Design of RFID-enabled Aircraft Reverse Logistics Network Simulation

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Abstract

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The reverse logistics (RL) of aircrafts pose a big challenge to its owners due to the complexity of its RL network, and the inherit problems of realizing a reliable system for efficiently monitoring and tracking the numerous parts of end-of-life (EOL) aircrafts in the RL network. Radio frequency identification (RFID) technology, through its automatic and wireless data capture capability, offers great potential for counteracting this problem. Although widespread and cost-effective, traditional barcode system, unlike RFID technology, requires manual scanning and line-of-sight for its use.

In this research, thorough review of literature was conducted to identify the technological and economical impacts of RFID technology in both forward and RL network, and the knowledge acquired was employed to develop a scenario based approach for determining suitable RFID solutions for use in different sections of the EOL aircraft RL network. Process maps for case-level barcode tagging, item-level RFID tagging, case-level RFID tagging and pallet-level RFID tagging in EOL aircraft RL were developed and simulated in Arena simulation software in order to comparatively analyze the Return-On-Investment (ROI) of the different RFID technology levels.

The results of our research, focusing on passive RFID technology, demonstrate that use of RFID technology in EOL aircraft RL network offers great potential compared to barcode system; however, the high initial investment cost of RFID technology deployment may necessitate proper planning, such as business process re-engineering (BPR), tag reuse and phased implementation, to achieve more positive ROI.

Keywords: Reverse logistics, EOL aircrafts, Radio Frequency Identification (RFID), Simulation model, ROI.

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I thank all my friends and colleagues for their wonderful companies, and for the exciting and inspiring times we shared together.

Thank you.

Dedication

I dedicate this work to all creative minds, working for peace, progress and prosperities.

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List of Acronyms

Acronyms	**Meanings**
AP	Aircraft Part
COO	Cost of Ownership
CPM	Construction Project Management
EOL	End-of-Life
EOQ	Economic Order Quantity
EPC	Electronic Product Code
FCM	Fuzzy Cognitive Map
FFA	Federal Aviation Administration
FFE	Furniture, Fittings and Equipment
FL	Forward Logistics
FMCG	Fast-Moving Consumer Goods
IMS	Information Management Systems
GA	Genetic Algorithm
IC	Integrated Circuit
IRR	Internal Rate of Return
IT	Information Technology
IS	Information System
MIP	Mixed Integer Programming
MRO	Maintenance, Repair, and Overhaul
RF	Radio Frequency
NPV	Net Present Value
RFID	Radio Frequency Identification
RL	Reverse Logistics
ROI	Return-on-Investment
SCOR	Supply Chain Operational Reference
SMEs	Small and Medium Enterprises
SCM	Supply Chain Management
VMI	Vendor Managed Inventory

Chapter 1:

Introduction

1.1 Background

“Reverse Logistics (RL) is the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal” (Rogers and Tibben-Lembke, 1998). Recapturing of values, in this sense, refers to the reuse, remanufacturing, or recycling of RL goods or materials. RL goods are considered reused if they can be re-employed in the forward supply chain without need for repair or refurbishment, and as remanufactured if they need to be repaired or refurbished before they can be re-employed in the forward supply chain. Recycling involves transforming RL goods to raw materials that can be used in new product manufacturing.

In the past few years, industrial trends and research directions have revealed renewed and invigorated interests in RL. These interests are spurred by the rising global awareness on environmental protection, which has resulted in the enactment of diverse environmental protection laws by Governments as well as influx of investments aimed at mitigating the impact of environmental pollution and greenhouse effect. For instance, the European Union, in year 2000, conferred on member states the mandate “to ensure that economic operators in their respective states develop systems for collection, treatment and recovery of EOL vehicles" (EU Directive 2000/53/EC). Also, the Federal and Quebec Governments of Canada, recently, created funds for researches aimed at exploring and devising procedures for dismantling, parting out and recycling materials of old aircraft (The Guardian, New aerospace centre to study recycling aircraft parts opens near Montreal, 2011).

When compared to forward logistics (FL), RL presents more complicated network due to the uncertainties inherent in product returns, complex nature of re-processing, and high implementation costs of RL systems. Hence, optimization of RL systems (e.g. collection-points maximization and cost minimization), and development of efficient information management systems (IMS) are widely researched in literatures. For instance, a recovery model for Small and Medium Enterprises (SMEs) that minimized fixed setup cost for facilities and recovery costs for processes, and a Mixed Integer Programming (MIP) model that solved the location problem of disassembly, collection and distribution facility, aside providing optimal values of production and transportation quantities of manufactured and remanufactured products, have been proposed by Swarnkar and Harding (2009), and Demirel and Gökçen (2008), respectively. Regarding the development of efficient IMS for RL system, research studies covering Radio Frequency Identification technology as state-of-the-art IT solution approach appeared frequently in literature.

"RFID is an automatic identification and data-capture technology that uses radio waves to provide real-time communication with objects at a distance, without contact or direct line of sight" (Sarac *et al*., 2008). Mathematical models, case studies and pilot projects, and simulation models have been employed by researchers to demonstrate the potentials of different RFID implementations (e.g. type of tags, tagging-level) in supply chains.

1.2 Problem statement

EOL aircrafts are made of several parts that can be classified in terms of material composition (metal, glass, synthetic), functions (e.g. mechanical, electronic, and furniture and fittings), RL states (e.g. reusable, recyclable, and disposable), grades (e.g. grade A and grade B) and so on. In order to achieve sustainability, there is need for a well-researched technological system for tracking and monitoring parts of EOL aircrafts in RL network, and a generally approved method for justifying investment in such system.

1.3 Objectives

The objectives of the research are to:

a) Develop a scenario based approach for determining suitable RFID solutions for use in different parts of the EOL aircraft RL network.
b) Develop simulation models for analyzing the ROI of selected RFID technology implementations in EOL aircraft RL network.
c) Verify the developed models with computer simulation.

1.4 Thesis organization

The rest of thesis report are organised as follow:

In Chapter 2, literature review of RL, RFID-based logistics, simulation models, ROI and cost is presented.

In Chapter 3, the problem under consideration is analysed in-depth.

In Chapter 4 the solution approach used to achieve the outlined objectives is discussed

In Chapter 5, our simulation models and a numerical application are presented.

In Chapter 6, our conclusions and recommendations for future works are presented.

Chapter 2:

Literature Review

In this Chapter, we review literatures on RL (Section 2.1), RFID technology (Section 2.2), RFID-enabled RL (Section 2.3), solution approaches used in RFID-enabled RL, simulation models, and costs.

2.1 Reverse logistics

The push for greener and pollution-free environment by many environmental awareness and social interest groups, and the enactment of several environment protection laws by Governments around the world, due to rising concerns for the negative impacts of environmental pollutions, have sparked a renewed and invigorated interests in RL and reverse Supply Chain Management (SCM) by concerned stakeholders in both public and private sectors. For instance, the European Union parliament and council promulgated the directive 2000/53/EC that demand economic operators in member states to develop systems for collection, treatment and recovery of EOL vehicles (Directive 2000/53/EC of the European Parliament and Council of 18 September 2000 on end-of life vehicles); the Taiwanese Government also brought into law a scrap home and computer recycling regulations that mandates manufacturers and importers to take back their products (Shih, 2001); while recently, the Federal and Quebec Governments of Canada made available funds for researches aimed at exploring and devising procedures for dismantling, parting out and recycling materials of old aircraft (The Guardian, New aerospace centre to study recycling aircraft parts opens near Montreal, 2011). Apparently, the current attitude towards RL and Reverse SCM has changed markedly, when compared to the past, with more fortified efforts made to minimize cost, maximize resources and process utilizations, and recapture highest possible value from returned products.

Aside the holistic tangible benefits that RL provides it also creates intangible benefits which companies are rapidly exploiting. Companies like EBay and Amazon that provide e-commerce services for used products and those with friendly warranty and product return policies have not only achieved remarkable financial profits and competitive advantages but also towering public perceptions.

In establishing the difference between RL and other existing recovery logistics, the existence of backward flow of goods and materials was cited by Rogers and Tibben-Lembke (1998) as the distinct characteristics of RL. Rogers and Tibben-Lembke (1998), therefore, classified activities such as remanufacturing and refurbishing, processing returned merchandise due to damage, seasonal inventory, restock, salvage, recalls, and excess inventory, recycling programs, hazardous material programs, obsolete, equipment disposition, and asset recovery as “reverse logistics”, while classifying activities such as redesigning packaging to use less material, or reducing the energy and pollution from transportation as “green logistics”.

Moreover, certain RL systems, like the Aviation RL system, have some characteristics or attributes that distinguish them from most RL systems. In most RL systems, the large distributions of consumers, and the uncertainty in goods or material returns, lead to construction of many collection or distribution centres. However, in the Aviation RL system, the small number of aviation operators and the fairly predictable return rates trivialize the need for constructing many collection centres. The complex nature of the Aviation RL system, which requires much advanced planning and financing, also imposes a limit on the number of collection centers.

Several papers have been published on the design, planning and optimization of RL systems and networks, and in most of the papers, mathematical programming models (Analytical approach) were proposed for optimizing the RL system models for end-of-life (EOL) product disposition. According to Shih (2001), the advantages of using a mathematical programming model for the system planning of EOL products disposition include: (1) obtaining an optimal system design to minimize total cost; and (2) incorporating the technological constraints as well as the local environmental regulations constraints. Mixed Integer Programming (MIP) and Genetic Algorithm (GA) are used mostly in formulating these mathematical models. For instance, MIP was used by Shih (2001) to optimize the infrastructure design and the reverse network flow of EOL computers and home appliances disposition; Fuzzy Cognitive Map (FCM) and GA were used by Trappey *et al.* (2010) to model and evaluate the performance of RFID-based RL operations; while GA was proposed by Lee and Chan (2009) to determine locations in order to minimize the coverage of customers.

2.2 Radio Frequency Identification (RFID) technology

"RFID is an automatic identification and data-capture technology that uses radio waves to provide real-time communication with objects at a distance, without contact or direct line of sight" (Sarac *et al.,* 2008). When compared to traditional barcode, RFID has a number of advantages over barcodes, as given by Wyld (2006); these advantages are presented in Table 2.1.

Table 2.1: Comparison of barcode and RFID (Adapted from Wyld, 2006)

Barcode	**RFID**
Barcodes require line of sight to be read	RFID tags can be read or updated without line of sight
Barcodes cannot be read if they become dirty or damaged	RFID tags are able to cope with harsh and dirty environments
Barcodes can only be read individually	Multiple RFID tags can be read simultaneously
Barcodes must be visible to be logged	RFID tags can be ultra thin and can be printed on a label, and they can be read even when concealed within an item
Barcodes can only identify the type of item	RFID tags can identify a specific item
Barcode information cannot be updated	Electronic information can be over-written repeatedly on RFID tags
Barcodes must be manually tracked for item identification, making human error an issue	RFID tags can be read automatically, eliminating human error

The RFID technology is made up of three main elements: namely, an RFID tag, an RFID reader, and middleware. The RFID tag is composed of a chip and antennae, and can be classified as active or passive tag, depending on how the chip is powered. Active tags contain onboard batteries that power their chips; thus, enabling them to transmit signals through their antennae to the reader. Passive tags, however, employ electromagnetic signals received from the reader through their antennae to power their chips; thus, allowing the tags to modulate the received signal waves and transmit them back to the reader. Aside the difference in the way they power chips, active tags differ from passive tags in terms of the following reasons:

a) Active tags have a longer read range (up to 100 ft) than passive tags (about few feet)
b) Active tags have bigger memory than passive tags.
c) Active tags have shorter lifespan than passive tags because their chips are battery-powered.
d) Active tags are more expensive than passive tags.
e) Active tags are bulkier than passive tags. This makes active tags suitable for large size products or containers and passive tags for small size products or containers.

Aside active and passive tags, there are also semi-active and semi-passive tags. Unlike their predecessors that are distinguished by their use or non-use of onboard-battery, both semi-active and semi-passive tags use on-board batteries (Banks *et al.,* 2007), however, in different ways. The semi-active tags do not transmit a beacon at regular interval like the active tags; hence, they have a longer battery life than the purely active tags (Banks *et* *al.,* 2007). On-board batteries are used in semi-passive tags to boost the power level of the IC chip and extend the read range of the tag.

RFID readers can be classified based on their communication protocol (Serial and network reader) and mobility (Stationary and handheld reader) (Banks *et al.,* 2007). Serial reader uses a RS-232 serial port to communicate and transfer data with host systems, while a network reader uses a wired or wireless connection to a computer, thus appearing as a network device (Banks *et al*., 2007). Stationary readers are fixed to fixed structures or moving objects, while handheld readers have integrated antennae that enable them to be used as handheld unit (Banks *et al*., 2007)

The middleware connects the RFID hardware with enterprise applications (e.g. database). The connection between RFID technology elements is illustrated in Figure 2.1.

The wireless automatic identification and data capturing capabilities of RFID make it a very viable technology for managing information in reverse and forward supply chain networks. Traceability and visibility of products throughout the entire supply chain can be improved with RFID (Tajima, 2007). With RFID, significant reduction in inventory inaccuracy, bullwhip effects, and replenishment inaccuracy can also be achieved (Sarac *et al.*, 2010). In essence, RFID can expedite operational processes such a tracking, counting and shipping, and also reduce inventory, handling and distribution costs.

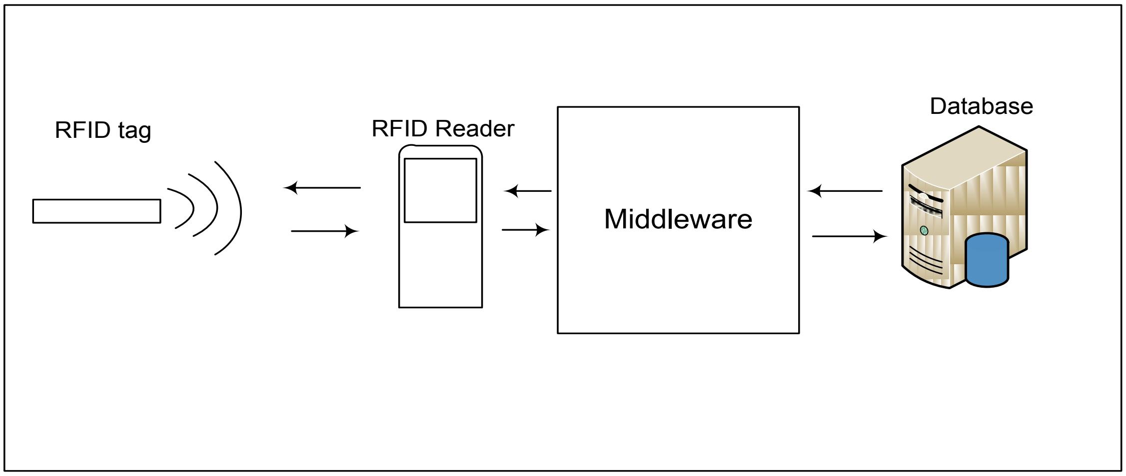


Figure 2.1: Information flow between RFID tag, RFID reader and middleware

2.3 RFID-enabled logistics

RFID technology has gained widespread adoption in FL while its use is on the increase in general RL and aviation RL.

Two leading pioneers of the RFID in FL are Wal-Mart and U.S. Department of Defence (DOD). In 2003, Wal-Mart directed all its suppliers to put RFID tags on products shipped to the retailer's distribution centers and stores (Wal-Mart Opts for EPC Class 1, V2, 2003), while in 2004 U.S. DOD published its final policy guidelines for use of both passive and active RFID tags in its supply chain (Roberti, 2004). In pioneering of RFID in RL, the U.S. Navy and the Dutch telecom carrier, KPN, are well-known. In 2005, the U.S. Navy completed a major RFID field trial, which showed that RFID can increase the visibility of parts in transit and reduce the manual labor in its RL network (Roberti, 2005b). In the same year, KPN embarked on a pilot project to establish how much RFID can improve the RL for its returned or unsold phones (Collins, 2005).

Due to interference-related concerns, which resulted in the approval of only passive RFID tags on individual airline parts by the Federal Aviation Administration (FAA) in 2005 (Roberti, 2005a), adoption of RFID tags in the aviation sector has been slow-paced. However, with the successful completion of pilot tests of high-memory RFID tags for aircraft parts tracking by Boeing and Airbus, and the Companies' proposed amendment to the Air Transport Association of America (ATA)'s specification 2000 to FAA, the widespread use of RFID technologies in aviation industries may soon be realized.

2.4 Solution approaches in RFID-enabled logistics

Academic works on RFID-enabled logistics can be categorized based on their problem-solving approach: namely, analytical, case-studies, simulation, and ROI-analyzes (Sarac *et al*., 2010) and the type of logistics: namely, forward and reverse logistics. We devote Section 2.4.1 to work that employed analytic approach in FL, Section 2.4.2 to work that employ analytic approach in RL (Differentiated as conventional RL and aviation RL in Section 2.2), Section 2.4.3 to work in aviation RL, Section 2.4.4 to works that employed case-studies approach, Section 2.4.5 to works that employed simulation approach, and Section 2.4.6 to work that involved ROI analyzes.

2.4.1 Analytical approach in RFID-enabled forward logistics

Analytical approach involves the use of mathematical expressions to model a system in order to identify conditions for its optimal performance or to simply understand its behaviour under prescribed conditions.

Heese (2007) analyzed the impact of inventory inaccuracy on optimal stocking decision and profits, and determined the cost thresholds at which RFID technology can be profitable in a supply chain model. Uçkun *et al.* (2008) studied the problem of finding the optimal investment levels on RFID technology integration that maximize profit by decreasing inventory inaccuracy in two echelon supply chain and proposed models for the centralized, decentralized, and extend cases. Szmerekovsky and Zhang (2008) analyzed Vendor Managed Inventory (VMI) system, with one manufacturer and retailer, that employed RFID technology under continous review policy, and no RFID technology under periodic review policy when shelf is limited, and they determined the optimal inventory policies for the centralized system. They also discussed how sharing of tags in a decentralized system can be exploited and used to coordinate the supply chain. Sounderpandian *et al*. (2008) suggested models for cost-benefit analyses of RFID implementations in retails stores. Costs such as RFID reader costs and infrastructural costs, and benefits such as reduced inventory level due to efficient shelf replenishment were included in their models. Their studies helped in determining beneficial RFID implementations. Poon *et al*. (2009) proposed an RFID case-based logistics resource management system for managing order-picking operations in a supply chain. They tested active and passive RFID tags to determine the efficient RF cover ranges for RFID systems, and developed case-based reasoning engine, triangulation localization scheme and material handling algorithm. The result of their research produced a simplified RFID adoptive procedure, improved visibility of warehouse operations, and increased productivity of the warehouse.

2.4.2 Analytical approach in RFID-enabled reverse logistics

RFID technology has ubiquitous presence and influence in FL, both in the industries and academia. However, the same cannot be said of RL which has only few relevant cases about the impact of RFID technology in the industries and academia. One good reason for this wide gap is the fact that the RL industry, and its infrastructures, which include the RFID technology, is still evolving, unlike the FL industry that has reached a good stage in this respect.

RFID technology has the potential of playing significant roles in RL just as it does in FL. RFID technology can help to track the quantities of returned products (Lee and Chan, 2009); record information, such as arrival times, about returned products; increase visibility across the whole RL network; reduce inventory inaccuracy and shrinkage; reduce inventory costs; and reduce labour cost.

Information and products flow in different ways in forward and reverse logistics as shown in Figure 2.2. In FL, products flow from manufacturers to distributor center and to retail shops while information flows in the opposite direction from retailer shops to distribution centers and to manufacturers. In RL, however, information and products flow in the same direction from collection point to distribution center and to process facilities. RFID technology can enhance information flow in both FL and RL by enabling product-related information to be collected and shared in real-time across the entire supply chain.

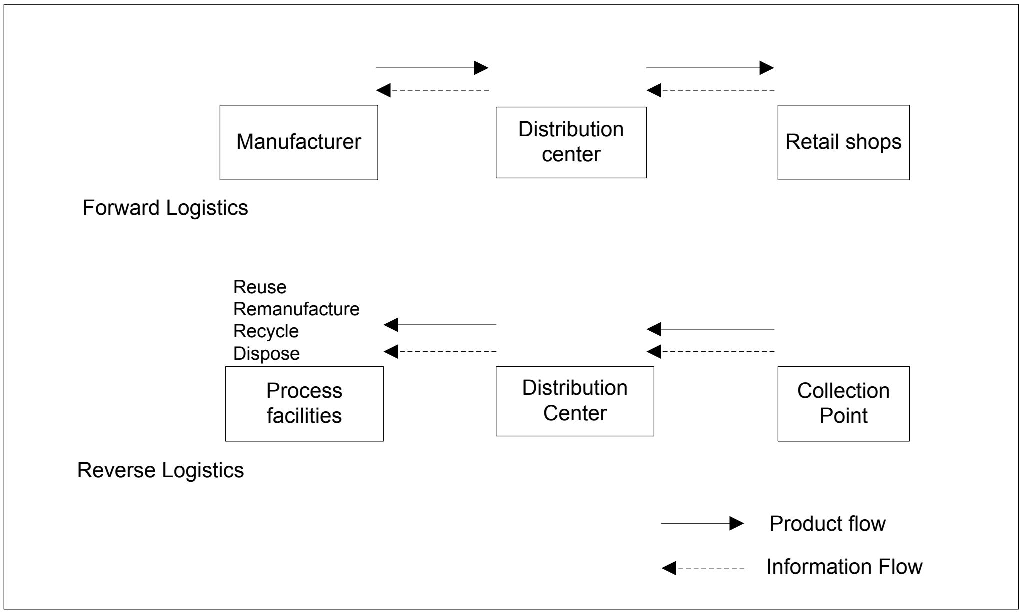


Figure 2.2: Flow of information and products in reverse and forward logistics

In regards to RFID-based RL, excluding aviation RL, Lee and Chan (2009) proposed a RFID-based RL framework, which used GA, a meta-heuristic approach, to determine locations of collection points that maximize the coverage of customers. RFID was used to collect data on returned products for the GA. The result of their work helped to identify and maximize the coverage of customers; thus, minimizing the holding time and depreciating value for returned products simultaneously. Trappey *et al.* (2010) presented a forecasting and decision support system, developed with FCM and GA, for RFID-based RL system. They used RFID technology to collect real-time data for the operation of the system.

2.4.3 General approach in RFID-enabled aviation logistics

On RFID-enabled aviation RL, no research papers were found; however, best management practice manual and white-papers that address specific aviation needs, for example those by Airbus, Boeing, and Aircraft Fleet Recycling Association (AFRA) were found.

A number of studies that focused on RFID technology applications in Maintenance, Repair, and Overhaul (MRO) operations in aviation industries have been done. Chang *et al.* (2006) presented a prototype of an RFID-enabled aircraft maintenance system which could be integrated with inventory control system and aircraft scheduling system to ensure on time performance and safety of passenger and cargo. They discussed the limitations of attaching RFID tags on current aircraft components and proposed modifications that can be made to ensure conformance with operating standards and requirements. Harun *et al.* (2008) discussed the various problems involved in aircraft parts manufacturing in areas such as quality assurance and control, production planning and control, product traceability, inventory visibility and labour productivity, and explained how the problems could be solved using RFID technology. They also presented a theoretical model of a generic RFID framework which they applied to a case-study to illustrate the impact of different cost factors in RFID-enabled manufacturing. Ramudhin *et al*. (2008) proposed a generic framework to support the selection of an RFID-based control system, and they applied the framework to MRO activities in aircraft engine manufacturing. They also presented two deployment scenarios, one a classical system with RFID tags on carts and trays and readers positioned at strategic points and the other with an intelligent system consisting of smart cart with wireless communications.

2.4.4 Case-studies approach

Case studies approach involves studying empirical evidences and drawing viable theories from them. This approach can help to show the difficulties and efficiency of RFID integration (Sarac *et al.,* 2010).

Tzeng *et al.* (2008) used five case-studies from Taiwan healthcare industry to show how RFID can have strategic impact and create business value. They established that RFID can improve the effectiveness of communications; improve the utilization of assets; optimize the patient care process; allow active participation of patients, and improve the visibility of data during workflow. By exploring the business processes of selected firms in the retail industry, Wamba *et al.* (2008) identified the impact of RFID technology and EPC network on the mobile B2B e-commerce. The impacts of RFID on Construction Project Management (CPM) have also been researched; with evidence from specific scenarios, Lu *et al.* (2011) established that "RFID shows great potential in improving CPM goals such as time, quality, cost, safety, and environment by applying it in the management of materials, labours and machinery".

2.4.5 Simulation model

Simulation refers to "a broad collection of methods and applications to mimic the behaviour of real systems, usually on a computer with appropriate software" (Kelton *et* *al.,* 2004). Based on this definition, one can define a simulation model as a representation or mimic of a real system, developed usually on a computer with appropriate software.

Models in general can be physical or logical. A physical model is a physical replica or scaled representation of the actual system (Kelton *et al.*, 2009). A logical model, on the other hand, is a set of approximation and assumptions about the way the actual system behaves (Kelton *et al.*, 2009). A logical model can be a mathematical or a computer simulation model. Simulation models are very good for modeling complex behaviours in systems which would have been impossible to achieve using mathematical models without over-approximations and over-assumptions. Simulation also makes testing of several alternative designs (current or future) of the actual system possible without incurring the huge infrastructural and logistical cost of building the real systems. Simulation models can also be classified as static or dynamic, discrete or continuous, and stochastic or deterministic. Static models are time-independent while dynamic model are time-dependent. Discrete models change states at discrete time interval, for example, in a bank transaction, customers can go through arrival, queuing, payment, and departure states, while continous models change state continuously, e.g the drop in water level as water flows out of a tank through the tap. A model can be mixed continuous-discrete (Kelton *et al.*, 2009), in which case, some parts of the system are continuous while some parts are discrete. Depending on the nature of the input, simulation model can also be deterministic or random (or stochastic) model. Deterministic models have non-random or fixed inputs while random models have random input. In this research, our simulation model is dynamic, discrete, and stochastic; it is a discrete–event simulation. Discrete-event simulation involves collecting observations at selected points in time, called events, when changes take place in the system (Rossetti, 2010).

