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Lifecycle Information of Aircraft Engine Components

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by

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Abstract

When an aircraft component needs replacement of a serially controlled item, the maintenance office uses the Scheduled Removal Component (SRC) card, which is used to track the component's lifecycle, to verify that the part is ready-for-issue and to verify how many flight-hours it still has left. Unfortunately, SRC cards are often missing; when they are present, their information is unreliable, which prevents the part from being immediately installed. This study analyzes the impact of the current paper-based lifecycle management of serially controlled parts in the naval aviation community. It investigates item-unique identification and radio-frequency identification technologies as alternative ways of tracking these parts throughout their lifecycles in order to increase aircraft operational availability.

Keywords: Aviation maintenance, process flowchart, radio-frequency identification (RFID), item-unique identification (IUID), Data Matrix ECC200

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I. Introduction

In a previous study, Ferrer (2009) demonstrated that there is an opportunity for operational improvement and cost savings by rationalizing the supply network for aircraft engine maintenance in the US Air Force. That study analyzed demand data for the F100-PW-200 and the F110-GE-100 spare engines used in the F-16 Fighting Falcon, and realized that pooling the inventories of Air Force bases within operationally acceptable distance would enable the reduction of nationwide-safety stock levels. The purpose of this study is to expand the inventory management analysis, which was originally focused on complete aircraft engines, to study the management of individual parts throughout their lifecycles and the impact of certain structural decisions on maintenance operations and on total cost of ownership.

Over the lifespan of an aircraft, specific parts are installed, removed and replaced during a variety of maintenance procedures. While transferring a part from one aircraft to another, custody and ownership rights generally transfer at both intra-organizational and inter-organizational levels. (For the US Navy, intra-organizational custody change entails part movement from one work center to another within a squadron, whereas inter-organizational custody change refers to the part being transferred to or from an outside command.) In order to properly service the aircraft and its components, technicians need information about individual parts such as the hours in use, maintenance history and inspection data. Because some of these aircraft parts are critical to flight safety, they have strictly specified lifecycle maintenance requirements that must be accurately completed, logged, tracked, and stored.

Early research has found that the process of tracking and logging maintenance parts is extremely beneficial for increasing readiness (Apte & Dutkowski, 2006). The success of inventory control through the use of accurate tracking and by maintaining a technical knowledge base has tremendous significance to the support of any combat system. The solution implemented in

Cross Field Amplifier components in the AEGIS program is an excellent example of a successful pursuit of reduction of total ownership cost due to component tracking.

The process of collecting and logging data for each part under maintenance in a paper-based system is manually intensive and error prone. For situations in which multiple parties give maintenance to aircraft components, at potentially different locations, the need for readily accessible maintenance history makes it necessary to keep an efficient information system.

These tracking databases serve two important purposes. First, they serve as a part-lifecycle data library, where the service technician can find the history of maintenance events. Second, examination of historical part-performance data by engineers can be used to refine current preventive-maintenance practices to minimize or prevent unexpected and catastrophic part failures. Ultimately, lifecycle management processes strive to ensure the highest levels of aircraft safety, operational availability, and squadron readiness.

To achieve these maintenance metrics, many civilian and military aviation organizations are starting to implement Product Lifecycle Management (PLM), a closed-loop procedure that encompasses internationally standardized data-exchange software technology. The PLM model takes a business approach toward managing part information from cradle to grave.

Automated information technologies such as radio-frequency identification (RFID) and two-dimensional unique item identification (UID) enable efficient tracking solutions for the aviation industry. With the FAA approval of the use of passive UHF RFID tags on individual airplane parts for commercial aircraft, the industry generated a number of potential RFID-based applications for airlines, air-freight carriers, aircraft maintenance and repair centers, and airplane manufacturers. Shortly after the approval, Boeing announced plans to tag 1,750 maintenance-significant parts for its 787 Dreamliner. The firm plans to incorporate RFID tags on high-dollar-value

items; line replaceable units (LRUs); limited-life parts that need to be frequently inspected, repaired, and replaced; and on-board emergency equipment.

Upon storing its unique identification attributes (part number, serial number and manufacturer's code) the maintenance technician should be able to access flight time and maintenance and inspection data. By logging a part's flight-hours, maintenance and repair histories in a centralized database, airline companies would reduce the cost of tracking and maintaining service history on parts. It would also reduce the time to solve in-service problems by improving the accuracy of information exchanged between customers and suppliers.

The ability to easily reference and update a part's maintenance history will facilitate the following: accurate configuration control and repair history, reduced warranty-claim processing costs, accurate and efficient spare-parts pooling, and easier identification of rogue parts. By storing maintenance records in centralized database, airlines will also reduce their reliance on paper records and ease future compliance with FAA documentation requirements.

Similar to civilian aircraft, military aircraft has much to benefit from the use of tracking technologies as well. Consider the F414-GE-400 engine, which is used in the F/A-18E/F Super Hornets and the E/A-18G Growler, each aircraft requiring two engines. The Navy plans to purchase 85 Growlers and have them home based out of Whidbey Island, WA, to replace the aging fleet of E/A-6B Prowlers. The engine has a modular design. Whenever necessary, these modules are repaired at the depot in the Naval Air Station (NAS) in Jacksonville, FL. However, the maintenance operation is initiated across the country in NAS Lemoore, CA, where engine modules are removed from the aircraft and replaced, unless the engine is repaired onboard a carrier's Aircraft Intermediate Maintenance Department (AIMD). The mission of Fleet Readiness Center (FRC) West Power Plants at NAS Lemoore is to manage the supply of the fleet's demand for the engines in Naval Air Facilities (NAF), both CONUS and OCONUS. Throughout the life of the aircraft, multiple components are removed, replaced, and repaired in order to be reused in the same

or in another aircraft. Engineering specifications driven by safety requirement indicate that these components must be serially managed, i.e., they should be uniquely tracked, controlled, or managed in maintenance, repair, and supply by means of their serial numbers.

