Radio Frequency Identification (RFID) Technology and its Applications in the Commercial Construction Industry

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Executive Summary

This paper is a report of Radio Frequency Identification (RFID) technology and its potential applications in the commercial construction industry. RFID technology offers wireless communication between RFID tags and readers with non line-of-sight readability. These fundamental properties eliminate manual data entry and introduce the potential for automated processes to increase project productivity, construction safety, and project cost efficiency. Construction contractors, owners, and material suppliers that believe technology can further develop methods and processes in construction should feel obligated to participate in RFID studies for the advancement of the construction industry as a whole.

RFID can increase the service and performance of the construction industry with applications in materials management, tracking of tools and equipment, automated equipment control, jobsite security, maintenance and service, document control, failure prevention, quality control, field operations, and construction safety. Contractors need to understand and take immediate advantage of the timesavings, low labor costs associated with new technologies, and lower rework costs that RFID systems ensure.

Lack of standardization, high costs of implementation, slow technology development and deployment risks, and the elimination of unskilled labor are all contributors currently preventing the adoption of new RFID technologies in the construction industry. Despite these drawbacks, this report analyzes the direct benefits of material management pilot studies conducted by Bechtel, Rohm & Hass and the National Institute for Standards and Technology (NIST). Furthermore, potential RFID applications,

economic development, and challenges of implementing these RFID ideas in the commercial construction industry are also presented.

According to Venture Development Corporation's latest market study, the RFID market is expected to grow approximately 23% annually; RFID interest is at its highest point ever and it is continuing to grow. Future case studies and project RFID sampling are needed to increase contractor and owner awareness of the potential savings of human life, project-scheduling times, and project costs. RFID technology would enable work to be done at lower labor costs than presently being used.

Today the construction industry as a whole must determine where RFID is applicable so that together they can overcome current limitations and provide improved RFID systems in the field of construction. Through further development and research, the testing of RFID in construction will make contractors and owners more familiar with their applications, opening the window of opportunity to a limitless potential of RFID applications in the construction field.

1. Introduction

Radio Frequency Identification technologies provide a wireless means of communication between objects and readers. Radio frequency identification (RFID) involves the use of tags, or transponders, that collect data and manage it in a portable, changeable database. Unlike bar codes, RFID has the ability to identify and track products and equipment in real-time without contact or line-of-sight and the tags can withstand harsh, rugged environments.

The radio frequency identification market is already a multi-million dollar industry and the applications of smart chip technologies are limitless. The transportation, agriculture, and manufacturing industries have all been affectively utilizing radio frequency technology for several years in applications such as toll collection, cattle tracking, and automobile manufacturing, respectively. Presently, retail industries believe they can reduce costs and increase revenues with better supply chain management.

This report first defines the logic and components behind RFID technology systems and evaluates their current and future applications in the construction industry. There is also an in depth analysis of the benefits and limitations that currently prevent the RFID market from exploding into “the next biggest thing” since bar codes. Through new and future applications this report also discusses how the growing awareness among consumers and marketing experts will soon illustrate the limitless potential RFID has to offer all industries.

Furthermore, RFID technology systems have the potential to increase the service and performance of the commercial construction industry. The following report analyzes current and future applications of materials management (tracking and identification of

materials, employees, documents, tools, and equipment), automated equipment control, and safety throughout all industries. Then it continues with a needs evaluation of RFID in commercial construction. It evaluates what the construction industry needs to do to further develop RFID applications that are beneficial to the industry. It also identifies the risks and challenges of implementing such applications.

2. What is RFID?

Radio Frequency Identification (RFID) tags have been in existence since the 1950's and two decades ago they were introduced as the ultimate replacement for bar codes (Stone et al). RFID tags, unlike bar codes offer the possibility of reading, writing, transmitting, and storing and updating information. According to WAKE, Inc., RFID tags can hold up to 32 mega bytes (tag ID: I-Q32T w/LED) of information making them more difficult to counterfeit than bar codes, and the data on existing tags can always be changed or updated. These tags have proven to be very useful in the deliver of construction materials where a shakedown of a large quantity and variety of items can be read simultaneously without having to be separated and scanned individually. Information is communicated electronically via radio waves and does not require contact or line-of-sight to transmit stored data, therefore, using RFID technology for the collection and transfer of information provides one with an inexpensive and non-labor intensive means of identifying and tracking products.

The smart chips (RFID tags) come in a large range of packaging options, they are reusable, and can withstand harsh environments. In fact, RFID tags can operate effectively in temperatures ranging from –40 to 200 ^{o}C. The chips are also capable of performing under rugged conditions or when they are dirty, and not until recently were they capable of overcoming the interference of metal objects. Today's active tags are now able to use metal objects that they are identifying as a device that amplifies its operating ability. Over the past five years the information technology industry has seen a surge towards the development of an affordable RFID tag. Such developments have lead to larger reading

ranges, greater memory capacity, and faster processing of radio frequency operating systems.

Unlike any other material management and material identification tag, RFID has a read – write capacity. A rewritable tag's ability to keep information up-to-date gives it the potential to strengthen national security and better inform people of maintenance and service records. Such a system could also alert automobile owners when an oil change or other routine maintenance is necessary. It also enhances the user's ability to locate objects when used in combination with GPS for real-time tracking.

2.1 Components

An RFID system is composed of tags, which carry the data in suitable transponders, and an RFID reader, which retrieves the data from the tags (CII, 2002). Products that contain RFID tags embedded in them or fastened to them enable stored information to be transferred from an RFID tag to a remote reader through radio frequency waves of a specific wavelength. There currently is not a definite industry standard for wavelength, but the most common applications around the world use wavelengths of 125 kHz and 13.56 MHz. Initially, data is written to the RFID tag enabling it to identify and characterize a product as a particular manufactured good with a determined application. At some later point, a RFID remote reader will scan and acknowledge the information once the tag is within range of an electromagnetic field activating the tag to perform a user defined function. Some of the components may be combined into one hand-held unit to allow user mobility. Also, many passive RFID transponders have antennas sealed with the tags to give them greater read-write abilities (see Figure 1.).

2.1.1 RFID Tags

There are two classifications of RFID tags: passive and active. The means in which they receive power for transmission determines their classification. Passive tags depend on a power source provided by the RFID reader's energy field and may have read-write or read-only capabilities, whereas, the active tags have an internal power source and are rewritable. Passive tags generally have shorter read ranges but have a life that usually outlasts the object that it is identifying. Active tags have longer reading ranges, high memory, and better noise protection. However, these tags are larger and heavier, more expensive, and have a shorter life (3 – 10 years) than passive tags. Read-only tags are used for simple identification purposes because they can only store a limited amount of information that cannot be altered. Such tags may be used to identify a package of nails or screws because they have many applications and are not designated to a particular item or activity.

Presently, these tags are being produced with the design weight of 50 grams, a life cycle of being written to 100,000 times, data retention greater than 10 years without power, and the durability to withstand being dropped to concrete from a height of 1 meter a multiple number of times (Identec Solutions, 2002) (see Figure 2.).

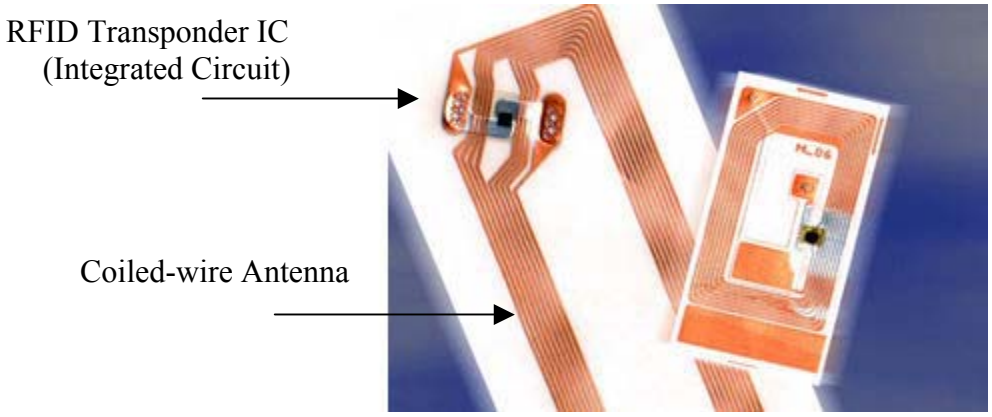


Figure 1. Antenna sealed with RFID tag

Figure 2. RFID tag
IDENTEC SOLUTIONS

2.1.2 Antenna

The function of the antenna attached to a reader is to transmit an electromagnetic field that activates a passive tag when it is within reading range. Once a passive tag is activated it can transmit information from its antenna to that of the reader where it is processed. During rewriting applications the antenna of the reader acts as a relay device in the reverse direction, the reader communicates a message through its antenna, which transfers and stores the new data to the activated transducer via its antenna. The RFID tag's antenna is practically maintenance free and can be configured in a variety of shapes and sizes ranging in size from a grain of rice to the size of a brick (Zebra Technologies, 2002). However, it is very common to see transponders and tag antennas packaged as smartlabels (sealed RFID tags) consisting of an integrated circuit (IC) attached to an antenna in the shape of a coil of wires as in Figure 1.

