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Application of RFID in Airline Maintenance Operations

Par

Parastoo A.Dastjerdi

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Résumé

La technologie *Radio Frequency Identification* (RFID) a été largement utilisée dans différentes industries au cours des dernières années. En dépit des inconvénients tels que le manque de maturité de la technologie dans des certains environnements conducteurs, la RFID peut fournir des avantages tels que la réduction des stocks, l'amélioration de la précision et de l'efficacité des procédés.

Cependant, l'utilisation de la technologie RFID a été très limitée dans l'industrie de l'aviation. Dans ce travail, la technologie RFID est explorée en relation avec les opérations de maintenance des compagnies aériennes. Les principaux objectifs de ce mémoire sont d'évaluer l'utilisation présente de la RFID dans la maintenance aéronautique et d'évaluer les possibilités futures, ainsi que les obstacles à cette technologie en ce qui concerne les opérations de maintenance des compagnies aériennes.

Dans ce mémoire, une revue de la littérature actuelle sur la technologie RFID et les opérations de maintenance de la compagnie aérienne est réalisée. Le mémoire utilise une approche empirique afin de construire une base théorique qui peut être utilisée par les praticiens pour la prise de décision. La recherche également identifie les catégories de pièces qui peuvent bénéficier le plus de la RFID.

Les résultats montrent que l'industrie du transport aérien a pris connaissance de la RFID et que l'utilisation de la RFID est de plus en plus répandue et le sera davantage prochainement. Les résultats montrent également que les compagnies aériennes sont confrontées à plusieurs obstacles pour l'application de la RFID. Les obstacles identifiés sont: le manque de connaissances, le coût des systèmes intégrés de type *Enterprise Resource Planning* (ERP), le coût des étiquettes, le manque de soutien des gestionnaires et l'immaturité de la technologie. À ce jour, en raison de l'immaturité de la technologie, les applications RFID pour les pièces à forte intensité de main-d'œuvre et pour l'outillage semblent être l'utilisation la plus efficace de la RFID. Comme la technologie évolue, les cas d'application sont plus nombreux et on peut s'attendre à ce que plus de compagnies aériennes vont utiliser cette technologie pour gérer leurs pièces et composantes.

Mots clés : Radio Frequency Identification, RFID, logistique, gestion de la chaîne d'approvisionnement, Aviation, l'industrie du transport aérien, compagnies aériennes, opérations de maintenance, maintenance aéronautique

Abstract

Radio Frequency Identification (RFID) has been widely used in different industries in recent years. Despite drawbacks such as the immaturity of technology in conductive environments, RFID may help in reducing inventory, improving accuracy and enhancing the efficiency of processes.

Although RFID has been employed widely in various industries, the use of RFID technology in the aviation industry has been very limited. In this work, the use of RFID technology is explored in relationship to airlines' maintenance operations. The main objectives of this thesis are to assess the current use of RFID in aviation maintenance and to evaluate future opportunities as well as the barriers to this technology in regards to airline maintenance operations. The research also identifies the category of parts that can benefit the most from RFID.

A review of the current literature on RFID technology and the maintenance operations of airlines is provided. The thesis uses an empirical approach in order to build a theoretical foundation that can be used by practitioners for decision making.

The results show that recently the airline industry has taken notice of RFID and the use of RFID is growing in a short period of time. The results also show that airlines are facing several barriers for RFID implementations. The identified barriers are: lack of knowledge, cost of Enterprise Resource Planning (ERP) integration, cost of tags, lack of support from managers and immaturity of technology. At this point of time, due to immaturity of technology and limited experiences, RFID applications for labor intensive parts and tooling appear to be the most efficient use of RFID. As the technology matures, the application cases widen and more airlines will likely use this technology to manage their parts.

Keywords: Radio Frequency Identification, RFID, Logistics, Supply chain management, Aviation, Air transportation industry, Airlines, Maintenance operations, Airline Maintenance

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List of Abbreviations

AC: Aircraft

AMO: Approved Maintenance Organization

APU: Auxiliary Power Unit

ATA: Air Transport Association of America (recently renamed to A4A: Airlines for America)

CIS: Commonwealth of Independent States

CSDD: Common Support Data Dictionary

DoD: Department of Defense

EPC: Electronic Product code

ERP: Enterprise Resource Planning

FAA: Federal Aviation Administration

GSE: Ground Support Equipment

IATA: International Air Transport Association

ICAO: International Civil Aviation Organization

IFF: Identification, Friend or Foe

MRO: Maintenance, Repair and Overhaul

MTBUR: Mean Time Between Unscheduled Removal

NHA: Next Higher Assembly

OEM: Original Equipment Manufacturer

PN: Part Number

PSU: Passenger Service Unit

RF: Radio Frequency

RFID: Radio Frequency Identification

ROI: Return on Investment

ULD: Unit Load Device

To Me

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The end of this thesis represents a new chapter in my life. After my many years as a student, I will start a new journey that will be focused on career development and personal achievement. I would like to thank everyone who helped me attain a good education and a solid foundation for my future.

1. Introduction

1.1. Motivation

100 years has passed since January 1st, 1914, when the first scheduled-flight flew across Tampa Bay. Even though the trip had only one passenger, Guinness World Records ranked it as the world's first commercial flight (Glenday, 2013). The aviation industry has evolved significantly ever since. In one century, the industry has grown from one passenger on one route, to eight million passengers on average per day on many routes (IATA, 2013c). The International Air Transport Association (IATA) reports that 3.1 Billion passengers flew in 2013 and this number is expected to increase to 3.3 billion in 2014 which is about 44% of the world's population (IATA, 2013c).

Aviation is an essential part of the global economy. Its worldwide transportation system is the number one enabler of globalization. As it was mentioned in the International Civil Aviation Organization (ICAO) convention in Chicago, aviation is a real facilitator for tourism and business development and "brings together the people of the world" (Abeyratne, 2013). A recent study of the Air Transport Action Group (ATAG) and Oxford Economics has confirmed that around 56.6 million jobs are supported by aviation globally. In addition, aviation generates about $2.2 trillion in global economic activities (ATAG, 2012).

Regardless of all the economic advantages that originate from aviation, the average industry profits are not significant and airlines are struggling a great deal in order to recover their cost of capital. Between 1970 to 2010, the average annual post-tax profit for airline industry has been calculated to be about 0.1% of the annual revenue (IATA, 2013b). Moreover, the structure of the airline industry is extremely complex. High value, long-service life and complex configurations are characteristics of capital equipment in the aviation industry, which make managing assets a challenge. Maintaining the aircraft in service for a timeline of thirty plus year is what drives profits (Amann, 2002). A further challenge is the entrance of new competition such as low cost airlines in the past decades (Franke, 2004).

All of these pressures result in constant demand in the market for innovative ideas that provide a competitive advantage. Innovation is directly related to activities and improvements that enhance economic growth and competitiveness. Technology affects competition significantly by impacting costs or other differentiating drivers that could affect the cost and result in relative competitiveness (Tidd & Bessant, 2009). Technologies that enable a more efficient value chain activity than the competitors are therefore a competitive advantage (Porter & Millar, 1985). In recent years, airlines have been looking for innovative ideas that can evolve their supply chain management as efficient supply chain management is the key to keeping their planes in the air, longer generating income, and enjoying high customer satisfaction ratings.

In the present work, "Supply Chain" is identified as the combination of all the stages that directly or indirectly affects a customer request (Fawcett & Clinton, 1997). The coordination of these stages in order to improve the functionality of supply chain can be termed as supply chain management (Lummus & Vokurka, 1999). The inspiration and reasoning of supply chain management lies within the concept of data synchronization and information sharing among different trading parties (Kouvelis, Chambers, & Wang, 2006).

Leading-edge enterprises confirm that the good performance of a supply chain system vastly relies on the information sharing and availability of data to the entire supply chain (Lee, Ma, Thimm, & Verstraeten, 2008). Time is a "competitive weapon" (Stalk, 1988) and therefore the real time sharing of product and process information can bring competitive advantages to the industry.

In the airline industry, important benefits of such information and data visibility lead to improvements in asset management and in asset utilization which are challenging areas for high value aircraft. The serviceability and maintenance of the aircraft is very important for airlines as airline operations can shut down without the existence of such systems. In addition, the logistics activities of an airline are directly related to the maintenance operations and strongly associated with the competitive advantages of the airline.

Radio Frequency Identification (RFID) is an automatic wireless system that has the ability to identify, capture and communicate information in order to facilitate data visibility and product traceability throughout the supply chain. RFID can create improvements in operational activities and result in cost reduction and therefore create a more efficient value chain (Sarac, Absi, & Dauzère-Pérès, 2010).

Considering the challenges in asset and inventory management and the need for innovation to create competitive advantage in airlines, airline maintenance operations present a suitable case for assessing the application of RFID.

1.2. Problem Statement

This thesis was conducted in collaboration with IATA. It uses a holistic empirical approach to investigate the application of RFID in Airline Maintenance Operations. The main objectives are to assess the current use of RFID in aviation maintenance and evaluate the future opportunities as well as the barriers to this technology in regards to airline maintenance operations.

The objectives can be categorized as below:

a) To explore the status of the industry regarding the use of RFID in maintenance operations
b) To identify the category of aircraft parts that can benefit the most from RFID tagging
c) To conduct an analysis demonstrating the return on investment in maintenance operations
d) To discuss the barriers to RFID implementations in maintenance operations and the future opportunities

1.3. Structure of the Thesis

Chapter two presents a literature review. This chapter is divided into two sections:

a) Section one studies relevant and important literature on RFID technology, its history and applications.
b) Section two overviews the literature on airline maintenance operations and its use of RFID technology.

Chapter three describes the methodology and introduces the sources of data that were used for the analysis section.

Chapter four describes the results of the IATA RFID survey which is the main source of data for this thesis.

The data analysis is performed in chapter five. The analysis section aims to categorize and structure the large amount of unstructured data that were collected through the data collection phase.

Chapter six presents an overall conclusion and summarizes the results of this research. Further, the research limitations and some possible future research directions are presented.

2. Literature Review

The first part of this chapter, overviews the literature on Radio Frequency Identification (RFID). The second part will present some literature review regarding airline industry and maintenance operations.

Literature appeared scarce regarding the application of RFID in airline maintenance operations. There is significant research efforts on RFID in general and on its application in various industries especially retail industry.

2.1. Radio Frequency Identification

This chapter aims to provide an overview of RFID technology, its history and applications, benefits and limitations.

2.1.1. Components of RFID

RFID systems are made of three main components: the RFID tag, the reader and the communication infrastructure that is called middleware. Middleware acts as a bridge between the RFID and the network database (Ngai, Moon, Riggins, & Yi, 2008).

The idea behind RFID is marking the object with a tag that acts as an identifier and usually has some writable memory to store data. The tag acts on one side as an identifier to locate the object and on the other side to make relevant information about the object available. The format of the data on the tag follows the Electronic Product Code (EPC) which is a global standard for electronic product identification (Weinstein, 2005). EPC assigns a unique serial number to every product. When an item is scanned, EPC communicates with the network database through the middleware and transmits the information about the product, time and the place of scanning (Alfio, 2008).

Figure 1 displays how all different components of RFID communicate together.

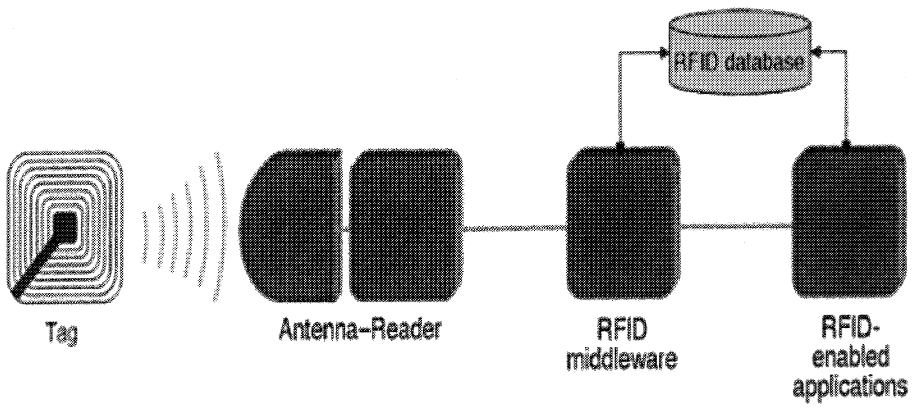

Figure 1. Extended RFID Infrastructure (Banks, 2007)

The different components of RFID tags are described in more details next.

Tag / Transponders

The RFID tag or the transponder contains the needed hardware to store data (memory) and to communicate with the reader device (antenna).

There are two types of tags: passive and active. Active tags work with the help of a power supply, which is a battery. Passive tags do not have a power source and communicate with the reader with the help of the energy that exists in radio frequency waves (Shepard, 2005).

Passive tags have short read ranges and do not function well in electromagnetic environments. However, they are smaller, less expensive and last longer since there is no battery to wear out (Garfinkel & Rosenberg, 2006). Passive tags are used for injection under animal or human skin, for car keys, and retail products (Thornton & Lanthem, 2006). They can read across a range of a few inches to 30 feet (Weinstein, 2005).

The distance range for the reader to communicate with active tags is much longer. However, they are also more expensive and larger compared to passive ones. An active tag can communicate with the reader across 20 to 100 meters. In general, active tags provide better data transmission and offer better noise immunity (Weinstein, 2005).

Readers

The reader has antennas that emit radio frequency waves to communicate with the tag. There is an RF module in the reader which can both act as a receiver and sender of radio frequency signals. Once the information is collected by the reader, it is coupled with the network database (McFarlane & Sheffi, 2003).

Four types of readers exist: handheld, vehicle-mounted, post-mounted, and hybrid. Handheld, vehicle-mounted and post-mounted types are designed to read only one type of tag, either passive or active, depending on the reader setting. However, hybrids are designed in a way to be able to switch their reading capabilities between active and passive tags (Ngai et al., 2008).

Antenna

Antennas are the means of communication among the tags and the reader. The antenna on the tag emits radio frequency waves to communicate with the antennae of the reader. The reader has an Radio Frequency (RF) module that can both act as a receiver and sender of radio frequency signals (McFarlane & Sheffi, 2003).

Middleware

Middleware is the software that acts as a bridge to collect the data on the tag from the reader. Once data is collected, middleware filters and formats the data to make it readable in other environments and various application programs such as the firm's ERP system (Wang, Ryu, Kim, & Hong, 2009).

2.1.2. History and Application of RFID

The history of Radio Frequency Identification (RFID) goes back to the end of World War II (Berger, 2005). However, just like other innovations, it took many years before RFID reached the maturity level that allowed large-scale production and mainstream applications (Roberts, 2006). In World War II, the British army located transponders (receivers) on their aircrafts to be able to distinguish between the returning British fleets and those of the opponent. The transponder on the aircraft received the signal sent from the base station radar and sent a response to confirm their British identity. They called this device the Identification, Friend or Foe (IFF) system (Dittmer, 2004).

RFID's most widespread adoption in recent years has been by Walmart and the US Department of Defense (DoD). Walmart for the purpose of products tracking started an RFID project at the beginning of the 2000s. Walmart mandated its top 100 suppliers to adopt the technology no later than 2004 (Shankar & O'Driscoll, 2002). US DoD had logistics issues during the 1991 Gulf war and decided to use RFID for logistics control. In 2003, DoD mandated its 30000 suppliers to adopt to RFID technology (Bhuptani, Moradpour, & Safari Books, 2005). Because of the large number of suppliers that DoD and Walmart have, their endorsement of RFID affected many organizations and therefore speeded up the increase of RFID use in retail applications especially (Poirier & McCollum, 2006).

In recent years, RFID has been widely used in several industries such as healthcare, fabric and clothing, food, library services, mining and retailing (Ngai et al., 2008). The total market worth of RFID in 2013 was estimated $7.88 billion, up from $6.98 billion in 2012. This number is forecasted to increase to $9.2 billion in 2014 and $30.24 billion in 2024 (Das & Harrop, 2013). Radio frequency identification (RFID) is believed to be the fastest growing smart label market with an annual estimated growth of 180 % (Ngai et al., 2008).

2.1.3. RFID Benefits

The ability of RFID to associate the physical objects with information (without the need for the objects to be physically accessed) has made RFID a very promising technology. This capability allows more efficient decision making in the firm as well as improves the accuracy and quality of the data. All of this eventually results in cost reduction (Shorey, Ananda, Chan, & Ooi, 2006).

The data of the part is stored on the tag as the part moves along the supply chain through different processes such as manufacturing, quality control and logistics. This reduces the errors that could occur by manual entry of data. In addition, the processes are fast and without delays which result in benefits such as labor reduction, productivity increase, supply chain improvements and theft reduction (Shorey et al., 2006).

RFID enables asset tracking and real-time information sharing through the supply chain. In other words, RFID can create data and product visibility in supply chain by means of information sharing (Delen, Hardgrave, & Sharda, 2007). Through real-time data visibility, RFID can improve the different aspect of supply chain management by improving inventory, saving time and access to accurate data for decision making (Sarac et al., 2010). These subsequently result in improvements in supply chain efficiency.