As a result of the significant gain in computing power and processing speed of computers, computer simulations are now much more efficient and faster than before. Moreover, the advent of special modeling programs and applications, such as Arena simulation software, have enhanced the usability and performance of simulations. According to Rossetti (2010), the methodology for building simulations models on computers and implementing the model, illustrated in Figure 2.3, includes the six phases of problem formulation, simulation model building, experimental design and analysis, evaluation and iteration, documentation and project plan, and create the conceptual model of the system. Proper planning and designing of the problem formulation phase will ensure that we build the right model, and collect the right input data. At the second phase, the model is programmed in a simulation language or developed using an application software like Arena simulation software which enables models to be built with drag-and-drop functionalities while auto-generating the code. To ensure an efficient and reliable simulation model, the computer program is verified to eliminate bugs and errors, and the model is validated to ensure that it actually models the real system. At third and fourth phases, experiments are designed and run multiple times to evaluate the performance of the simulation

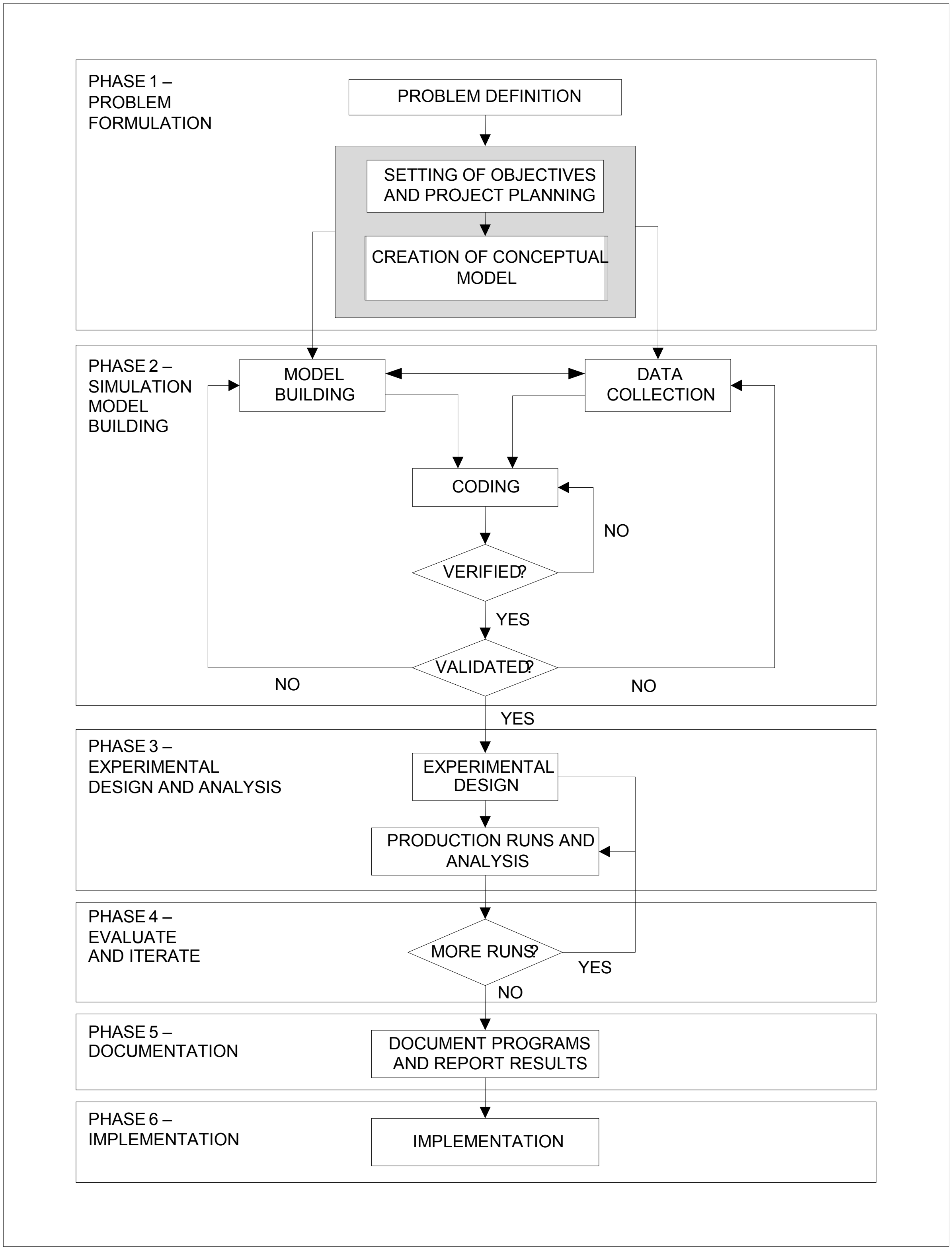


Figure 2.3:General simulation methodology (Adapted from Rossetti, 2007; Figure 1.35, pg 34)

model and collect the needed results. At the fifth phase, the program is documented and results are reported. Finally, at the sixth phase, the model is developed into the actual system.

In literature, simulation models have been used by many researchers to analyze and resolve supply chains management problems e.g. inventory inaccuracy and bullwhip effect.

Lee *et al.* (2004) analyzed the simulated impact of RFID technology on inventory accuracy, shelf replenishment policy, and inventory visibility in a manufacturer-retailer supply chain. The results of their analysis showed the potentials of RFID technology in reducing inventory inaccuracy, improving shelf replenishment policy and increasing visibility across the supply chain. Fleisch and Tellkamp (2005) employed simulation model to study the relationship between inventory and performance in a three echelon supply chain with one product in which end-customer is exchanged between echelons. They investigated a base model with mismatch in physical inventory and information system inventory due to low process quality, theft and unsaleable items, and a modified models, affected by same factors, but with physical inventory and information system inventory matched at the end of the period. The result of their studies showed that "elimination of inventory inaccuracy can reduce supply chain costs as well as the out-of-stock level" (Fleisch and Tellkamp, 2005).

Leung *et al*. (2007) proposed a simulation based business process model to calculate the indirect benefits of RFID technology. Sarac *et al.* (2008) performed a ROI analyzes to determine the economic impact of RFID on a simulated model of a three-level supply chain in which thefts, misplacements and stock-out lead to inventory inaccuracies with resultant decrease in supply chain performance. Wang *et al.* (2008) analyzed the impact of RFID system on the inventory replenishment of the thin film transistor liquid crystal display (TFT-LCD) supply chain using simulated pull-based multi-agents supply chain concept. An automatic inventory replenishment that used (s,S) policy with and without RFID technology integration were used in their studies. The result of their studies showed that RFID-enabled automatic inventory replenishment policy can decrease the total inventory cost by 6.19% and increase the inventory turnover by 7.60%. Tu *et al.* (2009) used simulations to evaluate the performance of the four different algoritms they proposed for locating the presence of RFID tags object. Karagiannaki *et al.* (2010) proposed a reference step-by step famework that illustrates the value of simulation modeling as a decision support tool to guide choice of RFID implementation in the supply chains. Su and Roan (2011) analyzed the simulated impact of different degrees of RFID applications, demand patterns, demand information sharing and lead time on the dynamic behaviour of the conventional beer distribution model, a multi-level supply chain. The degree of chaos in the dynamic behaviour of the supply chain was calculated using Lyapunov exponents, and one of their findings was that RFID application can effectively diminish the degree of chaos in the supply chain system.

2.4.6 Return-On-Investment (ROI) analyzes of RFID systems

The need for Companies planning to invest in RFID systems to justify their investments before embarking on its implementation makes ROI analyses very significant. With ROI analyzes, Companies can estimate the profit, in monetary time-value, they can get from investing on RFID technology. Schwalbe (2010) gave the following equation for calculating the ROI:

$$\text{ROI} = \frac{Total\ discounted\ benefit - Total\ discounted\ cost}{Total\ discounted\ cost} \tag{2.1}$$

A high positive value of ROI implies a highly profitable investment while a high negative value of ROI implies a highly unprofitable investment.

To reliably estimate the ROI for RFID systems, a clear knowledge of its benefits and costs is essential.

Benefits can be direct or indirect. Direct benefits often come as reduction in costs and increase in profitability while indirect benefits come as intangible advantages, such as innovative use of technology (Roh *et al.,* 2009), improvement in the corporate image or perception, and increase in customer satisfaction, which have more strategic impact. Roh *et al.* (2009) categorized the benefits that can be realized from RFID systems as cost savings, supply chain visibility and new product or process creation (Figure 2.4). Cost savings can increase through reduction in theft (or shrinkage), reduction in counterfeiting, reduction in labour cost, and reduction in inventory cost. Supply chain visibility can lead to improvement in supply chain performance through reduction in Bullwhip effect, reduction in uncertainty of product availability, reduction in out-of-stock, delivery and safety stock, and so on. Innovative developments, such as new process creation, communication of component parts to readers, and quality control, can bring about remarkable improvements in the performance of the supply chain.

Banks *et al.* (2007) classified the cost components for RFID implementation as hardware costs, software costs, system integration costs, installation service costs, personnel costs, and business process reengineering costs. The cost of RFID implementation increases from pallet-level to case-level to item-level; hence, the level of RFID tagging is an important cost factor (Sarac *et al.*, 2008) in RFID implementation. We summarize the

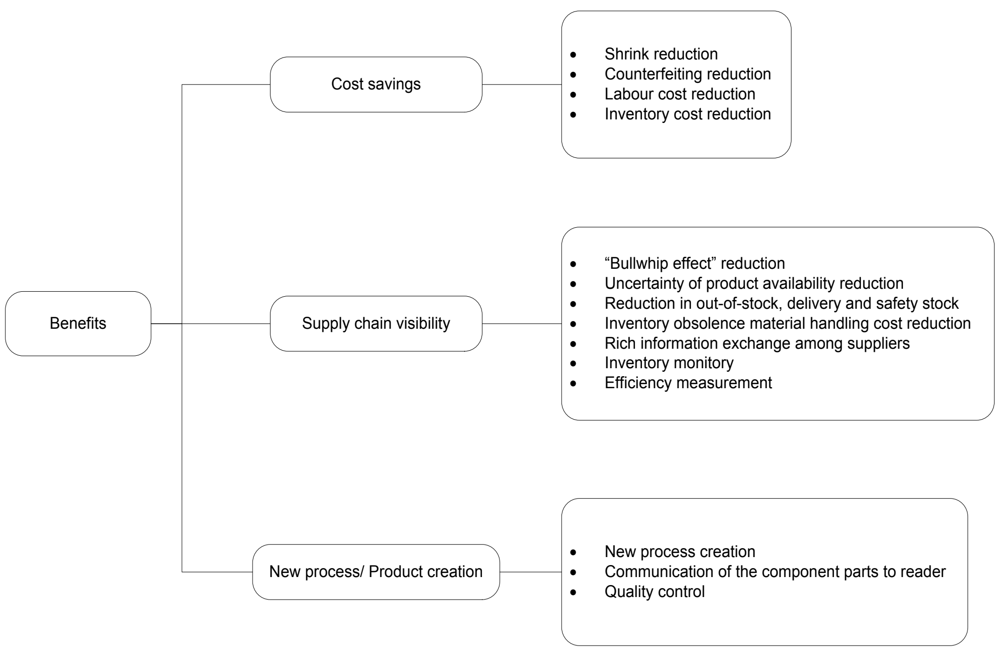


Figure 2.4:Benefits of RFID systems (Adapted from Roh et al., 2009; Table 1, pg 358)

discussions of Banks *et al.* (2007) on the cost components required for RFID implementations in Table 2.2

When viewed as supply chain performance measure (Fleisch and Tellkamp, 2007; Beamon, 1998), ROI can be considered as a quantitative monetary measure in which direct benefits and cost components are used. Other quantitative monetary supply chain performance measures are Net Present Value (NPV), Internal Rate of Return (IRR), costs, and sales. Customer response time and lead time are regarded as quantitative and non-monetary measures (Fleisch and Tellkamp, 2007; Beamon, 1998).

In literature, Betanni and Rizzi (2008) conducted a feasibility study to investigate the economic sustainability of RFID and EPC adoption in the Fast Moving Consumer Goods (FMCG) supply chain, comprising manufacturers, distributors and retailers. They considered the individual supply chain players and the entire supply chain in their study. Their study revealed that pallet-level RFID tagging provides positive ROI for all supply chain players while case-level RFID tagging gives positive ROI for only distributors and retailers. Véronneau and Roy (2009) performed a qualitative study of the cost-benefit of case-level and pallet-level RFID implementations in a cruise corporation global supply chain. Their study revealed that pallet-level RFID deployment does not bring enough benefits to the cruise corporation to justify its investment while case-level RFID deployment, provided tag cost is shared across the entire supply chain, brings enough direct benefits to justify its investment. Souza *et al.* (2011) analysed a case-study of an RFID-enabled supply chain ecosystem of a large multi-national corporation in Singapore, and proposed a ROI calculator, based on Supply Chain Operational Reference (SCOR) model, to assess the operational level benefits of RFID implementation in the supply chain.

Table 2.2: Cost components for RFID implementation (Adapted from Banks *et al*., 2007)

Cost Components	**Descriptions**	**Examples**
1. Hardware costs	These are costs required to procure tangible, physical assets for RFID solution deployment.	Cost of: ▪ RFID readers ▪ RFID tags ▪ RFID antennas ▪ Network switches
2. Software costs	These are costs of procuring components required for: ▪ Collecting electronic data ▪ Translating RFID event into business events for decision making	Cost of: ▪ Middleware systems ▪ Database systems ▪ Interface systems ▪ Maintenance
3. Integration costs	These are costs associate with integrating resultant data from RFID infrastructure into enterprise applications.	Cost of ERP systems
4. Personnel costs	These are costs associated with hiring external and internal personnel.	Cost of ▪ Labour ▪ Training
5. Installation service	These are costs of actual deployment.	Cost of: ▪ Wiring and power outlets ▪ Server installations ▪ Field test
6. Business Process Reengineering (BPR)	These are costs associate with re-engineering.	Cost of: ▪ Removing old processes ▪ Adding new processes

Some researchers have proposed analytical evaluation methods different from the traditional ones such as ROI, NPV, and IRR to determine the economic impact of RFID implementations. Kim and Sohn (2009) proposed a Cost of Ownership (COO) model to investigate RFID technology applicable to a ubiquitous city (u-city). Infrastructural costs, logistics costs and yield loss costs were considered in their model. They argued that the model offer more detailed economic evaluation than existing methods, such NPV and IRR, when building RFID logistics system under u-city. Lee and Lee (2010) also presented a supply chain RFID evaluation model based on the classic Economic Order Quantity (EOQ) model that helped determine the optimal investment level that minimizes the total cost.

2.5 Review of cost

Different types of costs exist. For this study, the following costs are considered necessary for review:

1. Fixed cost
2. Variable cost
3. Value added cost
4. Non-value added cost
5. Waiting cost
6. Holding cost
7. Usage cost

Variable cost change proportional to the quantity of items produced during the period of a project, while fixed cost remains unchanged (e.g. monthly salaries). Value added cost is the cost incurred when one or more resources are used in a value adding process. Non-value added cost is the cost, such as adverting cost, that adds to the total cost without adding a tangible or visible value to a product. Waiting cost is the cost incurred when a product is delayed in a queue. Holding cost is the cost of holding a product in inventory . Usage cost is the cost incurred for each usage of a resource in a system. Value added cost, waiting cost, holding cost, and usage cost are used in Arena simulation software.

2.6 End note

Our review of literatures showed that RFID has a number of advantages over traditional barcode which makes it preferred for tackling supply chains and logistics networks problems. RFID technology can enhance information flow in both FL and RL by enabling product-related information to be collected and shared in real-time in the entire supply chain. RFID can significantly reduce inventory inaccuracy, bullwhip effects, and replenishment inaccuracy (Sarac *et al.*, 2010) in supply chains.

In the study of RFID-enabled logistics, researchers have used analytic, case-studies, and simulation model approaches, and conducted cost-benefit or ROI analyzes. In terms of industrial applications, Wal-mart and U.S. DOD are renowned for applying RFID in forward supply chain while the U.S. Navy and KPN are renowned for applying RFID in reverse logistics. Although there is still restrain on the widespread adoption of RFID in the aviation industry due to interference related concerns, and approval of only passive tags by FAA, aviation companies like Boeing and Airbus have shown through pilot tests that high memory RFID tags can be successfully used for the tracking of aircraft parts.

Chapter 3:

Problem Definition

In this chapter, we discuss in-depth our problem statement and research objectives by elaborating on the components of aircrafts, challenges of processing dissembled EOL aircrafts in the RL network, and justifying the need for our study on simulation the ROI of RFID in the reverse logistics of aircrafts.

3.1 End-of-life aircrafts

Aircrafts consist of several parts, which can be categorized, as given in the Airframer index (2008), as materials, components, airframe systems, avionics, and power systems, with subcategories of adhesives, coatings, plastics, composites, lubricants, metals and non-metals, active and passive electronic components, mechanical and non-mechanical components, fasteners, cabin interiors, batteries and accessories, and engines (Table 3.1).

Aircrafts have an average life span of 25 years, and an estimated 6400 aircrafts will reach their end of service life by 2026 (Airbus, 2008). Moreover, this number is likely to increase with the phase-out and replacement of old and less fuel-efficient aircrafts with more fuel-efficient ones.

Proper tracking and monitoring of parts obtained from disassembled EOL aircraft is important in order to ensure that parts arrive at the right processing facility, and appropriate processing operations are applied. Also the processing of EOL aircrafts can be expedited if data on EOL aircrafts are easily accessible, resulting in faster decision

Table 3.1: Aircraft parts (Adapted from Airframer Index, 2012, Boeing 787 Dreamliner)

Categories	**Sub-Categories**
Materials	Adhesives, coatings, plastics, composites, lubricants, metals, non-metals
Components	Active electronic components, passive electronic components, actuation, electrical and electronic connectors, fasteners, lighting, mechanical components, non-mechanical components, sensors, transducers, detectors
Airframe systems	Airframe assemblies, cabin interiors, cargo systems, crew seating, environmental systems, fluid power, landing assemblies, safety and security systems
Avionics	Avionic components, communications, Indicator and instruments, warning systems
Power systems	Auxiliary power, batteries and accessories, electrical power systems, engine components, engines, fuel systems, power transmission

making process. Although historically, several EOL aircrafts have been dismantled, reused, remanufactured, recycled, and disposed, and best practice techniques have been proposed by leading commercial aircraft manufacturers and management associations, such as Airbus, Boeing, and AFRA, there is still need for a widely accepted, efficient and cost-effective system for tracking and monitoring parts of EOL aircraft in the RL network.

3.2 Justification for studies

RFID technology application in EOL aircraft RL network shows great potential for addressing the problems of tracking and monitoring EOL aircrafts in the RL network through its automatic, wireless and data-capture technology. RFID technology integration can bring about significant improvement in the monitoring, tracking and distribution of aircraft parts in the RL network; reduce mismatch between physical and information inventory; eliminate time-consuming processes resulting from identification of parts using manual barcode scanning, and bring about significant gain in the processing rates of parts on process-lines through real-time identification of parts and their processing requirements. Other benefits of RFID are cost-saving benefits, such as shrink reduction, labor cost reduction, and inventory cost reduction. These benefits can, however, be adversely affected by cost-heightening factors resulting from different RFID technology selection and implementations.

Hence, it is in an effort to substantiate the potentials of RFID technology for solving challenges of the EOL aircraft RL, and to justify investment in the technology that we conduct research to develop a selection model for determining the most suitable RFID solutions for use in different areas of the EOL aircraft RL network, and to analyze the ROI of the system.

3.3 End note

We have shown through our problem definition the problems of the EOL aircraft RL network and the need for this research on simulating the ROI of RFID in the RL of aircrafts.

Chapter 4:

Proposed Approach

The solution approach used to meet the research objectives listed in Section 1.3 is presented as follow:

The first objective is addressed through presentation of practicable scenarios of RFID technology implementations, as demonstrated in literature. We also proposed a framework for managing the data stored on RFID tags and enterprise application systems, particularly in relations to EOL aircraft RL network.

The second objective is addressed by first creating a hypothesized as-is process map in which case-level barcode tagging is employed and routing decision is based on aircraft part (AP) types and RL types. The as-is process map serves as the baseline or reference model. Through qualitative analysis of the reference process map, three other process maps that employ item-level, case-level, and pallet-level RFID tagging are developed. The process maps are then simulated in Arena simulation software to investigate the ROI and process improvements that are realizable.

Discussion of our proposed RFID technology selection model, requirements for EOL aircraft RL network information system, and conceptual models are presented in the subsections.

4.1 RFID technology selection model

To determine the most appropriate RFID solution for a given system, a number of factors which relates to the characteristics of different RFID technology and the system in which the RFID technology is to be deployed needs to be considered. We discuss these factors under (1) The RFID technology capabilities (2) The current system specifications. After, we analysed these factors in relation to EOL aircraft RL to obtain our proposed selection model. This problem-solving process is depicted in Figure 4.1.

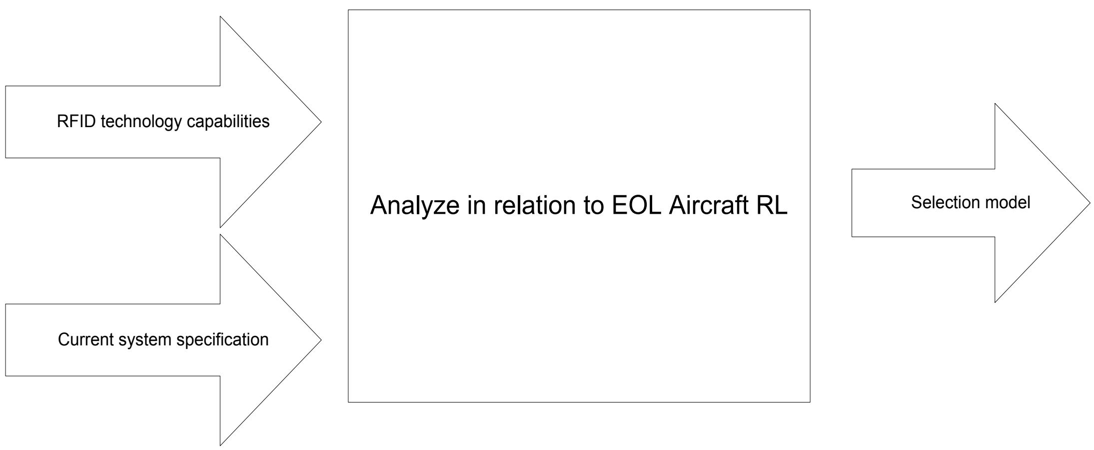


Figure 4.1: RFID technology selection process

4.1.1 RFID technology capabilities

Based on earlier works by Banks *et al.* (2007), and Khan *et al.*, (2009) on the characteristics of different types of RFID tags, we identify parameters for the different types of RFID tags as IC powering, signaling behavior, lifespan, range, memory, and cost, and present values for these parameters in Table 4.1.

From the information provided in Table 4.1, active RFID tags can be said to be suitable for use in situations where large data needs to be captured from an item at a distance up to 100 m, and for time period as long as the life-time of the on-board battery. However, for semi-active RFID tags, because their on-board batteries are only activated when they are within the read range of the reader or interrogator, which helps to prolong their life-span, they need to be close enough to the reader. The high cost of active RFID tags and semi-active RFID tags makes them in less demand than the passive tags.

For passive RFID tags, their small-size, small memory, and unlimited lifespan makes them suitable for holding small data about items throughout their lifecycle. Also, the short read range of passive RFID tags makes them more appropriate for tracking mobile or fixed items which are close to the reader. The presence of on-board battery in the semi-passive RFID tags helps to increase their range.

Where costs, size, and battery life span are not important, active RFID tags offers more flexibility (Banks *et al.,* 2007), in terms of range and tag memory usage.

Table 4.1: RFID tags technology capabilities (Adapted from Banks *et al.,* 2007; Table 3.1, pg 69)

	RFID Tag Types	**IC Powering**	**Signaling Behaviour**	**Life Span**	**Size**	**Range**	**Memory**	**Costs**
1	Active	Use on-board battery to power tag IC	▪ Sends signals at regular rate ▪ Use active transmission	Limited	Bulky	Long (< 300m)	< 100 Kilobytes	High
2	Semi-active	Use on board battery to power tag IC	▪ Sends signals only when interrogated by reader at a readable range ▪ Use active transmission	Limited	Bulky	Short (< 3m)	<100 Kilobytes	High
3	Passive tag	Use signal received from reader to power tag IC	▪ Sends signals only when interrogated by reader at a readable range ▪ Use Backscatter	Unlimited	Small	Short (<3m)	96 bits, 128 bits	Low
4	Semi-passive	Use on-board battery to power tag IC	▪ Sends signals only when interrogated by reader at a readable range ▪ Use Backscatter	Unlimited	Bulky	Long (<100m)	< 100 Kilobytes	High

We summarize our discussion in Table 4.2.

