Radio-Frequency Identification Applications in Construction Industry

By Edward J. Jaselskis,[1] Associate Member, ASCE, Mary Rose Anderson, Charles T. Jahren,[3] Member, ASCE, Yvan Rodriguez,[4] and Steven Njos[5]

Abstract: This paper provides information on radio-frequency identification (RFID) and its potential applications in the construction industry. RFID involves the use of miniature read/write transponders that are capable of storing data in harsh environments. These transponders can be used in situations where optical scanning is not practical because vision is blocked or because labels fall off or become unreadable due to dust, dirt, or other contaminants. The technology is currently used in several applications outside the construction industry (e.g., reading meters, preventing theft of store merchandise, tracking railroad cars and intermodal freight containers, collecting tolls, and performing agricultural and animal research), and is seen as having potential in the construction industry. Potential construction applications for RFID technology discussed here include concrete processing and handling, cost coding for labor and equipment, and materials control. Conceptual design systems for these applications are also considered and developed. Discussion of limitations of RFID technology for construction applications include proximity of equipment, nearby metallic objects, costs, and workforce attitudes. Conclusions are drawn regarding possible future impacts on construction industry.

INTRODUCTION

Radio-frequency identification (RFID) refers to a branch of automatic identification (auto ID) technologies in which radio frequencies are used to capture and transmit data. Automatic Identification Manufacturers, Inc., Pittsburgh (*AIM USA* 1993), describes RFID systems as those that read data from radio-frequency (RF) tags that are within the range of the RF-reading equipment. Data may be stored on the tag or transponder for the purpose of providing identification and other information relevant to the object carrying the tag.

The cost of buying and replacing tags has limited RFID applications to systems requiring a limited number of tags. However, new RFID technologies are being introduced that provide improved performance levels at lower cost. This makes RFID systems attractive to the construction industry, especially for applications such as concreting operations, cost coding for labor and equipment, and materials control. Other beneficial applications for RFID might also exist but are not covered in this paper.

RFID: General Description

RFID technology involves tags or transponders that can collect data and manage them in a portable, changeable database; communicate routing instructions and other control requirements to equipment; and withstand harsh environments. In certain applications, it outperforms other auto ID technologies. For example, in places where vision is blocked or where surfaces become dirty, it performs better than bar codes; physical contact is not required, which is an advantage that magnetic stripes and touch buttons do not have (Forger 1990). An RFID system consists of several components: tags (often reusable) mounted on a product (e.g., steel beams and air-conditioning units) or a product carrier (e.g., dump trucks and concrete trucks), an antenna or scanner (which interrogates the tag via an RF link), and a reader (frequently attached to the antenna). Tags are identified as either read-only or read/write. Fig. 1 shows a schematic diagram of a concrete truck being interrogated by a reader as it enters the construction site in order to obtain information about the truck and its contents. Data from the RFID tag could be expanded using a database program located on site due to the limited amount of information stored on a tag. Some

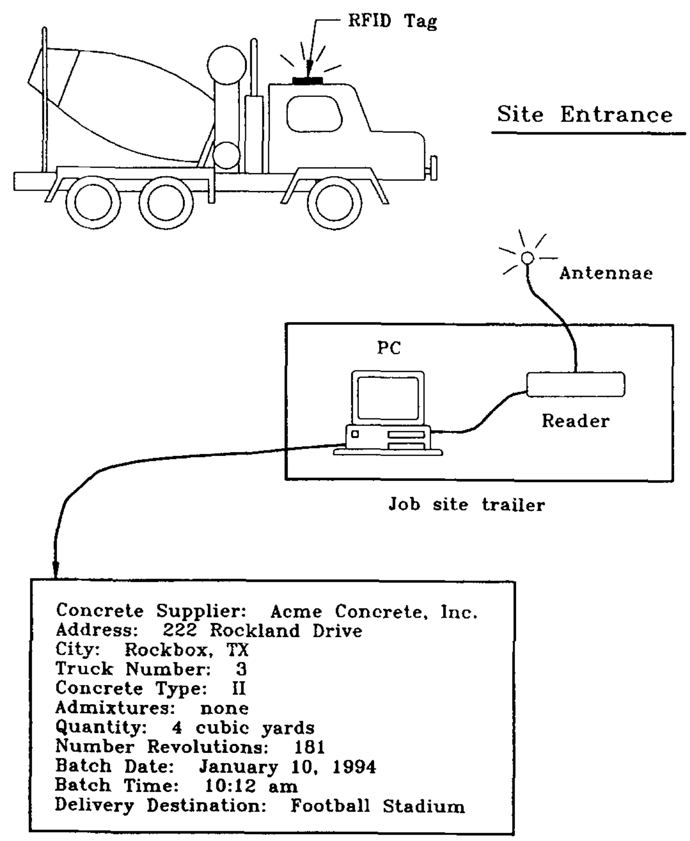

FIG. 1. Concrete Truck Interrogated by RFID Reader

[1]Assoc. Prof., Civ. and Constr. Engrg. Dept., Town Engrg. Bldg. Room 450, Iowa State Univ., Ames, IA 50011-3232.
[2]Information Tech. Specialist, 1617 Clark Ave., Ames, IA 50010.
[3]Asst. Prof., Civ. and Constr. Engrg. Dept., Town Engrg. Bldg. Room 454, Iowa State Univ., Ames, IA.
[4]Grad. Res. Asst., Civ. and Constr. Engrg. Dept., Town Engrg. Bldg. Room 427, Iowa State Univ., Ames, IA.
[5]Res. Engr., Bechtel Corp., 50 Beale St., P.O. Box 193965, Mail Stop 50/17/A6, San Francisco, CA 94119-3965.