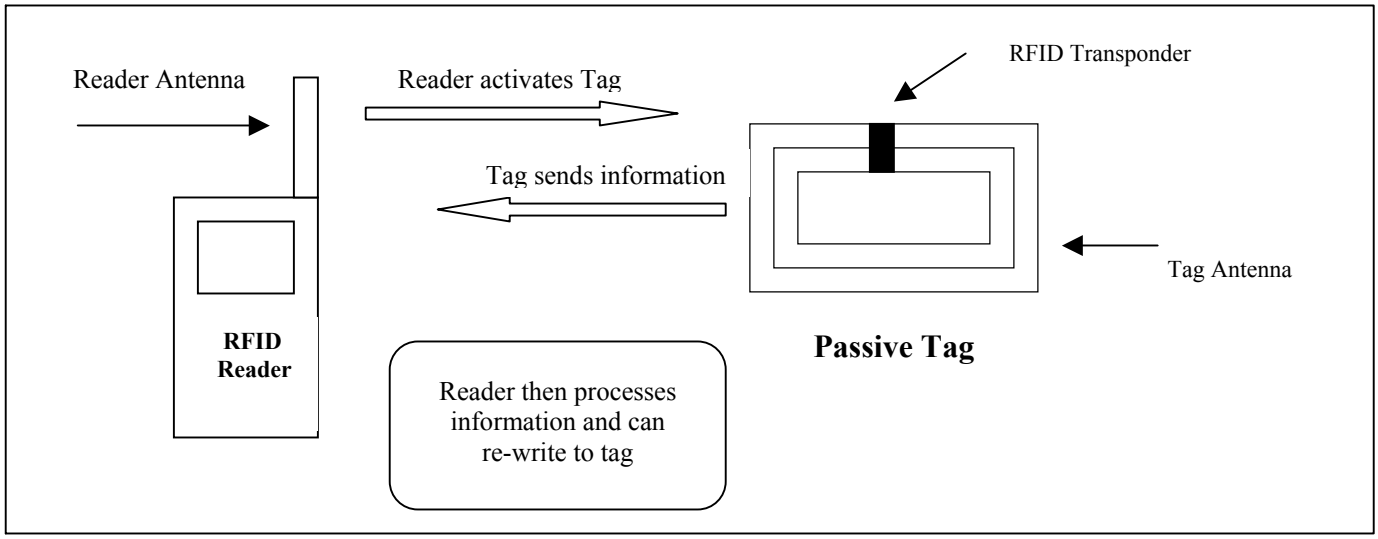


Diagram 1. RFID Reader and Tag Communication Flow Diagram

2.1.3 Readers

Readers may be integrated into handheld computers or they may be stationary and positioned at strategic points, such as a facility entrance or on an assembly line (Zebra

Technologies, 2002) (see Figure 3.). The handheld readers offer portability, however, the stationary devices offer a larger reading range. As stated above, readers have an antenna for sending and receiving signals and a processor for decoding them. The reader receives instructions and information from the antenna through the scanner, which is a part of the reader that examines analog output from the antenna. The scanner's information is then converted into a digital format by the reader, which the computer or processor can then use for data analysis, recording, and reporting (CII, 2001). There are readers today that can simultaneously read 100 to 2000 tags per second.

Figure 3. Handheld and Stationary Readers

2.2 Read Ranges and Tag Frequency

Reading range may be determined by the power available or the frequency of the tag. Generally, active tags that have power supplies embedded in them have a larger reading range than those of passive tags, however, they do come at a cost. Some companies on today's market claim that their active tags can be written to and read up to 100 meters in free air (Identec Solutions, 2002). Passive tags on the other hand have a read range of up to 2 meters. Other factors affecting reading distances include the frequency at which the tags communicate. Table 1 shows the classification of four frequency bands used in RFID tags, their frequencies, and their reading ranges.

The most commonly used tags are classified as low frequency because they more easily readable through materials and are not as orientation sensitive as higher frequency tags. Generally speaking, higher frequencies have greater reading ranges and are less sensitive to noise than the lower frequency tags. Conversely, RFID tags with microwave frequency do have greater read ranges and higher reading speeds than lower frequency tags, but they tend to be line of sight dependent, orientation sensitive, and require more power (Liard, 2003).

Table 1.
Frequency Classification Table

Frequency Classification	Frequency Band (Hz)	Reading Range
Low Frequency	125 kHz	0.3 meters
High Frequency	13.56 MHz	1 meter
Ultra High Frequency (UHF)	433 MHZ to 2.45 GHz	1-3 meters
Microwave Frequency	2.45 GHz to 300 GHz	2+ meters

(Zebra, 2002 and CMP Media, INC., 2001)

2.3 Benefits

There are many benefits to using RFID tags rather than the standard bar code. Bar codes must be separated and scanned individually by a reader, whereas radio frequency tags can be scanned simultaneously all at one instant. Bar codes do not compare to RFID tags in terms of durability. Bar codes are usually displayed on paper products or hard metals that make them vulnerable to harsh environments. Bar codes are deemed dysfunctional when they have been torn, disfigured, or detached from their objects. Furthermore, RFID tags are read more accurately, 99.9% read rate compared to 80% read rate for bar codes, because they eliminate manual data entry and can be read through most all materials (Conway, 2001).

Bar codes have a storage capacity of approximately 20 data characters, while a typical RFID tag can easily store between 8 and 32 MB of data. Furthermore, within the next five or six years it is projected that there will be a shortage of bar code combinations and products will either have to start duplicating code identification numbers or start adding an additional digit to their character strands. It may sound simple to just manufacturer bar codes with a longer identification number, but when you add in the costs of upgrading readers and processors with software to handle the new character strands it makes more sense, and cents, to think into the future.

RFID technologies are more reliable than bar codes because they have no moving parts and require no maintenance. RFID also provides higher security because each tag is extremely unique and almost impossible to duplicate (Durfee, 2003). Since RFID does not require a line-of-sight and has a greater read range than bar codes they prevent thievery and counterfeiting of products and goods. The continuous communication and rewritable capabilities of RFID enable electronic tags to be tracked in real-time through the use of GPS, and they can still be reused for other applications.

2.4 Limitations

2.4.1 Standardization

Currently standardization among RFID manufacturers' readers, tag frequencies, and recording software is causing lower consumer confidence in the RFID market. Technologists are hiding their information and avoiding standardization because it may give another manufacturer the competitive advantage that movers expect to gain in making the RFID market the next biggest thing (Roberts, 2002). On the other hand, there is a list of potential standards that industry associations, user groups, and vendors see that could

open the floodgates to extensive RFID deployment. According to AMR Research, eventual standards will affect the following issues: global RFID frequencies, interoperability, use of active or passive tags, data formats (syntax, data structures, and encoding), methods of identification and presentation, and communications between tags and objects and tags and readers (Kay, 2003). Standardized RFID tags would enable contractors to track and manage a variety of manufacturers' tags, which are fixed to different construction equipment and materials, with a single RFID reader. Until standards are set the cost of implementing RFID technologies will arguably outweigh the benefits.

2.4.2 Cost

The supply-chain revolution and widespread RFID implementation is expected to take place when the risk of investment is lower, some believe this will be when the price of an RFID tag reaches five-cents. Currently tags cost around fifty-cents, but that is about a quarter of the cost from four years ago. As RFID technology continues to develop and the demand of smart chips increases by the millions, the cost of each tag will continue to drop. Currently, RFID cannot economically compete with bar codes, but there soon will be a day when the benefits of RFID tags outweigh their costs.

When investing new technologies one must prepare a detailed business plan to make sure that they will have a profitable return on investment and they know what they are getting. However, there are many concerns that one must evaluate beyond the issue of cost: tag size and packaging, tag generation and application, quality, deployment environment, required physical infrastructure, required information systems infrastructure, and technology and communications standards (Hill, 2003). Buyers trying to minimize costs in determining which tags are most applicable and efficient to his/her situation must

keep two things in mind: the quantity of tags necessary and the capacity/limitations of each tag.