Table 4.2: Suitability of RFID tag technologies

Range	Memory	Life Span	Size	Costs
Long ▪ Active ▪ Semi-active	**Large Data** ▪ Active ▪ Semi-active ▪ Semi-passive	**Unlimited** ▪ Passive ▪ Semi-passive	**Big** ▪ Active ▪ Semi-active ▪ Semi-passive	**High** ▪ Active ▪ Semi-active ▪ Semi-passive
Short ▪ Passive ▪ Semi-passive	**Small Data** ▪ Passive	**Limited** ▪ Active ▪ Semi-active	**Small** ▪ Passive	**Low** ▪ Passive

4.1.2 Current system specifications

Clear understanding of the specifications of the current system is important in order to know if or not a RFID solution is required, and to identify the best fit solution for the current system. It also serves as a strategic plan that helps to identify the why, when, and where an RFID solution is required (Banks *et al.,* 2007).

We discuss the specification of the current system under the following sub-headings:

1. System and environment specifications
2. Item specifications

4.1.2.1 System and environment specifications

We consider the environment to be the physical surroundings of the RFID tags and the system to encompass all activities or operations existing in the environment. By answering a number of questions about the specifications of the environment and the system we can identify the best fit RFID solutions. We present these questions in Table 4.3:

Table 4.3: Questions on system and environment specifications

	Specifications	**Questions**
1	Logistic types	Is it a closed-loop or open-loop logistic network?
2	Spacing	Is it a more congested space (e.g. warehouse) or less congested space (e.g. spacious assembly line)?
3	Mobility	Is it a static (e.g. shelved items in stores) or dynamic (e.g. assembly line) system?
4	Transmission	Does the environment have metallic objects or liquids that can reduce the strength of signals transmitted from the reader?

In a closed logistic network, to track items throughout their lifecycle, at minimum costs and with basic data requirements, passive RFID tags may be more appropriate than the active RFID tags. For an open logistic network, however, any type of RFID tags can be used, depending on other factors.

The type of spacing can also determine the most suitable RFID tags and readers to use. In an open and less congested environment, like spacious assembly-lines, long range

RFID readers (active, semi-active, and semi-passive) with fixed readers, attached to predetermined locations, will be more suitable. On the hand, in a crowded environment, where items are closely positioned, passive RFID tags with handheld readers will be more suitable.

In a static system, where there is less likelihood of frictions due to regular movements of objects, passive RFID tags will be more suitable than active RFID tags, due to their small size and low costs. However, in a dynamic system, where items are moved around regularly, bulky or rugged RFID tags (active, semi-active, and semi-passive) may be more suitable than passive RFID tags due to their big size.

Metallic objects can significantly reduce the strength of transmitted signals from readers due to signal interference and cancelations (Banks *et al.,* 2007). Liquids can also reduce the strength of transmitted signals, however, through a process called signal absorption (Banks *et al*., 2007). These problems can be reduced or eliminated by using multiple readers, protected RFID tags, or non-metallic casings for items (Banks *et al.*, 2007).

These discussions are summarized with the system-based selection matrix presented in Table 4.4.

Table 4.4: System and environment based RFID technology selection matrix

RFID tags	**Logistics**		**Spacing**		**Mobility**		**Transmission**	
	Closed-loop	**Open-loop**	**More congested**	**Less congested**	**Static**	**Dynamic**	**Presence of Metal or Liquid**	**Absence of Metal or Liquid**
Active	_	✓	_	✓	_	✓	NA[1]	NA
Semi-active	_	✓	_	✓	_	✓	NA	NA
Passive	✓	✓	✓	_	✓	_	NA	NA
Semi-passive	_	✓	_	✓	_	✓	NA	NA
Protected RFID tags	NA	NA	NA	NA	NA	NA	✓	_

Keys

✓ - Suitable

_ - Not suitable

NA - Not applicable

[1] Protected RFID tags are special purpose tags that can be any of the normal RFID tags but contained in protective casing. As part of measures to protect RFID tags in aviation MRO use of RFID tags on containers or trays that holds parts, rather than directly on parts, was proposed by Ramuldin *et al*. (2008).

4.1.2.2 Item specifications

In this case, we consider, as shown in Figure 4.2, the physical characteristics of items, the volume of data needed on items and the amount of visibilities required for items as factors determining RFID technology selection.

RFID technology selection in terms of physical characteristics of items can be analyzed by considering the flexibility, size, and composition of items. Flexible RFID tags, which exist only in passive RFID tags, are more suitable for flexible items such as documents, while rigid or bulky RFID tags are more suitable for rigid items (Banks *et al.*, 2007). Likewise, for small sized items, small passive RFID tags are more suitable while for big sized items big RFID tags are more appropriate. If an item is metallic or liquid, special

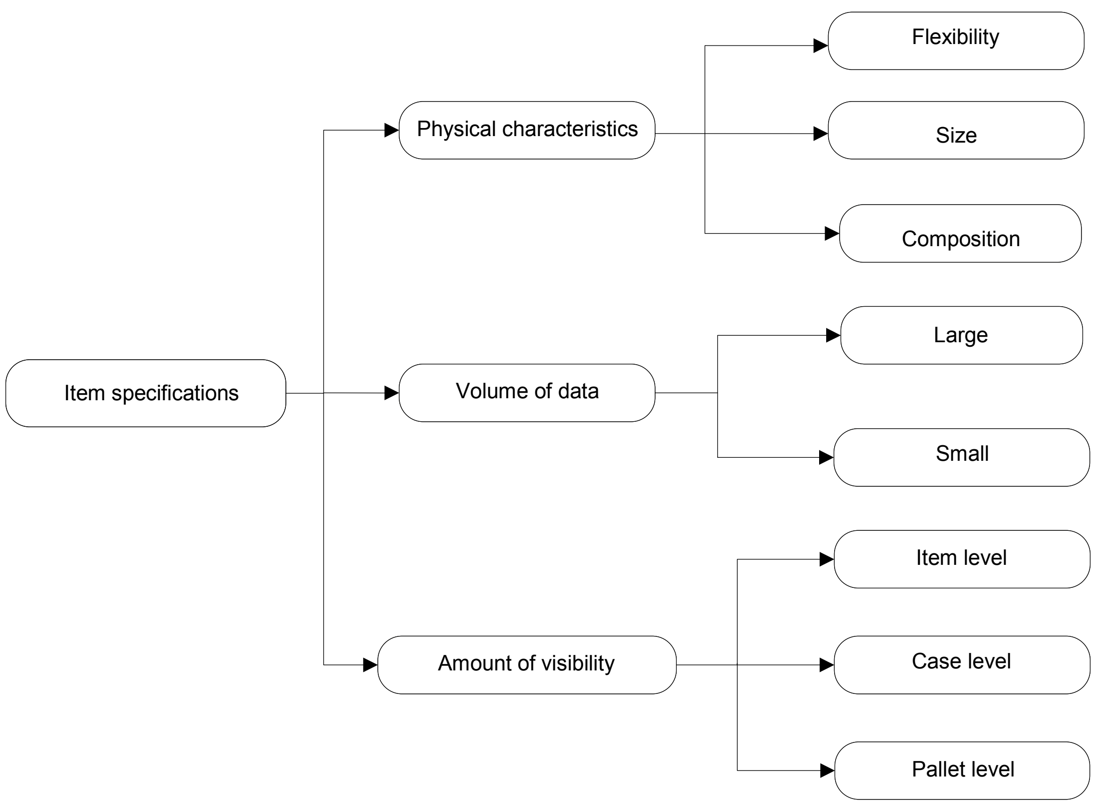


Figure 4.2: Item specification factors

RFID tags, with protective overlays, or non-metallic casing, in which items are placed, has to be used to prevent degradation of signals received from readers through signal interference in metals, and signal absorption in liquids (Banks *et al*., 2007).When large amount of data is needed on items, for instance in situations where a field-operator needs to know about the processing steps or work-order for items, large-sized memory tags (active, semi-active, and passive) will be more suitable for storing such data. However, when small amount of data about items is required, for example the part number, passive RFID tags will be more suitable.

In regards to required visibilities, the visibility of items increases from pallet-level to case-level to item-level. Equally, RFID tag cost increases from pallet-level to case-level to item-level. This relationship is depicted in Figure 4.3. Due to their low cost, we consider passive RFID tags, excluding other factors, most suitable for all tagging levels.

These discussions are summarized with the item-based selection matrix presented in Table 4.4.

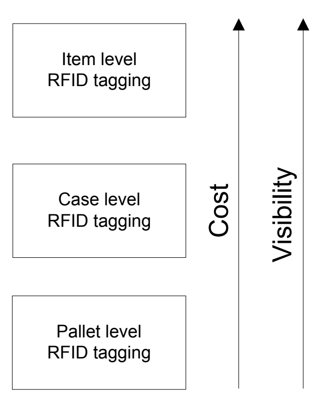


Figure 4. 3: Increasing cost and visibility of RFID tagging levels

Table 4.5: Item-based RFID technology selection matrix

RFID tags	Flexibility		Size		Composition		Volume of data		Visibility		
	Flexible	Rigid/Rugged	Small	Big	Presence of M/L	Absence of M/L	Small	Large	Item level	Case level	Pallet level
Active	–	✓	–	✓	NA	NA	–	✓	–	–	–
Semi-active	–	✓	–	✓	NA	NA	–	✓	–	–	–
Passive	✓	–	✓	–	NA	NA	✓	–	[2] ✓	✓	✓
Semi-passive	–	✓	–	✓	NA	NA	–	✓	–	–	–
Protected RFID tags	NA	NA	NA	NA	✓	✓	NA	NA	NA	NA	NA

Keys

✓ - Suitable

_ - Not suitable

NA - Not applicable

M/L - Metal or Liquid

[2] Passive tags are considered most suitable for all the tagging levels because of their low cost

4.1.3 RFID technology selection model for EOL aircraft RL

The environment of the EOL aircraft is a hypothesised open-loop RL network. The network represents the as-is or current systems in which case-level barcode tagging is used. Four environments can be identified from the process maps, namely:

1. Disassembling facility (less congested and dynamic environment with liquid and metals)
2. Physical store or inventory (more congested environment)
3. Shipping point (less congested and dynamic environment))
4. Processing facilities (less congested and dynamic environment with liquid and metals)

The dissembling facility is a secure area where parts are disassembled and are thereafter identified and stored in a secure place for the purpose of processing (AFRA, Best Management Practice, Management of Used Aircrafts and Assemblies, 2009) at a later time. The physical store serves as temporary storage for parts after they are disassembled, and before and after they are processed.

Before shipments, parts are picked from physical stores, scanned to update the information store and loaded on pallets. At this point, it is important that parts are properly identified to ensure their proper handover to shippers and their shipment to the right processing facilities. Also, parts need to be packaged in accordance with acceptable standards (AFRA, best management practice for management of used aircrafts and assemblies, 2009).

In the as-is system, described above, barcodes are attached to parts after they are removed from the EOL aircrafts, that is after the disassembly process. The use of RFID technology in place of barcode technology has a number of technological advantages, as given in Table 2.1. More specifically, RFID technology can help to enhance logistics operations and processes in the EOL aircraft RL network by enabling:

1. Automatic identification of parts in transits and on process floors
2. Prompt access to information about the origin and destination of parts
3. Easy access to work-order for processing of parts
4. In situations where RFID data are shared across the entire RL network, RFID can facilitate prompt access to, and update of, information across the entire RL network

Drawing from earlier discussions on item and system specifications, we present in Table 4.6 four scenarios, and the selection criteria for selecting suitable RFID technology (Scenarios 2, 3, 4) for the EOL aircraft RL network. In the first scenario, a traditional barcode system is used as the support technology for the physical store, the shipping point, the receiving point, and the processing facilities. In the second scenario only passive RFID tags are used, while in third scenario only active tags are used. In the fourth scenario passive tags are used in the physical store, while active tags are used for the shipping point, the receiving point, and the processing facilities. The second scenario is

Table 4.6: Selection model for EOL aircraft RL network

		Environments			
		Physical store **Activities:** Inventory counting, picking	**Shipping points** **Activities:** Checking, recording, routing decision-making, shipping.	**Receiving point** **Activities:** Checking, recording, storing	**Processing facilities** **Activities:** Reading and update of work order information, progress reporting
Barcode System	**Scenario 1**	Barcode attached to parts or cased[3] part(s), barcode scanner	Barcode attached to pallet, barcode scanner manually operated.	Barcode scanner manually operated.	Barcode scanner manually operated.
RFID technology	**Scenario 2**	Passive RFID tag attached directly to parts or cased parts, handheld reader	Passive RFID tag attached to pallets, handheld reader, RFID gate	Passive RFID tag attached directly to parts or cased part(s), handheld reader, RFID gate	Passive RFID tag attached to trays, fixed reader
	Scenario 3	Active RFID tag attached to parts or cased parts, handheld reader	Active RFID tag, handheld reader, RFID gate	Active RFID tag, handheld reader, RFID gate	Active RFID tag attached to trays, fixed reader
	Scenario 4	Passive RFID tag attached directly to parts or cased part(s), handheld reader	Active RFID tag, handheld reader, RFID gate	Active RFID tag, handheld reader, RFID gate	Active RFID tag attached to trays, fixed reader

[3] Parts for reuse and remanufacture are cased, to protect them from damage, with unit aircraft part in case representing item-level, multiple aircraft parts in case representing case-level and multiple cases on pallet representing pallet-level. A single part can also be cased to ensure safety and to reduce interference and absorption of RFID signals.

most suitable when small amount of data is required on RFID tags, while the third scenario is most suitable when large amount of data is required on RFID tags. The second scenario also has the advantage of long battery life with its use of passive RFID tags. In the fourth scenario, different RFID technologies are employed at different points; this is suitable if different technological advantages of passive and active tags are required.

No RFID or barcode technology is required for the disassembly facility.

4.2 Requirements for RFID – enabled Information System (IS)

We obtained the requirements for the EOL aircrafts RFID-enabled IS by exploring literatures on the structure and capacity of RFID tag memory, and the data required for the RFID tags, and proposing a possible layout or schema for the data stored in the IS database.

4.2.1 Structure of RFID tag memory

Meaningful communication between RFID readers and tags is achieved through communication protocol that defines how memory is organized on the tag and the basic sets of commands that the reader employs during its interrogation of RFID tags (Banks *et al*., 2007). While a standard protocol, or limited number of standard protocols, exist for passive tags, no such standard, or restrictions, exist for active tags, due their use of onboard batteries which gives active tag manufacturers the flexibilities of producing active tags with advanced memory layout structures and access protocols (Banks *et al*., 2007). The Electronic Product Code (EPC) is the widely adopted protocol for passive tags (Banks *et al*., 2007). The structure of the passive tag memory, as defined by the EPC standard, is depicted in Figure 4.4. As shown in Figure 4.4, the passive tag memory consists of four memory banks, namely:

1. Reserved memory (Bank 0)
2. EPC memory (Bank 1)
3. Tag identification (ID) memory (Bank 2)
4. User memory (Bank 3)

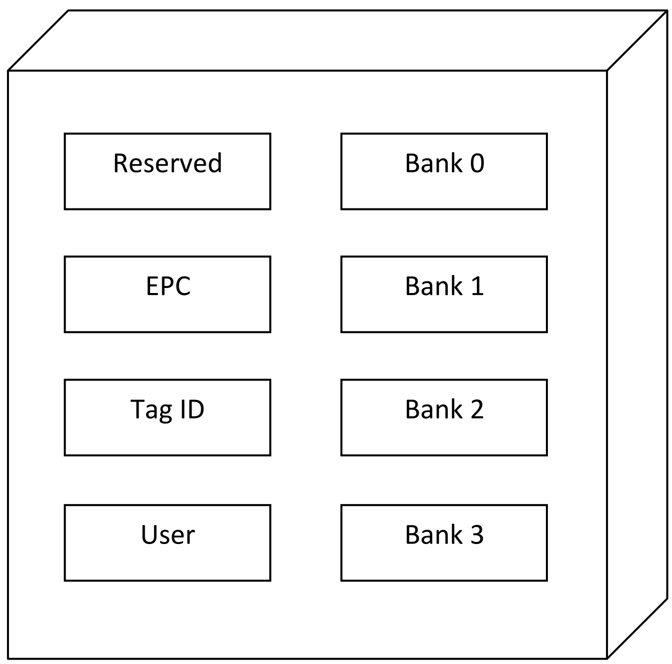


Figure 4.4: Tag memory layout (Adapted from Banks *et al.,* 2007, Figure 3.9, pg 82)

The functions of each of these memory banks are presented in Table 4.7. On the user-defined memory of passive tags, we can read and write small amount of data such as part number, part name, part origin, and part destination.

Table 4.7: Functions of passive RFID tag memory banks (Adapted from Banks et al., 2007)

	Memory Banks	**Functions**
1	Reserved	Contains the kill and access password
2	EPC	Contains a 16-bit cyclic redundancy check for validating the integrity of the rest of the data found in the EPC memory block
3	Tag ID	Contains an 8-bit ISO/IEC 15963 class identifier that is associated with the type or manufacturer of tag.
4	User	Contains user-defined data, where read and write can be targeted

4.2.2 Data requirement for the EOL aircraft IS and RFID tag memory

From the AFRA, best management practice, 2009, documentation, we identify five categories of information that are required for the identification of parts after parts are removed from the EOL aircraft. These five categories, and their contents, are given in Table 4.8.

To enable easy access to data on the enterprise application system, data needs to be properly organized in the IS in accordance with relational database rules. On RFID tags, data also need to be organized; but, in this case, it is done to ensure that RFID tag memories are not exceeded, and that only data relevant to any given process are available to the operator of that process.

Table 4.8: Data requirements for EOL aircrafts (Adapted from AFRA, Best Management Practice, Management of Used Aircrafts and Assemblies, 2009)

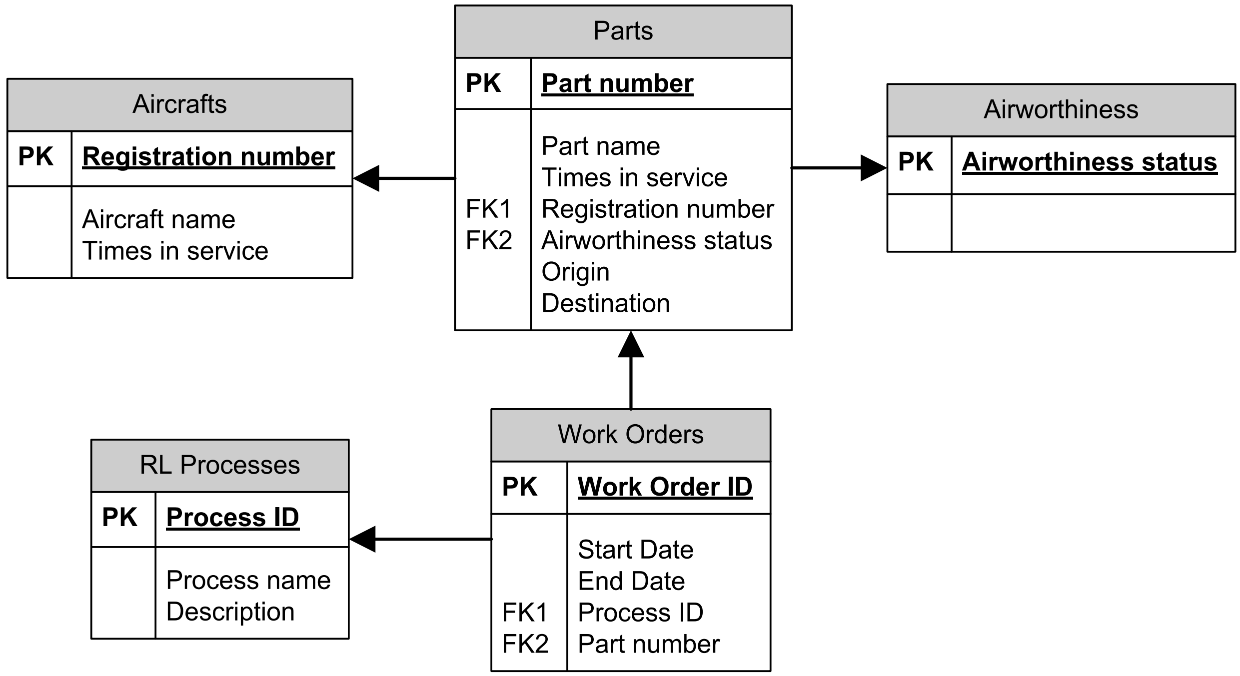
	Categories	Contents
1	Information that uniquely identifies the asset (i.e. EOL aircraft)	Registry number or serial number
2	Information that identifies process	Work order number or customer identification
3	Information that identifies the part	Part number, serial number, location from which part was removed
4	Information that identifies elements that contribute to the condition of the part	Total times/cycles on parts, total times/cycles on EOL aircraft (or asset)
5	Information about the airworthiness of part	Airworthiness identification ("Subject to airworthiness event" or "Not subject to airworthiness event")

4.2.3 Layout of data on the EOL aircraft RL network IS database

From the information provided in Table 4.8, the database of the EOL aircraft RL network IS is designed using the Entity-Relationship (ER) diagrams (Storey,1991; Cambel and Embley,1987) in Figure 4.5. Descriptions of the entities and fields in the ER diagrams are provided in Table 4.9. From the information in Figure 4.5 and Table 4.8, we see that an EOL aircraft is identified by its registration number, its name, and its times in service; a part is identified by its part number, its times in service, the registration number of EOL aircraft from which part was removed, its airworthiness state, and its origin and destination; a process is identified by its process ID, its name, and its description; and a work-order is identified by its work-order ID, the start date and end date of work, the process ID, and the part number.

Table 4.9: Descriptions of entities and fields of EOL aircraft IS

Entities	Fields	Descriptions	Sample values
Aircrafts	Registration number	Unique identifier for EOL aircraft	45445453412
	Aircraft name	Name of EOL Aircraft	Boeing 707
	Times in service	Times or cycles that EOL aircraft was in service	25 years
Parts	Part number	Unique identifier for part	PT45545
	Part name	Name of part	Gearbox
	Times in service	Times or cycles that part was in service	5 years
	Origin	Source of part	Montreal
	Destination	Destination of part	Ottawa
Airworthiness	Airworthiness status	Identifies if part is airworthy or not	Subject to airworthiness test, Not subject to airworthiness test
RL Processes	Process ID	Unique identifier for a process	RL4045
	Process name	Name of process	Recycle, Reuse, Remanufacture, Dispose
	Description (optional)	Description of process	Recycle at Montreal plant
Work Orders	Work order ID	Unique identifier for a work order	W97
	Start date	Start date of work	13/05/2012
	End date	End date of work	14/10/2013



Note: PK means primary key and FK means foreign key

Figure 4.5: ER diagram for EOL aircraft IS

4.2.4 Layout of data on RFID tags

The work-order table of the EOL aircraft RL IS has four fields of data:

1. Data required to identify work-order (i.e. work-order ID)
2. Data required to identify parts (i.e. part number)
3. Data required to identity origin and destination of parts (i.e. origin and destination fields)
4. And, data required to identify processes (i.e. process ID)

In order to store the data on RFID tags, and have them visible across the entire RL network, two solutions are proposed:

1. Use of low-memory tags (e.g. passive tags) with only the work-order ID stored on it, but with network connection that enables the retrieve, and update, of other data from IS database by using the work-order ID.
2. Use of high-memory tags (e.g. active tags) with most or all of the data stored on it, and with network connection that enables synchronization of the data on the RFID tag memory with the ones on the IS database.

4.3 Hypothesized models

4.3.1 Process map for as-is EOL aircraft RL network

The process map for the current or as-is EOL RL network, developed through information obtained from literature review (AFRA, best management practice manual, 2009; Bottani and Rizzi, 2008) and discussions with aviation experts, is given in Figure 4.6. The process map represents the hypothesized (design) model of the EOL RL network. It also represents the base model in which traditional barcode system is used for identifying parts. In earlier work by Sarac *et al.*, (2008), base model was first simulated to analyze the dynamic and stochastic behaviors of a supply chain in which inventory inaccuracy occurred with barcode system. In this work, however, we first analyze the base model in order to identify the business process re-engineering (BPR) (Banks *et al.*, 2007) which enabled the development of our to-be process maps in which item-level, case-level and pallet-level RFID tagging are used, and after, we simulate the base model and to-be process maps in order to measure the improvements achievable with the integration of RFID technology, and also determine the ROI. The processes in the process map are listed in Table 4.10.

