RFID-Enabled Materials Management in the Industrial Construction Supply Chain

Yassine El Ghazali, Élisabeth Lefebvre, Louis A. Lefebvre

Abstract — The construction industry, which accounts in average for 6.5 percent of Gross Domestic Product in OECD countries, represents a vital segment of the economy. Among the array of innovative Information and Communication Technologies that could be deployed in this sector, the radio frequency identification (RFID) technology stands out as a radical innovation that could enhance the efficiency of material flows between construction supply chain members, and consequently help to meet project deadlines. This paper, based on an exploratory field research, analyzes the potential of RFID for the management of materials across four layers of one construction supply chain. By allowing the identification and localization of materials in real time, RFID can lead to substantial cost reductions. Furthermore, an RFID-enabled materials management system will ensure more accurate inventories, more efficient quality controls, and, overall, a smoother optimization of day-to-day materials management.

Keywords — RFID Technology, Construction Supply Chain, Materials Management, Construction Industry

I. INTRODUCTION

The construction industry represents a vital segment of every economy [1], accounts in average for 6.5 percent of Gross Domestic Product (GDP) in OECD countries and employs more than 40 million people in the European Union, the United States of America, and Japan combined [2]. The construction industry can be divided into three main types: 1) Building construction that entails residential, commercial, and institutional building projects generally designed by architects and subsequently realized by contractors and specialty subcontractors; 2) Heavy and civil construction, which mostly comprises public infrastructures. The project designs for these infrastructures are prepared by engineers rather than by architect, and, heavy equipment and plants are involved in the construction process.

Radio Frequency Identification technology (RFID) was used for the first time during World War II, and more specifically, in 1935 [5]. It is perceived as “one of the ten greatest causal and contributory technologies of the 21th century” [6] and “one of the heralded automated tracking enabling technologies that has a big impact on logistics and supply chain management” [7]. RFID promises to deliver various benefits a wide range of applications [8] in numerous industries such as construction, manufacturing, retail, agriculture, healthcare, logistics, aerospace, packaging, transportation, and many others. Typically, an RFID platform consists of three layers:
1) The first layer is composed of RFID tags. Tags can be passive as their power is derived from the electromagnetic waves emitted by the reader’s antenna, or active as an integrated battery allows active transmission. Semi-passive tags incorporate a built-in battery which permits the storage of data on the microchip.

2) The second layer represents the antenna, the readers and other ancillary devices that allow the communication via radio frequency waves (i.e. without a line of sight).

3) The third layer corresponds to the middleware (or software platform) that behaves as an overpass between the hardware components found in the first and second layers and the host applications.

B. RFID applications for the industrial construction sector

Radio frequency identification technology (RFID) in the industrial construction industry represents an exciting area for research due to the limited number of studies that have been previously conducted. Previous research seems to focus on three main areas for RFID applications, namely supply chain management, identification and tracking, and quality management. With respect to supply chain applications, Wang and co-authors [9] demonstrate how the effectiveness of existing information flows and the convenience of data flows between offices and sites can be enhanced by integrating radio frequency identification (RFID) technology and web portals. This RFID solution leads to the real time monitoring and control of construction projects while at the same respecting project budgets and deadlines. In terms of tracking and identification applications, Goodrum et al. [10] examine the RFID tracking solutions based on active tags. Their research highlighted some major limitations of the RFID technology, namely metal interference and lack of standardization. Dziadak et al. analyze the use of RFID for the location of non-metallic buried pipes, and their research results show that pipes placed at a 2.8m depth were accurately located. Song and co-authors [11] perform field tests within a lay-down yard containing a large quantity of metal objects, thereby setting the technical parameters to automatically identify pipe spools. Results show that RFID technology can function accurately within such environments. Quality management represents the third area for RFID applications in the literature. For instance, the study conducted by Wang et al. demonstrates that both the effectiveness and flexibility of information flows in material test management, more specifically for the inspection of concrete specimens, can be improved with RFID technology. An array of additional applications involving RFID technology were either partially examined or not examined at all. Here are some specific examples:

- Reinforcement of job site visibility by implementing tools, equipment, and materials anti-theft systems;
- Strengthening of the construction project’s life cycle information database by updating data flows on labour, materials, equipment, and tools in real time;
- Support of maintenance operations by i) automating maintenance schedules and ii) by identifying in real time leak areas during the operation phase;
- Respect of environmental laws during the deconstruction and demobilization phases.