Technologists believe that Wal-Mart may influence the RFID industry in such a way that the rest of the world would follow suite. Wal-Mart's investment in the Auto-ID (RFID research and development) Center expresses the interest it has in developing RFID technology with the potential to cut cost and increase sales. Companies such as Wal-Mart, Coca-Cola, and Proctor and Gamble, multi-billion dollar sales companies, are looking to improve supply-chain efficiency with RFID tags that may cost as little as five-cents a piece. When these companies find a way to use RFID successfully the rest of the retail and consumer sales world will undergo a technological revolution. (rfidjournal.com/article/articleview/346/1/1/)

2.4.3 Interference

There are two identifiable causes of interference in reading RFID tags. Metal materials have caused big concerns from the start of RFID testing, and as the applications and use of radio frequency technology grows so does the concern with frequency interference. Other materials such as rubber and water may also cause shortened read ranges, but these are challenges that can be overcome with further research and testing.

2.4.3.1 Metal Interference

Although radio frequency devices do not require a line-of-sight and can be transmitted through almost any material, metal may be one material that can cause interference. Since metal is a familiar material on construction work sites the interferences caused by such materials may present limitations (CII, 2002). The RFID tag's orientation and fixture methods may have to be altered so that the tag can be clearly identified. The

newest RFID technologies claim to align the tag's antenna and a non-insulated metal material in such a way that the metal actually amplifies the signal of the RFID tag. However, passive tags still have trouble being read when attached with steel. Another challenge may be identifying two actively tagged metal materials that come in contact with each other, which could cause further interference.

2.4.3.2 Frequency Interference

Frequency interference may cause problems if a reader is attempting to identify a particular tag that is surrounded by a number of other tags operating at the same frequency band. As stated before there is a benefit to reading tags simultaneously, however there is also a limitation to the specific data that can be extracted from a single RFID mixed in with others.

As a result of the large storage capacity of the radio frequency tags, manufacturers are attempting to enable users to more quickly identify a particular function of the "addressable" RFID tags. Each addressable tag would have several storage addresses that store a specific type of information. For example, there may be zones for serial numbers, manufacturers' name, a description of the product, and the geographical destination tracking information.

2.4.4 Tracking people's freedom

In an attempt to make tracking and management more efficient the RFID industry is striving not to infringe upon the freedom of its users. A common use of RFID tags may be to tag clothing items or foods products, but the tag is only functioning properly (not infringing on the privacy and security of its owner) if it has a "kill switch" that is guaranteed to shut the tag off when a purchased items clears the store. In construction,

workers embedded with RFID should not be tracked once they leave the jobsite, preserving their civil liberties. However, there may be limitations for warranty items and tags that are used to track such things as vehicles and the transportation of goods.

3. Applications of RFID Technology

3.1 Current Applications

While the potential for RFID applications appears virtually limitless there are only a few applications that have been implemented and are continually being used. In the year 2000 the most common uses for radio frequency identification technologies included: transportation, materials management, and security and access control. Currently, there are a variety of other applications for RFID in agriculture, construction, and athletics.

3.1.1 Transportation

The transportation industry is one of the leading users of RFID technology because they have identified numerous applications. RFID applications in transportation include railroad car management, traffic management, tolls and fees, fare collection, equipment identification, fleet management, solid waste hauling, and fuel dispensing (CII, 2001). When a hometown commuter passes through an express toll lane an RFID tag alerts the tag reader that someone has passed through the toll and the reader then identifies the commuter and communicates the charge to an account setup in a networked computer system. Tractor-trailer traffic is also managed in much the same way through weigh stations. Once a semi tagged with RFID technologies enters an interstate highway it stops at the first weigh station along its journey on the interstate to be identified and approved, then throughout the rest of its passage along that same stretch of highway it is not required to stop at any other weigh stations. The truck is simply tracked by RFID technology along the highway.

Gasoline stations have also experimented with Exxon Mobil's *"Speedpass"* automatic payment RFID technology. By simply waiving the transponder attached to your

key chain across the reader your Speedpass account automatically gets charged like a credit card. Presently, Speedpass has created the Speedpass-enabled Timex Watch the enables customers to simply waive their watch in front of the RFID reader. The transportation industry and related businesses are dedicated to speeding-up traffic flow and decreasing delay time while making travel smart and efficient.

3.1.2 Security

Many businesses use RFID to control access to hotels and business facilities by attaching a tag to an employee's room card or ID badge. Such technology ensures that only authorized persons are allowed access to particular rooms or entrances. This application is also becoming more common in nursing homes and hospitals where the management and tracking of individuals is very important, and alarms are more discrete. Other security features include RFID chips embedded into automobile keys that enable the car only to start if the key has the proper chip embedded into it. Video stores and libraries are also applying radio frequency devices to checkout rentals and detect stolen or misplaced items. Law enforcement officers are now able to track credit cards, jewelry, vehicles and artwork by radio frequency tags embedded in these objects.

3.1.3 Manufacturing

Radio frequency identification systems allow the tracking of work-in-progress in automobile manufacturing and computer hardware manufacturing. Such technology allows managers to track goods through the manufacturing process and then the tags can either be reused on other products coming down the assembly line or they may stay permanently fixed to the product to provide a secure serial number (http://www.zebra.com/IS/manuf_electronics.htm). The tags also may contain important

information about a particular assembly method or piece of equipment necessary to complete the product (CII, 2001).

3.1.4 Agriculture

The agriculture and livestock industries have shown an increase of interest in food processing and distribution and animal tracking. In July 2001 the Canadian Cattle Identification Program (CCIP) mandated a mandatory cattle identification plan that has allocated more than 18.5 million RFID tags to traceback an outbreak of disease back to its origin. CCIP claims that tagging the cattle is more than cost-effective when tracebacks can be made quickly and efficiently, and fines of up to $500 are used to enforce the cattle identification mandate (www.canadaid.com/publications/news_articles/Dec_01.shtml).

3.1.5 Construction

Currently there is little use of RFID in construction, but there have been three uses identified by the Construction Industry Institute: compressed gas cylinder tracking, small tools management, and equipment monitoring (CII, 2001). Other potential applications in construction include ideas or case studies on the development of material delivery and management tracking systems, guided controls of equipment, tags that communicate fatigue or excessive stress in concrete and steel members, safety and several others that are discussed later.

Current, new, and future applications of RFID technology in the construction industry will be discussed in the Commercial Construction portion of this report.

3.1.6 Athletics

Golf ball identification and tracking devices have been implemented for accurate identification purposes; however, there may be a better market for the tracking of baseballs

in today's homerun hitting bonanza. Another use for RFID tags in athletics is implemented in almost all major track and field events. "Road races," running races or marathons in the streets, use shoelace RFID tags to get race results of runners as they cross the start and finish lines where there time is officially kept regardless of when the runner begins the race. These technologies are also being used to track athletes to verify that the path traveled is the same as the course defined by the race officials.

3.1.7 Global Positioning System (GPS)

Global Positioning Systems (GPS) have revolutionized the means to accurately locate and identify objects on the earth's surface using a system of satellites in space and transmitters and receivers on earth. The combination of GPS and RFID identification tags has made "real-time" tracking a reality. Materials and assets can be identified and tracked as they are installed or transported

3.2 New Applications

New applications for smart tags become apparent each and every day; there is simply no limit to the number of applications that could affect the way things are done in the future. Businesses are constantly looking for the latest information technology that will save them a buck, and construction contractors will always long for that new methodology that will give them the low bid or improve their worker productivity. Nevertheless, U.S. governments are trying to find ways to increase national security while decreasing the national debt; everyone is looking for an inexpensive way to do things more efficiently.

3.2.1 Airports – Security and Baggage Handling

RFID tags could be used to track and identify airline luggage and passengers increasing national security, speeding up luggage sorting and transfer, and decreasing expenditures resulting from heightened security measures. The International Air Transport Association (IATA) believes this technology has countless potential benefits for simplifying passenger travel for airports and airlines (Conway, 2001).

The major advantages of RF technology in baggage handling are an increased journey speed of luggage as a result of faster read rates and elimination of human intervention in misdirected bags and security procedures (Conway, 2001). Airline travel consists of 100 million customers each year making the cost of the tags and the read range of baggage a great concern. However, if the tag's cost can be reduced from its current price around 50 cents down to 15 cents and the IATA makes the 2.45 GHz frequency standard (doubling the read range of 13.56 MHz frequencies), this tagging application in the airline industry would takeoff (Conway, 2001). The numbers do matter, as demand increases and new developments are made the product cost will decrease leading to its implementation and cost savings. Airlines estimate that with a more efficient and accurate identification and sorting process they can save up to $100 on each misdirected bag.

In November 2001 Jacksonville International Airport became the first airport to begin constructing and implementing the world's first all-radio frequency baggage tracking and identification system (IIE Solutions, 2002). The RFID tagging system will make curbside check-in and security inspections more efficient by allowing readers to identify not only where the baggage is going, but also passenger information and a detailed history of the bag. However, until the entire airline industry follows suite there is going to be a double standard for those implementing new technologies.

