Radio Frequency Identification (RFID) and the Lean Construction Process

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Abstract

The demand for increasing efficiency in project delivery has stimulated the exploration of new technologies which may be implemented to improve productivity of construction work. One particular technology that has recently drawn the attention of the industry is Radio Frequency Identification (RFID) and its possible applications within the construction arena. RFID technology as applied to the construction industry is still in its infancy. While building on past successes, as revealed in the limited number of research studies, exploration of new uses continues. There are, obviously, many uses for RFID technology in the construction arena. Each of these uses is aimed at utilizing ones resources in a more efficient manner and streamlining the project management process. Some of the uses are (1) personnel tracking and safety, (2) material handling and yard management, (3) tool or equipment tracking, (4) theft deterrence, and (5) integration with BIM.

The purpose of this study is to explore the different uses of RFID technology in the construction industry and how these integrate with the Lean Construction Process. The case study methodology will be utilized to investigate how contractors are beginning to utilize the technology to increase efficiencies within the industry. By analyzing actual contractor’s use of this technology through the case study method, the industry will become more and more aware of and familiar with the technology, its applications and projected benefits.

Keywords: radio frequency identification, RFID, lean construction, technology, construction technology
1. Introduction

Radio Frequency Identification (RFID) is not a new technology. Its use dates back as early as World War II when it was used for friend or foe recognition for anti-aircraft gunmen. RFID is a versatile technology and is put to a wide variety of uses, such as security for retail stores, tracking transfer bags at airports, managing inventory and theft in manufacturing plants, electronic cashless payment cards, and electronic car keys (ERA Build, 2006). Its use has become so prevalent that some speculate that RFID will universally replace barcodes in the not too distant future (Hock, 2009). The use of RFID technology is slowly creeping into the construction industry as an innovative tool in supply chain and inventory management. Its adoption and implementation into a historically obstinate American construction industry has been slow, but as prices on tags continue to fall (as low as 5 cents) it is reasonable to expect that the industry will begin to take advantage of all that Radio Frequency technology has to offer (ERA Build, 2006).

Lean construction or Lean Project Delivery (LPD) is an innovative planning, design, and operational philosophy. It has been championed by co-founders of the Lean Construction Institute, Gregory Howell and Glenn Ballard, since the early 1990s (Post, 2007; ENR, 2007). Lean construction was inspired by lean production methods developed by Japanese automotive manufacturer, Toyota. The lean production initiative was headed by engineer Taiichi Ohno whose pioneering methods were primarily concerned with the elimination of waste and inventories. He was a student of Henry Ford, but saw too much waste in his operations and focused on perfecting the design of the production system: thereby decreasing defects and the need for re-work. Ohno disagreed with the production at all costs mindset and empowered his workers to make decisions (even stopping the assembly line upon receipt of a defect) requiring less management personnel. Lean production consist of four basic principles which have been modified and applied to the construction industry: (1) identify and deliver value to the customer, eliminate anything that doesn’t add value; (2) organize production as a continuous flow; (3) perfect the product and create reliable flow through stopping the line, pulling inventory, and distributing information and decision making; and (4) pursue perfection (Howell 1999).

2. Background of the problem

The construction industry is based on firms’ ability to constantly improve efficiency and productivity in order to survive in a competitive environment. New techniques and methods are constantly crafted and applied to the industry, from better equipment and machinery to highly detailed scheduling software. Lean Construction principles and Radio Frequency Identification are two such innovations and can vastly improve operational efficiency and productivity (Park, 2005).

Radio Frequency Identification (RFID) technology is an automatic identification technology that utilizes radio frequencies to transmit data. RFID involves the use of tags, also called transponders, which contain a portable, modifiable database which is capable of receiving data from and transmitting data back to a reader. Radio Frequency Identification is a sister technology to bar code labels and scanners. Bar code labelling is often seen in use on construction sites as well, but RFID
now performing some of the same tasks (Jaselskis & El-Misalami, 2003). Some predict that bar code technology will soon be obsolete (Mokhoff, 2008). RFID tags are able to withstand harsh treatment and environments and are now cheaper than ever with some priced as low as five cents (ERA Build, 2006; Atlas RFID, 2009). Due to their becoming more durable and cheaper over the last decade it is expected that RFID technology will quickly become more prevalent in the construction industry (Anderson, et al., 1995). RFID tags can be placed on any resource and track it throughout the entire construction process.

