RFID as an Enabler of Materials Management: The Case of a Four Layer Construction Supply Chain

Yassine El Ghazali, Élisabeth Lefebvre, Louis A. Lefebvre

***Abstract* —** Among the array of innovative Information and Communication Technologies (ICTs) that could be deployed in the construction industry, radio frequency identification (RFID) technology stands out as a radical innovation that can overcome materials flows deficiencies. 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. Results reveal that the RFID-enabled materials management application would lead to a more efficient communication within and between the four layers of the supply chain, more accurate inventories, a tighter project control, more efficient quality controls, and, overall, a smoother optimization of day-to-day materials management. Furthermore, the implementation of this RFID application will reduce project costs by an estimated 2%. Although this cost reduction (2%) appears to be marginal, the RFID project would have a decisive impact on the bottom line with an increase in profits ranging from 17% to 20%.

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

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 areas of activities: 1) Building construction that entails residential, commercial, and institutional building projects generally designed by architects and subsequently realized by contractors and specialty subcontractors; 2) Large scale and civil construction, which mostly comprises public infrastructures. The project designs for these infrastructures are usually prepared by engineers rather than by architects, and, heavy equipment and plants are involved in the construction process.

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Roads, highways, railroads, and bridges are the most common examples of this second type of construction; 3) Industrial construction that requires a high level of specialized knowledge and a wide array of multiple competencies [3]. Power generation, manufacturing, oil and gas plants are the key industries where industrial construction can be found. The industrial construction sector is very structured and can be viewed as a series of identifiable phases, namely project evaluation, feasibility study, pre-construction, construction, and commissioning, where the outcomes of each phase provide the basis for the work carried out in the next. Despite the fact that the industrial construction sector is knowledge intensive, highly specialized and well structured, it lags behind several others sectors with respect to the adoption, appropriation and diffusion of innovative Information and Communication Technologies (ICTs). This is particularly the case for the adoption of radio frequency identification (RFID) for materials management applications. This paper focuses on a specific RFID-enabled materials management application in one industrial construction supply chain and presents the main results from a field research conducted in four organizations. The objectives are threefold: first, to analyze the current processes, issues and problems related to materials management; secondly, to assess how the implementation of RFID could affect existing processes and address the main issues and problems; thirdly, to examine the anticipated benefits derived from the RFID implementation.

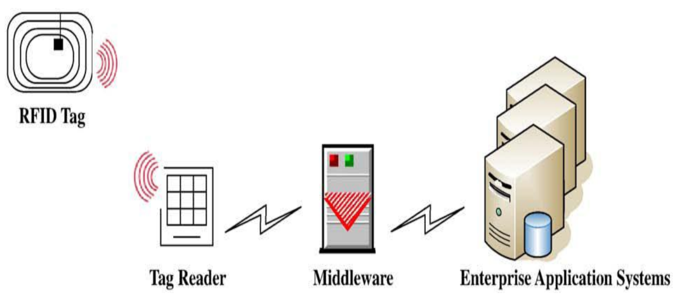
The paper is structured as follows. Section II provides an overview of the research context. It starts with a brief description of an RFID system, presents some potential RFID applications in the industrial construction sector, clarifies the concept of the industrial construction supply chain management and discusses the main issues related to materials management. The methodological approach retained for this study is discussed in section III. Preliminary results include the analysis of existing processes, the identification of current "pain points" [4] and prevailing issues, and the evaluation of anticipated benefits derived from the RFID-enabled materials management application.

II. BACKGROUND

A. RFID technology

Radio Frequency Identification technology (RFID) is perceived as "one of the ten greatest causal and contributory technologies of the 21st century" [5]. As an enabling technology for automated tracking and tracing applications, RFID has "a big impact on logistics and supply chain

management" [6]. More specifically, "the use of RFID technology affords an opportunity for greater visibility in the supply chain and further supply chain automation, making the processes more streamlined, providing accurate and timely automatic data capture" [7]. RFID has not only captured the attention of managers, professionals and public policy makers but is also considered as a stimulating research area [8].
Typically, an RFID platform consists of three layers as displayed in Figure 1:
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.



