



Tracking Next-Generation Automatic Identification Technology into 2035

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Air Command and Staff College
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Winner of the 2010 International
Society of Logistics Award

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Foreword

It is with great pride that Air Command and Staff College presents another in a series of award-winning student research projects from our academic programs that reach nearly 11,000 students each year. As our series title indicates, we seek to promote the sort of imaginative, forward-looking thinking that inspired the earliest aviation pioneers, and we aim for publication projects which combine these characteristics with the sort of clear presentation that permits even the most technical topics to be readily understood. We sincerely hope what follows will stimulate thinking, invite debate, and further encourage today's air war fighters in their continuing search for new and better ways to perform their missions—now and in the future.

A handwritten signature in black ink, appearing to read 'Anthony J. Rock', written in a cursive style.

ANTHONY J. ROCK
Brigadier General, USAF
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Abstract

This paper explores the advances in automatic identification technology, specifically radio frequency identification, and seeks to exploit these capabilities for use in the Department of Defense (DOD) supply chain. Using technological trends, a thorough literature review, and the opinions of experts, the paper compares current technology to a 2035 requirements forecast to identify capability gaps. The end goal is logistics situational awareness, whereby the DOD has the ability to provide end-to-end visibility throughout its supply chain and can rapidly mobilize, deploy, sustain, and redeploy forces in support of national security objectives.

Introduction

On 13 January 2035 at 0115 CST, the red blip on the computer screen startled Senior Airman Maddock as he sat at the security forces controller desk at Minot AFB, North Dakota. It was a cold night with a temperature of 15 degrees below zero, and he was happy to be inside drinking his coffee while many of his fellow Airmen were out on base patrol. The red blip and subsequent alarm ended his happy thoughts because he knew what had happened: a nuclear warhead was out of place in the munitions storage area. Airman Maddock immediately grabbed his checklist and started the phone calls in accordance with established procedures. His mind filled with possible outcomes, but he focused on the task at hand. Within minutes, eight security forces patrol cars surrounded the munitions storage area. The security forces set a cordon, and the on-scene commander, Colonel Buchanan, established communication with the 5th Bomb Wing battle staff. Activity in the munitions storage area came to a halt.

Forty-five minutes earlier, Technical Sergeant James, Staff Sergeant Cook, and Airman First Class Gilbreath had just started their midshift work. They received the normal midshift brief from Master Sergeant Gray and were given the task of building the munitions for the next day's B-52 flying schedule. The air-launched cruise missile (ALCM) load was an important certification for the munitions personnel, weapons load personnel, and aircrew for the next day's mission to Barksdale AFB, Louisiana. Strict procedures were in place, and the two-man rule was the norm for these die-hard ammo troops within the munitions storage area. The week before, the 5th Bomb Wing underwent a limited nuclear surety inspection and passed with a "satisfactory" rating. Unfortunately, in the rush to return to normalcy after the inspection, a nuclear-tipped ALCM was accidentally placed in the wrong storage case, the one marked "Inert—Captive Flight Only." As Sergeant Cook and Airman Gilbreath opened the case, they followed the technical data but had no idea that they had a live nuclear warhead. While the nuclear ALCM was loaded on the munitions trailer, the three-person team continued to assemble the other seven ALCMs. As the end of the shift neared, personnel loaded all eight ALCMs on the munitions trailers and started the slow transport to the weapons load facility,

where the ALCMs would be carefully populated on an empty rotary launcher. As Sergeant Cook drove the bobtail through gate 4 in the storage area, the alarms sounded. Everyone stopped dead in his or her tracks.

With the help of radio frequency identification (RFID) readers mounted on each munitions igloo and vehicle, munitions control was able to identify the location and status of all the munitions personnel, vehicles, equipment, tools, and munitions on base at the touch of a button. According to established procedures, Colonel Buchanan sent security forces personnel and the 5th Munitions Squadron munitions accountable systems officer into the munitions storage area with handheld sensors to verify each person, his or her qualifications, and the security clearance on his or her badge. Everyone was verified. Then the munitions trailer with the nuclear warhead was discovered at gate 4. Using the handheld sensors, security forces personnel promptly located the nuclear warhead, removed it, and stored it in the correct container. The nuclear warhead's RFID tag had alerted security personnel that it was out of place. The positive inventory control system enabled by RFID started the chain of events and averted another Minot-Barksdale nuclear weapons transfer incident.

A common axiom in military circles is that “amateurs study strategy, but professionals study logistics.” Throughout history, wars have been won or lost depending on a nation's ability to support and sustain a fielded force. Just ask the Nazis, who, during World War II, could not sustain the German war machine because of Allied destruction of logistical lines. The lessons to be learned today, though similar, are attenuated because of advances in technology, a globalized world economy, and interdependencies of nations waging war. Likewise, in a resource-constrained environment, nations and companies are “looking for ways to cut costs, improve quality, increase efficiencies and enhance their competitiveness.”¹ It is no different for the Department of Defense (DOD), especially in the area of global mobility and combat support. In fact, it is safe to say that logistics situational awareness is a critical enabler of global mobility and will dictate whether countries survive in the

future strategic environment. Today, the logistics tail of the DOD is ripe for improvement. Efficiencies in the daily movement of personnel, cargo, and equipment will effect large returns on investment. Most importantly, the ability to provide end-to-end visibility throughout the DOD supply chain will permit forces to rapidly mobilize, deploy, sustain, and redeploy in support of national security objectives.

This paper surveys the current automatic identification technology (AIT) capabilities, forecasts the 2035 requirements using environmental scanning and interviews, identifies the capability gaps, and provides inputs for an AIT implementation road map. The key question is, how will the DOD leverage AIT and help optimize the visibility of assets in the DOD supply chain for operations in 2035? DOD investments in AIT will promote efficient logistics operations, streamline supply chains, provide in-transit visibility, and enhance situational awareness to enable rapid global mobility, agile combat support, and power projection for the DOD in 2035.

Background

AIT is a tool set of technologies “enabling the automatic capture of data, thereby enhancing the ability to identify, track, document, and control assets.”² AIT encompasses a variety of data storage and transfer technologies, including “bar codes, magnetic strips, integrated circuit cards, optical laser discs, satellite tracking, and radio frequency identification (RFID) tags.”³ This paper primarily focuses on RFID technologies, applications, future trends, and implications. It is important to note that “AIT is not a system or a single product” but a family of technologies.⁴ When AIT is integrated with information systems, it becomes a powerful logistical tool. The situational awareness, or asset visibility, supplied by AIT is the “capability to provide timely and accurate information on the location, movement, status and identity of units, personnel, equipment, and supplies.”⁵ The DOD has invested over 30 years of research into AIT, starting with the bar code and progressing now to advanced technologies, and considers AIT a key enabler to daily operations.⁶ However, the DOD relies heavily on current com-

mercial investment and applications of AIT, more precisely RFID, which began much earlier.