3.2.2 Transportation and Access/Security

At the American Association of Airport Executives (AAAE) Conference in May 2002, TransCore and Gatekeeper systems, INC. partnered up to create a Ground Transportation Management System (GTMS) that would deal with travel and security around airports. The technology allows authorized vehicles (airport busses, taxis, cargo vans, etc.) to enter the grounds. This enables airports to have manless security checkpoints that monitor, track, control, record, and report vehicle operations. Nearby traffic congestion and air pollution from vehicle emissions would be reduced, and airport revenues from commercial vehicle access charges would increase because vehicles would be charged on a "per use" basis (Parker, 2002).

This technology is also being used at Fort McPherson Army base in Georgia. Passive sticker tags are being used at read ranges of approximately 20 feet, powered by the radio frequency that interrogates it, to identify, allow access, and record vehicles entering the army base. When a vehicle's tag is intercepted, photo identification and other information is sent to the computer at the guard post allowing security to verify that proper authorities and passengers are entering (Jackson, 2002).

3.2.3 Medical Applications

Medical applications include allowing restricted access and tracking patients and guest with authorized wristbands through hospitals. "Hugs with Kisses," produced by Xmark, is an electronic tagging and monitoring system for controlling the movement of newborn babies in a hospital environment (rapidttp.com/transponder/rfsupp91.html). The system comprises active transponders attached to the baby, monitoring receivers at

doorways and a computer networking system to reduce the risk of abduction and to ensure mother and child identification (xmarksystems.com/Product_pages/Kisses_main.html).

3.2.4 Supply-Chain Management

Retailers are very interested in turning the supply chain management industry into an RFID dependent business as long as it is cost efficient. Recently, Gillette ordered 500 million RFID tags from Alien Technologies for about 10 cents a piece (Frontline Solutions, 2003). They plan to tag every pallet and carton coming out of its distribution centers to reduce losses from out-of-stock, stolen or lost products, and the company believes that with increased tracking ability it will increase revenues by leveraging inventory information into smarter marketing to retailers (Schwartz, 2003). According to Frontline Solutions the success in reading RFID products was exemplified in a demonstration late last year (2002), when RFID readers on a dock door read 60 cases of Gillette razor blades in an instant.

Gillette's smart tags will also be used to track inventory through direct communication with "smart shelve" technology developed by the Auto-ID Center at Massachusetts Institute of Technology, Cambridge, Mass (Frontline Solutions, 2003). They claim that retailers and consumer goods firms in America lose around $30 billion a year in sales because shop shelves run out of products and stand empty (The Economist, 2003). According to IBM, the smart tag – smart shelf combination would shrink inventories by 5-25% increasing the efficiency of inventory management. The smart shelves would also be able to communicate the number of products left on shelves and send a message to the store staff when the shelves need restocking. The smart shelves also act as security devices, detecting and alerting store employees when there are a lot of

products that leave the shelf all at once. There are also other companies using RFID to track and manage their inventory to decrease product losses and increase revenues.

For example, Scottish Courage Brewing Ltd., which owns 45% of the U.K. draft beer market, is investing approximately $14 million in RFID to track 2 million kegs and 736 vehicles. RFID has helped the brewing company enjoy significant reductions in keg losses and a more efficient delivery process. Since the company deployed its RFID systems four years ago they have improved cycle times by four days. According to AMR Research's director of retail research, Peter Abell, the reduced cycles times have amounted to a cost saving of $1.5 million per day. This success story justifies the current ease of tagging "metal" beer kegs and opens the door for other metal products. (Kay, 2003)

3.2.5 Government Regulations – Tires

In the wake of massive Firestone tire recalls, the US Congress passed the TREAD (Transportation, Recall, Enhancement, Accountability, and Documentation) Act mandating that car makers closely track tires from the 2004 model year on, so they can be recalled if there's a problem (rfidjournal.com/article/articleview/269/1/1/). Government regulations have forced tire manufacturers into adopting RF technology; government influence may be the driving force behind the development of standardized and economical identification systems.

RFID tags embedded into tires will identify the manufacturer's name and plant, store the time and date of manufacture, tire dimension, and pressure specifications (see Figure 4.). Once the tire is installed on a new vehicle the tire identification number and the vehicles VIN (vehicle identification number) will be downloaded to a computer database enabling manufacturers to make targeted, quick recalls. Michelin has begun testing its tire

transponders and hope to begin selling RFID tagged tires for passenger vehicles and light trucks in the 2005 model year (Frontline Solutions, 2003). When Michelin took off-the-shelf, passive UHF transponders and embedded them into tires read distances were equal to three inches, so Michelin developed their own antenna from microchips produced by Fairchild Semiconductor and Phillips Semiconductor (868-915 MHz frequency band) to meet the 24 inch minimum read range requirement (rfidjournal.com/article/articleview/269/1/1/).

Michelin has not released the details on their design, but claims that rubber interference causes a 10% reduction in read range because electromagnetic waves travel differently through rubber than through air. There is a current price tag of a "several dollars," but with mass production, Michelin who produces 800,000 tires per day, will have a cost much lower than the present amount (rfidjournal.com/article/articleview/269/1/1/).

Figure 4. Michelin RFID tags

3.3 Future Applications

RFID has the capability to be applied in all industries, but as stated above, there is a high demand on standardization, economy, and versatility of radio frequency identification tags. Future ideas are derived from many of the new and current uses of RFID. However, there are several ideas that even government organizations may draw interest in.

The supply-chain and sales businesses have adopted the idea of introducing radio frequency technology to help persons such as pharmaceutical sales representatives to track inventory by simply walking into the drug storage room. The sales representative could determine which products are moving and assist drug companies how to better market their products (Schwartz, 2003).

Government agencies could identify and track inmates in jails and prisons in real-time to keep tight security surveillance on convicted criminals. Public schools could use RFID to determine student attendance and track suspicious kids for the safety of the public. These applications do impede on individual's personal rights of freedom but some day there may be a benefit to society that exceeds the cost of being tracked *within certain public bounds.*

Amusement parks are developing wristbands that function much like the wristbands in hospitals and nursing homes, but they would have the potential to be used to charge concessions and souvenir purchases to a user's account just as a credit card.

The automobile industry may have a jump start in tracking vehicle's maintenance and service records by means of smart tags located within the vehicle's tires. Such information in conjunction with the car's odometer could track the mileage of the vehicle and alert the driver when the tires need to be rotated and the engine oil needs changing. Since the tags are rewritable, standards would enable the car to have an up-to-date service and maintenance record regardless of the mechanic or station that has provided work.

The US military has discussed the idea of producing smart dog tags to easily identify troops and to track other important information such as medical history.

RFID technologies upgraded to produce instant location information, **Real Time Location Systems (RTLS),** may influence food distributors and grocery store chains to be completely RFID oriented. RTLS allows a reader unit to "see" the actual location of an RFID tagged item, without the tagged item being near the reader. Using special readers placed around a property, tags are located using a triangulation system. In a pilot study done by Associated Food Stores Inc. (AFS), a food distributor for 580 grocers in eight states, the company obtained 100% ROI (return on investment) within six months. According to Tim Van de Merwe, internal logistics manager at AFS, the company has saved $370,000 in reduced labor, more efficient yard management, and reduced freight costs, and has increased data accuracy from 30% to 100%. (Kay, 2003)

Exxon Mobil Speedpass radio frequency technology has introduced a whole new way of paying for goods and services. Although it is most commonly used at gas stations, products like Speedpass are expected to grow into fast food restaurants, movie theaters, and grocery stores. RFID testing is currently being conducted using RF tags on grocery items. Just as in the airline industry, there is going to be a double standard until there is complete adoption of RFID in supermarkets. See Figure 5 shows one of the first bar code/RFID scanner. IBM has contemplated the idea of an all RFID grocery store where the customer picks up the items that he/she is interested in purchasing and simply walks out the door. In this case the grocery items have RFID tags that when the customer leaves the store an RFID reader mounted at the doorway scans the items and directly charges customers account on the store's database. Furthermore, cell phones equipped with RFID may have the potential to make all of these transactions seem simple.

Figure 5. Bar code/RFID scanner

4. Market Analysis

According to recent research from the Venture Development Corporation (VDC) interest in RFID technology is at its highest point and climbing, yet sales and shipments have failed to meet industry forecasts (VDC Volume I, 2003). The traditional RFID market is nearly saturated so suppliers are depending on their ability to understand the factors impacting the market and to develop effective strategies to survive and stay competitive. VDC market data shows that the global market for RFID systems has not grown much over the past couple of years ($965 million in 2002, compared to $897 million in 2001).

