Material Management Using Radio-Frequency Identification (RFID) in the Construction Industry

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Abstract

The advent of Radio Frequency Identification (RFID) technology has created new opportunities for improving the material management function in the construction industry and is starting to provide major improvements in the efficiency of the material management process. The objective of the research reported herein was to introduce the benefits of RFID technology on material management in the construction industry .RFID technology is discussed and various aspects of this technology are investigated. Potential RFID applications on material management proposed by Construction Industry Institute (CII) Breakthrough Strategy Committee (BTSC) and Fully Integrated and Automated Technology (FIATECH) are spelled out. Finally, business analysis of RFID to estimate its impact is provided. It is concluded that there is a significant potential for improvement of material management function in the construction industry through the use of RFID.

Keywords : Radio-frequency identification, RFID, Bar Code, Materials Management, CII Model Plant

1. Introduction

On construction sites, materials management is a very difficult task because there is no way to efficiently keep track of materials ordered, received, used, and returned. Because so many materials are handled and stored on construction sites, it is very difficult to organize and update information on the materials residing there.

Traditionally, a manual approach has been used to count and check delivered materials. Not only is such a system prone to error, but additional time and effort are needed to physically locate materials when they are due to be installed, which may occur months after their delivery. Furthermore, at the time of installation, both the contractor and the owner have to verify that the materials have been installed and physically input that information into the project's status reports.

Looking up the necessary information to properly install or service plant-operating equipment also consumes significant time, both during the installation and over the operating life of the equipment. Operators and field engineers spend hours each month recording and reporting the number of hours that each piece of equipment is in use. Assessing the maintenance and service requirements of the equipment expends both operator and maintenance-personnel man-hours and can result in costly facility downtime.

Unavailable, dislocated or, "not trackable" materials have crucial impact on the performance of continuous construction site operations. As such, materials management functions may require up to 40% of a field supervisor's time and in many projects, too much of the craft workers' time. With foremen spending their time for searching materials and tracking/expediting purchase orders, their crews may be left unsupervised and control of labor productivity and safety may be lost (Bell & Stuckhart, 1985). Furthermore, unsuccessful searches for materials may force foremen to reassign workers, which may take more time than the task itself. Understanding the materials flow helps to increase labor productivity, reduce bulk materials surplus, and reduce materials management manpower (Bell & Stuckhart, 1986).

Up to dates, bar code is being regarded as the technology that improves current inefficient management process on a construction sites. In fact, many research activities are focus on the applications of

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bar codes and its potential impact in the construction industry. However, bar codes, the standard means of identifying and tracking products at the present time, being replaced by small, intelligent tags which are powered by radio-frequency signals. Though bar-code technology triggered a revolution in automatic identification systems when it was introduced, its applicability is limited by low storage capacity and the fact that only one-way communication is possible (Finkenzeller, 1999). RFID technology, on the other hand, offers the capability of storing large volumes of data and enables two-way communication. RFID technology has advantages over bar code such as (1) non-contact communication, (2) non-line-of-sight communication, (3) expanded data storage, (4) writable capability, (5) ease of incorporation in automated systems, (6) readability from the sunlight and (7) durable form the harsh environments like construction site (Jaselskis et al., 2000).

The advent of RFID has opened a new door of opportunity for improving the materials-management process in the construction industry and is starting to provide major improvements in the efficiency of the materials-management process. The use of RFID installed by manufacturers or fabricators of equipment and prefabricated bulk materials can theoretically save a significant number of man-hours and capital costs while potentially increasing productivity and reliability. Possibilities for improvements due to use of RFID technology include facilitating communication and availability of key information, enabling automatic inventory control by electronic means, and incorporating into the construction enterprise automatic self-monitoring and reporting of operating performance and wear of materials and equipment. The aim of the research reported herein is to introduce RFID technology, illustrate its potential applications and identify its impact on the construction industry.

2. Description of Radio Frequency Identification (RFID)

RFID is defined as an electronic labeling and data-collection system using RF signals to identify and track items without separating or scanning individually tagged objects (Nocero, 2001). With the rapid progress in information technology (IT), the development of RFID continues to yield wider reading ranges, larger memory capacity, and faster processing. Such advancements will ultimately bring down the cost of RFID and pave the way for the industry to adopt this technology on a grand scale.