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J. Constr. Eng. Manage., 1995, 121(2): 189-196

characteristics of RFID systems are as follows (Adams 1991; Floyd 1993; "Non Auto" 1993; *Amtech* 1994).

1. Detect, read, and/or write on information tags up to 73 m (Amtech AT5515 extended-life, dual-battery–powered transportation tag operating at 845–950 MHz); distances will vary depending on frequency range and power source. A beam-powered transportation tag, for example, has a typical working range of 0–9 m (Amtech AT5110 beam-powered transportation tag).
2. Store up to 40 alpha and numeric data (240 data bits) in each tag (Amtech AT5515 extended-life, dual-battery–powered transportation tag).
3. Withstand temperatures ranging from $-40°C$ to $85°C$ (operating temperature for Amtech AT5110 beam-powered transportation tag).
4. Withstand high noise levels, and various forms of hazardous contamination of the tags.
5. Communicate bidirectionally and multidirectionally.

Some transponders are so-called send-with transponders that enable the tagged item to be tracked by several agencies for the life of the item. For instance, when raw materials are tagged and tracked throughout their manufacturing process, the embedded tags are left to enable those in shipping and receiving to continue tracking the finished product as it is transported to its proper warehouse or buyer. For example, if the tagged item is the motor on a motorcycle that is later stolen and stripped, local police could scan the part if it is confiscated and return it to the victim. Another potential application of interest to the construction industry might be embedding tags in major structure components; once incorporated in a building, that tag can be used by inspectors for tracking and logging maintenance information for the life of the building.

RFID: Hardware/Software Required

RFID technology involves the transfer of information via a transponder that can be attached to nearly any object or living creature. In an RFID system, an identification tag or transponder sends and receives bidirectional radio signals to a reader. These signals are then sent to a host computer, whether a mainframe or microcomputer. In this system, transponder tags or microchips are attached to or implanted in the objects being identified. When an object passes by the reader, an antenna located in the reader creates a magnetic field. The tag uses the energy created by the magnetic field for transmitting the information to the reader, which is received by the reader and then sent to the host computer.

While the details of an RFID system may vary, the basic subcomponents will be similar. RFID subcomponents often can be purchased by vendors individually or in a combined system (Floyd 1993; Forger 1990, 1991). RFID subcomponents are described in greater detail in the following.

The tag, also called a chip or transponder, is often encapsulated to protect against shock, fluids, dust, dirt, and other contaminants. It handles information in one of two ways. Read/write tags can be reprogrammed over the RF link, while read-only tags have either a fixed code or a code that must be changed manually. Tags can be further divided as either passive or active. Active tags contain an internal power source, usually a lithium battery. Passive tags convert the RF signal from the reader into a voltage that supplies internal power. RFID tags range in size from one small enough to be injected into an animal's ear with a syringe to one the size of a brick (Arnold 1991; "Radio" 1990). Tags also vary by the amount of information they can hold, their life expectancy, recyclability, their attachment method, their reuseability, and their cost.

The antennae collect and transmit the RF signal. The antennae vary in size and shape. They can be freestanding or imbedded in other structures such as in a concrete block wall to detect personnel badges or passersby. The placement of the antennae depends on factors such as the system's operating frequency, the size of the tags and antennae in use, the nature of the surrounding materials, and the amount of free space (Floyd 1993).

The reader or scanner may be portable or stationary. The range from which a tag may be read has more to do with the technology of this device than with the tag itself. Readers range in size, and reading ranges and scanning capabilities vary greatly. Readers as small as 68 cm and 4.4 cm wide are now on the market (Small 1993). Their scanning range varies from centimeters to about 75 m. The requirements for scanning range must be carefully considered in selecting a reader. Usually, scanners are also lithium-powered. The newest power sources on the market, however, are solar-powered.

The RF link may operate on frequency bands ranging from low bandwidths (36 KHz) to high (microwave) bandwidths (2.45 GHz). Lower frequencies have slower data-transfer rates from tag to system; thus the tag must pass the reader at slower speeds. In addition, low frequencies have a lower reading range. Higher frequencies, on the other hand, are more expensive and, if high enough, require Federal Communications Commission licensing (Hill 1985; Floyd 1993).

Some RFID systems are capable of switching from high to low frequencies, as in the case of systems used by underground miners. Low-level frequencies are used for keeping time and attendance records as well as for tracking materials and equipment. But in the event of a mine collapse, some systems can switch to microwave frequencies, enabling workers to locate tagged miners who are still underground (Bernell 1993). Technology that enables users to switch from lower to higher frequencies on demand might offer a considerable long-term safety or cleanup benefit when used at construction sites subject to natural disasters, earthquakes, and structural collapses.

