PRODUCTION AND OPERATIONS MANAGEMENT
POMS
Vol. 16, No. 5, September-October 2007, pp. 554–568
ISSN 1059-1478 | 07 | 1605 | 554$1.25

Development of an RFID-based Traceability System: Experiences and Lessons Learned from an Aircraft Engineering Company

E. W. T. Ngai • T. C. E. Cheng • Kee-hung Lai •
P. Y. F. Chai • Y. S. Choi • R. K. Y. Sin
Department of Management and Marketing, The Hong Kong Polytechnic University,
Hung Hom, Kowloon, Hong Kong SAR, PR China
Department of Logistics, The Hong Kong Polytechnic University,
Hung Hom, Kowloon, Hong Kong SAR, PR China
mswtngai@polyu.edu.hk • lgtcheng@polyu.edu.hk • lgtmlai@polyu.edu.hk •
mschai@polyu.edu.hk • msstar@polyu.edu.hk • lgtryan@polyu.edu.hk

This paper presents a case study of the research and development of an RFID-based traceability system in an aircraft engineering company in Hong Kong. We report the system design and implementation, and discuss our experiences and lessons learned. The aim of the RFID system is to effectively support the tracking and tracing of aeroplane repairable items in the company. The study reveals eight critical success factors for the successful implementation of RFID systems, namely, create strong internal and external motivation for improvement, stir up desire to keep abreast of the latest technology for global competitiveness, strive for cross organizational implementation, avoid major process changes/limit process changes, start with a small RFID project scope, facilitate equipment vendor's investment, use cost-effectiveness reusable tags, and transfer RFID skills and knowledge from university to industry. We also summarize 13 lessons learned, including three lessons concerning RFID implementation at strategic level, six lessons at management level, and four lessons at operational level resulting from carrying out this project. Given the contextual details of the study, the lessons learned can help other firms to better anticipate the hurdles they will experience, and make them aware of the possible ways to cope with such difficulties before embarking on the journey of RFID implementation.

Key words: Radio Frequency Identification (RFID); traceability system; case study; critical success factors
Submissions and Acceptance: Received September 2005; revision accepted April 2006 and August 2006; accepted October 2006.

1. Introduction

Radio frequency identification (RFID) has been successfully used in transportation and manufacturing industries, and its use is growing rapidly as costs come down and benefits are recognized. Yet, there is paucity of academic studies that reveal the critical success factors of, and offers lessons learned from, successful real-life implementation of an RFID system. However, there are short cases in trade magazines, vendor leaflets, and white papers from RFID software and hardware vendors' websites, which are mainly journalistic and promotional in nature. This study seeks to fill this gap.

With the rapid development of RFID technology, academic researchers have become more interested in studying how RFID technology is developed and implemented in organizations. The broad adoption of RFID entails a large investment with significant risk and requires careful planning (Kulwiec 2005). Aiming to address the design and development issues of an RFID system, this paper provides technical details on how these two issues can be dealt with through the presentation of a real-life case study, offering a useful information source to researchers and practitioners with little technical background in RFID technology.

This paper describes the research and development of an RFID-based system that could effectively support the tracking and tracing of repairable items in an aircraft engineering company. The paper is organized as follows. In Section 2, we review previous studies on the application of RFID technology in different domains. In Section 3, we present our experience of actual implementation of an RFID-based traceability system in an aircraft engineering company in Hong Kong in the context of a case study. In Section 4, we summarize the lessons learned, and we reveal in Section 5, the critical success factors for the successful implementation of RFID systems. Finally, we give a detailed discussion of the main findings of this study, and we conclude the paper by proposing potential areas for further study.

2. Literature Review

There are only a few publications on the applications of RFID in academic journals. The following presents a brief review of the few studies that we have found in the research literature.

Ruff and Hession-Kunz (2001) described the application of RFID systems for reducing the number of collisions in metal/nonmetal mines. They reported on tests conducted on off-the-shelf RFID systems and the subsequent development of a custom RFID system that could be used for both surface and underground mining equipment. Karkkainen (2003) discussed the potential of using RFID technology for increasing the efficiency of a supply chain of products with short shelf-life. The paper focused on an RFID trial conducted at Sainsbury, and analyzed the potential impact of RFID on other supply chain participants. Kourouthanassis and Roussos (2003) described the design and implementation of a prototype system catering to consumers on the move by using a wirelessly connected cart with a display device and an RFID sensor that detects the objects placed in the cart. They presented the results and implications of the front-end and formative evaluation studies they had conducted of the second-generation pervasive retail system. Smith and Konsynski (2003) explored the applications and future commercial impacts of RFID technology. They summarized the ways in which organizations and academics are thinking about these technologies to stimulate strategic thinking about their possible uses and implications. Jones et al. (2004) examined some of the issues facing retailers in terms of the widespread use of RFID tags and the privacy concerns that are linked to data capture and data usage by retailers and third parties. Ni et al. (2004) presented LANDMARC, a location sensing prototype system that uses RFID technology for locating objects inside buildings. The major advantage of LANDMARC is that it improves the overall accuracy of locating objects by utilizing the concept of reference tags. Based on experimental analysis, they demonstrated that active RFID is a viable and cost-effective candidate for indoor location sensing. Prater and Frazier (2005) examined market drivers that are leading to RFID implementation in the grocery industry, and proposed a research framework that includes research using modeling techniques, RFID implementation, and the impact of RFID on daily operational issues. Ngai et al. (2007) presented the findings of a case study on the development of an RFID prototype system that is integrated with mobile commerce in a container depot. A system architecture capable of integrating mobile commerce and RFID applications was proposed. The case study illustrated the benefits, highlighted some of the most important problems and issues, and suggested directions of RFID applications in container depots. Smith (2005) reviewed the applied literature on RFID, as well as some documented practical experience of using RFID, and presented a basic model of viewpoints to understand the nature of the emerging RFID-based industry. The purpose of his paper was to provide management with a sense of importance of strategically leveraging the current and historic development of RFID in order to find inexpensive applications of Radio Frequency technologies in many areas. Song (2006) presented a model of the current tracking process to identify the potential economic benefits from using RFID technology in the automated tracking of pipe spools through a long supply chain of design, fabrication, interim processing, delivery, storage, installation, and inspection.

From the above literature review, it is observed that most of the RFID system research is primarily at the prototype stage. A ″real″ system investigation like the present study is necessary to demonstrate the successful design and development of an RFID system. Besides, we also reveal the critical success factors of successful implementation of an RFID system, and highlight the lessons we have learned from this case study. We believe that an important step towards advancing RFID knowledge requires proper understanding of the technology, and sharing of knowledge and lessons learned from implementing the technology in industry.

3. The Case Study

An in-depth case study of an RFID development project at an aircraft engineering company in Hong Kong was conducted to explore and identify the characteristics of an RFID-based traceability system. The case study presents a unique case providing details of the design and development of the RFID system. While the single case study has limited generalizability, it is useful at the initial stage of RFID system development. This case study, which allows a comprehensive examination of the RFID implementation exercise in a natural setting, and gives a full understanding of the nature and complexity of the phenomenon, is appropriate when few previous in-depth studies on RFID implementation have been carried out (Benbasat 1987).

