System Dynamics simulation for investigating RFID potential in aircraft disassembly operations

A Thesis

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Abstract

One of the main issues in modern supply chain management is the recovery of value from the end of life (EOL) or defective products by remanufacturing, reassembly, re-use and recycling. Despite the fact that reverse logistics would impose extra amount of complexity to the supply chain, it has captured a lot of attention as it is possible to recycle the materials where there are limited resources. Through reverse logistics companies will be able to minimize the overall production costs through reclaiming the unsold or defective products' values which in turn may lead to more productivity and growth, and more importantly reverse logistics may improve the quality of end products by finding the faults of the system and the points which directly or indirectly affect the ultimate product.

However, a number of challenges arise with reverse logistics; integration of the whole supply chain including both inbound activities and outbound activities, creating incentives for return and reuse, huge amount of inspections and imposed complexity to the supply chain as a whole since the number of partners may increase.

On the other hand, technologies such as barcodes, radio frequency identification (RFID), global positioning system (GPS), etc, have made it easier to cope with the aforementioned challenges and complexities of reverse supply chains.

In this thesis, our goal is to examine the potential of radio frequency identification (RFID) technology on disassembly operations of aircraft at the End of Life using system dynamics simulation. In particular, a case study on how RFID technology affects the time of disassembly

of a single helicopter has been conducted in cooperation with Bell Helicopters. The proposed System dynamics simulation model is developed using “AnyLogic”.
The results of our study show that employing RFID technology will lead to a reduction in total disassembly time of a helicopter. However, bringing motivations to the market to employ RFID technology in industries and developing trust in the promising benefits and results will require more challenging planning and managerial activities.

Keywords: Reverse logistics (RL), RFID, aviation industry, end of life products (EOL), System Dynamics simulation

Acknowledgment

Hereby, I would like to declare that this thesis could not be accomplished without the help of a number of people.

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At last, I would like to thank all my friends specially Negar Esfahani whose without their support and presence these years would not be as exciting and memorable.

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Dedication

I would like to dedicate this piece of academic work to my mother, Mrs. Fatemeh Gerami who is my true hero and without her love and support I would not be able to be successful at any point of my life.

Chapter 1

Introduction

1.1 Background

Green legislations and the importance and increasing value of recycled products combined with short life cycles of new products in the market have drawn a great deal of attention to the subject of reverse logistics (RL) and closed loop supply chains (CLSC). Environmental concerns about waste disposal and management have been increasing over the past decades. The scarcity of natural resources and the need to recycle and reuse the end of life products (EOL) have made the reverse logistics a point of interest and consideration. Logistics is defined by The Council of Logistics Management (By Karen Hawks, VP Supply Chain Practice- Reverse Logistics Magazine, 2006) as:

> *"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 origin to the point of consumption for the purpose of conforming to customer requirements".*

Reverse logistics includes all the activities mentioned in the definition above. However, the difference is that they operate in reverse. Therefore, reverse logistics can be defined as:

> *"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. More precisely, reverse logistics is the process of moving goods from their typical final destination for the purpose of capturing value, or proper disposal. Remanufacturing and refurbishing activities also may be included in the definition of reverse logistics." (By Karen Hawks, VP Supply Chain Practice- Reverse Logistics Magazine, 2006)

Donald F.Blumberg (2004), in his book "Introduction to Management of Reverse logistics and Closed Loop Supply Chain Processes", highlights the different strategic values associated with reverse logistics such as:

"reducing the cost of returns, increasing the value of the salvage merchandise, capturing vital information and reliability, maintainability, and dependability of products supported, reducing transportation and warehousing expenses and time including the partial or full elimination of small package shipments and automate and fully control the total returns process."

Reverse logistics cannot be considered the exact reverse form of the forward logistics since there are a number of differences and complexities associated with reverse logistics such as quantity, category of returns, cycle time, stock keeping units (SKU), as well as distribution paths. (Lee and Chan 2008)

A simple structure of a forward and reverse logistics network is provided below to have a more visual understanding of the difference between the two.

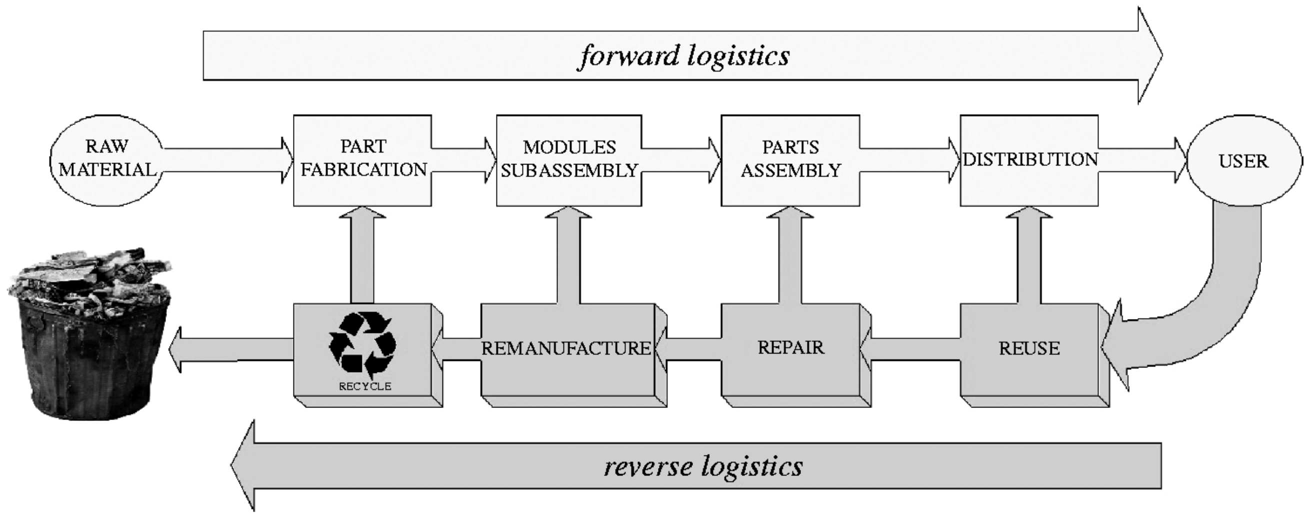

Figure4-1 Forward and Reverse Logistics (Hanafi *et al.* 2008)

1.2 Problem statement

The reverse logistic networks are complex with a variety of activities and processes that the company uses to collect used products, End of Life (EOL) products, outdated products, damaged products, unwanted inventories such as the stock balancing returns as well as packaging and shipping materials from the end users or resellers in the market. On the other hand, there are a number of activities and processes carried out such as returning the parts to the supplier, reselling the products into the second market, salvage, refurbish, remanufacture, recycle or reuse.

Since the reverse logistic networks are considered as a strategic weapon for different industries, an insightful management using an approved technological advance for tracking and monitoring the disassembled parts, data management and automation at some points will be of paramount importance and could bring great benefits to the industry.

Specifically, in the case of reverse logistics in aviation industries, the complexities still stand and in this research it has been tried to come up with a solution using RFID technology to reduce the total disassembly time of an aircraft, here a helicopter. There are inspection nodes in the process which to some extent are considered as non value added activities and are trying to reduce or eliminate these excessive times by employing the RFID technology using system dynamics simulation modeling.

The objectives of this research are as follow:

- Develop a simulation model using system dynamics methodology to evaluate the potential of RFID in disassembly operations of aircraft
- Conduct a case study for the same objective with Bell Helicopters

1.3 Thesis Preview

The following sections in this document will be organized and presented as follows: the next chapter covers the literature review of reverse logistics, RFID enabled logistics, RFID in reverse logistics, system dynamics and simulation modeling. In chapter 3 the current problem is analyzed and the proposed solution for the problem is discussed. In chapter 4, the simulated model is presented and in the last chapter, conclusions and suggestions for further research are advised.

Chapter 2

Literature review

2.1 Reverse logistics

According to the study carried out by Rogers and Tibben-Lembke (1998), there are many activities involved in reverse logistics such as refurbishing, reselling, recycling, product reuse etc. Some common activities of reverse logistics are presented in Table 2.1 below.

Material	Reverse logistics activities
Products	Returned to supplier
	Resell
	Sell via outlet
	Salvage
	Recondition
	Refurbish
	Remanufacture
	Reclaim material
	Recycle
	Landfill
Packaging	Reuse
	Refurbish
	Reclaim material
	Recycle
	Salvage

Table 2-10- Common reverse logistics activities

Reverse logistics during the past decades has become an important factor in logistics and supply chains. It has the costs as high as 4% of the total logistics costs that account for more than $35 billion only in the US (Stock *et al.* 2001). Hereby, consumers are the highest cause of return. According to the survey carried out with 311 logistics managers in the US in 1998, the average consumers return in retail industry is 6%. Table 2 shows different portions of return of each industry. (Dawe, 1995)

Industry	Percentage
Book publishing	10-30%
Magazine publishing- special interest	50%
Computer manufacturing	10-20%
Direct to consumer computer manufacturers	2-5%
Apparel	35%
Mass merchandisers	4-15%
Auto industry (parts)	4-6%
Internet retailers	20-80%

Table 11-2- Returns percentage by industries Dawe, 1995

Returned items could be of many varieties and forms; they could be end of life (EOL) products, defective products, products returned by consumers which are not defective, returns that come from excessive inventories, bad stock returns which may come from the products that are left for too long in the stock and many other forms.

Generally speaking, reverse logistics may be viewed as a strategic side of business and companies. Reverse logistics would bring competitive advantages as it provides opportunity for the customers to give back the product with which they are not satisfied for any reason to the manufacturer. This would provide customer satisfaction which indeed leads to competitive advantage. On the other hand, reverse logistics would also make it possible for the businesses and companies to clear out their inventories of obsolete products and replace it with new products. This could also affect the market in general since it may provide an incentive for retailers and other businesses to order more and not to worry about the excessive inventories. According to Rogers and Tibben-Lembke (1998) more than 65% of the strategic role of return accounts for the competitive advantage.

Despite all the values and benefits that reverse logistics and closed loop supply chains may bring, and the fact that it is considered as a strategic factor in industries, a great amount of managerial insights and effort as well as great monetary investments are required to make it successful. Managing the reverse supply chains, which are more complex than the forward supply chains, is of paramount importance and concern; reverse logistics require a separate chain of command and management with specialized and trained staff, market forecast is more difficult since the number of people who are willing to recycle or return their used products are fairly unknown, more quality control should be emphasized in reverse logistics networks and more contracts and negotiations with other parties and suppliers are needed. On the other hand, there are many advantages and benefits brought about by new technologies such as barcodes, radio frequency identification (RFID), geographical positioning systems (GPS), and etc, to assist in supply chain and reverse logistics operations management. Among the aforementioned technologies, RFID has become a very popular technology of today and near future to assist in different operational and managerial aspects of supply chain.

One of the factors to be considered in managing the reverse logistics and generally, supply chains is the cycle time. As the business dictionary defines cycle time is:

"The period required to complete one cycle of an operation; or to complete a function, job, or task from start to finish. Cycle time is used in differentiating total duration of a process from its run time."

There are a number of challenges in the management of reverse logistics and one of them is reducing the cycle time. Cycle time reduction would bring competitive advantage among other competitors since those companies which launch new products into the market earlier would be able to meet the dynamic nature of demand, gain bigger market shares and hence become more competitive. On the other hand, companies with reduced cycle times are able to reduce their costs and accordingly provide cheaper products to the market. According to several studies, reducing the cycle time in half and making the WIP inventory double, can increase productivity by 20% to 70%. Surprisingly, quartering the time for one step typically reduces the costs by over 20%. Also, with reduced cycle times, quality may be improved. Faster processes allow lower levels of inventory which will accordingly expose weaknesses and increase the rate of total improvement. RFID technology is believed to be able to reduce the overall cycle time by automating the processes. By providing visibility it provides the opportunity to spot the flaws or weaknesses or even the causes of defects and in turn improves the quality.

In a study carried out by Kara *et al.* (2006), a reverse logistic network is simulated to choose the best location for the transfer stations, disassembly plant and the drop-off points in terms of collection costs; it is found that Collection cost per part has an inverse relationship with the number of parts that can be remanufactured. Their study not only pinpoints the importance of reverse logistics, but also notes that reverse logistics is an important factor in any supply chain and of a strategic value to supply chain managers in order to come up with an efficient and effective reverse logistics structure. However, the study suggests that there are also other factors that influence collection cost such as collection strategy, transporters and transportation modes, disassembly plant location, delivery mode, inventory costs, and number of reusable components per each product. Giannetti *et al.* (2012) proposed a case study about a reverse logistics network for a steel recycling company. The model proposed suggested that reverse logistics will bring a number of environmental benefits. On the other hand, the employment of reverse logistics would also bring several advantages to the society as a whole which accordingly requires an effective policy and decision making by governments to make the benefits to the environment and the society bigger. They also note that their and other researchers' studies in reverse logistics will motivate other businesses and industries to view this as a win-win opportunity and be motivated to go green.

An empirical investigation was carried out by Coşkunb *et al.* (2012), in house appliance industry in Turkey comparing two sample factories to find out what are the drivers of reverse logistics. According to the authors, the drivers of reverse logistics could be economic reasons, legislations, and corporate citizenship, which is about the company's image in the eyes of the society. Based on their study, the main factors or drivers of reverse logistics were economic and monetary value of the products as well as the marketing factors.

2.1.1 Reverse Logistics Challenges

There are a number of challenges faced by different parties of reverse logistics networks in different industries. One of these challenges is the retailer-manufacturer conflict upon returns. These conflicts may arise from disagreements on the condition of items, the value of the items or the timeliness of responses. Poor data management is another challenge in reverse logistics networks. Since an efficient handling of returned products decreases the cost, improving and having efficient information handling mechanisms will be very effective. Managing the inventory efficiently and effectively requires perfect information and data handling.

Basically, the reverse logistics is not necessarily a vice-versa version of the forward logistics in a way that major modifications and extensions of the forward logistics design and methods may be needed. Reverse logistics follow the many-to-few network structure and they involve a huge amount of uncertainty. The uncertainty throughout the reverse logistics network is an increasing factor which partly counterbalances the material savings. There are a number of approaches to reduce the uncertainty such as large scale collection, transmission, and analysis of electronic data through, for instance, continuous monitoring of parts and unique identification of returned products. These methods provide statistical data about individual items and consequently make the forecast much easier.

Technically speaking, it is the interaction of new reverse material flow and the existing forward flow that adds extra complexity to the overall network whereas in some cases it is not even possible to treat and manage these two individually and they have to be managed and dealt with simultaneously to be effective. (Fleischmann *et al.,* 1997)

2.2 Reverse Logistics in aviation industry

The aviation industry has also shown interest in the reverse supply chain and logistics. For instance, a Boeing 747 may have over six million parts which could be disassembled. In some cases, 98% of this aircraft could be recycled and over 6.8 million dollars could be saved which is a spectacular amount. Before, the End-Of-Life aircrafts were simply parked in desert graveyards to be disintegrated gradually but during past few years, the aircraft manufacturing companies have realized the benefits of aircraft recycling; both environmentally and financially. The Aircraft Fleet Recycling Association (AFRA) is targeting 90% recyclability of global fleet by 2016. According to AFRA there are going to be 12,000 aircraft retiring with the next 20 years consequently, green supply chain in aviation will be a hot market and investing in the aircraft recycling will be beneficial. Airline manufacturers such as Boeing are trying to reduce aircraft manufacturing waste which goes into landfills by 25% by 2012. Airbus also predicts over 6000 aircraft in the passenger category will reach end of life over the next 20 years, and 1,500 of them will be Airbuses (Kerry Reals, 2011). On the other hand, aircraft manufacturing companies such as Bombardier are investing in the research and cooperating with many academic institutes such as Université du Québec à Montréal (UQAM) to investigate the new and more efficient ways and methods with which an aircraft could be recycled. AFRA, since its initiation in 2006, could brought approximately 2000 airplanes and scrapped more than 6000 commercial airplanes and 1000 military aircrafts, back to the market suggesting the corporation has been very successful and estimating that more airline manufacturing companies are willing to invest in aircraft recycling in the following years.

In March 2005, "Pamela" (Process for Advanced Management of End of Life of Aircraft) was launched as an aircraft dismantling demonstration project with support from the European Commission's "LIFE" initiative under the classification of "waste management, recycling and reduction of landfill". (Max Kingsley-Jones, Airbus's recycling master plan – Pamela, 2008).

According to Olivier Malavallon, (Airbus project director environmental affairs), in current situation, only 60% of the aircraft’s weight could be recovered and about 50% of this recovered materials and parts could be recycled which accounts for only 30% of the total weight. Hence, an efficient dismantling process should be advised. The benefits of employing a more efficient and effective smart dismantling process would be the opportunity to recover more than 80% of the scrap by weight for reuse. The Pamela project is broken down to three steps and processes:

- Decommissioning (D1); accounts for the safety measures, cleaning activities, draining the tanks and decontamination.
- Disassembling (D2); decomposition of aircraft's parts based on airworthiness regulations
- Smart dismantling and valorization (D3); includes the final draining of systems, removal of polluting and hazardous materials and finally the deconstruction of the aircraft. According to Malavallon, three quarter of aircrafts that enter the D1 will be returned to service for further use but once the decision is made to move the aircraft to D3, there is no turning back.

Recycling the aircraft parts and components and using them in different applications and even other industries such as car manufacturing industries, reduces the consumption of natural resources as well as landfill allocations. Aircraft recycling will also reduce the pollution of water, air and soil contaminations dramatically and will reduce the demand for energy. Each aircraft possesses hundreds of recyclable parts and components and this number will be increasing as the technological developments increase in the field of reuse and recycling. Basically, each aircraft is composed of different parts and components, materials, devices, carbon and glass composites, wires, aluminum, titanium, steel, foam, fibers, isolations, textiles and carpets, landing gears, fluids, avionics, engines and many other parts. These parts come with different complexities based on different types of the aircraft which may reduce the rate of the disassembly and that's why the manufacturers should focus on the EOL of the aircraft in early stages of design and manufacture.

There are some good quality devices, components and materials of an aircraft which could be recycled and reused directly which are described as follow by Asmatulu *et al.* (Recycling of Aircraft: State of the Art in 2011)

- Fluids (fuel, oil, and hydraulic fluids), safety and security equipments, batteries, avionic parts, tires
- Aluminum, titanium, and nickel alloys, steel alloys, wires, thermoplastics, foams, textiles, carpets
- Cabin and cargo lining, wastes, and other parts which go to the graveyard
- Composite parts including the fuselage and interior parts and components which could be used elsewhere
- The entire aircraft to be demonstrated in the museums and public exhibitions for various purposes

Figure 2.1 shows the life cycle of the aircraft including the reverse supply chain of an airplane. The average weight of an airplane is reported to be 106 tons and during the disassembly process, over 85% of the aircraft can be dismantled and the other 15% will be put into landfills. The 85% of the dismantled parts are whether re used directly, cleaned and put into inventory for future use, repaired or modified for other applications. Studies suggest that even the remaining 15% of recycle parts could be put back in use by further recycling. For instance, according to a study by Allred and Salas (2005), it is possible to transform all types of plastic such as rubber, thermoses, and thermoplastics into valuable products and even fuels.

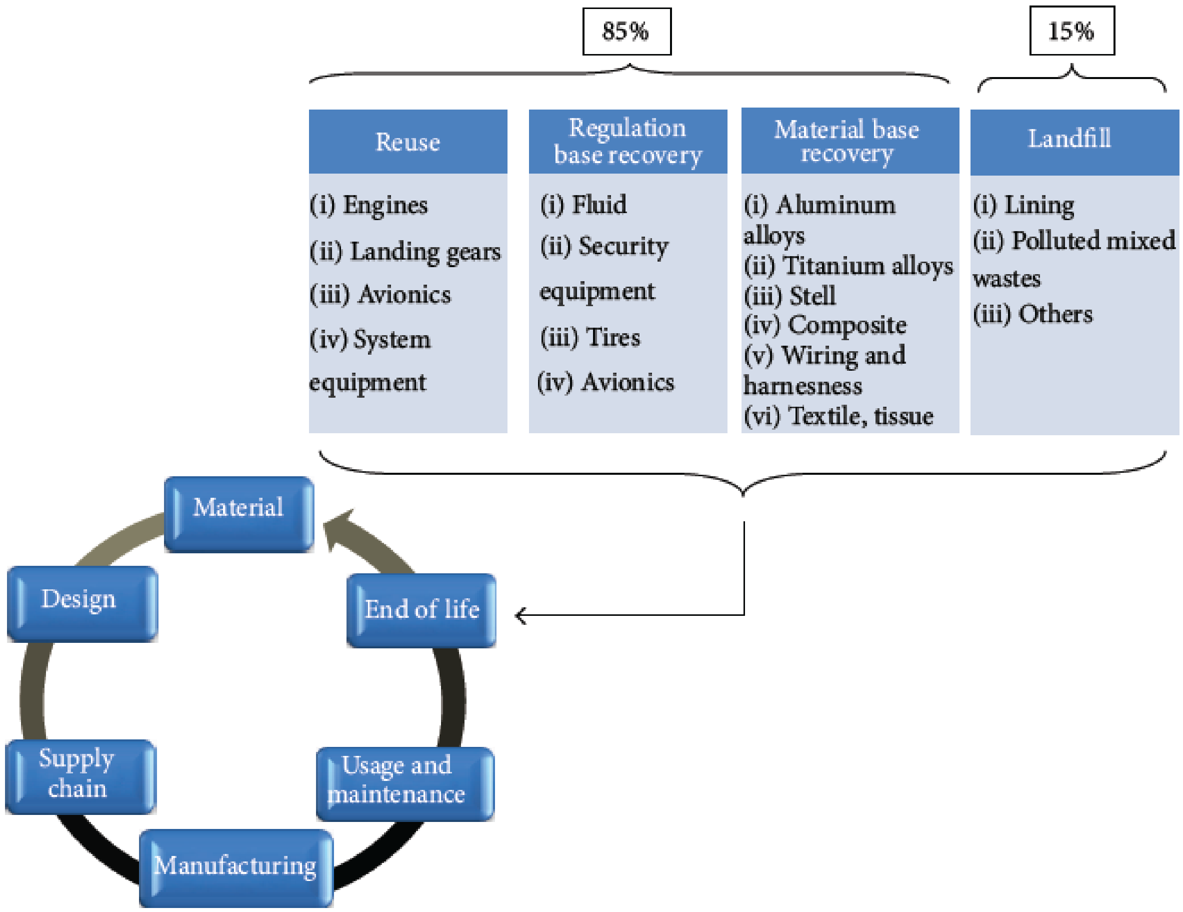

Figure 5-1 supply chain of aircraft (PAMELA-Life Project,Airbus France S.A.S 2008),Asmatulu et al. 2011

As we mentioned earlier, aircraft recycling will reduce the energy demand and consequently, recycling will reduce the greenhouse gas (GHG) emissions and minimize the global warming. Generally speaking, recycling aircraft parts will bring both environmental and financial benefits. For instance some materials and alloys like steel and aluminum may be very expensive to produce and regaining these from EOL aircrafts will be very beneficial in terms of monetary values as well as environmental considerations.

2.3 Radio Frequency Identification (RFID)

Radio frequency identification (RFID) has many technical as well as non technical or simpler definitions. The RFID journal defines radio frequency identification as:

> "*Any method of identifying unique items using radio waves, typically, a reader (also called an interrogator) communicates with a transponder, which holds digital information in a microchip. But there are chip-less forms of RFID tags that use material to reflect back a portion of the radio waves beamed at them.*"

In the past decades, Automatic Identification Systems (Auto-ID) have become prevalent and popular in many industries, from the service sector to manufacturing, logistic companies, retail industry as well as material flow systems. Auto-ID systems are being used to track information about people, animals, materials, and products in transit. Barcodes which have been a revolutionary technology for many years are not sufficient for this increasing amount of demand in products and data processing. Although they are pretty cheap but the fact that they cannot be reprogrammed and have a limited data storage capacity holds them back in the competition.

The success and efficiency of smart cards, contactless card such as bank cards, etc, has made it popular to use radio frequency waves to send and receive data. Radio frequency identification (RFID) has become very popular and accepted by many companies and the number of companies developing the RFID systems and technology has been growing on a fast pace. The growing number of RFID systems sold globally from 900 million in 2000 to over 2600 million in 2005, further draws attention to this technology's market growth. Figure 2.2 shows the growth of RFID.

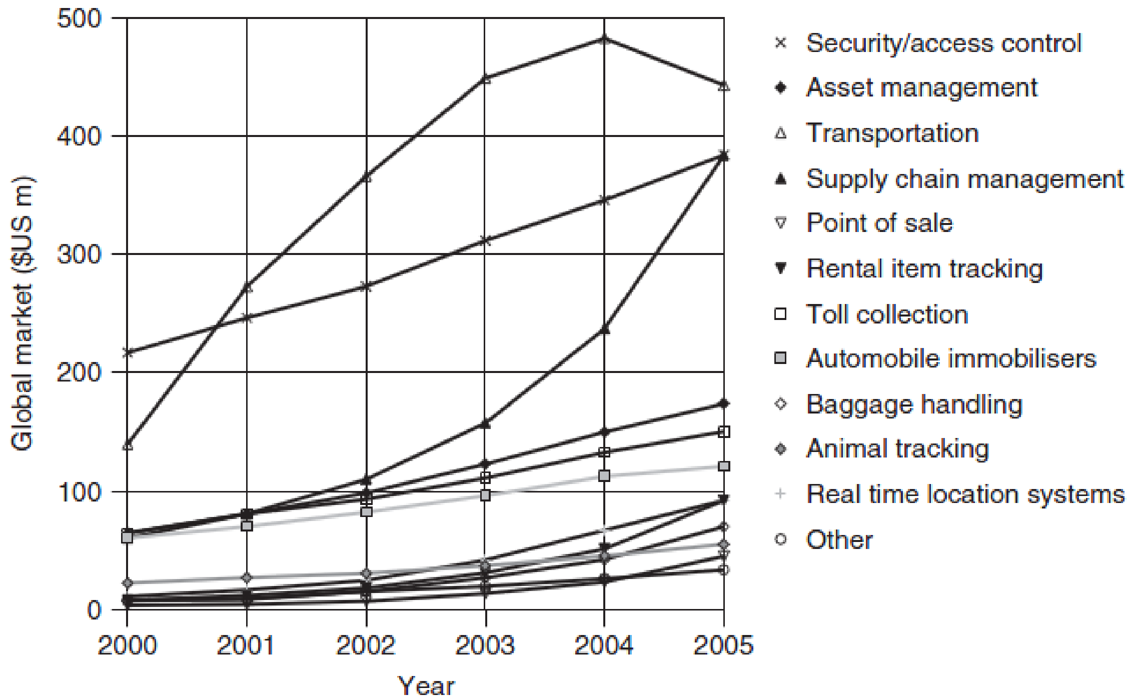

Figure 2-2 The estimated growth of the global market for RFID systems between 2000 and 2005 in million $US, classified by application (Krebs, n.d.)

RFID systems are very similar to smart cards. Both have a data storage capacity on an electronic data carrying device called the transponder. Unlike smart cards which have to be in contact with a reader to be able to transfer and receive data or provide a power supply, RFID systems uses magnetic or electromagnetic fields. Due to the numerous advantages of RFID systems compared with other identification systems, RFID technology is now becoming very prevalent. (Klaus Finkenzeller, 2010)

Table 2.5 provides a general comparison of different Auto-ID systems including the RFID.

System parameters	Barcode	OCR	Voice recognition	Biometry	Smart card	RFID
Typical data quantity (bytes)	1-100	1-100	-	-	16-64K	16-64K
Data density	Low	Low	High	High	Very high	Very high
Machine readability	Good	Good	Expensive	Expensive	Good	Good
Readability by people	Limited	Simple	Simple	Difficult	Impossible	Impossible
Influence of dirt	Very high	Very high	-	-	Possible	No influence
Influence of covering	Total failure	Total failure	-	Possible	-	No influence
Influence of position	Low	Low	-	-	Unidirectional	No influence
Degradation	Limited	Limited	-	-	Contacts	No influence
Purchase cost	Very low	Medium	Very high	Very high	Low	Medium
Operating cost	Low	Low	None	None	Medium	None
Unauthorized copying	Slight	Slight	Possible	Impossible	Impossible	Impossible
Reading speed	Low~4s	Low~3s	Very low >5s	Very low>5-10s	Low~4s	Very fast~0.5s
Maximum distance between data carrier and reader	0-50cm	<1cm	0-50cm	Direct contact	Direct contact	0-5m.microwave

Table 2-6 Comparison of different RFID systems showing their advantages and disadvantages (Klaus Finkenzeller 2010)

RFID technology's development began in 1950s and until now it has been a point of attention for many researchers in many fields.

2.3.1 RFID Market

The RFID technology has a widespread market around the world. In some parts of the world the use of such technology is very prevalent and known in particular in America, Europe, and Asia Pacific countries. Whereas other continents such as Africa, the technology is barely known. However, other countries such as Middle Eastern countries and South Americans are trying to become a part of such new technology and be a part of this growing market.

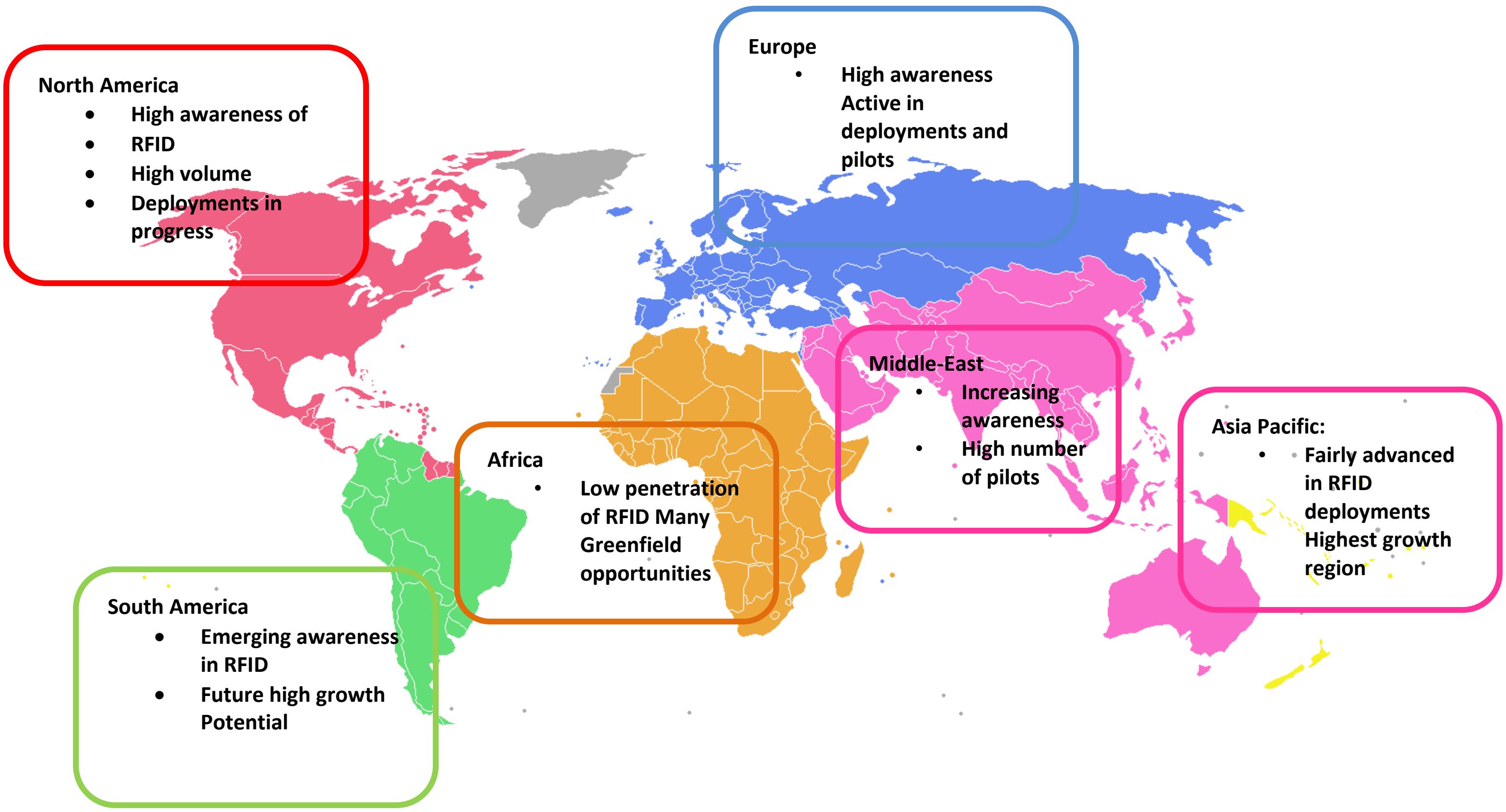

Figure 2-4 RFID around the world (*Susan Sahayan* Research Analyst Electronics and Security,Asia Pacific, 2012)

Figure 3 shows the trend and position of RFID technology in different continents and countries.

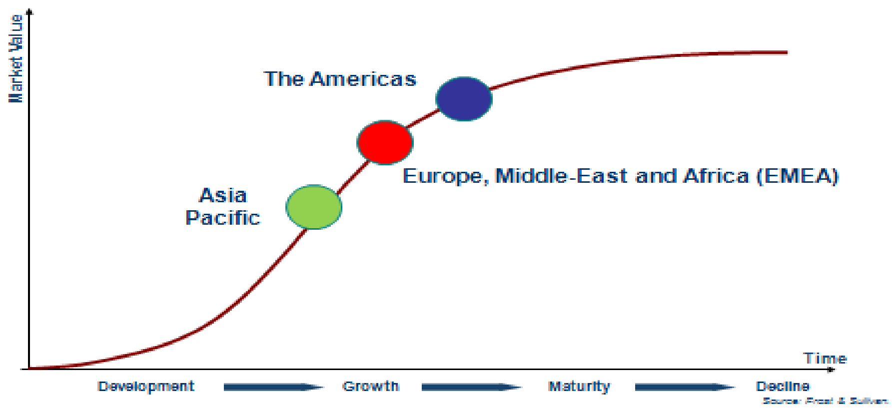

Figure 2-5 RFID value in different parts of the world (*Susan Sahayan* Research Analyst Electronics and Security,Asia Pacific, 2012)

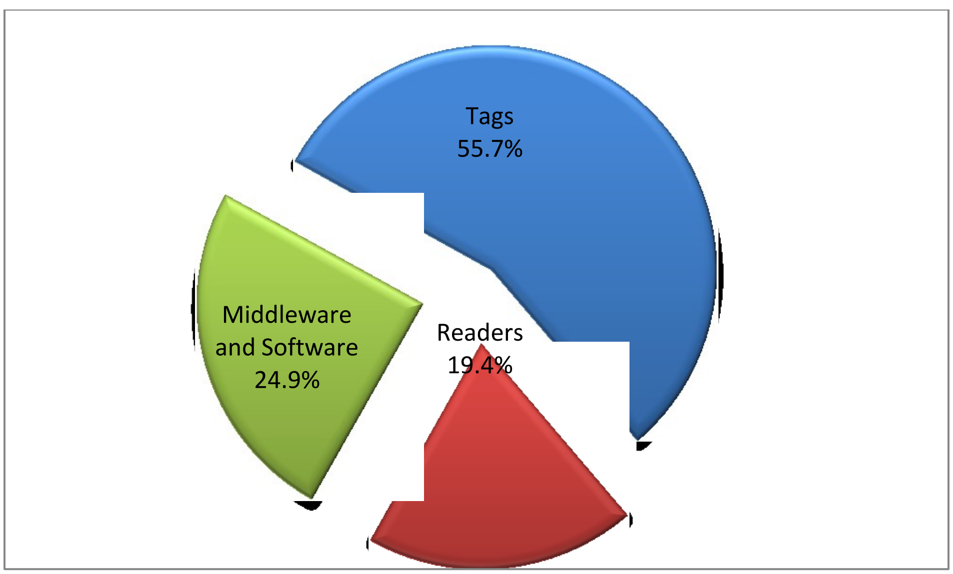

Figure 2-6 RFID revenue based on types (*Susan Sahayan* Research Analyst Electronics and Security,Asia Pacific, 2012)

In figure 2.6 we observe that, the majority of RFID revenue is generated from selling the tags to different industries, specially retail industries and manufacturers. The revenue is accounted for over 55%. Meanwhile, the revenue generated by selling the readers and the middleware software are 19.4% and nearly 25% respectively.

Figure 2.7 presents the percentage of revenue in different markets and industries as well as a revenue forecast for the upcoming year 2016. Figure 2.7 represents that transportation and industrial usage of RFID technology together account for over 50% of the revenue, whereas education and healthcare are 4.5% and 6.4% respectively which are the lowest. Retail sector, on the other hand accounts for more than 17%. More than 20% of the revenue generated by RFID comes from other market segments throughout the United States of America.

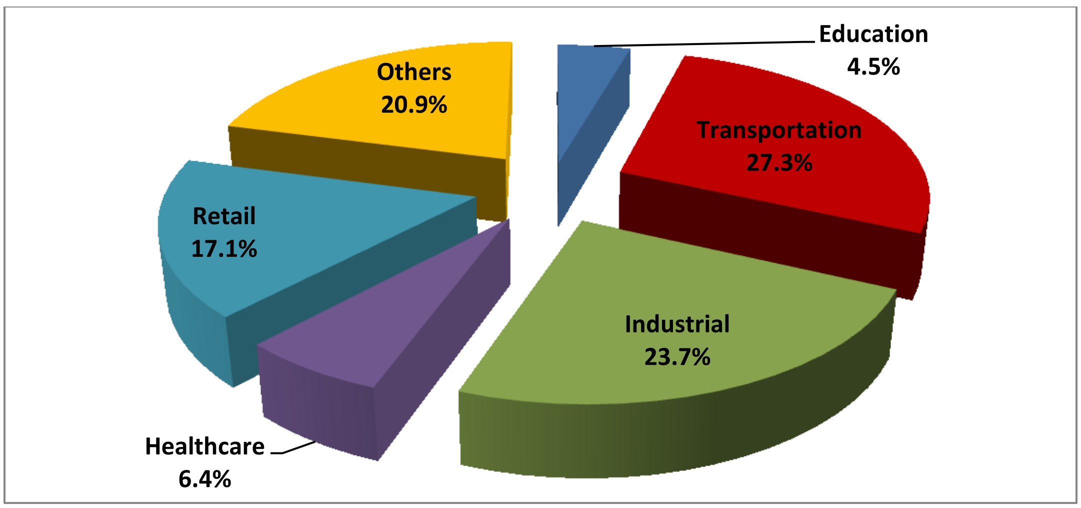

Figure 2-7 Percentage of RFID revenue in different sectors 2009 (*Susan Sahayan* Research Analyst Electronics and Security,Asia Pacific, 2012)

Figure 2.8 suggests that there will be some changes in the numbers in 2016. For instance, there has been an increase of over 1% in healthcare industry as well as in education. Other market segments are also expecting a 3% increase. Meanwhile transportation will experience a 4% decrease from over 27% to 23%. Industrial markets on the other hand will experience an increase of 2% from nearly 24% to nearly 26% in 2016. (Frost & Sullivan, 2012)

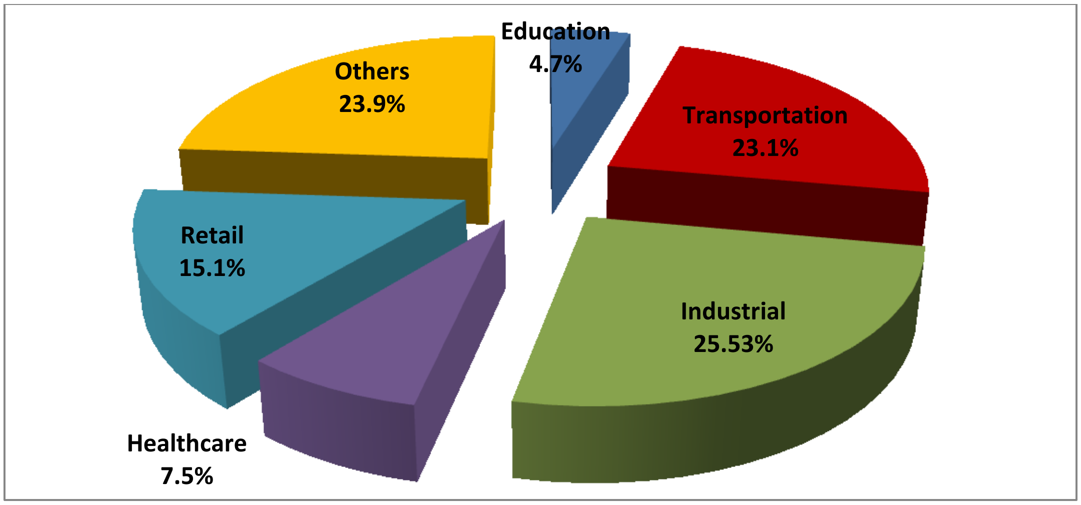

Figure 2-8 Percentage of RFID revenue in different sectors 2016 (*Susan Sahayan* Research Analyst Electronics and Security,Asia Pacific, 2012)

2.3.2 RFID Benefits

Information is the backbone of any supply chain or any network and its management and efficient use are of paramount importance. Using RFID technology, the products information as well as its description, dates, etc can be written into tags as an electronic product code (EPC) and embedded to products, pallets, etc to be further managed by information systems. RFID technology would make it possible to trace and track products and locate them at any point within the enterprise (inbound) and even outside of the enterprise (outbound).

Other benefits of RFID would be as follows:

- Enhance Supply chain visibility and control since it is possible to locate each and every product at any time with accuracy, it will be possible to manage and control the supply chain more efficiently and effectively.

- Enhanced Security and Authentication since RFID tags can be written using company's unique signature and this will be used as an authentication tool. On the other hand, RFID uses encryption and other security methods to secure and ensure the confidentiality of the data.
- Improved customer service and competitive advantage since RFID technology brings automation and reduces the cycle time, products reach the market faster hence the customers receive the products faster which makes the company stand out amongst competitors.