The majority of RFID market revenues are derived from hardware shipments, primarily transponders and readers (see Table 2). This spring (spring 2003) ThinkMagic, a Cambridge, Mass.-based technology design and development company, and Tyco Retail Solutions Group, an electronic equipment manufacturer, will be one of the first joint venture companies to begin mass production on an RFID reader that will read both HF (13.56 MHz) and UHF (860-928 MHz) tags. They were hired by the Auto-ID Center to develop and produce an RFID reader that will be able to read HF and UHF tags carrying the Auto-ID Center's Electronic Product Code and tags that conform to the ISO 15693 standard. Tyco executives believe primary applications will involve supply-chain management and that their tags will be more marketable because of their dual frequency readability, "We don't believe that one tag is going to be used for every application (rfidjournal.com/article/articleview/319/1/1/)."

Table 2.
Global Shipments of RFID Systems by Product Category
(Millions of Dollars)

Product Category	2001	2002
Transponders	$456.8	$463.1
Readers	$206.5	$239.8
Software	$44.6	$54.9
Service	$190.0	$206.7
Total	$897.9	$964.5

Venture Development Corporation, 2001 and 2002

Major growth of the RFID market has been slowed down by lack of industry and application standards, traditional RFID applications approaching their saturation points, and the highly fragmented, competitive environment (VDC I, 2003). The RFID market is slowly growing with the actions taken by Gillette, Michelin, and airport officials, but the market will not explode until costs drop, or until others see the return on investment (ROI) of companies currently participating in RFID applications.

4.1 Economic Sectors

The strongest shipment revenues for 2002 were concentrated among the industrial/manufacturing and transportation/distribution sectors, however over the next five years annual growth rates are projected to be greater for emerging health care, commercial, and retail service sectors (VDC I, 2003). The construction industry is so fragmented and complex that standardization and implementation of RFID in construction may not take place until several years after emerging sectors have adopted new RFID applications. However, an industry like construction that is looked at as a low-tech business still has an

unlimited potential for the use of RFID applications because owners depend on contractors to construct safe, quality projects using the most economically efficient methods.

Retail services are expected to expand from already concentrated RFID services involving inventory control, access/security, and automatic payment applications. Health care organizations are expected to expand RFID applications to waste management, access control, high-value asset tracking, record/document tracking, people identification, and real-time location systems. Whereas the commercial sector is expected to grow it's use of RFID in closed-loop applications including libraries and video stores. (VDC I, 2003)

4.2 Applications

While the potential for viable RFID applications appears virtually limitless, much of the RFID industry growth over the past three years came from traditional, establish applications such as access/security control, automobile immobilization, toll collection, and animal tracking. According to VDC the top five fastest growing and emerging applications still in early-adopter phases include baggage handling, rental item tracking, point of sale (POS) commerce, real-time location systems (RTLS), and supply-chain management. (VDC I, 2003)

Stronger growth is expected in the baggage handling industry over the long term as end users evaluate baggage handling systems and positive passenger bag matching programs resulting from multiple case studies being conducted across the globe. Systems in rental item tracking have already seen some benefits in library and video applications and are expected to grow in commercial laundry and uniform rental markets. As the cost of transponders is driven down and individual item tagging becomes more prevalent, RFID applications in POS commerce will grow. RTLS is expected to grow in theme park people

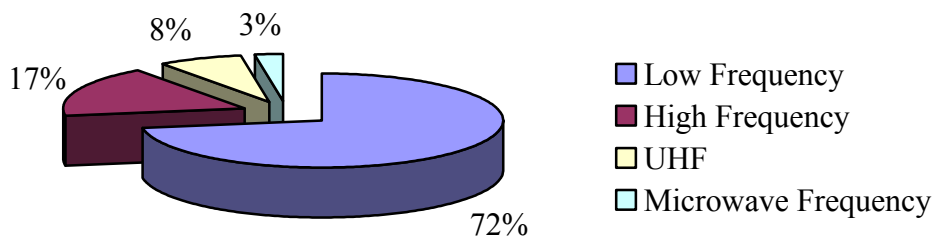
tracking, manufacturing processes, supply-chain management, and high-value asset tracking applications because of strong growth opportunities and competing suppliers. (VDC I, 2003)

VDC also believes that long term revenue opportunities are strongest in supply-chain management supporting applications in work-in-progress and container and pallet tracking. Supply-chain management and work-in-progress tracking may be the first applications developed in the construction industry because construction materials are vast in number and owners and managers depend on work-in-progress management to determine percent complete, project benchmarks, and project payment.

4.3 Transponder ICs

Low frequency transponder IC (integrated circuit) systems (primarily 125 kHz) are the most popular transponder ICs shipped globally, and they are widely used for mature, traditional applications of RFID applications (automobile immobilization, access/security control, animal tracking, etc.). As Chart 1 demonstrates, low frequency ICs consume nearly 75% of the transponder IC market. However, as the RFID market expands narrowly defined applications are moving toward specific frequencies. (VDC Volume II, 2003)

Chart 1
Global Shipment of Transponder ICs by Frequency



Venture Development Corporation Volume II, 2003
(percentage values have a +/- 2.5% variance)

Low frequency IC systems are projected to continue leading the RFID market in the near term because of their growing applications in electromagnetic environments (electronic manufacturing, automobile assembly, etc.) and emerging security applications. High frequency (13.56 MHz) applications comprise approximately 15-20% of the market and are more popular in Europe and Asia than in North America for uses in smartcard and smartlabel solutions (public transportation ticketing, garment tracking, etc.). American companies are seeking standards in UHF transponders (2.45 GHz) because of their increased read range distances, but increased read-range capabilities are more expensive. Applications driving the UHF market include rail car tagging, toll collection, and researchers believe that the tire identification tags (Michelin tags) are using UHF for longer read ranges. Microwave solutions are the most recent to develop RFID applications with increased read ranges and data transmission speeds, conversely, their tendency to be line-of-sight dependent and more expensive may hinder their growth. (VDC Volume II, 2003)

5. RFID in Commercial Construction

RFID has a place in commercial construction because it provides the industry a potential to improve construction productivity, quality, safety, and economy, cutting labor and material costs and enhancing project schedules. Contractors are interested in discovering ways that RFID can save time to provide more efficient project management. However, do not look for RFID technologies to be implemented industry-wide in the near future. Current risks and challenges associated with developing RFID technologies pose obstacles to strong growth and implementation of RFID.

Industry fragmentation, slow technology deployment, complex supply chains, high cost of individual research and development, cost of overall RFID packages, and proprietor business concerns are the leading factors affecting the implementation of RFID applications in the field of construction. However, several companies and development groups are using pilot studies to identify viable construction applications in determining the economic potential and risks associated with emerging technologies.

The construction industry as a whole must collaborate to fully realize the potential for new technologies. The industry should feel obligated to freely communicate and publicize the results of their studies in RFID to lower the burden of cost on individuals, to establish an industry standard, and to minimize risks. Since November 1998, when the Construction Industry Institute held an RFID workshop in Houston, Texas, researchers and participating companies (such as the CII and Bechtel) have joined together to test uses of RFID in materials and equipment management. Others have contributed through access/security studies and through publishing potential ideas and applications of RFID in construction management. However, the commercial construction industry must also take

a look at how other industries are applying RFID to their business sectors to provide an outlook and vision of what the future holds and also to identify the risks and challenges of specific applications in construction.

5.1 Construction component and Materials Management

5.1.1 Tracking Materials

Future materials tracking management systems may be able to provide owners the ability to determine construction progress and materials delivered by simply walking a site where all materials are identified and tagged using an RFID system. This would guarantee more accurate estimates of percent construction complete and the number and quantity of delivered goods. The following case studies present the benefits of using an RFID tracking system to identify materials and deliverables. However, until RFID is cheap enough to implement across all construction applications, bar codes and RFID may be used simultaneously as shown in Figure 6 (http://www.new-technologies.org/ECT/Other/barcoding.htm).