The case study company provides comprehensive aeronautical engineering services to airlines and airline operators in Hong Kong. It also provides a comprehensive line of heavy aircraft maintenance services, including extensive aircraft component overhaul (COH) support, avionic overhaul (AOH) support, and aircraft on ground (AOG)/aircraft recovery services at the Hong Kong International Airport at Chek Lap Kok.

While both Airbus and Boeing are piloting the use of RFID technology for tagging parts and components of aircrafts (Violino 2004), the company is considering maximizing the efficiency of life-cycle asset management by tagging containers of repairable items, parts and components, of which maintenance is needed. With the operation of two airline maintenance centres [one located at the Hong Kong International Airport at Chek Lap Kok (CLK) and the other at Tseung Kwan O (TKO), a large reclamation area in Hong Kong], the company considers there is great potential of applying RFID technology for improving asset visibility in the maintenance cycle between these two maintenance centres. Through this case study, we illustrate how RFID can be used to improve the efficiency of the company's internal physical facilities.

The company relies on a traditional manual system and a partial bar code system (which scans the bar code on the paperwork that accompanies each part) to record the receipt and sending out of repairable items to the maintenance centers for repair and maintenance, which suffers from three major disadvantages:

- The problem of long maintenance cycle for the parts, especially those being repaired at TKO, where the parts are repaired in different workshops. Currently, there is no system to keep track of and trace the parts in the workshops, and how long the parts stay in each workshop.
- The monitoring and tracking systems are inadequate for the maintenance of repairable items, so management finds it difficult to keep track of the request process of maintenance.
- The inputting to the repair order (RO) record of the arrival of repairable items at the TKO centre may be delayed as it is done manually. There is no systematic way of recording item arrivals, and there is inefficient record handling of the items to be sent back to CLK.

3.1. Research Questions

A research question evidently arises from these disadvantages. Can IT be used to improve this situation? What kinds of technologies would be most appropriately employed to tackle the problems? With these questions in mind, we propose a solution to the existing manual and partial bar code system. The proposed solution takes the form of an RFID-based traceability system using passive ultrahigh frequency (UHF) technology. The passive UHF system enables repairable item parts to be tracked automatically as they are received, and as they move from CLK to TKO, and vice versa. The use of an RFID-based traceability system is motivated by the goals of increasing the internal efficiency of the maintenance centers, reducing the cost of receiving repairable parts, capturing records of repairable parts in the inventory databases with reduced errors, and improving the management of the inventory of expensive airplane repairable parts.

3.2. Research Objectives

This project aims at designing and developing an RFID-based traceability system for the repairable items in the company for its maintenance facilities at both CLK and TKO, with a view to reducing the maintenance cycle between CLK and TKO. Specifically, the project objectives are stated as follows:

- Enhance operational efficiency and asset visibility in the maintenance cycle between CLK and TKO;
- Enable the automatic verification of items to be transported (i.e., pallets will have the correct contents and will be loaded into the correct locations);
- Provide the company with a deeper insight into the potential of developing an RFID-based traceability system for repairable items, ensuring and illustrating that such a system is workable in the company environment before full-scale adoption;
- Keep the company abreast of the latest development of RFID technology, so as to make the company stay in the vanguard of the international comprehensive aeronautical engineering industry in terms of technology and innovation.

3.3. Case Analysis

In undertaking this project, the company aims at minimizing the delay and eliminating the occurrence of temporary items loss due to its inherent inability to track items in the maintenance life cycle. In order to achieve these purposes, asset visibility in the maintenance cycle has to be improved. There are two maintenance sites in Hong Kong, which are located at Chek Lap Kok (CLK) and Tseung Kwan O (TKO), respectively. The repairable items are transported from the CLK office to the TKO workshop, and then shipped back to the CLK office when the job is completed. The company has found that it is not easy to identify problems in the maintenance cycle with the existing system without RFID technology to keep track of where the parts are. With an RFID-based tracing system, locations of the parts are easily tracked, and hence, the repair status of the parts is instantly known and updated.

3.3.1. Highlights of Implementation of RFID-based Traceability System. The following provides the case analysis, which is organized chronologically according to the three main phases of RFID development that are commonly followed in traditional case studies (Dyer and Wilkins 1991). The three main phases are (1) project scoping and planning, (2) business process analysis, and (3) implementation.

3.3.1.1. Project Scoping and Planning. The tasks of this phase consist of the following facets: project scoping, problem definition, and forming a steering committee to guide the development effort.

Project Scoping and Problem Definition

A clear project scope and definition of the problem simplify the tasks significantly and help generate a productive program. From our initial field study and interviews with the management, we found that the existing problem in the company is the long maintenance cycle for the parts, especially those being repaired at TKO, where parts are repaired in different workshops. Most of the RO record handling is conducted manually, and the monitoring and tracking systems are inadequate for the maintenance of repairable items.

Forming a Steering Committee

Forming a steering committee as a decision-making body of an RFID project is an important step towards deployment. System development should involve representatives from each department in which the proposed system will be used. Since RFID system implementation will impact on operations, it is essential that the company engages the key players in operations. In this case, the RFID consultants from a local university, the management information system (MIS) team of the company, and operations staff were put together to drive the project. The company team was responsible for formulating user requirements for implementation, while the team of consultants was responsible for business process analysis, technology evaluation and selection, and the implementation of the RFID system. Appropriate management approvals were obtained from senior management and budget was secured to conduct the study.

3.3.1.2. Business Process Analysis

Conduct Business Process Evaluation

It is essential that the researchers understand the current business processes and how the new business processes related to RFID will work before they make any changes. This ensures that the company can safely change the operations environment. It is also crucial that all business processes are fully documented. In this case, in order to have a comprehensive understanding of the existing processes of the company's item repair business, the project team made several visits to the CLK and TKO sites. Inhouse information and documents were obtained, and the project team tried to identify the critical areas that have major impacts on business performance and offer opportunities for improvement.