C. The construction supply chain

The concept of supply chain management (SCM) was initially hosted in the manufacturing industry and has played a significant role in a number of industries [12]. Reference [13] describes the supply chain as “the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer.” “The construction industry has been slower than other industries in adopting new management strategies [14].” It is generally characterized by low productivity, cost and time overruns, high fragmentation, conflicts and disputes. These problems can be categorized as supply chain management problems [15]. Construction supply chain management (CSCM) is recognized as an appropriate strategy among firms looking to realize operational efficiencies [16]. CSCM is defined as the “network of installations/resources and activities that provides added value to the final customer, in the functions of project design, contact management, acquisition/provision of materials and services, production and delivery of raw materials and management of the installations/resources.” The construction supply chain can be divided into three chains (figure 1). I) The materials supply chain corresponds to an unbroken chain of materials flows where materials are defined with respect to their procurement, shipping, receiving, and warehousing, followed by various installation activities. They are integrated, while the just-in-time concept, the accuracy of the inventory, and the quality control of the materials are duly respected. II) The equipment supply chain provides the requisite equipment used during the execution of construction activities (e.g. forklifts for lifting, trucks for transportation, and boom trucks for installation purposes) either from, to, or within a specific construction site. Different equipment suppliers are generally hired within an industrial construction site and their location contracts should be well managed and issued prior to the execution of the task necessitating this equipment. III) The skilled workers’ supply chain regulates and oversees the requisite skilled crafts to make use of the procured materials while also furnishing the necessary equipment.

There are a number of other key players in the construction of the supply chain (right end side of figure 1). The subcontractors, consisting of the various subcontracting firms are hired by the general contractor and are responsible for realizing either specialized or partial tasks as outlined in the overall plan of project duties. Engineering firms always take part in industrial construction projects and provide technical services to the general contractor or to the site owner client prior to the accomplishment of construction tasks, and even before the procurement of materials. Designing and/or modifying roads and bridges and developing construction plans are just some examples of the engineering firms’ many tasks. Consulting firms, increasingly involved in construction
work, provide either casual or daily support to the general contractor or to the site owner construction management team with the general purpose of delivering the project on time and within the existing budget constraints. Project estimation, planning, risk management, cost control, training, and documentation control are just some examples of the work provided by such companies.

Figure 1: An overview of the construction supply chain

D. Materials Management

The materials management field is perceived as an area with a great need for improvements, necessitating further research in the specific context of the construction industry [17]. Materials management is considered as one of the crucial fields in construction automation, accounting for nearly 60% of construction project costs [11], where each 1% of savings in expenditure corresponds to an approximately 7.3% increase in profits [18]. Construction project materials are classified into three classes: 1) off-the-shelf: available from almost all suppliers specializing in this type of material; 2) long-lead bulks, comprising materials necessitating a long lead time before their reception (e.g. valves in the oil and gas industries); and 3) engineered materials, composed of a variety of materials manufactured or assembled together based on designated design specifications [19]. Based on an extensive literature review, the materials management faces many criticisms, occasioned mainly by low productivity, cost overruns, and delays in construction schedules. The following reasons for these criticisms appear to be 1) lack of communication between project team members, 2) ambiguous and inexact exchanges of information between the parties carrying out the construction projects, 3) congestion and inadequate storage facilities, 4) poor materials coordination between supply chain partners, 5) unawareness of the enormous potential for the implementation of the supply chain management concept and many others management tools. To overcome most of these difficulties, RFID must enhance the effectiveness of the materials management processes Proper identification and localisation of the materials allows to save both time and money, to diminish rework activities, to enhance consistency, and to establish stringent standards for the industry as a whole, especially if we take into consideration the fact that a job site is a less controlled place compared to manufacturer’s storage areas [20].

III. RESEARCH METHODOLOGY

A. Research Design

As all research efforts aim at clarifying and understanding the potential of an RFID platform to manage materials in four layers of an integrated industrial construction supply chain, the research design corresponds to an exploratory research initiative. Grounded theory approach seems appropriate for two main reasons. First, although the management of RFID in industrial construction organizations, mainly at the materials management level, is of critical concern, it remains under-investigated. Second, RFID technology only bears its full potential for materials management when linking four layers of one industrial construction supply chain. However, past research mainly dealt with inter-organizational issues in a dyadic manner (supplier–contractor, or contractor-client relationships).