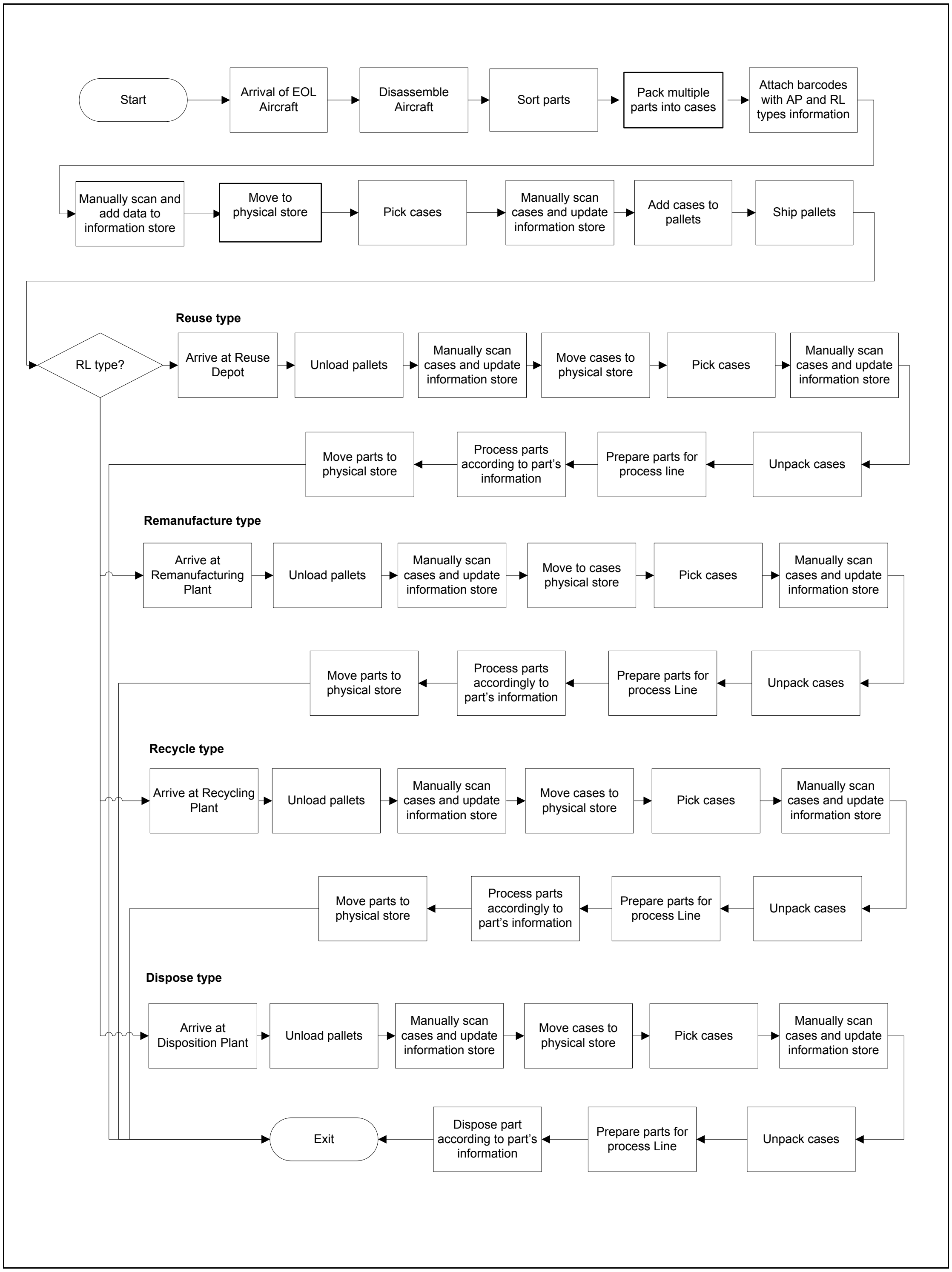


Figure 4.6: Process map for as-is EOL aircraft RL network with case-level barcode tagging

Table 4.10: Processes in as-is EOL RL network with case-level barcode tagging

S/N	**Processes**
1	Disassembling of aircrafts at disassembly facility
2	Sorting of parts
3	*Packing of two or more parts into case*
4	Tagging of cases with barcodes
5	*Manual scanning of tags and adding of data to information store*
6	Storing of cases in physical store
7	Picking of cases from physical store
8	*Manual scanning of cases and update of information store*
9	Adding of cases to pallets
10	Shipping of pallets to processing facilities
11	Unloading of pallets at processing facilities
12	*Manual scanning and update of information store at processing facilities*
13	Moving of cases to physical store at processing facilities
14	Picking of cases at processing facilities
15	*Manual scanning and update of information store at processing facilities*
16	Unpacking of cases
17	Preparing parts for process lines
18	Processing of parts according to part's information
19	Moving of processed parts to physical store

Five main processes can be identified in Table 4:10:

1. Disassembling
2. Picking
3. Shipping
4. Receiving
5. Processing (i.e. reuse, remanufacture, recycle, and dispose).

4.3.2 Process maps for to-be EOL aircraft RL network

Three process maps are built for the to-be RL network. They are:

1. The to-be EOL aircraft RL network with item-level RFID tagging
2. The to-be EOL aircraft RL network with case-level RFID tagging
3. The to-be EOL aircraft RL network with pallet-level RFID tagging

Discussions about each of the process maps are presented in the following subsections:

4.3.2.1 Process map for EOL aircraft RL network with item-level RFID tagging

The process map for the EOL RL network with item-level RFID tagging, which is derived from the base model, is presented in Figure 4.7. Processes in the EOL RL network are listed in Table 4.11. With the integration of RFID tagging at the item-level (Comparing Table 4.10 and Table 4.11), the following BPR are realized:

1. One part is packed per case
2. RFID tags are attached to parts after the process of disassembling, sorting and

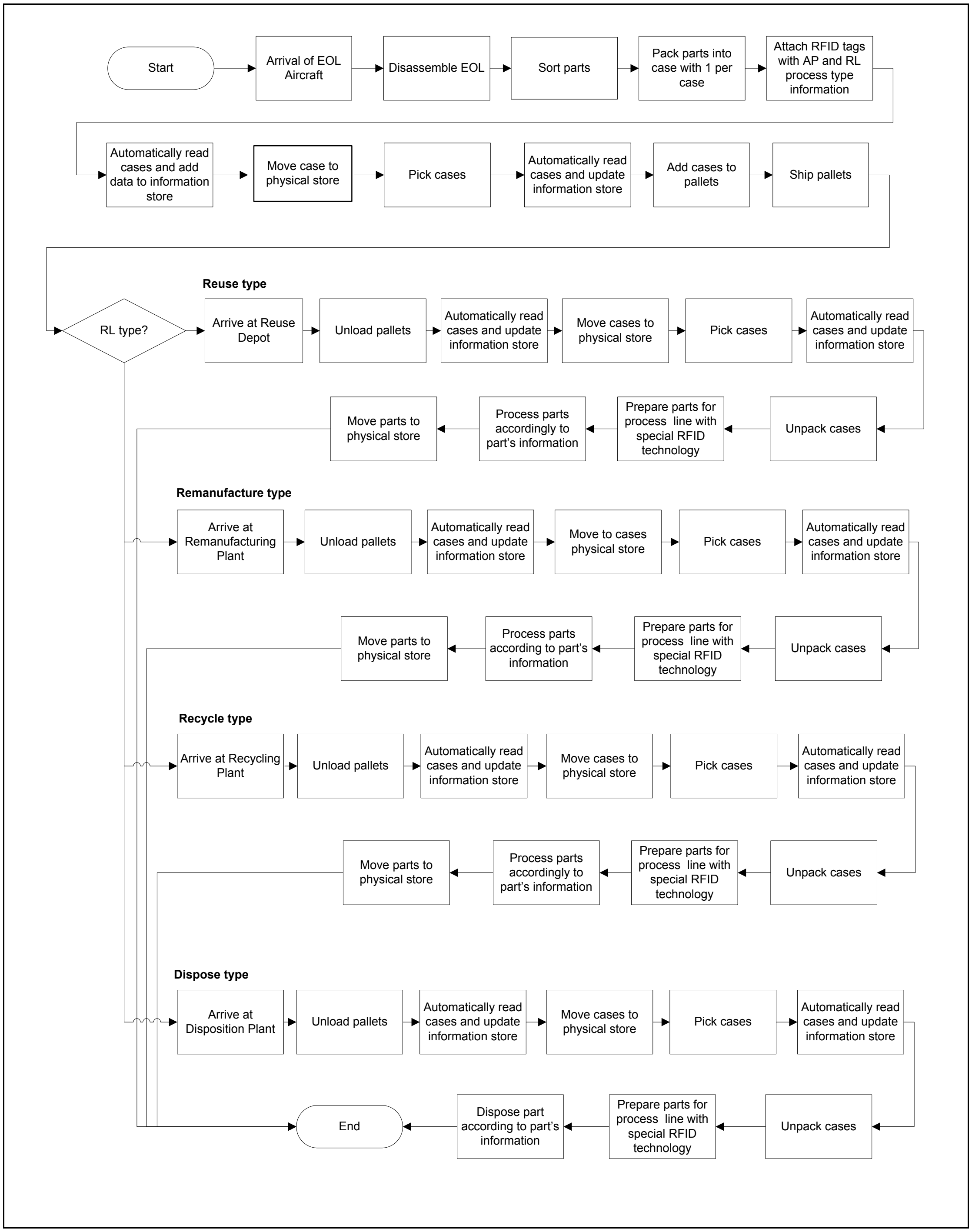


Figure 4.7: Process map for to-be EOL aircraft RL network with item-level RFID tagging

Table 4.11: Processes in to-be EOL RL network with item-level RFID tagging

S/N	Processes
1	Disassembling of aircrafts at disassembly facility
2	Sorting of parts
3	*Packing of one part per case*[4]
4	Tagging of the part or case containing single part with RFID tags containing data about the part
5	*Automatic reading of RFID tags and storing of data in information store*
6	Storing of cased part in physical store
7	Picking of cases from physical store
8	*Automatic reading of RFID tags on picked cases and updating of data in information store*
9	Adding of cases to pallets
10	Shipping of pallets to processing facilities
11	Unloading of pallets at processing facilities
12	*Automatic reading of RFID tags and storing of data in information store at processing facilities*
13	Moving of cases to physical store at processing facilities
14	Picking of cases at processing facilities
15	*Automatic reading of RFID tags on picked cases and update of data on information store at processing facilities*
16	Unpacking of cases
17	Preparing parts for process lines
18	Processing parts according to part's processing information
19	Moving of processed parts to physical store

[4] A single part, particularly reuse and remanufacture types, are cased to protect them from damage. A single part can also be cased to ensure safety and to reduce interference and absorption of RFID signals.

casing. In situations where a part needs to be protected from damage by placing the part in a case, an RFID tag containing information about the single part is attached to the case.

3. The sample data provided in Figure 4.8, with part number included, is stored per RFID tag memory
4. Data on RFID tags are automatically read and stored on information store
5. Inventory management is enhanced with RFID technology
6. Processing of parts on process lines is enhanced with RFID technology

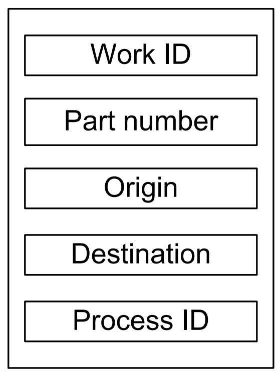


Figure 4.8: Sample data for item-level RFID tagging stored on active RFID tag memory

4.3.2.2 Process map for EOL aircraft RL network with case-level RFID tagging

The process map for the EOL RL network with case-level RFID tagging is presented in Figure 4.9. Processes in the EOL RL network are listed in Table 4.12. With the integration of RFID tagging at the case-level (Comparing Table 4.10 and Table 4.12), the following BPR can be identified:

1. Two or more similar parts are packed per case

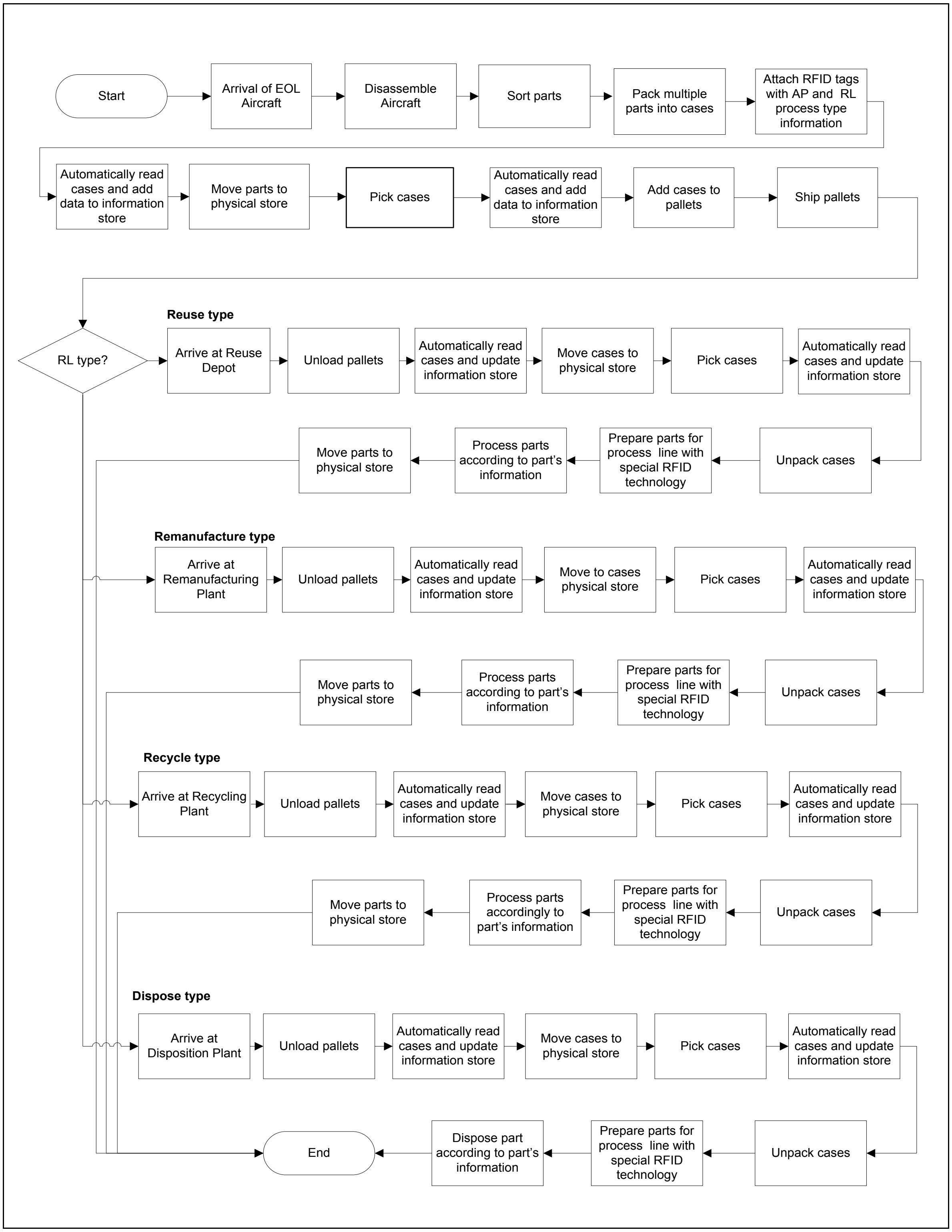


Figure 4.9: Process map for to-be EOL RL network with case-level RFID tagging

2. RFID tag are attached to cases containing multiple parts after the process of disassembling, sorting and casing
3. The sample data provided in Figure 4.10, with case ID replacing part number, is stored per RFID tag memory
4. Data on RFID tags are automatically read and stored on information store
5. Inventory management is enhanced with RFID technology
6. Transportation logistics is enhanced with RFID technology
7. Processing of parts on process lines is enhanced with RFID technology

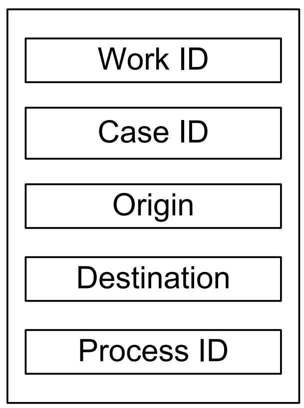


Figure 4.10: Sample data for case-level RFID tagging stored on active RFID tag memory

S/N	Case ID	Part ID
1	012323	N123323
2	012323	N344335
3	343434	N123323

Figure 4.11: Sample lookup table with case ID as search key

Table 4.12: Processes in to-be EOL RL network with case-level RFID tagging

S/N	**Processes**
1	Disassembling of aircrafts at disassembly facility
2	Sorting of parts
3	*Packing of two or more parts per case*
4	Tagging of the case with RFID tags
5	*Automatic reading of RFID tags and storing of data in information store*
6	Storing of cased parts in physical store
7	Picking of cases from physical store
8	*Automatic reading of RFID tags on picked cases and update of data on information store*
9	Adding of cases to pallets
10	Shipping of pallets to processing facilities
11	Unloading of pallets at processing facilities
12	*reading of RFID tags and storing of data in information store at processing facilities*
13	Moving of cases to physical store at processing facilities
14	Picking of cases at processing facilities
15	*Automatic reading of RFID tags on picked cases and update of data on information store at processing facilities*
16	Unpacking of cases
17	Preparing parts for process lines
18	Processing parts according to part's processing information
19	Moving of processed parts to physical store

4.3.2.3 Process map for EOL aircraft RL network with pallet-level RFID tagging

The process map in Figure 4.12 is employed for the scenario with pallet RFID tagging. Processes in the EOL RL network are listed in Table 4.13. The following BPR are identified for the scenario with pallet tagging:

1. One or more similar parts are packed per case
2. RFID tag are attached to pallets with multiple cases after the process of disassembling, storing, sorting, casing and picking
3. The sample data provided in Figure 4.13, with pallet ID replacing part number, is stored per RFID tag memory
4. Data on RFID tags are automatically read and stored on information store
5. Inventory management is enhanced with RFID technology
6. Transportation logistics is enhanced with RFID technology
7. Processing of parts on process lines is enhanced with RFID technology

The second BPR, which involves the application of RFID technology after the processes of disassembling, storing, sorting, casing and picking, has the effect of increasing value added cost due to the delayed use of the automatic and data capturing advantages of RFID technology for inventory counting and data capturing. On the hand, delayed application of RFID technology, can result in time-savings and cost reduction if routing and associated decision-making are postponed until after RFID technology integration[5] .

[5] Routing and decision-making can be done manually before integration of RFID technology. This will lead to increase in waiting time and cost.

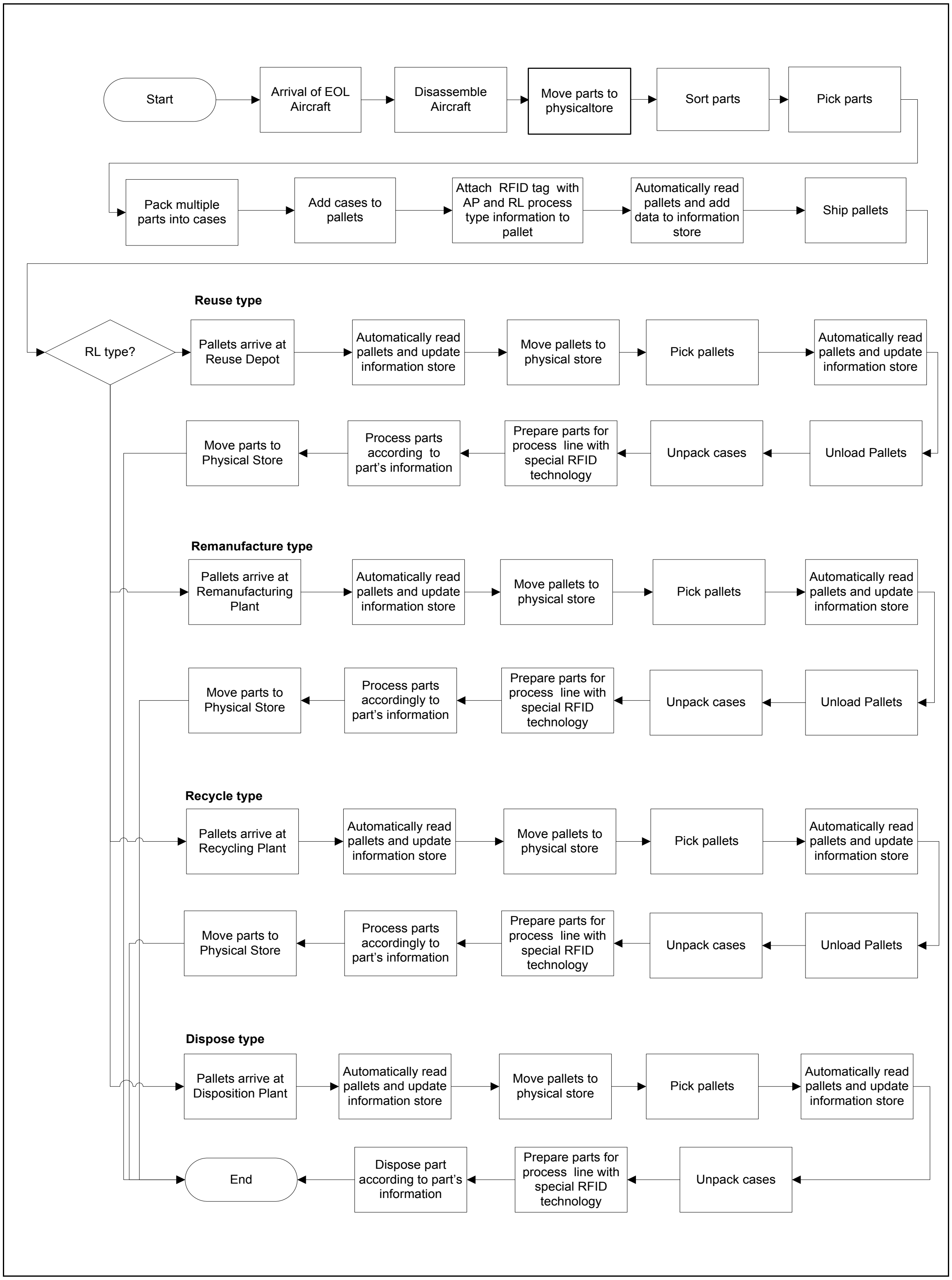


Figure 4.12: Process maps for EOL aircraft RL with pallet-level RFID tagging

Table 4.13: Processes in to-be EOL RL network with pallet-level RFID tagging

S/N	Processes
1	Disassembling of aircrafts at disassembly facility
2	Moving of parts to physical store
3	Picking of parts from the physical store
4	Sorting of parts
5	*Packing of one or more parts per case*
6	Adding of cases to pallet
7	*Tagging of pallets with RFID tags*
8	*Automatic reading of RFID tags on pallets and update of data on information store*
10	Shipping of pallets to processing facilities
11	Unloading of pallets at processing facilities
12	*Automatic reading of RFID tags on pallets and storing of data in information store at processing facilities*
13	Move pallets to physical store at processing facilities
14	Picking pallets at processing facilities
15	*Automatic read RFID tags on picked pallets and update data on information store at processing facilities*
16	Unloading of pallets at processing facilities
17	Unpacking of cases
18	Preparing parts for process lines
19	Processing parts according to part's processing information
20	Moving of processed parts to physical store

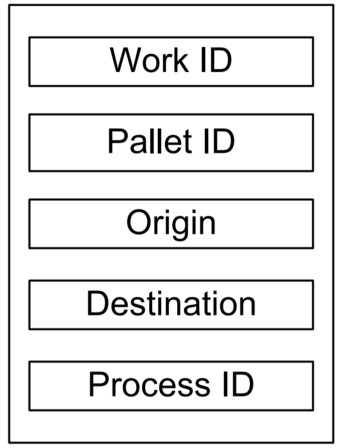


Figure 4.13: Sample data for pallet-level RFID tagging stored on active RFID tag memory

S/N	Pallet	Case ID	Part ID
1	443434	012323	N123323
2	443434	012323	N344335
3	469723	343434	N123323

Figure 4.14: Sample lookup table with pallet ID as search key

4.4 Requirements for conducting ROI analyzes for to-be RL network

As defined in Section 2.2.5, ROI is a form of performance measure (Fleisch and Tellkamp, 2005) in which the monetary time-value of a project is estimated using the direct benefits and the cost components of the project. Hence, as a first step towards calculating the ROI for the to-be EOL aircraft RL, we identify the direct benefits and cost components for inventory, picking, shipping, receiving and processing for the to-be RL networks. Next, we analyze the cost components to derive a formula for calculating total cost for the EOL aircraft RL network. From these analyzes, we create tables of operating costs and overhead costs for the EOL aircraft RL network. Finally, we employ the identified direct benefits and cost components in our simulation models to determine the ROI over a 5 year time period at a 5 percent discount rate (Discussed in Chapter 5).

4.4.1 Costs and benefits of EOL aircraft RL network

The cost and direct benefits for the processes and tagging levels of the EOL RL network are presented in Table 4.14.

4.4.2 Cost classifications

According to Bank *et al*. (2007), the cost components of RFID technology can be classified as RFID and Wi-Fi hardware (H/W) costs, network and application H/W and software(S/W) costs, integration costs, and personnel costs (Banks *et al*., 2007). The costs associated with this classification are presented in Table 4.15, Table 4.16, Table 4.17 and Table 4.18, respectively.

The network and application H/W and S/W costs in Table 4.16 include the cost of a 3-tier client-server architecture[6] configuration with web server, application server, and a database server. The capacities of the servers need to be properly determined by experts to ensure that the servers can adequately meet the demands of data-processing and service requests from client computers.