History of AIT and RFID

During the 1800s inventors such as Michael Faraday, James Clerk Maxwell, and Heinrich Hertz published theories on light and radio waves, which laid the foundation for understanding electromagnetic energy.⁷ The 1900s saw progress, with the birth of radar in 1922 and the early development of “identification, friend or foe (IFF) for aircraft” in the 1950s.⁸ During Vietnam the Igloo White system used RFID and other networked sensors to track enemy movements on the Ho Chi Minh Trail.⁹ While early DOD applications drove much of the initial research, commercial applications accelerated it. In the 1970s the retail supply chain pursued bar codes as the primary technology for auto identification.¹⁰ The 1990s saw technology developments in RFID for transportation and “wide scale deployment of electronic toll collection in the United States.”¹¹ More recently, RFID has been used to track positions of assets, identify personnel and vehicles, and sense an enemy sniper’s location using acoustic sensors coupled with RFID.¹² However, it was not until mid-2008 that RFID applications led to a breakthrough in industry. Experts attribute this development to two things: (1) passive tag technology in ultra-high frequency (UHF) stabilized, and (2) the apparel distributor, Dillard’s, began placing passive RFID tags on clothing items in the retail supply chain.¹³ Today applications are prolific, and RFID operates in “industrial manufacturing sites, in warehouses, at ocean and aerial ports, in retail stores, at ammunition storage and manufacturing sites, at transportation distribution facilities, and in austere environments.”¹⁴ The appendix provides a more complete list of current RFID applications.

At the basic level, “RFID is a generic technology that refers to the use of radio frequency waves to identify objects.”¹⁵ RFID is “an automatic identification method, relying on storing and remotely retrieving data using devices called RFID tags or transponders.”¹⁶ These tags can be attached to or incorporated on just about any object for identification and usually consist of two parts: (1) an integrated circuit

for storing information, processing information, and modulating radio frequency (RF) signals and (2) “an antenna for receiving and transmitting the signal.”¹⁷ RFID tags can be either active or passive. Active tags are powered by batteries and have one- or two-way radio transceivers, data storage memory, and a read range of up to 300 feet.¹⁸ Passive tags are powered by the current induced from an RF signal, have short read ranges of up to 15 feet, and have the advantages of reduced size, less upkeep, and greater cost effectiveness, making them prime candidates for nanotechnology miniaturization.¹⁹ Technologists agree that batch fabrication of passive RFID tags with mini-circuits and antennas would drive the unit price down and increase reliability.²⁰ As this technology continues to miniaturize, it may even be possible to embed tags on smaller objects, like metal bolts or washers.

The active or passive tags also rely on interrogators, fixed or portable handheld devices that “emit electronic signals to communicate with the tags.”²¹ The interrogators, or readers, are usually fixed on poles, loading docks, or doorways to allow for accessible read ranges in proximity to the tagged items. Additionally, a computer connected to a network helps control the interrogator, capture the necessary data, and send the data in the established technical architecture. Finally, the data read by RFID technology provides valuable information to decision makers. Software and information technology architectures help channel and mine the data for trends and decision tools; however, how the data is used becomes even more important than getting the data.

The tags, interrogators, computers, and data make up the main components of an RFID system. The system of interrogators and active tags work with networked information systems to provide visibility. As a networked tag is placed on an item, the user has the ability to inventory, determine where an object is located and where the object has been, remove outdated objects, eliminate stock-outs, and provide in-transit visibility on a global network.²²

Significance of RFID

According to the analyst firm IDTechEx, RFID is big business, with a global market of \$5.29 billion (2008).²³ Its market is predicted to grow, with some forecasting “a 15 per-

cent annual growth rate over the next five years.”²⁴ Many experts attribute the jump-starting of RFID applications to Walmart’s mandate in June 2003 to place RFID tags on pallets and cases from its top 100 suppliers.²⁵ Albertson’s, Target, Proctor & Gamble, and the DOD followed with pursuits to improve the supply chain and reduce costs.²⁶ Overall, every organization agrees that the pursuit of “information visibility (and the corresponding timeliness of information) is critical to supply chain operations.”²⁷ With RFID serving as a “business process enabler,” these organizations are reaping the benefits of increased visibility.²⁸ As one Walmart chief information officer said, “I view RFID as a strategy that offers tremendous competitive advantage.”²⁹

What is RFID’s significance for the DOD? Consider the recent decision by Pres. Barack Obama to send 30,000 more troops to Afghanistan.³⁰ The United States Transportation Command (USTRANSCOM) is charged with the daunting task of moving and distributing all troops and equipment. One Army brigade combat team (BCT) has approximately 3,500 personnel, 1,200 short tons of airlift cargo, and 200,000 square feet of sealift cargo, all of which requires 80 C-17 airlift missions and two ships.³¹ Multiply this by 10, and then consider the transportation modes to Afghanistan, where 50 percent of the cargo goes by truck, 30 percent by rail, and 20 percent by airlift.³² Imagine you are a commander in charge of deploying a BCT and all of your personnel and equipment must end up at your deployed location on a certain date. RFID, along with other AIT, will provide an efficient way to manage the personnel and cargo strewn out across the globe. RFID technologies will be crucial to providing asset visibility and in-transit visibility for the passengers and equipment moving from origin to destination by commercial airlift, sealift, and surface assets.