Interfacing equipment such as modems and computers may or may not be required, depending on the logistical layout and immediate needs of the operations being aided. Interfacing can be simple, if only a communications interface is required with a host computer for application processing. While many brands and models of microprocessor would work, most models at present are IBM PC–compatible 486DXs and up, due to processing speeds and data-handling capabilities (Floyd 1993; Hill 1985).

RFID: Current Applications

Several RFID applications have been developed for use in transportation, manufacturing, law enforcement, and agriculture. The applications involve:

1. Reading tags as an object passes a fixed scanner to record the movement of the object past the scanner.
2. Writing information on the tag that can be retrieved later.
3. Retrieving information from tags at a distance up to 73 m using a mobile scanner. This expedites information gathering or finding misplaced objects because the operator does not have to go to the exact location of the object.

These applications are discussed in the balance of this section and summarized in the following (K. Mead, personal communication).

J. Constr. Eng. Manage., 1995, 121(2): 189-196

- Material identification: to identify bulk or discrete solids, liquids, and gaseous and primary metals that may or may not be packaged. Parts and containers can be efficiently identified by attaching a tag to each item. This can lead to more efficient warehouse management, material handling, assembly testing, and bill-of-materials matching. For construction projects in particular, material identification can reduce a great deal of confusion regarding arrivals of ordered supplies and their whereabouts at a jobsite.
- Tool handling: to the work history of individual tools varying in size from handheld devices to larger molds, dies, welders, and huge mobile equipment. The embedded or attached tags are programmed with information on the tool name, its serial number, and information regarding maintenance and modifications. While lost, misplaced, and stolen tools are known to influence operating costs at a jobsite, lack of inventory control might also affect productivity rates more than the actual labor force itself.
- Automatic-guided-vehicle (AGV) control: to allow AGVs free operation in fixed locations. RF tags along the fixed travel paths can be used as path "correctors." The tags can simultaneously communicate storage and transfer locations information with the units en route. For construction jobs, this RFID application might be beneficial to—and increase the feasibility of—the automated construction systems of the future.
- Tolls and fees: to collect users fees for the transportation of materials, equipment, and people. Vehicles equipped with RF tags pass scanners on the highway that automatically debit the requisite toll from an account.
- Hazardous material: to identify hazardous materials at close range or from considerable distances in situations such as fires, natural disasters, or transportation emergencies. For example, drums containing hazardous waste in a repository can be RF-tagged and identified from a safe distance using a scanner.
- Meter-reading ID: to read water, gas, and electric meters from a safe distance by having a portable reading device pass by or be in the meter's vicinity. This also includes reading industrial meters such as those used in ground fueling operations for aircraft.
- Equipment maintenance: to read and write the maintenance history on RF tags while the equipment is in the service bay. This would greatly reduce paperwork related to factory warranties and time-consuming maintenance logs. Examples include automobile warranties, maintenance schedules, and industrial-use histories.
- Personnel: to use in personnel identification and control systems, including a greatly expanded military dog-tag system, in which medical and personnel information is also stored.
- Asset location and tracking: to define the location of a specific, identifiable item during normal operations and to find objects that are misplaced or stolen. Retail stores use this concept in monitoring merchandise as a shoplifting deterrent. RF tags are attached to clothing that is scanned as the shopper exits the store; an alarm sounds if an item has not been paid for. It also could be used to help construction project superintendents watch for expensive materials and tools leaving a jobsite. Automatic billing upon receipt of materials at a jobsite is also possible.

The transportation industry is becoming a leading user of RFID technology. Standards have been set for railcars, trucks, and intermodal freight containers.

In September 1991, the Association of American Railroads mandated the use of a universal RFID system for freight carriers. By July 1994, 1,400,000 railroad cars and 25,000 locomotives are expected to be tagged, and RF readers are being installed at strategic locations. Each car carries two 128B tags (20 cm by 5 cm by 2.5 cm), mounted on diagonally opposed corners, bearing the railcar or locomotive ID code that can be read at speeds up to 322 km/hr. These tags could be replaced with read/write tags providing detailed information regarding each car's contents. The technology is compatible with proposed advanced train-control systems (Kachmar 1992).

Increased efficiency is already evident in one test program aimed to eliminate the need for roadside weigh stations. Electronic interfaces link 40 weighing stations along the interstate that runs from Sault Ste. Marie, Mich., to Fort Lauderdale, Fla. RFID tags the size of a credit card are attached to the bumpers of trucks that travel along this route to identify each vehicle as it passes successive weigh stations. Thus, the truck needs to be weighed only once at the first station it passes, and the weight information is then transmitted from one station to the next (Ratan 1993).

In law enforcement, RFID tags are being used to track convicted criminals, racing dogs, and vehicles enrolled in crime-prevention programs (David 1993; Krause 1993; Kilbane 1993; Quinn 1993). When manufacturing motorcycles and cars, some tags (originally embedded in parts to track a vehicle on the assembly line) are left on the parts and are then used to provide law enforcement agencies with tracking capabilities in case of theft. These embedded tags also can be used to collect warranty information (Floyd 1993).