One controversial argument about RFID is the potential advantages of RFID over barcode. RFID offers the possibility of changing, updating or deleting the data. Data is easy to read with RFID without the need for the item to be in line of sight. In the case of barcode, the scanner needs to be in a short distance and with no obstacles in between to read the code. RFID offers a wider read distance and does not demand contact or line of sight. RFID allows for greater storage capacity for restoring data while having a longer life cycle. Barcodes get dysfunctional when they tear apart, detached from the item or disfigured, while many (selected) RFIDs are reusable and have the possibility of writing over them. RFID tags offer more security, each tag has its own unique design which increase the difficulty of data counterfeit and fake replications (White, Gardiner, Prabhakar, & Razak, 2007).

2.1.4. RFID Challenges

Common complaints about RFID technology are tag price, privacy concerns and the high initial cost of the technology as well as cost of re-engineering the existing enterprise system in order to comply with RFID. Furthermore, there are still challenges about the standards and harmonization between hardware, software suppliers, different users and regulatory parties (Poirier & McCollum, 2006).

The high cost of initial investments in RFID infrastructure and in some cases the inconvenience of challenges with standards leads to a "wait and see" approach which is the case for many Walmart suppliers. The "wait and see" or " slap-and-ship" approach means tagging the parts right before they leave the supplier site and then shipping them to the customer. This kind of approach is desirable by some companies as it postpones the need for further investments until the cost of technology decreases (Poirier & McCollum, 2006).

There are also obstacles with the capability of RFID technology around metal and water based environments and products (Weinstein, 2005). It has been reported by several researchers that RFID systems do not work well on conductive surfaces (Davis, Bowman, & Schmidt, 2010; Griffin, Durgin, Haldi, & Kippelen, 2006; Sydänheimo, Ukkonen, & Kivikoski, 2006).

2.2. Airline Maintenance Operations

The following section overviews the airline maintenance operations, its challenges, the classification of inventory in airlines and the use of RFID in maintenance operations.

2.2.1. Introduction to Airline Maintenance Operations

The role of airline maintenance operations is to perform maintenance, repair and overhaul (MRO) related activities related to the aircraft parts. This includes maintenance issues related to all different segments of the aircraft such as airframe, engine component and line maintenance, and Ground Support Equipment (GSE) (IATA, 2009).

2.2.2. Inventory Classifications

Generally air carriers classify airframe inventory into three types: Rotable Inventory, Repairable Inventory, and Expendable Inventory. However, for the purpose of maintenance operations and maintenance program, hard time, consumables, and LLP (life limited part) terms are also used (IATA, 2009).

In order to give a description of the different category of aircraft parts, the definitions of inventory classifications will be provided next. The definitions are in accordance with Common Support Data Dictionary (CSDD) (ATA, 2012) and IATA's Guidance Material and Best Practices for Inventory Management (IATA, 2009). It should be noted that the definitions are not strict and aircraft parts may be placed in more than one of the categories stated.

CSDD is a standard administered by the Air Transport of America (ATA)[1], to streamline data transmission between manufacturers, operators, and others within the aviation supply chain. The goal is to have inventory conventions set so that information can be exchanged clearly and concisely (ATA, 2012).

The goal of the IATA Inventory Management book is to introduce the concept of inventory management to airlines and to help airlines optimize the use of aircraft parts. Depending on the short and long term goals and the nature of the parts, operators can use different strategies to optimize their inventory (IATA, 2009).

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[1] Recently renamed to A4A, "Airlines for America

Rotables

A rotable is a component or item of the aircraft that when removed for repair, it can come back and be installed on the aircraft as a repaired part. Rotables are considered serviceable spares. The scrap rate of rotables is very negligible. Therefore, they are considered indefinitely repairable. Rotables usually stay as the asset of an airline and are resumed in service until they are put aside due to fleet retirement. Some examples of rotables are brakes, wheels, radar transceivers, altimeter and the engine of an aircraft.

Repairables

Repairables are component that are typically repaired and returned to service as repaired/overhauled or as new condition. Similar to rotables, repairables are counted as an asset for an airline due to their high value. However, unlike rotables, repairable items have a scrap rate that should be taken into account when calculating for spares and inventory, contracts, and other planning. Due to the scrap rate, a percentage of repairables will be replaced during the life-time of an aircraft. Examples of the repairable items are Auxiliary Power Unit (APU), starters and fire detectors.

Expendables

Expendables are items that have no authorized repair procedure. For such items the cost of repair is usually higher than replacement. Because of this, most expendables are used until they have a failure and then they are discarded. Examples of the expendables are lamps, seals and filters.

Consumables

These items are used only once and are utilized in maintenance and repair procedures for aircraft and equipment components. Examples of the consumables are bulk-type materials such as fuel, lubricants, paints, etc.

Hard Times

Hard Times are items which must be removed from service or be verified for serviceability at or before a previously specified time. These items usually need interval maintenance checks in order to verify their serviceability. Examples of such items are life vests and Oxygen generators.

Life Limited Parts

Life Limited Parts (LLP) are items which are obliged to be removed from service and must be discarded before a certain timeline or deadline is achieved. Like Hard times, LLPs require labor intensive maintenance tasks. Most engine parts are LLPs that require regular maintenance. In general, LLPs are considered assets for an airline.

2.2.3. Challenges in Airline Maintenance Operations

Maintenance, repair and overhaul (MRO) operations of an airline are an essential part of an airline operational activities. It is crucial for the aircraft to be at its fullest reliability and serviceability capabilities in order to assure safety and profitability.

Maintenance issues cause cancellation and delays of flights which are costly and translate into losses for an airline. The idleness of aircraft directly affects the profits of an airline as well as reliability and serviceability levels (IATA, 2009). An idle aircraft for the reason of unplanned maintenance, will cause an airline an estimated loss of $23,000 per hour (Brown, 2003).

Maintenance and logistic activities of an airline are in close relationship. In order to improve one, the other must be improved. If one is not efficient, it causes inefficiency to the other. Logistics activities manage the availability of parts which are essential to maintenance operations. For a reliable and safe aircraft, effective logistics activities must be in place in order to ensure the effective delivery of maintenance activities (Ellickson, 2006).

The long life of an aircraft and its complex part configurations have made the management of capital equipment a challenge (Amann, 2002). One of the unique things about managing an aircraft is the high value of spare parts which makes parts an asset for the airline. The high value parts of an aircraft are not consumed and discarded; instead, they keep being repaired and maintained in service. Moreover, parts must be available when they are needed in order to keep the aircraft in service. This creates a sense of emergency in parts management. This nature of the industry may lead to excess inventory being kept which would require more investment.

In general, the goal of logistics and parts management in airline operations can be classified in three parts. The goal of the first part is to increase dispatch reliability. This concept usually leads to keeping excess inventory on hold in order to maximize part availability. The second goal is to minimize the cost. Minimizing cost can be reached by fewer investments in inventory. This goal is, however, in contrast with the first goal which is maximizing the availability of the part. Maximizing dispatch reliability usually results in more inventory pile ups which would need more investments. The third goal, which rises out of the relationship between the first two goals, is a balanced strategy between dispatch reliability and cost reduction. This goal aims to balance the operational parameters in terms of cost and inventory level in order to optimize operations (IATA, 2009). This final goal, while simple in concept, can become quite complex when it comes to the execution.

High stock values can be reduced if a better predictability was available. A better predictability could be achieved by knowing when a part is needed, in what situations and how often such situations happen (Kashyap, 2012). This is feasible by having access to accurate, real-time data.

2.2.4. Application of RFID in Airline Maintenance Operations

RFID technology has high potential in the area of aircraft maintenance operations. According to Poirier & McCollum (2006), the DoD, aerospace and defense present the highest possible return for RFID and therefore are the most likely to find acceptance within their industry. US DoD already uses RFID for many parts of its operations. One of which is tracking parts of an airplane. Part tracking is one application of RFID in aerospace. RFID can help facilitate and accelerate parts tracking with the help of real-time information sharing (Poirier & McCollum, 2006).

In 2005, as an initiative to enable airlines to benefit from RFID advantages, the US Federal Aviation Administration (FAA), published a statement that allowed the use of passive RFID on commercial aircrafts. The statement mentioned that passive RFIDs do not cause any harm and safety issues to the aircraft (Chang et al., 2006).

The aircraft manufacturers, Boeing and Airbus, had started using RFID for asset and tool management in the late 1990s. However, in 2006, shortly after the FAA's approval of passive RFID, they started planning for RFID solutions and product developments for airline use (Harbison, 2013; O'Connor, 2005).

In 2007 Boeing teamed with Japan Airlines to demonstrate that RFID can speed the inspection process of Oxygen generators on board of a Boeing 777 commercial airline (Zaino, 2013). In the same year, a TAP and Airbus team also studied and deployed RFID solution for tracking parts in an engine repair shop (Edwards, 2012). In 2011, Boeing worked with Alaska Airlines on a pilot study to validate the significance of RFID use for labor intensive maintenance (Boeing, 2011).

Airbus also started tagging life vests and passenger seats across A350 XWB and A320 family, A330, and A380 production lines. In 2009, Airbus took the opportunity to include permanent tags in the aircraft's specifications, covering replaceable parts, LLPs, repairable parts and parts with a Mean Time Between Unscheduled Removals (MTBUR) of less than 60000 hours. Low MTBUR parts are parts that tend to fail more often. Some 2200 components were included for tagging (Harbison, 2013).

Following OEM initiatives, some airlines started implementing RFID technology for parts management. Delta Air Lines, for example, has been taking advantage of RFID in their maintenance operations. Delta has reported significant time and cost reduction as well as improvements in data accuracy and inventory management because of RFID implementations (Lewis, 2013).

Lufthansa Technik AG (LHT), a leading MRO service provider that is affiliated with Lufthansa Airlines, has also started using RFID for logistics purposes in order to track the components and parts of the aircraft (Canaday, 2011). In addition, they have started using RFID as an attachment to the documents that travels around with the parts. This allows them to track the movement of the part and the document along the supply chain. The company has reduced manual data entries and the associated errors, and therefore, has improved data accuracy and the speed of the process (Zhang, 2012).

From the literature review it appears that there are only few studies on the application of RFID in airline maintenance operations. Except for few academic and industry papers; there have not been any publications in regards to the application of RFID in airline maintenance operations. As a matter of fact, despite the recognized advantages that RFID can bring to areas such as inventory management and logistics in airlines, there are very few studies that can be used as a foundation to enquire about the use of RFID in the airline maintenance operations for the purpose of part management.

3. Methodology

It was decided for this thesis to assess the current use of RFID in aviation maintenance and evaluate the future opportunities as well as the barriers to this technology in regards to airline maintenance operations, using an empirical qualitative approach. The main research implication is to build a theoretical foundation in regards to the application of RFID in airline maintenance operations. This base will provide a knowledge point for practitioners in order to help them with decision making.

In recent years, the growth of empirical research has resulted in a broad collection of real world information which can help managers and companies with decision making. As a consequence, the disconnection between academic and practice has been overcome in many fields (Cassell, Buehrins, & Symon, 2006).

In qualitative research, different methods can be used: "participant observation, outside observation, field notes, structured, semi-structured and unstructured interviews, surveys and questionnaires and analysis of documents and materials" (Flynn, Sakakibara, Schroeder, Bates, & Flynn, 1990; Nielsen, 2011).

The next section will explain the data collection process and the sources of data for this thesis.

3.1. Data Collection

In order to get started, empirical data needed to be collected. After several meetings with IATA, it was decided that the data of one previously conducted survey about RFID would be appropriate for the purpose of the thesis. The survey is called IATA RFID Survey which contains real information collected from airlines and can act as a reliable source of data for the purpose of the thesis. More information about the IATA RFID survey is provided in section 3.2.

During the course of data analysis, it was understood that some areas would need further clarifications. Therefore more data collection iterations were added. This allowed building on the existing data of the survey and providing a more reliable knowledge database. Besides interviewing airline employees, other sources of data such as archived email communications, archived presentations, and report were used. The author also attended several IATA meetings which addressed RFID related issues. The observations and materials addressed in these meetings were taken into consideration when doing the analysis.

The data collection and the analysis for this thesis were iterative processes, as the researcher had to go back and forth between data collection and data analysis (Van de Ven, 2007) in order to identify the areas that required further clarifications and to plan for additional data collection.

3.2. IATA RFID Survey

The main source of data for this thesis was the IATA RFID survey. The survey was initiated by IATA due to several requests from different stakeholders.

Following several IATA RFID meetings with a number of airlines and manufacturers (mainly airframe OEMs), the major airframe OEMs and many airlines suggested having an industry survey conducted to understand the status, perception and needs of the industry regarding RFID technology and also to determine what significant aircraft parts could benefit from RFID.

A self-administered survey was designed by IATA on an excel format. The survey was designed with the input of two major airframe OEM companies, regulatory authorities and IATA staff. The IATA RFID Survey can be viewed in the Appendix I.

The survey was conducted from July 29, 2013 to September 27, 2013 with follow up questions for clarifications during the data analysis time as appropriate.

3.2.1. Structure of the Survey

The first part of the questionnaire aims to find out whether airlines are currently using the RFID technology and to find out more details regarding the RFID projects that are currently deployed at airlines.

The second phase of the survey, aims to find out the future opportunities for RFID implementation in airlines and to understand the perception and expectation of airlines regarding this technology.

The third part of the survey asks users to provide specific examples of parts that they think would benefit from RFID tagging.

Finally, the final part of the survey contains demographic questions which can help determine whether different group of respondents have different perceptions, expectations or needs.

The survey in total contained 13 questions which addressed different aspects of RFID application in Maintenance Operations. Refer to Appendix I for the RFID survey questionnaire.

The questions are as follow:

1. Does your airline currently employ any RFID applications?
2. Do your current RFID activities involve RFID tags on aircraft parts or non-aircraft parts? (In addition, for each category (aircraft vs. non-aircraft), respondents were asked to provide the specific parts or group of parts that they are tagging with RFID)
3. What is the approximate percentage of improvement in terms of process efficiency after RFID implementation?
4. What is the approximate split of your RFID activities between aircraft parts and non-aircraft parts? (The sum should be 100%)
5. Is your airline going to employ any RFID applications in the future?

6. Upon RFID deployment, in what functions of your organization, do you expect to see efficiency improvements?
7. What is the priority for the next group of parts that could potentially benefit from RFID tagging?
8. Regarding the maintenance history of the RFID tagged parts, what is your preference?
9. What would be the criteria for potential parts marking?
10. Do you prefer RFID tags to be installed at delivery or by the after-market?
11. Please list any data elements that you would like to see on an RFID tag?
12. Why do you think RFID tags have not been used so far in commercial aviation?
13. What would be your approximate expected return? (ROI and Payback)

3.2.2. Survey Demographics

The selected contacts were restricted to airline professionals who are and/or expected to be involved with decisions on using RFID in aircraft maintenance operations. The survey was available to airlines' personnel without discriminating whether the airlines were IATA members or not. This includes engineers, technical and IT professionals, supply chain, and senior management experts closely associated with an airline's technical operations (engineering and maintenance) division.

In order to capture the individual opinion of experts, it was mentioned that several responses from the same airline would be considered.

Response Rate

The survey was sent to over 538 individuals at 240 airlines. The airframe OEMs helped disseminating the survey though their customer service departments. At the end of the survey time period, 93 replies were received from 67 airlines. This gave a response rate of 17.3 percent on an individual level and a response rate of 28.3 percent on an airline level. The survey was sent to airlines only because:

a) IATA is an airline association.

b) Airlines would be the end recipients of the benefits; they directly or indirectly will pay for the services.

For clarification purposes, the Survey was also sent to Approved Maintenance Organizations (AMOs also known as MROs) that are wholly owned or closely affiliated with an airline.

Not all of the questions were answered by all respondents. Some questions presented a low rate of response because they were not applicable to some respondents. Therefore the sample size for each question is different based on the number of responses received.

As applicable, some questions were analyzed at airline level while some others were presented at individual level (since in some cases more than one survey response was received from the same airline). Note that, when presenting graphs, two notions were used to identify the sample size for each question:

a) The notion *N* presents the number of individual responses received per question, meaning how many individuals responded to this question.
b) Since it was possible that more than one individual from the same airline responded to the question, *N'* was used to indicate the sample size as an indication of the number of airlines that those individual respondents belong to.

Departmental Divisions

As seen in Figure 2, a high percentage of respondents belonged to the airlines' engineering department subgroup (40 percent). The second subgroup of participants was senior management (27 percent). Next subgroup was maintenance professionals who made 19 percent of the respondents. Supply chain/logistics and other technical professionals were the remaining functions on the respondents list.