Perform a Small-Scale Proof-of-Concept Testing

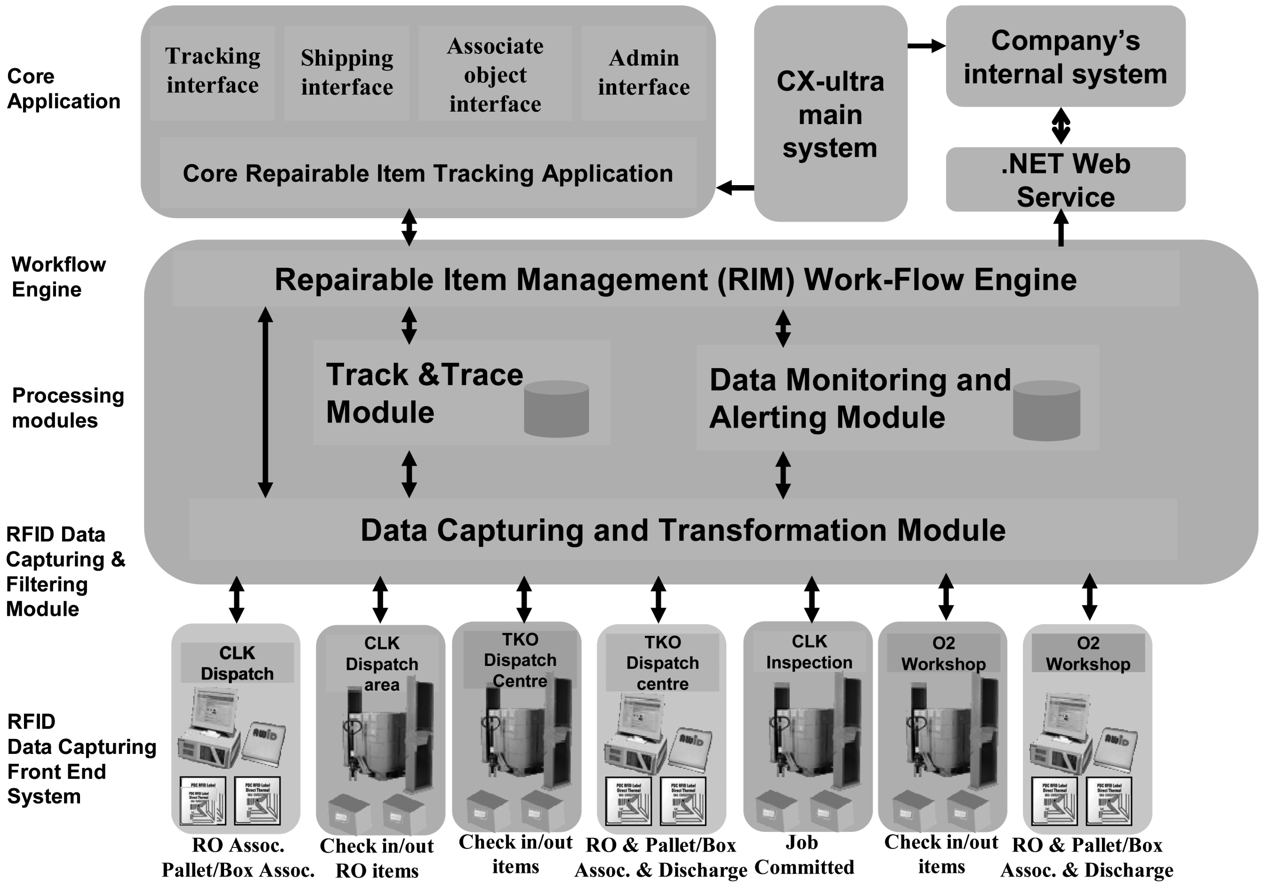
After understanding and documenting the business process, the next step before starting a trial is to perform some small-scale proof-of-concept testing. Before starting a trial, small-scale proof-of-concept testing was performed. In the testing, tagged boxes were loaded on the metal cage in a random manner as in real life. A temporary gate attaching several antennas in different orientations was set up. The metal cage was pushed to pass the gate and the read rate (the number of tags read per total number of tags attached on the RO items in each passage) was recorded. The angles of the antennas, the distance between the antennas, the speed of passing the gate, etc., were adjusted to obtain different sets of results. Some software prototypes were also developed and evaluated in proof-of-concept testing. The prototypes included the part of tag association and disassociation. The system would run on the .NET platform for windows, so all the program sources were coded in a .NET compatible language, mainly C#.NET. Microsoft Visual Studio .NET 2003 was used for the IDE, while configuration files were prepared in XML format.

3.3.1.3. Implementation. In this phase, software and hardware are acquired, developed, and tested. The materials of the items to be tagged were carefully studied, which are the containers for the repairable parts. For each read point, the desired read range, read reliability, and read redundancy were designed. There are two types of read points in the operation. One is for the association or disassociation of the tag with the tag data in the database system. The requirement of this type of read point is simple as it will read one tag at a time only, and the operator will interact with the reader directly via a system console. The read range is within 0.5 meter. As only one tag is read at a time, the read reliability need not be 100%, as any error can be corrected by the operator via the system console.

For the RFID gate door and tags, different readers and tags were evaluated and a Symbol's AR400 reader with high performance antennas and dual dipole tags were chosen, because this is the only combination that can archive a 100% read rate at the gate door with around 50 to 60 tags passing through at walking speed. As all the tags were preprinted and would be recycled, no printer was required.

As the operation involves two sites in different geographic locations, the middleware was also designed

Figure 1 System Architecture of the RFID-based Traceability System.



to be deployable at multiple sites and connected to the core application. Web Services was also used for integration with the company's internal systems. An import interface was also designed for the importation of RO data from Cathay Pacific (CX)'s ultra main system. Figure 1 presents the system architecture of an RFID-based traceability system.

The architectural framework of the RFID-based traceability system comprises five layers, namely RFID Data Capturing Front End System, RFID Data Capturing and Filtering Module, Processing Modules, Workflow Engine, and Core Application, which are necessary to ensure smooth operation of all the activities performed by the actors in the aircraft part items repairing process. Individual components of the system are illustrated as follows:

1. RFID Data Capturing Front End System. It is responsible for supporting the process of repairing aircrafts. There should be different data capturing front-end RFID systems to capture/update the necessary information, such as to/from the RFID tags stuck to the RO items/containers/pallets.

2. RFID Data Capturing and Filtering Module. This module serves as middleware between the Processing Modules and the RFID data capturing front end system. It provides synchronization of the data between the Processing Modules and the RFID Systems. The data include the timestamp, reader, and antenna identity (ID), etc. The major function of the middleware is to capture, filter, and accumulate RFID data from the RFID systems, write the data to RFID tags, and finally report the data to the Processing Modules. The capturing of real-time data could be achieved synchronously or asynchronously through different types of RFID readers.

3. Processing Modules. These modules capture filtered RFID data and provide general functions, such as the tracking and tracing of repair order (RO) items/pallets, which could be used by the aircraft items repairing process. In order to fulfill the data quality requirements of the aircraft items repairing workflow processes, data should be processed, packaged, and transformed into useful information according to some predefined rules. The Processing Modules include two submodules:

i. Track and Trace Module. This module could track and trace different RO items by obtaining real-time information such as in/out direction in the repairing processes.

ii. Data Monitoring and Alerting Module. This module provides real-time data monitoring features such as the idle time of items and the detection of abnormal repairing work flow procedures. If the module detects the occurrence of any mistake or error, it would generate an alert to the system for further action.

4. Workflow Engine. It provides the algorithm and repairing workflow logic based on existing business rules, supporting the processing modules. This also includes the .NET web service Application Interface (API) for integration with the company's internal systems.

5. Core Application. It provides four user interfaces for different business actors to use the system.

i. Associate object interface. It is for dispatch operators, dispatch riders, progress staff (CLK), progress staff (TKO), and inspection staff to associate/disassociate items/pallets/boxes with the tags.

ii. Shipping interface. It is for dispatch staff, dispatch operators, production staff, and AOH/COH/O2 staff to report the status of the items to the system.

iii. Tracking interface. It is for supply staff and all the company management level staff to trace the items' locations and analyze the data to identify process bottlenecks, support quality control, report process lead time, and estimate the lead times of similar processes, etc.

iv. Admin interface. It is for the MIS system administrator to monitor the status of the readers, preset alarm with email alert to the administrator, configure which read point is associated with which process, add and remove read points, etc.

4. Experiences for Sharing from Implementation

4.1. Technical and Deployment Issues and Concerns in Field Trial

Speed Effect

One of the challenges during the testing and tuning phase was that the cages/pallets passed through the gate door at different speeds. Sometimes, the operators would push the cages/pallets faster and sometimes slower, at their own pace. For the RFID system, the higher the speed at which the tag travels, the less the time power is available to each tag. If a tag cannot obtain enough power, it will not be able to send back signals to the reader's antennas. Therefore, the team had to measure the optimal speed for the cages/pallets.