Current State of RFID

Organizations pursue RFID to enhance information visibility. In fact, experts in supply chain management suggest that “the success of a supply chain system depends on the level (and timeliness) of visibility it has on the materials from suppliers to customers.”³³ With visibility as the overarching goal, industry and government organizations have

taken RFID technology, translated it into process efficiencies, and reduced costs. According to USTRANSCOM, the DOD's primary use of AIT is "to facilitate data management" by improving data accuracy, reducing data capture and processing time, reducing data latency, and enhancing supply chain management monitoring.³⁴

Current RFID Capabilities

To summarize the information found during environmental scanning, this section highlights some broad categories of AIT capabilities and provides current examples from government or industry:

- Automation
- Asset management
- Inventory management
- People management
- Layering AIT
- Standards

Automation. As industry and government seek ways to make processes more efficient and reduce costs, automation has been a key focus, especially in processes where humans conduct repetitious action. RFID helps eliminate manual entry, parses data, and is "not constrained by line of sight," which allows tags to be a distance away as long as they are within the reader's signal range.³⁵ Unlike bar codes, many RFID tags can be read simultaneously, which allows batch processing versus one-piece flow.³⁶ Another characteristic of RFID is its ability to operate in harsh environments where human access is prohibitive or less cost effective. Tags are "resistant to heat, dirt, and solvents and hence are not physically damaged easily."³⁷ One perfect example of automation is electronic toll collection. The first electronic tollbooth, opened in 1991 in Oklahoma, used RFID to automate a previously manual process.³⁸ Passive tags on cars pass through the readers (interrogators) located in the tollbooth. The RF signal sent from the readers attenuates the passive tags, and the interrogators read the attenuated return signal from each tag. The computer sys-

tem then links the unique passive tag on the car to a user account from which the toll is debited. Based on this example and others, it is clear RFID allows organizations to save time and labor by exploiting the technology's automation features.

Asset Management. It is logical that an organization needs to know where its assets are located. However, this is just one aspect of asset management. RFID also allows organizations to track and trace assets across an enterprise system. It answers the question, where is my asset? The ability to identify, locate, and sense the condition of an asset and automate timing or sequence in a timely manner provides great efficiency to any process. For example, after the Taiwan nuclear shipping incident of 2008, the Nuclear Weapon Center at Hill AFB, Utah, opened a new facility to manage nuclear-related material.³⁹ This facility uses the positive inventory control system (PICS) to track nuclear-related assets in storage, transit, or maintenance activities.⁴⁰ Using passive RFID tags, unique item identification (UID), handheld readers, portal interrogators, and an enterprise data system, the PICS manages the delivery, receipt, and verification of critical nuclear assets at any point in their lifecycles.⁴¹ Additionally, Airbus has implemented RFID to help manage assets at the A380 final assembly plant in Hamburg, Germany.⁴² Assembling an A380 requires 750 containers of parts, and the bulky containers are delivered across a four-story assembly plant.⁴³ The asset management system tracks over 3,000 containers from suppliers and ensures they are delivered to a specific assembly location "on time, the right time, the first time."⁴⁴ Airbus not only has saved time, money, and space, but also knows the timing, sequencing, and visibility of its containers.

Inventory Management. Inventory management answers the question, how much do I have? In government, retail industry, and health care, an accurate, real-time inventory is a critical process enabler and often improves safety. Take, for instance, the application of RFID to help in air-to-air refueling between KC-135 tankers and other aircraft. In June 2010 the USAF demonstrated the capability to read specialized passive RFID tags on aircraft being refueled; these tags identify the type of aircraft, time, location, and amount of fuel passed.⁴⁵ The biggest benefit is the

accuracy of the fuel inventory. Before, boom operators could not read tail numbers, or they miscalculated the fuel passed, which accounted for millions of dollars of unpaid fuel bills. Now all the fuel is accounted for, aircraft information is automatically recorded, and the boom operator can focus on safely refueling without having to record information.⁴⁶ Likewise, Walmart has found that RFID improves the efficiency and effectiveness of its processes. One study revealed that the company reduced out-of-stocks by 26 percent, reduced the number of receiving errors, improved the accuracy of inventory, and ultimately was able to better forecast and replenish items for customers.⁴⁷ These benefits have great relevance to the DOD distribution centers where assets are received, inventoried, stored, and shipped to customers worldwide.

People Management. RFID applications for people management include embedding chips in humans (similar to RFID chips in animals), but this capability is wrought with legal and privacy concerns. More common applications are identity cards, passports, or magnetic credit cards that provide identity verification, control access to buildings, or limit use of equipment. An example is the common access card (CAC) issued to DOD employees for positive identification and access to computer networks. The RFID tag in the card contains personnel information but is also capable of holding medical information, training qualifications, and other pertinent data.

While cards like the CAC are common in many industries, using RFID for people management is most prominent in the health-care sector. Not only do hospitals “track and manage medical devices, wheelchairs, and surgical equipment,” but they also monitor patients.⁴⁸ A US health-care provider has introduced infant ID tags that alert hospital staff when a tag is tampered with or lock doors when the ID tag is approaching an exit.⁴⁹ In addition, some medications are tagged to ensure the right patient receives the right dose at the right time.⁵⁰ In areas such as drug dosage, laboratory samples, or patient wristbands, health-care providers are seeing solid improvements in safety, cost, and process efficiency using AIT.

Layering AIT. AIT is a family of technologies, of which RFID is one. Because of the economic realities of business,

a layering of technologies has proven feasible. The sunk cost of legacy systems combined with the redundancy of technologies helps mitigate risk and provides flexibility in infrastructure planning. As the promises of passive RFID gained ground in the late 1990s, the bar code gave way to the electronic product code (EPC), an electronic bar code that uniquely identifies an object, even differentiating between like objects by using an extra set of numbers.⁵¹ In 2003 the DOD mandated the use of item unique identification (IUID), for which the EPC was well suited. The purpose of IUID was to “distinguish one item from another,” even identical part numbers, so the DOD could “achieve total asset visibility, improved item management, and clean financial audits for DOD property.”⁵² The IUID and EPC combination made an item globally unique, enabling it to be tracked in “operation, maintenance, storage, and finally disposal.”⁵³ IUID 2-D markings, EPC labels, integrated sensors, and the bar code are examples of other technologies commonly put on products in addition to RFID tags. In fact, the DOD has mandated that the “linear bar codes will remain as a recommended backup baseline AIT” for all items.⁵⁴

Packaging for distribution is a science with standardized practices to follow. Figure 1 illustrates the standardized consolidation layers the DOD employs. Different AIT media are used at each layer, and one can see that shipments can become complex when the stakeholders in the process have different infrastructure or capabilities to support the AIT media. One current example is the shipment of mine-resistant, ambush-protected (MRAP) vehicles to Afghanistan. Due to the MRAP size and value, active RFID tags are strapped to the vehicle’s bumper. As the ship or aircraft conveys the vehicle, the active tags work with GPS satellites and interrogators at all ports to track the shipment until the final destination. The layering of active tags, interrogators, and satellite networks provides the in-transit visibility for the MRAP shipment.