Other benefits that RFID would bring into the business are as follow:

- Reducing costs
- Reducing inventory levels
- Reducing lead times
- Reducing stock outs and shrinkage rates
- Increasing throughput
- Increasing quality
- Increasing inventory visibility and data accuracy

According to Poirier & McCollum, (2006), the useful features of RFID as compared to bar codes are as follows:

- A reader can scan multiple tags
- Automatic identification (no line of sight required)
- Content determination regardless of the material
- Durability (not prone to any damage)

- Data and information flexibility

Supply chain factor	Current state	RFID opportunity and challenge
Type of demand	Predictable	Improve leanness capabilities
Contribution margin	5-20%	Early adopters can increase the margin, need chap tags
Product variety	Low (10-20 variants per category)	Suitable to track products by pallets or cases
Average margin of error in demand forecast	10%	Room to improve forecasting through visibility of inventory and demand
Average stock out rate	1-2%	Opportunities for reduction in stock outs and increase margin significantly

Table 2-12 RFID benefits and challenges (1999- 2006 RFID4U)

According to electronic-cash-news (December 11th, 2009), RFID technology may bring many benefits to the supply chain, logistic operations, shipments and asset management. However, the benefits of RFID would be beyond the aforementioned advantages.

- Reduction in Clerical Errors hence Increase in Data Quality: Automation and accurate data gathering and management that RFID bring to some points in the process make it possible to eliminate the errors that are made by humans and this accuracy would lead to an increase in quality of both the ultimate data and products.

- Improving Asset Visibility and Utilization: RFID would make it possible to have a great deal of visibility at an item level. With this technology items, products, pallets, etc can be traced and tracked throughout the supply chain.
- Increase Efficiency: RFID technology eliminates the manual scanning efforts and despite barcodes, products and items are not required to be in line of sight to be read and can be read from distance. Any manual work such as inventory counting and other manual works now could be carried out by radio waves automatically hence increasing efficiency.
- Reduce Theft: RFID tags have this ability to be encrypted and on the other hand, since it provides almost a real time data analysis it can reduce or even prevent theft.
- Improve Customer Experience: RFID could assist customers in their purchase since it can be used and integrated in smart shopping carts, POS terminals, kiosks, etc it improves the customers' shopping experience by affecting their purchase decisions and anticipating their needs.
- Improve decision making through real time information gathering, analysis and provision. This would lead to better forecasts, reducing the risk of stock outs, reduction of the bullwhip effect throughout the supply chain and technically, provide better planning.

Based on the study carried out by Robert de Souza *et al.* (2011) on the return on investment for RFID ecosystem of high tech company, they found that RFID technology could play a very efficient and effective role in supply chains by improving the flow visibility and inventory control as well as responsiveness. In their study it was suggested that the cost of RFID tags may not be decreased to as low as barcodes and to be able to benefit from this technology one needs to focus beyond the factory. Basically, RFID not only provides quick data access strategically, but it could also be beneficial in the operational level of the supply chain.

2.4 RFID in reverse logistics

According to Nativi *et al.* (2011), using RFID technology in a decentralized supply chain with reverse logistic supply chain would bring both environmental and economical benefits. It was suggested, through 128 simulation runs, that the environmental benefits were through motivating the industries to return and use more recycled materials; returns collection increased by the average of 87%, and the firms were able to make decisions more efficiently and effectively since RFID technology would provide them with more realistic data than before making the forecasts to rely more on the accurate and actual data rather than the heuristics. On the other hand, the RFID technology would bring rapid adaptability through inventory visibility, information sharing, and real time monitoring. The average improvement through cost reduction was 19% through stable inventory control, reducing unnecessary safety stock hence reducing the out of stock, holding and storage cost as well as the procurement cost of the firm. Obviously, the economical benefits were not as significant as the environmental benefits so Nativi *et al.* (2011) take into the account the fact that in order to be more efficient in terms of financial improvements, more managerial support and insight is required.

According to Wei *et al.* (2011), RFID-enabled mixed-product loading strategy for outbound logistics, information sharing features and capabilities of RFID technology has helped many industries and supply chain managers to make more effective decisions. They suggest that the dynamic systems will operate more efficiently than deterministic systems when it comes to using

RFID technology. Using RFID technology, it is possible to use more data and other characteristics to make more efficient decisions (here, S/RPT and RPT truck loading and dispatching rules, using RFID, are more efficient as they use more dynamic data).

A case study by De Marco *et al.* (2011) studies the use of system dynamics to assess the impact of RFID technology on retail operations, RFID tagging at item level could maximize the benefits to retailers to enhance shop floor productivity, sales promotions and business performance. They employed system dynamics modeling to refine the past estimates and to understand the extent to which RFID technology might impact on the complex relationships between retail operations, inventory management, sales performance, and to provide cash flow analysis (CFA) with accurate inputs. Their study proves that system dynamics is a practical and predictable method to assist the task of evaluating both cost and revenue benefits that can be achieved out of RFID implementation in retail stores. RFID technology impacts profitability through revenue growth (5-10%) rather than cost reduction. On the other hand, it has the capacity to improve inventory management as well as the on-the-shelf availability. They gathered their data from different sources such as the process flows process mapping, interviews (logistics department, marketing department, and sales persons), direct observations (from warehouse, shipping and retail store operations) and previous works (heuristics) of over 800 brand stores in Italy. During the study disposable RFID tags were selected, hand held readers (distance up to 2m & simultaneity of 250 items) to support the staff in various activities such as goods receiving & treatment, picking, inventory taking, item positioning and dressing of shop windows. The result of the simulation suggests that using RFID the available time for customer care were increased as much as 2.5%; since the assisted sales factor increase, inventory turnover becomes quicker as sales rate increase hence the store will gain a huge competitive advantage. Generally speaking, RFID may bring automation to some processes in a company which makes it possible for the managers to focus more on the factors that have the potential to gain competitive advantage to their business confirming the fact that RFID technology would be able to enhance the decision making process in many industries.

In another study conducted by Qiao-lun *et al.* (2011), System Dynamics Analysis of RFID-EPC's Impact on Reverse Supply Chain, the authors tried to use system dynamics modeling to show the changing of the inventories, service levels and the profits when employing RFID in a supply chain. The results suggest great improvements in service levels, profits of different parties in the supply chain such as the collectors, remanufacturing centers and the disassembly centers. The surprising outcome was due to the fact that despite the inventory levels increased, the supply chain as a whole witnessed great improvements.

According to Lee *et al.* (2007) RFID-enabled systems affect consumers' trust and acceptance of u-commerce in a positive manner. The research provides insights into the development of RFID-based policies to increase consumers' trust in u-commerce. The model was developed and verified using system dynamics modeling. The study suggests that employing effective policies in the provision of privacy in RFID-enabled systems will have a great deal of impact on consumers trust to use ubiquitous commerce; *"the use of ubiquitous networks to support personalized and uninterrupted communications and transactions between an organization and its various stakeholders to provide a level of value over, above, and beyond traditional commerce"* (Watson *et al.*. 2002). RFID technology would bring many benefits to the business such as cost reduction through better inventory management, improved product tracking, better analysis of consumers' purchase behavior, habits and patterns hence increasing the sales revenue.

Zhou *et al.* (2010) investigate the potential of using RFID enabled adaptive learning system in remanufacturing system design, with RFID real time item level information, they were able to identify every single item at any time, the associated characteristics of items and possibly its ambient conditions whereas using the traditional system, all items are treated the same in throughout the manufacturing session and technicians would adjust the manufacturing configurations based on information collected from check points. The study suggested that with refined continual information on individual parts throughout the session, the technician is able to fine tune the manufacturing processes for better quality, thus reducing the rate of producing defective products. However, according to their study, with RFID-generated information visibility and post-data-processing, we are able to obtain two possible benefits: improve the manufacturing process and pinpoint possible quality issues related to individual defective products by considering its historical manufacturing data. This is when without RFID tracking and tracing ability, the information is based on statistical description at an aggregate level that deprives the ability to refine the manufacturing and remanufacturing process at an item level.

Based on another study accomplished by Hwang *et al.* (2010) RFID could bring a number of benefits for a centralized reverse supply chain in an apparel industry. The study suggests that RFID could bring the following benefits to the reverse logistics:

> ***"First****, using RFID with EPC Network, quality of tag information that user can obtain from the tag is better than legacy ID system such as bar code. Also, it ensures availability of relevant useful product information.*

***Second**, RFID with EPC Network ensures ready availability of product information which means timely convenience. We can obtain information such as tracking, real-time location, and state of product at the right time.*

***Third**, by using EPC Network, unique product "footprint" is made available. Item can have its own address to access, which means managers can handle and trace each product by item level. Hence, its accuracy of information becomes higher than ever before!"*

On the other hand, RFID could improve operational efficiency in retail backroom and decision making of return; the new information from smart shelves and smart fitting rooms could leverage retailers' effective return management. Also, their study suggested that efficient acquisition of product information using RFID readers can reduce inspection lead time in return process.

According to Hannan *et al.* (2011) RFID technology could also be effective in waste management. They studied the development of a waste management system for Malaysia using a package of technologies such as RFID, Cameras, GPS, GSM and GIS to enhance the waste collection operations, bin and truck monitoring, and management efficiency. The system also contributed to better decision making in truck locations and scheduling hence the proposed system can plan for better bin and truck distribution cooperating with information and telecommunication technologies.

Based on the study carried out by Lee *et al.* (2008) which was about the development of an RFID based reverse logistics system, genetic algorithms were used to determine the location of different collection points in the reverse logistics to maximize the coverage of customers. However, RFID technology has been used to count the collected items at each collection points and send the information to the central return center. The proposed system helps keep track of collected items in a real time basis to be able to decide upon the best and economical transportation from collection points to the collection center. Their study appreciates the use of RFID technology in having an efficient and optimized reverse logistics system.

2.5 RFID in Aviation

RFID technology is becoming popular in different industries. Today, RFID technology is being used in aviation industry as a promising and helpful technology for baggage handling, cargo tracking, managing inventory (both inside and outside the cabin), and for tagging different critical parts for maintenance operations. Technically speaking, RFID technology is becoming a suitable technology in MRO (maintenance, repair and overhaul). The fact that RFID technology has become popular in the field of MRO could be because of its ability to automatically identify items without the need of a line of sight. This would offer instant and real time visibility hence more efficiency and accuracy in data gathering, analysis and management. On the other hand, the authenticity that RFID provides makes it possible to differentiate between the fake and original components hence ensuring that the passengers are at no risk.

Another factor which makes RFID a good choice for MRO would be its ability to be modified and dynamic compared to Barcode which provides a more static identification. Mechanics and technicians after reviewing the items and components would be able to add or write the data on the tags to create a history or a log for that specific object so that once the data is read, a complete history of maintenance and repair of that component can be reviewed including the information of what has been done, where, when and even by whom.

Consequently, RFID technology would be a great tool to assist in the aviation industry when it comes to tracking the critical parts of the aircraft. The Federal Aviation Administration (FAA) has approved the use of RFID technology in components and critical parts of aircrafts which means there will be an incentive to employ RFID technology in a variety of sectors such as airplanes, air cargo, aircraft maintenance and repair centers, and airplane manufacturers. Employing RFID technology for logging a part's flight hours or life cycle, the history of repair and maintenance will reduce the cost of tracking and tracing the service history on a specific component. This, accordingly, will reduce the cycle time of problem solving and information exchange throughout the supply chain and logistics systems.

The ability to tracking and tracing the aircraft parts would help the mechanics and technicians to be able to update the data accounted for the maintenance history of components more quickly and efficiently than before which in turn, facilitates the configuration control and repair history, reduce the warranty claims processing time and cost, improving the quality and easily pinpointing the flawed components. On the other hand, this would reduce the paper work and bureaucracy in the supply chain.

Moreover, RFID tags could be attached to different maintenance tools providing visibility to what tools are available, which tools are being used and where, when and by whom (which department) a tool has left the storehouse and when it's got returned as well as information about the tasks and operations they have been used for.

RFID technology is also used in asset tracking and management. Assets such as tugs, trailers, forklifts and even containers will be tagged by RFID so that their location and numbers will be traceable in a real time basis. Moreover, the information about the maintenance of these assets will also be of great use to mechanics and service personnel.

Generally speaking, according to "Xerafy.com", the benefits of Radio Frequency Identification (RFID) in aviation industry would be:

- *"Improved aircraft configuration management and line maintenance*
- *Visibility of full maintenance history across organizations*
- *Reduced occurrence of "no fault found" conditions*
- *Life-limited parts tracking and optimization*
- *Reduced cost of compliance documentation*
- *Recorded pedigree for end of lease"*

As an example of an efficient and effective employment of RFID technology in aviation industries, Airbus and Boeing which are two of the biggest aircraft manufacturers in the world may be taken into account.

Before we get into more detail about the two aforementioned companies, first it is advised to take a look at the motives for using the RFID in aviation industries.

Based on Holloway (2006) the future trend of aviations industry will face a rise in terms of customer demand, revenue growth, etc. the revenue will grow from the launch of new models of aircrafts and low-cost airlines. On the other hand, the customer demand is said to be doubled by the end of 2020. Accordingly, safety has become a major point of concern and this has made the companies to invest in new technologies such as RFID to efficiently track and trace their components to ensure their quality.

Moreover, aerospace companies are under huge amounts of pressure to be environment friendly and are forced to some extend to eliminate waste.

However, investors in the industry would wish to see a greater return of investment (ROI) from their research and development departments and to reach this companies seek collaboration and effective information sharing facilities.

Airbus, which is one of the biggest aircraft manufacturers in Europe, has recently introduced an MRO strategy supporting the RFID technology for the purpose of supply chain visibility by tagging both flyable and non-flyable components over their total life cycle (Sweeny, 2010).

The motivations for adopting the RFID technology in Airbus were the need to reduce the costs and to increase the competitiveness among other competitors like Boeing. (Carlo K.Nizam, 2010)

According to Holloway (2006) Airbus deployed RFID technology for various purposes such as:

- Malfunction detection on early stages
- Reduction of inventories
- Establishment of audit trials for each specific component
- Ensuring that they have the correct parts on the correct place
- Efficient documentation for mechanics and technicians, including all the detail about the tasks, and parts and to be able to trace and track the approved parts on a real time basis
- Identification and tracking of tools location, usage history and repair requirements
- Authentication hence improving the security

Based on a research study carried out by Kim *et al.* (2011) from the School of Air Transport, Transportation & Logistics, Korea Aerospace University Goyang City in KOREA, RFID technology bring a number of benefits in the aviation industry and may solve many fundamental problems hence increase the ROI and decrease the costs. The tables 2.8 and 2.9 show the benefits as well as the potential problems that are believed to be solved using simulation study of an RFID based air cargo process.

Potential benefit area		Benefits
Reduce WIP	Reduced WIP	Benefit in terms of increase cash flow due to the decrease WIP
	Utilization of assets	Utilized benefit of asset (ULD)
Asset management	Capacity utilization	Reduction of the number of required existing assets which can be resold Reduction in the number of annual new asset purchases
	Asset Tracking	Reduction in shrinkage of ULD asset Inventory Reduction in replacement expenditures due to damage
	Yard control	Reduction of labor costs in ULD yard location
Damage or Loss Insurance	Reduction claim cost	Reduction in claim costs due to decrease in misplaced & delayed packages Reduction in claim costs due to more accurate value determination using RFID
	Reduced Insurance Cost	Reduction in insurance premium costs by reducing total number of claims

Table 2-13 Potential benefits (J.Y. Kim *et al.* 2011)

Area	Problems	Expected advantages of using RFID
ULD (unit load device) process	• Need to check several times for loading according to loading plan • Hard to detect miss-loading • Input data by labor at every process	• Information checking from RFID system automatically • Automatic input of correct information • Paperless work process
Movement Management	• Movement management according to an paper document 'work order' • Input related data after movement • Incorrect ULD number checking by labor • Problems of security and safety • Impossible to track and trace of ULD	• Paperless work process • Real time track and trace • Real time management • Improve security problems • Decrease human error
Asset Management	• Impossible to real time inventory management • Inventory check by labor, 2-3 times a month • Record history of washing/repairing of ULD on paper document • Impossible to manage the ULD turnover ratio	• Real time inventory control • Real time ULD condition control • Computerized ULD history management

Table 2-14 Current problems and expected advantages from RFID (J.Y. Kim, *et al. 2011*)

2.5.1 Airbus Application of RFID

The Airbus makes use of RFID in two ways; since many of the suppliers of Airbus (over 75%) are dispersed around the world, all of them are equipped with RFID tags instead of Barcode to provide more transparency and control over the components and assets in transit. By doing this, it will be possible to automatically detect any errors or problems associated with different parts as they are all equipped with RFID tags when they leave the suppliers.

According to RFID journal, 2009, Airbus has equipped its in-cabin items such as life jackets and even seats with RFID tags in its A330 and A340 models so that the configuration management as well as information gathering and exchange will be faster and more efficient.

On the other hand, all the tools and toolboxes in Airbus are equipped with RFID tags which may include information on the history, shipping data, routing and customers. (Holloway, 2006)

In this way, tools which are tagged by RFID will be much easier to manage and will have a more efficient and effective availability. They would require much less paperwork and have lower error rates hence the administration costs will be reduced.

"Airbus also leases its own tools for the highly-sensitive aircraft maintenance to other maintenance companies or airlines. In 1997, Airbus pioneered the use of RFID in its tools business. The motivation was to provide a better and quicker service to customers by improving the efficiency of administration." (Airbus, N.A. January 13, 2013 by Harvard case studies)

The deployment of RFID technology has brought many benefits to Airbus; the total visibility of the value chain has been dramatically improved, most of the processes are automated and more efficient which means shorter cycle times and less inventory. Also, the administration process has become more efficient since all the repair data and flight information of specific parts are electronically available to all the mechanics and service staff.

On the other hand, the inventories decreased and Airbus faced more stock reconciliations and an increase in labor productivity and supplier monitoring hence more accurate forecasts, more efficient decision making and improved supplier delivery performance.

Accordingly, the costs of MRO and inventory maintenance have been reduced and Airbus gained competitive advantage in the market; 8% reduction in incorrect deliveries (Holloway, 2006)

According to Sanquirgo (2006), Airbus saved 100,000€ in 2006 by leasing the tools compared to 180,000€ investment costs, and reduced the repair cycles by 6.5 days hence improving the inventory management. Sanquirgo (2006) also notes that over 6000 tools are already equipped with RFID technology and approximately 2000 to 5000 parts and components may require RFID tagging.

2.5.2 Boeing Application of RFID

Boeing is one of the largest aircraft manufacturing companies in the U.S and is the leading manufacturers of commercial jetliners and defense, space and security systems. Boeing is now supporting not only the U.S but over 150 other countries in their aerospace industry. Boeing offers a variety of services and products such as commercial and military aircrafts, satellites, weapons, electronic and defense systems, launch systems, advanced information and communication systems, and performance-based logistics and training. (Boeing official website 2013) In 2010, Boeing announced that it is starting a partnership program with Fujitsu to deploy an Automated Identification Technology (AIT) in its aircrafts throughout the repair, maintenance and inspection processes. The outcome of this partnership would be a solution called the "RFID Integrated Solutions" which is offered to Boeing's existing and new customers such as airline companies. The solution offered by Boeing was approved by FAA and provides its customers with Fujitsu's second generation EPC (Electronic Product Code) RFID tags which are designed for aerospace applications as well as RFID readers from Fujitsu, Motorola or Intermec and a middleware software hosted by Boeing as well as an integration and maintenance services from Fujitsu and Boeing. (RFID Journal Dec. 30, 2010) RFID integrated solutions will provide this possibility for airline companies to install RFID tags on different airplane parts so that data associated with that specific part would be stored into the tags and be available to the staff members at the time the part is under repair, inspection or maintenance. It is believed that using this solution, the process of inspection, repair, maintenance and documentation will be faster, easier and with fewer mistakes which may take place when the tasks are handled manually.

The aforementioned RFID solution underwent a trial with another partner of Boeing, Alaska airlines for a year. Boeing has started the trial with Alaska airlines on March (2011). There were 28 tags attached to different parts of a passenger aircraft within a regular flight schedule. During the trial which took 1 year, the tags were tested under various extreme conditions such as heat, cold, pressure, water and dirt to examine the performance of the tags. The data is gathered directly by airline's staff at different airports using a handheld reader to determine whether the tags are storing properly. Technically speaking, the RFID tags are attached to five different parts such as emergency equipment, rotables (rotating parts), reparable equipments, structural and cabin components. (RFID Journal, 2012)

The Boeing RFID integrated solution, promises to bring considerable cost savings and efficiencies: (Boeing commercial airplanes, marketing, 2013)

- Reduction of non-value-added tasks hence better utilization of maintenance technician's time
- Fewer operational errors
- Greater visibility of operations and information
- Reduce spares/in-process duration
- Improvement in human factors for maintenance technicians
- As well as a globally-based technical support team.

According to Lois Hill, technical operations manager - RFID Integrated Solutions at Boeing Information Services and former American Airlines maintenance planner, *"the environmental and operational tests of RFID technology are exceeding expectations.*" (Charles Chandler May 24, 2012)

Lois Hill also notes that all the parts that were tagged by RFID flew for over 2000 hours and put into more specific tests associated with both destructive and non-destructive related to component maintenance environments and the results were dramatically beyond expectations; all the RFID tags were fully functional and were able to transmit, receive and store data and the level of deterioration was non or very low.

"*During an operational test, the oxygen generators on a B 737-800 were inspected; a job that would normally take about four hours to complete. With RFID tags affixed to the generators, the inspector held the RFID reader at belt level and walked down the aisle from First Class past the last coach row. In one minute and 30 seconds, all the data from the oxygen generators was acquired and their status read. The same test was conducted on a B 777. It took 15 minutes to inspect all the oxygen generators,"* (Lois Hill)

Moreover, the RFID technology will provide more capacity to the company; it automates and facilitates the tasks done by aircrafts maintenance technicians and provides them with more time so that they could put more effort in trouble shooting, problem solving and decision making hence the company will gain competitive advantage and will be able to grow faster. (Read and Weep by Charles Chandler May 24, 2012)

2.6 RFID Issues and Concerns

Despite all the benefits and advantages that RFID technology brings to the companies and the motivation factors that are available throughout the market to deploy such technology or even replace barcode with RFID tags, there are still a number of concerns, issues and challenges against the employment of RFID which pushes different industries and market sectors back when it comes to using the RFID technology.

Such concerns may be as follows: (Serena Ong, Using RFID to Enhance Supply Chain Visibility - Airbus Case Study, 2010)

- High cost

  The initial installation costs of RFID technology are very high. The tags and the readers are expensive and require a high initial investment. On the other hand, the costs of change will be high. This includes the costs of new labor, training for the existing labor, software and hardware, process redesign, and generally changing the way the company used to operate. These costs concern the managers about the fact that they might not meet their planned ROI.

- Standardizations issues

  One of the concerns associated with using RFID is the lack of a global standardization system. Since many companies may use RFID for asset management and since many companies operate globally, managing different types of readers and tags in different countries would be a difficult task. On the other hand, the standardization systems are still evolving through time which means regular updates hence upgrade costs imposed to companies.

- Potential data interference and overload issues

  According to Holloway (2006) one of the other concerns associated to RFID is the interference of signals with the aircraft's systems; whether a strong signal activates all the other RFID tags at once or interferes with other signals that are transmitting in and out of the aircraft which may create danger and life threatening matters.

  On the other hand, there might be a data overload taking place since the readers are reading the tags on an ongoing basis to gather information. Data noise may occur making the readers to read the wrong information.

- Environmental factors

  Environmental factors such as pressure, heat, salty environments, humidity, detergents, etc may all affect the reliability of the tags and the readers which have to be addressed and put into several tests to examine the tolerance of the tags and the readers.

- Resistance to change from barcode

  The barcode technology has been in the industry for many years and has proved high levels of efficiency for many companies. Moreover, they are very cheaper and many companies have high levels of resistance to change their infrastructure from the barcode to another technology such as RFID.

- Partnership issues

Another issue in using RFID technology is the lack of integration within different parts of the supply chain, for instance, the RFID infrastructure may not be integrated with the ERP systems of the company and may not be able to update the information on a real time basis. On the other hand, some companies are not willing to share their information because of confidentiality issues and since information sharing is crucial to be able to get the most out of the RFID technology, the lack of integration and valid information may become problematic. (Holloway and Klein, 2006)

On the other hand, the European commission joint research center (JRC) in the article "RFID Technologies: Emerging Issues, Challenges and Policy Options" (2007) suggests some other issues associated with the deployment of RFID which are as follow:

- Social acceptance and trust

  The European commission joint research center suggests that the attitude of people towards RFID is in a way that they believe they cannot trust the technology. The lack of awareness about the existing security measures is a problem which has to be addressed.

- Ethical issues

  Ethical issues on the other hand may be at risk due to privacy matters in using RFID technology. People are concerned about their private and confidential information to be shared with others such as competitors and they demand high levels of security measures to ensure the safety and confidentiality of their data.

- Security and privacy concerns

  The widespread use of RFID in different industries and market sectors has casted doubt on the security and privacy issues of using such technology. People demand strong and effective legislations and policies to prevent any theft of data or copyright violations both from the government and internally from the company itself. "*Various initiatives, at EU level, to tackle RFID privacy and security concerns already exist; for example, the Article 29 Working Party has expressed its views on minimizing data collection and preventing unauthorized forms of processing through improved use of the technology.*"(JRC, 2007)

- Impact on employment

  RFID technology as any other new technologies may cause many jobs to be lost and many workers unemployed. According to the European commission JRC, over 10 years in the United States, over 4 million jobs may be lost due to the use of RFID. However, RFID may be an opportunity to create new jobs both in the service sector and in the industry.

- Barriers for smaller companies

  Smaller companies may face a variety of obstacles in deploying RFID since their budget is a bit tight. High initial costs, training costs, uncertainty on the technology's future, lack of a global standard and other factors may prevent smaller businesses to deploy RFID technology since they are more fragile.

- Fallback procedure

  Due to the fact that RFID technology may be used in industries which are more critical such as healthcare and aviation, there has to be some sort of fallback procedures in place as a contingency plan to make the system more reliable and foolproof. This will add extra expenditure on both training and deployment and itself may be another barrier to many businesses.

- Gap between leaders and followers

  This gap may prevent the technology to bring its promising benefits to the market fully and may constrain the development of such technologies in future. According to (JRC, 2007) "*closing the gap has positive growth implications as 'local' European firms will play an important role in the challenging ICT transformation processes that RFID brings.*"

- Reserved spectrum bandwidth

  The reserved amount of bandwidth that has been reserved already may or may not be sufficient for future uses of RFID for instance the bandwidth that the U.S has reserved is ten times bigger than the one Europe has reserved.

- Testing and certification

Since the RFID works with radio frequencies and is a wireless communication, efficient and effective testing and certifications are needed to make sure the system is secure and private enough.

- Semantic interoperability

  Despite all the different standards such as ISO or EPCGLOBAL, companies may have to establish their own interoperability semantics and standards to facilitate the exchange of information among all the enterprises of the supply chain.

- Huge amounts of data

  Since RFID technology may be used in a geographically dispersed manner and may produce a huge amount of data, collision avoidance and the development of procedures on the control and ownership of that dada have to be taken into account.

Chapter 3

Solution Approach

The proposed solution approach to understand the behavior of the disassembly of aircrafts comprises of four steps: RFID technology selection, RFID Implementation, RFID cost analysis and RFID simulation. Each of these steps is described in more detail as follows.

3.1 RFID Technology Selection

RFID technology comes in a variety of forms each of which has their own specifications and are used for different purposes and for different goals. RFID tags, generally speaking, come in a form of passive, active, semi-passive and semi-active. Each of which has different values in terms of cost, IC powering, signaling behavior, life span, size, range, and memory which are all described and illustrated in the table below. Different industries may choose different types of RFID tags and readers to serve their differing purposes, goals and strategies.

Basically, a passive RFID tag would be the one which does not have a battery source and the power is supplied by the radio frequencies emitted from the readers by creating a magnetic field. Passive RFID tags has so many advantages such as

- Durable; they have a long life span of over 20 years
- They don’t need a power source such as a battery

- The tags are so cheap and affordable
- Small size; as small as a single grain of rice
- Unlimited applications in different industries

On the other hand the passive RFID tags have some shortcomings;

- Short distance readability; a few feet
- The tags remain readable for a long time even after they are sold and are no longer being tracked

Active RFID tags, on the other hand, are the tags that are equipped with a power source such as a battery. Some active tags may use removable batteries so that the batteries could be replaced whereas others may have a sealed battery which cannot be removed and replaced. However, it is worth noting that the tags may also have the ability to be connected to an external power source.

The advantages and features of active RFID tags may be as follow: (barcode-rfid-labels.com 2013)

- Long reading distance; over hundred feet or more
- Having other sensors that may use electricity for power
- Capability of starting new communications
- Diagnostics abilities
- Higher data bandwidth

However, the disadvantage of active RFID tags may be as follow:

- Lack of functionality with the absence of the batteries
- Higher cost; $20 or more for each tag

- Larger size
- Higher maintenance cost compared to passive tags
- Battery outage may impose a huge amount of risk; expensive mistakes

Semi passive RFID tags, on the other hand, operate similar to the passive RFID tags but they have a battery source which makes them a bit more independent from the readers. However, these tags are still dependant to the readers' radio frequencies to power the tag response. Semi-passive RFID tags may have extended signal range and may be more effective as they use their own power source to monitor the environment such as the temperature. Table 3.1 represents different types of RFID in more detail.

RFID Tag	IC powering	Signaling behavior	Life span	Size	Range	Memory	Cost
Active	On board battery	• Active transmission • Send signal at regular rate	Limited	Bulky	Long	<100 KB	High
Semi-active	On board battery	• Send signal only when interrogated by reader at readable range • Use active transmission	Limited	Bulky	Short	<100 KB	High
Passive	Signal received from reader	• Send signal only when interrogated by reader at readable range • Use backscatter	Unlimited	Small	Short	96 bits,128 bits	Low
Semi-passive	On board battery	• Send signal only when interrogated by reader at readable range • Use backscatter	Unlimited	Small	Long	<100 KB	High

Table 3-1 Comparison of RFID tags- adopted from Kehinde Oluyemisi Adetiloye Thesis 2012

Taking into account the advantages of passive RFID tags including their low costs, their unlimited life span, their size and considering the fact that the under study reverse logistics network demands a very small sized printable tags, Passive RFID tags are believed to be the most suitable for of RFID tags to be used.

3.1.1 Force Field Analysis

Force field analysis is a tool which is widely used in the concept of change management and in the field of social sciences. The tool is introduced by Kurt Lewin in 1947. The force field diagram represents a set of driving and restraining forces. The driving forces are those motivations and benefits that make a certain change acceptable and on the other hand, the restraining forces are those negative aspects which make it difficult or constraints the change.

RFID technology as of any other evolving technologies is considered as a change imposed to the industries. Developing the force field analysis for RFID technology in reverse logistics, specifically in the aviation industries makes it possible to have a broad view upon the acceptance of RFID technology as a new change in the industry.

The values used in the following force-field analysis are based on different research papers. On each research study, the advantages and disadvantages of passive and active tags as well as the general benefits and challenges of RFID technology has been discussed and analyzed.

Huang *et al.* (2006), in his *study "Quantitative performance evaluation of RFID applications in the supply chain of the printing industry",* investigates the financial benefits of RFID in the paper industry and comes up with a feasibility study that suggests that RFID will bring cost savings and many other benefits such as cycle and operations time reduction to industries.

Baysan *et al.* (2007), investigates the popularity of RFID technology among different industries such as supply chain management, automated identification systems, etc. The study also evaluates the different costs of RFID tags as well as the influence of factors such as price, quality of the tags, and transfer batches on total system costs which may include the purchasing and reverse logistics costs of tags. Reusable RFID tags were found to be more cost effective since they can be reused and higher quality tags lead to lower system costs.

Many other studies have also conducted to investigate the integration of RFID systems in helicopters such as Pauly *et al.* (2011) which evaluates a global RFID system including the passive, battery assisted and active RFID tags. The study also investigates the polarization and positioning of these tags based on radio wave propagation.

Richard Paine from Boeing, (2007) has also investigated the different advantages and disadvantages of passive and active tags including their life cycles and challenges.

Savi Technology in its white paper on January (2002), investigated the technical characteristics of active and passive RFID tags, their functional capabilities, their applicability to supply chain visibility, their complementary uses and their corresponding challenges and standard initiatives.

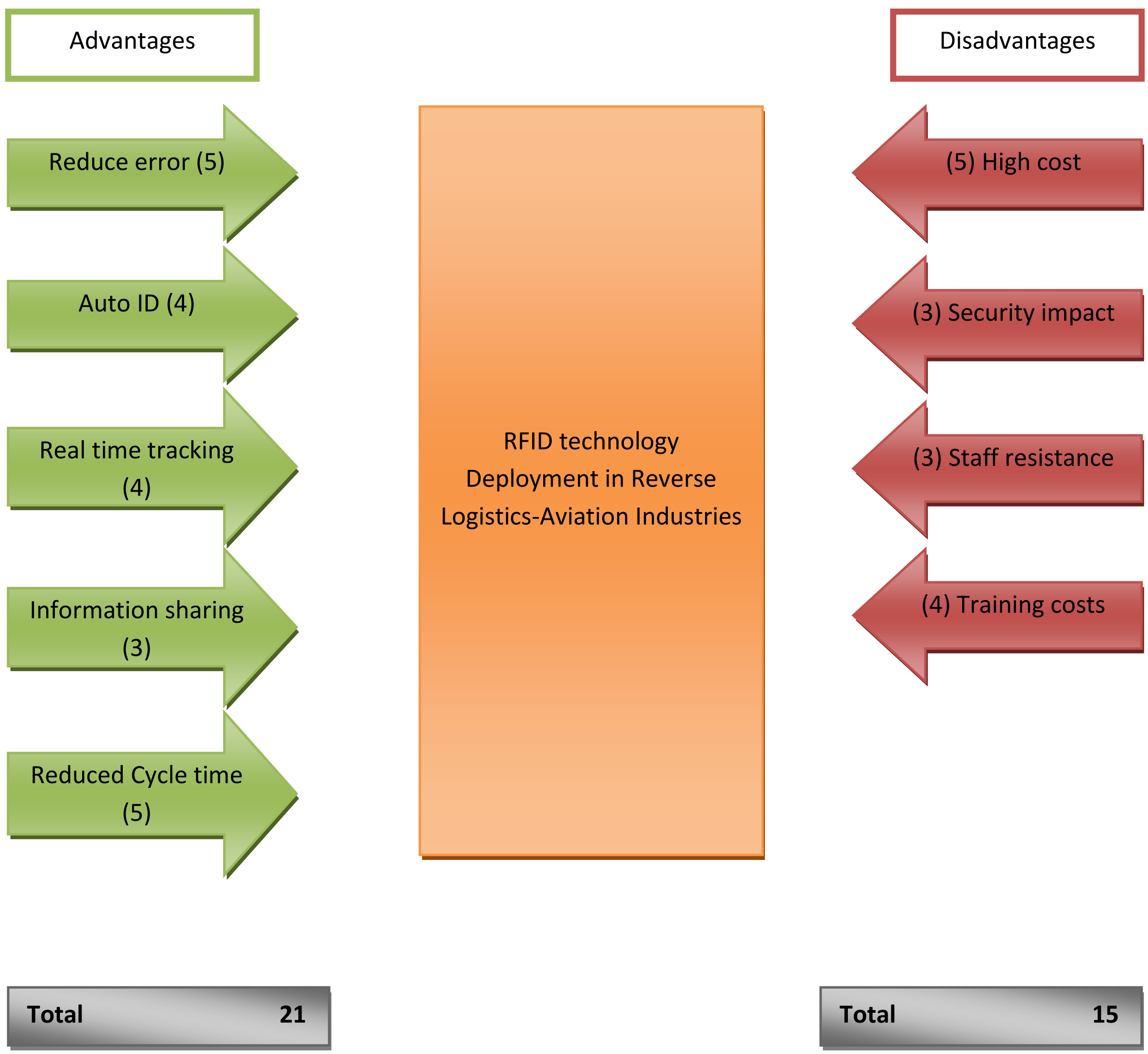

Figure 3-1 ForceField Analysis (RFID Technology)

We conducted a review of 35 research papers each of which addressed the advantages and disadvantages of RFID technology and as illustrated above, the total weight of the forces or the potential benefits and motives are 21 and the total weight for the disadvantages or the restraints against the RFID deployment is 15 which suggest that since the benefits outweigh the disadvantages, RFID selection and deployment is advised.

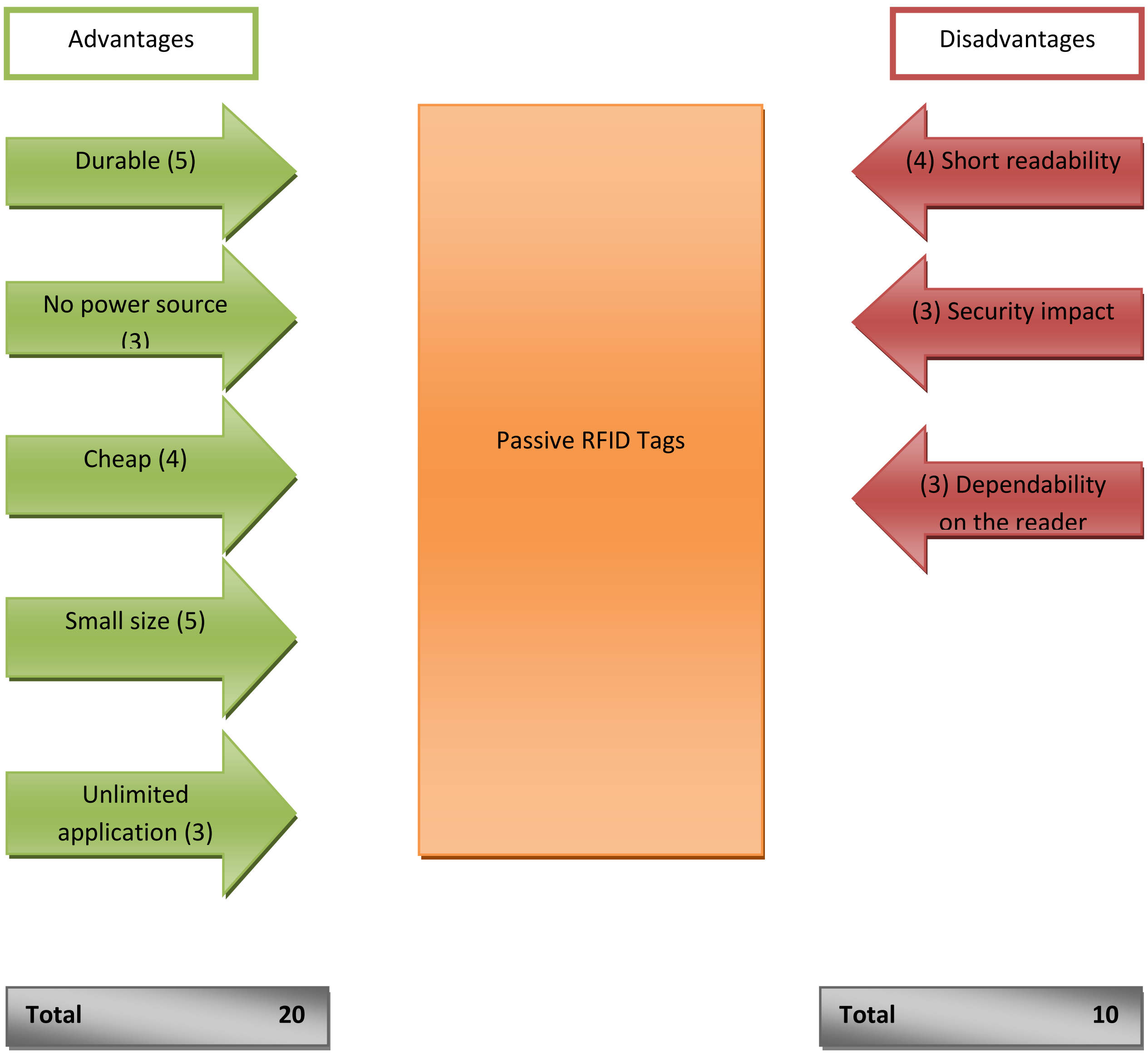

Figure 3-2 Force-Field Analysis (Passive Tags)

We conducted a review 28 research papers suggesting the potential benefits and the disadvantages of passive RFID tags and the results show that the weight associated with the advantages of passive RFID tags is bigger than the disadvantages.

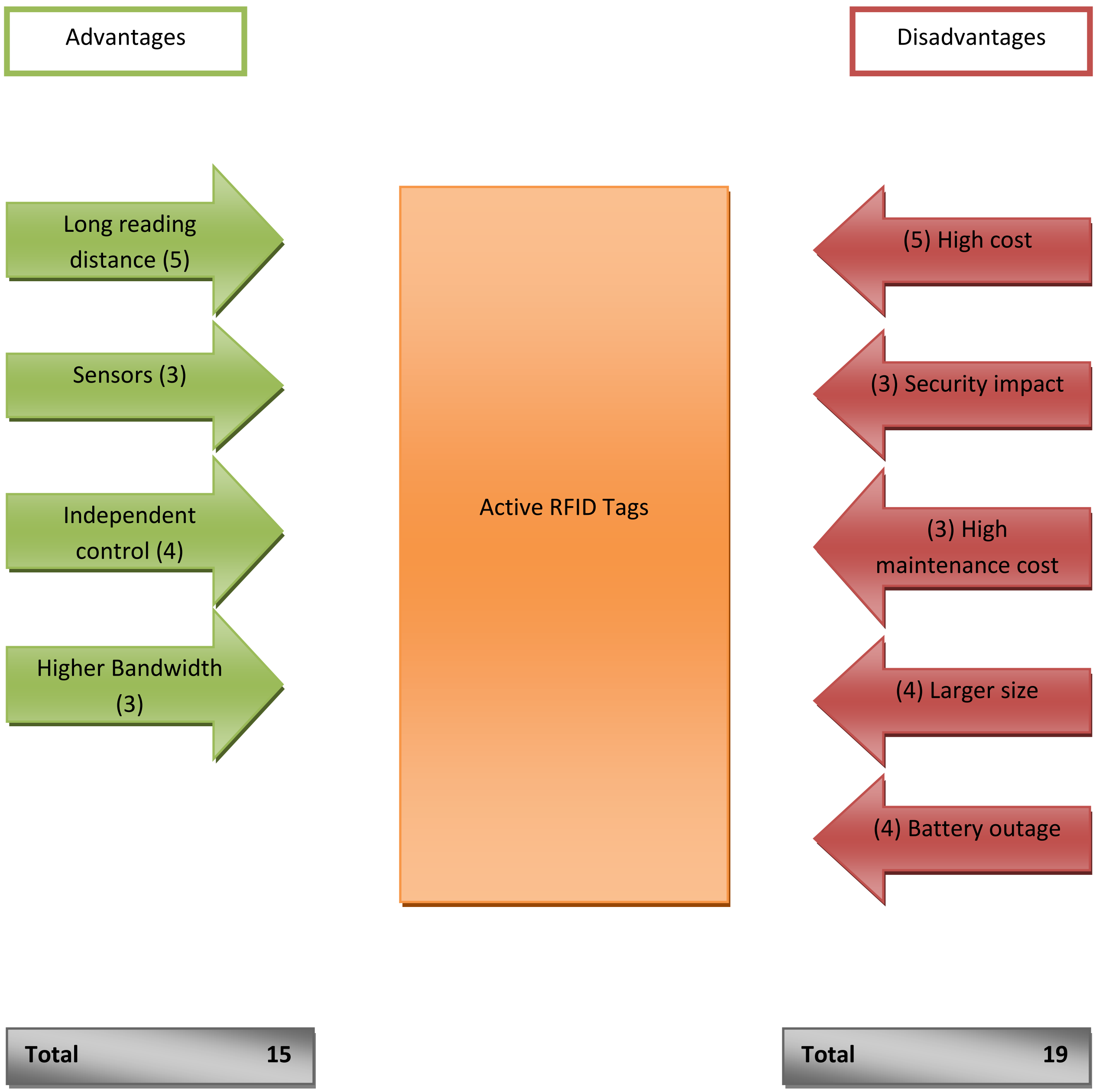

Figure 3-3 Force-Field Analysis (Active Tag)

We conducted a review 36 research papers suggesting the potential benefits and the disadvantages of active RFID tags and the results show that the weight associated with the disadvantages of active RFID tags is bigger than the advantages.

