

Publication V

Hinkka, Ville & Tätilä Jaakko:

RFID tracking implementation model for the technical trade and construction
supply chains,

Accepted in Automation in Construction

Reprinted with permission from Automation in Construction.

© 2013 Elsevier B.V.

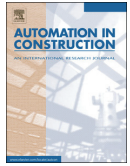


V



Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

RFID tracking implementation model for the technical trade and construction supply chains

Ville Hinkka*, Jaakko Tätilä¹

Dept. of Industrial Engineering and Management, Aalto University School of Science, BIT Research Centre, P.O. Box 15500, FI-00076 Aalto, Finland

ARTICLE INFO

Article history:
Accepted 26 May 2013
Available online xxx

Keywords:
Tracking
Radio Frequency Identification
Supply chain management
Construction
Technical trade
Finland

ABSTRACT

The use of RFID (Radio Frequency Identification) tracking has increased considerably in supply chain management during the past ten years. Despite the large diffusion of the technology, the use of RFID tracking has remained scarce in the construction industry despite the intense research. The particular design and temporary operating sites of the construction supply chains delay the diffusion, because the best-known RFID tracking systems in other industries are mainly designed to support the retailers' processes. The particular supply chain structure of construction industry, demands different business logic to build and gain benefits of RFID tracking systems. This paper presents RFID tracking implementation model for technical trade and construction industries. The approach for building feasible model was Technology Acceptance Model. The model design is based on the research project, where 16 manufacturing and wholesaler companies of technical trade were involved, and survey where customers of these manufacturers and wholesalers were interviewed.

© 2013 Elsevier B.V. All rights reserved.

1. Introduction

The use of Radio Frequency Identification (RFID) for tracking in supply chains has increased in the past ten years. RFID tracking is used in closed-loop operations in manufacturing, in streamlining processes in distribution centers, and in retailing [1,2]. Even if most of the current RFID tracking systems in use are designed to improve certain supply chain member's operations or specific task, the aim for RFID tracking system research has been to create an open standardized system, which could benefit the whole supply chain as most of the current barcode systems do today [3–5].

In a traditional supply chain, which consists of manufacturers, distribution centers and retailers, the more downstream in the supply chain the bigger the benefits are [6,7]. Therefore, the majority of existing RFID tracking solutions have been designed for the purposes of a single retailer, and not for supply chain-wide system. As an illustration, consider one of the best-known and largest RFID tracking implementations by Wal-Mart, the U.S.-based retailer. The implementation is based on Wal-Mart's strong position as a buyer with power and control over suppliers. Suppliers attach RFID tags only on shipments to Wal-Mart, and only because they are obliged to do so. Very few suppliers even consider using RFID tracking in their own operations and see little benefits of RFID tracking for their operations [7].

* Corresponding author. Tel.: +358 40 589 3280 (mobile); fax: +358 20 722 7000.
E-mail addresses: ville.hinkka@vtt.fi (V. Hinkka), jaakko.tatila@aalto.fi (J. Tätilä).

¹ Fax: +358 9 4702 3665.

If supply chain-wide RFID tracking system is seen as an extension of retailers' tracking system, building a tracking system for industries where the retailers have a minor role can be regarded to be challenging. The construction industry is part of this kind of industry as the products are mainly used by construction contractors or industrial companies, who source the products from the technical trade wholesaler. There are some retailers such as hardware stores or electrical and pipe supplies shops, but these stores handle only a small share of the total volumes of the industry. Therefore, building a supply chain-wide RFID tracking system for this industry based on retailers' need is not plausible.

Despite the low diffusion of applications of RFID tracking in the construction industry, the literature highlights the potential benefits of the technology for the industry and proposes useful application areas [8–10]. However, in this paper, we assume that the supply chain design in the technical trade and construction industries differs essentially from those supply chains where the use of RFID tracking applications is larger, and therefore technical trade and construction companies' motivation for adopting RFID tracking is different than those companies acting in supply chains dominated by retailers. In retail-driven supply chains, retailer companies try to improve their processes with support of their suppliers as in Wal-Mart's supply chain. Thus, the purpose of this paper is to study a possible implementation of RFID tracking to selected case supply network, the Finnish technical trade and construction, where the majority of the products are delivered by other distribution channels than retail stores. The research question is formulated as:

How should a supply chain-wide RFID tracking system be implemented in the Finnish technical trade and construction industries?

The objective of the paper is to define a conceptual model for the implementation, based on the ideas of Davis [11] about Technology Acceptance Model (TAM). The first approach of TAM, *perceived usefulness*, is studied by researching potential benefits of RFID tracking in technical trade supply chain. The second approach, *perceived ease-of-use*, is studied by analyzing the companies' motivation and effort needed to adopt RFID tracking in different phases of supply chain. The defined model needs to fulfill both approaches.

The paper is divided into six sections. After the introduction, the theoretical background of tracking and RFID adoption is presented and the lack of literature around the research question is expressed. The third section presents the used methodology. The case supply chain is presented, and results of the survey conducted are analyzed in the fourth section. Based on the analysis, the fifth section presents the proposed model for adoption of RFID tracking in technical trade and construction industries, and, finally, the sixth section discusses the results of the paper and suggests further research topics.

2. Theoretical background of tracking and RFID adoption

Tracking systems, in general, send a message to the tracking database when a tracked item arrives at a predefined checkpoint in the distribution network. Typically, some automatic identification technology (like barcode or RFID) is used for registering the passing of a checkpoint. Tracking systems are needed both for linking the information systems and the physical reality in the supply network and for introducing paperless and more accurate information systems [12,13].

At the moment, barcode is the most frequently used technology in tracking, even though the use of the technically advanced but more expensive RFID is increasing. One of the main advantages of using RFID technology instead of barcodes is that no line of sight is needed in reading the tagged items. The typical challenges in barcode environment – dirt and wear – are absent when RFID tracking is used, as radio waves may capture the data even through the sides of a lorry. One substantive benefit of RFID technology compared to the barcode technology is that all RF identifiers are unique [1,2,4]. If RFID technology is used for tracking, it will also enable the automation of operational supply chain processes and creates possibilities to offer information to support managerial processes [14]. RFID-based tracking systems are already being used in several industries from manufacturing to recycling and waste management. Several successful examples of RFID tracking implementations have improved supply chain operations considerably and brought significant savings for the companies that adopted it [1,15]. RFID tracking has also brought added value to many supply chain operations [16] and even opened doors for new business opportunities [17].

There are also numerous attempts to implement RFID tracking in the solutions used by construction industry. Li and Becerik-Gerber [9] list 39 academic research projects and industry use RFID cases from the construction industries. They conclude that even if the presented RFID projects cover different life-cycle phases of construction industry and demonstrate the active interest towards the technology, the mainstream of the industry has not adopted the technology [9]. In construction industry, RFID technology is proposed to be used in improving material management including locating construction materials [8,10,18,19], maintenance [20], construction quality [21], personnel management [22], and locating underground infrastructure [23].

