Aerospace ID

AUTO–ID LABS

# Automatic ID Systems: Enablers for Track and Trace Performance

***Thomas Kelepouris*, Samuel Bloch Da Silva**, Duncan McFarlane****
****Auto-ID Lab, University of Cambridge, UK***
*****Embraer S.A., Brazil***

**Auto-ID Labs White Paper** WP-BIZAPP-037

*Report Abstract: This report presents the results from a series of case studies regarding track and trace performance in the aerospace industry. The report briefly describes the tracking and tracing operations of the companies studied, and identifies the challenges they face with regard to tracking and tracing. The report analyzes the factors that affect track and trace effectiveness. It further analyzes how each factor affects performance and how automatic identification technologies can optimize effectiveness and efficiency in the respective operations. Finally, the report describes how these findings can provide the basis for a track and trace performance measurement framework, which will be able to assess the performance of a company in different track and trace operations.*



Published November 2, 2006. Distribution restricted to Sponsors until May 2, 2007

**Business Processes & Applications**

# Contents

# 1. Introduction

## 1.1. Aims

This report presents the results from a series of case studies conducted in companies in the aerospace industry regarding track and trace (T&T) practices. The aim of the report is to analyze the case study findings; demonstrate the tracking and tracing problems that companies encounter; and identify the way these affect decisions and business operations. Further, through this analysis the report aims to identify the factors that affect tracking and tracing effectiveness. As shown in Figure 1.1, these will act as a basis for the development of the traceability performance measurement framework, which we intend to develop in the next phase of this research.

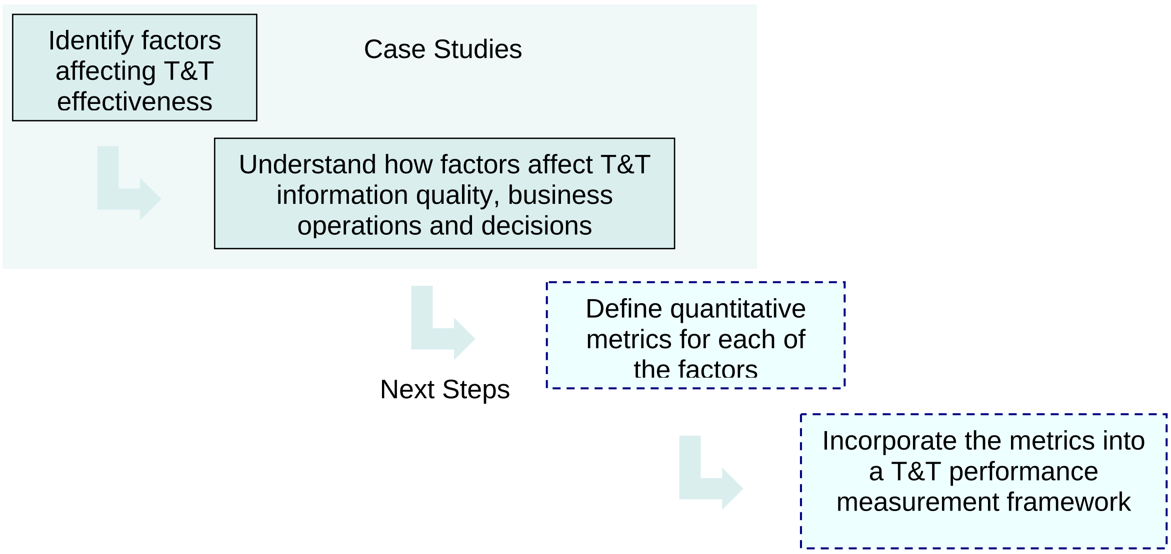


**Figure 1.1: Flowchart of activities for developing a T&T performance measurement framework**

## 1.2. Approach

Information collected from company visits and contacts with managers was used to understand the current tracking and tracing practices that companies apply. Based on this information we identified the tracking and tracing problems that companies face and the consequences these have on decisions and business operations. Analysis of the above revealed the main factors that affect a company's ability to track and trace information about a product. This report presents the afore-mentioned approach and the results it generated.

## 1.3. Definitions

Before presenting the case study results, we provide the basic definitions of concepts that will be thoroughly used throughout this report. The diversity of definitions found in the academic and industrial literature indicates that there is no common understanding of the definition of traceability [1]. For the purpose of this research we will adopt the definition provided by [2] and used by other researchers and practitioners in a similar way.

*Tracking* is a method of determining the ongoing location and state of items during their way through the supply chain. In this context, we will use 'tracking' to refer to monitoring the location and other information regarding an item's state at any time.

*Tracing* is a method of recording and/or having access to information regarding the composition of an object from raw material or sub-components and operations that the object has undergone during its lifetime. Tracing information enables *forward traceability* which refers to the exploration of where-used relations between objects and operations. For example, one can identify products that have consumed a specific raw material of interest or have undergone a specific operation. Similarly, tracing information also enables *backward traceability* which refers to the exploration of where-from relations between objects and operations, enabling the identification of the raw materials or sub-components used for a specific product or the operations it has undergone. The combination of forward and backward traceability provides full traceability in a supply chain, enabling effective identification of the cause of problem and efficient product recall management.

The above should make clear that tracking and tracing are distinct concepts and have different requirements to be met, as shown in Figure 1.2.

## 1.4. Report structure

The rest of this report is structured as follows: section 2 presents the results from the case studies that we carried out, summarizing the decisions and business operations affected by tracking and tracing performance. Section 3 identifies the factors that affect tracking and tracing effectiveness, providing the basis for the development of the traceability performance measurement framework. Section 4 concludes this report.

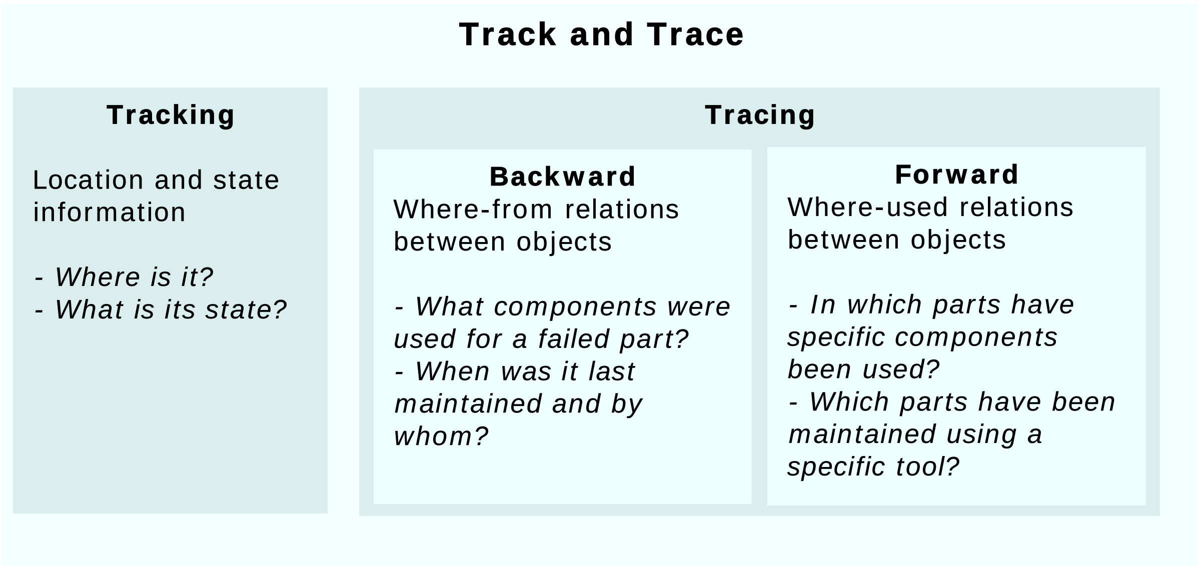


**Figure 1.2: Track and trace definitions**

# 2. Case Studies

The aim of this section is to present the findings from a series of case studies that were carried out in the context of Aero-ID technologies programme and the track and trace theme in particular. As the flowchart in Figure 2.1 illustrates, for each of the companies we briefly describe the track and trace practices that were studied and the problems that each company faces with regard to them. We also describe how tracking and tracing effectiveness affect

