# Design and Simulation of RFID-Enabled Aircraft Reverse Logistics Network via Agent-Based Modeling

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# Abstract


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Reverse Logistics (RL) has become increasingly popular in different industries especially aerospace industry over the past decade due to the fact that RL can be a profitable and sustainable business strategy for many organizations. However, executing and fulfilling an efficient recovery network needs constructing appropriate logistics system for flows of new, used, and recovered products.

On the other hand, successful RL network requires a reliable monitoring and control system. A key factor for the success and effectiveness of RL system is to conduct real-time monitoring system such as radio frequency identification (RFID) technology. The RFID system can evaluate and analyze RL performance timely so that in the case of deviation in any areas of RL, the appropriate corrective actions can be taken in a quick manner. An automated data capturing system like RFID and computer simulation techniques such as agent-based (AB), system dynamic (SD) and discrete event (DE) provide a reliable platform for effective RL tracking and control, as they can respectively decrease the time needed to obtain data and simulate various scenarios for suitable best corrective actions. The functionality of the RL system can be noticeably elevated by integrating these two systems and techniques. Besides, each computer simulation approach has its own benefits for understanding the RL network from different aspects. Therefore, in this study, after designing and constructing the RL system through the real case study from Bell Helicopter Company with the aid of unified modeling language (UML), three simulation techniques were proposed for the model. Afterwards the results of all three simulation approaches (AB, SD and DE) were compared with considering two scenarios of RL RFID-enabled and RL without RFID. The computer simulation models were developed using "AnyLogic 7.1" software.

The results of the research present that with exploiting RFID technology, the total disassembly time of a single helicopter was decreased. The comparison of all three simulation methods was performed as well.

**Keywords:** Reverse logistics (RL), RFID, aerospace industry, agent-based simulation, system dynamic simulation, discrete event simulation, AnyLogic

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Last, but not least, I would like to express my deepest gratitude to my brother who has always been a major source of inspiration in every aspect of my life.

# Dedication

I would like to dedicate my academic work to my beloved fiancée, Ms. Sima Nabavizadeh who has always been my motivation, and without her support and presence, I would not have been able to succeed.

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# List of Acronyms

| Acronyms | Meanings |
|---|---|
| AB | Agent-Based |
| ABM | Agent-Based Modeling |
| A/C | Aircraft |
| AFRA | Aircraft Fleet Recycling Association |
| AHP | Analytic Hierarchy Process |
| AIT | Automated Identification Technology |
| ANOVA | Analysis of Variance |
| ARAT | Active Reader Active Tag |
| ARPT | Active Reader Passive Tag |
| ATA | Air Transport Association |
| BOM | Bill of Materials |
| CCA | Crew Chief Agent |
| CE-MAT | Certification & Environmental Materials Database |
| CLSC | Closed-Loop Supply Chain |
| CMA | Contract Manager Agent |
| CPG | Consumer Packaged Goods |
| CRIAQ | Consortium for Research and Innovation in Aerospace in Quebec |
| DE | Discrete Event |
| DFE | Design for Environment |
| DOD | Department of Defense |
| EAEA | Electrical/Avionics Engineer Agent |
| EDI | Electronic Data Interchange |
| EOL | End-of-Life |
| EPC | Electronic Product Codes |
| ERP | Enterprise Resource Planning |

| | |
|---|---|
| FAA | Federal Aviation Administration |
| FCM | Fuzzy Cognitive Model |
| FL | Forward Logistics |
| GA | Genetic Algorithm |
| GDP | Gross Domestic Product |
| GIS | Geographical Information System |
| GMA | General Manager Agent |
| GPS | Global Positioning System |
| LPKBS | Logistics Process Knowledge Based System |
| MA | Material Agent |
| MAS | Multi-Agent System |
| MCDM | Multi Criteria Decision Making |
| MEA | Mechanical Engineer Agent |
| MIP | Mix Integer Linear Programming |
| MPS | Master Production Scheduling |
| MRO | Maintenance-Repair-Overhaul |
| MRP | Manufacturing Resources Planning |
| OEA | Overhaul Engineer Agent |
| OO | Object-Oriented |
| OR | Operational Research |
| PA | Planner Agent |
| PAMELA | Process for Advanced Management of End of Life of Aircraft |
| PCA | Procurement Agent |
| PCLA | Production Control & Logistics Agent |
| PMA | Project Manager Agent |
| POS | Point of Sales |
| PRAT | Passive Reader Active Tag |
| QEA | Quality Engineer Agent |

| | |
|---|---|
| RF | Radio Frequency |
| RFID | Radio Frequency Identification |
| RL | Reverse Logistics |
| RLSC | Reverse Logistics Supply Chain |
| RMA | Return Merchandize Authorization |
| ROI | Return of Investment |
| RSA | RFID System Agent |
| RTLS | Real Time Locating System |
| SA | Scheduler Agent |
| SCM | Supply Chain Management |
| SD | System Dynamic |
| SEA | Structural Engineer Agent |
| TD | Teardown |
| UML | Unified Modeling Language |
| UTD | Used On-Time Delivery |
| WIP | Work in Process |

# Chapter 1 : Introduction

## 1.1 Background

Conventional Supply Chain Management (SCM) is mostly dealing with the flow of raw material as an input of the system and finished products as an output. Nowadays, the area for SCM in the subject of environmental sustainability has expanded to contain the reverse flow of unsold finished products, parts and packaging materials and rework/refurbishing the goods [1]. With the emerging context of environmental importance, many organization and industries have commenced to decrease waste, recycle, and refurbish their goods for a long period of sustainability in coming future. Besides, in many countries governments are laying down more precise environmental regulations and laws on problems like disposal of chemical waste, clean production, and carbon emissions [2]. For these causes, today, reverse logistics (RL) has been put in practice remarkably by the aerospace and automotive industries specially spare parts markets, likewise, the electronics and computer hardware markets. The implementation of RL delivers various benefits to an organization in the context of tangibility and intangibility as below:

1. Companies have the capability to retrieve defective equipment and parts that can be recovered or refurbished and bring value to the companies as well from the defective parts.
2. The packaging and defective parts are gathered and recycled therefore produced scrap value back for the firm.
3. The company can obtain an excellent reputation of being responsible to deal with the dangerous wastes.

Therefore, organizations which can separate the returned goods with the fast pace rate and recover the valuable components of products early as well, can gain a competitive benefit [3].

## 1.2 Problem Statement

Reverse logistics and RFID technology have been two areas of concentration for aerospace industries due to the fact that one of the major causes for delaying contracts and over budgeting are deficiencies in monitoring and control. Process monitoring is necessary because adequate information, real-time and up-to-date actual data are important for on-time and accurate tracking of the performance of the ongoing processes. This gives a power to managers to rely more on analytical methods rather than on their own judgments. Traditional monitoring approaches that are based on manual data collection like paper-works and log files can be time consuming and inaccurate. Industries have been trying to exploit modern technologies to enhance the quality and accuracy of the collected actual data, and therefore improving monitoring performance and status of processes during their execution times. For example, Radio Frequency Identification (RFID) was utilized for monitoring and maintenance of aircrafts parts.

On the other hand, since the RL is a network with lots of complexities such as wide range of activities and processes, the RFID technology can play an important role. These processes contain the identifying and collecting of End of Life (EOL) products, broken and damaged products, and the inventories of parts with no function. Moreover, other processes include returning the damaged parts to the supplier to sell or repair, refurbish, recycle or reuse. For these purposes, an applicable advance technology like RFID can elevate the performances of tracking and monitoring of the dismantled parts and associated data in RL network that bring valuable benefits to the organization.

## 1.3 Research Objectives

The objectives of the research are as follows:

- Developing an integrated agent-based model by UML diagrams which will be used in simulation modelling design for determining the impact of RFID technology to the total disassembly time on the Bell Helicopters RL network case study.
- Developing system dynamics and discrete event simulation models for analyzing, comparing and validating the results of three simulation methods (agent-based, system dynamics and discrete event simulation).
- Verify the developed models with Anylogic 7.1 simulation software to investigate the effect of RFID technology in reducing the total disassembly time.

## 1.4 Dissertation Outline

The rest of this thesis is prepared in six chapters as follows:

In Chapter 2, literature review of RL, RFID Technology, RFID in RL, and modeling approaches in supply chain (forward and reverse logistics) is described.

In Chapter 3, the current process map is explained and the proposed solution for the system is offered. Designing of the model is presented via UML diagrams as well.

In Chapter 4, agent-based definitions and the model simulation with Anylogic 7.1 software is demonstrated.

In Chapter 5, numerical applications of RFID and Non-RFID enabled are discussed with the associated results.

In Chapter 6, conclusion and proposed suggestions for future works are presented.

# Chapter 2 : Literature Review

## 2.1 Overview

This literature review is comprised of four main literature areas: Reverse Logistics (RL), Radio Frequency Identification (RFID), RFID in RL, and Solution approaches in RFID-enabled in RL.

## 2.2 Reverse Logistics

In a conventional perspective of a standard supply chain, a product is developed to be manufactured and handed over to a customer by way of manufacture-distributor-wholesaler-retailer-customer. However, RL process contains much more complexity and steadily integrating activities [4]. In today's supply chain, product and service recovery throughout the process of handling products, components and materials play a significant role, to the extent that RL is compelled by various forces, like direct economic motives, competition and marketing motives and concerns with the environment [5].

The existence of RL is undeniable through these years; however the business world started to focus exclusively in this area since the last decade. Two comprehensive studies about RL were published from the Council of Logistics Management in 90s. The first book by Stock [6] implies more on the development and implementation of RL. This study talks about the benefits derived from fulfillment and managing RL activities for all companies with different industries, sizes, or locations. The other book by Rogers et al. [7] exhibited a wide-range of classified data for different RL business statistics by various industry types. According to this book, the paper-based industries assign the highest portion of returns to themselves, respectively such as magazine publishers (50%), book publishers (20-30%), catalog retailers (18-35%), and greeting cards companies (20-30%). In addition there are several research papers and articles which mainly discuss about the management and improvement activities in recoverable manufacturing systems to reduce as much as possible the environmental effect of companies by reducing usage of energy, reusing materials (or using reusable materials), and recycling or decreasing the wastes. As an example the article which carried out by Guide et al. [8] focus on seven complicates characteristics that intensify uncertainty in the management, planning and control of supply-chain activities. Brief description: the uncertainty of time and quantity of returns products; the inventory management issues like balancing existing demand with returns; the requirement of disassembly for the returned goods; the possibility of reusing the materials that used in returned products; the need to a RL network; the complexity of adjusting the materials with limitations; and the difficulties of selecting a right path for materials that used in remanufacturing and repairing process with fluctuating times.

Aside, for better comprehending the RL definition the practitioners has been developing different explanation since the time it was identified. Based on researches, real interpretation of RL is depending on the types of work and view of the companies or industries [9]. As an example the article carried out by Dowlatshahi [10] described a holistic view of the RL and summarized it to 11 insights for designing and utilizing RL network. Afterwards the insights classifies into two important factors which are strategic and operational factors. The strategic factors contain of customer service, strategic costs, quality, legislation and environmental concerns. On the other hand the operational factors contain of cost-benefit analysis, supply management, warehousing, transportation, reusing procedures (recycling and remanufacturing), and packaging.

### 2.2.1 Reverse Logistics Costs

As stated by Rogers et.al [7], RL encompasses a considerable amount of U.S. logistics costs. On the other side logistics costs are estimated to occupy nearly 10.7% of the U.S. economy. Based on the companies in the author's research, RL costs taking 4% of their total logistics costs. In terms of Gross Domestic Product (GDP) index, RL costs are estimated nearly 0.5% of the total U.S. GDP. In the other study by Delaney [11] logistics costs are reported to be $862 billion in 1997, as regards approximately $35 billion of that was the RL costs. This reveals the importance of RL and the related topics of that. Nevertheless most of the specialists in the logistics field are inclined to forward side cause by training and human nature. However, in today's business world, firms understand that by implementing forward-focused procedures and automation, they will be capable to improve efficiency and this will lead to optimization of RL process and substantial cost savings. In the research by Reece et al. [12], RL is no longer unimportant issue in the supply chain. They state that industrial equipment have return rates of nearly 4-8%, computer and network equipment returns rates are approximately 8-20%. This portions of return have a large effect on total U.S. revenue with estimation of 52-104$ billion. Further the related costs of RL in any organization are responsibility of the CEOs. Due to this managerial problem, Reece et al. [12] introduced the six hidden costs of RL that firms should be cognizant of them.

1. Labor

2. 'Grey market' items

3. Lack of visibility

4. Inability to forecast accurately

5. Credit reconciliation

6. Poor response time and brand toxicity

At the end of this research the authors' solution is to automate RL with a web interface. According to research firm Gartner, applying this procedure instead of call centers reduces costs from 35% to 50%. Additionally Return Merchandize Authorization (RMA) which is linked to Enterprise Resource Planning (ERP) can decrease costs by 50 to 80% on pre-printed return labels. There is no doubt that using these systems has an exceptional impact on Return On Investment (ROI) in a little period of time. However there is no comprehensive article in the subject of other technologies like Radio Frequency Identification (RFID) and RMA together.

### 2.2.2 Causes of Returns in Reverse Logistics

In RL, return of products and packaging contain several reasons. However returns extensively are separated to two different categories: first the ones indicated as unplanned and undesired which many call them '' traditional returns'', and those in opposite that are planned and desired. As stated by Amini et al. [13], unplanned returns are mostly including products that customers have purchased. These returns also divided in to new and used products. The reasons of returns of both are as follows and also categorized in Table2-1:

Returns of new products

- The customer decision changed
- The product was defective or the customer perceived them to be deficient
- The product was damaged in transportation
- Mistake of vendor in type or quantity of sent product

Returns of used products

- Warranty or recalls of product

*Table 2-1: Reasons of Returns [13]*

| | | |
|---|---|---|
| **Unplanned returns** | **Returns of new products** | The customer decision changed |
| | | The product was defective |
| | | customer perceived them to be deficient |
| | | The product was damaged in transportation |
| | | Mistake of vendor in type or quantity of sent product |
| | **Returns of used products** | Warranty returns |
| | | product recall |
| **Planned returns** | **Returns of products** | Returns of reusable packaging or shipping containers |
| | | Trade-in programs |
| | | Company take-backs (EOL) Product |
| | | Leased or rented products |
| | | Service work |

Planned returns have benefits for firms and more controllable and facile to be acquainted by type, quantity and time of the returns, moreover, the best action to maximize their values'. Amini et al. [13] and Rogers et al. [7] express alternatives which is include: Reuse – Repair/Repackage – Return to supplier – Resell (ordinary market or via Outlet) – Junk (Landfill) – Recycle – Renew (Refurbish, Remanufacture and Recondition). They called them the disposition choice to enhance the value from the returns products.

The other aspect of RL is 'Strategic Use'. During the last decade, many organizations clearly reach the conclusion that for having long-term impact, they must alter their responses to a problem or a situation from solely tactical or operational to also a strategic aspect. Table 2-2 presents the strategic roles of returns [7].

*Table 2-2: Strategic Roles of Returns [7]*

| Role | Percentage |
|---|---|
| **Competitive reasons** | 65.2% |
| **Clean channel** | 33.4% |
| **Legal disposal issues** | 28.9% |
| **Recaptured value** | 27.5% |
| **Recover assets** | 26.5% |
| **Protect margin** | 18.4% |

Noerk [14] observed that one of the most disregarded part of supply chain is return management strategies. Although, a suitable RL plan and technology can leading firms to savings in transportation, inventory costs, waste disposal costs and above all can significantly growth customer service, also lead to customer satisfaction and loyalty Marien [15]. Richey et al. [16] cited that due to intensive competition; a well-developed and well performed returns process can be the area for organizations and respective managers to enhance performance, efficiencies so they can cut down costs.

### 2.2.3 Concerns and Challenges of Managing Reverse Logistics

Dawe [17] identified six symptoms of problem returns.

1. Returns arriving faster than processing or disposal
2. Large amount of returns inventory held in the warehouse

3. Unidentified or unauthorized returns
4. Lengthy processing cycle times
5. Unknown total cost of the returns process
6. Customers have lost confidence in the repair activity.

One of the important challenges that companies are dealing with is the lack of information of their RL process. Even now, there are several firms that do not implement any formalized RL procedure for controlling and monitoring the related activities. Deficient data accumulation cause to uncertainty about return issues. Companies by enhancing the return process and handling returned goods efficiently will be able to diminish costs. Briefly the barriers in applying RL program are listed in Table 2-3 as below [7].

*Table 2-3: Barriers in Applying RL Program [7]*

| Barrier | Percentage |
|---|---|
| Importance of reverse logistics relative to other issues | 39.2% |
| Company policies | 35.0% |
| Lack of systems | 34.3% |
| Competitive issues | 33.7% |
| Management inattention | 26.8% |
| Financial resources | 19.0% |
| Personnel resources | 19.0% |
| Legal issues | 14.1% |

In the area of managing returns, there are several factors that are included in Table 2-4 as well.

*Table 2-4: Factors in Managing Returns [7]*

| |
|---|
| Gatekeeping |
| Compacting Disposition Cycle Time |
| Revers Logistics Information Systems |
| Centralized Return Centers |
| Zero Returns |
| Remanufacture and Refurbishment |
| Asset Recovery |
| Negotiation |
| Financial Management |
| Outsourcing |

Since the goal of RL study in this thesis is mainly intended to research on information system, compacting disposition cycle time and the entire respective subject, we are focused solely in these areas.

One of the most critical and important problems organizations is facing with in implementation of a RL process is the lack of feasible information systems. Many firms believe that information systems' resources lead to further enlargement of limitations. Therefore collecting resources are not a rational action for firms to build a RL information system which will lead to performing an action beyond the firms' boundaries and add more intricacy to their current problems as well. As a result of this trouble, RL applications are not a preference for information system departments, only if the RL information system is flexible Rogers et al. [7]. One of the simplest ways for firms is using three-color system. In this system the disposition decision for most returns products are not lean on individual opinions, it's the system that made the decision. Although this is an uncomplicated system, it contains various benefits like seriously decrease the disposition cycle, tracking returns, and controlling with measuring cycles times. Some firms applying Electronic Data Interchange (EDI) standards to expedite their RL process; however, there are companies which believe internet-style interface should be implemented instead of EDI transactions. In addition, other firms are examining and execute two-dimensional barcodes and RFID tags. Nowadays between the mentioned approaches, RFID technology has become more prevailing discussion in different business areas. In a survey by Sarac et al. [18], they stated the Inherent advantages of RFID technology in RL process in the area of cost reduction, inaccuracy in inventory, adding value to products, and the bullwhip effect and replenishment guidelines. These benefits of RFID technology also contain traceability enhancement, visibility and decrease inaccuracy of information, improve efficiency and process pace, diminution in inventory losses, reduced the overall cycle time, and expedite decision making for managers through its real-time information ability.

Another important element in RL is cycle time. Cycle time is a prominent subject from the matter of anticipating the quantity of returns and making proper inventory decisions by being aware of the average cycle times and variations. Knowing the cycle time will directly impact on accuracy of the delivery date.

### 2.2.4 Reverse Logistics in Various Industries

From the study performed by Aberdeen Group, Inc. research analysts, the companies with multiple industries are more concentrating on enhancing the RL operation. Gecker et al. [19] state that these firms desire to retake revenue, retain customers, obey the environmental regulations, diminish operating costs, and increase the quality of product and their uptimes. They surveyed a vertical look at the impact of RL in the following industries:

- Aerospace & defense,
- Consumer goods,

- High tech manufacturing,
- Industrial equipment manufacturing,
- Telecom/utilities, and
- Medical device manufacturing

Succeeding that they presented three consecutive comparisons and solutions as follows:

In the context of Industry Maturity Assessment, consumer goods firms are leading the other vertical counterparts in the initial value recaptured from returned parts or products by 31%, however still behind the best-in-class mark with 64%. Aerospace and defense firms in a prominent product quality metric were the solely industry to exceed in performance comparison to best-in-class by an approximately 5% of products returned for repair inside the first period warranty. The telecom/utilities and high tech organizations surpassed other industries in preventing the expansion of the RL cost, near 8% of revenues expenditure on RL and one percent less than best-in-class.

Aberdeen group performs several surveys on the mentioned industries. The following section is explained the industry best practices. Industrial equipment manufactures is the leader of employing vice presidents or higher-level executives to supervise profit and lost for service procedures which is the number one best-in-class approach for RL. Almost three-quarters of telecom/utilities companies transcend their vertical counterparts in service-based profits due to RL performances. In terms of responding to leveraging frequent measurement, high tech and telecom/utilities companies encompass the highest proportion of their RL operation with approximately 60%.

Aberdeen group also recommends solution actions for the service organizations in each industry to implementing an efficient and simplified RL structure with considering optimized and cost-effective operation. The following paragraphs are solution actions:

- Aerospace and Defense: Applying leverage reporting and analytics tools like data analysis and RFID technology with the aid of modeling and simulation to track RL performance.
- Consumer Goods Manufacturers: Implementing automated front-end returns management conformation systems like return merchandize authorization (RMA).
- High Tech Manufacturers: Carrying out the automation tools and system in RL as an example enterprise returns/service management systems and warranty claims operating systems.
- Industrial Equipment Manufacturers: Using the reverse function as a business solution and concentrating on strategic objectives for their processes.
- Telecom/Utilities Providers: Exploit outsourcing their possible RL processes by 3PLs.
- Medical Device Manufactures: implementing automated system wherever possible, using executive-level supervision and above the rest clarify the processes and responsibilities for RL.

### 2.2.5 Reverse Logistics in Aviation Industry

Lately, the end-of-service life for retired aircraft and related parts has turn into a significant topic in recycling industries. As stated by Aircraft Fleet Recycling Association (AFRA), for the next 20 years, approximately 12,000 aircraft which now utilized for various goals will be at the end of service life. Therefore, retrieving and recovering aging aircraft by applying environmentally methods and at the same time retaining the value as much as possible becomes an important subject. Many aerospace industries aim to decrease the consumption of natural resources and landfill allocations by recycling aircraft parts and reusing them in different applications. Moreover, recycling aircraft will diminish air, water, and soil contaminations besides energy demand.

One of the first aircraft companies which are also known as best practices in the field of aircraft dismantling operations is Bombardier. In 2010, the company successfully dismantled a CRJ100/200 regional jet, which brought the company to obtain a dismantling certification from the AFRA. Bombardier recovered 1,500 reusable parts, including 300 line-replaceable units per jet [20]. Bombardier in the terms of improving EOL performance is focused on two major goals:

1. Maximizing the products' recyclability

2. Minimizing the use of hazardous substances/materials

The company started the EOL tools in the early design stages, to enlarge the recyclability and facilitate the EOL dismantling of products by implementing the following tools:

- DFE recycling guidelines (Design for Environment) – user friendly designing products guidance that leads to easier dismantle the parts for enhancing components reuse materials recycling.
- CE-MAT (Certification & Environmental Materials Database) and Lifecycle Assessments – For tracking recyclability figures on continues basis.
- List of Prohibited and Restricted Substances – ensuring that hazardous substances are eliminated from products.
- ISO Standards – guidance on labelling polymers to facilitate their recycling at EOL

Furthermore, companies like Bombardier are determined to help and invest in the research academic institutes such as Université du Québec à Montréal (UQAM) and also work with the Consortium for Research and Innovation in Aerospace in Quebec (CRIAQ) to better understand EOL requirements and explore and devise new efficient methods as well, so that an aircraft could be recycled or reused. These new aerospace research leaded to open Centre Technologie En Aerospatiale near Montreal that is responsible for the recycling efforts. Moreover in a related development, the Ecole Polytechnique de Montreal use the research centers' labs to examine and invent procedures for dismantling and recycling materials from aging aircraft (Bombardier CRJ200) which has reached the end of its lifespan.

Aside, AFRA and Boeing intended to decrease the amount of aircraft manufacturing waste passed to the landfill almost 25% in 2012. According to the AFRA, the quality of the composite materials need to be improved and new applications and markets for internal and external the aviation sector should be defined. This recycling and reusing also have excellent benefits in both environmentally and financially [21]. Since the establishment of AFRA in 2006, the members of AFRA have dismantled thousands of aircraft, from the different sectors like commercial and military. These members returned approximately 2,000 aircraft to the market. This cooperation has been successful that cause to encourage many aircraft manufacturing companies to invest in aircraft recycling in the upcoming years.

The other example of recycling plan belongs to Airbus. The issues for Airbus began when the company enter unknown situation as it faced the downside of its sales a decade ago. Airbus knew that for the next 20 years, a quarter of the 6,000 airliners destined for the scrapheap will be Airbuses, and the company should be ready to manage its EOL in an organized and environmentally manner. As Olivier Malavallon, Airbus project director environmental affairs said: “we are closing the loop of product life-cycle management and the need for ‘end-of-life’ centers will become critical”.

This notion leads to the “Pamela” project in March 2005. Based on the Airbus documents “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”.

Malavallon also stated that with current practices approximately 60% of the aircraft’s weight will be recovered, and only 50% of the components and materials can be recycled which means only 30% of the total is recycled; therefore the “smart dismantling” process was proposed. Through this process 70-80% of the scrap by weight is recovered for reuse. Also this recycling process had more environmental advantages. Aluminum manufacturing has extremely energy-consuming process due to the electrolysis step; however using recovered aluminum for recycling (the re-fusion process) will save about 90% of the initial energy. This means that, first of all the raw material in the ground is preserved and also energy saved.

The three main dismantling process of the Pamela project is divided to the following steps:

1. Decommissioning (D1): The process of placing aircraft in a temporary storage for cleaning and decontamination, draining of tanks, and implementation of safety procedures.
2. Disassembling (D2): The decision process that aircraft is a spares source under the airworthiness regulations.

3. Smart dismantling and valorization (D3): The dismantling process which is the irreversible decision to turn the aircraft to waste and contains the final draining of systems, removal of polluting or hazardous materials and finally the "deconstruction" of the aircraft.

As mentioned before, recycling aircraft parts provides great environmentally benefits. Likewise, some materials like composites and alloys are costly to produce, therefore recovering these materials with considering a suitable price and responsible environmentally approach has a considerable interest for recycling and aircraft industries. Forasmuch as, each aircraft is comprised of various components, parts, and materials, Airbus facilitated the recycling process by applying reverse supply chain and broke down the aircraft components into four categories as Table 2-5[20]:

*Table 2-5: Aircraft Components Breakdown by Airbus [20]*

| **REVERSE SUPPLY CHAIN** | |
|---|---|
| • **Engines + APU**<br>• **Landing gears**<br>• **Avionics equipment**<br>• **Movable parts – structural parts** | Re-use upon condition |
| • **Fluids (fuel, oils, hydraulic fluid)**<br>• **Security and safety equipment**<br>• **Avionics (WEEE)**<br>• **Tires** | Specialized recovery channels (technology-oriented &/or regulation-based) |
| • **Aluminum alloys substrates**<br>• **Titanium alloys substrates**<br>• **HR steel and CRES alloys substrates**<br>• **Wiring, harnesses**<br>• **Thermo-plastics, foams, NTF**<br>• **Textiles, Carpets, tissues** | Specialized recovery channels (material-based) |
| • **Cabin and cargo lining**<br>• **Polluted mix and wastes**<br>• **Miscellaneous** | Landfill |

From Airbus Pamela project report, the average weight of an airplane is about 106 tons, and after three steps in the disassembly process, almost 85% of the aircraft materials are possible to be recovered and the remaining 15% enter landfills [22]. The 85% are either used in the same field or it can be modified for other applications like car industries. In some cases the companies are used direct recycling methodology for some aircraft parts and components, such as engines and avionics, or using aircraft components for decoration and furniture. The study by Reals [23] suggested that the remaining 15% of the airplane could be in other aircraft such as interiors. Also Allred and Salas (2005) investigated the possibility of converting all types of plastics in aircraft like rubber, thermoses and thermoplastics into valuable hydrocarbon products and fuels.

In the subject of energy consumption, recycling of materials need less amount of energy in contrast with the operations of virgin material. Additionally it will decrease gas emissions such as $CO_2$, CO, $NO_2$, and $SO_2$ and reduce the global warming.

## 2.3 Radio Frequency Identification (RFID) Technology

In recent years, radio frequency identification (RFID) technology emerges increasingly in the entire field of supply chain management. RFID plays an important role in providing support for logistics and supply chain processes due to the capability of identification, tracing and tracking information in every part the supply chain. This technology can deliver suppliers, manufactures, distributors and retailers extremely accurate real-time information regarding their products and also helps speed the handling of manufactured goods and materials.

RFID technology has several different interpretations in terms of technical and non-technical definitions. The RFID Journal defines it as [24, 25]:

“RFID is a generic term that is used to describe a system that transmits the identity (in the form of a unique serial number) of an object or person wirelessly, using radio waves. It's grouped under the broad category of automatic identification technologies.”

And also they describe it 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.”

Rouse [26] defines:

”RFID is a technology that incorporates the use of electromagnetic or electrostatic coupling in the radio frequency (RF) portion of the electromagnetic spectrum to uniquely identify an object, animal, or person.”

In today’s industry, Auto-ID technologies have been exploited throughout the supply chain to decrease the time and labor requirement to input data manually and enhance data accuracy as well. Due to the benefit of unneeded direct contact or line-of-sight scanning, some auto-ID technologies like RFID, is coming to use increasingly as an alternative to the barcode. In the following Table 2-6 is the comparison between these two auto-ID technologies are demonstrated [27, 28].

*Table 2-6: Comparison of RFID and Barcode [27, 28]*

| | **RFID** | **Barcode** |
|---|---|---|
| **Read Rate** | High throughput. Multiple (>100) tags can be read simultaneously. | Very low throughput. Tags can only be read manually, one at a time |
| **Read Range** | Passive UHF RFID:<br>• Up to 40 feet (fixed readers)<br>• Up to 20 feet (handheld readers)<br>Active RFID:<br>• Up to 100's of feet or more | Several inches up to several feet |
| **Line of Sight** | Not required. Items can be oriented in any direction, as long as it is in the read range, and direct line of sight is never required | Definitely required. Scanner must physically see each item directly to scan, and items must be oriented in a very specific manner. |
| **Human Capital/Automation** | Virtually none. Once up and running, the system is completely automated. | Large requirements. Laborers must scan each tag (labor intensive). |
| **Read/Write Capability** | More than just reading. Ability to read, write, modify, and update. | Read only. Ability to read items and nothing else. |
| **Identification** | Can uniquely identify each item/asset tagged. | Most barcodes only identify the type of item (UPC Code) but not uniquely. |
| **Durability** | High. Much better protected, and can even be internally attached, so it can be read through very harsh environments. | Low. Easily damaged or removed; cannot be read if dirty or greasy. |
| **Security** | High. Difficult to replicate. Data can be encrypted, password protected, or include a "kill" feature to remove data permanently, so information stored is much more secure. | Low. Much easier to reproduce or counterfeit. |
| **Event Triggering** | Capable. Can be used to trigger certain events (like door opening, alarms, etc.). | Not capable. Cannot be used to trigger events. |
| **Technology** | RF (Radio Frequency) | Optical (Laser) |
| **Interference** | Like the TSA (Transportation Security Administration), some RFID frequencies don't like Metal and Liquids. They can interfere with some RF Frequencies. | Obstructed barcodes cannot be read (dirt covering barcode, torn barcode, etc.) |

RFID technology is comprised of a tag (transponder), an antenna and transceiver (often combined into one reader) that connected to a computer system. The tags commonly have two parts, a chip and an antenna. Real time information about a product or a shipment is gathered and stored by the chip and simultaneously the antenna is received and transmitted those data via radio waves. The data stored in a tag is detected and recorded by the reader. This means tracking the physical movement of the tag with relevant information in real time and the item attached by the tag as well. Presently, two types of tags are being used: an active RFID tag which includes internal power source (typically a battery), and a passive tag which the power derive from the signal transmitted by the antenna (i.e. without any battery). The Table 2-7 below is a direct comparison between the two technologies [27, 28].

*Table 2-7: Comparison of Active and Passive RFID tags [27, 28]*

| | **ACTVIE RFID** | **PASSIVE RFID** |
|---|---|---|
| **Power** | Battery operated | No internal power |
| **Required Signal Strength** | Low | High |
| **Communication/Read Range** | Long range (100m+) | Short range (3m) |
| **Range Data Storage** | Large read/write data (128kb) | small read/write data (128b) |
| **Per Tag Cost** | Generally, $15 to $100 depending upon quantity, options (motion sensor, tamper detection, temperature sensor), and form-factor | Generally, $0.15 to $5.00 or more depending upon quantity, durability, and form-factor |
| **Tag Life** | Up to 10 years depending upon the environment the tag is in | 3-8 years depending upon the broadcast rate |
| **Tag Size** | Varies depending on application | "Sticker" to credit card size |
| **Fixed Infrastructure Costs** | Lower – cheaper interrogators | Higher – fixed readers |
| **Per Asset Variable Costs** | Higher – see tag cost | Lower – see tag cost |

| | | |
|---|---|---|
| **Best Area of Use** | High volume assets moving within designated areas ("4 walls") in random and dynamic systems | High volume assets moving through fixed choke points in definable, uniform systems |
| **Industries/Applications** | Auto dealerships, Auto Manufacturing, Hospitals-asset tracking, Construction, Mining, Laboratories, Remote monitoring, IT asset management | Supply chain, High volume manufacturing, Libraries/book stores, Pharmaceuticals, Passports, Electronic tolls, Item level tracking |
| **Readers** | Typically higher cost | Typically lower cost |

Besides the two mentioned tags, there are also semi-active/passive tags. These tags use a battery to activate the chip's circuitry, however communicate by drawing power from the reader. According to the RFID Journal, Semi- passive/active tags are more suitable for tracking high-value products which required to be scanned over long ranges, like railway cars on a track. The semi-active tags have a longer battery life than solely active tags and not sending RF frequencies on frequent interval as the active tags do [29].

Todays, RFID readers can be categorized base upon their usage. According to the White paper by Motorola [30] there are three types of readers: Handheld, Mobile and Fixed readers. Both handheld and mobile readers reveal a new vision of possibilities for read point. These readers give power to enterprise to fully leverage RFID technology to multiply benefit levels and likewise the return on investment (ROI). On the other side some researchers classified readers as: Passive Reader Active Tag (PRAT), Active Reader Passive Tag (ARPT) and Active Reader Active Tag (ARAT).

RFID systems commonly need middleware-software which is placed between RFID interrogators and organization software. The main functions of a middleware is to configure and manage the hardware, also process tag data, separate duplicate tag reads and accumulate the data

[31]. The following Figure 2-1 is representing the flow of information in RFID system architecture.

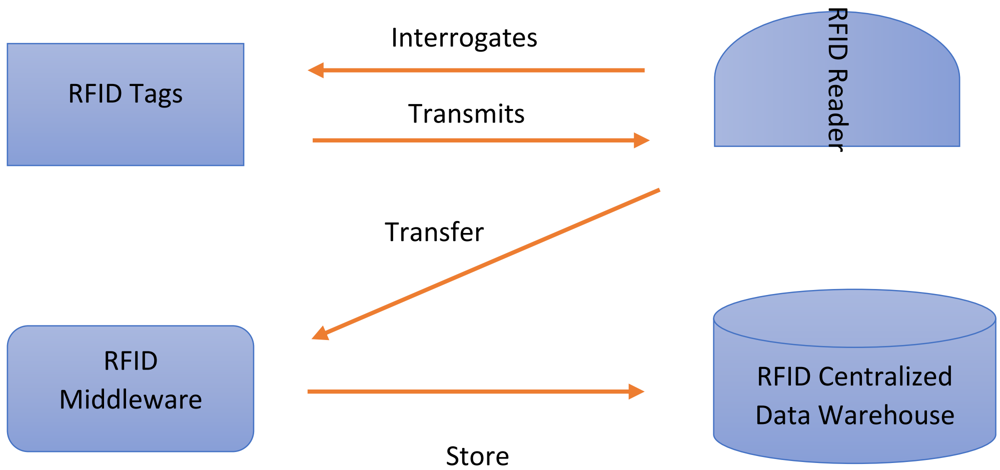


*Figure 2-1: Information Flow in RFID system [31]*

### 2.3.1 Benefits and Advantages

RFID eliminates the limitation of line-of-sight scanning of barcode systems [32]. This removes the requirement of human interference in different levels of supply chain. Automatic reading and recording decrease handling and raise accuracy and visibility [33]. There are three articles by Delanuay et al. [34], Rekik et al. [35] and Cakici et al. [36] which talk about the primary reasons for shrinkage. They believe theft and obsolescence are the main causes; thereby security and visibility with RFID system will minimize shrinkage and reduce the risk of stolen, expired and damaged products as well. Despite the fact that, when these issues happened RFID technology has the potential to recover rapidly or well-organized recalls the goods [37]. Mainly, product visibility leads to lessen average inventory level and the volume of lost sales. Therefore, inventory cost remarkably decreased [38] and in the long term, increased availability will lead to flatten the bullwhip effect and facilitate material flow throughout the supply chain [39, 18]. Figure 2-2 presents the benefit factors of RFID.

