\ date} = \frac{Replacement\_Labour\_Cost + Replacement\_Parts\_Cost}{Replacement\ Expiry\ date}$$
$$(Eq.4)$$

$$\frac{Repair\ mtc\ Cost}{Repair\ MTBUR} = \frac{Repair\_Labour\_Cost + Repairt\_Parts\_Cost}{Repair\ MTBUR} \quad (Eq.5)$$

$$\frac{Replacement\ mtc\ Cost}{Replacement\ MTBUR} = \frac{Replacement\_Labour\_Cost + Replacement\_Parts\_Cost}{Replacement\ MTBUR}$$
$$(Eq.6)$$

We define a model which is considering labour gains on the global DMC (Eq.2) and calculates the ratio between DMC with RFID and DMC without RFID. More details on the DMC model and ratios cannot be given for confidentiality reasons.

In the frame of this work, we plot several scenarios for sensitivity analysis to provide a better overview of the model behaviour. We analyse the improvement on labour costs from 0 % to 20 % through RFID. Then, the impacts on DMC are represented (in percentage for confidentiality reasons).

Numerical results

The charts in Figure 7, 3 and 4 represent the influence of labour profits on DMC in the following cases:

• **Case 1**. Preventive maintenance: Consideration of **Replacement** for new ones. We consider both preventive and corrective maintenances because parts which are submitted to preventive maintenance can follow the corrective process. The equations used are: Eq. 4 and Eq. 6.

• **Case 2.** Preventive maintenance: Case of Repair and Overhaul of parts. As before, a part which is under an overhaul expiry date can face a corrective maintenance action. The equations used are: Eq. 3, Eq. 5 and Eq. 6.

• **Case 3.** Corrective maintenance: A corrective maintenance can occur but the part is repairable. We consider a certain "percentage of reparability" of parts because sometimes they are also damaged and thus must be exchanged. The considered equations are Eq. 5 and Eq. 6.

• **Case 4.** Corrective maintenance: A corrective maintenance for only replacement of parts for new ones. It often occurs because many parts are not submitted to preventive maintenance and are not repairable. The considered equation is Eq. 6.

This study analysed all configurations considered in aircraft maintenance. It can be submitted to the MSM (Master Servicing Manual) and also face unplanned maintenance actions. Some parts are not under planned maintenance but can enter the maintenance process. This is called corrective maintenance.

For Case 2, each gain on labour is considered separately in the global gain model (considering other possibilities of maintenance actions). We wrote the DMC gain value next to the graph at 10 % labour reduction. Results are shown in Figure 7, 5 and 6.
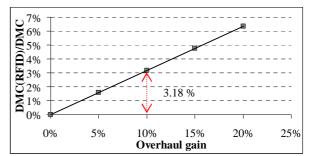

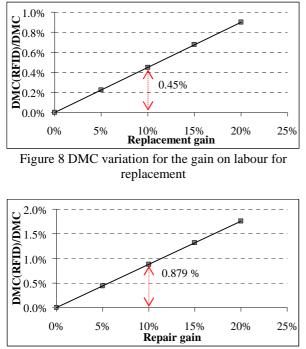Figure 7 DMC variation for the gain on labour for overhaul

Figure 8 DMC variation for the gain on labour for replacement

Figure 9 DMC variation for the gain on labour for repair

	Case 1	Case 2	Case 3	Case 4
Overhaul		**3.18 %**		
Repair		0.88 %	2.98 %	
Replacement planned	**3.50 %**			
Replacement unplanned	1.01 %	0.45 %	1.53 %	4.5 %

Table 1 Gain on DMC for 10% labour reduction and for several scenarios of maintenance

For other cases, results are listed in Table 1. The following conclusions can be drawn.

- **Case 1** has more impact on planned replacement than on unplanned replacement. It is due to the frequency between both. Planned maintenance for replacement comes three times more often than unplanned maintenance.

- **Case 2**: Overhaul has the biggest impact. It implies more parts and more labour time than repair or replacement. Moreover, Replacement is more influenced than replacement because it requires more labour time than replacement.

- **Case 3**: The explanation is the same than for Case 2.

- **Case 4**: Very large impact for unplanned replacement because this kind of parts sometimes requires a long time for identifying the part to be replaced. Wrong removals are also a problem encountered by this kind of parts.

CONCLUSION AND PERSPECTIVES

This study has shown that RFID has an important impact on maintenance processes. Results are focused on depot level of the maintenance process. The cost indicator chosen: DMC (Direct Maintenance Cost) is strongly impacted by RFID on man hours. This indicator is a reference for both aircraft manufacturer and aircraft customer. Thus, we can expect economic improvements and competitive advantages.

In a future work, we intent to broaden our study to another cost indicator: the DOC (Direct Operating Cost). It is an average cost per flight hour that takes into account additional factors such as labour cost. This indicator is interesting because it integrates all labour costs, where RFID technologies play a major role.

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