Possible Use of RFID Technology in Support of Construction Logistics

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Master Thesis in
Information and Communication Technology

Agder University College

Grimstad, 2004-06-01

Abstract

Radio Frequency Identification (RFID) is a relatively old technology that has gained enormous popularity in the later years, as more and more areas of business see it as a possible technology with which to improve their existing processes. It is often presented as a replacement for today's barcodes, but the technology has much greater possibilities, such as individual serial numbers for each item, and the possibility to read these numbers at a distance of several metres.

One of the areas that RFID technology may show great potential is the area construction logistics. Today, a construction site is a chaotic place, with materials stored at various locations and often little to none control as the materials arrive. The result of this is that delivery failures may not be discovered until the materials are to be used, which often creates unnecessary delays. If the materials were to be marked with RFID tags, these delivery failures may be discovered as the materials arrive at the construction site.

During the writing of this thesis, we were in close contact with representatives of the construction industry, and we gained much valuable information about the processes on a construction site and generally in the construction industry.

A prototype was also developed that was able to read the tags already present in the doors from Swedoor AB, the firm that our original external partner uses on most of their projects. The prototype is able to read the tags and send them to a server over the GSM network, where it can then be processed and the materials checked in. This prototype unveiled a serious problem with handheld scanners; the scanning distance is too short to use on a construction site due to limitations of the battery.

We conclude the report with the realization that RFID technology, as it is today, is too immature to deploy in the construction industry today.

Preface

This thesis is written as part of the Master degree in Information and Communication Technology at Agder University College. The work was carried out between January 2004 and June 2004. The thesis definition was supplied by Selvaag Bygg via their research department BlueThink. Unfortunately, our close cooperation with this company was short-lived as our contact got other responsibilities within the company. Instead we have worked with other companies, including Skanska, Swedoor and EMS-RFID.

We would like to thank our supervisor Associate Professor Lars Line at AUC, Ole Morten Sundsdal at Skanska, Niklas Hild at Automation System AB, Joel Lindau at Datalogic, Per Samuelsson and Ulf Svensson at Swedoor, Arve Engebretsen at Montér Grimstad, Stephen Crocker at Escort Memory Systems, Sune Granzow at Beta technic ApS, Morten Magelssen, Bente Skattør and Bo Terje Kalsaas at AUC, Tore Haugen at NTNU, Torer Berg and Ole Jørgen Karud at Byggforsk and finally Lars C. Christensen at Selvaag for bringing our attention to the original thesis concept.

Grimstad May 2004

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Introduction

Background

Radio frequency identification (RFID) is an up-and-coming technology that will be in use in several different areas in a few years. Especially in the retail industry, where the competition is fierce and cost reduction is the holy mantra. RFID is one of several technologies where the goal is to automatically identify goods with as little human intervention as possible. This is especially interesting in logistic-laden enterprises, as the aforementioned retail industry and, as this thesis will look at, the construction industry, where there are many different enterprises involved.

A construction site changes all the time, and various sites have vast differences. Storage areas change during the build process, and materials may not be where the workers look for them. This means loss of both time and money as they search for the materials. In addition there are tons of different materials coming into the site at all times. The pressure on time often means that there is little or no formal control of what is received. The materials are just moved directly to the place where they are meant to be used. By the time any mistakes are discovered, the materials are often placed deep within the construction site and unpacked. This makes repositioning or returning the materials difficult and time-consuming.

Now imagine a construction site where a central computer system "knows" the location of the materials at any time, and logs them as they are being moved. This may be a reality with the use of RFID. Any time someone moves the materials, a signal is being sent from a small computer attached to them and the location is updated in a database. This small computer is only a tiny chip with an antenna, and its only function is to send a signal when paged from a reader. This small computer is known as an "RFID tag".

Thesis Definition

Logistics on a building site is a dynamic and complex process. Storage and work areas change from project to project and even during the building process. The mixture of bulk materials and individual components complicates the logistics. It is time-consuming to plan and supervise logistics, and a lot of time is spent searching and waiting. The thesis will review existing logistics processes on a building site and examine how wireless technology for marking and identification (active/passive RFID) materials and components can support a process improvement.

