# Ubiquitous Tracking and Locating of Construction Resource Using GIS and RFID

J.Majrouhi Sardroud*, M.C. Limbachiya, A.A. Saremi

* School of Civil Eng. & Construction, Kingston University, Kingston upon Thames, KT1 2EE, UK

Tel: 09124804665
K0851129@kingston.ac.uk

## Abstract

This paper presents a study on applying an integrated application of Radio Frequency Identification (RFID), Global Position System (GPS) and Geographical Information System (GIS) technology for ubiquitous tracking and location of construction resource (e.g. materials). Accurate and timely identification and tracking of resource (e.g. materials) are vital to operating a well managed and cost efficient construction project. RFID integrated with the GPS provides an opportunity to uniquely identify materials and to locate and track them using minimal or no worker input where GIS will be used for analyzing collected data. RFID will be used for monitoring the resource in a construction phase and GPS will monitor the transport equipment of them. In this research, the proposed system can assist engineers in controlling and monitoring the construction resource in a real time basis.

**Keywords:** Construction materials management, GIS, GPS, Radio Frequency Identification (RFID).

## 1. Introduction

The construction industry is often criticized for delivering projects late and over budget due to failure in effectively tracking and locating construction resource (e.g. materials) and in accessing the related information. In other words, problems in poorly identifying, tracking and locating materials result in late deliveries, double-handling and misplacement of materials that lead to schedule delays and increased labor costs. Therefore, an efficient resource management and control can reduce construction conflicts and project delay.

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1- PhD researcher, School of Civil Engineering & Construction, Kingston University London, UK
2- Head of School of Civil Engineering & Construction, Kingston University London, UK
3- Head of Board of Director, Tajeer consulting architects, Tehran, Iran

The delivery and availability of construction resource (e.g. materials) at the right time and at the right place is very critical to obtain a successful construction project. Therefore, information concerning resource is a major issue and bad or incomplete information can create serious problems in a construction project and can significantly affect the success of projects. It is necessary to monitor all the materials in a construction phase in order to collect all the appropriate data and information needed. However, wrong delivery arrangement of materials causes general disorder on construction sites. This disorder is often require utilization of additional resources and accompanied by a need for unplanned facilities and/or activities such as additional site storage, work interruption, extra handling, breakage, and loss. Moreover, delays in shipping of pieces result in wasted resources (cranes and crews) at the site and consequent delays in construction schedules. Data collected using manual methods are not reliable or complete because they are dependent on workers' motivations and skills. Moreover, sometimes, collected information is not reliable or complete due to reluctance of workers to monitor and record the flow of large quantities of elements and data collected through these methods are usually transferred and stored in paper-based format, which is difficult to search and access, and makes processing data into useful information expensive and unreliable. Thus, some information items end up being unavailable to the parties who need access to them in a timely manner to make effective decisions.

In construction project accurate data is needed not only to control current projects, but also to update the historic database. Such updates will enable better planning of future projects in terms of costs, schedules, labor allocation, etc. Given the mentioned monitoring and tracking problems above, the construction industry can benefit from the advantages of combining RF-based technologies with Geographical Information System (GIS) where Radio frequency Identification (RFID) can be applied to collect the job site data by identifying resource automatically and the position of their external and internal transport vehicles (equipments) can be monitored with the help of Global Positioning System (GPS) in conjunction with GIS. These technologies can provide the GIS tool with all the information needed to analyze and help historical tracing of the materials in construction projects.

This paper demonstrates a system for effective management and control of construction materials and their transport vehicles. Most of the technologies which are used in this research are inexpensive and commercially available. This paper first reviews previous research and work that has been done by others relating to applications of RFID, GPS and GIS in construction, followed by an overview of the enabling technologies which are used in this research. Then it reveals the architecture of our integrated system for materials management. Conclusions are given in the end of paper.

## 2. Background and Literature Review

Li et al. (1996) reported on a system to map moving compaction equipment, transform the result into geometrical representations, and investigated the use of GIS technology to develop a graphical illustration depicting the number of roller passes (Li et al., 1996). In a study implemented by Cheng and Chen (2002), barcodes and GIS were the two basic components of an automated schedule monitoring system to control and track the erection of prefabricated concrete components in real-time (Cheng and Chen, 2002). Ergen et al., developed an automated tracking system based on RFID combined with GIS technology in order to locate precast concrete components with minimal worker input in the storage yard (Ergen et al., 2007). In another study, Lia et al. investigated the use of GPS integrated with GIS for reducing construction waste and improving construction efficiency (Lia et al., 2005).

