Simulation of aircraft maintenance improvement using RFID systems

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Abstract

The paper describes the maintenance process applied to an aircraft part along periodic maintenance operations and/or failure repairs. This paper deals with the assessment of RFID (Radio Frequency IDentification) technology contribution to the follow-up of aircraft parts. The construction of a simulation model and validation of the study are based on both experts' knowledge and data on flight and maintenance operations. Each stage of the maintenance process is modelled in terms of time (average times and boundaries) and the transition probability between stages. The impact of RFID technologies in the overall maintenance process is assessed. The main use of the analysis is the evaluation of different maintenance strategies and a first quantification of the impacts related to introducing RFID in maintenance processes. It should be helpful to support the decisions on RFID integration. The model could be used to design a decision support tool for maintenance designers and managers.

Keywords: Maintenance, RFID, Helicopter, Part tracking, Process modelling

1   Introduction

For a global maintenance process analysis, various parameters, i.e. the use of human resources, spares and equipment have to be combined to ensure that the entire system is properly modelled. The aim of this paper is not to model the complete detailed maintenance process, but rather to have a first relevant overview. Details concerning maintenance are studied and mapped when necessary, i.e. when RFID (Radio Frequency IDentification) technologies may play a significant role.

The benefits of RFID integration are assessed and quantified on the maintenance process through the model. This will lead to a global estimation of the process impacts. The purpose of the study in this paper is to emphasize the benefits in terms of availability improvement and cycle time reduction. The resulting model could help the flight and maintenance policy planners for the identification of maintenance performance improvements more thoroughly. The model is aimed at providing an experienced user, such as a maintenance designer or a maintenance manager, enough flexibility to consider a wide range of scenarios. They can be defined by the decision maker in accordance with his process.

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In a first part, the paper introduces the RFID integration in helicopters. In section 3, the maintenance process is described. The section 4 details the availability stake and the improvements due to RFID technologies. Section 5 defines the model and the input parameters. The result analysis is conducted in the Section 6 before concluding.

2   Context of the study

RFID systems are composed of a label (tag), a reader and software feeding data into dedicated IT systems. Nowadays, RFID technologies are mostly used in logistics because they enable real-time traceability of products. They represent a major stake for process optimization in industry.

This study deals with the impact of integrating RFID technologies in helicopters (on-board system). RFID technology integration on aircrafts (passive or active tags) requires specific development and compliance to aeronautical environment standards. Tags should be hardened so that the influence of temperature and vibrations will not degrade tag performances (*e.g.* Read / Write distances). Harsh conditions and confined environment also constitute constraints for the electromagnetic wave propagation.

RFID technologies allow parts to be identified and traced using dedicated IT systems. Although RFID may affect a significant number of activities and stakeholders (Suppliers, Final Assembly Line, Global Logistics, Maintenance…), the study focus is on maintenance and support processes.
Maintenance is an important part of an aircraft life cycle. Operations and support costs approximately represent 60% of the helicopter life cycle expenses [4]. Maintenance operations in aeronautics ensure the aircraft performance, its availability and airworthiness. An RFID data collection system will support a complete maintenance (preventive or corrective) follow-up of parts [3].

In the aeronautical context, RFID tags will be associated to aircraft parts to identify and follow them during their life cycle [3]. Real-time identification of aircraft parts is a challenge, as aircraft configurations change depending on missions and maintenance operations. Part follow-up (identification and usage) is currently mostly done through paper documents. The RFID system will allow a computerized follow-up and update of information (part identification and maintenance data), thus reducing human errors. The associated IT system will provide an accurate real time status of assets that are subject to maintenance operations.

The general benefits provided by RFID technologies in maintenance processes can be summarized as follows:
- **Easier and faster access** to product configuration,
- **Inventory control** improvement,
- Better maintenance task planning and anticipation [5] will reduce **intervention time** and improve **aircraft availability,**
- **Improvement** of maintenance tasks (Localization of parts, avoid manual capture of data, form filling, …),
- **Post-task checking** can also be assisted through RFID technologies.

These benefits will be emphasized in our detailed study of critical maintenance processes. The approach proposed in this paper is similar to the one described in [12].

3   Helicopter maintenance processes

3.1   Overview
In order to better understand at which level technologies can influence maintenance processes (improvements and modifications), characterization and assessment of current maintenance processes have been carried out at Eurocopter shops.

Helicopters are regularly maintained to keep them operational, airworthy and to minimize failures. Parts only submitted to corrective maintenance are justified when failure costs are low and when safety constraints are weak. The aircraft manufacturer specifies the maintenance periods of an aircraft in terms of accumulated flight hours. The periods sometimes have a tolerance period, which leaves a possibility to schedule the maintenance to some extent. Moreover, maintenance periods are sometimes adjusted in specific cases, *e.g.* for customers that use

their helicopters in hard operational conditions (sea, cold, *etc.*). That allows variability in the time between maintenance operations. This is not allowed for critical parts.