The Master Thesis will consist of:

- A review of RFID; technology, standards, research and business cases.
- A review the value chain and flow of goods into the construction site for selected components.
- An ethnographic study of the existing logistic processes on the building site that evaluates and prioritizes the potential for process improvement.
- Based on this a prototype will be developed and tests will be performed on a chosen process.
- Finally the thesis will look at how to integrate the data from the prototype with existing systems within the contractor firm.

The actual weighting of the above tasks will be decided together with the supervisor as the work evolves.

Thesis Outline

The next chapters will try to approach the task in a funnelled manner. Chapter two dwell upon the work that has been done as time progressed. In chapter three the secrets of RFID will be revealed, in chapter four the report will look at logistics in general and construction site logistics in particular. In chapter five the method of contextual design will be reviewed. Chapter six will look at the above mentioned themes and how these can be used to solve the actual task at hand. Chapter seven deals with the actual prototype, what specifications the prototype needs to meet and the choice of equipment that was made. Then the same chapter looks at the evolvement of the prototype software. Chapter eight will look at how the information flow from the RFID reader can be integrated with back-office systems. Finally chapter nine, ten and eleven are where the results are summarized, discussed and at last a conclusion being drawn from the lessons learned.

Work description

Introduction

Currently the RFID technology is still in its organizational infancy. There are some movement being made for standardizing the technology for the retail industry, but little is being done in the construction industry.

In this regard this thesis will look at how RFID can be employed on construction sites, specifically for looking at how the technology might assist in logistics.

The thesis will look at two points on the employment of RFID:

1. The feasibility of using RFID on constructions sites. This is due to the fact that construction sites are often quite unsuited for wireless technology. They are often widely spaced, with concrete and metal obstructions and filled with noise and interference from vehicles and construction-machines.
2. The cost-effect of using RFID. Are there any real problems on site that can justify the expense of the technology employment? Where are the possible savings located? In reducing errors, in increased work efficiency or in tying up back-office systems to the technology?

To this end, the work on the thesis will consist of getting to know the possibilities and restrictions on RFID-technology and the possibility of adding wireless functionality. In addition is the cost of the technology important. To find the possible cost-savings it is important to know the procedures on the site, the how's, what's and where's.

The original work plan

At first there was meant to be a literature study of RFID during the month of January. After this a meeting with Selvaag was scheduled for discussing the project and planning a field study of a construction site during February. This meant that we would need to acquire the necessary contextual design concepts prior to this in order to be able to employ them in the field study. With the information gathered during the field study we would set some requirements for the prototype while continually getting feedback from Selvaag. These requirements would give the parameters for the needed hardware, which was to be ordered during March. The implementation would be developed back-to-back with testing. Then a final test would be set during the last part of April or the first part of May. The time until May 18th, the non-mandatory (but highly recommended) deadline for delivering a first draft of the report, would be used for discussing the results and finishing the report. After this only polishing and refining was to be done on the report.

Actual work progress

Unfortunately our contact at Selvaag was given other assignments within the company and was therefore not able to assist us in this task. This meant that the all meetings and communications with Selvaag were cancelled. This also put a stop to the field study planned for February. Because of failure in communications the co-operation with Selvaag was not terminated until some time in March in concordance with the supervisor. This caused some displacement in our original schedule. Because of the non-appearance of the field study the time used on contextual design became a moot point. The whole process of contextual design derives from observing actual behaviour on site and developing new and (hopefully) better methods for completing the task. This could be described as a ‘pull’-process, in as much the information is ‘pulled’ in. Instead the project would now be more ‘push’-driven as we would produce a new method for the given task and *then* applying/testing it on site to see if it produced the desired result.

Given the loss of our link to the construction industry it was necessary to find alternative sources of information. A literature study of general logistics and construction site logistics was started fairly early, but it was difficult to find specific information regarding construction sites. In addition two interviews were conducted, one with an acquisition manager for a larger construction project in the local area and one with a daily manager for a construction material supplier. The acquisition manager kindly made himself available by email should any questions arise and also made testing the prototype possible on his current construction project. We were in continual dialog with Swedoor, a door manufacturer who uses RFID in their production line and EMS RFID, via their subcontractor Automation System AB, who implemented the RFID technology at Swedoor’s factory.

