Track and Trace Case Studies Report

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Report Abstract: As part of the track and trace theme of the Aero-ID programme, a series of case studies are being undertaken to establish the role of identification technologies can play in improving tracking and tracing. This report presents some initial results from two case studies focused on track and trace operations, which took place at a distribution centre for commercial aircraft parts and a military aircraft spare parts supply chain. The aims of the case studies were to analyze companies' main operations and to identify potential areas of operational improvement. The report explores issues regarding both logistics operations and repairable parts management. Through the study, we identify the needs for improved tracking and tracing information quality; we propose how automatic identification technologies can improve information quality and in turn optimize operational efficiency.

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Business Processes & Applications

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1. Introduction

1.1. Aims

The aim of this report is to present the results of the study about track and trace practices in the aerospace industry and identify opportunities for improvement through the use of automatic identification (auto-id) technologies. The report is based on case studies that took place at *Embraer Aviation International* distribution centre in France and the *BAE Systems Nimrod Programme* supply chain, in which a distribution centre and a front line repair base were studied. The focus of the study is to reveal tracking and tracing practices that companies in aerospace currently deploy, regarding both logistics and maintenance operations. The aim of the study is to understand current practices, to capture the industrial requirements for improving tracking and tracing operations and to identify the potential of automatic identification technologies towards this goal.

1.2. Approach

In order to understand the current track and trace practices in the aerospace industry, we analyzed the companies' operations by studying them on site and had personal contacts with managers that provided us with the insight of their operations. Based on the results of the companies' process mapping and in collaboration with the managers, we identified areas that provide significant potential for operational improvement using improved track and trace information. The managers provided us with useful information based on their experience and the problems they are experiencing. Finally, having identified the opportunities for improved tracking and tracing, we propose how automatic identification technologies can help to achieve this goal.

1.3. Report structure

The report consists of three main parts. In the first part we present the general operations of the companies with regard to parts handling and information flow. In the second part we identify the shortcomings of the processes and the problems that companies might face during these operations, especially regarding poor quality of tracking and tracing information that cause deficiencies and increase operational costs for the companies. Finally, in the third part we propose ways by which automatic identification technologies can improve track and trace information quality and consequently improve operational efficiency.

2. Companies' Operations

In this part of the report we outline the companies' general operations, describing at the same time the information flows that support the operations and the decision making process within them.

2.1. Overview

We briefly describe the aim of the operation of each company and the way it interacts with its partners.

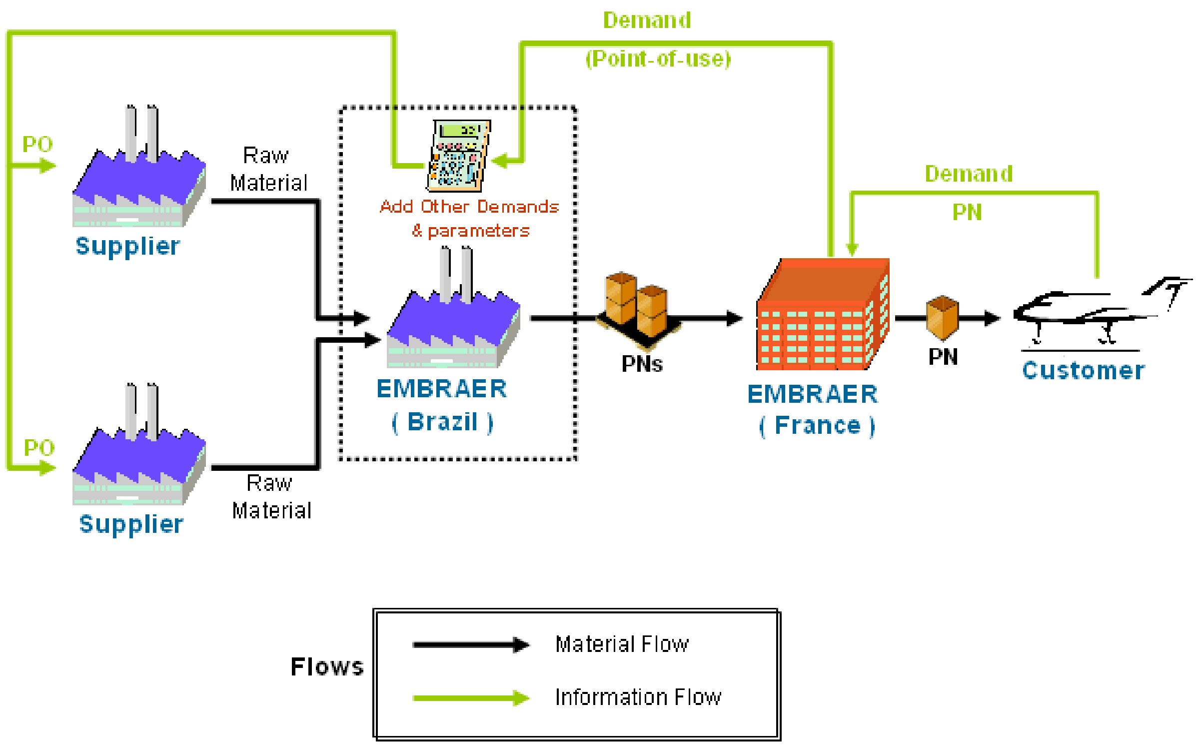


Figure 2.1: Embraer supply chain. Source: Embraer S/A

Embraer distribution centre in France plays the role of an intermediate inventory buffer that covers its customers' needs in spare parts for Europe as well as in other regions. The distribution centre receives new and repaired parts from Embraer Brazil and from original equipment manufacturers. It then forwards the parts to its customers according to their orders. The distribution centre guarantees availability of spare parts to customers that pay a fee for this service. Failed parts or parts that need to be maintained are sent to the distribution centre which assigns their repair to authorized repair centres. Figure 2.1 illustrates the structure of Embraer's supply chain.