The study of the use of tracking technologies, such as RFID and UID, for supply chain management application has seen rapid growth, but the impact of using tracking technologies for managing component lifecycles is still poorly understood. Although research is ongoing in regard to the use of RFID technology in a shipboard environment, the problems associated with tracking lifecycle information with the physical attachment of a Scheduled Removal Component (SRC) card to a specific part still needs to be addressed.

In order to investigate how the efficiencies can be attained in the logistics of the engine maintenance of the aircraft, this research focuses on the United States Navy's cradle-to-grave aviation-part-lifecycle process. The current process uses the SRC cards, and we use it as the benchmark method, considering the procedures at the Naval Aviation Logistics Command Operating Maintenance Information System (NALCOMIS) to track serially controlled components of the F/A-18 Hornet. More specifically, this research discusses the Automated Information Technology (AIT) mandate in the US Department of Defense (DoD) and why it should be implemented into a web-accessible database. Although the study centers on the Navy's F/A-18 Hornet community and its interaction with the ATCM Repository, the background, analysis and recommendations can be applied to any aircraft that has its serially controlled components tracked by SRC or any other hard-card-type process.

Our objective is to prevent the loss of critical part-history information, which centers on flight-hours and Technical Directives (TD) applicable to that part, and to reduce the number of errors incorporated in the component's lifecycle information. We highlight the problems associated with the use of SRC cards and propose an approach for their gradual discontinuation. We show that an important facet of

aviation maintenance would enjoy time and money savings due to decreased workloads, if the correct type of tracking technology configuration is employed.

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II. Existing Approaches for Component Tracking

Several parts installed on the F/A-18 Hornet require lifecycle tracking. Together, NALCOMIS and SRC cards track expended flight-hours and completed maintenance actions over a part's lifetime for each serially-managed part as it goes from one command to another. The complete maintenance history, installation, and usage data for all items designated as scheduled removal components are recorded on the SRC card. These parts have mandatory removal and replacement intervals as well as requirements for special monitoring, with emphasis on failure trends. The card is very thorough and unambiguous. It is used to record maintenance history on any item requiring monitoring, tracking, and trending of failure data. They are kept as part of the aircraft logbook or the aeronautical equipment service record as long as the component is installed. When the component is removed from the aircraft or equipment, the SRC card accompanies it as it flows through the supply chain. Updated and maintained on file by a maintenance administrator, an SRC card alone can have a direct input on squadron readiness. Occasionally, component paperwork is mishandled, particularly aboard ship due to space restrictions: Spare parts arrive and are unpacked, and, many times, the documentation that comes with them is lost in the heat of the moment.

The installation of a new serially controlled part in an aircraft is the event that originates the SRC card. Maintaining physical custody of the SRC card and documenting lifecycle history updates on the SRC card are the responsibility of the squadron's Logs and Records personnel. The controlled item is removed as the result of component failure or required periodic maintenance, at which point the card is retrieved and updated. The following process describes the steps followed by the

worn part and its card, if the card is properly located[1] when the part is removed for repair. Figure 1 illustrates the following:

1)   The non-ready-for-issue part (non-RFI) is removed and its SRC card is updated with the new status.

2)   A copy of the SRC card is sent to the Configuration Management Information System (CMIS), which keeps information of all serially controlled parts.

3)   The updated SRC card is packaged with the corresponding non-RFI component to be exchanged for a ready-for-issue (RFI) component.

4)   A requisition document, DD 1348, for a replacement RFI part is conveyed to the Aviation Support Division (ASD). The Document Control Unit (DCU) personnel process the request and determine if an RFI item is in stock.

    a.   If the RFI item is in stock, then the process moves to Material Delivery Unit (MDU). The MDU sends the RFI item to the squadron. The non-RFI part and its card are collected in exchange for the replacement RFI part.

    b.   If the RFI item is not available, then the squadron is informed. The SRC card of this non-RFI part is verified and updated. The non-RFI item is sent with its card to the Intermediate Maintenance Activity (IMA) facility for repair.

        i)   If the IMA has repair capability and the part is not beyond the capability of maintenance, then a work center and work priority is assigned to the part by Production Control (PC). The part is then transported to a work center, where it is repaired and receives RFI status.

        ii)   If the IMA work center does not have repair capability, then the part is sent to the next-higher-level repair facility, where it is repaired and receives RFI status.

5)   The squadron receives the part, opens the package, and verifies if the SRC card is included.

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[1] If the card is not properly located, the CMIS Repository is contacted to re-create an SRC card with the part's lifecycle history. From then on, the process follows from the 3rd step.

a. If the SRC card for the part in inventory is missing, then the part is not used because it cannot be established how many flight-hours are still available in it or that the part is RFI. CMIS Repository is contacted to re-create an SRC card with an estimate of the flight-hours that the part can still safely deliver. The squadron waits for response before installing the part.