Source: Wang Y.M. and co-authors, 2010 [9]

Fig. 1 Main components of an RFID system

B. RFID applications for the industrial construction sector

Radio frequency identification technology (RFID) in the industrial construction industry represents an interesting area for research due to the limited number of studies that have been previously conducted. Past research seems to focus on three main areas for RFID applications, namely supply chain management [10], identification and tracking and, quality management. With respect to *supply chain management* applications, Wang and co-authors [11] demonstrate how the effectiveness of existing information flows and the convenience of data flows between offices and sites can be enhanced by integrating web portals and radio frequency identification (RFID) technology. This RFID solution enables an effective real time monitoring and control of construction projects while at the same time respecting project budgets and deadlines. In terms of *identification and tracking* applications, Goodrum and co-authors [12] 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 and co-authors [13] 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 [14] 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 and co-authors demonstrates that material test management information flows efficiency, 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 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 [15]. Cooper and co-authors (1997) [16] describe the supply chain as "the integration of business processes from end user through original suppliers that provides products, services and information that add value for customers." Nowadays, intense competition mostly occurs between supply chains rather than single organizational entities and, as a result, the need for cooperation and collaboration with other supply chain players is greater [17]-[18].
In the construction industry, new management strategies tend to be adopted gradually compared to other industries [19]. This industrial sector is generally characterized by conflicts and disputes, high fragmentation, low productivity, lack of effective and efficient processes within and between organizations, and cost and time overruns [20]. These problems constitute key obstacles to successful supply chain management, although it is recognized as an appropriate strategy among construction firms looking to realize operational efficiencies [21]. The construction supply chain is defined here 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 2). First, 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. These activities are integrated and the

just-in-time concept, the accuracy of the inventory, and the quality control of the materials are duly respected. Second, 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 for an industrial construction site and their contracts should be well managed and issued prior to the execution of the task necessitating this equipment. Third, 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 supply chain (right end side of Figure 2).

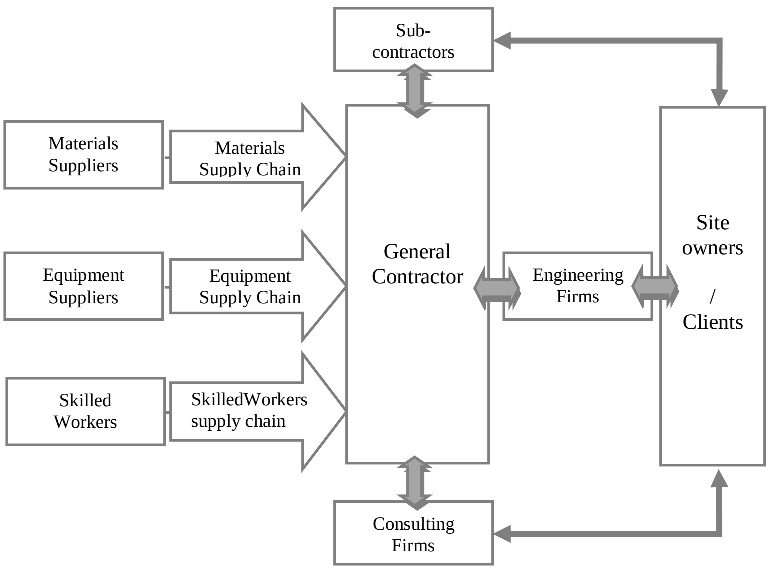


Fig. 2 An overview of the construction supply chain

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 are increasingly involved in construction work. They 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.

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 [22]. Materials management is considered as one of the crucial fields in construction automation, accounting for nearly 60% of construction project costs [14], where each 1% of savings in expenditure corresponds to an approximately 7.3% increase in profits [23]. Furthermore, a sophisticated construction materials management system is expected to enhance labour productivity by 10% to 12% [24] whereas an ineffective system can lead to approximately 18% work hour overruns. 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 [25]. 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 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 saving 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 area is not controlled as 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 (Figure 3), 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.