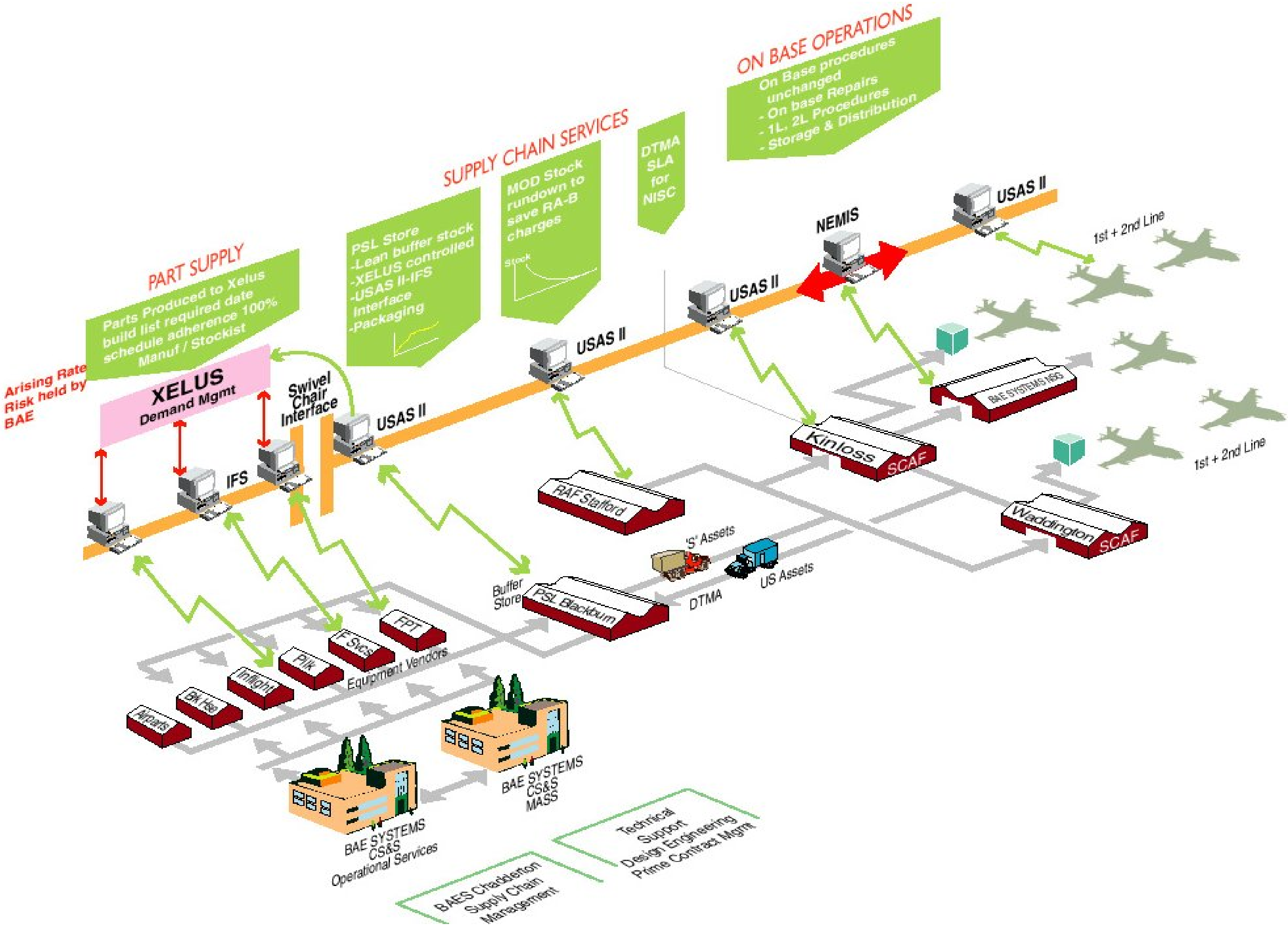


Figure 2.2: Nimrod Programme supply chain. Source: BAE Systems

The Nimrod supply chain is a supply chain that supports the maintenance of Nimrod aircraft for the British Royal Air Force. Its structure is depicted in Figure 2.2. In the first stage of the supply chain, manufacturers send parts to a central distribution centre where parts are repacked and forwarded to the respective warehouses of the front line repair bases. The front line repair bases are the sites where the aircraft is checked and maintained. Some parts are repaired and maintained on site, while others are sent back to the manufacturers, through the distribution centre, to be overhauled.

Part availability and tracking is critical for the effective and efficient operation of the supply chains outlined above. We will now describe specific operations within these supply chains.

2.2. Coding schemes

We briefly describe the coding schemes which the companies use for identifying items in their supply chains. We firstly describe the scheme that Embraer uses, which is in accordance with the commercial aviation ATA standard, and then we outline the scheme used in the BAE systems Nimrod supply chain. Both schemes are illustrated in Figure 2.3.

MFR . PNR . SER	ATA Scheme
e-Code	Embraer's additional scheme
NATO Stock Number . SER	Nimrod Supply Chain

Figure 2.3: Part coding schemes

In the case of Embraer, as defined by international regulations (ATA, 2005), any serialized aircraft part is identified by the manufacturer or supplier code (MFR), the part number (PNR) which defines the kind of the part (including its modifications) and the serial number (SER) which defines a specific instance of a part. The combination of MFR and SER uniquely identifies a part. In order to avoid confusion in the case that two different suppliers issue the same PNR for different products, Embraer uses an 8-digit Embraer code (e-code) which represents the kind of part in a unique and uniform way for all parts.

Apart from the part identification, Embraer uses lot (batch) numbers for traceability reasons through its supply chain. When Embraer receives non-serialized parts, the SAP information system automatically assigns a lot number to the received batch, which is used to track and trace the specific items from receipt until order dispatch. In this way Embraer keeps track of the parts that have been sent to specific customers. There are some cases in which a lot number is assigned to serialized parts as well, but in these cases there is a one-to-one correspondence between the lot number and part serial number.

Due to the fact that Embraer's distribution centre in France is currently in the process of upgrading its information system, the company is not currently using barcode for identifying received parts. The identification information is manually imported into the system, making the identification process error prone. However, 1-D barcode is available on the parts that the company receives and on the labels that it prints for internal identification. Once the migration to the new version of the information system is finished, the company plans to use barcode.

In the case of BAE systems, a part is identified by the NATO stock number which defines the kind of the part. For serialized parts, there is also a serial number which identifies a specific instance of a part. In the Nimrod supply chain, parts are identified mainly using human readable codes, which then have to be manually input into the information systems. Barcode is used only in some cases for internal warehouse management to speed up operations. Apart from the part identifying codes, the distribution centre in the Nimrod supply chain extensively uses the customer purchase order numbers to track items in the supply chain.

2.3. Information systems

In this section we briefly describe the information systems used by the companies for supporting their operations.

As mentioned earlier, Embraer uses SAP as the main information system for managing orders, deliveries and stock availability in its warehouses. The system is centralized and it provides stock visibility to the headquarters at Brazil for all Embraer's warehouses.

For internal use only, Embraer France uses office automation platforms (Microsoft Office, especially Excel) to support internal operations and assist information support to processes that require specialized information to be readily available (e.g. order reception and forwarding).

In the case of the Nimrod supply chain, several information systems are used. The two main information systems used by partners across the supply chain are called IFS and USAS. The IFS is owned by BAE systems while USAS is owned by the British Royal Air Force (RAF). These are used for ordering, stock visibility, tracking and warehouse management. Partners use one or both systems depending on the kind of parts they are dealing with and whether they have access to the system. Other information systems are also used for forecasting (Xelus) and other supportive operations.