3.2 RFID Implementation

In order to be able to grasp the ways with which RFID tags exchange data and at which stages of the disassembly process the information of RFID tags are being used, a simple network design for RFID implementation has been proposed. Within the following design we investigate the number of tags and readers that are used as well as the places, locations and the topology of the readers and information corners.

Our goal is to come up with the best and simplest RFID network design to make the network and the information exchange as straightforward and easy as possible. Since the locations at which the readers are placed, their distance, their type (whether handheld or not), as well as the location of tags on different parts will all have an impact on the way in which the information in exchanged, it is of paramount importance to be able to come up with an efficient and effective solution for designing the best RFID network possible.

According to McCarthy *et al.* (2009), the tag inlay, reader antenna polarization, conveyer speed, tag to antenna distance and sample component variation, will have significant impacts and effects on the overall performance of the RFID network. The study suggests that the reader antenna must be placed as close to the test sample as possible and under dynamic conditions, orientation insensitive tags must be placed at longer distances from the reader. Basically, the study reveals that the polarization will also have an effect on the overall performance of the detection network; it is suggested that circularly polarized readers are of more benefit if used rather than the linear polarization.

Based on the study carried out by Laniel *et al.* (2011), the antenna positions may have a major influence over the RFID readability. In their study, two different types of active RFID tags were used having different frequencies (915MHz and 433 MHz).

Deployment of RFID technology requires many initial investments in terms of the software, hardware, training for staff, maintenance and installation fees and so on. On the other hand, deployment of RFID and specifically, designing an RFID network demands a vast knowledge of different problems and challenges of RFID network design such as the redundancy of readers, collision of signals, blind spots, etc as accordingly the knowledge of different algorithms with which these challenges are addressed.

Since the main purpose of this research is not the design of RFID information system or network, we will not focus primarily on the design issue but rather on the general information processing flow using RFID technology. A simplified RFID flow network is presented in Figure 3.4 Technically, an RFID network generally consists of RFID tags, RFID readers (whether handheld or automatic), and a middleware which is software for information processing and is used as a user interface each of which may impose some amount of expense on the business. In our process there are nearly 300 parts which may need to be tagged by RFID and about 20 handheld readers may be needed and these numbers are subject to change.

Passive RFID tags price may vary from some cents to some 50 dollars. RFID readers vary in price ranging from $1000 to $2000 (according to frontierprice.com). On the other hand, the RFID middleware software is one of the most expensive aspects of RFID network which may cost thousands of dollars depending on the complexity and the size of the system.

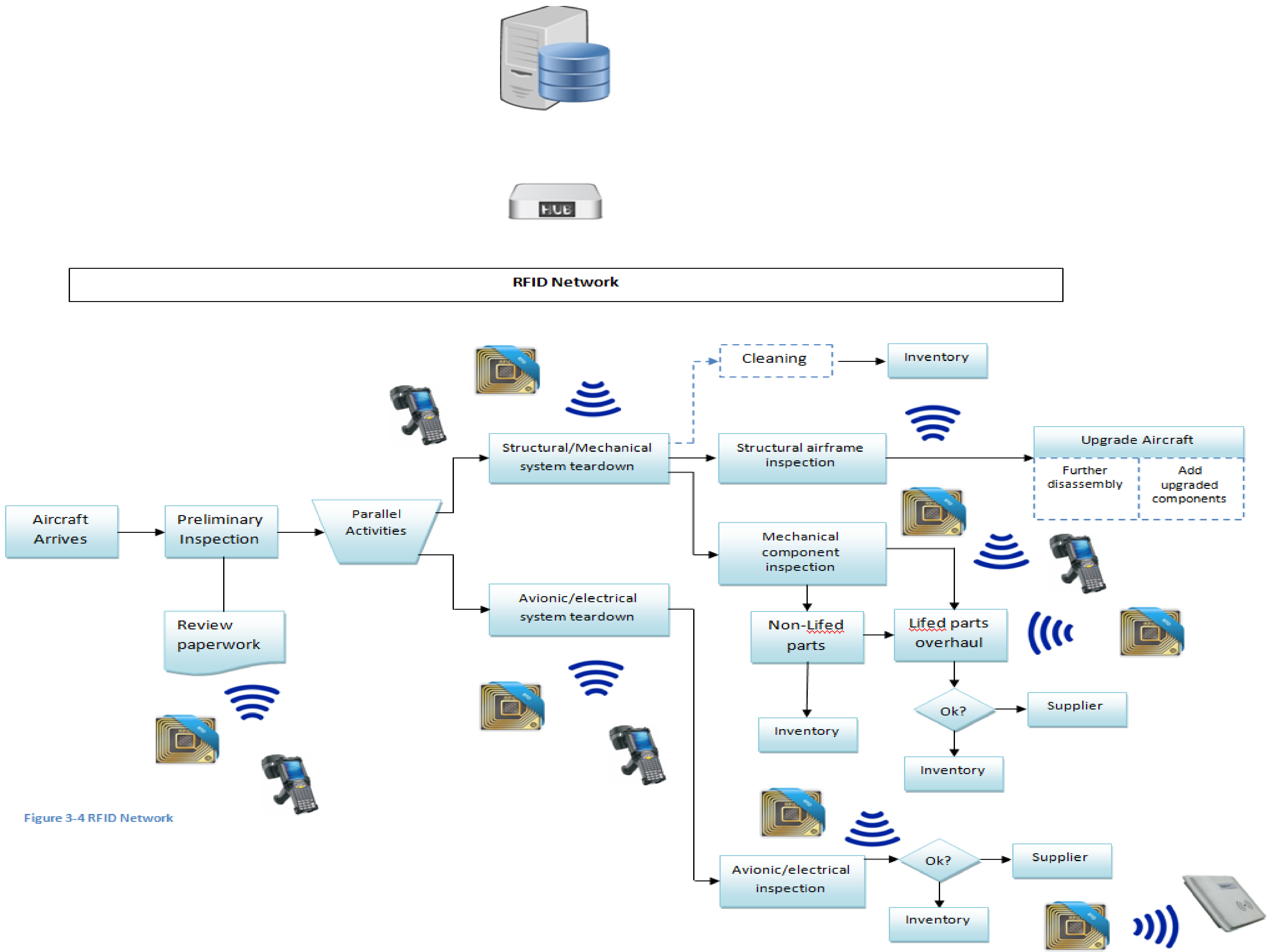

Figure 3-4 RFID Network

3.2 RFID Cost Analysis

An RFID cost analysis is conducted to make sure whether the RFID technology is financially feasible and generally how much expenditure is required. Since the RFID technology is a new technology and is considered as a strategic investment which most of the time requires and imposes extra expenses, managers are very concerned about the costs and the benefits or the amount of ROI they may receive after investing in such technology. Hence, an effective cost analysis will be of paramount help to give the managers the insight about the costs and benefits that RFID technology may bring in a way that they will be able to make more accurate financial decisions. Basically, ROI evaluates whether the investment is financially feasible and profitable over a certain period of time. According to Banks *et al.*, (2007) the costs of implementing the RFID is divided into six different categories; hardware costs, software costs, system integration costs, installation services costs, personnel costs and business process reengineering costs.

A simple form of an ROI formula is as follow;

$$\text{ROI} = \left(\frac{\textit{Gain from the investment} - \textit{costs of investment}}{\textit{costs of investment}}\right) * 100$$

Based on the formula above, the high and positive Return on investment (ROI) implies that the investment is worthwhile whereas, a high and negative ROI suggests that this is not a profitable investment and is not advised.

Through all the benefits that RFID brings, it can provide cost reduction, revenue increase, process improvement, service quality and many other consequent benefits. Banks *et al.* (2007)

Figure 3.5 represents the RFID benefits as well as the implementation costs of RFID have been illustrated in a form of a tree.

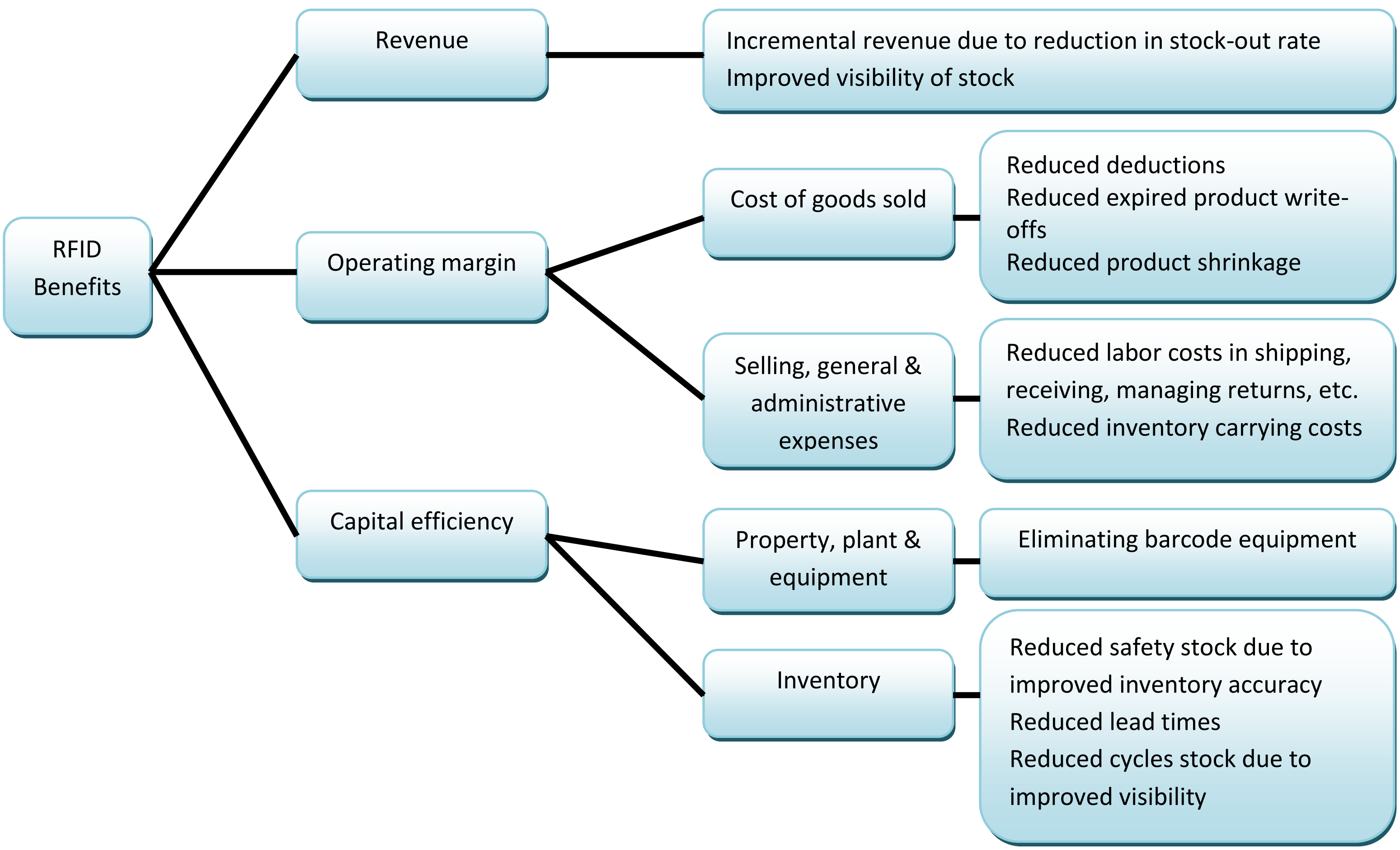

Figure 3-5 RFID Benefits (Leung *et al.*, 2007 & A. Sarac *et al.*, 2010)

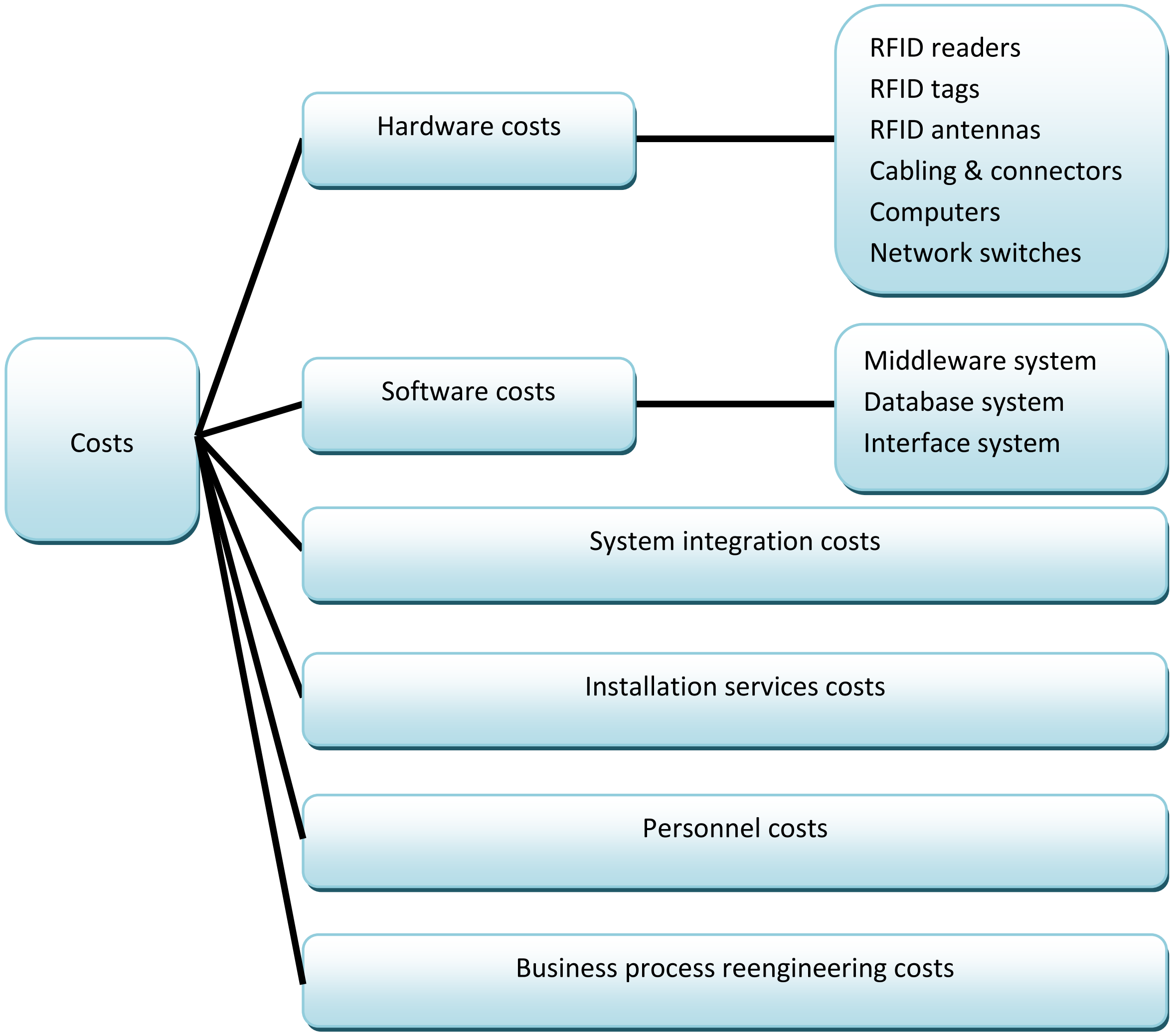

Figure 3-6 RFID implementation cost tree (Banks *et al.*, 2007 & A. Sarac *et al.*, 2010)

According to a research study by Ngai *et al.*, (2012) on the RFID value in aircraft parts supply chains, RFID could bring a significant reduction of per-lead-time-period expected cost for about 30% with full visibility that RFID provides at the item level on aircraft repaired components. The study suggests that RFID could bring financial values through the reduction of safety stocks while maintain the same low level of risk of interruption in the company's maintenance services. On the other hand, the result of the study show a 2% reduction in the repairing cycle which although not a big number, but is not insignificant. Through the full visibility at item level, the risk of being severely penalized for the failing to replace the damaged components due to poor inventory control is reduced while the abrupt interruption of the service due to mishandling the components and inventory will be almost eliminated.

The way that RFID technology is being deployed in a company may also have a great impact on the monetary and financial benefits and returns. Whether the RFID technology in implemented on a pallet level, case level, or item level, there may be different amounts of financial returns and there might be some or all of the stakeholders who actually benefit from the deployment of such technology. Several research studies have been carried out on this subject matter. Betanni and Rizzi, (2008) for instance, have conducted a study for a fast moving consumer goods company to examine the different potential benefits that RFID may bring based on the way it is implemented. Their research suggests that the deployment of RFID technology on a pallet level may benefit all the stakeholders of the company whereas, when it comes to the implementation on a case level RFID tagging, the benefits will only consider the retailers and distributors. Adetiloye, (2012)

Cost components	Descriptions	Examples
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
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
Integration costs	These are costs associate with integrating resultant data from RFID infrastructure into enterprise applications.	Cost of ERP systems
Personnel costs	These are costs associated with hiring external and internal personnel.	Cost of • Labor • Training
Installation service	These are costs of actual deployment.	Cost of: • Wiring and power outlets • Server installations • Field test
Business Process Reengineering (BPR)	These are costs associate with re-engineering.	Cost of: • Removing old processes • Adding new processes

Table 3-2 cost components of RFID, descriptions and examples (adapted from Bank *et al.*, 2007 & . Adetiloye, 2012)

3.3.1 Cost estimation

The cost estimation of the whole RFID system that is about to be used in our case may be a difficult one since the prices are different for different types of RFID tags, different RFID readers, different software and different companies and brands.

Here we use the Xerafy Company to get an estimate about the costs of RFID tags. The aforementioned company produces a variety of RFID tags for different purposes such as Rugged metal tags which are designed to be the smallest for critical and hazardous situations, Embeddable tags which are designed so that they could be embedded easily, Versatile on and off metal tags, high memory RFID tags, Metal skin RFID labels and Specialty RFID tags. The prices are different for different tags and for different amounts for example, a pack of 20 RFID tags would cost around $90 to $120.

On the other hand, Motorola which is one of the leading companies in the industry have various models and types of RFID readers which are designed for different purposes, frequency ranges and with different features such as Bluetooth, WI-FI, etc. the prices of handheld readers that Motorola offers may vary from $800 for older models to over $2000 for the newer models with specific features.

However, in our case, the number of RFID tags that are to be used in different parts of the aircraft is about 230 tags. These tags, based on the surface upon which they are about to be attached, may vary in shape, size and other features such as reusability. On the other hand, the numbers of readers that may be used in this system are assumed to be as the same number as the staffs who are directly working in with the aircraft at the disassembly facility which is let's say 11 employees.

Based on these numbers, the total cost of the RFID tags excluding the cost of installation would be between $20700 and $27600. The total cost of the handheld readers to be used in the system may also vary from $8.800 to over $22.000. However, the cost of the middleware software may vary from hundreds of dollars to thousands of dollars depending on the complexity and the number of elements to be tracked and analyzed. Consequently, the total cost of RFID for the aforementioned case may vary from $179500 to over $99600. On the next pages there are a complete RFID models available by the Xerafy Company as well as the handheld readers available by Motorola. Figures 3.7, 3.8 and 3.9 (see appendix) represent different models of tags and readers by Xerafy and Motorola.

3.4 RFID Simulation

Before we start considering the concept of simulation we take a look at the modeling and what is a model. Since the construction and development of an actual system or end product consumes a lot of time and effort and requires a number of investments in terms of money, people, tools and other resources, the outcome of the development process will be of great value and if any mistakes are found at the end of the development life cycle it will definitely be very costly to rollback and start again. Hence, a simplified or general representation of the future system to be developed is examined to see and analyze different aspects that may affect the outcome of the system and if the tests and analyses successfully met the planned objectives the completed version of the system will be developed.

Basically, a model is a simplified and working version of the actual system that possesses the main features of the actual system and is constructed beforehand for the purpose of enabling the analyst to predict the effect of changes to the system. The purpose of developing a model is to have a simplified version of the system so that the analysts are able to conduct experiments with them and see the general behavior of the system. In other words, the model should be a tradeoff between the reality and simplicity which as the analyses moves on the complexities are added on to it in an iterative way. However, the most important step in modeling a system is the validation of the model to be able to prove the model is working as realistic as we could build the actual system based on it. Simulation is the way to validate the model in which the model is presented with some inputs and is expected to provide some outputs that are then compared with the actual outputs of the system to see if the model is working and valid.

"Generally, a model intended for a simulation study is a mathematical model developed with the help of simulation software. Mathematical model classifications include deterministic (input and output variables are fixed values) or stochastic (at least one of the input or output variables is probabilistic); static (time is not taken into account) or dynamic (time-varying interactions among variables are taken into account). Typically, simulation models are stochastic and dynamic". (Anu Maria, State University of New York at Binghamton Department of Systems Science and Industrial Engineering Binghamton, NY 13902-6000, U.S.A.)

Simulation, technically, is considered a tool to evaluate the overall performance of the system and analyze its behavior over a period of time. According to Bruno Bachelet, (1999-2011) development of a general simulation model consists of following steps and shown in Figure 3.10 below.

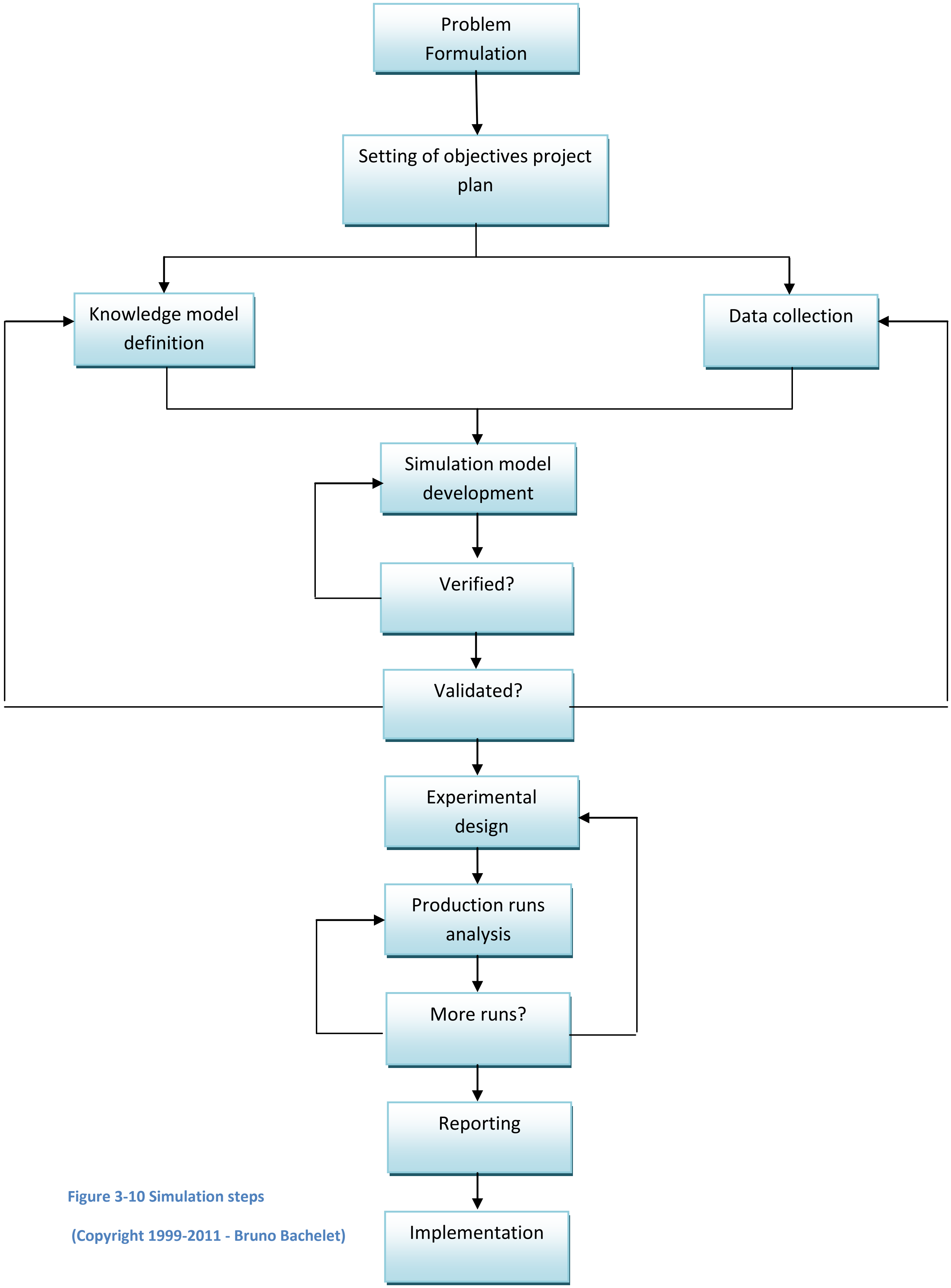

Figure 3-10 Simulation steps

(Copyright 1999-2011 - Bruno Bachelet)

There are a numbers of simulation types and approaches. Here, we describe three types of simulation: System Dynamics, Discrete Event, and Agent-Based simulation. All of these methods of simulation differ from each other for some points which are addressed in the table below:

System dynamics	Discrete Events	Agent-Based
Used for systems which naturally form flows- (top down approach)	Used for systems which naturally involve queues	Bottom up approach-(no concept of queues)
Macroscopic view	Microscopic view- passive entities	Active entities (agents)
Deterministic in nature- gives the same result after each run- needs to run only once	Stochastic in nature-gives different results after each run- needs to run several times	Stochastic in nature

Table 3-3 Comparison ofdifferent simulation methods (Robert Maidstone, 2012)

3.4.1 Process Map

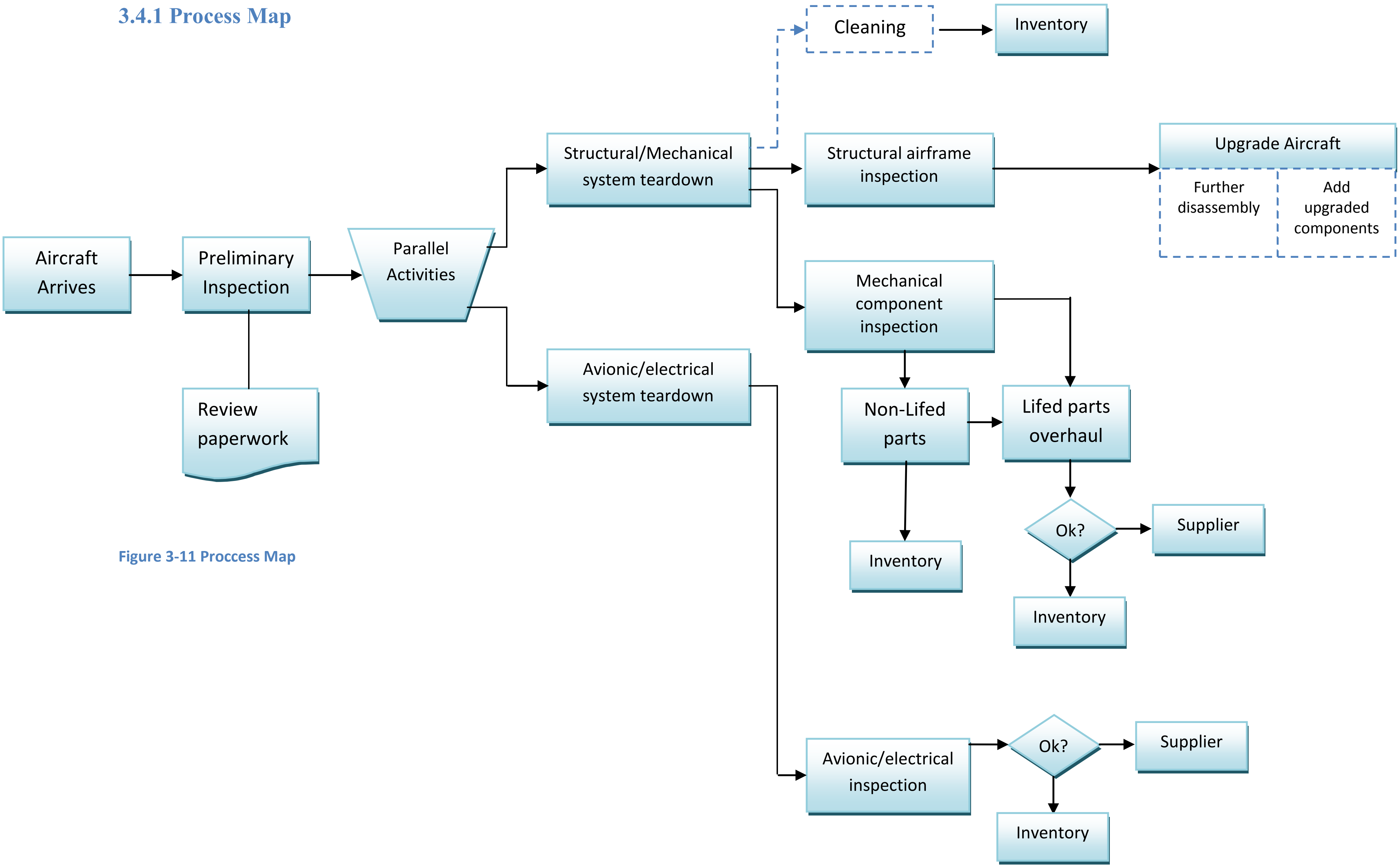

Figure 3-11 Proccess Map

3.4.2 Process description

The general process description of the disassembly of a single helicopter is shown in Figure 3.8 an aircraft enters the disassembly line. The next step is the preliminary inspection of the aircraft which would be the general inspection of the helicopter using the paperwork and the helicopter's technical logs. After that the helicopter is ready to be disassembled.

The next two steps will be started in a parallel way; the structural/mechanical components teardown and the avionics/electrical components teardown. The avionics/electrical components will then be inspected to distinguish between those parts that are still working and those that are broken or cannot be used anymore. Those parts that could be used again will be transferred to the inventory to be stored and those that cannot be used for any reason will be sent back to the suppliers. On the other hand, the structural/mechanical components will be divided into two different categories; one which is the structure or the fuselage of the helicopter and the smaller parts and components. Some parts will require cleaning which will be cleaned and sent to inventory and other mechanical components will be categorized into smaller groups; lifed and non-lifed parts. Those parts and components that lived enough and are considered being at their end of life cycle will be inspected and overhauled and those components that do not meet the specifications and requirements will be sent to the suppliers and the other parts will be sent to the inventory. On the other hand, those other parts which have not been living for too long will be sent directly to the inventory to be used again. Meanwhile, the fuselage or the mainframe of the helicopter will be inspected and proceeds to the end of the reverse logistics network to be reassembled again and produce an upgraded aircraft. At the last step, further disassemblies may be required and upgraded parts which are tagged with RFID tags will be attached and reassembled.

3.4.3 System Dynamics Simulation Model for RFID Enabled Aircraft Disassembly Operations

According to the system dynamics society, (systemdynamics.org/what is system dynamics, 2013), "*System dynamics is a computer-aided approach to policy analysis and design. It applies to dynamic problems arising in complex social, managerial, economic, or ecological systems -- literally any dynamic systems characterized by interdependence, mutual interaction, information feedback, and circular causality.*"

System dynamics is a system thinking approach and methodology to study the complexities of a system. Using this system thinking approach, complex feedback systems can be modeled and analyzed. In another words, system dynamics approach is a methodology to study and model complex systems in a more simplified form to examine and validate its consistency and usefulness. Some key features of system dynamics approach that make it standout are as follows:

- Using system dynamics, only the problem in question can be modeled instead of the whole system of the real world.
- System dynamics approach assumes that all the problems have an internal cause.
- It assumes patterns and structures
- Problem boundaries are identified which is of paramount importance
- It provides an opportunity to challenge and test hypotheses

3.4.4 Constraints and Assumptions

The only constraint that is faced in the process of developing the model was the fact that the model has been created and developed inside the lab environments and outside the company or the supply chain. It must be noted that if the model was created and developed within the company's facilities, we would have more flexibilities and efficiencies available to us.

The assumptions used in the developed model are as follow:

- Only one aircraft enters the disassembly process and it will take one working month to upgrade a single helicopter.
- The reverse logistics system has already been designed and put into practice and all the average times for each step of the disassembly is known and given.
- Passive RFID tags have been used to tag the aircraft's parts
- Passive RFID tags have been examined under severe conditions to be approved; resistance to heat, cold, water and salty environments has been examined under the laboratory conditions.
- All the information provided by RFID tags at each step will be available throughout the reverse logistic system for other departments.
- Total disassembly time = SUM of the times of each disassembly step.

3.4.4 Mathematical expressions and Concepts

Basic modeling foundations of system dynamics including an explanation of each standardized elements used in this model are given below:

3.4.4.1 Stock

Stock is one of the static elements of system dynamics modeling. The stock element is used to represent the real world processes and demonstrates the accumulation process. Usually, the stock is explained through the concept of water flow where the stock is presented as any form of a water container such as a tank or even a simple bucket which may be filled or drained by water based on a specific rate. Generally, the mathematical equation of stock is as follow: (Pfaender, 2006)

$$\int_{t}^{t0} (F_i - F_O)dt + S_{t-1}$$

Where

- S_t is the value of stock at time t
- F_i is the sum of the inflow rates
- F_0 is the sum of the outflow rates
- dt is the time step

Usually, the stock is represented by a simple box which will be connected by or to another stock using a number of inflow or outflow rates. Pfaender (2006)

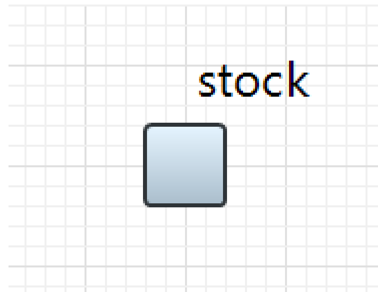

Figure 3-12 a simple stock

3.4.4.2 Flow

The flow will be represented whether as an inflow or an outflow which goes in or comes out of the stock. Stock and flows are always come together to demonstrate the rates by which the stock is being filled or emptied. Basically, flow can be defined as a rate through the following equation as follows: (Pfaender 2006)

$$\frac{df(t)}{dt} = g(x_1, x_2, \dots, t)$$

Where

- $\frac{df(t)}{dt}$ is the rate of change per unit time represented by the flow
- g is the function describing the flow
- x_n are the dependant variables
- t is time

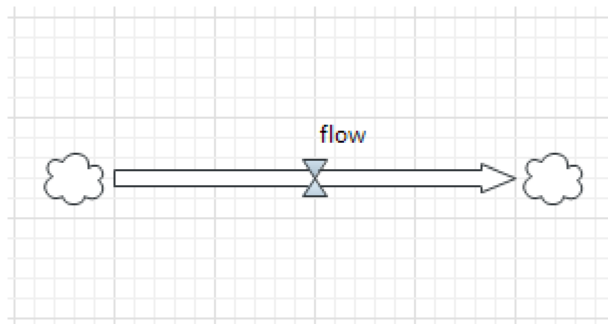

Figure 3-13 a simple flow

As illustrated in figure 3.13, a flow is presented in a form of an arrow. The two cloud shaped elements at the two sides of the flow represents that there is an inflow accumulating the stock and an outflow which decreases the value of the stock based on the value or rate of the flow.

3.2.4.3 Influence

An influence, as the name suggests, represents the dependency and influence of each variable on one another. The mathematical function describing the relation between input and output variables is given by. (Pfaender 2006)

$$y = f(x_1, x_2, \dots, t)$$

Where

- y is the output

- f is the function describing the outputs
- x_n is the dependant variables
- t is time

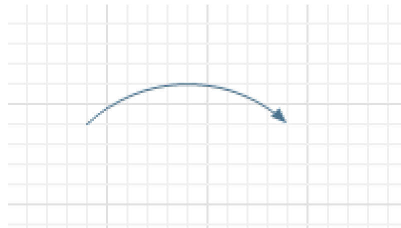

Figure 3-14 a simple influence

In Figure 3.14, an influence is shown as a simple narrow arrow which can also have a positive or negative polarity to show whether the variables have positive or negative impact upon each other. They can also be delayed showing that the impact of variables can be delayed by time rather that immediately.

3.4.4.4 Auxiliary Variable

While stock and flow diagrams may contain only stocks and flows, it is a good practice to define intermediate concepts with auxiliaries. Commonly auxiliaries consist of functions of stocks and constants or exogenous inputs. (AnyLogic help and support center, 2012)

The elements of the functions used in an auxiliary variable have to be connected to each other or have an influence on one another using the influences.

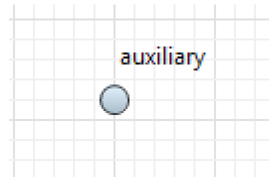

Figure 3-15 a simple auxiliary variable

3.4.4.5 Parameter

Active object may have parameters. Parameters are frequently used for representing some characteristics of the modeled object. They are helpful when object instances have the same behavior described in class, but differ in some parameter values. (AnyLogic help and support center, 2012)

All parameters are visible and changeable throughout the model execution. Thus, you can simply adjust your model by changing parameters at runtime. If you need, you can define action to be executed on a parameter change.

Active object parameters can be linked to parameters of embedded objects. In this case, parameter changes are propagated down the active object tree along the parameter dependencies. This mechanism is called parameter propagation. Propagate values of parameters down the objects hierarchy when:

- You need to change parameters of several embedded objects (perhaps of different classes). You can simply do this by creating single parameter of the capsule object and propagating its value to several parameters you need to change.

- You need to perform some experiment varying, optimizing, or calibrating some parameters of a non-root object. In this case, you also need parameter propagation since you can optimize model by changing only the root object parameters.

There is a clear difference between variables and parameters. A variable represents a model state, and may change during simulation. A parameter is commonly used to describe objects statically. A parameter is normally a constant in a single simulation, and is changed only when you need to adjust your model behavior.

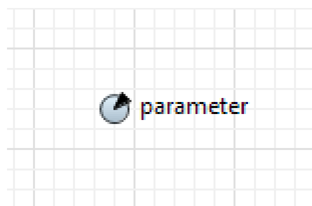

Figure 3-16 a simple form of a parameter

3.4.5 Causal Loop Diagram

The causal loop diagram (CLD) is a system thinking tool that shows the relationships of different variables involved in the system to show how these variables are connected and how they affect each other. CLD uses arrows to connect the variables. The arrows may hold a negative or positive influence showing which variable is negatively or positively affects the other. Before developing the actual system dynamics simulation model, the causal loop diagram is developed to understand the relationships of all the variables involved in the model. Figure 3.17 represents the causal loop diagram before RFID implementation whereas Figure 3.18 shows the causal loop diagram after RFID implementation. There are positive and negative loops in the diagrams suggesting that there are positive or negative influences. For instance, RFID and staff training are negatively affecting the RFID preliminary inspection time which is the time of preliminary inspection time after implementing RFID whereas the preliminary inspection is positively affecting the ready to disassembly aircraft variable suggesting that the more the inspection takes, the more it takes to move forward in the process.