[6] Client tier, middle tier (web server and application server) and database tier

Table 4.14: Cost and direct benefits of RFID in EOL aircraft RL (Adapted from Bottani and Rizzi, Table 3 pg 556)

Processes	**Item level tagging**	**Case-level tagging**	**Pallet level tagging**
Inventory	Costs: ▪ Cost of RFID tags for cased single part ▪ Cost of packaging ▪ Cost of RFID readers ▪ Cost of printers and print labels Savings: ▪ Cost of manpower required to perform manual inventory count ▪ Cost of manpower required to perform manual update of information system ▪ Cost of shrinkage	Costs: ▪ Cost of RFID tags for cased multiple parts. ▪ Cost of packaging ▪ Cost of RFID readers ▪ Cost of printers and print labels Savings: ▪ Cost of manpower required to perform manual inventory count ▪ Cost of manpower required to perform manual update of information system ▪ Cost of shrinkage	Costs: ▪ Cost of manpower required to perform manual inventory count ▪ Cost of manpower required to do manual update of information system ▪ Cost of shrinkage
Picking	Costs: ▪ Cost of RFID readers Savings: ▪ Cost of manpower required to perform manual check operations on picked packaged parts ▪ Cost of manpower required to manually update information system	Costs: ▪ Cost of RFID readers Savings: ▪ Cost of manpower required to perform manual check operations on picked packaged parts ▪ Cost of manpower required to manually update information system	Costs : ▪ Cost of manpower required to perform manual check operations on picked parts ▪ Cost of packaging ▪ Cost of manpower required to manually update information system
Shipping	Costs: ▪ Cost of RFID gates	Costs: ▪ Cost of RFID gates	Costs: ▪ Cost of RFID tags for pallets ▪ Cost of RFID gates ▪ Cost of printers and print labels

Table 4.14 Continued

Processes	Item level tagging	Case-level tagging	Pallet level tagging
	Savings: ▪ Cost of manpower required to perform operations on shipped parts ▪ Cost of manpower required to manually update information system	Savings: ▪ Cost of manpower required to perform operations on shipped parts ▪ Cost of manpower required to manually update information system	Savings: ▪ Cost of manpower required to perform operations on shipped parts ▪ Cost of manpower required to manually update information system
Receiving	Costs: ▪ Cost of RFID gates Savings: ▪ Cost of manpower required to perform check operations on received parts (check-in and error corrections) ▪ Cost of manpower required to manually update information store	Costs: ▪ Cost of RFID gates Savings: ▪ Cost of manpower required to perform check operations on received parts (check-in and error corrections) ▪ Cost of manpower required to manually update information store	Costs: ▪ Cost of RFID gates Savings: ▪ Cost of manpower required to perform check operations on received parts (check-in and error corrections) ▪ Cost of manpower required to manually update information store
Processing	Costs: ▪ Cost of fixed readers ▪ Cost of manpower required for uncasing ▪ Cost of handheld readers ▪ Cost of RFID tags for trolleys Savings: ▪ Cost of paper-based work-orders ▪ Cost of manpower required to manually update information system ▪ Cost of shrinkage	Costs: ▪ Cost of fixed readers ▪ Cost of manpower required for uncasing ▪ Cost of handheld readers ▪ Cost of RFID tags for trolleys Savings: ▪ Cost of paper-based work-orders ▪ Cost of manpower required to manually update information system ▪ Cost of shrinkage	Costs: ▪ Cost of fixed readers ▪ Cost of manpower required for uncasing ▪ Cost of handheld readers ▪ Cost of RFID tags for trolleys Savings: ▪ Cost of paper-based work-orders ▪ Cost of manpower required to manually update information system ▪ Cost of shrinkage

Table 4.15: RFID and Wi-Fi H/W costs (Adapted from Banks et al., 2007; pg 180, Table 6.6)

	RFID and Wi-Fi H/W Description
1	Active tag
2	Passive tag
3	Active tag reader
4	Passive tag reader
5	RFID gate reader
6	Antennae
7	Antennae installation HW
8	Handhelds
9	Power and Cabling Infrastructure
10	Wi-Fi Access Point
11	Wi-Fi-Repeater

Table 4.16: Network and application H/W and S/W costs (Adapted from Banks et al., 2007; Pg 181, Table 6.7)

	Network and Application H/W and S/W Description
1	Web Server
2	Application Server
3	Database Server
4	UPS
5	Network Switch
6	Database System
7	Web Server Software
8	Application Server Software
9	Middleware Application
10	Tracking Application (per year)

Table 4.17: Integration costs (Adapted from Banks et al., 2007; pg 181, Table 6.8)

	Integration and Interfacing Description
1	Integration with Inventory Management System (IMS)
2	Integration with Shipping Logistics System (SLS)
3	Integration with Processing Facility System (PFS)
4	Integration with Client Service System (CSS)

Table 4.18: Personal costs (Adapted from Banks et al, 2007; pg 181, Table 6.9)

	Personnel Description
1	Training of Personnel

Table 4.19: Barcode system costs

	Barcode Description	**Unit Cost ($)**
1	Barcode	0.5
2	Barcode scanner	700

4.4.3 Cost calculations

For the EOL aircraft, we calculate the total cost as:

Total cost = operating costs + overhead costs

$$= (IC_{i=0} + VC_i) + (VAC_i + WC_i + NVAC_i) \qquad (4.1)$$

Where,

$IC_{i=0}$ is the investment for year i = 0, $i \in T_i$, where T_i is a set of yearly periods

VC_i is the variable cost for period i

VAC_i is the value added cost for period i

WC_i is the waiting cost for period i

$NVAC_i$ is the non-value added cost for period i

For the operating cost,

$VC_i = C_m * Q_m$ for ∃i in T_i (4.2)

Where C_m is the unit cost of RFID technology component m, and Q_m is the quantity of m. Since C_m is constant and Q_m is variable, VC_i varies with Q_m.

For the overhead cost, VAC_i for a given period i can be calculated as:

$VAC_i = h \times VAT_i + (\sum_{j \in R_i} b_j) \times VAT_i + (\sum_{j \in R_i} u_j) = (h + \sum_{j \in R_i} b_j) \times VAT_i + (\sum_{j \in R_i} u_j)$

(Rossetti, 2010; pg 452) (4.3)

Where,

h is the holding cost rate

VAT_i is the value added time for period i

u_j is the usage cost associated with j^{th} resource used during an activity

b_j is the busy cost associated with j^{th} resource used during an activity

R_i is the set of resources used by the entity in an activity period

Waiting cost, WC_i and non-value-added cost, $NVAC_i$ for a given period i are calculated as:

$WC_i = h \times WT_i$ (4.4)

$$NVAC_i = h \ x \ NVAT_i \qquad (4.5)$$

Where,

WT_i is the waiting time for period i

$NVAT_i$ is the holding cost for period i

Value added cost, waiting cost, holding cost rate, usage cost, and busy cost are used in Arena simulation software. Holding cost rate (h) is the cost per time incurred when an entity (e.g. aircraft parts) is waiting in the system or in any process (Arena Variables Guide, 2005).

4.4.4 Operating and overhead costs for EOL aircraft RL network

Drawing from our discussions on cost, we present for the EOL aircraft RL network the overhead costs and operating costs in Table 4.20 and Table 4.21, respectively. Quantity, c, represents a constant value; quantity, x, represents a variable value that depends on the quantities of parts that requires processing; and VAC_i, WC_i, $NVAC_i$ represents time dependent costs.

Table 4.20: Overhead costs

Cost type	**Cost ($)**
Value added cost	VAC_i
Waiting cost	WC_i
Non-value added cost	$NVAC_i$

Table 4.21: Operating costs (Adapted from Banks et al., 2007)

Categories	**Cost components**	**Unit cost ($)**	**Quantity**	**Total**
Investment costs	Web server	5,000	c	5000c
	Application server	10,000	c	10000c
	Database server	15,000	c	15000c
	UPS	1,000	c	1000c
	Network switch	2,500	c	2500c
	Database system	50,000	c	50000c
	Web server software	20,000	c	20000c
	Application server software	20,000	c	20000c
	Middleware application	100,000	c	100000c
	Power and Cabling Infrastructure	50,000	c	50000c
	Tracking Application	150,000	c	150000c
	RFID gate reader	1,500	c	1500c
	Active tag reader	2,500	c	2500c
	Passive tag reader	500	c	500c
	Antennae	1,500	c	1500c
	Antennae installation HW	200	c	200c
	Handhelds	500	c	500c
	Wi-Fi Access Point	1,000	c	1000c
	Wi-Fi-Repeater	200	c	200c
	Integration with IMS	80,000	c	80000c
	Integration with SLS	80,000	c	80000c
	Integration with PFS	75,000	c	75000c
	Integration with CSS	75,000	c	75000c
Variable costs	Active tags	25	x	25x
	Passive tags	10	x	10x

4.5 End note

In this chapter, we presented selection metrics based on system and environment specifications and item specifications for selecting the most suitable RFID technology solutions. We, thereafter, proposed a selection model for the EOL aircraft RL network with scenarios that use (1) only passive RFID tags (2) only active RFID tags (3) and both passive and active RFID tags for four environments (Physical store, shipping point, receiving point, processing facilities) identified in the EOL aircraft RL network.

Following our discussion of the requirements given in the AFRA best management practice manual, we proposed a possible schema or layout (ER-relationship diagram) for the EOL aircraft IS data and for the RFID tag memory. We also presented four process maps: one process map (Case-level barcode tagging) for the as-is EOL aircraft RL network, and three process maps (Item-level RFID tagging, case-level RFID tagging, and pallet-level RFID tagging) for the to-be EOL aircraft. The to-be process maps were developed from the as-is process maps by analyzing the as-is process map and identifying the BPRs that are required to develop the to-be process maps.

Finally, we discussed the requirements for performing ROI analyzes of RFID technology implementation in the EOL aircraft RL network by identifying the benefits and costs for our proposed RFID-enabled systems, enumerating and classifying the cost components of RFID technology and barcode systems, and formulating mathematical equations for calculating the total cost of RFID or barcode technology for the EOL aircraft RL network.

Chapter 5:

Simulation Model and Numerical Application

In this chapter, the constraints and assumptions guiding our simulation models (Section 5.1), the procedures for developing the simulation models to calculate the ROI for the EOL aircraft RL network (Section 5.2, a numerical application of our simulation model (Section 5.3), and results obtained from the numerical application are presented.

5.1 Constraints and assumptions

The constraints and assumptions guiding our simulation models are as follow:

Constraints:

1. Experiment is conducted in a lab environment with simulation models

Assumptions:

1. Disassembly, inventory, shipping, receiving and process facilities already exist; hence, their setup costs are not included in the ROI analyzes.
2. All parts are contained in special casing that helps to protect the parts and prevent interference and absorption of RFID signals.
3. Passive tags are used in the to-be systems.
4. Data on RFID tag memory is shared across the EOL aircraft RL network.
5. Simulation clock (Rosetti, 2010, Kelton *et al.*, 2009) runs 8 hours per day for 365 days

6. Total cost = operating cost + overhead cost

5.2 Elements of simulation model

A number of terms are used in discrete event simulations to describe the characteristics, behaviours, states, and performance of a system being modeled. Discrete event simulation can be done by hand using mathematical formulas. Use of Arena simulation software, however, helps to save the long hours and overhead costs of performing hand simulation by providing computer-based tools and graphical objects for creating simulation models, verifying the simulation models to identify and eliminate errors, and obtaining results for the simulation after running the simulation.

Terms use in discrete event simulations that are relevant to our work, and their representations in Arena simulation software are presented in the following subsections:

5.2.1 System

In discrete event simulation, a system encompasses all components, such as entities, processes, and resources, including their input data, that function together to generate the performance or output of the system. For the problem under consideration, the system is the EOL aircraft RL network, and its key components are the EOL aircrafts, the EOL aircraft parts, the processes they pass through as they flow though the system, and the resources they consume or utilize as they pass through these processes. Steps for creating a new model of a system in Arena simulation software are provided in Appendix A.1.

5.2.2 Entities

"Entities are the dynamic objects in the simulation that are created, moved around for a while and disposed as they leave [the simulation]" (Kelton *et al.*, 2009). Entities have attributes that uniquely identifies them in a system. The entities in the EOL aircraft RL network are the aircrafts, aircraft parts, cases, and pallets. Although RFID tags are also entities, they are modelled as attributes of the EOL aircraft parts in our simulation model. The holding cost rate for entity *EOL aircraft part* (See Table 5.2) is $20 per hour. Steps for creating entities in Arena simulation software are provided in Appendix A.2.

5.2.3 Attributes

An attribute is a characteristic of an entity. Entities are distinguished from one another when they have one or more attributes with different values, for example two entities with different colors, sizes, costs, and ID numbers. Attributes can be common to multiple entities or specific to one. In Arena simulation software, common attributes, such as entity picture, holding cost, and so on are created when the entity is created (Figure 5.3b). Steps for creating attributes in Arena simulation software are provided in Appendix A.3.

5.2.4 (Global) Variables

"A variable (or global variable) is a piece of information that reflects some characteristics of a system, regardless of how many or what kind of entities might the around" (Kelton *et al.*, 2009). In Arena simulation software, there are two types of variables: built-in variables, and user-defined variables (Kelton *et al.*, 2009). Examples of (user-defined) variables in the EOL aircrafts RL network are the number of aircraft parts, the number of

RFID tags, the number of processed parts, the total costs of RFID tags, and so on. Steps for creating variables in Arena simulation software are described in Appendix A.4.

5.2.5 Resources

Resources are used by entities as they pass through the system. Examples of resources in the EOL aircraft RL network are manpower, RFID readers, movers, and shippers. Steps for creating resources are provided in Appendix A.5. In Arena simulation software, associated with resources are the resource costs such as busy cost, idle cost, and per usage cost. Costs of resources used in our models are provided in Table 5.1. These values with the value added time obtained in Arena simulation software are used to calculate the value added cost given in Equation 4.3.

Table 5.1: Resource costs

Resource	**Busy cost per hour (b_j) ($/hr)**	**Per usage cost (u_j) ($)**
Disassembly machine	100	10
Processing plant	100	10
RFID reader	5	2
Barcode scanner and labour	40	10
Human Labor	40	10
Shippers	50	10
Movers	15	5

5.2.6 Events

An event is an action that affects the state of an entity in one way or another when it occurs. In Arena simulation software there are several events such *Create, Dispose, Process, Store, Hold, Pick, Batch, Separate, Decide, Assign,* and *Record*; and a system must have at least *Create, Process,* and *Dispos*e events. In the EOL aircraft RL network, all its processes can be modeled as events. Steps for creating events in Arena simulation software are provided in Appendix A.6.

5.2.7 Advanced process module

The discrete event simulation objects discussed so far are all in the *Basic* process module of Arena Simulation software. The *File, Expression,* and *Readwrite* objects are part of the *Advanced* process module.

5.2.8 File

The *File* object represents a file on the hard-drive from which data can read from or written to from Arena simulation software. The file can be a sequential file (.txt), Microsoft Excel and Microsoft Excel 2007 (*xls, *xlsx), LOTUS spreadsheet (*wks), ActiveX Data Objects (ADO) and eXtensible Markup Language (*xml). In our work, Microsoft Excel 2007 was used to store the input and output data from our simulation models. Steps for creating *File* object in Arena simulation software are provided in Appendix A.7.

5.2.9 Expression

The *Expression* object is used to represent a mathematical expression that is required in multiple places in the simulation model. The mathematical expression used in the *Expression* object can be typed or read in from an external file.

5.2.10 Readwrite

The *Readwrite* object helps to read values for variables and attributes from an external file, and write values from variables and attributes to an external file.

Descriptions of model objects used in our simulation models are presented in Table 5.2 and screen-shots of running simulations for case-level barcode tagging, item-level RFID tagging, case-level RFID tagging, and pallet RFID tagging are presented in Appendix C.

5.2.11 Input data

After completing the models of the four process maps for the EOL aircraft RL network, using the approach described in Section 5.2, we use numerical data to test the simulation models and obtain results. Although Arena simulation software allows input data to be supplied directly in the model objects, for instance by specifying the arrival distributions of EOL aircrafts in the *Create* event or the time distributions for processes in EOL aircrafts RL network in the *Process* event, we choose to separate the input data from the model by keeping the data in a Microsoft Excel file and accessing them in the simulation model using the *File, Readwrite* and *Expression* model objects. This approach has the advantage of facilitating the testing of simulations models with different input data, without the rigor of modifying data directly in the simulation models each time new data inputs is used. This approach also enables people who do not have strong knowledge of the simulation models but understand the data requirements to use the simulation models; thus, protecting the simulation models from damage.

Table 5.2: Simulation model objects

Model object names	**Examples on simulation models**	**Descriptions**
Entity	EOL aircraft parts	Entity that represents aircraft parts
	Case	Entity that represents cases for parts
	Pallet	Entity that represents pallets
Attribute	Nparts	Number of parts
	Materials	Array attributes that holds data on materials in aircraft
	Component	Array attributes that holds data on components of aircraft
	Aircraft frames	Array attributes that holds data on components in aircraft
	Avionic	Array attributes that holds data on avionics in aircraft
	Power system	Array attributes that holds data on power systems in aircraft
Variable	vMaterial	Variable that counts number of materials
	vComponent	Variable that counts number of components
	vAircraftFrames	Variable that counts number of aircraft frames
	vAvionics	Variable that counts number of avionics
	vPowersystems	Variable that counts number of power systems
Create	Arrival of EOL aircraft	Events that initiates arrival of EOL aircrafts
Process	Disassemble, sort, package, etc.	Same as on process maps
Resources	Disassembling machine	Resource of disassembling plant
	Sorter	Resource of part sorters
	Manpower	Resource of manual labor
	RFID reader	Resource of RFID reader
	Mover	Resource of movers of parts to physical store
	Shippers	Resource of shippers
	Processing plants	Resource of processing plant

Table 5.2 Continued

Model object names	**Examples on simulation models**	**Descriptions**
Separate	Disassemble aircraft	Event that represents separation of EOL aircraft
Batch	Batch_1, Batch_2, etc.	Events that represent separation of EOL aircraft
Decide	Aircraft part type?	5-way condition to decide type of aircraft part
	Material RL types?	4-way condition to decide RL type of aircraft materials
	Avionic RL types?	4-way condition to decide RL type of aircraft avionics
	Aircraft frame RL type?	4-way condition to decide RL type of airframes
	Power system RL type?	4-way condition to decide RL type of aircraft power system
	Component RL type?	4-way condition to decide RL type of aircraft component
Dispose	End1, End2, End3, etc	Events that represent exit of EOL aircraft
Assign	Assign aircraft part types	Assigns distribution values from record-set to materials, components, aircraft frames, avionics, power systems attributes
	Count aircraft, etc.	Assigns new value to aircraft
	Attach RFID tags with AP and RL types	Assigns RL type to tags on part, case or pallet
Readwrite	Check-in	Reads data on EOL aircrafts from Excel file and assigns data to attributes in simulation model
	Record count	Writes counts of RL types for materials, components, aircraft frames, avionics, power systems to Excel file
Expression	ILProcesses, CLProcesses, ILBatchsizes, etc.	Model object that holds mathematical expressions for process distributions, and batch sizes
File	File EOLAircraftData, FileProcessDistribution, FileILBatchSizes	File objects that represents Excel files containing data for EOL aircrafts, process distributions, batch size, respectively.

The names of the Microsoft Excel files used for the input data, and the functions of the data contained in the files are provided in Table 5.3. Worksheets of EOLAircraftData.xls, ProcessDistributions.xlsx, ProcessDistributions_barcode.xlsx, Batchsize.xlsx, and ROI.xlsx are provided in Appendix B.

5.3 Numerical applications

Based on the constraints and assumptions provided in Section 5.1, we simulated the process maps for the EOL aircraft RL network for case-level barcode tagging, item-level RFID tagging, case-level RFID tagging, and pallet-level RFID tagging with this numerical application:

In a year, EOL aircrafts arrive exponentially with a mean inter-arrival rate of one aircraft per 20 days, and work is performed on the aircraft 8 hours per day with the time distributions for processes given in Tables 5.4, Table 5.5, Table 5.6, Table 5.7 for case-level barcode tagging, item-level passive RFID tagging, case-level passive RFID tagging, and pallet-level passive RFID tagging. It takes between 5 to 10 minutes to perform manual scanning, while it takes few seconds, assumed to be 5 to 10 seconds, to perform automatic read or write with RFID tags. The batch sizes for containers are given in Table 5.8. The time distributions for all other processes are the same for barcode and RFID technology. With the initial investment given in Table 5.9 and Table 5.10 for RFID and barcode technologies at year 0, ROI analyzes is conducted for a 5-year period and discount rate of 5 percent to measure the performance of RFID technology deployment relative to the case-level barcode system.

Table 5.3: Files and data used in simulation models

File names	**Data in named range of worksheet**	**Function of data**
EOLAircraftData.xlsx	Named range *EOLAircraftData* on worksheet *EOLAircraft Data*	Contains data on the model of EOL aircraft, and increasing percentages of part types and RL types in the EOL aircrafts
ProcessDistributions.xlsx	Named range *ILDistributionProcesses* on worksheet *Process Data*	Contains data on time distributions for processes in EOL aircraft RL network with item level RFID tagging
	Named range *CLDistributionProcesses* on worksheet *Process Data*	Contains data on time distributions for processes in EOL aircraft RL network with case level RFID tagging
	Named range *PLDistributionProcesses* on worksheet *Process Data*	Contains data on time distributions for processes in EOL aircraft RL network with pallet level RFID tagging
ProcessDistributions_barcode.xlsx	Named range *BDistributionProcesses* on worksheet *Process Data*	Contains data on time distributions for processes in EOL aircraft RL network with barcode tagging
Batchsize.xlsx	Named range *ILBatchsize, CLBatchsize, and PLBatchsize* on worksheet *Batchsize*	Contains the batch size for item level, case level, and pallet packaging

Table 5.4: Time Distributions for processing case-level barcode tagging

Processes	**Time distributions**	**Time Unit**
Disassembly	TRIA(5,6,7)	days
Sorting of parts	TRIA(5,8,10)	minutes
Casing of parts	TRIA(15,20,25)	minutes
Attach barcodes with RL types information	TRIA(5,8,10)	minutes
Manually scan barcode and add data to information store	TRIA(3,5,7)	minutes
Move case parts to physical store	TRIA(20,22,25)	minutes
Pick cases	TRIA(20,22,25)	minutes
Add cases to pallet	TRIA(20,22,25)	minutes
Ship pallets	TRIA(20,22,25)	minutes
Arrive at reuse depot	EXPO(10)	minutes
Unload pallets	TRIA(20,22,25)	minutes
Unpack cases	TRIA(20,22,25)	minutes
Prepare parts for process lines	TRIA(20,22,25)	minutes
Process parts according to part's information	TRIA(20,22,25)	minutes

Keys:

TRIA (Min, Mode, Max) - Triangular distribution with minimum, modal, and maximum values

EXPO (Mean) - Exponential distribution with mean value

Table 5.5: Time distributions for processing item-level RFID tagging

Processes	**Time distributions**	**Time Unit**
Disassembly	TRIA(5,6,7)	days
Sorting of parts	TRIA(5,8,10)	minutes
Casing of parts	TRIA(15,20,25)	minutes
Attaching of RFID tags	TRIA(5,8,10)	minutes
Automatically read data and update information store	TRIA(5,8,10)	seconds
Move cased parts to physical store	TRIA(20,22,25)	minutes
Pick cases	TRIA(20,22,25)	minutes
Add cases to pallet	TRIA(20,22,25)	minutes
Ship pallets	TRIA(20,22,25)	minutes
Arrive at reuse depot	EXPO(10)	minutes
Unload pallets	TRIA(20,22,25)	minutes
Unpack cases	TRIA(20,22,25)	minutes
Prepare parts for process lines with special RFID technology	TRIA(20,22,25)	minutes
Process parts according to part's information	TRIA(20,22,25)	minutes

Keys:

TRIA (Min, Mode, Max) - Triangular distribution with minimum, modal, and maximum values

EXPO (Mean) - Exponential distribution with mean value

Table 5.6: Time distributions for processing case-level RFID tagging

Processes	**Time distributions**	**Time Unit**
Disassembly	TRIA(5,6,7)	days
Sorting of parts	TRIA(5,8,10)	minutes
Casing of parts	TRIA(15,20,25)	minutes
Attaching of RFID tags	TRIA(5,8,10)	minutes
Automatically read data and update information store	TRIA(5,8,10)	seconds
Move cased parts to physical store	TRIA(20,22,25)	minutes
Pick cases	TRIA(20,22,25)	minutes
Add cases to pallet	TRIA(20,22,25)	minutes
Ship pallets	TRIA(20,22,25)	minutes
Arrive at reuse depot	EXPO(10)	minutes
Unload pallets	TRIA(20,22,25)	minutes
Unpack cases	TRIA(20,22,25)	minutes
Prepare parts for process lines with special RFID technology	TRIA(20,22,25)	minutes
Process parts according to part's information	TRIA(20,22,25)	minutes

Keys:

TRIA (Min, Mode, Max) - Triangular distribution with minimum, modal, and maximum values

EXPO (Mean) - Exponential distribution with mean value

Table 5.7: Time distributions for processing pallet-level RFID tagging

Processes	**Time distributions**	**Time Unit**
Disassembly	TRIA(5,6,7)	days
Sorting of parts	TRIA(5,8,10)	minutes
Casing of parts	TRIA(15,20,25)	minutes
Attaching of RFID tags	TRIA(5,8,10)	minutes
Automatically read data and update information store	TRIA(5,8,10)	seconds
Move cased parts to physical store	TRIA(20,22,25)	minutes
Pick cases	TRIA(20,22,25)	minutes
Add cases to pallet	TRIA(20,22,25)	minutes
Ship pallets	TRIA(20,22,25)	minutes
Arrive at reuse depot	EXPO(10)	minutes
Unload pallets	TRIA(20,22,25)	minutes
Unpack cases	TRIA(20,22,25)	minutes
Prepare parts for process lines with special RFID technology	TRIA(20,22,25)	minutes
Process parts according to part's information	TRIA(20,22,25)	minutes

Table 5.8: Batch size of containers

	Item level	**Case level**	**Pallet level**
Batch size	One item	Two items	Two cases each with two items