Standards. Before 2000, privacy activists had many concerns about standardization; however, the start-up of EPC-global and Walmart’s 2003 decision to use RFID tags helped cement the robust standards still in place today. RFID follows several standards, including the International Organization for Standardization (ISO), International Electrotechnical

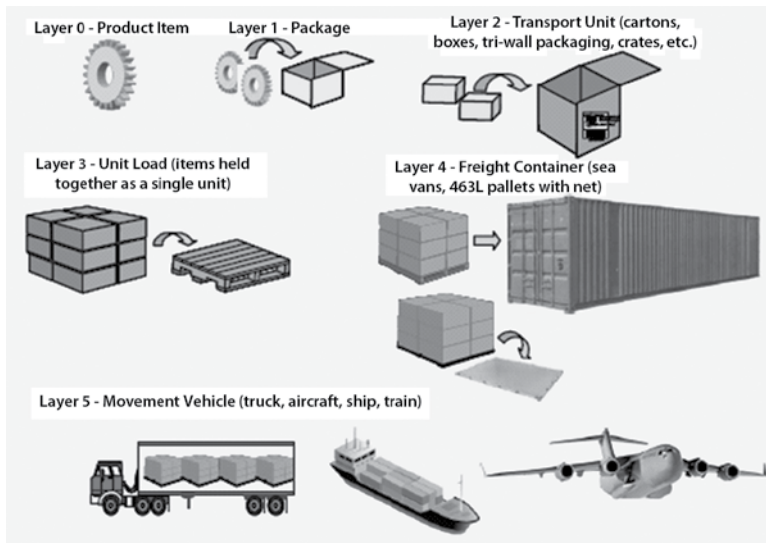


Figure 1. Consolidation Layering. (Reprinted from USTRANSCOM, *DOD Automatic Identification Technology Concept of Operations for Supply and Distribution Operations*, 11 June 2007, 3-10.)

Commission (IEC), EPCglobal, and European Telecommunications Standard Institute (ETSI).⁵⁵ Standard frequency ranges for RFID include low frequency (LF), high frequency (HF), UHF, and microwave frequency, with RFID readers supporting UHF and microwave frequencies in recent years.⁵⁶

For the DOD, USTRANSCOM is the lead agent responsible for RFID and AIT standards, security, and technical matters. Additionally, USTRANSCOM participates in DOD, commercial, national, and international standards committees and forums.⁵⁷ In the DOD, “application of the various AIT technologies shall be based to the maximum extent practicable on consensus based commercial standards” as dictated by public law.⁵⁸ In other words, the DOD follows commercial investments in standards to cut costs and facilitate interoperability with commercial systems.⁵⁹

Current Limitations and Shortfalls

Current AIT capabilities have some limitations and shortfalls requiring thought, further research, or investment. This section summarizes some broad categories of limita-

tions and shortfalls and raises issues that need further exploration. The following limitations are discussed:

- Expectation versus reality
- Form factor
- Readers or interrogators
- Data management and security
- Interoperability
- Cost

Expectations versus Reality. The single biggest limitation of RFID is not with the technology itself but with users' expectations. The hype over Walmart's 2003 implementation has given way to disillusionment over how to use RFID technology and the data it provides. In fact, experts currently place RFID in the "trough of disillusionment" or "slightly up the slope of enlightenment" on the hype cycle.⁶⁰

One expectation is that RFID will supersede the bar code. Government and industry have approached RFID as a bar code replacement system and consider it better than the bar code.⁶¹ However, the bar code has many advantages: bar code reading is a line-of-sight operation; it requires no power source; one bar code is read at a time; the bar code is less expensive than RFID; it can be used around water and metal; and it can be preprinted.⁶² The myth is that every process will benefit from RFID, when, in fact, the bar code or some other method might be sufficient. An expert has suggested that "80 percent of a process must use some type of AIT media to make the investment even worthwhile."⁶³ Unless the technology enables the process, the process details—not necessarily the technology—are critical.

The second expectation is that item-level visibility is better than pallet-level visibility. Some say the "slap and ship" approach to individual items enhances the process, while others say the pallet-level tags limit visibility in the supply chain. Given an apples-to-apples comparison, this may be true, but consider this example: Federal Express, one of the world's logistical leaders, does not use RFID tagging because it slows down operations.⁶⁴ The time it takes to put a tag on a package and read the package on high-speed con-

veyors suboptimizes the process. The lesson for the DOD is that not every process may benefit from RFID applications.

Form Factor. Form factor refers to the technology's size, packaging, durability, data capacity, and attaching or affixing methods.⁶⁵ Currently both active and passive tags must get smaller, since many processes demand that small items be tagged to provide the item-level visibility needed. However, how small is too small? Antenna technology is limited by physics, circuit technology by manufacturing, and data capacity by size; packaging may dictate orienting a tag on top of the item. These factors will affect tag size. Additionally, tag power is a critical feature affecting size and performance. Passive tags have no battery, but "the life of an active tag is directly related to battery life."⁶⁶ Therefore, durability is an issue when choosing whether to include a battery. Another performance tradeoff is between the attaching or affixing method. Will the tag be reusable? Will the tag be imbedded in the item? Will layering of AIT still be required? Will the tag be durable enough to withstand harsh conditions? Can the tag be attached to cardboard, wood, plastic, or metal?⁶⁷ These are all complex questions whose answers limit RFID tag capabilities.

Readers and Interrogators. Not only are the RFID tags affected by their environment, but readers and interrogators have similar limitations. Primarily, the read range of current interrogators is constrained. Bar codes require line of sight, passive tags readable at 10 to 20 feet, and active tags readable up to 300 feet away.⁶⁸ Read ranges, in turn, affect mobility and quantities of the reader infrastructure. These performance requirements severely limit the footprint and layout of distribution centers or portals. While handheld readers provide some mobility, other characteristics such as size, ergonomics, power, and connectivity to back-end databases also affect performance.

Another common complaint about RFID readers involves their less-than-perfect read rates. Not all tags that pass within range of the interrogators are read. It is well documented that RF signals do not perform well around liquids and metals.⁶⁹ Attenuation and RF interference play a significant role in degrading a reader's performance. Additionally, signal frequency, signal power, packaging, and physical obstructions also affect the read rates. In fact, one recent

study of palletized consumer products found that readability was most dependent on forklift speed through the reader portals.⁷⁰ Overall, RFID readability rates have not reached full potential because of several complex technical limitations.

Data Management and Security. When industry and government organizations implement RFID, a common question is, how do we use the data captured? Data management is a big hurdle—data can be difficult to understand, manipulate, and consolidate. However, the data must be usable. In many cases, filtering data may be necessary because of missing reads, multiple reads, layout problems, or hardware malfunctions.⁷¹ Also, the decision software, network capacity, and network architecture need “to handle vast quantities of data generated by RFID.”⁷² Upfront planning is needed to manage this volume of data flow.