Although the project could have encompassed the entire range of materials flowing into the building site, and even tried to find a way to track the movement of tools, it was decided fairly early that the emphasis was to be placed on the processes of windows and doors. This is because two producers of doors and windows are known which are of a fair size in the Norwegian construction industry that uses RFID in their production line. These are Swedoor, a Swedish door manufacturer, and NorDan, a Norwegian window manufacturer. Selvaag used both of these and since the logistic processes of doors and windows are closed related it was decided to look at doors as a main emphasis, thereby introducing a close cooperation with Swedoor and their aforementioned RFID partners EMS RFID and Automation System AB.

The hardware was ordered during the last quarter of March and arrived by the last week of April. Upon testing and further inspection of the hardware it was discovered that the hardware did not manage to read compliant tags and that it was marked with the label of a low frequency reader, when we ordered a high frequency. When in contact with the company who sold us the equipment they denied that it could be a low frequency reader when they in fact did not sell any such readers yet, they were only in a prototype state. Later it was discovered that they had in fact sent a low frequency reader and that this was the reason that it could not read high frequency tags; they promptly sent a replacement reader. This arrived in early May. It then turned out that the system libraries that accompanied the software were erroneous. These were replaced, first by a second set of erroneous libraries and then a functional set by the middle of May. Work on the prototype followed. Final editing and approval from the supervisor of the report was done up to the deadline of June 1st. No testing of the prototype was performed except for rudimentary testing of the basic functions during development.

Summary

As can be seen by the work description, some of the tasks set in the thesis definition were not given as much weight as might have been hoped. The review of the RFID technology went according to plan. The review of the value chain was made difficult and somewhat cut short by the loss of our external partner Selvaag, as they would have given invaluable insight into the construction industry, the introduction of other sources, literature and interviews, somewhat compensated for this. For the same reasons did the ethnographic study of a construction site fail to happen. Here too was interviewing and literature study an attempt to alleviate this shortcoming. In addition did this lead to the somewhat wasted study of contextual design insofar it could not be used on an actual site. The thesis therefore bears some calculated guesswork on what would actually be in want by the end users. The design and development of the prototype takes into account what the previous chapters have revealed, even though there should have been more testing done had the time been available. Especially would it have been interesting with an actual test on site with the actual persons who would use the equipment. This was in fact a distinct possibility as the local acquisition manager gave permission to conduct a test on their site. But because of the above given problems it could not be done within the timeframe. Finally there was to be a study into how to integrate the information flow from the RFID system with the existing back office systems that the company used. Once again was the loss of our external partner a prime reason for this not being finished, as much time was being spent on gathering other information.

About RFID

Introduction

One of the large buzzes in retailing the last years has been the testing and implementation of automatic identification of goods and its implications on the entire business structure. The technology to do this might prove to be Radio Frequency Identification, RFID for short.

The technology itself dates back to the Second World War where it was used for friend-or-foe detection on airplanes. It was largely ignored until the mid-eighties when manufacturers started using it to monitor production systems. Still no mutual standards were evolved and the systems were mainly close-looped (the identification only takes place within the company's own system) and using proprietary coding and technology (meaning that other companies cannot necessarily read the information). It is often referred to as the replacement for barcodes, but RFID poses more possibilities than as a mere replacement. And given today's technology and the cost of RFID tags, barcodes will still be in existence for many years to come.

Today the focus is on setting standards which will enable companies to harvest the wealth of opportunities that is inherent in RFID. Making consent to mutual standards means that the identification of items can be used between companies all over the world and even by the end-user.

This chapter is partly based on a pre-study report, done by this and two other groups, which exists in a beta-edition; it is included in on the accompanying CD.

The technology

Radio frequency identification (RFID) is an automatic identification technology which does not necessitate contact between the reader and the tag and without the need for line-of-sight.