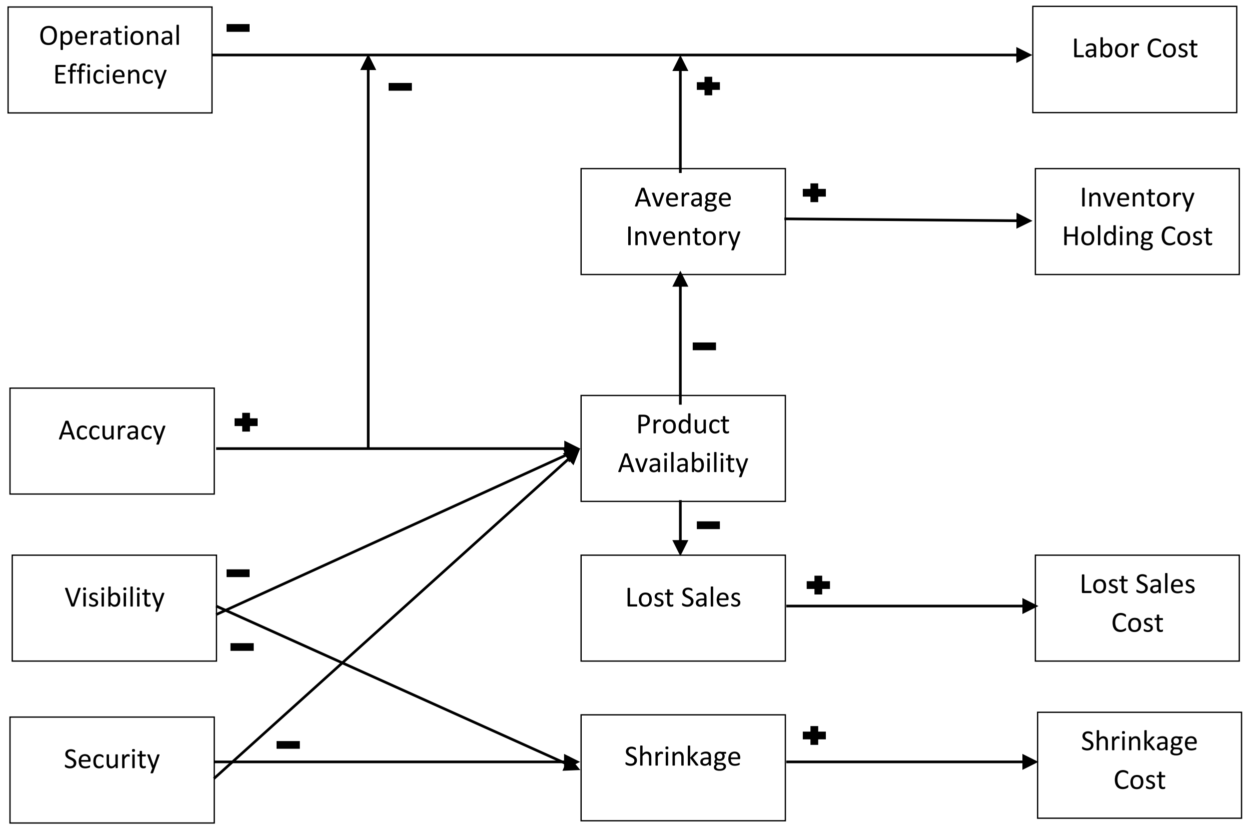


*Figure 2-2: RFID Benefit Factors [39, 18]*

### 2.3.2 RFID System Costs

An ordinary classification, proposes three cost categories: 1. Hardware cost, 2. Middleware cost, and 3. Service cost. Hardware cost covers the costs of all tangible items of RFID system, like tags and readers. The tags price is the great barrier towards widespread implementation [39]. Tag cost is composed of chip cost and assembly cost and when the amount of production growth, chip cost will be reduced. However in many cases economics of scale do not apply to assembly cost [40]. Today's supply chain is helping to collect vital demand to decrease the tag cost to the acceptable level for encouraging companies to implement RFID system [41]. There are many researchers like Ustundag [42] believe that although reusable tags combine with RL may gratify enterprises through multiple use, it is considerable that reusable tags should be consist of more durable materials and an extra cost of rewriting as well. Ilie-Zudor [33] stated that detailed level of tagging give more advantages but also a higher cost. Reader and connected infrastructure costs are considered as fixed cost compare with tag cost which is variable Gauklerw et al.[43].Second cost is RFID middleware cost which is the connection between ERP platform and the hardware part. It links software and service, manage hardware, and process tag data. The cost of middleware rely on the intricacy and complexity of application, arrange of data storage, and the degree of maturity of the technology for the system [44].Finally service cost which is consist of system design, customization, and configuration cost; however Rundh [45] said for widespread supply chain adoption some retailers such as Wal-Mart or Metro group consider compliance cost as well. Service cost frequently prevents suppliers to adopt RFID and exploit of becoming a member of the supply chain. Some researchers like Bunduchi [46] state that service cost is directly related to the maturity of the system. It means that in the beginning stages, service cost appear as a development and direct implementation cost, however later it is formed as an initiation and holistic direct implementation cost. Furthermore, the cost of all the works for balancing the prior with new system and administer a transition with no obstacles is considered as switching cost.

### 2.3.3 RFID Issues and Concerns

Notwithstanding the whole benefits of RFID system presents to the enterprises which even lead to change the other auto-ID technology to RFID, there are several problems and challenges versus the implementation of RFID. These issues and concerns will pullback many industries and firms from employing RFID technology.

Based on the study carried out by Darcy et al. [40] RFID issues are respectively composed of three basic and one additional obstacle as follows:

1. RFID Security: Concerns of security, also known as Intrusion Detection. In details, five main issues are introduced regard to RFID security:
    - Eavesdropping
    - Unauthorised Tag Cloning
    - Man-in-the-Middle (MIM) Attack
    - Unauthorised Tag Disabling
    - Unauthorised Tag Manipulation

    Presently, many studies recommend methods and techniques to decrease the troubles referred to RFID security. In the below Table 2-8, there are approaches corresponding to their researchers.

*Table 2-8: RFID Security Techniques*

| **Techniques** | **Researchers name** |
|---|---|
| **Tag Deactivation and Encryption** | Karygiannis et al.[41] |
| **Mutual Authentication** | Konidala et al. [42] |
| **Detections in Tag Ownership** | Mirowski et al. [43] |
| **Reader Analysers** | Thamilarasu et al. [44] |
| **Certain Data Cleaners** | Darcy et al.[47] |

2. RFID Privacy: The problems surrounding the privacy of the data captured. This privacy can be associated with unknowingly releasing critical information [48] or collecting a record of all item newly found on a person [49]. In Table 2-9, there are methodologies offered from several researches.

*Table 2-9: RFID Privacy Methodologies*

| Methodologies | Researchers name |
|---|---|
| **General approaches of Encrypting/Rewriting – Hiding/Blocking Tags** | Langheinrich [48] |
| **Killing/Sleeping the tags** | Juels [49] |
| **Carrying around a privacy-enforcing RFID device** | |
| **Releasing certain information based solely on distance from the reader** | |
| **Introducing Government Legislation** | |

3. RFID Characteristics: The characteristics associated with the nature of RFID. The challenges according to RFID characteristics include in Table 2-10 [40].

*Table 2-10: RFID Characteristics Challenges [40]*

| RFID characteristics Challenges | Description |
|---|---|
| **Low Level Data** | The raw observational readings being taken by the RFID Reader |
| **Error-Prone Data** | RFID problem with capturing the data |
| **High Data Volumes** | The ongoing obstacle with managing exponential RFID data streams |
| **Spatial and Temporal Aspects** | The aspect of RFID's freedom in being capable of being used in all situations |

4. RFID Anomalies: This problem refers to RFID observational data which are recorded with the correct RFID readings (see Table 2-11). Figure 2-3 is an example of a RFID-enabled shelf which has illustrated the three anomalies [40]:

*Table 2-11: RFID Anomalies [40]*

| RFID anomalies | Description/ Stem from problems | Researchers name |
|---|---|---|
| **T2: Wrong Reading (Unreliable Reading or Ghost Reads)** | Data captured where it should not be /Technical Problem or additional unnecessary labor | Bai et al.[50] |
| **T3: Duplicate Readings** | A tag is observed twice rather than once /More than one reader, tag pass within overlapped region, scanned item stays in the reader range for a long period of time and attach multiple tag | Bai et al. [50]<br>Carbunar et al. [51] |
| **T4: Missed Readings** | A tag is not read when and where the object it is attached to should have been physically within proximity/ Tag collisions, Tag Detuning, Water/Metal interference and Misalignment of the tags | Engels [52]<br>Floerkemeier et al. [53]<br>Rahmati et al. [54] |

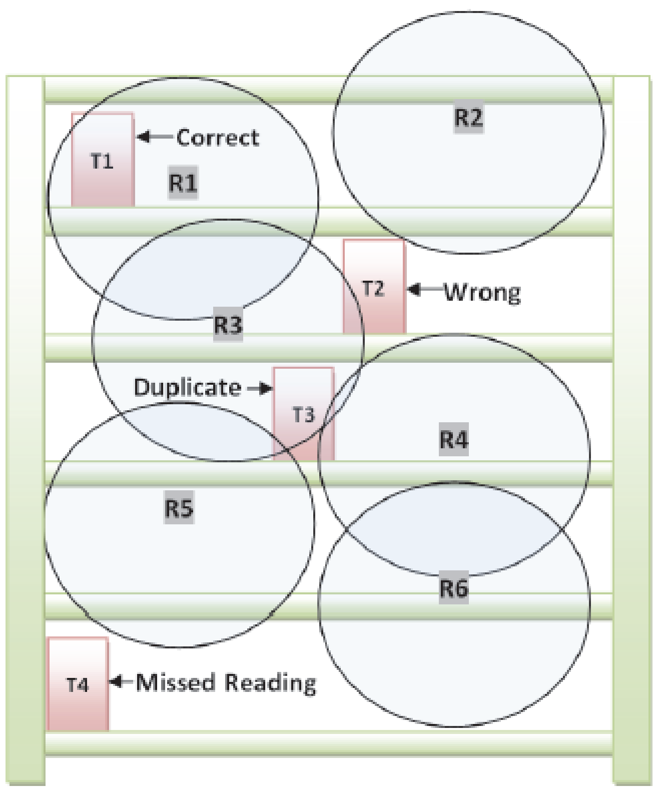


*Figure 2-3: A Graphical Example of a RFID-enabled Bookshelf with the Data Anomalies that May Occur Highlighted [40]*

Table 2-12 provides a brief summary of all the techniques investigated to correct or generate the RFID issues [40].

*Table 2-12: RFID Correction Techniques [40]*

| | Methodology | Anomalies Corrected | | | Anomalies Generated | | |
|---|---|---|---|---|---|---|---|
| | | Wrong | Duplicate | Missed | Wrong | Duplicate | Missed |
| **Physical** | Tag Orientation | - | - | X | X | - | - |
| | Weighing | - | X | X | - | - | - |
| | Multiple Tags/Cycles | - | - | X | X | X | - |
| | Eccopad | - | - | X | - | - | - |
| **Middleware** | Edge Filtering | X | X | X | X | X | X |
| | Anti-Collision | - | - | X | - | - | - |
| | Thresholds | - | - | X | - | - | - |
| | Statistical Approx. | X | X | X | X | X | X |
| **Deferred** | P2P Collaboration | X | X | X | - | - | - |
| | Proximity Detection | X | - | X | - | - | - |
| | Cost-Conscious Cleaning | X | X | X | X | X | X |
| | Data Mining Techniques | X | X | X | X | X | X |
| | Probabilistic Inference | - | - | X | X | - | - |
| | Event Transformation | X | X | X | X | X | X |
| | Intelligent Classifiers | X | X | X | X | X | X |

From the management point of view, issues are classified as below [55]:

- RFID deployment and return expectations
- Business value from RFID technology
- Mandated RFID adoption and institutional responses

### 2.3.4 RFID in Different Industries and Markets

The application of RFID has been used in different industries. RFID has an excellent potential in supply chain management, logistics and any quick response systems. RFID can be exploited to identify and track locations of shipping containers and objects such as apparel, book, drugs, and etc., in warehouses and throughout the shipping route. In inventory control system, RFID can be used to accurate the system. Based on the research by Collins [56], RFID will be the fastest raising among all the auto-ID technologies in near future. The author believes that by some factors like descending prices, technological advances and the execution of uniform RFID communications standards, this growth will be more quickly.

In another study conducted by Zhu et al. [55], they talk about the information collecting, storing and passing capability of the RFID tag that gives an opportunity to different kinds of usage to occur. Researchers divided the usage of the RFID in various companies through the type of the tags (Passive or Active). For a passive tag, the general usage is in product, postal package and airline baggage/passenger tracking, building access control, and so on. Firms like Wal-Mart, P&G, GAP, Old Navy and JC Penney employ passive RFID tags in their supply chain management (SCM). The other common usage is the EZ- Pass highway toll lanes, where drivers have RFID technology in their vehicles. The US Department of Defense (DOD) used active tags to decrease search and lost in logistics and to enhance supply chain visibility. Another application example of active RFID tag is for educators in where the students in a class use clicker device each which they hit in their responses to a teacher’s question and instantly through the signal transmitting to a computer the frequency distribution is displayed. In the following paragraphs, there are examples of RFID technology application in different industries:

Retailing industry – CPG (consumer packaged goods): Based on RFID Journal [57], Wal-Mart required its U.S. suppliers to add RFID tag on all pallets and cases of all products till the end of 2005. The report by Songini [58] contains that one of the Wal-Mart top providers of consumer goods, Procter & Gamble (P&G) utilized the RFID requirements of Wal-Mart and faced with considerable improvement. In a study carried out by Weier [59], the

Sam’s Club suppliers would face a fee if the company did not have pallet-level RFID till the October 2009 and item-level RFID by 2010 as well.

Smart shelf operations: According to Gillbert [60], when a shipping container or a pallet, transfer from manufacturing plant to warehouse, the attached RFID tag not just will make the monitoring of its location possible, also its efficient routing. In 2003, Wal-Mart examined Gillette products using RFID to create smart shelf in a store.

Retailing in industry – apparel: as mentioned before many US apparel firms such as American Apparel, Ann Taylor, Calvin Klein, Old Navy and GAP use RFID in smart shelf and on the products in the field of Point of Sales (POS) to first of all decrease inventory shrinkage and to increase their supply chain performance. An R&D strategist at American Apparel, Zander Livingston is quoted in an article by Gaudin [61] that the company enumerates in-store inventories two times per week to secure product availability. By this counting they may restock and reorder items. In general these processes require four people for 8 hours. However at the RFID-enabled store, the required human and time resource reduce to two employees for 2 hours for the same task. Livingston stated that sales rate growth by 15% to 25% whereas all items are available on the floor. Also he believes, the RFID system has caused to 99% of sales-floor inventory visible to customers.

RFID used in fitting room: one of the remarkable uses of RFID enabled is by the Galeria Kaufhof, a German department store. When men go to a change room to try a suit, an automatic suggestion by a ‘smart mirror’ in the change room will recommend him what type of shirt or tie he can purchase with it. The system is performing by this way: an RFID reader on a mirror in the dressing room decides which merchandise has been brought into the fitting room by the attached RFID tag to the clothes, after that shows perfecting clothing choices or accessories. Furthermore, the system is combined with ‘smart shelves’, which make it possible to know what goods in different styles, sizes and colors, are currently available in stock.

Food and restaurant industry: Mostly, the products can rot or spoil in limited useful life. To prevent useful time reduction, the transportation is critical in this industry. Two main factors are saleable life which is related to the revenue generating window and outdated or expired product that can be hand over to a customer with disastrous result. The US Food and Drug Administration (FDA) have estimated more than 20% of foods are thrown away as a result of spoilage in the whole supply chain. RFID technology can decrease this issue significantly due to its tracking ability in real-time with no need of product movement, scanning or even human participation. Ngai et al. [62] explain the design and development of RFID in a conveyer-belt sushi restaurant. This system is formed to obtain better inventory and food safety control, and responsive replenishment to enhance the service quality.

Health care industry: One of best industry that RFID can reveal its capability and usefulness can be found in the health care industry. RFID is used to make patient monitoring and safety better, improve asset utilization with real-time tracing and in the same way by tracking medical devices, decrease medical faults and errors. Many healthcare industries exploit the RFID system to enhance supply chain efficiencies. Harrop [63] declares that the business market for RFID tags and the whole system in healthcare industry will swell quickly from $90million in 2006 to $2.1 billion in 2016. This augmentation will initially be as a result of higher level of drugs tagging and real-time locating system (RTLS) for patients, staff and assets. In the case study Amini et al. [64] demonstrate a simulation study guided at a regional hospital. They used RFID-based system to gather data that were related to trauma patient movement. Through the implementation of the system, they recognize that RFID data provide foundation for successful simulation modeling.

Logistics Industry: Thiesse et al. [65] conducted a RFID-based, real-time location system (RTLS) case example in compound and complicated manufacturing process. In this implementation which is in a semiconductor plant, they used a simulation model to examine the value of RTLS data information on the different places of physical items in a production system. They realize that in comparison to traditional material-tracking system, RTLS technology gives the chance for novel levels of visibility and control. The advantages come from entire speeding up the current process and an extra efficiency add through new dispatching rules by considering real-time information on the logistic process on the plant floor. Wang et al. [66] recommend a real-time vehicle management system which is contained RFID, Global Positioning System (GPS), and Geographical Information System (GIS), to schedule vehicles best routings through real-time data in logistics or distribution services. In their system, they exert heuristic method to formulate the scheduling and seek for the related optimal solution. Moreover, they carry out numerical experiments to present the feasibility of the system.

Furthermore, application of RFID use in Travel and tourism industry. As an example, according to Contactlessnews [67] US Government issued 10 million new passport which obtain RFID chips in 2005, and they estimated for 2006 this number would be 13 million. One of the best locations that RFID can reveals its capability over barcode or magnetic strip systems is in Library system. RFID could aid staff to accelerate inventory management process, diminish human errors and time of “shelf-reading”, and enlarge the accuracy of inventory records. Other applications of RFID can be found in the military, paper industry and in auction.

### 2.3.5 RFID in Aviation

As mentioned in the previous section, RFID is an evolving technology which can significantly enhance operational efficiencies and also customer service in different industries. Nowadays, the Aerospace industry is extremely influenced by:

- The politics, economy, government regulations.
- Growth of the Asian markets (Specially China).
- The Airbus-Boeing competition to eliminate waste by creating lean enterprise programmes
- Outsourcing of Maintenance-Repair-Overhaul (MRO).
- The growth of low-cost regional carriers.
- Industry investors looking for greater Return On Investment (ROI) from their R&D investments.

Aerospace companies require to decrease the long product-development cycle time, besides concentrate on delivering high quality product as before.

In addition aerospace companies require intensifying their process performance by enhance cycle times, output, and extensive effectiveness in the areas such as: control system, quality, execution, tracking and tracing, and visibility. On the other hand, aerospace manufactures need to diminish non-value-added activities or work from the related manufacturing processes, decrease inventory costs and remove stock outs [68].

Since aviation companies outsource most of their products, the requirement for real time visibility, agility, and accuracy are prime importance in facing up to demand fluctuations, supply chain interruption, and satisfy the expectations of customers. In detail, the value is receiving the correct decisions on the shortest notification, so that it will facilitate the complexity of activities between multitudes of partners. The direct impact of this is on productivity, profitability, and remains competitive [68].

Based on Holloway [68] the application of RFID in the aerospace industry has several proven benefits, with considering being continued air safety. He said “RFID will:

- Improve airline configuration control, by increasing the accuracy of the known "as-delivered" configuration.
- Reduce ownership costs, by identifying rogue parts; this will also help minimize airline inventories.
- Provide reliable part traceability.
- Reduce internal processing and cycle time to solve service-related problems.
- Improve the accuracy of information exchanged between the airline industry and suppliers.

In addition, RFID technology offers a competitive advantage through support for:

- No line of sight requirement.
- Dynamic read/write capability.
- Simultaneous reading and identification of multiple tags tolerance in harsh environments.

With the need for strict safety, and therefore identity, the industry has been looking at ways to uniquely identity parts and assemblies."

Aerospace Manufactures must organize and supervise production processes among various facilities, which add a novel scale to Work-in-Process (WIP) Tracking. This WIP Tracking requires including logistics and conveyance tracking processes for inter-facility shipments. Automating logistics processes in comparison to traditional WIP tracking with RFID make deployment simple, as a result of shipments are traced and tracked by customer order rather than the individual component level. OATSystems discover that RFID Inter-Facility Tracking remarkably enhance on-time delivery for manufactures.

OATSystems and RFID Journal describe key areas for RFID Process Automation in Aerospace and Defense manufacturing with corresponding performance metrics. These areas are as below Figure 2-4:

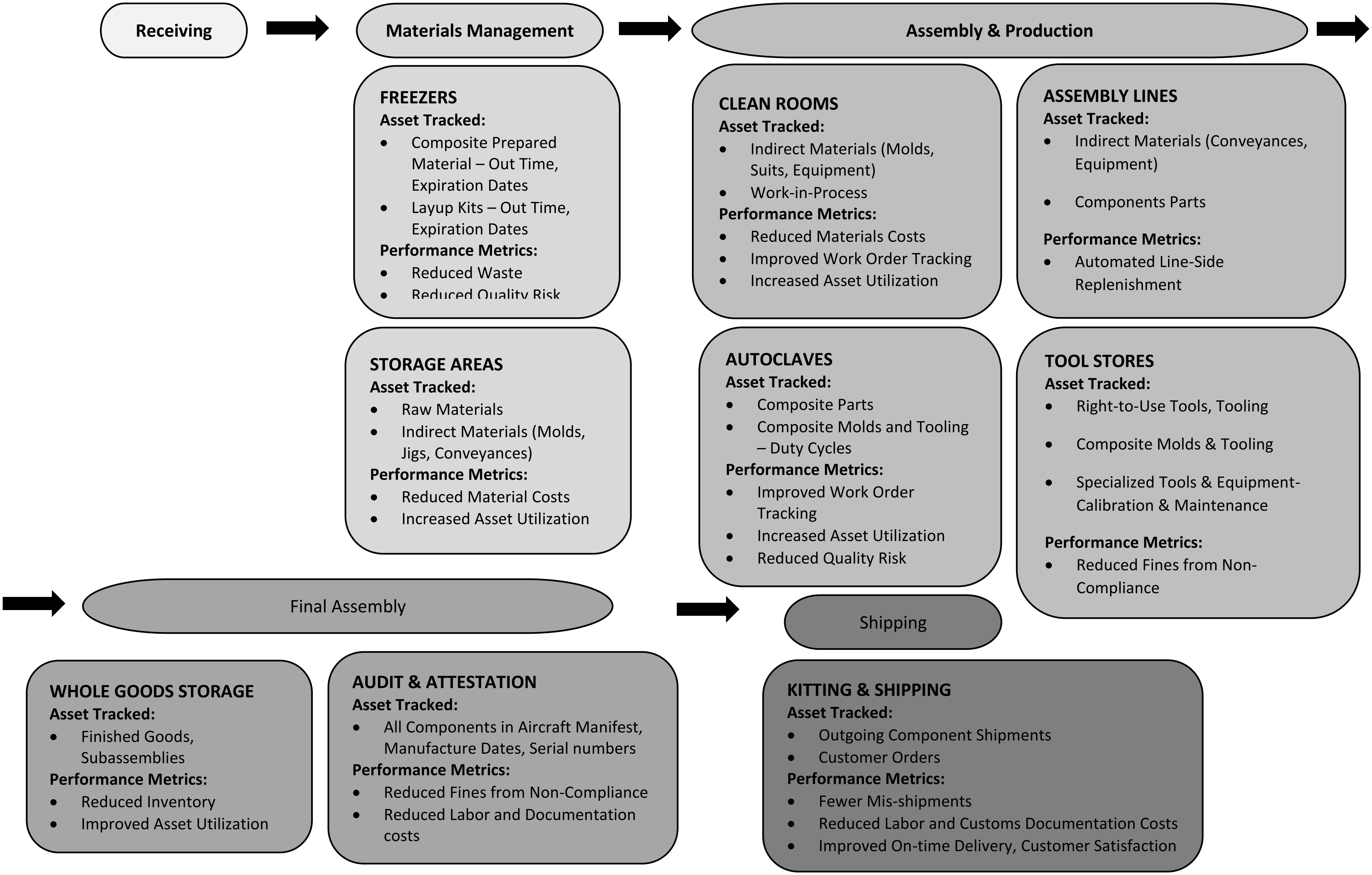


*Figure 2-4: Key Areas for RFID Process Automation in Aerospace and Defense Manufacturing [68]*

Moreover, in Aerospace, Defense and Industrial Machinery, a missing tool on the shop floor can be more costly compare to a missing component part. Often these specialized tools are single-sourced, custom made, and hard to replace like laser scriber, a lift table, and hard or soft molds. Also it may take weeks to replace, therefore it will causes delays in schedule. Automating Tool Tracking with RFID and RTLS technology can give several advantages as follows:

1. Labor savings
2. WIP visibility
3. Tool cost savings
4. Improved Foreign Object Damage Management
5. Audit compliance
6. Calibration
7. ERP efficiency

In the following sections, Airbus and Boeing that are two biggest aircraft manufacturers in the world and other examples will be considered on the usage of RFID technology in aviation industry.

Before talking about the two companies in separate, in 2004, Airbus and Boeing held industry forums to promote the adoption of industry-standard solution for RFID on commercial aircraft parts. They invited world's airlines, regulatory agencies, parts suppliers, and third—party MRO shops. The purpose was to train, notify, and unify the industry on standard which is needed for identifying parts. As stated by Holloway [68] both companies:

- Recognized the necessity of permanent parts marking.

- Saw the need for an industry standard for automatic data capturing based around standardization of RFID in Air Transport Association (ATA) Spec2000.
- Are aware of the different requirements on permanent parts marking, depending on the part and its environment.
- Support the application of the appropriate marking technology (human-readable nameplate, bar code, or RFID) for each type of material.

The companies expressed that they confident that RFID give major advantages for the whole industry. The manufactures receive accurate information about demands and also decrease parts inventory and repair plane time. On the other side suppliers will reduce inventory, enhance the efficiency of their manufacturing processes, and exploit the technology to verify to Airbus and Boeing that parts they receive are genuine, therefore diminishing the numbers of unapproved goods that enter the supply chain. Both Airbus and Boeing are also considering getting their suppliers passive UHF tags which is carrying Electronic Product Codes (EPC) on transport containers and other transportation vehicles used in aerospace industry supply chain. Boeing may change to EPC tags on containers of parts rapidly after EPCGlobal finalized its specifications.

Holloway [68] declared that Airbus and Boeing join with product-life-cycle management vendor Sopheon plc and Siemens Business Services, to set an industry-wide Internet portal to choose reference source for RFID implementation. The Siemens works is intended to promote standardization of RFID usage and Sopheon responsibility is to observe a place for RFID in product-life-cycle management applications. This collaboration offers novel possibilities of applying RFID in product development, maintenance, and end-of-life (EOL) recycling of aircraft and automotive parts.

#### *2.3.5.1 Airbus*

In the Airbus Company there were various kinds of methods to communicate contracts procedures, and compound demands and orders with 75% external suppliers [69]. On the other side, due to the competitive pressure and large-scale projects like A380 and A350 bring about proofs to improve the entire supply chain management. Therefore, in 2001 Airbus created a web-based platform in the name of "Sup@airworld" project that can be accessed through internet to facilitate connectivity and integration. One sub-domain of this project is about e-supply-chain to unite all suppliers' communication and improve the collaboration among all owners. To increase visible horizon and speed up the reaction to wrong deliveries from the suppliers, Airbus established the RFID-technology.

The main reasons that Airbus deployed RFID in their company are summarized as follows [68]:

- Minimize unplanned maintenance and detect malfunction early
- Manage and reduce airline parts inventories
- Establish audit trails for each uniquely identified object
- Ensure that the correct part is being used in the right place
- Mechanics can access document, task, and parts data, and locate and track approved spare parts in real time
- Identify and track tool location, usage history, and repair requirements
- Improve safety and security by authenticating components

According to Sullivan [70] Airbus established the RFID system to extensively enlarge their transparency and visibility to enhance the reactivity. Its purpose is to "error-proof and automate" its supply chain and manufacturing processes to decrease aircraft production and maintenance costs. Airbus employs the RFID technology in two ways:

1. Airbus Suppliers applied RFID tags on their own products instead of old-fashioned barcodes.
2. Airbus employs RFID technology in all its tools and toolboxes. This caused to more effective availability, needed less paperwork (bureaucracy), reduced error rate, and diminish of the administrative and logistics efforts for the entire cycle.

Airbus started RFID tags on its ground equipment such as jigs and tools that loans to airline maintenance centers in 2000. The A350 widebody will be the first aircraft to employ the passive RFID tags on flyable parts. Airbus would also apply RFID high memory tags to A350 extra wide-body [XWB] components at the source of manufacturing. Data information from the tags is more useful to assist aircraft configuration management and line maintenance, repair shop optimization and life-limited parts monitoring. Presently, Airbus expects that up to 3,000 aircraft parts will be tagged on each plane, with 2,000 of these tags being high memory tags. After the planes are conveyed into service started in 2013, carriers will employ the high-memory tags (4 kilobytes) to store maintenance histories directly from particular flyable airplane parts and components. The information from data will be used to enhance a host of processes which contain configuration management, repair operations and warehouse logistics [71].

The A380 will contain 10,000 passive RFID chips on removable parts. These parts are replaceable units with short life cycles like a passenger seat and brakes with respectively five-year life cycle and 1,000 landings, but wing of an airplane is a non-removable part with a 30-year life cycle.

The improvement in inventory management brought Airbus profits. Airbus saved 100,000€ in 2006 by leasing the tools in comparison to 180,000€ investment costs, and also decrease the repair-cycle by 6.5 days [71].

#### *2.3.5.2 Boeing*

In 1999, Boeing started RFID-enabled in aircraft tool management, and employed RFID microchips in all its tools and toolboxes which had history, such as shipping, routing, and customs information.

In 2010, the company announced the partnership program with Fujitsu to apply an Automated Identification Technology (AIT) in aircrafts in all three processes of repair, maintenance and inspection. The result of this collaboration would be a solution which was named the “RFID Integrated Solutions”. This solution proposed to current and new customers like airline companies (Alaska Airlines). The Federal Aviation Administration (FAA) has certified the solution, thereby Boeing offers to its customers the second generation EPC (Electronic Product Code) Fujitsu RFID tags. These tags are exclusively designed for aviation applications besides RFID readers that are from Motorola, Fujitsu or Intermec and middleware software by Boeing and also other such as maintenance and integration by both Fujitsu and Boeing companies [72, 73]. In addition, RFID solution was examined in different harsh conditions like pressure, dirt, water, heat and cold to measure the performance of the tags. Most of the tags are used in various parts such as reparable equipment, retables parts, emergency equipment (Life vest and Oxygen mask), structural and cabin component [73].

As an example, Boeing has stated it will employ RFID tags for “maintenance-specific parts” on the 787 Dreamliner. The goal of this program is for time-controlled, life-limited parts and replaceable units to be identified with “smart labels”. These labels include a microchip, an antenna, and store data that containing part and serial numbers, country of origin, manufacturer codes, and date of installation and inspection, and maintenance information. This information is useful in maintenance of aircrafts thorough several stages of its life-cycle.

#### *2.3.5.3 Other Companies*

In 2011, Bell Helicopter, a civil and military aircraft manufacturer, used on-time delivery (OTD) by implementing RFID system to 99.81% on the internal movement of parts and containers during the production of helicopters. Since the installation of the RFID solution which was designed by OATSystems, Bell Helicopter estimates that it got back its investment within a year. They stated the financial return are regarding to decrease in the number of labor hours employees devote to searching for missing parts, besides performing related stock adjustments. Moreover, the great traceability of parts has significantly decreased the potential for disturbance to the production schedule. They also declared that RFID solution reduces lost parts and associated stock adjustments by 27.6% [74].

## 2.4 RFID in Reverse Logistics

Although RL contains numerous complicated components in comparison to forward logistics (FL) [75], the information topics like management and technology play the critical role to construct an efficient supply chain [76]. According to the research by Guide et al. [77] ‘’ Managers must take actions to reduce uncertainty in the timing and quantity of returns, balance return rates with demand rates, and make material recovery more predictable. Managers must also plan for the collection of products from end users. The use of information systems with new production-planning and control techniques makes management of those activities more predictable.''

Ordinarily RL deals with activities which are involved in the return and processing of returned products. In general situation these goods are gathered at the point of sale or collection points; afterward expert workers are inspected and classified them. Therefore these mentioned products are expended specific amount of time before other actions like reassembly or repairing [78]. Due to the benefits of RFID technology on bulk reading and automation with no need of direct vision, the related time and cost are dramatically decreased. Additionally, Visich et al. [79] state that the valuable data like quality information which derive from RFID identification and tracking ability is an appropriate solution to enhance the value of the returned goods in term of decision making to repair, refurbish, remanufacture, cannibalize or recycle the products. On the other aspect an authentic and accurate RL contains correct data collection with productive reporting system. In today's competitive global markets, it's a necessity that firms gather coherent and organized data regarding the causes of product return for negative or positive reasons and its current condition [80]. One of the most successful technologies to achieve this purpose is RFID. The immense progress in RFID technology lead to tag almost every physical objects to interact with information services [81, 82] .Hence researchers reach consensus on the advantages of the RFID-based RL which deliver significant cost reductions in various industries and businesses such as automotive, aerospace, retailers, and pharmaceutical, possessing on their inventory management performance, diminish thievery, and obtain new capability by exploiting the real-time data.

The research study by Nativi et al [83] on decentralized inventory control model in a reverse logistics provide knowledge about information sharing and suited inventory policies with applying RFID to achieve more environmental and economic cost reduction. By real-time continuous inventory review, additional demand can be reached, therefore expanding return's orders. Also they believe the holding and shortage costs will be reduced as a result of better and enhanced reorder point. They were performed regression and sensitivity analyses to comprehend better the situation and factors to attain greater economic benefits to prepare guidelines and insights for managers in their decisions.

In summary, in below there are reasons that why RFID should be implemented in Revere Logistics:

- To have accurate inventory of products;
- To know the bill of materials (BOM) of products, thereby enabling easier identification of defective parts or subcomponents;
- To trace locations from and to which the returned goods are shipped, know the reason and time of return;
- To update product information on the chip, etc., which is not possible with technologies like barcode;
- To maintain a centralized database where the information collected from RFID tags of returned products can be stored and shared across multiple locations in real time for quality control purposes;
- To perform advance recall of products that have used common defective components identified using BOM and avoid extra costs involved in transportation handling of returned products returned at later stages.

Furthermore, in the study by Yoo et al.[84], they proposed network infrastructure which supports logistics activities for the all over process from the recycling of goods materials to the disposal through including reverse logistics to current forward logistics. They also conduct a database model that integrates data information scattered between manufacturers, suppliers and consumers which offers coherent visibility to the general state of process, improve the reliability of information, and efficient information for decision making. Finally RFID technology was developed to the entire computing based smart network as it alters from the basic identification of objects to history tracking and tracing, state information and real-time monitoring, and control and autonomous services.