Table 5.9: Initial investment for RFID technology

Components	Unit cost ($)	Quantity	Total
Web server	5,000	2	10,000
Application server	10,000	2	20,000
Database server	15,000	2	30,000
UPS	1,000	6	6,000
Network switch	2,500	3	7,500
Database system	50,000	2	100,000
Web server software	20,000	6	120,000
Application server software	20,000	6	120,000
Middleware application	100,000	1	100,000
Power and Cabling Infrastructure	50,000	1	50,000
Tracking Application	150,000	1	150,000
RFID gate reader	1,500	5	7,500
Active tag reader	2,500	5	12,500
Passive tag reader	500	5	2,500
Antennae	1,500	10	15,000
Antennae installation HW	200	1	2,00
Handhelds	500	5	2,500
Wi-Fi Access Point	1,000	1	1,000
Wi-Fi-Repeater	200	1	200
Integration with IMS	80,000	1	80,000
Integration with SLS	80,000	1	80,000
Integration with PFS	75,000	1	75,000
Integration with CSS	75,000	1	75,000
			1,064,700

Table 5.10: Initial investment for barcode technology[7]

Components	Unit cost ($)	Quantity	Total
Web server	5,000	2	10,000
Application server	10,000	2	20,000
Database server	15,000	2	30,000
UPS	1,000	6	6,000
Network switch	2,500	3	7,500
Database system	50,000	2	100,000
Web server software	20,000	6	120,000
Application server software	20,000	6	120,000
Middleware application	100,000	1	100,000
Power and Cabling Infrastructure	50,000	1	50,000
Tracking Application	150,000	1	150,000
Barcode scanner	200	10	2,000
Wi-Fi Access Point	1,000	1	1,000
Wi-Fi-Repeater	200	1	200
Integration with IMS	80,000	1	80,000
Integration with SLS	80,000	1	80,000
Integration with PFS	75,000	1	75,000
Integration with CSS	75,000	1	75,000
			1,026,700

5.4 Presentation of results

In the simulated 8 hours daily operations lasting 356 day (2910 hours), fifteen EOL aircrafts were disassembled. Each aircraft was disassembled into 100 parts with the percentages values given in Table 5.11. The models were verified for errors, and no error was found. Results obtained from the simulation of the four simulation models for the first year, with eight replications, are presented in Table 5.12, Table 5.13, Table 5.14, Table 5.15, Table 5.16, Table 5.17, Table 5.18, and Table 5.19. The results contain the variable costs, which includes costs of tags, and overhead costs, which include the

[7] With the assumption that the network and integration costs for barcode and RFID technology are the same

Table 5.11: Distributions of part types and part RL types in EOL aircrafts

EOL Aircrafts	# of Parts	Materials (RS, RC, RM, DS) (%)	Components (RS, RC, RM, DS) (%)	Airframe (RS, RC, RM, DS) (%)	Avionics (RS, RC, RM, DS) (%)	Power System (RS, RC, RM, DS) (%)
1	100	10 (25, 25,25, 25)	20 (25, 25,25, 25)	20 (25, 25,25, 25)	30 (25, 25,25, 25)	20 (25, 25,25, 25)
2	100	10 (25, 25,25, 25)	20 (25, 25,25, 25)	20 (25, 25,25, 25)	30 (25, 25,25, 25)	20 (25, 25,25, 25)
3	100	10 (25, 25,25, 25)	20 (25, 25,25, 25)	20 (25, 25,25, 25)	30 (25, 25,25, 25)	20 (25, 25,25, 25)
4	100	10 (25, 25,25, 25)	20 (25, 25,25, 25)	20 (25, 25,25, 25)	30 (25, 25,25, 25)	20 (25, 25,25, 25)
5	100	10 (25, 25,25, 25)	20 (25, 25,25, 25)	20 (25, 25,25, 25)	30 (25, 25,25, 25)	20 (25, 25,25, 25)
6	100	10 (25, 25,25, 25)	20 (25, 25,25, 25)	20 (25, 25,25, 25)	30 (25, 25,25, 25)	20 (25, 25,25, 25)
7	100	10 (25, 25,25, 25)	20 (25, 25,25, 25)	20 (25, 25,25, 25)	30 (25, 25,25, 25)	20 (25, 25,25, 25)
8	100	10 (25, 25,25, 25)	20 (25, 25,25, 25)	20 (25, 25,25, 25)	30 (25, 25,25, 25)	20 (25, 25,25, 25)
9	100	10 (25, 25,25, 25)	20 (25, 25,25, 25)	20 (25, 25,25, 25)	30 (25, 25,25, 25)	20 (25, 25,25, 25)
10	100	10 (25, 25,25, 25)	20 (25, 25,25, 25)	20 (25, 25,25, 25)	30 (25, 25,25, 25)	20 (25, 25,25, 25)
11	100	10 (25, 25,25, 25)	20 (25, 25,25, 25)	20 (25, 25,25, 25)	30 (25, 25,25, 25)	20 (25, 25,25, 25)
12	100	10 (25, 25,25, 25)	20 (25, 25,25, 25)	20 (25, 25,25, 25)	30 (25, 25,25, 25)	20 (25, 25,25, 25)
13	100	10 (25, 25,25, 25)	20 (25, 25,25, 25)	20 (25, 25,25, 25)	30 (25, 25,25, 25)	20 (25, 25,25, 25)
14	100	10 (25, 25,25, 25)	20 (25, 25,25, 25)	20 (25, 25,25, 25)	30 (25, 25,25, 25)	20 (25, 25,25, 25)
15	100	10 (25, 25,25, 25)	20 (25, 25,25, 25)	20 (25, 25,25, 25)	30 (25, 25,25, 25)	20 (25, 25,25, 25)

Keys:

Distribution = Percentage of part- type (percentage of reuse, percentage of remanufacture, percentage of recycle, percentage of dispose) value added cost and waiting cost, for the as-is system and to-be systems. The variable costs in Table 5.12, Table 5.33, Table 5.14, and Table 5.15 are calculated by using the quantities or counts of tags obtained from Arena in (Microsoft) Excel formula of Equation 4.2; the value added cost and waiting cost are derived programmatically in Arena simulation software from Equation 4.3 and Equation 4.4. We sum these values to obtain the overhead cost in Table 5.16, Table 5.17, Table 5.18, and Table 5.19.

Table 5.12: Variable costs for case-level barcode tagging

Components	Unit cost ($)	Quantity	Total cost
Barcodes	0.5	1,500	750

Table 5.13: Variable costs for item-level RFID tagging

Components	Unit cost ($)	Quantity	Total cost
Passive tags	10	1,500	15,000

Table 5.14: Variable costs for case-level RFID tagging

Components	Unit cost ($)	Quantity	Total cost
Passive tags	10	7,500	7,500

Table 5.15: Variable costs for pallet-level RFID tagging

Components	Unit cost ($)	Quantity	Total cost
Passive tags	10	375	3,750

Table 5.16: Overhead cost for case-level barcode tagging

Cost type	Cost ($)
Value added cost	344665.01
Waiting cost	2231.22
Non value added cost	0
Total =	346896.23

Table 5.17: Overhead cost for item-level RFID tagging

Cost type	Cost ($)
Value added cost	365400.03
Waiting cost	2097.06
Non value added cost	0
Total =	367497.09

Table 5.18: Overhead cost for case-level RFID tagging

Cost type	Cost ($)
Value added cost	314725.66
Waiting cost	1952.66
Non value added cost	0
Total =	316678.32

Table 5.19: Overhead cost for pallet-level RFID tagging

Cost type	Cost ($)
Value added cost	321593.30
Waiting cost	3282.05
Non value added cost	0
Total =	324875.35

5.5 Discussion of results

We discuss results obtained from the simulations by analysing the variable cost, value added cost, waiting cost, and overhead cost for the barcode and RFID systems for the first year, and ROI for the RFID systems since they represent measures of performance for the systems.

5.5.1 Variable cost

Plot of variable costs (costs of tags and labeling) for case-level barcode, item-level RFID tagging, case-level RFID tagging and pallet-level RFID tagging is shown in Figure 5.1. Cost of case-level barcode tagging is very low, while cost decreases linearly from item-level RFID tagging, case-level RFID tagging, and pallet-level RFID tagging.

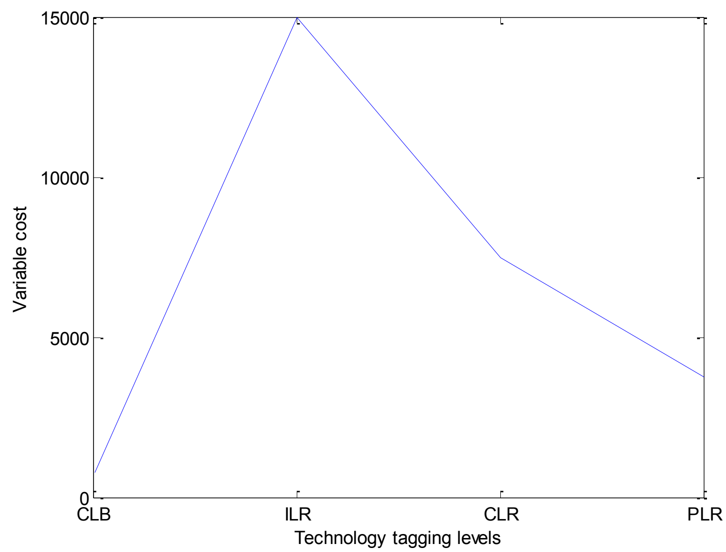


Figure 5.1: Plot of variable costs for case-level barcode (CLB) tagging, item-level RFID (ILR) tagging, case-level RFID (CLR) tagging and pallet-level (PLR) RFID tagging

5.5.2 Value added cost

Plot of value added costs for case-level barcode tagging, item-level RFID tagging, case-level RFID tagging and pallet-level RFID tagging is shown in Figure 5.2. The plot shows a high value added cost of $344665.01 for case-level barcode tagging. Relative to the value added cost of case-level barcode tagging, the value added cost of item-level RFID tagging increased by 0.06%. However, relative to the value added cost of case-level barcode tagging, the value added cost of case-level RFID tagging and pallet level RFID tagging decreased by 0.09% and 0.07%, respectively. Noticeable is the slightly higher value added cost of pallet-level RFID tagging relative to case-level RFID tagging. This can be accounted for by BPR used in pallet-level RFID tagging, which is different from the BPR used in case-level RFID tagging and item-level RFID tagging. In pallet-level RFID tagging, part tagging with RFID is withheld until the point where cases are added to pallets, thus eliminating the cost of holding sorted parts in separate inventories.

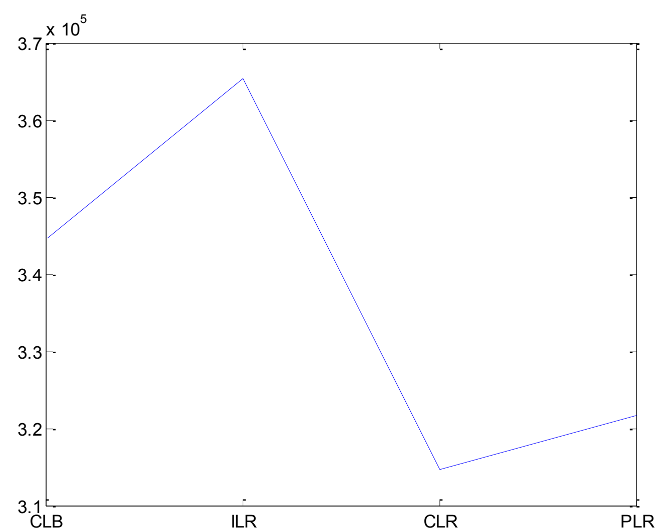


Figure 5.2: Plot of value added cost for case-level barcode (CLB) tagging, item-level RFID (ILR), tagging, case-level RFID (CLR) tagging and pallet RFID (PLR) tagging

5.5.3 Waiting cost

Plot of waiting costs for case-level barcode tagging, item-level RFID tagging, case-level RFID tagging, and pallet-level RFID tagging is shown in Figure 5.3. The plot shows a waiting cost of $2231.22 for case-level barcode tagging. Relative to the waiting cost of case-level barcode tagging, the waiting cost of item-level RFID tagging and case-level RFID tagging decreased by 0.06% and 0.12%, respectively. The waiting cost, however, increased by 0.47% for pallet-level RFID tagging.

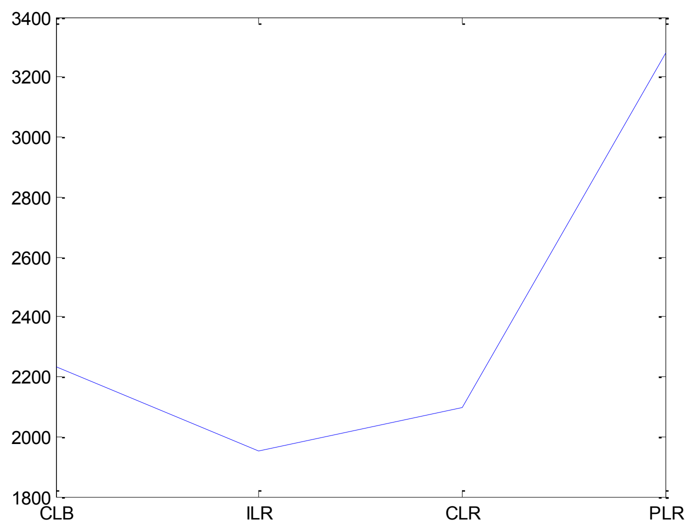


Figure 5.3: Plot of waiting costs for case-level barcode (CLB) tagging, item-level RFID (ILR) tagging, case-level RFID (CLR) tagging and pallet RFID (PLR) tagging

5.5.4 Overhead cost

Plot of overhead costs for case-level barcode tagging, item-level RFID tagging, case-level RFID tagging and pallet-level RFID tagging is shown in Figure 5.4. Since the overhead cost is the sum of value added cost and waiting cost, the plot is a superimposed plot of value added cost (Figure 5.2) and waiting cost (Figure 5.3). The plot shows that relative to the overhead cost case-level barcode tagging ($34896.23), there is an increase of 0.07% in the overhead costs of item-level RFID tagging, and decrease of 0.08% and 0.06%, respectively, in the overhead costs of case-level RFID tagging and pallet RFID tagging.

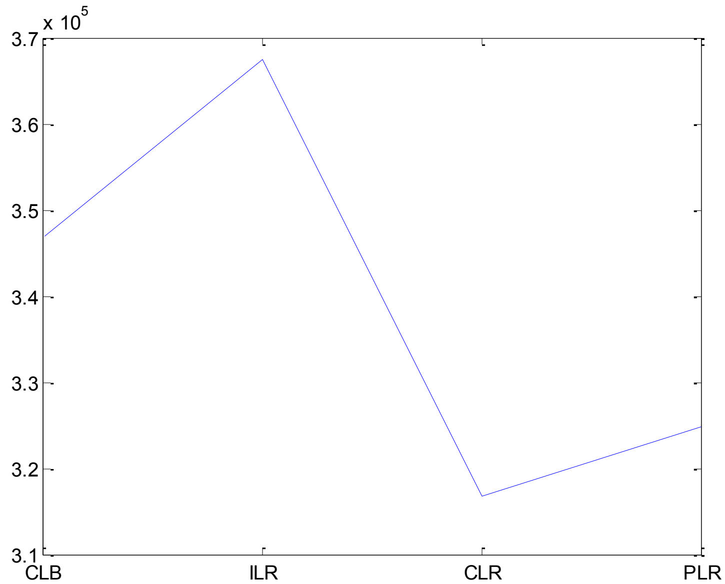


Figure 5.4: Plot of overhead costs for case-level barcode (CLB) tagging, item-level RFID (ILR) tagging, case-level RFID (CLR) tagging and pallet RFID (PLR) tagging

5.5.5 Return-On-Investment (ROI)

The ROI calculations for case-level barcode tagging, item-level RFID tagging, case-level RFID tagging and pallet-level RFID tagging are presented in Table 5.20, Table 5.21, Table 5.22 and Table 5.23, respectively. The ROIs obtained for all tagging levels are negative; this implies that projects are not profit yielding. These results are acceptable since financial returns from sales of RL products are not included in the analysis. The

Table 5.20: ROI for case-level barcode tagging

Year	**0**	**1**	**2**	**3**	**4**	**5**	
Discount rate = 5%	1	0.9524	0.907	0.8638	0.0829	0.7835	
Cost							
Investment cost ($)	1,026,700	0	0	0	0	0	
Variable cost (Tags and labels) ($)	0	7,500	7,500	7,500	7,500	7,500	
Overhead cost ($)	0	346,896	346,896	346,896	346,896	346,896	
Cost of correcting errors on entered data ($)	0	5,000	5,000	5,000	5,000	5,000	
Cost of shrinkage ($)	0	5,000	5,000	5,000	5,000	5,000	
Total=	1,026,700	346,896	346,896	346,896	346,896	346,896	
Discounted cost	1,026,700.00	347,050.97	330,507.38	314,765.46	30,208.45	282,566.32	2,331,798.58
Benefits							
Savings from data capturing (C_0) ($)	0	37,307.93	37,307.93	37,307.93	37,307.93	37,307.93	
Savings from delays (D_0) ($)	0	2,231	2,231	2,231	2,231	2,231	
Total =	0	5000	5000	5000	5000	5000	
Discounted benefit	0	44539.15	44539.15	44539.15	44539.15	44539.15	159,877.73
ROI =	-0.931						

Keys:

Total cost of capturing data with barcode scanner, $C_0 = b_j + u_j = 37,307.93$

Waiting cost of case level barcode tagging, $D_0 = 2,231.22$

Table 5.21: ROI for item-level RFID tagging

Year	**0**	**1**	**2**	**3**	**4**	**5**	
Discount rate = 5%	1	0.9524	0.907	0.8638	0.0829	0.7835	
Costs							
Investment cost ($)	1,062,700	0	0	0	0	0	
Variable cost (Tags and labels) ($)	0	15,000	15,000	15,000	15,000	15,000	
Overhead cost($)	0	365,400.03	365,400.03	365,400.03	365,400.03	365,400.03	
Total =	1,062,700	380,400.03	380,400.03	380,400.03	380,400.03	380,400.03	
Discounted cost	1,062,700	362,292.96	345,022.80	328,589.52	31,535.16	298,043.40	2,430,183.84
Benefit							
Savings from data capturing (C_0-C_1) ($)	30,156.38	30,156.38	30,156.38	30,156.38	30,156.38	30,156.38	
Savings from delays ($D_0 - D_1$) ($)	3,015	3,015	3,015	3,015	3,015	3,015	
Savings from correcting errors on entered data($)	0	5,000	5,000	5,000	5,000	5,000	
Savings from shrinkage ($)	0	5,000	5,000	5,000	5,000	5,000	
Total =	0	43170.934	43170.934	43170.934	43170.934	43170.934	
Discounted benefit	0	41,116.00	39,156.04	37,291.05	3,578.87	33,824.43	159,602.16
ROI =	- 0.938						

Keys:

Total cost of capturing data with RFID reader, $C_1 = b_j + u_j = 9{,}434.92$

Total cost of capturing data with barcode scanner, $C_0 = b_j + u_j = 37{,}307.93$

Waiting cost of item-level RFID tagging, $D_1 = 2097.06$

Waiting cost of case-level barcode tagging, $D_0 = 2{,}231.22$

Table 5.22: ROI for case-level RFID tagging

Year	**0**	**1**	**2**	**3**	**4**	**5**	
Discount rate = 5%	1	0.9524	0.907	0.8638	0.0829	0.7835	
Cost							
Investment cost ($)	1,062,450	0	0	0	0	0	
Variable cost (Tags and labels) ($)	0	7,500	7,500	7,500	7,500	7,500	
Overhead cost ($)	0	334,808	334,808	334,808	334,808	334,808	
Total=	1,062,450	342,308	342,308	342,308	342,308	342,308	
Discounted cost	1,062,450.00	326,014.14	310,473.36	295,685.65	28,377.33	268,198.32	2,291,198.80
Benefits							
Savings from data capturing (C_0-C_2) ($)	31,896.95	31,896.95	31,896.95	31,896.95	31,896.95	31,896.95	
Savings from delays ($D_0 – D_2$) ($)	279	279	279	279	279	279	
Savings from correcting errors on entered data($)	5000	5000	5000	5000	5000	5000	
Savings from shrinkage ($)	5000	5000	5000	5000	5000	5000	
Total =	42175.51	42175.51	42175.51	42175.51	42175.51	42175.51	
Discounted benefit	40,167.96	38,253.19	36,431.21	3,496.35	33,044.51	40,167.96	151,393.21
ROI =	-0.932						

Keys

Total cost of capturing data with RFID reader, $C_2 = b_j + u_j = 5,410.98$

Total cost of capturing data with barcode scanner, $C_0 = b_j + u_j = 37307.93$

Waiting cost of case-level RFID tagging, $D_2 = 1,952.66$

Waiting cost of case-level barcode tagging, $D_0 = 2231.22$

Table 5.23: ROI for pallet-level RFID tagging

Year	**0**	**1**	**2**	**3**	**4**	**5**	
Discount rate = 5%	1	0.9524	0.907	0.8638	0.0829	0.7835	
Costs							
Investment cost ($)	1,062,700	0	0	0	0	0	
Variable cost (Tags and labels) ($)	0	3,750	3,750	3,750	3,750	3,750	
Overhead cost ($)	0	338,195	338,195	338,195	338,195	338,195	
Total =	1,062,450	341,945	341,945	341,945	341,945	341,945	
Discounted cost	1,062,450.00	325,668.42	310,144.12	295,372.09	28,347.24	267,913.91	2,289,895.77
Benefits							
Savings from data capturing (C_0-C_3) ($)	34,187.50	34,187.50	34,187.50	34,187.50	34,187.50	34,187.50	
Savings from delays ($D_0 – D_3$) ($)	-1,051	-1,051	-1,051	-1,051	-1,051	-1,051	
Savings from correcting errors on entered data($)	0	5,000	5,000	5,000	5,000	5,000	
Savings from shrinkage ($)	0	5,000	5,000	5,000	5,000	5,000	
Total	0	43,136.67	43136.67	43136.67	43136.67	43136.67	
Discounted Benefit	0.00	41,083.36	39,124.96	37,261.46	3,576.03	33,797.58	154,843.39
ROI =	-0.931						

Keys

Total cost of capturing data with RFID reader, $C_3 = b_j + u_j = 3120.43$

Total cost of capturing data with barcode scanner, $C_0 = b_j + u_j = 37307.93$

Waiting cost of pallet-level RFID tagging, $D_2 = 3282.05$

Waiting cost of case-level barcode tagging, $D_0 = 2231.22$

current ROIs can be improved by reusing RFID tags and implementing the RFID technology in phases.

5.5.6 Sensitivity analysis

We present in Table 2.24 the outcomes of the experiments we performed to investigate the impact of varied percentage distributions of AP and RL types on the ROI. The high total discounted costs, relative to the total discounted benefits, which exclude the financial returns from sales of RL parts, account for the low negative ROI values. The ROIs increase positively from item-level RFID tagging to case-level RFID tagging and pallet level tagging, and with two-sample standard deviations of 0.0048, 0.0054 and 0.0066, respectively, relative to case-level barcode tagging. From the results presented in Table 2.24, one can deduce that the performance of case-level barcode tagging in terms of ROI is comparable to item-level RFID tagging.

5.6. End note

In this Chapter, we presented the constraints and assumptions guiding our simulation models, described the elements of our simulation models, and presented results obtained from the simulations with discussion of the results.

Summary of results of the numerical application discussed in Section 5.1 is presented in Table 5.25. The result showed negative ROI values for all the tagging levels. The negative value means that these projects are not profitable[8]. Pallet RFID tagging has the most positive ROI, followed by case-level RFID tagging and item level RFID tagging. Although the ROI of item-level RFID tagging is the lowest, it can be selected based on the fact that it provides the lowest waiting cost, and the highest visibility of parts.

[8] Financial returns from sales of RL products are not included in the analysis, therefore there is no profit.

Table 5.24: Sensitivity analysis

# of Parts	Materials (RS, RC, RM, DS) (%)	Components (RS, RC, RM, DS) (%)	Airframe (RS, RC, RM, DS) (%)	Avionics (RS, RC, RM, DS) (%)	Power System (RS, RC, RM, DS) (%)	ROI of CLB	ROI of ILR	ROI of CLR	ROI of PLR
1500	10 (25, 25, 25, 25)	20 (25, 25, 25, 25)	10 (25, 25, 25, 25)	20 (25, 25, 25, 25)	10 (25, 25, 25, 25)	-0.933	-0.936	-0.919	-0.918
1500	10 (25, 25, 25, 25)	20 (25, 25, 25, 25)	20 (25, 25, 25, 25)	30 (25, 25, 25, 25)	20 (25, 25, 25, 25)	-0.933	-0.934	-0.927	-0.922
1500	10 (25, 25, 25, 25)	20 (25, 25, 25, 25)	40 (25, 25, 25, 25)	20 (25, 25, 25, 25)	10 (25, 25, 25, 25)	-0.932	-0.963	-0.956	-0.951
1500	10 (25, 25, 25, 25)	40 (25, 25, 25, 25)	20 (25, 25,25, 25)	15 (25, 25, 25, 25)	15 (25, 25, 25, 25)	-0.932	-0.935	-0.931	-0.929
1500	10 (25, 25, 25, 25)	20 (30, 30, 30, 10)	10 (30, 30, 30, 10)	20 (25, 25, 25, 25)	10 (25, 25, 25, 25)	-0.937	-0.937	-0.932	- .978
1500	10 (40, 30, 20,10)	20 (25, 25, 25,25)	20 (40, 30, 20, 10)	20 (25, 25, 25, 25)	10 (25, 25, 25, 25)	-0.937	-0.933	-0.924	-0.914

Keys:

Distribution = Percentage of part- type (percentage of reuse, percentage of remanufacture, percentage of recycle, percentage of dispose)

CLB – Case-level barcode tagging

ILR – Item-level RFID tagging

CLR – Case-level RFID tagging

PLR– Pallet-level RFID tagging

Table 5.25: Summary of results

TTL	**Performances measured relative to CLB tagging**				
	VC	**VAC**	**WC**	**OC**	**ROI**
CLB	750	344,665.01	2231.22	346,896	-0.931
ITR	1900% increase	0.06% increase	0.06% decrease	0.07 % increase	-0.938
CLR	900% increase	0.09% decrease	0.12% decrease	0.08% decrease	-0.932
PR	400% increase	0.07% decrease	0.47% increase	0.06% decrease	-0.931

Keys

TTL - Technology and Tagging Levels

CLB - Case-level barcode tagging

ITR - Item level RFID tagging

CLR - Case level RFID tagging

PLR - Pallet level RFID tagging

VC - Variable cost

VAC - Value added cost

WC - Waiting cost

VC - Variable cost

OC - Overhead cost

Chapter 6:

Conclusions and Future Works

In this Chapter, we present our conclusions and recommendations for future work

6.1 Conclusions

In this research, by extensively reviewing literature on the technological potentials and economical impacts of RFID technology, we have been able to create selection model for determining the most appropriate or suitable RFID solution for the EOL aircraft RL network. We have also proposed a layout or schema for managing data on the RFID tag memory and database for EOL aircraft RL network IS. We have developed process maps of hypothesized as-is EOL aircraft RL network with case-level barcode tagging and hypothesized to-be EOL RL network with item-level RFID tagging, case-level RFID tagging, pallet-level RFID tagging. We modeled and simulated the process maps in Arena simulations software to analyze and compare the ROI investments for the to-be systems.