2.4. Processes

We briefly describe the basic processes that take place at the companies as a basis to discuss tracking and tracing issues later in this report. Apart from some operational details specific to the studied companies, the general operational architecture should be similar for most of the companies in the aerospace industry and therefore the track and trace issues that we shall discuss may be generalized to a certain extent. In the following sections we describe the operation starting from those at Embraer's distribution centre and proceed to the respective one at the Nimrod supply chain.

2.4.1. Customer orders placement

Embraer's customers contact the Embraer customer orders department at Brazil to place orders for parts. The orders department has access to stock information through SAP and checks whether the part that a customer needs is currently in stock at France distribution centre. If so, they place the order which automatically generates a "picking list" at France for the order to be processed. This operation will be analyzed in section 2.4.3. If the part is not available at the distribution centre, it is either shipped from Brazil to France or is ordered from the respective supplier.

In the case of Nimrod supply chain, orders are either generated by the forecasting information system or manually placed. Through the USAS system, orders pass to the IFS system which is accessible by the manufacturers who will actually deliver the order. If a part is available at the intermediate distribution centres, then it is forwarded from there to the front line repair base.

2.4.2. Products delivery – receipt

Products are delivered at Embraer's distribution centre by many different carriers. The carrier that delivers the products provides some evidence of the products delivered but this is not formal. In most cases there is an advanced shipment notice for products to be delivered, but not always. For internal optimization, Embraer France generates an Excel worksheet of the expected products, so that the ones that need to be directly shipped to customers are given higher priority than those to be put to stock. An Excel worksheet is also used for internal traceability to record the orders that have been actually received.

Once received, each package is opened to review the accompanying documentation which contains the PNR and SER for the serialized parts. This information is manually entered into SAP which then indicates the lot number the part is coming from and the customer it should be shipped to, if so. This information is printed on a label which is then attached to the part (the label also includes the barcode for the e-code but it is not currently used). Through this procedure, Embraer France officially confirms that the part has been received and is now available at its warehouse. Before this point there is no visibility as to whether the parts sent to the distribution centre have been received or not.

An essential part of product receipt procedure is *quality control*. After each part has been registered to SAP it undergoes quality control by authorized staff. The employee manually enters the e-code to the SAP system which then lists a set of quality checks that the part should undergo. This set is defined by international regulations and Embraer. Although the part comes with a certificate of conformance from its manufacturer, Embraer must issue a new airworthiness certificate which guarantees the airworthiness of the part, based on the quality checks mentioned above. Embraer only issues certificates for new parts. Repaired parts are treated differently as analyzed in section 2.4.4.

The final step of the receiving process is to assign a stock location number to the part. Each part (per e-code) is kept at a specific location in the warehouse which is indicated by a location number. If there is already a location number for the specific kind of part then it is printed on it, otherwise a new one is assigned to it.

Similarly, in the case of Nimrod supply chain, products are delivered at the distribution centre by different carriers which provide some unofficial evidence of the kind of products. Products may sit in the receiving dock without being processed for 24 hours, which creates a big visibility gap in the tracking process. Once processed, package contents are cross-checked with the certificates of conformance that come with them. Product quantities, descriptions and part serial numbers (for serialized parts) are checked. A simple visual inspection also takes place to ensure that the part is not damaged. Finally, the part is recorded in the information system as received. Contrary to the case of Embraer distribution centre, parts are put in any available location in the warehouse which is indicated by the IFS information system (i.e. the location is not standard per part type). Location number is then stored in the IFS and used when the item needs to be picked up.

2.4.3. Orders processing

In the case of Embraer, when a customer order is placed and all parts are available in the warehouse, a *picking list* is generated which indicates which items should be picked from the warehouse to be put in the order and then shipped. There are three priority classes of picking lists:

- *Aircraft On Ground (AOG)*: In this case an aircraft cannot fly because of a part failure and therefore the part should be replaced as soon as possible. Embraer's distribution centre must ship this part within 1 hour from the time the order is received.

- *Critical*: In this case a part has failed and should be replaced, but the aircraft can still fly. Embraer must ship the part within 16 hours.
- *Routine*: This is the case of a typical part order for routine maintenance purposes. It is typically shipped within 3–5 days.

In the case of Nimrod distribution centre, an order is received either though IFS or USAS or by fax/email in the case of emergency situations (AOG). The order is then updated/synchronized on both information systems manually and a *picking ticket* is printed which indicates the location from which the items should be picked up according to the code stored on IFS. The available items are wrapped in a package and sent to the customer. The process of merging individual items into a bigger shipping container is supported by barcode. Both individual item packages and shipping containers carry barcode labels. When an item is placed into a container, the barcodes of the item and the container are scanned so that the information system is updated that the specific item has been shipped in the specific container. The container is also assigned to a purchase order number. In this way, the distribution centre can keep track of which items are sent in which containers under specific purchase orders.

As described above, parts are then picked up from warehouse according to the location numbers indicated in the picking list/ticket. Both case studies showed that there are cases where an item cannot be found at its location. This causes serious delays to order processing. The main causes of the above problem listed by the managers are:

- Errors in the inventory count. The companies are experiencing a problem with inventory accuracy.
- Misplaced items in the warehouse. Items are often put in the wrong location number place when received or while searching.
- Mismatches in lot numbers of parts (in the case of Embraer). There are some cases of parts with a wrong lot number sent to customers, which results in a mismatch of the lot numbers that actually remain at the warehouse.
- Parts are blocked in transfer zones in the warehouse (e.g. quality control) and are left there, while they appear available on information systems.

2.4.4. Repairable parts handling

Repairable parts undergo different handling than new ones. In the case of Embraer distribution centre, once a failed part is returned from a customer an *Authorization Return Number* is assigned to it, which is then used to track the part throughout the whole repair procedure. The part is then sent either to its original manufacturer or other repair station for repair. When it is received after repair, the part number and serial number are checked to confirm that the same part has been sent back. The part then undergoes a visual inspection and finally put back in stock. It is important to note that Embraer does not issue certificates for repaired parts and therefore is not held responsible for their airworthiness. This responsibility lies with the repair station.

Along with the failed part, a checklist including information about the removal reason, failure conditions, flight hours and cycles is sent back to the repair station. The information regarded as essential for the repair staff is the part's flight hours and cycles undergone.

In the case of Nimrod supply chain, parts are removed from the aircraft at the front line repair base and are either repaired on site or sent back to manufacturers if are unserviceable. Parts are then sent back to the distribution centre from which they are sent to the respective manufacturers to be repaired. Returned repairable parts are carefully handled by the distribution centre so that they do not get mixed with new or serviced ones and sent back again for use. No information is sent along with the part when it is sent for repair with regard to the reason of failure or operational history. This is because manufacturers that are part of the Nimrod programme supply chain generally do not need this information as parts are always repaired to be as good as new, regardless of the failure. This is done so that the parts are under guarantee when repaired, as this is currently the preferred policy that BAE systems follows.