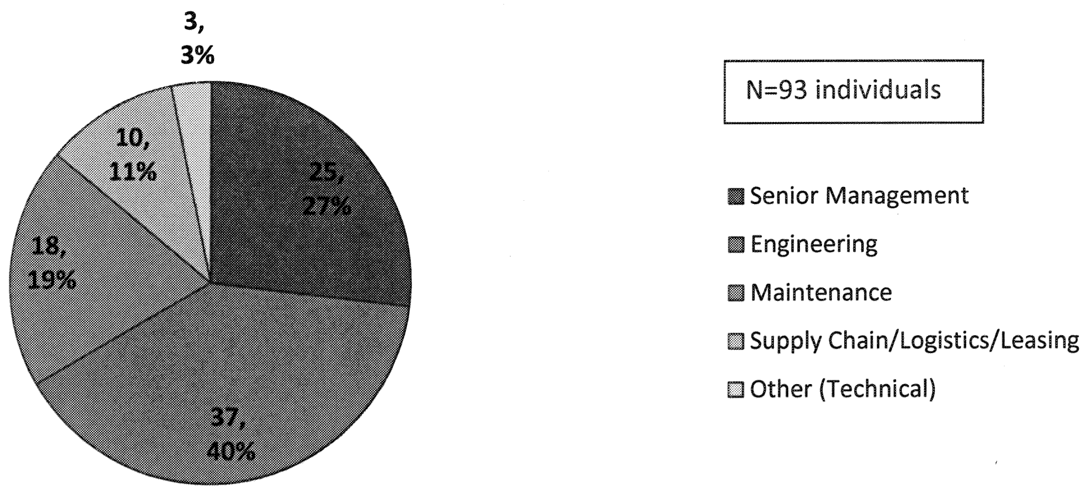

Figure 2. Distribution of respondents per field of expertise

Geographical Regions

Figure 3 displays the distribution of the participating airlines per geographic region. Most of responding airlines were from Europe including the Russia and the Commonwealth of Independent States (CIS). It should be noted that Europe is home to many airlines in the world as the result of recently opened aviation market, the transformation of a plethora of national carriers and the bilateral traffic right arrangements between individual European states and other countries around the world. In North America, consolidation of the industry has significantly reduced the number of airlines.

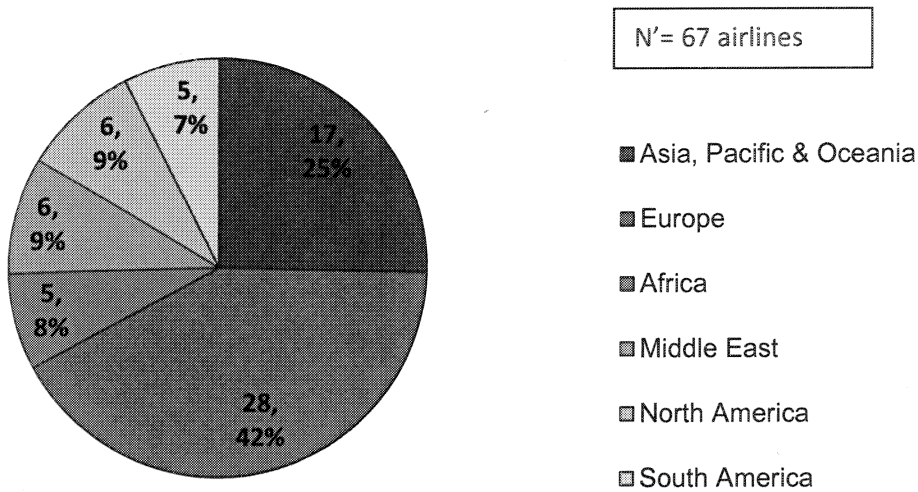

Figure 3. Survey respondents' distribution per geographical region

Figure 4 reflects the percentage distribution of IATA member carriers per region. Figure 4 illustrates the 239 IATA member airlines around the world distributed per region.

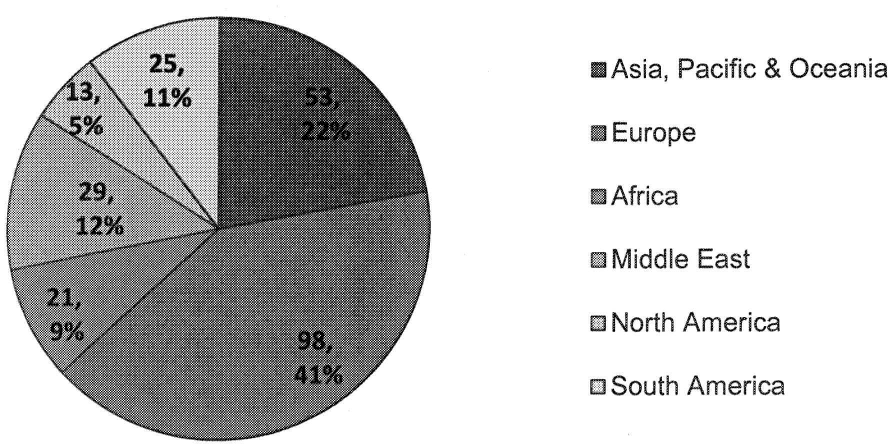

Figure 4. IATA member airlines distributed per geographic region

As seen in Figure 5 the distribution of our sample size reflects the distribution of IATA member airlines.

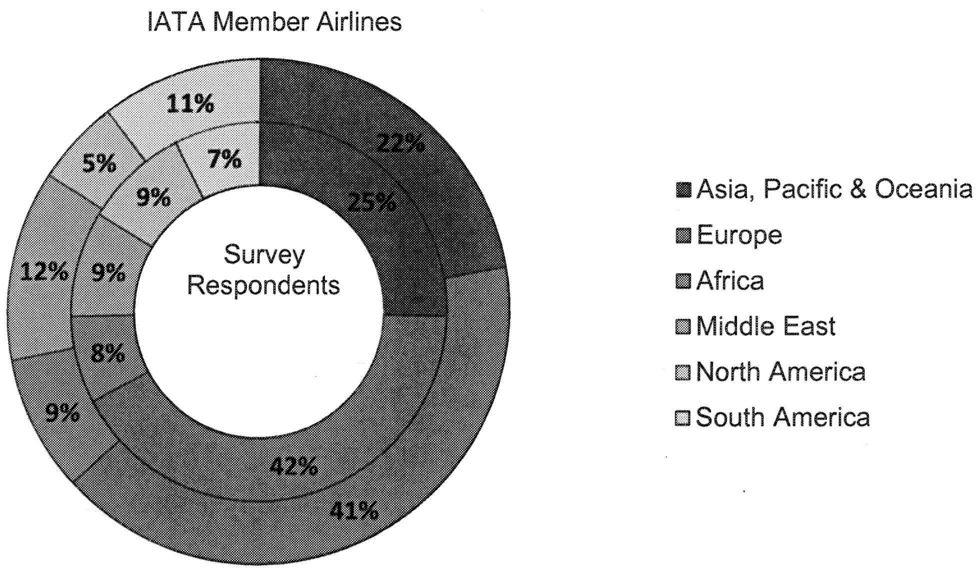

Figure 5. Survey Respondents vs. IATA Airline members- distributed by region

Fleet Size

Figure 6 displays the distribution of the participating airlines per fleet size category. There is a fair distribution of fleet size categories throughout the population.

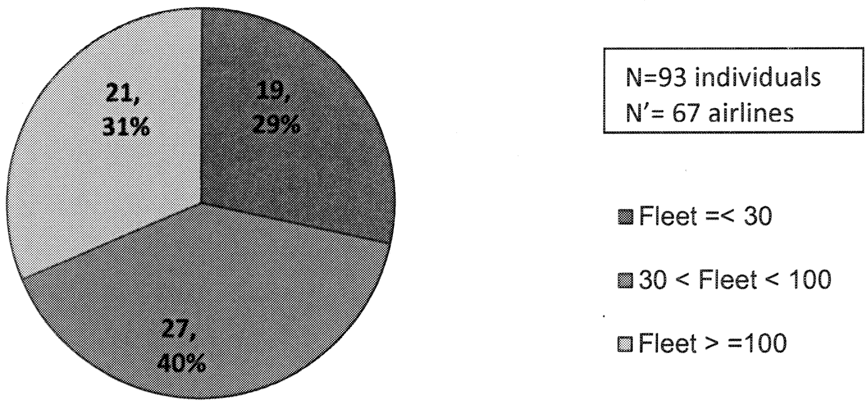

Figure 6. Airline distribution per fleet size category

Table 1 combines the findings as shown by Figure 3 and Figure 6.

	Fleet ≤ 30	30 < Fleet < 100	Fleet ≥ 100	Total
Africa	3	2	0	5
Europe	10	11	7	28
North America	1	0	5	6
South America	1	2	2	5
Asia Pacific & Oceania	3	8	6	17
Middle East	1	4	1	6
Total	19	27	21	67

Table 1. Airline distribution per fleet size and region

3.3. Additional Data Sources

In addition to the RFID survey, interviews, archival data and observations were used.

A series of semi-structured interviews were conducted with airlines managers who are involved in RFID implementations or have a proven knowledge about the matter. Informal interviews were also conducted when clarifications were needed on certain aspects or answers to the RFID survey.

3.4. Data Confidentiality

All participants in the study were ensured anonymity of data.

When analyzing the survey data, a number was assigned to each participant in order to respect and maintain the anonymity of the responses (Véronneau, 2008). This numbering system allowed tracking the responses to the participants when clarifications were needed.

3.5. Data Validity

The concept of validity does not have the same meaning in qualitative research as it does in quantitative. The goal of qualitative research is to ensure that the study has achieved its investigation purposes and is useful in its context in order for the findings to be applied (Malterud, 2001). At all times great care was taken to ensure that the data collection is serving the purpose of the study and that additional data are collected when clarification needed.

4. Results of IATA RFID Survey

This section of the thesis presents the results of the IATA RFID survey. IATA RFID survey served as a major source of data for the analysis.

Below the result of each question is presented.

Question 1: Does your airline currently employ any RFID applications?

Question 1 asked the respondents whether they are currently implementing any RFID activities. All 93 individuals replied to this question. 19 respondents replied that their airline is implementing RFID at the moment. These 19 individuals belonged to 12 airlines (18 percent). The remaining 74 individuals from 55 airlines (82 percent) stated that their airline has not implemented any RFID projects yet.

A limited number of airlines had embarked in RFID pilot studies a few years ago (2005 – 2008); however these studies were discontinued. These studies have not been included as current RFID projects. Figure 7 demonstrates the responses at an airline level.

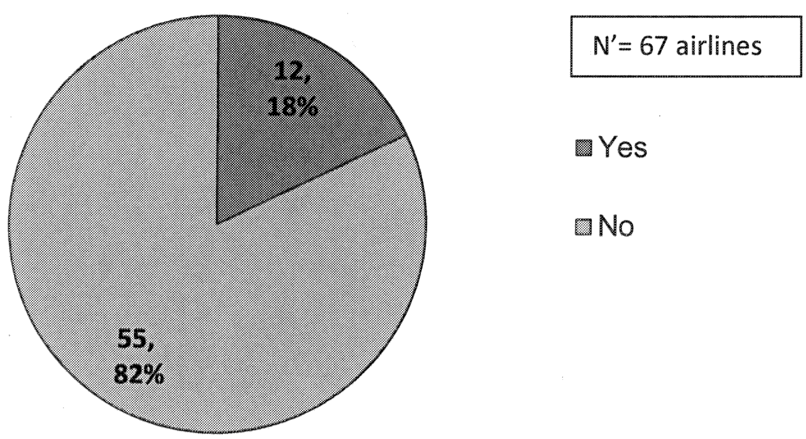

Figure 7. Does your airline currently employ any RFID applications?

In Table 2 the list of region and fleet size of the 12 airlines that are implementing RFID at the moment is displayed.

	Fleet ≤ 30	30 < Fleet < 100	Fleet ≥ 100	Total
Europe	**0**	**3**	**4**	**7**
North America	**0**	**0**	**2**	**2**
Asia Pacific & Oceania	**0**	**1**	**2**	**3**
Total	**0**	**4**	**8**	**12**

Table 2. Airlines w/ current RFID projects distributed per region and fleet size

To better visualize this information, please see Figure 8.

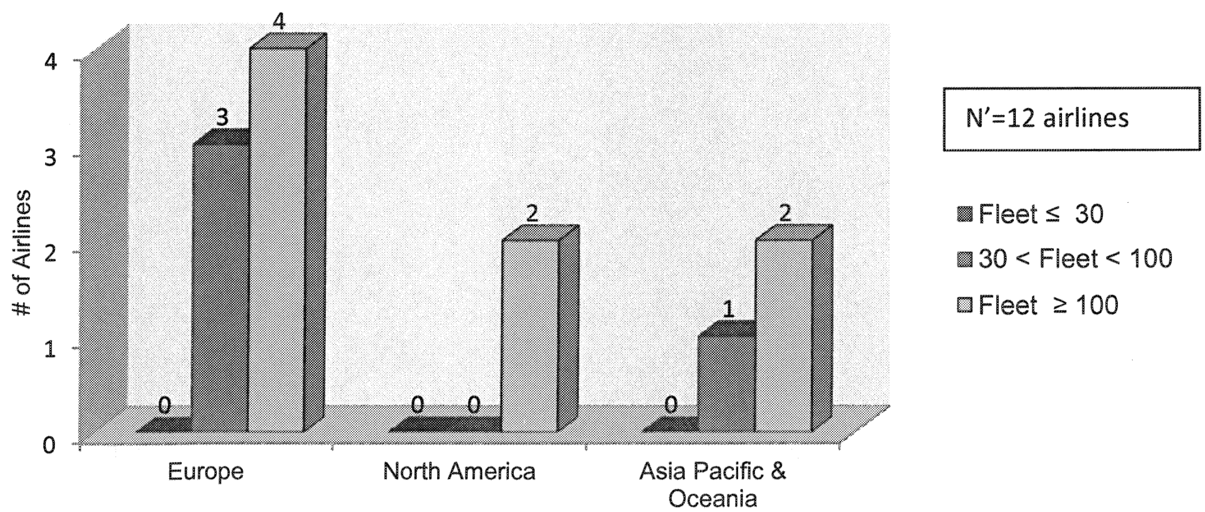

Figure 8. Airlines w/ current RFID projects distributed by region & fleet size

Question 2: Do your current RFID activities involve RFID tags on aircraft parts or non-aircraft parts?

In Question 2, those airlines that are currently employing RFID were asked to provide details regarding the nature of their RFID activities: Flyable (Aircraft Parts) vs. Non-Flyable (Non-Aircraft) parts.

Out of the 12 airlines which have current RFID projects, 4 said they implemented RFID on Aircraft (Flyable) parts only, 4 on both aircraft and Non-Aircraft (Non-Flyable), and 4 implemented it on Non-Aircraft parts only. Please see Figure 9.

Note that for this question, the respondents were allowed to choose more than one answer.

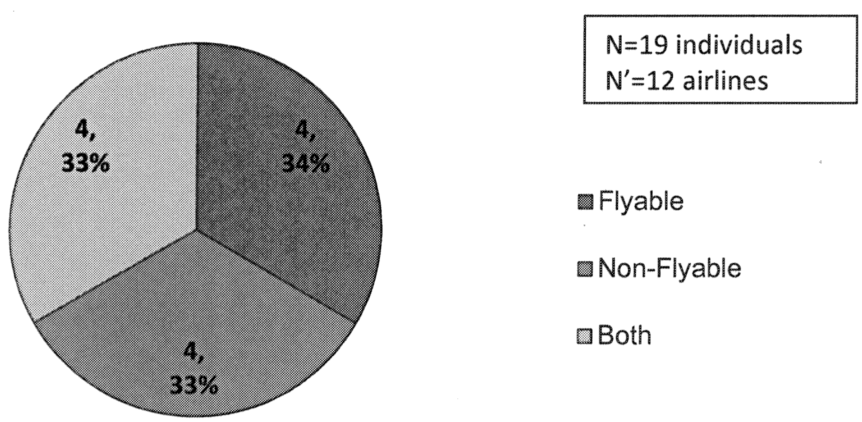

Figure 9. Distribution of RFID activities per participating airlines

Respondents were also asked to provide the specific parts or group of parts that they were tagging. Figure 10 displays the responses for tagged Aircraft parts.

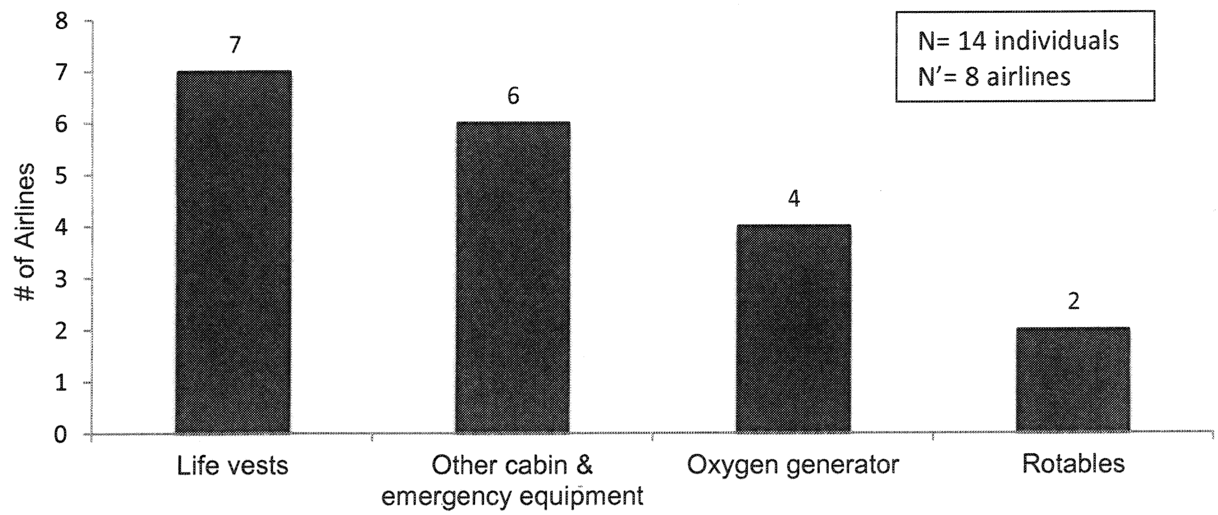

Figure 10. RFID activities on aircraft parts

Respondents also provided the specific cases for application of RFID on Non-Aircraft parts. Figure 11 displays the current application of RFID on non-aircraft parts.