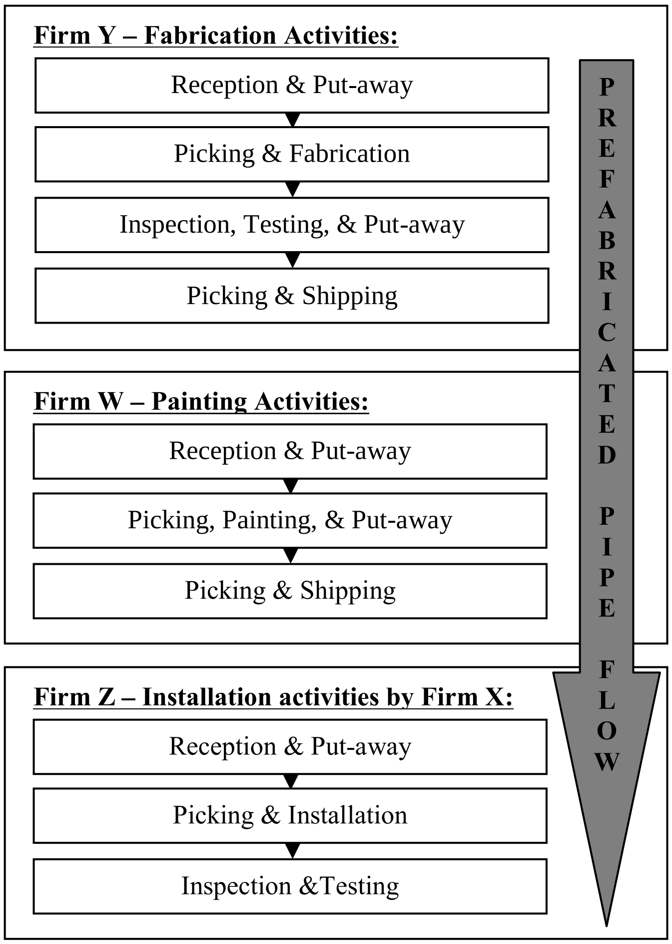


Fig. 3: The Industrial Construction Supply Chain

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 better understand "the dynamics present within single settings" [26]. Ultimately, a preliminary conceptual framework will be drawn from these initial empirically based findings, defined in accordance with grounded theory [27].

The field research study was conducted over a two-year period. The study consists of the 11 steps (Table 1). As illustrated in Table 1, we have retained a process-based perspective since such a perspective is considered as "a more dynamic description of how an organization acts" [28]. Moreover, this process-dependent viewpoint focuses on how tasks are realized at the intra-organizational [29] and inter-organizational levels and will enable construction organizations to move away from the traditional functional structures and to focus instead on the value creation.

Steps	***Description***
Step 1	Define the research project parameters and settings
Step 2	Identify material critical activities in the four layer construction supply chain
Step 3	Proceed to data collection
Step 4	Map processes as they are accomplished now ("as is" processes) in the four layer construction supply chain
Step 5	Validate the mapped business processes (on an "as is" basis)
Step 6	Identify the best practices for each critical activity and corresponding appropriate processes in the four layer construction supply chain
Step 7	Elaborate RFID technological and business scenarios for the f four layer construction supply chain
Step 8	Analyze key scenarios and select the most appropriate
Step 9	Map processes integrating the RFID platform ("to be" processes) in the four layer construction supply chain
Step 10	Validate processes integrating the RFID platform with key actors from the four layer construction supply chain
Step 11	Determine the anticipated benefits derived from the RFID platform for the four layer construction supply chain

Table 1: Field research study

B. Participating companies and respondents

The field study involves four key players in the construction supply chain, namely one general contractor, two sub-contractors, and one customer (Table 2).

Firms	**Role**	**Annual revenues** (in millions $**)**
Firm X	General contractor	± $100M
Firm Y	Fabrication shop	± $15M
Firm W	Paint shop	± $5M
Firm Z	Oil refinery	± $15,00M

Table 2: Profile of participating companies

Firm X is the subdivision of a multi-billion dollar construction contractor operating for more than 100 years in North America. Performing under a network of decentralized offices, the organization tackles world-class projects in different industry segments; namely transportation, civil, mining, building, power, and oil and gas industries. Firm X offers 1) industrial construction and maintenance, 2) building and maintenance of power plants and gas networks, 3) manufacturing of complex piping arrangements and modules, and 4) services in several industrial sectors such as oil, gas, and chemicals, mining and metallurgy, power, and pulp and paper. The company is certified ISO9001, ISO14001, and OHSAS 18001.

Firm Y is perceived as a leading piping fabrication shop specialized in providing mainly North American industrial contractors with piping systems of various bore sizes, schedules, types, and configurations, either in carbon steel, stainless steel, or any other alloy. Firm Y also fabricates pressure vessels and boilers, and, participates in shutdowns and facility upgrades mostly in the Oil and Gas Industry. The company is a member of a large set of quality programs, codes and standards (i.e. ISO ISO9001, ISO14001, OHSAS 18001, API, ASME, ANSI, and ASTM).

Firm W is maintaining a leading position in the field of surface preparation and anti-corrosive liquid coating. The organization operates in a plant of more than 20 000 square feet of floor space and serves a huge market from different industrial sectors such as oil and gas (i.e. piping systems, tanks refurbishing, etc.), industrial infrastructures (i.e. structures), and power generation (i.e. penstocks, transmission towers).

Similarly to Firm Y, Firm W has to follow many standards like the NACE (The National Association of Corrosion Engineers) and the SSPC (Steel Structures Painting Council).