The main benefits of RFID systems are elimination of manual data entry, support of automation solutions, contribution to building of an information-management structure, the ability to read through most materials (except metal), integration of business-process flows, the capability of being reprogrammed, and amenability to use in harsh environments (d'Hont, 2000). RFID systems can be used for materials management and materials identification. When used to manage materials, RFID systems facilitate supply-chain management and interactivity. RFID systems used in materials identification decrease the time spent in identifying products and enhance real-time control of access to materials.

According to the Venture Development Corp. (VDC), the overall market for radio-frequency identification will grow from $890 million in 2000 to about $2.65 billion by the year 2005 (VDC, 2002). Furthermore, the RFID market is poised to grow more rapidly as technology advances and industry standards coincide with economies of scale.

2.1 Components

An RFID system commonly consists of tags, which store the data in suitable transponders, and an RFID reader, which retrieves data from the tags at an appropriate time and place for particular applications (Jaselskis et al., 2000).

While bar codes can store only 20 characters, RFID is capable of handling up to 1 megabyte of data, which translates into 500,000 characters. The data in RFID tags serve not only as means of identification but also include the location of each item to be used in

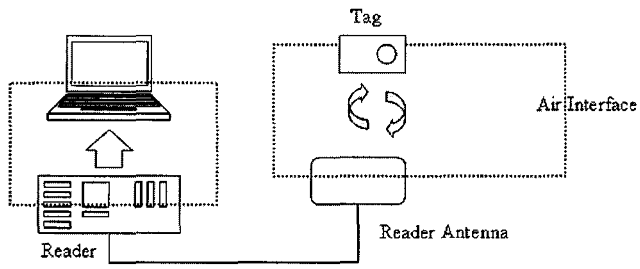

Figure 1. RFID Process and Components

an automation process together with instructions for its operation (AIM, 2001). Figure 1 shows the RFID process and components.

2.1.1 RFID Tags

RFID tags are classified as either passive or active, depending on the methods by which the devices derive their power. Active tags have internal power and are rewritable. They offer long reading ranges, considerable memory, and better noise protection. However, active tags are expensive, have a short lifetime, and are large in size compared with passive tags. Passive tags derive their power from the

RFID reader and are therefore lighter, smaller, and less expensive than active tags, and their operational lifetime is unlimited (AIM, 2001).

2.1.2 RFID Reader

The RFID reader, which communicates with the tags and facilitates data transfer, will differ from one system to another, depending on the type of tag used (AIM, 2001). A reader typically contains a transmitter and receiver, a control unit, and an element that couples it to the tag (Finkenzeller, 1999).

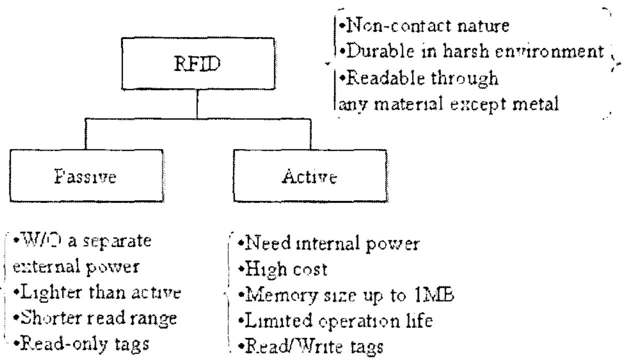

Figure 2. Characteristics of RFID Tags

2.2 Reading Range

The reading range is determined by the power available at the reader and the tag. Active tags with embedded power typically have a wider reading range than passive tags. In addition, environmental conditions and the configuration of the structure being read may significantly affect the range (Jaselskis et al., 2000). Generally, active tags can be read at distances of up to 20 meters from the reader, while passive tags can be read up to 2 meters away.

2.3 Operating Frequencies

There is a trade-off between reading range and the cost associated with the frequency band. Low-frequency bands, with a bandwidth of 100 to 150 kHz, are inexpensive and offer good penetration through physical obstacles, but they have short reading ranges and low reading speeds. High-frequency bands, with a bandwidth of 10 MHz to 5.8 GHz, offer long reading ranges and higher reading speeds, but they are expensive and require that the tag be within the line of sight of the reader (Hill, 2000). Figure 3 shows the characteristics surrounding operating frequencies.