Although information provided by RFID tracking clearly has several benefits, the additional costs must be addressed as well. In general, all the shipments should be marked with an identifier on item-, parcel-, pallet-, and shipment level [24]. Currently most of these identifiers are barcodes but the use of RFID tags is increasing. However,

especially when moving to a more exact level in tracking, the question about the price of an RFID tag arises. The simplest UHF Gen2 RFID tags, which can be used as an identifier for any level of tracking, cost about 0.05–0.10 euro apiece. This price is a significant cost factor especially in item-level RFID tracking comparing to the barcode, which can be printed on the product package usually with none or minimal costs. Therefore, Wal-Mart's RFID tracking system works currently mainly with pallet- and parcel-level, while for items the products' barcodes are used as identifiers [25,26].

Another domain to investigate regarding RFID adoption, in addition to benefits and costs related to technological considerations is technology acceptance and implementation of RFID tracking. Some generic user acceptance and implementation models of Information and Communications Technology (ICT) have been adapted and applied to RFID tracking adoption, one such being TAM by Davis et al. [27], which originally hypothesized that computer use is positively influenced by perceived usefulness and perceived ease-of-use that users experience. For example, Hossain and Prybutok [28] and Müller-Seitz et al. [29] tested TAM in RFID setting on consumers and retail customers, respectively, and found support for the TAM hypotheses. Carr et al. [30] found evidence supporting TAM hypotheses in adoption of RFID in healthcare organizations. However, Hossain and Quaddus [31] argue that the individual level ICT adoption and implementation models, such as TAM, are not applicable on the organizational level because of complexities that such models of individual's cognition do not capture. Based on the Expectation Confirmation Model [32], they propose an adoption model where intention to continued RFID use is explained by RFID expectations, satisfaction and self-efficacy, in addition to technological, organizational and external environment characteristics. Still, ICT adoption models applicable to RFID tracking, perceived usefulness and perceived ease-of-use, or similar cognitive constructs, seem to play a focal role.

In summary, improved tracking clearly has benefits to supply chain management, and RFID has proved to be a cost-effective technology to realize tracking in several industries. Still, in construction industry, the use of RFID tracking has remained relatively low comparing to other industries. To gain ground in construction industry, the implementation of RFID tracking needs to be perceived useful and ease-of-use among construction industry companies. Therefore more research about the achievable benefits and presentation of a model which could offer simple enough way for construction companies to implement RFID tracking to gain these benefits lacks from current literature.

3. Methodology

3.1. Research design

To research the possibilities of adopting RFID tracking in construction industry, a case supply chain, Finnish technical trade, was selected, and an exploratory case study project was conducted [33]. The primary objective of the study was to research which kind of open supply chain-wide RFID tracking system best suits the Finnish technical trade industry, if the implementation is justified. First, the aim was to find common understanding about the form of an industry wide RFID tracking system, and then to find a model of a supply chain-wide RFID tracking system for the industry to implement. The research approach applied in the project was design science, the idea being that researchers take an active role in designing the solution – or artifact – which is subject to empirical evaluation and theory building afterwards [34]. The ideas behind TAM [11] were used as theoretical framework behind iterative design process of the aimed solution model.

The core research project was conducted by two universities and GS1 Finland. 16 companies acting in the technical trade industry – 12 manufacturers, 3 wholesalers and one Logistics Service Provider (LSP) – participated in the case study. They gave information about

current processes of the industry and company perspectives of adoption, and most of them also tested RFID tracking in their operations during the project. Majority of the companies specialize in heating, plumbing and air-conditioning (HPAC) products and all of them are international, but their units in Finland were active in the project. Construction and other customer companies of technical trade manufacturers and wholesalers were omitted from the core research project, because the key players in the supply chain – technical trade wholesalers – stated already in the design phase of the project that they need to get their incoming logistics tracked before it is useful to extend the system to cover outgoing logistics.

The case study was divided into two parts. In the first part, the purpose was to find the benefits of RFID tracking in the project participants' processes, such as in production, in the logistics operations between production sites and wholesalers, and in wholesalers' operations. The purpose of the second part was to find possible application areas of RFID tracking among the customer companies of wholesalers and other technical trade products user companies. The objective in both parts of the case study was to find usefulness of an RFID tracking in the supply chain, which would also offer the requirements for RFID tracking system design and the motivation to build it. After analyzing the results of these two parts of the case study, there was enough background information to design an RFID tracking system in a way that the same tags attached in the manufacturing phase and the same system used upstream in the supply chain could bring added value for those downstream in the supply chain, and the downstream of supply chain do not perceive RFID tracking adoption too difficult. The structure of the case study with two parts and the respective research and data collecting methods are illustrated in Fig. 1.

In the first part of the case study, the participating manufacturer and the wholesaler companies found RFID tracking useful in their operations to consider larger implementation. During the tests in that part, they also found ways to simplify the challenges in RFID tracking adoption by tackling major industry specific problems of the technology, such as ensuring the reading on metal components typical of the industry. This paper does not deal with these findings more. Instead, this paper concentrates on the second part of the case study, which focuses on defining the way that the RFID tracking systems should be designed to bring benefits for the whole technical trade supply chain. Sections 3.2 and 3.3 present the research methodology to achieve this aim.

3.2. Data collection and analysis in the downstream of supply chain

The research strategy employed in the downstream of case supply chain was survey with mixed methods [35]. It was chosen because during the first part of the case study, the significance of supplier and wholesaler tiers in the technical trade supply chain was identified and the basic structure and operations of the supply chain were understood. Thus, more descriptive and quicker strategy of survey was selected. The survey included two data collecting methods – face-to-face interviews and an Internet-administrated questionnaire – in order to provide

data triangulation [36,37]. The structure of this concurrent triangulation design is illustrated in Fig. 2, using framework provided by Creswell [35], and explained thereafter.

The semi-structured interviews were used in an explorative manner to collect qualitative data in order to understand the target companies' operations, namely the potential application areas and benefits of RFID tracking in their logistics. Each interview was slightly adapted to focus on areas that were perceived as the most important in each context, and additional questions were asked when needed. Furthermore, since some interviewees knew only little about RFID, the interview dealt mainly with logistical problems of operations in which RFID tracking could contribute instead of discussing the technology itself. The structure for interviews was formulated based on the literature of RFID tracking usage in supply chains, and was further refined based on observations and discussions made during visits to core 16 project participant companies. The underlying purpose of the interview was to go through different processes or RFID tracking application areas: goods receiving, storing (management of material) and maintenance & repair (post-logistics use of RFID tracking). For each area, questions under three categories were asked: (1) What are the current processes, (2) what are the problems there, and (3) how could RFID tracking be used? The interview outline is presented in Appendix A.

The Internet questionnaire was used to collect mainly quantitative data on the same topics as the interview did in order to complement the interviews with quantitative measures and to triangulate the data. It had a role to assure that the more exploratory, qualitative data of the interviews were analyzed correctly. Mainly opinion data on a Likert scale with 7 response categories was asked but also descriptive text fields were used to screen for themes or issues that had not been identified so far by the researchers.