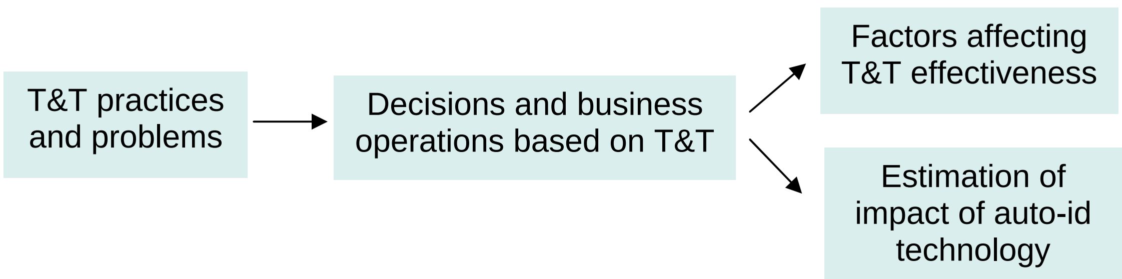


**Figure 2.1: Track and trace case studies approach**

decisions and business operations. Finally, we identify the factors that affect tracking and tracing effectiveness and provide an estimation of the impact of automatic identification technologies towards improving this effectiveness.

## 2.1. Overview

Before analyzing the case studies and findings in detail, we provide the reader with an overview, presented in Table 2.1. We studied tracking applications that aimed to provide location information of items travelling along the aerospace supply chain. Also, we studied how companies record and access product lifecycle traceability information. The effectiveness of practices appears to have a direct impact on business decisions regarding ordering policies and production planning. Moreover, it affects the efficiency of maintenance decisions. Manually-processed information and the degree of standardization are the key factors that affect tracking and tracing effectiveness.

| Company | Track and Trace Practices Studied | Critical Decisions affected by T&T effectiveness | Key Findings |
|---|---|---|---|
| **Airbus** | Internal tracking of aircraft equipment during receipt, storage, internal transport and assembly operation | React to delayed or wrongly shipped products<br>Production planning | Processing delays and human intervention reduce tracking effectiveness |
| **Embraer** | Tracking of aircraft parts orders across the supply chain | Ordering – Inventory management<br>Production planning | Processing delays and human intervention reduce tracking effectiveness |
| | Part lifecycle information tracing (operational/maintenance history, configuration) | Maintenance decisions<br>Determine part's residual life<br>Maximize part utilization<br>Warrantee management | Human-generated information reduces information quality. Lack of information standardization. Poor information accessibility |
| **Messier-Dowty** | Record product composition information to ensure configuration traceability | Optimize efficiency of traceability queries | Reduced configuration information quality. Manually processed traceability information |
| **British Telecom (BT)** | General approached to T&T | Product tracking<br>Product configuration management<br>Product recalls | Confirmation of case study findings. Auto-ID and system integration critical for effective T&T |

**Table 2.1: Case studies overview**

## 2.2. Detailed case studies

### 2.2.1. Airbus

In the context of track and trace research theme we focused on a specific tracking project that Airbus carries out. The project examines the use of automatic identification technologies for optimizing internal tracking of equipment to be installed in an aircraft. The overall process is briefly depicted in Figure 2.2. The equipment is picked up from the supplier by a carrier which delivers the material at Airbus' receiving warehouse. The received material is then inspected, cross-checked against the accompanying documentation and booked into the SAP system. During this phase, barcode labels are printed and attached to the equipment and customs processes are handled. The material is then sent through internal transport to the sorting facility. Upon arrival, the material is again inspected and booked into the SAP system. Labels are printed and attached to equipment defining the aircraft that it should be used in and the exact manufacturing process. This information is indicated by SAP. The material is sorted in trolleys, each of which is dedicated to a specific assembly line. The


**Figure 2.2: Airbus' equipment supply chain**

material is then sent accordingly to the appropriate assembly line through internal transport channel.

*Tracking challenges*

The company's primary aim is to be able to determine the ongoing location of the equipment within its facilities. However, Airbus is facing several tracking challenges during the process described above.

Airbus receives a notification of the time when the material is picked from the supplier, but has no visibility of its transportation progress until the time it is delivered at the receiving warehouse. Once delivered, the material remains in the receiving area for some time before being booked into SAP. Therefore, although delivered, the goods do not appear on the information system, as they are regarded to be still in transit. Furthermore, the manual product and documentation inspection along with the manual booking into SAP create a serious operational burden for the company. An important issue during product inspection is the detection of products that do not comply with the specifications of the product type that was ordered. Timely detection of these products is important for taking contingency actions.

The challenges are similar when the equipment is sent to the sorting facility. The material again needs to be manually inspected and booked into the system, which leads to a significant operational delay and causes the system to be temporarily outdated. Moreover, the company cannot monitor the location of equipment that has left the receiving warehouse and has not yet been received and booked in the sorting facility. For this reason, tracking of material along this process is fragmented.

The management of manufacturing-process information is also a challenge for Airbus. Loading trolleys with the correct equipment and associating it with the respective information (manufacturing job number, assembly line, and so on) includes great amount of effort. This information cannot be encoded in barcodes. It is, therefore, managed in paper, which accompanies the equipment up to the assembly line. This results in risks of data inaccuracies that need to be resolved during the assembly.

### *Impact on decisions and business operations*

The above make clear that Airbus has moderate visibility of the ongoing location of equipment across its facilities. This creates problems to production planning since the company operates on a just-in-time delivery. Moreover, timely confirmation of the appropriateness of received material and detection of non-conformances to specifications also plays a significant role in production planning. Exceptions should be detected and handled in time so that alternative solutions can be sought, minimizing effects on production effectiveness. Location visibility is the basis for optimizing production planning for Airbus.

Manual item inspection, identification and booking into the system create a significant operational bottleneck. This has a major impact on the quality of tracking information, since there is a significant delay from the moment the material is received and the moment it actually appears on the system. This is also related to the production planning efficiency discussed earlier.

Manufacturing information quality directly affects the efficiency of manufacturing operations and the quality of the final product. The company has several people dedicated to recording and keeping track of manufacturing information for this purpose. Problems related to this information result in incurring costs for resolving them and costly delays in production.