In hazardous-workplace-safety markets, RFID systems are being used in underground work environments such as mining operations (Bernell 1993). To improve safety conditions, the RFID antennae and tags are used to monitor the miners, the props that support mine roofs and walls, and the carts (carts stop near miners when they detect the presence of the miner's RFID tag) and conveyors that carry coal to crushing machines. In addition, RFID tags record the duration of time each miner spends below ground to assist in the timekeeping, attendance, and payroll operations.

In home and business security systems, RFID technology has a growing market. For example, RFID cards may be used to provide a hands-free access control system. With an embedded tag that will act as the "key" to apartments and homes, the card opens the door when it passes within close proximity, eliminating the need to fumble with keys or locks (Kilbane 1993; "New Products" 1993; "RFID Cards" 1993).

Agricultural fields may well be considered the birthplace of RFID technologies. This technology grew in large part out of government-sponsored programs in the early 1970s to manage animals. Animal tagging remains a large part of the business, and it is the one industry farthest advanced in the development of international standardization (Kachmar 1992). Perhaps the most widely publicized example of RFID animal applications involves the TIRIS system, first introduced by Texas Instruments in 1991. For instance, RFID is being used by breeders to track exotic animals such as ostriches, which require close monitoring and are easily disturbed by humans nearby. RFID tags are implanted in ear tags of standard breeds of cattle as well. And more recently, near-microscopic TIRIS tags are being implanted in Antarctic penguins for long-term study ("Breeders Track Ostriches" 1993; "Farmers" 1993; "TI Enters" 1991).

POTENTIAL APPLICATIONS IN CONSTRUCTION INDUSTRY

Three potential applications of RFID in the construction industry are discussed in this section. Concepts are developed

J. Constr. Eng. Manage., 1995, 121(2): 189-196

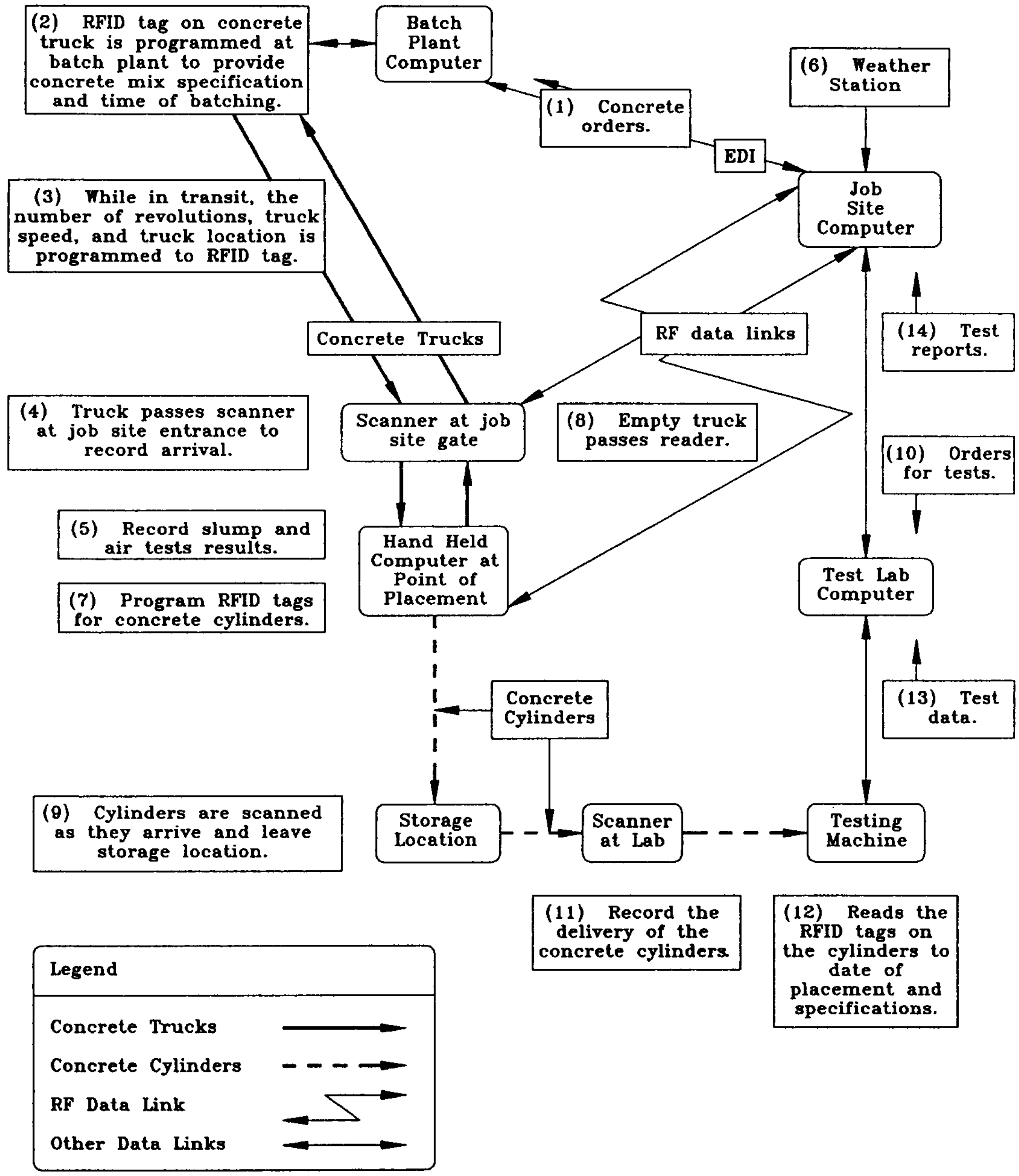

FIG. 2. Concrete Operation Using RFID

for concreting operations, cost coding for labor and equipment, and material control. These applications were chosen because RFID technology offers incremental improvements over existing methods:

- Ability to scan items at a distance, which allows trucks to be scanned while in motion as they pass through a gate, material to be scanned while being picked up by material-handling equipment, and misplaced items to be found by scanning in likely places.
- Ability to scan several items simultaneously such as a truckload of material or several concrete cylinders in a tank.
- Ability for the tag to retain information on the contents of trucks or attributes of the construction material.

They represent a sample of possible RFID applications, and other uses within the industry are virtually limitless.

Concrete

RFID technology could be incorporated into a system that would ensure proper delivery, billing, and quality control for concrete. Although the proposed system blends a variety of technologies, RFID tags provide critical information by identifying concrete trucks and concrete test cylinders.

The process is illustrated in Fig. 2. The process starts when the contractor places an order with the concrete supplier using electronic data interchange (step 1). At the concrete plant, a supervisor would review the order and assign concrete trucks. The requirements for the concrete mix and the ID numbers for the assigned trucks would be transmitted to a computer in the batch plant. A read/write RF scanner would be placed in the loading area. This scanner would read the truck RFID tag and a computer would ensure that the truck ID matched the assignment. Next, the RFID tag would be programmed to provide concrete mix, admixtures, time of loading, and delivery location (step 2). This information could also appear on an on-board computer display to inform the driver. When the truck departs, the jobsite could be informed by electronic data interchange (EDI) with a message that gives the truck ID number, concrete mix specification, and time of departure. As the truck drives to the jobsite, data could be recorded regarding the number of revolutions of mixing, truck speed,