The interview outline worked as a descriptive framework in data analysis since both the interview and questionnaire were formulated so that they dealt with logistics operations or problems in which RFID tracking could be used hypothetically. The analysis of interview answers was mostly variable-oriented [37] and the data was used to look for typical issues and patterns among the sample. This approach is typical of the employed survey strategy [38]. The analysis had also some case-oriented features as some interviewed companies were treated independently but no explicit synthesis of each company was given. The qualitative data analysis performed to interview data consisted of three activities: data reduction, data display and conclusion drawing [38]. The questionnaire data was analyzed using descriptive and some inferential statistics. Calculated values were compared with the overall picture created from interview data to see if there is convergence in the two data sets [35], and to yield stronger results and conclusions if this was the case. Later, the conclusions were discussed with the experts of the project participant companies in order to get insights from the industry and validate the results.

The limitations of the research methods employed included a lack of quantitative measures and process data. The research relied mostly

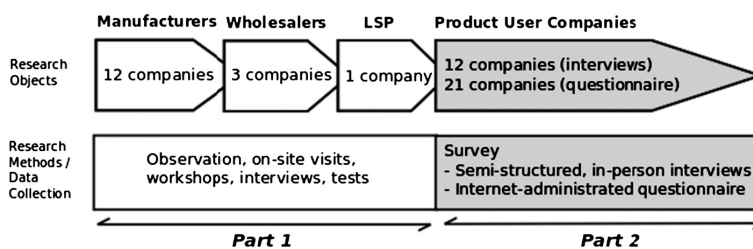


Fig. 1. The research design of the explorative case study comprising parts 1 and 2.

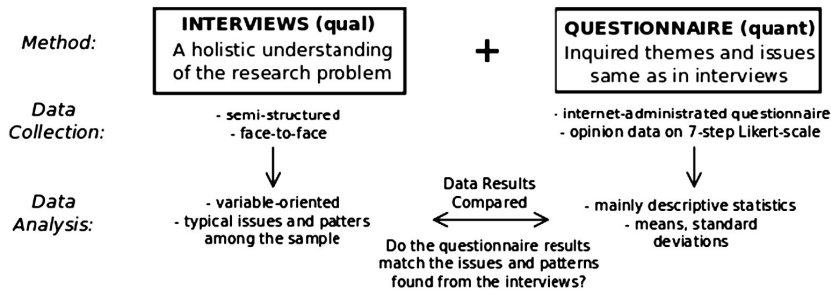


Fig. 2. Concurrent triangulation design of the survey in framework by Creswell [35].

on opinion data, which was either qualitative interview data or quantitative questionnaire data. Thus, evaluating the size of problems and other issues was challenging. The interviewees and respondents were not all very informed about RFID tracking, which hindered their ability to articulate the most important issues. However, the rather big number of interviewees and the triangulation of data made sure that a wide-enough view of the research problem was acquired. In addition, the collected data give an overview of the size of problems where RFID tracking could contribute, which offers an outline for potential users of RFID tracking in the downstream of technical trade supply chain, even if the need for improvements in tracking does not necessarily mean that companies are ready to invest in the development efforts required.

3.3. Data sampling in the survey

The target population of the survey was companies that use HPAC products. Both the interview and questionnaire samples were formed on a non-probability, purposive basis. The aim for selection was to get responses from the biggest companies using HPAC products, since it was assumed that the technology adoption starts from the biggest companies with smaller companies having limited resources or need to utilize RFID tracking. The survey population does not settle for construction companies solely, because the upstream companies would be pleased to see that also their other customers can utilize RFID tags, which increases their motivation to implement RFID tracking.

For the interview, the project participant companies provided contacts for their biggest customers, and to widen the sample, the authors searched for other suitable companies and contacts. 19 interviews were conducted in total, representing 12 different companies, some of which have subsidiaries. To identify suitable respondents for the Internet questionnaire, the membership lists of different interest groups of building services technology contractors were scanned for their biggest member companies in terms of turnover. In addition, a list of the biggest contractors in industrial classification 432 (Electrical, plumbing and other construction installation activities) was acquired from Statistics Finland to ensure that all relevant companies belong to the sample [39]. From these two sources, the aim was to select companies which had turnover of over 10 million euro in 2009. Some companies were omitted because their size or area of business, and not all companies had a respondent that could be reached. Furthermore, two companies were added to the sample based on expert statement. The final sample size for the Internet questionnaire was 23 out of 30 invitations sent (response rate 76.7%), comprising 21 different companies. As comparison, there were 43 companies with revenue over 10 million euro in the company list of industrial classification 432.

The interviewees were mainly procurement managers since they were perceived to have good understanding of logistics of their

companies during the first few interviews. Furthermore, there were not any other personnel more knowledgeable about both the RFID tracking and supply chain management in the companies. Each interview took approximately an hour, and the interview outline was sent beforehand. Respondents for the Internet questionnaire were selected mostly from procurement managers in order to enable comparison with the interview data.

We believe that the selection of companies to the sample had a modest effect in the results. Selecting the most relevant companies in the supply chain with the help of project participant companies ensured that the sample was representative enough to conduct an exploratory study and form suggestions based on it.

4. Case: Finnish technical trade supply chain

First, this section presents the case, Finnish technical trade supply chain, and HPAC industry. Afterwards, the section presents the main findings from the interviews and questionnaire conducted in companies downstream in the technical trade supply chain: Section 4.2 presents the overall picture of companies' logistics operations, including the perceived problems. Then the possibilities for RFID applications in companies' logistics are explored in the following section, drawing on findings from Section 4.2. Finally, questionnaire data are presented in Section 4.4 to triangulate the findings from the interviews.

4.1. Technical trade and HPAC supply chains in Finland

The total value of technical trade in Finland in 2010 was about 7.7 billion euro of which about a third consisted of the trade of construction materials [40]. The total value of HPAC trade, which this paper focuses on, was about 0.9 billion in 2010. This value is almost fully divided between four companies (Companies A–D), which control HPAC wholesaling in Finland. More information about these companies is presented in Table 1. That information is based on interviews of the representatives of the case study participant Companies A, B and D.

80% of the volumes of the HPAC products that the biggest wholesalers sell in Finland are also manufactured in Finland. This high share of domestic products is a consequence of many international Finnish manufacturing companies in the industry, all of which have high brand value in Finland. The customers of Companies A–C are other companies which need HPAC products in their operations. The Company D is mainly delivering its products to its retailer stores and private customers. Based on interviews in Companies A and B, the following rough estimations for the shares of wholesalers' A–C customers in HPAC products are made:

- Small HPAC contractors: 55%
- Large construction companies, and infrastructure builders: 25%

Table 1

Summary of four companies sharing HPAC wholesaling in Finland.

	Company A	Company B	Company C	Company D
Business areas	Electricity, HPAC, and steel products wholesaling	HPAC products wholesaling	Electricity and HPAC products wholesaling	Hardware and interior product retail chain
Countries operating	Finland, Russia Norway, Poland, Sweden, and the Baltic states	The owner of B operates in 64 countries in similar areas	Finland, Russia, Estonia, Sweden, Denmark, and Norway	Finland, Russia, Norway, Sweden, and the Baltic states
Market share	44%	26%	23%	7%

- Industry (e.g. process pipe systems): 17%
- Hardware and pipe stores, and other retailing: 3%.