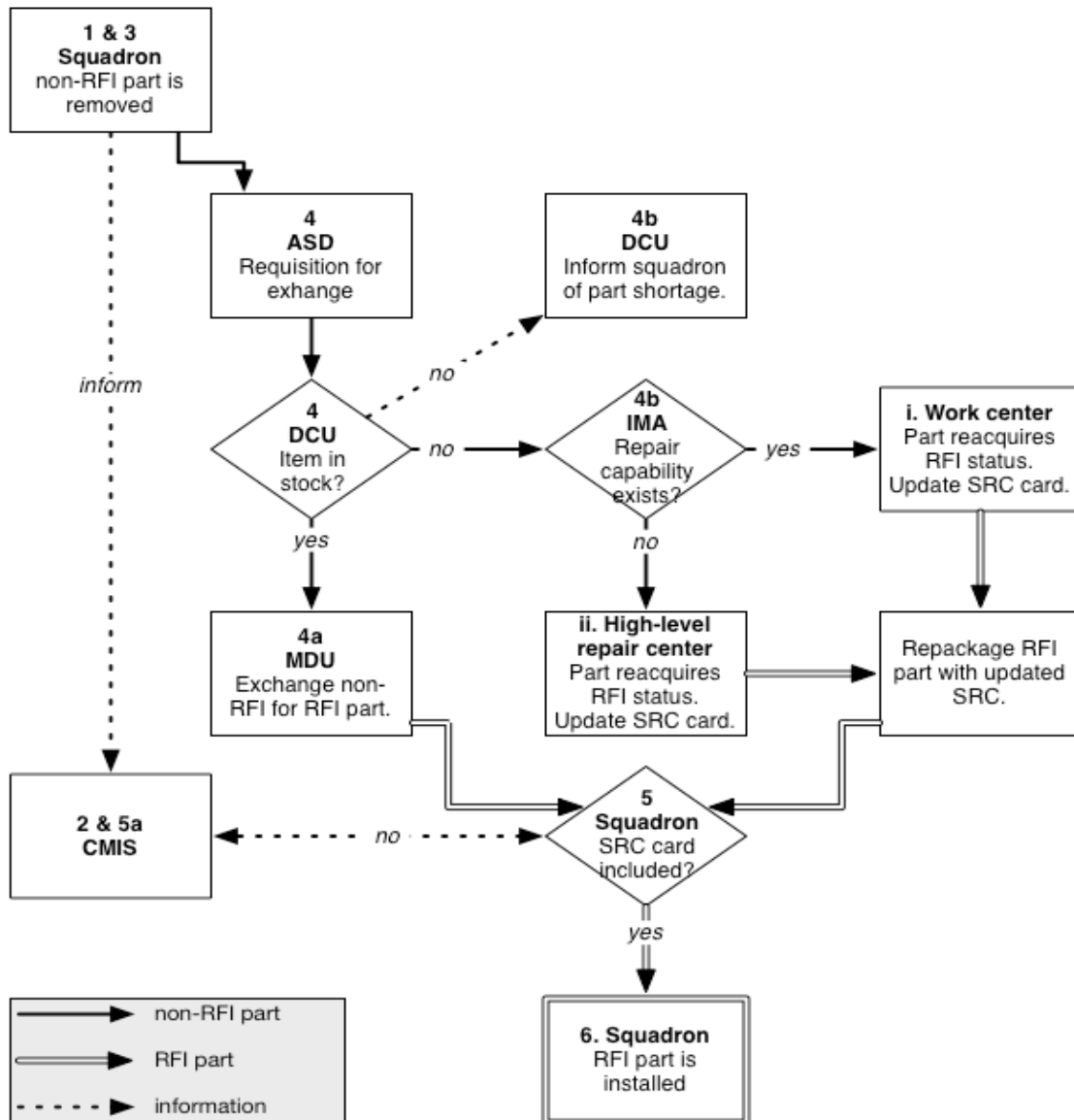6) Once the SRC card is confirmed to be with the part, the card is updated and the part is installed in the aircraft.

Figure 1.   Process Flowchart for Serially-Managed Parts Controlled with SRC Cards

One problem is quite evident in this process: the procedure for exceptions when the process fails. One could praise the process as being conservative because it is prepared to handle exceptions such as missing cards (step 4.a.ii) and inventory shortage (step 4.b). However, these exceptions happen quite often, and the prominence of them indicates serious deficiencies in the management of serially controlled items by the US Navy. Because of these deficiencies, there are many instances when the fleet is faced with readiness levels below plan. The improvement of this process is a priority for the aviation community, and it can be achieved with a process redesign that includes the use of tracking technologies.

A.   RFID Technology

Table 1 compares two initiatives at the Department of Defense: item-unique identification (IUID) and radio-frequency identification (RFID). They are separate but integrated initiatives that use different technologies and different business rules to track DoD-owned assets.

Table 1.   Comparison between RFID and IUID Implementation Initiatives

	IUID	RFID
Mark	Item	Package
Technology	2D Data Matrix	UHF RF w/EPC encoding
Purpose	Lifecycle visibility	Supply chain visibility
Threshold	Item value > $5000 +	Ship To DDC; Class of Supply
Implementation	1 Jan 04	1 Jan 05
Data Submission	WAWF ASN +	WAWF ASN

RFID has been widely used in military supply chain applications. In October 2003, the DoD established the policy for RFID adoption and initiated a strategy to take maximum advantage of the inherent lifecycle asset management efficiencies that can be realized with the integration of RFID throughout the DoD. Moreover, the DoD announced that its 43,000 suppliers would be required to implement RFID at the pallet and case level by 2005.

RFID technology is and will remain one of the hot topics in operations and supply chain management for a long time. It is expected to receive widespread adoption, considering that many organizations that have experimented with this technology have already found benefits. However, in addition to its benefits, RFID technology has some limitations, which prevent it from gaining wider use in supply chain operations.

The initial benefits gained from RFID integration in a warehouse or distribution center are derived from automating manual processes and effectively using large amounts of data. RFID technology provides various benefits and solves many different problems. For example, using RFID tags to automate the receiving operation can reduce the labor cost for that function, enhance accuracy, and increase inventory turnaround by decreasing the amount of time that an item spends in a distribution center (Dew, 2006; Landt, 2001).

RFID technology supports the information flow in the supply chain by increasing visibility, facilitating the automation of processes, and providing greater data accuracy, as shown in Figure 2. Visibility is the ability to retrieve inventory information as needed. Automation is the ability to update the changes in inventory information as they happen, without the need for manual data entry, which reduces errors and the number of hurdles preventing the database from staying up-to-date. Automation and visibility help reduce wasted time by preventing situations when a misplaced part or item needs to be found from a large inventory. It also provides data accuracy and faster information update. Combined, these benefits increase process capacity and reliability (Ferrer, Dew & Apte, 2010).