Lean construction is a production management-based approach to project delivery that focuses on maximizing value and minimizing waste through collaboration and teamwork in job planning, design, and management (Ballard & Howell 2007). The lean philosophy can be applied to any type of construction, but it is particularly useful on complex, uncertain and quick projects. It challenges the belief that there must always be a trade between time, cost, and quality (Howell, 1999). Lean construction encourages teamwork and a willingness to shift burdens along the supply chain. The problem with the current method of job design, planning, and management is that production systems do not operate well when every person tries to optimize their performance without understanding how their particular job affects the rest of the activities on-site. The current method focuses on speed of production at all costs. Lean construction focuses on managing dependencies and variation in production rates and supply of materials throughout the production system. Managers can minimize waste and maximize customer value through management of variation, dependencies, and backlogs; thereby increasing productivity and efficiency (Ballard & Howell 2007).

3. Purpose of the study

The purpose of this study is to examine what strategies involving lean construction principles and Radio Frequency Identification technology construction firms are employing to become more efficient and productive. All construction firms are interested in gaining a competitive advantage through efficiencies in cost and time. The findings of this study are meant to make the construction industry, academic and non-academic, aware of methods that are improving the way the industry operates (Coady, et al., 2008).

There is a general lack of academic literature incorporating both lean construction initiatives and RFID technology (Coady, et al., 2008). Some studies have been written solely on the lean construction principles and methods and some focus only on RFID technology. It would be beneficial to the construction field to expose a range of issues and situations in which RFID and lean construction philosophies can be applied to the industry. This study aims to combine the technological and philosophical aspects of RFID and Lean to provide general contractors with ways to increase productivity in their company operations.
4. Lean construction

Lean construction has been in existence since the early 1990s when Gregory Howell and Glenn Ballard became enamored with the lean philosophy that Toyota Motor Corporation used to gain a competitive advantage in the automotive industry under engineer Taiichi Ohno (Post, 2007; ENR Staff, 2007). Howell and Ballard converted Toyota’s manufacturing practices into a philosophy that could be applied to the construction industry which they aptly dubbed lean construction (Howell, 1999).

Lean construction, in essence, is the process of minimizing waste through increased collaboration, predictability, innovation, and accountability (Post, 2007). It includes contractors in the design phase, which helps facilitate collaboration among the parties involved with the building process. Therefore, questions can be asked and conflicts can be resolved before construction begins (ENR Staff, 2007). Lean Production Design also focuses on the way the work itself is actually planned and managed. If the planning system is under control, managers can control inventories and excess capacities of labor and/or materials and avoid causing variation in work flow (Howell, 1999).

5. RFID

Radio Frequency Identification technology has been in use for over 70 years in a wide variety of ways, but it has not been in use in the construction industry for long (ERA Build 2006). The oldest literature found on RFID’s possible influence on the construction industry is journal article by Anderson, Jahren, Rodriguez, and Njos titled Radio-Frequency Identification Applications in Construction Industry written in 1995.

Radio Frequency Identification (RFID) is an automatic identification technology that utilizes radio frequencies to transmit data. RFID involves the use of tags, also called transponders, which contain a portable, modifiable database which is capable of receiving data from and transmitting data back to a reader. The reader and the tag must be within a designed range of each other to operate properly (Anderson, et al, 1995).