The majority of the products of the Finnish technical trade seem to end up for construction and manufacturing industries. In general, the boundary between these industries is indefinite and fuzzy [41], which indicates that manufacturing customers of technical trade have partly the same operations as the construction industry customers.

The supply chains in the construction industry differ from other industries. Construction supply chains are temporary, usually built around certain project, and the construction site differs in every project. The construction project is led by a principal construction company, who is a primary contact for the first tier customers and who manages the construction processes by dividing it for smaller parts for first tier subcontractors. The first tier subcontractors usually subcontract partly their share for second tier constructors, which may continue the chain by subcontracting their work for the third tier suppliers and so on. A principal company in one project may be the first or the second tier subcontractor in another project [41]. According to experts from project participant companies, the construction industry in Finland operates similarly.

To manage the multiple processes of the construction project, different kinds of information systems are used, even if IT penetration in building industry is substantially less widespread than in other branches of industry [42]. Some construction companies use inter-organizational information systems (IOIS) with their key suppliers to support their collaborative processes [43]. In construction process, Building Information Modeling (BIM) is widely used among the biggest companies. The adoption of BIM has increased the collaboration and data-sharing of different stakeholders of a construction project such as architects, contractors, engineers and clients, which enables better coordination and scheduling of work, decreasing risks and time or material waste, and improving possibilities for life-cycle management of the building [44–48]. In Finland, there are several companies that develop and provide this kind of advanced software, and the major construction companies in Finland have adopted BIM and some kinds of IOIS already several years ago.

4.2. Logistics operations and problems of end user companies of the technical trade supply chain

The companies of the interview sample were somewhat heterogeneous in their businesses and operations, the only initial common factor being that they all procured technical trade products. In order to achieve some structure for generalization, the companies were categorized into five different categories as presented and described in Table 2. The categorization was formed mainly according to the business unit categorization that companies use themselves. Included in the categories are either companies, subsidiaries or business units, but they will be simply referred as companies from here on. The sample contains mostly BST (Building Service Technology) companies, which is in accordance with the big share of HPAC contractors and construction companies that are wholesalers' customers as stated in Section 4.1.

The interviewed companies ordered goods for a specific need and stored them only temporarily until installation. The main place for temporary stocking was sites. The exceptions were the companies which ordered for known needs for some sort of spare part supplies. Goods, shipped on pallets and in parcels containing mixed products, were inspected mainly manually. Goods were checked against packing lists or order lists in some companies, parcels were counted and then the goods were marked as received. Whether a system entry of received goods was made varied from company to company. Most companies relied on suppliers, especially on wholesalers, for fast deliveries and good availability of products. For example, vendor managed inventories were found in all categories and mainly regarded as a good practice. However, the use of electronic ordering varied. Some companies ordered almost everything electronically, while some ordered less or even practically nothing.

The most significant and influential difference among the companies' logistics was the place for receiving, handling and storing products. BST and I-BST categories mainly handled their goods at construction sites except some temporary warehouse stocks in I-BST companies. IM companies had spare part supplies and some products were ordered and shipped directly to sites. Their material handling was, thus, operated mainly in a stable warehouse environment. ME companies operated their logistics processes mainly at construction sites with direct shipments to sites, although one company had a modest warehouse for spare parts. The M company differed from other companies significantly since it assembled semi-finished goods at a factory and had a well-managed factory warehouse for components and sub-assemblies.

The formality and precision of material handling varied, mainly depending on whether goods were received in a warehouse or at a site. Especially the BST companies received the goods very unsystematically: goods were checked without order lists, receiving was not documented into information system and no records of stock balances were kept. The orderliness of material handling was a little better in I-BST companies and IM companies even mentioned partial use of barcodes. Compared to other companies, the M company had very standardized systems and the documentation of receiving and stocking was in good order.

Table 2

Classification of companies into five categories.

Category	Number of companies	Short description
Building Service Technology (BST)	7	Install and maintain building services technology
Industrial Building Services Technology (I-BST)	3	Install and maintain building services technology for industrial facilities
Industrial Maintenance (IM)	2	Maintain and service industrial facilities and equipment
Municipal Engineering (ME)	2	Install and maintain municipal engineering products
Manufacturing (M)	1	Assembles products

The problems in logistics operations were in accordance to division between on-site and warehouse material handling. BST companies suffered from the challenging conditions of construction sites. The receiving process was not standardized and systematic: goods might be received by the wrong person – if they were received at all but just left on site by the carrier; orders could not be verified because the receiver lacked the order list; inspection was done carelessly; and information of the receiving was not transferred electronically, in general. There were problems in the stocking as well. Although used just for temporary storing, stocks were rather disordered: goods often had to be searched for – although this was site-dependent; shortages happened to some extent but had the possibility to cause great disruptions to tight schedules; waste was a moderate problem but it was not measured and guesses about it varied from one to five per cent. I-BST companies had the similar receiving and stocking problems as BST companies although notably fewer in amounts. IM and ME companies faced even less stock-related problems and only few problems in receiving. M company faced different kinds of problems, because of its factory environment. Comparing to other company categories, its warehouse operations were in good order, but the interviewee still thought that the operational efficiency could be improved.

The shipments could also be improved. For instance, contents in parcels, and especially information about post-deliveries, could be marked more clearly and explicitly. Just-in-time deliveries from suppliers were seen as one way to ease material handling. On the whole, erroneous shipments were perceived as a minor problem.

In summary, the biggest problems in material handling arose because of inadequate receiving processes and barely existent stocking process at sites. The receiving of goods could be performed more systematically, and was somewhat neglected at sites because the management efforts emphasize production planning and installation schedule over material handling. Problems arise because of the fundamental underdevelopment of processes – a lack of order lists and information systems, for instance. In stocking, the adverse conditions of sites can be partly attributed to inferior performance, but the lack of the development effort for stock management causes also problems. If stocking is done in a warehouse, problems diminish substantially, as noted in IM, ME and M companies. These companies also face stocking problems but they are interested in improving the quality and aims of their stocking process.

4.3. Possibilities for RFID adoption among the end user companies of the technical trade industry

RFID tracking was not used in logistics by any of the companies at the time of the study. However, there had been moderate interest in it. The nearest to possible RFID tracking adoption were a BST company that was thinking of ways to use RFID, an I-BST company which had already piloted the technology, and an IM company which wanted to have a database of machines that it services. In total, nine out of total 15 companies had had some consideration of RFID tracking.

Interviewees were asked to identify possible usage areas for RFID tracking, both in receiving and stocking. In BST companies, the use of RFID tracking in receiving goods was considered more useful than in stocking, in general. They believed that relieving their major problems in receiving would also help managing the temporary storages they had. I-BST companies envisioned almost similarly as BST companies, but stocking applications were perceived to be more useful. IM companies viewed the use of RFID tracking mostly from a warehousing perspective by considering the automation of receiving and stocking processes. ME companies considered that receiving to the warehouse could be automated and receiving at the site could be made more meticulous. Again, the M company perceived that RFID tracking could speed up receiving and provide more accurate information.