### *Insights – Factors affecting tracking effectiveness*

Based on the above analysis, we identify the following factors that affect the company's ability to track material across its supply chain:

- *Product processing delays*: There are significant delays until a product is booked into SAP, which cause inconsistencies between the actual state of the product and the one that appears on the system. This poses a limit to the tracking ability of the system.

- *Checkpoints granularity*: The amount of points along the supply chain at which an item's location is recorded directly affects the effectiveness of the tracking application. In the case of Airbus, visibility is lost at some points because the ongoing location of products is not recorded due to lack of infrastructure or because of the operational costs involved.
- *Manually-processed information*: Information that is either manually entered in SAP or handwritten reduces the level of information accuracy. Moreover, it affects information timeliness. Both have a direct impact on production planning efficiency.

### 2.2.2. Embraer

In the case of Embraer, we studied both logistics tracking operations and operational as well as maintenance traceability practices.

#### 2.2.2.1. Embraer logistics operations

Before describing the tracking challenges that Embraer faces, we will briefly present its main supply chain, depicted in Figure 2.3.

A purchase order (PO) is placed by the central warehouse at Brazil to the supplier, who acknowledges the order when all material is available for shipment (step 0). Once acknowledgement is received, Embraer Brazil notifies the freight forwarder to pick up the material in order to ship it to Brazil. The freight forwarder picks the material from the supplier (step 1), and keeps it temporarily at his central distribution centre where it is assigned an 'on-hand' number for tracking purposes. The material might be consolidated with orders from other suppliers into a single shipment which is assigned a house number. The house number and the respective 'on-hand' numbers it includes are sent to Embraer (step 2) for tracking purposes. Once Embraer gives authorization for shipment (step 3) the material is sent to Brazilian Customs (step 4). After customs process is finished, the forwarder clears the material which is then delivered to Embraer warehouse (step 5). Upon arrival, each delivery is identified from the billing documentation it carries and booked in the information system. Thus Embraer has information about the goods arriving at its facilities. After receipt, all material is inspected, cross-checked against the respective purchase order as well as other documentation and booked into SAP. After passing quality control, the material is put to stock and is therefore available for production operations. Products are picked from the warehouse according to a production order and delivered to assembly line through an internal transportation channel.

*Tracking challenges*

The main challenge for Embraer is to have as much visibility as possible about the ongoing location of a part from the supplier up to the assembly line. However, the company faces some problems that prevent it to do so.

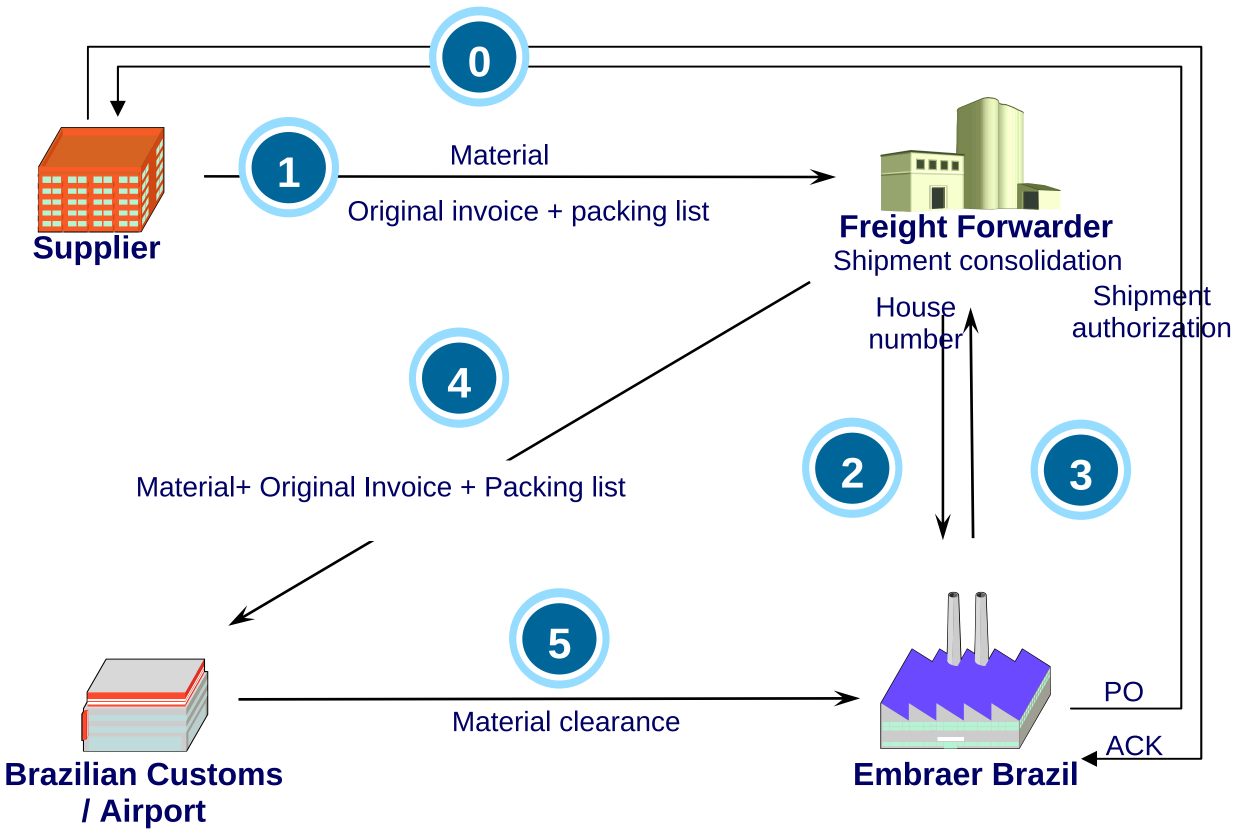


**Figure 2.3: Embraer Logistics Process. Source: Embraer S.A.**

After being picked from the supplier, products sit at the freight forwarder's warehouse for a long period of time (typically 1–3 days) until they are assigned an 'on-hand' tracking number. Also, Embraer does not receive any notification when products are picked from the supplier. As a consequence, Embraer has no visibility as to whether and when products have left the supplier and have reached the forwarder's warehouse, until an 'on-hand' number has been issued and sent to them. This creates a 'black hole' of information for Embraer in the logistics process.

Fragmented shipping also causes problems in Embraer's logistics operations. Products that belong in the same purchase order can be shipped in different 'house numbers'. However, this information is not indicated in any way. Therefore, this creates confusion and additional burden when tracking an order across the supply chain.

Incoming products inspection at Embraer warehouse creates a significant bottleneck in the logistics process. Products need to be inspected and cross-checked with documentation manually, which results in a 4–6 days processing delay. This also results in significant operational costs for the company.

### *Impact on decisions and business operations*

Poor tracking information quality has a significant impact on Embraer's decision effectiveness and operational efficiency.

Production planning is heavily based on part delivery progress information. Therefore, poor tracking information seriously affects the effectiveness of production, especially in the case of unexpected events in which parts are needed out of schedule (for example, a part has proved to be inappropriate for assembly and another one should be used which is still in transit).