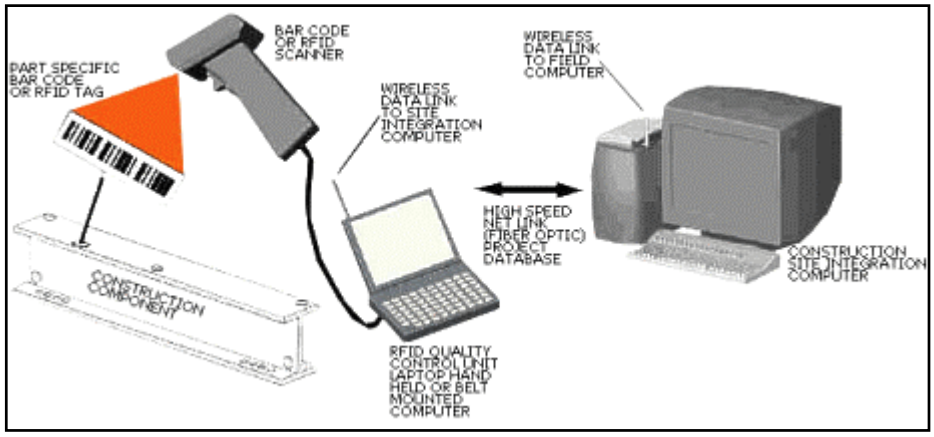


Figure 6. Schematic information flow for discrete component tracking (www.new-technologies.org/ECT/Other/barcoding.htm)

5.1.1.1 Tracking Materials (Construction Industry Institute Pilot Studies)

The most conventional use RFID has seen thus far in construction is in its ability to improve the efficiency of the materials management process. Large amounts of time and money can be saved when materials can be properly identified and located. In fact, in a case study conducted by Bechtel in their $338 million Red Hills Project, time spent locating and tracking pipe supports and hangers was reduced by 30% (159 minutes per 100 hangers) as a result of the RFID system used. Also, the inspection process was much easier and more accurate than that of the traditional manual process. (CII, 2002)

Bechtel's Baytown Project was also a pilot study for the tracking of pipe supports on a coking unit at the Exxon Mobil Baytown Refinery. While exact timesavings were not reported they were said to be positive. This project identified its primary strength to be the development of Bechtel's Procurement Tracking System (PTS) and the assurance that RFID tags can be reused without a problem. (CII, 2002)

Rohm & Haas conducted an RFID pilot study that received, identified, and tracked Honeywell smart instruments throughout their installation and loop checking processes. As the tagged instruments arrived, an inspector read the tags and answered questions related to the installment process. Benefits from the case study include: inventory shrinkage, lower rework costs, improved tracking and inventory control, and improved data integrity. (CII Research Team 151 Presentation, 2003)

Limitations to these pilot studies include metal interference with readers, a lot of bending down to read the tags, and sun glare (making it difficult to view the reader screen). There is also a concern that bulk items may pose problems to accurate material tracking. From the latest research done in other industries, future construction tags may have the

ability to be read without interference from metal and with greater read ranges that would prevent workers from bending over so much. It is also believed that costs of the tags can be driven down if smartlabels, which are also very durable, can be applied to construction applications instead of the bulkier, yet very versatile tags.

5.1.1.2 Potential Materials Tracking Applications

Potential applications for materials tracking in commercial construction include concrete placement operations and steel frame components tracking. These applications provide viable uses because they offer incremental improvements over existing methods, reduced labor costs, real-time identification and tracking, and they provide the potential for automatic billing upon receipt of materials at a jobsite.

5.1.1.2.1 Concrete Placement

RFID has the ability to scan items at a distance, which allows concrete trucks to be scanned while in motion as they pass through a gate. Concrete mix design and admixtures, loading time, and delivery location could also be identified as the materials are being placed into material-handling equipment. RFID can be used to track and relate concrete cylinders to truck number and placement time. RFID can also retain very important information on the attributes of the batched construction materials such as concrete mixing time, temperature, and number of drum revolutions. An RFID concrete placement system would provide critical information for invoicing, payment, and testing through the identification of concrete trucks and concrete test cylinders, ensuring proper delivery, billing, and quality control. (Jaselskis et al., 1995)

5.1.1.2.2 Steel Frame Components and Sub-Assemblies

NIST (National Institute for Standards and Technology), CII FIATECH (Fully Integrated and Automated Technology), and AISC (American Institute for Steel Construction) are partnering to provide the technical infrastructure necessary to permit real-time identification and position tracking of steel frame components and sub-assemblies on a construction site. Objectives include eliminating interferences caused by metal or steel and to design RFID rugged enough to withstand the tough environments encountered within construction worksites. The NIST Comp-TRAK project is addressing the problem of identifying, registering and tracking discrete construction (steel frame) components and sub-assemblies on a construction site.

This project is an ongoing research study aimed to answer four questions: (1) was the component the right one for that location?; (2) where was it finally positioned and what was its orientation?; (3) were there any problems associated with the component (was it incorrectly fabricated) or with its placement into the structure?; and (4) do the appropriate managers, engineers, and planners know this information? Presently, this information is collected manually and is not efficiently communicated to all participants in the construction process. Knowledge of this information, in an on-demand format, would enhance the construction industry by dramatically reducing cycle times, reducing the amount of rework, improving reliability, setting an industry standard, and setting the foundation for real-time 4D CAD construction project management software. (Saidi, 2003)

Other potential materials management operations include material takeoff, requisition, issuance, installation, inspection, shipment and export, receipt of materials, in-storage maintenance of materials, and return of materials (CII, 2002).

5.1.2 Tools and Equipment

The machine tool industry has been using embedded systems such as RFID technology to track tool usage and to prevent tool mishandling and wrongful installation (Lewis, 2000). Although the construction industry is generally not as high tech as the manufacturing industry, tools and equipment cost can be critical to complete projects within estimated budgets. Interest in tool-tracking technologies is on the upswing because it holds the potential for reduced expenditures and tighter job costing (Marshutz, 2002).

5.1.2.1 Tracking

Based on Tool Watch market research conducted in 1997-98, a mechanical contracting company with 30 employees spends $30,000 annually in tool expenditures without a tracking system. However, companies with a tool tracking system had annual tool expenditures 40% lower than those companies without (Marshutz, 2002). This technology may prove beneficial to the commercial construction industry as well as with the tracking of high-value assets that tend to walk off of construction jobsites.

Smart gang boxes equipped with a record of RFID tagged tools inside has the potential to increase worker productivity as a result of being able to accurately and quickly identify the location of particular tools. Project tool costs could also be precisely charged to proper job number and contractors could significantly improve cost coding and inventory control of high-value assets. Other information that RFID has the capacity to provide is tool work history, tool name, and serial number. The tool's possession could also be tracked with RFID tagged workers, reducing the risk of lost or stolen tools. HOUNDware Corporation has been using bar codes for tools tracking for quite some time, but recently they have been testing RFID tool-tracking systems with wireless data collection software (www.houndware.com/website/systems/Toolhound.html).

Commercial construction is also an industry highly dependent on its equipment and operators. Many contractors do not have the capital to fully supply each jobsite with all the equipment it needs, therefore, equipment must be able to be located at all times on all projects that the contractor is constructing.

Commonly operated equipment by commercial construction contractors includes generators, air compressors, backhoes, material fork trucks, dozers, scrapers, loaders, and crawler and rubber-tired cranes. Tracking these pieces of equipment would enhance a contractor's ability to evaluate their active purpose and to better manage efficient usage of equipment on simultaneous projects. Active RFID systems would also store equipment compliance records and information regarding its operational capacities to prevent dangerous usage. In-cab readers and active tags could be powered by the power source of the equipment, minimizing the cost of the readers and tags, and these devices would have a life cycle as long as the equipment's. The GPS monitor in Figure 7 illustrates the potential to combine RFID and GPS technologies to in-cab applications. However, lack of standardization may play an important role in implementing this technology in an industry that has such a complex list of equipment, tool, and materials suppliers.

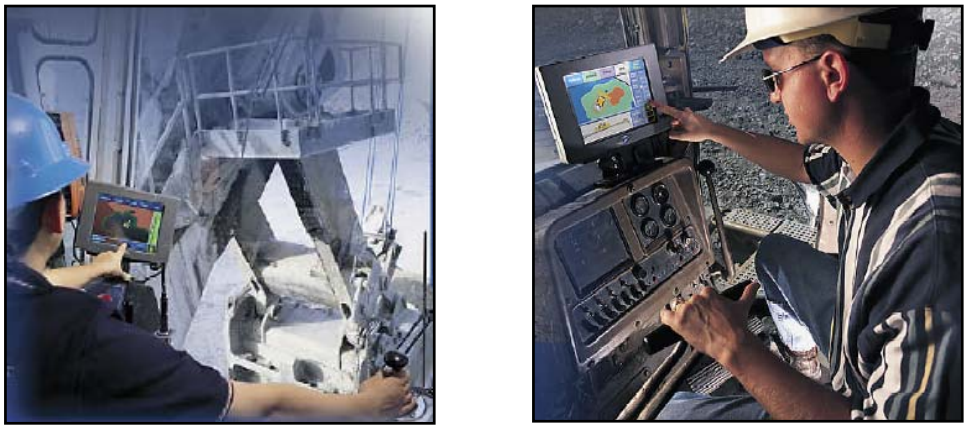


Figure 7. ProVision™ GPS Excavation

5.1.2.2 Guiding

Automatic-guided-vehicle (AGV) control allows automated operations in fixed locations. RFID tags along fixed travel paths can be used to guide equipment more efficiently and effectively. The tags can simultaneously communicate storage and transfer location information with units en route. This RFID system application may be beneficial to automated construction processes of the future. (Jaselskis et al., 1995)

Commercial construction applications may include equipment with RFID technology that allows automated trenching and soil excavations with backhoes, automated hoe rams for rock fracturing, and instructional guidance to crane operators about load capacity and range of movement. The technology would also record the number of movements and engine run-time to improve cycle times, to track an accurate account of material quantities moved, and to create time savings for contractors.