Jaselskis and El-Misalami implemented RFID to receive and keep tracking of pipe spool in the industrial construction process. Their pilot test demonstrated that RFID could increase operation efficiency by saving time and cost in material receiving and tracking, but the workers check RFID-tagged materials manually by using a hand-held computer (Jaselskis and El-Misalami, 2003). Song et al. developed an RFID based method to automate the task of tracking, delivery, and receipt of fabricated pipe spools in lay down yards and under shipping portals (Song et al., 2006a, Song et al., 2006b). In another study, Caldas et al. investigated the use of GPS integrated with a handheld device to track the position of pipe spools on lay down yards in order to improve the process and reduce the number of lost items (Caldas et al., 2006). Jang et al. developed an Automated Material Tracking system based on ZigBee localization technology with two different types of query and response pulses (Jang and Skibniewski, 2007). GPS was used to track the real-time location of equipment on construction sites in several research studies.

Although various studies exist for resource management in construction, studies focusing on detailed application of full automatic materials/components models are scarce and the application to an open environment like a construction site is still unproven.

## 3. Description of Technology

Advancements in field data capture technologies, such as RFID enable collecting, storing and reusing field data accurately (i.e., without inaccurate recording of manual process), completely (i.e., without missing data), and timely (i.e., whenever needed). Some application of advanced tracking and data storage technologies (e.g., RFID) in construction information management have been indicated previously e.g., (Akinci et al., 2006) and (Behzadan et al., 2008).

Advanced Tracking and Data Storage Technologies is important in successfully controlling and managing construction projects, particularly in enhancing communication and coordination among participants.Based on the description of the current practice described in the previous section, data collection was identified as the primary focus for improvement by utilizing advanced tracking technologies where it will be possible to identify a piece that delivered to the construction job sites and to find location of them in storage yard with minimal or no worker input. Using advanced tracking and data storage technologies such as RFID will meet the needs of five objectives of construction project management such as scope, quality, safety, cost and time. 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 (Jaselskis et al., 1995). RFID tags is more durable and suitable for a construction site environment because they are not damaged as easily, does not require line-of sight for reading and writing, can be read in direct sunlight, and survive harsh conditions, reusable and permit remote.

Automated tracking systems can be divided into positioning and locating systems. In positioning systems object tags calculated their own locations, while in locating systems tagged objects is being located by the infrastructure. On one hand, positioning systems require considerable computations on RFID tags. On the other hand, locating tracking systems have limited coverage area and hence requires costly infrastructure for a scalable location. To overcome the disadvantages of both techniques, a combination of RFID and GPS technology has been identified as a viable tracking tool when locating hundreds of materials on construction site is considered.

Spatial information of resource can be displayed on an electronic geographical map using Web-based Geographical Information System (WebGIS) technology. The employment of WebGIS facilitates the dynamic visual representation of the spatial information of the resource distribution on an electronic map. WebGIS is a new technology that combines the Internet and GIS. End users can search and analyze the GIS data intuitively on the Internet using browsers. Luo et al. (2001) propose a framework to provide a new model for WebGIS services in a network environment (Luo et al., 2001).

## 3.1 RFID Overview

RFID is a wireless sensor technology that is based on the detection of electromagnetic signals and radio frequencies are used to capture and transmit data from a tag or transponder. In other words, RFID is a method of remotely storing and retrieving data by utilizing radio frequency in identifying, tracking, and detecting various objects that can be used in construction phase. An early, if not the first, work exploring RFID is the landmark paper by Harry Stockman, "Communication by Means of Reflected Power", Proceedings of the IRE, pp1196-1204, October 1948 (Landt, 2005). Two decades ago RFID was introduced as the ultimate replacement for barcode. RFID tags is more durable and suitable for a construction site environment because they are not damaged as easily, does not require line-of sight for reading and writing, can be read in direct sunlight, and survive harsh conditions, reusable and permit remote. A RIFD system consists of tags (transponder), a reader (transceiver) and host terminal (middleware). A typical RFID system is shown in Figure 1.