Firm Z represents the job site owner/client where Firm X realizes its construction tasks. Distinguished as one of the strongest energy company in the world, the organization is specialized in refining oil products. Its objective is to achieve the production of more than one million barrels per day in the near future. The field research was conducted within one of its facilities in North America which is producing more than 120 000 barrels per day of gasoline, heavy fuel oil, distillates, and solvents.

Figure 4 gives a snapshot of one of the research sites where the field research was conducted. It shows some prefabricated pipes after their installation.

Fig. 4: One research site: some prefabricated pipes after their installation

C. *Data Collection*

In order to facilitate the triangulation process [30], 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 who 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.

Firms	Roles
Firm X	2 executives, 4 project managers, 3 superintendents, 3 field engineers, 2 drafters, 1 planner
Firm Y	1 executive, 1 field engineer, 1 quality engineer, 1 bar coding technician
Firm W	1 operations manager, 1 technician
Firm Z	1 project manager, 2 operations managers

Table 3: Participants to the field study 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 conducted a detailed process mapping for one type of material, namely a prefabricated pipe as it moves from Firm Y to Firm W to Firm Z, as illustrated in table 4. Firm Y is responsible for the fabrication of the pipe that requires a judicious mixture of materials with different 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 sent 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 3), 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.

Firm Y – Fabrication processes	
Reception & put-away	P1.1 Receive, inspect, unload, then put-away the received materials' (spools, valves, and fittings) pallets;
Prefabricated pipes picking & fabrication	P1.2 Prepare the spool sheet design after the reception of isometrics from the site owner; P1.3-Send welding procedures and qualification tests to Firm Z representatives for approval; P1.4-Receive welding procedures and qualification tests approval from Firm Z representatives; P1.5-Release the spool sheet drawings to the production floor then attach a bar code label on each of them; P1.6-Send a picking order to the warehouse manager from the fabrication shop manager; P1.7-Send a paper picking order from the warehouse manager to the forklift driver; P1.8-Move the forklift to pick the requested spools', fittings', and valves' pallets from the dedicated lay down area or shelves; P1.9-Repeat the same activity until all requested lots are brought to the designated fabrication area; P1.10-Cut pipes by flame or arc cutting; P1.11-Proceed to fitting while respecting the procedures and specifications; P1.12-Proceed to welding while respecting the procedures and specifications;
Inspection, testing, non-destructive examination, and put-away	P1.13-Send inspection and test plan (ITP) for approval from the shop quality manager to Firm Z representative; P1.14-Inspect visually the welded areas by the shop quality manager; P1.15-Proceed to a non-destructive testing (NDT) by an external laboratory to determine if the work is conforming or not with the specifications; P1.15.1-If the work is conforming, send NDT records to client's (Firm Z) representative then move to 1.16*; P1.15.2-If the work is non-conforming, treatment of non-conformities followed by other inspections and NDTs shall be realized before moving to 1.16; P1.16-Attach a bar code label to each prefabricated pipe**; P1.17-Put away the prefabricated pipes pallets using the forklift in the lay down area; P1.18-Repeat the same activity until all lots are putted away; **If a fabrication shop hydrostatic testing is specified on isometric drawings, carry out activities similar to P.3.9, P.3.10, P3.11, P3.12, P3.13 then move to P3.16.* ***The bar code label consists of the plant number, the commodity symbol, the line number, the isometric drawing sheet number, & the spool sequential number.*
Picking & shipping	P1.20-Pick then ship the pre-fabricated pipes to Firm W reception zone;

Table 4.1: Detailed mapping of Firm Y "As Is" Processes

Firm W – Painting processes	
Reception & put-away	P2.1-Receive, inspect, unload, then put away the prefabricated pipes;
Prefabricated pipes picking, painting, & put-away	P2.2-Send a picking order from the paint shop manager to the forklift driver; P2.3-Move the forklift to pick the requested prefabricated pipes pallets from the dedicated lay down area; P2.4-Identify the lot in between other lots; P2.5-Repeat the same activity until all requested pallets lots are brought to the designated painting area; P2.6-Based on isometric drawings, if the prefabricated pipe shall not be insulated, skip P2.7 and move to P2.8; P2.7-Based on isometric drawings, if the prefabricated pipe shall be insulated, move to P2.7.1; P2.7.1-Grit blast the prefabricated pipes to be insulated*; P2.7.2-Put one coat of primer to the prefabricated pipes to be insulated*; P2.8-Prepare the surface of the prefabricated pipes*; P2.9-Apply different coat to the prefabricated pipes*; P2.10-Put on a dry film thickness; P2.11-Apply insulation to the prefabricated pipes if specified on isometric drawings; P2.12-Put the coated prefabricated pipe on a pallet; P2.13-Put away the prefabricated pipes pallet using the forklift in the dedicated lay down area; P2.14-Repeat the same activity until all lots are putted away; **Inspection and reporting are carried out at the end of these phases;*
Picking & shipping	P2.15-Pick and ship the coated prefabricated pipes with corresponding packing slip/list to Firm X within the site owner (Firm Z);