The real-time nature of RFID technology provides the latest inventory or item location information to decision makers, enabling better responsiveness in the supply chain (Kärkkäinen, 2003; Niederman, Mathieu, Morley & Kwon, 2007). An additional benefit of the RFID technology is providing the manager with the ability to identify and count items, follow their movements, and help the related personnel to determine the location of the items in a warehouse or depot. This is a consequence

of a fundamental attribute of RFID technology: it does not require direct line-of-sight between the reader and the tags, owing to its ability to communicate with all the tags in the effective zone of its radio signal in milliseconds, keeping the database accurate at all times.

Faster information flow results in a reduction of the required time and effort to document component movement during maintenance activities. Better visibility and faster information flow leads to faster processes throughout the supply chain, helping the managers in their decision-making process and the users in the system to access reliable information. With increased capacity, labor is reduced in both the receiving and delivery points responsible for identifying, counting, locating, documenting, and managing the movements of the items. Automated documentation benefits the maintenance process by helping the technician to use accurate information about the component's lifecycle in every maintenance event.
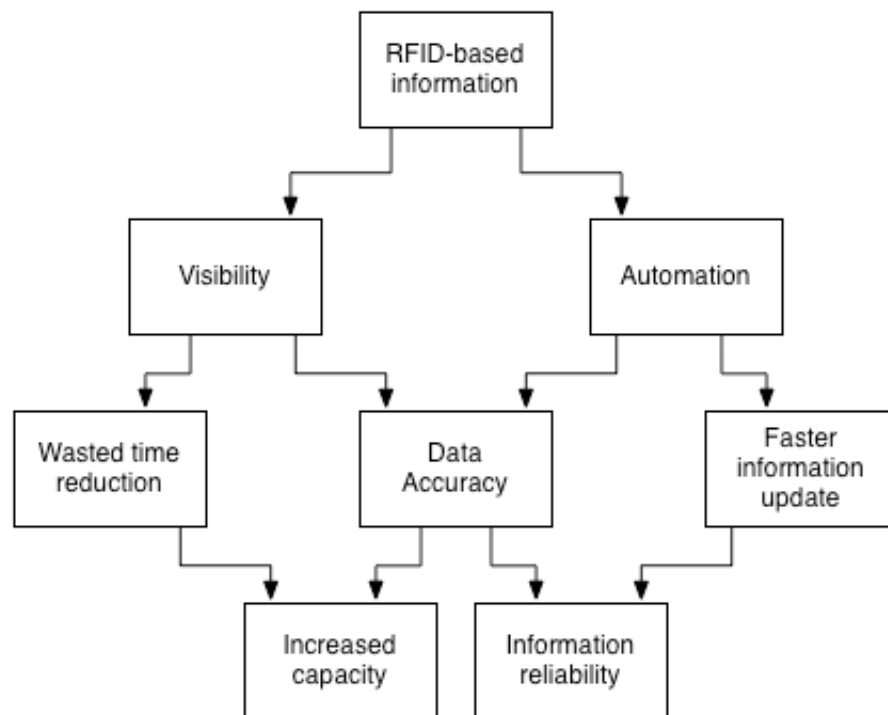

Figure 2.   Benefits Derived from Using RFID in Lifecycle Tracking

Unfortunately, moving from a familiar and trusted technology to a new one poses a challenge in any organization, especially when it requires process change. Many manufacturing facilities and distribution centers have been using barcode systems for tracking materials for years, rendering this technology mature and efficient. Consequently, switching to RFID or any other tracking technology requires substantial investment that is difficult to justify. Likewise, an SRC card is a tested and tried approach to managing serially controlled components. If the cards are kept with the components at all times, and information is entered accurately, then it serves the purposes of the maintenance process as intended. However, there are too many "ifs" in this process that make it unreliable. As a result, resistance to change is one of the greatest challenges preventing the adoption of RFID technology for tracking serially controlled items.

Despite its benefits, RFID technology is still an immature technology and has some limitations. It is undergoing several rapid changes that can spell difficult challenges for managers who attempt a half-hearted adoption (Lahiri, 2005). The physical properties of the materials that require tracking as well as their surroundings can affect the reliability of readers. For example, liquids absorb radio frequency signals, but metal reflects them. As a result, the materials in the tagged item can significantly affect reading performance. Furthermore, external factors like radio frequency (RF) noise from nearby electric motors can impact its performance. These physical limitations are more relevant in some applications than others. Navy ships and depots have a multitude of equipment and surfaces that are made of steel and other dense materials that reflect away the RF signals. Consequently, the adoption of RFID technologies to track serially controlled items requires careful planning and design.

Data overload and data noise also affect the performance of RFID systems. Data overload results from continuously scanning the RFID tags within reader range and sending the repeated information to the host computer. For this reason, the network capacity, the features of the host computer, and the quality of the

middleware are determinant factors in preventing the overload to keep the system operating. Data noise is a consequence of the torrent of the RFID data, especially in overlapping areas covered by multiple readers. This prevents read rates from reaching 100%, due to unreadable, damaged, and missing tags, or to tags that are blocked by shielding materials nearby. In addition, mistakes can happen because the reading is based on proximity between tag and reader, so if a tag is within reach of multiple readers, it may be counted twice. To prevent inaccurate data from being transmitted to enterprise applications, a successful RFID solution must be able to detect and correct erroneous or missing information, which is not always possible (Tzeng, Chen & Pai, 2008).

B.   IUID System

Item-unique identification (IUID) is an asset identification system instituted by the United States Department of Defense (DoD) to uniquely identify discrete, tangible items and distinguish each of them from other items owned by the DoD. The identification takes the shape of a machine-readable, two-dimensional (2D) optical code using the Data Matrix ECC200 symbol. It is known in DoD parlance as the Unique Identification (UID), and it is formatted in accordance with specified standards (MIL-STD-130) (a sample is shown in Figure 3). The Data Matrix ECC200 symbol has a checkerboard appearance, with each uniformly spaced, square-shaped cell corresponding to a data bit. The symbol is constructed as a combination of light and dark elements that must all be read before any characters can be recognized (Drews, 2009). The formatted data is called a Unique Item Identifier (UII). Once assigned to an item, the UII is never changed, even if the item is modified or re-engineered. Like an automobile license plate, or a social security number, someone reading the UII itself will not be able to learn much about the item. A UID reader is able to identify just the unique characters marking the item.