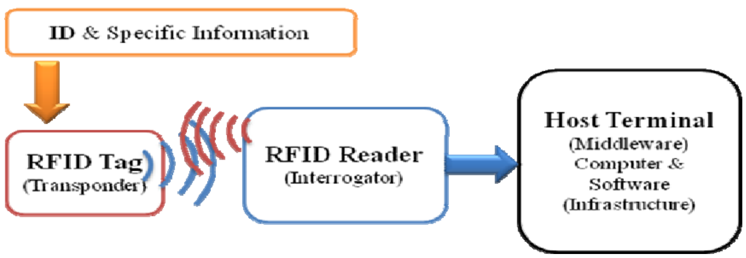


Fig. 1 A typical RFID system

An RFID tag is an electronic label, such as an adhesive sticker, is a portable memory device on a chip that is encapsulated in a protective shell and can be embedded in any object and store dynamic information about the object. Tags which consist of a small integrated circuit chip coupled with an antenna to enable them to receive and respond to radio frequency queries from a reader. Tags can be categorized as read-only (RO), write once, read many (WORM) and read-write (RW) in which the volume capacity of their built-in memories varies from a few bits to thousands of bits. RFID tags can be classified into active tags (battery powered) and passive tags, which powered solely by the magnetic field emanated from the reader and hence have an unlimited lifetime. Reading and writing ranges depend on the operation frequency (low, high, ultra high and microwave). Low frequency systems generally operate at 124 KHz, 125 KHz or 135 KHz. High frequency systems operates at 13.56 MHz and ultra high frequency (UHF) use a band anywhere from 400 MHz to 960 MHz (ERABUILD, 2006). Tags operating at ultra high frequency (UHF) typically have longer reading ranges than tags operating at other frequencies. Similarly, active tags have typically longer reading ranges than passive tags. Tags also vary by the amount of information they can hold, life expectancy, recycle ability, attachment method, usability, and cost. Communication distance between RFID tags and readers may decrease significantly due to interferences by steel objects and moisture in the vicinity, which is commonplace to a construction site. Active tags have internal battery source and therefore have shorter lifetime of approximately three to ten years (Jaselskis and El-Misalami, 2003). Some tags have an LED (light-emitting diode) that notifies the user with a blinking light when a tag and a reading device are communicating.

The reader, combined with an external antenna, reads/writes data from/to a tag via radio frequency and transfers data to a host computer. The reader can be configured either as a handheld or a fixed mount device. The host and software system is an all-encompassing term for the hardware and software component that is separate from the RFID hardware (that is, reader and tag); the system is composed of some components such as: Edge interface/system, Middleware, Enterprise back-end interface, Enterprise back end (Lahiri, 2005).

## 3.2 GIS Overview

Geographic Information System (GIS) is a computer-based system (a collection of computer hardware, software, and geographic data) to collect, store, integrate, manipulate, analyze, and display data in a spatially referenced environment, which assists to analyze data visually and see patterns, trends, and relationships that might not be visible in tabular or written form. In other words, GIS is a dynamic set of technologies that allow data from a variety of sources to be mapped and analyzed (ESRI, 2008). A detailed history of GIS is not well understood because GIS technology evolved through multiple parallel but separate applications across numerous disciplines. Harvard Graduate School was a key institution in the birth and early development of GIS and a grid-based mapping program called SYMAP, developed at the Laboratory for Computer Graphics and Spatial Analysis at the Harvard Graduate School of Design in 1966, was widely distributed and served as a model for later systems (Mark et al., 1997).

GIS takes layers of information that are tied to locations on the earth and overlays them for viewing and analysis. These layers are represented as points, lines, polygons, and annotation. Due to the fact that each layer has attributed data associated to it through a database. Applications of GIS are mapping, site selection, visualization, resource inventory and management, and more. The infrastructure to any GIS is made up of four components whose interrelation is shown in Figure 2. These components can be listed in order of importance as follows: (a) Methods and People, although GIS is a powerful tool, it will not work without some well-adapted methods and trained people. (b) Data, the needed raw material to be processed by the system. Data (information) is the foundation of GIS applications. (c) Software, the computer programs needed to run GIS. (d) Hardware, the machinery on which GIS operates (Davis, 1996). GIS refers to three integrated parts namely: Geographic of the real world, the spatial realities; Data and information, their meaning and use; Systems, the computer technology and support infrastructure. GIS therefore refers to a set of three aspects of our modern world, and offers new ways to deal with them. GIS allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts.


Fig. 2 Components of a GIS

GISs essentially perform five processes or functions: (1) Input, the data must be converted into a suitable digital format. (2) Manipulation, before information can be integrated, it must be transformed or manipulated to the same scale e.g. degree of detail or accuracy. (3) Management, efficient digital storage and retrieval for easy by using a computer software as a database management system to help store, organize, and manage data. (4) Query and Analysis, simplifying the data or the world and its processes to understand how things work. (5) Visualization, presenting data in various ways for easy understanding of maps and reports. The appropriate GIS software has the following capabilities: modeling of the geometry of the construction project, identification of the objects e.g. materials that have been used and record their precise location in the construction artifact (origin, place of previous storage, conditions of storage, etc.) (Kirkinezou and Angelides, 2007).