## 2.5 Modeling Approaches In Supply Chain (Forward and Reverse Logistics)

To construct more efficient RL from the economic viewpoint, the correct planning and control are necessary. With no data accuracy information, planning and controlling cannot be as efficient as in Forward Logistics (FL). By employing RFID technology, manufacturers can acquire useful information that will be vital for standardizing and planning Closed-Loop Supply Chain (CLSC). It can be described more tangibly by seeing the MRP and Master Production Scheduling (MPS) table, a planning tool. For instance it reveals lead time, forecasting volume, demand and available to promise are the information required to perform the MPS. This information can be gathered by way of implementing RFID in the supply chain. The collected information helps the Reverse Logistics Supply Chain (RLSC) to diminish the uncertainties. These uncertainties have been classified into five main groups: Quantity (Inventory control and planning), Variety, Quality, Cycle time and Market trends (Customers demand). Once these uncertainties decreased, a more accurate planning for production, inventory and distribution happens that gives manufacturers the power to standardize their activities and optimize them [85].

Many academic studies and surveys on RFID-enabled logistics can be classified according to problem solution methods such as Math-based, Heuristic, Qualitative/Mapping, and others. On the other hand some of them are sorted as the type of logistics like forward logistics and reverse logistics. In this section, we will unify the entire solutions as supply chain modeling methods and for several approaches we will move forward to the detailed levels considering case studies and examples especially in RFID-enabled logistics. Figure 2-5 depicts all the problem solution methods and techniques for supply chain.

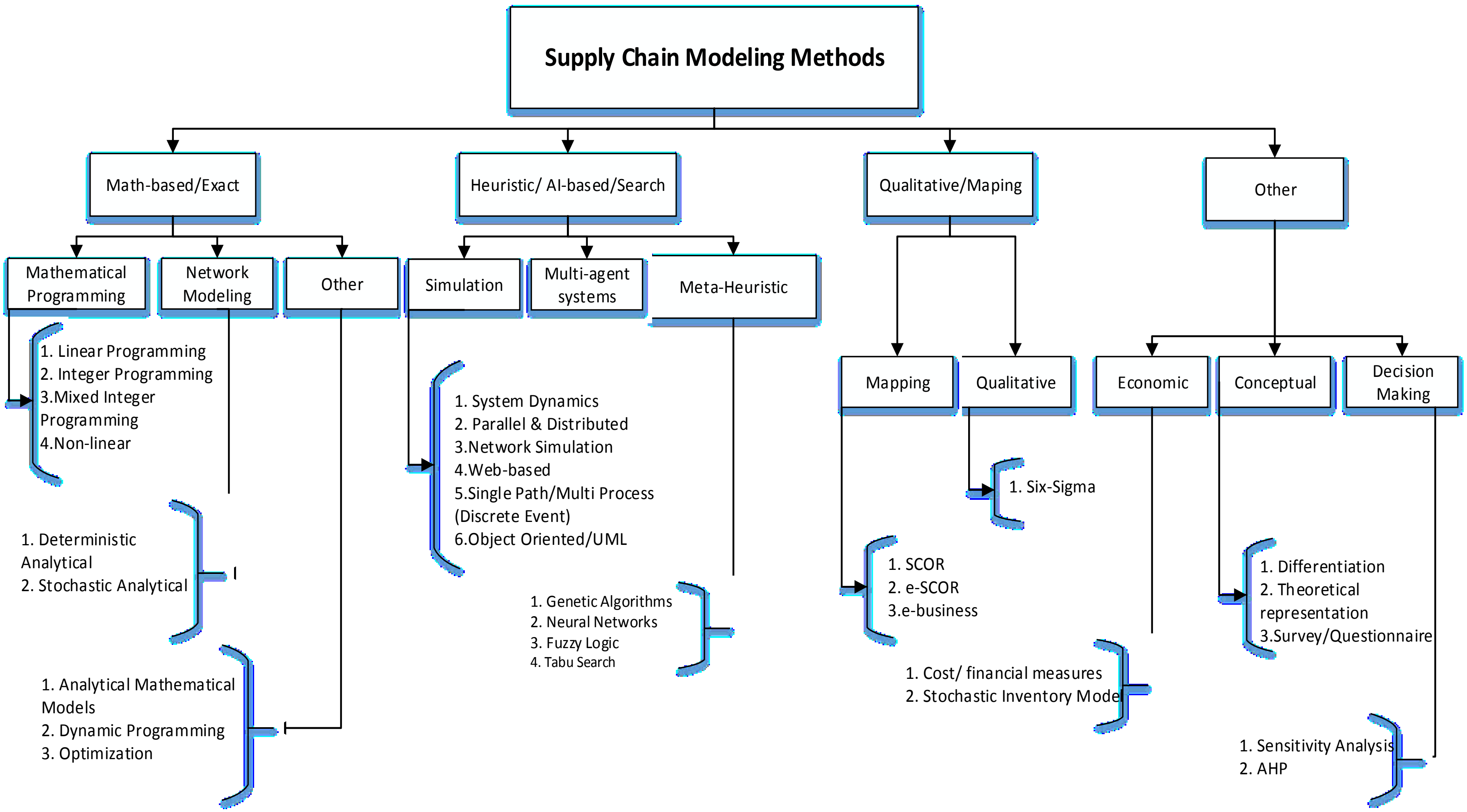


*Figure 2-5: Supply Chain Modeling Methods*

### 2.5.1 Analytical Approaches (Math-Based)

Analytical methods contain the usage of mathematical functions to model a system, so that to find conditions for its optimal performance or to clarify and simplify the behavior of a real system under certain conditions to comprehend it better. Most of the researches used in analytical models are dealing with inventory management system regarding various replenishment policies and models. One of the first studies on inventory inaccuracy because of fault transactions which use analytical modeling method was by Iglehart et al. [86]. The study and their formula were on a single-item, periodic-review inventory and reorder point replenishment policy (s,S). The formula was intended to optimize the frequency of physical inventory counting for the purpose of correcting inaccurate data and safety stock. In 2007, Lee et al. [87] monitor that random distribution on errors and uncertain demand make the previous model an approximation so they installed RFID Technology to that model. They find out that, depending on the fault and the demand, RFID can reduce the inventory cost related to errors of transaction by 5.9%. Gaukler et al. [88] model the effect of RFID on supply visibility in the (Q,R) policy. They offer a model to examine how a retailer can use order process information data acquired by RFID in an uncertain replenishment lead time and demand condition. According on numerical experiments, 47-65% of cost saving are earned on the order process information. Telkamp [89] performs an analytical model to examine the potential effect of RFID on product availability. Based upon the results inventory inaccuracy reduces service level around 7% and also reduce the values of reorder point. DeHoratius et al. [90] examine a multi-period inventory system for a single product with periodic review. They adopt an intelligent inventory management tools using a Bayesian analysis of the physical inventory level. The assumption is that data records are inaccurate and surplus demands are lost and unseen. They present that a Bayesian inventory record is an effective alternative technique that can give good replenishment policies and the needed parameters can be estimated from current data sources.

Sarac et al. [91] examine the effect of RFID on a newsvendor model that includes inventory inaccuracy as a result of out of stocks because of misplacements, thefts, outdated and useless products. The research states that RFID are not ideal and their effectiveness improve with the cost of RFID systems. An analytical model is offered in order to analysis how RFID technology can reduce the inventory inaccuracy and to calculate the best profitable system cost. The results reveal that there is a specific RFID cost that drives the profit optimum. The cost is proportional to the price of the item as well as its ordered quantity.

Jayaraman et al. [92] construct an analytical model to estimate the value in the reverse logistics. First, they establish some cost and revenue terms which apply to an organization involved in RL. They assume an initial capital investment in determining systems to handle the different RL activities and after that incurs recurring annual costs to manage the different activities and to sustain the infrastructure. Based on mathematical model, they conclude that use of RFID tagging; in compare to barcodes can reduce the acquisition, testing, sorting and disposition activities around 67%. This leads to 33% of 90billion (30 billion) saving for all cost components.

### 2.5.2 Heuristic Approaches

Jayaraman et al. [92] designed a heuristic for the solution of Non-deterministic Polynomial-time hard (NP-hard) model. Traditional Mix-integer-linear programming (MIP) tools were unsuccessful in this case caused by complex problem and large amount of variables and constraints. They offered algorithm with three parts: Random selection of potential collection and refurbishing sites, heuristic concentration part, and heuristic expansion component. They also used CPLEX program to solve sub-problems to reach the optimality.

#### *2.5.2.1 Simulation Modeling Techniques*

One of the heuristic methods is simulation modeling. Simulation provides better comprehending of complex model with a meaning of dynamics of the systems.

Kara et al. [93] applied simulation modeling to examine the performance of the reverse logistics network. They found out that the factors such as collection strategy, transporter and transportation mode, disassembly plant, one or bi-directional delivery, inventory costs at station, and number of reusable components affected the collection cost. The advantage of the simulation model in this case is the outcome analysis by determining the most influential factors on the system design.

Biehl et al. [94] used a simulation modeling technique on a carpet recycling network to analyse the effect of the system design and environmental factors on the operational performance of the RL system. They considered experimental factors such as the number of collection centers, the standard deviation of collection rate, and alteration in the collection rate over time, core's recyclability, and control system. They tested forty eight experimental scenarios to measure the performance of the network regarding of customer service, manufacturer cost, and environmental performance index. By simulating, they achieved the result that expanding the number of collection centers is the most effective factor.

Joshi [95] applies a simulation method to analysis the value of information visibility in a supply chain by using RFID technology. Information availability and visibility is one of the success points of software installations. He works on the "bullwhip effect" and simulates various supply chain scenarios. In his simulation, he changes the level of information visibility and varies collaboration of the supply chain components by considering RFID technologies were implemented in the system. The outcomes show that information visibility and collaboration reduce 40-70% of inventory costs. The other result he reaches was that the lessening in lost sales enhances customer service as a result of timely order deliveries and real time traceability.

Leung et al. [96] design a simulation model to analyze the effect of RFID on supply chain management. The main concentration was on the cause of inaccuracy like shrinkage errors. They examine with or without RFID models. By the assumption of RFID can remove the inaccuracy by 100%, they concluded that the backorder quantity reduces by 1%, the average inventory grows by 20% and the inventory levels decreased.

Saygin [97], implement a RFID technology on the inventory management of time-sensitive materials in a simulation environment. He designs and compares four different inventory models so that to examine the effect of RFID in a complex decision making manufacturing system. In each models he use the Rockwell Arena simulation package and also applied Analysis of Variance (ANOVA) to obtain the statistical analysis of the performance. By assuming that RFID system offers 100% visibility of the entire inventory levels, he concludes that RFID can reduce manufacturing costs with a higher service level and lower inventory and waste levels.

Ustundag et al. [98], research on the importance of RFID tags quality on RL cost by simulate an imaginary firm. The example shows that high quality and high price reusable tags are more impact the reduction of the total cost. Their study just considered the batch size, the tag price and the quality of the tags factors.

*2.5.2.2 Multi-Agent Systems (MAS)*

Wang et al. [99] examine the effect of RFID technology in the thin film transistor liquid crystal (TFT-LCD) industry. In their study, they design and develop a simulation model of a pull-based multi-agent supply chain which compare an automatic inventory replenishment policy (s,S) with or without RFID system. Their analysis reveals that RFID collaboration with the automatic replenishment policy can decrease the total inventory cost by 6.19% and cause the growth of the inventory turnover rate by 7.60%.

Vrba et al. [100] evaluate the usage of RFID technologies in industrial applications for the real-time programmable logic controller (PLC) – based manufacturing control. They establish a RFID integrate simulation model to an agent-based control system. Unique RFID agents were identified as mediators among the physical readers and other control agents. The resource agents like machines, transport system components used the RFID data. They used Manufacturing Agent Simulation Tool system for their model.

Chow et al. [101] developed a real-time knowledge-based system called Logistics Process Knowledge based System (LPKBS) to perform logistics process through integrating the knowledge of staff members by the use of agent technology and RFID technology within the dynamic logistics operations processes environment. The collaboration of two technologies has brought out a considerable improvement in the operational efficiency and performance of the logistics process in Eastern Worldwide Company case study.

*2.5.2.3 Genetic Algorithms, Fuzzy Logic and Tabu Search (Meta-Heuristic) Approaches*

The approaches and techniques in this part are mostly use for large size complex and real life problems.

Schleifer et al. [102] applied genetic algorithms (GA) for constructing a large scale reverse logistics network in Europe's automotive industry. The goal is to minimize overall costs and environmental impact by recognizing the number of dismantling and retraction facilities, locations and capacities. They proposed a pre-optimization level for dismantling facilities which required more process in detail so that to decrease the number of optimal places. They also suggested exploiting the Fuzzy-C mean algorithm to group the single supply points into a number of clusters.

Trappey et al. [103] propose a fuzzy cognitive model (FCM) for enhancing RL process decision support. They used FCM to build a RL network with the application of RFID technology to gather real-time data from daily operations. These data was for network performance forecasting and decision support. They also presented a cold storage container management case with using the inference analysis and decision analysis to predict future logistic operation parameters to control the system performance better. The results show the potential of FCM methodology for improving competitiveness and efficiency of dynamic and complex RL networks.

In another article by Trappey et al. [104] they offered a FCM model for decision makers to better comprehend the results of RL processes. First of all, domain experts defined the model based on their experience and after that a GA is applied to generate weights for the model. In the end, the model is integrated with the RFID technology to give the network performance evaluation. Like their other paper, they used a case; however this time it is an automobile repair service. They concluded that FCM model has the potential for enhancing customer service response in a complex and dynamic chains.

Min et al. [105] conducted GA for solving the MINLP model. They are showing the development of a multi-echelon RL network. The solution contains of binary values, which representing decision variables related to the initial collection points, centralized return centers, and collection periods. The outcomes of using the GA present a robust behavior to changes the parameters.

Lee et al. [106] discussed the RFID-based Reverse Logistics System which indicating the benefits of employing a computational intelligence (e.g.GA) method and RFID technology to construct an integrated model for optimizing the coverage of customer's product returns locations. They use RFID to track the quantity of returned products at each collection point, therefore to specify the economical transportation from collection point to collection centers. The outcomes of this model presented that ability to acquire the optimal coverage, minimize the holding time, reduce value of the returned products simultaneously and increase efficiency of logistics operations.

Lee et al. [107] proposed the logistics network design for end-of-lease computer products recovery. They developed a deterministic programming model for systematically managing forward and reverse logistics flows. These networks are compound and complex and therefore they applied a two-stage heuristic approach (e.g. Tabu research) to decompose the integrated design of the distribution into an allocation problem of location and a revised network flow problem.

### 2.5.3 Others Approaches

#### *2.5.3.1 Case Studies and Experiments Approach*

These approaches can help companies to reveal the difficulties and the efficiency of the integration of various systems together. Moreover, companies have the chance to evaluate their related costs and profits. By doing this, companies can use realistic models as an important tool for decision making. Questionnaires and interviews are commonly used in case study research articles, so that to analyze the supply chain actors on the different technologies such as RFID, the feasibility and the difficulty of their adoption in sectors of supply chain like reverse logistics.

Tzeng et al. [108] study the effects of integrating RFID technologies implementation in healthcare industry. They talked about five case studies with five hospitals in Taiwan to recognize the organizational impacts, strategic effects and business values of RFID in healthcare environments. They show that RFID-enabled can remarkably alter processes and human resources, improve customer satisfaction and enhance efficiency and effectiveness of process redesign.

Hou et al. [109] examine an empirical study by questionnaires and interviews to analyze the costs and advantages of RFID installation in the supply chain of the printing industry. They check the feasibility of RFID implementation by way of interviews on eight main actors of different printing companies. They offer several models with changing complexity and propose quantitative cost and benefit analyses of RFID-enabled system.

Manik et al. [110] developed an RFID-enabled project in an automotive industry supplier company to enhance the efficiency of the production process. By the way of functional experiment, they found out the benefits of RFID system and to examine the operational experience and actual implementation cost.

O'Leary [111] conducted RFID technologies and design architectures to use real-time information and autonomic supply chain. They also analyzed different actors such as knowledge-based event managers, database and system integration, intelligent agents, and enterprise resource planning systems in Procter and Gamble and tainted dog food and spinach companies. Through their analysis, they present real-time decision support systems and autonomous system architectures.

#### *2.5.3.2 Decision Making Modeling Methods*

Decision making models intend to conceptualized the process of determining a set of actions between alternatives and help the decision maker. In these models preferences and weights of criteria can be either objective or subjective. Analytic Hierarchy Process (AHP) is one of the most common Multi-Criteria-Decision-Making (MCDM) techniques. Doerr et al. [112] used AHP to measure intangible advantages with Return of Investment (ROI) analysis and simulation. Lin [113] established a five-level, 24 factor fuzzy AHP model to show the integrated framework of RFID development in Taiwanese companies. On the other hand, many researchers use Sensitivity analysis which is the classical tool for dealing more with uncertainty and also has been employed in RL together with deterministic models. Saadany et al. [114] examined the impact of three various parameters: amount returned, number of disassembly locations, and batch size on relative cost. In other research, Kara et al. [93] used a sensitivity analysis to examine the impact of incoming products, the fixed and variable costs of transport, the load and unload times and inventory cost in their assessing the uncertainty and performance in RL network for white good collection.

## 2.6 Research Gaps

A review of the literature reveals that RFID technology could have a significantly positive impact on the FL and RL network of aviation and other industries. However, systems and approaches that simultaneously can provide real-time data and in addition evaluate, forecast and analyze the performance of the process for making a corrective action in an integrated RL network are still rare or under development. As an example, there is lack of research on applying agent-based modeling and simulation technique in the area of RL network in aerospace industry. Besides, wide range of studies focused on discrete event or system dynamics simulation methods in simulation area or other approaches like analytical, case studies, etc.

This research addresses the aforementioned shortfalls by proposing an effective RFID system and simulation method (agent-based modeling) together in which real-time data taken from a RFID system and are modeled with UML diagrams for using in the agent-based simulation software. The proposed framework will enable organizations to track and test the effectiveness of the impact of RFID system on the performance and progress of the RL network.

On the other hand, Anylogic 7.1 simulation software which is used in this research is the best tool for the comparison between agent-based simulation method with other methods (system dynamic and discrete event). Other simulation software like Arena, Vensim, etc., do not have the capability of building up the model in three different simulation methods and verifying the results of all three models at the same time.

The other gap is the lack of case studies with real data in the subject of RL. It means that most of the studies are based on assumptions and hypothetical data. However, in this research with the collaboration of the R&D department of Bell Helicopter Company the actual data were provided and used in the three simulation approaches (agent-based, system dynamics and discrete event). Thus, the results of the simulations are more realistic and reliable that can be used for the future studies.

## 2.7 Summary

The literature discussed in this chapter covers the research work conducted in the areas of RL system and RFID technology, especially in the aerospace industry. Large amount of research work has been carried out in areas of costs, challenges and concerns, advantages and benefits, and considering both subjects (RL and RFID) at the same time in different industries.

In the study of supply chain management, researchers have used different modeling approaches such as analytical (math-based), heuristic, case studies (experimental) and decision making.

Through reviewing the candidate approaches and techniques for modeling the RL system which is RFID-enabled, it was shown that conventional math-based methods are usually insufficient in modeling the RL system due to the uncertainty and complexity in the RL system. The main problem of mathematical approaches is that those methods have limited ability of obtaining many practical factors. This critical issue will result in the failure of those methods in the real-life cases. Instead, heuristic approaches like simulation modeling are ideal for investigating complex, uncertain systems. Simulation modeling is flexible to model a network with various levels of details.

# Chapter 3 : Solution Approach

## 3.1 Framework Overview

In this chapter, the RFID technology will be proposed as a solution approach for the disassembly process. Two steps of RFID technology selection and RFID implementation will be described in more detail in the following sections.

On the other hand, this research also proposes a simulation-based modeling framework of RFID-enabled aircraft process in the RL network with the help of Unified Modeling Language (UML). Simulation modeling is highly flexible to model complex and uncertain systems with various parts in details and scope. To achieve the research objectives, techniques from multiple disciplines are effectively integrated.

The first level of modeling is to give a description of the necessary information to define a system. For the purpose of better communication, documentation and model reuse, it is desirable to develop models in a more scientific manner. When developing a framework for system modeling, one critical criterion is that the framework should contain a library of entities that provide a level of abstraction in the platform of simulation modeling. A key to the creation of a simulation package is the use of a class inheritance hierarchy. A framework is used to describe collections of classes that provide a set of specific modeling facilities. It may consist of one of more class hierarchies. Those collections make the use and reuse of simulation modeling features more intuitive and provide for greater extensibility. In Section 3.4 this issue will be described in detail.

## 3.2 RFID Technology Selection

Nowadays, in this fast pace world, competition is a vital part of every industry. For achieving success, it is necessary for every individual and organization to focus more on their skills to obtain a competitive advantage over their contenders. Many industries believe that one of the best ways of acquiring a competitive advantage is preparing high quality services with the highest reliability, availability and security.

The aerospace industry has always been the leader and pioneer in founding standards, new technology and solutions across all the other industries and organizations. Two well-known aviation companies are already using the RFID tags on flyable parts and also for "maintenance-specific parts" to better support aircraft configuration management and line maintenance, repair shop optimization and life-limited parts monitoring [115].

According to Boeing Company [116], RFID-enabled technology proposes various applications to extensively bring solutions to help the companies. These solutions will present their benefits in different sections of the aviation organization which is categories as below:

Interior Lifecycle Management

- Emergency Equipment Management
- Interior Management

Component Lifecycle Management

- Rotables Management (Component or inventory item that can be repeatedly and economically restored to a fully serviceable condition. Also service method in which an already-repaired equipment is exchanged for a failed equipment, which in turn is repaired and kept for another exchange)

- Repairable Management

Airframe Lifecycle Management

- Airframe Degradation Management

In addition, Boeing argues that RFID technology will provide significant cost saving and efficiencies via:

- Better utilization of maintenance technician's time through reduction of non-value-added tasks
- Fewer operational errors
- Greater visibility of operations and information
- Reduced spares/in-process duration
- Improvement in human factors for technician

## 3.3 RFID Implementation

The following proposed RFID system specifications and design will carry out a simple RFID system or network, since the subject of this study is not on the design of RFID technology framework. The structure of the RFID system is shown in the Figure 3-1. Major components of the RFID system include:

1. A Radio Frequency Subsystem: it contains of components that are related for performing identification and wireless communications. Readers and Tags are a part of the RF subsystem.
2. An Enterprise Subsystem: it contains of a backend database (SQL Server) and a RFID server.

a. Backend Database: The backend database consists of information such as the tag identification number, the secret key shared between the tag and the database and item description of the tagged item.
b. RFID Server: This composes of systems and applications that communicate with the readers and process data received form the RFID server:
    i. Reader adapter: an interface to connect the readers.
    ii. Middleware: an intermediate part between the lower RF subsystem and the upper level database that consists of pre-processes data collected from the RF subsystem and gives secured and cleaned data to the upper components.
    iii. Tag database: secured and cleaned tag data is stored in the database. This database is designed to be used by the high level applications.

The communications between readers and RFID tags are by wireless channels. The RFID server is connected to the upper level applications and processes.

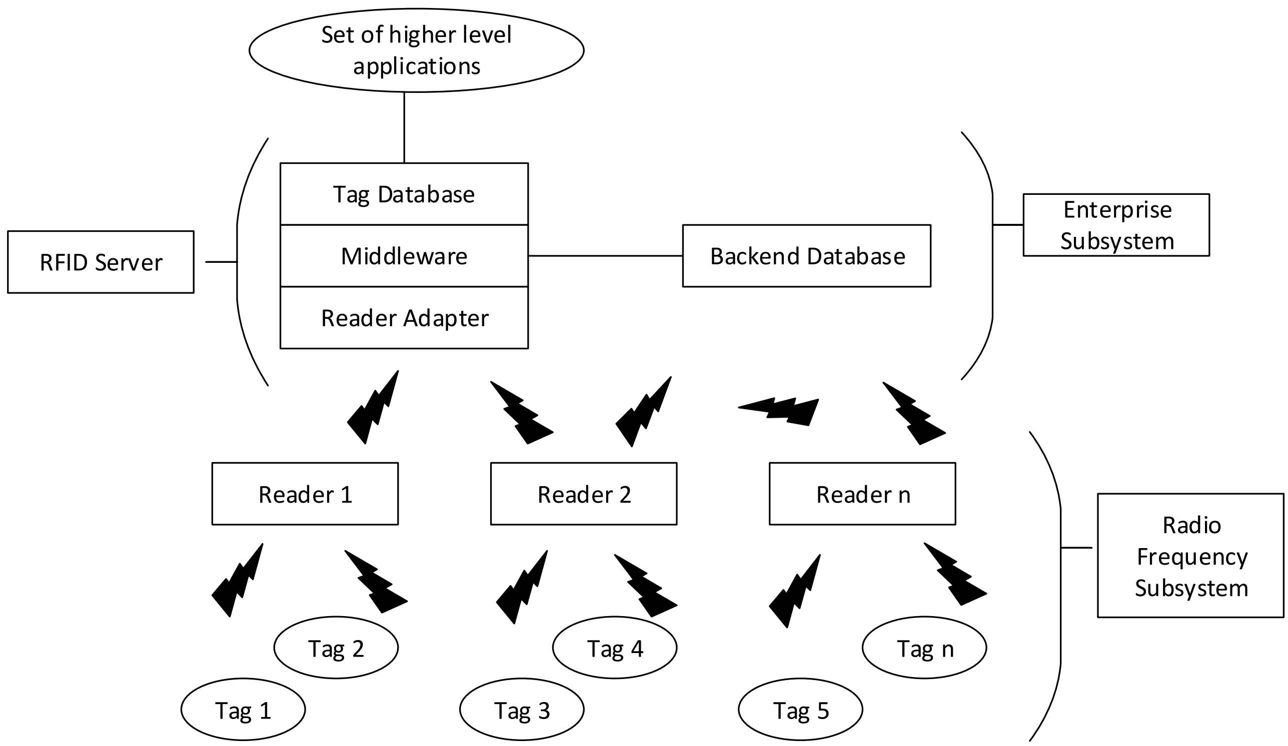


*Figure 3-1: RFID System Components*

Figure 3-2 represents a RFID framework based on the process map which consists of all the above mentioned specifications and components of a RFID network.

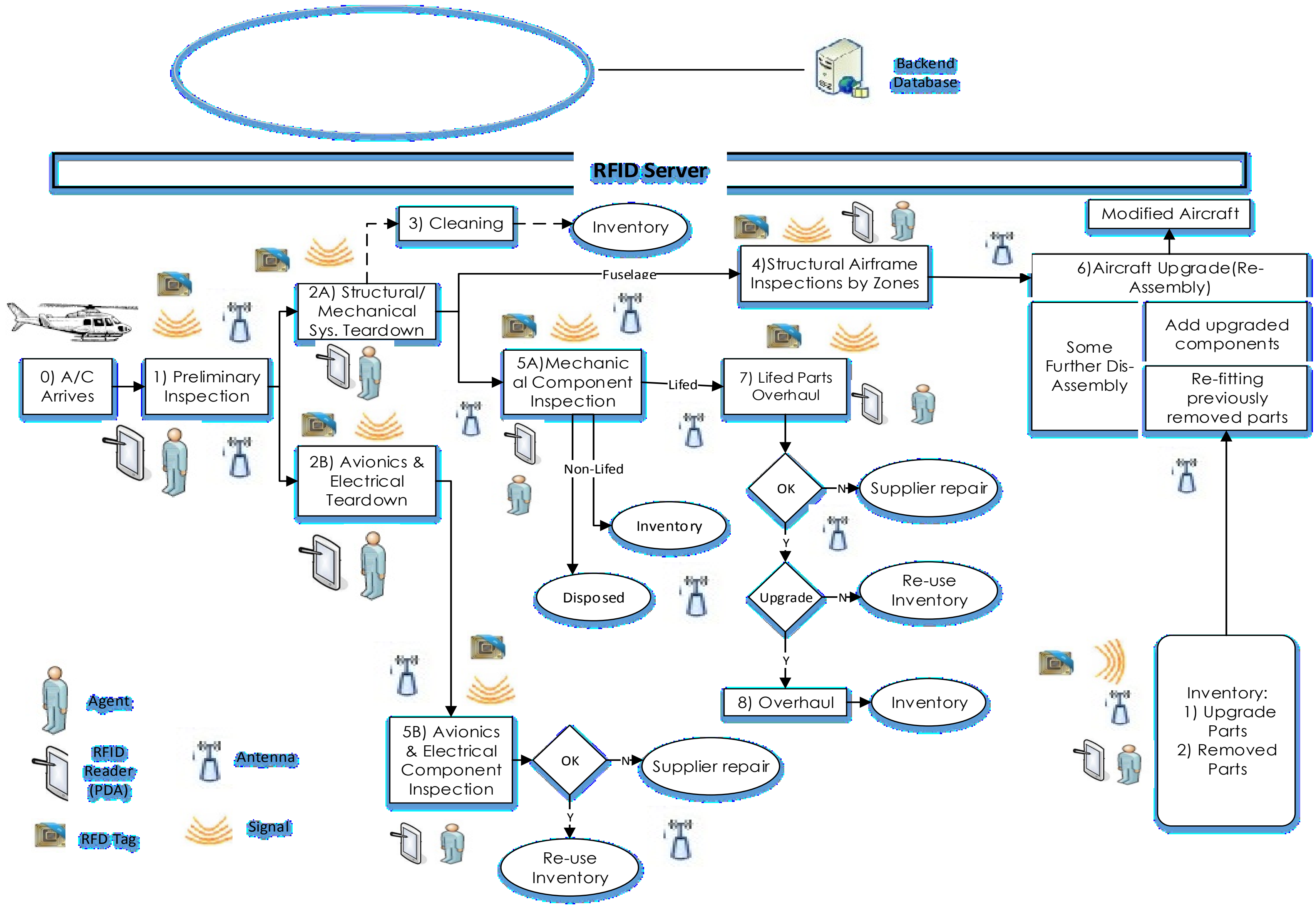


*Figure 3-2: RFID System*

### 3.3.1 Process Map

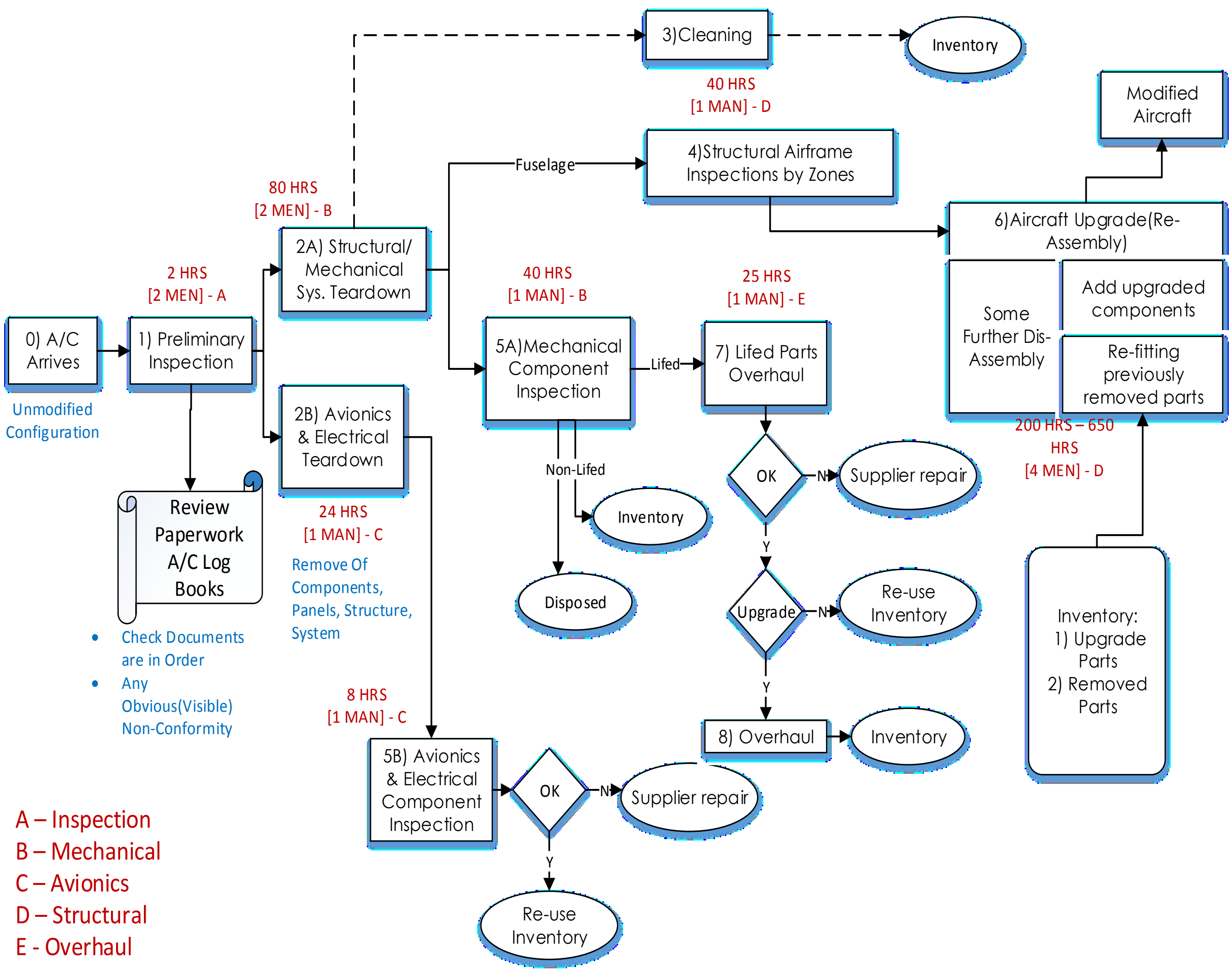


*Figure 3-3: Disassembly Process Map*

### 3.3.2 Process Map Description

The high level of disassembly process of a helicopter is shown in Figure 3-3. The first step of the process starts with the arrival of an unmodified configuration aircraft at the disassembly line. In the next step the inspection team (A) which contains two men will perform the preliminary inspection for two hours. This task would be the general inspection of the aircraft such as reviewing paperwork's of the aircraft log books, inspecting any obvious (visible) non-conformity and checking the order of documents. At the end of this level the helicopter is ready to be disassembled in two parallel ways; the structural/mechanical components system teardown and the avionics/electrical components teardown. The structural/mechanical parts will be separated into two different divisions; the main part which is structure or the fuselage of the helicopter and other parts are the smaller components and parts such as Rotor Blade and Tail Boom. On the same station where the fuselage parts such as Cowl, Transmission, Engine, Skid and Cabin Doors are disassembled by two mechanical experts (B); the other mechanical parts like stabilizer Bar, Swash plate, Tail Rotor, Tail Skid, Synchronized Elevator and 90 & 45 degree Gearbox will be disassembled by the same mechanical engineer for almost 80 hours overall. However some parts need cleaning which will be sent to the cleaning station and after that directly to the inventory (the cleaning station is not included in the scope of this thesis). Afterwards all the structural (Airframe) and mechanical parts should be inspected for more details and further testing by zones through structural (D) and mechanical (B) inspectors for 40 hours separately. From the mechanical inspection, components will be divided into three categories; lifed, non-lifed and disposal parts. Some parts are useless so they will be sent to disposal; the other components that did not perform and lived sufficiently (non-lifed) will be transported to the inventory for using in the reassembly process. However the lifed parts which already reached their end of life cycle will be inspected and overhauled. In this process if the lifed parts are not functional, it means they do not meet the specifications and standards, they will be sent to the supplier for repair but if they are useful, the overhaul experts (E) will consider them for using in the upgraded aircraft, therefore they will be sent them to the re-use inventory. On the contrary, the other parts should go to the overhaul and after that will be transferred to the inventory. The avionics/electrical components also have the similar process, where one avionics expert (C) removes components, panels, structures and systems for approximately 24 hours. Later the same specialist (C) will be inspecting the teardown components to differentiate between functional and working parts with those which are wrecked or are not useful anymore. The components that have the capability of being used again will be sent to the inventory for usage in the upgraded helicopter and the remains that could not be used for any cause will be transferred to the suppliers. At the same time, the airframe (fuselage) of the helicopter will be moved forwards to the end of RL network for reassembling and refitting with the previously removed parts and adding some new upgrade parts from the inventory which are tagged already with RFID tags to manufacture an upgraded helicopter.

