How could construction supply chain benefit from RFID/GPS integration: A knowledge management perspective

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ABSTRACT

Construction materials and equipment are essential building blocks of every construction project and may account for 50-60 per cent of the total cost of construction. The rate of their utilization, on the other hand, is the element that most directly relates to a project progress. A growing concern in the industry that inadequate efficiency hinders its success could thus be accommodated by turning construction into a logistic process. Although mostly limited, recent attempts and studies show that Radio Frequency IDentification (RFID) applications have significant potentials in construction.

However, the aim of this research is to show that the technology itself should not only be used for automation and tracking to overcome the supply chain complexity but also as a tool to generate, record and exchange process-related knowledge among the supply chain stakeholders. This would enable all involved parties to identify and understand consequences of any forthcoming difficulties and react accordingly before they cause major disruptions in the construction process.

In order to achieve this aim the study focuses on a number of methods. First of all it develops a generic understanding of how RFID technology has been used in logistic processes in industrial supply chain management. Secondly, it investigates recent applications of RFID as an information and communication technology support facility in construction logistics for the management of construction supply chain. Based on these the study develops an improved concept of a construction logistics architecture that explicitly relies on integrating RFID with the Global Positioning System (GPS).

The developed conceptual model architecture shows that categorisation provided through RFID and traceability as a result of RFID/GPS integration could be used as a tool to identify, record and share potential problems and thus vastly improve knowledge management processes within the entire supply chain. The findings thus clearly show a need for future research in this area.

KEY WORDS

Supply chain, RFID, knowledge management, continuous improvements, automation.

INTRODUCTION

One of the recent paramount issues that have been a growing concern in the construction industry is the role of logistics in managing the supply chain (ERABUILD, 2006). Logistics, appropriate or inappropriate, to a great extent influences the efficiency of construction activities with materials and equipment being essential building blocks of construction

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projects. Among the elements that comprise the construction process, construction materials may account for 50-60 per cent of the total cost of a project and most directly represent project progress (Song 2005, Song et al. 2006). Successful delivery and subsequent distribution of these materials to various interconnected points where they are required is an important aspect of the overall project duration.

Intensecomp (2005) reported that a wrong delivery arrangement of materials causes general disorder on construction sites. This disorder is often accompanied by a need for unplanned facilities and/or activities such as additional site storage, work interruption, extra handling, breakage, and loss. Similar challenges were also reported by the Strategic Forum for Construction in 2005. The report suggests that 50% of skilled craftsmen time is spent on un-skilled tasks, time that they could have otherwise devoted to supervising workers. A research by BSRIA noted in this report shows that 10% of working hours on site is wasted due to inefficient logistics management. The effects of the logistic related waste thus result in 30% of extra construction cost and exceeded project duration.

Radio Frequency Identification (RFID) is an auto-ID technology that connects products, items/objects through a supply chain to an extranet database. The technology has been applied in many industries to improve and enable traceability and identification of tagged objects as they traverse the supply chain. Although RFID technology is still emerging, governments and companies are already implementing RFID applications (Smith and Konsynski 2003). However, a report by CITB (2006) suggests that the construction industry was not utilising bar coding for product ordering, or e-tagging for tracking products through the process, to the extent that seems appropriate.

Other industries depend on and are progressively improving efficiency in logistics to achieve smooth processes, programme certainty and cost predictability. Honda-UK Manufacturing Ltd (HUM) for instance has initiated what could be one of the largest Ultra-High-Frequency (UHF) Radio Frequency Identification (RFID) installations in the automotive industry (Bacheldor 2006). The company used the technology to track components as they traverse HUM's supply chain, moving from suppliers through out Europe to HUM's manufacturing plant in England. In the similar way an RFID smart box developed by DHL in conjunction with the Fraunhofer Institute for Factory Operation and Automation can tell users what it contents are, and – with Global Positioning System (GPS) and later, Galileo – where it is located. The system can identify the box's cargo and location, as well as internal environmental conditions (Wessel 2007).

AIMS AND OBJECTIVES

The aim of this research is to show that the RFID technology should not only be used for automation and tracking to overcome the supply chain complexity but also as a tool to generate, record and exchange process-related knowledge among the supply chain stakeholders.

In order to achieve the above research aim the study intends to undertake desktop analyses with the following objectives:

- to review technical capabilities of RFID technology including its limitations particularly in terms of its applicability to construction,
- to gain an in-depth and generic understanding of how RFID technology has been used in tracking and locating materials within industrial supply chain management,
- to investigate the application of RFID as an information and communication technology support facility in construction logistics for the management of construction supply chain,
- to propose an improved construction logistics model base on RFID and integrated technologies such as GPS for improved construction logistics,

- to analyse knowledge management implications of the improved model in terms of early problem identification and knowledge exchange.