Random Tag Direction

As the operators would put containers in the cages/pallets randomly, the direction of tags is uncontrollable. It is very difficult to tune the antennas' direction so that it can read tags of different orientations perfectly. In this case study, we designed a special tag on the container to alleviate the problem.

Multipath Effect

Multipath occurs when radio waves emitted from a single source take different routes (paths) to the same receiver. In such a case, interference of waves occurs and the waves are either "in phase", where constructive interference occurs resulting in performance enhancement, or "180 degrees out of phase", where destructive interference occurs resulting in a missed read opportunity. The multipath effect has a particularly significant impact on tags applied to metallic surfaces. Radio frequency is reflected at metallic surfaces creating a longer path relative to the signals that are not reflected by the product. Therefore, the team suggested having as few metallic materials as possible at points where readers were set up.

Form Factor of Tag

Size—For different applications, the requirements of the sizes of the tags will be different. In this case, the company does not mind using tags of larger sizes. Therefore, the team could design tags of larger sizes but with better performance even in a metallic environment.

Shape—In this study, the tags sealed with a hard plastic case are put in a plastic bag that would be attached to a container. Therefore, the shape of the tag has to fit the size of the plastic bag.

Protection—In some harsh environments, such as tagging of items in manufacturing plants, the tags are required to be protected by packaging them with plastic protection. In the case study, the tags are also protected by plastic casing to ensure that they would not be damaged during the transportation of the repairable items.

We observe from this case study that any RFID implementation effort is likely to be plagued by the following deployment issues.

1. Lack of Local RFID Expertise for Deployment

A recent survey by the Computing Technology Industry Association revealed that 80% of the responding companies said there are not sufficient numbers of skilled RFID professionals. Two-thirds of the companies said training and educating their employees on RFID technology is one of the biggest challenges they face in order to succeed in the RFID market (Morrison 2005). We believe that the problem is more serious in Asian countries. In Hong Kong, there is a lack of strong expertise in RFID technology deployment. Local large-scale deployments are usually made by foreign companies. It is difficult to find local experts in the RFID field with large-scale deployment experience. At present, only a few local universities offer short RFID courses. We hope that more local universities will offer expanded RFID and related curricula in the future.

2. Lack of Technology Support from Local Vendors
There is also a lack of local RFID solutions for deployment. At present, both RFID hardware and software in Asian markets are mainly from the U.S. Although RFID solutions are from foreign vendors with the support of local distributors, which provide limited technical assistance, as most of their staff are marketing oriented. We found that most RFID hardware providers in Asian markets lack technical support staff, and their RFID teams mainly consist of salesmen and marketing staff. This is due to the fact that RFID is an emerging technology in most Asian countries.

3. The Standard Problem
The RFID industry has been mainly using two different proposed standards. One is being developed by the International Organization for Standardization (ISO), widely used in Europe. The other is the Electronic Product Code (EPC) system, which is being commercialized by EPCglobal (GS1), a nonprofit organization set up by EAN International and the Uniform Code Council. The lack of global standards for RFID implementation is a deployment issue also. Although EPCglobal has defined the global standard for RFID, most of the standards are still not ready for deployment. For example, although the EPC generation-2 tag standard has been ratified, there is no such tag in the market at this time. On the software side, all the standards have not been ratified yet. In this case, we used Class-0 tags (read only; factory programmed), and readers that follow the EPC standard. However, for the software, the team had to design and develop customized software.

4. Hardware Performance
For most cases, the critical problem of RFID deployment is hardware performance. As the technology is not mature yet, it is difficult for users to guarantee that a tag can be read if multiple tags are read at the same time. The performance of hardware products in the market varies and a lot of efforts need to be devoted to hardware evaluation and testing. Also, the performance of RFID system varies in different environments. The solution is to tightly integrate the hardware equipment with the software system. The software system should be able to correct any problems due to unreliable data captured via RFID.

5. RFID Middleware
The middleware for most RFID systems in the market has not advanced and reached the stage of "plug-and-play", which means that initial adopters will have to expend considerable time and effort on integrating an RFID system with their existing business processes.

5. Critical Success Factors of Developing the RFID-based Traceability System

The successful implementation of RFID project at the aircraft engineering company depends on a set of critical success factors (CSFs). To avoid repeating familiar factors that have often been cited in traditional information systems development such as top management support, training, etc., we just present the most important and distinctive CSFs of the RFID system reported in this case. We categorize the CSFs into four dimensions, namely (1) high organizational motivation for improvement, (2) implementation process, (3) cost control, and (4) effective university-industry interaction.

1. High organizational motivation for improvement and competitiveness
This dimension comprises the following two CSFs:

- CSF1: Strong internal and external motivation for improvement

The project was initiated by the Material and Supply Department of the case company. The department has a high motivation to enhance operational efficiency and asset visibility in the maintenance cycle between CLK and TKO, and to enable the automatic verification of items to be transported between the two maintenance centers.

There are also requests from external customers to provide visibility in the maintenance process. It was difficult to meet customers' requests to update them on the status of their items in the maintenance process, as there was no automatic way to keep track of the status and locations of items. With the RFID technology becoming more mature, the customers are also suggesting the company to improve the visibility of the maintenance lifecycle using RFID technology.

- CSF2: Strong motivation to keep abreast of the latest technology for global competitiveness

Global competition has exerted tremendous pressure on the company to keep abreast of the latest developments in RFID technology to ensure that it keeps up with best practices in the aviation industry, e.g., Airbus, Boeing (Violino 2005), Virgin Atlantic Airways (Swedberg 2005), etc., are using RFID technology to track their inventory of airplane parts. The successful implementation of innovative ideas and technologies will keep the company at the forefront of technology and innovation adoption in the aviation industry, thus enabling it to continue to deliver superior value to its clients.

2. Implementation process efficiency
This dimension focuses on the implementation process of the RFID project. The CSFs are related to managing the RFID system, which can greatly contribute

to the success of implementation. We discuss the implementation issues as follows.

- CSF3: Cross organizational implementation

The implementation team for the RFID system consisted of three parties: the MIS team, the operation team, and the university's consulting team. The implementation was led by the consulting team with the company's management support. The consulting team first secured top management's buy-in for the RFID implementation. Afterwards, it was necessary to work with the staff from the MIS department. It was also necessary to ensure they understand that the new system would not be an overhead for the MIS team, and that it would benefit the company's operations. Initially, there was a lot of disagreement on system implementation issues because the RFID system might not be able to be integrated easily with the company's internal systems. The MIS team was also concerned about how they could maintain the system after the system is handed over upon successful implementation.

In order to solve the problems, the consulting team first arranged technical tutorials on RFID for the MIS team to ensure that they understand what RFID is. A meeting was then set up to discuss how the system should be implemented to ensure that it can be easily integrated with the company's internal systems. There were disagreements such as the software solution of the RFID system was not using the same programming language as that used by the company's internal systems. The consulting team then proposed the Service Oriented Architecture (SOA), which makes use of Web Services to interface with the company's internal systems. The consulting team also prepared some case studies that show that the SOA approach has been used by many enterprise systems to solve the integration problem.