## 3.3 GPS Overview

GPS is a Global Positioning System based on satellite technology. GPS uses "man-made stars" as reference points to calculate positions accurate to a matter of meters. The most important applications of the GPS are positioning and navigating. The activities on GPS were initiated by the US Department of Defence (DOD) in the early 1970s under the term Navigation Satellite Timing and Ranging System (NAVSTAR). The first of a nominal constellation of 24 GPS satellites was launched in 1978, and the system was fully operational in the mid- 1990s. Galileo is a European Union Global Positioning System, Glonass is a Russian and BeiDou is the Chinese system (Kaplan and Hegarty, 2006, Xu, 2007).

GPS is comprised of three segments: space, control, and user equipment segments. The space segment consists of nominally 24 satellites that circulate the Earth every 12 sidereal hours on six orbital planes with four satellites in each plane that provide the ranging signals and data messages to the user equipment. The orbits are equally spaced 60◦ apart from each other, and each orbit has an inclination angle of 55◦. GPS is a typical Medium Earth Orbit (MEO) system with an orbit altitude of approximately 20,200 km with regard to mean sea level. The control segment is responsible for monitoring and controlling the satellites subsystem health, status and signal integrity and maintains the orbital configuration of the satellites and consists of one Master Control Station and four unmanned monitor stations located strategically around the world. Finally, the user receiver equipment performs the navigation, timing and etc. (Kupper, 2005). Each GPS satellite transmits signals at three distinct frequencies, namely: L1 (1575.42 MHz), L2 (1227.60 MHz) and L5 (1176.45 MHz). The L1, L2 and L5 carrier frequencies are generated by multiplying the fundamental frequency by 154, 120 and 115, respectively. Two levels of navigation and positioning are offered by the GPS. They are the Coarse Acquisition Code (C/A-code, ), sometimes called the “Civilian Code” or “the Standard Positioning Service (SPS)” and the Precise, or Protected Code (P-Code) sometimes called the Precise Positioning Service (PPS). Each satellite carries its own unique code string. The SPS is a positioning and timing service which is modulated onto the L1 carrier and focusing on the civilian user and the PPS is a positioning, velocity, and timing service which is modulated onto the L1, L2 and L5 carriers allowing for the removal of the effects of the ionosphere and is used for military applications (Xu, 2007).

Each receiver has a clock, enabling it to measure the travel time of signals from the satellites. Measuring the signals TOF from the satellites, whose positions are known, enables the calculation of the receiver’s 3-D position based on the trilateration principles. The satellites do this by transmitting a radio signal code that is unique to each satellite. Receivers on the ground passively receive each visible satellite’s radio signal and measures the time that it takes for the signal to travel to the receiver. The only thing needed by the user to calculate distance from any given satellite is a measurement of the time it took for a radio signal to travel from the satellite to the receiver. To calculate locations, the readings from at least four satellites are necessary, because there are four parameters to calculate: three location variables and the receiver’s time (French, 1996).

To get metric or sub metric accuracy in positioning data, a pair of receivers perform measurements with common satellites and operate in a differential mode. For dynamic positioning, the principle of differential GPS can be applied in two ways: using range measurements, called DGPS, and using phase measurements, called ‘‘kinematic GPS’’. In DGPS two receivers are used. One receiver measures the coordinates of a stationary point, called the base, whose position is perfectly known in the reference geodetic system used by GPS. The 3-D deviation between the measured and actual position of the base, which is roughly equal to the measurement error at a second receiver at an unknown point (called ‘‘rover’’), is used to correct the position computed by the latter (Peyret et al., 2000). The RTK GPS can further enhance the positioning accuracy to centimetre (even millimetre) levels by combining the measurements of the signal carrier phases from both base and rover receivers with special algorithms.