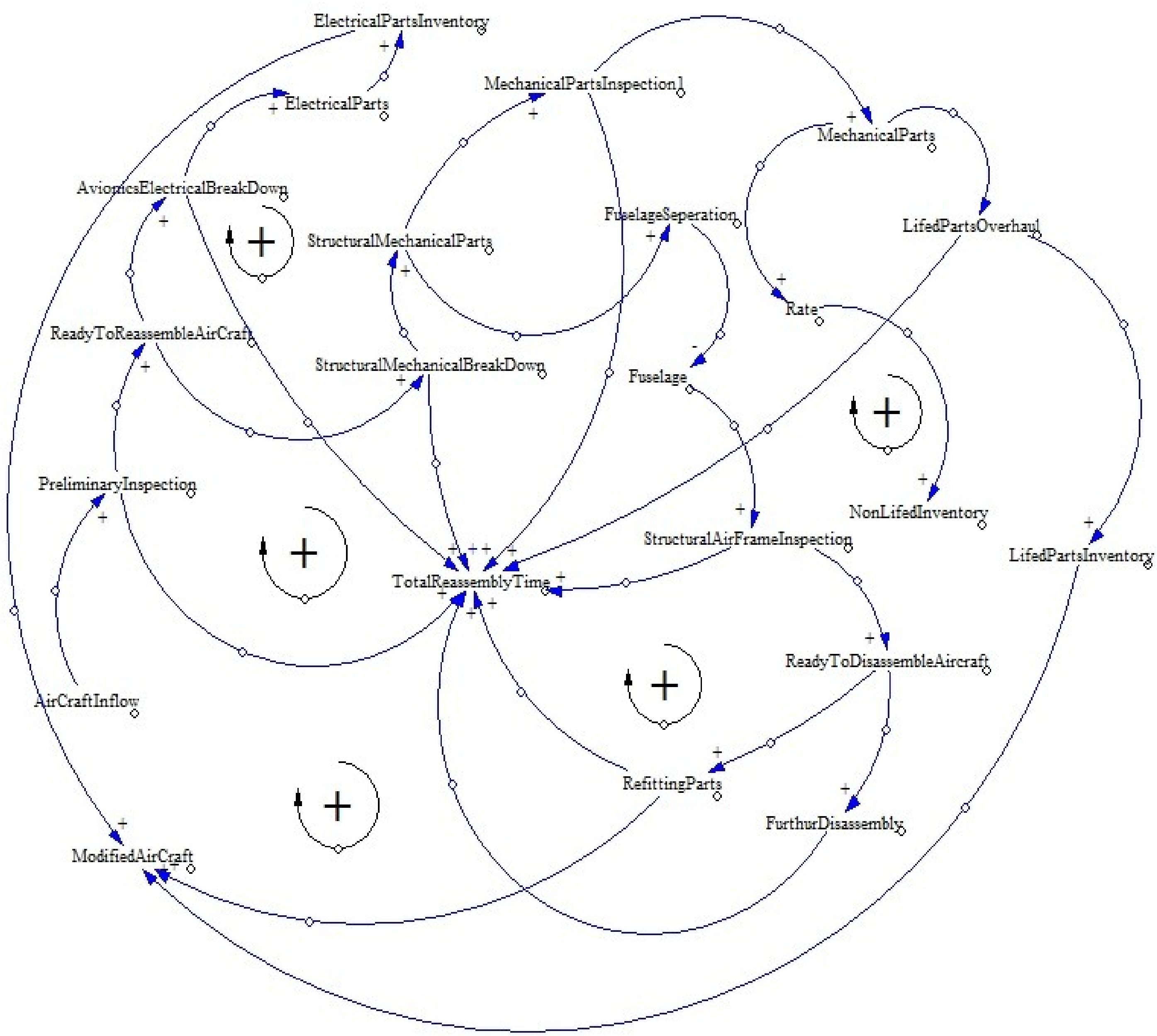

Figure 3-17 Casual Loop Diagram before RFID

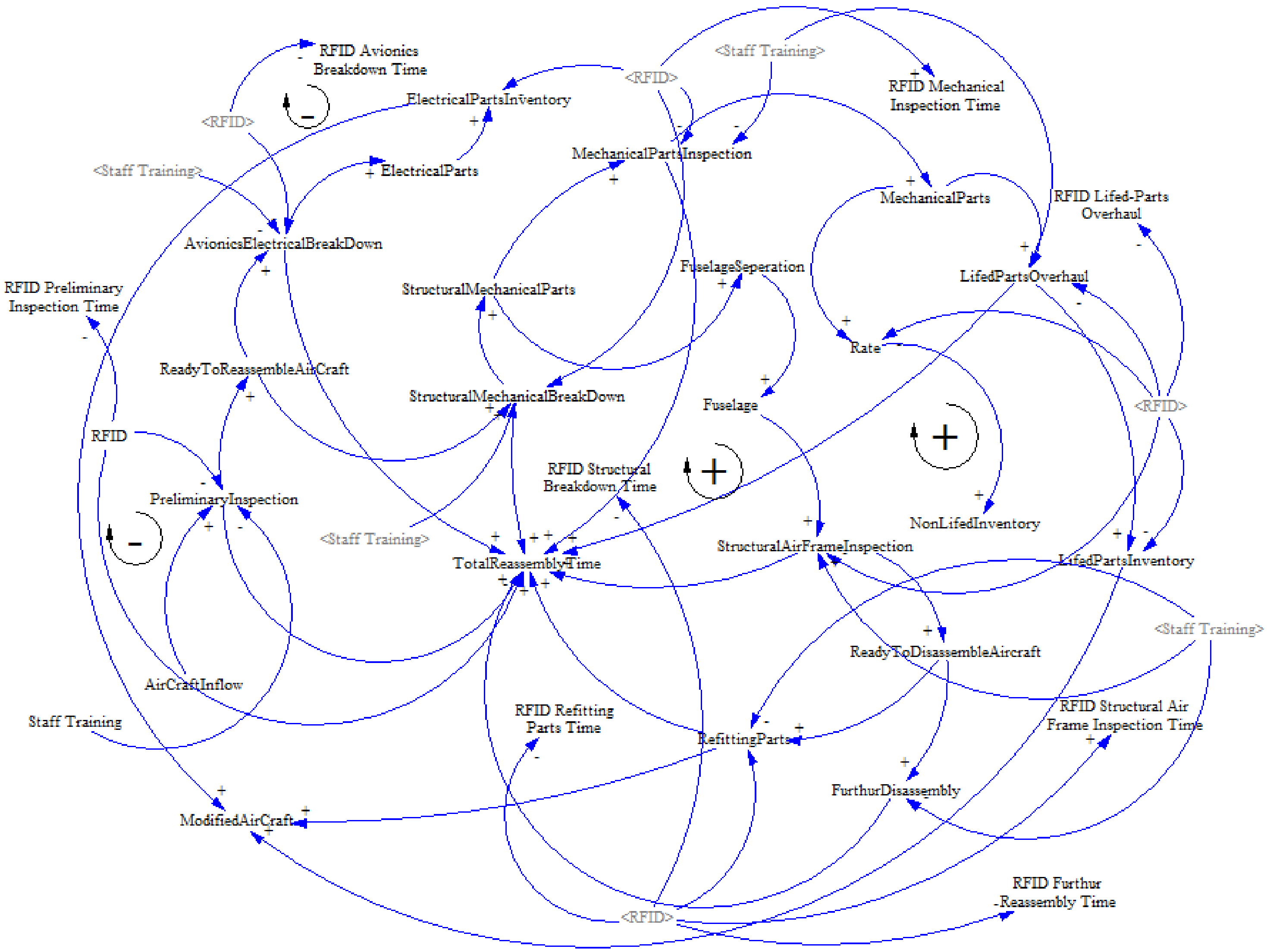

Figure 3-18 Casual Loop Diagram after RFID

3.4.6 Simulation Software

The simulation software that has been used for this project is AnyLogic, University 6.9.0 version. Based on the AnyLogic official website's overview, "*AnyLogic is the only simulation tool that supports all the most common simulation methodologies in place today: System Dynamics, Process-centric (AKA Discrete Event), and Agent Based modeling. The unique flexibility of the modeling language enables the user to capture the complexity and heterogeneity of business, economic and social systems to any desired level of detail. AnyLogic's graphical interface, tools, and library objects allow you to quickly model diverse areas such as manufacturing and logistics, business processes, human resources, consumer and patient behavior. The object-oriented model design paradigm supported by AnyLogic provides for modular, hierarchical, and incremental construction of large models.*"

Some benefits of AnyLogic software are as follows: (AnyLogic Support Center, 2012)

- The development process speed is very high
- Java based software which makes a very strong and platform free tool
- The ability to incorporate pre-built simulation elements using the existing libraries
- Object oriented structure
- Easy conversion facilities from other simulation software such as Vensim

AnyLogic provides a strong simulation tool for a wide variety of models such as system dynamics, agent based modeling, etc. It also provides other visual tools such as state charts, action charts, analysis tools, 3D objects and connectivity from outside sources such as Excel and other databases.

3.4.7 Mathematical Expressions

The complete list of all the auxiliary variables, parameters, flows, and stocks as well as their corresponding mathematical formulas and initial values are presented in the tables (3.4) to (3.8) below:

The following values are obtained using AnyLogic simulation software after modeling the system. All the data is based on average values.

Table 3.4 represents all the time parameters involved in the simulation model including their default value.

Parameter name	Default value (time, hour)
PreliminaryInspectionTime	2
AvionicsElectricalBreakDownTime	24
StructralMechanicalBreakDownTime	80
MechanicalPartsInspectionTime	40
LifedPartsOverhaulTime	25
ElectricalPartsInspectionTime	8
StructuralAirFrameInspectionTime	40
FurthurDisassemblyTime	200
RefittingPartsTime	650

Table 3-4 List of Time parameters

Table 3.5 represents all the constant parameters used in the simulation model including their corresponding values.

Parameter Name	Value
AvionicsStaff	1
MechanicalStaff	2
MechanicalStaff2	1
OverhaulStaff	1
StructuralStaff	1
StructuralStaff2	4
InspectionStaff	2

Table 3-5 List of Staff Parameters

Table 3.6 represents all the stock elements used in the simulation model including the mathematical expressions defined for each.

Stock	Expression
AirCraftReceived	AirCraftInflow - PreliminaryInspection
ReadyToReassembleAirCraft	StructuralAirFrameInspection - (FurthurDisassembly + RefittingParts)
ElectricalParts	AvionicsElectricalBreakDown-(ElectricalPartsInspectionAccepted + ElectricalPartsInspectionRejected)
MechanicalParts	MechanicalPartsInspection - (LifedPartsOverhaul + Rate)
Fuselage	FuselageSeperation - StructuralAirFrameInspection
StructuralMechanicalParts	StructuralMechanicalBreakDown - (MechanicalPartsInspection + FuselageSeperation)

ReadyToDisassembleAircraft	(PreliminaryInspection) - (AvionicsElectricalBreakDown + StructuralMechanicalBreakDown)
Supplier	(ElectricalPartsInspectionRejected + InspectionUnSuccessful)
NonLifedInventory	Rate
LifedParts	LifedPartsOverhaul - (InspectionUnSuccessful + InspectionSuccessful)
LifedPartsInventory	InspectionSuccessful
ModifiedAirCraft	(FurthurDisassembly + RefittingParts)
ElectricalInventory	(ElectricalPartsInspectionAccepted + ElectricalPartsOutflow)- ElectricalPartsOutflow

Table 3-6 List of Stocks

Table 3.7 represents all the auxiliary variables used in the simulation model including the mathematical expressions defined for each element.

Auxiliary Variables	Expression
Step1Time	PreliminaryInspection*RFIDPreliminaryInspecionTime
TotalReassemblyTime	((Step1Time) + (Step2ATime) + (Step2BTime) + (Step4Time) + (Step5ATime) + (Step5BTime) + (Step6Time) + (Step7Time))
Step6Time	(FurthurDisassembly+RefittingParts)*(RFIDRefittingPartsTime+RFIDFurthurDisassemblyTime)
Step5BTime	ElectricalPartsInspectionRejected*RFIDElectricalPartsInspection
Step7Time	LifedPartsOverhaul*RFIDLifedPartOverhaulTime
Step4Time	StructuralAirFrameInspection*RFIDStructuralAirFrameInspectionTime
Step5ATime	MechanicalPartsInspection*RFIDMechanicalInspectionTime
Step2ATime	StructuralMechanicalBreakDown*RFIDStructuralBreakDownTime
Step2BTime	AvionicsElectricalBreakDown*RFIDAvionicsBreakDownTime

RFIDPreliminaryInspectionTime	RFID*PreliminaryInspectionTime
RFIDElectricalPartsInspection	RFID*ElectricalPartsInspection
RFIDLifedPartOverhaulTime	RFID*LifedPartOverhaulTime
RFIDMechanicalInspectionTime	RFID*MechanicalInspectionTime
RFIDStructuralBreakDownTime	RFID*StructuralBreakDownTime
RFIDAvionicsBreakDownTime	RFID*AvionicsBreakDownTime
RFIDRefittingPartsTime	RFID*RefittingPartsTime
RFIDFurthurDisassemblyTime	RFID*FurthurDisassemblyTime

Table 3-7 List of auxiliary variables

Table 3.8 represents the flow elements used in the simulation model as well as their corresponding values which are defined as in a form of mathematical expressions.

Flow	Value
PreliminaryInspection	(AirCraftReceived/(InspectionStaff*StaffTraining))
AvionicsElectricalBreakDown	(ReadyToDisassembleAircraft/(AvionicsStaff*StaffTraining))
ElectricalPartsInspectionRejected	(ElectricalParts/(AvionicsStaff*StaffTraining))
MechanicalPartsInspection	(StructuralMechanicalParts/(MechanicalStaff*StaffTraining))
Rate	(MechanicalParts/(MechanicalStaff2*StaffTraining))
LifedPartsOverhaul	(MechanicalParts/(OverhaulStaff*StaffTraining))
InspectionSuccessful	(LifedParts/(OverhaulStaff*StaffTraining))
InspectionUnSuccessful	(LifedParts/OverhaulStaff*StaffTraining)
StructuralMechanicalBreakDown	(ReadyToDisassembleAircraft/(MechanicalStaff*StaffTraining))
StructuralAirFrameInspection	(Fuselage/(StructuralStaff*StaffTraining))

FuselageSeperation	(StructuralMechanicalParts/(MechanicalStaff*StaffTraining))
FurthurDisassembly	(ReadyToReassembleAirCraftParts/(StructuralStaff2*StaffTraining))
RefittingParts	(ReadyToReassembleAirCraftParts/(StructuralStaff2*StaffTraining))
ElectricalPartsInspectionAccepted	(ElectricalParts/(AvionicsStaff*StaffTraining))
AirCraftInflow	1
AirCraftOutFlow	1

Table 3-8 List of Flows

Figure 3.20 represents the simulation model which is developed based on the process map. As mentioned earlier, aircrafts enter the process and undergo a series of inspection phases and are accordingly separated into different steps to be dismantled by different departments such as structural and mechanical or avionics and electrical department. Necessary cleaning, recovery and overhaul takes place and all the materials worth using again are stored in inventories whereas other materials that require repair are sent back to suppliers. The yellow boxes in the simulation model are present for visual assistance and to demonstrate each steps of the process separately.

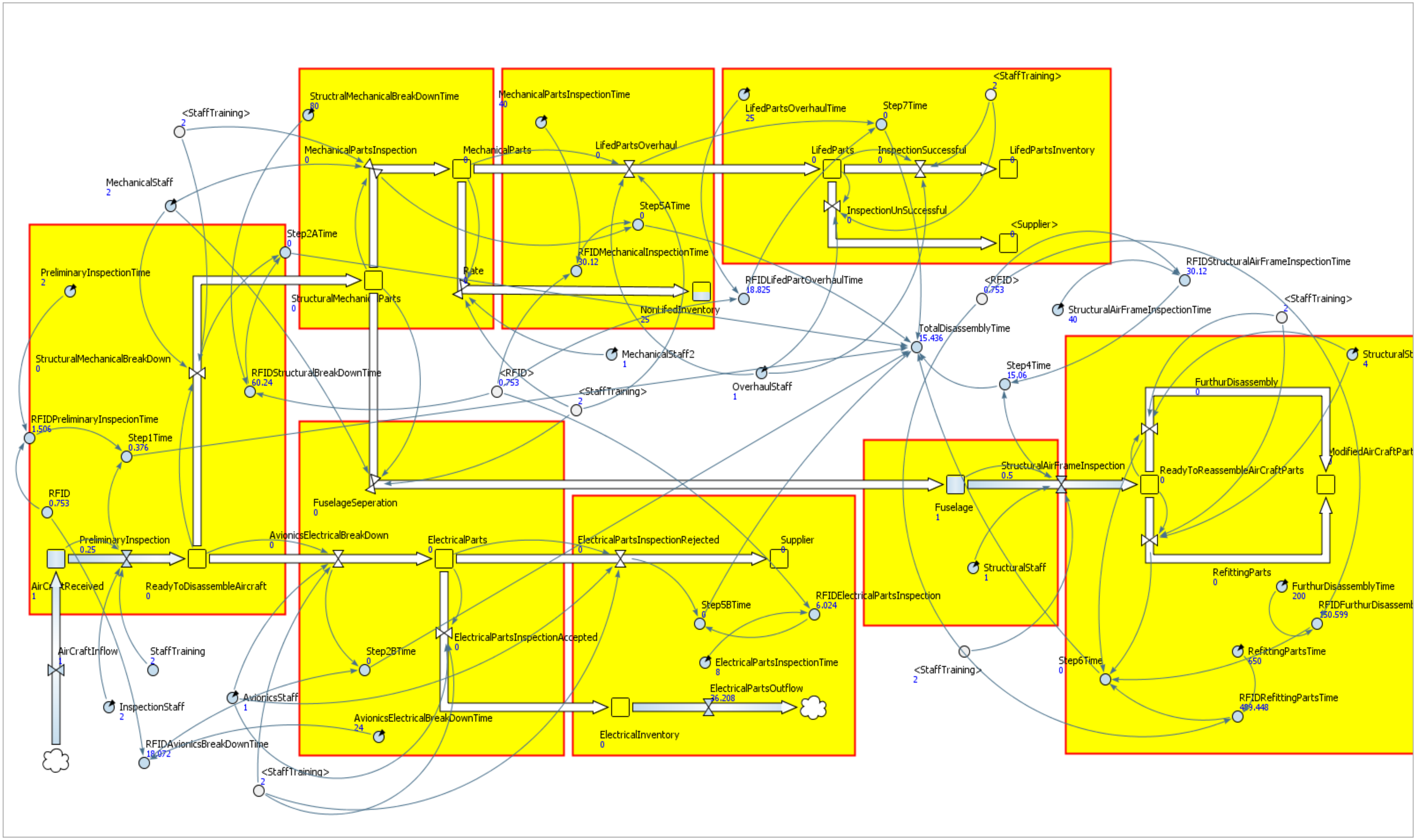

Figure 3-20 System Dynamics Model

3.4.8 Design of Experiments (DOE)

Conducting an experiment is very important for various reasons such as process optimization, evaluation of properties of the system, product design and development, and component and system tolerance determination. An experiment is a test or a series of tests carried out with the goal of verification, falsification or proving the validity of a hypothesis. Experiments would be considered as a cause and effect analysis by illustrating what effects the inputs have on the outputs. Experiment may have various benefits such as reducing the time to design, develop and process products, improving performance of existing processes, improving reliability and performance of products, achieving product and process robustness and evaluating the materials, design alternatives. (Design and Analysis of engineering experiments by Douglas C. Montgomery)

Design of experiments (DOE) or experimental design is considered as a process of planning an experiment or study to meet specified objectives. To have an effective and efficient experiment considering the right factors, right type of data and a sufficient sample size are very important. Experimental design begins with setting up an objective of an experiment and then selecting the factors to be studied. The general process model commonly known as the “Black Box” process model is shown below.

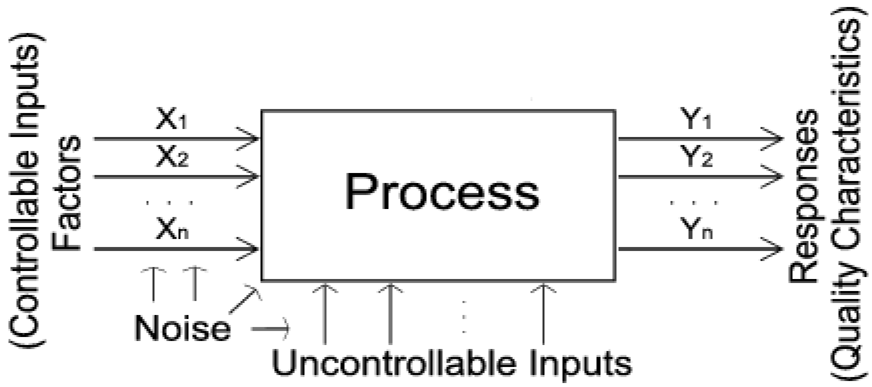

Figure 3-21 Black Box Process Model (DOE)

Full factorial design is considered as a common experimental design consisting of all input factors having two levels known as High and Low levels. A full factorial design includes all the possible combinations of a set of factors and is the most fool proof design approach. Full factorial designs are the most conservative of all design types and the only disadvantage that is associated with full factorial design is the cost of implementation since the sample size grows exponentially in the number of factors.

In this thesis the Full Factorial design of experiments (DOE) is used to identify the key factors influencing aircraft disassembly time. In particular, DOE is used to experiment the correlations and the effects of different inputs or factors on the output. The factors considered here are the Number of staff, Number of Aircrafts received, Types of RFID technology and the Level of Training for staff. On the other hand, the ultimate response variable or the output of the experiment is the Total Reassembly Time. It is tried to experiment which of these factors impact the Total Reassembly Time using full factorial design.

Accordingly, different charts have been developed and illustrated to examine the results.

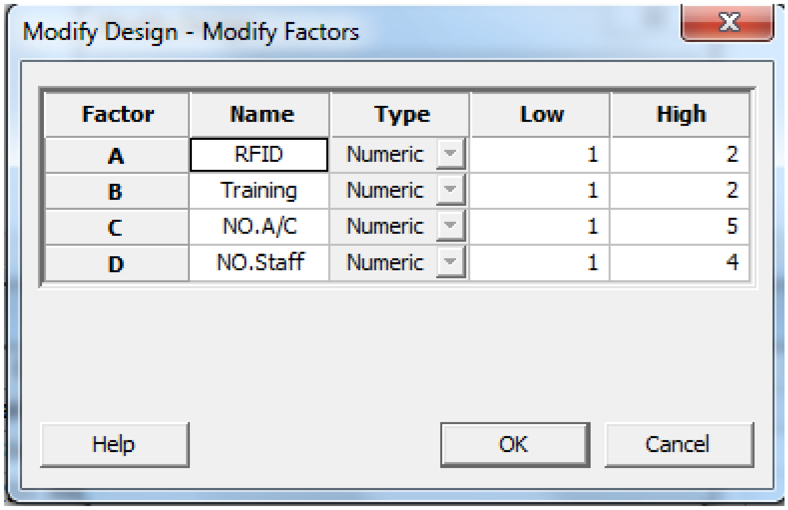

Figure 3-22 Factors

Table 3.22 above represents the four factors that are used in the experiment. These factors are as follows: Factor A which is the RFID, Factor B which is the Training, Factor C which is the Number of Aircrafts, and Factor D which is the Number of Staff. The levels for different factors have also been defined. Six replications of the experiment have been conducted to have a bigger sample size of 80. The data for the Total Reassembly Time (Hour) have been gathered directly from the simulation model after the implementation of RFID. Table 3.23 (see appendix) represents a partial view of the data generated using Minitab.

The following have been illustrated below for further analysis:

- Normal plot of the standardized effects
- Pareto chart of the standardized effects
- Normal probability plot for Total Reassembly Time
- Residuals vs. Fits for Total Reassembly Time
- Residual Histogram for Total Reassembly Time
- Residuals vs. Order for Total Reassembly Time

- Main effects plot for Total Reassembly Time
- Interaction plot for Total Reassembly Time

Figure 3-24 (see appendix) suggests that Factor A (RFID factor) is found to have a significant effect on the Total Reassembly Time. Figure 3-27 (see appendix) represents the main effects plot suggesting that RFID has more effects on the Total Reassembly Time than other factors.

From the interaction plots represented on Figure 3-28 (see appendix) it can be concluded that there is an interaction between the different types of RFID and number of aircrafts, between the level of training, types of RFID and the number of aircrafts, and other factors such as the number of aircrafts and the level of training. The interaction plots also suggest that RFID technology is the main effect and Training, Number of staff and Number of aircrafts are dependent on RFID to affect the Total Reassembly Time.

From the Figure 3.28 (see appendix) it could be concluded that the data is normally distributed and the factors are positively correlated. RFID has been found to be a significant factor to affect the Total Reassembly Time which is illustrated by the charts. On the other hand, the equations for one way and two ways ANOVA has been illustrated below to dive into more detail about the coefficients, P-values, and other statistical information such as the means and standard deviations. As illustrated, the p-values are all greater than the 0.1 (confidence interval 90%) and the coefficient of variances are high suggesting that there is high amount of dispersion amongst factors.

Factorial Fit: total time versus RFID, Training, NO.A/C, NO.Staff

Estimated Effects and Coefficients for total time

Term	Effect	Coef	SE Coef	T	P
Constant		295.81	16.03	18.46	0.000
RFID	**57.45**	**28.73**	**16.03**	**1.79**	**0.078**
Training	6.72	3.36	16.03	0.21	0.834
NO.A/C	-1.60	-0.80	16.03	-0.05	0.960
NO.Staff	-16.80	-8.40	16.03	-0.52	0.602
RFID*Training	12.29	6.15	16.03	0.38	0.703
RFID*NO.A/C	11.71	5.85	16.03	0.37	0.716
RFID*NO.Staff	-36.10	-18.05	16.03	-1.13	0.264
Training*NO.A/C	-5.54	-2.77	16.03	-0.17	0.863
Training*NO.Staff	2.46	1.23	16.03	0.08	0.939
NO.A/C*NO.Staff	-7.70	-3.85	16.03	-0.24	0.811
RFID*Training*NO.A/C	-8.50	-4.25	16.03	-0.27	0.792
RFID*Training*NO.Staff	-1.77	-0.88	16.03	-0.06	0.956
RFID*NO.A/C*NO.Staff	-24.14	-12.07	16.03	-0.75	0.454
Training*NO.A/C*NO.Staff	4.43	2.21	16.03	0.14	0.891
RFID*Training*NO.A/C*NO.Staff	25.60	12.80	16.03	0.80	0.427

S = 143.332   PRESS = 2054419
R-Sq = 9.19%   R-Sq(pred) = 0.00%   R-Sq(adj) = 0.00%

Analysis of Variance for total time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	72615	72615	18153.7	0.88	0.479
RFID	**1**	**66014**	**66014**	**66014.3**	**3.21**	**0.078**
Training	1	904	904	904.2	0.04	0.834
NO.A/C	1	51	51	51.5	0.00	0.960
NO.Staff	1	5645	5645	5644.7	0.27	0.602
2-Way Interactions	6	33741	33741	5623.5	0.27	0.947
RFID*Training	1	3022	3022	3021.8	0.15	0.703
RFID*NO.A/C	1	2741	2741	2741.0	0.13	0.716
RFID*NO.Staff	1	26058	26058	26058.4	1.27	0.264
Training*NO.A/C	1	614	614	613.9	0.03	0.863
Training*NO.Staff	1	121	121	121.1	0.01	0.939
NO.A/C*NO.Staff	1	1185	1185	1185.0	0.06	0.811
3-Way Interactions	4	13553	13553	3388.2	0.16	0.955
RFID*Training*NO.A/C	1	1446	1446	1445.9	0.07	0.792
RFID*Training*NO.Staff	1	62	62	62.4	0.00	0.956
RFID*NO.A/C*NO.Staff	1	11653	11653	11652.5	0.57	0.454
Training*NO.A/C*NO.Staff	1	392	392	392.0	0.02	0.891
4-Way Interactions	1	13106	13106	13106.3	0.64	0.427
RFID*Training*NO.A/C*NO.Staff	1	13106	13106	13106.3	0.64	0.427
Residual Error	64	1314828	1314828	20544.2		
Pure Error	64	1314828	1314828	20544.2		
Total	79	1447843				

Estimated Coefficients for total time

Term	Coef
Constant	622.779
RFID	**-236.255**
Training	**-253.963**
NO.A/C	**-141.585**
NO.Staff	**-118.177**
RFID*Training	**183.975**
RFID*NO.A/C	**102.720**
RFID*NO.Staff	80.404
Training*NO.A/C	70.2924
Training*NO.Staff	77.544
NO.A/C*NO.Staff	46.9711
RFID*Training*NO.A/C	-51.1678
RFID*Training*NO.Staff	-53.5534
RFID*NO.A/C*NO.Staff	-33.6450
Training*NO.A/C*NO.Staff	-24.1235
RFID*Training*NO.A/C*NO.Staff	17.0661

One-way ANOVA: total time versus RFID

Source	DF	SS	MS	F	P
RFID	1	66014	66014	3.73	0.057
Error	78	1381829	17716		
Total	79	1447843			

S = 133.1   R-Sq = 4.56%   R-Sq(adj) = 3.34%

```
                                Individual 90% CIs For Mean Based on
                                Pooled StDev
Level   N   Mean  StDev  ----+---------+---------+---------+-----
1      40  267.1  104.4  (---------*---------)
2      40  324.5  156.7                  (---------*---------)
                         ----+---------+---------+---------+-----
                           245       280       315       350

Pooled StDev = 133.1
```

Other Experimental designs have also been carried out for other time factors such as Preliminary Inspection Time, Avionics Breakdown Time, Electrical Parts Inspection Time, Lifed Parts Overhaul Time, Mechanical Parts Inspection Time, Refitting and Further Disassembly Time, Structural Breakdown Time, and Structural Airframe Inspection Time, to find out which factors (RFID, Number of Staff, Training, and Number of Aircrafts) have had significantly affected the time in each step.

3.4.8.1 Design of experiment for Preliminary Inspection Time

Experimental design carried out for the preliminary inspection time suggests that RFID*Training*NO.A/C and NO.Staff*NO.A/C as well as NO.A/C have found to be significantly affecting the time. According to the coefficients NO.Staff and RFID*Training*NO.Staff from the negative points and the RFID*NO.Staff and Training*NO.Staff from the positive points are the points of interest in this design of experiment.

Figure 3-29 (see appendix) represents the normal plot for the Preliminary Inspection Time. It suggests that Number of Aircrafts, Number of staff*Number of Aircrafts and RFID*Training*Number of Staff have significant effects on the Preliminary Inspection Time.

Factorial Fit: Preliminary Inspection versus RFID, Training, No.Staff, NO.A/C

Estimated Effects and Coefficients for Preliminary Inspection Time

Term	Effect	Coef	SE Coef	T	P
Constant		1.9695	0.07653	25.73	0.000
RFID	-0.1111	-0.0555	0.07653	-0.73	0.471
Training	0.0767	0.0384	0.07653	0.50	0.618
No.Staff	-0.1234	-0.0617	0.07653	-0.81	0.423
NO.A/C	**0.2789**	**0.1395**	**0.07653**	**1.82**	**0.073**
RFID*Training	-0.2298	-0.1149	0.07653	-1.50	0.138
RFID*No.Staff	0.1166	0.0583	0.07653	0.76	0.449
RFID*NO.A/C	0.0626	0.0313	0.07653	0.41	0.684
Training*No.Staff	-0.1494	-0.0747	0.07653	-0.98	0.333
Training*NO.A/C	0.0050	0.0025	0.07653	0.03	0.974
No.Staff*NO.A/C	**-0.3121**	**-0.1560**	**0.07653**	**-2.04**	**0.046**
RFID*Training*No.Staff	-0.0396	-0.0198	0.07653	-0.26	0.796
RFID*Training*NO.A/C	**0.2915**	**0.1457**	**0.07653**	**1.90**	**0.061**
RFID*No.Staff*NO.A/C	-0.0937	-0.0469	0.07653	-0.61	0.543
Training*No.Staff*NO.A/C	0.0260	0.0130	0.07653	0.17	0.865
RFID*Training*No.Staff*NO.A/C	0.2195	0.1098	0.07653	1.43	0.156

S = 0.684530   PRESS = 46.8582
R-Sq = 22.91%   R-Sq(pred) = 0.00%   R-Sq(adj) = 4.84%

Analysis of Variance for Preliminary Inspection Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	2.2251	2.2251	0.55628	1.19	0.325
RFID	1	0.2466	0.2466	0.24664	0.53	0.471
Training	1	0.1177	0.1177	0.11766	0.25	0.618
No.Staff	1	0.3046	0.3046	0.30455	0.65	0.423
NO.A/C	**1**	**1.5563**	**1.5563**	**1.55626**	**3.32**	**0.073**
2-Way Interactions	6	3.8011	3.8011	0.63351	1.35	0.248
RFID*Training	1	1.0562	1.0562	1.05616	2.25	0.138
RFID*No.Staff	1	0.2719	0.2719	0.27191	0.58	0.449
RFID*NO.A/C	1	0.0783	0.0783	0.07825	0.17	0.684
Training*No.Staff	1	0.4461	0.4461	0.44611	0.95	0.333
Training*NO.A/C	1	0.0005	0.0005	0.00050	0.00	0.974
No.Staff*NO.A/C	**1**	**1.9481**	**1.9481**	**1.94813**	**4.16**	**0.046**
3-Way Interactions	4	1.9201	1.9201	0.48001	1.02	0.402
RFID*Training*No.Staff	1	0.0314	0.0314	0.03144	0.07	0.796
RFID*Training*NO.A/C	**1**	**1.6994**	**1.6994**	**1.69944**	**3.63**	**0.061**
RFID*No.Staff*NO.A/C	1	0.1756	0.1756	0.17559	0.37	0.543
Training*No.Staff*NO.A/C	1	0.0136	0.0136	0.01357	0.03	0.865
4-Way Interactions	1	0.9640	0.9640	0.96404	2.06	0.156
RFID*Training*No.Staff*NO.A/C	1	0.9640	0.9640	0.96404	2.06	0.156
Residual Error	64	29.9892	29.9892	0.46858		
Pure Error	64	29.9892	29.9892	0.46858		
Total	79	38.8995				

Estimated Coefficients for Preliminary Inspection Time

Term	Coef
Constant	1.61388
RFID	-0.47718
Training	0.53952
No.Staff	**-1.06073**
NO.A/C	-0.102883
RFID*Training	-0.10418
RFID*No.Staff	**0.909383**
RFID*NO.A/C	0.220983
Training*No.Staff	**0.612333**
Training*NO.A/C	0.092417
No.Staff*NO.A/C	0.311133
RFID*Training*No.Staff	**-0.491967**
RFID*Training*NO.A/C	-0.074417
RFID*No.Staff*NO.A/C	-0.250783
Training*No.Staff*NO.A/C	-0.210867
RFID*Training*No.Staff*NO.A/C	0.146367

One-way ANOVA: Preliminary Inspection Time versus RFID

Source	DF	SS	MS	F	P
RFID	1	0.247	0.247	0.50	0.483
Error	78	38.653	0.496		
Total	79	38.900			

S = 0.7040   R-Sq = 0.63%   R-Sq(adj) = 0.00%

```
                                Individual 90% CIs For Mean Based on
                                Pooled StDev
Level   N    Mean   StDev  -----+---------+---------+---------+----
1      40  2.0250  0.7259          (-----------*-----------)
2      40  1.9139  0.6813  (------------*-----------)
```

3.4.8.2 Design of experiment for Avionics Breakdown Time

Experimental design carried out for the avionics breakdown time suggests that RFID*NO.A/C is found to be significantly affect the time. On the other hand, amongst the coefficients RFID and Training from the positive values and RFID*Training, NO.Staff*Training and NO.A/C*Training from the negative values are the points of interest.

Figure 3-32 (see appendix) represents the normal plot for the Avionics Breakdown Time. It suggests that RFID*Number of Aircrafts have significant effects on the Avionics Breakdown Time. Figure 3-33 (see appendix) represents the Pareto chart suggesting that the RFID*Number of Aircrafts is the most important among other factors.

Factorial Fit: Avionics Breakdown versus RFID, NO.A/C, NO.Staff, Training

Estimated Effects and Coefficients for Avionics Breakdown Time

Term	Effect	Coef	SE Coef	T	P
Constant		15.1035	0.7093	21.29	0.000
RFID	1.2412	0.6206	0.7093	0.87	0.385
NO.A/C	1.1286	0.5643	0.7093	0.80	0.429
NO.Staff	0.9236	0.4618	0.7093	0.65	0.517
Training	-1.1178	-0.5589	0.7093	-0.79	0.434
RFID*NO.A/C	-1.0211	-0.5106	0.7093	-0.72	0.474
RFID*NO.Staff	0.0506	0.0253	0.7093	0.04	0.972
RFID*Training	-1.2308	-0.6154	0.7093	-0.87	0.389
NO.A/C*NO.Staff	1.7815	0.8907	0.7093	1.26	0.214
NO.A/C*Training	-0.9276	-0.4638	0.7093	-0.65	0.516
NO.Staff*Training	-0.0281	-0.0141	0.7093	-0.02	0.984
RFID*NO.A/C*NO.Staff	-1.5746	-0.7873	0.7093	-1.11	0.271
RFID*NO.A/C*Training	-1.1060	-0.5530	0.7093	-0.78	0.438
RFID*NO.Staff*Training	-0.8016	-0.4008	0.7093	-0.57	0.574
NO.A/C*NO.Staff*Training	-0.8786	-0.4393	0.7093	-0.62	0.538
RFID*NO.A/C*NO.Staff*Training	-1.4791	-0.7395	0.7093	-1.04	0.301

S = 6.34421 PRESS = 4024.90
R-Sq = 12.75% R-Sq(pred) = 0.00% R-Sq(adj) = 0.00%

Analysis of Variance for Avionics Breakdown Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	98.34	98.34	24.5847	0.61	0.656
RFID	1	30.81	30.81	30.8115	0.77	0.385
NO.A/C	1	25.47	25.47	25.4748	0.63	0.429
NO.Staff	1	17.06	17.06	17.0607	0.42	0.517

Training	1	24.99	24.99	24.9918	0.62	0.434
2-Way Interactions	6	131.90	131.90	21.9833	0.55	0.771
RFID*NO.A/C	1	20.85	20.85	20.8549	0.52	0.474
RFID*NO.Staff	1	0.05	0.05	0.0513	0.00	0.972
RFID*Training	1	30.30	30.30	30.2974	0.75	0.389
NO.A/C*NO.Staff	1	63.47	63.47	63.4713	1.58	0.214
NO.A/C*Training	1	17.21	17.21	17.2088	0.43	0.516
NO.Staff*Training	1	0.02	0.02	0.0158	0.00	0.984
3-Way Interactions	4	102.34	102.34	25.5852	0.64	0.639
RFID*NO.A/C*NO.Staff	1	49.59	49.59	49.5873	1.23	0.271
RFID*NO.A/C*Training	1	24.47	24.47	24.4669	0.61	0.438
RFID*NO.Staff*Training	1	12.85	12.85	12.8496	0.32	0.574
NO.A/C*NO.Staff*Training	1	15.44	15.44	15.4370	0.38	0.538
4-Way Interactions	1	43.75	43.75	43.7547	1.09	0.301
RFID*NO.A/C*NO.Staff*Training	1	43.75	43.75	43.7547	1.09	0.301
Residual Error	64	2575.94	2575.94	40.2490		
Pure Error	64	2575.94	2575.94	40.2490		
Total	79	2952.27				

Estimated Coefficients for Avionics Breakdown Time

Term	Coef
Constant	11.6992
RFID	**4.5527**
NO.A/C	0.99302
NO.Staff	-0.03383
Training	**3.9247**
RFID*NO.A/C	-1.23708
RFID*NO.Staff	-1.22583
RFID*Training	**-3.86712**
NO.A/C*NO.Staff	-0.69517
NO.A/C*Training	**-1.77035**
NO.Staff*Training	**-1.97438**
RFID*NO.A/C*NO.Staff	0.95423
RFID*NO.A/C*Training	1.35912
RFID*NO.Staff*Training	1.88947
NO.A/C*NO.Staff*Training	1.18625
RFID*NO.A/C*NO.Staff*Training	-0.986067

One-way ANOVA: avionic breakdown time versus RFID

Source	DF	SS	MS	F	P
RFID	1	1.9	1.9	0.08	0.780
Error	78	1929.5	24.7		
Total	79	1931.5			

S = 4.974   R-Sq = 0.10%   R-Sq(adj) = 0.00%

```
                               Individual 90% CIs For Mean Based on Pooled StDev
Level   N    Mean  StDev      +---------+---------+---------+---------
1      40  17.609  5.689          (---------------*---------------)
2      40  17.297  4.136      (---------------*----------------)
                              +---------+---------+---------+---------
                           16.00     16.80     17.60     18.40
```

Pooled StDev = 4.974

3.4.8.3 Design of experiment for Electrical Parts Inspection Time

Experimental design carried out for the electrical parts inspection suggests no specific significant point but it doesn't necessarily mean that none of the specified factors significantly affect the time as all the factors are gathered around the straight line. However, from the coefficients, NO.Staff, NO.A/C, and Training from the negative values and RFID*Training and NO.A/C*Training from the positive values were found to be the points of interest.

Figure 3-35 (see appendix) represents the normal plot for the Electrical Parts Inspection Time. It suggests that there are no significant factors affecting the Electrical Parts Inspection Time using %90 confidence interval since all the factors are gathered around the straight line.

On the other hand, from Figure 3-36 (see appendix) it is evident that Number of Aircrafts*Number of staff is found to be more important that other factors since it is very close to the straight line.

Factorial Fit: Electrical parts versus RFID, NO.A/C, NO.Staff, Training

Estimated Effects and Coefficients for Electrical parts inspection time

Term	Effect	Coef	SE Coef	T	P
Constant		6.3570	0.1876	33.89	0.000
RFID	0.5395	0.2698	0.1876	1.44	0.155
NO.A/C	-0.1072	-0.0536	0.1876	-0.29	0.776
NO.Staff	-0.5655	-0.2827	0.1876	-1.51	0.137
Training	-0.3989	-0.1994	0.1876	-1.06	0.292
RFID*NO.A/C	-0.0323	-0.0162	0.1876	-0.09	0.932
RFID*NO.Staff	0.0266	0.0133	0.1876	0.07	0.944
RFID*Training	0.2499	0.1250	0.1876	0.67	0.508
NO.A/C*NO.Staff	0.6176	0.3088	0.1876	1.65	0.105
NO.A/C*Training	-0.2864	-0.1432	0.1876	-0.76	0.448
NO.Staff*Training	0.0201	0.0101	0.1876	0.05	0.957
RFID*NO.A/C*NO.Staff	0.0051	0.0025	0.1876	0.01	0.989
RFID*NO.A/C*Training	-0.2373	-0.1186	0.1876	-0.63	0.529
RFID*NO.Staff*Training	0.3365	0.1683	0.1876	0.90	0.373
NO.A/C*NO.Staff*Training	-0.5978	-0.2989	0.1876	-1.59	0.116
RFID*NO.A/C*NO.Staff*Training	0.1291	0.0646	0.1876	0.34	0.732

S = 1.67783 PRESS = 281.510
R-Sq = 17.06% R-Sq(pred) = 0.00% R-Sq(adj) = 0.00%

Analysis of Variance for Electrical parts inspection time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	15.629	15.629	3.90730	1.39	0.248
RFID	1	5.822	5.822	5.82228	2.07	0.155
NO.A/C	1	0.230	0.230	0.22984	0.08	0.776
NO.Staff	1	6.395	6.395	6.39467	2.27	0.137
Training	1	3.182	3.182	3.18242	1.13	0.292
2-Way Interactions	6	10.561	10.561	1.76009	0.63	0.709
RFID*NO.A/C	1	0.021	0.021	0.02093	0.01	0.932
RFID*NO.Staff	1	0.014	0.014	0.01415	0.01	0.944
RFID*Training	1	1.250	1.250	1.24950	0.44	0.508
NO.A/C*NO.Staff	1	7.627	7.627	7.62736	2.71	0.105
NO.A/C*Training	1	1.640	1.640	1.64050	0.58	0.448
NO.Staff*Training	1	0.008	0.008	0.00812	0.00	0.957
3-Way Interactions	4	10.537	10.537	2.63425	0.94	0.449
RFID*NO.A/C*NO.Staff	1	0.001	0.001	0.00052	0.00	0.989
RFID*NO.A/C*Training	1	1.126	1.126	1.12575	0.40	0.529
RFID*NO.Staff*Training	1	2.265	2.265	2.26465	0.80	0.373
NO.A/C*NO.Staff*Training	1	7.146	7.146	7.14610	2.54	0.116
4-Way Interactions	1	0.333	0.333	0.33334	0.12	0.732
RFID*NO.A/C*NO.Staff*Training	1	0.333	0.333	0.33334	0.12	0.732
Residual Error	64	180.166	180.166	2.81510		
Pure Error	64	180.166	180.166	2.81510		
Total	79	217.227				

Estimated Coefficients for Electrical parts inspection time

Term	Coef
Constant	10.7465
RFID	-0.54673
NO.A/C	**-1.80380**
NO.Staff	**-1.00443**
Training	**-2.60048**
RFID*NO.A/C	0.65820
RFID*NO.Staff	-0.27307
RFID*Training	**0.73548**
NO.A/C*NO.Staff	0.592900
NO.A/C*Training	**1.03355**
NO.Staff*Training	0.32548
RFID*NO.A/C*NO.Staff	-0.127400
RFID*NO.A/C*Training	-0.452417
RFID*NO.Staff*Training	0.190467
NO.A/C*NO.Staff*Training	-0.328350
RFID*NO.A/C*NO.Staff*Training	0.086067

One-way ANOVA: Electrical parts inspection time versus RFID

```
Source  DF      SS    MS     F      P
RFID     1    5.82  5.82  2.15  0.147
Error   78  211.40  2.71
Total   79  217.23

S = 1.646   R-Sq = 2.68%   R-Sq(adj) = 1.43%


                         Individual 90% CIs For Mean Based on
                         Pooled StDev
Level   N   Mean  StDev  ---------+---------+---------+---------+
1      40  6.087  1.525  (----------*----------)
2      40  6.627  1.759                (----------*----------)
                         ---------+---------+---------+---------+
                                6.00      6.40      6.80      7.20

Pooled StDev = 1.646
```

3.4.8.4 Design of experiment for Mechanical Parts Inspection Time

According to the experimental design carried out for the avionics breakdown time, NO.Staff has found to be the significant point. According to the coefficients, Training, RFID*NO.A/C and Training*NO.A/C from the negative values and NO.A/C and RFID*Training from the positive values are the points of interest. Figure 3-38 (see appendix) represents the normal plot for Mechanical Parts Inspection Time. It suggests that Number of Staff is a significant factor among other factors.