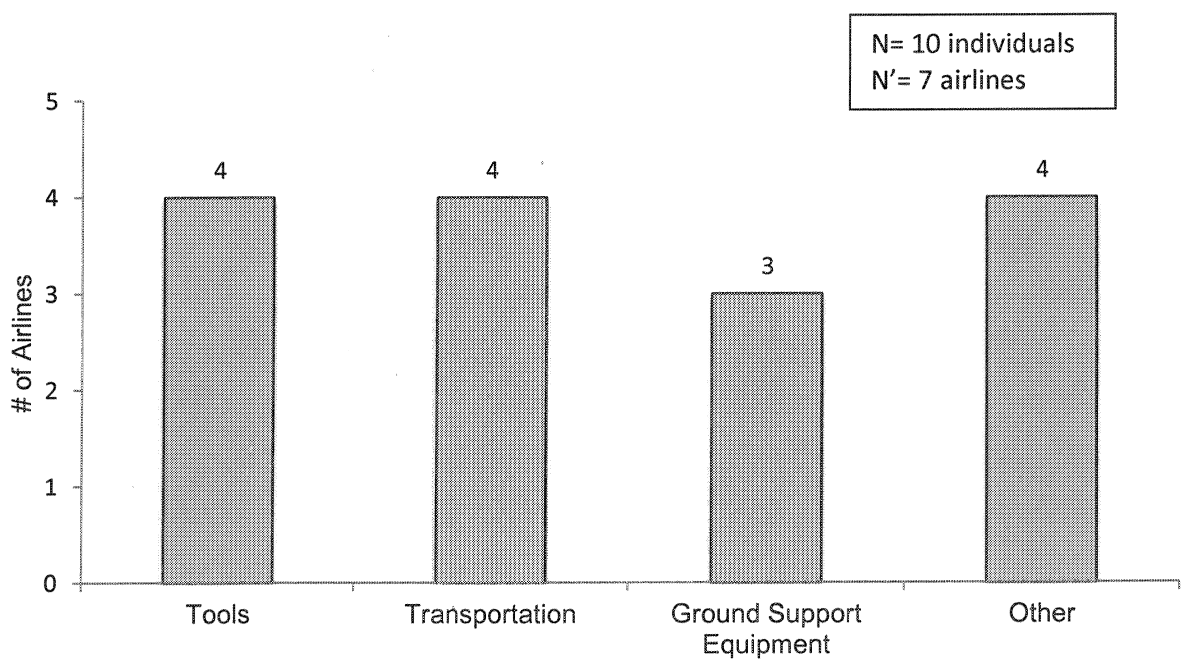

Figure 11. RFID activities on non-aircraft parts

"Transportation" category refers to transportation equipment and fleet.

In the category "other", shop towels, Employee IDs and Unit Load Devices (ULD) were mentioned.

Question 3: What is the approximate percentage of improvement in terms of process efficiency after RFID implementation?

In question 3, respondents were asked about the approximate percentage of improvements they believed RFID brought to their tasks. Although this question is subjective, it shows what each individual perceives regarding the benefits of RFID. Figure 12 displays the results based on 12 responses from 9 airlines. The responses circled together come from different individuals within the same airline. 3 airlines did not provide an answer. These respondents specifically mentioned that their RFID project has not been fully incorporated yet and therefore this question was not applicable to their situation.

The responses circled together come from different individuals within the same airline. Differences between individuals from the same airline are explained from:

a) The individuals work on different projects.
b) The perception was slightly different although showing very close trend.

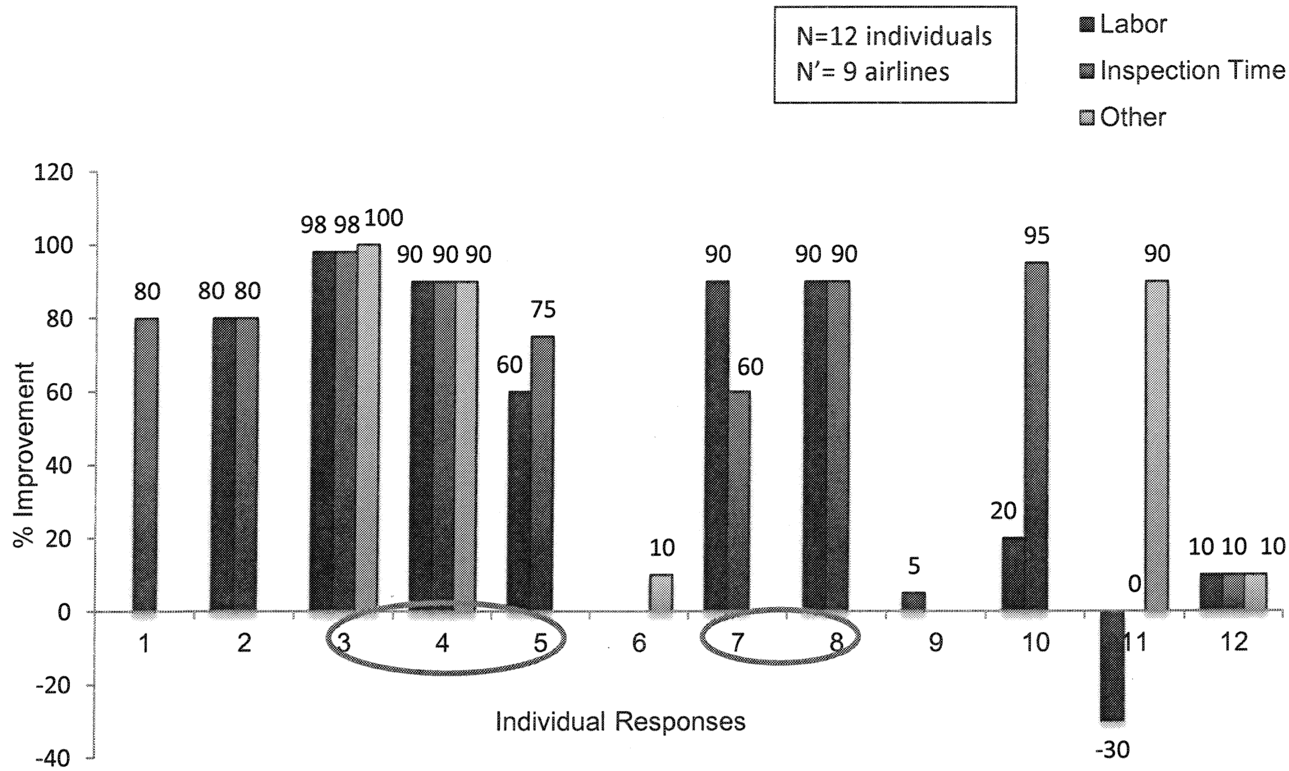

Figure 12. Improvements upon RFID use[2]

Respondent 11 reported the implementation of RFID to track shop towels in their engine shop. This was done primarily to improve safety and compliance (i.e. ensuring towels are removed from a component prior to release to service). Although, as seen it negatively impacted labor productivity by 30 percent, the safety benefits and 100 percent compliance far outweighed the more cumbersome process. Therefore, it was an accepted trade off. Previously, the technicians were free to just grab towels from a bin whenever they needed one. But, after implementing RFID, the technicians had to go through a check-in/check-out process for every shop towel they used.

[2] The responses circled together come from different individuals within the same airline.

Question 4: What is the approximate split of your RFID activities between aircraft parts and non-aircraft parts?

Those implementing RFID were asked about the split of their RFID activities: Aircraft vs. Non-Aircraft parts. Figure 13 displays the results. The responses circled together come from different individuals within the same airline.

Due to departmental application and perceptions, in some cases, people from the same airline gave slightly different responses. The individuals' titles and functions were looked up or they were contacted to ensure that there were no deviations in interpretation.

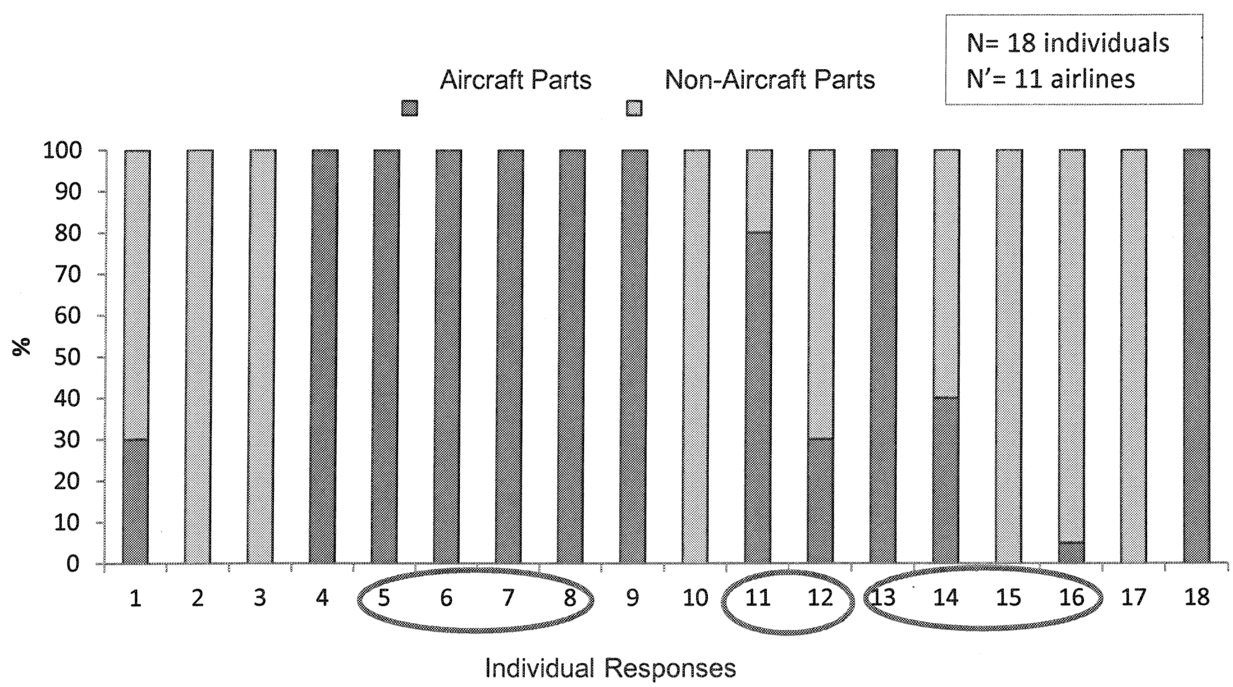

Figure 13. Split of RFID activities[3]

[3] The responses circled together come from different individuals within the same airline.

Question 5: Is your airline going to employ any RFID applications in the future? If yes, what is the timeline for your future RFID activities?

This question aimed to find out if airlines are planning any RFID projects in the future. 87 respondents provided an answer to this question, 76 percent of which replied "Yes" (Figure 14).

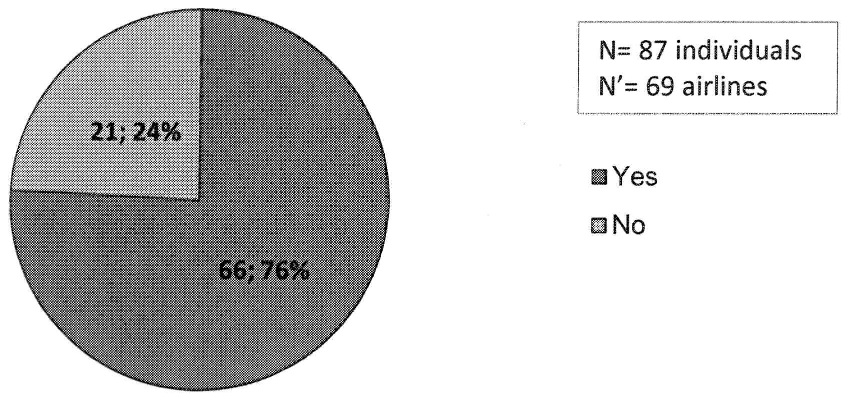

Figure 14.Future RFID activities

24 percent of respondents replied that they are not planning any future RFID projects at the moment. Digging more into the characteristic of those who answered "No", they were 21 respondents from 21 airlines. Figure 15, below, demonstrate that they mostly belong to smaller size airlines.

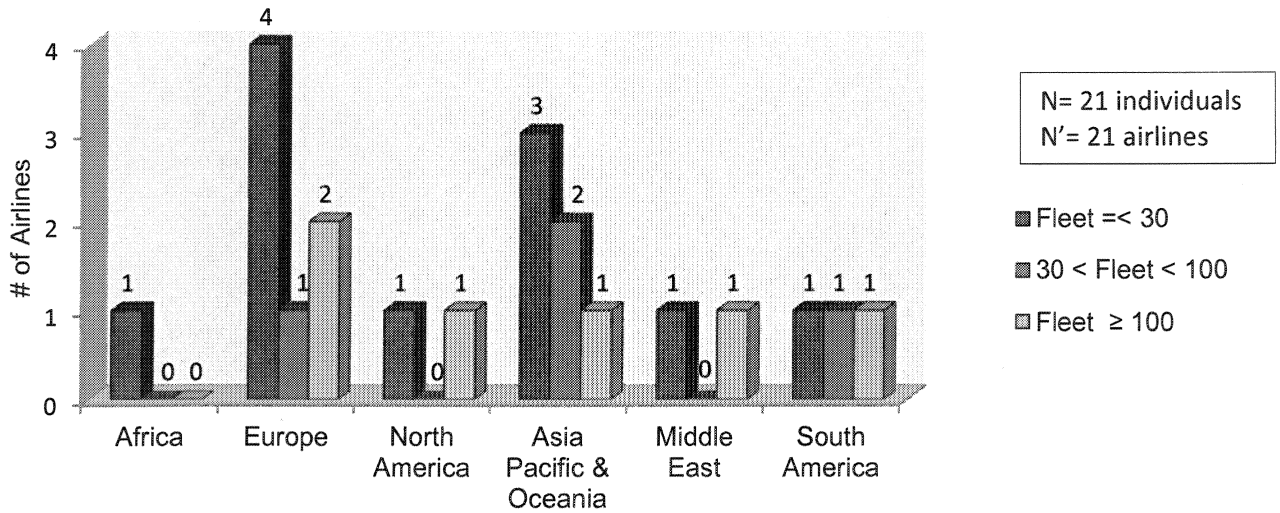

Figure 15. Distribution of airlines that are not planning future RFID projects

Those who answered "Yes" to future RFID activities were asked to provide a timeline for future RFID plans. Please see Figure 16.

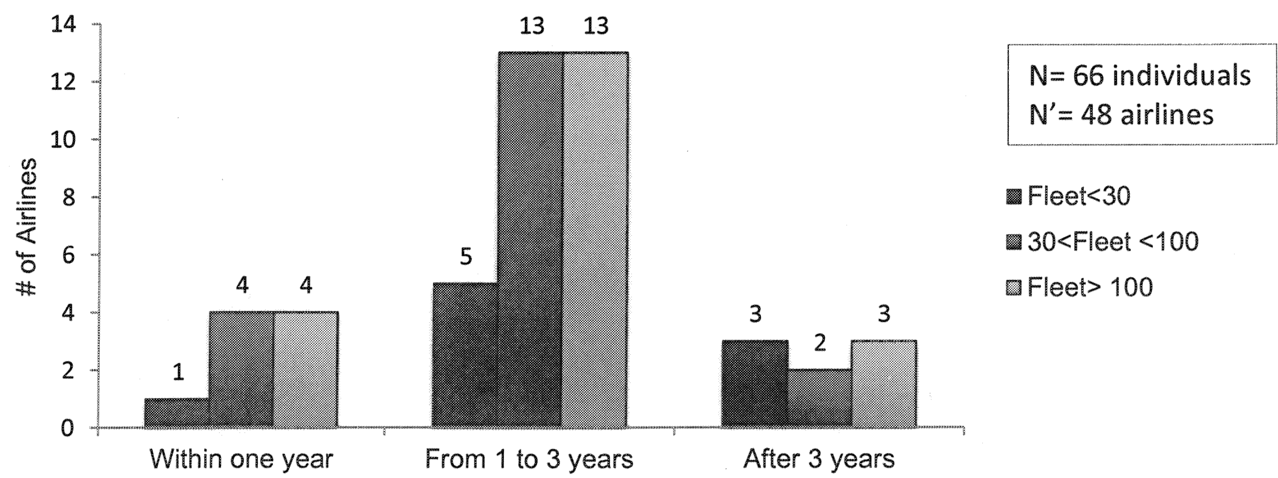

Figure 16. Timeline for future RFID projects

Question 6: Upon RFID deployment, in what functions of your organization, do you expect to see efficiency improvements?

Figure 17 below is self-explanatory.