## 4. Proposed System

The tracking system utilized in this research is combination of GPS, GIS and RFID, and as such, takes advantage of the respective strengths of each. RFID integrated with the GPS and wireless communication technologies provides an opportunity to uniquely identify materials and components and to track and locate them using minimal or no worker input. RFID technology will be used for monitoring the materials in a construction site. GPS technology will monitor the equipment that transports the materials. The system mainly consists of three types of hardware components; namely, (i) RFID technology (RFID tags, readers, antenna); (ii) GPS technology (GPS receiver); and (iii) Wireless communication technology (Wi-Fi, ZigBee, GPRS/SMS). Figure 3 illustrates the simple architecture of the integrated system using RFID, GPS and GIS technology for ubiquitous tracking and locating of construction resource.

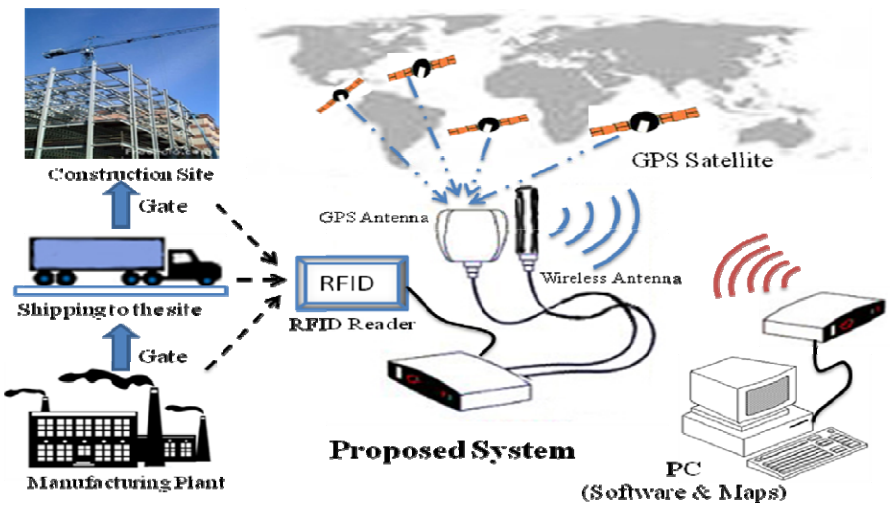


Fig. 3 Automatic data collection during production, shipping, and installation

In this approach, tracking process begins with RFID tags that contain unique ID numbers and carries data on its internal, microchip-based memory about the host such as item specific information or instructions and can be placed on any object (engineered-to-order/ materials), and an RFID reader is mounted on the internal transport vehicle such as mobile gantry crane. Suppliers will attach RFID tags to all materials, components and possibly some bulk engineered items which are to be delivered in unit sets (e.g. pallets, packages, bags, etc.). Each time a piece is picked up and moved, the ID information of the piece is captured by the RFID reader. At the times of pick up and release of the load–which are identified by the RFID reader, the location of the crane (and thus the piece) is read from a GPS receiver, which is also mounted on the crane. The ID and location information of the piece is then sent to a database. A schematic model of materials management and control is shown in Figure 4.

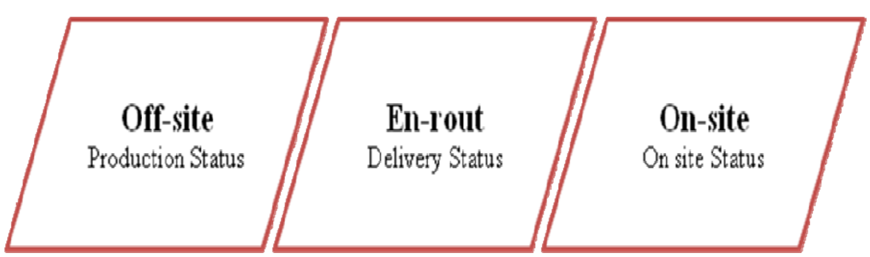


Fig. 4 Materials management and control schematic model.

Proposed system can be used to control the movements of high value objects on construction site. For instance, an active tag on a high value asset could be set to signal an alert if the asset starts to move so that it could be located and stopped before it is removed from the site or an active tag on a internal transport vehicle could be set to create an alert if the internal transport vehicle did not move to the next process within a specified period of time. One extreme case is to store only the unique component IDs directly on RFID tags and store all of the related component information in one or more databases which will be indexed with the same unique IDs and the other extreme case is to store all the data in RFID tags locally and not to store any data in the server. The delivery vehicle is equipped with a tracking system combining the RFID and GPS technologies (including a tag, a reader, and GPS module). The delivery vehicle's RFID tag would give information on the vehicle ID number, the vehicle owner and the content of the vehicle. Arrival of the vehicle at a construction site is recorded automatically by the RFID reader mounted on the gate. As the delivery truck departs for the construction site, components that are shipped will be automatically identified at the gate, a corresponding invoice will be created automatically and notification of shipping will be sent to the appropriate construction site.