Although all parts of EOL aircraft are assumed cased to protect them from damage, to ensure safety, and to reduce interference and absorption of RFID signals, this assumption holds true particularly for parts meant for reuse or remanufacture. For parts designated for recycling or disposal this assumption may not necessarily apply; in this situation, normal RFID tags or protected RFID tags can be attached to the parts. Also, data obtained at the end-of-life of aircrafts, and used in the RL network, can be enhanced with historic data. As demonstrated in the RFID integrated solution developed by Boeing (Swedberg, 2012), service-life information on aircraft parts can be captured using RFID technology.

The results obtained from this simulation demonstrate that compared to barcode system, RFID technology has greater capacity to reduce running costs of the EOL aircraft RL network. However, due to the huge initial investment cost of RFID technology, properly planning, such as BPR, tag reuse, and phased implementation, may be required to achieve more positive ROI.

6.2 Future works

In present work, we developed hypothesized models of the EOL aircraft RL network with the assumption that only passive tags were used in the simulation models. Our simulation models were verified to ensure that they work as required and that they are error free. The simulations models were validated partially by comparing with the provisions in the AFRA best management practice manual.

In future works, the simulation models will be validated with real systems, and required modifications or improvements will be incorporated. Pilot test will be performed to measure the process improvements realizable with different tags, and data obtained will be used in our simulation models. Simulated studies will be conducted to evaluate the impact of tag reuse, BPR, and phased implementation on the ROI of RFID-enabled EOL aircraft RL network.

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Appendix A

A.1. Procedures for creating new simulation model

1. We create new model by clicking *File*, and *New*, on the main menu or pressing <Ctrl + N> on the keyboard
2. We click run from the main menu, clicking *Setup*, and provide the title of project in the project title textbox menu under tab *Project Parameters* (Figure A.1)
3. We specify the number of replications, replication length, time units, hours per day, base time units and terminating conditions under the *Replication Parameters* tab of the *Run Setup* dialog box (Figure A.2).

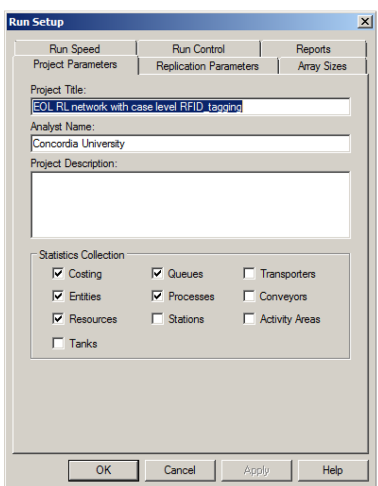


Figure A.1: Project parameter

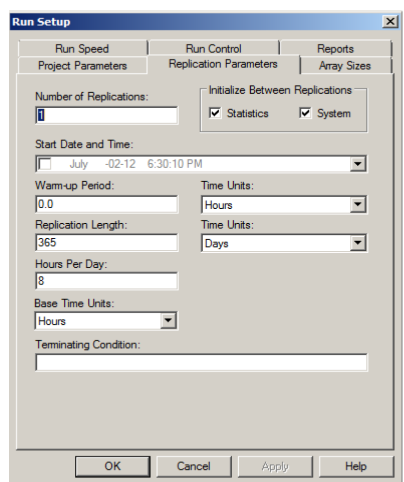


Figure A.2: Replication parameters

A.2. Procedures for creating entities

1. We click *Entity* from the *Basic Process* tab of the *Project Bar* menu (Figure A.3).
2. We create an entity by double clicking the data module underlining figure.
3. We specify the entity type, initial picture, holding cost/hour and initial costs for the entity in the entity data module.

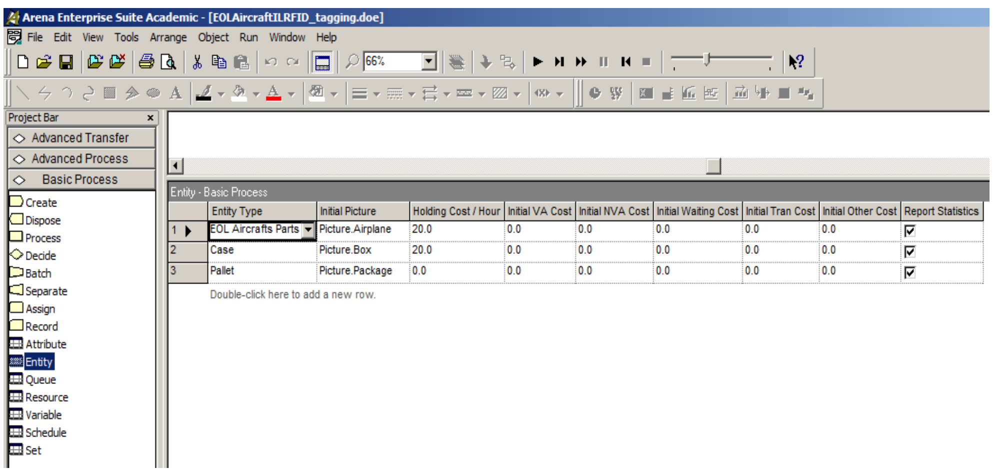


Figure A.3: Create an Entity

A.3. Procedures for creating attributes

1. We click *Attribute* from the *Basic Process* tab of the *Project Bar* menu to display the attribute data module in the Arena plain area as shown in the Figure A.4.
2. We double click the data module to create a new attribute.
3. We provide the name, rows and columns (for array attributes), data type and initial value for the attribute in the attribute data module.

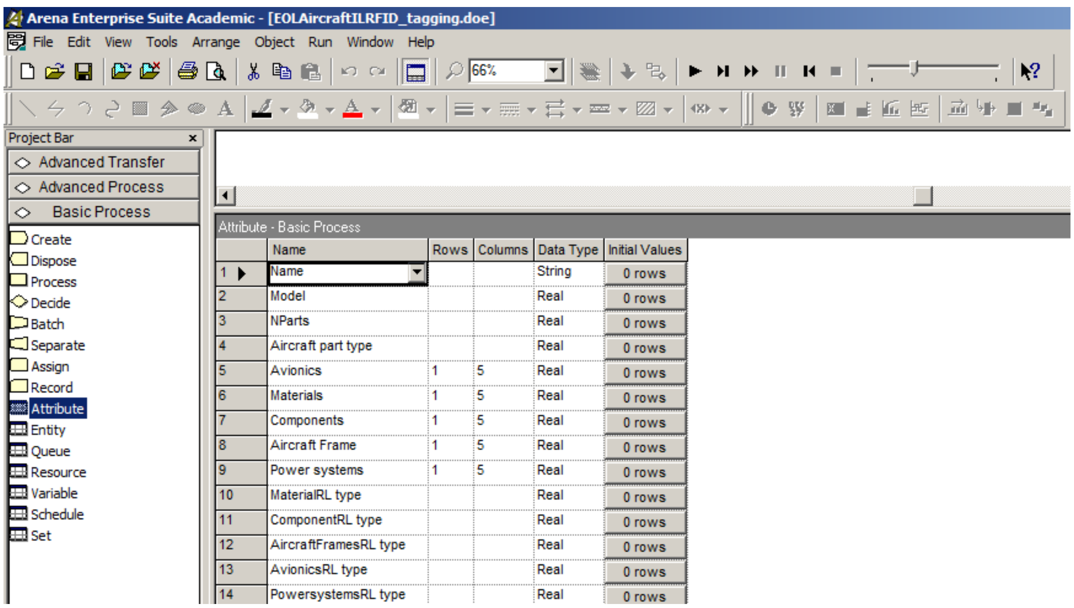


Figure A.4: Create an Attribute

A.4. Procedures for creating variables

1. We click Variable from the Basic Process tab of the Project Bar menu to display the variable data module in the Arena plain area as shown in Figure A.5.
2. We double click the data module to create a new variable.
3. We provide the name, rows and columns (for array attributes), data type and initial value for the variable in the variable data module.

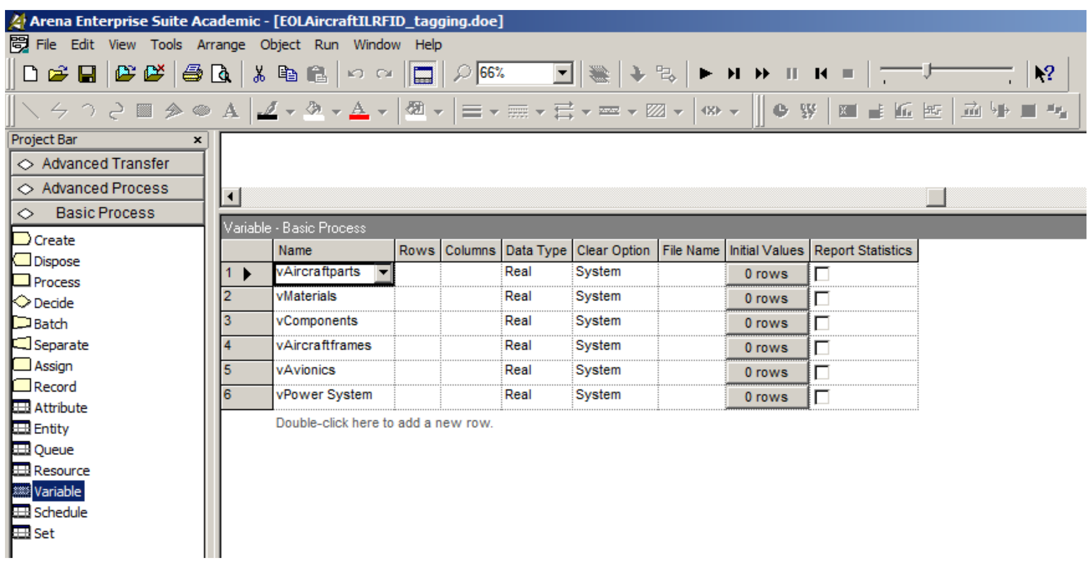


Figure A.5: Create a Variable

A.5. Procedures for creating resource

1. We click *Resource* from the *Basic Process* tab of the *Project Bar* menu to display the resource data module in the Arena plain area as shown in Figure A.6.
2. We double click the data module to create a new resource.
3. We provide the name, type (Fixed capacity or schedule), busy hour, idle hour, per user, and failures.

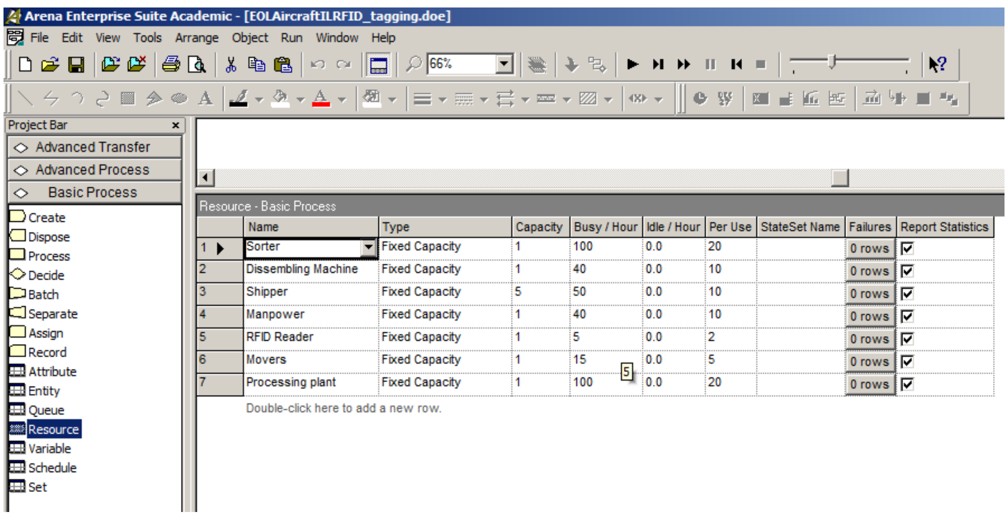


Figure A.6: Create a Resource

A.6. Procedures for creating events

To create a *Create* event

1. We click on the *Create* event (yellow-shaped polygon) under the *Basic Process* tab of the *Project Bar* menu and drag it to the plain area of the page as shown in Figure A.7.
2. We double click the event to display its properties .

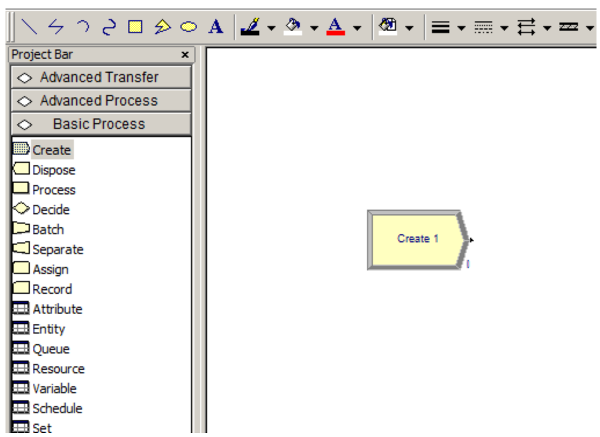


Figure A.7: Make a Create event

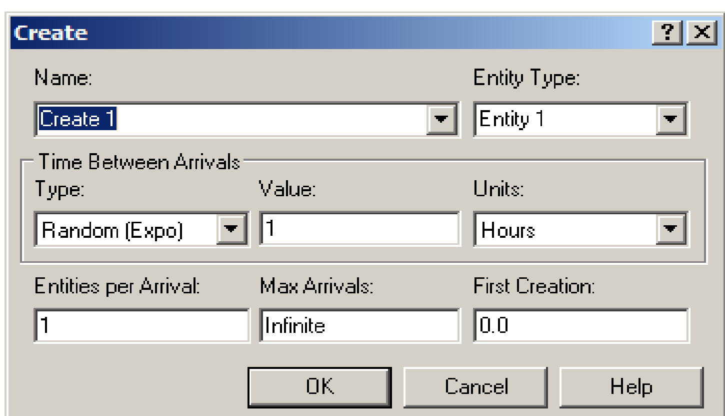


Figure A.8: Edit the properties of Create event

To create a *Process* event

1. We click on the *Process* event (yellow-shaped polygon) under the *Basic Process* tab of the *Project Bar* menu and drag it to the plain area of the page
2. We connect the *Process* event and *Create* event with a connector.
3. We double click the event to display its properties.
4. We modify the properties of the *Process* event as required.

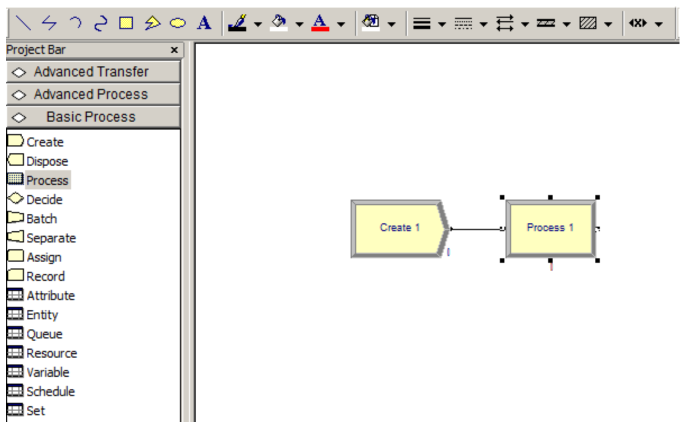


Figure A.9: Make a Process event

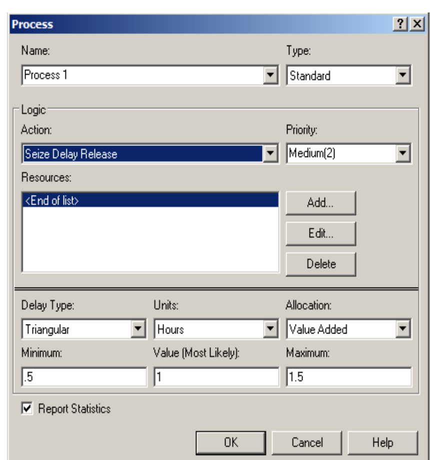


Figure A.10: Edit the properties of the *Process* event

To create a *Dispose* event:

1. We click on the *Dispose* event (yellow-shaped polygon) under the *Basic Process* tab of the Project Bar menu and drag it to the plain area of the page
2. We connect the *Process, Create*, and *Dispose* events with a connector .
3. We double click the event to display its properties.
4. We provide the name of the event, and check the record entity statistics checkbox.

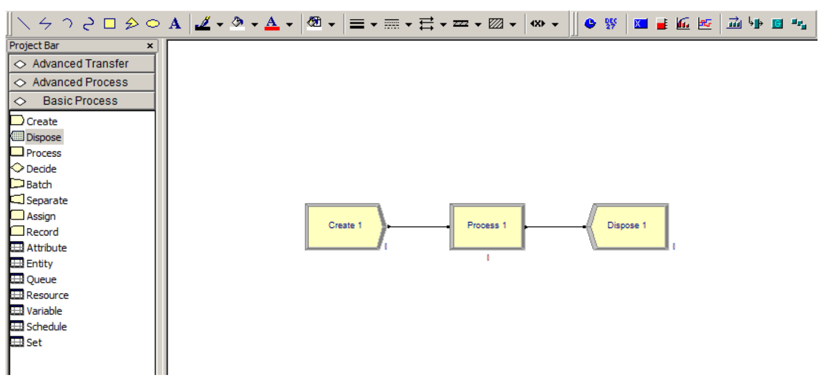


Figure A.11: Make a *Dispose* event

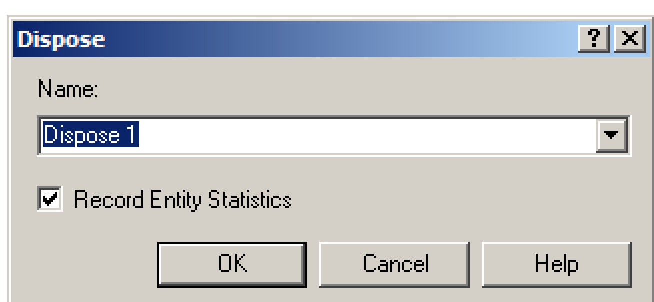


Figure A.12: Edit the properties of the *Dispos*e event

A. 7. Procedures for creating file object

Step 1:

1. We create a Microsoft Excel 2007 file on the hard drive.
2. We open the file and create a new workbook and worksheet
3. We select and name a range (termed “named ranged”) on the worksheet where we want to read data from or write data to (Figure A.13).

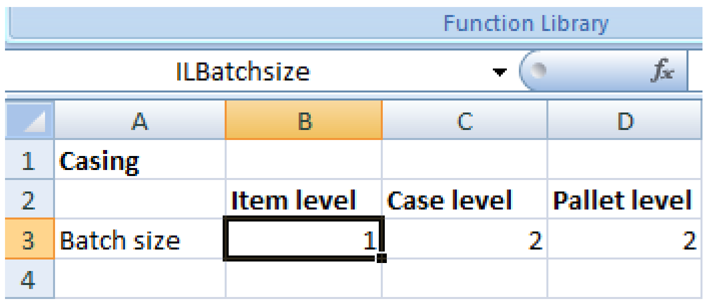


Figure A.13: Create a named range

Step 2:

1. In Arena simulation software, we click *File* from the *Advanced Process* tab of the Project Bar menu to display the *File* data module in the Arena plain area as shown in Figure A14.
2. We double click the data module to create a new *File* object.

   We provide the name of the *File* object, the access type (Microsoft Excel 2007), the location of the file on the hard-drive, the end of file action (disposed and the initial option (hold)). The last column of the file object, called *Recordsets*, is very important, it is discussed in the next step.

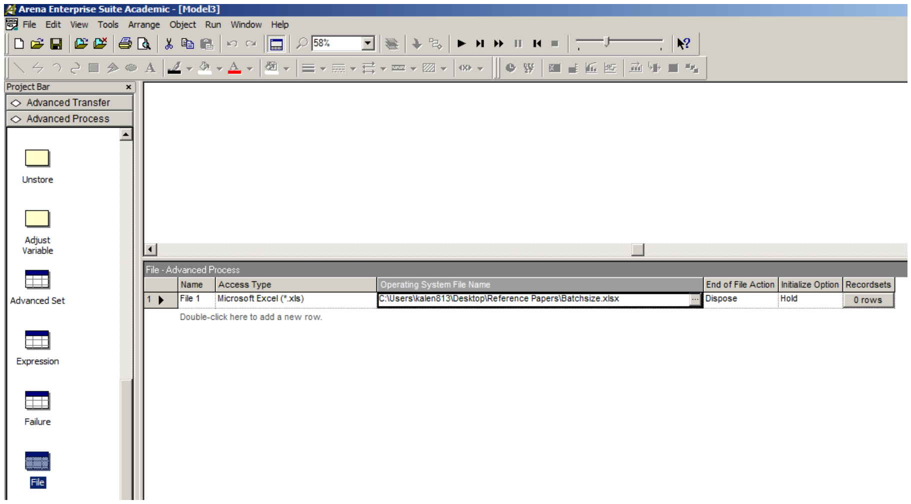


Figure A.14: Create a File object

3. We click the *Recordsets* column to display the dialogbox in Figure A.15.

4. We specify the name of the recordset (Recordset 1), and the named range (*ILBatchsize*), and click on the *Add/Update* button to create the recordset.