Despite preventive maintenance, aircraft systems remain subject to random failures that prevent flight operations. Helicopter maintenance relies upon a complex system based on safety assurance, tests and continuous improvement. It is divided into three intervention levels (increasingly specialized) which can take place at customer premises, at supplier OEM (Original Equipment Manufacturer) or at rotorcraft OEM/subsidiaries premises. This implies numerous interactions between entities for stock level issues, team availability and parts under repair which have to be delivered. Support contracts usually include Turn Around Time (TAT) constraints and delay penalties.

3.2   *Detailed presentation of maintenance operations*

This part details the studied process flow. Dedicated aircrafts are chosen for flight operations of the day. A pre-flight check is carried out before the first flight of the day. After the pre-flight inspections, the aircraft waits on the airfield until it departs for the flight mission. The flight missions usually follow a predefined plan and schedule with a specific time of flight. A flight report is generated after each flight by the pilot. Between flights, the aircraft undergoes turnaround inspections and replenishments. Maintenance of this type is referred to as everyday maintenance. If failures are not found, the aircraft is ready for a new flight mission. At the end of the day, the operational aircraft is returned back to the hangar.

The assumption is made that the operation is using a CMMS system. After this step, maintenance data are gathered at the CMMS (Computerized Maintenance Management System). This system insures the airworthiness of the aircraft by gathering pilot reports. It generates the Work Orders (WO) concerning the maintenance to perform in due time. The work order can concern preventive and corrective maintenance. The CMMS manages all maintenance operations that are required. The CMMS elaborates the aircraft maintenance according to the mission constraints and maintenance shop constraints (see Fig. 1).
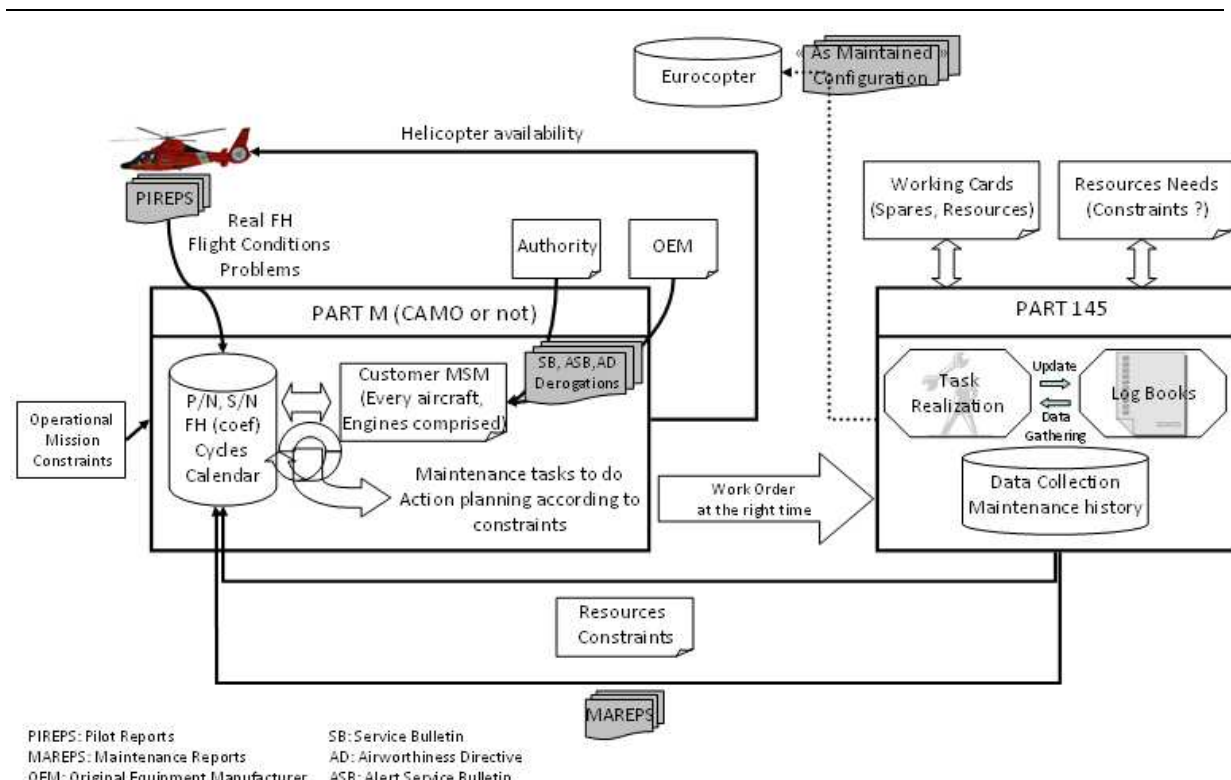

Fig. 1. CMMS process detailed

The WO sends the part to be maintained at the right maintenance shop. In practice, the allocation of tasks is done at different levels according to the task complexity, the part type (avionics, mechanics, etc.) but also based on the availability of resources. Aircraft requiring maintenance are directly transferred to appropriate maintenance

facilities. However, according to what is discovered at each level, a transfer to the higher level may be necessary (see Fig. 2 and Fig. 3).