Data security is another contentious RFID issue. Sparked mainly by consumer privacy advocates, fear has spread that proliferation of RFID tags on consumer products will threaten civil liberties.⁷³ In business applications, corporate espionage is a sizable risk because of the unsecure wireless data sent between the tag and reader.⁷⁴ Currently, commercial EPC tags “do not offer access controls for reading the EPC, only for write-protecting data on the tag.”⁷⁵ This is an information assurance risk for the DOD as well, since many active tags store data and are susceptible to adversary intelligence collection. Overall, the shortfalls in data security could reduce competitive advantages in business sectors and put personnel or equipment at risk in future DOD ventures.

Interoperability. With the many commercial, national, and international standards in place for RFID, operating global supply systems has become a challenge. Interoperability between RFID hardware and various information technology systems requires robust middleware that is not yet mature.⁷⁶ Many organizations operate enterprise resource systems that compile and store all back-end data, but this data migration is costly. To complicate matters, implementation with legacy systems in any organization is also IT intensive. Additionally, most RFID devices work in certain frequency ranges (for example, UHF for most supply chain applications), but international infrastructure may operate on different frequency bands. As a result, organiza-

tions (the DOD especially) may have limited visibility in certain locations due to incompatibilities. These risks require strong mitigation plans and in-house experts to consider viable alternatives.

Cost. Cost is a prohibitive factor for many organizations seeking to implement RFID systems. Infrastructure alone creates the largest bill (readers, software, computers, and data storage), but the unit cost can be sizable too. Current bar codes cost pennies compared to passive tags costing 20 cents to \$5 and active tags costing \$70 to \$100, depending on capability.⁷⁷ One recent study found that USAF base-level supply should remain with current bar-code technology because of the investment cost-benefit and reduced risk.⁷⁸ In particular, bar-code technology is a fielded technology, has less risk for read errors, has user confidence, and is capable of handling the process volume.⁷⁹ Interestingly, volume was the most significant variable in the base supply and distribution process examined.⁸⁰ Additionally, a Government Accountability Office (GAO) report in 2006 highlighted that the “DOD’s current RFID policy does not require active tags to be returned or reused even though these tags are designed for repeated reuse.”⁸¹ With the DOD having purchased over 1.1 million active tags by 2006 at an average unit price of \$100, the report urged more efficient management of active tags and mandatory reuse to potentially save millions of dollars in active tag purchases.⁸² As one can see, economic considerations drive many RFID implementation decisions and will keep some potential users out of the market until costs decrease.

Future State of RFID

As Dwight D. Eisenhower once said, “In preparing for battle I have always found that plans are useless, but planning is indispensable.”⁸³ While many people discount the accuracy of forecasting and futures research, the real value is in the process of future forecasting. Future forecasting is not magic, but rather understanding the strategic environment and trends and applying the rigor of common sense.

Future Trends

It is important to keep in mind that the DOD logistics system must maintain a strategic advantage to win the nation's wars. To do so, DOD leaders must understand the future strategic operating environment. To characterize this operating environment, I have identified the following future trend categories as most relevant to AIT:

- Political, social, and economic environment
- Future warfare
- Computing
- Power
- Sensors
- Wireless networks

Political, Social, and Economic Environment. While the United States is expected to be a dominant power, differences between developed and undeveloped countries will narrow by 2025, with nonstate actors increasing in strength.⁸⁴ Economic growth is expected to boom in Brazil, Russia, India, and China (BRIC) over the next 20 years with the shift of “manufacturing and service industries to Asia.”⁸⁵ As the global population increases, the “demand for food will rise by 50 percent by 2030,”⁸⁶ and “energy scarcity will drive countries to take actions to assure their future access to energy supplies.”⁸⁷

This scarcity will increase threats to US interests and strain energy resources as well as economic and diplomatic relations with global partners. While the United States will continue to grow economically, limited resources will force companies to push efficiency, improve processes, reduce labor costs, and seek automation. The trend toward complexity will continue to the point that no major global event is isolated in a globalized economy.

Future Warfare. What will warfare be like in the next 25 years? Irregular warfare will be the order of the day, but the United States must be able to fight a major conventional confrontation with a near-peer adversary. As the military intervenes in humanitarian assistance, peacekeeping, stability and reconstruction, or counterinsurgency operations,

its ability to mobilize forces and project power around the globe will be critical. The United States will continue to fight wars with approaches similar to those it has used in the past: favoring casualty-sensitive, technology-oriented, expanded battlefields (to control the tempo, size, and depth) and desiring short-duration conflicts.⁸⁸ The demands for accuracy, speed, and versatility in future warfare dictate close coordination and interoperability with US government agencies, commercial industry, coalition partners, and nongovernmental organizations.⁸⁹ Nonlinear operations in a highly networked battlespace will be the norm as simultaneous movement along multiple lines of operation will be required. Sustaining trained and equipped forces will also be complex as there may be limited access to sea or aerial ports in contested environments or difficult terrain.

Computing. Many futurists, strategists, and policy makers predict large commercial investment in micro- and nanotechnologies with benefits of increased information throughput, reduced size, reduced weight, and robust materials that will enable AIT. With this form-factor reduction, mobile communication devices will have an ever-increasing computing power. In fact, “digital electronics with increased density (~ 128X) is projected by the integrated circuit industry over the next 15 years.”⁹⁰ As the integrated circuit density increases, trends toward new structures (dual-gate and depleted, silicon-on-insulator integrated circuits), effective power management, and increased computational power will continue.⁹¹

Data memory has also benefited from micro- and nanotechnologies, with a “62.5-fold increase in data-storage capacity” since 1998.⁹² Active research in carbon nanotube-enabled memory, phase-change memory, magneto-resistive random-access memory, and ferro-electric random-access memory has shown potential to provide larger capacity, reduce manufacturing costs, maintain nonvolatility, and reduce power consumption.⁹³

Power. According to RAND, “Batteries and power-storage devices . . . have the greatest potential to influence future growth of mobile-computing devices.”⁹⁴ The advances in nanostructured material research continue to fuel the potential for these devices as researchers seek “to increase the capability and computational power . . . while minimiz-

ing the power they consume.”⁹⁵ Thin-film batteries hold great promise over conventional batteries because of the composition of solid-state materials, wide operating temperatures, longer shelf life, producible form factors, and fixed cost per area.⁹⁶ These thin-film batteries are ideally suited for “embedded power on printed circuit boards . . . smart cards, and smaller active-RFID tags.”⁹⁷ Additionally, research with carbon nanotubes has shown that electrodes with more surface area have a greater charge capacity.⁹⁸ This makes ultracapacitors a possible choice for mobile devices because of their resistance to shock and temperature.⁹⁹ Other energy-harvesting technologies to harness the energy of sunlight or mechanical vibration are mature; however, the harvested energy must still be stored.¹⁰⁰