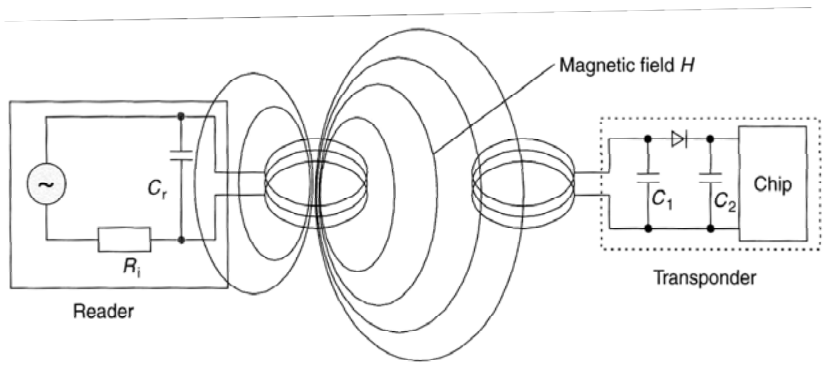
RFID consist of an antenna, a transceiver and a transponder. The antenna sends out radio signals to activate the tag to read and write data to it. The antenna is the channel between the tag and the transceiver, which control the systems data access and communication. The antenna is available in all kinds of forms and shapes. For instance they can be built into door frames to receive tag data from persons passing trough. The electromagnetic field produced by the antenna can be constantly present when several tags are continuously expected. If constant interrogations are not necessary, the fields can be activated by a sensor device.

At its most basic level, RFID is a wireless link that identifies unique objects, processes, transaction or events. RFID systems include electronic devices called transponders or tags, as well as reader electronics to communicate with the tags. These systems communicate via radio signals that carry data either unidirectionally or bidirectionally.

When a transponder enters a read zone, its data is captured by the reader and can then be transferred through standard interfaces to a host computer, printer or programmable logic controller for storage or action.

RFID does not require line-of-sight. Radio frequencies are used to communicate between the tag and reader. This means that an item can contain its label on the inside, so it doesn't get damaged in shipping or handling.

The reader performs several functions, one of which is to produce a low-level radio frequency magnetic field. The RF magnetic field emanates from the reader by means of a transmitting antenna, typically in the form of a coil. The magnetic field serves as a "carrier" of power from the reader to the RFID card or tag.



Inductive coupling RFID [Finkenzeller, 2003]

The RFID card or tag contains an antenna, also in the form of a coil and an integrated circuit (IC). The IC requires a small amount of electrical power in order to function. The antenna in the tag provides a means for gathering the energy present in the magnetic field produced by the reader and converts it to an electrical form of energy for use by the IC.

When a card or tag is brought into the magnetic field produced by the reader, the converted energy powers the IC. This enables the transmission of the IC's memory contents in the form of an electromagnetic signal to the reader via the tag's antenna. This means that RFID is not suited for pin point localization. A tag will report itself to an antenna within its proximity, but its location will only be within the range of the antenna. It is possible to let several antennas overlap and as such give a greater degree of accuracy.

The tag information is received by an antenna within the reader and converted back into an electrical form. The reader contains a sensitive receiving system that is designed to detect and process the tag signal. Once the tag data has been processed, a microcomputer within the reader checks to verify that the signal received is valid. Once the reader has checked and validated the received data, the data is then decoded and restructured for transmission to the end-user's host computer. This restructuring provides the data in both an electrical form and a protocol (or format) that is required by the host computer system. Once the restructuring process is complete, the data is transmitted to the host system.

Reading tags by backscatter modulation
Most passive RFID tags – those without a battery to power their circuitry -- gather energy by coupling to the reader's communication field. That is, the coiled reader antenna sends out radio waves. When the waves reach the coiled antenna on the tag, they form an electromagnetic field. The tag draws power from this field.

The tag sends back data passively, usually by a method known as backscatter. Tags that use backscatter take the incoming waveform and reflect back a modulated wave. The modulated wave has to pass through all the energy coming from the reader, so the reader has to be very sensitive to pick it up.
Source: *www.rfidjournal.com/article/articleview/207*

There are a lot of different tags and readers available from different producers and vendors, examples are Philips, EMS-RFID, Texas Instruments, SAMSys, matrics and Alien Technology. The readers can be placed as a drive through portal, mounted on vehicles and handheld. The tags, typically divided into passive and active, come in many shapes and sizes, all dependent on price and use. Active tags that need an external power source can be fairly bulky in size up to about a shoebox to the smallest passive tags that are the size of pepper grains.