2.4.5. Repairable parts pool activity

In this section we describe the way companies use a repairable parts pool in order to cover their or their customers' needs.

Embraer offers a spare parts pool service to its customers, using which they can cover their needs for spare and repairable parts. Embraer keeps sufficient stock of parts to cover its customers' needs and guarantees their availability. In this way, airline companies do not have to invest money to the *initial provisioning list* that includes a predefined set of spare parts for a new aircraft in order to support its operation. This service saves companies from \$5 million to \$10 million in initial investment on a new aircraft purchase.

Embraer holds parts stock and guarantees part availability for its customers. The customers pay a fixed fee per aircraft per month and a fee per part per flying hour for all aircraft and parts that are included in the service.

The parts flow in the pool activity is depicted in Figure 2.4. In brief, when a customer requests a part, Embraer sends the part to him (step 1) exchanging it for the failed one. The failed part is sent from the customer to a logistics hub (step 2) from which it will be sent to the appropriate repair station (step 3). Finally, the part, once repaired, is returned to Embraer for future use.

1. Embraer to Customer: If the part is available in stock, or once it is received from the supplier, it is sent to the customer as described in section 2.4.3.

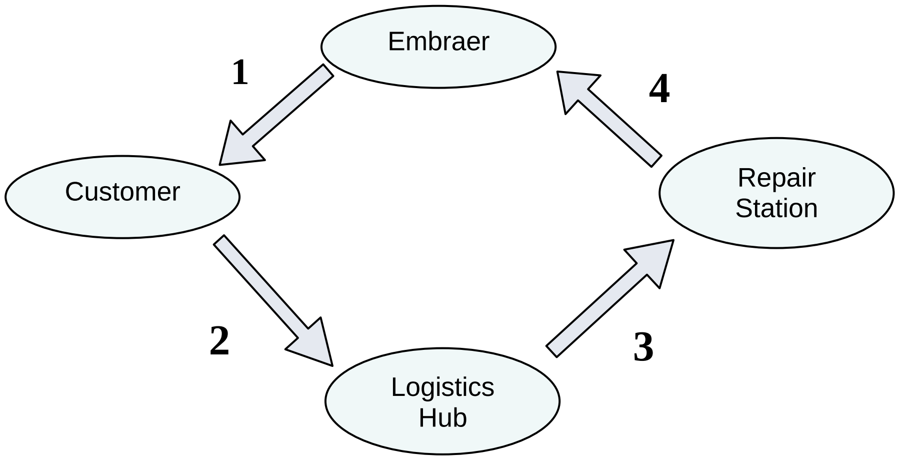


Figure 2.4: Parts flow in pool activity for Embraer

2. Customer to logistics hub: The customer informs Embaer about the part failure, sends (via fax) relevant information regarding the status of the part (reason of failure, flight hours, cycles) and sends the part to the logistic hub. While the part is in transit, Embraer decides on the repair station that the part should be sent to. When the part is received by the logistics hub operator the part is visually inspected and cross-checked against the enclosed documentation regarding its part number, serial number, the quantity, general condition and other accompanying documents. All parts received for repair should be accompanied by the *log cards* that contain information regarding the operational (aircraft, flight hours, cycles) and maintenance history of the part. This information is vital for the airworthiness of the part and without it a part cannot be used on an aircraft. Finally, if needed, the part is repackaged and is ready to be shipped to the repair station.

3. Logistics hub to repair station: The part is sent to the repair station indicated by Embraer along with all the needed documentation (invoices, log cards etc.). The repair station estimates repair time and informs Embraer. The part is then repaired if it is financially viable to do so.

4. Repair station to Embraer: Once the part is repaired it is either sent directly to a customer through a drop shipment process or sent back to the logistics hub from which it is finally returned to Embraer's distribution centre. The part passes a quality control and is then made available in stock for future use.

In the case of Nimrod supply chain, the RAF keeps a repairable parts pool in the front line repair base. The route of a part from the repair base until it is repaired is depicted in Figure 2.5.

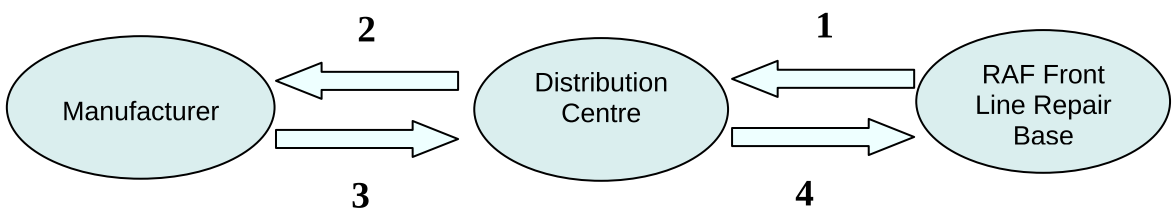


Figure 2.5: Repairable parts pool activity for Nimrod supply chain

1. Repair Base to distribution centre: Once a part is uninstalled from an aircraft, it is stored in the repair station warehouse. If the stock of available parts drops, then failed parts are sent back to the manufacturers for repair to replenish the stock. The failed parts are then sent to the distribution centre.

2. Distribution centre to manufacturer: The distribution centre forwards the part to be serviced in the appropriate packaging to the right manufacturer.

3. Manufacturer to distribution centre: The manufacturer estimates the cost for general overhaul and negotiates the price with BAE systems. Once the part is repaired to an "as-good-as-new" state it is sent back to the distribution centre, along with the respective certificate of conformance that guarantees the good operation of the part.

4. Distribution centre to repair base: Repaired parts are either directly forwarded to the repair base or stocked at the distribution centre. We should note that the distribution centre issues different certificates of conformance that are attached to the part when sent to the repair base. These of course are related to the ones that the manufacturer has issued and in case of an unexpected part failure, the manufacturer that has originally guaranteed airworthiness of a part can be traced.

3. Shortcomings – Requirements for T&T Improvement

In this section the main shortcomings that were observed during our study and the requirements for improving tracking and tracing within a company and across the aerospace supply chain will be analyzed, based on our observations described above. We will describe these with regard to the ability of a company to determine the *state* of part at present (*tracking*) as well as the ability to tell with certainty what the state the part was in, in the past (*tracing*). The state of a part, apart from its identity and location, includes the condition of the part with regard to its reliability and airworthiness. Therefore, the state of the part is affected by a set of variables. This dependence can be represented as a Bayesian Network, in which the state of the part is dependent on the values of the observed variables that affect it, as depicted in Figure 3.1.