Periodic maintenance constitutes a major part of all maintenance operations. Based on historical data from customers and the experience at Eurocopter, preventive maintenance happens on average three times when corrective maintenance only happens once. The frequency of periodic maintenance is based on cumulated usage hours of the aircraft and is given by the MSM (Master Servicing Manual). According to the variability of the maintenance operations, the workload of repair shops varies. Regular maintenance operations are planned and scheduled in advance to balance the maintenance work in all the maintenance levels [10]. Additional damages can be identified when preventive maintenance is performed which implies a higher level of maintenance. Besides planned maintenance tasks, possible component failures are preliminary analysed during turnaround inspections. Aircrafts that are not Mission Capable are assigned and sent to an appropriate repair facility.

A schematic view of the flight and maintenance process is shown in Fig. 2. with the different level of maintenance shops. The levels ensure the continued flight integrity and safety of airframes and related flight systems throughout their service lives.
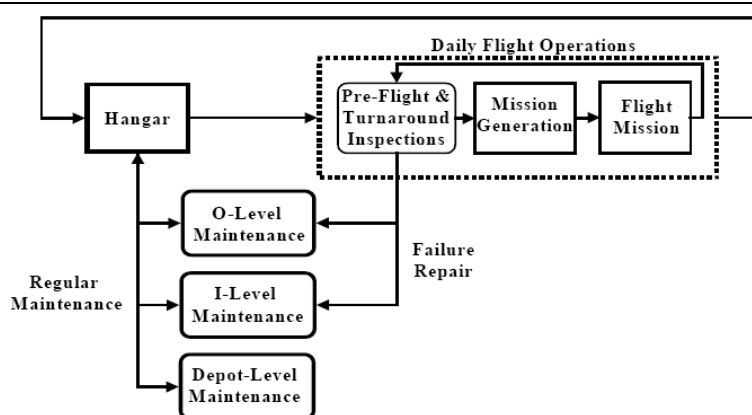

Fig. 2. Overview of the maintenance process [10]

Turnaround and pre-flight inspections, some periodic maintenance as well as minor failure or damage repairs are conducted at the O-level. It is generally referred as the **Organizational or Operational level**. The model considers an arrival time at the O-level shop. This arrival time is a random variable. The O-level maintenance is most of the time performed at the operator site and typically involves simple repairs or the replacement of modular components concerning both preventive and corrective maintenance. This level requires a specific stock which is not always available. The replenishment is not needed at every maintenance action. We considered an availability of 85% for a part submitted to preventive maintenance. The spare part waiting time is associated to the remaining 15% [6]. For corrective maintenance, the availability of parts is lower and the replenishment time remains the same. The total time of O-level maintenance is determined according to the effective maintenance realization and the waiting time for replenishment.

Sometimes, the customer has separate aircraft repair shops that are located in the airbases. These repair shops handle more elaborate periodic maintenance and failure repairs. They are referred to as **Intermediate level** (I-level). The I-level maintenance involves more difficult repairs and maintenance, including the repair and the testing of modules that cannot be realised at the O-level. At this step, the process modelled is very similar to the one described at the O-level. An assumption is done on the probability of transition between the O-level and the I-level. Then, the time of arrival to the I-level maintenance shop is estimated. The total maintenance time is evaluated with both the maintenance execution time and the replenishment time (when necessary).

The most elaborate maintenance tasks take place at **Depot-level** (D-level) repair shops. This involves performing maintenance beyond the capabilities of the lower levels, usually on equipment requiring major overhaul or rebuilding of end items, subassemblies, and parts. This level is most of the time realized at the OEM premises except in exceptional cases. The D-level is separated according to preventive and corrective maintenance for both mechanic and avionic parts. However, the corrective maintenance implies an irregular workload for man

power. The task is not always anticipated due to emergency caused by the unplanned maintenance. The spare parts are also ordered on a case by case basis without any planned replenishment.