2.4 Current RFID Applications in the Outside of the Construction Industry

The main areas of RFID application are security, transportation, manufacturing, agriculture, and supply-chain management. According to the Venture Development Corp. (VDC), security and access control are the most popular applications, accounting for 33% of total use. Transportation and supply-chain management occupy second and third place, at 30% and 20%, respectively (VDC, 2002).

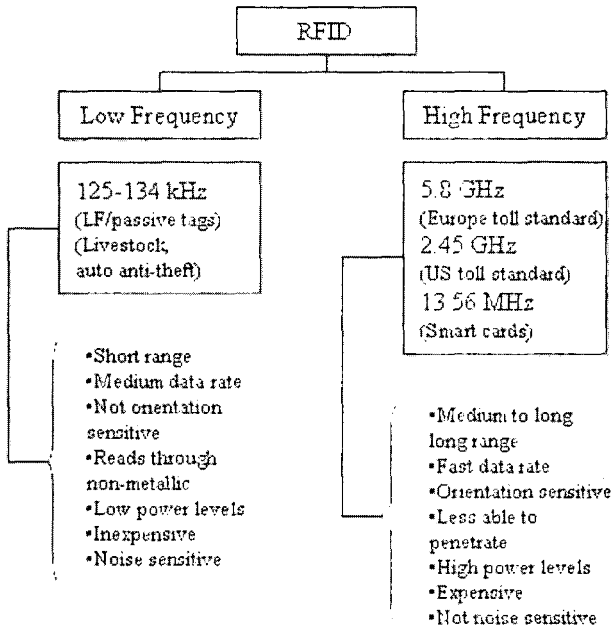

Figure 3. RFID Operating Frequencies

2.5 Limitations of RFID

2.5.1 Standardization of RFID Systems

One limitation of RFID is the lack of standards. Currently, there is no agreement among manufacturers as to the configuration of RFID systems. The proprietary nature of RFID technology means that one manufacturer's reader may not be able to decode information that has been encrypted into tags produced by another manufacturer. This poses a problem when contractors need to track or identify products supplied by several different subcontractors (Jaselskis et al., 2000). However, industry standards are presently being discussed which would allow chips from one manufacturer's reader to communicate with tags produced by another firm (Maloney, 2001).

2.5.2 Non-Transmissibility through Metal

While bar codes have to be within the line of sight of a bar-code reader, RFID can transmit through any material, with the exception of metal (Jaselskis et al., 2000). This exception is a serious drawback in the construction industry, where metal is in heavy use.

2.5.3 Reading Range

Usually, active tags can be read up to 20 meters from the reader and passive tags can be read at distances of up to 2 meters. While efforts to increase the range are ongoing, the nature of the construction industry demands even greater reading ranges than are currently under consideration. This limitation militates against the use of RFID in certain applications (Jaselskis et al., 2000).

3. Potential Applications on Material Management Using RFID Technology

In the construction industry, the potential applications for RFID are enormous and extensive. The study conducted by a CII RFID research team suggests that RFID technology may assist in streamlining the material management process in the construction industry (Jaselskis et al, 2000). However, this study did not envisage detail outline of implantation of RFID technology on material management. In this section, this paper describes the Intelligent Jobsite concept using RFID technology on material management in the construction industry proposed by Construction Industry Institute (CII) and Fully Automated and Integrated Technology (FIATECH). The Intelligent Jobsite concept using RFID technology is the vision of a fully sensed and responsively controlled work site. It enable the construction industry to define materials, equipment, tools, labor, and inspections needed, to define the