The field research includes multiple case studies in order to not only gain a better understanding of “the dynamics present within single settings” [21] but also to explore the structure, the ongoing collaboration within and between these organizations, the dynamics of their relationships and their materials management strategies. More specifically, this research will attempt to describe, characterize and map the concerns of construction materials management, which will be duly challenged by the advent of an RFID platform. These issues are expected to diverge across the various industrial construction supply chain layers and across the construction-project life cycle phases. Empirical findings will be confronted with existing concepts derived from the ongoing literature review. Ultimately, a preliminary conceptual framework will be drawn from these initial empirically based findings, defined in accordance with grounded theory [22].

B. Participating companies and respondents

The field study involves four players of the construction supply chain, namely one general contractor, two subcontractors, and one customer (Table 2).

<table>
<thead>
<tr>
<th>Firms</th>
<th>Role</th>
<th>Annual revenues (in millions $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firm X</td>
<td>General contractor</td>
<td>± $100M</td>
</tr>
<tr>
<td>Firm Y</td>
<td>Fabrication shop</td>
<td>± $15M</td>
</tr>
<tr>
<td>Firm W</td>
<td>Paint shop</td>
<td>± $5M</td>
</tr>
<tr>
<td>Firm Z</td>
<td>Oil refinery</td>
<td>± $15,000M</td>
</tr>
</tbody>
</table>

Table 2: Profile of participating companies

C. Data Collection

In order to facilitate this triangulation process [23], the following three sources of evidence were thoroughly examined and analyzed:

(i) Publicly available information on the construction industry, its stakeholders, the different organizations involved, and the current RFID applications in the
management of strategic materials at the intra-organizational and inter-organizational levels;

(ii) Semi-structured interviews with professionals, managers and technicians participated to the field research (Table 3), for a total of 24 participants;

(iii) Multiple on-site observations within Firm Y, Firm W, and Firm Z, in addition to semi-structured interviews based on open-ended questions with the following interviewees:

<table>
<thead>
<tr>
<th>Firms</th>
<th>Roles</th>
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<tbody>
<tr>
<td>Firm X</td>
<td>2 executives, 4 project managers, 3 superintendents, 3 field engineers, 2 drafters, 1 planner</td>
</tr>
<tr>
<td>Firm Y</td>
<td>1 executive, 1 field engineer, 1 quality engineer, 1 bar coding technician</td>
</tr>
<tr>
<td>Firm W</td>
<td>1 operations manager, 1 technician</td>
</tr>
<tr>
<td>Firm Z</td>
<td>1 project manager, 2 operations managers</td>
</tr>
</tbody>
</table>

Table 3: Participants and their role

IV. PRELIMINARY RESULTS FROM THE FIELD STUDY

A. Current Context and Issues

The materials management processes rely on basic manual and semi-automatic techniques for daily operations. Within the scope of this paper, we will map the processes for one type of material, namely a prefabricated pipe as it moves from Firm Y to Firm W to Firm Z. As illustrated in Figure 2, Firm Y is responsible for the fabrication of the pipe that requires a judicious mixture of materials with different schedules, grades, and specifications, leading to the fabrication of uniquely engineered and prefabricated pipes. Firm Y is considered as a key strategic collaborator in the industrial materials’ supply chain and plays a major role in the success or failure of an industrial construction project.

Once the prefabricated pipes have been inspected, they are shipped to the painting shop (Firm W) which specializes in metal preparations and coatings. From the painting shop, the prefabricated pipes are shipped to the Oil and Gas Refinery (Firm Z) where Firm X (General contractor) is responsible for their installation. From the on-site semi-structured interviews with the 24 participants (Table 4), some problems were identified and validated. Problems seem to occur within any level of the supply (i.e., internal problems in firms X, Y, W and Z) but are also due to inappropriate coordination between these four firms. Internal problems may be overbuying Problems also arise prior to, during, and after the fabrication, painting, and installation activities (Table 4). With respect to the use of ICTs, it is clear that Firm Y is the only organization that uses bar coding technologies to track its materials, although mainly at the level of fabrication and warehousing processes. More precisely, an operator firm Y places a barcode label on each prefabricated pipe and scans it at the completion of each of the following activities: drawing of the fabricated pipe, reception of the mark corresponding materials, passage of the materials within the fabrication shop, cutting and welding of the materials together, quality testing, expedition to the paint shop, and finally, shipping to the construction site lay down area. Based on on-site observations, the procedures for the above mentioned activities are inadequately followed and entail frequent manual verifications and monitoring. The operator who is responsible for scanning the barcode label occasionally fails to carry out his task in a timely manner and the barcode label attached to the prefabricated pipe in the fabrication shop may not be read again during the painting or construction stages.