There are two distinct types of tags; passive and active. A passive tag is one that lacks a battery supply and therefore must be activated by the emission of a specific frequency from a reader. Passive tags have an unlimited life and are usually smaller, lighter, and cheaper than active tags, but also have a shorter range or operable distance from the reader. Active tags are those which operate on a limited battery supply and intermittently emit a frequency to be interpreted by a reader. Active tags have longer reading ranges and can store more data, but are relatively large, heavy, and expensive compared to passive tags (Taylor et al., 2009). Passive tags have a shorter reading range than active ones because they operate on a lower frequency. As the operational frequency of the device increases, the distance at which the tag can be read increases and so does the speed with which the information will be exchanged between the tag and the reader. A low frequency tag operates at around 120-135 kHz and an extremely high frequency tag operates at about 2450 MHz (Taylor et al., 2009).
The applications of RFID in the construction industry continue to expand. Active tags have been cast in concrete to monitor the temperature of the mix and provide workers real-time temperature readings, which aids in monitoring the curing process (Gaudin, 2008). Some within the industry are tagging job-site equipment with high-frequency active tags in order to monitor its location, deter theft and locate equipment should it be stolen (Gaudin, 2008). Worker identification cards can be loaded with passive tags so that management can monitor an employee’s location on site. There is also evidence to support the idea that an employee’s productivity can be determined, to a degree, by their location on the jobsite throughout the workday (Jaselskis & El-Misalami, 2003). RFID technology can be implemented to record on-site inventory as it arrives, document where and when it was received, and locate specific items electronically as they are being installed (Taylor et al., 2009).

6. Case study

This specific case study pertaining to RFID applications within the construction industry was performed on a power plant expansion project constructed by Bechtel Corporation in the Northern United States. The expansion project consists of two coal-fired steam-turbine generating units, as well as supporting facilities, and related civil work. The contractor’s scope of work consists of engineering, procurement, construction, and start up. The project will cost an estimated $2.15 billion dollars, with construction scheduled from 2005 to 2010. Of the two units, one is scheduled to begin operation in 2009, and the second is scheduled to begin operation in 2010.

6.1 Materials management process without RFID

The materials management process for the project is comprised of a series of activities or processes that ultimately lead to the installation of a component into the facility. A majority of the steel and piping for the project was received on site via truck. Some components for the project were shipped by boat. Materials are delivered to the site along with a packing slip, which details the material item, where it came from, contact information, date of shipment, etc. Each material component comes with its own specific material identification code for the project that is written on the surface of the component. The entire receipt process and the entry of items into the materials management database was performed with a paper based manual method. The materials are accounted for and manually entered into the materials management database system, so that construction activities could be coordinated depending on the availability of materials.

As material components arrive at the job-site, they are taken to the lay-down yards and placed within a specific grid. Caldas et al. refer to this stage as “Sorting” (Caldas, et al, 2006). The components are grouped within grids according to characteristics and material identification code. Different groups of materials are assigned a color scheme. Specific colors and twisted combinations of colored flags are attached to the respective groups of materials for future identification and locating purposes.

Materials are stored in the lay-down yard until needed for installation. When a construction crew or trade is prepared to construct a certain portion of the facility, the necessary materials have to be retrieved from the lay-down yard. For this, a superintendent coordinates with a field engineer and
communicates the plans for assembling a certain area of the facility. The field engineer would generate a material withdrawal request (MWR), which listed all of the necessary materials that the superintendent’s crew needed in order to complete the specified scope of work. The MWR is sent to the Materials Management staff, where they develop a “pick ticket”. The pick ticket lists the materials needed, along with the respective lay-down yard and grid location of the component.

Workers would take the pick ticket to the lay-down yards and visually locate the materials that were needed for installation. Once located, the components were flagged, organized, and staged so that the pick-up process of those materials would be easier and more efficient. The materials would be loaded and taken to the construction area where they were turned over to the construction team. Once the materials had been turned over to the construction team, the receiving foremen would sign off on the materials to assure that they have received them.

6.1.1 Problems presented with the manual system heading

The issues presented for materials management on Bechtel’s power plant expansion revolve around the ability of personnel to locate and flag specific material items (flagging) so they can be organized for convenient pick-up and transporting. When materials required for installation are not ready at the time they are needed, installation crews become idle and non-productive, which can increase craft labor hours up to 16 - 18% (Torrent and Caldas, 2009).

The sheer volume of materials required on the construction site presented the materials management team with several problems. The $2.15 billion power-plant project is comprised of an incredibly large number of intricate components of steel, piping, and other structural and functional components. Individual piping pieces can become very difficult to identify when they are closely stacked together in areas of what can be thousands of square meters per lay-down grid.