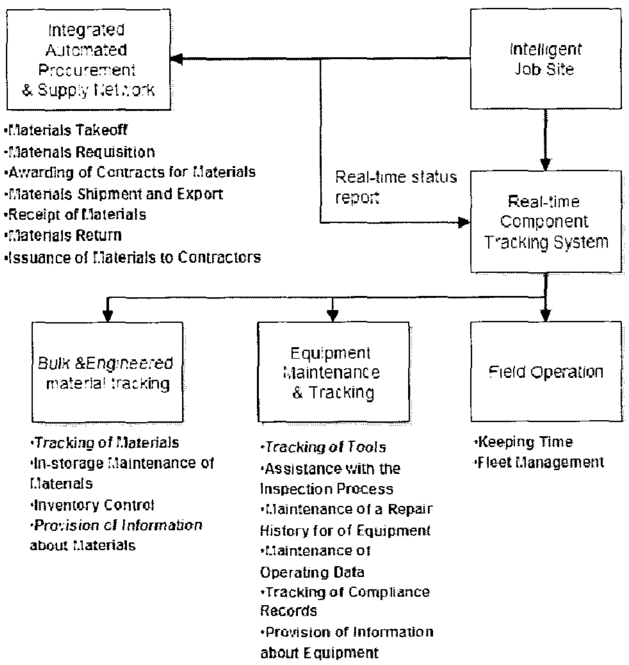

Figure 4. Illustration of the Use of RFID on Material Management

schedule, the work processes, and the resources required and to provide full and current knowledge of the location and status of all materials, workers, equipment, and other resources on site. The site management system will link to the procurement system to provide automatic resource inventory monitoring and reorder as well as continuous reporting of progress against the plan. The Intelligent Jobsite concept using RFID is consisted of (1) Integrated, Automated Procurement & Supply Network and (2) Real time Component Tracking System. Detailed description of theses components will be followed (Figure 4).

3.1 Integrated, Automated Procurement & Supply Network

RFID may be the breakthrough technology needed to improve procurement and supply network in the construction industry. Correct material handling is necessary for effective logistics management. Particularly, just-in-time (JIT) management on job sites can help to raise productivity levels (Pheng & Chuan, 2001). Lean production techniques allow to supply the right amount of materials at the right time and in the right place (Tommelein et al., 1999). The JIT concept asks for zero storage and no waiting or inspection times. The successful completion of a project step depends on the effective coordination of supply network and procurement.

With RFID, every item that contributes to the construction process (whether bulk material or a component of a piece of equipment) in essence carries its name around within itself and is able to identify itself to RFID reading devices. Receipt, inventory control, and progress statusing can all be greatly simplified if the appropriate databases are automatically updated and real-time status report is generated when they sense a signal emitted by one of these RFID tags. Real-time status report is instantly and automatically sent to the supplier and contractor and it would give a change to expedite and improve the process of procurement. Potential areas of improvement in procurement and supply network within the construction industry that would accrue from the use of RFID includes: Materials takeoff, Materials requisition, Awarding of contracts for materials, Materials inspection, Materials shipment and export, Receipt of materials, Issuance of materials to contractors, and Materials return.

3.2 Real-Time Component Tracking System

RFID technology can be used in construction environments to identify and track tagged items more effectively than other automatic identification approaches, such as bar codes and infrared technology. Similar to tracking cell phone location, the underlying concept of this technology for identification and tracking is that a number of interconnected readers interrogate over a shared channel a large number of RFID tags when in a certain range and retrieve their identification and programmed information. Triangulation using time-of-flight and received signal strength are the most common approaches to estimating range between a RFID tagged object and multiple readers. One of outstanding examples of real-time component systems is NIST component tracking system. As part of a research project ("Real Time Construction Component Tracking System"), the National Institute of Standards and Technology (NIST) is investigating the use of RFID tags for automatic identification of structural steel components on construction sites.

The NIST component-tracking system consists of RFID, portable computers, wireless communication, and real-time 3D measurement systems. Encoded information embedded in RFID tags for individual objects is scanned directly into a portable computer and is then transmitted to a wireless, remote, temporal project database (a repository of transient information associated with items anticipated to be on site, along with reference pointers to 3D part catalogs. The temporary database returns a 3D CAD model, including ancillary information such as a visual description of unique fiducial points. Field personnel acquire the positions of key fiducial points by using a coordinate-measurement device. With these data, an off-premise localizer determines the object's position and orientation in the job-site coordinate system.