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**Figure 2: Research activities**
The retained technological scenario represents an RFID-enabled materials management application that would lead to more accurate inventories, more efficient quality controls, and, overall, a smoother optimization of day-to-day materials management.

Certain technological assumptions have been taken into consideration concerning the product value chain of each of the firms:
1. Programmed RFID tags are placed on the procured materials by Suppliers;
2. Programmed RFID tags are placed: 1) on the prefabricated pipes shipping pallets, 2) at the end of the inspection phase of each prefabricated pipe; and 3) at the put-away/picking location in the storage area, or lay-down area, of Firm Y, Firm W, and Firm Z;
3. Programmed RFID tags are placed on the Firm Y trailer;
4. Forklifts and boom trucks are mounted with RFID readers;
5. There are hand-held RFID readers;
6. There are readers at the entrance/exit doors of Firm Y, Firm W, and Firm Z
7. A middleware application can be integrated to the firms’ WMS, and this can be readily implemented.

V. CONCLUSION

Implementing an RFID-enabled material management system creates a strong synergy, transparency, and visibility among the industrial construction supply chain partners, and thereby allows higher levels of strategic, operational, and tactical efficiency. Participants also anticipate a streamlined integration of information flows throughout the entire chain, and thereby preventing delayed responses, conflicts, and misunderstandings. Although these benefits are compelling, the RFID-enabled materials management application may face critical inter-organizational issues. Indeed, as long as the strategic intents for this application are convergent for all partners, this RFID application appears to be viable. However, the competitive nature of the industry does not encourage a complete sharing of information and limits certain practices between participating firms since today’s subcontractors will become tomorrow’s competitors. Moreover, there is a residual lack of trust between construction firms, due mainly to the limited duration of construction projects, which hinder construction organizations from cooperating and collaborating over long periods of time, and thus learning to trust one another.

ACKNOWLEDGEMENT

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REFERENCES


Table 4: Current problems and issues

<table>
<thead>
<tr>
<th>Processes</th>
<th>Description</th>
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<tbody>
<tr>
<td>Reception</td>
<td>-Reception of the wrong order or a missing material, because of i) an inaccurate materials take-off from drawings and design documents, or ii) a wrong shipment from the supplier (1,2); -Overbuying and duplication of the procured prefabricated pipes’ materials. Early reception of materials, causing deterioration of the materials’ quality, and inventory costs or delays in their reception.</td>
</tr>
<tr>
<td>Put-away</td>
<td>-Put-away of the 'received' materials randomly in a storage or lay-down area without filling out the put-away form, leading to potentially lost of materials (1,2); -Off-loading materials in the wrong warehouse/storage location without prior notification to the construction site project manager or the site engineer.</td>
</tr>
<tr>
<td>Picking</td>
<td>-U$ilization of the wrong piping materials during the fabrication process (1); -Hasty procedures for the execution of cutting, fitting, and welding activities without correctly respecting the specifications, leading to a non-acceptance of the materials during the inspection, necessitating a rework (1); -Total duration and execution of cutting, fitting, and welding processes can occasion changes, depending on the pipe fitters’ experience. This can also lead to some reworks (1); -Reception of rush orders from the general contractor leading to delays at the level of existing orders; -Utilization of the wrong painting code and specifications during the painting process; -Non-constructible items due to missing parts or materials.</td>
</tr>
<tr>
<td>Shipping</td>
<td>-Shipping of misidentified prefabricated pipes to the painting shop and then to the construction site; -Shipping the wrong order from the painting shop to the construction site.</td>
</tr>
<tr>
<td>Inspection</td>
<td>-Inappropriate non-destructive testing (NDT) and inadequate hydrostatic testing specifications.</td>
</tr>
</tbody>
</table>

1 Delivery delay of a minimum of 1 week to more than 3 weeks is applicable
2 Pre-fabricated pipes’ fabrication will only begin pending the availability of all the required materials