The Pareto chart represented in Figure 3.39 (see appendix) suggests that Number of staff is one of the significant factors. However, RFID*Training is also very close the straight line suggesting that it could also be a significant factor affecting the Mechanical Parts Inspection Time.

Factorial Fit: Mechanical Parts versus RFID, NO.A/C, NO.Staff, Training

Estimated Effects and Coefficients for Mechanical Parts Inspection Time

Term	Effect	Coef	SE Coef	T	P
Constant		4.8695	0.3173	15.34	0.000
RFID	-0.0594	-0.0297	0.3173	-0.09	0.926
NO.A/C	0.5234	0.2617	0.3173	0.82	0.413
NO.Staff	**1.4971**	**0.7485**	**0.3173**	**2.36**	**0.021**
Training	0.3969	0.1984	0.3173	0.63	0.534
RFID*NO.A/C	-0.5081	-0.2540	0.3173	-0.80	0.426
RFID*NO.Staff	-0.5796	-0.2898	0.3173	-0.91	0.365
RFID*Training	1.0089	0.5044	0.3173	1.59	0.117
NO.A/C*NO.Staff	-0.4556	-0.2278	0.3173	-0.72	0.475
NO.A/C*Training	-0.4202	-0.2101	0.3173	-0.66	0.510
NO.Staff*Training	0.4094	0.2047	0.3173	0.65	0.521
RFID*NO.A/C*NO.Staff	-0.1272	-0.0636	0.3173	-0.20	0.842
RFID*NO.A/C*Training	-0.0147	-0.0074	0.3173	-0.02	0.982
RFID*NO.Staff*Training	-0.6529	-0.3264	0.3173	-1.03	0.308
NO.A/C*NO.Staff*Training	-0.2344	-0.1172	0.3173	-0.37	0.713
RFID*NO.A/C*NO.Staff*Training	-0.5890	-0.2945	0.3173	-0.93	0.357

S = 2.83844 PRESS = 805.672
R-Sq = 18.07% R-Sq(pred) = 0.00% R-Sq(adj) = 0.00%

Analysis of Variance for Mechanical Parts Inspection Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	53.525	53.525	13.3812	1.66	0.170
RFID	1	0.071	0.071	0.0705	0.01	0.926
NO.A/C	1	5.479	5.479	5.4795	0.68	0.413
NO.Staff	1	44.825	44.825	44.8247	5.56	0.021
Training	1	3.150	3.150	3.1502	0.39	0.534
2-Way Interactions	6	43.275	43.275	7.2125	0.90	0.504
RFID*NO.A/C	1	5.163	5.163	5.1628	0.64	0.426
RFID*NO.Staff	1	6.719	6.719	6.7193	0.83	0.365
RFID*Training	1	20.357	20.357	20.3566	2.53	0.117
NO.A/C*NO.Staff	1	4.152	4.152	4.1519	0.52	0.475
NO.A/C*Training	1	3.532	3.532	3.5318	0.44	0.510
NO.Staff*Training	1	3.353	3.353	3.3526	0.42	0.521
3-Way Interactions	4	9.952	9.952	2.4879	0.31	0.871
RFID*NO.A/C*NO.Staff	1	0.324	0.324	0.3237	0.04	0.842
RFID*NO.A/C*Training	1	0.004	0.004	0.0043	0.00	0.982
RFID*NO.Staff*Training	1	8.525	8.525	8.5249	1.06	0.308
NO.A/C*NO.Staff*Training	1	1.099	1.099	1.0986	0.14	0.713
4-Way Interactions	1	6.938	6.938	6.9378	0.86	0.357
RFID*NO.A/C*NO.Staff*Training	1	6.938	6.938	6.9378	0.86	0.357
Residual Error	64	515.630	515.630	8.0567		
Pure Error	64	515.630	515.630	8.0567		
Total	79	629.319				

Estimated Coefficients for Mechanical Parts Inspection Time

Term	Coef
Constant	3.9053
RFID	-0.58923
NO.A/C	**2.74045**
NO.Staff	1.04640

```
Training                        -2.18105
RFID*NO.A/C                     -1.59837
RFID*NO.Staff                   -0.72037
RFID*Training                    1.29330
NO.A/C*NO.Staff                 -0.77860
NO.A/C*Training                 -1.46515
NO.Staff*Training                0.04615
RFID*NO.A/C*NO.Staff            0.546567
RFID*NO.A/C*Training             0.96690
RFID*NO.Staff*Training           0.30745
NO.A/C*NO.Staff*Training        0.510850
RFID*NO.A/C*NO.Staff*Training  -0.392650
```

One-way ANOVA: Mechanical Parts Inspection Tim versus RFID

```
Source  DF      SS    MS     F      P
RFID     1    0.07  0.07  0.01  0.926
Error   78  629.25  8.07
Total   79  629.32

S = 2.840   R-Sq = 0.01%   R-Sq(adj) = 0.00%

                         Individual 90% CIs For Mean Based on
                         Pooled StDev
Level   N   Mean  StDev  --------+---------+---------+---------+-
1      40  4.899  3.080    (-----------------*------------------)
2      40  4.840  2.579  (------------------*------------------)
                         --------+---------+---------+---------+-
                              4.40      4.80      5.20      5.60

Pooled StDev = 2.840
```

3.4.8.5 Design of experiment for Lifed Parts Overhaul Time

According to the design of experiments carried out for the Lifed parts overhaul time, NO.A/C, Training and RFID*NO.A/C*NO.Staff have been found to be significant. According to the coefficients, RFID, NO.A/C and NO.Staff from the negative values and Training, RFID*NO.A/C and RFID*NO.Staff from the positive values are the points of interest.

According to Figure 3-41 (see appendix) the normal plot for the Lifed Parts Overhaul Time, Training, Number of Aircrafts and RFID*Number of Aircrafts*Number of Staff are significantly affecting the Lifed Parts Overhaul Time. According to Figure 3-42 (see appendix) Pareto Chart for the Lifed Parts Overhaul Time, Training, Number of Aircrafts and RFID*Number of Aircrafts*Number of Staff are significant factors affecting the Lifed Parts Overhaul Time.

Factorial Fit: lifed parts over versus RFID, NO.A/C, NO.Staff, Training

Estimated Effects and Coefficients for lifed parts overhaul time

Term	Effect	Coef	SE Coef	T	P
Constant		18.184	0.5909	30.77	0.000
RFID	-1.599	-0.800	0.5909	-1.35	0.181
NO.A/C	**-3.114**	**-1.557**	**0.5909**	**-2.63**	**0.011**
NO.Staff	0.398	0.199	0.5909	0.34	0.738
Training	3.333	1.666	0.5909	2.82	0.006
RFID*NO.A/C	0.657	0.329	0.5909	0.56	0.580
RFID*NO.Staff	0.845	0.422	0.5909	0.71	0.477
RFID*Training	-0.785	-0.393	0.5909	-0.66	0.509
NO.A/C*NO.Staff	-0.402	-0.201	0.5909	-0.34	0.735
NO.A/C*Training	0.718	0.359	0.5909	0.61	0.546
NO.Staff*Training	0.822	0.411	0.5909	0.70	0.489
RFID*NO.A/C*NO.Staff	**-3.240**	**-1.620**	**0.5909**	**-2.74**	**0.008**
RFID*NO.A/C*Training	0.548	0.274	0.5909	0.46	0.644
RFID*NO.Staff*Training	0.541	0.271	0.5909	0.46	0.649
NO.A/C*NO.Staff*Training	0.551	0.275	0.5909	0.47	0.643
RFID*NO.A/C*NO.Staff*Training	0.672	0.336	0.5909	0.57	0.572

S = 5.28544 PRESS = 2793.58
R-Sq = 30.09% R-Sq(pred) = 0.00% R-Sq(adj) = 13.71%

Analysis of Variance for lifed parts overhaul time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	470.40	470.40	117.600	4.21	0.004
RFID	1	51.16	51.16	51.162	1.83	0.181
NO.A/C	**1**	**193.93**	**193.93**	**193.927**	**6.94**	**0.011**
NO.Staff	1	3.16	3.16	3.162	0.11	0.738
Training	1	222.15	222.15	222.151	7.95	0.006
2-Way Interactions	6	62.29	62.29	10.381	0.37	0.894
RFID*NO.A/C	1	8.64	8.64	8.640	0.31	0.580
RFID*NO.Staff	1	14.27	14.27	14.269	0.51	0.477
RFID*Training	1	12.33	12.33	12.332	0.44	0.509
NO.A/C*NO.Staff	1	3.23	3.23	3.233	0.12	0.735
NO.A/C*Training	1	10.31	10.31	10.306	0.37	0.546
NO.Staff*Training	1	13.51	13.51	13.509	0.48	0.489
3-Way Interactions	**4**	**227.84**	**227.84**	**56.960**	**2.04**	**0.099**
RFID*NO.A/C*NO.Staff	**1**	**209.91**	**209.91**	**209.913**	**7.51**	**0.008**
RFID*NO.A/C*Training	1	6.01	6.01	6.008	0.22	0.644
RFID*NO.Staff*Training	1	5.85	5.85	5.854	0.21	0.649
NO.A/C*NO.Staff*Training	1	6.07	6.07	6.065	0.22	0.643
4-Way Interactions	1	9.03	9.03	9.030	0.32	0.572
RFID*NO.A/C*NO.Staff*Training	1	9.03	9.03	9.030	0.32	0.572
Residual Error	64	1787.89	1787.89	27.936		

```
  Pure Error                    64  1787.89  1787.89   27.936
Total                           79  2557.45
```

Estimated Coefficients for lifed parts overhaul time

```
Term                              Coef
Constant                       30.6981
RFID                           -9.6047
NO.A/C                        -6.29012
NO.Staff                      -6.76722
Training                        4.7506
RFID*NO.A/C                    3.88610
RFID*NO.Staff                  4.73665
RFID*Training                 -1.65838
NO.A/C*NO.Staff                2.28542
NO.A/C*Training                0.75773
NO.Staff*Training              0.93105
RFID*NO.A/C*NO.Staff          -1.75185
RFID*NO.A/C*Training          -0.57182
RFID*NO.Staff*Training        -0.62257
NO.A/C*NO.Staff*Training      -0.48838
RFID*NO.A/C*NO.Staff*Training 0.447967
```

One-way ANOVA: Lifed parts overhaul time versus RFID

```
Source  DF      SS    MS     F      P
RFID     1    51.2  51.2  1.59  0.211
Error   78  2506.3  32.1
Total   79  2557.5

S = 5.669   R-Sq = 2.00%   R-Sq(adj) = 0.74%


                          Individual 90% CIs For Mean Based on
                          Pooled StDev
Level   N    Mean  StDev  --------+---------+---------+---------+-
1      40  18.984  5.950                 (------------*------------)
2      40  17.384  5.372  (------------*-----------)
                          --------+---------+---------+---------+-
                               16.8      18.0      19.2      20.4

Pooled StDev = 5.669
```

3.4.8.6 Design of experiment for Refitting and Further disassembly Time

Experimental design carried out for the refitting and further disassembly time suggests that RFID*Training is a significant factors. Based on the coefficients, RFID, NO.A/C, NO.Staff and Training from the negative values and RFID*Training, RFID*NO.Staff and NO.Staff*Training from the positive values are the points of interest. Figure 3-44 (see appendix) represents the normal plot for Refitting and Further disassembly Time. It suggests that RFID*Training is the most significant factor among other factors affecting the Refitting and Further disassembly Time. Figure 3-45 (see appendix) represents the Pareto chart for Refitting and Further disassembly Time. It suggests that RFID*Training is the most significant factor among other factors affecting the Refitting and Further disassembly Time.

Factorial Fit: refitting time a versus RFID, NO.A/C, NO.Staff, Training

Estimated Effects and Coefficients for refitting time and further disassembly

Term	Effect	Coef	SE Coef	T	P
Constant		145.586	4.694	31.01	0.000
RFID	10.786	5.393	4.694	1.15	0.255
NO.A/C	1.147	0.574	4.694	0.12	0.903
NO.Staff	13.173	6.587	4.694	1.40	0.165
Training	-7.344	-3.672	4.694	-0.78	0.437
RFID*NO.A/C	2.608	1.304	4.694	0.28	0.782
RFID*NO.Staff	-0.498	-0.249	4.694	-0.05	0.958
RFID*Training	**28.498**	**14.249**	**4.694**	**3.04**	**0.003**
NO.A/C*NO.Staff	11.370	5.685	4.694	1.21	0.230
NO.A/C*Training	5.726	2.863	4.694	0.61	0.544
NO.Staff*Training	-5.643	-2.821	4.694	-0.60	0.550
RFID*NO.A/C*NO.Staff	-9.224	-4.612	4.694	-0.98	0.330
RFID*NO.A/C*Training	-3.496	-1.748	4.694	-0.37	0.711
RFID*NO.Staff*Training	-7.976	-3.988	4.694	-0.85	0.399
NO.A/C*NO.Staff*Training	0.534	0.267	4.694	0.06	0.955
RFID*NO.A/C*NO.Staff*Training	6.810	3.405	4.694	0.73	0.471

S = 41.9858   PRESS = 176281
R-Sq = 21.73%   R-Sq(pred) = 0.00%   R-Sq(adj) = 3.38%

Analysis of Variance for refitting time and furthur diss

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	6902	6902	1725.5	0.98	0.425
RFID	1	2327	2327	2326.6	1.32	0.255
NO.A/C	1	26	26	26.3	0.01	0.903
NO.Staff	1	3471	3471	3470.6	1.97	0.165
Training	1	1079	1079	1078.5	0.61	0.437
2-Way Interactions	**6**	**20262**	**20262**	**3376.9**	**1.92**	**0.092**
RFID*NO.A/C	1	136	136	136.0	0.08	0.782
RFID*NO.Staff	1	5	5	5.0	0.00	0.958
RFID*Training	**1**	**16242**	**16242**	**16242.4**	**9.21**	**0.003**
NO.A/C*NO.Staff	1	2586	2586	2585.7	1.47	0.230
NO.A/C*Training	1	656	656	655.7	0.37	0.544
NO.Staff*Training	1	637	637	636.8	0.36	0.550

3-Way Interactions	4	3224	3224	806.1	0.46	0.767
RFID*NO.A/C*NO.Staff	1	1702	1702	1701.7	0.97	0.330
RFID*NO.A/C*Training	1	244	244	244.4	0.14	0.711
RFID*NO.Staff*Training	1	1272	1272	1272.4	0.72	0.399
NO.A/C*NO.Staff*Training	1	6	6	5.7	0.00	0.955
4-Way Interactions	1	927	927	927.5	0.53	0.471
RFID*NO.A/C*NO.Staff*Training	1	927	927	927.5	0.53	0.471
Residual Error	64	112820	112820	1762.8		
Pure Error	64	112820	112820	1762.8		
Total	79	144135				

Estimated Coefficients for refitting time and further disassembly

Term	Coef
Constant	467.052
RFID	**-207.536**
NO.A/C	**-54.9663**
NO.Staff	**-62.7605**
Training	**-197.372**
RFID*NO.A/C	31.2594
RFID*NO.Staff	**45.2739**
RFID*Training	**128.120**
NO.A/C*NO.Staff	16.4547
NO.A/C*Training	24.6864
NO.Staff*Training	**32.0855**
RFID*NO.A/C*NO.Staff	-9.88460
RFID*NO.A/C*Training	-14.8458
RFID*NO.Staff*Training	-24.2545
NO.A/C*NO.Staff*Training	-6.63173
RFID*NO.A/C*NO.Staff*Training	4.53992

One-way ANOVA: refitting time and further disassembly versus RFID

Source	DF	SS	MS	F	P
RFID	1	2327	2327	1.28	0.261
Error	78	141809	1818		
Total	79	144135			

S = 42.64   R-Sq = 1.61%   R-Sq(adj) = 0.35%

```
                              Individual 90% CIs For Mean Based on
                              Pooled StDev
Level   N    Mean  StDev   -+---------+---------+---------+--------
1      40  140.19  41.08   (----------*----------)
2      40  150.98  44.14              (----------*----------)
                           -+---------+---------+---------+--------
                          130       140       150       160
```

Pooled StDev = 42.64

3.4.8.7 Design of experiment for Structural Airframe Inspection Time

Design of experiment carried out for the Structural airframe inspection time suggests points of significance but the results from the coefficients suggest, RFID, NO.A/C, and NO.Staff from the negative values and Training, RFID*NO.A/C and RFID*NO.staff from the positive values, are points of interest in this experiment. Figure 3-47 (see appendix) represents the normal plot for the Structural Airframe Inspection Time. It represents that there are no factors using 90% confidence interval which significantly affect the Structural Airframe Inspection Time.

Figure 3-48 (see appendix) represents the Pareto chart for the Structural Airframe Inspection Time. It represents that there are no factors using 90% confidence interval which significantly affect the Structural Airframe Inspection Time.

Factorial Fit: Structural Airframe Inspection Time versus RFID, NO.A/C, NO.Staff, Training

Estimated Effects and Coefficients for Structural Airframe Inspection Time

Term	Effect	Coef	SE Coef	T	P
Constant		18.184	0.5909	30.77	0.000
RFID	-1.599	-0.800	0.5909	-1.35	0.181
NO.A/C	**-3.114**	**-1.557**	**0.5909**	**-2.63**	**0.011**
NO.Staff	0.398	0.199	0.5909	0.34	0.738
Training	**3.333**	**1.666**	**0.5909**	**2.82**	**0.006**
RFID*NO.A/C	0.657	0.329	0.5909	0.56	0.580
RFID*NO.Staff	0.845	0.422	0.5909	0.71	0.477
RFID*Training	-0.785	-0.393	0.5909	-0.66	0.509
NO.A/C*NO.Staff	-0.402	-0.201	0.5909	-0.34	0.735
NO.A/C*Training	0.718	0.359	0.5909	0.61	0.546
NO.Staff*Training	0.822	0.411	0.5909	0.70	0.489
RFID*NO.A/C*NO.Staff	**-3.240**	**-1.620**	**0.5909**	**-2.74**	**0.008**
RFID*NO.A/C*Training	0.548	0.274	0.5909	0.46	0.644
RFID*NO.Staff*Training	0.541	0.271	0.5909	0.46	0.649
NO.A/C*NO.Staff*Training	0.551	0.275	0.5909	0.47	0.643
RFID*NO.A/C*NO.Staff*Training	0.672	0.336	0.5909	0.57	0.572

S = 5.28544   PRESS = 2793.58

R-Sq = 30.09%   R-Sq(pred) = 0.00%   R-Sq(adj) = 13.71%

Analysis of Variance for Structural Airframe Inspection Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	470.40	470.40	117.600	4.21	0.004
RFID	1	51.16	51.16	51.162	1.83	0.181
NO.A/C	**1**	**193.93**	**193.93**	**193.927**	**6.94**	**0.011**
NO.Staff	1	3.16	3.16	3.162	0.11	0.738
Training	**1**	**222.15**	**222.15**	**222.151**	**7.95**	**0.006**
2-Way Interactions	6	62.29	62.29	10.381	0.37	0.894
RFID*NO.A/C	1	8.64	8.64	8.640	0.31	0.580
RFID*NO.Staff	1	14.27	14.27	14.269	0.51	0.477
RFID*Training	1	12.33	12.33	12.332	0.44	0.509
NO.A/C*NO.Staff	1	3.23	3.23	3.233	0.12	0.735
NO.A/C*Training	1	10.31	10.31	10.306	0.37	0.546
NO.Staff*Training	1	13.51	13.51	13.509	0.48	0.489
3-Way Interactions	**4**	**227.84**	**227.84**	**56.960**	**2.04**	**0.099**
RFID*NO.A/C*NO.Staff	**1**	**209.91**	**209.91**	**209.913**	**7.51**	**0.008**
RFID*NO.A/C*Training	1	6.01	6.01	6.008	0.22	0.644
RFID*NO.Staff*Training	1	5.85	5.85	5.854	0.21	0.649
NO.A/C*NO.Staff*Training	1	6.07	6.07	6.065	0.22	0.643
4-Way Interactions	1	9.03	9.03	9.030	0.32	0.572
RFID*NO.A/C*NO.Staff*Training	1	9.03	9.03	9.030	0.32	0.572
Residual Error	64	1787.89	1787.89	27.936		
Pure Error	64	1787.89	1787.89	27.936		
Total	79	2557.45				

Estimated Coefficients for Structural Airframe Inspection Time

Term	Coef
Constant	30.6981
RFID	**-9.6047**
NO.A/C	**-6.29012**
NO.Staff	**-6.76722**
Training	**4.7506**
RFID*NO.A/C	**3.88610**
RFID*NO.Staff	**4.73665**
RFID*Training	-1.65838
NO.A/C*NO.Staff	2.28542
NO.A/C*Training	0.75773
NO.Staff*Training	0.93105
RFID*NO.A/C*NO.Staff	-1.75185
RFID*NO.A/C*Training	-0.57182
RFID*NO.Staff*Training	-0.62257
NO.A/C*NO.Staff*Training	-0.48838
RFID*NO.A/C*NO.Staff*Training	0.44796

One-way ANOVA: structural airframe inspection versus RFID

```
Source  DF    SS   MS     F      P
RFID     1   116  116  1.04  0.311
Error   78  8732  112
Total   79  8848

S = 10.58   R-Sq = 1.31%   R-Sq(adj) = 0.05%


                         Individual 90% CIs For Mean Based on
                         Pooled StDev
Level   N   Mean  StDev  ---------+---------+---------+---------+
1      40  31.47  10.32              (-------------*-------------)
2      40  29.06  10.83  (-------------*-------------)
                         ---------+---------+---------+---------+
                               28.0      30.0      32.0      34.0

Pooled StDev = 10.58
```

3.4.8.8 Design of experiment for Structural Breakdown Time

Design of experiment carried out for the structural breakdown time suggests no significant values. However, the coefficients suggest that, RFID, NO.Staff and Training from the negative values and RFID*NO.Staff, RFID*Training and NO.Staff*Training from the positive values are the points of interest in this experiment.

Figure 3-50 (see appendix) represents the normal plot for the Structural Breakdown Time. It suggests that no factor using 90% confidence interval is significantly affecting the Structural Breakdown Time. Figure 3-51 (see appendix) represents the Pareto chart for the Structural Breakdown Time. It suggests that no factor using 90% confidence interval is significantly affecting the Structural Breakdown Time.

Factorial Fit: Structural Breakdown Time versus RFID, NO.A/C, NO.Staff, Training

Estimated Effects and Coefficients for Structural Breakdown time

Term	Effect	Coef	SE Coef	T	P
Constant		23.881	1.194	20.00	0.000
RFID	1.580	0.790	1.194	0.66	0.511
NO.A/C	2.040	1.020	1.194	0.85	0.396
NO.Staff	1.422	0.711	1.194	0.60	0.554
Training	1.874	0.937	1.194	0.78	0.436
RFID*NO.A/C	-1.520	-0.760	1.194	-0.64	0.527
RFID*NO.Staff	-1.011	-0.506	1.194	-0.42	0.673
RFID*Training	0.691	0.346	1.194	0.29	0.773
NO.A/C*NO.Staff	1.872	0.936	1.194	0.78	0.436
NO.A/C*Training	2.665	1.332	1.194	1.12	0.269
NO.Staff*Training	1.325	0.663	1.194	0.55	0.581
RFID*NO.A/C*NO.Staff	-0.711	-0.355	1.194	-0.30	0.767
RFID*NO.A/C*Training	-0.783	-0.391	1.194	-0.33	0.744
RFID*NO.Staff*Training	-2.587	-1.293	1.194	-1.08	0.283
NO.A/C*NO.Staff*Training	-0.098	-0.049	1.194	-0.04	0.967
RFID*NO.A/C*NO.Staff*Training	1.287	0.644	1.194	0.54	0.592

S = 10.6824   PRESS = 11411.4
R-Sq = 9.39%   R-Sq(pred) = 0.00%   R-Sq(adj) = 0.00%

Analysis of Variance for Structural Breakdown time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	243.87	243.87	60.968	0.53	0.711
RFID	1	49.94	49.94	49.944	0.44	0.511
NO.A/C	1	83.23	83.23	83.232	0.73	0.396
NO.Staff	1	40.45	40.45	40.447	0.35	0.554
Training	1	70.25	70.25	70.249	0.62	0.436
2-Way Interactions	6	323.42	323.42	53.904	0.47	0.826
RFID*NO.A/C	1	46.19	46.19	46.187	0.40	0.527
RFID*NO.Staff	1	20.46	20.46	20.457	0.18	0.673
RFID*Training	1	9.55	9.55	9.552	0.08	0.773
NO.A/C*NO.Staff	1	70.08	70.08	70.080	0.61	0.436
NO.A/C*Training	1	142.02	142.02	142.018	1.24	0.269
NO.Staff*Training	1	35.13	35.13	35.131	0.31	0.581
3-Way Interactions	4	156.35	156.35	39.088	0.34	0.848
RFID*NO.A/C*NO.Staff	1	10.10	10.10	10.100	0.09	0.767
RFID*NO.A/C*Training	1	12.25	12.25	12.249	0.11	0.744
RFID*NO.Staff*Training	1	133.81	133.81	133.810	1.17	0.283
NO.A/C*NO.Staff*Training	1	0.19	0.19	0.192	0.00	0.967
4-Way Interactions	1	33.14	33.14	33.143	0.29	0.592
RFID*NO.A/C*NO.Staff*Training	1	33.14	33.14	33.143	0.29	0.592
Residual Error	64	7303.30	7303.30	114.114		
Pure Error	64	7303.30	7303.30	114.114		
Total	79	8060.09				

Estimated Coefficients for Structural Breakdown time

Term	Coef
Constant	66.9928
RFID	**-24.4141**
NO.A/C	-8.7279
NO.Staff	**-15.5416**
Training	**-32.7598**
RFID*NO.A/C	4.22453
RFID*NO.Staff	9.07152
RFID*Training	18.7885
NO.A/C*NO.Staff	2.64728
NO.A/C*Training	5.80623
NO.Staff*Training	10.0167
RFID*NO.A/C*NO.Staff	-1.52418
RFID*NO.A/C*Training	-2.92810
RFID*NO.Staff*Training	-6.02340
NO.A/C*NO.Staff*Training	-1.31998
RFID*NO.A/C*NO.Staff*Training	0.85820

One-way ANOVA: Structural Breakdown time versus RFID

Source	DF	SS	MS	F	P
RFID	1	50	50	0.49	0.488
Error	78	8010	103		
Total	79	8060			

S = 10.13   R-Sq = 0.62%   R-Sq(adj) = 0.00%

```
                             Individual 90% CIs For Mean Based on
                             Pooled StDev
Level   N   Mean  StDev  --------+---------+---------+---------+-
1      40  23.09   8.62  (------------*-------------)
2      40  24.67  11.45          (------------*-------------)
                         --------+---------+---------+---------+-
                              22.0      24.0      26.0      28.0
```

Pooled StDev = 10.13

Chapter 4

Numerical Application

At this stage the simulation model will be tested by several input data under different conditions; Non-RFID, RFID, and the comparison of these two. A design of experiment or a sensitivity analysis will be performed to examine which specific factors may have the most impact on the ending results.

5.1 Non-RFID Scenario

Under the non-RFID scenario, the reverse logistics system works in a way that the used aircraft arrives at the system to be updated and put into use again. The aircraft will go through a preliminary inspection which is carried out by 2 workers manually and takes 2 hours. At this point the workers should go through the aircraft's logbook and all the documents and examine the aircraft to see whether there are any obvious flaws or non-conformity associated with the aircraft. The next step will be the aircraft's teardown where the mechanical and structural parts as well as the electronic and avionic parts will be disassembled. On average it takes around 80 hours by 2 mechanical employees to do the mechanical and structural parts teardown and it takes

24 hours by 1 worker from the avionics department to tear down the electrical parts of the aircraft. After the teardown process another inspection phase begins to make sure which parts may need an upgrade or cleaning and differentiate the end of life components and those which may need to be fixed or replaced. The avionics components will be checked to see if they are in a good condition. If so, they will be transferred to the inventory for re-use and if they were not in a satisfactory condition, they will be transferred or sent back to the suppliers to get repaired. This inspection process takes 8 hours by 1 worker from the avionics department. On the other hand, the mechanical parts will be inspected to differentiate between the lifed and non-lifed components which usually take 40 hours by 1 worker from the mechanical department. The lifed parts components will be undergone a further overhaul to decide which parts should be sent back to suppliers for repair and which parts should be transferred to the inventory. Another output of the mechanical and structural teardown process will be the fuselage of the aircraft which will go through an inspection process taking 40 hours by 1 man from the structural department. Meanwhile, if any mechanical component needed cleaning, it will be cleaned and put into inventory for further use. At this final point, all the necessary components for the aircraft upgrade are disassembled and ready to be reassembled. During the process, any parts or components which may need the RFID tag will be tagged and marked to be used in the reassembly process. The ultimate output of the aforementioned process will be an upgraded aircraft equipped with upgraded components which are tagged by RFID technology

Parameter name	Default value (time, hour)
Preliminary Inspection Time	2
Avionics Electrical Breakdown Time	24
Structural Mechanical Breakdown Time	80
Mechanical Parts Inspection Time	40
Lifed Parts Overhaul Time	25
Electrical Parts Inspection Time	8
Structural Airframe Inspection Time	40
Further Disassembly Time	200
Refitting Parts Time	650

Table 4-1 Non-RFID Scenario Input Data

Parameter Name	Value
AvionicsStaff	1
MechanicalStaff	2
MechanicalStaff2	1
OverhaulStaff	1
StructuralStaff	1
StructuralStaff2	4
InspectionStaff	2

Table 4-2 List of Staff Parameters

On the other hand, it is worth noting that in the non-RFID scenario we do not have any training variable for the staff and of course, the RFID element will not have any effect on the overall performance of the system since it is set to 1.

5.2 With RFID Scenario

Several studies suggest that RFID technology can save the companies a lot of time. For instance, according to the case study conducted by Intermec Technologies Corporation, 2007, RFID technology reduced the inventory management time by 98% in the US navy.

According to another company in the apparel industry, the use of RFID has shown some interesting results. According to the Falabella company, "*within a two-person operation, the first count time of 40,000 items clothing is cut from five working days to 2.19 working days, with the time-saving ratio of 56.2 percent; the second count time is reduced from one working day to 0.25 working days, with the time-saving ratio of 75 percent; and the time of the sampling count is decreased from one working day to 0.259 working days, with the time-saving ratio of 75 percent. Therefore, within a two-person operation, the time of conducting inventory counting is reduced from seven working days to 2.69 working days, with the time-saving ratio of 62 percent.*"(American Society of Transportation and Logistics, Wen *et al.* 2010)

MercadoLibre Company which is the eBay of the Latin America has deployed RFID technology in its operations and inventories. The manager of the company, Ariel Moreno, has announced that the RFID technology could have reduced the inventory time from one week to three days.

The CBP which is one of the Departments of Homeland Securityhave used RFID technology for security and information sharing reasons and gained a number of benefits. According to the CBP, the critical information needed for inspection purposes by the officer will be available to them prior to the passengers' arrival so that it will reduce the inspection time from an average of 30 to 40 seconds down to an average of 10 seconds which is above 70%.

On the other hand, RFID technology could bring above 95% information accuracy to many companies compared to barcode which is only accounted for 50 to 60%. RFID technology could reduce the cycle time by 75-92% as well as the receiving time by 91% which is a very dramatic improvement. In the developed model after deploying RFID technology into the helicopters the disassembly process will be as follow: the reverse logistics system works in a way that the used RFID-enabled aircraft arrives at the system to be updated and put into use again. The aircraft will go through a preliminary inspection. At this stage the tags which have a great deal of information will be read by the RFID readers and the information associated with the inspection department will be available to the inspection staff so that the inspection can reduce the amount of time it takes to go through all the paperwork and documents and are able to gather the required information much faster and accurate than before.

The next step will be the aircraft's teardown where the mechanical and structural parts as well as the electronic and avionic parts will be disassembled. Since these tasks are done in parallel, RFID technology could be very useful by providing information on a real time basis for both departments. RFID tags will provide necessary information such as the components' code, the date of their installation, their repair history and log and every other necessary information to the staff so that they know which parts and components may need repair or may not need to get dismantled hence saving a lot of time for them.

After the teardown process another inspection phase begins to make sure which parts may need an upgrade or cleaning and differentiate the end of life components and those which may need to be fixed or replaced. At this stage RFID tags are read whether manually or automatically to gather necessary information about different components and parts. The information will be available to both the avionics and structural departments' staff.

The avionics components data will be checked to see if they are in a good condition. If so, they will be transferred to the inventory for re-use and if they were not in a satisfactory condition, they will be transferred or sent back to the suppliers to get repaired. This is where the RFID technology may play an important role by providing relevant information about each part and component suggesting which one of them may need to be sent back to suppliers or transferred to the inventory for re use.

On the other hand, the mechanical parts will be inspected to differentiate between the lifed and non-lifed components where RFID may become very helpful by providing detailed information about the components including their record of repair or the amount of time they flew. The lifed parts components will be undergone a further overhaul to decide which parts should be sent back to suppliers for repair and which parts should be transferred to the inventory based on the information that RFID tags provide.

Another output of the mechanical and structural teardown process will be the fuselage of the aircraft which will go through an inspection process where RFID tags may provide information on the repair history of the fuselage, how much time the fuselage has been used and flew, and etc. Meanwhile, if any mechanical component needed cleaning, it will be cleaned and put into inventory for further use. At this final point, all the necessary components for the aircraft upgrade is disassembled, tagged if necessary, and ready to be reassembled again. During the process, any parts or components which may need the RFID tag will be tagged and marked to be used in the reassembly process. The ultimate output of the aforementioned process will be an upgraded aircraft equipped with upgraded components which are tagged by RFID technology.

The input data of the with-RFID scenario has been given below to demonstrate that RFID technology now can reduce the total disassembly time by a dramatic percentage. The detail of these input and outputs will be discussed in the next section where the Non-RFID and With-RFID scenarios will be compared in more detail.

In the with-RFID scenario we have considered some extra variables to be able to demonstrate the overall effects of RFID technology on different parts of the system. We have introduced the following extra elements into the system dynamics simulation model.

Parameter name	Value
RFIDPreliminaryInspecionTime	PreliminaryInspectionTime*RFID
RFIDStructuralBreakDownTime	StructralMechanicalBreakDownTime*RFID
RFIDMechanicalInspectionTime	MechanicalPartsInspectionTime*RFID
RFIDLifedPartOverhaulTime	LifedPartsOverhaulTime*RFID
RFIDAvionicsBreakDownTime	AvionicsElectricalBreakDownTime*RFID
RFIDElectricalPartsInspection	ElectricalPartsInspectionTime*RFID
RFIDRefittingPartsTime	RefittingPartsTime*RFID
RFIDFurthurDisassemblyTime	FurthurDisassemblyTime*RFID
RFIDStructuralAirFrameInspectionTime	StructuralAirFrameInspectionTime*RFID
RFID	max(0,normal(0.25, 0.75))
StaffTraining	2

Table 4-3 With-RFID Input Data

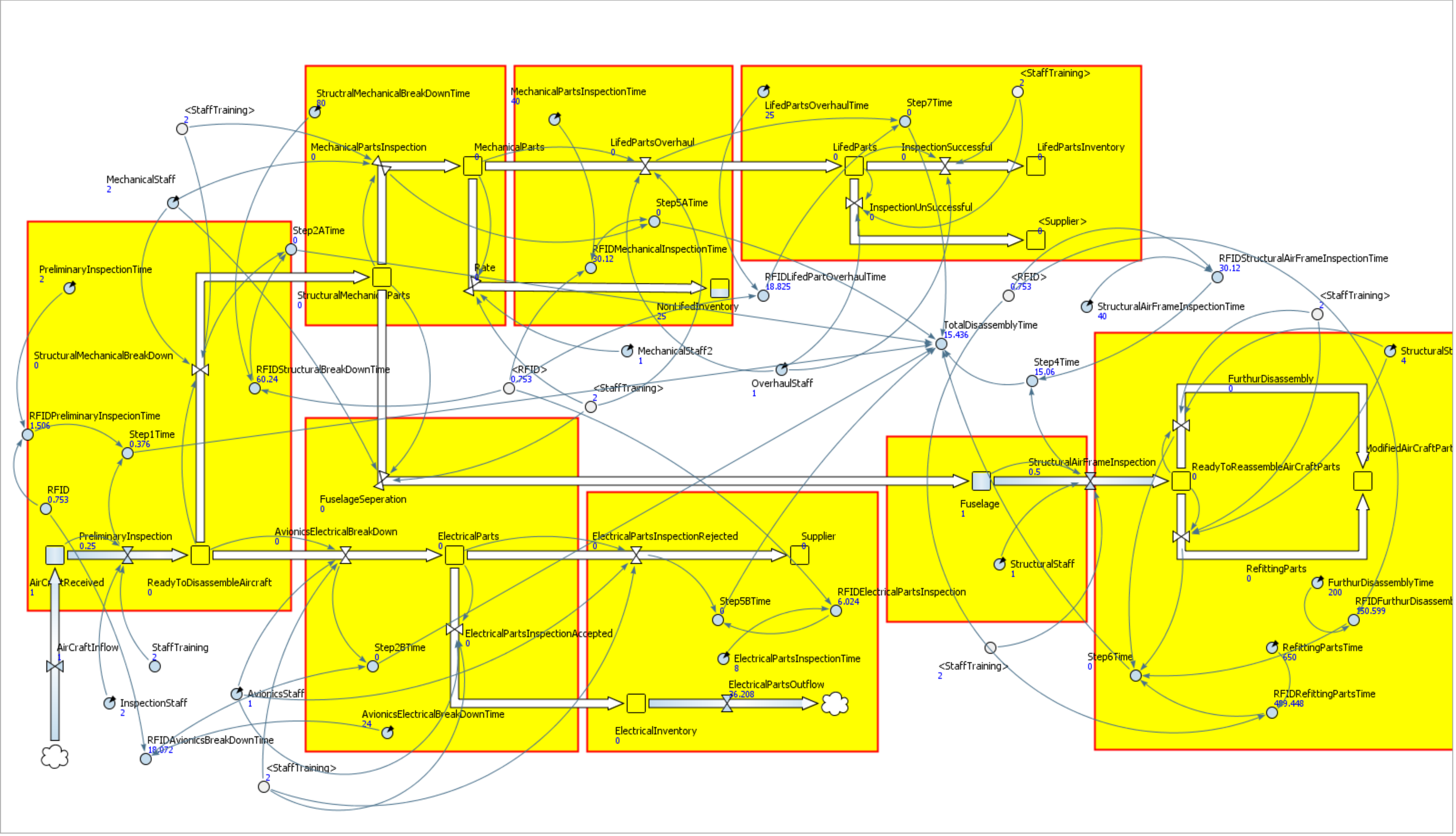

Figure 4-1 With-RFID simulation Model

5.3 Results (RFID vs. Non-RFID Scenario)

In the model developed in this thesis, it is assumed that the aircrafts getting into the disassembly system are not equipped with RFID technology and it is during the process that the RFID tags are attached to different components and parts. The good side of the story is that at the time that the RFID enabled aircraft arrives at the system to be upgraded again in the future, RFID technology will definitely save a lot of time and manual effort and may lead to an increase in the aircraft turnover. In the current system, the aircraft turnover is only one in a month. The with-RFID scenario will start the same as the non-RFID scenario where the aircraft is received by the reverse logistics system to be disassembled and upgraded. At the preliminary inspection process, the technicians will have the information associated with the aircraft at hand as the aircraft has been already scanned and information have been gathered from the RFID tags attached to different components of the aircraft. At this point, the inspection crew will not have to go through all the documentations and log files and all the necessary data will be available to them in a matter of few seconds. RFID technology could reduce the preliminary inspection time by 75% from 2 hours to 30 minutes on average. The next step would be the teardown process where the avionics and electronic parts as well as the mechanical and structural parts will be dismantled and go into different categories. At this stage, all the necessary information for each department whether avionics or mechanical department will be provided for the technicians and crews. At this point, the staff knows which parts should be taken off the aircraft, which parts need repair and which parts should be dismantled. RFID technology at the stages of mechanical and structural teardown and the electronics and avionics teardown, could have reduce the amount of time required to disassemble different parts of the aircraft; from 80 hours to 20 hours on average in the structural and mechanical system teardown stage and from 24 to 6 on average in the avionics and electrical component teardown stage which is a 75% reduction. The avionics and electrical components inspection time has also witnessed a dramatic reduction in time; from 8 hours to around 2 hours on average. On the other hand the inspection time of the structural airframe inspections have been decreased after the RFID technology was deployed from 40 hours to 10 hours on average. Moreover, the mechanical components inspection time have also been reduced from 40 hours to 10 hours on average since based on the information that RFID tags provide for the technicians, they are now able to figure out which parts are lifed and which parts are non-lifed hence saving them a lot of time. On the other hand, the lifed parts overhaul process now takes 75% less to be performed; it has decreased from 25 hours to 6 hours and 15 minutes on average. At the last stage which is where the aircraft is being upgraded, RFID technology reduces the time of further disassemblies from 200 hours to 50 hours on average. However, the RFID technology may not play an important role in the final sub stage which is the refitting of all the dismantled and upgraded components but from another perspective, the time reductions that RFID technology could have brought into the reverse logistics system, may also reduce the number of staff at each stage suggesting that the reduced number of staff could be utilized at the ending stage to help with the reassembly process as it takes 650 hours on average for 4 technicians. RFID technology may reduce this time by more than 65% from 650 to 430 hours on average.