J. Constr. Eng. Manage., 1995, 121(2): 189-196

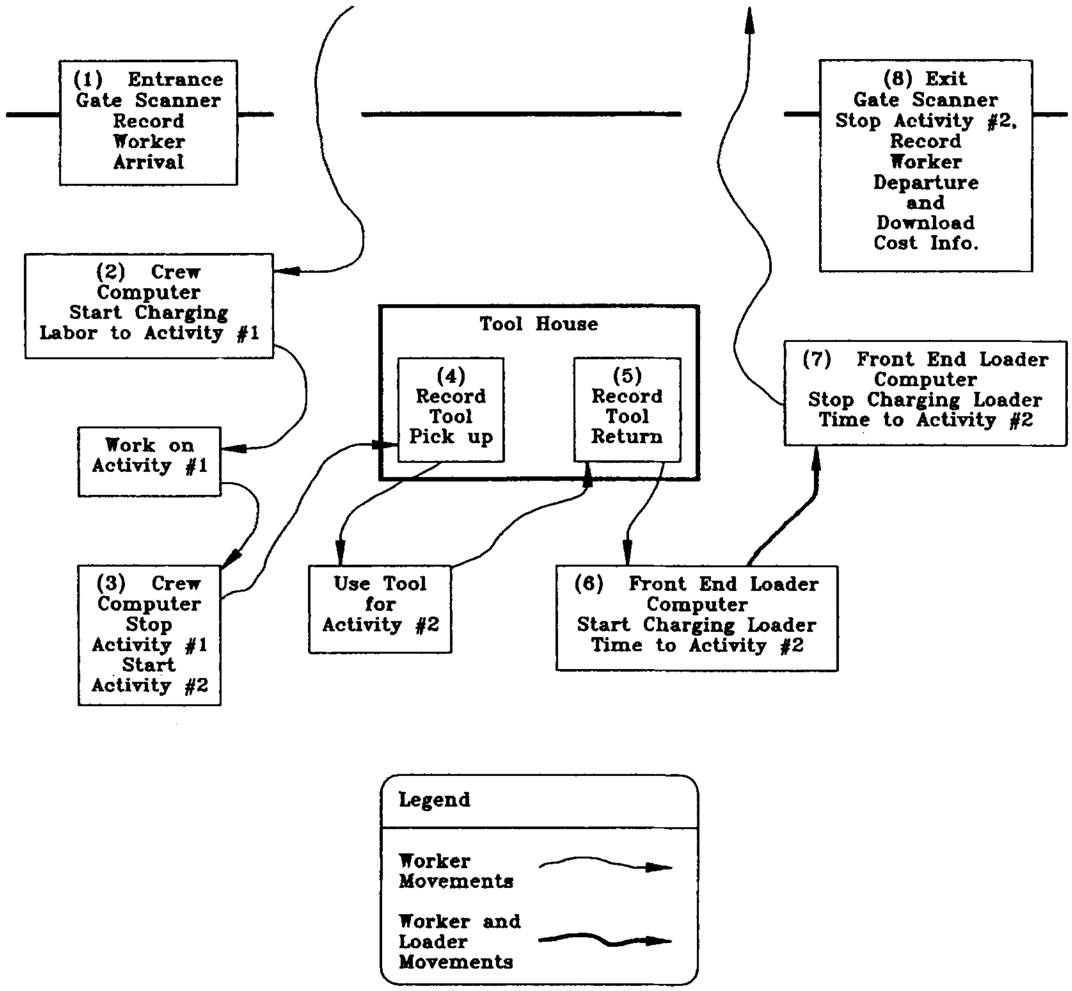

FIG. 3. RFID for Cost Coding of Labor and Equipment

and truck location, if the truck is equipped with Global Positioning System equipment (*GPS* 1989) or some other location-sensing device (step 3).

When the truck arrives at the jobsite, a scanner would read the RFID tag and communicate by RF link to the jobsite computer (step 4). The RFID tag information would be matched with the EDI information from the plant. The computer would also check to ensure that the number of revolutions and delivery time met the specification. If any exceptions are noted, personnel at the point of concrete placement would be notified.

The results of the air test and slump tests would be entered into a handheld computer at the point of placement (step 5). The RFID tag on the truck would allow the computer to associate the test data with the truck ID. If weather information is desired at the time of placement, the contractor could maintain a weather station that is continuously monitored by the computer (step 6). As concrete test cylinders are cast, read/write RFID tags would be attached (step 7). Using the handheld computer and a read/write scanner, these tags would be associated with the current concrete delivery by truck ID and delivery time. These tags will be used to track the concrete cylinders.

After the truck has completed the delivery, it would again pass the scanner (step 8). The delivery completion time would be transmitted to the concrete supplier by EDI so that the supplier could make plans for the next truck assignment. When the truck returns to the concrete plant, the scanner at the batch plant could obtain truck speed and route information and note any exceptions.

When freezing conditions are present, it is often necessary to monitor the temperature of the recently placed concrete to prove that it has not frozen prematurely. Temperature transducers could be placed in the concrete and miniature data recorders could place temperature data on a read/write RFID tag (not illustrated in Fig. 2). On a regular basis, an inspector could scan the RFID tags to obtain temperature information. Since the tags could be scanned from a distance of up to 73 m, the data collection process would be expedited.

After the concrete placement is completed, the RFID tags may be used to track the location of concrete cylinders. Some cylinders may be used to verify when sufficient strength has been gained so that curing may end or so that traffic may be placed on the concrete. In this case the cylinder will be stored next to the newly placed concrete so that the cylinder is subjected to conditions that are identical to those of the newly placed concrete. Other cylinders are used to prove that the concrete gains the specified strength under standardized curing conditions. These cylinders will be placed in curing tanks. As the cylinders are stored, the RFID tags may be read and associated with the storage location in a computer database (step 9). Each day the computer could create a list of cylinders that should be broken and their storage location. This information could be transmitted to the testing lab by EDI (step 10). If a cylinder is misplaced after its storage location is recorded, a handheld scanner could be taken to possible storage locations to aid in the search for the missing cylinder.

As the cylinders are transported to the lab, RF scanners could track the progress of their shipment (step 11). At the lab, a scanner on the testing machine could identify the cyl-