The process flows in Fig. 3 and Fig. 4 show in more detail the maintenance process.
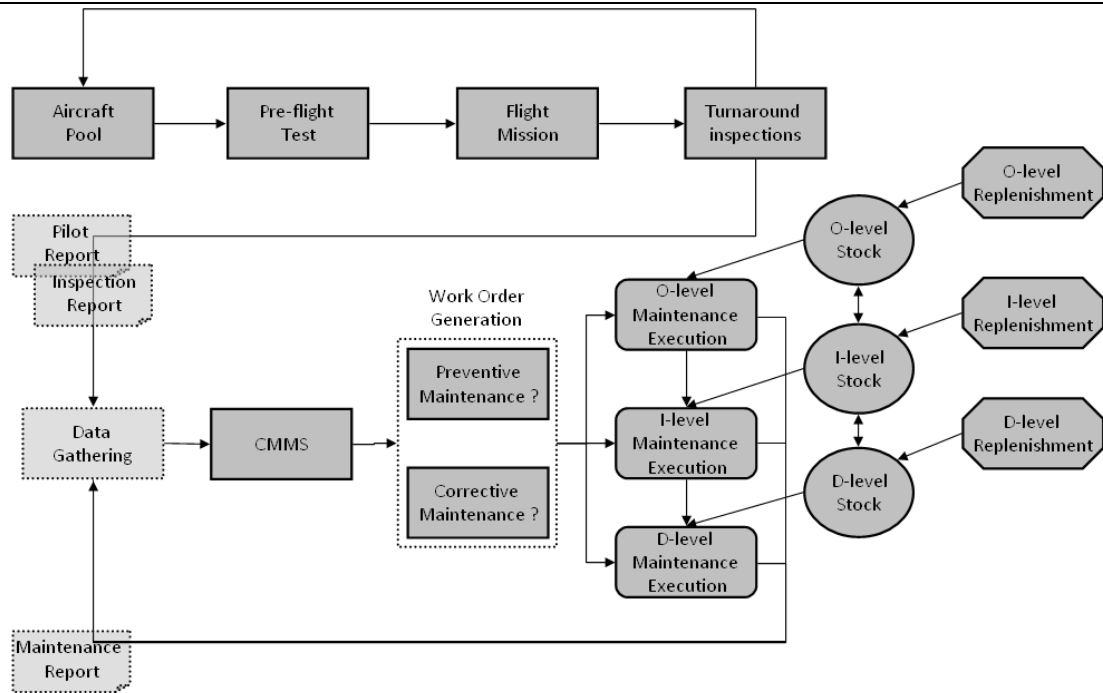

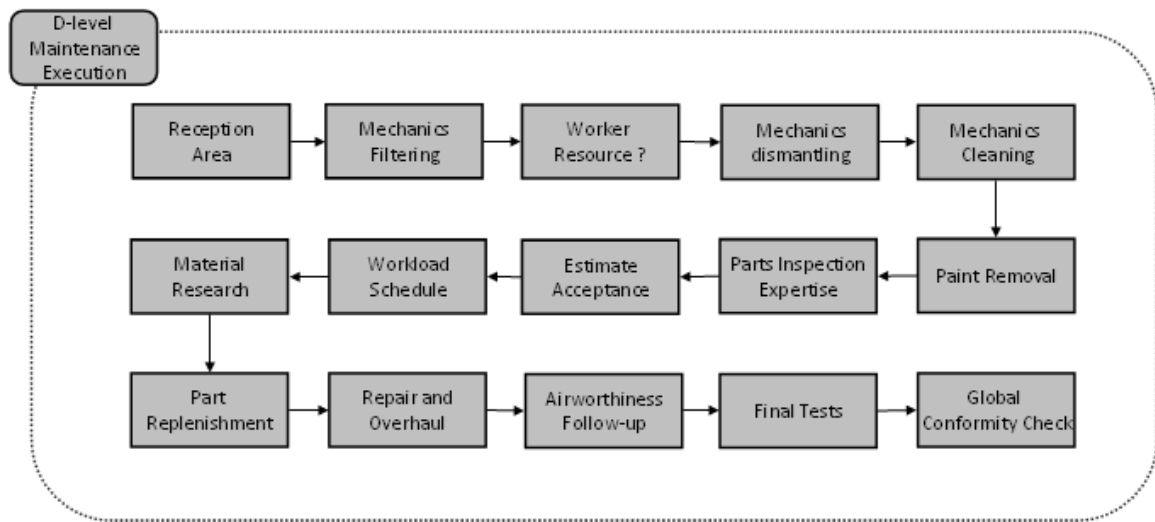Fig. 3.The maintenance process for helicopters (preventive and corrective maintenance)

Fig. 4. D-level maintenance process: A detailed view for mechanical part overhaul

4   Impact of RFID technologies on availability

The above process (Fig. 3 and Fig. 4) was used as a basis for identifying potential benefits using RFID technologies. A first analysis was performed on a representative performance indicator in aeronautics. The Direct Maintenance Cost (DMC) is widely used by OEMs and operators for benchmarking. The study showed that RFID technologies can improve the DMC by 4 to 5% [7], assuming a global RFID integration in maintenance processes [9]. The Direct Maintenance Cost is a well known cost indicator and is one of the most important

indicators in aeronautics. This paper analyses another important element for aircraft operators: the aircraft availability.