Ordering and inventory levels decisions are also based on tracking and lead time information. The visibility of progress of products' delivery across the supply chain affects ordering decisions. Also, accurate information about the exact time at which a product will be delivered reduces uncertainty, thus significantly decreasing inventory levels at the warehouse.

Furthermore, a significant cost to be considered is the operational burden of resolving a tracking query each time a product needs to be tracked across the supply chain. Currently, this involves significant amount of personal contacts and manual queries.

### *Insights – Factors affecting tracking effectiveness*

The above findings reveal the following factors, which affect tracking effectiveness in Embraer's logistics process:

- *Product processing delays*: Products sit for a long period of time in receiving areas without being processed and booked into an information system; therefore, they appear to be at a previous stage of the supply chain or they do not appear at all to partners of the later stages of the chain.
- *Fragmented shipping*: The lack of information about fragmented shipping results in great confusion when an order needs to be tracked. Fragmentation occurs when packages from a common invoice are separated at shipment, and arrive in separate containers of even in different dates at their destination. This issue is related to effective management of aggregated packaging and the respective information.



Published November 2, 2006. Distribution restricted to Sponsors until May 2, 2007

### 2.2.2.2. Embraer maintenance operations

Embraer faces significant problems regarding part traceability in its maintenance operations as well. Once a part is removed from an aircraft, either for scheduled maintenance or because of failure, it is returned to Embraer repair station for repair[1]. Each part is accompanied by documentation, which among other, provides the following information about the part[2]:

- Identification information (manufacturer, part number, serial number)
- Guarantee information
- Storage information – shelf life
- Installation – removal information
    - Aircraft number
    - Flight hours – cycles
    - Reason for removal
- Maintenance Information
    - Actions taken – inspection results
    - Parts replaced

The above information is critical both for the reliability of the part and the efficiency of maintenance operations, and therefore should be kept accurate and updated at all times. However, like most of the companies in the aerospace industry, Embraer has problems keeping accurate traceability information about the history of the part.

*Traceability challenges*

Airlines and operators keep track of the important events that take place with parts. These events are recorded in the operator’s information system and are sent electronically to Embraer on a periodic basis of 20–30 days.

In the case of a part being removed from an aircraft, the technician manually records the reason of removal and other lifecycle information (flight hours, cycles, etc.) which is then entered in the system. This information is also manually recorded in the documentation accompanying the part. The part is then sent to Embraer’s repair shop for maintenance/repair.

The biggest challenge for Embraer is to have access to accurate and updated part-lifecycle information when the part arrives at the repair shop for maintenance. Currently, the company

[1] Some of the parts that are removed from Embraer aircrafts might as well be sent to repair shops that do not belong to Embraer. In this report we focus on the maintenance operations that take plane in Embraer.

[2] For detailed information about the contents of a log card refer to AERO-ID-CAM-008 Track and Trace Case Studies Report (06/2006), Section 3.4.

faces significantly inaccurate lifecycle information which results in great amount of effort for resolving part information discrepancies. The main reason for this is the fact that information is manually recorded on paper documents.

The accuracy of reason-for-removal information is also of particular importance for Embraer. Currently, the descriptions of reasons for removal are poor, inaccurate and not particularly descriptive. For this reason, technicians need to inspect each part in order to find, reproduce and confirm the cause of failure.

### *Impact on decisions and business operations*

Inaccurate part lifecycle information undermines decision making during maintenance. The flight hours and cycles that a part has undergone are highly important to determine the treatment that the part should receive and the remaining lifetime that it should be assigned. Poor information accuracy may lead to under-utilization of the part and may increase maintenance costs related to resolving information discrepancies and taking unnecessary maintenance actions in order to assure part reliability when no information is available. In the worst case, parts are scrapped if lifecycle information about them is considered unreliable.

Information regarding reason for removal is important for the efficiency of maintenance operations as well. Inaccuracies or incompleteness in failure descriptions result in the need for inspecting and testing the returned part to find and confirm the failure reason. High quality information would save time from inspection and fault detection, enabling focused repair according to failure.

### *Insights – Factors affecting traceability effectiveness*

The above analysis indicates the following factors that affect a company’s ability to trace a part’s lifecycle information:

- *Human recorded information:* Lifecycle information is recorded manually on paper, which results in a high percentage of errors. Also, paperwork is often lost resulting in information loss.
- *Lack of standardization of fault description:* Failure description currently lies in the subjective judgement of each technician, resulting in vague or inaccurate descriptions. Standardization in this area would improve the quality of information communicated to the repair shop.
- *Information communication:* Aircraft manufacturers rely on airlines and maintenance providers to retrieve lifecycle information about parts. This is not an automatic process, and has a relatively long cycle (~1 month). As a consequence, manufacturers have access to outdated information, the management of which is out of their control.

## 2.2.3. Messier-Dowty

In the context of the track and trace theme, we reviewed Messier-Dowty's (referred henceforth in this report as MD) manufacturing process and studied the traceability challenges the company encounters. Before analyzing the challenges, we provide a brief overview of the company's manufacturing process, which is depicted in Figure 2.4.