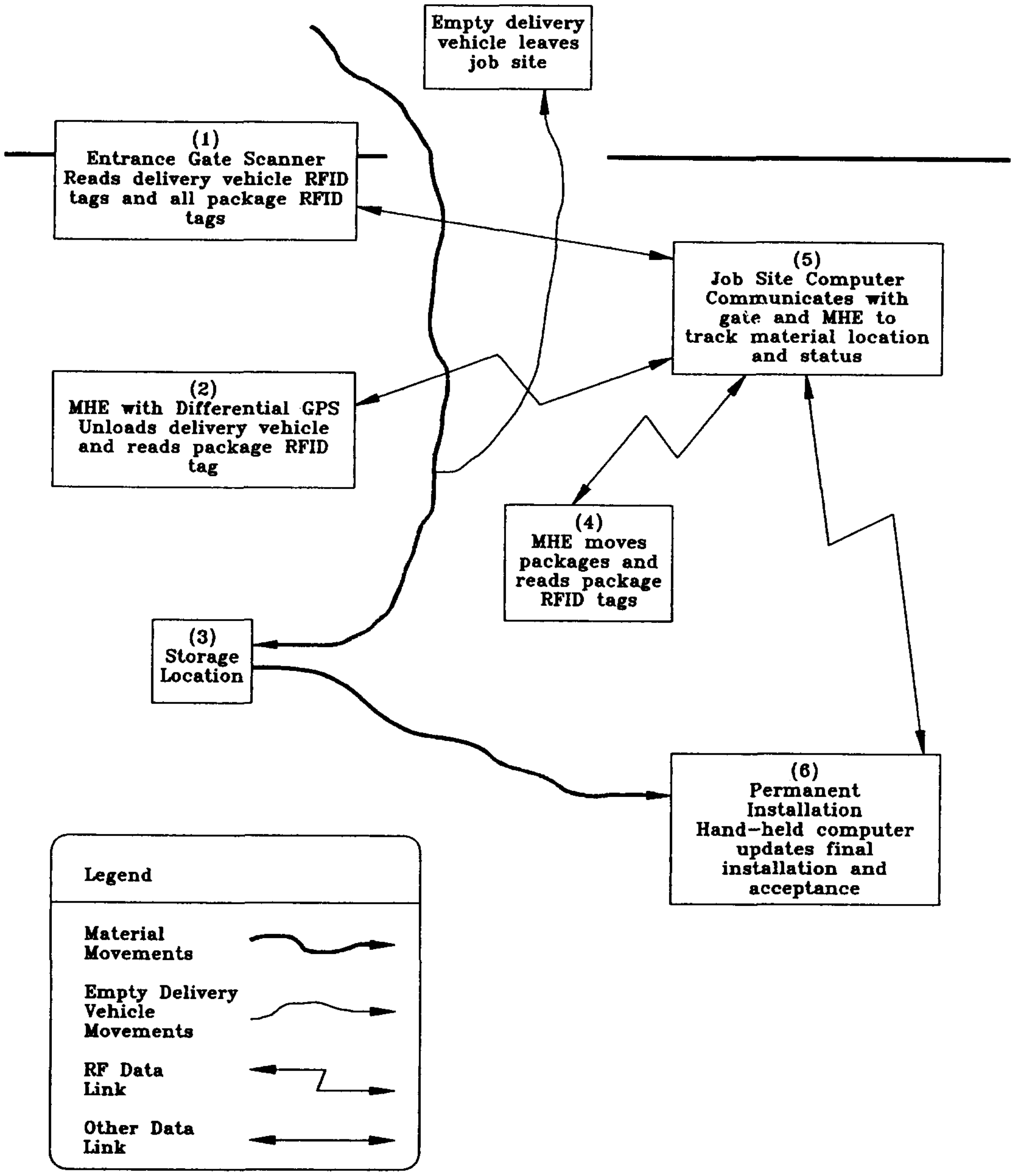

FIG. 4. Material Control with RFID Applications

inder and read information concerning the time and location of the concrete placement (step 12). This could be incorporated into a testing report (step 13). The test data could be automatically added to the test report and exceptions to the specifications could be noted. The test reports could be transmitted by EDI back to the jobsite (step 14) and the concrete supplier. At the end of this process, a summary placement report could be generated and transmitted by EDI to the owner.

The information that is generated from this process could facilitate invoicing and payment for the concrete supplier, the contractor and the testing lab. The delivery of material, the quality of material, and the performance of services would all be documented. Invoices could be delivered and funds could be transferred by EDI. Computer programs could verify the accuracy of the invoices before funds are released.

Cost Coding for Labor and Equipment

RFID technology could be used to track the activities of workers and equipment; the resulting records could be used to update the cost-control system. Each worker would have a read/write RFID tag to record the worker's activities. The tag would be approximately the size of a credit card and could be used as a worker identification badge. A method for using this tag is explained in the following paragraphs. The process is illustrated in Fig. 3.

At the beginning of the day, the tag would be scanned as the worker enters the gate and the jobsite computer would indicate that the worker had arrived at the jobsite (step 1). This would give managers a list of the workers who are on the jobsite at the beginning of the day. The worker would proceed to the crew meeting point, and would use a handheld computer to record the cost code for the day's first work activity (step 2). First, the scanner would read the RFID tag of each crew member and place the name on the screen for verification. Next, a menu of short phrases that describe each work activity (e.g., placing concrete, stripping forms, excavating, and driving piling) would be called up. One work activity could be selected simultaneously for several crew members. The computer would record the time, date, and

J. Constr. Eng. Manage., 1995, 121(2): 189-196

cost code for the start of the work activity. The record could be recorded in three different ways:

- Sent by RF data link to a jobsite computer.
- Retained in the memory of the crew's handheld computer. At the end of the day, this computer could be downloaded to the jobsite computer.
- Written to the workers' RFID tag. At the end of the day, the tag could be scanned to download the information. When the worker returns the next day, the scanner and the computer could verify that the information was properly recorded on the jobsite computer and erase the tag.

To ensure the safety of the information, it would be advisable to store the information in more than one way. Whenever the work activity is changed, the workers return to the computer and note the change (Step 3).

The use of equipment would be tracked by associating the equipment with the operator and the operator's activity. The system could be adapted for both tool-room checkout and large equipment management (e.g., front-end loaders and trucks).

At the tool room, the worker's tag would be read at the checkout desk. Each tool would be equipped with a tag, and that tag would be read as the tool is checked out (Step 4). The time and work activity would be noted, and the worker would be associated with the tool. When the tool is returned (Step 5), the worker's tag and the tool tag would be read, and the worker and the tool would be disassociated. The number of hours that the tool was used and the charge for the use of the tool would be recorded.

Each piece of large construction equipment could be equipped with an RFID tag, and equipment activities could be tracked in a manner similar to the workers. In cases where the equipment changes work activities frequently, the equipment could be equipped with a small computer that functions similarly to the crew computer (Steps 6 and 7).