The detailed information on the inputs and the output of both scenarios (RFID and Non RFID) has been demonstrated below to see how much time RFID technology may save in the reverse logistics.

According to Figure 4.2 the benefits in time saving brought about by RFID technology is surprising. RFID technology could have reduced the total disassembly time by over 30% on average. On the other hand, RFID technology may be very helpful in the inventory management as many studies and researches may suggest and this could also lead to a huge decrease in the total costs both in the reassembly and inventory management hence higher return on investment (ROI).

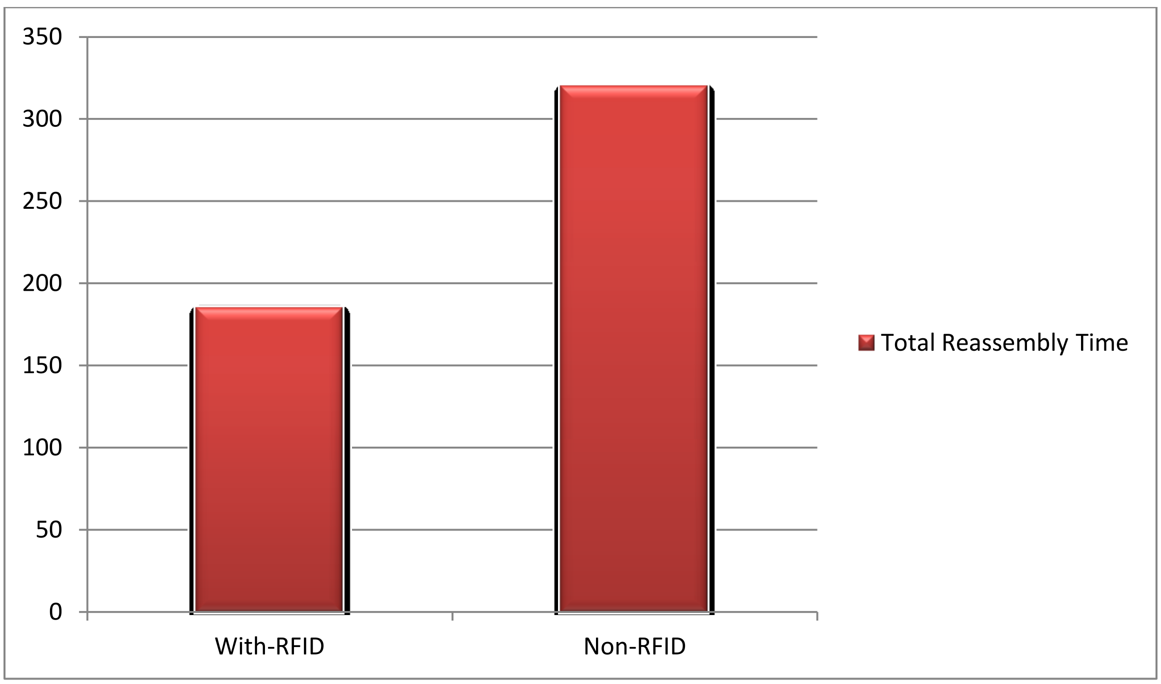

Figure 4-2 RFID vs. Non RFID Total Reassembly Time (Hours)

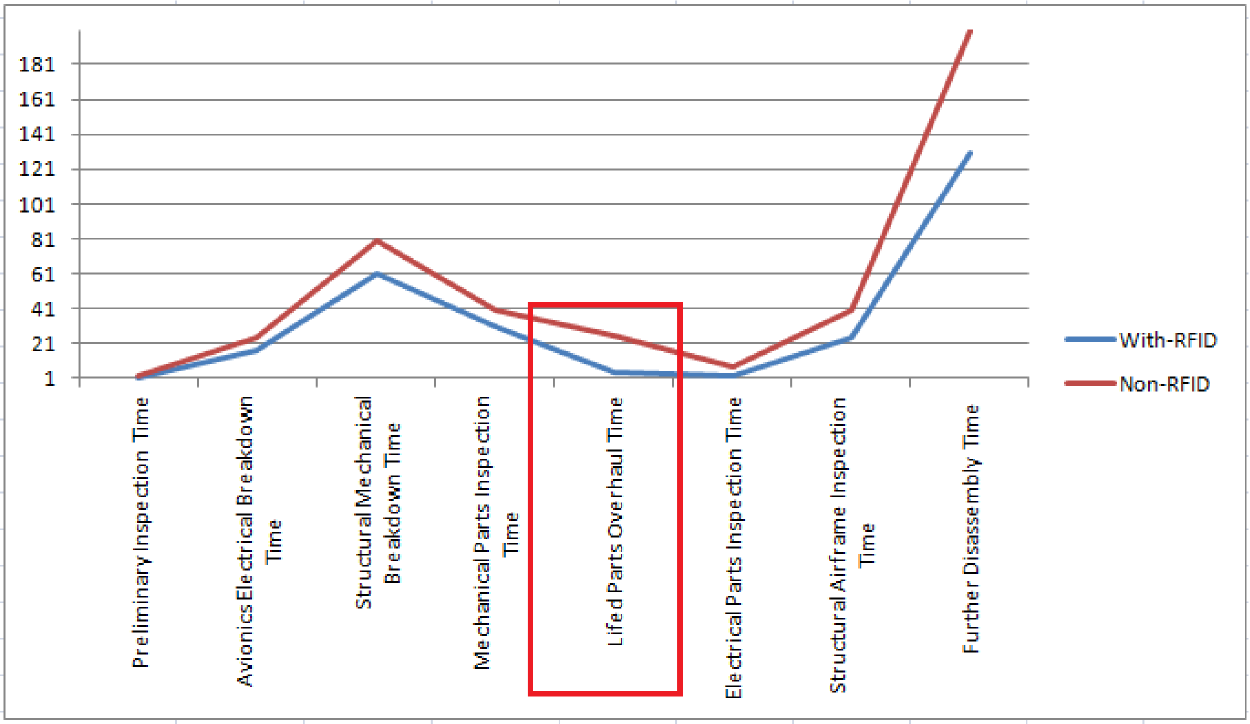

Figure 4-3 RFID vs. Non RFID time Comparison (Hours)

Figure 4.3 represents the total time reduction after deploying RFID technology. It represents that the average Total Reassembly Time has been reduced after RFID implementation compared to Non-RFID scenario.

Chapter 5

Conclusion and Future works

5.1 Conclusion

In this thesis we investigated the potentials of RFID technology in disassembly operations of aircrafts and proposed a four step based solution approach namely:

a) RFID Technology Selection

   In this step we investigated different types of RFID. We conducted several Force-Field analyses based on research papers, articles and books about different RFID types and we drew the conclusion that passive RFID is the most suitable for this thesis.

b) RFID Implementation

   In this step we investigated the RFID implementation and mapped the implementation to the process map.

c) RFID Cost Analysis

   In this step we investigated the cost components of RFID technology to analyze the feasibility of RFID technology and to investigate how much investment may be required based on the number of different tags and readers.

d) RFID Simulation

   In this step we developed a system dynamics simulation model based on a case study with Bell Helicopters to investigate the behavior and complexities of the process after introducing RFID technology. In the end we analyzed the results to make sure RFID technology is effective in reducing the total aircraft's disassembly time of

5.2 Transitioning Towards RFID

The results of this research show that employing RFID technology will lead to a reduction in total disassembly time of a helicopter. However, developing trust in the promising benefits and results on one hand, and bringing motivation to the market to employ RFID technology in such industries on the other hand will require a more challenging planning and managerial activities.

There have been many research and case studies relating to RFID technology in supply chain management and reverse logistics networks in many industries such as retail industries, apparel industries, food industries, and traffic and transportation. Meanwhile, the research area for RFID in aviation industries specifically, the reverse logistics in aviation industries, is very narrow and there are only a few research papers published. In my opinion, there should be more focus on the aforementioned area to explore more benefits of using such technology in aviation reverse logistics.

RFID technology and basically, the Automated Identification systems are evolving on a fast pace. Companies and different industries tend to deploy such technologies since they have been proved very useful and beneficial. On the other hand, RFID technology is foreseen to be a part of our everyday lives, from when we are driving, shopping, to going out for dinner, auto payment systems and many more everyday examples. However, since the initial setup costs as well as the costs of training and maintenance of such complicated systems are high, companies may refuse to abandon their legacy barcode systems and may not have enough incentives to change to RFID.

Hence, the more research and experiment towards the development of cheaper and more effective RFID tags and readers, and the more research on the benefits and efficiencies that this technology may bring to the company, the more incentive and motivation there will be for other industries to be willing to change from their old legacy systems to new technologies such as RFID to benefit from all the advantages that they offer.

5.3 Future Works

In this thesis our main focus was on the disassembly process and how RFID technology affects different stages of the disassembly process such as inspection times, mechanical and structural parts as well as the electrical and avionics components teardown and so on and so forth. However, the other aspect of the reverse logistics which is the reassembly of all the components and parts that have been dismantled from the aircraft has not been taken into account dramatically. The future works of this study, however, may be focused more on the other side of the process which is the reassembly process which itself takes a great deal of time (over 800 hours). In my opinion, RFID technology may also reduce the total reassembly time as well the total disassembly time since it provides a paramount amount of information on a real time basis for inventory management. As the inventories are managed properly and the inventory time decrease, the reassembly time on the other hand may be decreased since it has a close connection and cooperation with inventories.

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Appendix

	Versatile On and Off Metal Line				Specialty Tag Line		High Memory Line		Flexible Metal Line	
Series	Trak Series				Specialized Series		XL Series		Metal Skin™ Series	
Product	 Cargo Trak	 Versa Trak	 Data Trak II	 Global Trak II	 Bric	 Xylinder	 Sky-ID™	 Pico XL	 Mercury Metal Skin	 Titanium Metal Skin
Operating frequency	902-928 MHz (US) 866-868 MHz (EU)	902-928 MHz (US) 866-868 MHz (EU)	902-928 MHz (US) 866-868 MHz (EU)	860-960 MHz (Global)	902-928 MHz (US) 866-868 MHz (EU)	902-928 MHz (US) 866-868 MHz (EU)	860-960 MHz (Global)	860-960 MHz (Global)	860-960 MHz (Global)	860-960 MHz (Global)
IC type	Alien Higgs-3	Alien Higgs-3	Impinj Monza 4E	Impinj Monza 4E	Alien Higgs-3	Alien Higgs-3	Tegochip XL	Tegochip XL	Impinj Monza 4E	Impinj Monza M5
Memory configuration	96 EPC bits, extend-able to 480 bits (512 bit user memory)	96 EPC bits, extend-able to 480 bits (512 bit user memory)	48-bit serialized TID, 496 EPC bits, (128 bit user memory)	48-bit serialized TID, 496 EPC bits, (128 bit user memory)	96 EPC bits, extendable to 480 bits (512 bit user memory)	96 EPC bits, extendable to 480 bits (512 bit user memory)	96 EPC bits, extendable to 496 bits (8k byte user memory)	96 EPC bits, extend-able to 496 bits (2k bit user memory)	48-bit serialized TID, 496 EPC bits, (128 bit user memory)	48-bit serialized TID,128 EPC bits
Read range on metal	Up to 39 ft (12 m)	Up to 26 ft (8 m)	Up to 14.8 ft (4.5 m)	Up to 8 ft (2.5 m)	Up to 19 ft (6 m)	Up to 19 ft (6m)	Up to 4 ft (1.2 m)	Up to 1 ft (0.3 m)	Up to 13 ft (4 m)	Up to 4 ft (1.2 m)
Read range off metal	Up to 20 ft (6 m)	Up to 13 ft (4 m)	Up to 8 ft (2.5 m)	Up to 6 ft (1.8 m)	Up to 13 ft (4 m); 6.5 ft (2 m) when embedded 2 in (50 mm) in concrete	Limited	Limited	Limited	Up to 16 ft (5 m)	Up to 4 ft (1.2 m)
Case material	ABS plastic	ABS plastic	Polycarbonate	Polycarbonate	Engineering grade nylon polymer	Engineering grade nylon polymer	Engineering grade polyester FR-4	Engineering grade nylon polymer	Not applicable	Not applicable
Mounting system	Rivet hole, ø 0.14 in (3.5 mm); adhesive (optional)	High performance adhesive	Adhesive; built-in ø 0.1 in (2.6 mm) tethering hole	Adhesive; built-in ø 0.1 in (2.6 mm) tethering hole	Mounted or embed-ded in concrete	High performance adhesive	High performance adhesive	High performance adhesive	High performance adhesive (dry)	High performance adhesive (dry)
Operating temperature	-22°F to +185°F (-30°C to +85°C)	-22°F to +185°F (-30°C to +85°C)	-40°F to +185°F (-40°C to +85°C)	-40°F to +185°F (-40°C to +85°C)	-40°F to +185°F (-40°C to +85°C)	-40°F to +185°F (-40°C to +85°C)	+32°F to +158°F (0°C to +70°C)	+32°F to +158°F (0°C to +70°C)	-40°F to +185°F (-40°C to +85°C)	-40°F to +185°F (-40°C to +85°C)
Application temperature	-40°F to +185°F (-40°C to +85°C)	-40°F to +185°F (-40°C to +85°C)	-40°F to +185°F (-40°C to +85°C)	-40°F to +185°F (-40°C to +85°C)	-40°F to +194°F (-40°C to +90°C)	-40°F to +302°F (-40°C to +150°C)	-67°F to +302°F (-55°C to +150°C)	-67°F to +302°F (-55°C to +150°C)	-40°F to +185°F (-40°C to +85°C)	-40°F to +185°F (-40°C to +85°C)
Compression strength	29 psi (200 kPa)	26.1 psi (180 kPa)	14.5 psi (100 kPa)	14.5 psi (100 kPa)	93 psi (641 kPa)	80 psi (551 kPa)	203 psi (1400 kPa)	174 psi (1200 kPa)	Not applicable	Not applicable
IP classification	IP68	IP54	IP54	IP54	IP68	IP68	IP68	IP68	Not applicable	Not applicable
Dimensions	3.94 x 1.02 x 0.35 in (100 x 26 x 8.9 mm)	1.97 x 0.67 x 0.20 in (50 x 17 x 5 mm)	1.50 x 0.51 x 0.15 in (38 x 13 x 3.8 mm)	1.50 x 0.51 x 0.15 in (38 x 13 x 3.8 mm)	2.75 x 1.25 x 0.43 in (70 x 32 x 11 mm)	ø 1.26 x 0.25 in (ø 32 x 6.5 mm)	1.39 x 0.80 x 0.17 in (35.2 x 20.2 x 4.4 mm)	0.70 x 0.43 x 0.19 in (17.7 x 10.9 x 4.8 mm)	4 x 1.5 x 0.031 in (101.6 x 38 x 0.76 mm) Smart Label	1.77 x 0.22x 0.03 in (45x 5.6 x 0.86 mm)
Weight	0.61 oz (17.2 g)	0.11 oz (3 g)	0.09 oz (2.6 g)	0.09 oz (2.6 g)	0.85 oz (24 g)	0.26 oz (7.4 g)	0.21 oz (6 g)	0.07 oz (2 g)	0.07 oz (2 g)	0.11 oz (3 g)
Sample applications	Vehicle chassis and trailer tracking, Unit Load Device identification, yard management	Instrument tracking, pallet tracking, RTI management, storage rack identification	IT asset management, Datacenter servers, Healthcare equipment, Cables	Global supply chain logistics, IT asset management, datacenter servers	Facility management, yard management, work in progress	Gas cylinder tracking, container management, smart grid identification, ATEX certified	SAE AS5678 and ATA Spec2000 compliant, aircraft parts, configuration management, MRO management	Aircraft parts maintenance, IT management, MRO management	Product authentication, IT asset tracking, global supply chain, cylinder tracking, foil-based packaging	Product authentication, IT asset and laptop tracking, radio and mobile equipment, foil-based packaging

Figure 3-8 Xerafy RFID tags 02

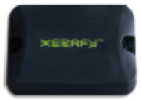
	Rugged Line						Embeddable Line for Source Tagging and Extreme Conditions				
Series	X II Series				XS Series		iN Series			XS Series	
Product	 Micro^{x} II	 Nano^{x} II	 Pico^{x} II / Pico^{x} II Plus	 Pico-On Plus	 Dash-On XS	 Dot-On XS	 Micro-iN	 Nano-iN	 Pico-iN / Pico-iN Plus	 Dash-iN XS	 Dot-iN XS
Operating frequency	902-928 MHz (US) 866-868 MHz (EU)	902-928 MHz (US) 866-868 MHz (EU)	902-928 MHz (US) 866-868 MHz (EU)	902-928 MHz (US) 866-868 MHz (EU)	902-928 MHz (US) 866-868 MHz (EU)	902-928 MHz (US) 866-868 MHz (EU)	902-928 MHz (US) 866-868 MHz (EU)	902-928 MHz (US) 866-868 MHz (EU)	902-928 MHz (US) 866-868 MHz (EU)	902-928 MHz (US) 866-868 MHz (EU)	902-928 MHz (US) 866-868 MHz (EU)
IC type	Alien Higgs-3	Alien Higgs-3	Alien Higgs-3	Alien Higgs-3	Alien Higgs-3	Alien Higgs-3	Alien Higgs-3	Alien Higgs-3	Alien Higgs-3	Alien Higgs-3	Alien Higgs-3
Memory configuration	96 EPC bits, extendable to 480 bits (512 bit user memory)	96 EPC bits, extendable to 480 bits (512 bit user memory)	96 EPC bits, extendable to 480 bits (512 bit user memory)	96 EPC bits, extendable to 480 bits (512 bit user memory)	96 EPC bits, extendable to 480 bits (512 bit user memory)	96 EPC bits, extendable to 480 bits (512 bit user memory)	96 EPC bits, extendable to 480 bits (512 bit user memory)	96 EPC bits, extendable to 480 bits (512 bit user memory)	96 EPC bits, extendable to 480 bits (512 bit user memory)	96 EPC bits, extendable to 480 bits (512 bit user memory)	96 EPC bits, extendable to 480 bits (512 bit user memory)
Read range on metal	Up to 33 ft (10 m)	Up to 20 ft (6 m)	Up to 6.6 ft (2 m); 10 ft (3 m) for Pico^{x} II Plus	Up to 10 ft (3 m)	Up to 6.6 ft (2 m)	Up to 5 ft (1.5 m)	Up to 20 ft (6 m) when embedded	Up to 13 ft (4 m) when embedded	Up to 3.3 ft (1 m); 6.6 ft (2 m) for Pico-iN Plus when embedded	Up to 5 ft (1.5 m) when embedded	Up to 3 ft (1 m) when embedded
Read range off metal	Limited	Limited	Limited	Limited	Limited	Limited	Limited	Limited	Limited	Limited	Limited
Case material	Engineering grade nylon polymer	Engineering grade nylon polymer	Engineering grade nylon polymer	Ceramic	Ceramic	Ceramic	Ceramic	Ceramic	Ceramic	Ceramic	Ceramic
Mounting system	Rivet hole, ø 0.12 in (3.2 mm); adhesive (optional)	High performance adhesive	High performance adhesive	High performance adhesive	High performance adhesive	High performance adhesive	Embedded	Embedded	Embedded	Epoxy, embedded	Epoxy, embedded
Operating temperature	-22°F to +185°F (-30°C to +85°C)	-22°F to +185°F (-30°C to +85°C)	-22°F to +185°F (-30°C to +85°C)	-22°F to +185°F (-30°C to +85°C)	-22°F to +185°F (-30°C to +85°C)	-22°F to +185°F (-30°C to +85°C)	-22°F to +185°F (-30°C to +85°C)	-22°F to +185°F (-30°C to +85°C)	-22°F to +185°F (-30°C to +85°C)	-22°F to +185°F (-30°C to +85°C)	-22°F to +185°F (-30°C to +85°C)
Application temperature	-40°F to +482°F (-40°C to +250°C)	-40°F to +302°F (-40°C to +150°C)	-40°F to +302°F (-40°C to +150°C)	-40°F to +302°F (-40°C to +150°C)	-40°F to +302°F (-40°C to +150°C)	-40°F to +302°F (-40°C to +150°C)	-40°F to +302°F (-40°C to +150°C)	-40°F to +302°F (-40°C to +150°C)	-40°F to +302°F (-40°C to +150°C)	-40°F to +302°F (-40°C to +150°C)	-40°F to +302°F (-40°C to +150°C)
Compression strength	181 psi (1259 kPa)	166.8 psi (1150 kPa)	174 psi (1200 kPa)	170 psi (1176 kPa)	790 psi (5447kPa)	790 psi (5447kPa)	Packaging dependent	Packaging dependent	Packaging dependent	Packaging dependent	Packaging dependent
IP classification	IP68	IP68	IP68	IP68	IP68	IP68	IP68	IP68	IP68	IP68	IP68
Dimensions	2.01 x 1.43 x 0.30 in (51 x 36.3 x 7.5 mm)	1.25 x 0.51 x 0.19 in (31.7 x 12.8 x 4.8 mm)	0.70 x 0.43 x 0.19 in (17.7 x 10.9 x 4.8 mm)	0.47 x 0.28 x 0.12 in (12 x 7 x 3 mm)	0.48 x 0.12 x 0.09 in (12.3 x 3 x 2.2 mm)	ø 0.24 x 0.1 in (ø 6 x 2.5 mm)	1.18 x 1.18 x 0.12 in (30 x 30 x 3 mm)	0.98 x 0.35 x 0.12 in (25 x 9 x 3 mm)	0.47 x 0.28 x 0.12 in (12 x 7 x 3 mm)	0.48 x 0.12 x 0.09 in (12.3 x 3 x 2.2 mm)	ø 0.24 x 0.1 in (ø 6 x 2.5 mm)
Weight	0.92 oz (26 g)	0.18 oz (5 g)	0.07 oz (2 g)	0.05 oz (1.4 g)	0.016 oz (0.44 g)	0.012 oz (0.34 g)	0.49 oz (14 g)	0.13 oz (3.6 g)	0.05 oz (1.4 g)	0.016 oz (0.44 g)	0.012 oz (0.34 g)
Sample applications	Bulk container tracking, vehicle tracking, post-paint oven baking, autoclave	Tool tracking, WIP conveying equipment, IT/telecom management, instrument tracking, weapons tracking	Tool tracking, weapon tracking, medical device management, instrument tracking	Tool tracking, electronic device management, instrument tracking	Instrument tracking, tool tracking, medical device management, source tagging	Instrument tracking, tool tracking, medical device management, source tagging	Reusable container logistics, heavy machinery tracking, automotive parts identification	IT asset identification, weapons tracking, tool management	IT and laptop tracking, tool tracking, embedded bolt identification, weapons tracking	Instrument tracking, tool tracking, medical device management, source tagging	Instrument tracking, tool tracking, medical device management, source tagging

Figure 3-7 Xerafy RFID tags 01

Figure 3-9 Handheld RFID readers by Motorola

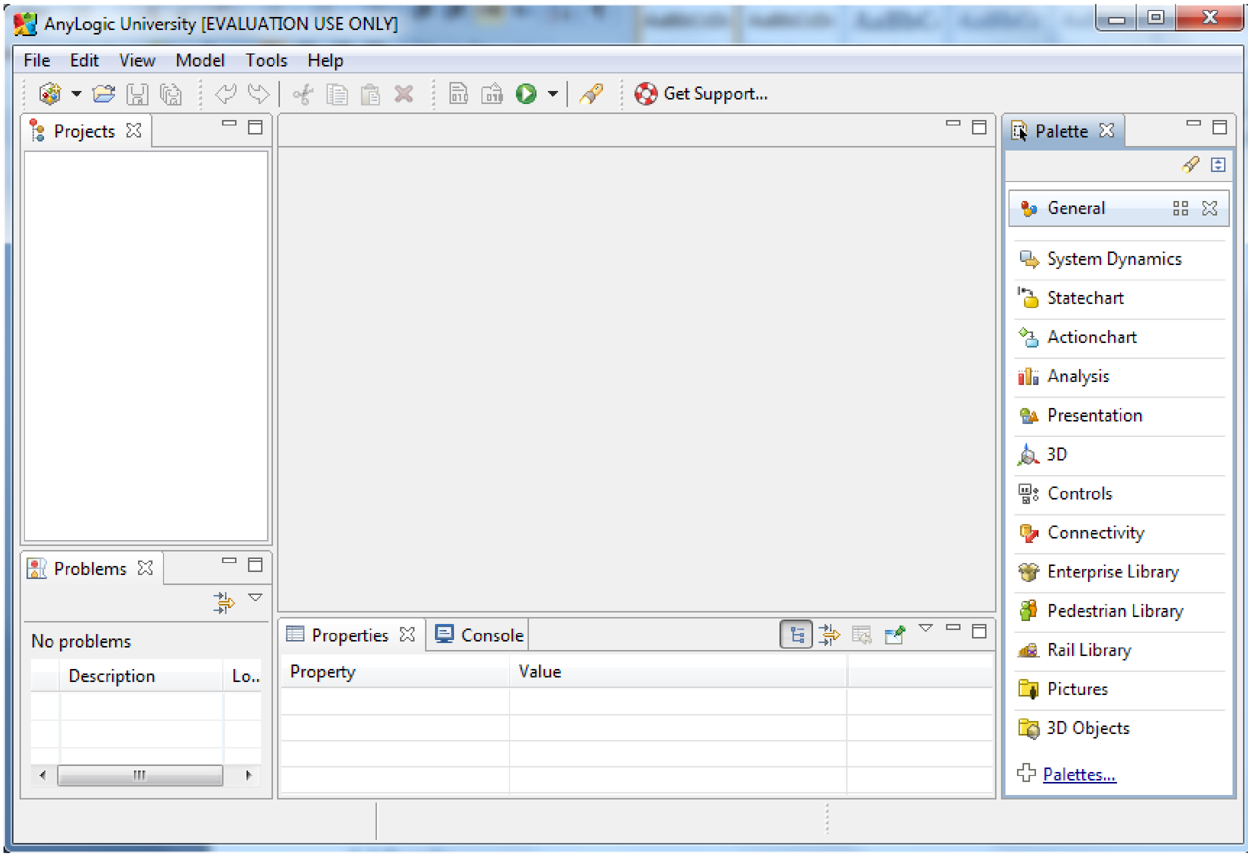


Figure 3-19 AnyLogic overview

Design of Experiments Charts

↓	C1	C2	C3	C4	C5	C6	C7-T	C8	C9
	StdOrder	RunOrder	CenterPt	Blocks	NO.Staff	NO.A/C	RFID Type	Training	Total Reassembly Time
1	1	11	1	1	1	1	Passive	1	90.086
2	2	25	1	1	4	1	Passive	1	70.043
3	3	68	1	1	1	5	Passive	1	33.626
4	4	81	1	1	4	5	Passive	1	87.966
5	5	54	1	1	1	1	Active	1	69.223
6	6	50	1	1	4	1	Active	1	106.692
7	7	18	1	1	1	5	Active	1	141.466
8	8	63	1	1	4	5	Active	1	294.497
9	9	38	1	1	1	1	Passive	2	138.455
10	10	69	1	1	4	1	Passive	2	210.481
11	11	10	1	1	1	5	Passive	2	178.167
12	12	67	1	1	4	5	Passive	2	510.415
13	13	30	1	1	1	1	Active	2	253.661
14	14	40	1	1	4	1	Active	2	266.699
15	15	85	1	1	1	5	Active	2	349.621
16	16	86	1	1	4	5	Active	2	377.663
17	17	2	1	1	1	1	Passive	1	427.660
18	18	33	1	1	4	1	Passive	1	425.880
19	19	26	1	1	1	5	Passive	1	245.307
20	20	20	1	1	4	5	Passive	1	348.667
21	21	43	1	1	1	1	Active	1	348.867
22	22	82	1	1	4	1	Active	1	346.193
23	23	88	1	1	1	5	Active	1	172.808
24	24	66	1	1	4	5	Active	1	652.712
25	25	83	1	1	1	1	Passive	2	304.874