Sensors. Integrating advanced monitoring and sensing devices is also an emerging AIT capability. Specifically, wireless sensor nodes (“motes”) and microelectromechanical systems (MEMS) show great promise “to revolutionize low-cost, low-power sensing.”¹⁰¹ The goal is “to enable networked surveillance” by “improving the security and efficiency of supply chains.”¹⁰² These sensors provide the ability to detect movement, acceleration, pressure, biological substances, chemicals, fluid flow, and audio.¹⁰³ For the DOD, the interest lies in monitoring “condition and health indicators of operating systems to warn of conditions such as equipment failures, needed maintenance, or breaches to security.”¹⁰⁴ So “fundamental changes in sensing architectures” will be needed for the integration of “multi-spectral, multifunctional sensors.”¹⁰⁵

Wireless Networks. The growth of mobile devices has skyrocketed in the past few years with the help of cell phone technology. Some futurists predict that by “giving so many more people the tools and ability to connect, compete, and collaborate,” the technology will act as an “equalizing power” for societies.¹⁰⁶ Technological progress depends on open communication, collaboration, and easy access or exchange of information. This trend will drive systemic and integrated hardware for communication networks linked by software.

Another key trend is the need and technical feasibility for longer-range wireless networks and ubiquitous computing for intelligent autonomous operations. In fact, a 2006 RAND study ranked RFID tagging and ubiquitous information ac-

cess in the “top 16” technology trend areas for 2020 with a strong market need and high technical feasibility.¹⁰⁷ As RFID tags gain the capability to double as readers, a “mesh network” is formed with the ability to sense the surrounding environment. These connected nodes provide a continuous, redundant, and reliable network that can operate even when a node or connection breaks.¹⁰⁸ As wireless networks expand, software will be required to control a mobile device’s range, power consumption, and data rate, in addition to operating and communicating using multiple frequencies and protocols.¹⁰⁹ Interoperability will be crucial as AIT operates in a multisensory environment consisting of passive tags, active tags, UHF, LF, ultra wideband, Wi-Fi, and a “low-power wireless technology called Zibee.”¹¹⁰

Requirements Forecast for 2035

As the maxim says, “If all you have is a hammer, everything looks like a nail.” In other words, our first inclination is to look at future requirements through the lens of today’s technology. Though helpful initially, this approach blinds us to many possibilities and future courses of action. While recognizing that RFID is not the only AIT, this forecast has limited the courses of action by focusing on RFID. However, the observations and judgments gleaned from this research show RFID to be the most promising and widely flexible technology within the AIT technology family. This study seeks to avoid portraying RFID as a “plug and play” or “one-size-fits-all technology” for the future and instead focuses on its inherent capabilities.

As stated in the introduction, the purpose of this paper is to help the DOD navigate the advances of technologies and exploit the capabilities of logistics situational awareness to win the nation’s wars in the coming decades. The AIT requirements for 2035 are listed below.

- **Identification:** The DOD needs the ability to uniquely identify an item with a part number, serial number, manufacturing information, value, and maintenance history (similar to UID or EPC).¹¹¹ It also must be able to move a single item through a supply chain and distinguish it from other items, even if part of a consolidated shipment.

- **Location:** The logistics system should be able to dynamically update the precise position information of any asset, in any location (fig. 2). This is especially important for “critical items that are in short supply.”¹¹²
- **Condition Monitoring:** The technology should allow trackers to monitor an asset “in the supply chain to detect a specific condition that would be adverse to the serviceability, functionality, safety, or security of the item.”¹¹³
- **Connectivity:** The DOD needs flexibility in connecting continually to wired, wireless, mesh, or ad hoc networks to enable synchronized, reliable data delivery.
- **Interoperable Architectures:** The AIT media, readers, and IT infrastructure must be able to operate on multiple networks and frequencies in austere locations. This architectural framework must be capable of managing a sensor-based logistics system with coalition, commercial, and government agencies. This includes command and control data architecture interoperable with commercial or coalition standards and physical architectures that are mobile and deployable.

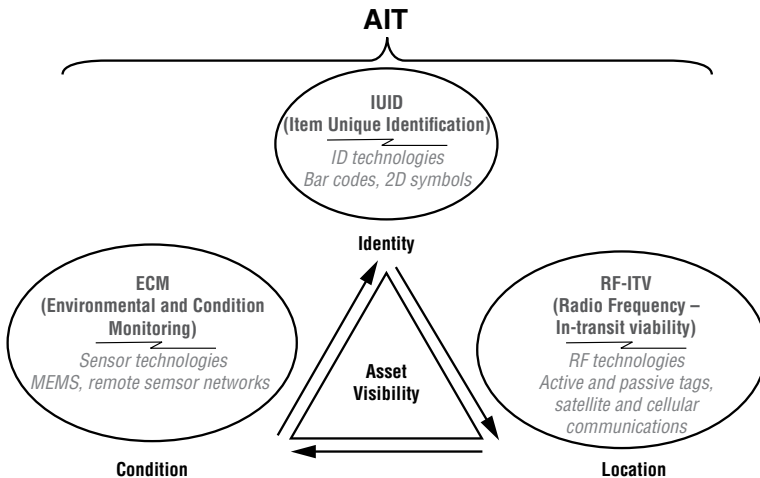


Figure 2. Three Dimensions of Asset Visibility. (Reprinted from US-TRANSCOM, *DOD Automatic Identification Technology Concept of Operations for Supply and Distribution Operations*, 11 June 2007, 4-11.)

- **Software:** The architectural framework demands user-friendly software that seamlessly links legacy systems and a sensor-based system. The goal of the software is to enhance visibility across an enterprise, which necessitates collecting, integrating, storing, and analyzing data to enable better decisions.¹¹⁴
- **Dynamic Routing:** A combination of AIT should facilitate tracking, evaluating, and redirecting shipments in real time using a combination of AIT. Using the information of a networked battlespace, the DOD must move and track assets with accuracy and enough flexibility to adapt to the fog and friction of war.
- **Security:** The DOD needs to move assets and pass information without threat of loss, theft, interference, or monitoring. Security requirements include “access control, data encryption, message authentication, key exchange, and certification of trust.”¹¹⁵
- **Reliability and Survivability:** Maintenance-free devices must provide reliable read rates while withstanding harsh operating conditions and surviving those operating conditions throughout the life cycle. Devices must be able to transition quickly from powered state to unpowered state or power harvest to minimize power consumption.¹¹⁶

RFID Challenges for 2035

Gen George C. Casey once said, “Somewhere on the far end of the supply and distribution chain is a customer who needs something . . . amplified by distance and time. Our job is to respond and deliver.”¹¹⁷ So what are the capability gaps and risks in delivering these AIT capabilities for the future? Using the 2035 requirements forecast as a future state, the following challenges and hurdles must be overcome for full implementation of the 2035 vision.