Applicability of RFID tracking in product maintenance was also investigated. The aim was to find out if item-level RFID tags could be used after installation to help in servicing and maintaining products. There were some interest towards these kinds of applications but applications in logistics aroused more discussion. Perceived RFID tracking applications in servicing included: storing technical data of products, recording service history, enabling mobile work of repairmen, and speeding up the identification of products. The interests seemed to stem from two perspectives. Companies that did not keep electronic records of the installed equipment – mostly BST companies – were interested in storing equipment data electronically with the help of RFID tracking. Other companies, which already had an electronic database of installed equipment, could benefit from RFID tracking by speeding up and making servicing more efficient.

Interviewees were also asked about ways to adopt RFID tracking and possible obstacles to adoption. Investments in hardware and costs were not considered a problem in most of the companies. Alternatively, most of the interviewees probably had imprecise information about the magnitude of the investments and some even noted this. Interviewees were mostly against paying a premium to suppliers if their products had an RFID-tag. Then again, six of them mentioned that a premium could be paid if RFID tracking could be utilized and proved to yield benefits in operations. One BST and one ME company mentioned that their currently underdeveloped logistics processes decrease substantially their possible benefits of RFID tracking. The scope of the RFID tracking system was also an issue since many of the logistics applications and problems where RFID tracking could contribute require that the majority of the goods delivered are RFID-tagged. Five companies mentioned that the wholesaler could be an innovator in RFID tracking usage and, furthermore, eight companies thought that they might start using RFID tracking if wholesalers tagged their products or shipments with RFID.

4.4. Comparing interview results with quantitative data of the questionnaire

Finally, the interview data is triangulated with questionnaire data on the same issues that were asked in the interviews. The responses were comparable only with BST, I-BST and IM categories because of the chosen questionnaire sample. The questionnaire data consist of respondents' opinion to statements. Each statement was evaluated by the respondents on a Likert scale with 7 categories. Categories were given numerical values so that 1 = completely disagree, 2 = disagree, 3 = slightly disagree, 4 = neither agree nor disagree, 5 = slightly agree, 6 = agree, and 7 = completely agree. In addition, "I don't know" category was provided. In the analysis, mean value and standard deviation of responses were calculated for each statement, and each mean value was tested for hypothesis that mean is equal to 4 (= neither agree nor disagree) and resulting one-tailed p-value was calculated using t-statistic. The aforementioned statistics to statements selected at the discretion of the authors are presented in Appendix B.

Overall, most mean values were quite close to 4, indicating mild opinions on average. This, together with small sample size and high variability, makes it hard to draw strong conclusions based on the data. However, the purpose of the questionnaire was to supplement the interview data. The questionnaire data were analyzed to see if it supports the findings made in the interview, not to provide basis for completely new ideas or theory.

The data from questionnaire seems to be mostly in accordance with the interviews. According to questionnaire data, problems in receiving include careless inspection of amounts and general laboriousness, which highlights the underdevelopment of receiving process that was found out during the interviews. The need to look for goods on sites, suggested by the questionnaire, relates to disarray in stocking that was expressed in the interviews. Furthermore, it seems that better supply chain-wide visibility and accurate delivery information, which are

both hypothesized benefits of RFID tracking, would have potential to improve companies' operations (mean values 5.26 and 6.00, respectively). Some interviewees expressed these needs as well.

The investigated application areas of RFID (goods receiving, stocking, maintenance) did not differ statistically significantly in the questionnaire, however, each of them was valued positively, above 4 in mean value. The questionnaire could not distinguish statistically significantly between preferences on product and parcel level tagging. The mean values (5.38, 5.63, 4.47, respectively) give, though, similar indications that the interviews gave: pallet level was considered too inaccurate for shipments of mixed products, and rather parcel or product level could be utilized depending on products' size and amounts.

Investments were not considered a large obstacle to adoption, on average (mean value of 2.80). However, it was not clear if companies will begin using RFID tracking if wholesalers begin tagging their products although this idea was brought up in the interviews.

RFID tracking was considered mostly from a logistics viewpoint in this survey, but respondents still consider that RFID tags can be used also after installation (mean value 5.60). However, their use in maintenance was not considered as useful as in logistics applications, either in interviews or in questionnaire.

5. Synthesis of the results

5.1. Applicability and benefits of RFID tracking in technical trade

As mentioned in Section 3.1, the project participant companies – mainly manufacturers and wholesalers – found enough benefits in their operations in the upstream supply chain during the tests to consider larger RFID tracking implementation. These benefits could mainly be achieved by improving material handling processes such as dispatching, receiving and inventory, which would improve the reliability of shipments and decrease the lead time upstream in the supply chain, in addition to easier measurable benefits such as alleviating laborious material handling tasks.

Possible applications and benefits of RFID tracking clearly exist also downstream in the technical trade supply chain, as discussed in Section 4. First of all, the previously neglected goods receiving could be made more accurate and reliable with RFID tracking, which would establish system entry of goods receipt and comparison of goods received with the order, to name just a few applications. These improvements would enhance the entire goods handling in the long run since RFID receiving would enable more accurate stock balances, resulting to fewer out-of-stocks and reduction of excess stock. Concrete stocking-related applications of RFID tracking – such as inventory counting, searching and organizing – would be most beneficial only to the few companies that have warehouses. However, RFID receiving alone has a potential to improve stocking indirectly as received goods could be recorded to electronic systems. Another, advanced tracking application in stocking would be establishing item dwell-time alerts, which could speed up material flow and prevent slow moving, project-specific products to stall on sites [49]. Applications and benefits of RFID tracking have potential in service and maintenance as well but there is a dilemma: companies without electronic record keeping would benefit most if RFID-enabled electronic record keeping was applied, but the lack of existing information technology systems would require more work to build an RFID tracking system. Alternatively, existing electronic records would ease RFID tracking adoption, but the possible benefits are more subtle.

The applicability of RFID tracking, which was investigated on receiving, storing and maintenance, can be thought to represent the perceived usefulness of TAM. Perceived usefulness has originally been described as “the degree to which a person believes that using a particular system would enhance his or her job performance” [11].

Although the respondents are not the final users of the RFID technology in this context, the usefulness they perceive RFID tracking would give to their organization is a critical factor since they or their peers are the decision-makers who decide if RFID tracking will be adopted in the organization. From this point of view, RFID tracking's perceived usefulness in the organizations seems to be overall positive since various usages and benefits in receiving, storing and maintenance were found. Thus, there are indications that RFID could be implemented to companies under study from the perspective of perceived usefulness.

Importance of the other pivotal construct of TAM – perceived ease-of-use – described as “the degree to which a person believes a particular system would be free of effort” [11], comes to a play when the initiator of the RFID tracking system is considered. As suggested by the respondents, they are likely to adopt RFID system if wholesaler, that is someone else than they, designed the RFID tracking implementation. This would lower their effort in RFID tracking use and especially in the implementation.

5.2. Proposed RFID tracking implementation model for technical trade

The findings from both parts 1 and 2 of the exploratory case study indicate that RFID tracking has multiple benefits and could improve the supply chain of technical trade. From the TAM's perspective, perceived usefulness of RFID tracking in the companies was at least adequate as several benefits in material handling processes could be identified. The question that remains unanswered, however, is how RFID tracking should be deployed. As technical trade product user companies are not interested in taking an active role for RFID tracking deployment – one hypothetical reason being that RFID's perceived ease-of-use (TAM) was not considered high enough as companies did not have enough familiarity with the technology – and retailers are few in number in the industry, the initiative must come from further upstream. The key role of wholesalers in the technical trade supply chain, elaborated in Section 4.1, suggests that the wholesalers have great potential to be initiators when deploying RFID tracking system, especially with the HPAC products.