Alien technology's ultra-small tags seen inside the 'D' on a silver dollar [www.rfidjournal.com]

The frequencies

RFID operates in a wide spectre of the available bandwidth and are commonly divided into low (LF), high (HF), ultra high (UHF) and microwave frequencies. The specific use of frequencies is governed by each country's radio regulation legislation, in Norway this is the Norwegian Post and Telecommunication Authority. Especially the ranges allotted to industrial, science and medical (ISM) purposes are interesting and often used in connection with RFID.

Low Frequency

The range of the low frequency RFID differs a lot from one product to another because the RFID producers do not follow a standard. The range lies between 30 up to 500 kHz. The frequencies around 125 kHz is one of the more common ranges that has been used for low frequency tags and readers.

Low frequency systems have short reading ranges and lower system costs. The vast majority of the low frequency systems operate without the need of integrated battery in their tags. They are most commonly used in security access, asset tracking and animal identification applications. They are not too sensitive to metal and electrical noise. The entire range below 135 KHz is of interest because of its ability to operate inductively coupled systems in places with high magnetic field strengths [Finkenzeller, 2003].

High Frequency

High frequency systems operate between 10 – 15 MHz, but 13.56 MHz is very commonly used. High frequency systems have longer read ranges and higher reading speeds than the low frequency systems. The cost of these systems is inexpensive, but more expensive than the low frequency system. These systems are typically used in access control and smart cards.

Ultra High Frequency

Ultra high frequency systems operate between 400 MHz to 1000 MHz and 2.4 GHz to 2.5 GHz. This technology can be very expensive compared to the systems above, though the EPC standard has set limits to how much a reader and tag can cost and the industry strives to meet this. These systems have a very long read range and a high reading speed. Unlike the other systems, line of sight is required for the ultra high frequency system. Ultra high frequency systems are used for such applications as tracking railroad cars and automated toll collection.

Microwave Frequency

This range overlaps partially with the UHF and some count 2.4 GHz as microwave. Upwards there exist some RFID applications in the 5.8 GHz range. Hardware within this range is expensive.

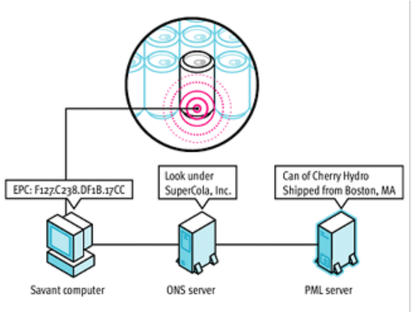
The standards

One of the problems that companies who want to implement RFID faces is the existence of two competing standards. If the company is using RFID as a closed-loop solution, this is only a minor problem (the company could even make its own standard), but if the company is going to share its implementation with another company, the possibility of conflicts arises.

The two standards are EPC (Electronic Product Code), which was created by Auto-ID Center, and the set of standards set by the International Organization for Standardization (ISO). EPC has also received the support of UCC (Uniform Code Council) and EAN (European Article Numbering). EPC has not been put forward as a standard. Instead, Auto-ID Center "hopes that it will become a de facto standard. That is, if everyone adopts it, it will, in effect become the standard."[1]. The other standard (or, to be precise, the other *set* of standards) is made by the International Organization for Standards (ISO).

ISO has three technical committees working on RFID. RC104 is focused on freight containers, TC204 on road informatics, and TC122 on packaging. ISO has also formed a Joint Technical Committee (JTC1) with the International Electrotechnical Commission (IEC), an international body that publishes standards for all electrical, electronic and related technologies. This committee has many subcommittees. SC31 deals with automatic data capture technology, and have four work groups. WG4 deals with RFID.

WG4 has a number of subgroups. Of these, subgroup 3 is focused on using RFID for automatic identification and item management. (Tracking items in the supply chain). Subgroup 3 is responsible for a proposed standard called ISO 18000, which covers the air interface for the major frequencies used around the world.[2] Of these the ISO 18000 – 6 is of particular interest since it covers the UHF frequency range which is predicted to be the favoured range for supply chain management. ISO 18000 is expected to be published as international standards by April 2004. There are also other ISO standards, dealing with different areas of the system, such as formatting of the data on the tag or how the reader and tag communicates. None of these are finalized at this point.



A graphical display of an EPC-system.

How does the EPCglobal Network function?