Figure 3.   Data Matrix ECC200 (a.k.a., UID)

Unlike radio-frequency identification technology (RFID), in which much of the item information can be recorded within the device's memory, virtually all UID data is stored offline. To have information about the item with the UID mark, the user needs to access a central database, the IUID Registry, and learn permanent data elements associated with the mark—the item's "birth record." Most of this baseline data is static; it is never changed during the life of the marked item, except to record its permanent retirement. In order to register a baseline UID item pedigree, the following acquisition data elements are required in the first nine fields of the database:

1. UID type, and

2. Concatenated unique item identifier.

Based on the UID type, one or more of the following elements may be required:

3. Issuing agency code,

4. Enterprise identification number,

5. Original part, lot or batch number,

6. Current part number,

7. Serial number,

8. Item description, and

9.   Unit of measure.

In addition to these elements, other acquisition data elements may be required.

As the number of vendors for common aircraft parts increases, part and serial numbers may accidentally be duplicated on different components. This can result in the ordering of an incorrect part based on correct part numbers. IUID is being implemented to address that problem. A UII is exclusively designated for a particular part, which is then registered in a master DoD file—the IUID Registry. The Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics mandated the use of Unique Item Identification (UID) for all solicitations on or after January 1, 2004, for equipment, major modifications, and spares under the Policy for Unique Identification (UID) of Tangible Items New Equipment, Major Modifications, and Reprocurements of Equipment and Spares. Each vendor that does business with the DoD now has to obtain a UID number from the master UID database to ensure that no part in the DoD can be confused with another part. This mandate was an initial step toward uniquely identifying all DoD assets that meet certain cost and management criteria: All purchased items delivered to the Government require item-unique identification or a DoD-recognized unique identification equivalent if the delivered item costs $5,000 or more. In addition, a serially-managed sub-assembly, component or part embedded within a delivered item (in addition to the parent of the serially-managed item) are required to have their UII and, consequently, must be marked with a UID (OUSD(AT&L), 2004). Finally, legacy items that meet these criteria have to be uniquely identified according to the IUID system (DoD, 2005).

The fundamental benefit of this policy is that the UID, is a permanent marking for serially-managed items and the perfect lifecycle tracking enabler. The IUID system provides the backbone of the IUID Registry, which allows traceability of the item throughout its life within the DoD operational, inventory, and maintenance environment. Additional steps toward this goal include identifying DoD-

manufactured items as well as legacy assets currently in-service. Figure 4 illustrates the UID mark lifecycle and business rules at each phase.
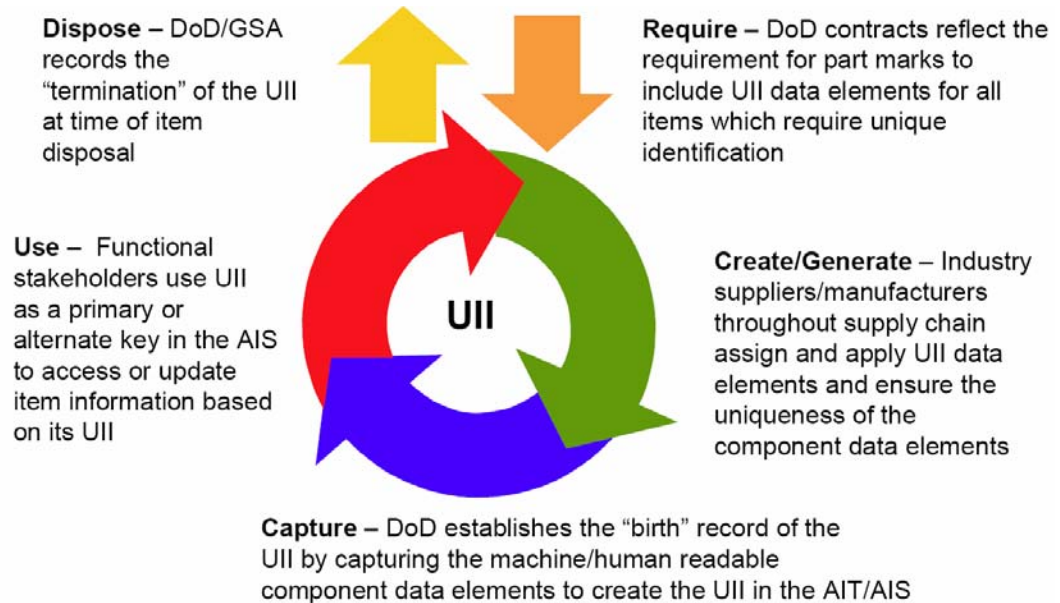

Dispose – DoD/GSA records the "termination" of the UII at time of item disposal

Require – DoD contracts reflect the requirement for part marks to include UII data elements for all items which require unique identification

Use – Functional stakeholders use UII as a primary or alternate key in the AIS to access or update item information based on its UII

Create/Generate – Industry suppliers/manufacturers throughout supply chain assign and apply UII data elements and ensure the uniqueness of the component data elements

Capture – DoD establishes the "birth" record of the UII by capturing the machine/human readable component data elements to create the UII in the AIT/AIS

Figure 4.   UID Mark Lifecycle
(OUSD(AT&L), 2004)

1.   IUID Registry

The IUID Registry is the ultimate repository where all IUID data is captured. It serves as an acquisition gateway for identifying the following information:

- what the item is,

- who received the item originally,

- the initial value of the item, and

- the contract and organization from which the item was acquired.