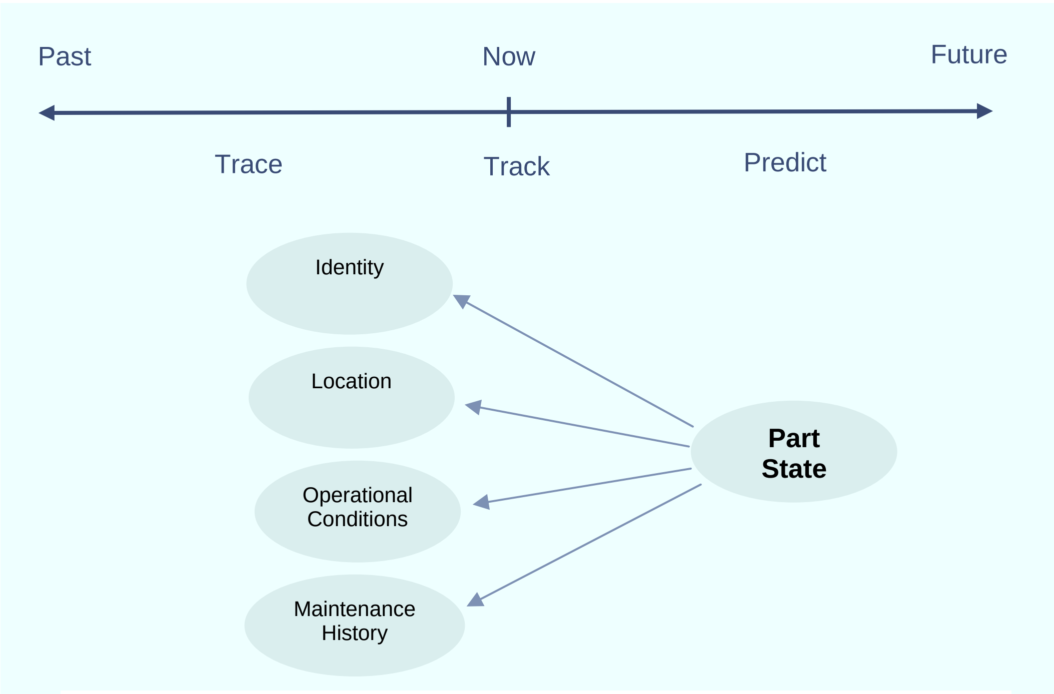


Figure 3.1: Track and trace time dimension and state dependence

3.1. Product delivery

It is made clear from the study of both companies that products delivered to the distribution centres usually spend some time sitting in the receiving dock without being processed. During this period there is a “black hole” in the tracking line of each product as the carrier may claim that he has delivered the product, whereas the product will appear “not-received” in the information system, as it will not have been processed for some time. Therefore, the company managers lose track of the part for a short period as the information system does not reflect the actual state of the product.

A special feature that is desired in the aerospace distribution centres is the ability to rapidly locate and forward products that the customer needs urgently, as soon as these arrive at the receiving dock, especially in AOG situations. Currently this operation is done by monitoring what is received and cross-checking it with a list of products that need to be shipped as soon as possible. Ideally, items that arrive in the receiving dock should generate an alarm that indicates a need for immediate handling, making the process more efficient.

Another common process in the aerospace industry is quality control during product delivery or shipment. Quality control, which can be viewed as assuring the current state of a part, can be assisted by automating the processes of retrieving quality checklists according to the part code or even embedding this information on the part itself (however this might be too large to store, probably an index to a network location would be preferable). In this way quality control can be optimized.

In brief, the main issues that need improvement with regard to tracking and tracing during product delivery are:

- Automating information system update about product delivery
- Increasing the speed of critical parts forwarding to customers
- Optimizing quality control processes

3.2. Warehouse management

Warehouse management is mainly related to the current state of a part rather than its past states and is highly focused on its identity and location more than the other dimensions of its state. However, there are some cases in which other dimensions are required, e.g. the environmental conditions for the case of perishable products.

The main requirement for an effective warehouse management process is to be able to provide *high quality information* about the quantity of products available currently in the warehouse, as well as their precise location in it. High quality information would ensure part availability when this is needed, as well as effectiveness and efficiency during the picking up procedure before shipping. Apart from the above, quality stock information will diminish phenomena of lost/misplaced parts that result in significant costs for companies.

An important perspective of warehouse management is the management of limited shelf-life parts that may either expire or need periodic reconditioning/calibration/quality check. Companies need to know the exact lifetime left for each part, as the customers should be informed about it. Furthermore, there is a need to be able to efficiently control perishable products and manage the environmental conditions they are subject to and/or taking appropriate action were needed (e.g. recalibration). In either case, parts should be available in the warehouse in a reliable condition to be delivered to the customer at any time.

During order pickup, as mentioned in section 2.4.3., there are some cases in which different parts (of the same part number) are shipped in place of others, creating inconsistencies between the information system and the actual state of the warehouse. Ideally, there should be a procedure to assure that the right parts are shipped with an order so as to avoid these problems.

As revealed by the case studies, there are a lot of cases in which parts are left and forgotten in transfer zones in the warehouse (e.g. quality control). As a result, the company loses visibility to the state of these parts and loses their track. In order to overcome this problem, companies should be able to monitor the parts throughout the warehouse operations.

In conclusion, warehouse management traceability requirements mainly focus on the location of a part in the warehouse with the exception of limited shelf-life parts where life-left and storing conditions information is required.

3.3. Hazardous materials

Hazardous materials handling is an application area that managers of the aerospace industry can see potential for improvement with regard to tracking and tracing. Hazardous materials require special handling under specific instructions that are not readily available in many cases. Companies need to efficiently identify hazardous materials and have available information regarding its handling and storage. Moreover, transport and storage monitoring of these materials is essential both for regulation compliance and human safety.

3.4. Repairable part management – Log cards

Repairable parts management requires, apart from the logistics information, information regarding the operational history and maintenance history of the part. This is not only required by international regulations, but is essential for companies as well so that they are able to guarantee the part's airworthiness. This information is recorded on log cards that accompany the part throughout its lifetime. A typical log card contains the information shown in Table 3.1. We note that for data that refer to repeated events (e.g. reconditioning), multiple records of the same type of data are entered in the card.

Data category	Data field
Part identification	Part Number
	Serial Number
	Manufacturer
	Supplier
Certification of inspection	When new
	When repaired – reconditioned
Weight info	Weight of part
Authorized part life	Shelf life

	To recondition
	To scrap
Guaranteed part life	In shelf
	In use
Transfer – Installation – Removal Information	Date
	From Aircraft No
	To Aircraft No
	Flight hours installed
	Reason for change/ removal
	Certification (stamp)
Reconditioning – Repairs – Servicing	Date
	Repair unit and location
	Job No
	Work details
	Certification
Engineering Changes	Date
	Change No
	Date completed
	Inspection
	Maintenance officer
	Repair unit and location
Major components fitted (some parts include subcomponents that might be replaced during lifetime)	Part Number
	Serial Number
	Description
	Authorized life
	Life used at fitment
	Life used at removal

Table 3.1: Typical log card information

If this information is unavailable (e.g. the log card is lost) or found to be inaccurate for any reason, the corresponding part must be removed from the aircraft and scraped. This results in significant costs both for the airlines and the suppliers. Apart from the above, log card information is essential for decision making across the aerospace supply chain, starting from the repair bases of the airlines who decide on the airworthiness of a part, the distribution centres that decide whether a part is worth repairing, where to send for repair and whether it is airworthy and finally the repair stations for which life time information is essential for appropriately repairing the part. Given the above, the quality of lifetime information that is available to the companies that handle the part is important for reducing costs and improving the effectiveness of decisions.