The EPCglobal Network uses radio frequency identification (RFID) technology to enable true visibility of information about items in the supply chain. The network is comprised of five fundamental elements: the Electronic Product Code (EPC), the ID System (EPC Tags and Readers), Object Name Service (ONS), Physical Markup Language (PML), and Savant.

Essentially, the EPC is a number designed to uniquely identify a specific item in the supply chain. The EPC number sits on a tag comprised of a silicon chip and an antenna, which is attached to an item. Using radio identification technology (RFID), a tag "communicates" its number to a reader.

The reader then passes the number to a computer or local application system, known as the Object Name Service (ONS). ONS tells the computer systems where to locate information on the network about the object carrying an EPC, such as when the item was produced.

Physical Markup Language (PML) is used as a common language in the EPCglobal Network to define data on physical objects.

Savant is a software technology that acts as the central nervous system of the EPCglobal Network. Savant manages and moves information in a way that does not overload existing corporate and public networks.
Source: www.epcglobalinc.org

EPC; the other standard, is a more open standard. Developed by the Auto-ID Center and its sponsors, the goal was "to bring the cost of the hardware down to a level where RFID can be used to track individual items."[3]. They're also working "to create a new, open, global network that will allow companies to take advantage of low-cost RFID tags." [ibid.].

EPC is built up as a series up numbers; a header, and three sets of data. The header (8 bits) identifies the EPC's version number, thereby allowing for different lengths or types of EPC later on. Auto-ID Center has proposed EPCs of 64 and 96 bits, but there could be more. The 96-bit number provides unique identifiers for 268 million companies. Each of these companies can have 16 million object classes (often used to identify a specific product), and 68 billion (10^9) serial numbers in each class, which should be sufficient for years to come. As the sidebar shows the EPC standard entails more than the encoding on the tag, there are also specifications on how a network should be set up. In addition it defines how the tag should be physically set up and how the air interface should work. In addition EPCglobal Inc. strives to bring forward low cost tags and readers. They have set a suggested price of 5 cents for the tags and $100 for the readers.

ISO 18000–6 versus EPC

There are some concerns about the presence of two major contestants to be *the* RFID standard. Although there are many ISO standards that encompass different RFID issues, one of most debated is the 18000-6 which deals with the UHF frequency range. This is because of the EPC standard that also looks at the UHF range and is already adopted by many large companies in the USA and Europe. Most notable among these are the retail chain Wal-Mart and the US Department of Defence (DOD). Many companies ask themselves whether they have to choose between the two and if one choice is wiser than the other.

Among these is the DOD. Even though the military itself would like to go for the EPC standard the Pentagon says it will support the ISO standard. DOD’s chief of Logistics Automatic Identification Technology Office Ed Coyle says in an interview with RFID Journal: *"We want to try to encourage each industry to move toward the same standard. [..] We have general support within each of those groups to reduce the number of standards out there or to make them interoperable."*[4].

Chris Turner, Chief Technical Officer of RFIP Solutions Ltd., claims that there is no barrier for the two technologies to interoperate. He says that the ISO 18000-6 only defines the air interface and that there should be no problem that for example the ISO 18000-6 type A protocol could easily meet the needs of the EPC tag structures[5].

In response to the growing concerns EPCglobal Inc. wants to release a generation 2 of their Class 0 and Class 1 tags which includes full global operability within the UHF (868-956 MHz) band, secure communications, a kill-switch command (*See Privacy below)* and compatibility with the ISO 18000-6 standard.

RFID standards versus existing standards

There exists a multitude of existing standards that will be used by actors in all branches of business. Let alone within barcodes there exists standards in abundance; UPC, EAN, Bookland, ISSN, Code 39, Code 128, Postnet, Interleaved 2&5, Codabar, MSI Plessey are some of them[6]. Within the construction industry there are different standards on how to label materials and other related information. In Norway for instance there exists a building material database that tries to gather the information related to the construction industry, today it consists of some 350 000 products. This uses a NOBB (Norsk Byggevarebase)-numbering. If any industry adapts the RFID technology they would have to make a stand on which RFID standard to use, but also how to ensure interoperability with existing standards. In 1999 NOBB and EAN agreed that both are necessary and they complement each other.[7] Internationally the International Foundation Classes (IFC) by the International Alliance for Interoperability (IAI) that: "[…]specify how the 'things' that could occur in a constructed facility (including real things such as doors, walls, fans, etc. and abstract concepts such as space, organization, process etc.) should be represented electronically."[8]

RFID privacy and security

Closely related to the development of the RFID-technology there has been some controversy regarding its ability to track customers. There are also some concerns as to how this new technology can be guarded against tampering. This section will look into these issues.