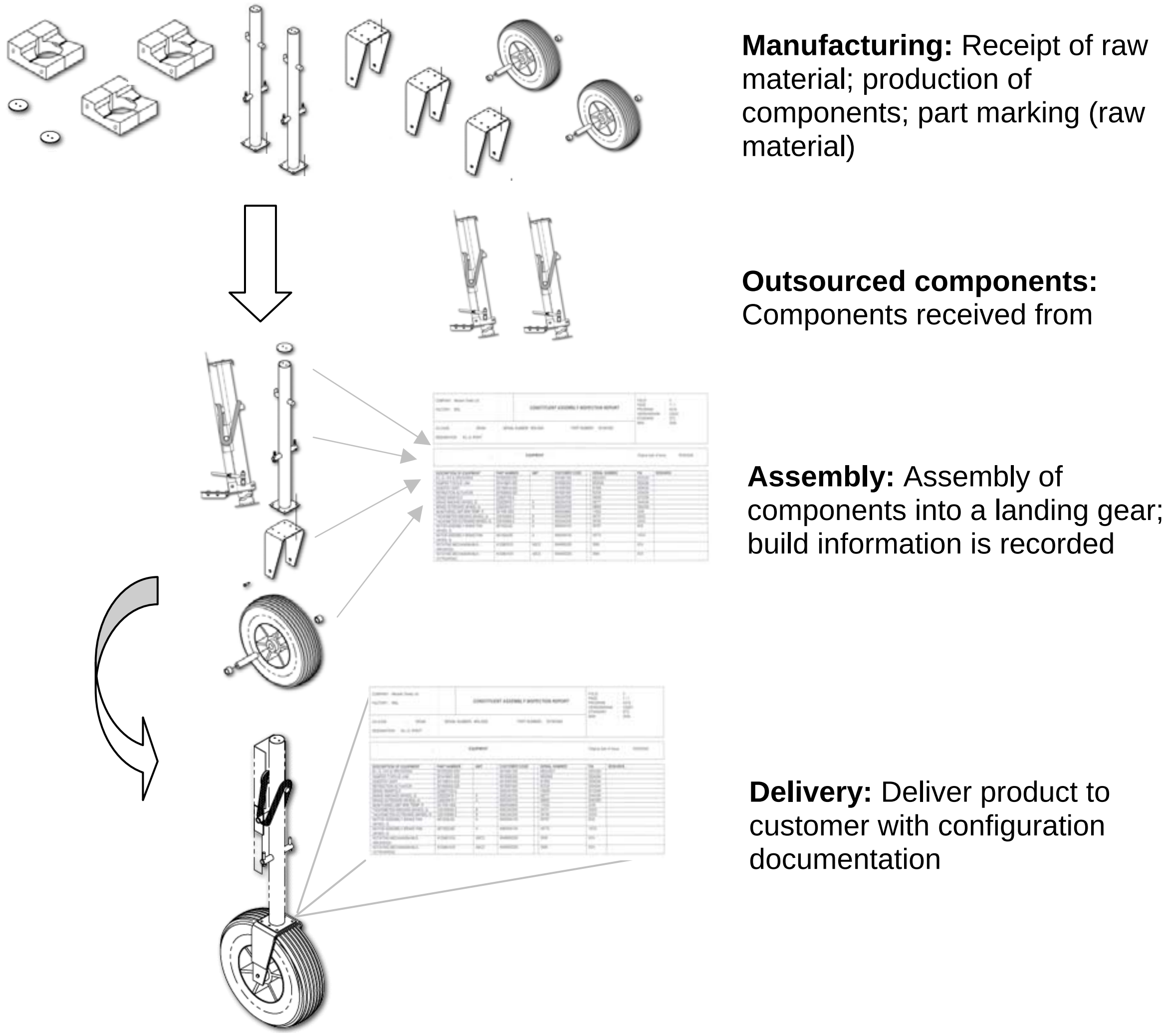


**Figure 2.4: Landing gear manufacturing and assembly process**

MD receives raw material for component production which already carries a serial number. The company then assigns an internal MD serial number. The association between the original and the new serial numbers is recorded in paper records and in electronic worksheets.

The material then undergoes a series of manufacturing operations to reach its final state and be ready for assembly. During this process, a document — , containing the serial numbers of materials that were used for manufacturing as well as the description of operations that the component underwent — accompanies the component. Batch numbers of non-serialized materials are recorded in free text fields in the same document. All information is then manually entered into the MRP system. The final step of the manufacturing process consists of physically marking the components with the part number and serial number that has been assigned to them.

The next step in the production process is gear assembly, in which individual components are mounted together to form the final product. During this process, the serial numbers of critical components[3] are recorded so that a detailed build record is created for each final kit. The serialized components are manually identified and recorded on paper during this process. At a later stage, build record information is typed into an information system to generate build record documents for each final product.

Finally, the landing gear is delivered to the customer along with documentation that, among others, describes all serialized parts contained in the final kit.

### *Traceability challenges*

The primary aim for MD is to effectively and efficiently record accurate traceability information for products and having it available in a form that will enable efficient query answering. However, MD faces recurrent problems when capturing and recording traceability information, which affect its quality.

Many of the serialized parts have a handwritten serial number, rather than one which is encoded using an identification technology (barcode, laser print etc). This creates two problems during the production process. The first one is the obvious operational cost of reading the code and then writing it on the appropriate document or typing it in an information system. The second, and most important in traceability terms, is the percentage of errors that take place during this process. This results in accuracy issues associated with information when it is first recorded, requiring additional effort to resolve errors when these are detected.

As mentioned before, batch numbers for non serialized items are manually entered in MRP free text fields, which, apart from the obvious operational burden and risk of mistakes, limits traceability queries on batch numbers. Moreover, the relationship between suppliers forging serial number and MD serial numbers is maintained in a basic Excel matrix. This restricts visibility within the organization requiring additional resource to investigate and answer traceability queries.

Finally, MD faces some issues regarding the integration of information systems that are used along the production process. Pieces of traceability information are kept in separate information systems, which makes the traceability querying process inefficient.

[3] The critical components belong to the top of three classes of components and are approximately 80 per kit.

*Impact on decisions and business operations*

The fact that identification information is in some cases handwritten creates a significant operational cost for MD. Parts need to be manually identified and the numbers are handwritten on paper for traceability records and then manually typed into the information system. This creates an operational bottleneck in the production process.

Improving accuracy of traceability information will save MD from the cost of time and effort spent on resolving issues of inaccurate traceability information (e.g. a serial number that appears to have been used twice according to the information system record). The recurrent nature of similar situations leads to an imperative need for a solution to this problem. Fragmented traceability information, held in different non-integrated information systems or paper records, makes the construction of a full traceability record for a part a costly process.

*Insights – Factors affecting traceability effectiveness*

The analysis of Messier-Dowty operations reveals the following factors that affect the nature of traceability information and the company's ability to record and retrieve it:

- *Accuracy of identification process:* the identification method affects the accuracy of information. Human readable serial numbers significantly reduce accuracy of identification information [N.B. : It is a requirement of the Aerospace Industry to provide human readable information ; electronic identification could be only used for secondary identification for in-service components].
- *Manual data recording*: manual data input (either handwritten or typed into a system) similarly affects the accuracy and efficiency of information capturing, therefore reducing the overall information accuracy. Moreover, both above factors, apart from information accuracy, affect the operational efficiency of information capturing.
- *Information integration*: The lack of connectivity between business systems results in duplication of data entry and inefficiency when generating traceability reports/build records.

### 2.2.4. British Telecom (BT) auto-ID services

BT was involved in this study to provide their input from the solution provider point of view. BT has already deployed several systems that support traceability in a number of companies.

Personal contacts within BT confirmed most of our findings and added some useful insights. Discussions confirmed that identification accuracy and timeliness are key factors that affect tracking effectiveness. Automatic identification technologies such as barcode and RFID are the enablers that can ensure high performance in this respect. Another key point that emerged is the criticality of effective system integration for achieving full traceability. There are many cases in which companies use different systems to record information which is needed to constitute the full traceability record of the final product. The effective integration of these systems is a key factor for delivering full traceability and to efficiently query recorded information. Moreover, it should be pointed out that the customized need of each company with regard to tracking items and recording traceability information plays a significant role to the factors that affect the effectiveness of the overall process.

## 2.3. Summary

The case study findings reveal a set of common challenges that companies face with regard to tracking and tracing, which affect decision effectiveness and operational efficiency. We discuss these findings, which are also summarized in Table 2.2.

*Common challenges*

Product *identification and processing delays* appear to be a major reason for poor tracking effectiveness, keeping the tracking information systems outdated for long periods of time. Moreover, the *configuration of tracking infrastructure*, i.e. the number and placement of checkpoints along the supply chain, fundamentally affects tracking effectiveness. However, the placement of checkpoints also includes significant installation and operational costs per checkpoint which should be considered. The management of aggregated shipments and the respective *aggregated information* appears to be a key enabler for efficient tracking as well. Accuracy and trust of aggregated information can significantly support effective tracking.

The *accuracy of captured information* clearly affects both tracking and tracing effectiveness. Non-automated identification practices introduce significant percentage of errors in business operations. Moreover, *non-standardized information* storage and representation also affects the usability and accessibility of traceability information, which has a major impact on maintenance decisions and traceability queries.