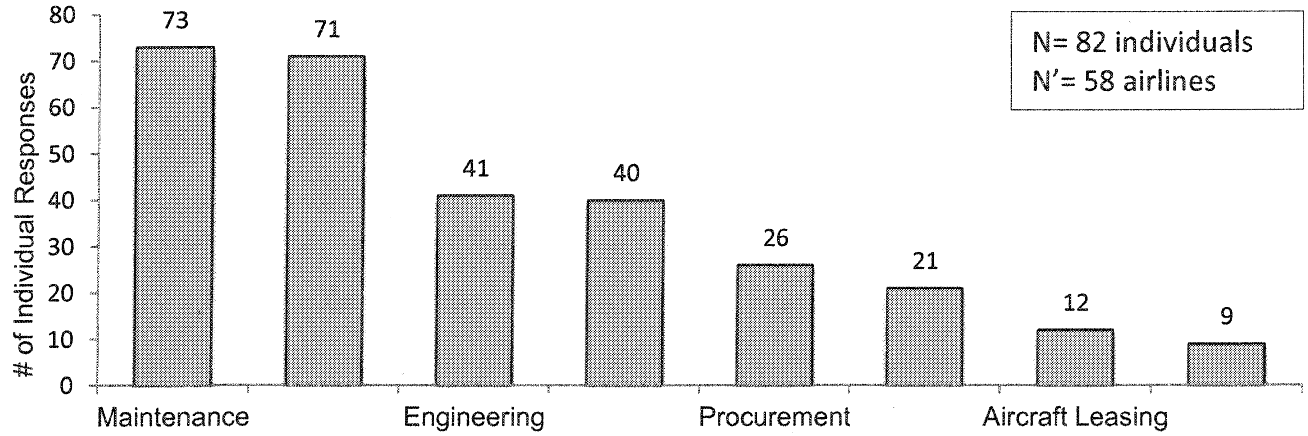

Figure 17.Departmental improvements upon RFID deployment

In the category "other", the following were mentioned:

- Part pooling
- Asset tracking
- Operational health and safety

Question 7: What is the priority for the next group of parts that could potentially benefit from RFID tagging?

Figure 18 is self-explanatory.

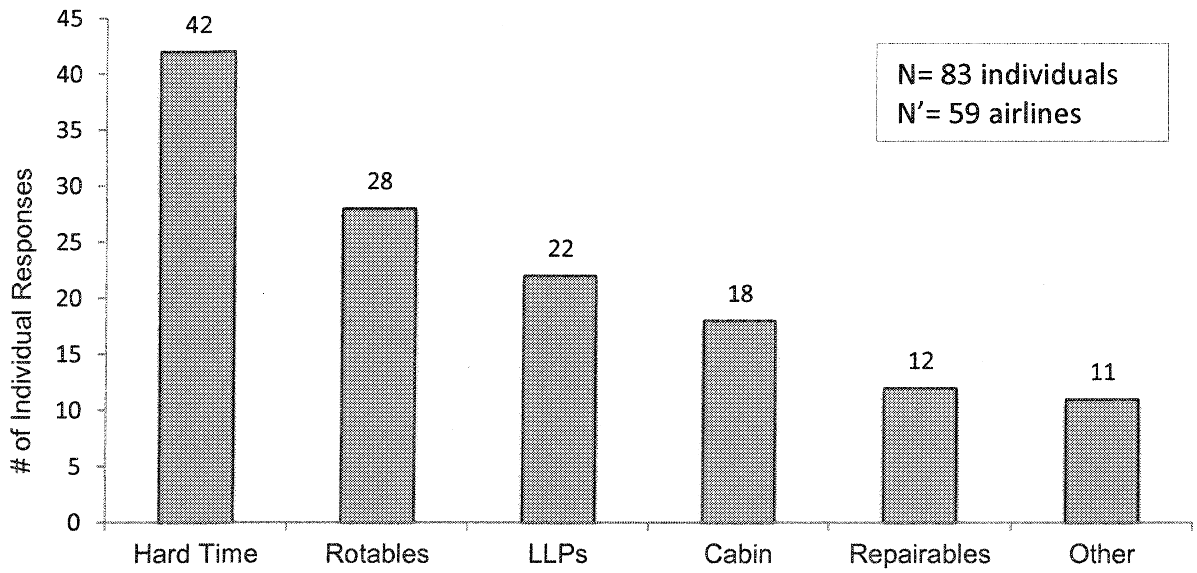

Figure 18.Tagging priority

In the category "other", some respondents mentioned:

- Tools & calibrated equipment
- Ground Support Equipment (GSE)
- In Flight Entertainment (IFE) systems
- Consumables
- Chemicals
- Expendables.

Question 8: What would be the criteria for potential parts marking?

The survey asked the respondents to specify the criteria that could allow decisions on whether a part should be tagged with RFID or not.

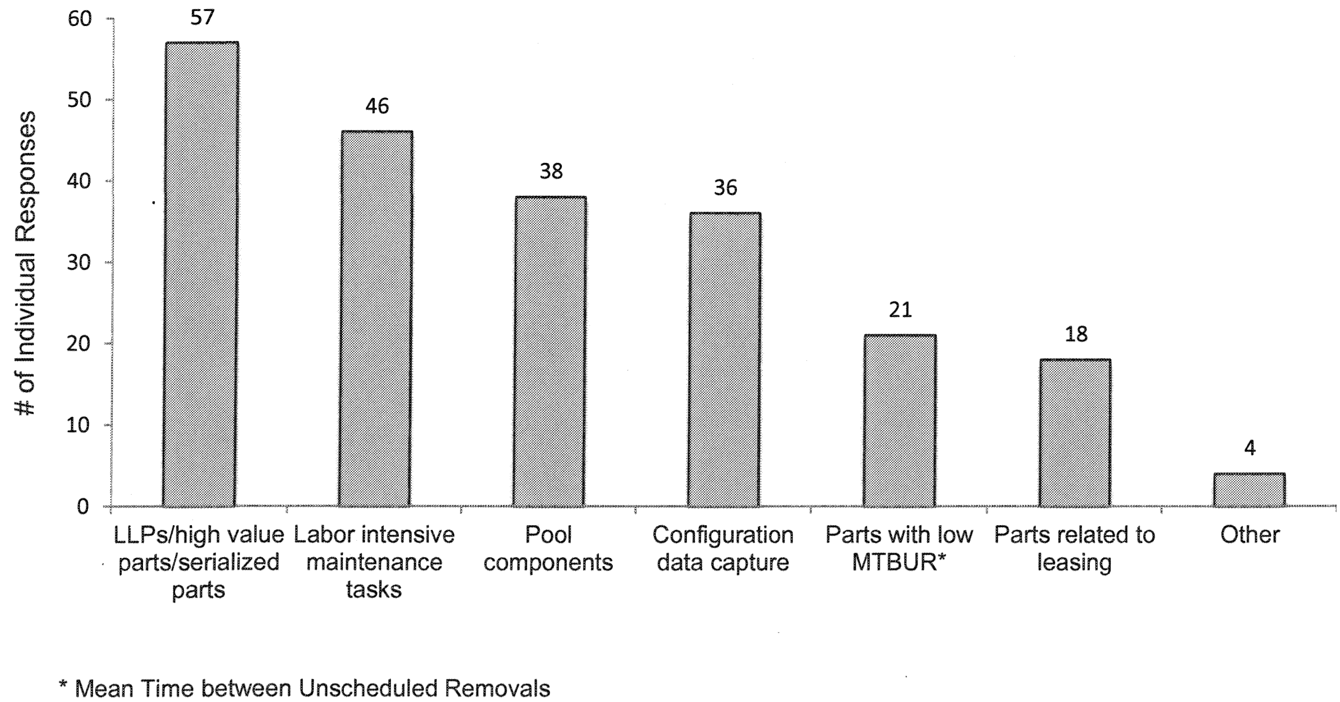

Figure 19. Criteria for tagging parts

Some respondents mentioned “other” criteria such as:

- Parts with high quantity fitted per aircraft
- Parts of difficult access
- Parts with complex compliance logic requirements

Q 9: Regarding the maintenance history of the RFID tagged parts, what is your preference?

Respondents were asked to specify their preference regarding the maintenance history on the tags with the following two options:

a) Maintenance history to be stored fully on the RFID tag (high memory)
b) Maintenance history to be obtained from the ERP system while RFID serves as an identification (low memory)

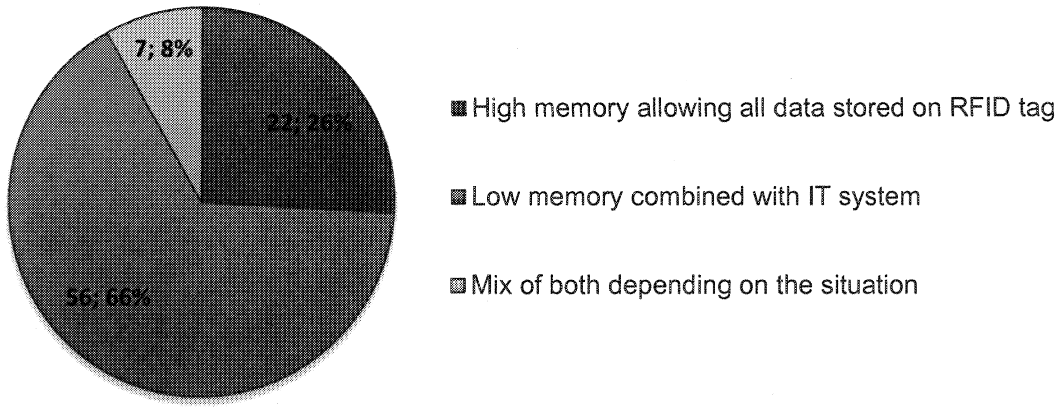

Figure 20. Preference for storing part information and history

Most respondents replied that best solution would be a low memory tag to be served as identification to link and obtain the maintenance records from IT/ERP system.

Note that some of those who replied "low memory", when asked for the data elements on the tag (see Figure 21), answered "all maintenance history". It seems that some respondents perceived low memory tags to be able to store more information than it actually could. The low memory tag is able to only store the basic information of the part.

One possible reason for this wrong perception could be the lack of knowledge as explained in Figure 23. It could also be because the word "low" was not defined in the questionnaire and therefore it caused confusions.

Please note that for industry experts, a "low memory" tag in aviation is defined as a tag with approximately 2 kilobits of memory which is able to store an abbreviated version of Birth Record Data (Hamlin, 2012).

Birth Record Data is a number of separate data elements found in the birth record. These data are programmed and protected by OEM at "birth" and include items such as weight, hazmat codes, customs commodity codes, air worthiness certificate number and etcetera (IATA, 2013a) .

Q 10. Do you prefer RFID tags to be installed at delivery or by the after-market?

Respondents were asked whether they prefer retrofit service (after market) or installation of tags by OEMs. All respondents answered both.

RFID installed at delivery is an option for new aircraft; however for those aircraft already in-service aftermarket solutions would be necessary. This confirms that airlines are interested to take advantage of the technology for the aircrafts in-service as well.

Q 11. Please list any data elements that you would like to see on an RFID tag?

Respondents were next asked to identify the data elements that are required to be on RFID tags.

Figure 21 below demonstrates the results. Respondents were allowed to pick more than one answer.

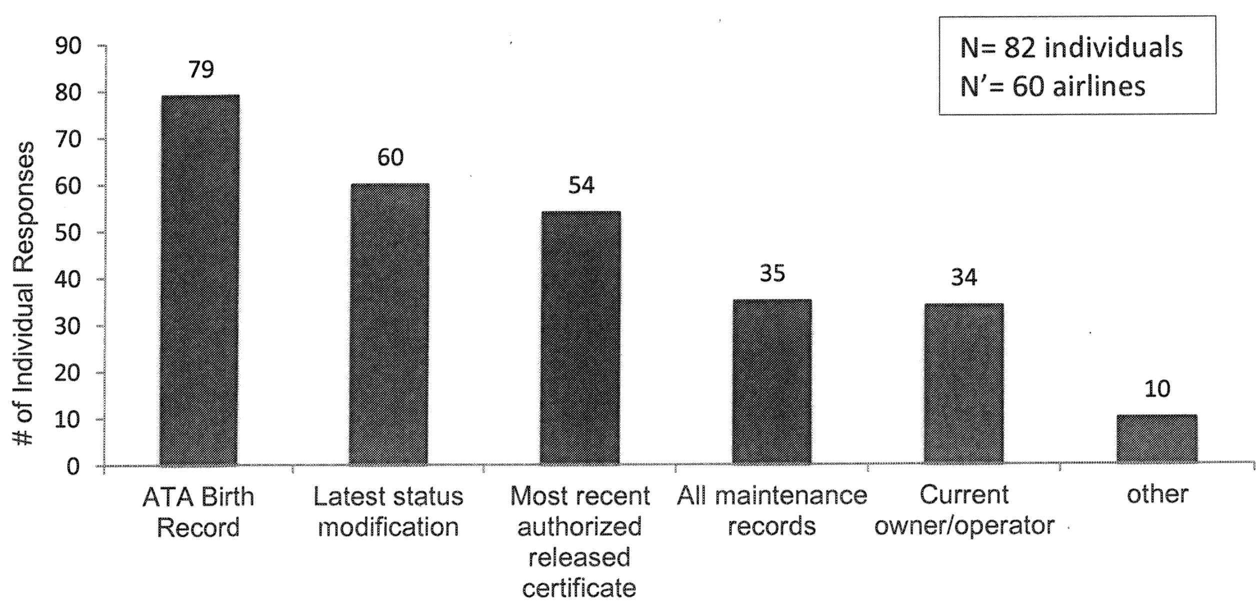

Figure 21. Data elements on RFID tags

According to ATA SPEC 2000, Birth Record is the minimum information a tag should contain. Some respondents checked other options, but did not check ATA birth record. This is either because the respondents felt that the ATA birth record is not really needed or it is due to "lack of knowledge" as explained in Figure 23.

In the category "other", airlines mentioned other items to be saved on the tag such as:

- 2D barcode with birth record included on tag and on OEM data placard/plate
- Last and next inspection date
- Next Higher Assembly (NHA)
- Effectivity code
- Location on aircraft
- Life expiry dates upon applicability
- Active calibration certificate reference (for tools)

Effectivity code is a code that is used in order to identify the same type of aircraft that is maintained in a facility. In a maintenance facility, all the documents contain this code in order to differentiate between the parts that come different aircraft types.

Q 12. What would be your approximate expected return? (ROI and Payback)

Airlines were asked to provide estimates on Return on Investment (ROI) and payback period.

Figure 22 displays the results.

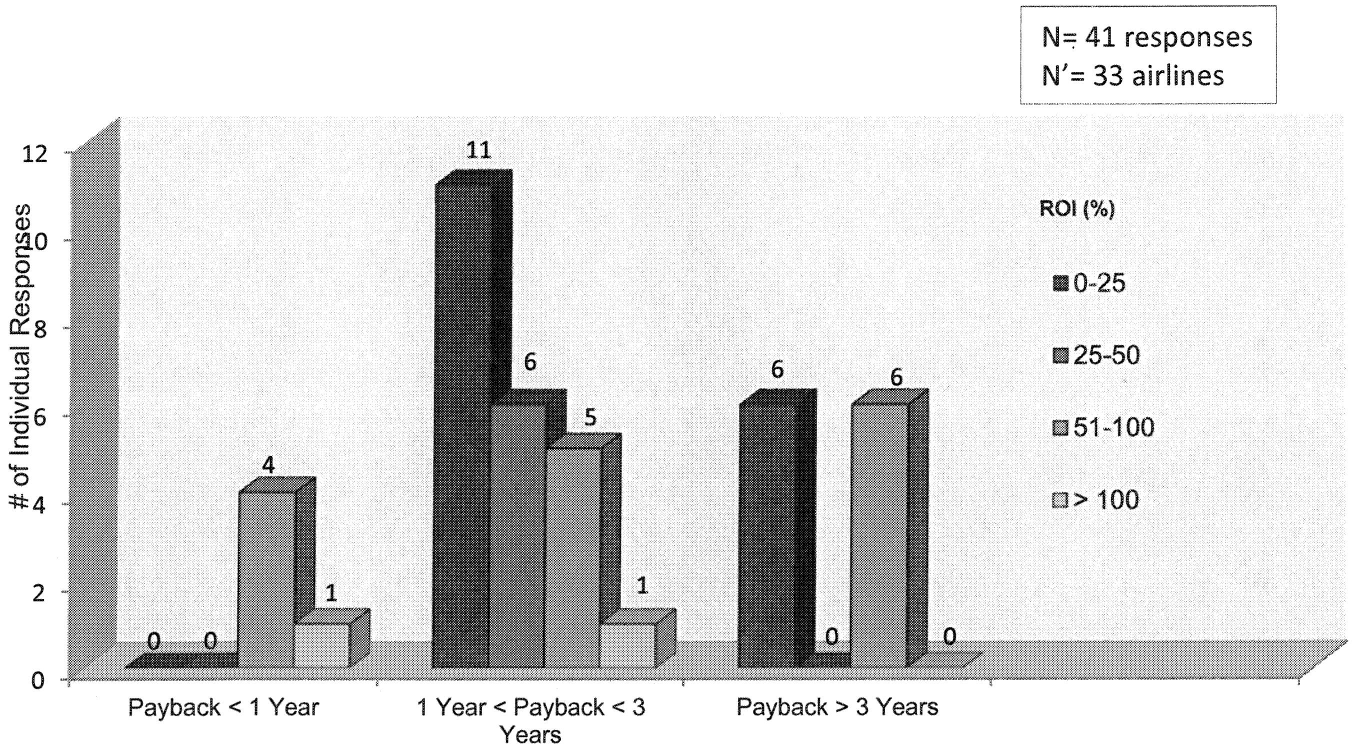

Figure 22. Expected ROI and payback period

Q 13. Why do you think RFID tags have not been vastly used so far in commercial aviation?