The MIS team was also invited to get involved in the system design by defining which real-time data are to be obtained from the proposed RFID system to help in their data analysis process. Finally, all the major issues were resolved, and the university team prepared a detailed system architecture and functional specifications and presented them to the MIS team. Both teams agreed on the implementation approach to ensure that the implementation could be carried out smoothly.

For the operation team, it is relatively difficult to let the operation staff understand the technical details of RFID. Most of them do not understand what RFID is and how it can help the operation. Some operators deemed RFID as a tool for the company to monitor their daily jobs. Also they thought the new process flow may increase their workload, and thus were reluctant to accept changes in their business processes. To solve the problem, similar to the approach taken to handle the IT team, the consulting team first provided tutorials on RFID to the operation staff of the company.

- CSF4: Avoid major process changes/Limit process changes

Organizations, groups or individuals resist changes that they perceive may threaten them. It is best to avoid changes to existing business operations processes. In this case, given the automation of existing business operations, we tried to avoid making major changes or limit the changes to existing processes. Since RFID implementation is new to most of companies and their operation staff, and the case company is without exception, most of the operation staff were reluctant to accept the process changes suggested in our pilot study. Bearing this in mind in the implementation, we showed to the operation staff that there would be few or no formal changes to the processes, except that the small inevitable changes involved only a few new steps of adding/removing tags to/from the items/objects in the business operations processes.

3. Effective cost control

This project started with a limited budget as the management of the case company would like to limit the investment before seeing the actual benefits. This posed a great challenge to the research team as RFID implementation requires RFID equipment, software integration, and human resources to carry out the analysis of the business process study.

- CSF5: Start with a small RFID project scope

"Think globally, act locally". For RFID implementation, it is ideal to consider a company-level project and limit the implementation to no more than eight read points with one or two warehouses/maintenance centers. In order to show the real benefits from the project, the consulting team first worked with the operation team to limit the scope of the study by identifying the critical points at which the RFID read points can be added to reap the greatest benefits. By limiting the scope, the number of read points was reduced from around twenty to five only, excluding the process points inside the workshop. This was proposed as the scope of the first phase of the RFID implementation effort under way. We found that it is best to start work with a comprehensive straightforward RFID initiative, which will serve as the foundation for a widely deployed RFID network.

- CSF6: Equipment vendor's investment

Currently, RFID equipment is still very expensive. To further limit the cost outlay of the project, the consulting team identified an RFID equipment vendor and negotiated with it to get involved in the project. By letting the vendor understand the project background and the future plan for a large-scale deployment of the RFID system, the consulting team successfully persuaded the vendor to collaborate on the project by loaning RFID equipment to the case company on the

Table 1 The CSFs of RFID Implementation

CSFs	Dimensions	Details of CSF
CSF1	Strong organizational motivation	Strong internal and external need
CSF2		Keep abreast of the latest technology
CSF3	Implementation process efficiency	Cross-organizational implementation
CSF4		Avoid major process changes/Limit process changes
CSF5	Effective cost control	Start with a small RFID project scope
CSF6		Equipment vendor's investment
CSF7		Use of cost-effective reusable tags
CSF8	Effective university-industry interaction	RFID skills and knowledge transfer

understanding that the latter would consider buying the loaned equipment, and possibly other pertinent support facilities, after successful implementation of the system. The consulting team also requested the case company to provide spare servers and computer systems for the implementation. This greatly reduced the hardware cost required for the project.

- CSF7: Use of cost-effectiveness reusable tags

Item-level tagging is arguably the final hurdle of RFID deployment. From a practical standpoint, item-level tagging is fraught with challenges. Cost-effectiveness is one of the key issues. In this case, reusable tags were used for the RFID system, which achieved a 100% read rate at item level tagging. While reusable tags are generally more expensive than one-use tags, they are meant to be used for multiple times and so are less expensive per RFID read or event.

4. Effective university-industry interaction through undertaking collaborative research projects

Companies tend to employ independent consultants to lead them through projects on RFID deployment. This is typically because no one in the company has the requisite expertise in RFID technology and application experiences, while busy staff in the company cannot devote full-time effort to take care of the RFID initiatives. In this case, consultancy services were provided by a local university. Collaboration with the university consultants provides the case company with a cost-effective means to learn and pick up appropriate RFID technology that fits its purposes at a lower cost and with less inherent risk. A trustful relationship, i.e., the case company is confident that its partner, the university consultants, will perform as expected, is particularly crucial to the success of the project.

- CSF8: RFID skills and knowledge transfer

University-industry partnerships/collaboration represents an organizational form designed to integrate disparate pools of expertise and resources. In this project, we leveraged knowledge, learning and innovation in forming university-industry partnerships from different research fields such as electronic engineering, logistics management, and IT. University-industry collaboration also provides a way to transfer skills, knowledge and technologies to a greater breadth and depth than would normally be possible through internal development. For universities, the benefits include private funding support for research as a result of technology transfer activities (Barnes 2002). The collaboration was managed effectively and maximum benefits were achieved upon the successful implementation of the traceability system in the company with the corresponding smooth transfer of RFID knowledge and skills from the university to the company. With the research team's expertise and experience in RFID implementation, strong trust was built between the company and university teams.

Based on the above discussions of CSFs of developing RFID systems, we summarize all the CSFs in Table 1.

6. Some Lessons Learned

RFID is an enabling technology, as illustrated in this case study, that a company can adopt to enhance asset visibility and improve operations, like improving receiving and picking accuracies, and reducing human errors in handling repairable items by automation. There are several lessons that can be learned from the findings of the successful implementation of the RFID-based traceability system in our case study company. Table 2 provides a summary of the "lessons learned" at strategic, management, and operational levels. The lessons learned (LL) from carrying out this project are elaborated in the following:

Strategic Considerations

Three lessons concern RFID implementation at strategic level:

- LL1: *Identify the advantages and return on investment (ROI)*

Advantages and ROI should be identified first. Many companies are at a wait-and-see stage and are moving cautiously towards RFID adoption due to the absence of clear first-mover advantages and the complexity of the technology. We suggest that companies analyze potential applications with respect to the main criteria of creating potential added value to business and the degree of difficulty to cope with. For this project, we see that the reported RFID-traceability system yielded

Table 2 Some "Lessons Learned" at Strategic, Management, and Operational Levels

Lessons Learned (LL)	Considerations	Details of lessons learned
LL1	Strategic Level	Identify the advantages and return on investment (ROI)
LL2		Determine the business value and the scope
LL3		Choose the right partners
LL4	Management Level	Secure top management support
LL5		Understand the top management requirements and needs
LL6		Get managers know that RFID is not a magical technology
LL7		Obtain management and user commitment and understanding on the RFID system
LL8		Adapt of the top-down approach
LL9		Leverage available knowledge and experience
LL10	Operational Level	Perform a small-scale proof-of-concept testing
LL11		Carry out tags performance evaluation
LL12		Use standard hardware and software system and appropriate standard
LL13		Examine radio frequency reflecting and absorbing materials

a number of advantages, which provided strong incentives for implementation. The advantages of the RFID-based traceability system can be found in the Section 7.