## 3.4 Modeling by Unified Modeling Language (UML)

In the past years, graphical design has been the most successful application of the object-oriented (OO) and agent-based modeling (ABM). At the same time, OO and AB modeling and architectures of graphics systems have undergone development too. Among the OO analysis and design techniques that are also applicable for ABM, the Unified Modeling Languages (UML), that is a commonly applied graphics, standards notion in system modeling, is the most favorable.

Therefore, this thesis adopts the integration of OO, ABM and UML for modeling in simulation-based decision making. OO and ABM design have excellent ability in balancing the visibility and confidentiality through encapsulation. The hierarchy structure with various relations makes the design highly reusable, extensible and easy to understand. The system developed based on OO and ABM design is generally more adaptive to changes overtime. It greatly reduces the risk of building complex systems because they are developed to evolve incrementally from smaller systems. UML is an excellent descriptive tool for OO and ABM design. It provides a suit of diagrams for capturing both static structure and dynamic behaviors in the system. The employment of graphical techniques enables it as a highly communicative tool. It is noted that UML is independent of the particular programming languages, development process and hardware platform.

In details, UML most directly unifies the methods of Booch et al [117, 118], but its reach is wider than that. It is a notational system that can help in modeling systems using mostly OO concepts. It is “a language for specifying, visualizing, constructing, and documenting the artifacts of software systems, as well as for business modeling and other non-software systems” [119]. It can be applied to understand user requirements, to design components at different stages, and to browse, configure, maintain, and control information. It supports most existing OO and ABM development processes.

UML defines a set of nine basic diagrams that provide the multiple perspectives (static and dynamic) of the system under analysis or development. Standard modelling techniques may standardise and facilitate the development process through the use of common concepts, notations and supporting tools and thus increase compatibility with other software systems.

The heart of object and agent oriented problem solving is the construction of a model. The model abstracts the necessary details of the underlying problem from its usually complex real world. The model should aid to make our thinking simple, help our comprehending of the system, assist to clearly describe the needs of the system and help in visualising how to construct the system. The development of the aircraft disassembly process model involved a repetitive process which its context is the on-site disassembly processes and its scope is the type of information about such processes and the participants (e.g. resources, materials and etc.).

In the analysis and design phase, the UML catches the static structure and dynamic behaviour information of the disassembly process or algorithm. As an example, use case diagrams help to catch scenarios, interaction diagrams aid to capture the behaviors of use cases, and class diagrams aid to catch objects, agents and describe the types that are involved in the system. The diagrams work together to describe and depict different aspects of the system. Therefore, the UML is used to model the Aircraft Disassembly Process.

To understand the needs and acquire the behaviour of a system, its sub-systems and its external environment, the modeller first uses the "use cases diagram" to explain the sequences of scenario for the processes requested by external actors. The use cases diagrams contain various use case scenarios, and these use case scenarios show the system in terms of actors, actions and the relationships among the elements. Use case diagrams are the foundation to comprehend what the users exactly want, since use case diagrams are important for testing and understanding executable systems through forward engineering and reverse engineering.

Defining and identifying a conceptual model is the second step. The conceptual model is illustrated in a set of diagrams that describe objects and agents. It contains recognition of the concepts, attributes, and connections in the problem domain.

Meanwhile, interaction diagrams work on object and agent interaction and message passing. These diagrams designate sequence of message exchange among roles that implement the behaviour of the system. Typically, there are two kinds of interaction diagrams: sequence diagrams and collaboration diagrams. In sequence diagrams, a set of messages are shown in time sequence. Lifelines show each classifier's role (objects and agent), and arrows represent message passing between different lifelines. A collaboration diagram allocates the responsibilities to objects and illustrates how they interact via messages; also it shows the roles as geometric arrangements. The messages are shown as arrows attached to the relationship lines connecting classifier roles, and a sequence of numbers which are attached to the beginning of message descriptions indicate the sequence of messages [117].

In the end, the specification of a system is then presented in forms of class diagrams. A class diagram not only illustrates a collection of static model elements, as an example classes, types, and their components and relationships, but also includes certain operations which are expressed in other diagrams, such as collaboration diagrams. In most modeling processes, class diagrams are the final product.

For the purpose of modeling of the disassembly system, this thesis employs the most useful types of diagrams such as class diagrams, use case diagrams, activity diagrams, and sequence diagrams, to model the static structure and dynamic control of the system, respectively. In the remaining part of this section, a collection of objects and agents in the system are captured by the class diagrams. Then the applications of use case, activity and sequence diagrams for representing the disassembly process are discussed.

### 3.4.1 Building Classes

The first step of OO and AB design is to identify and develop a library of objects and agents, which can be mapped with a real disassembly environment. Class diagrams in UML are used to capture the generic objects and agents. Both objects and agents can be organized in a hierarchy structure indicating their relationships. The definitions of objects and agents with their relationships could aid the modeller to formally define the broadness and depth of the modeling environment regarding the specific cases.

Based upon the classification of Mize [120], three top-level classes are defined for the system: physical objects, information objects and control objects. These classes also can be used for the agents of the system. The physical object/agent is an object/agent with tangible correspondent in the real world system (e.g. disassembly process), such as materials, machines and operators. The information object/agent is a carrier that is involved in information-related activities. They could either be tangible or intangible, such as bill of materials (BOM) and routings. The control object/agent is responsible to coordinate different objects/agents to fulfill certain functionality of the system. Each class has a set of subclasses that are organized in a hierarchical structure. The remainder of this section describes the class definitions in details.

1. Physical classes

   Four derived-classes are defined for the physical class. They are resource class, process class, material class, and queue class as shown in Figure 3-4.

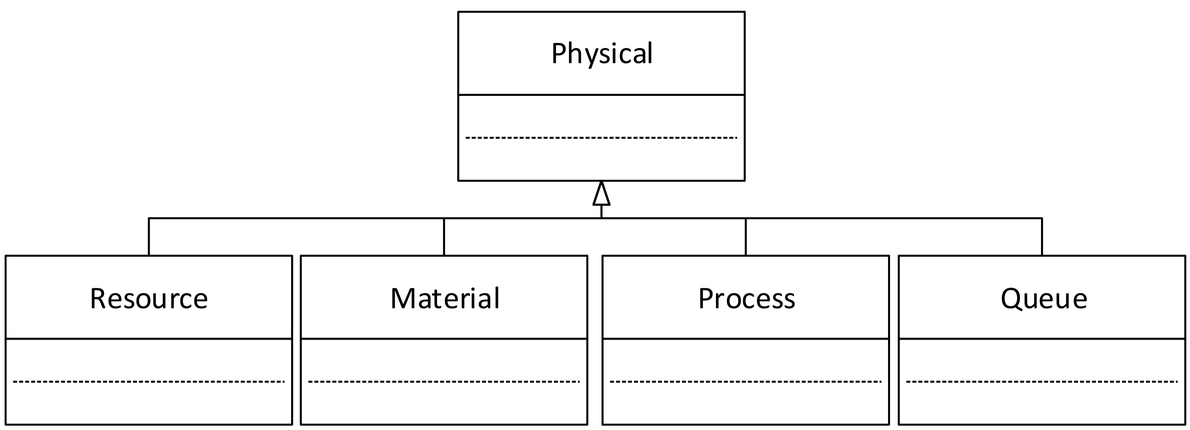


*Figure 3-4: Physical Classes*

- Resource: it is an abstraction of elements that facilitates and supports the implementation of disassembly process. Each resource has attributes of name, description, and the system it belongs to. Costs include overhead cost and operational cost. Resource is further classified into two subclasses: Equipment and Labor. According to the resource characteristics, four classes inherit from equipment. These classes are machinery, workstation, material handling device, and RFID System. Machinery, RFID System and workstation are core equipment that facilitates the physical transformation like disassembly or assembly and quality control of materials. On the other hand, material handling devices act as auxiliary resources. Transporter and overhead crane are two types of material handling device (Figure 3-5). The RFID system includes tag, reader, RFID server, backend database, reader adapter, tag database and RFID middleware. The attribute of tagID shows the unique number for each tag in the whole system Figure 3-6.

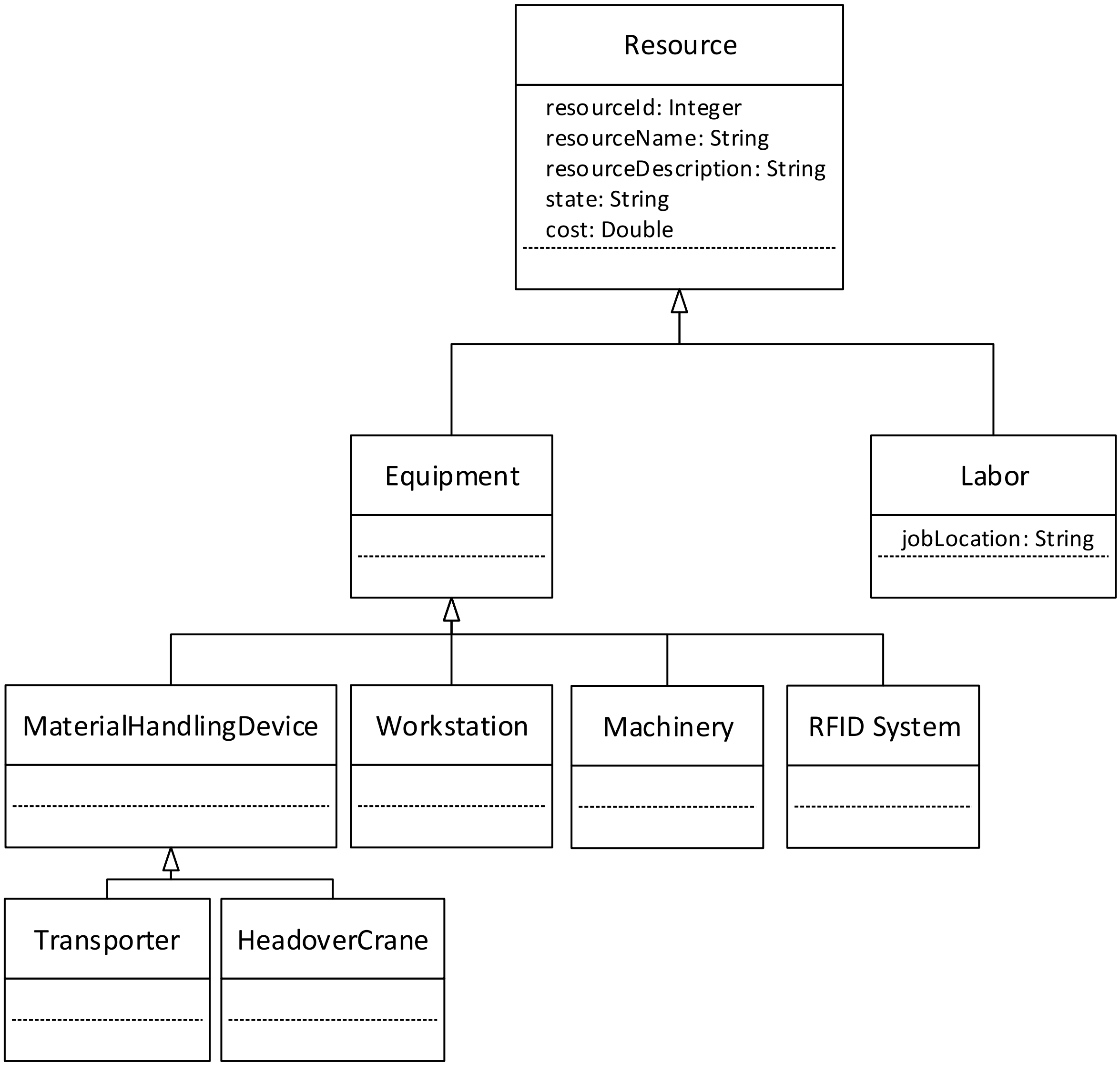


*Figure 3-5: Resource Classes*

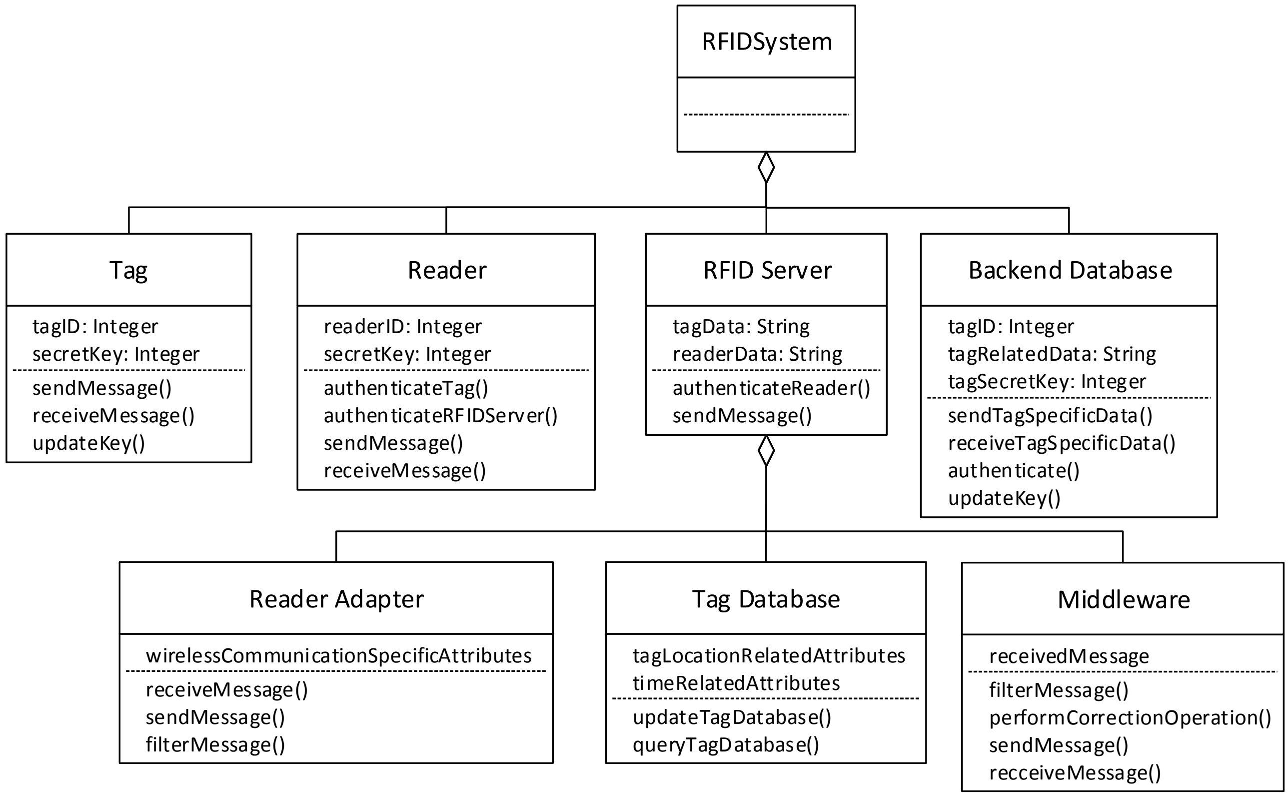


*Figure 3-6: RFID System Classes*

Meanwhile two classes inherit from the Labor class. These classes are Manager and Engineer. Managers inside the Manager class have the responsibility for monitoring processes and generating work orders and allocate them to Engineers inside the Engineer class. Manger consists of General Manger, Contract Manager, Project Manager and Crew Chief. Engineers have the responsibility for performing the jobs and activities allocated by managers. Such as Planner, Scheduler, Procurement, Mechanical, Structural, Electrical/Avionics, Overhaul, Quality and Production Control & Logistics.

These sub-classes of Resource class have a potential to be considered as agents of the system (Figure 3-7).

The agents in the disassembly framework are listed as follows:

1) General Manager Agent (GMA)

As GMA is the interface between customer and company, it is their responsibility for sending customers order to project manager. GMA is also involved in preparing the contract draft and sending it to the customer for signing.

2) Contract Manager Agent (CMA)

   This agent has the duty to prepare contract draft with the help of GMA. For this purpose CMA requests required information from project manager.

3) Project Manager Agent (PMA)

   PMA is responsible for checking capacity availability from crew chief by asking for the feasibility of the customer's order. After that it books the aircraft arrival from the crew chief. In the meantime PMA requests the procurement agent for purchasing needed tools and materials, and also order planner agent for preparing the related instructions and documents. At the whole time of the disassembly, PMA monitors the process.

4) Crew Chief Agent (CCA)

   The CCA is responsible for do the feasibility study, receiving the original aircraft and sending the modified one to the customer. During the process, CCA is responsible for coordinating tasks between the other engineer agents. In addition, it is responsible for constantly tracking and monitoring the disassembly status based on the data received from the RFID system for being aware in case of machine breakdown or any disruption of the process. Additionally, CCA collects material processing information from the RFID system or materials which are tagged with RFID, and updates the system database. The duty of labeling components with no RFID tags is under the supervision of CCA.

5) Planner Agent (PA)

   This agent is responsible for creating a tag which is containing detail disassembly instructions for each material based on order information received from PMA. Also PA is responsible for checking the engineers and materials availability, and project lead times.

6) Scheduler Agent (SA)

   SA agent is responsible for evaluating human resource availability and order priority. In addition, SA does the detail plan with estimating capacity to prepare the schedule and sends it to the other agents like PMA and CCA. This agent links up with the RFID system database to retrieve and save the overall system information for having an actual schedule.

7) Procurement Agent (PCA)

   This agent is responsible for all the related works with materials such as evaluating materials availability, requesting invoice for the purchased ones with their lead times, and at the end ordering required materials like new components, tools.

8) Production Control & Logistics Agent (PCLA)

   The PCLA is responsible for selecting and verifying materials. The agent has to do the regular warehouse activities such as sign logs, check spaces, attach labels, and transfer materials to their allocated places (Mechanical and Electrical Warehouses) and finally complete data entry. On the other hand PCLA has the responsibility to solve space problems in the warehouses and periodically order to adjust the inventory.

9) Mechanical Engineer Agent (MEA)

The MEA is responsible for tasks which have been allocated by the CCA. These tasks contain of mechanical teardown parts and inspecting those parts as well. Another task is to separate lifed parts, non-lifed parts, disposal parts in inspecting process and refitting the aircraft.

10) Electrical/Avionics Engineer Agent (EAEA)

This agent has the same responsibility as MEA but in the area of electrical and avionics components.

11) Structural Engineer Agent (SEA)

The SEA is responsible for checking and testing fuselage and airframe of the aircraft by zones.

12) Overhaul Engineer Agent (OEA)

The OEA is responsible for overhauling the lifed parts of the aircraft that are reusable or can be upgraded.

13) Quality Engineer Agent (QEA)

This agent is responsible to do preliminary inspection process to find out any non-conformity and check that components are in order when the aircraft arrived in the system. Also QEA is responsible for repairing and disposal the related materials. Finally after re-fitting and assembly the components, QEA is responsible to do the final inspection check.

14) RFID System Agent (RSA)

The RSA is responsible for the provision of the RFID information from the RFID readers. This information is translated by the agent from the raw signals into the readable format and sends to the PMA, CCA and PCLA. This information that is pending by the RFID readers will be read by the agents in default time intervals. The agent has its own RFID information database.

15) Material Agent (MA)

The MA is responsible for the provision of the material information and material location information from the attached RFID tag. The information will be send to the CCA and RSA. This agent represents a corresponding material (e.g. fuselage, mechanical parts and electrical/avionics parts [121].

- Material: it is an abstraction of components and final products in the system. The attribute of materialType indicates the physical form of the material, which could be component, or finished product (e.g. assembled helicopter). 'sysNumber' is defined for the information identification of materials, which may refer to part number, work unit number, RFID tag ID or serial number. The material condition is represented by the attribute of materialCondition. The basic candidate values include reassemble-able, reassembled, and new materials. The material cost also could be assigned if necessary (Figure 3-8).
- Process: it is abstracted from operations in both reassembling and assembling. While a process may not require any resources, often times a process may need one or more resources to fulfill the activity. Costs as performance measure is also defined for the process. In addition, subclasses that are inherent from the Process are defined in Figure 3-8.

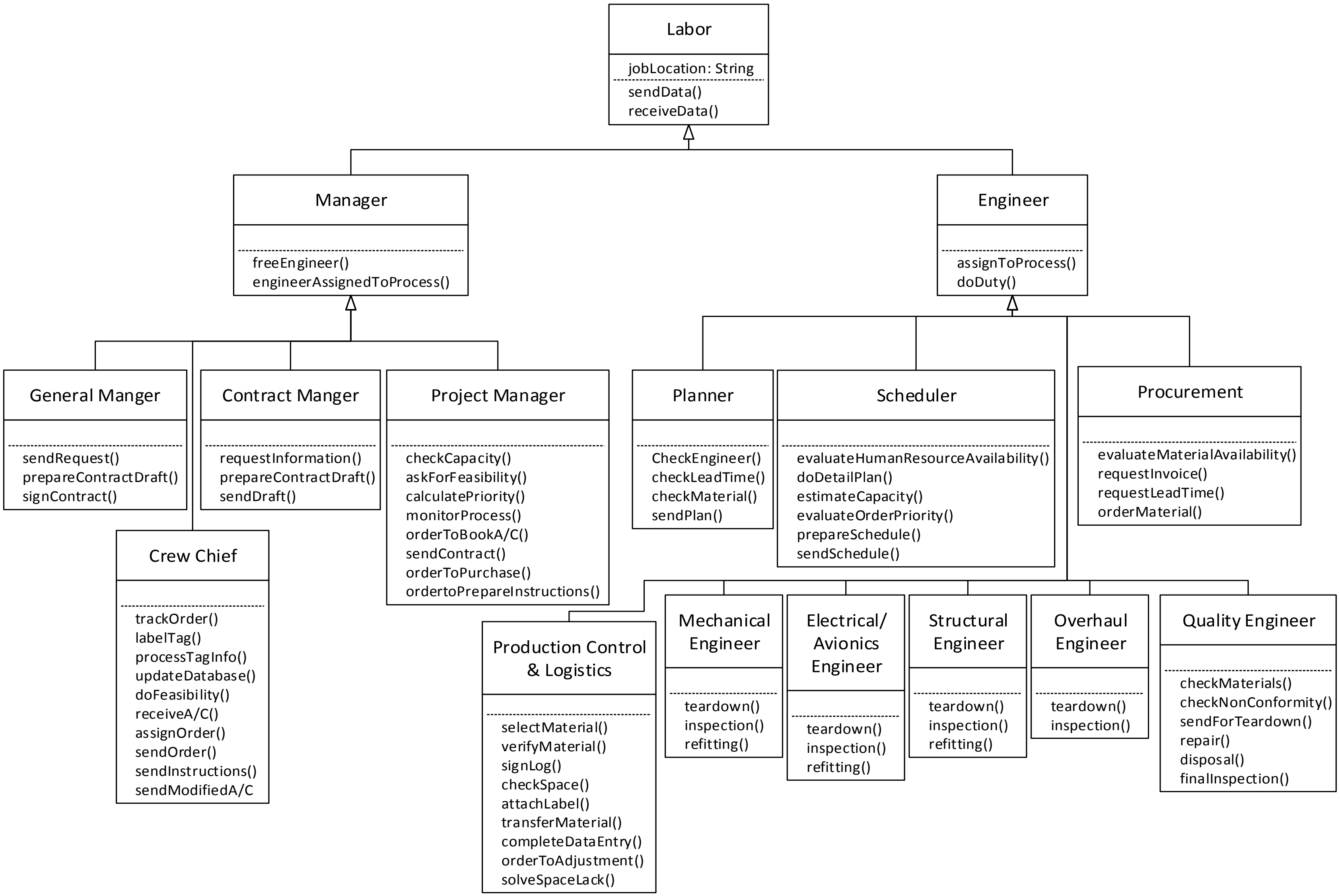


*Figure 3-7: Labor Classes*

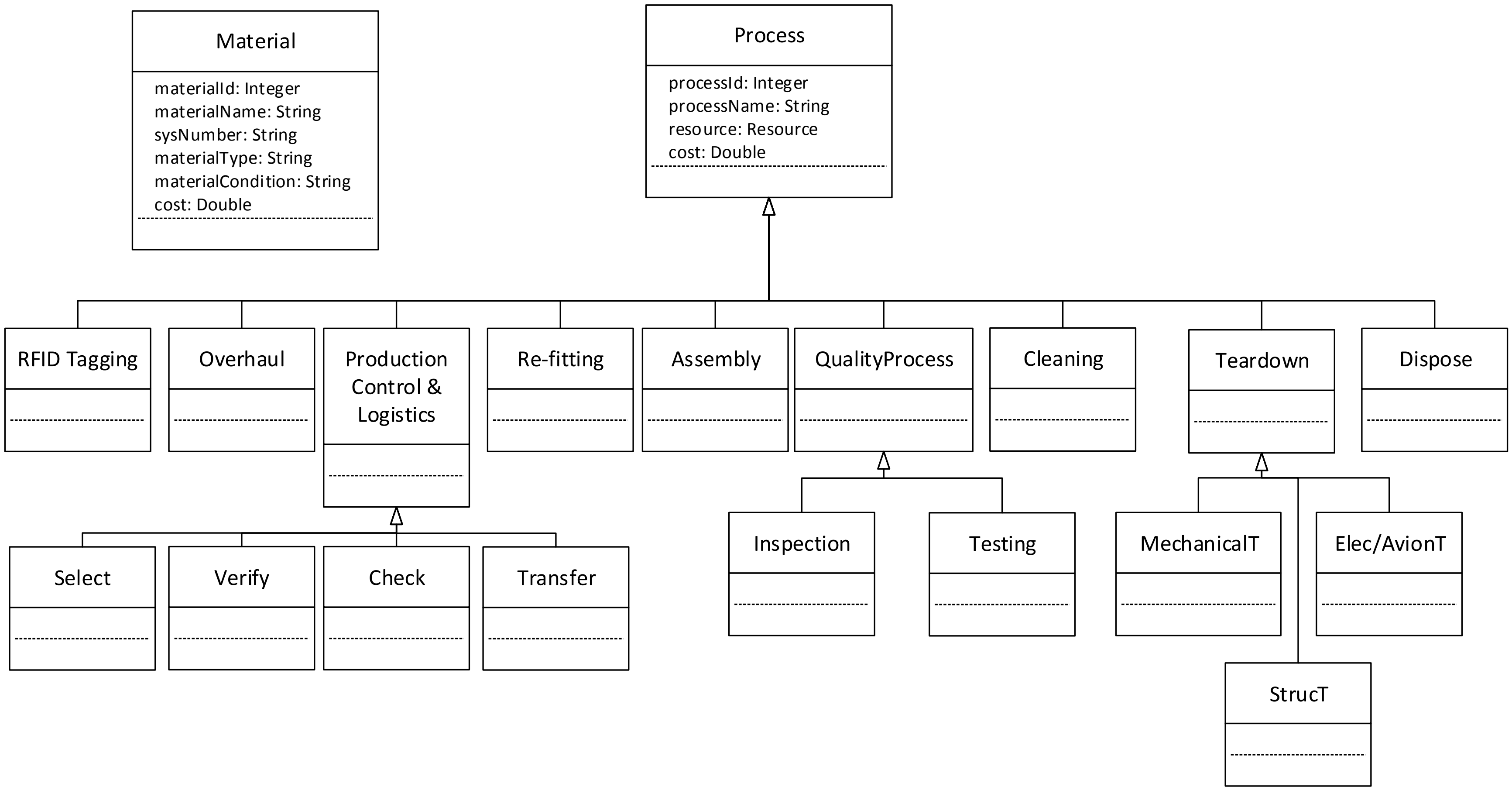


*Figure 3-8: Material and Process Classes*

- Queue: it refers to a group of entities with the same state in the system. The attributes of 'enterTime' and 'leaveTime' denote the time when the entity joins and leaves the queue, respectively. Performance measure, including costs is also associated with a queue. A new entity in the queue is created through operation 'addQueue()'. While an entity is dismissed through 'deleteQueue()', the candidate state could be 'waiting', 'on hold' or 'in process'. The state of waiting basically refers to the case when entities are waiting for available resources or processes. 'On hold' is applied when an entity is suspended due to non-resource related issues, such as order confirmation and inventory control. An entity is 'in process' when it is being processed by resources. There are two types of queues: process queue and job queue [122].
    a. A process queue is formed when two processes are requesting the same resource or resources. Priority rules in scheduling are designed to resolve the conflict.
    b. A job queue consists of jobs that are suspended in a location. JobQueue is always involved in disassembly and assembly scheduling and inventory control. Figure 3-9 shows the Queue elements and its sub-classes [120].

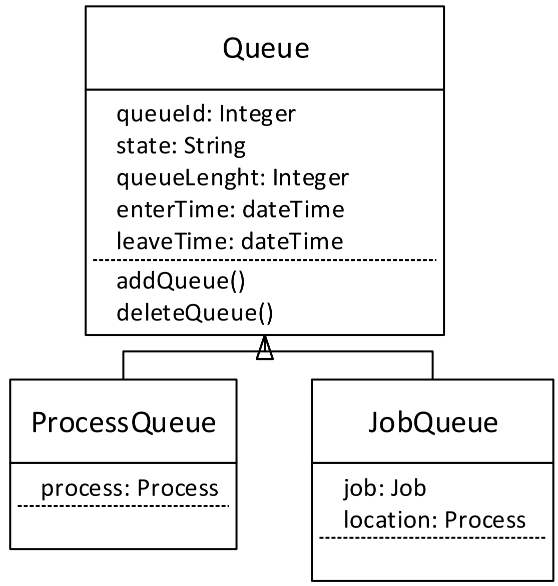


*Figure 3-9: Queue Classes*

2. Information classes

Figure 3-10 shows four sub-classes derived from Information class with their attributes.

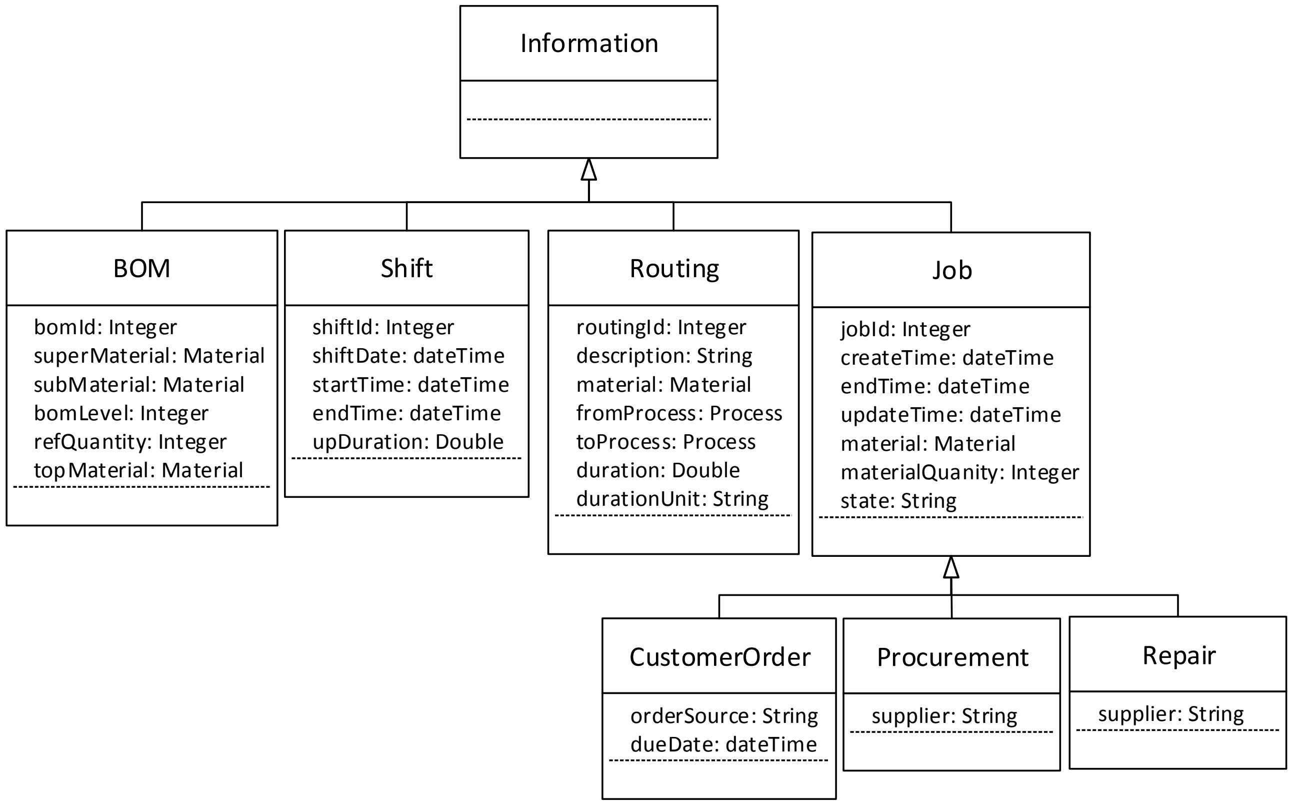


*Figure 3-10: Information Classes*

- BOM: it is an abstraction of bill of material (BOM). A BOM is a hierarchical structure describing the components in a product. Mostly, a finished product is composed of various assemblies while each assembly is further made of parts or even raw materials. A BOM mainly indicates the relationships between materials; therefore BOM is an association class for the Material classes. The attributes, 'superMaterial' and 'subMaterial', represent the parent-child relationship between two materials. The attributes of 'refQuantity' designates how many 'subMaterial' are in one 'superMaterial'. The 'bomLevel' specifies the current position in the product hierarchy while 'topMaterials' shows the final product in order that BOM for different products could be differentiated [120].

- Shift: it represents the scheduled period of a disassembly and assembly resource. A day could be assigned in ‘shiftDate’. The attributes, ‘startTime’ and ‘endTime’, indicate the time a shift starts and ends, respectively. The ‘upDuration’ indicates the workable time. The capacity planning is to link the Shift and Resource through assigning quantity of resources for the shift.
- Routing: it is an association class between Process and Material. The ‘material’ refers to the parts or components involved in the routing. The upstream process (fromProcess) and downstream process (toProcess) of the material are also identified by the reference of Process class. The ‘duration’ indicates the time period during which the material stays at the ‘fromProcess’ while ‘durationUnit’ shows the time unit. The base level of material flows modeling in the simulation is identified by routing [120].
- Job: this class can be a customer order, repair or a procurement order. Its main attributes are time-related attributes like ‘createTime’, ‘endTime’ and ‘updateTime’. In each job, the kind and quantity of material are specified. State is specified to show the status of the job. In the customer order, the ‘orderSource’ of a ‘CustomerOrder’ could be either from internal disassembly/assembly needs or from external market demands. These demands are depending on the production driver such as ‘push’ or ‘pull’ environment. In our case, orders are generated regarding customer demands which are a ‘pull’ system. The procurement and repair classes are designed for material procurement or repair from external suppliers [120].

3. Control classes

The control classes are identified to show the decisions of the disassembly system. Generally, in the areas of production, assembly and disassembly, there are three kinds of control classes, as illustrated in Figure 3-11.

- CapacityPlan: it is designed to cover the capacity planning area. The class is in relationship with the classes of shift and resource.
- Scheduling: the attribute of 'queuePDR' is the priority dispatching rule to prioritize queues that are inherent in two sub-classes of 'Scheduling'. The class of 'ProcessQueueScheduling' contains an attribute of 'processQueue' to collect a group of process queues for scheduling. In similar manner, the 'JobQueueScheduling' is an abstraction of scheduling for various job queues. Therefore, it can be made of multiple job queues. The class involves attributes of batch size and specification.
- InventoryControl: it controls the job queues which are associated with the repair and procurement of materials. The decisions for inventory like control strategy, order quantity and order-to-level, are identified to reveal the control policy. The attribute of 'curLevel' shows the current inventory level, which is contained of the on-hand inventory, backorder inventory and work-in-process (WIP). The last attribute is 'reviewTime' to show and record the next review. The class of 'inventoryControl' could control the materials in either disassembly or assembly.