Generally speaking, the organization marking an item sends the following data to the IUID Registry: acquisition information (e.g., manufacturer, date of manufacture, cost, part number, serial number, nomenclature, custodianship, etc.);

parent/child relationships with other items in the registry; point of contact for the person and organization that supplied the registry with the information; and, of course, the unique and unambiguous text string of the respective item. Updates, when necessary, are also sent to the registry, indicating if the item was removed from service or if there was a change of custodianship. The information retrieved from the IUID Registry is used to confirm if the uploading procedures were correct and if information within the registry is accurate.

The registry is neither intended nor designed to be a working database for individual programs. In fact, the registry itself does not perform any value-adding activity. Rather, its purpose is to serve as an anchor to other information systems used for lifecycle product management, such as maintenance management systems, property management systems, and other systems that may or may not yet exist. Historically, we observed similar experience with the Social Security Number in the United States, which was originally created to track retirement contributions and benefits of individuals, and is now used in a variety of private and governmental information systems to manage taxes, banking, credit worthiness, insurance, employment records, education records, etc. Many benefits were derived from uniquely identifying individuals with the Social Security Number. Likewise, it is expected that other benefits could be derived from uniquely identifying valuable and critical assets with item-unique identification.
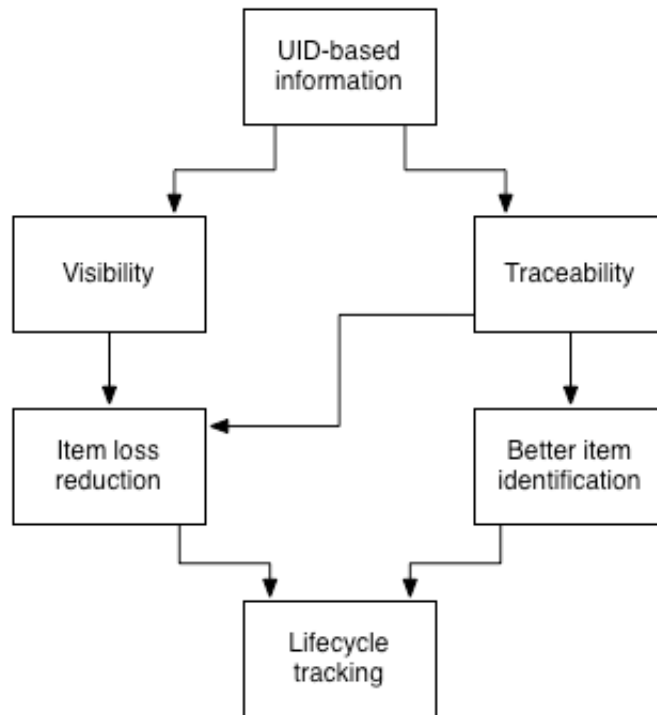
Figure 5.   Benefits Derived from Using UID in Lifecycle Tracking

Figure 5 shows how the use of information compiled with the help of IUID can enhance lifecycle tracking. Traceability is the ability to store asset information as it passes through multiple hands in its lifecycle. Visibility is the ability to retrieve inventory information as needed, which is obtained with correct registration of UIDs in the IUID Registry. Combined, visibility and traceability ensure accurate item identification and the reduction of item losses—important requirements for lifecycle tracking.

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III.   Analysis

Currently, the adoption of RFID and IUID for tracking serially-managed items in the naval aviation community is at very slow pace. We don't have current information about their adoption in other communities in the DoD. However, based on anecdotal conversations with officers in a variety of maintenance positions in the Department of Defense, this situation seems to be the norm, not the exception. That is, SRC cards remain the preferred mode of managing serially-managed items in the naval aviation community. The process described in Figure 1 reveals one step that is common to all part-replacement processes: step 5, where the maintenance officer checks the presence of the SRC card with the RFI part. A survey of experienced maintenance officers found that missing SRC cards is a rather frequent event, with significant impact in the operational availability of assets (Staffieri, Holsti & Gray, 2009). As the flowchart indicates, a missing card leads the squadron to contact the customer service at the Configuration Management Information System/Aeronautical Time Cycle Management Program (CMIS/ATCM) Repository. The CMIS is in charge of keeping accurate data about serially managed component usage, based on copies of the SRC cards that they receive every time a used component is removed from the aircraft, or when an RFI component is installed. If the corresponding card is missing or is inconsistent with the part, they are able to indicate the last time that particular part was installed, and using that information, they can make a sound estimate about the number of hours remaining in that part. In practice, that estimation is difficult to execute, and arbitrary flight-hour penalties are imposed in those components, reducing their value and accelerating their retirement.

Staffieri et al. found that in the six-month period from October 2008 to March 2009, the ATCM received cards corresponding to 17,318 component replacements, an average of 140 cards per business day, corresponding to an arrival rate of 17.5 cards per hour. There are three clerks that serve at the ATCM and, based on

internal estimates, each of them is able to process six cards per hour. This leads to a capacity utilization of 97% (i.e., 17.5/(3*6)).

In a deterministic process, utilization lower than 100% indicates that the system has capacity to perform the tasks as they arrive, without delay. However, two issues remain: The capacity at the ATCM is probably over-estimated, and the process is not deterministic. There is no indication that the capacity measured incorporates typical distractions that happen during the day (interruptions, restroom breaks, etc.), which would lead effective capacity to a number lower than six cards per hour. In fact, being a tedious activity, it is likely that service times vary substantially from card to card and are probably exponentially distributed. Moreover, job arrivals are independent, and most independent arrival processes follow a Poisson distribution. Poisson arrivals and exponential process times characterize a Markov process, meaning that substantial waiting lines are formed when process capacity approaches 100%, as described.

Staffieri et al. (2009) observed the development of large waiting lines. The backlog of cards to be processed at the Aeronautical Time Cycle Management program oscillated between 5,500 and 9,400 cards from October 2008 to March 2009, the equivalent to a backlog of 7.5-13 weeks of operation. Consequently, when an SRC card is missing, it may take a long time for the ATCM to determine if the part has any flight-hour left and if it can be installed in the aircraft; it might well be that the most recent update on that individual part is among one of the thousands of cards in the backlog. Some immediate action is necessary to contain the problem.