RFID TECHNOLOGY: FUNDAMENTALS

Automated tracking of materials, equipment and labour through the supply chain has become technically visible with advances in Automated Data Collection (ADC) technologies. RFID is one of the heralded automated tracking enabling technology that has a big impact on logistics and supply chain management (ERABUILD 2006, Wilding and Delgado 2004). Some of the technical characteristics of RFID that gives the technology a competing stand with other ADC such as bar-code are its ability to identify, locate, or track objects, or assets.

TECHNICAL CHARACTERISTICS OF RFID

RFID are technically categorised into Passive RFID and Active RFID depending on their powering method. Both use radio frequency to communicate between a transponder or tag and a reader or interrogator. Active RFID uses an internal power source (battery) within the transponder to continuously power the tag and its radio frequency (RF) communication circuitry, whereas Passive RFID relies on energy transferred from the reader to transponder to power the transponder (Savi Tech. 2006, Furlani and Stone 2005). The current RFID systems consist of Transponders or tags, Interrogators or Readers, and a host computer.

The RFID tags are attached to host objects to be identified or tracked. A tag carries data on its internal, microchip-based memory about the host such as identification and item specific information or instructions. These tags use radio frequency to communicate with the readers. To produce radio wave tags require a source of energy to power inbuilt electronics. For Passive RFID the communication range is limited by the need for a very strong signal to power the tag limiting the reader range to 3 meters. Active RFID tag on the other hand has a tiny battery, a microchip, and a tiny antenna built in and is thus not constrained on power. It can therefore provide communication ranges of 100 meters or more (Savi Tech. 2006, Wilding and Delgado 2004, and Asif and Mandviwalla 2005).

A reader is a fixed or mobile device that reads and may write to the tag through radio frequency wireless communication when tags come within its read range. The capabilities of reading depends on particular category of RFID employed (Song et al. 2005, Savi Tech. 2006). With an independent power supply active RFID tags allow greater communication ranges, higher carrier frequencies, greater data transmission rates, better noise immunity, and larger data storage capacity than passive RFID tags, and are typically read/write.

RFID CAPABILITIES

The data capacity of the RFID tags enable them to carry more information than barcodes and some other similar auto-ID technologies (Wu et al. 2005, Jaselskis et al. 1995). Tags also vary by the amount of information they can hold, life expectancy, recycleability, attachment method, usability, and cost. Reading and writing ranges vary depending on the need of a battery (active versus passive) and operation frequencies (low, high, ultra high and microwave).

Passive RFID tags operate at low and ultra-high frequencies. 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 (ERABUIL 2006). The world is more or less divided into three regions with respect to the applicable frequencies:

- Europe and Africa that mainly operates on 866 MHz,
- North and South America that operate between 902-928 MHz and
- Australia and Asia that operates around 915 MHz.

Passive RFID tags are powered by a magnetic field emitted by a reader and hence have an unlimited lifetime (Edward et al. 2003). Passive low and high frequency tags use a transmission method known as *Inductive coupling*. They have shorter read/write ranges (few inches to 30 feet). Passive UHF systems use *Propagation coupling*. A tag gathers electromagnetic or radio frequency energy emitted from a reader antenna and a microchip uses the energy to change the antenna load and reflects back the appropriate signal that can be interpreted by software as Boolean data. Being an evolving technology, new RFID systems have consistently decreasing costs and increasing data storage capacities (Ergen et al. 2006)

Active RFID tags are more reliable in performance than passive RFID tags in highly metallic environment and rough weather conditions. They are more expensive than their counterparts and there are two types available (Jaselskis and El-Misalami 2003):

- Transponders which operates within the flux of signal receive from a reader and
- Beacon which emits a signal with its unique identifier at pre-set interval usually in real-time location systems.

Active tags have internal battery source and therefore have shorter lifetime of approximately three to ten years (Jaselskis and El-Misalami 2003, Ergen et al. 2006). They can read, write and store significant amount of information, and be attached to sensors to store and communicate data to/from these devices.

RFID APPLICATIONS

There are various applications of RFID technology in different industries for both logistical traceability–tracking the location and progress of an object, and qualitative traceability–associating any additional information to products (Karkkainen, 2005).