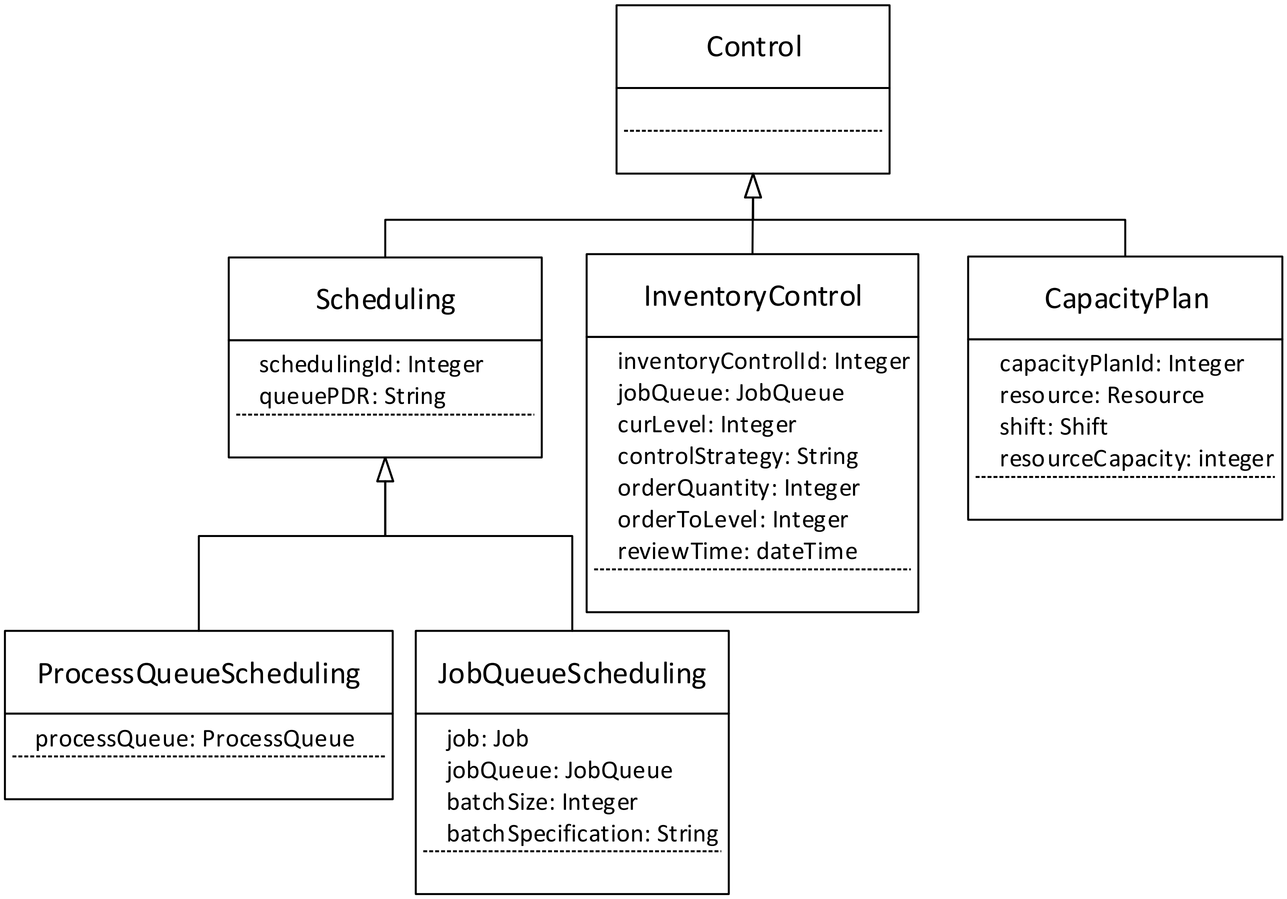


*Figure 3-11: Control Classes*

The class diagrams have been designed and identified to acquire the static structure of objects and agents in the system. However, the class diagrams are not enough to model all aspect of the system such a dynamic behaviors. Therefore, other diagrams like activity diagrams, use case diagrams and sequence diagrams are used to accurately show how the different objects and agents perform and interact with each other to complete disassembly and assembly processes. Figure 3-12 shows that the identified classes are organized in accord with their relationships for disassembly of an aircraft. Figure 3-12 focuses on the classes which are involved in the mechanism for disassembling an aircraft along a path. As an example, we can see the abstract class of Resource with two children, RFID system and Process. Both of these classes inherit the attributes and operations of their parent which is Resource. The class Material has an association to BOM class and two inheritance relationships with Job and Routing classes. It means that the instance object of both BOM and Material class are connected together.

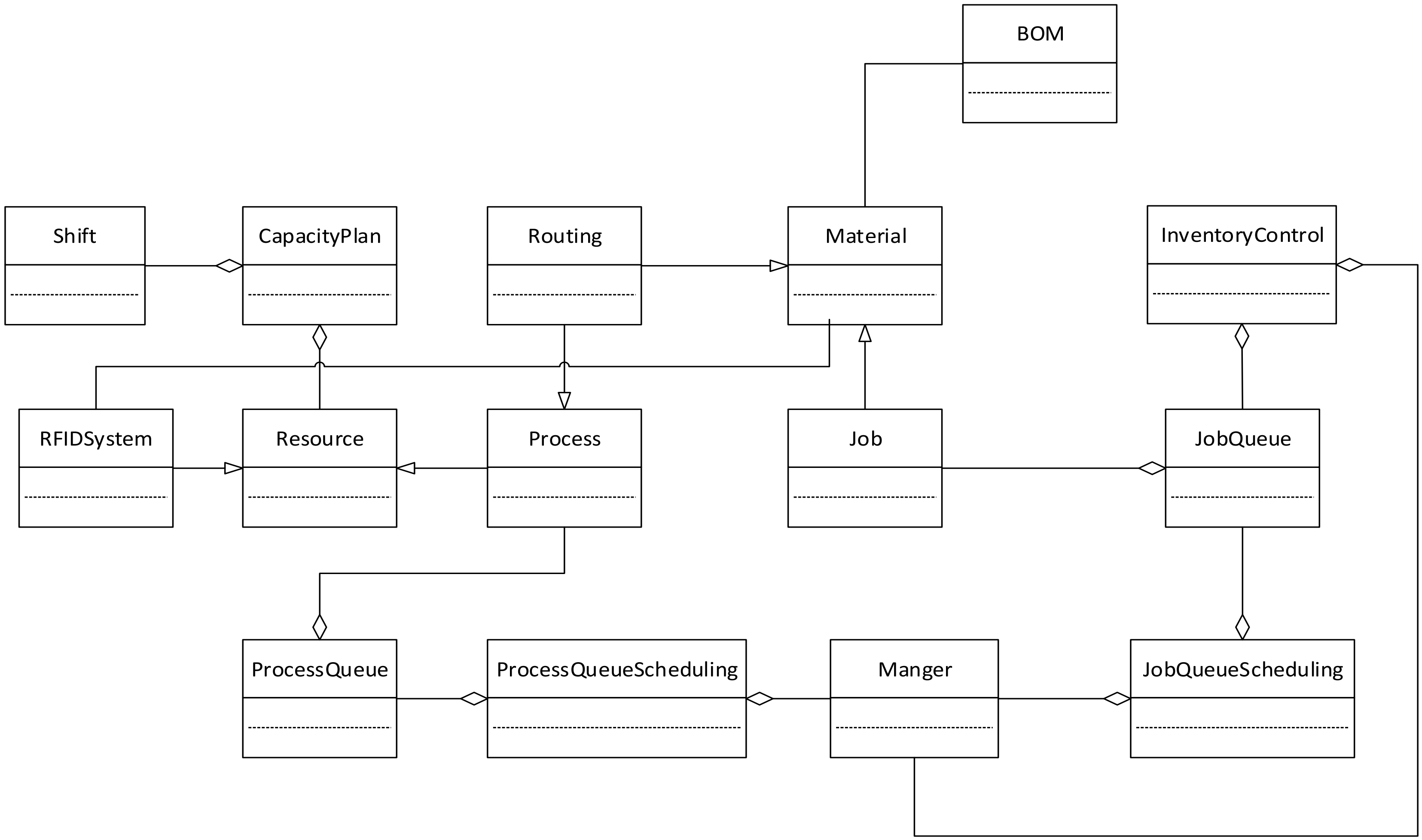


*Figure 3-12: Relationships among Classes*

### 3.4.2 Constructing Activity Diagrams

An activity diagram shows flows from activity to activity within a system [117]. It illustrates the dynamic aspects of the process and system, since it emphasizes the flow of control between activities. Figure 3-13 is an example of such diagram which reveals the production control & logistics process flow. Each round-corner box includes an execution of a statement or activity. For example, the activity diagram starts at the receiving material. After that an arrow leads to the next step of selecting material. The flow in the activity diagram provides important perspectives to complex operations. With proper notation, such as a start state sign, a final state sign, arrows, diamond decision signs, and fork nodes with multiple labeled exit arrows. And also Figure 3-14 shows the disassembly process activity diagram.

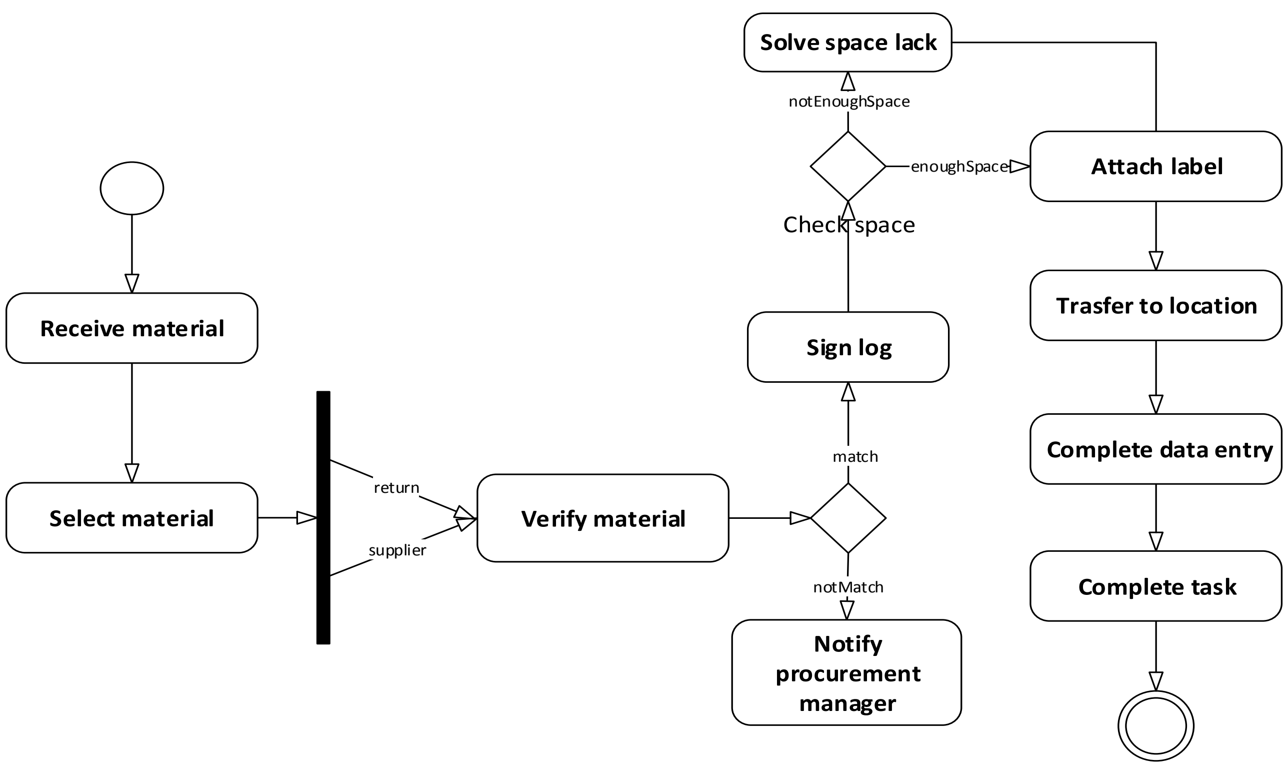


*Figure 3-13: Production Control & Logistics Activity Diagram*

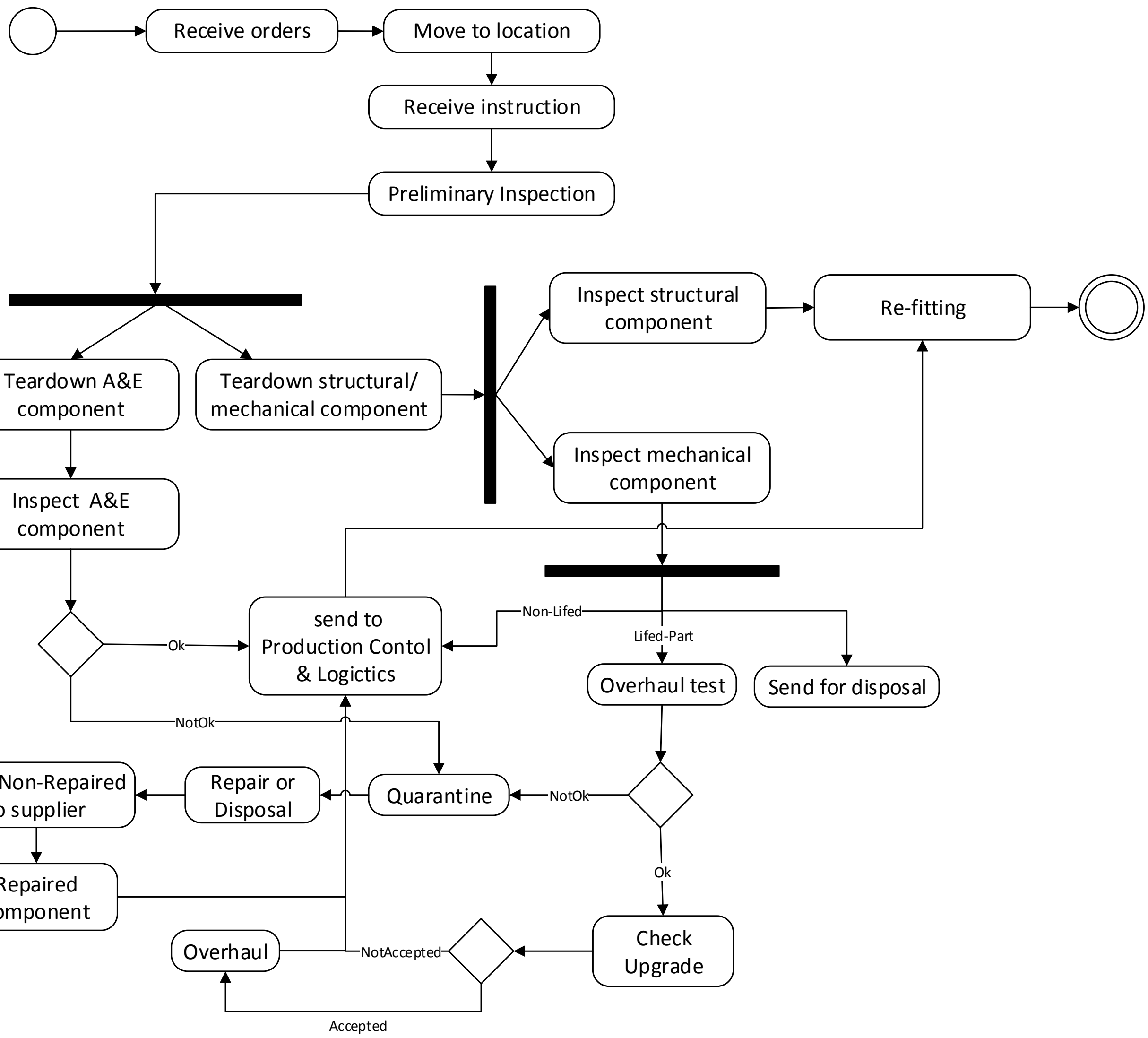


*Figure 3-14: Disassembly Activity Diagram*

The figure is similar to the process map Figure 3-3 in Section 3.3.1. However, for modeling the dynamic aspects of the process we can use activity diagram. This diagram focuses first on the activities that take place among objects and agents. In that regard, activity diagram are similar to process map diagram. An activity diagram is essentially a flowchart that emphasizes on activities that take place over time. This diagram looks at the operations that are passed among objects or agents. As UML User Guide mentions that "the execution of an activity ultimately expands into the execution of individual actions, each of which may change the state of the system or communicate message". It shows the importance role of using activity diagrams in dynamic modeling. However, the other advantage of activity diagram is for constructing executable systems through forward and reverse engineering.

### 3.4.3 Employing Use Cases to Define Disassembly Process

Use case diagram is mainly useful for modeling the behaviour of a system, a subsystem, or a class. Use case diagrams are important for visualizing, specifying, and documenting the behavior of an element of a system.

To perform the Disassembly Process by way of agent-based methodology, the objects and agents to be used must be clarified. Thus, it is important for ABM to adopt a proper modeling process during system analysis and design. In UML, a use case is a narrative document that describes the sequence of events of an actor using a system to complete a process [118]. Usually, use cases are scenarios or cases of using the system. They explain and indicate needs in the scenarios. Therefore, use cases gather the behaviors and functional requirements of a system, and define processes in terms of goals, responsibilities, pre-conditions and post-conditions. Figures 3-16, 3-17, 3-18, 3-19 and 3-20 show the use case diagrams of the whole system process. As an example, there are eleven use cases in the production control & logistics process. The Verify Material use case is one of the system's use cases. Figure 3-15 shows the definition of the Verify Material use case.

| | |
|---|---|
| **Use Case:** | **Verify Material** |
| Purpose: | Verifying different material from the system |
| Type: | Primary and essential |
| Description: | An instance (return or from supplier) of system should be verified by production control & Logistics agent and this agent determines each instance category and location of the item which should be stored. |

*Figure 3-15: Verify Material Use Case*

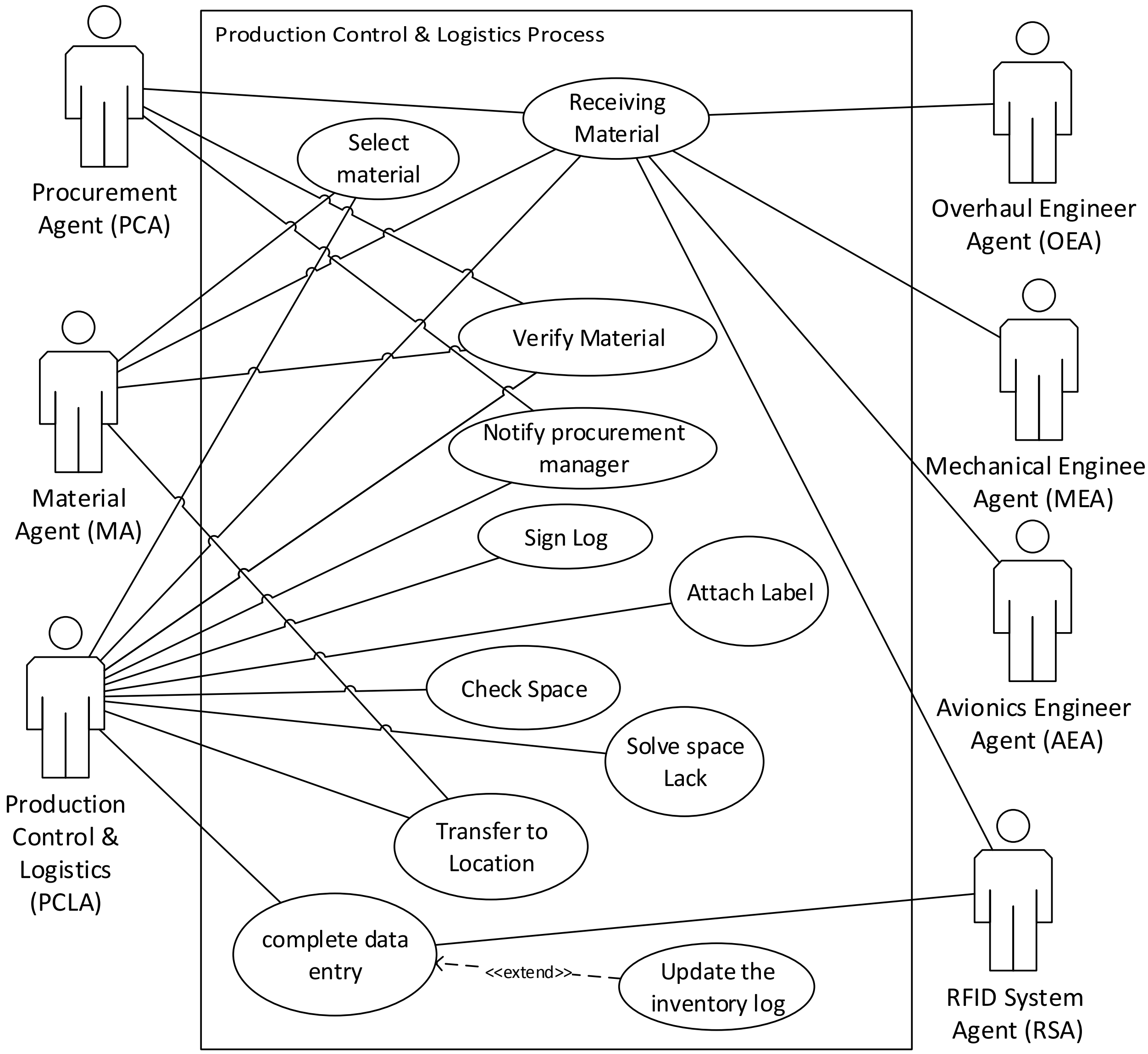


*Figure 3-16: Production Control & Logistics Process Use Case*

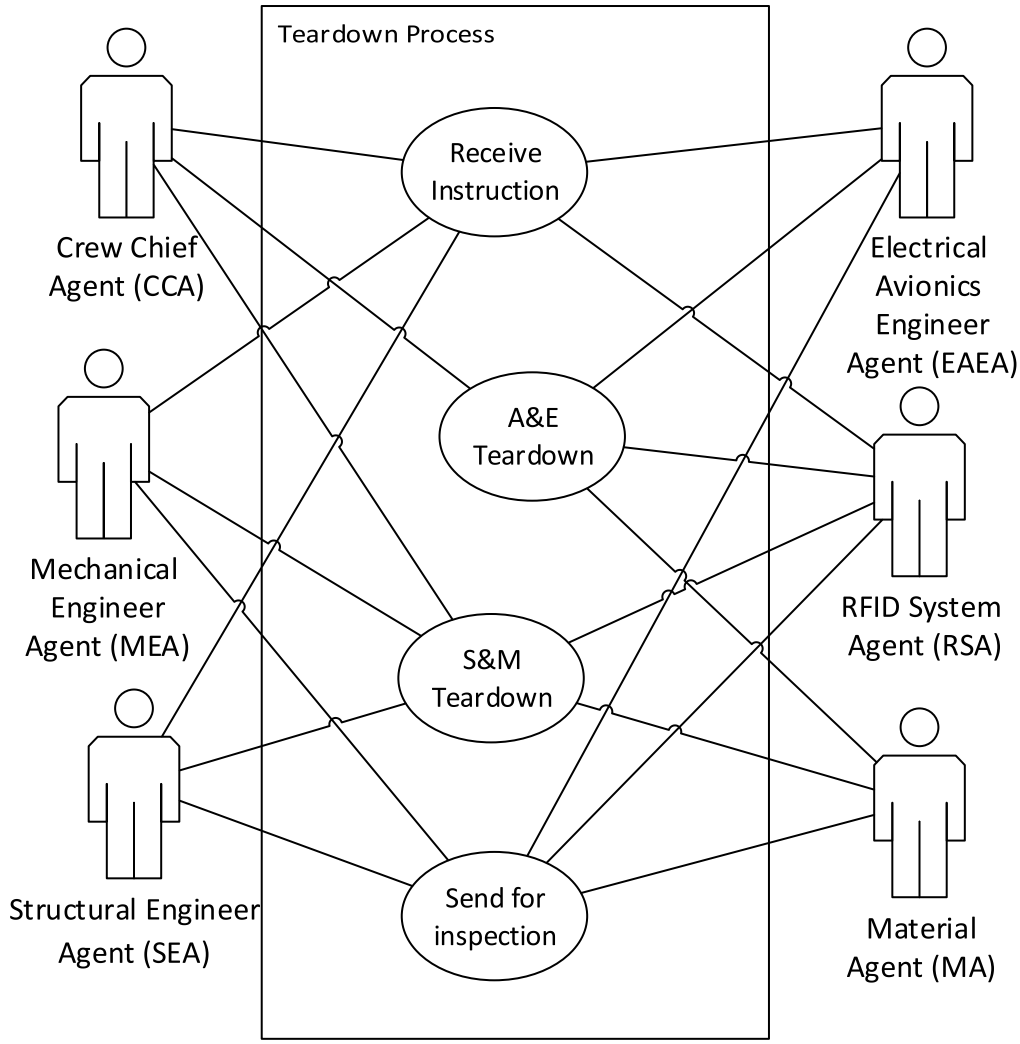


*Figure 3-17: Teardown Process Use Case*

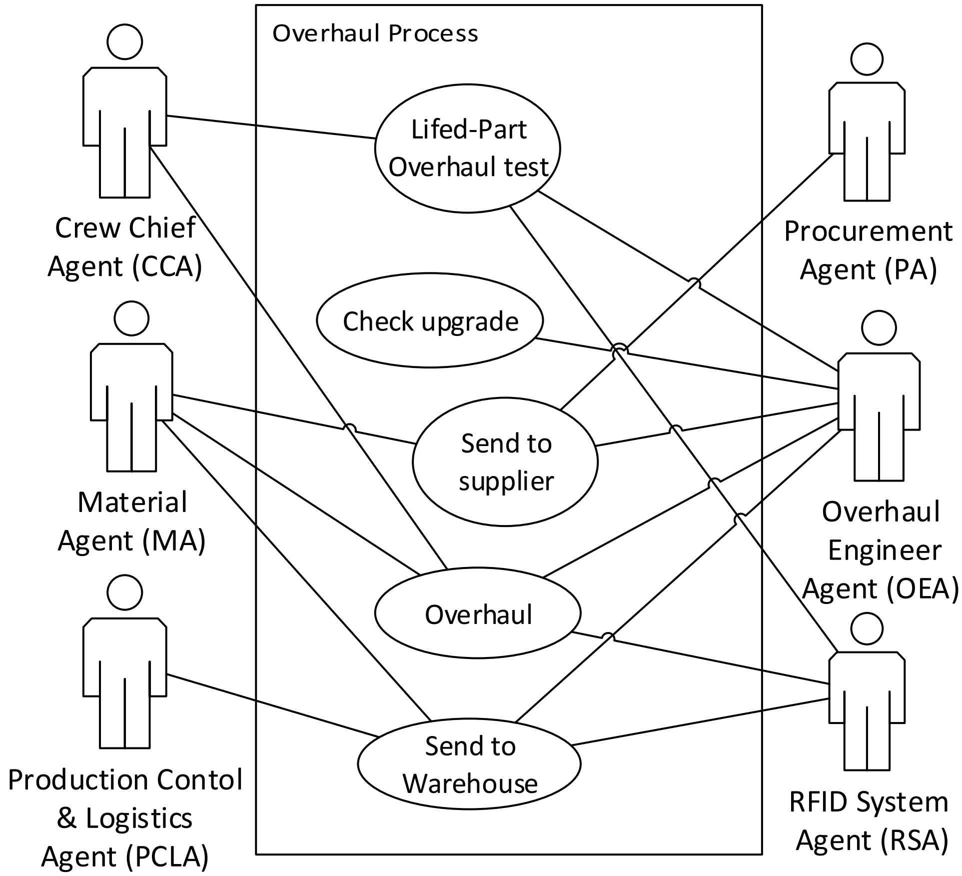


*Figure 3-18: Overhaul Process Use Case*

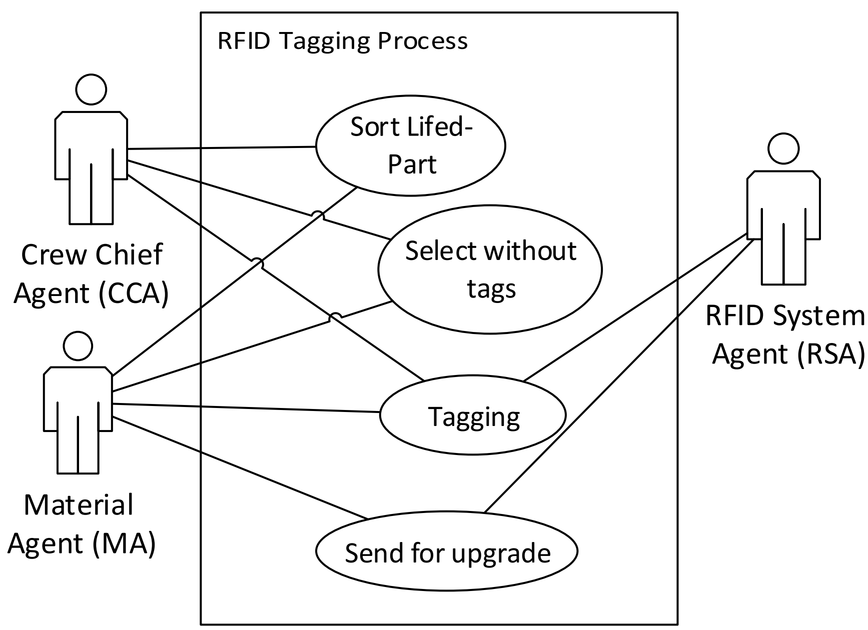


*Figure 3-19: RFID Tagging Use Case*

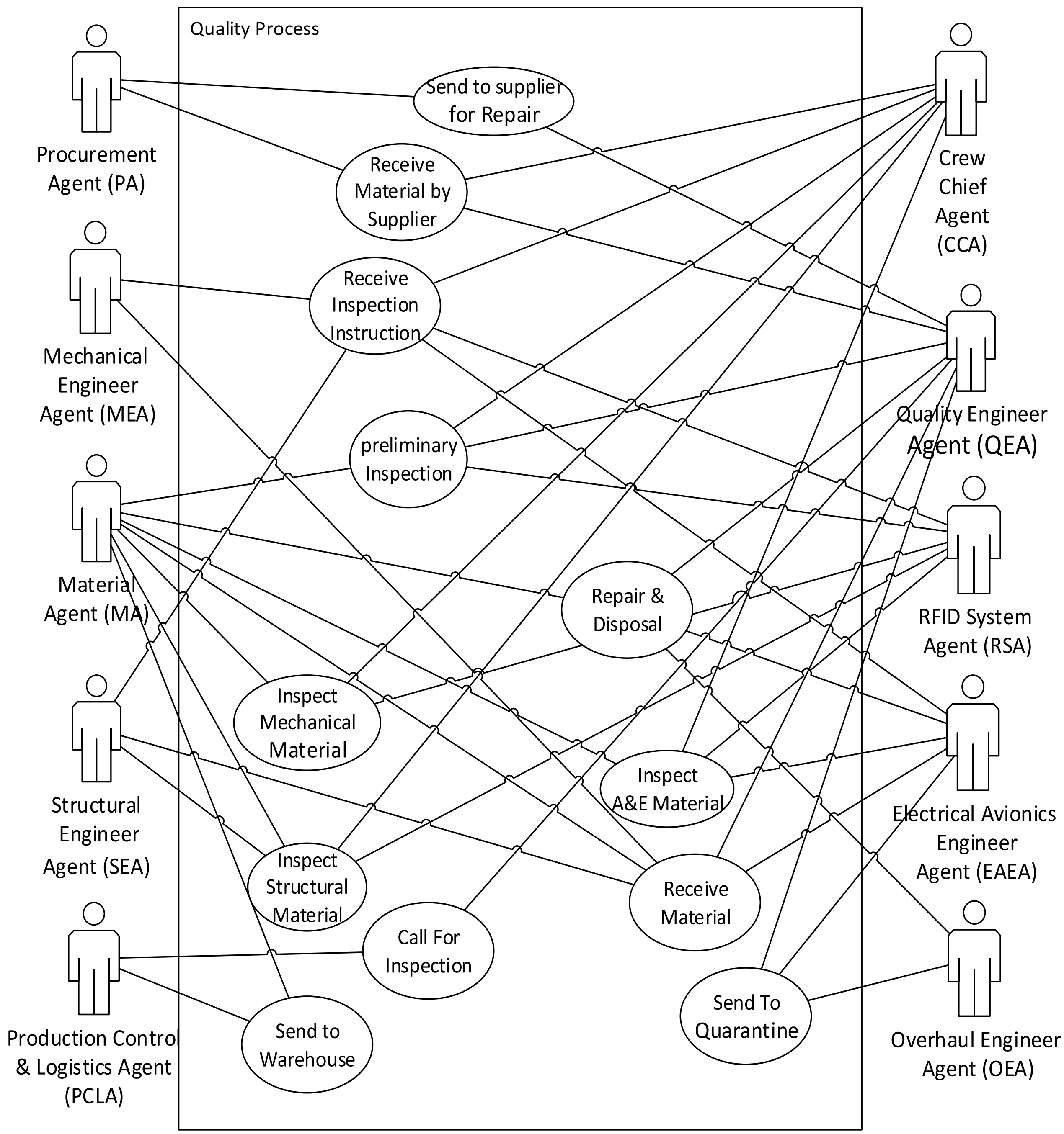


*Figure 3-20: Quality Process Use Case*

### 3.4.4 Modeling Sequence Diagram

One of the best notation tools for communication is sequence diagram which shows the message exchange between objects/agents. In sequence diagram, each object/agent is delineated by a vertical line, and messages that can be function calls, are represented from one object/agent to another one as horizontal arrows. In such diagram, one of the important components is time that flows downward and can be physical and logical.

The message sequence diagram for disassembly process is shown in Figure 3-21. There are seventeen agents in the process. The black bars represent processes which take place inside the agents, and it is possible to finish with a message sent to another agent. As we see in Figure 3-21, the process begin with an order from the customer to the general manager who is the interface with customer and also responsible for receiving outside orders. Automatically, the general manager sends the request to contract manager. Since contract manager needs information for preparing the primary contract draft, he will ask for information from the project manager. Project manager starts to gather information from different departments. First of all, he checks the capacity availability such as time, human resources, tools, spare part and other needs of the customer from the scheduler and also asks the feasibility of the contract from crew chief. At the same time, crew chief does the feasibility study of the contract and sends requested information by project manager back, while the scheduler checks human resource availability on his own and respectively checks lead time preparation of needed instructions with planner and checks availability of buying resources of the contract with procurement department. Procurement team will request for invoice and lead time of the contract needed resources and new parts and send those information back to the scheduler. Afterwards, scheduler will estimate the capacity with the information received by the other departments and send the schedule for project manager. Now that the information is ready, project manager will send them to contract manager for preparing the contracts' draft. Contract manager with the supervision of general manager starts to prepare the contracts' draft and after that will send it to the customer for signing. When both sides sign the contract, as an internal responsibility, the general manager delivers the signed contract to the project manager for further processing in order to book an aircraft. This order and original contract are sent to the scheduler for preparing with editing the actual timetable then sending it to procurement department for the use of actual lead times of the orders. Also the project manager will order the procurement to purchase required resources by sending the singed contract and as soon as they received the contract, the ordering process will commence. These orderings will include the needed resources such as equipment, spare parts and new parts for refitting. In addition, the project manager will order the planner to prepare the instruction. With the use of the contract, the planner will do the detailed planning with instructions and required parts and at the end send it for crew chief and project manager. Before receiving the aircraft, the crew chief will send the plan which is containing of disassembly instruction to the engineers (mechanical, electrical/avionic, structural and overhaul engineers). In the meantime, the needed resources will be sent by the suppliers and will be received and stored in the inventory by the production control and logistics department.