The central station is a monitoring station, where the accurate position of each construction resource is displayed on a GIS map, and the information of each resource can be queried. For example, by using functions in a GIS system, the central station can get the current location of a materials and estimate the travel time of them before it arrives at a predetermined construction site. GIS facilitates the complete management and control of the system for Tracking and monitoring the construction resource e.g. materials and equipments. The data that are collected with the help of the specific system will be analyzed with GIS. Collected information is shown on GIS map in Figure 5.

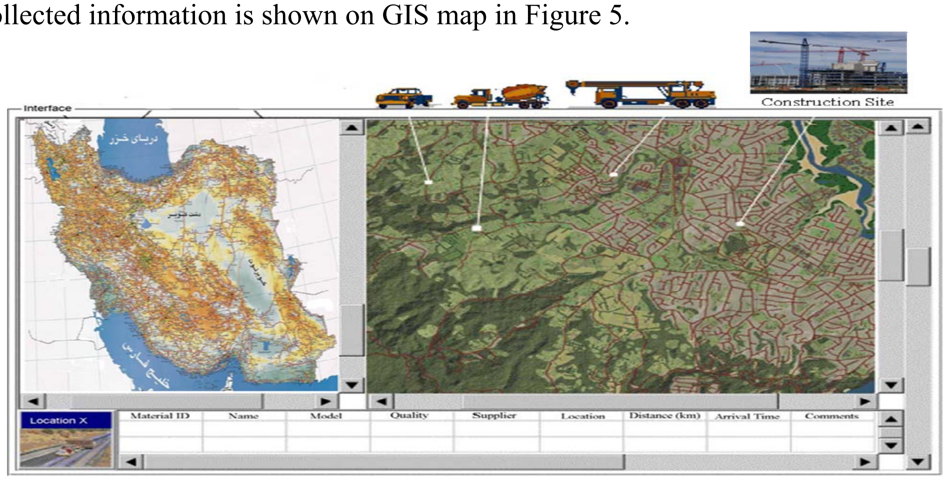


Fig. 5 Collected information on GIS map

In this system collected data (ID, date, location, quality etc.) retrieved from RFID readers and GPS is transferred via wireless communication to a central database. Central database stores the status data collected during manufacturing, shipping, storage and installation. Therefore, data collection is done continuously, autonomously, and it is not influenced by the conditions on-site, such as line of site and weather and information is transmitted back to the engineering office for analysis and documentation, enabling the generation of reports on productivity, cycle times, volume and material type, etc. Project manager controls the progress and the scheduling software can automatically place further orders for subsequent activities according to predetermined lead times. Such an arrangement would only trigger the ordering process when the construction site is ready for the material to be delivered and avoids deliveries being processed too early or too late.

Citing factors such as screen size for RFID reader, outdoor readability, battery power, physical unit size and robustness are important considerations in the selection of appropriate hardware for the construction site. To minimize the performance reduction of selected technology under harsh conditions (e.g., rain or possible impacts from different pieces of equipment) and while in contact with metal and concrete, RFID tags will be encapsulated or insulated.

## 5. Conclusion

Proposed system is an application framework of RFID technology integrated with GPS, GIS and wireless technology for effective construction resource management. The aim of this research is to identify opportunities for applying advanced tracking and data storage technologies in construction resource management and to develop a model that explores how these technologies can be used in construction site environments to retrieve and transfer on-site information. This system will improve the construction efficiency through increasing the effective working hour of construction equipment and reducing construction duration and thus the cost of workforce. This system is very helpful for construction projects especially in regions where the space for material storage on a construction site is very limited. The main benefits could be summarized as follows: Monitoring the resources ensures the disposal of them at the right time and place; Recording the history and characteristics of resource, facilitates the detection of causes, the assessment of legal consequences in a potential failure of the construction and the improvement of the processes of suppliers as well as the improvement of future projects. The model permits real-time control enabling corrective actions to be taken. In this manner, costs and handling unnecessary traffic of resource are reduced. In addition, up-to-date information is available. Proposed system is unsuitable in closed environments, such as underground structures, and it needs assessments in varying conditions to test its performance in real-life environments. In practice, this system can deliver a complete return on investment within a short period by reducing operational costs and increasing workforce productivity. The authors believe that full automation of the Operation in construction industry can increase the efficiency and quality of the operation and lead to reductions in project costs and time.

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