*Impact on business decisions and operations*

The quality of tracking information has a direct impact on the effectiveness of *production planning* and *manufacturing performance*, as the case of Airbus and Embraer demonstrated. Similarly, accurate tracking information can enable an efficient *inventory policy* and optimized *ordering decisions*. Moreover, product identification and processing during receipt at each stage of the supply chain creates significant *operational bottlenecks* across it. Furthermore, the quality of lifecycle information affects *maintenance decisions* and the general maintenance strategy for products. Also, poor accuracy of traceability information results in significant operational costs for *resolving information discrepancies.*



Published November 2, 2006. Distribution restricted to Sponsors until May 2, 2007

| Company | Company's aims with regard to T&T | Problems | Decisions based on T&T information | Factors that affect T&T information/performance | Impact of T&T information on business operations |
|---|---|---|---|---|---|
| **Location Tracking Applications** | | | | | |
| **Embraer Logistics Operations** | - Have as much visibility as possible (ideally complete) of order progress from supplier to Embraer warehouse and finally up to assembly line | 1) Products wait too long (1–3 days) at freight forwarder for a reference tracking number to be assigned to them, creating problems for production scheduling and operational costs for searching products<br>2) In case of fragmented shipping it is difficult to track order progress, resulting in confusion and management costs for resolving it<br>3) Manual product identification and inspection on receipt causes 4–6 days of processing delay, resulting in labor costs and delayed system update | For problems 1–3 the decisions influenced by T&T information are:<br>- Production planning according to part delivery progress<br>- Inventory planning according to lead time and delivery information | - Delay of product processing/ identification and manual generation of data, which results in inaccurate and non-timely tracking information<br>- Poorly managed, fragmented shipping information reduces tracking accuracy and information reliability | Improving T&T info regarding problems 1–3 would lead to:<br>- Improved production scheduling<br>- Reduced delivery delays and component shortages in assembly line<br>- Reduced inventory levels through better planning<br>- Reduced human intervention for resolving tracking issues and reduced operational costs |
| **Airbus** | - Determine the ongoing location of products/ components within facilities<br>- Have as much visibility as possible of orders from supplier to Airbus facilities<br>- Timely detection of late or wrongly-shipped products | 1) Poor location visibility while with forwarder, resulting in limited ability to schedule production/assembly<br>2) Delayed product acknowledgement on receipt and need to cross-check case contents against order<br>3) Operational cost of data input, time delay of system update resulting in process delays and limited data accuracy<br>4) Poor accuracy of additional data accompanying the product during manufacturing process (job numbers, aircraft number, etc.) resulting in problems during manufacturing operations and costs for resolving data discrepancies | Decisions affected by poor tracking information related to problems 1–3 are:<br>- Production scheduling<br>- Confirmation of correct product configuration that corresponds to order specifications<br>Decisions related to problem 4 refer to assembly operations | - Lack of a system that will provide visibility while in transit<br>- Delay in product processing/ identification and the lack of trust about the information of products in a specific case (poor accuracy of aggregation information)<br>- Information is either handwritten or manually entered to the information system | Improving tracking information will:<br>- Enable better production scheduling<br>- Minimize operational costs, speed up receiving process and improve data accuracy of components received that are available for assembly<br>- Optimize assembly operations providing accurate information |

| Company | Company's aims with regard to T&T | Problems | Decisions based on T&T information | Factors that affect T&T information/performance | Impact of T&T information on business operations |
|---|---|---|---|---|---|
| **Configuration and Lifecycle Traceability Applications** | | | | | |
| **Embraer Maintenance Operations** | - Accurate information about aircraft configuration and ability to associate parts with flight hours, cycles, etc.<br>- Access to quality information about part failure and ability to treat accordingly | 1) Poor accuracy of part lifecycle information (operation, maintenance) undermines maintenance decision making<br>2) Poor accuracy of failure information prevents the efficient processing at the repair shop | Poor tracing information regarding problems 1 and 2 affects:<br>- Maintenance decisions according to part history<br>- Part utilization<br>- Rogue parts detection<br>- Repair according to failure | - Part failure information is human written and then typed to system. There are no standard fault codes. Information is passed in paper back to repair shop | Improving traceability information quality will:<br>- Reduce time spent on fault detection<br>- Enable maintenance according to fault<br>- Optimize part utilization according to operational and maintenance history |
| **Messier-Dowty** | - Reduce the time to answer traceability queries and improve traceability data quality<br>- Record traceability information more efficiently<br>- Have accurate and complete bill of materials information for each assembled kit | 1) Hand-written serial numbers make it difficult to identify parts resulting in operational delays and poor data accuracy<br>2) Manual data entry of part configuration information during manufacturing process<br>3) Errors in serial numbers when recording configuration information<br>4) Configuration information is recorded in free text fields for non-serialized parts<br>5) Poor information system integration causes inefficiencies in traceability information recording and queries | Poor traceability information quality regarding problems 1–4 affects the efficiency and effectiveness of traceability queries | The factors that affect the quality of traceability information with regard to each problem are:<br>Problem 1: Accuracy of part identification<br>Problem 2: Efficiency of identification process<br>Problems 3–4: Accuracy of information recording/ manual data input, non formalized data recording<br>Problems 5: Poor integration of different legacy systems. | Improving the quality of traceability information will lead to:<br>- Reduction of costs of investigating and resolving issues regarding configuration information that appear to be wrong<br>- Elimination of operational bottleneck for recording configuration information<br>- Improvement of traceability queries effectiveness, efficiency and reliability |

**Table 2.2: Summarized track and trace case study findings**

# 3. Tracking and Tracing Effectiveness

## 3.1. Aims

The aim of this section is to analyze the factors that affect tracking and tracing effectiveness based on the case study findings, which were presented in the previous section. It also aims to provide a basis for defining quantitative metrics for the development of track and trace performance measurement framework.

## 3.2. Approach

Our approach for analyzing the critical factors that affect tracking and tracing effectiveness is shown in Figure 3.1. We describe each of the factors separately, analyzing its causes and the way it affects tracking and/or tracing information quality. We also provide implications as to how automatic identification technologies could overcome the obstacles that these factors set and enhance information quality. Moreover, based on the way tracking and/or tracing