A.   Jointly Adopting RFID and IUID to Track Serially-Managed Items

One solution to improving the CMIS/ATCM Repository backlog would be to increase data entry capacity by adding another clerk to the system. The additional clerk will help reduce capacity utilization to just 73%. It is simple to show that a Markov process with four servers with hourly capacity of 6.0 jobs and demand of

17.5 customers would experience an average waiting line of about 4.2 cards, as shown in Table 2. However, it is possible that the effective capacity per clerk is probably lower than the estimated 6.0 cards/hr. As a result, the number of jobs waiting to be processed could be much larger, as shown by the examples in the table with lower clerk capacity. If clerk capacity is too low, the system is unstable and the waiting line would increase indefinitely, a situation that we noticed at ATCM.

Table 2.   Expected Number of Cards Waiting to Be Processed, as a Function of Capacity, When Demand Is 17.5 Cards/Hr.

		3 clerks	4 clerks	5 clerks	6 clerks
clerk capacity	3.8 cards/hr	n/a	n/a	14.1	6.1
	4.4 cards/hr	n/a	194	6.1	4.5
	5.0 cards/hr	n/a	8.7	4.4	3.8
	5.9 cards/hr	137	4.4	3.3	3.0
	6.0 cards/hr	39	4.2	3.2	3.0

As shown in Table 2, the addition of a new clerk would contain the problem at CMIS/ATCM, but it does not address the issue of the missing SRC cards, a reoccurring issue facing maintenance officers and leading to grounded aircraft. Lost or inaccurate SRC cards can result in substantial part-life penalties that indirectly convert to dollars lost with the arbitrary reduction of the flight-hours remaining in each part that is missing the card. The root of the problem lies in the lack of reliability of the card-based system. Moving to an automated Product Lifecycle Management (PLM) system would address these issues and help eliminate part penalties due to unreliable information management.

Figure 6 shows the potential benefits that may be derived from integrating the use of IUID with RFID to track components that exchange hands multiple times in their lifecycle. These two technologies provide traceability, visibility and automation with many positive consequences, as shown in Figures 2 and 5, leading to improved lifecycle tracking, increased capacity, and information reliability. Their integration

takes the benefits further: it provides sustained operational availability, which translates into more aircrafts availability. The unique item identification (UII) in each part would ensure their correct identification against a part lifecycle database (such as PLM), and the automation provided by the RFID technology would ensure that the data is accurate and up-to-date, provided that the infrastructure is correctly installed.
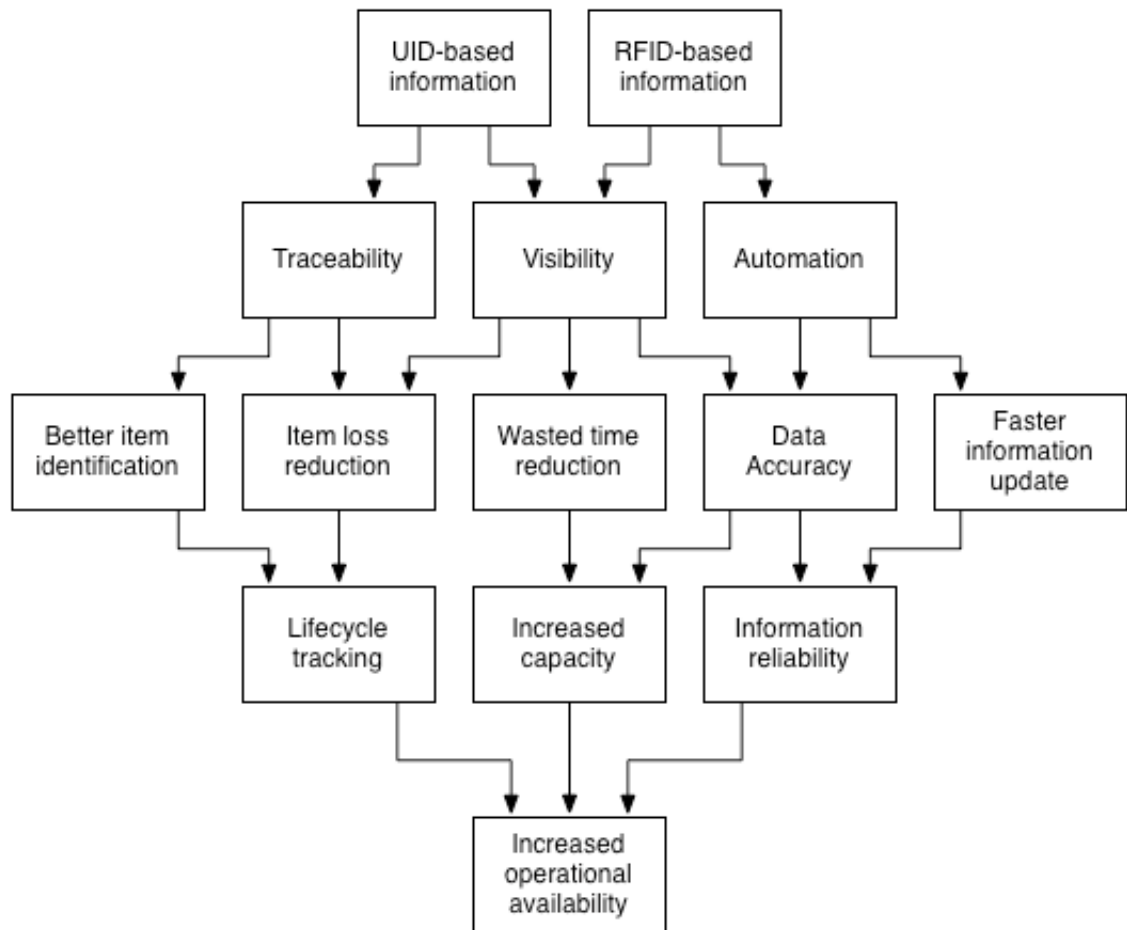

Figure 6. Benefits Derived from Jointly Using RFID and IUID for Lifecycle Tracking

IV.   Conclusions

This paper examined the issue of grounded aircraft due to misinformation regarding the availability of critical maintenance parts: the serially-managed items. Figure 1 describes the part-replacement process, indicating both the material and the information flow and exposing a weakness in the process: the potential that a part retrieved from replacement-parts inventory is missing a correct SRC card and, for this reason, cannot be installed in the aircraft. Unfortunately that seems to be a common occurrence, for which the process designates a corrective action: obtain a new card from the data repository.