Aircraft availability is defined as the fraction of Mission Capable (MC) time to the total amount time [8]. This notion is used as the primary measure of performance by aircraft operators. A number of other aeronautical indicators can be monitored and help to analyze aircraft performances. However, the availability is a major stake for aircraft operators, which has been widely studied in the literature. When a fault / a problem is identified on an aircraft, the No Trouble Found (NTF) action results in a Non Mission Capable (NMC) status if the item is considered to be mission essential which means that the aircraft cannot fly. The availability indicator combines failure frequency with repair efficiency, and thus is dependent on reliability, maintainability, and supply process. For example, if a part needed to repair a failed component is not available, then the resulting logistics or supply time adds to the down time, over and above the time needed to replace the component once available. Therefore, component or subsystem repair times alone are not sufficient to model down time due to failure of the item, supply times must be considered. Scheduled maintenance activities on aircraft also affect the NMC status. As long as the aircraft remains under maintenance status, it is recorded as NMC over the unavailable period.

Kang et *al.* [8] developed some strategies for reducing repair cycle times (and as a consequence improve aircraft availability) in naval aviation depots. They present a scenario model, which primarily concentrates on the repair of aircraft components that are critical to readiness due to short supply. In [11] and [2], the availability of fleets of aircrafts and helicopters, respectively, are modelled. Both of these papers consider battlefield operations. In our case, only the civil fleet of medium size of helicopters is considered.

Balaban et *al.* [1] worked on a simulation model designed to estimate the MCR (Mission Capable Rates) for different military aircraft modernization schemes to be implemented. In this paper, the threshold to meet the availability requirement is based on an expected 75% rate due to new aircraft configurations. Mission Capable Rate less than 75% equates to a high-risk assessment in a battlefield context. A simulation approach has been used in estimating the availability of operational aircraft under war situations.

Virtanen and Raivio [13] presented a discrete-event simulation model for maintenance operations analysis in an uncertain operational environment. It provides the effect of maintenance policies on the overall performance of the aircraft fleet. A study is presented in [2], where a simulation model was used in the analysis of the combat maintenance operations of a helicopter fleet. In [10], a discrete event simulation model for the operations of a fleet of aircrafts during their peacetime use is constructed. The model describes the accumulation of the flight hours, failure occurrence, regular maintenance and failure repairs. Model input is based on real collected data collected.

The referenced articles show that assessing aircraft availability is well represented in the literature. In our study, we apply the same kind of methodology to our specific case. To our knowledge, no previous research has been performed on modelling and analysing the impacts of new communicating technologies such as RFID on aircraft availability. The reference studies were focusing on aircraft changes or process improvements. No new technology introduction was assessed so far.

5   A simulation model of the impacts of RFID technologies on maintenance processes

5.1   Objectives

The goal of each aircraft operator is to achieve the highest possible level of readiness, commonly expressed as operational availability, Ao = uptime / (uptime + downtime) = MTBM / (MTBM + MDT); where MTBM is the Mean Time Between Maintenance, and MDT is the Maintenance Down Time, which includes repair time, administrative and logistics times. Operational availability can thus be improved by increasing MTBM (i.e., increasing reliability) or decreasing MDT (i.e., reducing repair time or logistics time).

Reducing cycle time in the logistics channel (repair depots, intermediate-level maintenance, inventory control points, and supply centres) means that more spares are available and so more global aircraft availability. Some papers aim at shortening the cycle time in the maintenance process [13]. In our case, the reduction of cycle time is provided through the introduction of RFID technologies. At the supply level, it will reduce replenishment waiting time (anticipation of spare part needs) and improve stock level accuracy through improved data reliability. Maintenance execution will be more efficient thanks to a better follow-up of parts, location of parts,

accurate information, and reduction of paper forms. The workload schedule can be optimized, which will lead to the reduction of overloads. The RFID will considerably reduce or remove these problems and thus reduce cycle times.

5.2 Model description and parameters

In the model, the maintenance operations at O-level, I-level and Depot-level are characterized by the duration of the maintenance, the supply impact, and the manpower availability for the maintenance operation. For simplicity, the maintenance personnel are assumed to have homogeneous skills. The duration of maintenance is defined as the amount of total man-hours needed to perform it. In the model, time periods are considered. According to the minimum and maximum values of each period, a random variable generates a time value for each instance. We consider 420 instances with random variables uniformly generated in the periods. This large number of instances is necessary to ensure global stability.

Flight operations are modelled to follow the average daily cycle as described earlier. Instead of using predefined flight mission schedules, missions are stochastically generated with an average number of flight missions per day. The flight mission itself is modelled as a random flight time. These simplifications are justified, because the primary interest in a flight mission is just the accumulation of flight hours [10]. For the maintenance process at Eurocopter, we first considered real data coming from the D-level. The D-level process can be detailed as follows. After a transition time to the D-level (submitted to a certain probability), the part under maintenance is filtered after reception. The conformity between the part (or the assembly) and the paper form is checked. A first technical expertise is performed at this step. The time of filtering varies a lot. Sometimes there is no conformity at all, the paper form is not fully informed or there are some human errors. Return from the customer can lead to a long queue time (several months). It can also be very fast if the conformity is respected at the reception of the part. The workload is then anticipated, the part replenishment is planned and the task force foreseen. A waiting time for resource worker availability is added in the model for some exceeding load consideration. The assembly is dismantled, cleaned, and the paint is removed. For these steps, the time spent is not varying a lot because it is common for workers. A global expertise of each part allows an estimate to be generated. Then the repair and overhaul is performed: Parts are changed, repaired when necessary (with sometimes a replenishment time) and the documentation form is filled out. Finally, the reassembly is performed just before final test and the maintenance report generation.