Table 4.2: Detailed mapping of Firm W "As Is" Processes

Firm Z – Installation activities by Firm X	
Reception & put-away	P3.1-Arrival of the coated prefabricated pipes in addition to other key materials (bolts, gaskets, flanged valves, etc…) compulsory to erect final product. These materials are inspected unloaded and putted-away;
Picking & installation	P3.2-Send a paper picking order from the site superintendent or foreman to the forklift driver; P3.3-Move the forklift to pick the requested prefabricated pipes/key materials pallets from the dedicated lay down area; P3.4-Identify the lots in between other lots; P3.5-Repeat the same activity until all requested lots are brought to the designated installation area; P3.6-Proceed to a complete installation[*] of piping based on isometric drawings and support notes while respecting standards and specifications; P3.7-Repeat the same activity until all piping is successfully installed; *[*] To raise prefabricated pipe, a boom truck is used;*
Inspection & testing	P3.8-Proceed to a non-destructive testing (NDT) by an external laboratory to determine if the work is conforming or not with the specifications: P3.8.1-If the work is conforming, move to P3.9; P3.8.2-If the work is non-conforming, treatment of non-conformities followed by other inspections and NDTs shall be realized; P3.9-Proceed to a hydrostatic test: P3.9.1-If the hydrostatic test is specified on isometric drawings, move to P3.10; P3.9.2-If the hydrostatic test is not specified on isometric drawings, move to P3.11.1 then to P3.14; P3.10-Send hydrostatic testing procedures to Firm Z's representative for approval; P3.11-Make sure that: P3.11.1- All non-conformities have been fixed and approved by Firm Z's representative(s); P3.11.2-All procedures have been approved by Firm Z's representative; P3.12-Proceed to hydrostatic testing[*]; P3.13-Record accurately all hydrostatic pressure tests[**]; P3.14-Deliver the final product to Firm Z representative[***]; *[*]Isometric Piping systems to be tested shall include information such as the test medium. test pressure, location of vents and drains, requirements for isolation;* *[**]Example of information that shall be recorded is: 1)the name of the hydrostatic testing contractor; 2) the tested piping line identification; 3) the hydrostatic test date, start time and stop time; 4) the ambient air temperature; etc….;* *[***]Firm X shall furnish all the reports, certificates, and relevant documents to Firm Z.*

Table 4.3: Detailed mapping of Firm X "As Is" Processes

Tables 5.1 (a & b), 5.2, and 5.3 display the most significant comments made by the participants with respect to current problems or issues. The right hand side of Tables 5.1, 5.2, and 5.3 indicate the relationship of each comment to one or several processes displayed in 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.

Firms	Comments from Firm Y participants	Related processes
Firm Y	I.1-"Put-away of the received materials randomly in a storage or lay-down area without filling out the put-away form, leading to a potential loss of materials"[1&2] (Executive)	P1.1,P1.17, P1.18
	I.2-"Utilization of the wrong piping materials during the fabrication process"[1]; (Quality Engineer)	P1.6, P1.7, P1.11
	I.3-"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]; (Field Engineer)	P1.10, P1.11, P1.12
	I.4-"Total duration and the way of accomplishing the cutting, fitting, and welding processes can occasion changes, depending on the pipe fitters' experience. This can also lead to some reworks"[1]; (Executive)	P1.10, P1.11, P1.12