- **Implementation Challenges:** The focus should be on processes and not just implementing AIT across the board. There is a risk of suboptimizing a process by using AIT to enable efficiencies in one area but creating bottlenecks in the overall process.¹¹⁸ AIT should be a process enabler “linked to a valid business approach.”¹¹⁹

In a resource-constrained environment, the high infrastructure cost of AIT must demonstrate an investment return.

- **Operating Environment:** The DOD must possess the ability to provide global logistics support for widely dispersed operations while retaining the ability to determine the time, tempo, and terms of the conflict or operation.
- **Expeditionary Capability:** Likely deployment locations will not have the IT infrastructure to support RFID. Deployable infrastructure and mobile readers are needed to establish mobile port-opening capability packages with the necessary command and control functions.
- **Transportation Infrastructure Dependencies:** The DOD must manage the complex interaction among capacity, demand, and reliability to assure on-time delivery. The transportation system must adapt to constraints in various ways, including shifting modes, shifting demands in time and space, moving manufacture points, choosing alternative points of entry, and changing prices.¹²⁰ The reliance on commercial transportation networks and international ports increases the risk of timely access to the global lines of communication.
- **Information Assurance:** If AIT sensors are all over the world gathering and transmitting information, the DOD may face problems with customer profiling, manipulation of data by adversaries, and theft of intellectual property. In addition, the reliance on IT creates increasing DOD vulnerabilities, which produce asymmetric avenues of approach for adversaries that must be secured. Capturing, securing, and accessing the data are the main concerns. In some cases, keeping data on an active tag is necessary. In other cases, data could be stored in a secure database and referenced with a license plate scan. Data encryption will not be enough if interoperability is a key performance attribute. Some may say, "To have more security we have to give up some privacy."¹²¹ AIT benefits are great in a networked environment; however, experts suggest a cautious approach to ensure that data security and privacy violations are open for public debate.

- **Data Capture:** In a multisensory environment, bandwidth and frequency spectrum deconfliction will be paramount. Multipath propagation effects, jamming, and data latency will affect data delivery and must be minimized.¹²² Additionally, more research is needed for AIT read rates and errors around water, metal, or glass. The most severe limitation of RFID is the read ranges possible. Right now, AIT capabilities are layered (for example, passive tags, linked to active readers, linked to satellite communications) to account for this limitation; however, integration and expense remain high.
- **Data Integration:** As mentioned previously, RFID systems generate huge volumes of data. The future wireless multisensor network will require “making the sensor data available and finding an optimal way to store those data so they can be available for other services and applications.”¹²³ This is further complicated by interoperability requirements with coalition, commercial, and other US government agencies for ongoing irregular warfare operations, which require a shift to security cooperation and whole-of-government approaches for stability, reconstruction, and transition operations. Each service has legacy stovepipe systems with fragmented data that other systems may need. The challenge is in integrating the DOD supply chain enterprise and providing the stored data to the customer in need. Most importantly, what system or portal helps commanders manage the deployed inventory and reach back to the enterprise resource-system data?
- **Software:** The architectural framework to fuse legacy systems and new enterprise resource systems is very software and middleware intensive. After the data is captured, using and analyzing all the data becomes a complex software issue as well. Artificial intelligence systems will have to enable the decision-making software to recognize patterns or cue the decision maker. Additionally, CAC network access for handheld readers and tag read/write IT systems will require software patches.

- **Item-Level versus Container-Level Visibility:** Tracking shipping containers has limitations, since users remain blind to what is inside the container. The DOD will need the ability to update changes to containers and track those items accurately. Odin Technologies demonstrated a “SMART container” in 2009 that uses “passive RFID readers to interrogate tagged items within a container” and then pass the information to an active tag or satellite communications.¹²⁴ This is only a small step in the right direction.
- **Design Challenges:** Form factors are limited by the physics of antenna design, power sources, sensing capabilities, data storage capabilities, and manufacturing capabilities for mass production. In addition, the power source limits the ability to sense the environment for extended periods and is a factor in reuse capabilities. Further, certification of items operating in an RF environment (munitions and nuclear material) and items with embedded RFID tags proves challenging. To complicate matters, these performance characteristics affect the durability and reliability of devices over a life cycle, which undermines requirements for maintenance-free and reusable devices.

Conclusions

While the challenges are daunting, the benefits of RFID make it worthy of further investigation and investment to provide in-transit visibility for the DOD’s logistics system. While RFID is not the panacea technology for the future, a noteworthy attribute is the flexibility to enhance processes in a myriad of environments. RFID will continue to have a disruptive effect on outdated business processes.

As Staff Sergeant Briscoe inspected the HC-130’s #3 engine truss mount bolt, he noticed something was not right. The aircrew had reported weird vibrations during today’s mission, and the troubleshooting tree pinpointed this area. Black soot hid the cracked bolt head, but not many aircraft discrepancies could get by this keen-eyed dedicated crew

chief. As a part of the 71st Expeditionary Rescue Squadron (ERS), Sergeant Briscoe had adjusted to the sweltering heat and stink of Djibouti. The Horn of Africa was an austere location where progress was being made to oust terrorists trying to find sanctuary in weakly governed African nations. The 71st ERS was there to help. As the sun beat down at 1430 local time, Sergeant Briscoe walked over to his toolbox, scanned his ID card over the reader on the side of toolbox, and then picked up his torque wrench with attachments. He really liked the new RFID-tagged tools and the efficiency of the new tool accountability system. With his laptop, he referenced the necessary technical orders, filled out the electronic aircraft forms, and removed the bolt. The process was seamless and quick; however, Sergeant Briscoe laughed at how the maintenance actions now took longer than the paperwork. As he inspected the bolt, Sergeant Briscoe found the 2-D UID on the bolt and scanned it using the laptop's reader. The UID information combined with the laptop's access to the Global Supply Enterprise Network (GSEN) allowed Sergeant Briscoe to order parts direct from the flight line. As usual, the bolt was not available on base; however, 13 truss mount bolts were available at the supply warehouse in Ramstein AB. Master Sergeant Perry, the production superintendent, came to the aircraft to discuss the situation and verify that the part needed to be ordered as a mission capable (MICAP) request. Sergeant Perry scanned his ID card to verify the MICAP. In 20 seconds, the GSEN provided the optimized solution. The bolt would arrive at 2320 tonight on the C-17 rotator. Sergeant Perry was pleased and selected the MICAP tracking feature to have auto-updates on the bolt sent directly to his laptop. He could now track the bolt from Ramstein AB to Djibouti. The currently broken aircraft would make tomorrow's scheduled humanitarian mission to Sudan, and there would be enough time to reconfigure the aircraft before the bolt arrived. Sergeant Briscoe finished the electronic forms, scanned his tools for turn-in, briefed the oncoming shift crew chief, and headed to the dining facility. It had been a busy but productive day in the world of aircraft maintenance.