The results showed a large dispersion coming from the randomization of data. We reduced the time period at each stage to limit this dispersion. Results presented in this paper use these new data. However, the global behaviour and average values globally remain the same. As mentioned before, this work aims at a first estimation of the impacts of RFID integration on availability. For instance, the filtering time at D-level shop actually spreads from 12h to 1440h, the later only in case of important problems that do not occur frequently. The range was then reduced to [12h, 100h] because most filtering durations are short. One of our perspectives consists in studying probability distributions that model times in a more realistic way.

Maintenance resources, like spare parts, are assumed to be sometimes unavailable with a certain percentage within an associated supply time. Assumptions on maintenance resources, stocks, and time of replenishment are based on real data provided by maintenance shops. For preventive maintenance, we observed that the times at each stage are smaller than for corrective maintenance. It is assumed that a repaired component becomes a "as good as new" component through the repair process. Therefore, "Time Between Failure" and "Time To Failure" are the same. The values for maintenance time and replenishment time also depend on the type of parts (mechanical or avionic). Thus, the net duration for an incoming maintenance task is a function of the allocated maintenance manpower, the potential replenishment time and the expected maintenance duration (possible transfer between maintenance levels) [6].

5.3 Scenarios for RFID integration

As the characteristics of the model are adjustable to a large extent, it can describe normal operations with suitably chosen values of input parameters. As an example of possible applications of the model, a scenario with the introduction of RFID technologies in maintenance processes is presented. We study how the changes in the maintenance policy affect fleet performance and specifically aircraft availability. Several scenarios are presented below.

Sensitivity analyses were conducted to find out how responses of the current model are affected by varying important input parameters and to evaluate the extent to which these results affect the model output. Sensitivity

analysis with respect to the most important model parameters, like the average duration of the maintenance operations and the manpower capacities of the repair facilities, is carried out. Besides the actual model use, sensitivity analysis provides information on the accuracy with which the input parameters have to be estimated.

First, we consider the global concept of RFID introduction in aircrafts (tags, reading modules and Data Concentrator Unit embedded), called **Full RFID** in this paper. We independently assess the impact on stock availability and replenishment time, O-level improvement, I-level improvement, and D-level improvement. For each of these impacts, we made several hypotheses. For confidentiality reasons, we cannot provide precise benefits due to RFID, and we only use a range of impacts. The stock impact is based on 5, 10, 15 and 20% on stock and resources availabilities, and on waiting time of spares. The O-level (and I-level) gain spreads from 5 to 20% on the transit time and on the maintenance time execution. For the D-level, it is slightly different, since we have more details on this process. It was well defined because the access to data of this maintenance level is easy whereas, for the O-level and I-level, it often happens at the customer premises. That is why such information is not available. We consider a fixed gain on the filtering time and on material research. Through an electronic documentation, these two steps can be reduced a lot. The filtering time is nearly divided by two and the material research is divided by a factor of ten. For other stages, like transit time, documentation time, expertise time, repair transit time, repair time, reverse from repair transit time, reassembling time, report time, the range is still between 5 and 20%.

Secondly, we consider the simple concept of RFID introduction, called **Partial RFID**. In this scenario, only tags will be fixed on parts without any update in real time of tag information (usage data). In this second level of RFID integration, the benefits are not the same. For stocks, the knowledge in advance of part status will not be given soon enough. Thus, the range of gain considered is 2.5, 5, 7.5, and 10%. At the O-level and I-level, the values of improvements remain the same. Impacts on the transit time between shops and maintenance execution have the same improvement assuming that data in the tag are the same as for the Full RFID scenario. At the D-level, we also take the same benefits as for the Full RFID scenario. The only characteristic that does not change with the RFID introduction is the filtering time. Indeed, even if data are electronic, lacks and errors could exist in the Partial RFID solution.

6   Computational analysis

First, we plotted the availability for each of the four impacts that are considered (stock, O-level, I-level and D-level). For the stock level, the availability impact spreads from 0.4% to 1.5% (for global savings on the maintenance cycle time between 5% and 20%). The variability of the results is very small, and is explained by the fact that stock values in the model are not concerned by random values. For the O-level and I-level, a huge variability in the results can be noticed. It is explained by the fact that the impact is small (applied to small parts of the corresponding process) and the process is not thoroughly analyzed so far. Indeed, we need more details on these processes to define potential improvements on how customers operate. For the D-level, the impact is quite large. This process was analysed in detail and the potential impacts were validated by specialists. The availability impact varies from 2% to 5%.