Based on findings reported in Section 4 and synthesis presented in Section 5.1, the authors propose the following, three-step RFID tracking system adoption model for technical trade supply chain in Finland. Each step is first described and thereafter the reasoning behind it is explained. The model offers a structured, sequential way to implement RFID tracking so that it covers most of the supply chain as can be seen in Fig. 3.

Step 1) *The wholesalers develop their inbound logistics with the manufacturers, who are encouraged to attach RFID tags to their shipments.*

The wholesalers were seen as the most dominant players in the supply chain and they also could benefit increasingly from RFID, so they have the most power to push through the RFID adoption. The leverage of the wholesalers arises from the following features: most products in the supply chain go through wholesalers – some suppliers do not even sell without wholesaler acting as a middleman; there are only four of them; and they have strong buying power over suppliers, who are afraid of losing markets to foreign competitors.

Step 2) *After successfully introducing the RFID tracking upstream, the wholesalers can enlarge tracking to cover their own operations and internal transports between their own sites. Then the wholesalers would have an adequate RFID tracking infrastructure to offer RFID tracking solutions for their customers.*

Wholesalers have motivation to develop RFID tracking system also for their internal operations since they could improve their

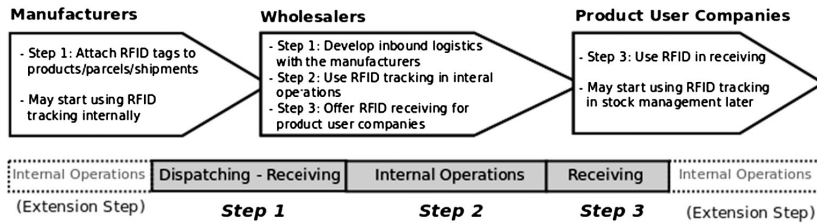


Fig. 3. Three-step adoption model for RFID tracking in technical trade supply chain. The bar at the bottom highlights the RFID tracking coverage in the supply chain.

material handling processes considerably with RFID tracking, as was found out in part 1 of the case study. This step would be less complicated to achieve than the first step since wholesalers are the only stakeholders involved. The suppliers, also, have the opportunity to start using the RFID tags in their internal operations.

Step 3) *Having the biggest improvement potential in goods receiving, the wholesalers may start to offer shipments with RFID tags that would enable customers to automate the receiving process by matching the goods with the orders electronically, which would reduce errors. If the initial service offered proves to work for the customers, it may spark the use of RFID tracking even further down in customers' operations – for instance in stock management.*

Since customer companies perceived RFID tracking to be useful, they would be willing to adopt it if wholesalers helped them to increase the ease-of-use, i.e. to overcome the effort, as can be stated in TAM's terms. The wholesalers' motivation to strive for this step is the possibility to tighten their relationship with the customers by improving services based on high reliability and better visibility, which would facilitate the order receiving of the customers.

The participating wholesaler companies are willing to take the role of an initiator in the deployment. They did not perceive adoption of RFID tracking too difficult, because they feel their operations and processes are rather straightforward comparing to their manufacturer, suppliers and customers. The wholesalers' purchasing power over suppliers may give them a good advantage to push through step 1 of the model, and then they can work internally with step 2. Step 3 can be seen as a long-term goal: part 2 of the case study identified the possible uses of RFID tracking but did not provide specific means for deployment. However, the following guidelines can be given for the implementation of step 3.

As downstream companies were not willing to be proactive in adopting RFID tracking, the key issue in product user companies' adoption of RFID tracking for shipments – whether the accuracy is pallet, parcel or product – is that the system must be useful for them and not too difficult to adopt. In practice, the wholesalers need to offer a clear and usable service or solution to their customers. The interviews revealed that downstream companies are not likely to adopt RFID tracking if only generic tags are offered. Instead, we suggest that interactive planning and co-operation in the development is needed to ensure that customers can contribute to their problems with RFID tracking. Co-operation in planning is also needed to overcome their fears of technological problems, costs and complexity. Searching the results of suitable on-going and conducted RFID tracking tests and pilots around the world also from other industries may give clues to overcome problems or help to find new application areas. The best solution for wholesalers may be to follow the same idea which was used in the exploratory case study: take a few of their biggest and most technologically advanced customers and start co-operation with them. When RFID tracking can be shown to

work with them, it becomes easier to implement it with a wider customer base.

6. Discussion

The case supply chain of Finnish technical trade has several challenges in material handling operations at every stage – be it at manufacturer, wholesaler or end user company tier. Improved tracking could contribute to the solution of many of those problems if the processes are at the same time developed in a way that the opportunities of the improved tracking can be easily captured. The great benefit of RFID technology is that it offers more cost-effective tracking than other available technologies.

The research question of this paper was based on an assumption that the low diffusion of RFID tracking applications in construction and technical trade industries arises from the fact that the operations of the downstream of supply chain differs essentially from the operations of traditional supply chains, which consists of manufacturers, distribution centers and retailers. While in traditional supply chains the retailers have pushed forward RFID tracking initiatives, construction companies and other interviewed customers of technical trade clearly indicated that they will hardly implement RFID tracking alone even if they are aware of potential benefits of the technology and they have general interests in RFID tracking. However, we believe that the holistic approach taken in this research provides great insight into how to implement RFID tracking supply chain-wide in technical trade and construction industries, not just for a few participants. The implementation must initially be started on a smaller scale, from one point of the supply chain, but considering early on every tiers' operations, challenges and opportunities in implementation of RFID tracking gives a firm foundation for eventual supply chain-wide implementation.

On the other hand, RFID is relatively an expensive technology to use on a large scale, and therefore careful consideration of costs and benefits is needed. However, the implementation model presented in this paper has several advantages in a viewpoint of construction companies:

- Implementation of RFID tracking in material management applications is relatively simple and offers easily capitalized benefits, as RFID tags would already be attached to at least certain types of products (e.g. HPAC products), if the products are procured from a wholesaler, who is using RFID tracking in its operations.
- Different RFID standards become minor problem as upstream companies need to agree about the common industry-wide standards in order to use RFID tracking in their own operations. In the case study project, GS1 was involved to help in implementing the most common commercial standards.
- RFID tracking applications in logistics require considerable amount for RFID equipment in use and perhaps some RFID infrastructure in construction sites. Expanding RFID tracking from logistics applications to cover other application areas, such as personnel management, asset tracking (tools and other construction machinery), and waste

management is easier when the RFID system is already there.

- When incoming products have RFID tags, it could be possible to integrate RFID tracking as a part of the information systems of the companies. In construction literature, there are some papers presenting pilots, where RFID tracking has been taken as a part of BIM to enable the link between the virtual model of the building with the actual products used in building construction [50,51]. If the construction companies start to use especially item-level RFID tracking in their incoming logistics as presented in this paper, the opportunities to apply these “RFID in BIM” pilots to the production use are considerably simpler, as the RFID tags would exist anyway in the components.