At a certain time, the customer will send the aircraft for teardown. Aircraft will be located on the special platform under supervision of the crew chief. Afterwards, the crew chief will request the two inspectors for preliminary inspection which include checking any obvious non-conformities and checking that the components are in order. When this step is done, both inspectors will inform the crew chief and he will send orders to mechanical, structural and electrical/avionics engineers for tearing down the aircraft in parallel process. Therefore all the requested engineers will ask for requested parts from the production control & logistics department. By receiving the needed resources, engineers will begin to disassemble the aircraft. As the electrical/avionics teardown has less time so after the disassembly process, the related agents will inform the crew chief and he will order for electrical/avionics inspection which will be performed by the same engineer. When the inspections are finished the engineer will separate components to two types. First the airworthy (used) components that will be sent to the production control & logistics to store them for re-using in the refitting processes and the second components are those that required repair (quarantine) or disposal so these components will be sent to quality department for this purpose. While quality engineers will repair and disposal some of the components and send repaired ones to inventory, the other components with coordination of the procurement department will be dispatched to the supplier for repair. Meanwhile, after mechanical engineers finish the teardown process, they will inform the crew chief and he will order for inspection to mechanical and structural engineers. In the process of mechanical testing and inspecting, the engineers will sort the components to three types which will be lifed parts, non-lifed parts and disposal parts. Lifed parts will be overhauled by the related engineer and after that process will be the same as electrical/avionics process. For the other types, non-lifed parts will be sent to warehouse for storage in the inventory and disposal parts will be delivered to quality engineers for quarantine and disposal. While all these teardown and inspection process are performed, the supplier will be delivering the repaired and new parts which will be placed in the warehouse and inspectors will do the quality check on them.

When the disassembly process finished, crew chief will order the structural, mechanical and electrical/avionics engineers to be prepared for the re-assembly process. At the same time production control & logistics will send the airworthy and new parts for assembly on the fuselage. The assembly process is composed of adding upgraded components, re-fitting previously removed parts and some further dis-assembly. At the end, quality engineers will perform the final inspections; therefore the modified aircraft will be ready to be delivered to the customer. The whole sequence diagram process is illustrated in Figure 3-21.

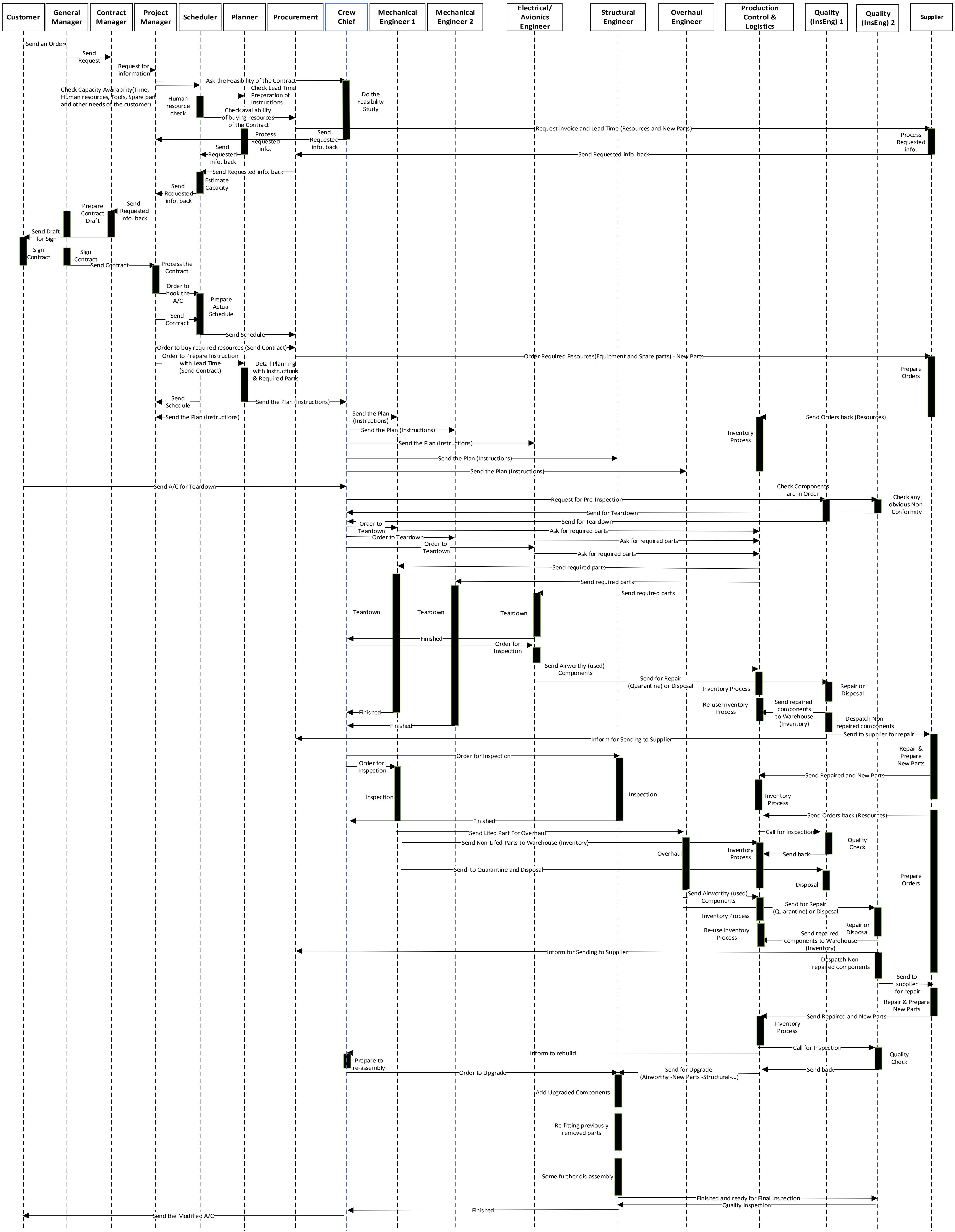


*Figure 3-21: Sequence Diagram Process*

## 3.5 Summary

In this chapter, we presented RFID technology selection based on the wide range of benefits for the RL system in aerospace industries like Boeing.  Then, we proposed a possible RFID network for the aircraft RL system with the use of real case study process map of the Bell Helicopter Company. The proposed RFID network contains of simple components such as RFID tags, RFID readers, middleware and server that can be placed in our process.

Afterwards, we described the Bell Helicopter process map for better comprehending the RL system. This description helps us to know the requirements of the RL process in the design phase of the study.

The chapter also presents an integrated framework with details in the RL system. As the first step, a three level procedure for disassembly modeling in the RL system is proposed. After that UML diagrams have been defined and each model is conducted to analyse and to give better understanding on the RL system behavior. Besides, UML is employed to document the static and dynamic structure of the disassembly system in a formal way which is a basis to implement the computer model. Class diagrams are used to denote the class/objects or class/agents in the RL system while activity diagrams are developed for the process flow and use case diagrams construct to present the relationship of agents in the system. At the end, a sequence diagram is built for the behavior of RL system and to illustrate the existing message procedure in the Bell Helicopter Company's RL network.

# Chapter 4 : Simulation of RFID-Enabled Aircraft Disassembly Process via Agent-Based Modeling: Case Study of the Bell Helicopter Company

In this chapter, the agent-based modeling (ABM) will be explained in more details. In the next step, with the emphasis on models designed on Chapter 3, the agent-based simulation model will be constructed with Anylogic 7.1 software.

## 4.1 Agent-Based Modeling (ABM)

ABM has become known mostly for thoroughly investigating complex systems as an in depth simulation technique. The nature of any complex systems is composed of autonomous components (agents), interactions between the components (agents) and even adaptive individual behaviours. According to Laskowski [122] “ABM is systems modeling, approached from the ground up or from the perspective of its constituent parts, in order to build an aggregate picture of the whole. ABM’s conceptual depth is derived from its ability to model emergent behaviour that may be counterintuitive or, at minimum, its ability to discern a complex behavioural whole that is greater than the sum of its parts.” One of the main questions in ABM is: Who are the Agents? Agents in an ABM can stand for many varied objects such as human beings, equipment, vehicles, companies or their projects’, ideas, countries, etc. From feasible viewpoint, agents contain fundamental characteristics which are described by Macal et al. [121] as follows:

- An agent is an independent, modular, and identifiable individual. The modularity need implies that an agent has limitations. It means that one can easily specify whether something is part of an agent or not or maybe is a shared and common attribute. Agents have attributes that allow the agents to be differentiated from and identified by other agents.

- An agent is autonomous and self-directed. An agent can work independently in its environment and in its interactions with other agents. An agent has behaviours which connect information perceived by the agent to its decisions and actions. An agent's information is processed and notified through interactions with other agents and with the environment. An agent's behaviour can be clearly described by simple rules to the extent of abstract models, such as neural networks or genetic programs that relate agent inputs to outputs through adaptive mechanisms.
- An agent has a state that changes over time. It means that a system has a state consisting of the collection of its state variables; besides an agent has a state that shows the crucial variables associated with its current condition. An agent's state contains of a set or subset of its attributes. The state of an agent-based model is the collective states of all the agents along with the state of the environment. In an agent-based simulation, the state at any time is all the information required to move the system from that point forward.
- An agent is social having dynamic interactions with other agents that influence its behaviour. Agents have protocols for interaction with other agents, such as for communication, movement and contention for space, the capability to respond to the environment, and others. Agents have the ability to recognize and distinguish the traits of other agents.
- An agent may be adaptive, for example, by having rules or more abstract mechanisms that modify its behaviours. An agent may have the ability to learn and adapt its behaviours based on its accumulated experiences. Learning requires some form of memory.

- An agent may be goal-directed, having purposes to achieve with respect to its behaviours. This allows an agent to compare the outcome of its behaviours relative to its goals and adjust its responses and behaviours in future interactions.
- Agents may be heterogeneous. Agent simulations consider the full range of agent diversity across a population. Agent characteristics and behaviours can be different in their extent and complexity. Thus, the amount of information is considered in the agent's decisions, the agent's internal models of the external world, the agent's view of the possible reactions of other agents in response to its actions, and the extent of memory of past events the agent retains and uses in making its decisions.

The agents for this thesis are previously identified and described in details in the Section 3.4.1 of Chapter 3.

## 4.2 Constraints and Assumptions

There are several constrains which is faced in the procedure of building the model and simulating with Anylogic software. First of all, although most of the useful data gathered from inside of the company, the need of more practical data and details is still evident for designing and developing the model. Due to this limitation most of the process has been built inside the lab environments with assumptions and estimations. On the other hand, since the version of Anylogic simulation software applied for designing the model is evaluation version for researchers, we faced limitation on the number of agent types in the model (limit to 10). It must be mentioned that if the model was created and developed for instance with professional version of Anylogic, we would have more flexibilities to design the model similar to the real UML models such as sequence diagram. Regarding the mentioned constraints, there are lots of conceptual and visually differences between the design phase of the model (UML models) and the simulation model.

The assumptions used in modeling design and developments are as follow:

- According to the company's data, only one helicopter goes into the reverse logistics process and also the entire process to upgrade a single aircraft will take one working month.
- The disassembly process has already been developed and carried out. All the data (time, staff numbers and process map) is known and given by the R&D department.
- At the of RFID enabled s
- cenario, passive RFID tags have been examined under the laboratory conditions and applied to tag the helicopter's parts.

## 4.3 Simulation Software

In this study, we apply agent based simulation to model the RFID enabled aircraft disassembly process. To deliver a connection with Java based object-oriented, we chose a Java agent based simulation platform, Anylogic 7.1 University Researcher version. Anylogic has turned into an industry leader with the well-known buyers and clients like Boeing, IBM, Caterpillar, McDonald's, Us Navy and National Aeronautics and Space Administration (NASA). In addition, Anylogic has the capability to generate a Java applet which enables users to run a model anywhere. Hence, the mentioned framework could be developed to the extent that customers will not require buying an Anylogic runtime license. Regarding to why Anylogic is one of the functional and beneficial simulation tools, the official webpage of the Anylogic describe it [123], "

**Reduce development cost and time:**

- AnyLogic's visual development environment significantly speeds up the development process
- The included object libraries provide the ability to quickly incorporate pre-built simulation elements
- Reusability through fully object oriented structure
- A visual integrated development environment makes it easy to convert from other widely used IDEs to AnyLogic
- Pre-built object libraries show how the experts did it! Those objects can be easily reused

**Develop more models with one tool:**

- Develop agent-based, system dynamics, discrete-event, continuous and dynamic system models, in any combination, with one tool
- AnyLogic supports the seamless integration of discrete and continuous simulations
- The native Java environment supports limitless extensibility including custom Java code, external libraries, and external data sources
- An extensive statistical distribution function set provides an excellent platform for simulating the uncertainty inherent in all systems
- A powerful experimental framework, built-in support for Monte Carlo simulations and advanced forms of optimization support a wide variety of simulation approaches

**Improve the visual impact of the models:**

- AnyLogic's simple yet sophisticated animation functions allow the development of visually rich, interactive simulation environments

- Automatic applet creation allows users to quickly build simulations that can be broadly disseminated — they can even be placed on a website

**Run models anywhere:**

- The native Java environment provides multi-platform support. Both the AnyLogic IDE and models work on Windows, Mac and Linux
- You don't need a runtime license — with one click you can generate a Java applet that allows users to run a model anywhere
- An AnyLogic model is completely separable from the development environment and can be exported as a standalone Java application"

### 4.3.1 Elements of Simulation Model and Concepts

For better understanding the procedure of agent-based modeling with Anylogic software some fundamental elements should be explained which are described as follows:

#### *4.3.1.1 Statechart and Agents*

A statechart which is similar to state diagram in UML, is a beneficial simulation modeling tool for visual building of an event and time-driven behavior of different objects. This tool is diversely applied in agent-based models, and also the other benefit of statecharts emerge when the modeller wants to use it with other simulation methods like discrete event (process flow) and system dynamics models.

Two major components of statecharts are States and Transitions. States are used to define the sequence of actions and reactions of the object for any internal and external events. The mentioned reactions are the kind of state that is determined by exiting transitions. Exiting transitions contain trigger and these triggers can be a condition, a timeout, or a message arrival. At the time a transition is fired (happened) the related state will change and therefore new reactions become functional [124].

In our model we separate the engineer agents with material agents. All the human agents have similar states and transitions. These agents are named: Electrical – Inspector – Mechanical – Overhaul – Structural. Engineer agents contain two states of action and reaction namely “Idle” and “Working” with two transitions. The first state is triggered by “Perform” message , therefore state of the agent will change from “Idle” to “Working” and the corresponding agent perform the action by timeout transition till the task is done and become “Idle” again. All the statecharts of engineer agents are given below (Figures 4-1, 4-2, 4-3, 4-4, and 4-5):

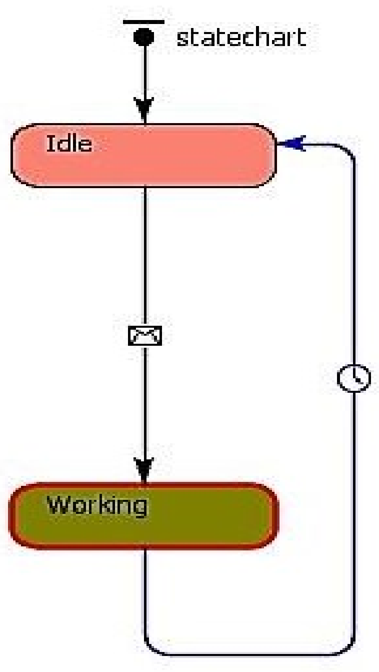


*Figure 4-3: Mechanical Agent Statechart*

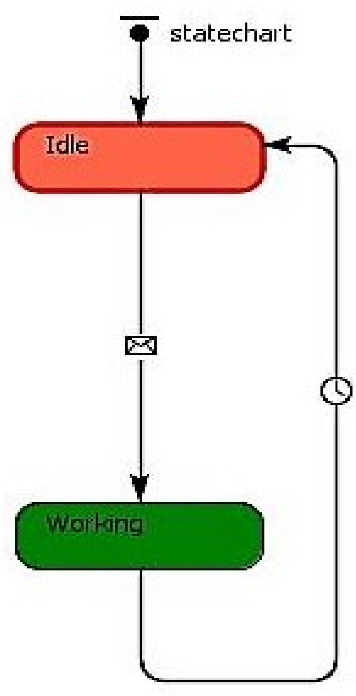


*Figure 4-2: Structural Agent Statechart*

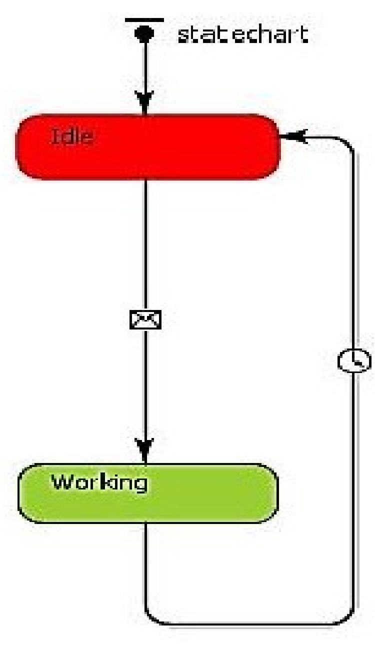


*Figure 4-1: Inspector Agent Statechart*

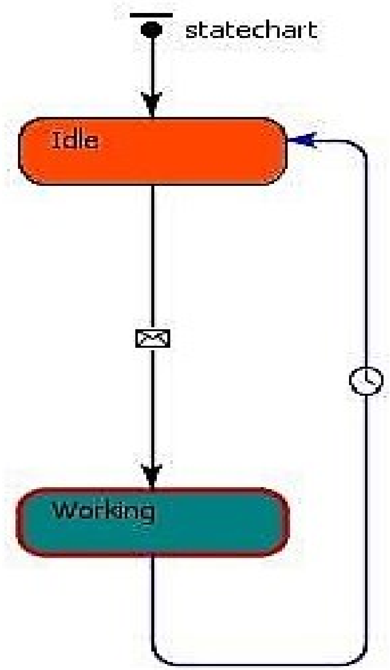


*Figure 4-4: Electrical Agent Statechart*

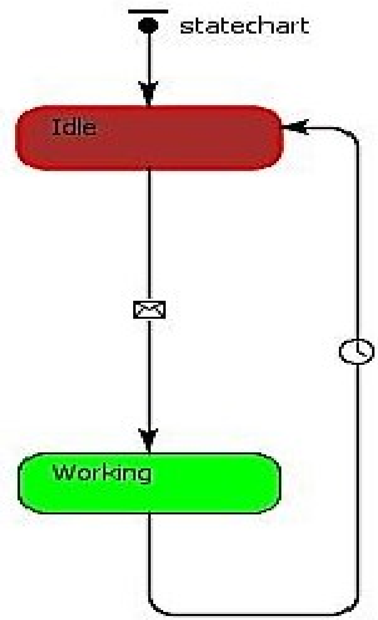


*Figure 4-5: Overhaul Agent Statechart*

On the other hand material agents also are following similar states and transitions with few differences. These agents are: Airframe (Aircraft) – Mechanical Parts (MEParts) – Electrical/Avionics Parts (AEParts). Aircraft agent which is the main frame and fuselage of a helicopter will start its states with the “SignedContract” action. After contract signed, automatically “Start” message will be fired to order the aircraft to move to the next state “Moving”. The sequence will continue by Agent Arrival transition to “Preliminary Inspection” state and then will be released by the timeout transition (inspection timeout) and moving for the next state “StrucMechTeardown”. This action and reaction procedure (teardown and moving) will be repeated in the order of “Moving”, “StructuralInspection”,”Moving” and “Assembly”. Simultaneously the Agent Arrival and Timeout transitions will be occurred insofar as the new assembled helicopter is “ReadyForDelivery”. Figure 4-6 illustrates the whole process.

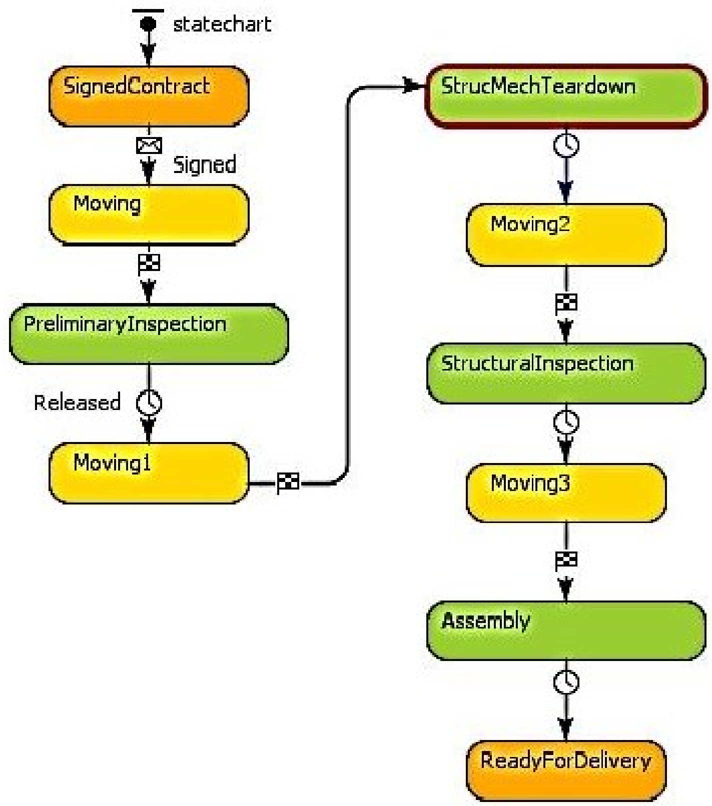


*Figure 4-6: Aircraft Agent Statechart*

While the Aircraft agent process is happening, the MEPart and AEPart agent processes also take place. This means, all the three agents will perform the same process at the same time till the parallel teardown processes ("StrucMechTeardown" and "AvionElecTeardown"). After the material agents are separated from each other, MEPart and AEPart will continue their own processes correspondingly as "MechInspection" and "AvionElectInspection". Subsequently, both agents will be sent to the logistics & production control department for storing, repairing or sending them to the suppliers. The mentioned actions are named as "InventoryMech" and "InventoryAE" states in the Anylogic software. The only difference is in the MEPart process where the action of "LifedPartOverhaul" is also comprised. At the end, both agents will perform the same routine like aircraft agent which is “Moving”, “Assembly” and “ReadyForDelivery”. Figures 4-7 and 4-8 show the process.

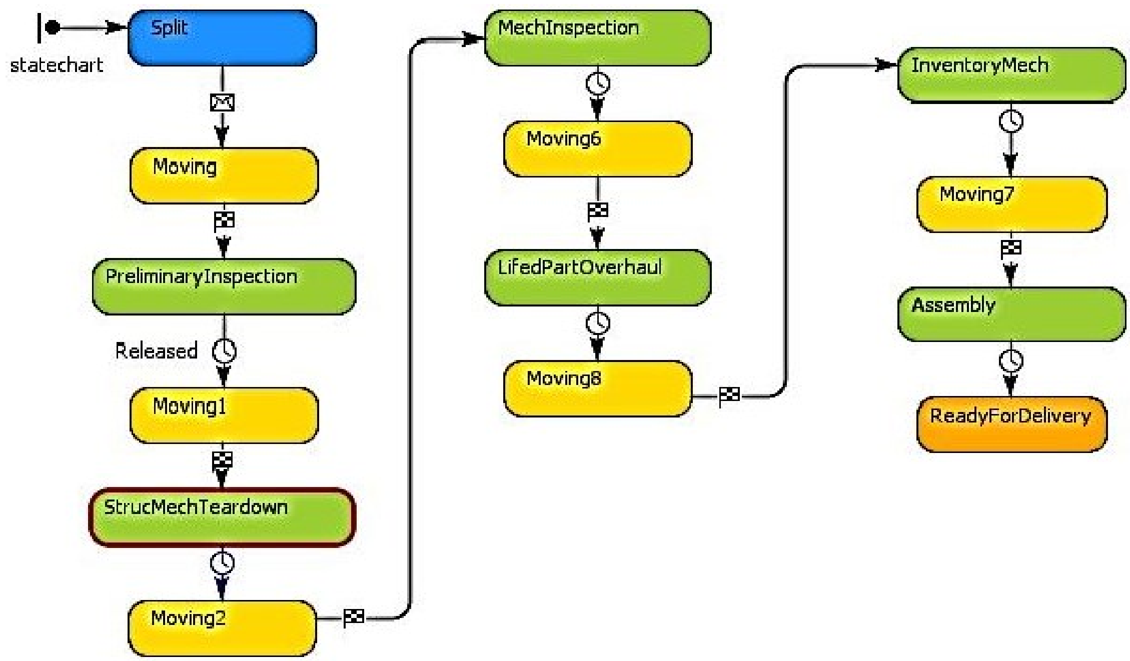


*Figure 4-7: MEPart Agent Statecharts*

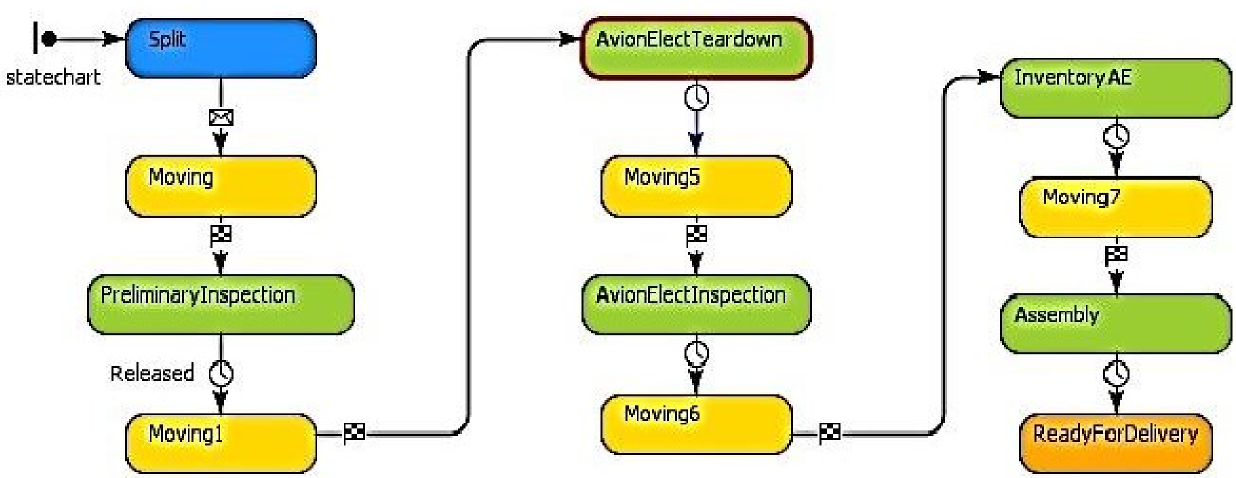


*Figure 4-8: AEPart Agent Statechart*

All green oval-shape states are action states and all the yellow ones are reaction states (“Moving”). Two blue “Split” states stand for MEPart and AEPart moving message transition order “Go” separately. The actions including customer and company interactions are represented as orange states of “SignedContract” and “ReadyForDelivery”. Inside all of these oval-shaped states, there are commands and orders like calling the related engineer agents for performing tasks or moving to a specified place (station). As an example, after “PreliminaryInspection” all the material agents should move to their teardown stations. This moving action command will be sent by an Entry action inside the “Moving” state. The same condition will happen to “Assembly” state, as when all the material agents reached the assembly station, automatically “Perform” commands will be ordered to inspector, mechanical, structural and electrical engineer agents for doing their refitting tasks.

#### *4.3.1.2 Parameter of Agents*

In agent-based modeling simulation, agents/objects may have parameters, which regularly are applied for showing characteristics of the imbedded agent or object in the model. Since some object/agent instances contain the similar behavior and actions in their class, it is beneficial to use parameters that the only differences are in their values. According to Anylogic help, a parameter is commonly used to describe objects statically. A parameter is normally a constant in a single simulation, and is changed only when the modeller needs to adjust the model behaviour. In addition, all parameters are visible and changeable throughout the model execution. Therefore, by the changing parameters at runtime, we can easily adjust the model.

One of the important subjects in parameters and agent interaction is Parameter Propagation. It means that the modeller can associate a parameter of an agent type with a parameter of its embedded object. In this situation, by changing an agent type, parameter throughout the model runtime, the associated object parameter depending on it is also changes. This applies for all parameter dependencies down the agent tree from the modification point. Anylogic help and support explains parameter propagation as below [124]:

Propagate values of parameters down the objects hierarchy when:

- You need to change parameters of several embedded objects (perhaps of different types). You can do this by creating single parameter of the capsule object and propagating its value to several parameters you need to change.
- You need to optimize the model by changing the parameter of a non-root object. In this case, you also need parameter propagation since you can optimize the model by changing only the root object parameters.

In Figure 4-9, time of the actions like teardowns and inspections are represented by parameters which acquire their values with the real data from excel file. Numbers of the engineer agents are shown as parameters as well.

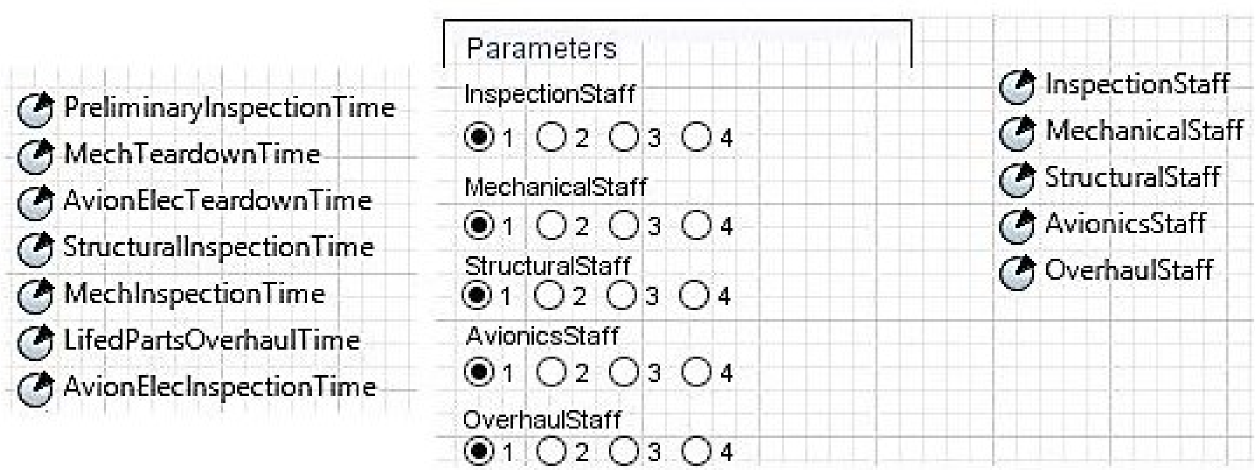


*Figure 4-9: Parameter of Agents*

### 4.3.2 Model Execution (Runtime)

In this section, the simulation model runtime will be described step by step. However, first the whole list of all the parameters and their values are shown in Tables 4-1 and 4-2 below:

Table 4-1 demonstrates all the main parameters included in the simulation model with their actual values.

*Table 4-1: Actual Time Parameters*

| Name | Time (minutes) |
|---|---|
| Preliminary Inspection Time | 120 |
| Mechanical and Structural Teardown Time | 4798 |
| Electrical and Avionics Teardown Time | 1440 |
| Structural Inspection Time | 2401 |
| Mechanical Inspection Time | 2414 |
| Electrical and Avionics Inspection Time | 480 |
| Lifed Parts Overhaul Time | 1500 |

Table 4-2 represents numbers of the engineer agents used in the simulation model as staff parameters with their corresponding values.

*Table 4-2: Staff Parameters*

| Name | Value (No.) |
|---|---|
| Mechanical Staff | 2 |
| Inspection Mechanical Staff | 2 |
| Structural Staff | 1 |
| Electrical/Avionics Staff | 1 |
| Overhaul Staff | 1 |

The following figures represent the step by step simulation model runtime based upon the process map described in Chapter 3, Section 3.3.1. The first step is when the aircraft is delivered by the customer and goes through the various inspection processes.

As we can see from the Figure 4-10, the aircraft is located in the preliminary inspection room. Both aircraft and inspectors become green visually for showing that they are in the working state.

Next step is the phase of separation which structural and mechanical parts undergo a series of teardown process in the teardown room (TD room) via their corresponding engineer agents. Electrical/Avionics parts, as well, go through the electrical room to be dismantled by the electrical engineer. In all the processes both material and engineer agents will be changed to greenish colors for showing they are in the working state or reddish for the idle state. Figure 4-11 presents the teardown process in the simulation run time mode.

After disassembly process took place, all the material agents need to be tested and inspected by the same associated engineer agents. Figure 4-12 is based on the inspection processes.