Privacy

One of the great consumer concerns, widely published in popular media, is RFID's presumed ability to closely track purchases and consumer habits. Gillette attracted groups of protesters outside its Boston headquarters when it was revealed that they photographed customers who picked up tagged razorblades, and when these customers left the shop[9]. In response to the founding of Auto-Id Center, which developed the Electronic Product Code (EPC), David Holtzman, an Internet security researcher and former Network Solutions chief technology officer expressed concerns: "People might not be comfortable walking around with items that identify themselves as medication, condoms or pornography. They also might not be comfortable with manufacturers tracking where products go after being purchased."[10]. In a RFID Journal article, "Creating an RFID Privacy Plan"[11], Richard M. Smith, a consultant and privacy advocate, says that the privacy issue can be boiled down to two issues. Firstly, embedded tags in clothes, car tires etc, can be used to track our movements. Secondly, the companies can fairly easy collect vast amounts of information about us. This information can be used by law enforcement agencies, marketers and in lawsuits against us.

These concerns are somewhat limited, due to the fact that the numbers of tagged products on the item level are few in numbers. (Primary focus today is on the pallet and case level.) But this will change as companies gather data on the benefits of implementation. If the numerous calculations on the potential return on investment are verified, more companies will invest in it and those that have already invested will probably move on to item level tagging.

So what should be done to protect consumer privacy concerns? "It's […] important to understand that perception is reality."[12] Whatever the company may mean to do with the possibilities of RFID it doesn't matter if this isn't conveyed to the customer in a satisfactorily manner. Also the popular media can misperceive or mistrust the information given. In an interview for RFID Journal with Linda Dillman, Wal-Mart CIO, she comment on an article published about a field test in Tulsa, Oklahoma in collaboration with Procter & Gamble, Gillette and Philip Morris. In the article, which was generally filled with inaccurate facts regarding RFID, it is claimed that during the field test the whole city of Tulsa was rigged with readers. This would be practically impossible to do. Dillman says: "I raise this because if, as an industry, we don't manage the communication and the press it has the potential to kill this technology and the benefits. It's our job to manage it."[13].

One of the first hurdles is giving clear and concise information to the public about how the company is going to use the information it gathers. If this is backed up by legislation consumers may even more at ease. As a comparison, there are few public concerns about the potential misuse by telephone providers. In addition companies might give the consumers the choice to participate in information gathering (e.g. loyalty programs) and to what degree they want to be targeted by marketing. For those consumers who don't want to be a part of this there must be ways of giving them reassurance that the technology can't be used against them. One way of doing this is the "kill switch" introduced in some standards (amongst others the Auto-ID Centers EPC-tag), which makes the tag unreadable. Wal-Mart plans to implement that every tag is automatically "killed" at checkout[14]. Gillette has already tested some smart-shelves where each razor-package is tagged. These shelves are clearly marked with a sign that informs the customer that the items are tagged and that these can be removed at checkout, or that they can be given equal goods which are untagged.[15] Mauro Benetton, founder of Lab ID which tests its tags on a line of Benetton clothing, says in an interview with RFID Journal about the privacy issue: "Benetton will decide whether they want to apply the transponder after the point of checkout, or if the consumers want the transponder removed, they will remove it in the store. With a [cellular] phone, they know where you are, and what you are doing, so it's silly to focus on an RFID tag in the garment. We have to clarify the issue for the consumer. I don't think there is an issue there, but if the consumer does, then they can remove the tag."[16]

Security

One other major concern regarding RFID is on the retailer side. How does one protect against tampering on the tags? Can companies "scan" trucks from competing companies to see what deliveries are being made? If sensitive information is stored in the tags, how do you prevent those with malicious intent from reading it?