Respondents were asked to mention the limitations and barriers towards RFID implementation. Lack of knowledge, high cost of ERP interface and high cost of tags were the main barriers according to the respondents.

Figure 23 displays the results.

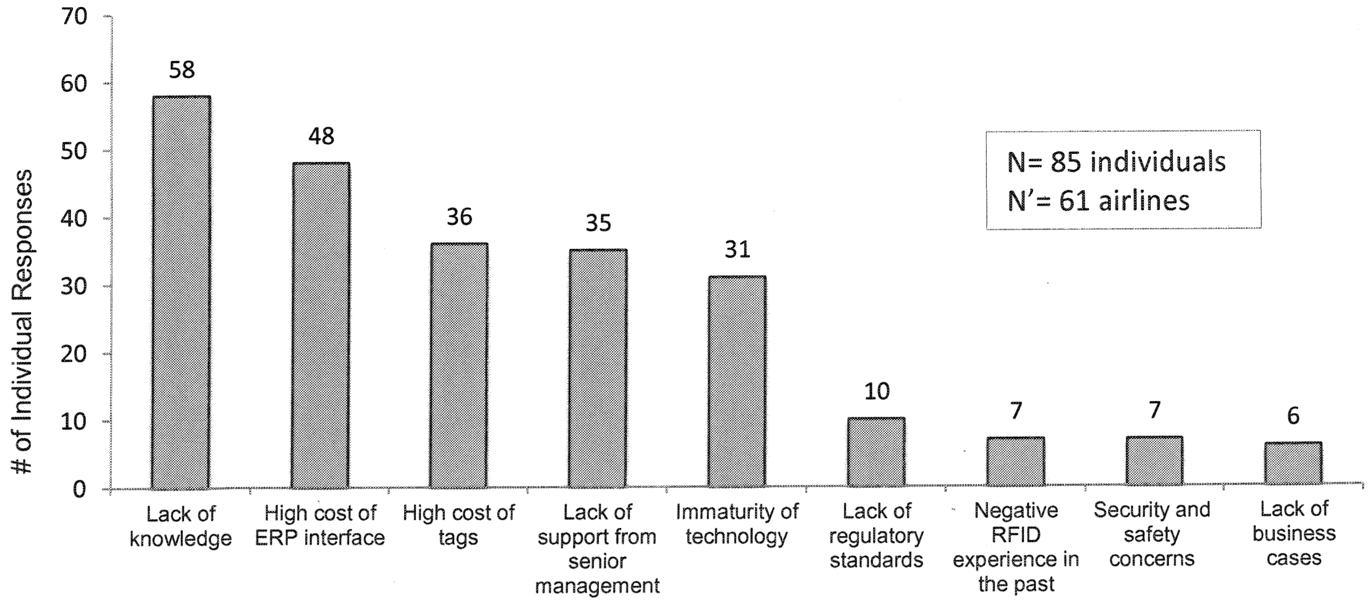

Figure 23. Barriers to RFID implementation

“Lack of knowledge” was identified as the number one barrier. This barrier is visible in some of the responses that were provided. As previously seen in the results to question 9 for example, there seems to be a lack of knowledge with respect to some fundamental aspects of RFID. As an example, the high cost of tags mentioned is related to “lack of knowledge”. Low memory tags todays cost about $1 US or less depending on the volume purchased, therefore it is not a high cost item.

This will be analyzed in more details in the analysis section.

5. Analysis

This section presents the analysis of the survey results and of some other findings that were discovered through other data collection means such as interviews, presentations, archival data and meetings. The analysis can be used as a tool by practitioners for decision making while it may also be used to identify the areas of concern for future research directions.

5.1. Airline Industry Applications of RFID in Maintenance Operations

5.3.1. Airlines with Current RFID Projects

12 airlines are currently employing RFID activities. This is around 18 percent of participating airlines. The remaining 55 airlines (82 percent) stated that their airline has not implemented or is not implementing any RFID projects.

As observed in survey results in Figure 8, large airlines have predominately explored using RFID rather than medium size airlines. No small airline is working with the technology as of the time the survey was conducted.

This could be explained by the fact that larger airlines can spread investments over a larger fleet. The benefits from efficiencies in larger fleets are significantly higher. As it is shown in the cost benefits analysis of Oxygen generators in section 5.5, the initial investment only slightly changes when the fleet size increases. Therefore, airlines with larger fleet have better cost advantages.

Another aspect that must be considered is the type of airline that is being operated. The type of airline directly affects the strategy for parts management. Besides the differences that rise between the passenger and cargo airlines, there are also differences to consider in terms of the type of network operated by the airline. This means considering whether the airline is a point to point, hub & spokes or a hybrid operator. Also, taking note of whether the airline is a charter airline or an airline that operates on a regular schedule may be relevant. (IATA, 2009).

When such factors are considered, it is understood that depending on the size of the airline and its network, inventory management strategies will be different. Smaller size airlines have a smaller network; therefore inventory management is less challenging than an airline that has larger fleet size and a bigger network covering long distances.

The inventory management strategy directly impacts the decision of an airline to use RFID technology.

5.3.2. Current RFID Applications

Respondents were asked to identify specific parts or groups of parts they were tagging. As shown in Figure 10 of survey results, life vests are the most popular application of RFID in flyable parts so far; 7 out of the 8 airlines mentioned using RFID for life vests.

RFID tags are placed on life vests to facilitate and speed up the maintenance checks. While the technician walks through the aisle with a hand-held reader, the status of each vest can automatically be determined by looking at the reader screen. The RFID tag emits signals to the reader and would mark any missing life vests with a red light on the screen indicating absence (loss of signal from the specific life vest). The rest of life vests are given a green light. Therefore, the technician will only check those life vests with a red light, instead of having to manually inspect each and every life vest Due to pre-synchronization between the life vest and the RFID tag, the technician knows which life vest has the problem (Lewis, 2013).

In addition, RFID is used increasingly for other cabin items. The Industrial Development Director for maintenance components at a major European Airline mentioned using RFID on seat covers and textile at his airline. This allows the airline to track the number of washes for each cover. He explains that some airlines are allowed to perform only a limited number of cleaning per item therefore RFID would be a very useful solution to track the number of washes. He continues: "You have to be able to identify you Part

Number (PN) with the textile tag attached to it. If the textile tag (not RFID) is not readable, you have to throw away your part, even if some potential cleaning remains and the item is still usable. Since the PN is necessary in order to track the number of washes, with the RFID tag, you should be able to identify the good PN and re-issue a proper textile tag to have your item serviceable and traceable. In addition, in a warehouse where you have textile it is very tough to do inventory; RFID can provide an easy solution for this problem.

Furthermore, as seen in Figure 11, the use of RFID to track tools is another popular application which affects maintenance operations directly. Such uses relate to tool check in/check out by a technician/mechanic, tool location by use of active tags, tools calibration and etcetera. Tools for aviation applications are very specialized and have specific designs that require regular calibration at certain time intervals. In addition, the highly trained aircraft engineers are costly to employ. RFID can minimize the time to look for and to locate tools and allows delegating tasks such as tool calibration to less trained staff (Price, 2007).

In addition, two major European airlines mentioned using RFID to tag rotables such as engine components. The tags used are low memory and only used as identification for warehouse purposes for now. High memory RFID tags that allow storage of the main history of maintenance of a part are not used for this purpose yet.

5.3.3. Future RFID Applications

Based on the survey results, current use of RFID application is limited to 18 percent of the industry but this number should be growing, as 76 percent responded they are going to have RFID projects in the near future.

RFID is the fastest growing technology (Ngai et al., 2008) and a source of competitive advantage (Berger, 2005). Moreover, one should not forget that many of the major companies that are implementing RFID are reluctant to discuss their programs with outsiders (Berger, 2005). Therefore, the lack of visibility of major projects should not be taken as a cause for complacency. Lots of learning is already taking place and benefits are delivered.

As seen in Figure 15, most of the airlines that are not planning to use RFID belong to small sized airlines. In order to understand this, some smaller airlines were interviewed to understand their perception.

The result of the interviews suggested that smaller size airlines normally have a component spare agreement and do not own their own parts; therefore they do not see a reason to use this system. In addition, some mentioned that in smaller airlines it is easier to manage parts manually and there is no need for RFID.

However, being a small airline can be an advantage for RFID adaptation. A literature review confirms that the smaller organizations can make the adaptation of RFID and utilization of the productivity potential easier (Strüker & Gille, 2010). In addition, occasionally, a carrier may still own or track their assets even if their maintenance is done by a third party on a time and material basis, but per contract, the carrier provides the inventory to the vendor for installation during the repair process (IATA, 2009). In such cases and also for the labor intensive inspections such as checking life vests and Oxygen generators, RFID can bring advantage regardless of the size of an airline.

Furthermore, some carriers that had or witnessed negative RFID experience were interviewed to gain more details.

As an example, a major Asian Airline mentioned that they implemented a pilot RFID project for their Oxygen generators in the past but they decided to discontinue. As the airline explained, the main reason for discontinuing at the time was the immaturity of the technology. When technician was walking through the aisle to scan the generators, if more than one tag was in the neighborhood, the hand terminal reader read the incorrect data. In addition, sometimes the reader was not able to read the tag. In such cases, the technician had to open the Passenger Service Unit (PSU) in order to access the tag. This resulted in worsening the situation and decreasing work efficiency. It was also mentioned that the reader weighted about 1.4 kilograms and it was heavy for a mechanic to carry. Therefore the airline decided that the maturity of technology was not sufficient, and hence they stopped the implementation.

There have been studies in the literature that confirm the immaturity of RFID in conductive environments. These studies state that passive tags do not perform well against metal objects (Davis et al., 2010; Griffin et al., 2006; Sydänheimo et al., 2006). In addition, hand and arm position impacts the read capability in such environments (Davis et al., 2010).

5.2. Category of Parts that Can Benefit the Most from RFID Tagging

5.2.1. High Value Components

RFID can provide benefits to high value components and allow ease of tracking. This includes high value components that require scheduled and unscheduled maintenance attention such as repairable, rotable and life limited parts. Over time, high value parts get modified and upgraded, changing the part number, mod level status, etc. All this information can be easily traced and accessed with the help of RFID.

In regards to read/write capabilities, since high value parts get often modified and upgraded, therefore, in this case, the RFID capability would be at maximum if the data on tag has "Read and Write" capability.

Latest status modification and most recent authorized release are few pieces of key data that could be quickly accessible and updated with RFID. There are other data that is crucial for the aircraft maintainer to know quickly which can be easily accessed by RFID. Multiple maintenance records on the RFID tag show who did what to a part and when. This provides information of when the part was installed, removed from which aircraft, by which company; when/where/who repaired/overhauled the part, if it was bought from another company and if it was exchanged with another part. The expectation is that part traceability will be found on the part to every player's advantage across the industry.

5.2.2. High Volume & Labor Intensive Parts

The use of RFID on high volume and labor intensive maintenance parts such as life vests is also beneficial.

It allows data to be read quickly during inspections and therefore reduces labor intensive tasks (in both man-hours and inspection time). Airlines require accelerated and reliable preflight checks focusing on emergency cabin interior equipment. Such items could benefit from "read only" tags with low memory which would allow airlines to monitor the discard date. In addition, RFID in this case can also increase the safety and security.

As an example, by the help of RFID the crew can see at any time if the life vest is present in order to avoid thefts, destruction or absence.

5.2.3. Tools/ULD/GSE

RFID for tools, Unit Load Devices (ULD), Ground Support Equipment (GSE) is another useful application. This category can bring benefits to the maintenance program and facilitate logistics. Tooling and aircraft equipment is the key due to maintenance requirements and potential to move around the airport. RFID on fleet of vehicles is also beneficial due to high asset values and it allows control of incidents.

As an example, Airbus started using RFID for tool management back in 1999. The tags on the tools were capable of including data history of the tool as well as the information about shipping, routing and customs information (Harbison, 2013).

5.2.4. Expendables

Despite the name, expendables are an important aspect to any carrier's overall inventory strategy, for a low cost fastener can ground an aircraft as surely as a $750,000 flap assembly. Careful management of expendables is necessary since many airlines may carry one-quarter to one-third of their overall inventory balance in expendables. In addition, expendables are generally tracked in lots for traceability, facilitating the segregation of material if a part recall is issued by a manufacturer. Financially and operationally, expendables clearly require substantial attention (IATA, 2009). In such cases, RFID can also help with monitoring expendables.

5.2.5. Parts with Low MTBUR

One key aspect of making data visible is providing more information to the front line people who need it. With that being in mind, one can understand the advantages RFID can bring to parts with low MTBUR. Low MTBUR parts are parts that tend to fail more often. This information can easily become visible to the technicians and engineers and can help them in making decisions and take necessary actions.

5.2.6. Pool Components

In addition, tags could be used to identify and track pool components. Aviation industry is a global industry. Airlines regularly borrow or loan parts; RFID can bring advantages to provide from simple visibility across the supply chain to full access to maintenance history.

Read Distance

In regards to read distance, most airlines mentioned that the read distance is subject to the level of difficulty to access the part. If the part is located at an obscure location, longer read distances would allow for the part to be located. Lower read distances could be more suitable for items that are at line of sight. Some commented that the read distance should be at the maximum for the user to decide how to manage it. Note that the cost of the RFID system increases as the read distance capability increases.

With all this mentioned, one must also remember the immaturity of RFID in conductive environments. Therefore, even though RFID can bring value to managing many aircraft parts, however due to its limited range and reading capabilities, it may not be the most suitable solution especially for parts that are in obscure locations

5.3. Potential Benefits of RFID in Airline Maintenance Operations

The benefits that result from RFID implementations can be categorized as follows:

a) Enhancing visibility & data accuracy
b) Improving inventory management
c) Speeding up the processes
d) Increasing safety & compliance

5.3.1. Enhancing Visibility & Data Accuracy

By implementing RFID, airlines can establish visibility of part flow across the entire supply chain and therefore improve different functions of the organization. This can positively affect the responsiveness of supply chain and decision making processes (Heinrich, 2005).

The RFID visibility system can offer a way to get a complete view into all of the supply chain functions, including procurement, inventory, transportation, logistics planning and engineering. RFID can enable efficient and secure asset and service parts management. In addition, transparency of “maintenance intervals and execution status, actual configuration/calibration of tools, time scheduling of tools (spare-parts, location, and time), utilization duration, and utilization date” is gained (Heinrich, 2005).

Furthermore, RFID tags can help the operators deal with the transition of parts from operator to vendor and other operators, service providers, suppliers. This will allow for maintenance tasks to be conducted in a more efficient and lean way. When a part fails, it is a common task for both the operator and the vendor to evaluate the failure of a part and decide on whether to replace or to repair it. By having visibility on the information, and the integration of data with the help of RFID, the maintenance procedure will be done in a more efficient and timely manner. RFID will allow for the information exchange between different parties of supply chain such as vendors, operators, and MROs. This collaborative information sharing will decrease the overall costs and increases the efficiency of maintenance procedures (Lee et al., 2008).

That being said, due to regulation and standards, some areas will benefit the most while others will benefit less. For example in case of aircraft leasing, there is much standardization and industry harmonization to be done in order to reduce the lessor companies' leverage and risks. Since the lessors have the power to decide and enforce through contracts what documentation and level of history they need for components, the airlines cannot take advantage of the ease of data transmission by the help of RFID. Lessors also have regulatory obligations that mandate them to be responsible when transferring aircrafts therefore at this moment only paper documents for data history are accepted. If regulations allowed, RFID would be able to facilitate the transfer of leased aircrafts. By using RFID, aircraft parts and their maintenance history can be quickly accessed and assessed to simplify aircraft transfers and meet aircraft leasing requirements. This area however needs further attention by both lessors and lessees to address efficiency gains for both parties.

5.3.2. Improving Inventory Management

By enhancing visibility, RFID enables airlines to predict and avoid the costly stock outs as well as the unnecessary stocks. RFID reduces parts idle time, lost parts and the cost for manual search.

5.3.3. Speeding up Processes

RFID results in time reduction by reducing the man hours required performing certain jobs. As an example, RFID is able to reduce the overall inspection time for items such as life vests and Oxygen generators. RFID allows data to be read quickly during inspections and therefore reduces the time spent on labor intensive tasks.

Also by providing visibility, airlines do not spend time to identify and locate parts. As an example, a major carrier in Europe uses RFID tags to enhance and speed up all the subsequent identification of a part. The tag is attached as an identifier to the document that travels with the part along the process.

5.3.4. Increasing Safety & Compliance

Airlines use RFID to increase safety and compliance. This can by far be the most important benefits of implementing RFID.