The scanable ID cards, the toolbox auto-checkout, handheld readers to scan old parts, the wireless laptop to view

real-time supply levels, the time-definite delivery solution, and the in-transit tracking of the MICAP part are all enabled by RFID technology. While the maintenance scenario described above is not possible today, the technology for streamlining logistics using networked RFID tags holds great promise. Coupled with the positive trends in enabling technologies, RFID will reshape logistics and facilitate real-time decisions because of complete DOD asset visibility.

Recommendations for an AIT Implementation Road Map

While USTRANSCOM has an established road map and implementation plan in its 2007 concept of operations, the following inputs should be added to the plan in light of the research provided in this essay. The DOD should

1. Invest heavily in frequency agile architectures (LF, HF, UHF, very high frequency [VH], etc.) and network architectures (Wi-Fi, Zigbee, ultra-wide band, mesh, ad hoc, cloud computing, etc.) to capture data in a multisensor environment.
2. Develop balanced research strategies to invest in software, software architectures, and middleware that exploit the data available from AIT, enable interoperability with legacy systems, and provide business intelligence for decision making.
3. Move decisively to develop a deployable command and control architecture and infrastructure that facilitate real-time decision making.
4. Ensure that information assurance requirements are compliant at all levels of the supply chain with continued exploitation of encryption, anticounterfeiting, and secure transmission.
5. Evaluate the costs and benefits of RFID implementation according to each unique business process to prevent a cookie-cutter implementation across the DOD.
6. Continue investigating and monitoring microsensor and satellite linkages to extend the range and functionality of AIT media.

7. Seek opportunities to develop a prototype and integrate new MEMS technology in RFID tags and mobile reader applications.
8. Invest in item-level versus pallet-level visibility where the business process demonstrates a return on investment (e.g., the SMART container).
9. Collaborate with and provide incentives to commercial logistics organizations to implement AIT infrastructure and ensure that each transportation mode is capable of item-level visibility.
10. Monitor the commercial progress of embedded RFID tags within items and selectively invest research and development resources in those that have direct application to the supply chain.

Research Results

Someone once said, “No matter how much you push the envelope, it’ll still be stationary.” Advances in AIT have grabbed the attention of scientists, researchers, futurists, governmental officials, the military, and the public. Technology applications have flourished in health care, global logistics, manufacturing, nuclear material accountability, maintenance tool accountability, and intelligence tracking for humans or equipment. Furthermore, AIT and RFID hold great promise for streamlined supply chains, efficient inventory operations, and situational awareness of assets anywhere.

While micro- and nanotechnologies promise intriguing future capabilities for AIT, technology management and system integration will dictate what is possible over the next two decades. A recent GAO report highlights the imperative for logistics: “Lack of visibility over inventory and equipment shipments increases vulnerability to undetected loss or theft and substantially heightens the risk that millions of dollars will be spent unnecessarily.”¹²⁵ More importantly, an inefficient DOD distribution system will not get critical supplies to combat forces and will impede combat readiness. Now and in the future, it is imperative to sustain forces with the right stuff, delivered to the right place, at

exactly the right time. Such an imperative is enabled by a logistics system trusted by the customer that saves money, improves performance, and ultimately saves lives. Therefore, the DOD must continue to invest wisely in AIT areas by methodically addressing the infrastructure, hardware, and software capability gaps to exploit the capabilities of logistics situational awareness in the coming decades. In the networked battlespace of 2035, the United States must have the ability to provide end-to-end visibility throughout the DOD supply chain and enable commanders to make real-time decisions. AIT, specifically RFID, will be the lynchpin of DOD operations to ensure US forces can rapidly mobilize, deploy, sustain, and redeploy in support of national security objectives.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

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Appendix

Radio Frequency Identification Applications*

- ISO container tracking
- Vehicle tracking
- Fleet management
- Deployment support
- Air pallet tracking and accountability
- Repair parts tracking
- Warehouse management and inventory
- Manufacturing production control
- Sensitive items inventory/issue
- Reusable container tracking
- Ammunition tracking, receipt, and inventory
- Supply chain management
- Cargo security
- Cargo classification
- Reparable parts tracking and financial credit verification
- Personnel locating
- Personnel access control
- Baggage tracking
- Marathon runner tracking/timing
- Library book inventory/sign-out
- Retain antitheft
- Industrial clothing cleaning plant control
- Biometrics validation
- Materials handling equipment tracking
- Medical equipment locating
- Criminal tracking
- Livestock tracking
- Pharmaceutical accountability/safety
- Passports
- Credit cards
- Toll collection

*This list is based on US Army, "Frequently Asked Questions," Army AIT Program Office website, <http://www.ait.army.mil/technology/faqs.html>.

Abbreviations

AIT	automatic identification technology
ALCM	air-launched cruise missile
BCT	brigade combat team
BRIC	Brazil, Russia, India, and China
CAC	common access card
DOD	Department of Defense
EPC	electronic product code
ERS	expeditionary rescue squadron
ETSI	European Telecommunications Standard Institute
GAO	Government Accountability Office
GSEN	Global Supply Enterprise Network
HF	high frequency
IEC	International Electrotechnical Commission
IFF	identification, friend or foe
ISO	International Organization for Standardization
IT	information technology
IUID	item unique identification
LF	low frequency
MEMS	microelectromechanical system
MICAP	mission capable
MRAP	mine-resistant, ambush-protected
PICS	positive inventory control system
RF	radio frequency
RFID	radio frequency identification
UHF	ultra-high frequency
UID	unique item identification
USTRANSCOM	United States Transportation Command
VH	very high frequency

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