Figure 3-23 Data Sheet

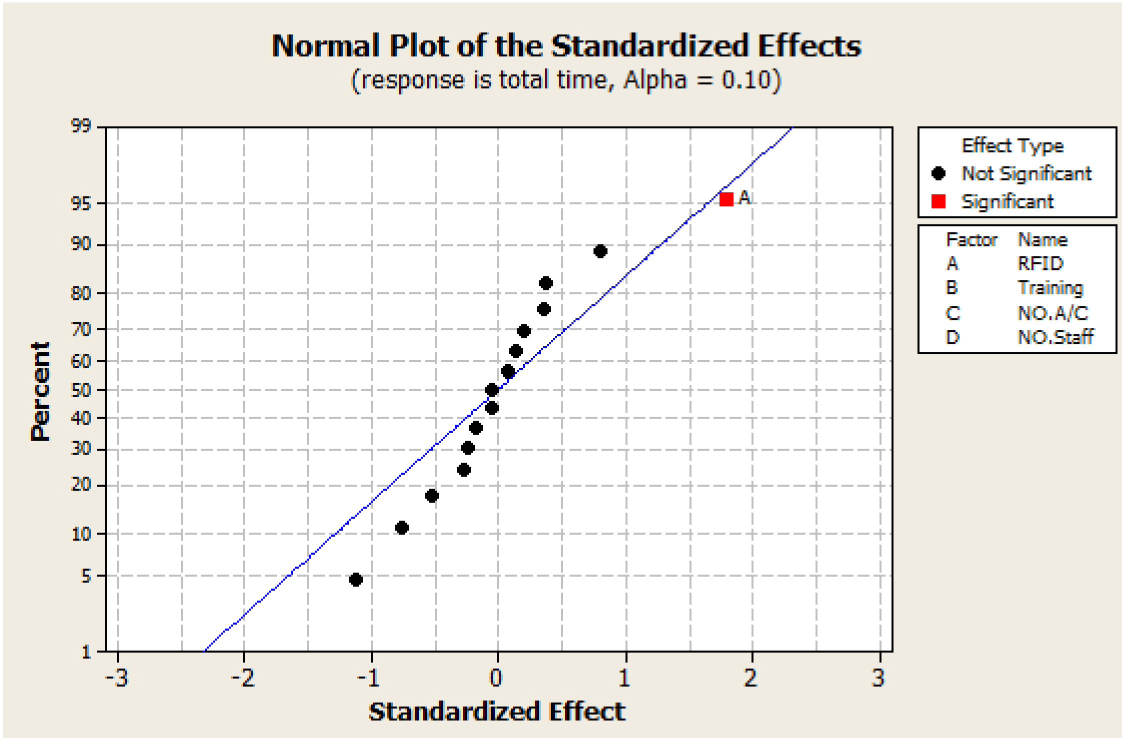


Figure 3-24 Normal Plot of Standardized Effects

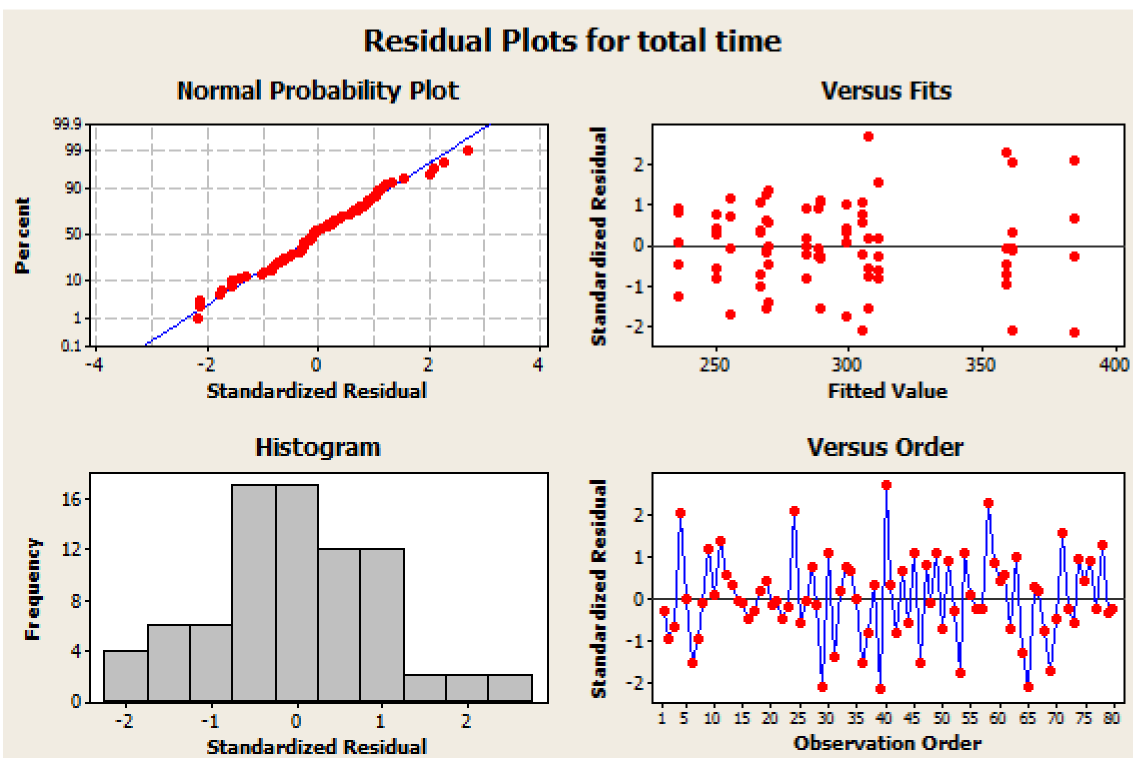


Figure 3-25 Residual Plots For Total Reassembly Time

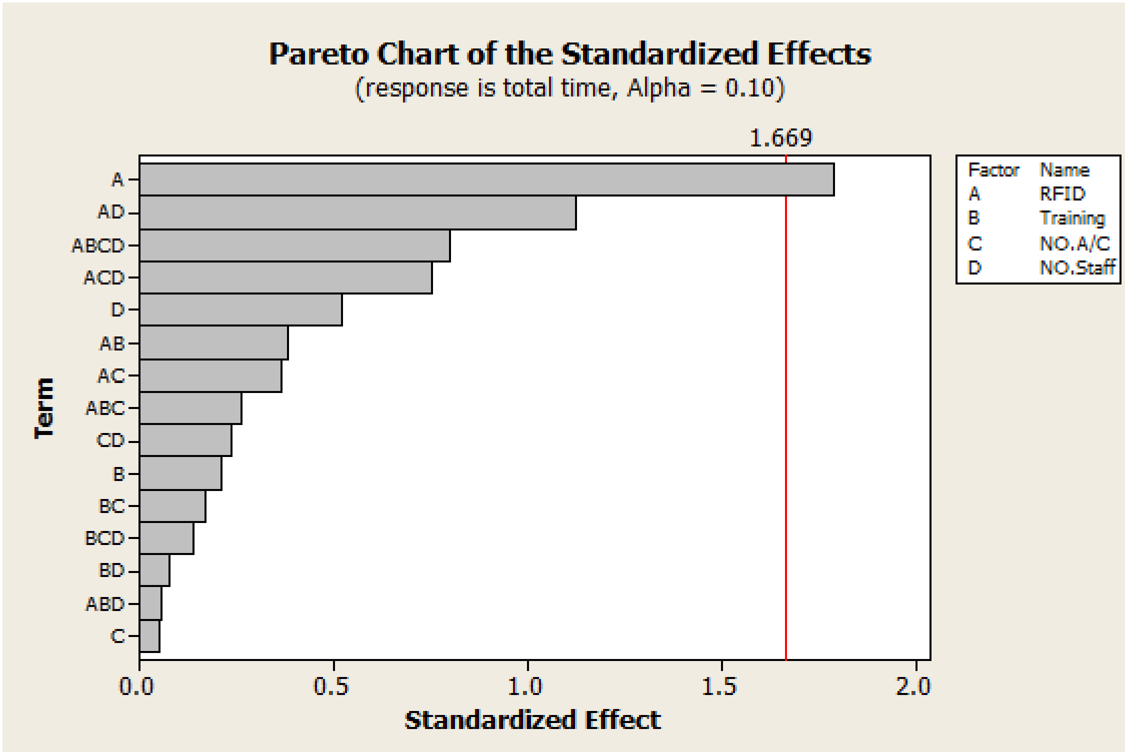


Figure 3-26 Pareto Chart

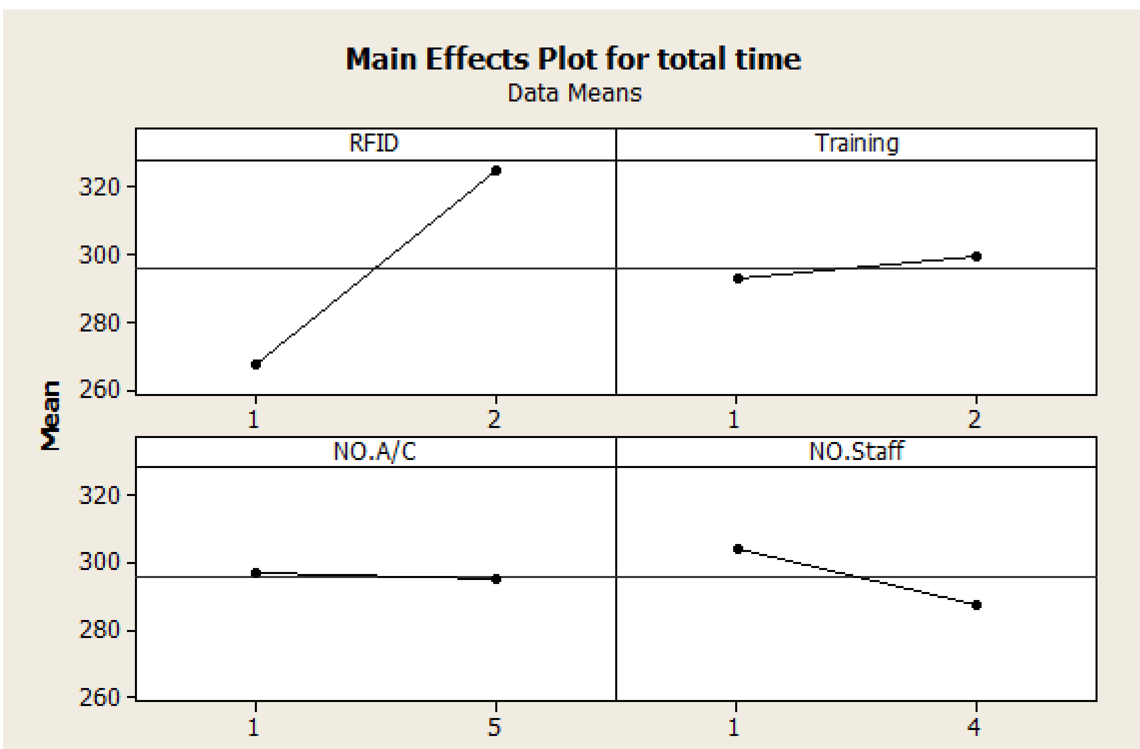


Figure 3-27 Main Effects Plot

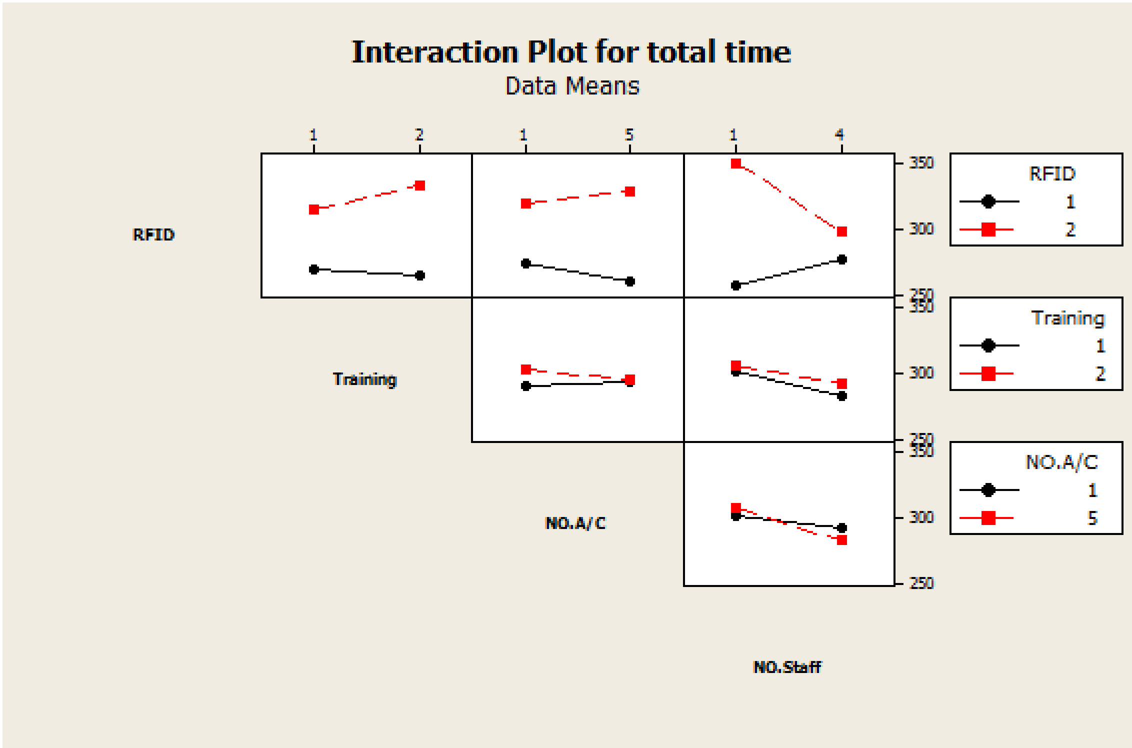


Figure 3-28 Interaction Plot

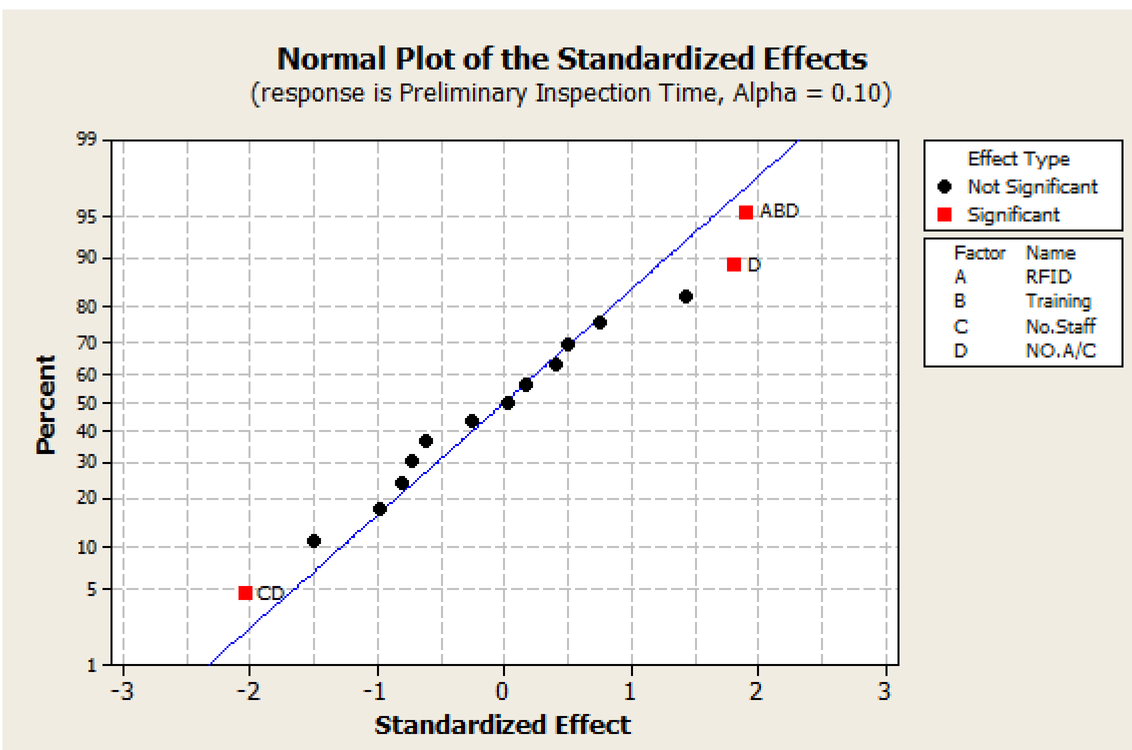


Figure 3-29 Normal Plot-Preliminary inspection time

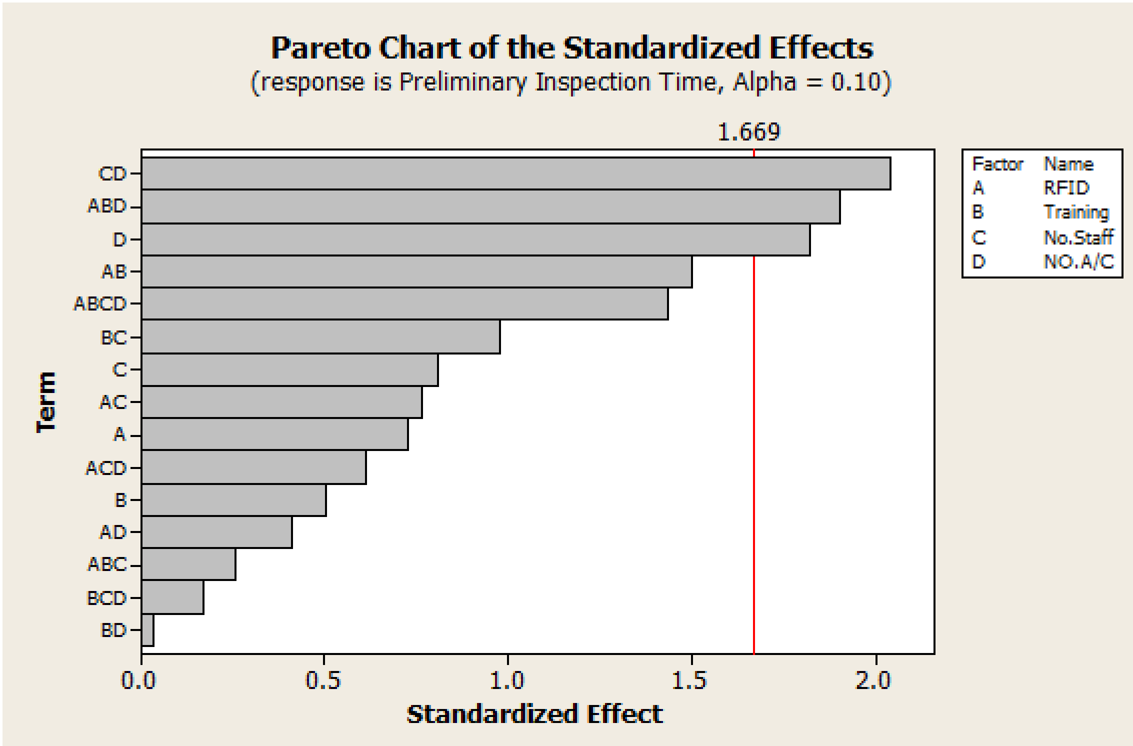


Figure 3-30 Pareto chart-Preliminary inspection time

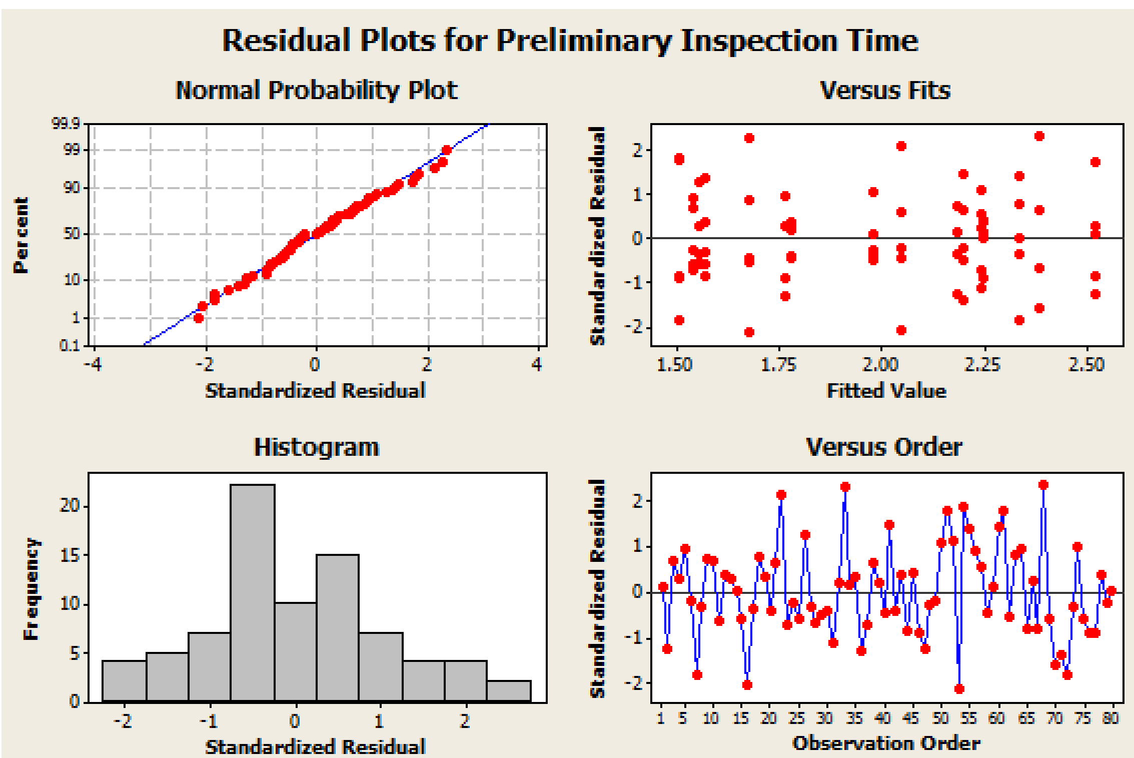


Figure 3-31 residual plots-Preliminary inspection time

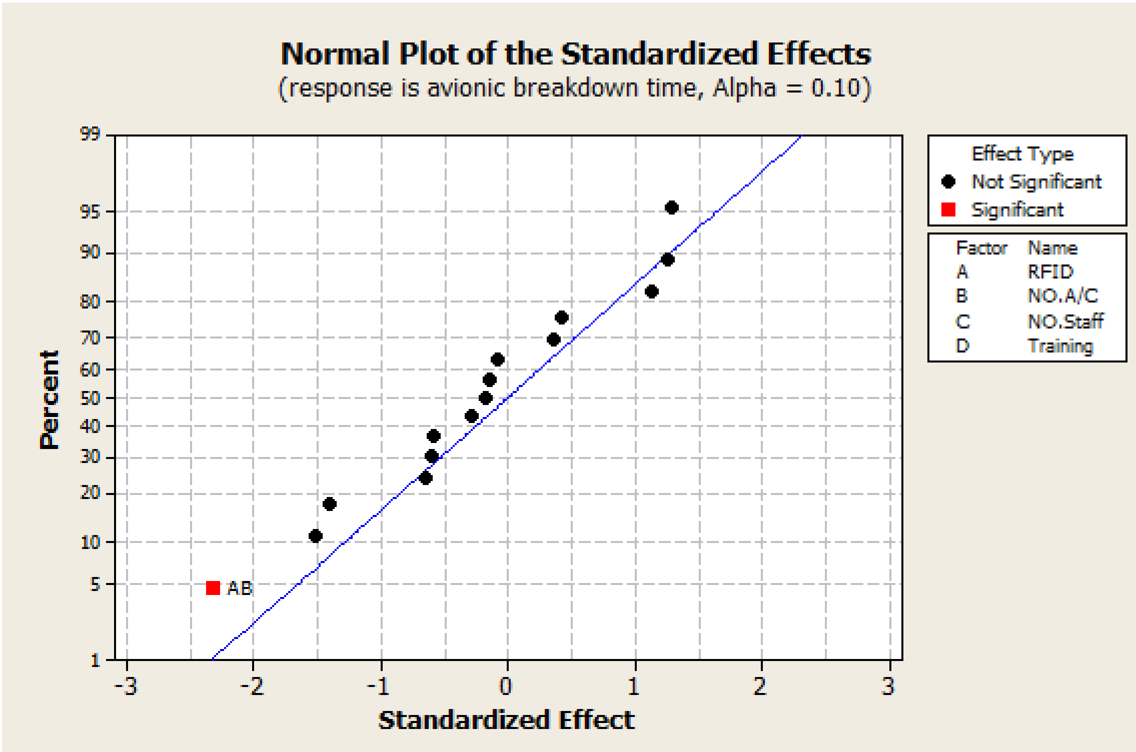


Figure 3-32 normal plot-Avionics Breakdown Time

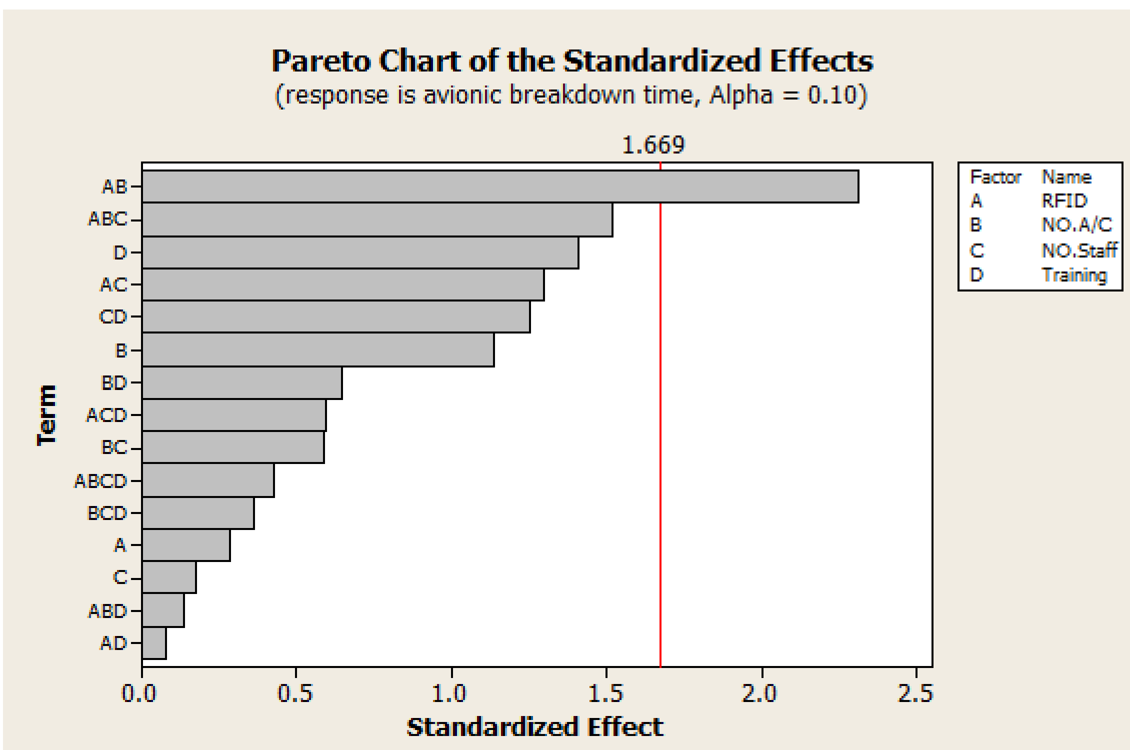


Figure 3-33 Pareto chart-Avionics Breakdown Time

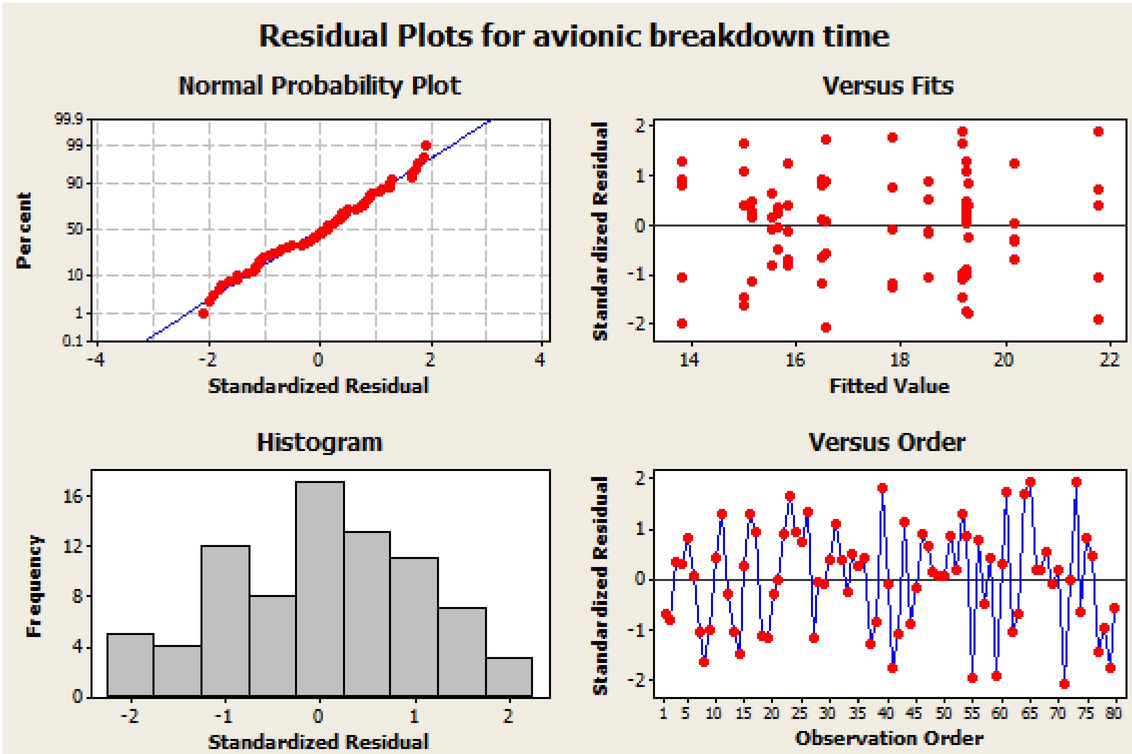


Figure 3-34 Residual Plots-Avionics Breakdown Time

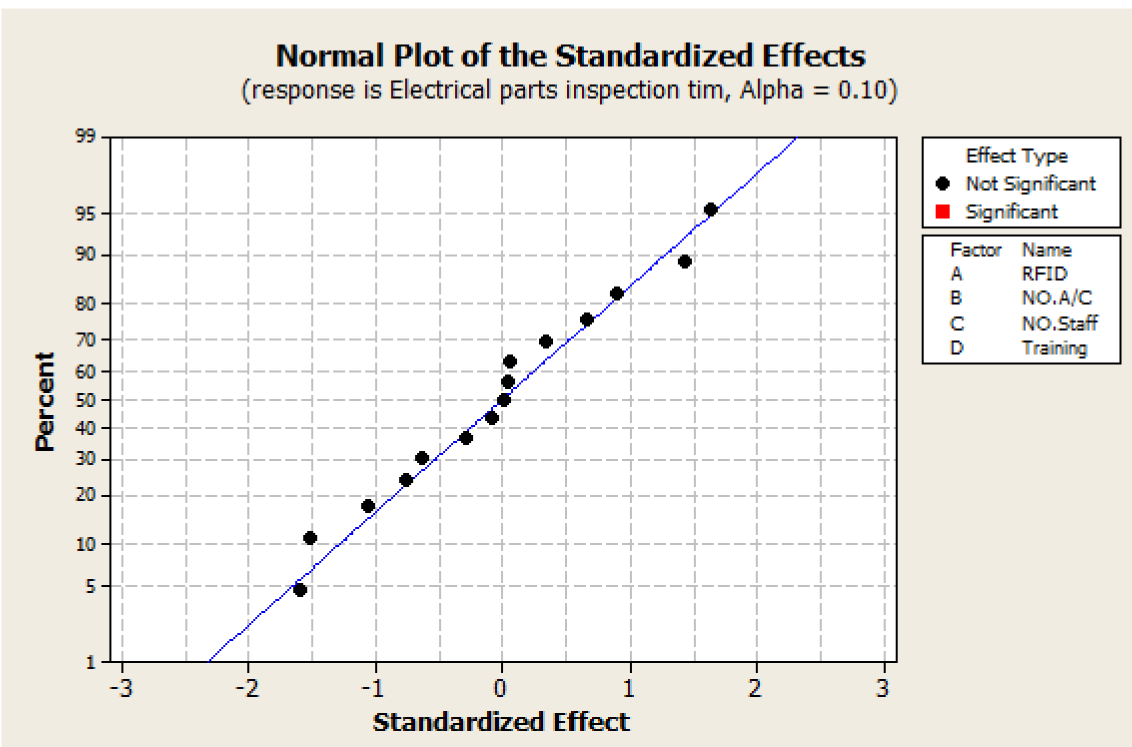


Figure 3-35 Normal Plot- Electrical Parts inspection time

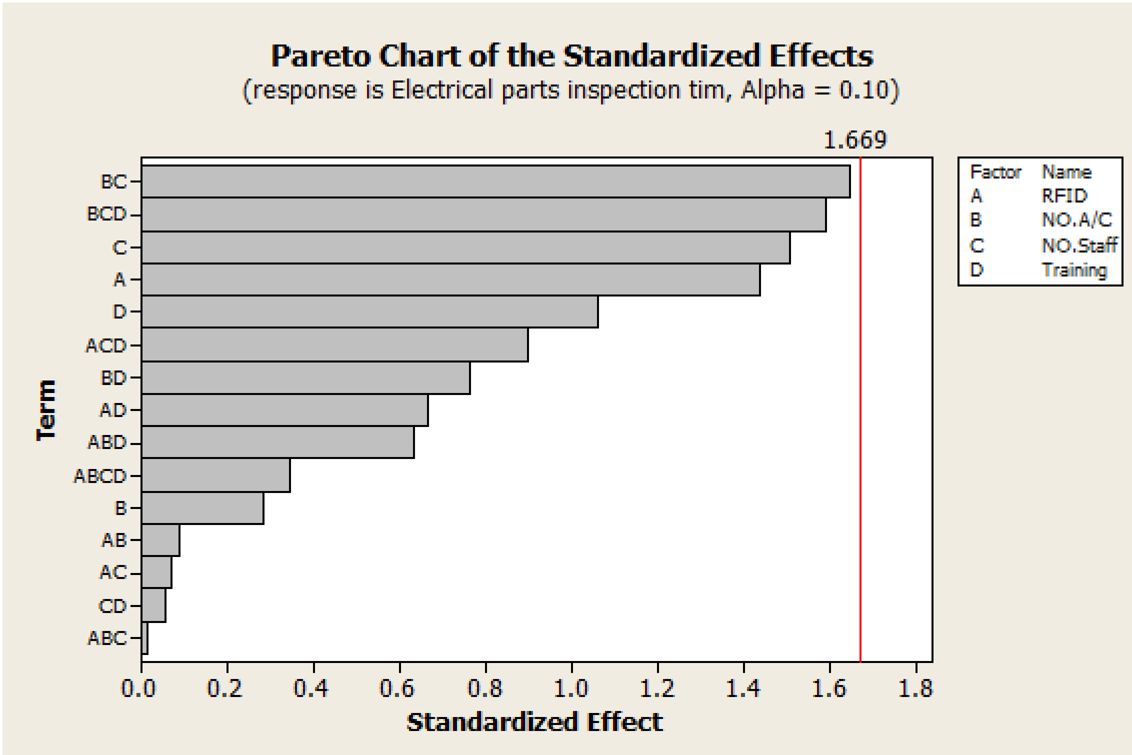


Figure 3-36 Pareto Charts-Electrical Parts inspection time

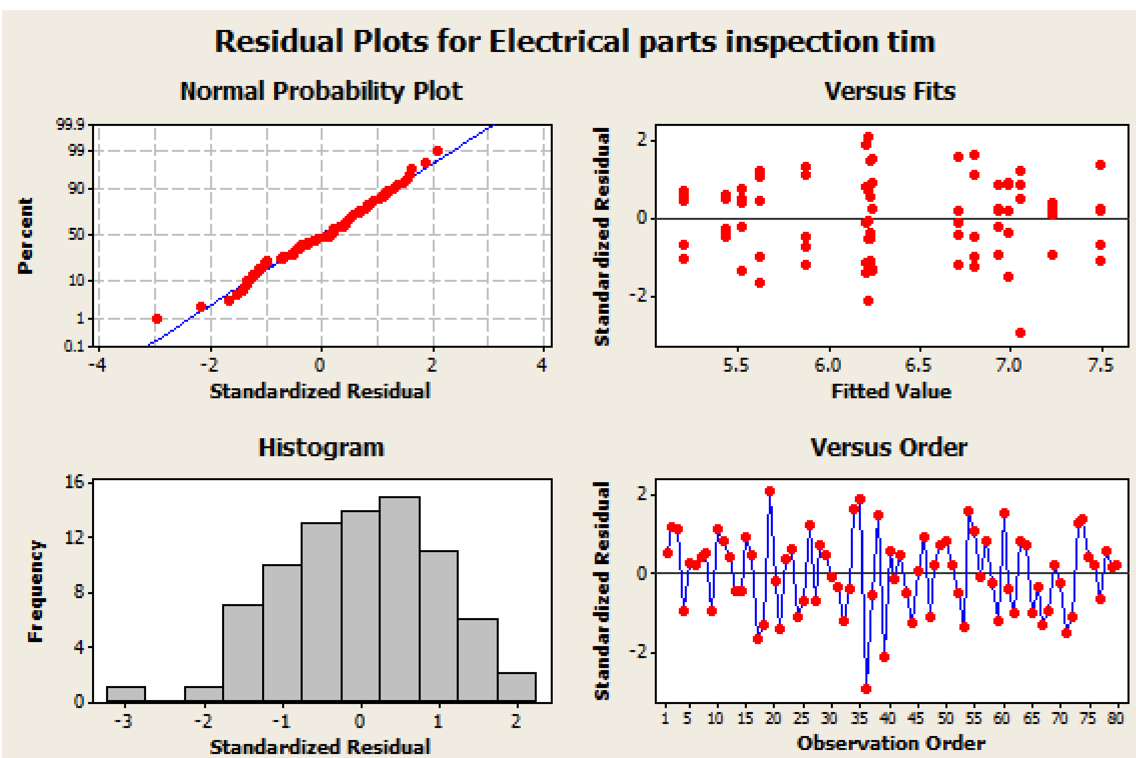


Figure 3-37 Residual Plots-Electrical Parts inspection time

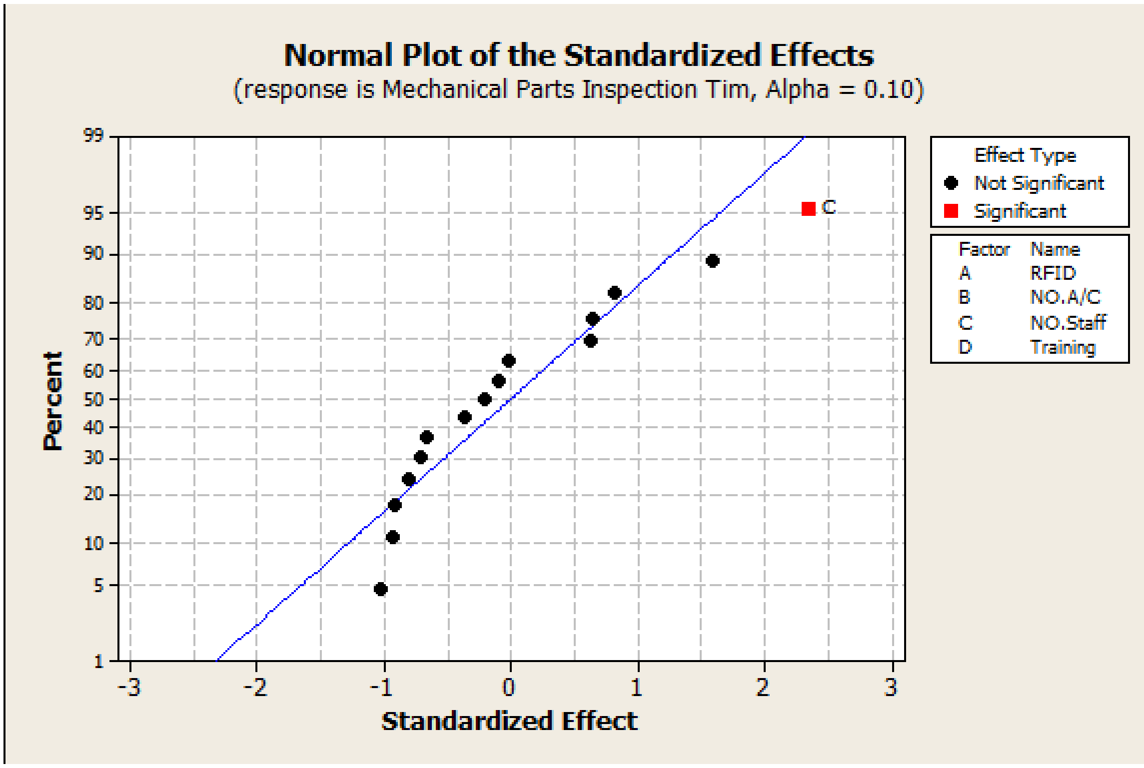


Figure 3-38 Normal Plot- Mechanical Parts Inspection Time

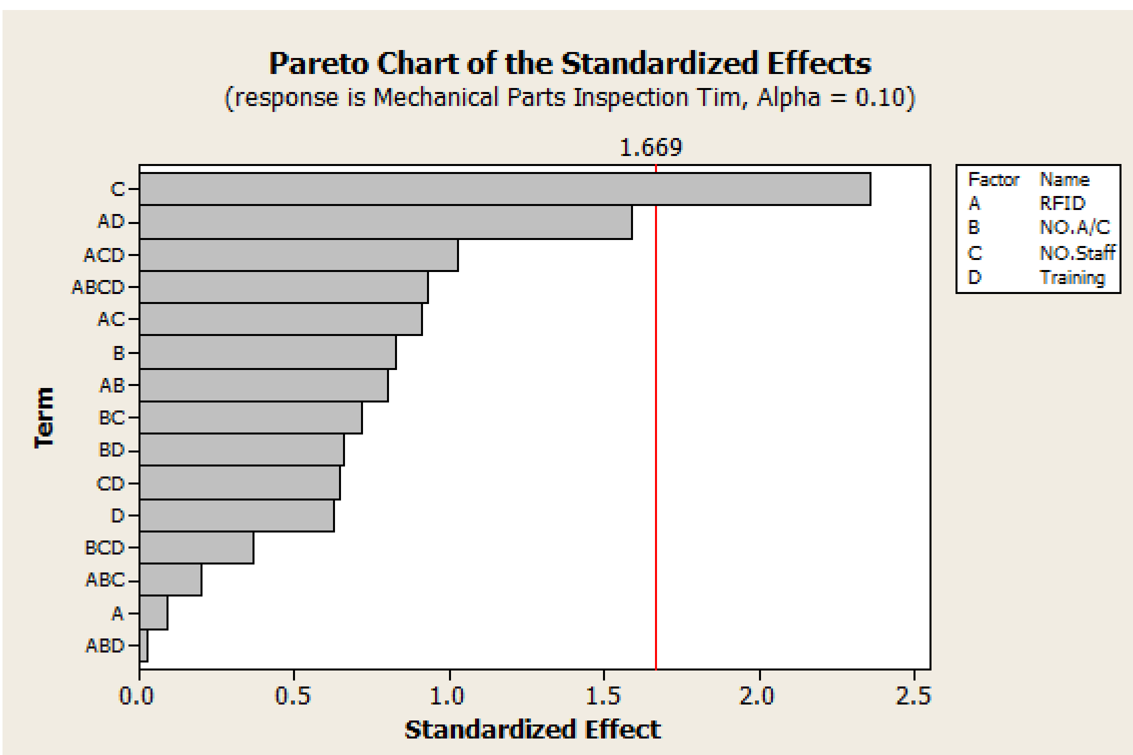


Figure 3-39 Pareto Chart- Mechanical Parts Inspection Time

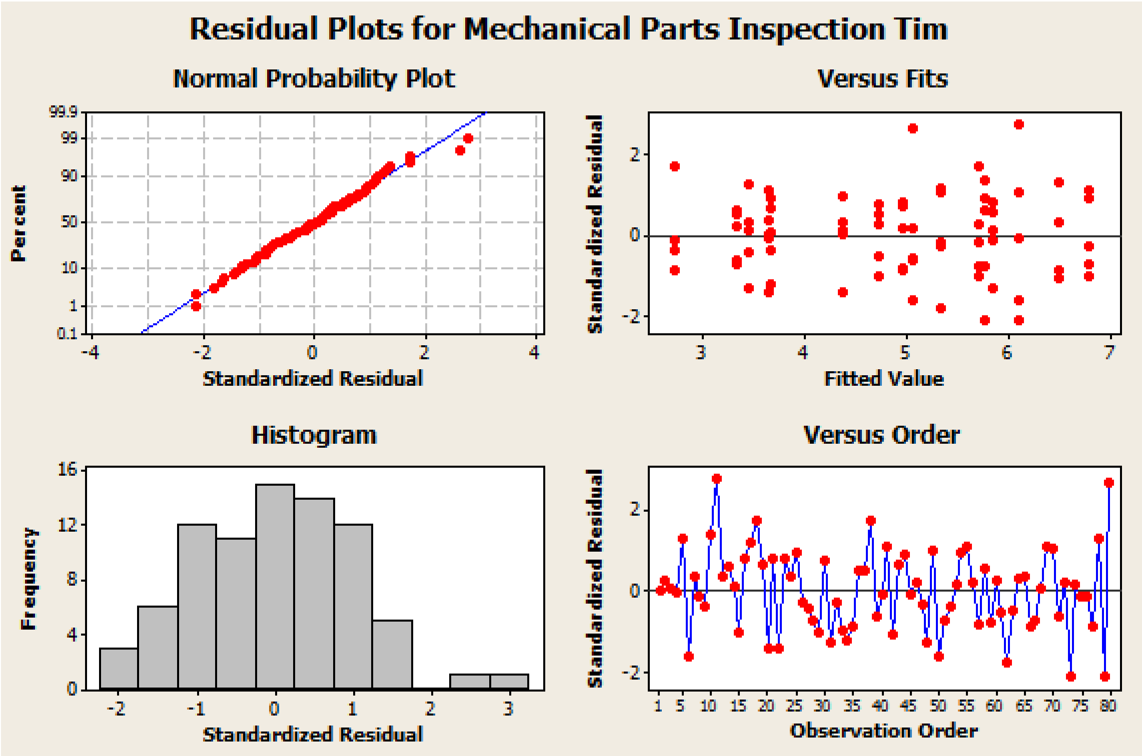


Figure 3-40 Residual Plots-Avionics Breakdown Time

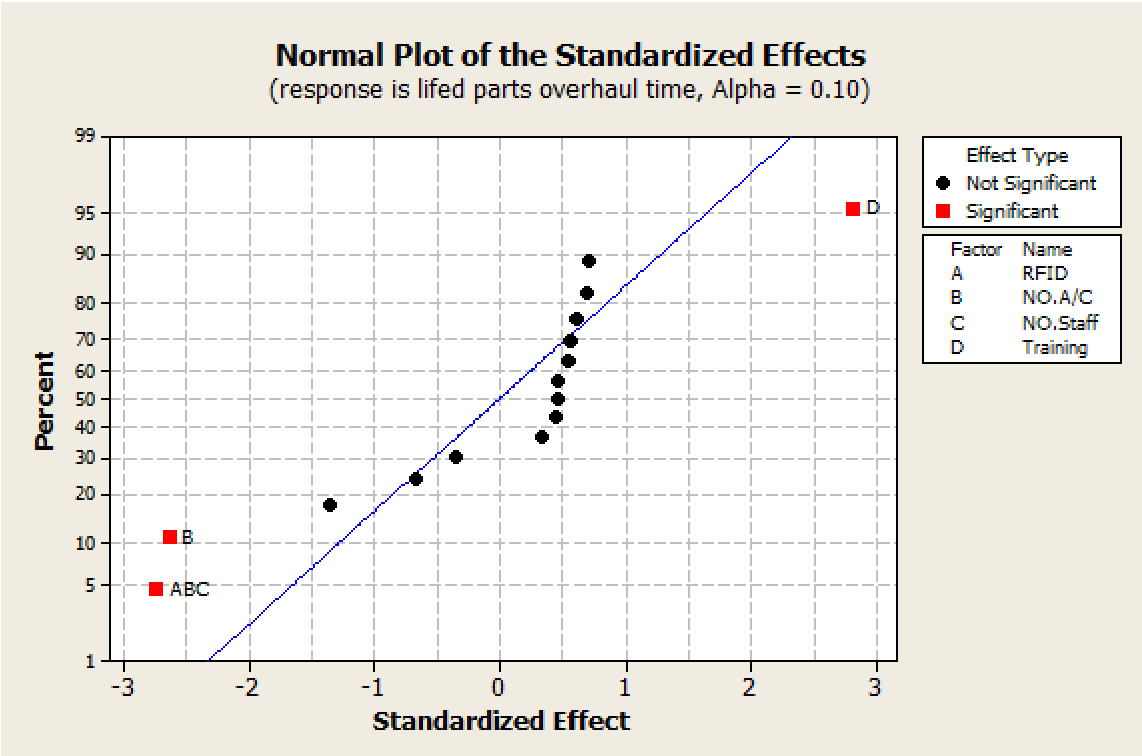


Figure 3-41 Normal Plot- Lifed Parts Overhaul Time

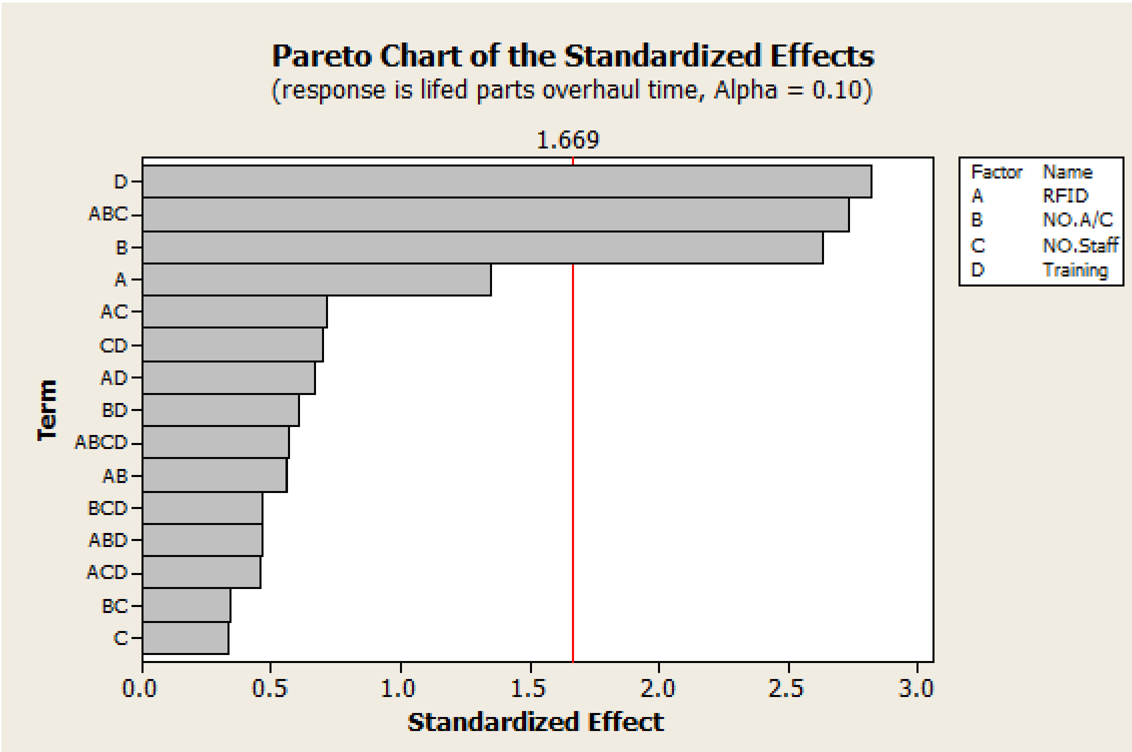


Figure 3-42 Pareto Chart-Lifed Parts Overhaul Time

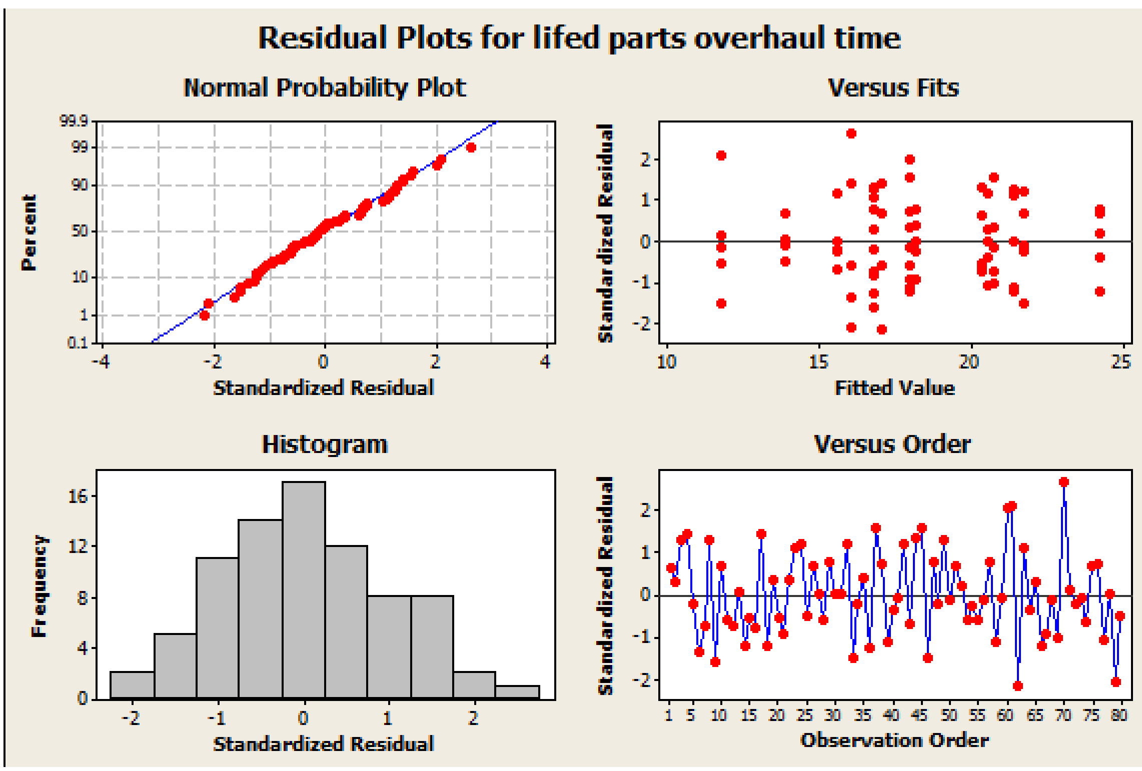


Figure 3-43 Residual Plots-Lifed Parts Overhaul Time

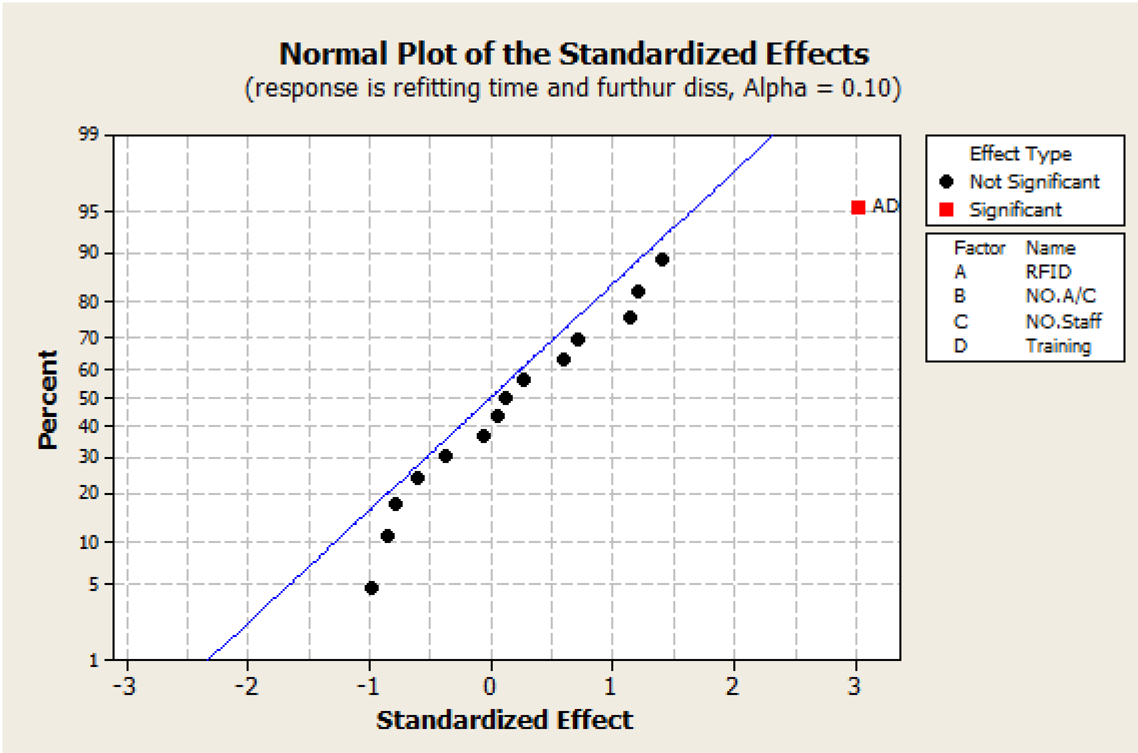


Figure 3-44 Normal Plot-Refitting and Further disassembly Time

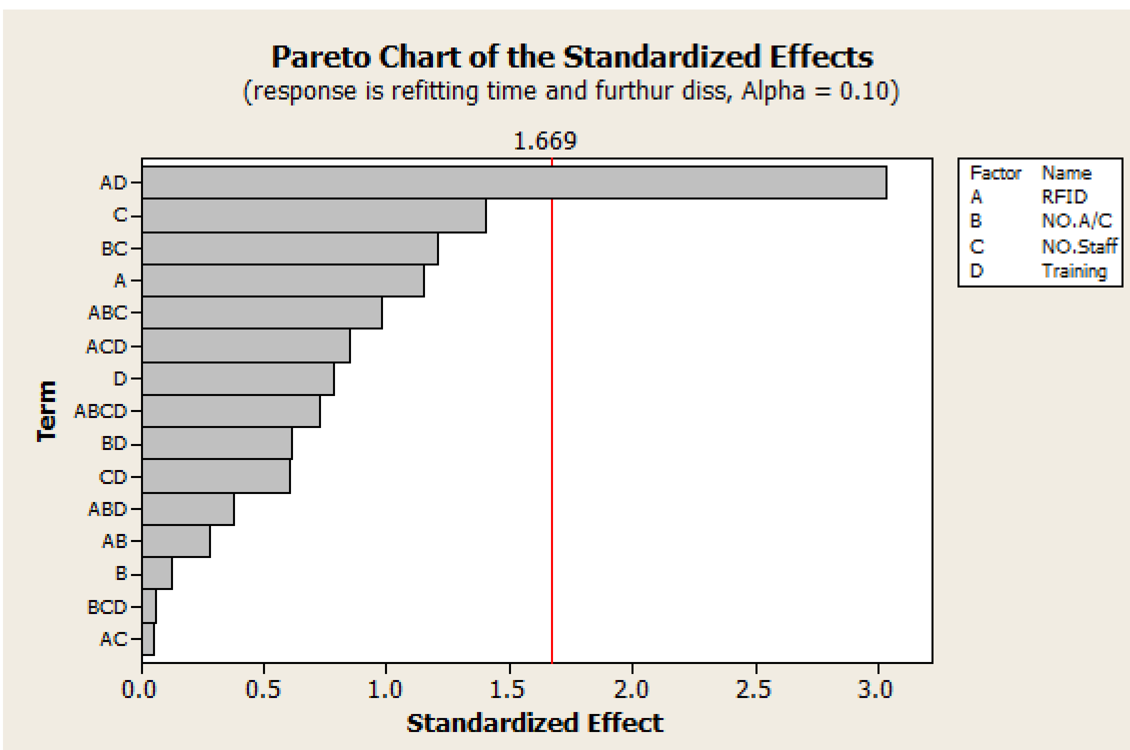