As an example, a major American carrier reported the implementation of RFID to track shop towels in their engine shop. This was done primarily to improve safety and compliance. The process was put in place to ensure that towels are removed from a component prior to release to service.

A major Asian Airline explains that without RFID, expired Oxygen generators are found on planes due to miscalculations of expiry dates. With RFID, such mistakes are avoided and compliance is ensured.

Also, by automatically inserting records electronically on RFID tags, no one has to copy and paste records, read and type data, and do manual entries. This eliminates sources of human errors and results in 100 percent compliance.

5.4. Return on Investment

RFID may be an excellent technology but if it doesn't provide a Return on Investment (ROI), its application will be questioned.

Airbus has been using RFID for logistics and parts/tools tracking purposes since 2005 and has achieved clear ROIs (Harbison, 2013).

Looking at airlines, Lufthansa Technik is one example of successful implementation. They use RFID to identify and track LLPs in their chemical cabinets. Lufthansa has reported "97 percent accuracy and 80 percent time reduction and significant cost savings" (Greengard, 2013).

Delta Air Lines has also seen significant inventory and labor reductions by use of RFID (Lewis, 2013). Delta has seen 98 percent time reduction in labor by using RFID to check Oxygen generators (Swedberg, 2013).

However, in all these examples, the business processes were internal and easily controllable which was the key to initial success with this technology. As the RFID manager of a major American Airline explains, it is important to consider that there is no "one size fits all" approach. The key is to make sure that the technology is applied in a manner that makes sense, so there is value added to the individual process or enterprise.

The technology should be used in a manner that supports a good business/maintenance process, not just because there is the capability. The correct mix of technologies and tools will add value. The goal is to create a paradigm that can change as a result of moving from a visual world to a digital one. Eventually the industry will mature and get more sophisticated with this technology and there will be broader benefits addressing more business problems.

5.5. Cost Benefit Analysis of Oxygen Generators

As mentioned earlier, there is no generic technology cost or benefit that can be determined apart from the business problem trying to be solved. Knowing what the costs are for different components and processes will help determine where the focus should be.

There are several RFID systems that can be made by combination of different tags, different readers, different frequency and reading capabilities, etc. (Sarac et al., 2010). The potential cost and benefits would be different depending on all these criteria.

That being said, to illustrate the benefits of RFID, the example of Oxygen generators will be shown.

5.5.1. Benefits

Below we will demonstrate the benefits specific to the example of Oxygen generators.

The expected life cycle of Oxygen generators is on average 14 years. Some of its useful life is spent on the aircraft, but some is wasted on the shelf and some is wasted by replacement when a part is removed prior to its expiration date.

The life that is wasted on the shelf is due to keeping buffer inventory for unknown demand just in case and not just in time. The problem flows upstream, causes bullwhip effect as explained by Forrester (1985) and increases the cost to fill a shelf. Delta as an example has estimated that the generators lose up to 15 percent of their life-span due to sitting in stock (Swedberg, 2013).

In addition, generators need to be regularly checked in order to ensure that they have not expired. If all generators on the aircraft had the same date of manufacturer, those generators would all be replaced at once. However, due to mixing from the delivery, interior configuration changes, replacement due to defect and etcetera, the expiry dates of generators are uncontrolled and different. Without RFID the expiry date of a generator is calculated on average every 18 months. If the remaining life of generator exceeds 18 months, it is kept; otherwise, the generator will be replaced.

Approximately, 20 percent of the generators get discarded on inspection every 18 months visit. When a generator is removed from the aircraft, it will be transferred for disposal. Average unit cost of an Oxygen generator is $400 US. In addition, one must count for the additional time spent to activate generators, for the disposal transportation of Oxygen generators that were removed, and the hazardous waste disposal fees (barium). Let us assume a total cost of $600 US for each early removal. If RFID can delay early replacement of 20 percent of generators on a Boeing 777 with 300 seats, it would result in $36000 US of savings every 18 months. This is the savings for only one aircraft. The bigger the fleet size, the more savings can be realized.

There is also the labor cost to be considered. A standard date check for the Oxygen generators on a Boeing 777 aircraft takes about 4 hours. With RFID, this task can be performed under a minute.

One must consider that RFID also makes the process more accurate and increases safety and compliance. Although it is difficult to estimate a monetary value for such qualitative and intangible benefits, such intangible safety and compliance benefits exist and will increase the overall advantages associated with RFID implementation.

For the purpose of this analysis, an approximate total saving of $36,000 US, related to tangible benefits, is assumed for every 18 months period.

5.5.2. Costs

In addition to benefits, the costs involved must be considered when doing a cost benefit analysis.

Banks et al. (2007) categorizes the cost of RFID in six sections. This includes: “cost of hardware, cost of software, system integration tools, installation costs, cost of personnel and the cost of business process re-engineering” (Banks, 2007).

Figure 24 below illustrates the costs.

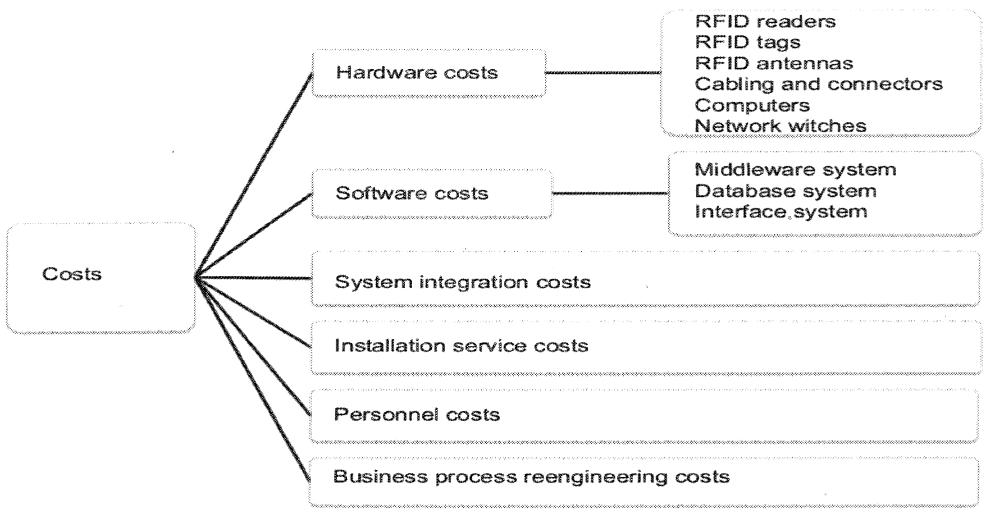

Figure 24. RFID Implementation Cost Tree (Banks, 2007)

In order to estimate the cost for the case of Oxygen generators on a Boeing 777, the following estimations[4] were made.

Although this example applies to Oxygen generators case only, one can easily extrapolate how benefits can be achieved by applying similar cost methodology and assumptions to other items such as life vests.

Hardware Costs

For the case of Oxygen generators, handheld readers are the most suitable as it allows movement and flexibility. The cost of one handheld reader is $4,000 US. Having two readers is necessary, in the case one breaks down. Therefore the cost for the readers is $8,000 US.

For the cost of tags, several suppliers were contacted. It was concluded that for Oxygen generators, simple low memory tags are used which could cost as low as $2 US in volumes of 3000 tags and $1 US in volumes of 15000 tags. Note that when buying the

[4] Estimates were provided by a supplier whose identity is confidential.

tags in bulk, the tags can be used for more than one aircraft. Each Boeing 777 needs about 300 tags. Assuming a price of $2 US per tag, the cost would be $600 US.

There is no associated cost for antennas, cabling, connectors and network switches for Oxygen generators. However, for the reference, the approximate costs of these items can be seen in Table 3.

Airlines usually have computers in place that can be used. However, if one had to be purchased, the cost would be around $2,500 US.

Readers-handheld	$4,000 US
Readers – fixed*	$1,200 US
Fixed Antennas*	$250 US
Cabling & connectors/antenna*	$100 US
Computers	$2,500 US
Network Switches*	$500 US
RFID Tags	$2 US/tag

*Not applicable for RFID systems of Oxygen generators.

Table 3. Cost of Hardware for RFID System

The total cost of hardware for RFID system on Oxygen generators of Boeing 777 is $11,100 US (readers $8,000 US + tags $600 US + one computer $2,500 US).

Software Costs

The system software (middleware) will cost $2,500 US per plane for a single aisle plane.

The database system necessary for Oxygen generators can be run off a laptop computer running a SQL Server database which would cost about $6,000 US.

The cost of interface system is zero as the software on the handheld comes with the per plane cost and includes the interface system cost. Table 4 shows the cost of software for RFID system.

Middleware Systems	$2,500 US
Database System	$6,000 US
Interface System*	0

* The cost of interface is included in the cost of handheld.

Table 4. Cost of Software for RFID System

The total cost of software for RFID system on Oxygen generators of Boeing 777 is $8,500 US (middlewear system $2,500 US + database system $6,000 US).

System Integration Costs

The database can easily become enterprise capable with the help of a database support package with backup and automatic failover. The cost of such extra system would be about $10,000 US.

The system integration cost for RFID system on Oxygen generators of Boeing 777 would be $10,000 US.

Installation Service Costs

Installation costs per fixed reader and antenna is $500 US, however for Oxygen generators handheld readers are used and therefore this cost is zero.

Software installation can cost up to $10,000 US, if the supplier was to send staff to the airline's site to install the software. The $10,000 US is the estimated cost for travel, accommodation and labor rate. However, in most cases, the system installation is done long distance; the supplier can remote-in to airlines system and install it. The cost associated with this is included with the cost of software and therefore is considered zero. For this analysis, it was assumed that the system installation is done remotely.

In regards to the cost of tagging, it takes approximately 2 hours for two people to tag Oxygen generators on a Boeing 777. Assuming a labor rate of $50 per hour, the cost in this case is $200 US.

Per fixed reader & antenna*	$500 US
Software install on server**	$10,000 US
Cost to tag O2 Gens per AC	$200 US

*Not applicable for RFID systems of Oxygen generators.

Table 5. Cost of Installation service for RFID System

The total installation service cost for RFID system on Oxygen generators of Boeing 777 is $200 US.

Personnel Costs

It will take a mechanic half an hour to learn the handheld process in the plane. However, half a day (four hours) should be allocated to this activity to ensure all the aspects of the training are covered. Assuming a labor wage of $50 US per hour, the user cost would be $200 US per mechanic.

System administration trainings would take on average about 10 days. The cost is an internal cost to airlines for their own employees and is assumed to be approximately $5000 US.

System Administrator	$5,000 US
Users	$200 US

Table 6. Cost of Personnel for RFID System

The approximate total cost of personnel is 5,200 USD.

Business Process Re-engineering Costs

By far the biggest and most difficult cost to estimate is in the reengineering costs. This cost includes actions such as new job cards and authority approvals (FAA, EASA, etc.). As an example, the job cards and approvals can physically be done in a week by one person, but how many people are involved in how many meetings over how many months in order to approve the new processes, is the costly unknown part. As estimation, $100,000 has been allocated to this cost.

The total cost of RFID for Oxygen generators on a Boeing 777 is approximately 135,000 USD. The cost varies depending on the supplier and also the options the airline chooses.

Some of these costs such as cost of re-engineering the processes, cost of readers, cost of hardware and software, and cost of training are a one-time cost and not associated solely to one aircraft or one type of tagging activity. In Table 7 the fixed and variable costs associated with implementing RFID on Oxygen generators are identified.

Cost	Fixed	Variable
Readers-handheld	$8,000 US	
Computers	$2,500 US	

RFID Tags		$2 US/tag
Middleware Systems		$2,500 US/AC
Database System	$6,000 US	
System Integration	$10,000 US	
Cost to tag O2 Gens per AC		$200 US/plane
System Administrator Training	$5,000 US	
Users		$200 US/technician
Business Process Re-engineering	$100,000 US	

Table 7.Fixed and variable costs associated with implementing RFID on O2 Gens

As the fleet size of an airline increases, for a slight increase in initial investment, the return on investment goes higher and therefore, the breakeven point is achieved more quickly.

Assuming an airline whose fleet consists of one Boeing 777, the $135,000 US initial investment would be recovered only by the associated benefits of tagging one aircraft. These benefits were estimated to be $36,000 per 18 months.

In this case, assuming a linear relationship between time, cost and benefits, the cost of RFID system for Oxygen generators on a Boeing 777 will be recovered in over 5 years. See Figure 25.

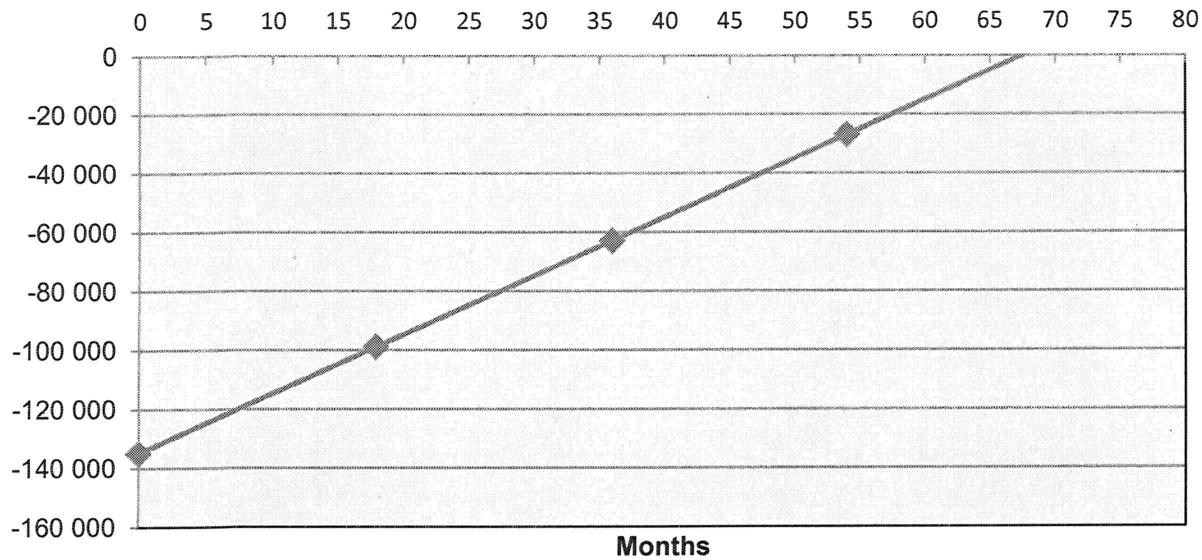

Figure 25. Breakeven point for RFID system on O2 Generators of one B-777

For a fleet size of five Boeing 777s, with two technicians, the initial investment is calculated to be $148,400 US which is only slightly increased. However, the benefits associated with the 5 aircraft are $36,000 US multiplied by five every 18 months, which equals $180,000 US. As seen in Figure 26, the initial $148,400 US investment would be recovered in less than 18 months and just a little over a year.

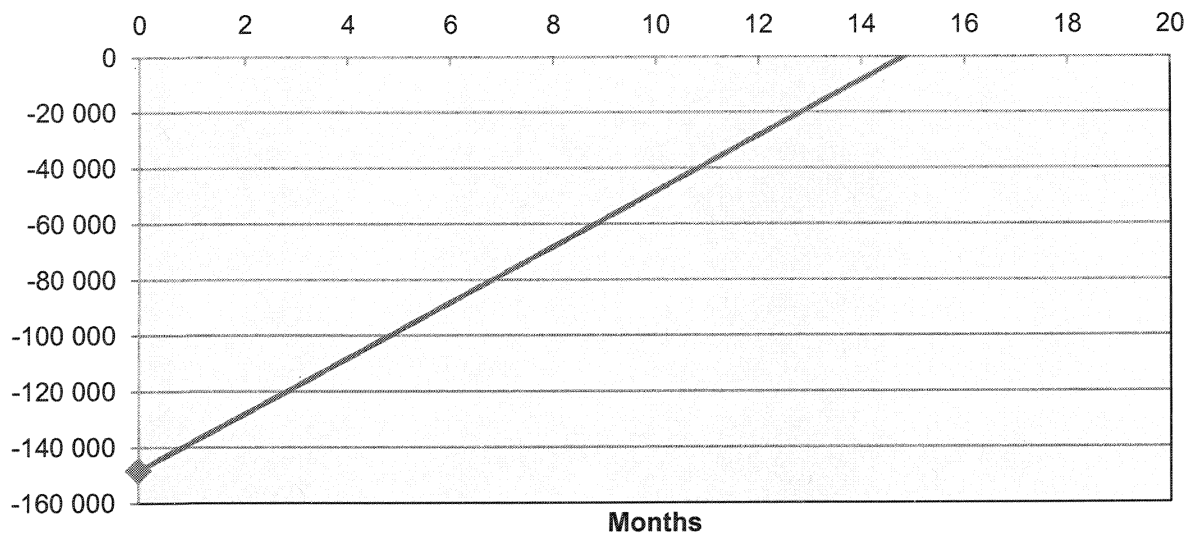

Figure 26. Breakeven point for RFID system on O2 Generators of five B-777

For a fleet size of ten Boeing 777s, with three technicians, the initial investment cost would be $165,100 US. In this case, the breakeven point is achieved in less than a year. Please see Figure 27.