Retail, food, defence, pharmaceutical, healthcare, manufacturing and transport are just some of the sectors where RFID has already been extensively applied (Wilding and Delgado 2004, ERABUILD Report 2006, and Smith and Konsynski 2007). Tagging provides asset visibility, identification and positioning, and enables total inventory management. Different sectors require different approaches but a common factor to all is adequately determining a basic unit or unit set for tagging (e.g. pallets, packages, single items, containers, etc.).

RFID IN CONSTRUCTION

The construction sector has been faced with the challenge to sustained improvement in logistics of the supply and delivery of materials to site (Egan 1998). On-site materials handling operations are error prone and the errors that occur significantly decrease productivity (Caldas et al. 2006).

Traceability of construction materials as they move through the supply chain from the suppliers to the point of installation on sites provides significant benefits. Song et al. (2006) further substantiate this fact in tracking the location of materials on construction job sites. They presented an approach by which materials tagged with RFID tags can be automatically identified and positioned on a construction site. The excessive amount of working time and labour effort negatively affecting project schedule consumed in locating and identifying materials on a construction site was reduced. It was concluded that automated tracking of materials has the potential to both improve project performance and enable effortless measurement of key performance indicators.

Jaselskis et al. (1995) went a step forward by integrating RFID and Global Positioning System (GPS). While the research indeed provided valuable information on the application of RFID in construction no information was given on the performance accuracies and limitations of the integrated system although the authors claim that the integrated system made a dramatic improvement in terms of materials control, and cost coding for labour and equipment. Ergen et al. (2006) conceptualized and applied the use of RFID and GPS to eliminate existing problems associated with manual methods of identification, tracking and locating highly customised prefabricated components. The authors associated the existing problems with late delivery, double-handling, misplacement of components, and incorrect installations that lead to schedule delay and increased labour costs. The research pointed out that both the RFID tags and the GPS were designed to withstand harsh environment, and no problems were encountered in terms of receiving the signals from RFID tags and a GPS unit in the field conditions. Though the research achieved 60% location information within acceptable limits, a low success was attributed to inaccuracies of the inexpensive GPS that was used. Song (2005) examined the feasibility of applying the RFID technology to automating the tracking of materials and components on construction projects. The research presented an approach in which the combination of extremely low cost RFID tags and GPS technologies formed the backbone of construction materials tracking systems based on an open-air experiment. However, the study was restricted to the tracking of only one material unit and the challenges of applying conventional GPS technology for construction material management were not explicitly presented (Lu et al. 2007). Navon and Berkovich (2005) utilise the application of RFID in collecting data related to material arrivals and dispatches but no information was given on tracking the status of materials and equipments on transit.

Various other tests of RFID technology have been reported in the studied literature but they mostly rely on one-off single-unit approaches that lack a generic conceptual framework. It is therefore clear that widespread RFID applications in construction would require a very clear material classification and codification, and a generic conceptual framework enabling RFID integration across the supply chain.

RFID/GPS CONCENPTUAL FRAMEWORK FOR CONSTRUCTION

The current practice of materials management and project planning systems depend largely on human observation and reporting of supply chain material, including plant and equipment (Wood and Alvarez, 2005). The evolution of current technologies like RFID, GPS, Bluetooth, etc. offers a unique advantage for construction logistics application.

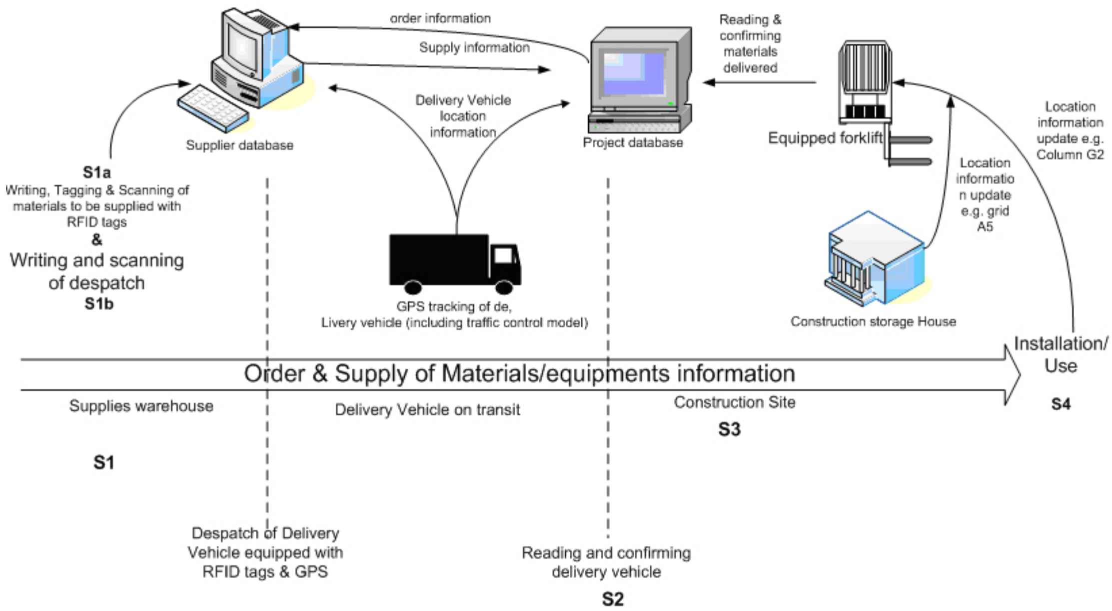
The proposed model will build on the existing models but try to avoid a one-off approach by developing a conceptual framework that can be applied to a construction supply chain irrespective of the nature of a project.