Other uses of automatic-guided-vehicles and equipment may include paint trucks that mark roadway lanes, asphalt-paving machines, and underground bore machines. Lane marking could be much more efficient if RFID was embedded into the pavement and paint trucks with in-cab readers. This would reduce the labor costs, and these tags could be embedded during the construction of the roadway to measure asphalt pavement maturity (this will be discussed later in the report). Also, tunneling timesavings could be achieved if underground bore machines had an RFID guidance track that ensured accurate and precise movement of the equipment.

Risks and challenges for use of RFID in AGV include operator judgment decision-making issues. For example, in a simple trench excavation one may encounter existing

utilities, under these circumstances a man-guided piece of equipment would stop operating but AGV operations would never understand the circumstances and continue excavating.

5.1.2.3 Security

RFID can also provide security to construction jobsites. Workers, operators, and equipment tagged with RFID can record and make certain proper usage and handling of equipment, materials, and documents. These systems would also ensure that only qualified equipment operators have the ability to operate restricted equipment, reducing the likelihood of misuse and accidents (Goodrum, 2002). Besides tracking objects and people within the jobsite, it would also secure the site from unauthorized people and vehicles.

5.1.2.4 Service and Maintenance

RFID technology can be a helpful record-keeping tool for high-value assets and equipment service logs. Applications would allow mechanics in the service bay to read and write to the tags, reducing the amount of paperwork related to warranties and time-consuming maintenance logs. It will also encourage operators and managers to keep better track of their assets because there are not hundreds of different pages mixed around for a variety of tools and equipment. The equipment would display its records upon request via an in-cab smart tag display powered by the equipment. The tag would store information regarding maintenance and moderations, tire pressure and dimension for rubber-tired tools and equipment, service history, inspections, and operating or erection information and checklists.

These devices could also enhance fleet management. RFID linked to onboard sensors that monitor equipment performance could determine if certain set point values are exceeded. If point values are exceeded the fleet management software would indicate a

potential problem with the specific piece of equipment, prompting a mechanic to investigate the problem. (CII, 2001)

Other benefits may include quicker scaffolding erection and more accurate measuring and testing instruments, as a result of improved maintenance and calibration records. Construction managers would also see increased overall life cycles of high-value assets (tool and equipment) that contractors depend on to get projects completed on time and under budget.

5.1.3 Document Control

The construction industry is an industry that is very dependent upon paper for transmittals of shop drawings, plans and specifications, change orders and billing, and RFIs (requests for information). Although the Internet has allowed the use of e-mailing documentation there is still a mailed copy sent to other players involved (contractors, architects, engineers, owners, etc.). When the costs of RFID technology is more reasonable, applications that embed tags into construction documents, files, or file folders would significantly reduce the amount of time and money spent managing files, and until the industry is paperless there will always be a way to more efficiently manage documents.

Tiny integrated circuits (ICs) can be made into labels or embedded into the paper itself (www.electronicstalk.com/news/hit/hit105.html). The Hitachi embedded RFID tag is 0.4-mm square and is wireless accessible at 2.45 GHz allowing files to be secured and managed more efficiently (see Figure 8.). Documents equipped with RFID tags enable files to encode file identification numbers making them easier to locate and secures them from being removed without authorization from designated

Figure 8. Hitachi Mu-chip

filing areas. This technology could be implemented with automated checkout capabilities with RFID tagged employees or an alarming system that identifies documents leaving a secured area. (Faber, 2002)

Current Risks and challenges include the movement towards electronic file transfers and small reading ranges of the technology. The Hitachi chip is stated to have a read range of one-foot, indicating that readers would have to be installed in each file cabinet drawer and within close proximity to entrances to implement such technologies (http://www.rfidjournal.com/article/articleview/337/1/1/).

5.2 Service and Maintenance of Built Construction Projects

Equipment and materials with RFID systems installed in them provide benefits to contractors and owners. Contractors benefit during the construction process in several ways: accurate and quick identification and tracking of jobsite equipment and materials that are permanent fixtures in the completed project, lower costs of rework because of more efficient tracking, and automatic billing to owners, enhancing their request for payment invoicing. Owners receive the benefit of having a real-time, accurate account of materials on-site, tracking of materials through installation, and measures to evaluate total quality. They also can monitor materials and equipment for routine maintenance and failure prevention.

RFID technologies have the *potential* to enhance the abilities of constructors and owners to evaluate percent complete of the total project by simply walking through the site with an RFID reader. Potential is stressed because at this time read ranges are inadequate and the cost of readers and tags are not economically feasible. Risks of increased costs and

lack of trust in the technology also hinder the use of RFID in service and maintenance applications.

5.2.1 Service Records

RFID and mechanical sensor technology could benefit HVAC, fire protection, elevator systems, and other major equipment assets through service and maintenance monitoring systems. Much like construction equipment maintenance and service monitoring, owners could more efficiently identify and manage routine maintenance and warranty information on installed parts and systems.

5.2.2 Failure Prevention

The use of electronics technology in civil structures, buildings, dams, bridges, and tunnels, may prevent, or at least warn engineers of fatigue or failure. Micro-size sensors will be deeply embedded within these structures, constantly supplying data on shear, strain, pressure, and other forces that can affect them. These applications would save the expense of sending out safety inspectors and engineers to monitor these structures; we will depend on computerized data centers to constantly monitor every conceivable parameter to prevent failure of civil structures. (Electronic Design, 2002)

Commercial construction may apply this technology to major structural components of buildings to strengthen structural members and to prevent their failure. A tag may be able to detect the strain in a column that is under an amount of stress equivalent to its buckling stress and provide a warning. It may also activate piezoelectric actuators, which send a strong current through the column at a specific location, creating an additional force on the column to stabilize it. Such experimentation has shown that the

critical load can be increased by a factor of 2.9 before the column buckles. (Chase et al., 1999)

5.3 Other Potential Uses for RFID in Commercial Construction

5.3.1 Concrete and Asphalt Pavement Maturity Monitoring

RFID applications measuring temperature fluctuations within an identifiable location of placed concrete or asphalt pavement provides interesting information regarding strength and maturity.

WAKE, Inc. and IDENTEC SOLUTIONS have created an active UHF RFID tag that monitors concrete maturity by burying the tag in the concrete and taking temperature readings at user defined intervals. The raw temperature data provides the information to determine optimum concrete strength, curing rates, and documented quality control data for the project. The benefits to commercial construction contractors and the construction industry as a whole include: accelerated schedules from time savings, early formwork removal, accelerated pre-stressed release times, determination of precise sawing times for joints, identification of weak spots in the concrete, hydration rate and remedial action warning. Also, by implementing the concrete maturity method system (CMMS) of in-situ strength testing, concrete cylinders could eventually be phased out. The data from the tag is stored in the handheld PC and can be easily transferred to a desktop PC. (WAKE, Inc., 2003)

The temperature accuracy of the CMMS exceeds ASTM C1074-93 requirements, however, there is still an issue of trusting technology in an area of construction that ensures a safe working platform from which to build, concrete slabs and foundations. Furthermore, the cost of implementation may be an issue that the industry must decrease in

order to make such RFID applications marketable. Current prices on WAKE and IDENTEC SOLUTIONS' tags range from $67.38 [1] to $34.68 [10,000-100,000]. Readers range from $878 to $2,264, and there are other costs associated with software, data storage cards (I-Card) and antenna, and technical support (see Figure 9.).

Figure 9. Compaq iPac
Pocket PC with transceiver

5.3.2 Field Operations

RFID tags embedded in workers' hard hats can be used in the automated tracking of personnel instead of manual data recording and data entry of workers time sheets. This process would eliminate unnecessary labor expenses and provide an accurate payroll account. (CII, 2002)

5.3.3 Safety

RFID tags containing pertinent safety information could be attached to safety equipment such as slings, safety harnesses and belts, scaffolding, and hardhats making them easier to track and ensuring that they are in safe operating condition. The benefits of

improved safety records include lower labor costs, lower direct and indirect costs associated with injuries, accidents, and deaths, and a more comfortable working environment (Goodrum, 2002).

Another safety application for RFID technology is hazardous materials tracking. Identifying hazardous waste and hazardous construction materials from a safe distance will prevent accidental contact and keep workers informed of the type and location of Haz-Mat on site. Underground work environments such as tunneling, mining, and work in confined spaces may find value in using RFID systems to improve safety conditions. RFID tags can be used to monitor workers, support systems protecting the workers, and equipment operating around them. In mining operations RFID has been used to prevent coal carts and conveyors from injuring workers by having shut-off signals alert the machinery when it detects a miners RFID badge (Jaselskis, 1995).