We also considered the gain on maintenance cycle time through RFID introduction. The maintenance cycle includes the repair time for each part. This impact is again very large for the D-level shop. This level has an impact on maintenance cycle time between 8 and 20%. We combine both availability and maintenance cycle time in Fig. 5 and Fig. 6. The savings plotted on the x-axis represent the cycle time reduction related to stock impact (Fig. 5) or D-level impact (Fig. 6). The y-axis shows the improvements on the global availability of the aircraft. The results correspond to the average values of the 420 simulated instances. These graphs represent the RFID impact on the two most important processes. It is clear that RFID technologies impact maintenance processes very much. Although data quality could be improved to better fit reality, these results give a good indication of what could be gained with RFID technologies.
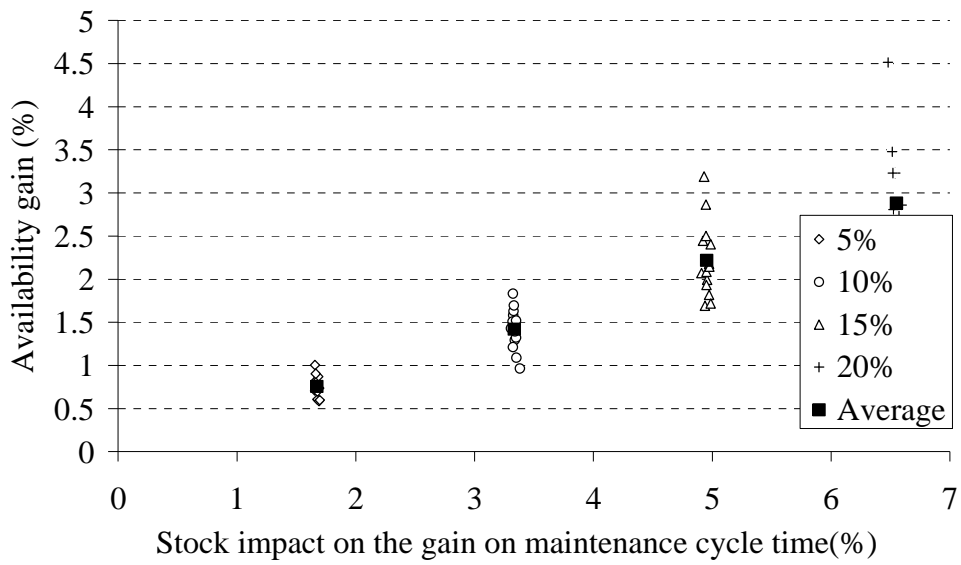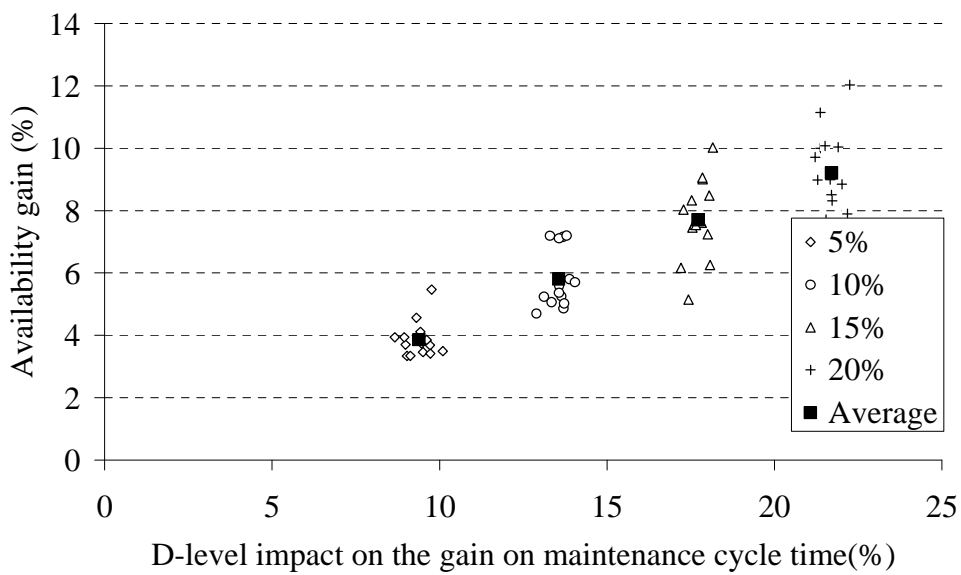
Fig. 5. Stock Impact for Full RFID