3.2.1 Bulk and Engineered Material Tracking

Materials and installed equipment for a construction project comprise three categories (Halpin et al., 1987); off-the-shelf, long-lead bulks, and engineered items. Off-the-shelf materials such as pallets of bricks are often ordered by the constructor on site, normally available at the short notice and stocked on an inventory-level basis in the project warehouse. Long-lead bulk materials are ordered by a procurement office that is part of either the engineer's or project manager's organization, and fabricated based on drawings and specifications provided and delivered by a vendor. Typical items are bent reinforcing rebar, piping spools, and structural steel components. Engineered items are ordered by the procurement office as well, but they require the vendor to perform the detailed design of the component using performance specifications. Typical engineered items are pressure vessels for a chemical process plant. The different categories of materials and installed equipment vary in costs, delivery lead time, and interchangeability. Generally, engineered items are available at higher costs in smaller quantities with unique properties than long-lead bulks and off-of-shelf items, thus implying longer lead time and requiring more front-end planning (Tommelein, 1998). On the other hand, the availability of long-lead bulks and off-the-shelf items is of concern to short-range planning and execution of the work at the crew level. The work package planning by crews involves the responsible foreman identifying complete resource requirements for each task and verifying the availability of those resources. Subsequently, warehousing personnel find the requisite items, select, sort, and mark the items for the crew, and preposition the materials in the crew's work area during an off shift. This ideal approach is seldom achieved in a practice.

RFID can provide assistance in the tracking of bulk and engineered materials such as pipe spools and in the handling of certification for mechanical equipment. Use of RFID could bring about considerable savings in both time and money needed for location and tracking of bulk materials. In the Bechtel Red Hills Pilot test by CII, for example, the time spent on location and tracking of pipe was reduced by 30% as a result of the use of RFID (Jaselskis et al, 2000).

3.2.2 Equipment Maintenance and Tracking

The construction industry could benefit from use of RFID to collect information during the operation of mechanical and electrical equipment (pumps, motors, air compressors, etc.) that is commonly incorporated into capital-project facilities. In addition, manufacturer-installed RFID could contain installation, maintenance, and servicing instructions accessible by simple hand-held readout devices, eliminating much of the cost of data transmittal, filing/archiving, and searching for information that accompanies servicing activities.

Potential applications of RFID in this area are including: Tracking of tools, Assistance with the inspection process, Maintenance of a repair history for each piece of equipment, Maintenance of operating data, Tracking of compliance records and Provision of information about equipment.

3.2.3 Field Operations

- Keeping Time: RFID tags embedded in workers' hard hats can be used to track their hours worked. Cost savings in the form of reductions in manual data entry and tracking costs can be realized (Jaselskis et al, 2000).
- Fleet Management: A field inspector can easily check and update maintenance records of equipment and vehicles equipped with RFID tags (Jaselskis et al, 2000).

4. Business Analysis of RFID Technology in the Construction Industry

Up to date, there is no study to reveal RFID technology impact to the construction project. It is very hard to estimate its impact because currently there is no construction site which RFID technology is applied on a whole process. The benefits associated with new technology including cost impact is hard to predicted because resource requirements, task durations, organizational structures and information flow are all significantly impacted by the implementation of technology (Back and Bell, 1995). However, it should give sense to construction industry how RFID technology would impact on construction process in terms of cost. In this section, total saved cost is estimated in order to demonstrate the impact of applying RFID technology to the pipe fitting process. Even though pipe fitting process is not representing whole construction project, but it may give understanding on RFID technology impact.

4.1 Basic Assumptions

The basic assumptions that have gone into this business analysis are based on data from CII pilot test. RFID was applied to the process of receiving materials such as pipe supports and hangers at the Bechtel Red Hills Project, a $338 million construction project. Bechtel had collected data using the manual approach and it shows that the average time to unload one hanger is 1.07 minutes, the average time to receive the pipe hangers and supports is 2.42 minutes and the average time to enter the data into the Bechtel PTS is 0.56 minutes (Jaselskis et al., 2000).

With RFID approach, an RFID tag, attached to the pipe supports at the fabrication shop with data of materials, was verified through RFID reader instead of manually recording information on the site. The information is then uploaded into Bechtel's PTS, producing a material-receiving report.

Thanks to the benefits of RFID, approximately 159 minutes was saved in the receiving process for every 100 hangers, representing a 30% savings of time for that process alone (Table 1) (Jaselskis et al, 2000).