An RFID system initiative takes time, financial resources, and commitment. The roll out of the applications and the scale up of the RFID network are usually based on a target ROI or key business metric related to advantages and impact. To identify the advantages and ROI, we suggest users to identify high value assets and tools in their operations. Savings from inventory reduction and better tools utilization among multiple departments can be huge for high value assets and tools. For this project, most of the items tagged are of high values, and thus, it is not difficult for the implementation to have a positive ROI. It is also suggested that users pay attention to the labor cost savings and operation lead time reduction. RFID can help streamline manufacturing and supply chain operations, thus reducing labour cost and operation lead time. On the other hand, it is also important to identify the tag cost and reader cost, which are key drivers in ROI analysis. The cost of tag can be one of the largest costs for an RFID implementation. Therefore, if the tags are reusable, the cost can be greatly reduced. There are also some advantages that may not directly contribute to ROI and may not be applicable to all industries. For example, RFID may help facilitate regulatory compliance or may help in threat detection of a company's operations.

- LL2: *Determine the business value and the scope*

Any implementation effort should be driven by business values. A clear business rationale for deploying RFID technology is essential. Identifying the business problem is a critical step in RFID project deployment. The project team should identify the business units and processes for inclusion in the business case for RFID implementation. In our case study, the objectives were to improve efficiency of the maintenance operations and shorten the maintenance life cycle by identifying potential bottlenecks in operations, and confining the scope of the study to the two maintenance centres at TKO and CLK. The best way is to start with a small scope because the lessons learned from the success of a small project can be easily transferred to a company-wide RFID implementation project. The business case must reflect current practices and realize operational realities. For example, in this case, rotating cages with RFID tagged pallets were eventually abandoned by management as they would adversely affect operation flows.

- LL3: *Choose the right partners*

Another key lesson learned is that the project partner for RFID implementation should be chosen based on their actual experience and proven capabilities. As RFID is a relatively new technology with a promising future, many companies try to launch new services or products that are related to RFID. However, these companies may neither have the actual experience of RFID implementation nor industry specific knowledge. As various RFID frequencies and standards are available in the market, it is anticipated that the partner/vendor can support multiple RFID frequencies and standards. In this case study, the university consultancy team has strong expertise in IT project management, transportation logistics, as well as RFID technology. In addition, leveraging of the hardware partner's expertise in radio frequency engineering also contributed to the success of the RFID project.

Management Considerations

The way in which the process of developing and implementing an RFID system is managed can greatly influence the success of system implementation. The followings are some lessons based on management considerations learned from this case study.

- LL4: *Secure top management support*

Secure top management support is essential. Like any other projects, top management support is a must for success. Obtaining management and executive support is the first step towards success as management's commitments of time, personnel and resources are key to any project's success. It is critical that management has confidence in the implementation, because they are the ones who make the final decisions. In this case, both the company and system solutions provider were committed to applying an innovative technology to improve the company's operational efficiency. From our case study, we also found that with top management taking the initiative to embark on a project, the likelihood of project success significantly increases.

In order to secure management support, it is suggested an RFID needs assessment be performed by a multifunctional RFID team comprising representatives from different departments such as operations, IT, distribution, etc. Having the team review the "pain points" that RFID may help solve, then present the RFID initiative to senior management with concrete objectives and milestones of the project, senior management would have a clear picture of how RFID can bring value to the company and provide strong support in seeing that the project is worth investing.

- LL5: *Understand top management's requirements and needs*

It is essential to understand top management's requirements and needs. Sometimes the organizational background of a company will influence management's expectation of the results from field trials. In this project, the case company is one with a strong engineering background, and management expects more scientific justifications, sufficient data support, and in-depth explanations on both practical and theoretical aspects in field trials to fulfill their expectations. It seems that management will be more ready to buy in when they are provided with more objective data and facts to support and justify the proposal of organization-wide RFID implementation.

- LL6: *Get managers know that RFID is not a magical technology*

It is necessary to let line, unit managers, and senior managers know that RFID is not a magical technology that makes everything happen automatically once tags and readers are installed. Overexpectations can lead to disappointment of the managers, especially in initial applications. It is important to convince management of the difficulty in achieving a 100% read rate at the item level. If people expect quick, large savings from RFID technology but do not get them, they will withdraw their support for such ventures. The same problem can also be found on the user side. In this project, the company staff all expected that there should be 100% accuracy in reading RFID tags, which sometimes is not feasible in practice. A lot of efforts were expended on explaining the technology and educating the users. Executive level training on RFID concepts, best practices, and case studies should be provided to managers. This ensures that managers will not overestimate the benefits of RFID system. Besides, management should understand that the RFID system can provide visibility to business processes. However, such visibility can only identify potential problems in the processes. Further studies are required to come up with solutions for the identified problems

- LL7: *Get management and user commitments and understanding of the RFID system*

Sometimes the organizational culture of a company may be so hostile to innovations that it makes it difficult to introduce RFID technology. If the attitudes of organizational members are poor towards attempts to introduce RFID technology, then introducing new RFID technology will be more difficult. In this case, we had to gain management and user commitments to the project during the stages of development and installation to ensure that everyone understand the problems the system was designed for addressing, and that the system was developed to solve the target problems, and know the benefits of the system.

- LL8: *Adaptation of the top–down approach*

The RFID-based traceability system reveals and makes things transparent in workflow processes. In the case study, the RFID implementation ensured clear responsibilities among different departments involved in the operation. When an item is lost, it is much easier to track which department would be responsible for the delay or loss. As responsibilities became much clearer, some operations staff were reluctant to change as the entire process could be easily monitored. They may foresee more control and more accountability. Therefore, a top–down approach must be used to enforce the changes.

- LL9: *Leverage available knowledge and experience*

The implementation team should also leverage available knowledge and experience to minimize trials-and-errors. In this case, the company team leveraged the RFID expertise of the consultants from a local university in RFID implementation, including the design and development of the RFID system, and conducting antenna patterning tests, and reader performance tests. The hardware vendor's scientific knowledge was too leveraged with respect to performing the tag characterization tests and the reader's RF safety tests.

Operational Considerations

The next four lessons concern RFID implementation at operational level. Based on the case study, these lessons help facilitate carrying out the RFID implementation.

- LL10: *Perform small-scale proof-of-concept testing*

Before starting a trial, small-scale proof-of-concept testing should be performed. It is also important that the system be tested in environments that are similar to the real operational environment. In this case, the team used the cages, containers, and items that are actually used in the production environment for testing. However, it was not possible to perform the tests at the defined read points. Therefore, the team carried out a thorough site survey, replicated the environment, clearly defined the necessary test data, and meticulously recorded all the test data. Deploy testing covered things like profiling radio frequency interrogation zones out of various antennas. Application testing included understanding reader configurations for a dock door.

To perform small-scale proof-of-concept testing, it is suggested that the implementation team first identify the critical path in the RFID implementation. For example, if a 100% item level read rate is the critical, the proof-of-concept should focus on it and ensure the goals are achievable with comprehensive testing. For most of the cases, it is necessary to include two read points for the proof-of-concept testing with a simple track and trace.

- LL11: *Carry out tags performance evaluation*

It is necessary to determine the variability of tag types and evaluate the RFID tags at key points before the tags are used in operation. Although RFID technology is becoming mature, there is still the possibility that some of the RFID tags are with defects or damaged during operation. In this case, tags were evaluated when tags were associated and disassociated with repairable items, at the start and end points of the operation. In addition, the vendor should be willing to sign off on the accuracy of tag testing.