[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

Table 5.1 (a): Firm Y's current problems and issues

Firms	Comments from Firm Y participants	Related processes
Firm Y	I.5-"It is a mess in the storage area after the reception of rush orders from the general contractor, leading to mix-ups during the put-away and picking activities"; (Executive)	P1.1, P1.8, P1.9, P1.17,P1.20
	I.6-"Paper-based picking processes, leading to wasting time while searching, localizing, and completing the picking order"; (Quality Engineer)	P1.6
	I.7-"Ignoring the unavailability of the picking materials within stock moments prior to transition to fabrication"[1&2]; (Executive)	P1.6, P1.7, P1.8, P1.9
	I.8-"Misidentification, delays, deficiencies, and difficulties in locating materials in or around the fabrication shop"; (Field Engineer)	P1.8, P1.9
	I.9-"Inappropriate application of the non-destructive testing (NDT) and hydrostatic testing specifications"; (Quality Engineer)	P1.13, P1.14, P1.15
	I.10-"Inefficient use of barcoding technology (Failings to scan the barcode label in a timely manner at the completion of each fabrication stage)"; (Bar coding Technician)	P1.5, P1.16
	I.11-"Raw materials or even prefabricated pipes are misplaced or even missing after their fabrication and put-away"; (Field Engineer)	P1.1, P1.17
	I.12-"There exists no system that allows the tracking of the person who either put-away or pick raw materials or prefabricated pipes. This leads to misperceptions especially when a material is missing"; (Executive)	P1.1, P1.8, P1.9, P1.17,P1.20
	I.13-"Once they are painted, prefabricated pipes pallets are sometimes shipped by mistake to the wrong client (or wrong construction site). This results into schedule delays and costs overruns"; (Field Engineer);	P2.15
	I.14-"Quality engineer and pipe fitters must identify the prefabricated pipes that must be tested. This is time consuming"; (Executive)	P1.15, P3.8, P3.9
	I.15-"The list of all previous conformities and non-conformities is documented on paper. Hence their tracking becomes difficult in the case of conflicts with the client (Firm Z)"; (Quality Engineer)	P1.15.1, P1.15.2, P3.8.1, P3.8.2

[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

Table 5.1 (b): Firm Y's current problems and issues

Firms	Comments from Firm W participants	Related processes
Firm W	II.1-Same as I.1, I.6, I.7, I.8; (Operation Manager)	P2.1, P2.2, P2.3, P2.4, P2.5, P2.12,
	II.2-Same as I.4 while accomplishing insulation and/or coatings processes; (Technician)	P2.7, P2.8, P2.9,
	II.3-"Unuse of the barcoding labels during the painting stage"; (Operation Manager)	P2.2, P2.3, P2.5, P2.7.2, P2.8, P2.10,
	II.4-"Non-following of the right specifications while preparing prefabricated pipes surfaces"; (Operation Manager)	P2.8
	II.5-"Application of the wrong painting code and specifications during the painting process"; (Technician)	P2.9
	II.6-"Unreliability of some documentation specifications data (i.e. Metals' Temperature, Ambient Air Temperature, etc…)"; (Operation Manager)	P2.8, P2.9, P2.10
	II.7-"Conducting simple warehousing functions is too labour intensive compared with the core business activities". (Operation Manager)	P2.1, P2.2, P2.4, P2.5, P2.14

Table 5.2: Firm W's current problems and issues

Firms	Comments from X and Z participants	Related processes
Firm X within Firm Z	III.1-Same as I.1 - "Off-loading of the materials in the wrong warehouse/storage location without prior notification to the construction site project manager or the site engineer"; (Project Manager and Executive); (Project Manager)	P3.1
	III.2-Same as I.2, I.3, I.4 and I.9; (Superintendent)	P3.6, P3.8, P3.12
	III.3-Same as I.6, I.7, and I.8; (Executive)	P3.2, P3.3, P3.4,
	III.4-Same as I.14 prior to installation; (Project Manager)	P3.2, P3.3, P3.5
	III.5-"Same as I.10 within the construction site".(Executive and Project Manager)	P.3.3, P3.4, P3.5

Table 5.3: Firm X & Z's current problems and issues

B. Retained Scenarios Integrating RFID Technology

The retained technological scenario represents an RFID-enabled materials management system (Tables 6.1, 6.2, and 6.3) that could address most problems and issues raised by the 24 participants (Tables 5.1, 5.2, and 5.3). Certain technological assumptions have been taken into consideration concerning the product value chain of each of the firms:

1. Programmed passive 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. An identification (ID) card embedding a passive RFID chip will be used to identify each participating project member;
5. Forklifts and boom trucks are mounted with RFID readers;
6. RFID readers are hand-held;
7. There are readers at the entrance/exit doors of Firm Y, Firm W, and Firm Z;
8. A middleware application can be integrated to the firms' WMS, and this can be readily implemented.