Thus the business analysis of pipe fitting that is outlined in this paper is based on the following data:

The estimates of welding costs presented in this paper are based on the following data, which combine the scope of the CII Model Plant project, a hypothetical installation valued at about $85 million that is to be constructed in 78 weeks, with basic data on labor and equipment costs taken from R.S. Means (2002):

- Number of hangers: 12,514 (CII Model Plant Project)
- Bare wage of skilled pipe fitter: $26 per hanger (R.S. Means, 2002)

4.2 Cost for Pipe Fitting

The bare wage of a skilled pipe fitter is $26 per hanger (R.S. Means, 2002). Once overhead is figured in, the cost of labor rises to about $36.87 per hanger (R.S. Means, 2002). Thus the total labor cost of pipe fitting in the construction of the CII Model Plant is about $0.46 million.

Table 1. Comparison Chart between RFID and Manual Approach

Activity	Manual (Min)	RFID (Min)	Time Savings	
Unload 100 hangers	107	107	0	0%
Verify 100 hangers	365	242	123	34%
Enter 100 hangers into PTS	56	20	36	64%
Total time required	528	369	159	30%

4.3 Expected Saving from RFID Technology

The total labor cost of pipe fitting for the CII Model Plant project is about $0.46 million (Table 2). And expected saving cost from RFID technology is 30% of total cost of pipe fitting (Red Hills Project), $0.13 million for only pipe fitting process. Pipe fitting process is only small part of whole construction project, but we may understand on RFID technology impact after RFID technology is extensively used. However, this research identified the impact of RFID technology on receiving process of pipe materials. Inventory control, progress and inspection process can also be simplified and accurate than that of traditional manual process if the appropriate database is automatically updated when they sense the signal emitted by one of RFID tags. RFID

Table 2. Total Direct Cost of Pipe Fitting

Bare Wage of Skilled pipe fitter: $26 per Hanger	$26.00
Worker's Compensation insurance	
Average for U.S.: 18.7%	$4.86
Incremented Employee Cost per Hanger	$30.86
Average Fixed Overhead	
Federal and State Unemployment Insurance Costs: 7.0%	$0.18
Social Security Taxes (FICA): 7.65%	$1.99
Builder's Risk Insurance Costs: 0.3%	$0.08
Public Liability Costs: 1.55%	$0.40
Incremented Employee Cost per Hanger	$33.51
Other Overhead Costs	
Average for U.S.: 10% (depends on factors such as the contractor's annual volume and staff requirements)	$3.35
Incremented Employee Cost per Hanger	$36.87
Number of Hangers	12,514
Total Labor Cost	$0.46 M

Sources : R.S. Means(2002) and CII Model Plant Project technology would bring reliable location estimates, object tracking, and state sensing for machinery and processes which improve project control's sophistication and response time for quantity tracking, maintenance, and productivity determination to the construction industry.

5. Conclusion

Because of the rather large size of most construction sites and the need to handle literally thousands of items in the construction process, materials management has been regarded as one of the most difficult tasks faced by the construction industry. One area of technology that affords an opportunity for bringing about radical improvements in the materials-management process is Radio Frequency Identification (RFID). Overall, the market for RFID is expected to grow to about $2.65 billion by the year 2005 (VDC, 2002).

RFID technology offers a number of advantages over the use of manual techniques for the handling of materials on construction sites, such as elimination of manual data entry, facilitation of automated solutions to the kinds of problems that crop up on construction projects, opening up of possibilities for development of an underlying information-management structure, the capacity to "read right through" most materials (metals being a major exception), integration of various business-process flows into a single information-management system, the capability to reprogram the materials-identification process as needed or desired, and the capability of being used in harsh environments (d'Hont, 2000).

The CII BTSC has joined with CII FIATECH in forming a consortium to find the solution of limitations and expedite the use of RFID technology in the construction industry. In order to facilitate standardization of RFID technology and generate widespread awareness of RFID applications that would benefit the industry, the consortium includes owners, contractors, and suppliers.

It would seem that there is a significant potential for improvement of productivity in the construction industry through the use of RFID. Because of the many advantages of this technology, it should be only a matter of time before RFID sees wide use in the construction industry.

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