5. We click the *OK* button to close the dialogbox.

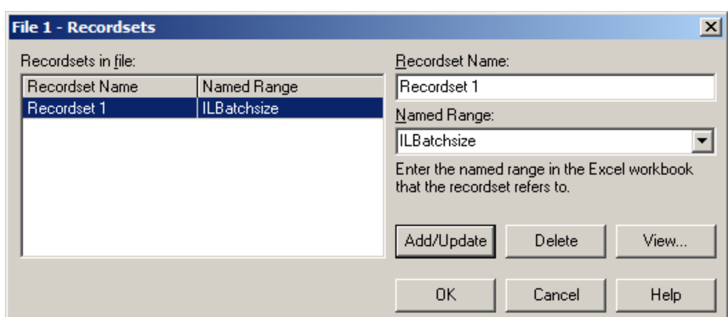
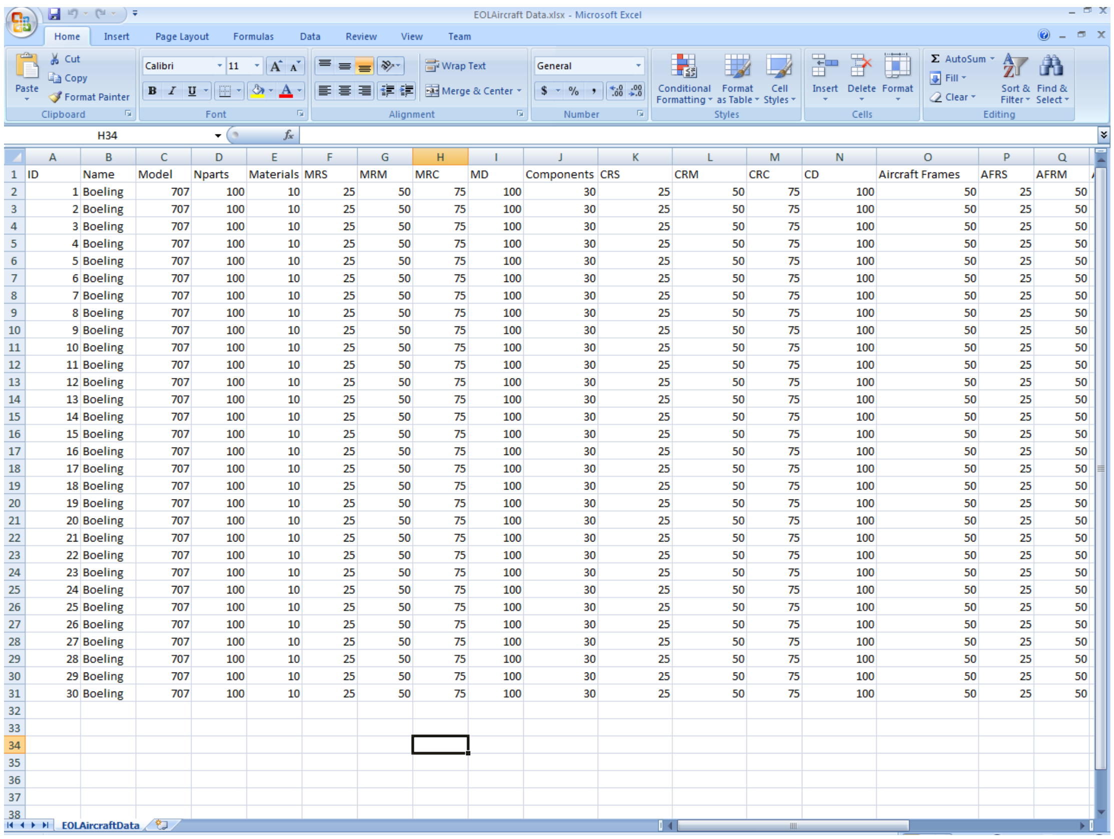


Figure A.15: Create a *Recordset* for the File object

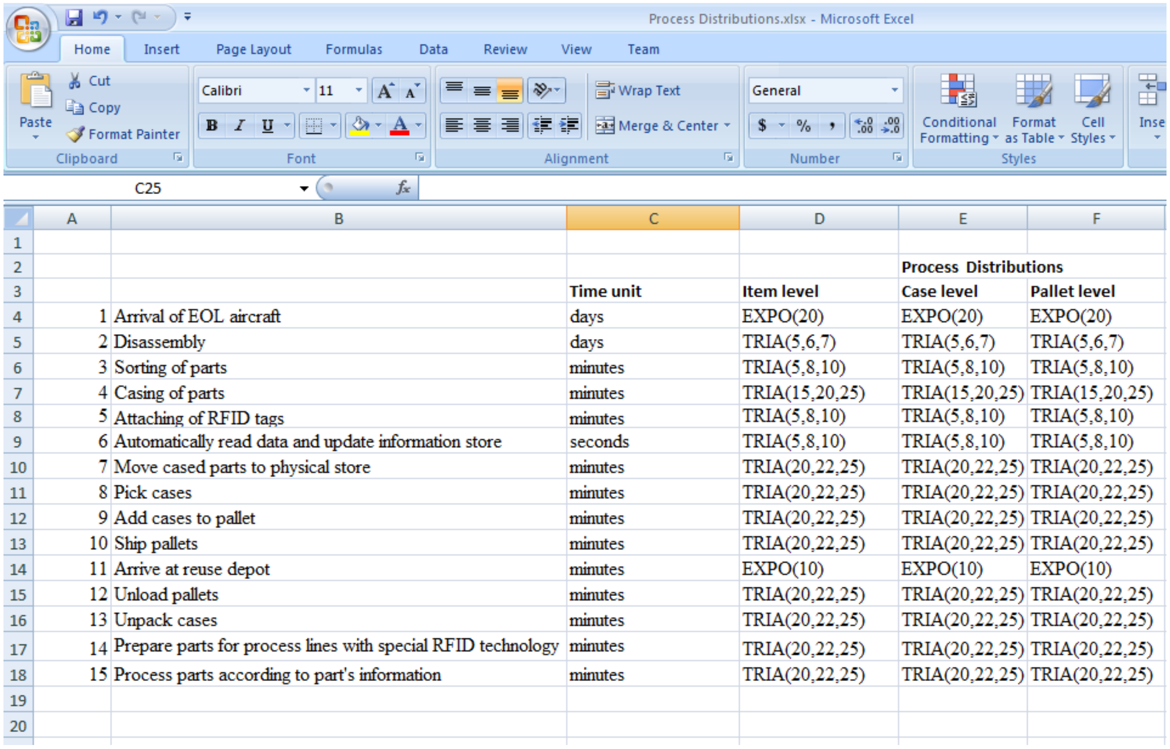
Appendix B

B.1. EOLAircraftData.xlsx



ID	Name	Model	Nparts	Materials	MRS	MRM	MRC	MD	Components	CRS	CRM	CRC	CD	Aircraft Frames	AFRS	AFRM
1	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
2	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
3	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
4	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
5	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
6	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
7	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
8	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
9	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
10	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
11	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
12	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
13	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
14	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
15	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
16	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
17	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
18	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
19	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
20	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
21	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
22	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
23	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
24	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
25	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
26	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
27	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
28	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
29	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50
30	Boeling	707	100	10	25	50	75	100	30	25	50	75	100	50	25	50

B.2. ProcessDistributions.xlsx



		Time unit	Item level	Case level	Pallet level
				Process Distributions	
1	Arrival of EOL aircraft	days	EXPO(20)	EXPO(20)	EXPO(20)
2	Disassembly	days	TRIA(5,6,7)	TRIA(5,6,7)	TRIA(5,6,7)
3	Sorting of parts	minutes	TRIA(5,8,10)	TRIA(5,8,10)	TRIA(5,8,10)
4	Casing of parts	minutes	TRIA(15,20,25)	TRIA(15,20,25)	TRIA(15,20,25)
5	Attaching of RFID tags	minutes	TRIA(5,8,10)	TRIA(5,8,10)	TRIA(5,8,10)
6	Automatically read data and update information store	seconds	TRIA(5,8,10)	TRIA(5,8,10)	TRIA(5,8,10)
7	Move cased parts to physical store	minutes	TRIA(20,22,25)	TRIA(20,22,25)	TRIA(20,22,25)
8	Pick cases	minutes	TRIA(20,22,25)	TRIA(20,22,25)	TRIA(20,22,25)
9	Add cases to pallet	minutes	TRIA(20,22,25)	TRIA(20,22,25)	TRIA(20,22,25)
10	Ship pallets	minutes	TRIA(20,22,25)	TRIA(20,22,25)	TRIA(20,22,25)
11	Arrive at reuse depot	minutes	EXPO(10)	EXPO(10)	EXPO(10)
12	Unload pallets	minutes	TRIA(20,22,25)	TRIA(20,22,25)	TRIA(20,22,25)
13	Unpack cases	minutes	TRIA(20,22,25)	TRIA(20,22,25)	TRIA(20,22,25)
14	Prepare parts for process lines with special RFID technology	minutes	TRIA(20,22,25)	TRIA(20,22,25)	TRIA(20,22,25)
15	Process parts according to part's information	minutes	TRIA(20,22,25)	TRIA(20,22,25)	TRIA(20,22,25)

B.3. ProcessDistributions_barcode.xlsx

	A	B	C	D
1				
2			**Process Distributions**	
3			**Time unit**	**Barcode**
4	1	Arrival of EOL aircraft	days	EXPO(20)
5	2	Disassembly	days	TRIA(5,6,7)
6	3	Sorting of parts	minutes	TRIA(5,8,10)
7	4	Casing of parts	minutes	TRIA(15,20,25)
8	5	Attach barcodes with RL types information	minutes	TRIA(5,8,10)
9	6	Manually scan barcode and add data to information store	minutes	TRIA(3,5,7)
10	7	Move case to physical store	minutes	TRIA(20,22,25)
11	8	Pick cases	minutes	TRIA(20,22,25)
12	9	Add cases to pallet	minutes	TRIA(20,22,25)
13	10	Ship pallets	minutes	TRIA(20,22,25)
14	11	Arrive at reuse depot	minutes	EXPO(10)
15	12	Unload pallets	minutes	TRIA(20,22,25)
16	13	Unpack cases	minutes	TRIA(20,22,25)
17	14	Prepare parts for process lines	minutes	TRIA(20,22,25)
18	15	Process parts according to part's information	minutes	TRIA(20,22,25)
19				
20				
21				
22				
23				

B.4. Batchsize.xlsx

	A	B	C	D
1	**Casing**			
2		**Item level**	**Case level**	**Pallet level**
3	Batch size	1	2	2
4				

B.5. ROI.xlsx

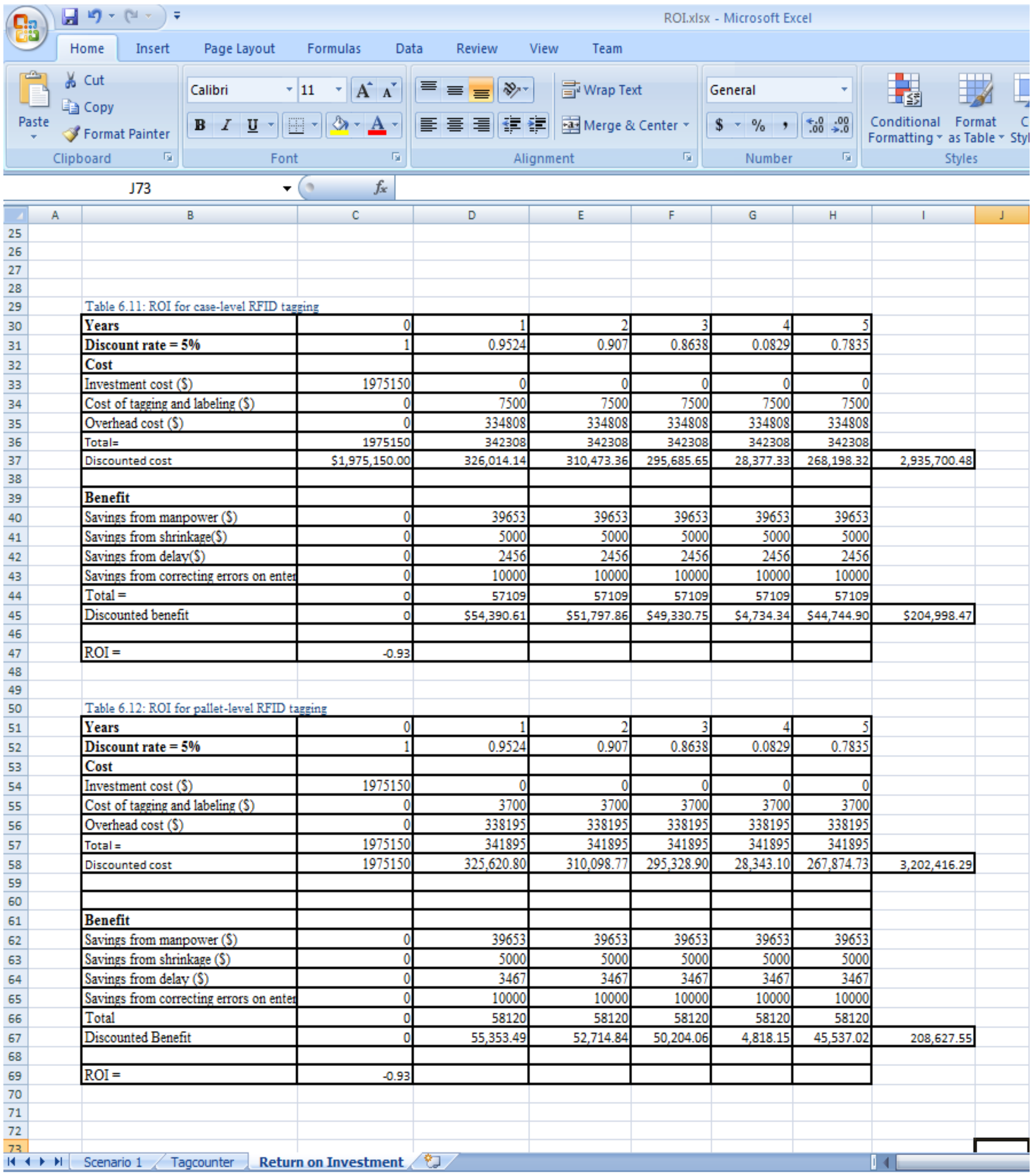


Table 6.11: ROI for case-level RFID tagging

Years	0	1	2	3	4	5	
Discount rate = 5%	1	0.9524	0.907	0.8638	0.0829	0.7835	
Cost							
Investment cost ($)	1975150	0	0	0	0	0	
Cost of tagging and labeling ($)	0	7500	7500	7500	7500	7500	
Overhead cost ($)	0	334808	334808	334808	334808	334808	
Total=	1975150	342308	342308	342308	342308	342308	
Discounted cost	$1,975,150.00	326,014.14	310,473.36	295,685.65	28,377.33	268,198.32	2,935,700.48
Benefit							
Savings from manpower ($)	0	39653	39653	39653	39653	39653	
Savings from shrinkage($)	0	5000	5000	5000	5000	5000	
Savings from delay($)	0	2456	2456	2456	2456	2456	
Savings from correcting errors on enter	0	10000	10000	10000	10000	10000	
Total =	0	57109	57109	57109	57109	57109	
Discounted benefit	0	$54,390.61	$51,797.86	$49,330.75	$4,734.34	$44,744.90	$204,998.47
ROI =	-0.93						

Table 6.12: ROI for pallet-level RFID tagging

Years	0	1	2	3	4	5	
Discount rate = 5%	1	0.9524	0.907	0.8638	0.0829	0.7835	
Cost							
Investment cost ($)	1975150	0	0	0	0	0	
Cost of tagging and labeling ($)	0	3700	3700	3700	3700	3700	
Overhead cost ($)	0	338195	338195	338195	338195	338195	
Total =	1975150	341895	341895	341895	341895	341895	
Discounted cost	1975150	325,620.80	310,098.77	295,328.90	28,343.10	267,874.73	3,202,416.29
Benefit							
Savings from manpower ($)	0	39653	39653	39653	39653	39653	
Savings from shrinkage ($)	0	5000	5000	5000	5000	5000	
Savings from delay ($)	0	3467	3467	3467	3467	3467	
Savings from correcting errors on enter	0	10000	10000	10000	10000	10000	
Total	0	58120	58120	58120	58120	58120	
Discounted Benefit	0	55,353.49	52,714.84	50,204.06	4,818.15	45,537.02	208,627.55
ROI =	-0.93						

Appendix C

C.1. Simulation of case-level barcode tagging

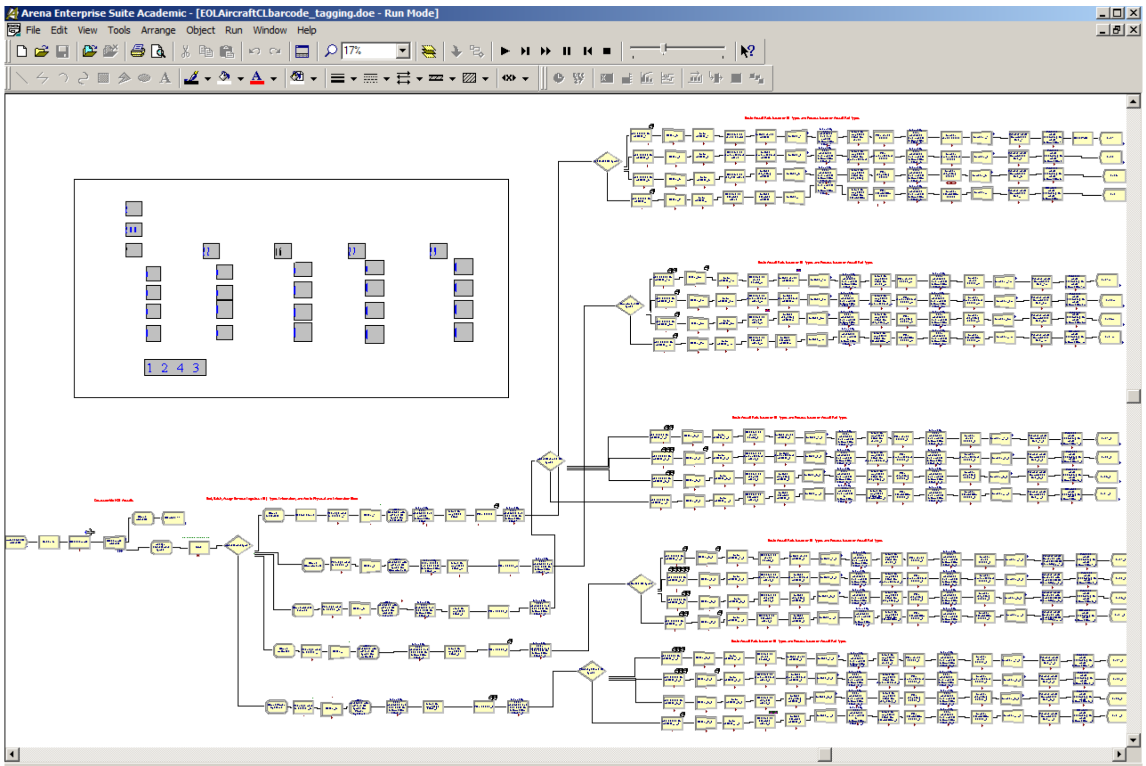


Figure C.1: Screen-shot of simulation for case-level barcode tagging

C.2. Simulation of item-level RFID tagging

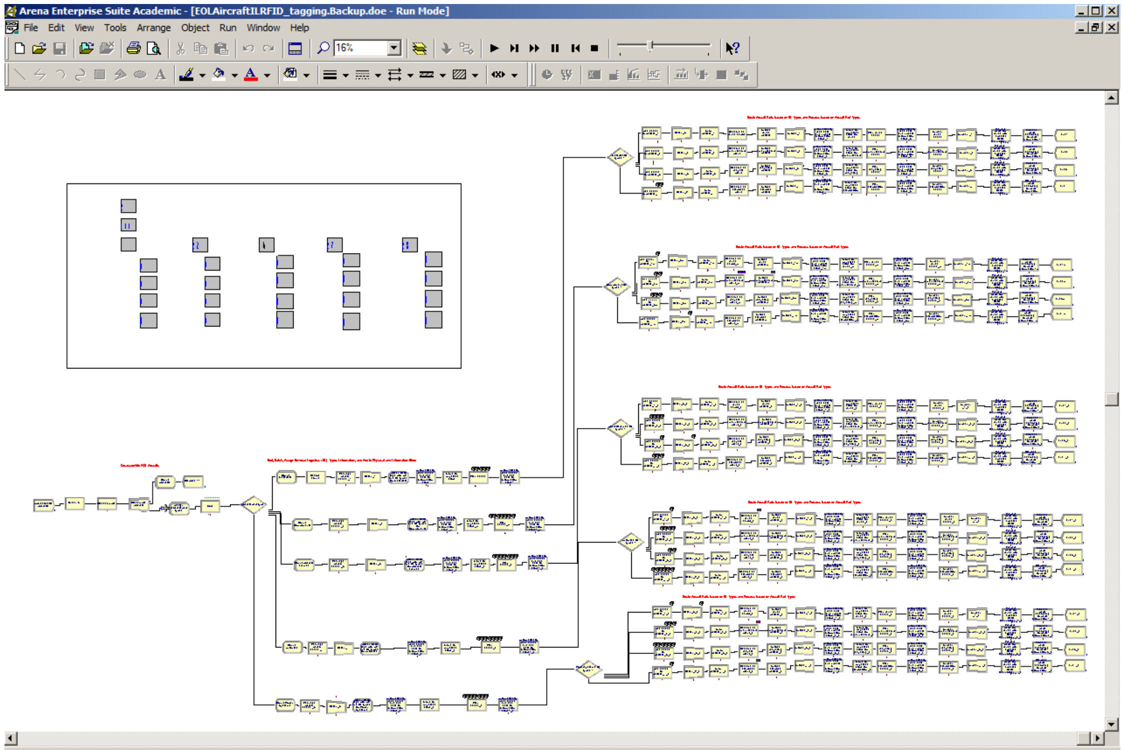


Figure C.2: Screen-shot of simulation of item-level RFID tagging

C.3. Simulation of case-level RFID tagging

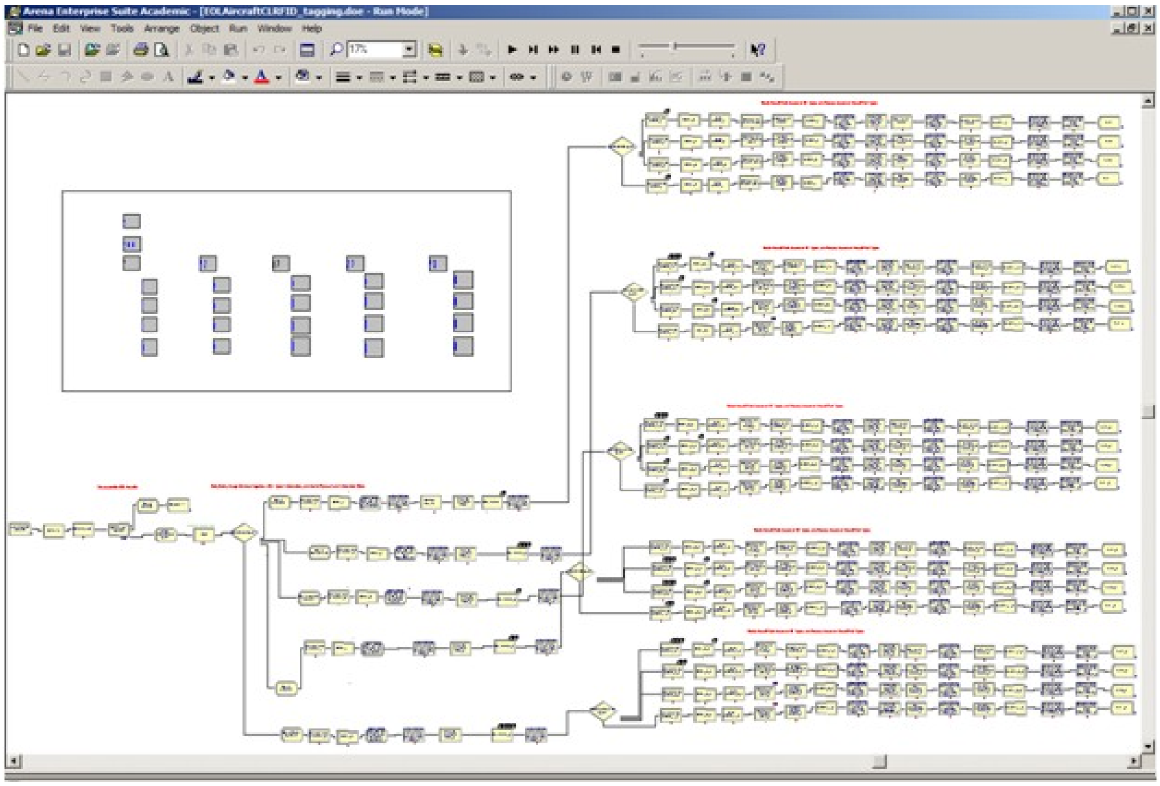


Figure C.3: Screen-shot of simulation for case-level RFID tagging

C.4. Simulation of pallet-level RFID tagging

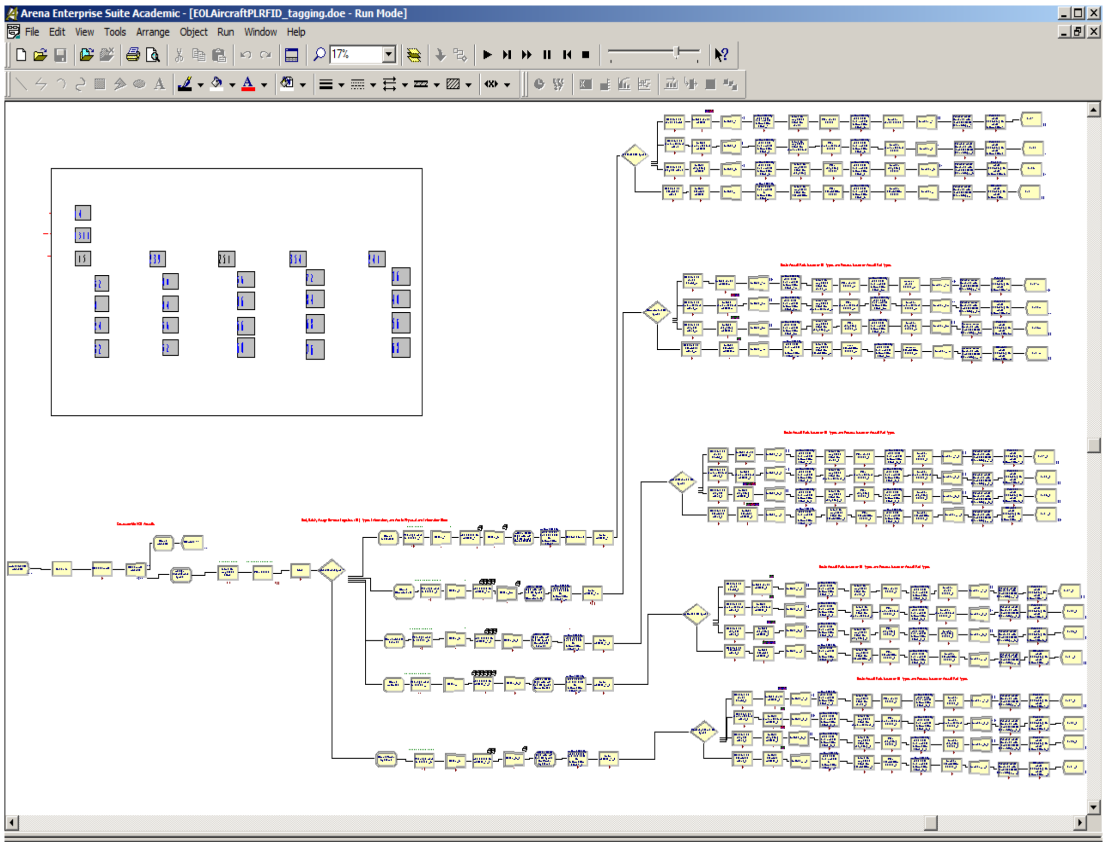


Figure C.4: Screen-shot of simulation of pallet-level RFID tagging