Firms	Main activities	RFID benefits on prefabricated pipes' processes	Resolved issues
Firm Y	**Picking**	B1.1 Automatically localize the lay-down or storage location area prior to materials picking via the mounted RFID forklift/boom truck;	I.5, I.6
		B1.2 Eliminate misplacements, recovery time, and even loss of the prefabricated pipes prior to fabrication by tracking them in the lay-down area;	I.5, I.6, I.8
		B1.3 Eliminate picking check-in time, thus standardizing picking procedures and processes;	I.6, I.8
		B1.4 Semi-automate the validation processes (i.e. picked pallets counting);	
		B1.5 Allow a better visibility and management of out-of-stock materials;	I.7
		B1.6 Allow an accurate wave picking method where more than one craft can pick the required parts in the same order prior to fabrication;	I.6, I.8
		B1.7 Facilitate accurate picking-to-fabrication eliminating the staging processes;	I.6, I.8
		B1.8 Allow authentification by ensuring that only authorized employees are picking raw materials prior to fabrication	I.12
	Fabrication	B1.9 Proceed to an accurate semi-automatic identification (using a handled RFID reader) of the prefabricated pipes materials' specifications (exact sizes, diameters, rating (classes), types, schedules, grades, and lengths) that will be used during the fabrication stage;	I.2
		B1.10 Standardize the fabrication (cutting, fittings, and welding), painting, and installation processes by monitoring their workflow and sequences;	I.3, I.4
		B1.11 Track the past events for fabricated and prefabricated pipes;	I.11
	Put-away after fabrication	B1.12Automatically assign a put-away storage or lay-down area upon the fabrication of the prefabricated pipes (location information is extracted from mounted RFID forklift/boom truck);	I.1
		B1.13 Eliminate put-away searching time, hence standardizing put-away procedures;	I.1, I.6
		B1.14 Increase yield and capacity utilization by eliminating the put-away mess in the storage or lay-down areas;	I.1, I.5
		B1.15 Track in real-time the location of prefabricated pipes storage. This enhances security;	I.11
		B1.16 Update in real-time the warehouse management system (WMS) database;	I.10
	Picking after fabrication and prior to shipping	B1.17 Automatically link the picked prefabricated pipes with the corresponding order prior to shipping;	I.13
		B1.18Allow an accurate batch picking, also known as mixed order picking, thus increasing picking operations productivity;	I.13
		B1.19 Allow an accurate picking-to-trailer, eliminating the staging processes;	I.6, I.8
		B1.20 Receive the right orders at the right place and the right time while informing the fabrication shop manager about the shipping status of the prefabricated pipes;	I.5, I.6, I.13
		B1.21 Eliminate shipping errors, and hence, the returns claims;	I.13
	Inspection, testing, & non-destructive examination	B1.22Automatically identify the prefabricated pipes to be tested;	I.9
		B1.23 Semi-automatically identify the prefabricated pipes that must be tested;	I.14
		B1.24 Semi-automatically approve testing acceptance;	I.15

Table 6.1: RFID-enabled prefabricated pipes management at Firm Y

Firms	Main activities	RFID benefits on prefabricated pipes' processes	Resolved issues
Firm W	Picking	Same as B1.1, B1.2, B1.3, B1.4, B1.5, B1.6, B1.7, B1.8;	-
		B2.1 Automatically identify the prefabricated pipes to be coated (within Firm W);	II.1
	Painting	Same 1.9 and B1.10;	-
		B2.2 Identify accurately and semi-automatically (using a handled RFID reader) of the prefabricated pipes painting codes and specifications prior to the painting phase;	II.2, II.4, II5, II.6
	Put-away after painting	Same as B1.12, B1.13, B1.14, and B1.15;	-
		B2.3 Provide greater visibility of prefabricated pipes inventory;	II.1
		B2.4 Reallocate resources for added value activities, hence improving productivity;	II.7
		B2.5 Automate and semi-automate data collection tasks (e.g. pallets' counting, receipts versus packing slips);	II.1, II.7
	Picking prior to shipping	Same as B1.17, B1.18, B1.19, B1.20, and B1.21;	-
	Inspection and testing	Same as B1.22, B1.23, and B1.24;	-

Table 6.2: RFID-enabled prefabricated pipes management at Firm W

Firms	Main activities	RFID benefits on prefabricated pipes' processes	Resolved issues
Firm X within Firm Z	Picking	Same as B1.1, B1.2, B1.3, B1.4, B1.5, B1.6, B1.7, B1.8;	-
		B3.1 Automatically identify the prefabricated pipes to be installed by reading their mark number* (MK);	III.4
	Installation	Same 1.9 and B1.10;	-
	Inspection and testing	Same as B1.22, B1.23, and B1.24.	-