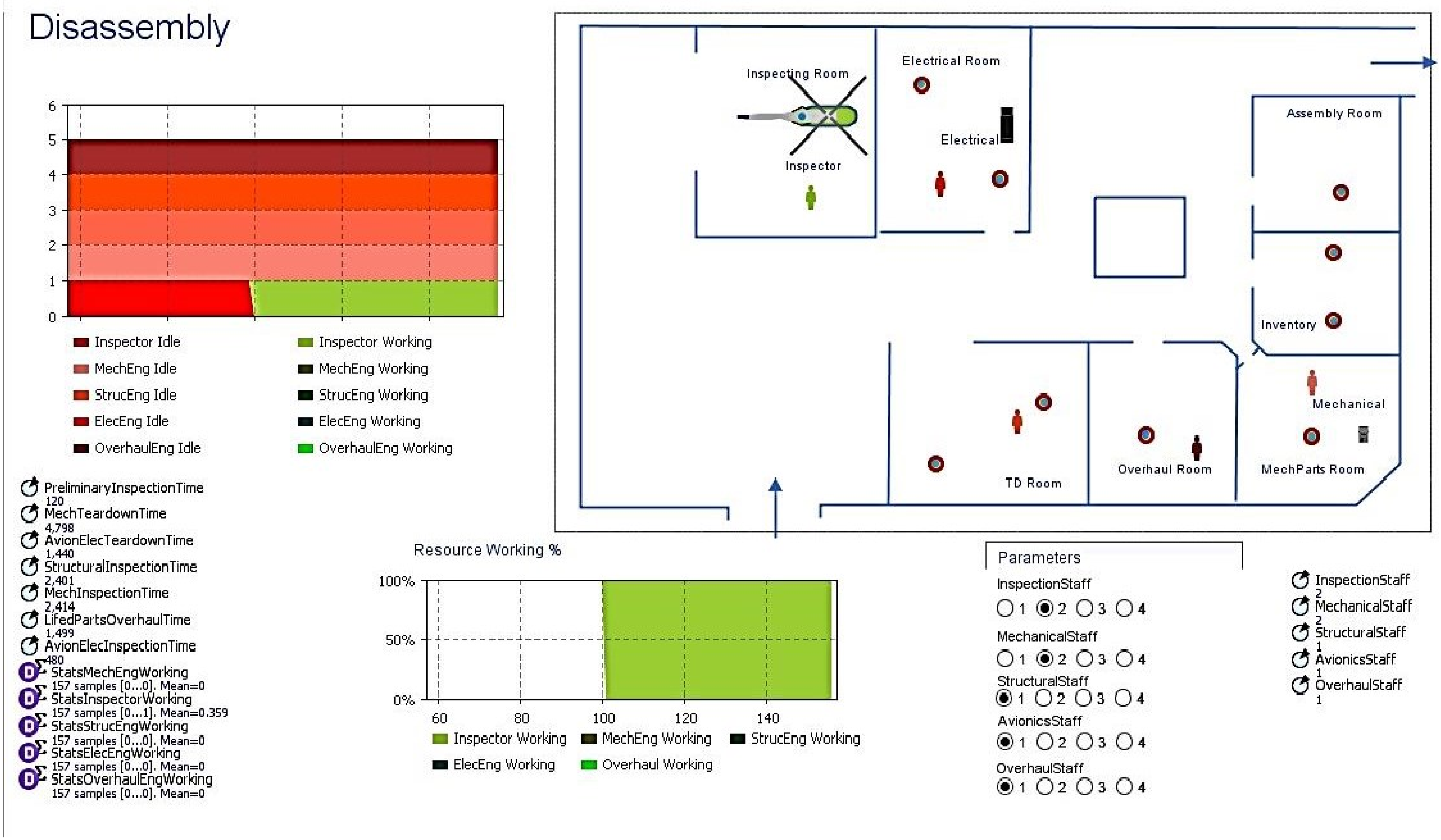


*Figure 4-10: Preliminary Inspection Step*

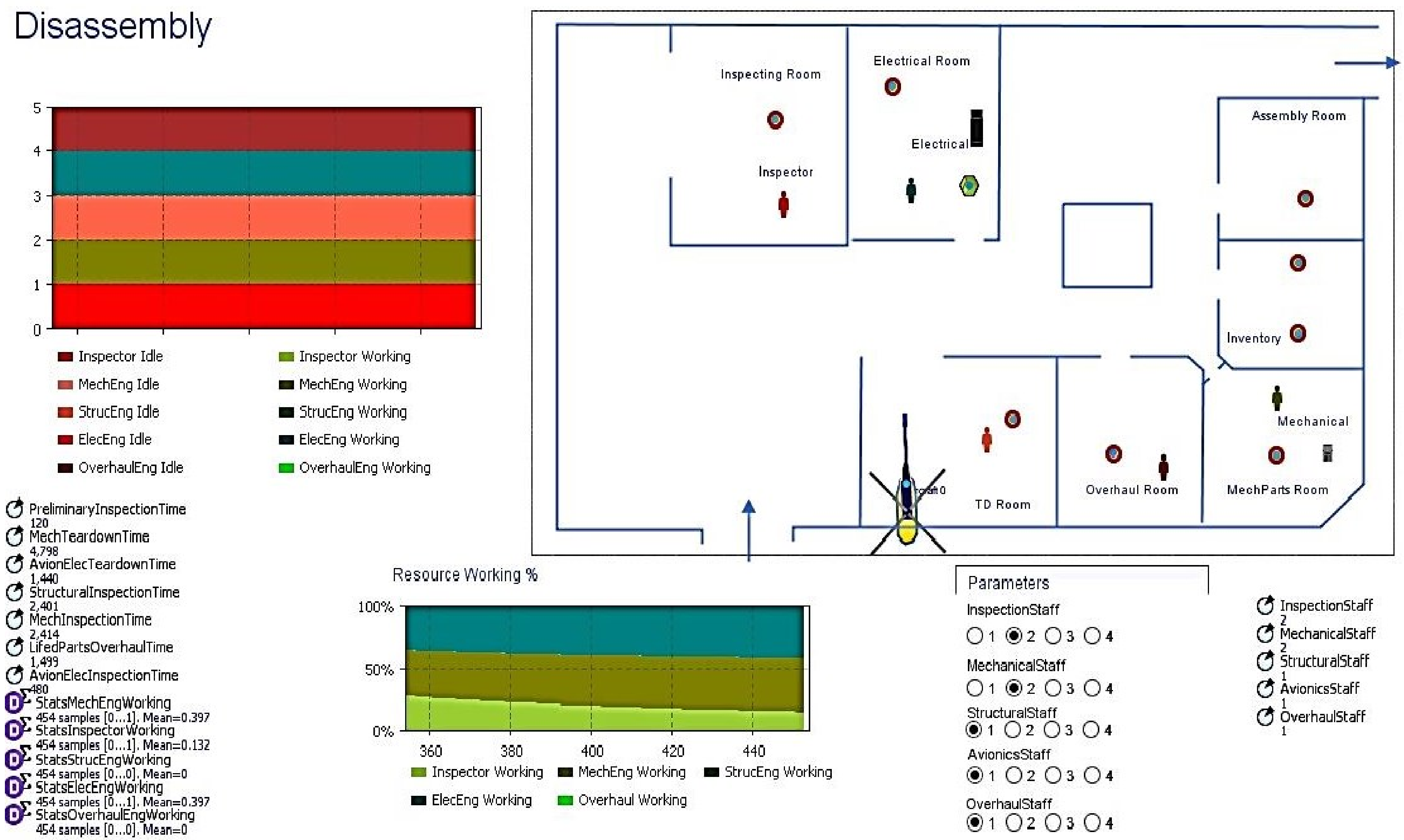


*Figure 4-11: Teardown Step*

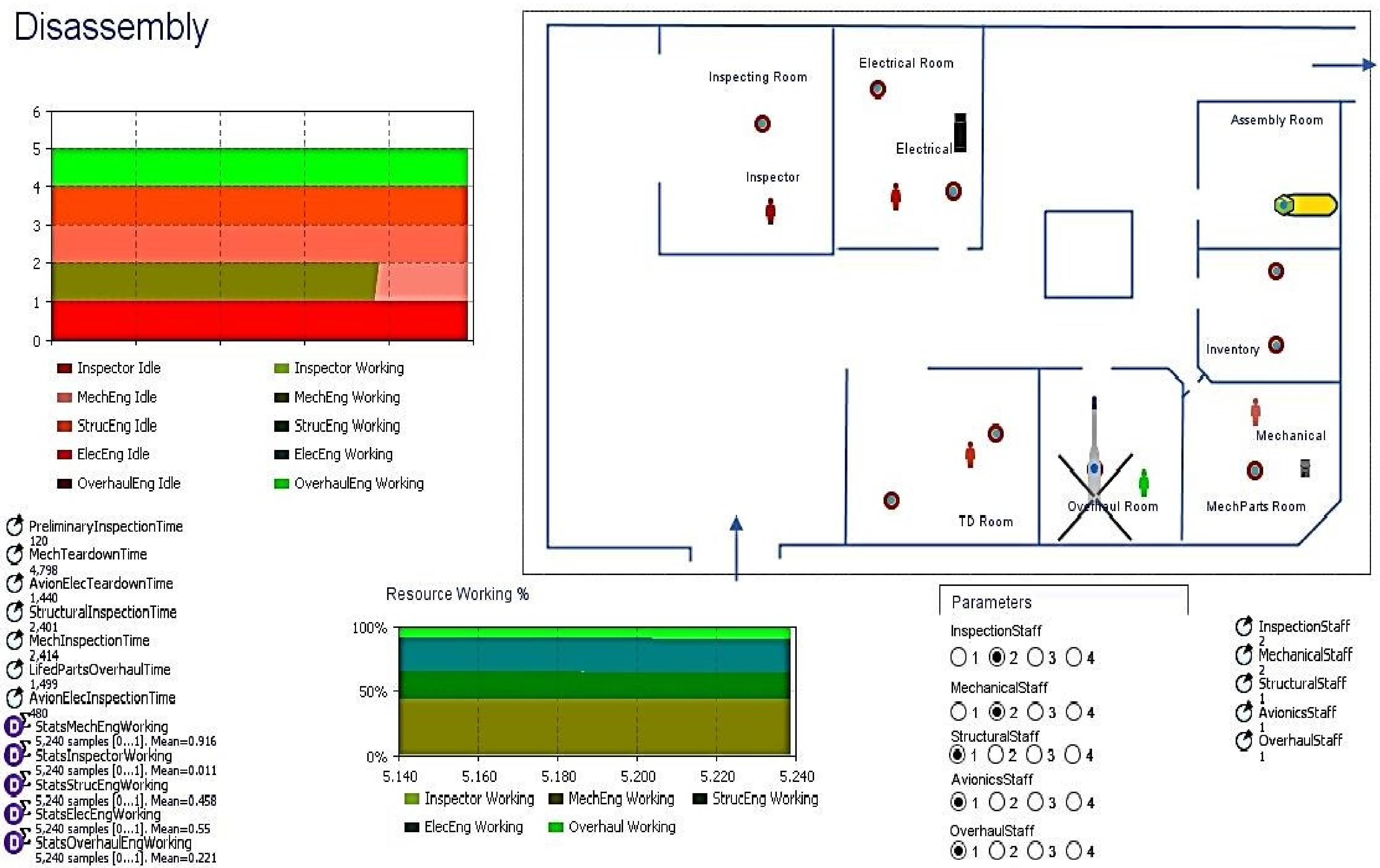


*Figure 4-12: Inspection Step*

It is important to mention that while the structural and mechanical inspection are performing, electrical/avionics parts are already stored in the avionics/electrical inventory section of the warehouse and ready to be refitted again.

Since some mechanical parts are lifed-parts, they need to be overhauled; therefore they will be transported to the overhaul room. Figure 4-13 shows the location of the overhaul room and the lifed-parts.

Figure 4-14 represents the final step of the model which is the assembly phase and all the material agents will be gathered together in the assembly room. In this stage, inspection, mechanical, electrical/avionics and structural engineers will do their tasks (refitting) and delivered the modified aircraft to the customer.

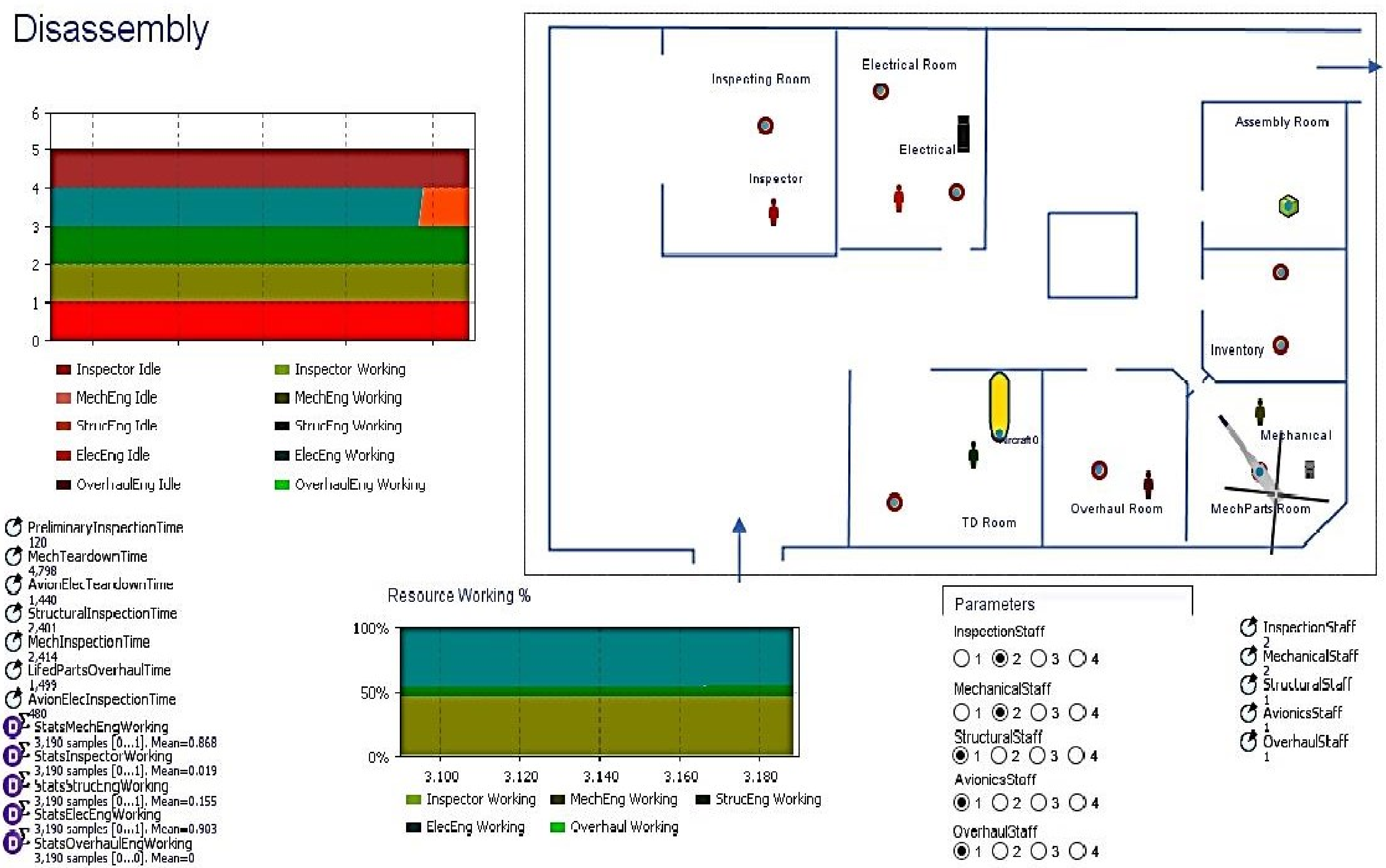


*Figure 4-13: Overhaul Step*

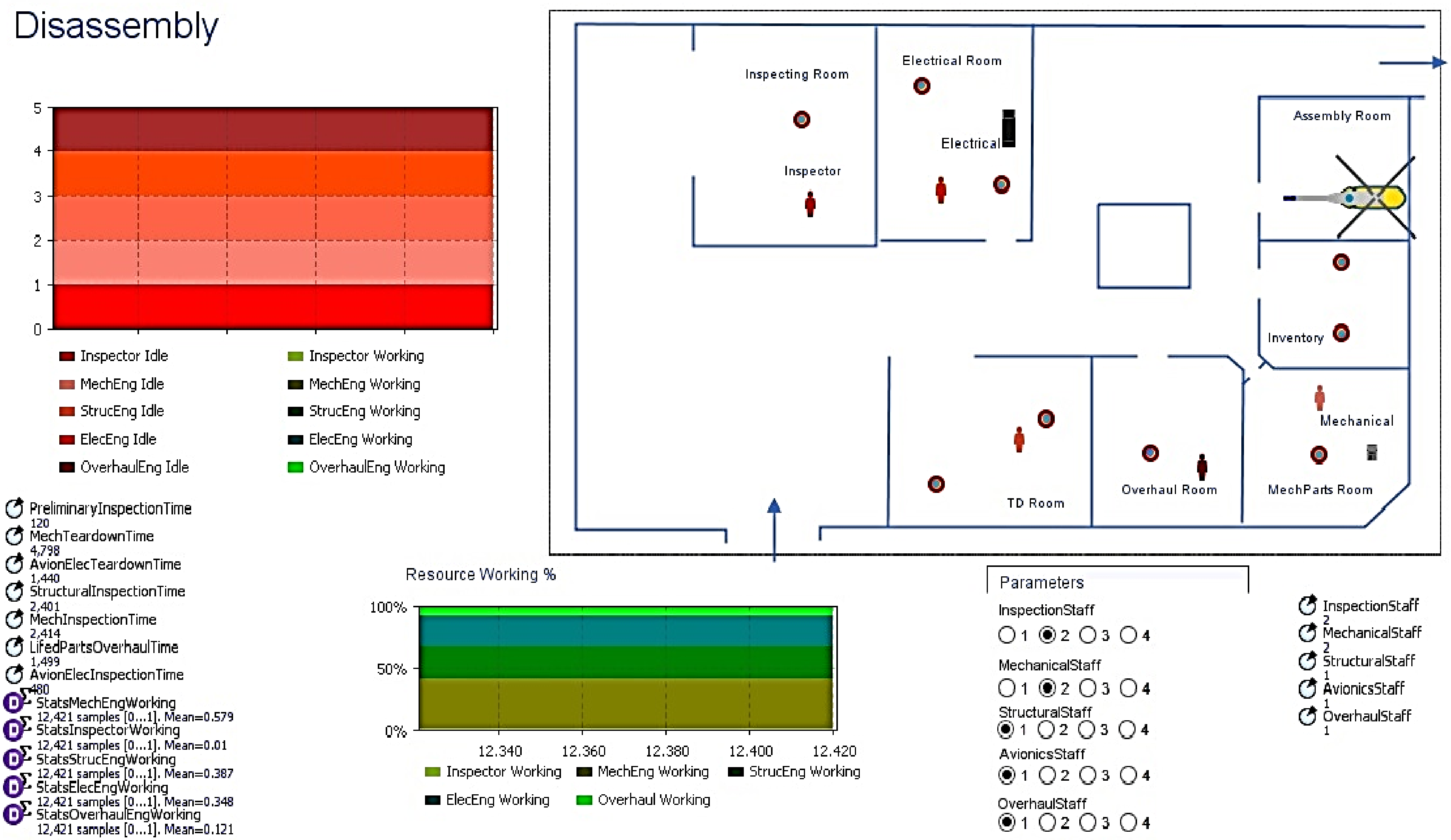


*Figure 4-14: Assembly Step*

## 4.4 Summary

This chapter discusses about who or what can be our agents in the agent-based modeling, then introducing Anylogic 7.1 as an implementing simulation tool for the models as designed in Chapter 3. The purpose of applying Anylogic package is discussed as well. In addition, the critical constrains and assumptions during the implementation are discussed. The integration of UML, agent-based modeling and simulation software (Anylogic 7.1) aids to develop usable, complete, simple, comprehensive and reusable RL models.

# Chapter 5 : Numerical Applications

In this phase, three different approaches of simulation modeling will be executed by the same input data with various conditions. These methods are Agent-Based (AB), System Dynamics (SD) and Discrete Event (DE) undergoing without RFID enabled and with RFID enabled situations. Afterwards each of the mentioned approaches will be compared with each other, also with Non-RFID and RFID conditions as well. It means that, six different simulation runtime will be illustrated in the following sections. Eventually, all the executed simulation models will be stored in a table for comparison purpose. By this comparison we will show and conclude which method has the most impact on the model in two scenarios (without RFID, with RFID).

## 5.1 RL without RFID-Enabled

The without RFID enabled is the baseline framework that discussed before in Section 3.2.1. In the following sections, three simulation methods will be developed and explained through figures.

### 5.1.1 Agent-Based (AB) of RL

This section is the same as Section 4.4 with the exception that the total disassembly time will be used in the results section.

### 5.1.2 System Dynamics (SD) of RL

Since agent based simulation is the main goal in our study, for the evaluation this purpose other methods will applied as well. One of the methodologies is System Dynamics (SD) that according to Sterman [125] "System dynamics is a perspective and set of conceptual tools that enable us to understand the structure and dynamics of complex systems. System dynamics is also a rigorous modeling method that enables us to build formal computer simulations of complex systems and use them to design more effective policies and organizations. Together, these tools allow us to create management flight simulators-microworlds where space and time can be compressed and slowed so we can experience the long-term side effects of decisions, speed learning, develop our understanding of complex systems, and design structures and strategies for greater success."

The main usage of System Dynamic method is when the modeller desires to build a model by considering long-term and strategic model with high level of aggregation of the objects being modeled.

For better understating and evaluating our ABM, Anylogic simulation software is used again. In Figure 5-1, SD methodology is designed and executed. This SD model is applied before in another study by Sandani [126]. The only difference is, we used actual data for our model and redesign it as well.

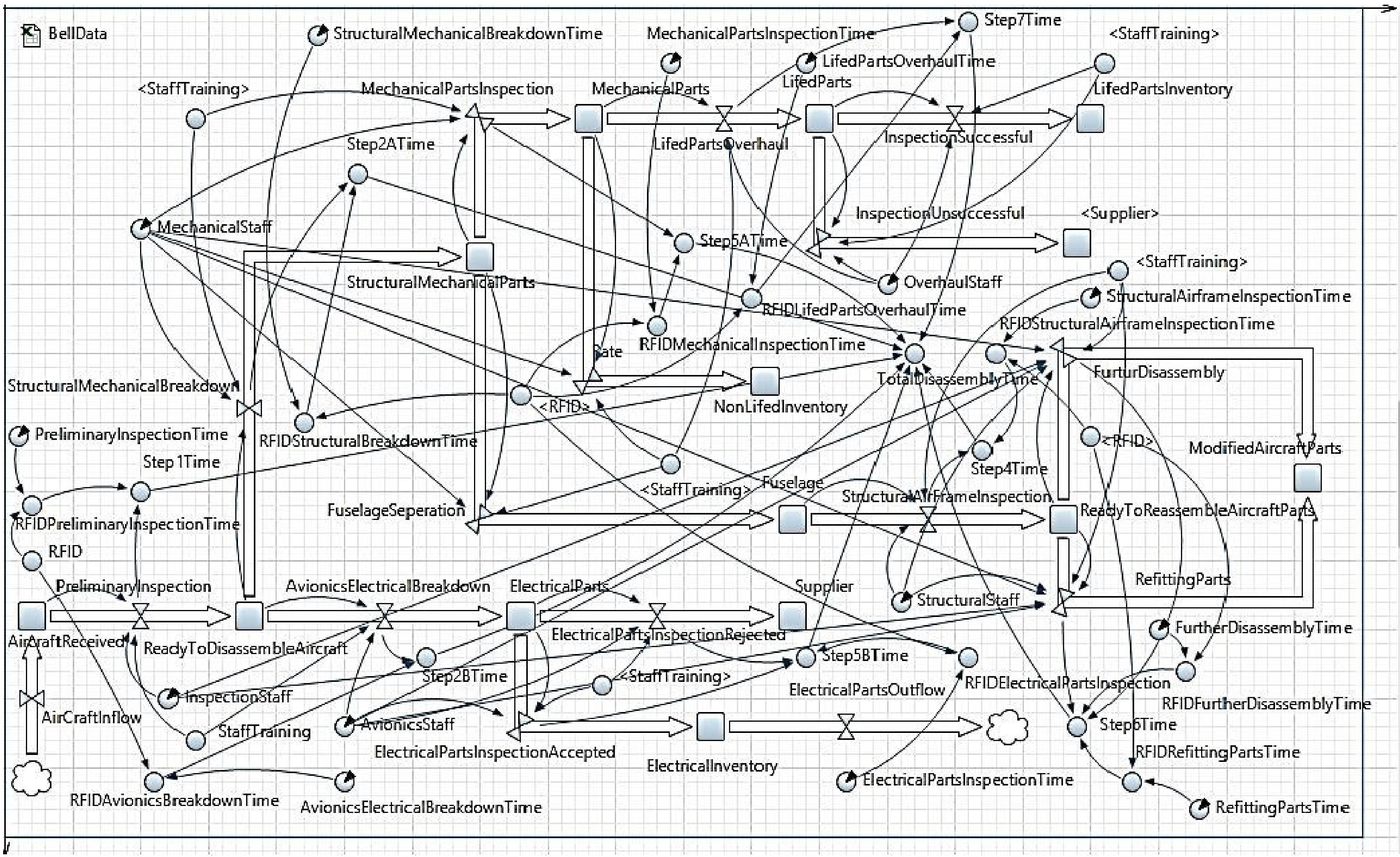


*Figure 5-1: System Dynamic Model*

In the aforementioned model all the input data such as time and staff parameters are same as agent-based model data. Forasmuch as SD methodology is not the primary object of this study and previously done, therefore the details of implementing will not be described. However, the total disassembly time will be compared with other methods on the results section.

### 5.1.3 Discrete Event (DE) of RL

The word Discrete Event is mostly applied for symbolizing "Process-Centric" modeling which standing for the system being analyzed as a sequence of operations or processes being performed on entities of specific types like people as customers, parts, vehicles, bank transactions and phone calls. Mainly entities in discrete event are passive, however can have attributes that influence the way they are handled or even alter as the entity flows through the process. According to Anylogic [124], "Process-centric modeling is a medium-low abstraction level modeling approach. Despite the fact that each object is modeled individually as an entity, typically the modeller ignores many 'physical level' details such as exact geometry, accelerations, and decelerations." Discrete event is mostly applied in the manufacturing, logistics, and healthcare industries.

As the same reason stated before, this research is not going to talk about how to design and build DE model in Anylogic, nevertheless presenting an overview of the model will be appropriate for better comprehension.

In DE modeling, one of the fundamental aspects of designing the model is identifying resources that will be used in the model and corresponding parameters. The procedure of disassembly process in design phase is included of various features. These features can aid the modeller to represent the model in a more understandable way by making use of 3D, 2D and Logic visualization. Figures below illustrate the benefit of using these features respectively.

Figure 5-2 is an example of 3D view of the model which the structural and mechanical parts of the aircraft are being teardown in teardown room (TD Room 1) and simultaneously electrical/avionic parts are dismantled in the Electrical Room. In both rooms the respective engineers are performing their tasks.


*Figure 5-2: Discrete Event 3D View*

Figure 5-3 demonstrates the same process in Figure 5-2 on the 2D view.

Figure 5-4 represents the logical view of the model with eight resources. In DE modeling, due to the fact that all the structural, mechanical, electrical/avionics and overhaul engineers have similar responsibilities and also because of the limitation in the evaluation version of Anylogic, all the engineers are defined as Technician.

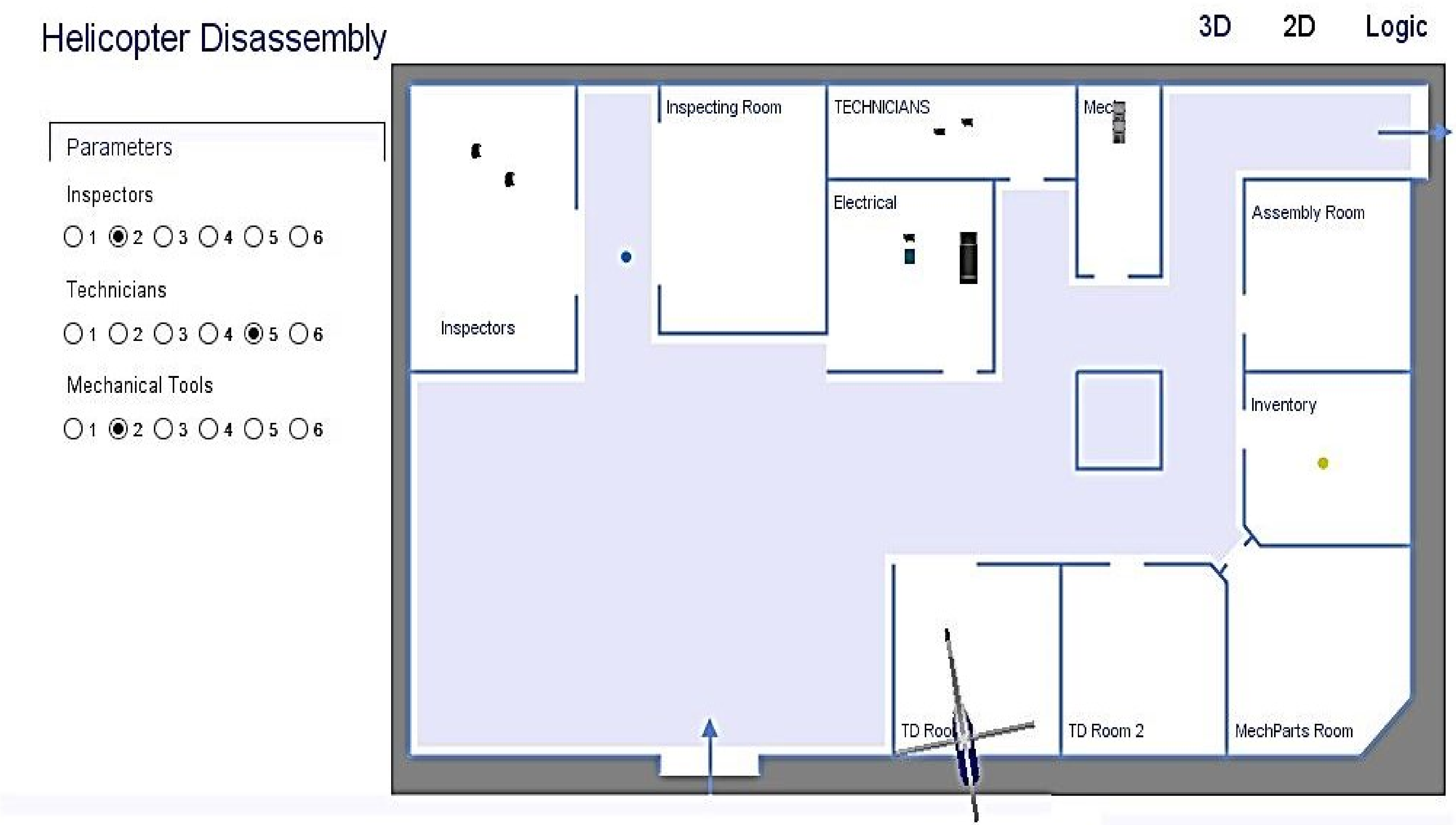


*Figure 5-3: Discrete Event 2D View*

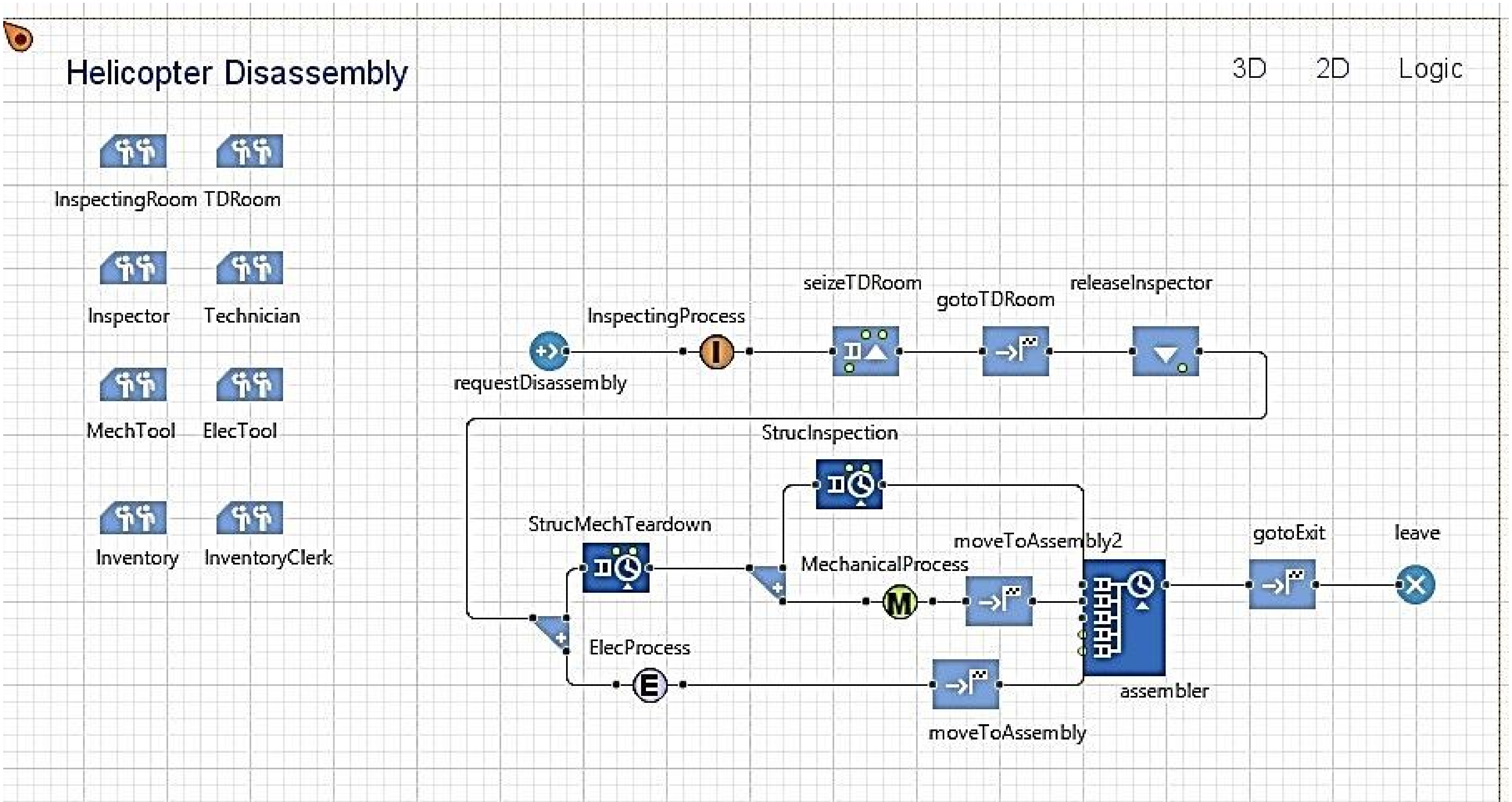


*Figure 5-4: Discrete Event Logic view*

In addition, based on the boundaries of the evaluation version of Anylogic, only 25 processes can be implemented. So for solving this problem, three sub-processes designed as follows:

1. I : Inspection Process
2. M : Mechanical Process
3. E : Electrical/Avionics Process

Figures 5-5, 5-6 and 5-7 all these sub-process and corresponding parameters which represent the resources are shown.