There are several issues in the proposed model regarding further research. Firstly, this paper settles for explaining a framework of the adoption model based on the exploratory research in one case supply chain. Still, there are numerous details requiring more investigation such as dividing costs of the implementation and sorting out the most suitable tagging level. Secondly, the examination in this paper focused mostly on HPAC supply chains in technical trade. We believe that the proposed implementation model could be applied similarly to other areas of construction industry in Finland, since there were also electricity, paint and home interior supplier companies involved in the case study. Furthermore, majority of the HPAC wholesalers operate also in other business areas as can be seen in Table 1. Thirdly, the model is designed for companies, which operate in Finland. The companies involved in the case study would like to apply RFID tracking also in other countries since they are all international, and some of them already tested RFID tracking in their Swedish or Estonian units during the first part of the case study. However, the model may need modifications when applied in countries where the variety of supply chain parties is different. For example, vertical integration in the supply chain may change the position of the wholesaler. Also introduction of RFID tracking in HPAC supply chains in Finland relies on the wholesalers’ co-operation with large domestic manufacturers and suppliers. Introducing RFID tracking upstream in the supply chain might be more difficult if the majority of the products are sourced from different countries. Finally, the utilization of RFID tags in property maintenance offers interesting research topics. Item-level RFID tagging is justified at least for bigger products, and the interviewed customer companies considered these tags could be useful also after the installation, but they could name only a few applications.

Obviously, executing the proposed model in practice is challenging. The perceived usefulness and perceived ease-of-use components used in the model design worked as guideline, but the adoption of RFID tracking is a result of several persons’ decision, and therefore simplifying the main challenges of adoption to measurements normally used to assess an individual’s cognition, might turn out to be too limited. There are neither currently any reported supply chain-wide RFID tracking implementations that are open and as large as proposed in this case study. However, the wholesaler companies involved in the case study are currently enlarging their tests together with some suppliers, aiming to realize the plans. Following the progress of this pioneering deployment offers interesting insights both for practitioners and academics also outside construction industry.

Appendix A. The interview outline

Basic information

- Interviewee’s position in the organization
- Technical trade products that the company procures
- Amount of products and suppliers
- Spend in technical trade products

Knowledge of RFID

- Interviewee’s knowledge of RFID
- (Possible introduction to RFID technology given by the interviewer)
- Has RFID been used or has it been considered to be used in the company

Receiving

- Description of how receiving is done
- Inspection, marking shipments received (IT systems and EDI)
- Errors in receiving and their size
- Improvements in the markings of shipments
- Erroneous shipments and extra work caused by them
- Biggest problems and challenges in receiving
- Applications and benefits of RFID in receiving

Stocking

- Description of how stocking is done
- Markings needed in stocking
- Accuracy of stock balance records
- Amount of waste and its sources
- Finding products from warehouse/site
- Out-of-stocks and their costs
- Biggest problems and challenges in goods handling
- Applications and benefits of RFID in stocking

Using RFID after installation

- Description of how products are serviced
- Information needed in servicing
- Benefits of automatic identification in servicing
- Recording information in servicing
- Applications and benefits of RFID in servicing
- Disposal of products

Transfer units (pallets and such)

- Units used and their ownership
- Price and amount of the units
- Problems with the units
- Applications and benefits of RFID in controlling transfer units

Other/general issues

- Counterfeits and authentication of products
- Visibility to amount of products inside the company
- Visibility to entire supply chain
- Needs for traceability of products
- Product recalls

Possibilities for RFID adoption

- Investments in hardware and software
- Likelihood of adoption in the near future
- Willingness to pay premium for RFID-tagged product

Appendix B. Questionnaire statistics

The scale for mean values is from 1 to 7.

Null hypothesis for the *t*-test (see: *p*-value) is “mean = 4”. Alternative hypotheses for all the statements are “mean > 4” but for the second last (“Hardware and software investments...”) “mean < 4”. Formulations of alternative hypotheses are based on interview findings.

Categories and statements	Mean value	Standard deviation	p-Value
Problems			
Receiving goods is burdensome	4.57	1.34	0.03
Inspection of amount of goods received is done carelessly	4.78	1.48	0.01
Goods have to be looked for from the sites often	5.04	1.30	*
Visibility to vendor's stock balances would ease our operations	5.26	1.42	*
More accurate information of delivery times would ease our operations	6.00	1.17	*
Application areas			
RFID tracking is useful in goods receiving ($n = 15$)	5.33	1.05	*
RFID tracking is useful in stocking ($n = 15$)	5.33	0.90	*
RFID tracking is useful in maintenance ($n = 16$)	5.13	1.31	*
Accuracy of tagging			
Pallet level RFID tagging is useful ($n = 15$)	4.47	1.85	0.17
Parcel level RFID tagging is useful ($n = 16$)	5.63	0.96	*
Product level RFID tagging is useful ($n = 16$)	5.38	1.09	*
General issues on RFID applicability			
Hardware and software investments are an obstacle for RFID adoption in our company ($n = 15$)	2.80	1.55	*
Our company will begin using RFID tracking if wholesalers begin tagging their products ($n = 12$)	4.58	1.38	0.09
RFID tags are useful also after installation ($n = 15$)	5.60	0.74	*

Mean values, standard deviations and p-values (* = value < 0.01) for selected statements. Sample size is 23 unless otherwise noted in brackets.