*A mark number is the serial number of each prefabricated pipe identified (e.g.: $\underbrace{\text{P.P. 8954521 -}}_{\text{PO number}}\underbrace{\text{1-5-445B2B}}_{\text{Line number}}\text{-}\underbrace{\text{Sht 2-MK1}}_{\text{Sheet number}}$)

Table 6.3: RFID-enabled prefabricated pipes management at Firm Z

C. Anticipated benefits

The overall expectation of the participants with respect to RFID can be summarized as follows: RFID technology could help their firms to meet the demands of their customers' portfolio and to reduce their operating costs. If we take a closer look at the way RFID would modify or transform the current processes (Tables 6.1, 6.2, and 6.3), we get a more detailed and accurate assessment of anticipated benefits. For the fabrication, painting, and installation activities, the system would eliminate non-added value processes, automate or semi-automate existing processes, and could allow the emergence of more intelligent processes. The analysis of the results presented in Tables 6.1, 6.2, and 6.3 demonstrates that the implementation of RFID in the four layer industrial construction supply chain can have a positive impact and added value to the current materials management processes, mainly with respect to: 1) communication (B1.1, B1.9, B1.11, B1.14), 2) project control (B1.5, B1.10, B1.21, B2.2, B3.1), 3) inventory control and management (B1.3, B1.5, B1.12, B1.13, B1.17, and B1.19), and 4) quality management (B1.22, B1.23, B1.24).

Communication features can also be improved using RFID technology. By automating business processes and integrating information flows through the entire materials' supply chain, key players will be constantly kept informed of the status of the material (incorporated in the RFID tag) whenever needed.

Costs	Costs description	~ % of total project Cost
Direct costs	Pipe Fitters Salaries	45.5%
	Welders Salaries	11.5%
Indirect costs	Project Manager Salary	8.0%
	Forman Salary	6.5%
	Project Controller	6.5%
	Safety Agent	6.0%
	Boom Truck	12.0%
	Compressors	2.0%
	Pick-up Rentals	1.0%
	Office Trailer	0.5%
	Tools	0.5%
Total		**100%**

Table 7: An example of the cost structure for the installation phase for one typical project

This will lead to a stronger interaction and prevent misunderstandings, conflicts, and delayed responses. Additionally, its adoption will permit managers to smooth over complexities, and eliminate paperwork within and between organizations, for instance by automatically generating an electronic bill of lading and a packing list.

With respect to the **project control level** including planning and cost control, RFID technology represents a key trigger for the diminution of a given construction project's end date. This enables managers to cut down schedule lags, delays, and better manage construction project schedules by monitoring the exact reception date of the procured materials. On-site monitoring of start and final completion installation dates enables planners to use this schedule as a reference for future projects.

Based on the cost structure of one typical project (see table 7), the participants estimated that the envisioned RFID yields savings of at least 2%. Although this costs reduction (2%) appears to be marginal, the RFID project would have a decisive impact on the bottom line with an increase in profits ranging from 17% to 20%.

At the level of **inventories' control and management**, by automating the reception, put-away, picking, and shipping processes using RFID technology, prefabricated pipes can be tracked and instantly traced, relevant data can be gathered automatically, and the remaining quantity of the materials' inventory will be controlled promptly and efficiently. In other words, the coupling of the technology with the inventories' processes will help to facilitate the entire visibility of the prefabricated pipes' inventory, which will in turn facilitate decision-making, improve work productivity by limiting avoidable mishaps, decrease time spent on searching for misplaced materials, and prevent their robbery, loss, and deterioration.

From a **quality management perspective**, RFID technology will improve the quality of services by automating (i.e. the reception of an e-mail/text message indicating the shipped date of the material and its expected reception date), if not eliminating non-added value processes (i.e. paperwork).

Moreover, in so doing, increased trust will be secured between the construction supply chain's key players, and better relationships will likewise be reinforced. Moreover, in Firm X, the Firm's quality technicians and inspectors will start reporting precise and concise information within their inspection and test plans (ITPs). Additionally, materials' installation procedures will be ensured (i.e. recording the right valve pressures and locations on the RFID tag), which will thereby help to prevent breakdowns, and facilitate maintenance operations whenever they are needed, based on the scheduled maintenance priorities.

V. Conclusion

Implementing an RFID-enabled material management system is expected to create 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. A close examination of the impacts of RFID on current processes reveals that the RFID-enabled materials management application would lead to a more efficient communication within and between the four layers of the supply chain, more accurate inventories, a tighter project control, more efficient quality controls, and, overall, a smoother optimization of day-to-day materials management.

Although the above mentioned 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, RFID implementation 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.

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