To perform tag evaluation, it is suggested different brands of tags with different protocols, form factors and features be tested. The testing environment should be free from interference. Different readers should be used to test the tags. It is also necessary to find out the percentage of dead tags so that you can estimate what percentage of dead tags exists during deployment.

- LL12: *Use of standard hardware and software systems and appropriate standards*

The project team implemented the system based on global standards and best practices. If a proprietary system is used, it may not be possible to use the RFID equipment developed by different vendors in the same system. This approach can drive down the total cost of the system, and ensure scalability and extensibility for future expansion. For different industries and applications, different standards could be used. For example, for supply chain applications, it is recommended that the EPC standard be used as it is an accepted standard for product identification around the world, and it can uniquely identify each item in a supply chain.

- LL13: *Examine radio frequency reflecting and absorbing materials*

Both metallic items and liquid material items affect the performance of an RFID system. Metallic items are the most likely to be radio frequency reflecting while liquid material items like water, liquid, and others, are radio frequency absorbing. In this case study, the greatest technical challenge was the metallic environment, as some of the containers carrying airplane repairable parts are made of metal. It was very difficult to achieve a 100% read rate, even in the controlled test environment. It is understandable that UHF with a shorter wavelength has a worse effect of diffraction compared with High Frequency (HF). Therefore, it is very difficult to read tags attached to containers that are put in cages or on pallets in random positions. In the case environment, many of the repairable items contained conductive materials. The items were put in containers that may also be partially metallic. The cages that contained the containers and the forklift that carried the pallets were also metallic. However, it does not necessarily mean that it is impossible to apply RFID for such an environment. With a special customized tag design and repeatable testing of angle adjustments in the operation, and the help of a customized work flow system, this problem was solved.

In order to examine radio frequency reflecting and absorbing materials, it is suggested that the environment that will cause interference of RF signals be identified. Some examples of causes of interference include conveyor belts, wireless LAN, electronic motors, etc. The composition of the items to be tagged has to be examined as well. It is also necessary to examine the environment at different time in different weather conditions as the RFID equipment's performance may deteriorate with high humidity. With these factors examined, you may determine whether an array of readers and antennas would be needed for the particular environment under investigation.

7. Conclusions and Further Study

This paper described the research and development of an RFID-based system that could effectively support the tracking and tracing of repairable items in an aircraft engineering company, and discussed their benefits and advantages. Hopefully, the experience and lessons learned from this study can be shared with the reader, and they will be beneficial to organizations that are contemplating the implementation of RFID systems, and to those that are in the throes of adopting them.

There exists a need for research on RFID development for business and industry. With the rapid development and increased deployment of RFID technology, academic researchers have become more interested in engaging in scholarly investigations of how RFID technology is developed and implemented in organizations. At present, users need to be working with RFID solution or middleware providers that have direct experience of customer applications. It is very difficult to find some robust RFID case studies that are publicly available in academic journals or privately. The need for RFID academic research was highlighted as a research agenda in Ngai et al. (2007). This area of research is relatively underexplored and may be fruitful for further research on the adoption, implementation and deployment of RFID systems in organizations.

Since RFID technology is still relatively new and the complete range of its potential is not yet fully known, it is important to examine its proposed and speculative uses. Since the development of such a passive UHF system can require significant resources, it is important to understand the benefits up-front and to solidify the quantification of these benefits (Lee and Özer 2007) before embarking on implementation. At present, the RFID-based traceability system reported in this study has yielded a number of advantages as follows:

1. Improving lead time

By applying RFID technology in the maintenance cycle, the company could keep track of the status of each repair order. In case an item is delayed due to scheduling, an alert will be sent, and immediate action can be taken to correct the problem. The system can also help identify bottlenecks in the maintenance cycle so that management can focus on solving problems instead of finding problems.

2. Competitive differentiation

The company can gain a competitive advantage over its competitors by offering customers timely information about an item, including its status, estimated job completion time, etc.

3. Saving from reusing RFID tags

In the RFID system, RFID tags are associated and disassociated with the repair order for the maintenance cycle of each item. This allows the tags to be reused. As the cost of RFID tag is still high nowadays, this can reduce the running cost of the RFID system.

4. Breakthrough productivity by automation

It can automate in/out registration of repairable items. The RFID system provides the operators with a means to keep track of the status of all the repair orders. They will also be warned if there is any abnormality. Management can also receive status reports in a customized format automatically. This results in improved productivity of the maintenance operation.

5. Reduce human errors in handling the repairable parts

As all the repair order related information is tracked by the RFID system, the system would stop operators from shipping wrong items between the two sites by giving warnings at each RFID check point. This could reduce human errors in picking and sending wrong items, as well as any unauthorized use of them.

6. Improve inventory management of the expensive repairable parts

As the RFID system provides improved visibility of each item within the two sites, the inventory level and the location of expensive parts can be tracked. This saves the time needed to look for replacement parts. With further improvement in the RFID system, the shipping and maintenance schedules can be planned automatically. This allows better utilization of replacement parts in the maintenance site, thus reducing the inventory level of the parts.

7. Reduce manpower and manual data recording

Unlike bar code and other manual data capture systems, RFID can capture data automatically without human intervention. This reduces the manpower needed and human errors during the data capturing process.

8. Real time monitoring and access to detailed information

The RFID system also provides real time information on each item in the maintenance cycle. Detailed information such as the full history of an item can be tracked in the system. Such information can be further analyzed for the improvement of the maintenance operation.

9. Reduction of repairable parts loss

Temporary loss of items sometimes occurs in the maintenance operation. With the RFID system, where an item has been sent is tracked, if an item is lost, the operators can immediately identify the last point where the RFID system tracked the item. With this information, chances of losing an item can be reduced.

10. Improve customer relationships

With the RFID system and by opening the tracing application to customers, detailed information on repairing schedules, repairing status, etc. can be tracked by customers. Such customer services can improve customer relationships and attract more new customers.

Although RFID technology is a promising technology, it is not without challenges in system implementation. The extent to which information systems researchers and operations management researchers collaborate with other disciplines will provide a deeper and more meaningful stream of interdisciplinary research in the context of RFID technology. From this study, we propose that further research focus on the following areas:

- *Integration with internal systems*

The integration RFID with a company's internal systems is challenging. In this case study, the RFID system was developed as a separate system, which would need to integrate with existing systems. Integration is likely to bring about changes to both the RFID system and the existing legacy system. In order to minimize changes to existing systems, a Web services interface for the retrieval of RFID captured data was proposed as a solution. A Web Service Definition Language file was defined for the generation of both Web services server and client server. Software codes were then generated and passed to existing internal systems for integration. Currently, the RFID system provides interface for the company's internal systems to obtain data from the RFID system. However, we still have not studied how these data can be used within the company's internal systems. Further study with the company's MIS team would be required so that the company can make further use of the RFID data to enhance its internal operations.

- *Extending the RFID system to the supply chain partners*

The maintenance of the repairable items requires collaboration with their partners, e.g., airlines, and could eventually be rolled out across the supply chain. Extending the RFID-based system by sharing tracking information with the company's supply chain partners would achieve better customer services as reports based on consolidated tracking data could be provided.