3.5. Summary

We summarize the requirements for improved tracking and tracing in the application areas that were revealed from our case study. Table 3.2 shows which variables that affect the assessment of the part state are especially important for each of the application areas. We should note that the list of application areas and variables that define the state of the part are by no means exhaustive, but a result of the case studies and research so far.

State variables / Application areas	Identity	Location	Maintenance history	Operational conditions history	Miscellaneous information (shelf life, hazardous type info etc)
Product delivery – Shipment	Identify the part	Define part's location			Priority class for shipment
Warehouse management	Identify the part	Define part's exact location in the warehouse			Manage limited shelf life and recondition cases
Repairable parts management	Identify the part	Define part's exact location within pool, progress of repair	Ensure airworthiness and estimate lifetime left	Assist repair decisions and ensure airworthiness	Define warranty, shelf life, proposed operational life etc.
Hazardous materials handling	Identify the part	Define where the part is stored and where it has been in the past			Provide information about special handling and precaution measures

Table 3.2: State variables used in different application areas

Finally, Figure 3.2 illustrates the time scope of each application area in the track and trace time horizon.

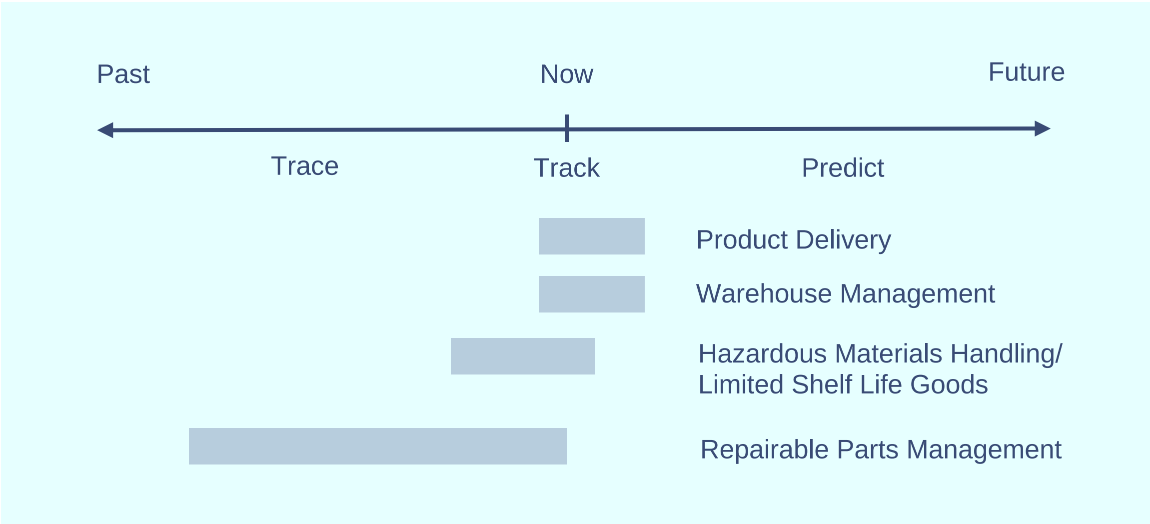


Figure 3.2: Application areas track and trace time scope

4. Automatic ID Technologies Potential

In this section we will analyze the opportunities that automatic identification technologies offer for improving track and trace performance in the application areas that were described above. We will propose some elements of information quality that automatic identification technologies (especially RFID) can have an impact on, and subsequently we will suggest how enhanced information quality can have an impact on the studied application areas.

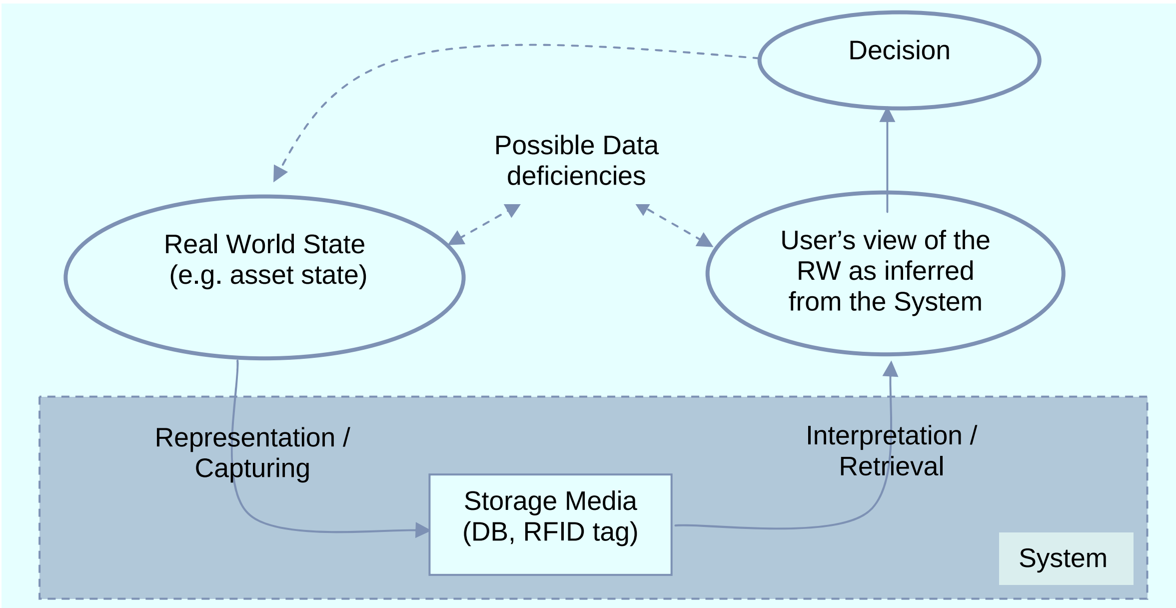
4.1. Information quality

In this section we propose some elements of information quality that auto-id technologies can affect. We should note that the set of information quality attributes/dimensions defined in this section are not intended to be an exhaustive framework that reflects all aspects of information quality, but rather a step towards a framework that describes the impact of auto-id technologies on information quality.

We assume that there is a real world state that is captured by the system. The users interpret the information in the system to infer their view of the world. We can view an information system as a representation of the real world as captured by the system. The information system is said to be a representation of the real-world system if observing the state of the information system at a given time enables the inference of a state of the real world (at the same or other time) (Wand & Wang 1996). A data deficiency is an inconformity between the view of the real-world system that can be inferred from a representing information system and the view that can be obtained by directly observing the real-world system.