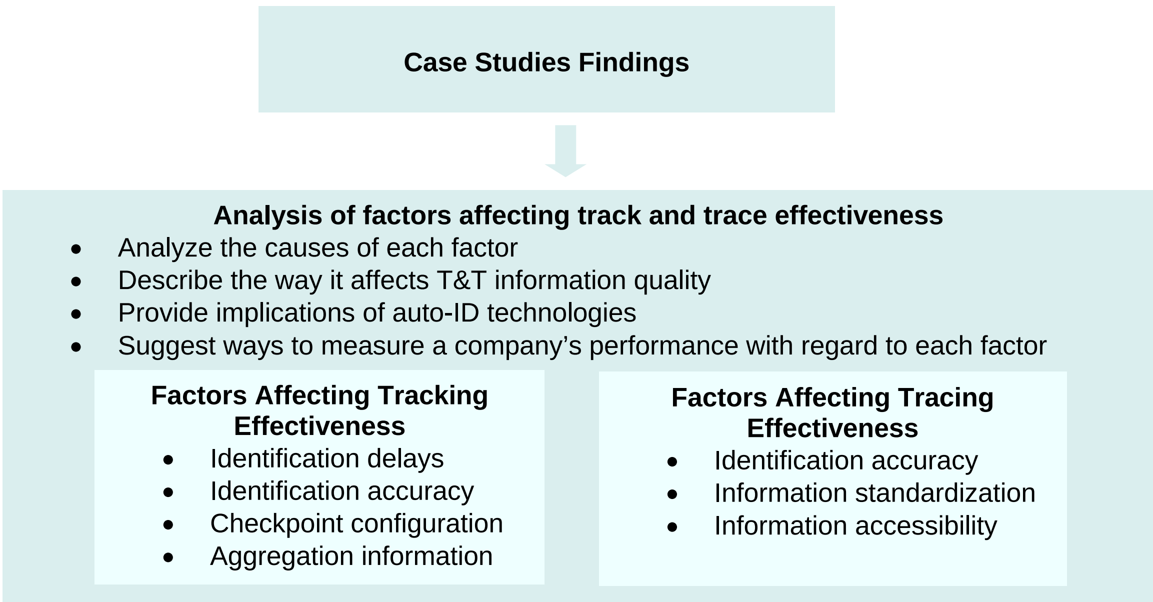


**Figure 3.1: Approach for analyzing the factors that affect T&T effectiveness**

information quality is affected, we suggest a way to measure the performance of a company with regard to each factor.

## 3.3. Factors affecting track and trace performance

In this section we present the factors that, according to the case studies, play a key role in traceability performance and the way they affect information quality. The analysis is split in two sections which refer to location tracking and lifecycle information tracing performance respectively, since most of the factors that affect each of them are distinct.

### 3.3.1. Location tracking performance

*Identification delays*

The case studies indicated that it is very common for products to arrive at a warehouse (or other supply chain site) and wait for long periods of time in the receiving area without being booked into the information system. This keeps the information system outdated until the products are processed. During this delay, the information in the system represents a false state of the real world, as the products may have arrived but they appear to be still in transit, as shown in the example of Figure 3.2. This results in the tracking information to be inaccurate for a significant period of time.

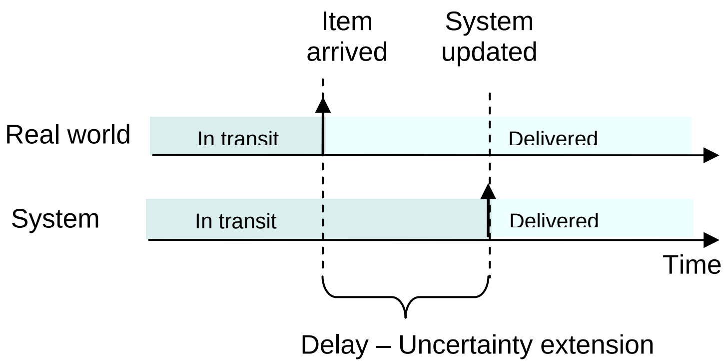


**Figure 3.2: Product processing delay**

The significance of the impact that these delays have on the performance of the system relates to the duration of the delays compared to the frequency that an item's state changes in the supply chain. Indeed, as Balou *et al*. [3, 4] suggest, the timeliness of information is affected by the *currency* of information and the *volatility* of the state evolution. The currency of information includes the time at which the information is stored in the information system before queried and its age. The age of information is the time difference between the moment when the real-world event occurred and when the data was entered into the system [5]. The volatility of information in the tracking case relates to the frequency that an item's state changes and can be represented by the average period between state changes. Therefore, a way to measure the timeliness of tracking information is provided by the following formula:

$$\text{Timeliness} = \max\left[\left(1 - \text{currency} / \text{volatility}\right), 0\right] \quad (1)$$

The identification delays observed in the case studies affect the currency of information. However, a 12-hour delay in system update is much more significant if the products change status/location every 1–2 days than if they change status every two weeks on average.

### *Identification accuracy*

The accuracy of identification process has a direct impact on the performance of the tracking system. The identification method used for this purpose is the main factor that affects the effectiveness of the process. Automatic identification technologies such as barcode, contact memory buttons and RFID usually provide identification accuracy close to 100%. However, human intervention in the identification process (for example, hand-written serial numbers or manual data entry) introduces a high percentage of errors resulting in reduced information accuracy. It is clear that identification accuracy is critical for the performance of the tracking system. Identification errors will lead to inaccurate product status updates. Additional time is required to resolve errors, if detected at all, and bring the information system to an accurate state.

### *Configuration of checkpoints*

The number and location of checkpoints along the supply chain is a fundamental factor affecting the information provided by the tracking system. Checkpoints are the locations at which objects are identified and information is communicated to the tracking system indicating the object identity, the location, the timestamp and any other relevant information about the item to define its state. When an object is observed at a checkpoint, there is minimum uncertainty about its state. As time passes, until the next observation, uncertainty grows, since there is no information about the object. The more dense the checkpoints and the less the time between object observations, the less the average uncertainty across the supply chain. Figure 3.3 demonstrates an example of two different configurations of checkpoints along a supply chain. In this case, location uncertainty is represented by a probability distribution of the possible location of an object at different time instances. Wider distribution indicates increased uncertainty about the location of the object.

Another factor that should also be considered with regard to checkpoint configuration is the installation cost and operational cost of each checkpoint. This creates an interesting and challenging trade-off between information quality and cost of obtaining it.



Published November 2, 2006. Distribution restricted to Sponsors until May 2, 2007