The arrangement of the material yards is also a factor which can contribute to decreased efficiency in the flagging process, as well as the rest of the material management process. The farthest lay-down yard was almost three miles from the construction site. Therefore, minimal time spent at the storage yard was desired since it took a significant amount of travel time to get there and back.

Another factor affecting the material management process was the weather conditions. Extremely cold temperatures, combined with rain and snowfall, were the main areas of concern regarding severe weather that could affect construction productivity. The flagging process was made much more difficult after heavy snowfalls for the obvious reason that the materials would get covered in snow and the material ID codes must be uncovered, with shovels or by hand, in order to be properly identified.

6.2 Experience with automated systems and lean construction

Due to the problems associated with the manual tracking system, the decision was made by management to implement a full scale RFID/GPS based system for the entire on-site materials management process. ERA Build noted that long implementation time and difficulty in obtaining the
skills and knowledge on the technology can be key operational and technical barriers that face companies in adopting the technology (ERA Build, 2006). This was the company’s first full scale application of the technology. The decision to invest and employ the technology on a large scale was made less difficult, in large part, due to the company’s previous participation and involvement in pilot tests. Bechtel hosted an academic study pertaining to RFID technology on one of its construction sites in 2005.

Bechtel’s field test was performed over approximately three months on a twin-boiler project in Rockdale, Texas. Chief sponsors of the pilot were the Construction Industry Institute (CII) and FIATECH, and the research team was comprised of about two dozen individuals representing universities, construction firms, institutes, and technology vendors (Saywer, 2008). The field tests compared the times of the typical paper based manual method of locating steel items, to the RFID/GPS based automated method for tracking down components in the lay down yards. The trial results found that the average time taken to locate a specific component with the manual process was 36.8 minutes. The average time taken to locate materials with the automated method was 4.6 minutes. Also, when using the manual method, 9.52% of material components “were not immediately found,” compared to the 0.54% of the automated method. The research team regarded the success rate of the automated system to be quite significant considering the fact that the failure to locate critical items can lead to costly slowdowns, and sometimes even re-procurement (Saywer, 2008).

6.2.1 Lean strategies

Bechtel utilizes Lean management strategies throughout their business processes and construction projects. Lean aims to decrease the amount of defects, or errors, or failures that a company might encounter throughout its business processes. Lean aims to develop quantifiable business improvements via statistical analysis of data. The experience gained through the field study proved to be valuable for Bechtel, in regards to developing future applications. Not only did the field studies produce valuable data for statistical analyses, but the relationship that was gained with the technology vendor during the field tests, was able to be continued, and developed into a business relationship for their full scale implementation.

RFID technology fits well with the Lean production philosophy fulfilling all four of the goals previously mentioned. Utilization of the RFID material tracking system allowed the integration of the delivery, storage, stocking and supply processes through a single automated system thereby providing the client with a more productive and efficient materials management system.

6.2.2 Technological specifications: Tags and readers

The tags utilized in this full scale implementation were active RFID tags. These active tags continually “wake up” and send out their ID information at pre-configured intervals (i.e. every 1 second, every 2 seconds, every 10 seconds, etc.). The active tags are Ultra High Frequency (UHF), and they operate on a 915MHz frequency level. The lifespan of the tags is generally five years. The physical dimensions of the tags measure about 5 x 1 x .85 inches and weigh about 50 grams. Tags with these characteristics and reading ranges cost approximately $25(US) each.
The reading units utilized in this application were a combination of RFID reader and Global Positioning System (GPS) receiver. The readers were mobile, handheld computers, or personal digital assistants (PDA), suitable for field readings. The readers’ operate with Microsoft Windows. Approximately six handheld readers were utilized on the entire project; usually a team (i.e. iron-workers) would have its own reader which was designated for them each day. RFID/GPS readers such as those utilized in this study currently cost approximately $5,000(US).

The automated materials management process also used barcode scanners for association purposes. The scanners were mobile, handheld devices that utilize Bluetooth technology. The scanners operate on High Frequency (HF) radio waves at a 13.56 MHz frequency level. The scanners are rechargeable. The physical dimension of the barcode scanner is about 4.8 x 2 x 1.3 inches and weighs 132 grams (about 0.3 pounds). These barcode scanners currently cost around $450-$500(US). Server software is also required for the system and it cost approximately $35,000 - $50,000(US) depending on the software and the vendor.