In the case of part state tracking and tracing, the information system can be viewed as the set of technologies that contribute towards monitoring a part's state throughout its lifetime. This might consist of an information system and a data capturing technology that communicates data to the information system (e.g. barcode, RFID etc.). In this section we will focus on the impact of automatic identification technologies in this process.

Automatic identification technologies can be used both for capturing the real world state and for retrieving information from it, in the case where data is stored on the tag itself. We shall now analyze each case and define the most important and applicable information quality dimensions in the context of the aerospace track and trace applications. The aim of this report is not to define a comprehensive list of information quality dimension but to propose the ones that auto-id technologies can have an impact on. For a comprehensive list of information quality dimensions see (Boritz 2005;Miller 1996;Wand & Wang 1996;Wang & Strong 1996).



Source : Some elements of figure from (Wand & Wang 1996)

Figure 4.1: Ontological representation of an information system

4.1.1. Data capturing

The data capturing process refers to the process of capturing the state of the real world and storing it in an interpretable and semantically acceptable manner in a data storage medium. We identify six critical information dimensions in this process (Ballou et al. 1998; Wand & Wang 1996).

- *Accuracy:* The degree to which the stored state matches the real world state
- *Completeness*: The degree to which all states of the real world are captured and represented by the system
- *Meaningfulness*: The degree to which all states represented in the system have a respective real world state
- *Unambiguousness*: The degree to which no two or more states of the real world are represented by one state in the system

- *Conciseness*: The degree to which every real world state is represented by no more than one state in the system
- *Timeliness*: The degree to which the state represented in the information system is up-to-date with the real world state. Timeliness is affected by two factors — the currency of the captured information and its volatility. Currency of information is the result of the age of information when captured and the period that it has been in the system. Volatility of information is the frequency/speed that the state that the information system represents changes. We should note that timeliness should not be confused with the accessibility of information, i.e. how quickly and easily information can be captured and/or retrieved.

Automatic identification technologies can ensure high performance in the quality dimensions defined above, when used for capturing the real world state. For example, auto-id can be used for locating products in a warehouse and define their accurate location. Table 4.1 summarizes the contribution of auto-id technologies to each of the aforementioned information quality dimensions.

4.1.2. Data storage – Retrieval

Apart from data capturing, auto-id technologies can be used for storing and retrieving information. For example, maintenance and operational information about a part could be stored on an RFID tag attached to the part which will readily provide the required information upon request. The academic and industrial literature provides an extensive list of information quality attributes/dimensions in this area, most of which refer to the subjective measure of whether information provided is understandable, easily interpretable and useful. At this point we shall focus on the information quality dimensions that we regard as more objective and those affected by the use of auto-id technologies in this process. As a result, we propose the following set of information quality dimensions regarding data storage and retrieval:

- *Accessibility*: The degree to which information can be effectively and efficiently accessed, usually measured in means of time to access and/or cost required
- *Security*: Defines the degree to which data storage and data retrieval take place under well-established data security principles (confidentiality, integrity, authorization, non-repudiation etc.)
- *Reliability/ Availability*: The degree to which data stored in the system is readily available for retrieval. Reliability can also be viewed as the probability that the system will respond to a data query in the way it is supposed to, delivering the right stored information.
- *Consistency*: The degree to which stored information is made available to the end user in the same way each time it is requested

Automatic identification technologies can significantly improve the information quality dimensions related to data storage and retrieval as summarized in Table 4.1.

Information quality dimension		Auto-id technologies ability
Data Capturing Process	Accuracy	Highly automated and reliable data capture
	Completeness	Automatic capturing of all instances of products and their states
	Meaningfulness	Elimination of meaningless data entries using predefined coding schemas and standardized procedures
	Unambiguousness	Unique product instance identification and state definition per item instance
	Conciseness	No data redundancy using coding standards and automatic filtering mechanisms
	Timeliness	Fully automated scanning with no need of manual effort results in near-real time state capture
Data Storage and Retrieval Process	Accessibility	Automatic data retrieval technologies provide data at reduced cost (no need for manual data entry or laser beam scan); access even when no network is available (if data is stored on tag)
	Security	Public key infrastructure (PKI) can be used for securing on board data
	Reliability/Availability	Resistance to operational conditions and high data availability
	Consistency	Standardized interfaces for data retrieval guarantee consistency in communication and data format

Table 4.1: The abilities of Auto-iD technologies to enhance information quality

In the following sections we describe how auto-id technologies can have an impact on the business processes that were analyzed in the first part of this report through improving the quality of track and trace information.

4.2. Logistics

The contribution of auto-id technologies in the logistics part of the aerospace supply chain relies mainly on the data capturing aspect of information quality. During logistics operations there is an imperative need for high quality information about the location and the identity of each product. We briefly analyze the need and contribution of auto-id in the different application areas of logistics operations as these were analyzed in the first part of this report.

Product delivery – Shipment

Auto-id technologies can provide high quality information (covering all data capture quality dimensions as analyzed in section 4.1.1.) about product delivery, making the delivery/receiving process highly automated and efficient. Products received in the receiving dock of each supply chain node can be automatically identified and cross-checked against the expected orders. In this way, companies can have quality information about products as soon as these arrive at their premises, giving them the opportunity to tune their forwarding operations. Hence, quality information can be used to reduce operational costs and minimize problems related to lack of information. Moreover, auto-id technologies can bridge the informational gap analyzed in section 3.1, providing full information visibility to the supply chain partners, as the receipt can be confirmed automatically and be updated on the respective information system.

Manual data input

Auto-id technologies can eliminate manual data entry (and manual system synchronization) that takes place in many stages of the supply chains studied in our case studies. This can not only result in significant data error reduction but also in important operational efficiency improvement. Taking into account that data entry takes place in many of the studied operations (product receipt, quality control, storage, order processing, shipping) the deployment of auto-id technologies would significantly reduce the operational costs and would increase companies' throughput. Therefore, the elimination of manual data entry by the use of auto-id will result in improved information quality and reduced operational costs.

Quality control

Auto-id technologies provide a high potential for optimizing quality control. Quality checks and part specifications can be easily accessed possibly on the tag itself or by an appropriate network resource indicated by the tag. In this way, the retrieval of expected values of variables against which the state of the part should be assessed is optimized. Embedding part quality-related information on the tag attached to the part will improve the data storage and retrieval information quality dimensions as described in section 4.1.2. As a result, quality control will become more efficient and effective.