At the end of the day, the workers would be automatically checked out when the scanner reads their RFID tags at the exit gate (Step 8). Computer software would review the worker and equipment activity information, and make the appropriate charges to the cost-control system.

The functions described in this application could also be accomplished with a bar-code system. However, the use of RFID eliminates the need for optically scanning tags on workers and tools. Also, the tags could be used to store cost-code information.

Materials Control

RFID technology could also be used as an aid in managing critical materials. RFID tags could be used to track material-delivery vehicles, material-handling equipment, and the material itself. This process is illustrated in Fig. 4.

The tracking process would start at the jobsite gate (Step 1). Each delivery vehicle would be equipped with an RFID tag. The vehicle tag would give information on the vehicle ID number, the vehicle owner, and the contents of the vehicle. Each package of critical material would also have an RFID tag. The package tag would give the contents of the package, the vendor, the purchase-order number, and the invoice number. Both the vehicle and package tags would be read at the gate and recorded on the jobsite computer.

Next, the delivery vehicle would move to the storage location and the material-handling equipment (MHE) would meet the delivery vehicle (Step 2). The MHE would have an RF tag reader and a device that would track the MHE location such as a differential GPS (*GPS* 1989). As the material is unloaded, the MHE would read the delivery vehicle tag and the package tags. When the material is placed in its storage location (step 3), the MHE would record the storage location using an automated positioning system. The automatic positioning system could be a differentially connected GPS. Laser positioning systems may also be applicable (Williams et al. 1993). Such automatic positioning information would be helpful for congested storage areas that stock components difficult to identify visually. Position information would also be helpful for situations where material must be moved several times before it is incorporated into the structure.

The material-tracking information would be sent to the jobsite computer by RF data link or retained in the MHE on-board computer and downloaded at the end of the day. As the packages are moved from place to place on the jobsite, the MHE would update the location (step 4) and the jobsite computer would track the materials (step 5). The time of permanent installation and owner acceptance could be recorded on handheld computers, if appropriate (step 6). If an item is misplaced, it would be found using a handheld scanner to search possible storage locations.

In some cases the materials will be stored in a warehouse and distributed to workers. In these cases the material check-out process could be similar to the tool checkout process described in the previous section.

The jobsite computer would maintain databases of materials on hand and their storage location, as well as materials installed. This information could be used to trigger payments from the contractor to suppliers and generate requests for progress payments from the contractor to the owner.

LIMITATIONS

To develop the conceptual system designs just described, there are some limitations regarding RFID technology that need to be addressed. Currently most RFID systems are still closed, meaning one supplier's tags cannot be read by another supplier's reader. This does not present a problem to manufacturers because they use a standardized system that operates within the confines of the plant. However, if a construction company wants to track material from several different suppliers, it may be difficult to get the suppliers to agree on a common RFID technology. Several groups are now working to establish common protocols and technology standards for RFID applications in specific industries. The work of these organizations is not moving quickly, however, due to associated political, economic, technological, and even sociological issues.

The strongest barriers to commercial adoption of RFID technologies involve the psychological barriers within the workforce and the cost of hardware. Psychological barriers include the perception that RFID is too sophisticated, expensive, or time-consuming for an ordinary business to design and implement. Also, because increased monitoring is possible, employees might fear that businesses will invade their privacy and demand unrealistic levels of productivity. The cost of the actual RFID tag or transponder still prohibits the widespread adoption of this technology. In general, a passive chip with limited memory and read only capabilities can run as low as \$10 while more sophisticated, recyclable tags used in automated manufacturing plants cost more than \$100 each. Portable hand held scanners cost between \$1,000 and \$4,000. If GPS is also used, as described in the material control application, the cost is approximately \$20,000 for differentially connecting a base station and \$5,000–\$10,000 for each materials-handling unit. Software costs can be expensive as well, since most of the applications will need to be developed for each proposed application.

RFID systems may malfunction in certain environments.

J. Constr. Eng. Manage., 1995, 121(2): 189-196

RFID operations can be hampered by nearby metals and the operation of other RF-linked systems in the vicinity.

CONCLUSIONS

RFID technology is a promising technology for the construction industry that can be integrated into systems that can track materials, identify vehicles, and assist with cost controls. RFID is currently used in several applications outside the construction industry (e.g., meter reading, container tracking, and tolls collection). Three conceptual construction RFID systems were discussed related to concrete operations, cost coding for labor and equipment, and materials control. Other applications have been previously tested in other industries and therefore, require little development effort. One example is attaching a tag to trench and tunnel workers so that in a collapse they can easily be found. RFID may have as much impact upon organizational operations as the personal computer had 25 years ago.

Final considerations regarding RFID applications for the construction industry include: (1) Construction firms can save time, money, and effort with effective use of RFID technology for several operational procedures; (2) contractors must first learn more about this technology; (3) when considering RFID technology for a particular application, it is wise to consider other existing, competing and/or compatible automatic identification technologies for use and/or future interface as well; (4) central to the successful implementation of an RFID system is the involvement of all who will be directly or indirectly using the technology in the planning process; and (5) as standards are developed and costs decrease, RFID applications will gain significance to the construction industry and many of its operations.

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