References

- Attaran, M., RFID: an enabler of supply chain operations, *Supply Chain Management: An International Journal* 12 (4) (2007) 249–257.
- Ngai, K., Moon, F., Riggins, C. Y., Economical assessment of the impact of RFID technology and EPC system on the fast-moving consumer goods supply chain, *International Journal of Production Economics* 112 (2) (2008) 510–520.
- Spekman, P., Sweeney, R., RFID: from concept to implementation, *International Journal of Physical Distribution and Logistics Management* 36 (10) (2006) 736–754.
- Wyld, D., RFID 101: the next big thing for management, *Management Research News* 29 (4) (2006) 154–173.
- Zhou, W., RFID and item-level information visibility, *European Journal of Operational Research* 198 (1) (2009) 252–258.
- Hinkka, V., Holmström, K., Främling, T., Ala-Risku, T., RFID tracking in the book supply chain: the transition from postponed to speculative tagging, *International Journal of Logistics Research and Applications* 15 (3) (2012) 194–214.
- Soon, C.-B., Gutiérrez, J., Effects of the RFID mandate on supply chain management, *Journal of Theoretical and Applied Electronic Commerce Research* 3 (1) (2008) 81–91.
- Lu, W., G., Huang, H. L., Scenarios for applying RFID technology in construction project management, *Automation in Construction* 20 (2) (2011) 101–106.
- Li, B., Becerik-Gerber, L., Life-cycle approach for implementing RFID technology in construction: learning from academic and industry use cases, *Journal of Construction Engineering and Management* 137 (12) (2011) 1089–1098.
- Young, D., Haas, P., Goodrum, C., Caldas, V., Improving construction supply network visibility by using automated materials locating and tracking technology, *Journal of Construction Engineering and Management* 137 (11) (2011) 976–984.
- Davis, F., Perceived usefulness, perceived ease of use, and user acceptance of information technology, *MIS Quarterly* 13 (3) (1989) 319–340.
- Holmström, K., Främling, T., Ala-Risku, T., The uses of tracking in operations management: synthesis of a research program, *International Journal of Production Economics* 126 (2) (2010) 267–275.
- Kärkkäinen, T., Ala-Risku, K., Främling, T., Efficient tracking for short-term multi-company networks, *International Journal of Physical Distribution and Logistics Management* 34 (7) (2004) 545–564.
- Visich, S. L., B. Khumawala, P. Reyes, Empirical evidence of RFID impacts on supply chain performance, *International Journal of Operations & Production Management* 29 (12) (2009) 1290–1315.
- White, M., Johnson, H., Wilson, R., RFID in the supply chain: lessons from European early adopters, *International Journal of Physical Distribution and Logistics Management* 38 (2) (2008) 88–107.
- Lin, C.-Y., Lin, Y.-H., Ho, C., RFID technology adoption and supply chain performance: an empirical study in China's logistics industry, *Supply Chain Management: An International Journal* 14 (5) (2009) 369–378.
- Martinez-Sala, E., Egea-Lopez, F., Garcia-Sanchez, J., Garcia-Haro, A., Tracking of returnable packaging and transport units with active RFID in the grocery supply chain, *Computers in Industry* 60 (3) (2009) 161–171.
- T.-H. Shin, S. Chin, S.-W. Yoon, S.-W. Kwon, A service-oriented integrated information framework for RFID/WSN-based intelligent construction supply chain management, *Automation in Construction* 20 (6) (2011) 706–715.
- Razavi, S., C. Haas, Using reference RFID tags for calibrating the estimated locations of construction materials, *Automation in Construction* 20 (6) (2011) 677–685.
- C.-H. Ko, RFID-based building maintenance system, *Automation in Construction* 18 (3) (2009) 275–284.
- L.-C. Wang, Enhancing construction quality inspection and management using RFID technology, *Automation in Construction* 17 (4) (2008) 467–479.
- A. Costin, N. Pradhananga, J. Teizer, Leveraging passive RFID technology for construction resource field mobility and status monitoring in a high-rise renovation project, *Automation in Construction* 24 (1) (2012) 1–15.
- B. Kumar, J. Somerville, A model for RFID-based 3D location of buried assets, *Automation in Construction* 21 (1) (2012) 121–131.
- GS1 standards in transport & logistics, <http://www.gs1.org/services/publications/online>, (Accessed March 9, 2011).
- V. Hinkka, Challenges for building RFID tracking systems across the whole supply chain, *International Journal of RF Technologies Research and Applications* 3 (3) (2012) 201–218.
- E. Bottani, A. Rizzi, Economical assessment of the impact of RFID technology and EPC system on the fast-moving consumer goods supply chain, *International Journal of Production Economics* 112 (2) (2008) 548–569.
- F. Davis, R. Bagozzi, P. Warshaw, User acceptance of computer technology: a comparison of two theoretical models, *Management Science* 35 (8) (1989) 982–1003.
- M. Hossain, V.M. Prybutok, Consumer acceptance of RFID technology: an exploratory study, *IEEE Transactions on Engineering Management* 55 (2) (2008) 316–328.
- G. Müller-Seitz, K. Dautzenberg, U. Creusen, C. Stromereder, Customer acceptance of RFID technology: evidence from the German electronic retail sector, *Journal of Retailing and Consumer Services* 16 (1) (2009) 31–39.
- A.S. Carr, M. Zhang, I. Klopping, H. Min, RFID technology: implications for healthcare organizations, *American Journal of Business* 25 (2) (2010) 25–40.
- M. Hossain, M. Quaddus, The adoption and continued usage intention of RFID: an integrated framework, *Information Technology & People* 24 (3) (2011) 236–256.
- A. Bhattacharjee, Understanding information systems continuance: an expectation-confirmation model, *MIS Quarterly* 25 (3) (2001) 351–370.
- R. Yin, *Case Study Research: Design and Methods*, second ed. Sage Publications, California, 1994.
- J. Holmström, M. Ketokivi, A.-P. Hameri, Bridging practice and theory: a design science approach, *Decision Sciences* 40 (1) (2009) 65–87.
- J.W. Creswell, *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, third ed. Sage Publications, Thousand Oaks, CA, 2009.
- J.W. Creswell, *Qualitative Inquiry and Research Design: Choosing Among Five Traditions*, first ed. Sage Publications, Thousand Oaks, CA, 1998.
- M. Miles, A. Huberman, *Qualitative Data Analysis: An Expanded Sourcebook*, 2nd ed. Sage Publications, Thousand Oaks, CA, USA, 1994.
- C. Robson, *Real World Research: A Resource for Social Scientists and Practitioner-Researchers*, first ed. Blackwell Publishers, Oxford, UK, 1993.
- Statistic Finland, <http://www.stat.fi/>, (Accessed January 25, 2011).
- Technical trade association of Finland, statistics about technical trade. In Finnish <http://tekninen.fi/>, (Accessed October 30, 2011).
- A. Segerstedt, T. Olofsson, Supply chains in the construction industry, *Supply Chain Management: An International Journal* 15 (5) (2010) 347–353.
- H.-M. Lönngren, C. Rosenkranz, H. Kolbe, Aggregated construction supply chains: success factors in implementation of strategic partnerships, *Supply Chain Management: An International Journal* 15 (5) (2010) 404–411.
- P. Hadaya, R. Pellerin, Determinants of construction companies' use of web-based interorganizational information systems, *Supply Chain Management: An International Journal* 15 (5) (2010) 371–384.
- Y. Arayici, Towards building information modeling for existing structures, *Structural Survey* 26 (3) (2008) 210–222.
- Y. Jung, M. Joo, Building information modelling (BIM) framework for practical implementation, *Automation in Construction* 20 (2) (2011) 126–133.
- W. Kymell, *Building Information Modeling: Planning and Managing Construction Projects with 4D CAD and Simulations*, McGraw-Hill Professional Publishing, New York, 2008.
- R. Sebastian, Changing roles of the clients, architects and contractors through BIM, *Engineering Construction and Architectural Management* 18 (2) (2011) 176–187.
- T. Hartmann, H. van Meerveld, N. Vosseveld, A. Adriaanse, Aligning building information model tools and construction management methods, *Automation in Construction* 22 (1) (2012) 605–613.
- J. Holmström, A. Tenhällä, M. Kärkkäinen, Item dwell time in project inventories: a field experiment, *Computers in Industry* 62 (1) (2011) 99–106.
- H. Hämäläinen, J. Ikonen, Requirements for RFID tagging process of concrete elements in building project, *Proceedings of 16th International Conference on Software, Telecommunications and Computer Networks*, Split, Croatia, 25–27 September, 2008, pp. 238–242.
- H. Xie, W. Shi, R. Issa, Using RFID and real-time virtual reality simulation for optimization in steel construction, *Journal of Information Technology in Construction* 16 (2011) 291–308.