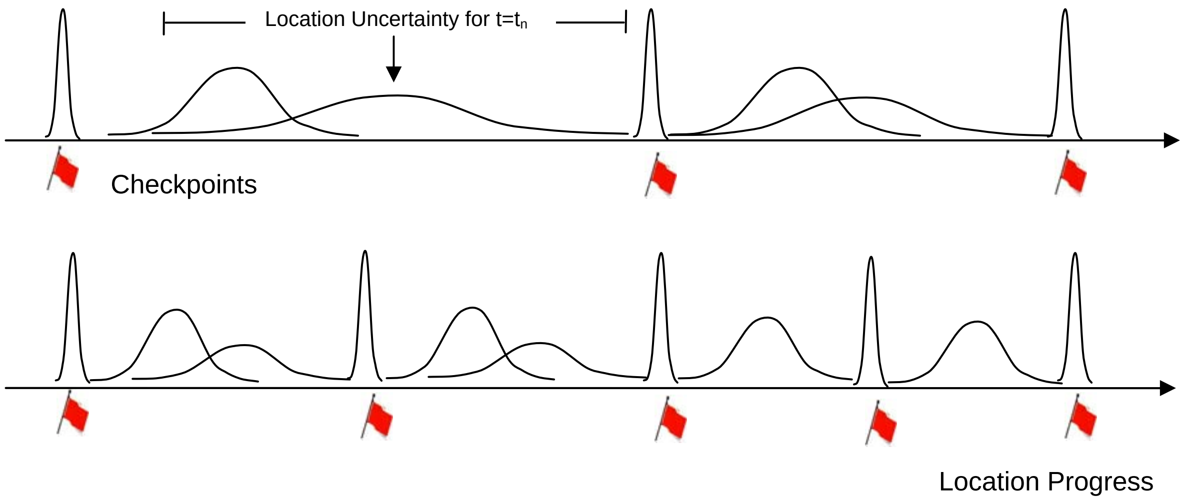


**Figure 3.3: Location uncertainty for different checkpoint configurations**

### *Aggregated shipping*

Most of the times, objects are shipped in containers or pallets which carry an identifier. This identifier can be used to track a shipment in the supply chain. However, the reliability of aggregation information, referring to the individual objects that the container actually includes, seriously affects tracking performance. First, reliable aggregation information enables tracking objects based on the aggregation identifier they appear to be contained in. Once the container is observed, all objects that are contained in it can be assumed observed. Secondly, high trust in aggregated packaging would enable efficient logistics processing, diminishing the need to physically inspect the container and cross-check its contents with the aggregation information. The above make clear that the accuracy of aggregation information is critical if it is used to infer tracking information about individual objects, as well as to optimize logistics operations. An error in aggregation information could result in significant costs, e.g. a product is assumed to be contained in a pallet that is tracked perfectly and arrives on time but actually does not contain the product. Emergency action needs to be taken which usually incurs higher costs than usual operations. Modern automatic identification technologies and RFID, in particular, can solve this problem, as they can provide information about the contents of a container without opening it, provided that physical conditions are favourable.

### 3.3.2. Lifecycle information tracing performance

*Identification accuracy*

Similar to the case of tracking effectiveness, object identification accuracy is critical for the performance of lifecycle information tracing. In this case identification accuracy affects the quality of information both during the information recording and the information retrieving process. Again, the identification technologies used play a key role for assuring high accuracy percentage. The case studies revealed that when no automatic identification technologies are used then a significant amount of errors occur when product composition information is recorded during the production process. Similarly, errors occur when lifecycle information such as number of cycles a part has undergone or important maintenance events is recorded. The identity of the part is the basis for the accuracy of this information and therefore it is crucial that it is recorded and retrieved correctly.

*Information standardization*

Apart from the identity of an item, in most of the cases there is additional information that should be recorded in order to have a complete trace history for an item. This information may refer to operations and operational parameters that the item has undergone (for example, heat treatment during manufacturing or shocks and acceleration suffered during operation) and important events during its lifetime that cannot directly be described by predefined numbers and need further description (e.g. the event of a hard landing or a specific maintenance action). The case studies revealed that the usefulness of this information is poor because in many cases it is not descriptive enough or it is incomplete. A representative example is the poor description about a part failure that repair shops usually receive with a returned part. Lifecycle information is valuable when it meets a certain level of detail and completeness. In order to measure the quality of this information and improve it, the process of recording and retrieving this information should be standardized. The ATA Spec2000 standard already specifies a set of well defined data fields which should be used for each piece of important information, along with standard ways of recording and representing this information. The use of predefined codes for common data fields will enhance the accuracy and completeness of information (for example, fault codes for common part failures). The percentage of lifecycle information that is accurate and useful for decision making is a way to measure the current effectiveness of a traceability system, although this may be difficult to measure objectively. Also, the degree of information standardization is an indicator of how accurate and useful the currently used lifecycle information.

*Information accessibility*

Although both identity and lifecycle information may be accurately recorded, there are many cases in which information is not accessible to the decision maker or the person who seeks it. The main reason for this is the fact that the entity that needs the lifecycle information for decision making is different from the entity that records this information and therefore the information needs to be communicated in some way between the two. Similarly, but rather in a smaller scale, lifecycle information may be recorded by different information systems within the same company and needs to be integrated in order to establish a full traceability record (for example, information regarding the product composition from different production stages). Consequently, the degree to which lifecycle information is readily accessible directly affects traceability performance. This degree should include both the percentage of information that is actually available to the decision maker and the delay and cost after which it is finally made available.

### 3.4. Implications for a traceability performance measurement framework

The analysis so far has identified a set of factors that affect tracking and tracing performance in a company. We have analyzed the problems that companies are facing and we have identified the main reasons for poor performance. The identified factors that affect traceability performance can be used as a basis for defining a set of metrics that will be used to measure the performance of a company with regard to the respective aspect of the problem. The analysis of the performance factors in the previous section provided an insight of how the metrics should be defined and what these should measure.

In order to develop a framework that will deliver useful measurements, which can be used to assess and improve traceability performance, a number of principles need to be satisfied.

- The metrics that will be used need to be very clearly defined so that they are robust and allow no misinterpretation of the indicator that should be measured.
- The measurements should include minimum subjective input in order to reflect the real company performance.
- The measurement output should be in a uniform format that allows comparison between different systems and companies.

The findings analyzed in this report will provide input for the development of the track and trace performance measurement framework. A set of metrics will be defined, in accordance with the aforementioned principles, providing a measure of performance in each of the factors that affect track and trace performance analyzed in this report.

## 4. Conclusions and Future Work

In this report we have presented the results from a series of case studies on tracking and tracing practices undertaken recently in the aerospace industry. We have examined logistics tracking and lifecycle information traceability applications. The case study analysis revealed a number of problems that companies face which undermine their performance with regard to track and trace operations. We analyzed the problems and identified the main factors that affect the effectiveness of these applications, which mainly relate to the accuracy and efficiency of object identification and the configuration of the traceability system.

The factors that affect tracking and tracing effectiveness were analyzed. The analysis revealed that the lack of effective and efficient identification methods is one of the main reasons for poor performance. Moreover, the configuration of the traceability system and the way information is communicated between the participating entities also affects tracking and tracing effectiveness. The analysis described in section 3 of this report provides a basis for defining a way to measure the performance of company with regard to these factors, so that it can be monitored and potentially improved.

Based on the results of this study, the next step will comprise defining the track and trace performance measurement metrics that will constitute an overall performance measurement framework. The metrics will reflect a company's performance in the respective indicators. The output produced will be in uniform format, independent of the company or the system studied. The results of a track and trace performance assessment shall enable the identification of shortcomings in specific application areas and enable continuous monitoring to facilitate improvement.

# 5. References


[1] van Dorp, K.J., *Tracking and Tracing: a structure for development and contemporary practices.* Logistics Information Management, 2002. **15**(1): p. 24-33.

[2] Jansen-Vullers, M.H., C.A. van Dorp, and A.J.M. Beulens, *Managing traceability information in manufacture.* International Journal of Information Management, 2003. **23**: p. 395-413.

[3] Ballou, D., et al., *Modeling information manufacturing systems to determine information product quality.* Management Science, 1998. **44**(4): p. 462.

[4] Ballou, D.P. and H.L. Pazer, *Designing Information Systems to Optimize the Accuracy-timeliness Tradeoff.* Information Systems Research, 1995. **6**(1): p. 51.

[5] Wand, Y. and R.Y. Wang, *Anchoring data quality dimension in ontological foundations.* Communications of the ACM, 1996. **39**(11): p. 86-95.