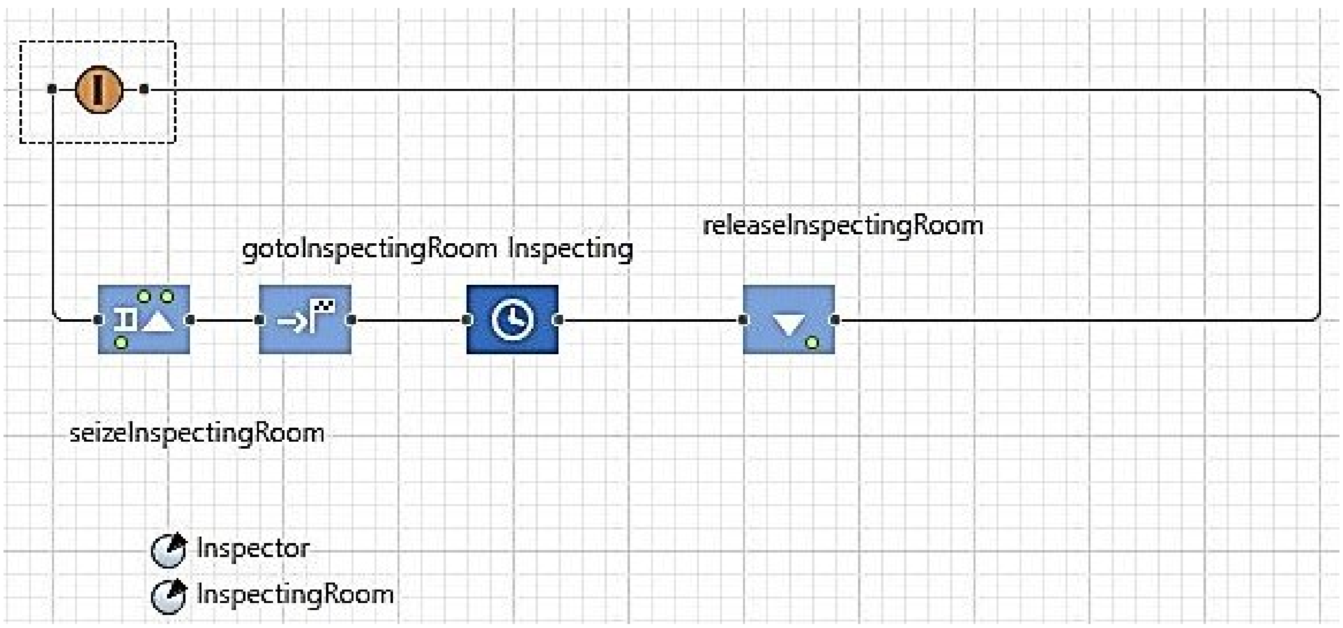


*Figure 5-5: Inspection Process Logic*

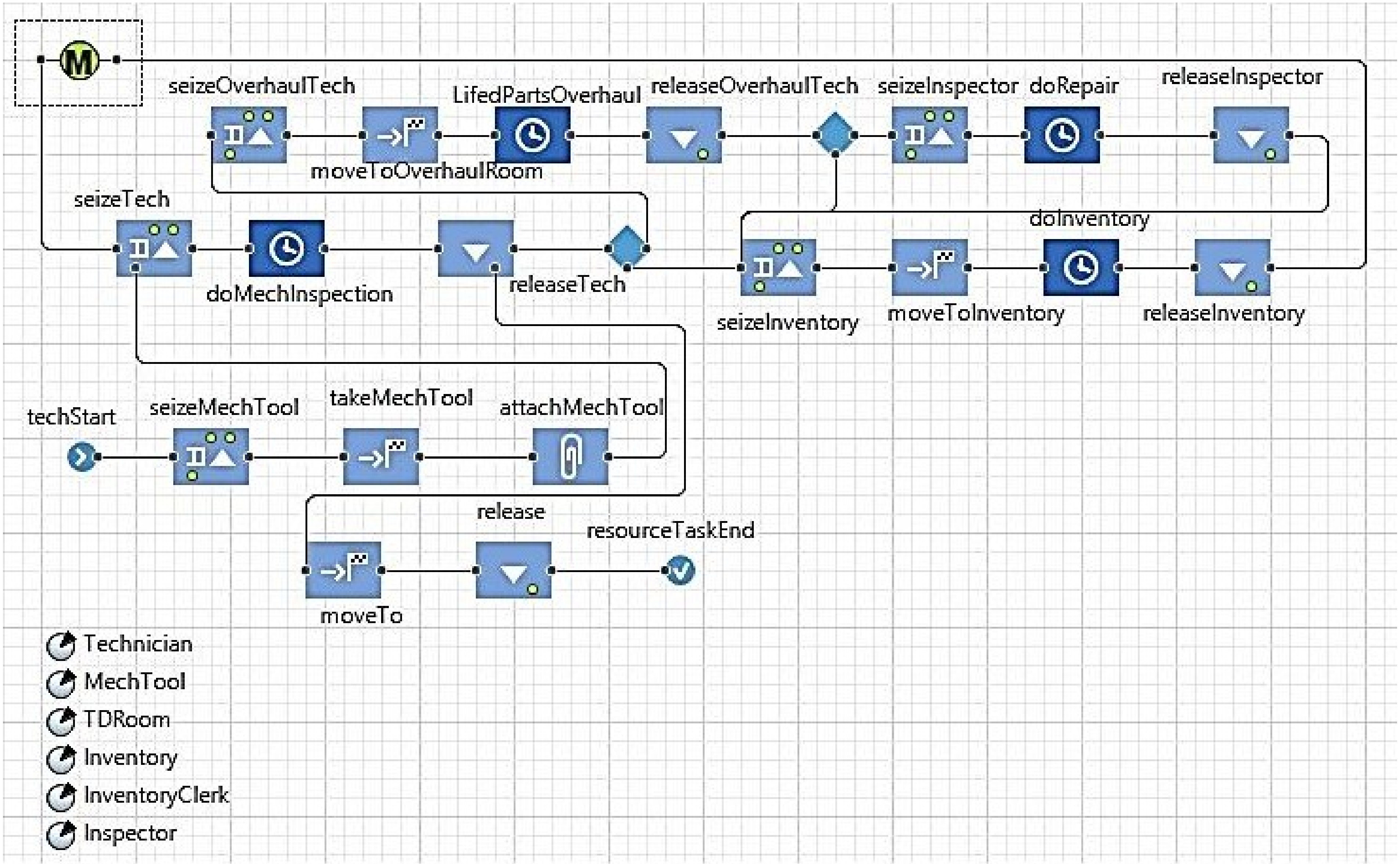


*Figure 5-6: Mechanical Process Logic*

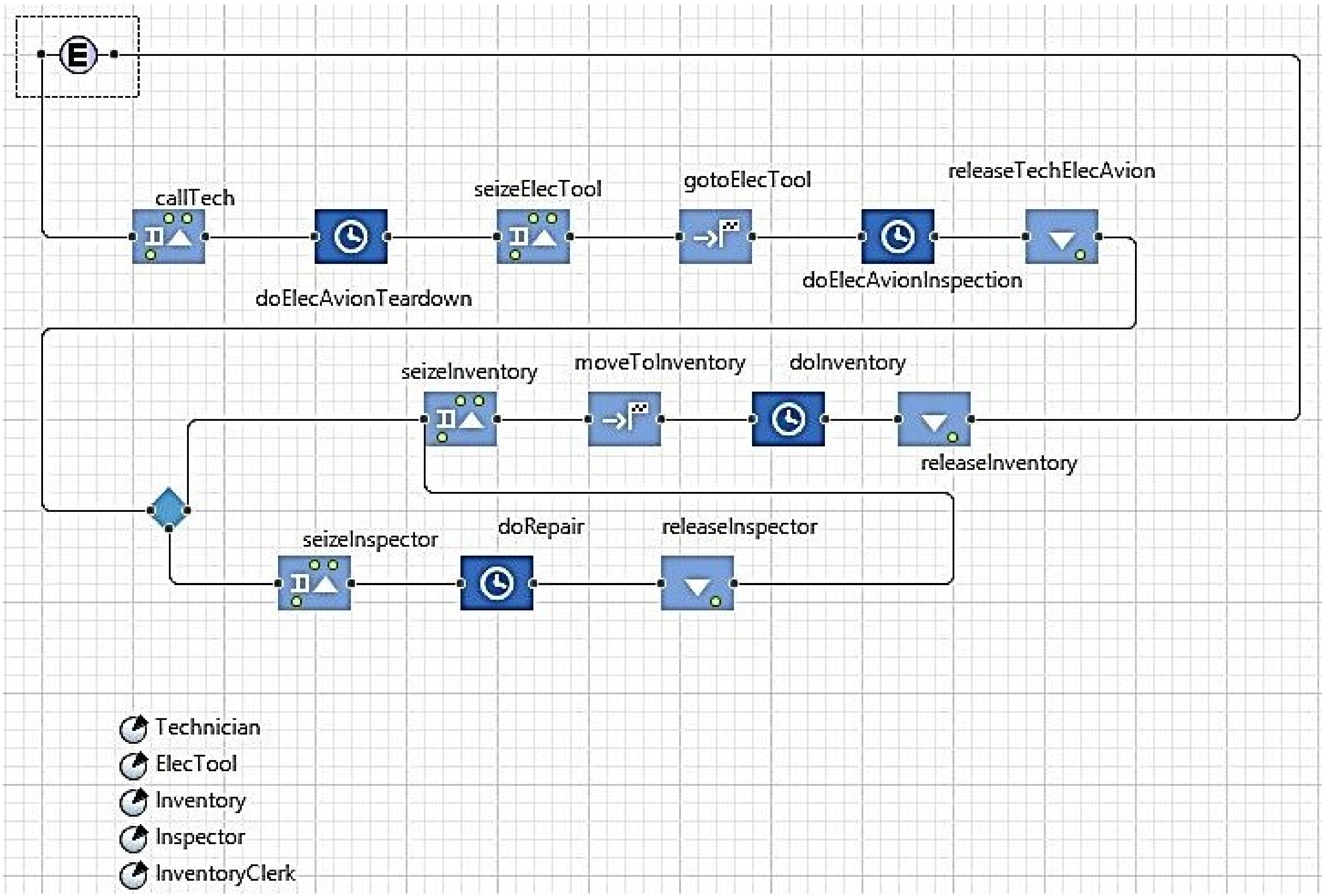


*Figure 5-7: Electrical/Avionics Process Logic*

## 5.2 RL with RFID-Enabled

The main modification in the developed model after implementing RFID technology into the aircraft's components will be removing the labeling and record findings tasks from all the processes such as inspection, teardown and overhaul. In the agent based Section 5.2.1 details of the mentioned changes will be more explained.

### 5.2.1 Agent-Based (AB) of RL

The RFID-enabled aircraft in our reverse logistics process enters to the system to be modified and upgraded for reusing. The helicopter will undergo a preliminary inspection. At this phase of the process the RFID tags will be read by the readers that placed in appropriate locations. The preliminary inspection information will be easily provided for the inspection engineers; therefore the inspection time can be dramatically decreased by removing all the paper works and related documentation. On the other side, inspectors are capable of collect all the needed data faster and more accurate. Afterwards, in the parallel teardown phase, all the parts such as structural, mechanical and electrical/avionics will be dismantled. RFID tags which are used in most of the aircraft parts will provide important information like components' code, maintenance and repair history, assembly date, and any other useful information. From the tags data, engineers can make precise decisions of which components need repair or teardown and there are no needs of labeling the dismantled components and record findings by paperwork's as well, hence this will save time.

The next step is the inspection stage that for structural and mechanical parts are testing and inspecting components and for electrical/avionics parts, numbers of removal activities are included as well. The inspection phase embedded for various aims such as which parts need an upgrade or need to be fixed or replaced by the new parts and also separates the lifed components from non-lifed and disposal components. With the same procedure like before, RFID tagged parts will be read by fixed or mobile readers by the associated inspection staff from different departments (structural, mechanical and electrical/avionics).

After mechanical parts being inspected, a wide range of valuable data will be exploited by the aid of RFID technology such as detailed information of the components about repairing or the fly time amount. Then the lifed-parts will be going through an overhaul process to find out the defective and unrepairable by the quality department components which should be dispatched to the suppliers. The other parts (non-lifed, disposal) will be sent to the warehouse for reuse or discarded.

For electrical/avionics parts the scenario will be same. It means that RFID system could have an immense impact on providing information for selecting between the deficient and intact components. Therefore, electrical staffs comprehend which component should be sent to suppliers or returned to the warehouse for reuse or discard. In addition, when an engineer is doing the removal and inspection tasks, there is no need to record the parts number or serial number due to the fact that RFID technology will make it easier and efficient.

Same inspection process will be applied to structural parts. The structural parts (fuselage) of the helicopter will undergo a testing and inspection for cracks, corrosion and general conditions of the airframe. Since most the parts including RFID tags so spending the amount of time for knowing and recording the history of inspected components will be significantly reduced. At the last phase of the RL process, all the essential parts for assembly and upgrading the helicopter will be collected and those which need RFID tags will be labelled. Afterwards, all the aforementioned parts will be refitted and assembled. The final version will be the upgraded aircraft equipped with new, repaired and upgraded components which is tagged by RFID.

The new time parameters of the with-RFID scenario have been given at the below Table 5-1. These parameters will be used in the with-RFID model as well (Figure 5-8). The detail of the comparison between different scenarios will be discussed and demonstrated in the result Section of Chapter 5. Also, numbers of the engineering staffs are as the same as without-RFID scenario.

*Table 5-1: With-RFID Time Parameters*

| Name | Time (minutes) |
|---|---|
| Preliminary Inspection Time | 100 |
| Mechanical and Structural Teardown Time | 4663 |
| Electrical and Avionics Teardown Time | 1333 |
| Structural Inspection Time | 2185 |
| Mechanical Inspection Time | 2043 |
| Electrical and Avionics Inspection Time | 387 |
| Lifed Parts Overhaul Time | 1499 |

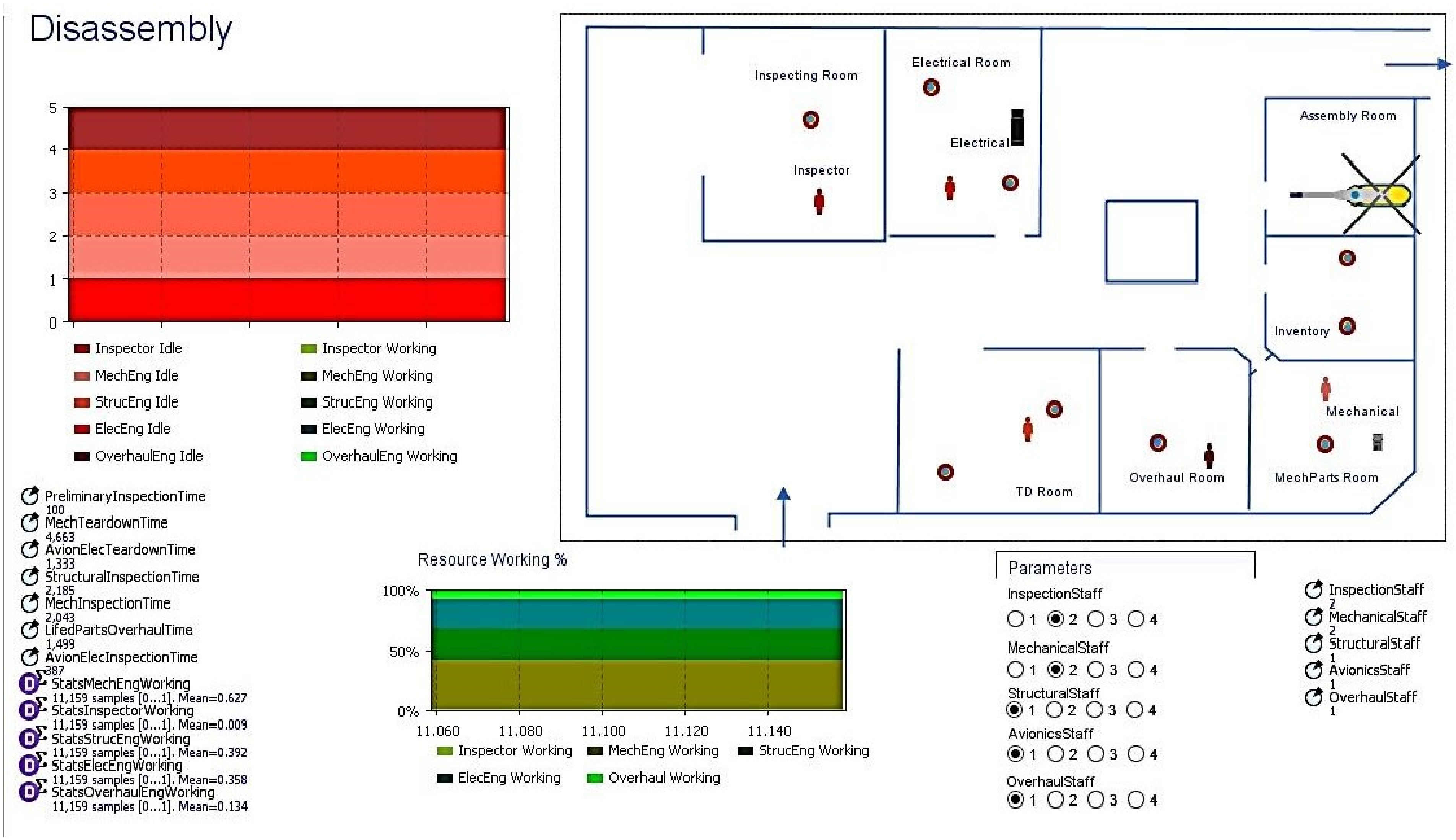


*Figure 5-8: Agent-Based Model With-RFID Enabled*

### 5.2.2 System Dynamics (SD) of RL

Likewise, SD scenario has an identical procedure as SD model without-RFID enabled. However, in SD model with-RFID the entire parameter values used are the same values as AB scenario with-RFID. Figure 5-9 implies on this subject.

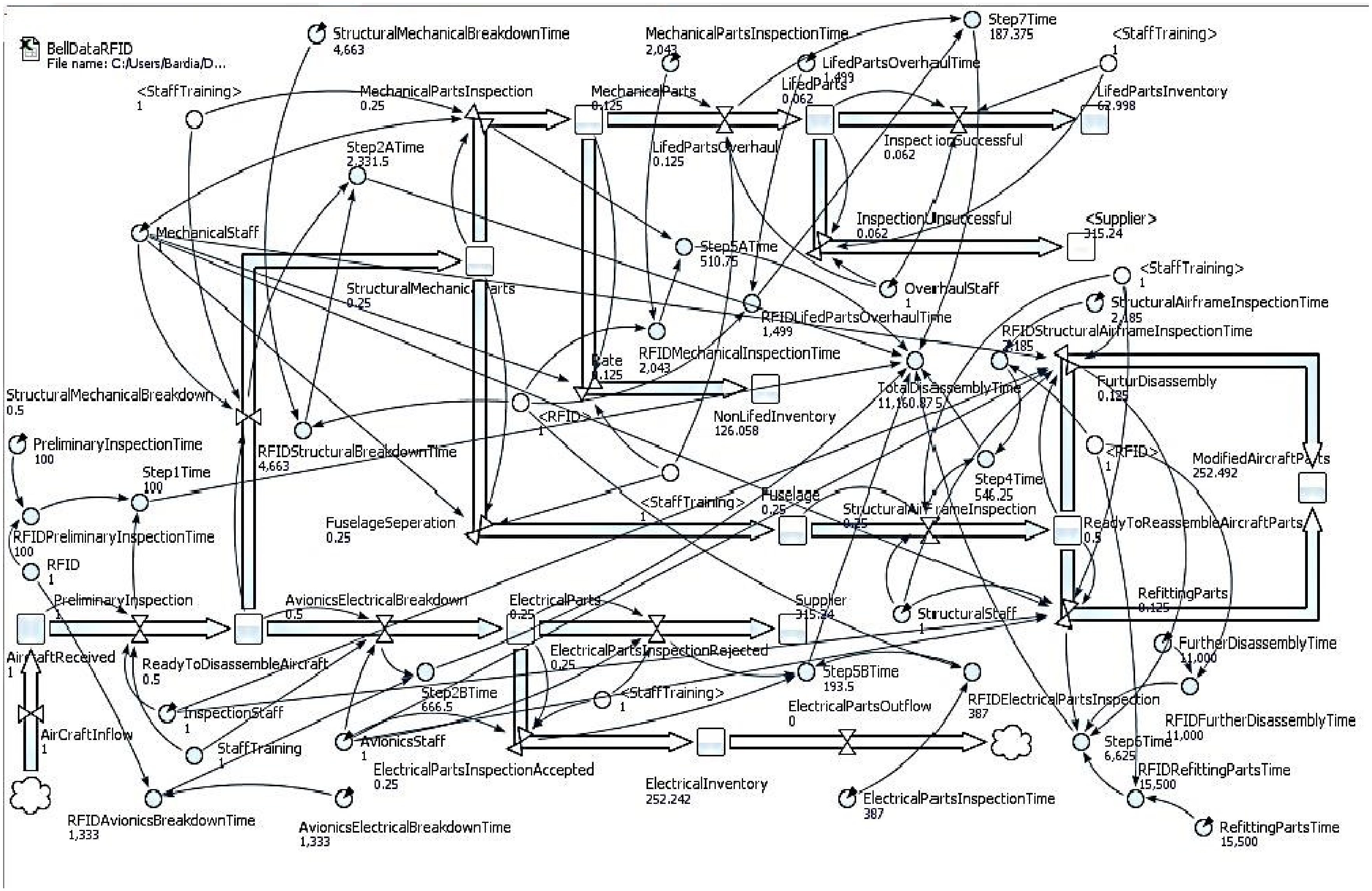


*Figure 5-9: System Dynamic With-RFID Enable*

### 5.2.3 Discrete Event (DE) of RL

Similarly, DE scenario has an identical process as DE model without-RFID enabled. Except that in DE model with-RFID all the parameter values used are the same values as AB and SD scenarios with-RFID. Figure 5-10 demonstrates the DE model with-RFID.

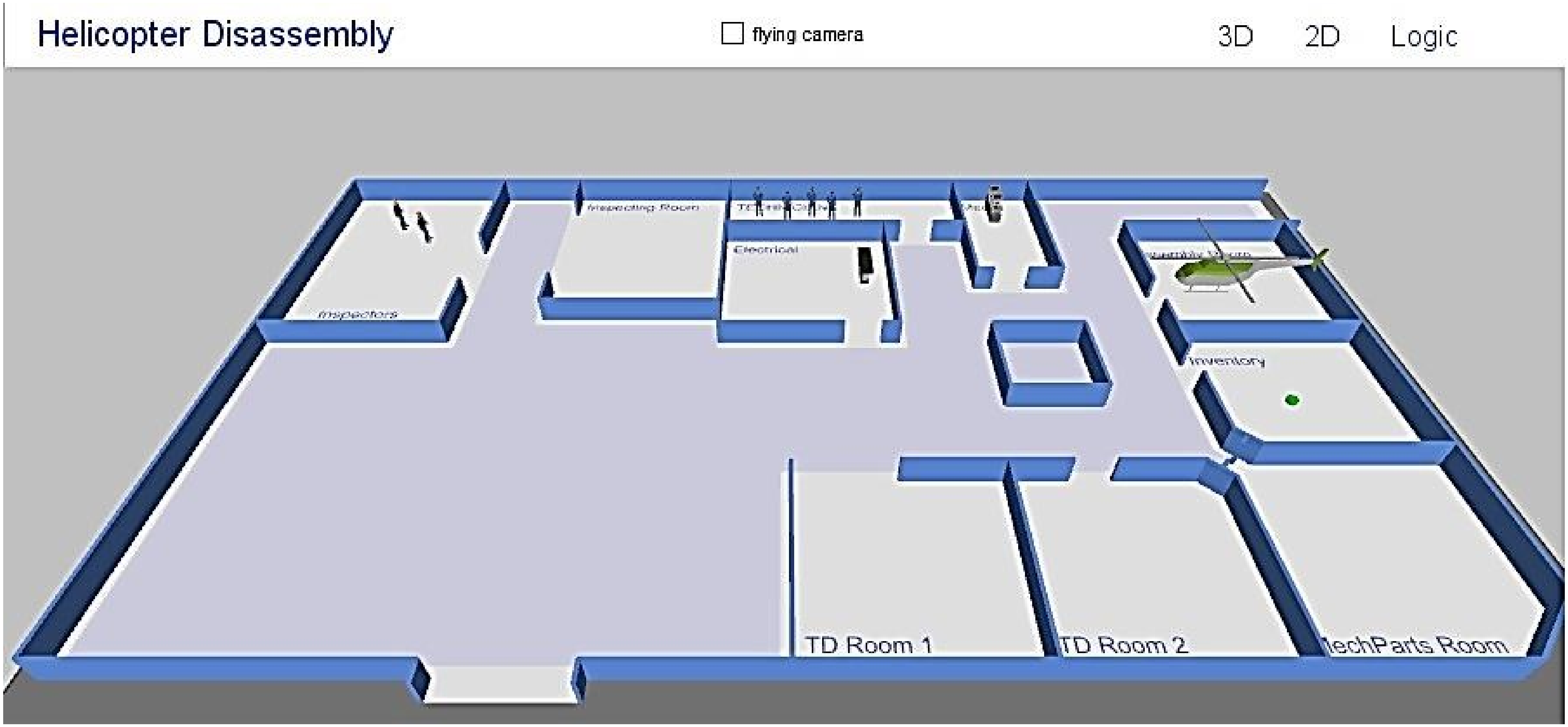


*Figure 5-10: Discrete Event With-RFID Enable*

## 5.3 Results

In both scenarios (without-RFID and with-RFID), all the developed models are assumed that some components of the helicopter parts arriving into the disassembly process are equipped with RFID labels and some parts that need to be labelled will be tagged during the process. As explained before, in both situations (with-RFID and without-RFID) the reverse logistics process commence in the same way. It means when the helicopter is delivered by the customer, at the preliminary inspection process, the inspectors already have the needed information for doing their tasks. However, the difference now is that they will use static and mobile readers for scanning and gathering all the required inspection information instead of doing time consuming paper works, log files searching and documentation activities. Hence, this advantage will help them to reduce the preliminary inspection time by almost 20% from 120 minutes to 100 minutes. On the teardown stage, all the mechanical, structural and electrical/avionics parts will go through separate disassembly process. Like the preliminary inspection stage, all the required information and equipment such as bill of materials, spare parts, removing instructions, sequence of the dismantling and other necessary tools will be provided for the associated engineers (technicians). In this stage also, due to the RFID technology usage the actual amount of time respectively for the mechanical and structural teardown process will be decreased by 3% from 4798 minutes to 4663 minutes and for electrical/avionics teardown process will be reduced by 8% from 1440 to 1333 minutes. For the next stages which are the inspection stages (mechanical, structural and electrical/avionics) the same procedure will be applied. On the structural inspection process, all the tasks like separation inspecting, corrosion inspecting, general component conditions inspection, cracks checking and inspecting all the visible or hidden damages will be performed by the structural engineer that takes 2401 minutes. However, by exploiting the RFID technology, this time will diminish by almost 9% to 2185 minutes. Additionally, the mechanical inspection time has been decreased from 2414 minutes to 2043 minutes (approx. 16%) as well. On the other hand, the electrical/avionics inspection process which is including three main activities of removing, inspecting and recording the part/serial numbers, due to the deployment of RFID technology, all the recording tasks will be eliminated. Therefore, the inspection time will be reduced by 20% from 480 minutes to 387 minutes. Based on the disassembly process after mechanical inspection stage, the lifed parts overhaul process will be performed. This stage also will be witnessed the least reduction of amount of time by 1%. In the final stage that the aircraft is ready to be upgraded, due to the fact that all the time data are not actual and collected by assumptions, RFID technology diminishes the time of further disassembly from 200 hours to 50 hours on average and not a considerable time changing in refitting of all the dismantled and upgraded parts [126]. However, according to Sandani's research [126], RFID technology could reduce the number of staff at each phase of the process so that the decreased number of engineers could be utilized at the refitting stage and that will result in reducing the time from 650 hours to 430 hours on average. Figure 5-11 represents the comparison between before and after RFID implementation in each stage of the reverse logistics process.

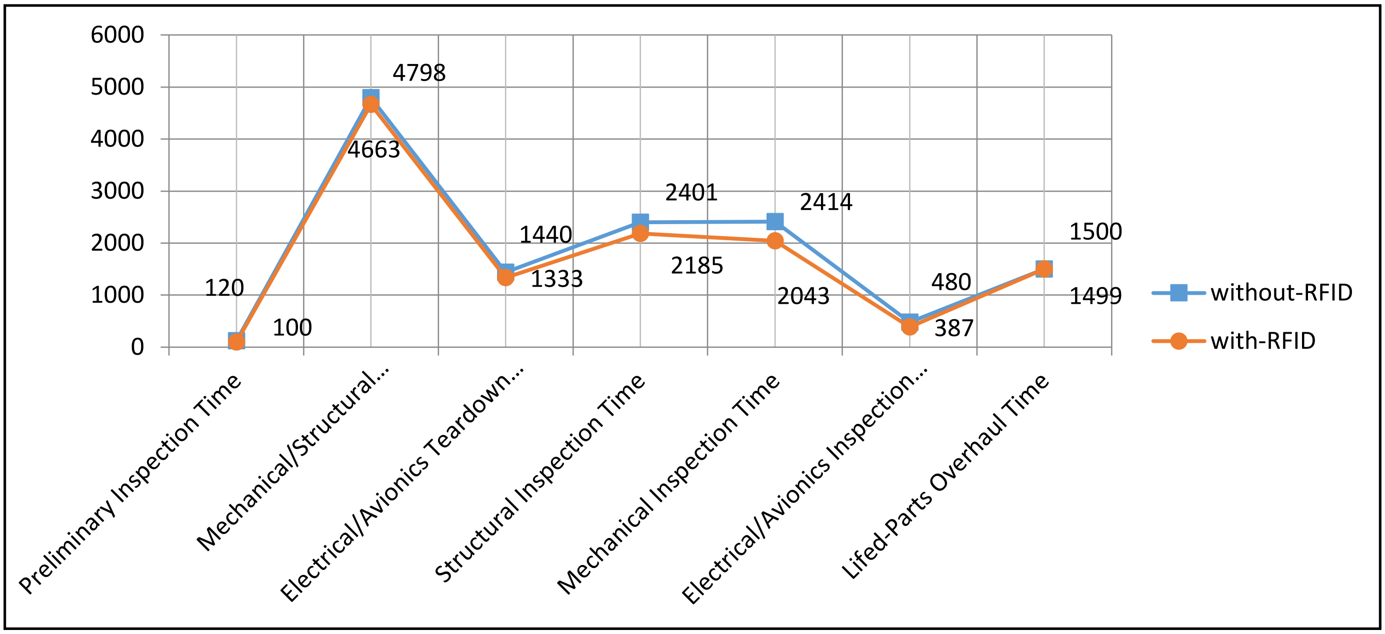


*Figure 5-11: Non-RFID vs RFID Time Comparison (Minutes)*

After discussing about the actual time changes in various stages of the reverse logistics process, the comparison between RFID and Non-RFID scenarios has been demonstrated below to show the total disassembly time in different simulation methods (AB, SD and DE).

Based upon Figure 5-12, the advantages of implementing RFID technology in the reverse logistics system is presented. Through RFID technology the total disassembly time has been decreased by approximately 10% for all three different simulation methods (AB, SD and DE). From the other point of view, the total disassembly time variation between these three simulation methods in both scenarios (RFID and Non-RFID) is negligible.

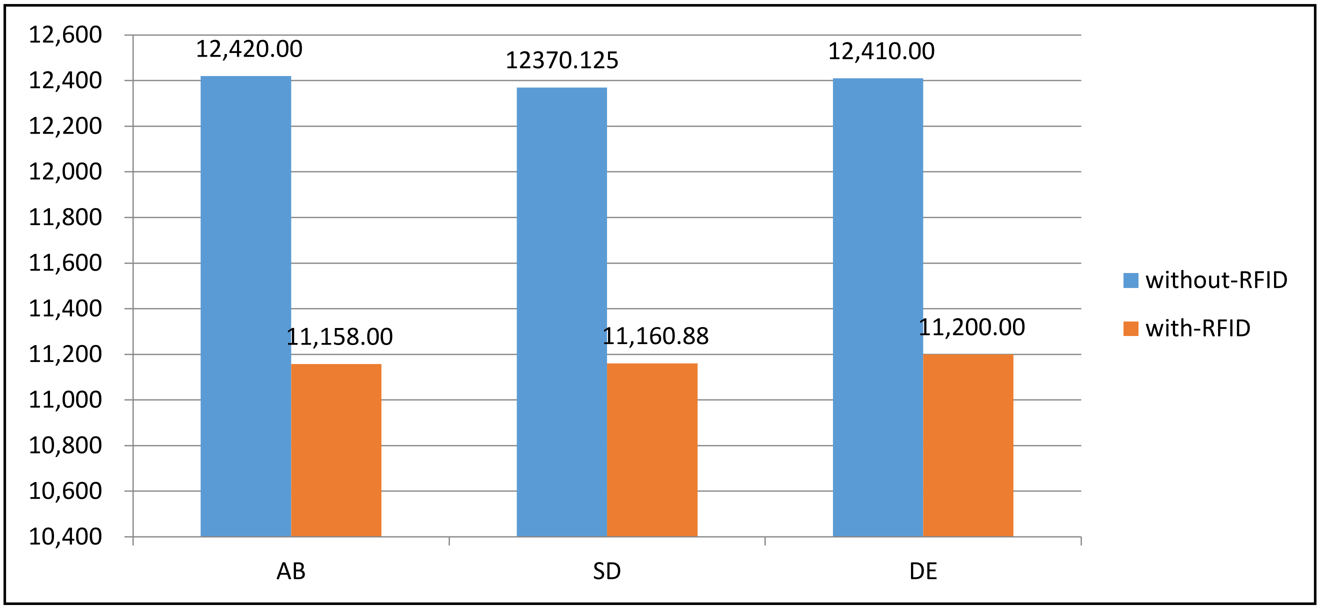


*Figure 5-12: Total Disassembly Time Comparison for Without-RFID and With-RFID Scenarios (Minutes)*

## 5.4 Summary

Three different simulation modeling techniques (AB, SD and DE) which include designs and executions are discussed in this chapter. Through implementing all three approaches, we determine the best solution(s) by analyzing and comparing those tools. The first section has conducted the examination scenario of the RL system without considering RFID technology in the system. Succeeding that, a similar RL system was developed, but this time considering RFID technology in the system as a new scenario. Finally we presented results obtained from the simulation scenarios via AB, SD and DE tools with discussion of the results.

The summary of the results of the numerical application discussed in Sections 5.1 and 5.2 is presented in Figure 5-12. The results showed reduction on the total disassembly time on all three simulation methods. The 10% reduction means that, by utilizing RFID technology in RL system the total disassembly time will be diminished.

# Chapter 6 : Conclusions and Future works

This chapter contains of conclusions and proposed future works for the area of reverse logistics system.

## 6.1 Conclusions

This thesis is widely reviewing the design of object-oriented and agent-based models by applying UML diagrams for understanding the impacts of RFID technology in a real case study of Bell Helicopter Company's reverse logistics system. Since the main objective of this research is in the agent-based modeling area, we have offered the agent-based modeling simulation through Anylogic 7.1 software. The basic reason we choose this software is due to the fact that this software is one of the best software's in the supply chain areas which is extensively integrated with UML design paradigm. On the other hand, forasmuch as we planned to validate our agent-based model results by comparing with system dynamics and discrete event models, Anylogic played an important role in our study. This role is that we exploit the unique capability of developing and implementing three different simulation methodologies with one tool.

After the obtained results from the entire simulation methods, we have been able to determine the most appropriate and suitable method for our case study. We can differentiate benefits of the methods in our conclusion based on the fundamental concepts and definitions of all three methods.

By using AB approach, we are able to capture more real life events than SD or DE approaches. Although, this does not mean AB is a better substitution for SD or DE approaches. There are various kinds of case studies or events where DE or SD approach can accurately and efficiently find solutions for their problems. Besides, AB modeling for some cases is not suitable, even, will make the problem more complex, less efficient, harder to design and develop, and not close to the nature of the problem. This is the situation, where we can use SD or DE approaches. Based upon the Anylogic Book [124], the AB approach is a bottom-up approach where the modeller focuses more on the behavior of the individual objects and also can be used at all levels (strategic, tactical and operational). The system dynamics method assumes a high abstraction level and is primarily used for strategic level problem. The process-centric (DE) method is mainly used on operational and tactical levels. As an example, in our case study if we did not have the desire to build our model with UML diagrams and also identifies different agent behaviours, traditional approaches can be more practical. According to Keenan et al. [127], agent-based modeling is the best tool for modeller who desire to go beyond the limits of DE and SD methods, particularly, when the model includes active objects like people, units, vehicles, products, companies, etc., with timing, sequence of event ordering or other types of behaviours. The other advantages of AB modeling with Anylogic is that, Anylogic not only allows to develop agents with minimum coding needed, it also enable to consider applying different modeling paradigms for various parts of the simulation model which called Multimethod Modeling. As an example, the disassembly process inside the Bell Company can be modeled using discrete events, whereas the communication between the companies' people and customers, also their behaviors can be modeled using agent based model. In addition, system dynamics can be used in the upper level of the company for cost analysis and company turnover. When we are combining the three methods, we should consider solving a complex system problem from all different aspects. These aspects can be individual data (use an AB approach), owning only information about global dependencies (use SD method) and describing system as a process (use a DE approach).

The Table 6-1 below presents the comparison of three simulation methods [128].

*Table 6-1: Comparison of Simulation Methods [128]*

| AB | SD | DE |
|---|---|---|
| More widely used in operational research (OR) area - no concept of queues – problem is when modeling many OR problem simultaneously | Applied for system form flows or looking at more larger system in a simpler way | Applied for systems having queues or when queueing structure is not obvious |
| Microscope and macroscopic- Active (agents have their own behavior) | Macroscopic (take a more overall perspective) | Microscopic (smaller details of a system) - Passive (entities is determined by the system) |
| Stochastic | Deterministic (run once) | Stochastic (different results on different runs)- run multiple times to gain full understanding of the system- statistical methods have to be used to analyse the runs |
| More time consuming to develop model and to run (complex systems) | Spend more time conceptually modeling the system | Modellers spent more time modeling and verifying/validating the model (more complex systems) |
| Extreme example of a bottom up approach | Top down approach | Bottom up approach |

From another perspective, after executing all three methods based on the real case study to explore the details behavior and complications of the process via introducing RFID technology, we verify the results of all methods which show all of them follow the same results pattern.

Therefore, we conclude that employing RFID technology will lead to reduction of 10% in the total disassembly time of the system.

## 6.2 Future Works

In our study, although most of the data were used for different phases of the disassembly process were collected from the real time practices; the reverse logistics system does not only include disassembly process like dismantling and overhaul. Moreover, the reassembly and refitting stages of upgrading the aircraft should be taken into consideration, since these processes are assigned a large amount of time. I should be noted that by having the mentioned actual times, we will be able to observe that RFID technology could diminish the total disassembly and reassembly times more than 10%. Likewise, it is suggested to consider the impact of the RFID enabled in inventory management and redesign of the model by considering the new parameters, times and activities.

From the other point of view, as we used the evaluation version of Anylogic software for modeling our case, we faced several obstacles in designing the model. With the professional version, we can build and simulate more practical models in detail. As an example, we can design our model more similar to the UML diagrams discussed in Section 4.1 such as activities, use cases and sequence diagrams. Therefore, we do not have the limitation of using only 10 agents and 25 processes in the software, and the results of the executed model will be more real.

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