- *Development of analytical models to measure the impact*

It is desirable to develop analytical models to measure the impact of RFID technology on the value (Gaukler et al. 2007) and productivity for system development. A better understanding of the RFID system's impact on the enterprise after its roll out is essential, in particular when considering scaling up the RFID network.

- *Sustainability of the RFID system*

The sustainability of an RFID system during the postimplementation period needs looking into, too. There is a lack of a clear understanding of the strategic needs and requirements for sustaining the effectiveness of large-scale information systems after a period of relative stability following initial implementation. Sustainability management of RFID is therefore a very important research direction that needs to be explored to maximize the benefits of an RFID investment.

- *Analysis of the data captured using data mining*

After the system is deployed, we can start analyzing the data captured from the RFID system. Currently, we can only identify when and where bottlenecks occur in the maintenance cycle. However, the causes of the bottlenecks will need further careful investigations. Further process studies can be carried out after analyzing the captured data to find out the root causes of the problems.

- *Standardization in aviation industry*

As RFID is becoming mature, aircraft manufacturers may add RFID tags to parts of the system. In order to allow the whole industry to make use of RFID tags, standards need to be defined. Further studies on how the existing RFID system can be migrated to follow and make use of industry standards is needed to ensure that the company can leverage the benefits from industry standards and best practices. Recently, the U.S. Federal Aviation Administration approved the use of RFID tags on individual airline parts (Roberti 2005).

Understanding the critical success factors, and sharing the experiences and lessons learned from this case will enable managers to be more proactive and better prepared for RFID system implementation. The experience obtained from this project can be further analyzed and generalized for RFID adoption in other maintenance facilities such as automobiles, ships, railways, etc. There should be similarities in maintenance facilities in other industries. Other maintenance facilities will also encounter the problems of being unable to identify bottlenecks in their maintenance cycles. Although our research was only for a specific company, there is nothing unique about the environment of the case study, and thus this approach could be generalized to any company. We believe that management should be ready to understand all the potential impacts of RFID technology. It may come sooner than most of us think it would. Managers should plan the introduction of this emerging technology after analyzing their potential impacts. We believe RFID technology can change our world. Let us be ready to make the best of it.

Acknowledgments

We are grateful for the constructive comments of the guest editors and the senior editor. This research was supported in part by The Hong Kong Polytechnic University under a research grant from the Area of Strategic Development in China Business Services, "IT for Logistics Management in China (Grant Number A632)". We appreciate the ina Elite Technology Co. Ltd.), for their support. Thanks are also due to all the personnel from different departments of the aircraft engineering company for providing details of the business workflows for the repairing parts, expressing their requirements for the traceability system, and offering expert opinions on generating specific reference data, and those that are currently acting as gatekeepers in the system.

References

Alter, S. 2003. 18 reasons why IT-reliant work systems should replace "the IT artifact" as the core subject matter of the IS field. *Communications of the Association for Information Systems* **12**(23) 366–95.

Benbasat, I., D. K. Goldstein, M. Mead. 1987. The case research strategy in studies of information systems. *MIS Quarterly* **11**(3) 369–386.

Curtin, J., R. J. Kauffman, F. J. Riggins. 2005. *Making the 'Most' out of RFID technology: A research agenda for the study of the adoption, use and impacts of RFID.* Working Paper, MIS Research Center, Carlson School of Management, University of Minnesota, Minneapolis, Minnesota, February.

Dyer, W. G., A. L. Wilkins. 1991. Better stories, not better constructs, to generate better theory. *Academic of Management Journal* **16**(3) 513–619.

Fao, A., A. Gershman. 2002. The future of business services in the age of ubiquitous computing. *Communications of the ACM* **45**(12) 83–87.

Finkenzeller, K. 2003. *RFID Handbook Radio-Frequency Identification Fundamentals and Applications.* John Wiley & Sons, Ltd., England.

Gaukler, G. M., R. W. Seifert, W. H. Hausman. 2007. Item-level RFID in the retail supply chain. *Production and Operations Management* **16**(1) 65–76.

Handfield, R. B., E. L. Nichols. 2003. *Introduction to supply-chain management.* Prentice Hall, Englewood Cliffs, New Jersey.

Hertz, D. B., H. Thomas. 1983. *Risk analysis and its applications.* John Wiley, United Kingdom.

Jones, P., C. Clarke-Hill, P. Shears, D. Comfort, D. Hillier. 2004. Radio frequency identification in the UK: Opportunities and challenges. *International Journal of Retail & Distribution Management* **32**(3) 164–171.

Juttner, U., H. Peck, M. Christopher. 2003. Supply chain risk management: Outlining an agenda for future research. *International Journal of Logistics: Research and Applications* **6**(4) 197–210.

Karkkainen, M. 2003. Increasing efficiency in the supply chain for short life goods using RFID tagging. *International Journal of Retail and Distribution Management* **31**(10) 529–536.

Kourouthanassis, P., G. Roussos. 2003. Developing consumer-friendly pervasive retail systems. *IEEE Pervasive Computing* **2**(2) 32–39.

Kumar, R. 2002. Managing risks in IT projects: An options perspective. *Information & Management* **40**(1) 63–74.

Kulwiec, R. 2005. AIDC status review—After the RFID explosion. *MHOVE* **6**(2) 1–3.

Levy, J. B., E. Yoon. 1995. Modelling global market entry decision by fuzzy logic with an application to country risk assessment. *European Journal of Operational Research* **82**(1) 53–78.

Lee, H., Ö. Özer. 2007. Unlocking the value of RFID. *Production and Operations Management* **16**(1) 40–64.

Morrison, J. 2005. Help wanted. *RFID Journal,* March/April, 13–20.

Ngai, E. W. T., T. C. E. Cheng, S. Au, K. H. Lai. 2007. Mobile commerce integrated with RFID technology in a container depot. *Decision Support Systems* **43**(1) 62–76.

Ni, L. M., Y. Liu, Y. C. Lau, A. P. Patil. 2004. LANDMARC: Indoor locating sensing using active RFID. *Wireless Networks* **10**(6) 701–710.

Prater, E., G. Grazier. 2005. Future impacts of RFID on e-supply chains in grocery retailing. *Supply Chain Management: An International Journal* **10**(2) 134–142.

Roberti, M. 2005. FAA to publish passive RFID policy. *RFID Journal*, Newsletter, June.

Ruff, T. M., D. Hession-Kunz. 2001. Application of radio-frequency identification systems to collision avoidance in metal/nonmetal mines. *IEEE Transactions on Industry Applications* **37**(1) 112–116.

Smith, H., B. Konsynski. 2003. Developments in practice X: RFID—An Internet for physical objects. *Communications of the Association for Information Systems* **12**(19) 301–311.

Smith, A. 2005. Exploring radio frequency identification technology and its impact on business systems. *Information Management & Computer Security* **13**(1) 16–28.

Song, J., C. T. Haas, C. Caldas, E. Ergen, B. Akinci. 2006. Automating the task of tracking the delivery and receipt of fabricated pipe spools in industrial projects. *Automation in Construction* **15**(2) 166–177.

Stanford, V. 2003. Pervasive computing goes the last hundred feet with RFID systems. *IEEE Pervasive Computing* **2**(2) 9–14.

Swedberg, C. 2005. Virgin use RFID for plane parts. *RFID Journal*, Newsletter, August, 16.

Violino, B. 2004. RFID takes wing. *RFID Journal*, October, 13–17.