Figure 3-45 Pareto Chart-Refitting and Further disassembly Time

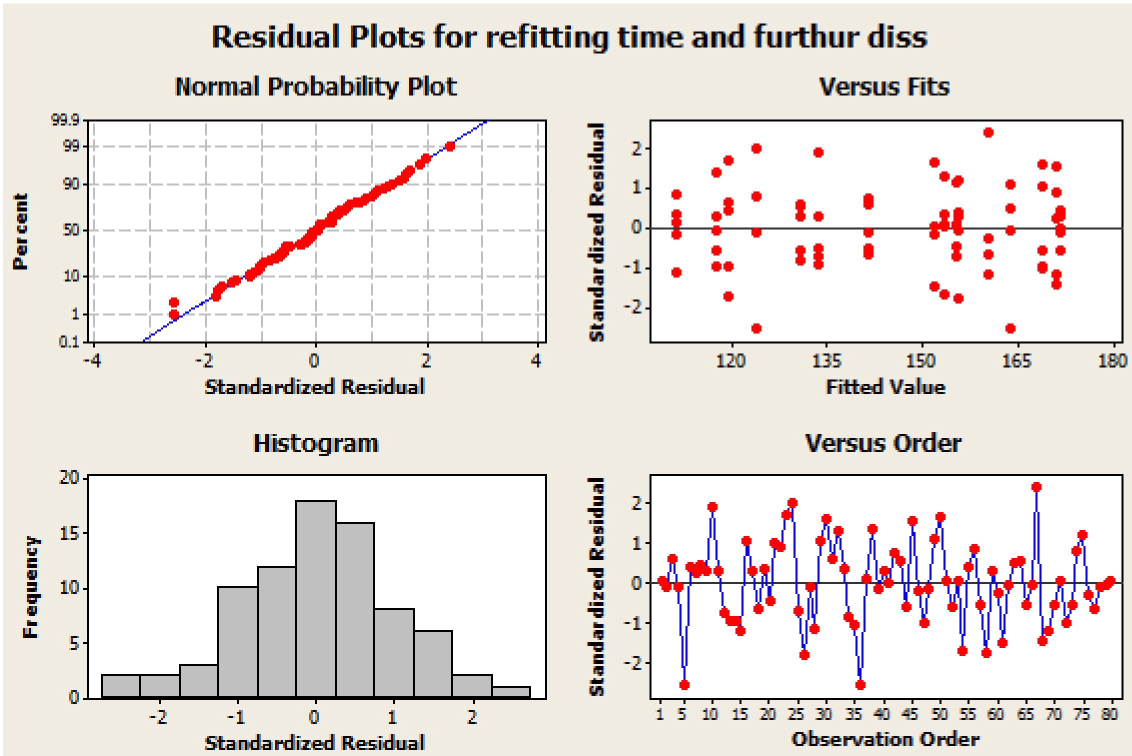


Figure 3-46 Residual Plots-Refitting and Further disassembly Time

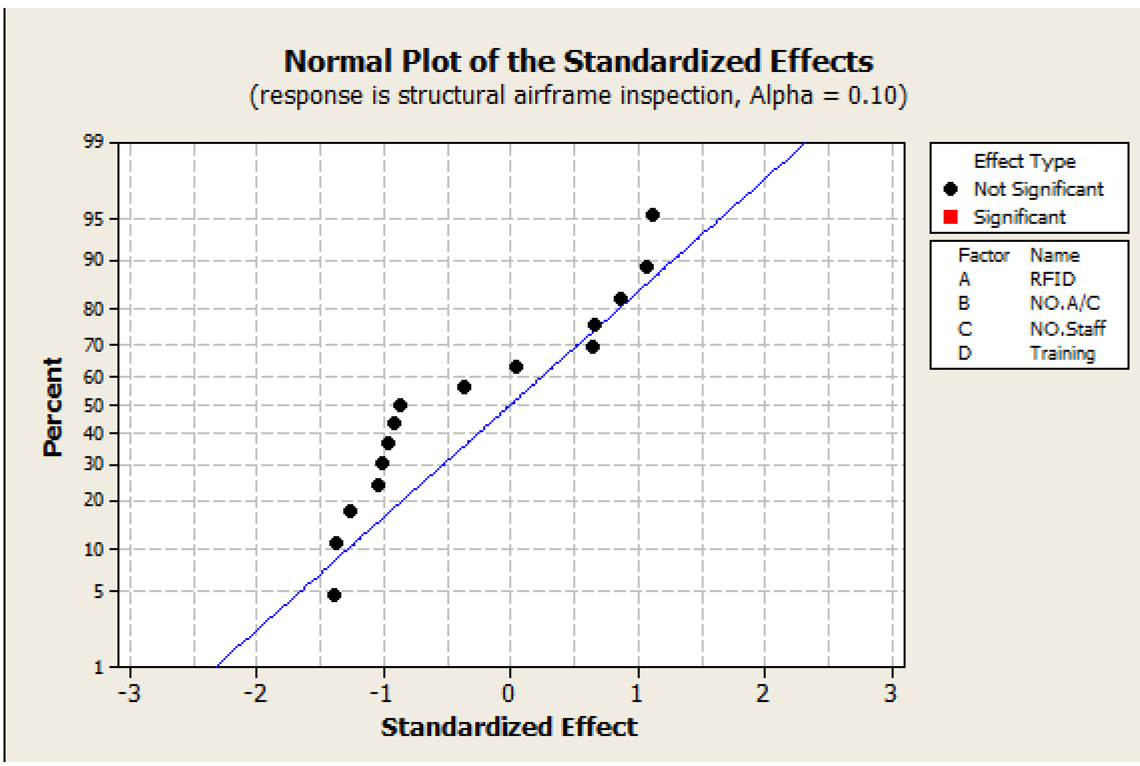


Figure 3-47 Normal Plot-Structural Airframe Inspection Time

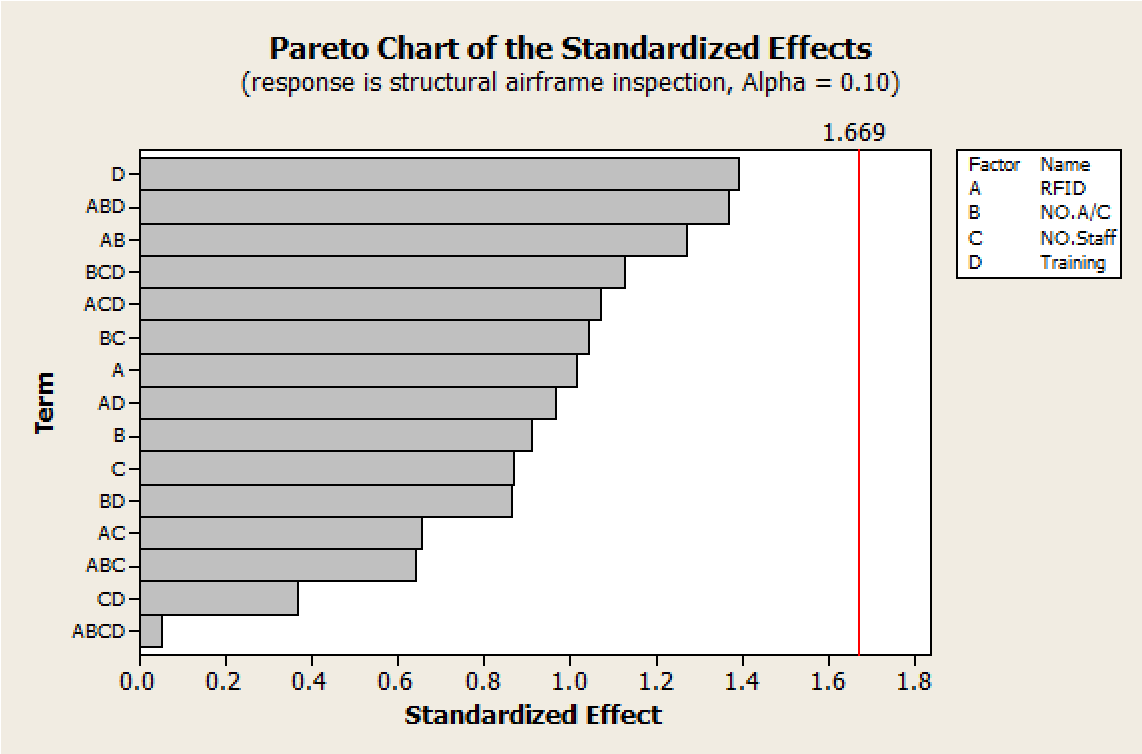


Figure 3-48 Pareto Charts-Structural Airframe Inspection Time

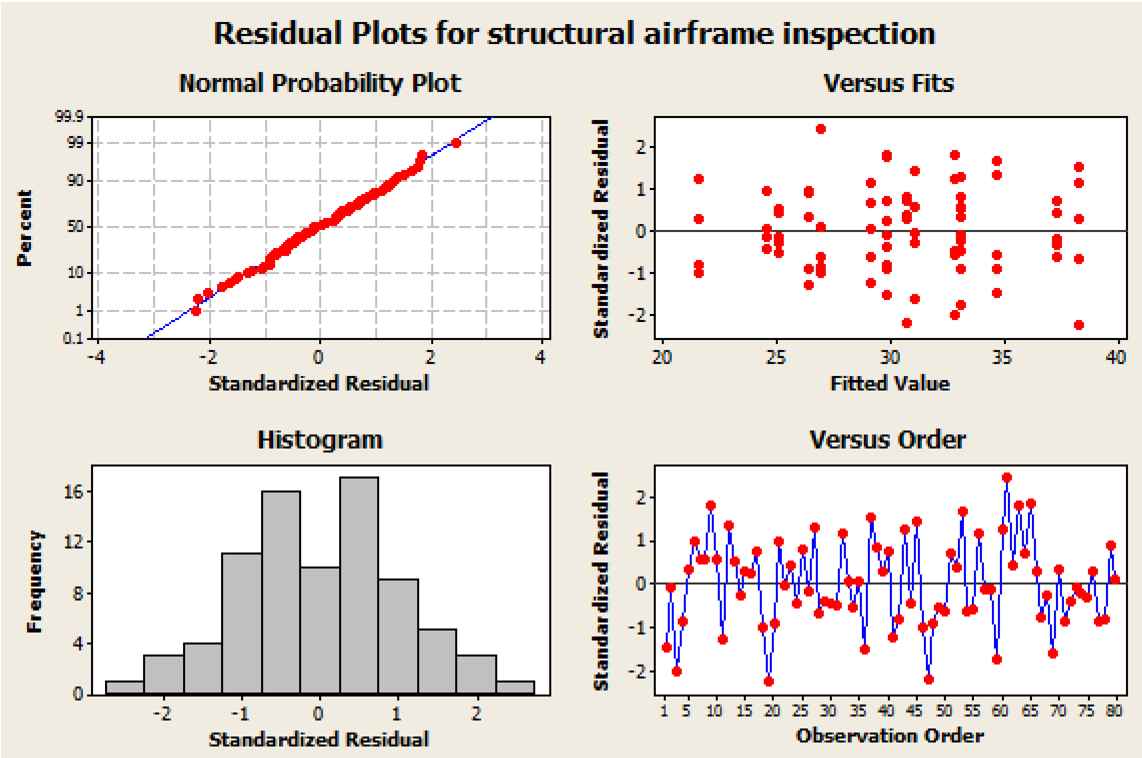


Figure 3-49 Residual Plots-Structural Airframe Inspection Time

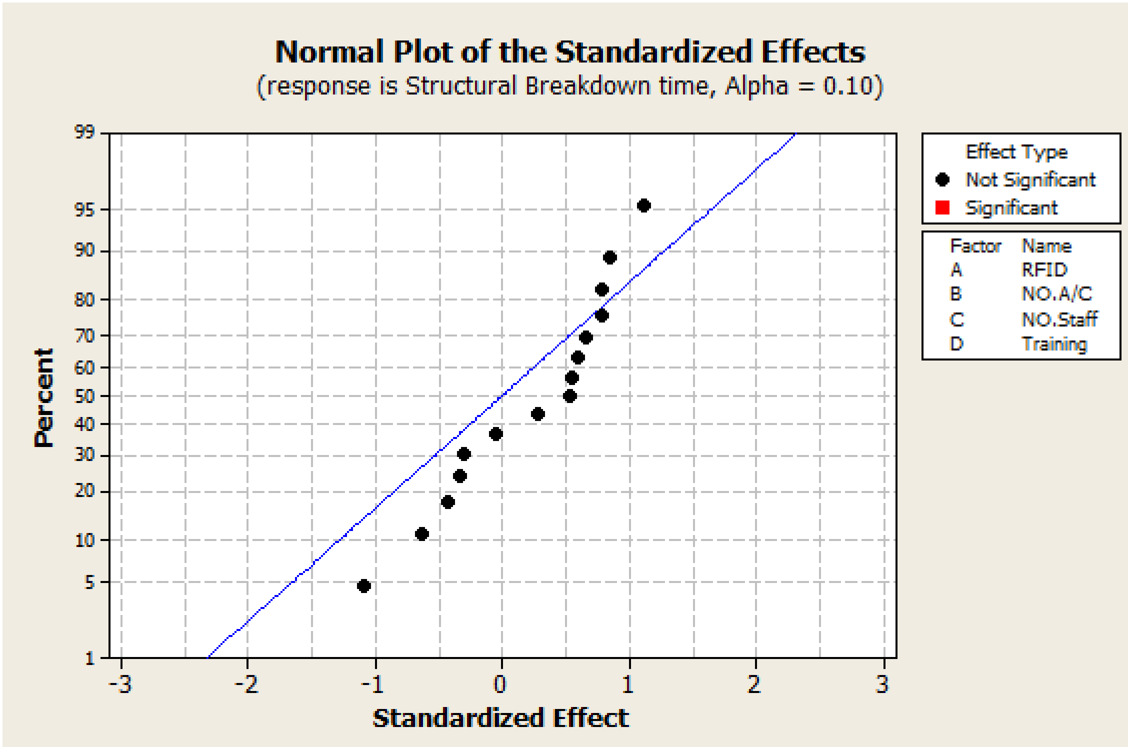


Figure 3-50 Normal Plot- Structural Breakdown Time

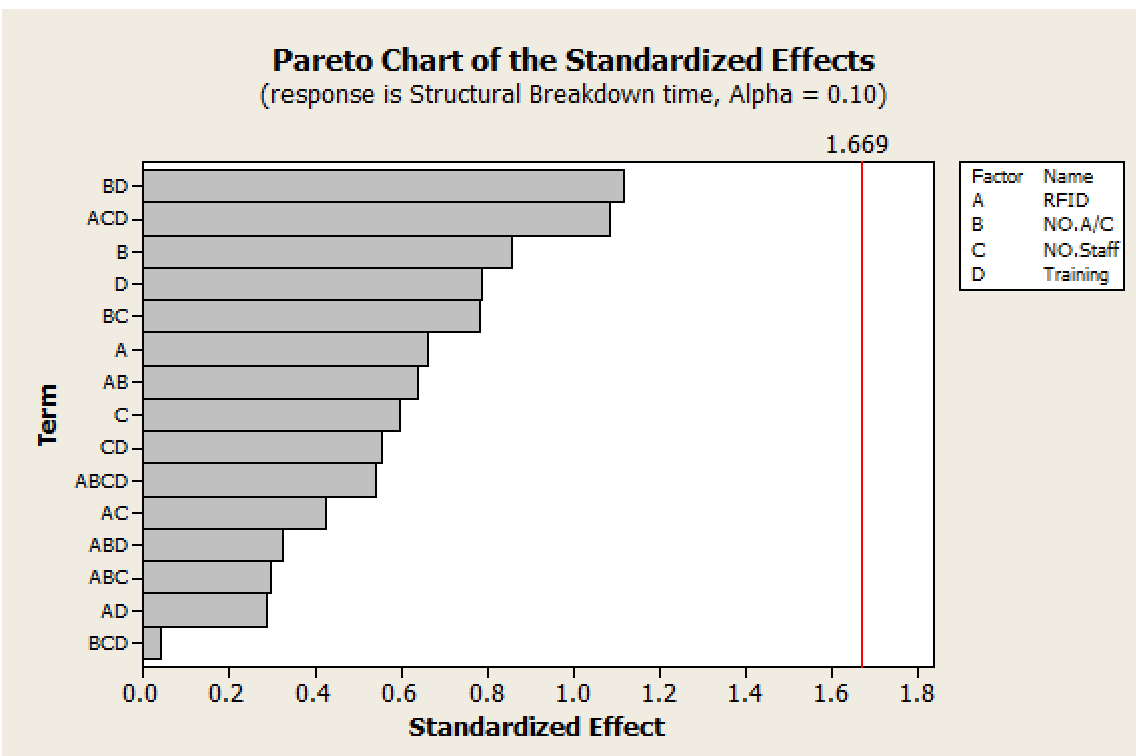


Figure 3-51 Pareto Chart- Structural Breakdown Time

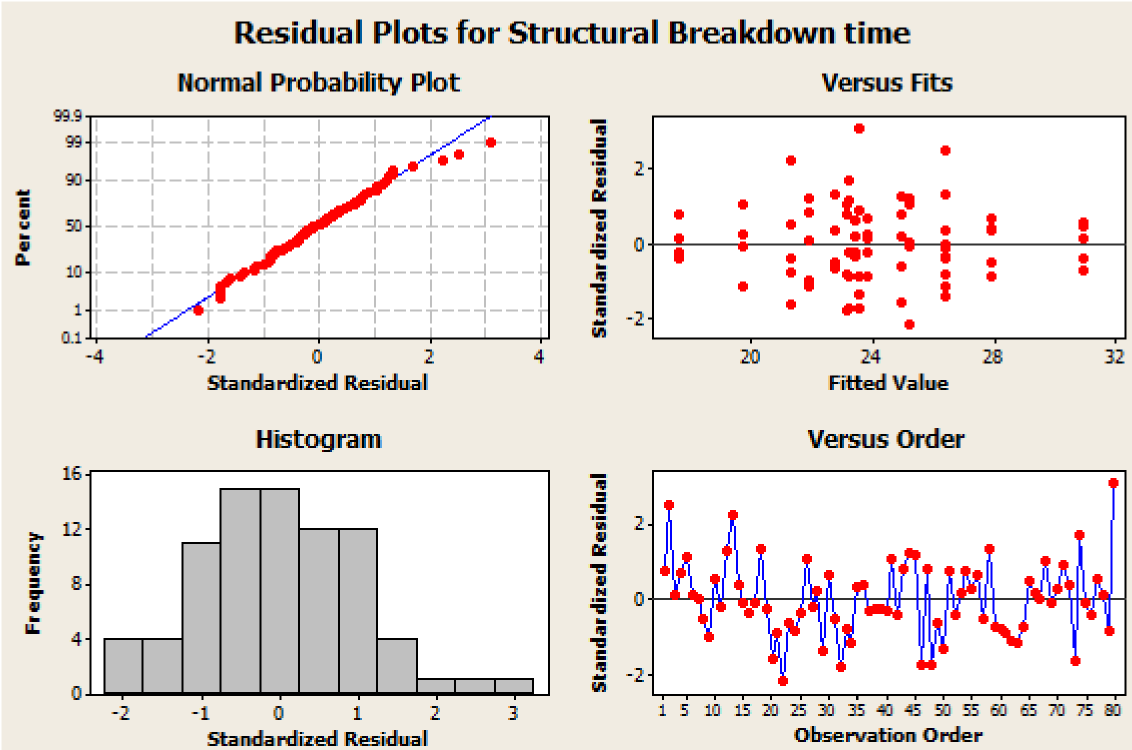


Figure 3-52 Residual Plots- Structural Breakdown Time

Simulation Results

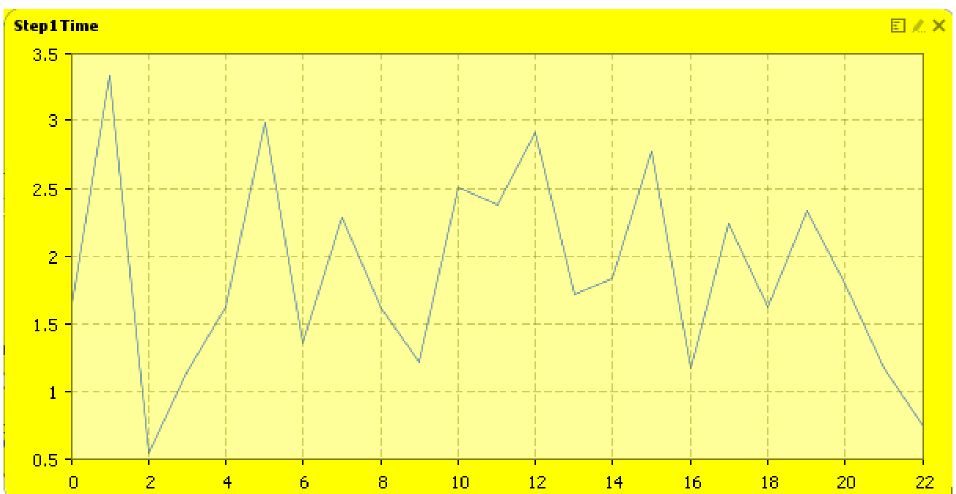


Figure 4-4 Step 1 (Preliminary Inspection Time,Hours/Simulation Runs With RFID)

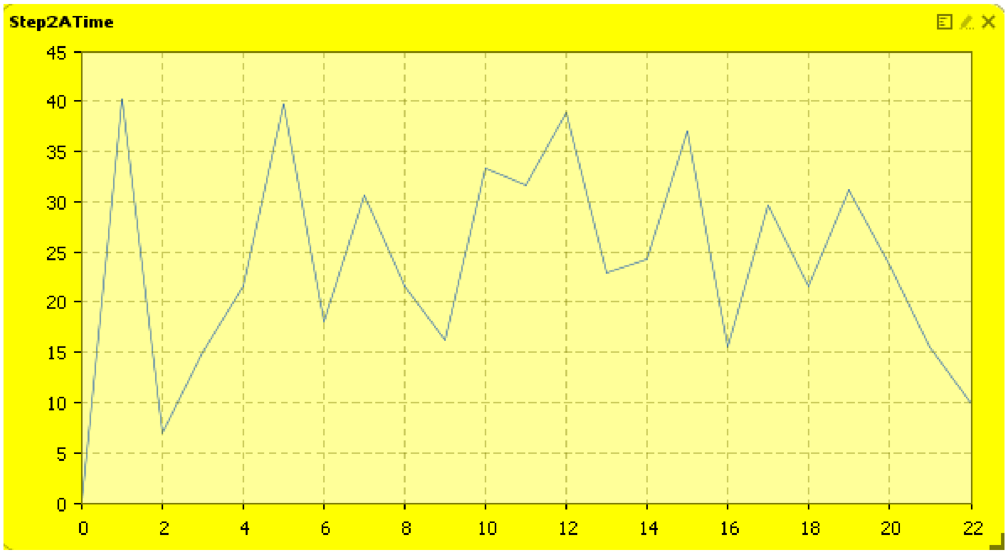


Figure 4-5 Step 2A (Structural Mechanical Breakdown Time, Hours/Simulation Runs With RFID)

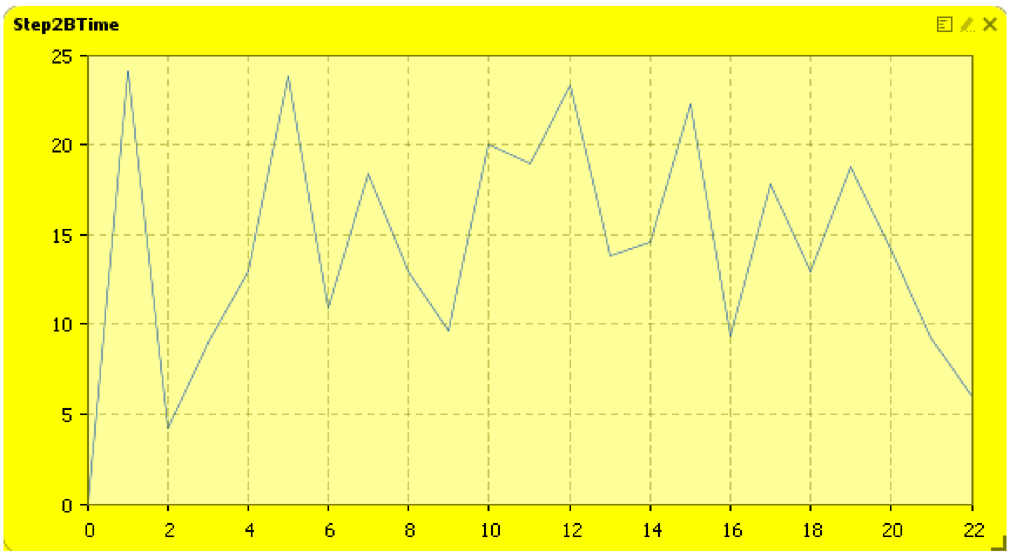


Figure 4-6 Step 2B (Avionics Breakdown Time, Hours/Simulation Runs With RFID)

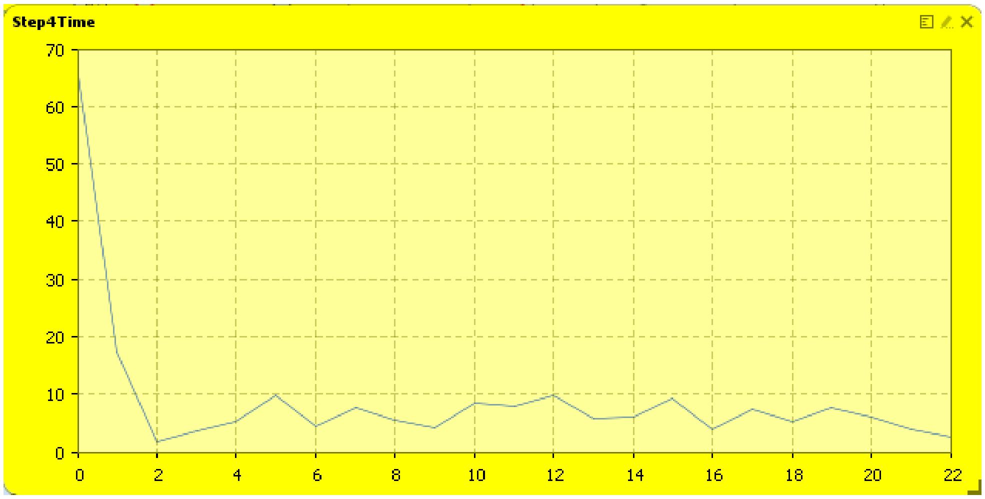


Figure 4-7 Step 4 (Structural Airframe Inspection Time, Hours/Simulation Runs With RFID)

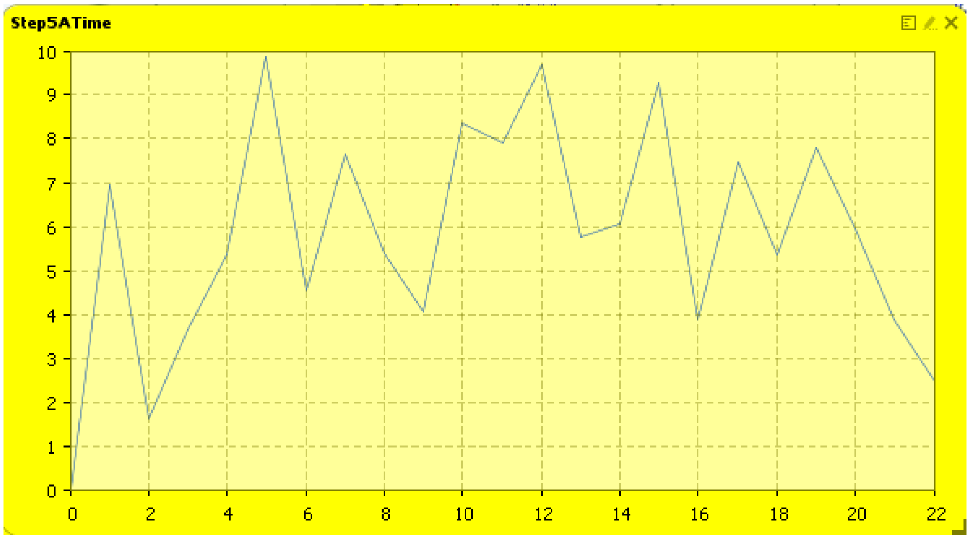


Figure 4-8 Step 5A (Mechanical Parts Inspection Time, Hours/Simulation Runs With RFID)

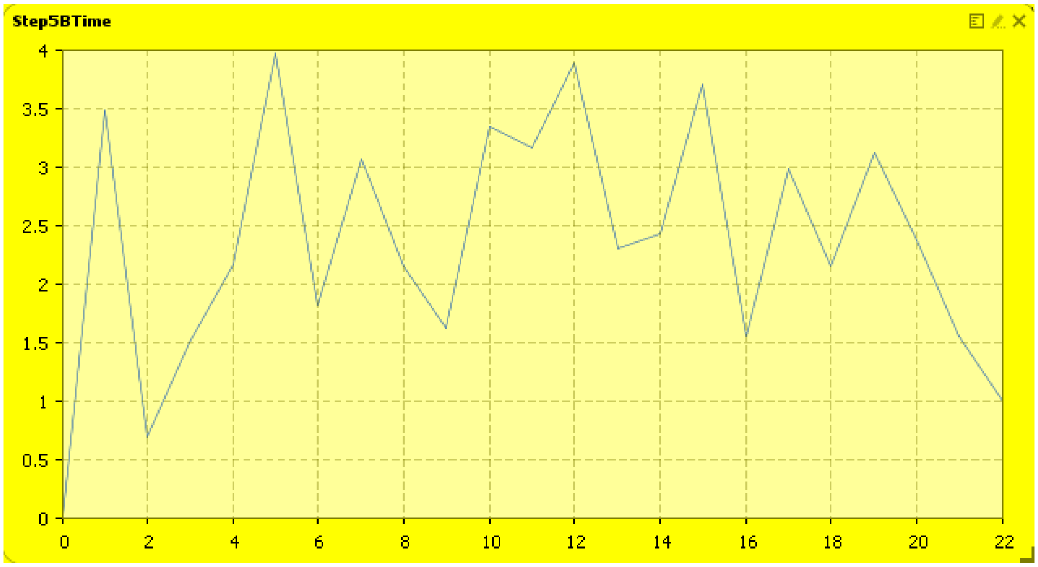


Figure 4-9 Step 5B (Electrical Parts Inspection Time, Hours/Simulation Runs With RFID)

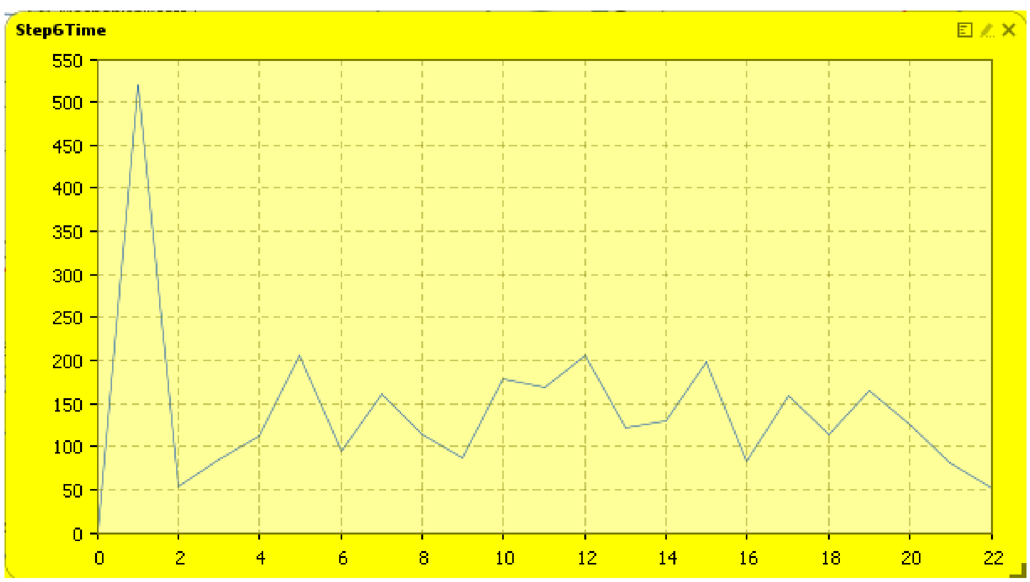


Figure 4-10 Step 6 (Further Disassembly and Refitting Parts Time, Hours/Simulation Runs With RFID)

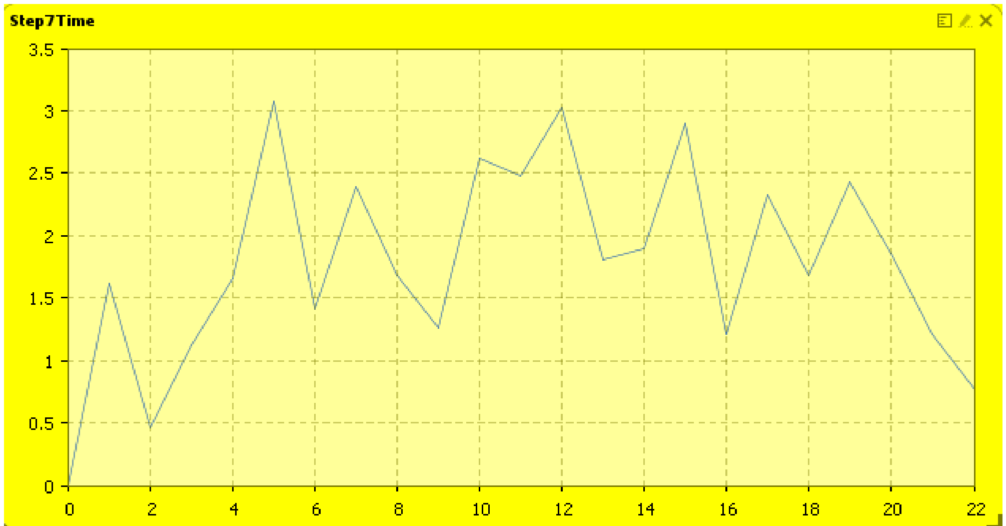


Figure 4-11 Step 7 (Lifed Parts Overhaul Time, Hours/Simulation Runs With RFID)

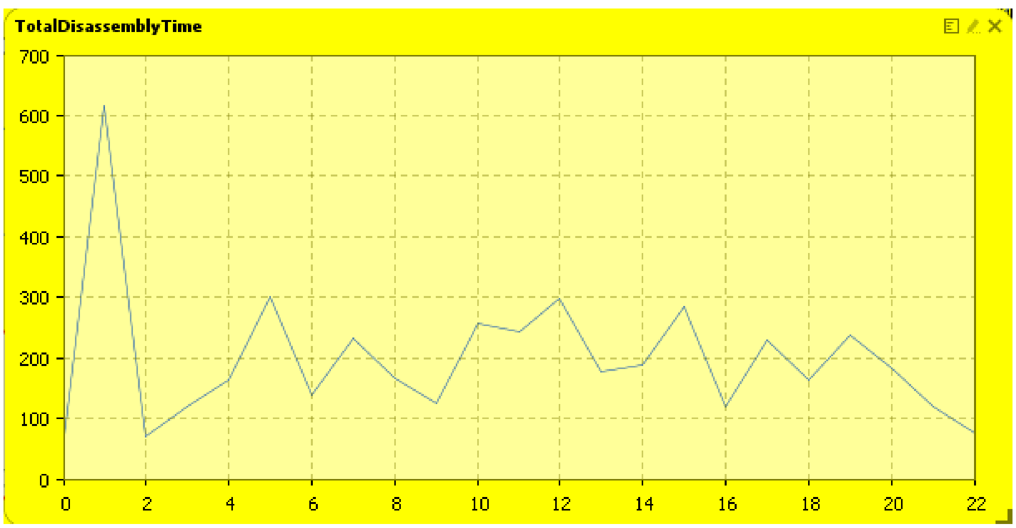


Figure 4-12 (Total Disassembly Time after RFID, Hours/Simulation Runs With RFID)

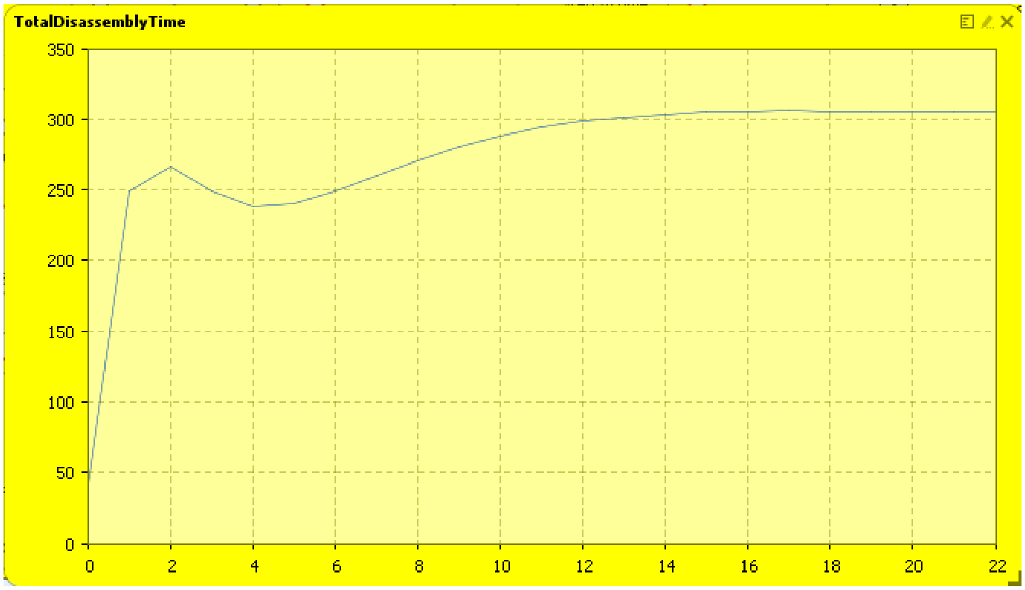


Figure 4-13 Total Disassembly Time before RFID, Hours/Simulation Runs Without RFID