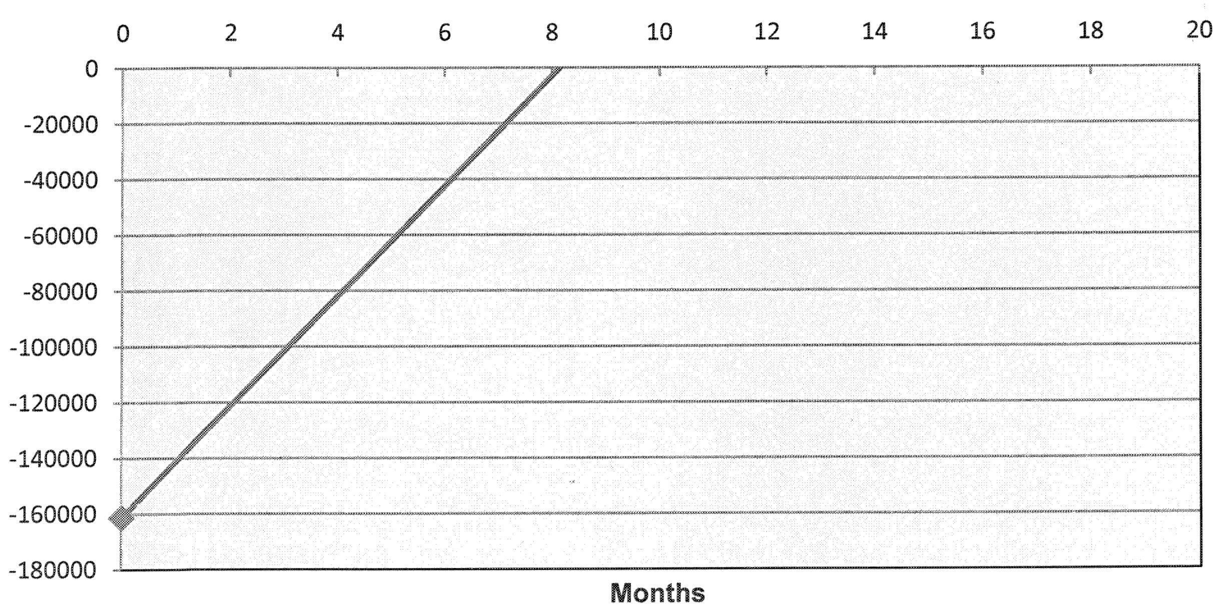

Figure 27. Breakeven point for RFID system on O2 Generators of ten B-777

Considering the examples shown, it is safe to conclude that benefits increase rapidly as the fleet size gets bigger. This could explain why larger airlines are currently implementing RFID. However, in the examples shown, it was demonstrated that even for an airline with a fleet size as small as 5 aircraft, RFID implementation can be profitable.

It is also important to mention that the hardware and software are trivial compared to the Peopleware considerations of making RFID a successful project. That's why a financial analysis of all the tangible factors is not necessarily a deciding factor. A company should understand the capability of its employees and consider the change management aspect of the project and do most of its investment there as that is the most deciding factor in making a RFID project successful.

5.6. Barriers to RFID Implementation

Airlines responded in the survey, three so-called high problems on the way of RFID implementations are the lack of knowledge, cost of ERP interface and the high cost of tags.

5.6.1. Lack of Knowledge

Many respondents replied that it was too difficult to obtain the skills and knowledge necessary to successfully implement a complete system, due to the complexity of configuring and operating numerous hardware and software components. The literature review confirms that even after attending seminars and training, a business' staff member often would have "little knowledge about and skills with RFID technology", therefore in some cases, it would be "more expensive to invest in acquiring RFID know-how skills than acquiring RFID devices". It was concluded by many potential adopters that it was challenging to gain the necessary knowledge and skill for implementation of RFID systems. The configuration and system characteristics are complex and require extensive knowledge (Huang, Qu, Zhang, & Yang, 2012).

5.6.2. Cost of ERP Integration

Respondents also showed significant concerns about the costs of reengineering their processes to support RFID, and to integrate the RFID system with their existing information systems. As seen in literature, the high cost of initial investments in RFID infrastructure in some cases leads to a “wait and see” approach which is the case for many Walmart suppliers. The “wait and see” or “slap-and-ship” approach means tagging the parts right before they leave the supplier site and shipping to the customer. This kind of approach is desirable by some companies as it postpones the need for further investments until the cost of technology decreases (Poirier & McCollum, 2006).

The application for cabin items such as life vests, Oxygen generators does not necessarily need integration with the ERP system. As a major American airline explains, for Oxygen generators and life vests, the airline has acquired specific software that connects to the tags and readers and can validate the expiry and also the availability of the vests and generators on the plane.

The use of RFID without the full ERP integration would allow airlines to take advantage of the value RFID can offer to some extent without worrying about the investment required in ERP integration.

5.6.3. Cost of Tags

Some respondents showed some concern about the high cost of tags. However this concern is mostly attributed to their “lack of knowledge”. A tag can cost as low as less than $1 US if ordered in quantities. High memory tags can cost more depending on memory size and volume. However, prices are dropping fast and will drop substantially, once the industry firmly commits to the technology.

5.6.4. Lack of Support & Regulatory Standards

Next on the list, many respondents mentioned a lack of support from senior management. There is also the lack of regulatory standards and limited support from authorities.

Some airlines mentioned that there is lack of a real initiative by the type certificate holders and equipment OEMs to create the approvals for items; e.g. where and how the tags should be installed on each part so that it does not create interference in installation or other system problems. Lack of standards, interfaces with suppliers and MRO ERP systems are great barriers on the way.

Acceptance of uniform industry standards are required to eliminate complexities and achieve interoperability and higher data security. This is extremely important especially for pool parts; all the operators should be able to read the RFID informations. Not many MRO systems vendors have provided RFID interfaces yet. Therefore, one of the main focuses should be on harmonization and standard through the industry in order to facilitate the adaptation of RFID technology. The OEMs should do more than just informing airlines and providing vision and goals. They should also communicate with airlines a detailed implementation timeline that allows airlines to understand the operating factors of RFID as well as the resources required.

5.6.5. Immaturity of Technology

Immaturity of technology is another main barrier. Research shows that passive tags do not work well against conductive surfaces. Also hand and arm position affect the read capability (Davis et al., 2010; Griffin et al., 2006; Sydänheimo et al., 2006).

In aircraft maintenance, the consequences of tag failure in aircraft maintenance are more severe than it would be in other industries and therefore, this incapability can act as a real burden (Davis et al., 2010).

5.6.6. Lack of Business Cases & Other Concerns

There is significant skepticism around RFID's ability to live up to the performance and capability claims being made by the solution providers. Even though solution providers promise great read distances and trouble free implementations, some airlines tend to be quite reserved.

Business cases and industry examples will pave the way. One airline mentioned that "it would vastly improve acceptance of the technology if an airline could visit a peer with a working solution and see first-hand that RFID actually works and delivers a quantifiably significant benefit." There are a few cases where an airline is acknowledging a vendor's solution. In these cases, some kind of co-marketing agreement could be setup where an airline would be agreeable to help sell an RFID solution in exchange for a share in the profits generated and/or massive discounts.

Such arrangements are common for MRO software solutions and it does greatly influence a purchase decision to know if:

a) A competitor is using a product
b) They are happy with it
c) An airline is willing to let others see in person why they are so happy with it

6. Conclusion

The landscape of the aircraft maintenance industry is evolving rapidly. If carriers want to become more competitive or maintain an existing comparative advantage in terms of overall operating costs, they need to be more conscious than ever about maintenance dynamics.

RFID can help improve visibility, inventory management, safety and compliance, and speed up processes. These advantages make RFID applications extremely useful and interesting for airlines.

Certainly the airline industry has taken notice of RFID, as evidenced by the previously mentioned results which showed that 76 percent of the airlines surveyed are planning RFID projects for the future. Comparing this to the 18 percent of airlines surveyed which currently have RFID project in place, one can see how RFID usage is poised to grow in this industry. All of this indicates that future study and improvements in this area would not only be warranted but welcomed by any organization which is searching for better and quicker ways to do their business.

This work has also identified the category of parts that can benefit the most from RFID.

The use of RFID for labor intensive parts such as life vests and Oxygen generators is recommended. RFID for tools, ULD, GSE and fleet management is another useful application. This category can bring benefits to the maintenance program and facilitate logistics. Depending on the inventory management strategy, an airline may also consider application of RFID for other categories such as expendables, parts with low MTBUR, pool components, corrosion monitoring, etc.

Due to some technology barriers, when it comes to conductive surfaces and also due to harsh operating conditions of aircraft, RFID may not be as efficient for tagging parts that are in obscure locations.

In addition, the barriers to RFID implementations in airlines were identified. Some barriers mentioned are: lack of knowledge, cost of ERP integration, cost of tags, lack of support and regulatory standards, the immaturity of technology, lack of business cases and etc.

The number one barrier was identified as the lack of knowledge. Organizations like IATA have a key role in enhancing the knowledge in the industry. IATA regularly hosts RFID events that encourage experience and knowledge sharing. These events and workshops will have a positive impact on the overall industry knowledge and should be endorsed by airlines' higher management.

Other barriers such as cost of tags and support from authorities and regulatory standards would improve as the technology use becomes more widespread. The growth of RFID use in aviation in the future will contribute to the acceptance and harmonization throughout the airline industry.

The immaturity of the technology is another barrier that will be overcome as suppliers will design more sophisticated RFID systems over time. As mentioned previously, there are airlines which have chosen to not use RFID after bad experiences. Improvement in the specificity of the RFID system that eliminates the extra hassles they encountered would be the key to having them adapt to this technology. Sharing business cases can also combat other barriers such as skeptics about safety and capability issues.

Further, as literature review confirms, one of the greatest challenges in RFID research is to bridge the gap between practitioners and researchers (Ngai et al., 2008). This thesis aimed to give managers and practitioners the type of data and the information that can help them in decision making. Practitioners can take advantage of the results of this thesis to understand the status and perception of their peer airlines regarding RFID use. The challenges, costs and the benefits associated with RFID implementations identified in this thesis can also be used as a theoretical model for future implementation projects in the airlines.

6.1. Study limitation

Certain questions in the questionnaire were not clear enough and therefore may have caused confusions for the respondents. This could have affected the responses provided. However, in questions where possible confusions were suspected, the respondents were individually contacted for clarifications.

6.2. Future Research

A literature survey of RFID shows that about a third of all RFID research concentrates on RFID technology and in particular its components (i.e., tags, readers, and antennae). As the technology matures, there should be more attention being paid to less developed research areas, such as business and organizational applications. (Ngai et al., 2008).

That being said and considering the potential of RFID use in the airline industry, much research can be done as to how best to make use of this technology. Specifically, how can RFID be improved upon to address the current concerns over its utility. Future studies should also aim at studying the impact of RFID and advantages on the entire aviation supply chain from suppliers to OEMs to MROs to airlines which are the end users.

Further studies can also be done as case studies at the site of the airlines that are implementing RFID or have previously done so. Such research will focus on the use case of RFID and determine the areas of improvements needed in order to make the technology use more widespread.

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8. Appendix

8.1. Appendix 1: RFID Survey

ENGINEERING & MAINTENANCE
PAPERLESS AIRCRAFT OPERATIONS
RFID SURVEY 2013

Airline Name: ______ **Airline IATA Code:** ______

1	DOES YOUR AIRLINE CURRENTLY EMPLOY ANY RFID APPLICATIONS?	○ YES ○ NO
	IF YOUR ANSWER TO THE ABOVE QUESTION IS YES, PLEASE ANSWER QUESTIONS 2,3 AND 4. IF NOT, PLEASE MOVE TO QUESTION 5.	
2	DO YOUR CURRENT RFID ACTIVITIES INVOLVE RFID TAGS ON AIRCRAFT PARTS OR NON AIRCRAFT PARTS?	☐ FLYABLE (AIRCRAFT PARTS) ☐ LIFE VESTS ☐ OXYGEN MASKS ☐ OXYGEN GENERATORS ☐ SEAT COVERS ☐ OTHER ______ ☐ NON-FLYABLE (NON AIRCRAFT PARTS) ☐ TOOLS ☐ DOCUMENTS ☐ TRANSPORTATION ☐ GROUND SUPPORT EQUIPMENT ☐ CHEMICALS ☐ OTHER ______
3	WHAT IS THE APPROXIMATE % OF IMPROVEMENT IN TERMS OF PROCESS EFFICIENCY BEFORE AND AFTER RFID IMPLEMENTATION?	LABOR ___ % INSPECTION TIME ___ % TURN AROUND TIME ___ % SAVINGS ___ % OTHER ______ ___ %
4	WHAT IS THE APPROXIMATE SPLIT OF YOUR RFID ACTIVITIES BETWEEN AIRCRAFT PARTS AND NON AIRCRAFT PARTS? (THE SUM SHOULD BE 100%)	FLYABLE (AIRCRAFT PARTS) ___ % NON FLYABLE (NON AIRCRAFT) ___ %
5	IS YOUR AIRLINE GOING TO EMPLOY ANY RFID APPLICATIONS IN THE FUTURE?	○ YES ○ NO IF YES, PLEASE SPECIFY THE TIMELINE. ______
6	UPON RFID DEPLOYMENT, IN WHAT FUNCTIONS OF YOUR ORGANISATION, DO YOU EXPECT TO SEE EFFICIENCY IMPROVEMENTS?	☐ MAINTENANCE ☐ ENGINEERING ☐ SECURITY CHECKS ☐ PROCUREMENT ☐ INVENTORY ☐ TRANSPORTATION ☐ AIRCRAFT LEASING ☐ OTHER ______

7	**WHAT IS THE PRIORITY FOR THE NEXT GROUP OF PARTS THAT COULD POTENTIALLY BENEFIT FROM RFID TAGGING? PLEASE ALLOCATE NUMBERS TO YOUR PRIORITY SELECTION WITH 1 BEING THE HIGHEST PRIORITY.**	EXPENDABLES ☐ CONSUMABLES ☐ ROTABLES ☐ REPAIRABLES ☐ LLPs ☐ IFE SYSTEM ☐ CHEMICALS ☐ CABIN ☐ HARD TIME* ☐ OTHER ☐ PLEASE SPECIFY ☐ * HARD TIME: ITEMS WITH EXPIRY DATES
8	**REGARDING THE MAINTENANCE HISTORY OF THE RFID TAGGED PARTS, WHAT IS YOUR PREFERENCE?**	○ MAINTENANCE RECORDS TO BE STORED ON THE RFID TAG (HIGH MEMORY) ○ RFID TAG (LOW MEMORY) TO BE SERVED AS AN IDENTIFICATION TO LINK AND OBTAIN THE MAINTENANCE RECORDS FROM IT SYSTEM ○ OTHER ☐
9	**WHAT WOULD BE THE CRITERIA FOR POTENTIAL PARTS MARKING? PLEASE SELECT ALL THAT APPLY.**	☐ HIGH VALUE PARTS ☐ PARTS RELATED TO AIRCRAFT LEASE ☐ PARTS WITH LOW MTBUR* ☐ LIFE LIMITED PARTS ☐ NON SERIALIZED PARTS ☐ SERIALIZED PARTS ☐ CONFIGURATION DATA CAPTURE ☐ POOL COMPONENTS ☐ PARTS WITH REPEATING MAINTENANCE TASKS ☐ OTHER ☐ * MTBUR - MEAN TIME BETWEEN UNSCHEDULED REMOVALS
10	**DO YOU PREFER RFID TAGS TO BE INSTALLED AT DELIVERY OR BY THE AFTER MARKET?**	☐ INSTALLED AT DELIVERY ☐ BY AFTER MARKET, FOR SELECTED EXISTING AIRCRAFT PARTS: ☐
11	**PLEASE LIST ANY DATA ELEMENTS THAT YOU WOULD LIKE TO SEE ON AN RFID TAG? PLEASE SELECT ALL THAT APPLY.**	☐ ATA BIRTH RECORD (SERIAL NUMBER, PART NUMBER, ETC.) ☐ CURRENT OWNER / OPERATOR OF THE COMPONENT ☐ MOST RECENT AUTHORIZED RELEASE CERTIFICATE (FAA FORM 8130-3 / EASA FORM 1, OTHER) ☐ LATEST STATUS (MODIFICATION, SB STATUS) ☐ ALL MAINTENANCE RECORDS OF THE PART ☐ OTHER ☐
12	**WHY DO YOU THINK RFID TAGS HAVE NOT BEEN USED SO FAR IN COMMERCIAL AVIATION?**	☐ HIGH COST OF TAGS ☐ HIGH COST OF IT TO INTERFACE WITH AIRLINE ERP / MIS / IT SYSTEM ☐ LACK OF KNOWLEDGE OF RFID AND ITS POTENTIAL ☐ RFID TECHNOLOGY IS NOT MATURE ☐ NOT A PRIORITY FOR SENIOR MANAGEMENT ☐ TRIED RFID IN THE PAST AND HAD NEGATIVE EXPERIENCE ☐ AFRAID THAT DATA CAPTURED CAN BE USED AGAINST AIRLINE'S INTERESTS ☐ OTHER ☐
13	**WHAT WOULD BE YOUR APPROXIMATE EXPECTED RETURN?**	RETURN ON INVESTMENT ☐ % PAYBACK PERIOD ☐