The fleet response plan for most carrier-based aircraft is based on a 27-month cycle. Within that cycle, a squadron must always maintain a minimum number of aircraft that are fully mission capable (i.e., "ready for tasking"). The actual number of mission-capable aircraft in the squadron is counted each day to provide a monthly average, one of the performance measures for the squadron. In the particular case of the F/A-18E, they are organized as a 12-craft squadron that must maintain at least nine mission-capable aircraft during deployment, but may have as little as 4.5 mission-capable aircraft when not deployed. Many times the squadrons do not meet these minimum standards for lack of part availability, leading to grounded aircraft. Some of the unavailable or unusable parts can be tied directly to the inadequate SRC-card process, discussed earlier.

Many organizational issues can be addressed by implementing a combination of improvements in either a short or long time span, with costly or not-so-costly organizational reengineering. We proposed two solutions: one low-cost change with immediate impact, and a process redesign that requires substantial investment and broad commitment from all levels of leadership in the fleet.

A.   Process Change with Immediate Impact

We have seen that the CMIS/ATCM Repository is understaffed, which has led to almost 13 weeks (three months) of backlog, rendering customer service completely powerless to serve the maintenance officers in the aviation community. To meet the recurrent demand (without adding to the current backlog), it is necessary to have four clerks maintaining the database. Considering the existing backlog, holidays, leaves and other distractions that prevent any process from continually operating at full capacity as well as the costly impact of not providing immediate responses to maintenance officers assigned to deployed squadrons, five clerks should be the standard staffing level at the database repository.

Even with five clerks, it may take 23-39 weeks (5-9 months) to clear the existing backlog while meeting continued demand. Maintaining this staffing level would prevent backlog build-up, a common phenomenon in services with high capacity utilization and variable arrival and service rates.

B.   Process Change with Permanent Impact

Increasing the staff level at the CMIS/ATCM Repository, however, is not the cure, just the palliative solution. While the additional staff addresses the backlog at the SRC-card database, it is important to address the source of the problems, the SRC card itself. Figure 6 shows how the joint utilization of IUID and RFID can increase operational availability through traceability, visibility, and automation.

In 2007 the Naval Air Systems Command (NAVAIR) adopted the Optimized Organizational Maintenance Activity (OOMA), an automated system that provides maintenance officers with aircraft information on which to base daily decisions. Fortunately, both OOMA and the database software used by the CMIS/ATCM Repository have the ability to use UII as the part identification reference. Since the Department of Defense mandates that manufacturers mark serially-managed items using UID technology, NAVAIR should accelerate the adoption of UID as the main aircraft-part identifier. Moreover, these tags should be coupled with passive RFID in

order to ensure timely and accurate record keeping, eliminating the number of instances in which a part that is believed to be ready-for-issue is of unknown quality because of the lack of reliable records.

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List of References

Apte, A., & Dutkowski, E. (2006). *Total ownership cost reduction case study: AEGIS microwave power tube.* Acquisition Research Sponsored Report Series: NPS-AM-06-008. Monterey, CA: Naval Postgraduate School.

Office of the Under Secretary of Defense for Acquisition, Technology and Logistics (OUSD(AT&L). (2004). *Unique identification 101—The basics.* Defense Procurement and Acquisition Policy. Washington, DC.

Department of the Defense (DoD). (2005). *Approach to Unique Identification (UID) Initial Operating Capability (IOC) at DoD maintenance depots.* Washington, DC: Office of the Secretary of Defense Materiel Readiness and Maintenance Policy.

Dew, N. (2006). *The evolution of the RFID technology system.* Monterey, CA: Naval Postgraduate School.

Drews, K. (2009). Optical codes. In Bartneck, N., Klaas, V., & Schoenherr, H. (Eds.) *Optimizing processes with RFID and Auto ID, 38-56.* Erlangen, Germany: Publicis Publishing.

Ferrer, G. (2009). Open architecture, inventory pooling and maintenance modules. In Avery, A. & Tehrani, M. *10th International Decision Sciences Institute Conference*, 1198-1227. Nancy, France: International Decision Sciences Institute.

Ferrer, G., Dew, N., & Apte, U. (2010). When is RFID right for your service? *International Journal of Production Economics, 124*(2), 414-425.

Kärkkäinen, M. (2003). Increasing efficiency in the supply chain for short shelf life goods using RFID tagging. *International Journal of Retail & Distribution Management, 31*(10), 529.

Lahiri, S. (2005). *RFID sourcebook.* Upper Saddle River, NJ: IBM Press.

Landt, J. (2001). *Shrouds of time: The history of RFID.* Pittsburgh, PA: AIM.

Niederman, F., Mathieu, R.G., Morley, R., & Kwon, I.-W. (2007). Examining RFID applications in supply chain management. *Communications of the ACM, 50*(7), 93-101.

Staffieri, A., Holsti, E., & Gray, W. (2009). *An analysis of the United States Naval Aviation Schedule Removal Component (SRC) card process* (Master's Thesis). Monterey, CA: Naval Postgraduate School.

Tzeng, S.-F., Chen, W.-H., & Pai, F.-Y. (2008). Evaluating the business value of RFID: Evidence from five case studies. *International Journal of Production Economics*, *112*, 601-613.

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