6.3 Implementing the RFID/GPS based system

The RFID/GPS based materials management process was not implemented from the beginning of the project. It was only after the problems mentioned above arose, that the decision to implement the automated tracking system was made. At that time, around 65-75% of the materials for construction had already been delivered to the site. Having the majority of the materials on site meant that the materials management process would have to be retro-fitted with the technology. Roughly 6-10 employees were assigned the task of attaching tags to materials in the lay down yards, and associating those tags to the specific material piece in the management system. This project tagged 20,000+ unique material components with RFID tags. Approximately 12,000 tags were utilized for this project, as tags are reusable.

6.3.1 Attaching and associating RFID tags to materials

RFID tags were attached to the material components with plastic zip ties. Once the tags are attached, they must be associated with the respective material to which they are attached, for future tracking purposes. Some materials arrived on site with a barcode label that indicated the component’s material ID. Others did not have barcodes attached, and their material ID would be written on the exterior of the component.

If the material component had been delivered with a barcode label, then the association process becomes very simple and almost instant. The barcode label on the material component is simply scanned along with the barcode label on the RFID tag attached to it. The barcode scanner is able to instantly transmit the material ID and RFID tag’s ID into the RFID reading device wirelessly via Bluetooth technology. Once the material ID and tag ID had been input into the RFID reader, the worker could hit “associate” on the RFID reader to initiate communication with the tag while next to it, and that specific RFID tag’s ID would then be linked to the material component on which it was attached. Once the tag was associated, the workers would hit the “locate” button on the RFID/GPS reader, and the component’s latitude and longitude is stored in the reader. The tag had been
associated to the specific material component and now that specific material component was ready to be tracked. When items arrived with barcode labels, the association process, after the tag had been attached, was very simple, and completely automated. The association process takes approximately 10 seconds.

### 6.3.2 GPS mapping and RFID tag locations

Before the system was implemented, the lay-down yards throughout the site were geo-coded, mapped and entered into a geographic information system (GIS), which divides the yards into their respective co-ordinated grids. As Torrent and Caldas explained, GPS receivers can be set to transform collected systems into a coordinate system. The default latitude and longitude degrees for a global system can be transformed into a “local projected system” so that it “simplifies the implementation of the localization mechanisms by providing coordinates in fundamental units of length, such as meters (Torrent and Caldas, 2009). An image of the digital lay down yard on an office desktop easily identifies the material and its location in the lay-down yard.

### 6.3.3 Tag item location with RFID/GPS system

When there are a large number of material items, attaching individual GPS receivers to each piece of material has been deemed an infeasible option for the purposes of locating construction materials (Torrent and Caldas, 2009). Therefore, the project in this study utilized six RFID reading devices that were equipped with GPS receivers, and the material components were tagged with RFID tags. The GPS receivers are able to determine their own location at any given time. The active RFID portion of the reader could then be utilized with localization methods, which are algorithmic based location projections based on strength of signal and reader location, as described by Torrent and Caldas, for the projected locations of the RFID tagged components that were within reading range of the reader. Periodic updates are made in order to update the projected locations of materials.

### 6.3.4 Automated locating process

With the RFID/GPS system in place, the goal is to make the material locating (flagging) process much easier and faster. With the automated system in place, after the Engineer has developed a material withdrawal request (MWR), the materials management office staff generates a pick ticket packet which included a list of the required materials and each item’s specific yard and grid, as well as a supplemental image, which would give the workers the approximate location of each component within their respective grid, assigned by the GPS/RFID localization methods. The workers go to the correct lay down yard and grid, and go approximately to where the printed map had indicated the material’s location to be within that grid.