Fig. 6. D-level Impact for Full RFID

For partial RFID integration, the impact remains the same for the O-level and the I-level. However, we again represent the stock impact and the D-level impact in Fig. 7 and Fig. 8. These two levels are impacted by the reduction via RFID technologies in a partial solution. We see that the degradation in the RFID impact on board leads to a reduction on availability and on maintenance cycle time.
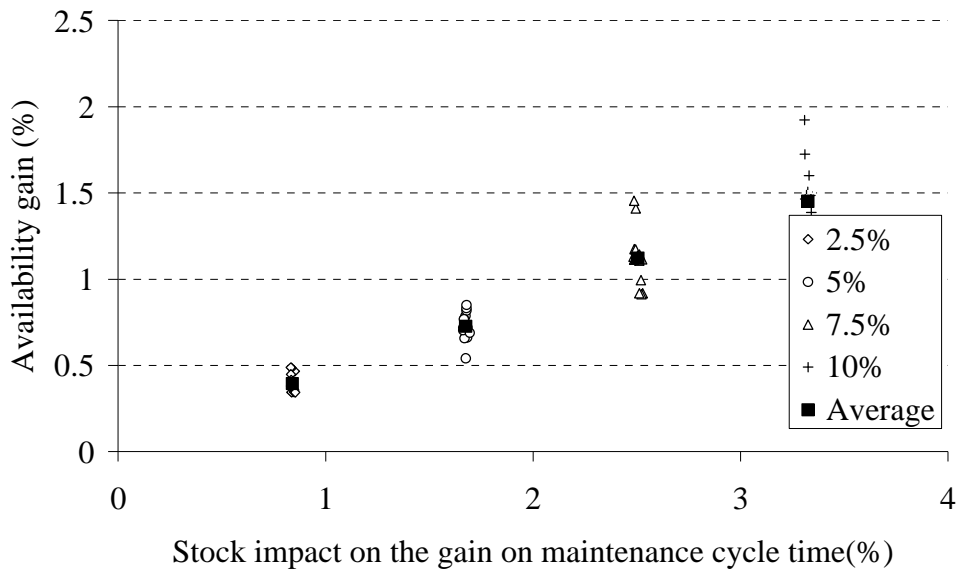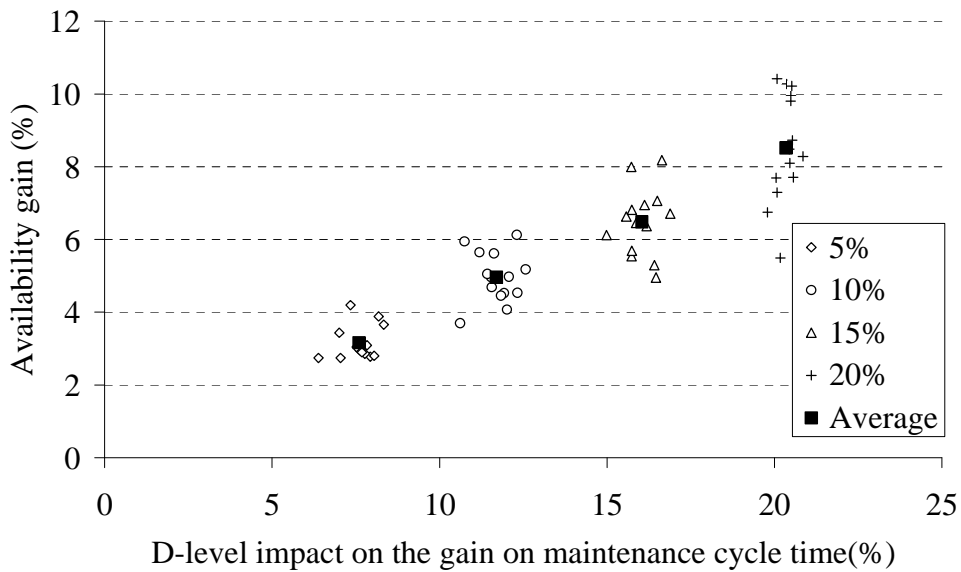
Fig. 7. Stock Impact for Partial RFID

Fig. 8. D-level Impact for Partial RFID

7   Conclusion and perspectives

The primary objective of the simulation model presented in this paper is to gain insights into the effect on maintenance of introducing RFID technologies. The model includes the essential features of flight and maintenance operations, and provides a quantitative assessment and potential improvements on the maintenance system. The introduction of RFID technologies significantly impacts aircraft availability and maintenance work efficiency (D-level cycle time).

The implementation of maintenance models requires detailed, accurate information on maintenance processes. However, the data used in the model presented in this paper could be improved to better fit dedicated situations. The next step will be to consider appropriate probability distributions (such as the gamma distribution for

instance) for data instead of the uniform distribution. More details on O-level and I-level processes could lead to a better impact assessment through the introduction of RFID technologies. This requires a thorough analysis of actual customer processes. Finally, a dynamic simulation model can also be built to estimate the effect of the assumptions more accurately.

8   Acknowledgements

9   References

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