Warehouse management

The contribution of auto-id technologies in warehouse management is well known and tested in the industry. Contributing mainly to the data capturing part of information quality, auto-id technologies can significantly improve inventory information, tracking products within the warehouse in a manner that covers all aspects of data capturing quality dimensions. In this way, companies can save costs regarding misplaced/lost parts, operational inefficiency, excess stock and improve their operational performance utilizing the information provided. In specific, auto-id technologies can provide solution to the following problems that were discussed in part one of this report:

- Inaccurate inventory: Auto-id technologies and especially RFID can provide accurate inventory information in a timely manner, covering the information quality dimensions discussed in section 4.1.1.
- Misplaced products: Accurate location information can be provided using RFID technology in the warehouse environment, locating parts that have been misplaced or left in transfer zones (e.g. quality control).
- Lot number mismatch: The use of auto-id technology can ensure the shipment of the right product each time, eliminating errors and inaccuracies in inventory information caused by the shipment of wrong products in place of others.

Auto-id technologies can be of great assistance in the case of AOG situations. Using auto-id technologies a critical item that needs rapid handling can be automatically identified and potentially an alarm can be generated to indicate its presence and location, thus speeding up order processing and shipping to the customer. In this way, companies can efficiently handle the critical AOG situation.

Apart from capturing high-quality inventory information, auto-id technologies can help optimizing limited shelf-life products management, providing information about their state and residual life.

Hazardous materials handling

Auto-id technologies can effectively track and trace hazardous materials providing information about the past and present state of each product. Apart from this, auto-id technologies can provide additional information about special handling requirements and precaution measures readily retrievable from the tag on the part itself. The contribution of auto-id technologies in this application area is based on the improvement of both data capture and data storage/retrieval aspects of information quality. The European project CoBIs demonstrates the use of auto-id technologies for effective handling of hazardous materials (Spiess, 2005).

4.3. Maintenance – Repairable parts

The contribution of auto-id technologies to repairable parts maintenance relies on the ability to store and provide high quality information regarding the operational and maintenance history of a part. RFID tags can be used to store information regarding the above on the part itself. The information stored on the tag could be a subset of the information currently recorded in log cards (see section 3.4). In this way, companies can have access to high quality information, including all quality dimensions analyzed in section 4.1.2. As a result, problems regarding unavailability of maintenance or operational information can be eliminated and companies can maximize parts utilization, reducing costs from parts disposal, under-utilization and operational inefficiencies because of lack of information.

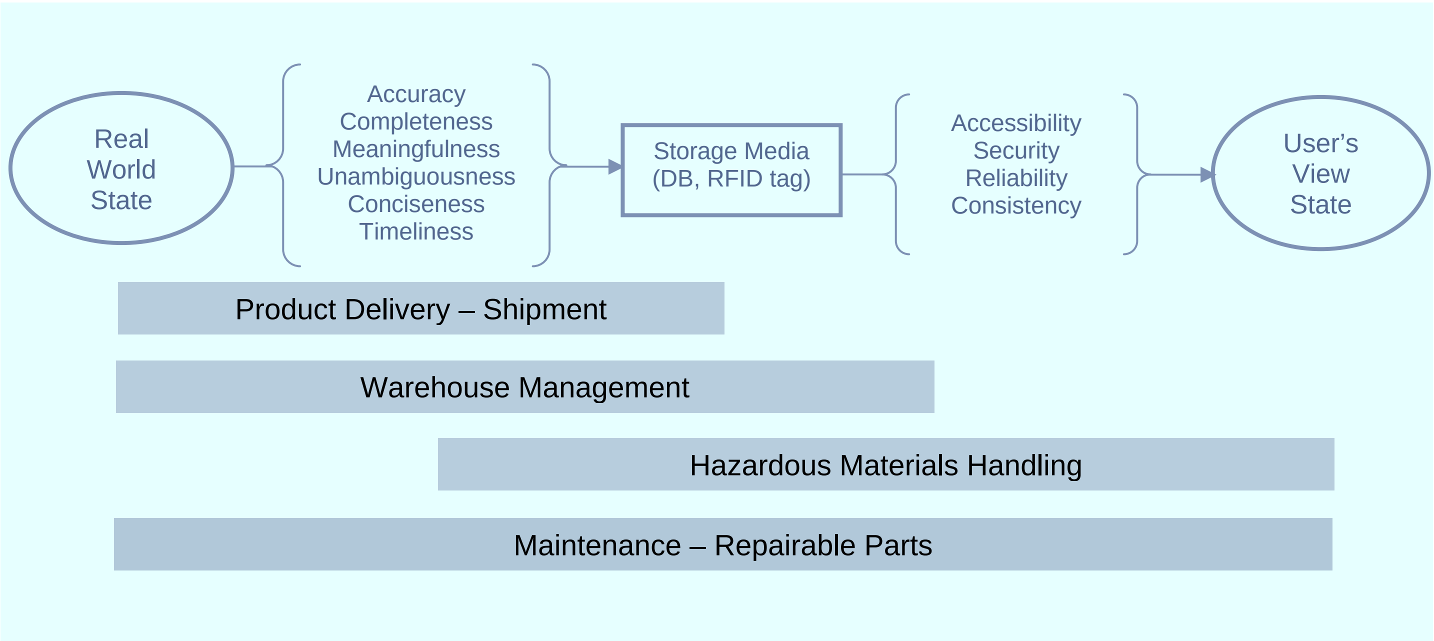


Figure 4.2: Impact of information quality dimensions on different application areas

Moreover, improved information quality regarding maintenance and operational history can support effective decision in all stages of the repair pool activity cycle (Figure 2.4). This, in combination with efficient logistics management as analyzed above, can reduce part repair time and the overall turnaround time for a part to be removed, sent for repair and made again available for use. In this way, companies can reduce their stocks and save significant holding costs.

In addition, auto-id technologies eliminate the danger of accidentally mixing parts that need to be repaired with the repaired ones, putting in danger the airworthiness of an aircraft. Information about the status of the part with regard to its airworthiness and intended shipping can be stored on an RFID tag attached to the part itself, preventing from any handling and shipping errors.

Finally, once the use of auto-id technologies has reached a mature level of adoption in the aerospace industry, the tags attached to the parts could potentially store digitally signed certificates of conformance. This could eliminate costly paperwork management and would increase the efficiency of the operations that involve certificates management. Moreover, companies would be able to efficiently track and prove the entity that had guaranteed for the airworthiness of a part in any case.

Figure 4.2 demonstrates the different information quality aspect (data capture – data storage/retrieval) and the respective dimensions that can be utilized in each application area to improve its efficiency.

5. Conclusion

In this report we have presented the results of the two case studies which took place at Embraer's distribution centre in France and at the BAE systems Nimrod supply chain in Great Britain. The studies were focused on current track and trace practices. We have provided a brief description of the companies' operations and we have highlighted the problems with regard to tracking and tracing from both the logistics and the maintenance aspect of repairable parts management. Furthermore, we have identified the requirements for improvement according to the input from the managers and the potential for operational optimization. Finally, we have proposed how automatic identification technologies can contribute towards improving tracking and tracing information quality, helping to improve operational efficiency and decision making.

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