In commercial construction, RFID systems with the capacity to warn workers that heavy equipment is operating in the immediate vicinity may prevent the number of fatalities and accidents resulting from persons coming in contact with machinery. Any number of fatalities resulting from workers caught in the blind spots of equipment and machinery is way too many. Workers and equipment armed with RFID alert systems, such as a vibrating hardhats and equipment kill switches, may prevent unnecessary accidents from happening and create a new safety awareness about the project. All too often experienced workers get too comfortable with their surrounding and new employees try to illustrate their potential through hard work are less attentive to small movements that place them in harms way (Korman et al, 2002). RFID systems that alert workers when

equipment is nearby may have an active role in rejuvenating worker attentiveness to potential dangers.

However, like any other "new" idea, the industry cannot afford to simply implement the application, allow it to become mundane, and not follow up with another method or process to keep workers on their toes. Conversely, if tags are used to restrict equipment operators to only those that are authorized to operate the equipment, there may be a long-term safety advantage in operator security applications.

Fall protection and prevention is also a major contributor to construction accidents and fatalities. RFID applications that may enhance a worker's ability to evaluate and prevent actions leading to falls include: alerts that one is approaching a guardrail or a nearby boundary with a steep change in elevation. Guardrail alert systems would function similarly to the equipment alert examples above, however the falls from steep grade changes (major excavations) or from fatal heights (roof structures or multi-story floor elevations) may use more complex RFID technology. As in equipment guiding applications of RFID, fall protection RFID would require the layout of an RFID "danger" bound. Once the network of tags is laid-out the system would function like invisible electric dog fences, except they would be called invisible fall protection fences in construction. Challenges presented by this technology include an alert system that can effectively change the behavior of a worker and prevent him/her from mistaking courage with stupidity or ignorance. Time and costs associated with setting up such a network must also be overcome. Users must also overcome the risk of fully trusting such lifesaver systems because radio frequency reception and transmission may be influenced by interferences from other objects or frequencies.

6. Needs Evaluation

6.1 Current State of the Construction Industry

The construction industry is constantly being challenged to improve its worker productivity and increase jobsite safety and efficiency. Recent statistics from the U.S. Bureau of Labor Statistics shows that labor productivity in construction is not keeping up with the economy of its industry (see Chart 2.).

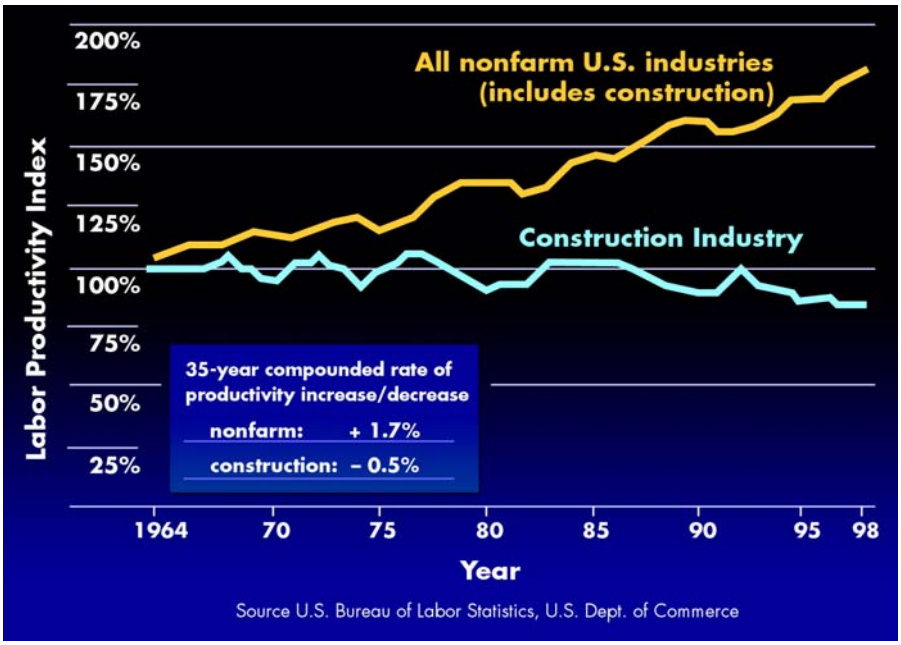


Chart 2. Construction Labor Productivity Index versus all Non-farm U.S. industries

This information may not reflect the true change in construction productivity because unit labor costs are lower than before, the fragmentation and complexity of the construction industry prohibits researchers from gathering adequate amounts of information, true costs indexes of materials are variable, and quality of work put in place is not evaluated over time. However, the negative perception on the construction industry has caused some contractors and industry leaders much concern. As a result they may

strive to find technological innovations to increase productivity in hopes of elevating the industry's reputation because past technological advancements, such as the pneumatic nail gun, have enabled workers to perform the same tasks in a far less amount of time. Labor costs for many construction skills are already inexpensive, so others believe that there is no hurry to automate many applications and functions that manual labor provides to the industry.

New innovations that create more efficient projects for owners and contractors do make sense to pursue once they are proven to effectively save time and money or they provide safer working environments. The industry is currently at a vulnerable point where the adoption and pursuit of new technologies comes with cost and risk, but the industry as a whole must join together to spread the cost and risk of implementing new methods and processes.

6.2 Needs of the Construction Industry

At this time, the CII has started the ball rolling in evaluating the "needs" and applications of RFID in construction, however it is only a start to a revolution (RFID revolution) whose applications seem limitless. Increasing industry awareness and collaboration is key to marketing a product that one-day will be economically feasible and will efficiently produce construction projects at lower costs, in shorter amounts of time, and more safely. The initial sacrifice of costs, risks, and reliance on automation may lead to future developments in construction industry standards.

Industry leaders should think in terms of RFID concepts, economic potentials, and risks or challenges that may limit the use of RFID in construction. First materials suppliers, contractors, and owners must form ideas and applications of RFID that

economically make sense, and then they must evaluate the cost and risks associated with implementing these concepts.

To make RFID a reality in construction, construction contractors, project owners, and material suppliers must examine where RFID has the potential to replace existing construction processes. Contractors and material suppliers need to investigate processes that already use identification technologies (bar codes for example) and determine if RFID is a better fit, and owners need to take an active role of implementing RFID on construction projects. As discusses throughout this report, RFID systems do not have the same limitations as other identification and information technologies, so their applications may provide a greater benefit than today's tracking systems. (CII, 2001)

7. Conclusions and Recommendations

Despite the growing RFID market, the construction industry has yet to adopt methods of construction that utilizes RFID technologies on the jobsite. Lack of standardization, high costs of implementation, slow technology development and deployment risks, and the elimination of unskilled labor are all contributors currently preventing the adoption of new RFID technologies in the construction industry.

Pilot studies have proven that RFID is an effective method of reducing project activity times and saving project costs. However, project owners and construction managers have not yet comprehended the benefits of using RFID. As RFID technologies develop the cost of RFID equipment and software will continue to become more affordable to all industry users. Just in the last four years the price of RFID tags has shrunk by 75%. Besides, RFID systems require no maintenance and can be used repeatedly.

The benefit that RFID offers the commercial construction industry far outweighs the initial start-up costs, the costs associated with training and implementation of RFID on the worksite. RFID can benefit the construction industry with applications in materials management, tracking of tools and equipment, automated equipment control, jobsite security, maintenance and service, document control, failure prevention, quality control, field operations, and construction safety. In fact, pilot tests have shown that complete ROI can be recovered in a matter of months. There is also data to support an estimated 3-5% reduction in costs with the use of RFID (Kay, 2003). Contractors need to understand and take advantage of the timesavings and lower rework costs that RFID systems ensure.

Pilot studies in construction have also illustrated that workers are interested in the new technology and are not concerned that their job functions will be one day replaced by

automation. Furthermore, the complexity of construction projects makes it impossible to have completely automated construction, however construction processes and methods that implement the use of automation have the potential to complete projects more efficiently.

Future case studies and project RFID sampling are needed to increase contractor and owner awareness of the potential savings of human life, project-scheduling times, and project costs. However, the construction industry must be the collaborative driving force behind the development of construction RFID technologies. The industry as a whole must determine today where RFID is applicable so that together they can overcome current limitations and produce transponders with greater read ranges, systems with cheaper implementation costs, and tags with increased durability in the future. Business proprietorship is a major issue in construction; therefore, one must be willing to sacrifice an initial investment to reap the potential benefits of RFID. Further testing of RFID in construction will make contractors and owners more familiar with their applications and with familiarity comes adventure. Once contractors start adventuring into the potential that RFID has, the greater the construction industry will benefit.

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