MODEL ARCHITECTURE

The model architecture is based on a realistic assumption that required materials and equipment are delivered to a particular construction site subject to orders being placed by a main contractor to its suppliers. It is envisaged that a particular order is being placed automatically by scheduling software in advance according to relevant lead times. The order itself is then being stored in the project management database.

The tracking process begins when an order for the supply of materials or equipment is being placed. The materials or equipment need to be equipped with RFID tags and are to be delivered in unit sets (e.g. pallets, packages, bags, etc.). The tags are programmed to contain supplier- and project-specific information like content, the supplier's address, transport and installation instructions, purchase order details, relevant project activity code and sequence, etc. The delivery vehicle is equipped with a tracking system combining the RFID and GPS technologies (including a tag, a reader, 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.

Figure 1: Materials/equipment logistics: writing, tagging, scanning and tracking



The collective information is sent automatically to a project database in two stages (see Figure 1):

- Scanning tags for materials/equipment that are to be delivered in n-th delivery (S1a)
- Scanning a tag for a vehicle that is to deliver the materials/equipment in n-th delivery (S1b).

When despatched, the vehicle's position can be continuously monitored by the supplier and a project manager through the GPS using digital maps (Lu et al. 2007). Arrival of the vehicle at a construction site is recorded automatically by the RFID reader mounted on the gate. This corresponds to the third scan (S2) in Figure 1 confirming the arrival of the vehicle. Confirmation of the vehicle's ID and contents is made by an automatic comparison between the tag scan with corresponding codes on the project database and the vehicle is allowed to proceed only if the two match. If successful in a project schedule allocated internal transport vehicle is automatically notified to unload the delivery vehicle and store materials/equipment into an allocated storage or directly proceed with installation (e.g. forklift, tower crane, etc.). A forklift for instance can be equipped with a reader that automatically scans each unloaded unit set and updates the project database on its location. In the case of a tower crane scanning would need to be manual and performed by the crew on the ground. This read corresponds to the fourth scan (S3) in Figure 1 confirming that the delivered material/equipment is stored in an allocated storage and ready to be installed/used.

Installation or use of materials/equipment is the last stage in the construction process but not necessarily the last one from the logistic point of view. Construction site needs to be cleared out, equipment checked and returned to suppliers, constructed facility handed over, etc. Considering the vast amount of different materials and equipment this stage may need to be divided into several sub stages. For example, concrete blocks or bricks are normally delivered on pallets and each pallet has to be scanned separately before installation (S4). On the other hand bulk materials are delivered on site using bags and containers, while concrete is delivered by concrete mixers each requiring a slightly different method of recording delivery.

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. Further to that the software can also be pre-programmed to order sequential delivery of materials that are all needed at the same time in order to avoid line ups of delivery vehicles at the site gate.

MODEL REQUIREMENTS

One of the essential requirements is to assign each material/equipment item or unit set a unique identity code that can be referred to while tracking its location. The reporting of tracking information for a particular product is usually based on the product identity code (Karkkainen 2005). EPCglobal have developed a UHF Electronic Product Code (EPC) to provide a degree of compatibility with a global technical standard code in different industries (ERABUILD 2006). EPC enables product identification and supports the use of RFID. The EPCglobal *General Identifier* is defined for a 96-bit EPC, and is independent of any existing identity specification or convention. The general identifier composed of three fields: the general Manager Number, Object Class and Serial Number, as shown in Table 1.