Once in the area, the workers utilize the RFID/GPS reader to narrow in and find the component. The reader could pull up two different modes for finding the items. The map view utilizes the GPS portion of the reader. The digital map of the yard can be displayed on the handheld screen and the GPS receiver will show where the employee is standing, and the projected location of the material. The employee’s positioning on the screen is represented by a blue dot, and the material component is
represented by a red dot. Another method was to set the reader into what was referred to as the Geiger counter mode. A Geiger counter is an instrument that can detect and measure radioactivity (Iovine, 2000). The Geiger counter mode of the reader allows the worker to communicate only with the specific tag that is desired. The Geiger counter can be utilized within 150ft proximity from the tagged components. As the worker moves with the reader, the GPS receiver determines and gathers information on the location of the reader. The RFID portion communicates with the desired tag, and the reader utilizes localization methods based on the positions of the reader (gathered by GPS), and the received strength of signal from the desired tag at those positions (gathered by RFID). A compass pointed the employee in the direction of the tag with which the reader was communicating. When the reader is within a couple of meters from the tag, the compass would change to a cross-hair and display the words “WITHIN RANGE”.

6.3.5 Performance of the system

The performance of the technology was satisfactory and it was noted that there were very few malfunctions. One issue of concern was whether or not the technology would perform in very cold temperatures. They found that the system worked down to -26 degrees Fahrenheit. Also, it was mentioned that at extreme temperatures below that mark, the readers were affected by the cold before the tags, so workers would warm the readers by means such as holding the readers inside their coats. Tags could easily be read through a couple of feet of snow.

Although the tags were durable, moving materials or placing heavy materials on top of each other can sometimes damage the tags. It was proven that if the outer shell of the tag has been damaged, but the internal battery and antenna device had not been affected, the tag maintained its readability function.

6.3.6 Results and future plans

Jim Rogers commented on the current standing of the automated system and the effects that RFID/GPS have had on the project: “We used all the (RFID) tools, and the application of LEAN to eliminate a wasteful flagging step. We now send the loading crew straight to the material rather than having another pair of people go ahead to make sure they can find the material, flag or identify it with colored ribbon, in order to optimize the loading crew’s time, and that of the crane. The quantified savings were centered on eliminating the flaggers, although many other benefits are known, e.g. schedule, supply chain risk, staging space savings.”

The RFID/GPS based system utilized on the project described in this case study will continue to be used by the company for upcoming projects of similar type. Two new projects will utilize the same technology are recently getting underway in Ohio and Illinois. In this case study, the automated system was retrofitted to the existing materials already on site and in the lay down yards, however, future applications will aspire to implement the system so that the materials will be tagged with RFID before they arrive on the project site. When commenting on further developments of RFID based solutions, and the processes that will be impacted and changed, Rogers noted: “The whole supply chain, from engineering through procurement, field material management, construction, and some selected components (that need maintenance) by the customer. We started with the greatest need,
with a compelling business case, and we will build from there.” The future goals will be to track different components throughout the entire supply chain, as well as while on site, and selected components that will need maintenance in the future, could also remain tagged with RFID after installation to facilitate easier identification for maintenance. To do this, it will require increased cooperation and coordination with suppliers, customers, and others involved in the supply chain process.

7. Conclusions

Although RFID technology solutions for the construction industry are still in the early stages of development, case studies are showing that custom solutions can be proven beneficial for some construction companies’ processes. Solid business cases for RFID based solutions that can be uniformly applied across the construction industry remain to be seen. This may be in large part due to the fact that each construction project will be unique to a certain degree, whether it is by size, complexity, life-cycle, geographic location, etc. Also, depending on the size and structure of a construction company, it may or may not be able to accommodate, and assign overseers for the adoption of a new technological system. Those companies that remain curious and open minded towards the technology will be more likely to realize potential benefits.

Materials management systems utilizing RFID technology may be further refined in the future if manufacturers are encouraged to place the tags on the materials during the manufacturing process. Materials ordered with RFID tags in place will truly be in line with the Lean construction process.

Another technology that may facilitate the transition from tracking field materials to in-place materials is in the area of building information modelling (BIM). As more and more projects are becoming BIM based, a natural progression will be to link the RFID solution to the BIM solution. This would mitigate the problems currently encountered with reading tags of in-place materials and the loss of data once a battery ceases to operate. If the owner receives an as-built model, the facilities management process can eventually be streamlined. This is truly in line with the lean construction philosophy.

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