Table 1: The General Identifier (GID-96) includes the General Manager Number, Object Class and Serial Number in addition to the Header

General Identity (GID-96)	Header	General manager No.	Object Class	Serial No.
	8 bits	28 bits	24 bits	36 bits
	00110101 (Binary value)	268,435,455 (Max. decimal value)	16,777,215 (Max. decimal value)	68,719,476,735 (Max. decimal value)

The Header is 8-bits, with binary value of 00110101, the General Manager Number identifies essentially the company, manager or organisation. EPCglobal assigns the General Manager Number to an object or product and ensures that each General Manager Number is unique. The Object Class**,** similar to a Stock Keeping Unit (SKU) (ERABUILD 2006) is the object class number that is unique within each General Manager Number domain. An example of Object Classes could refer to component parts in an assembly or a unit set of materials required for the execution of a particular task (e.g. classes/types of beams, columns, etc.). The Serial Number code is the specific, non-repeating number within each object class code (EPCglobal 2006).

A coding system that can be easily recognised by various standard databases in use in the construction supply chain would need to be developed if RFID is to be effectively implemented in construction. The absence of a standard coding system for materials has been a major barrier for the adoption of automated industry wide data collection in construction. It would be important for suppliers to adopt a coding system in their product catalogue database that provide information on the identification and specifications of a particular product. A coding system in use by the Building Supplies R Us Ltd. in the UK is a good example needed elsewhere in the supply chain (see Table 2).

Table 2: A sample of material codes (source: Building Supplies R Us Ltd.)

Product Categories	Type	Code	Description
Drainage	Concrete Diamond Domestic Sewage Treatment Plant	11142	Diamond DMS2 up to 6 Domestic person-each
		11143	Diamond DMS3 up to 11 Domestic person-each
		11144	Diamond DMS4 up to 15 Domestic person-each
Sand and Aggregates	Plastering Sand	9540	Plastering sand-bag
	Sharp Sand	9541	Sharp sand-bag
	Granular Dust	95442	Grano Dust-bag
Foundation Block and Damp Proofing	Concrete Foundation Block	9508	3.6N/mm2, 440mmX215mmX275mm-sqm
		9509	7N/mm2, 440mmX215mmX200mm-sqm
	Flexible Damp Proof Course	9510	Flexible Damp Proof Course 100mm-roll

Another requirement is a standard project database that uses the materials database in the scheduling software. Logistics is thus based on coded materials/equipment stored in the database and tied with the scheduling software where materials/equipment are allocated as resources to corresponding activities including:

- Supplier, project, manager, activity and storage identification numbers
- Internal transport identifier
- Lead time for ordering subject to an overall progress
- Risk identification numbers and risk register

The above identifiers should also facilitate checking and confirmation of delivered materials/equipment (e.g. updating database on each scan, notifying internal transport vehicle, etc.).

RFID FOR KNOWLEDGE MANAGEMENT

Although RFID may vastly improve production by adding traceability that enables relatively straightforward monitoring of materials/equipment flow, construction will never eliminate complex interactions between various project stakeholders. There are activities that progress in parallel requiring work synchronization between various trades working simultaneously, inconsistent predictability and so on.

However, RFID has a potential of reaching far beyond material/equipment tracking. The technology relies on coding systems that can be extended to include quantitative as well as qualitative data and there is a possibility of integrating the materials/equipment and activity coding systems with a risk register. Risks from a risk register could be assigned to each activity and hence material/equipment by a unique identifier. These identifiers could then automatically start processes designed to eliminate or reduce impact/frequency of a relevant risk including procedures and major stakeholders (e.g. notifications, procedures, etc.).

RFID has thus potentials of providing construction companies with tools to automate risk identification and develop appropriate mitigation procedures before construction even starts. Having risks assigned to individual activities and materials/equipment is clearly a step away of constant firefighting where risks are dealt with when they appear. Even more, the RFID driven, automated and database supported risk identification can be shared among all involved stakeholders giving additional opportunities to appropriately mitigate risks.

CONCLUSIONS

The literature widely recognizes the scope for construction process automation. RFID on the other hand is a proven technology that has seen many successful and continuing applications in various sectors hence the attractiveness. Although the technology is used primarily for the tracking purposes and is widely used in heavily industrialized sectors it may offer entirely new possibilities for construction.

The presented conceptual model clearly builds on a logistic interpretation of a construction process requiring further empirical studies and optimization. Nevertheless it shows that there are several points in the supply process where quantitative data required for tracking can be supplemented by qualitative data on particular materials/equipment, related activities and associated risks.

The implications for knowledge management are therefore significant. Not only will the technology enable quick access to quantitative data, it will provide reliable monitoring of qualitative data, site specifics and open a whole new frontier of studies.

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