According to an RFID Journal article[17] the three main areas of concern are;

1. Protecting data stored on tag.
2. Protecting the integrity of the tag.
3. Protecting data related to the serial number on the tag.

Protecting data stored on tag

When it comes to protecting the data there are two issues involved.

1. Preventing someone from reading the tag.
2. Preventing someone from eavesdropping on the communication between the reader and the tag.

There are two proposed standards to how information should be structured and handled by RFID systems, ISO 15961 and 15962. These standards recommend that data be encrypted, preferably on application level. This ensures that should the company wish to change the encryption algorithm it is more easily done. The standard will likely (it has not yet been approved) recommend that an ID-number burned into the silicon on the chip is used in the encryption algorithm scheme. The other big contender to standardization, Auto-ID Center, has a somewhat different approach to the level of data stored on the tag. This standard states that there is written an EPC (Electronic Product Code) to the tag, which is in turn used to look up the relevant data concerning this serial-number on a centrally placed information server via the internet. (Just recently Verisign has gotten the job of managing this system[18].) This places the security risk on the handling of communication between the application and the server.

To secure the communication between the reader and the tag Auto-ID Center suggests limiting the times a reader broadcasts an ID number to the tag. The reader can, for example, break up the serial number and only broadcast a part of it. The tags which shares this part of the serial responds with its full number. Thus the full number is only sent "[…] in the reverse channel, which is a whisper, compared to the forward channel, which is by necessity a lot louder."[19]. This reduces the probability that an eavesdropper obtains the complete ID number.

Protecting the integrity of the tag

To protect the integrity of the tag is of importance since this also means protecting the integrity of the product. Today it is usual to use pressure sensitive labels to prevent anyone switching price tags. In this regard it is possible for criminals to develop a reader that rewrites the information stored on the RFID-tag to get the item for a lesser price. Another problem is that they can place fake tags on counterfeit items.

Though it will not as easy to fake RFID-tags as bar-codes, which have had some fraud cases, the companies should still be aware of the possible weaknesses of the technology. Some points out the built-in kill command, present in many tags, could be exploited by giving the tag the kill-command and then placing a fake tag on the item. To prevent this, the Auto-ID Center's specifications says that one need to send a secret kill code. If the code is incorrect the tag will not respond to the kill-command for another half hour. Says Tom Pounds, VP for RFID products at Alien Technology: "We've calculated that, on average, it would take at least 65 hours to crack the code, which is a long time to spend in a supermarket aisle."[20]. Nonetheless insiders might still sell the secret code to outsiders and companies that sell high-priced, high-risk items might want to invest in more costly tags that can be encrypted. (Insiders might be inclined to sell the encryption too, though.)

But just cramming security into the technology won't help if good internal security procedures don't exist. Says Piyush Sodha, CEO of Matrics: "Beyond technology, the next layer of protection has to be process, security of databases, and integrity within the corporation. These are more fundamental than beating more security measures into the silicon."[21]

Protecting data related to the serial number on the tag

Just protecting the information stored on the tag itself is not sufficient. It is of importance to secure the information that is related to the tag also. Within the ISO standard this is done by having a common encryption-algorithm, in which one uses a public key. By using this one can read the encrypted tags from cooperating companies. As mentioned above Auto-ID Center's standard is based on a distributed system where the only thing placed on the tag is a unique serial number. The data relating to the number is placed on central servers, which demands a look up, much like the regular internet works. It is preferable that several actors can view this data (customers might want to look up nutritional values for a given food item, vendors might want to know in-prices and selling-prices and the producer the amount of items of this specific type in the pipeline.) and it is vital that not all have the same rights to same amount of information. To cope with this one could set up role based access to the information server. Now one could set the amount of insight others can have to the information. Even though companies are often quite reluctant to share information with others it is essential to exploit the full richness of possibilities that exists in RFID-technology. It might be wise to let a third-party run these servers, and recently Verisign has been given the task to manage the first of these.

The cost of RFID technology

When considering the cost of RFID technology it is important to take into account all the various factors that might incur. The obvious costs are the immediate expenditure for buying the technical equipment, tags and readers. In this cost it would be logical to include the necessary infrastructure to relay the signals from the reader to a central unit. RFID systems create massive amounts of data. This puts a big demand on the backend systems that handles the dataflow. E.g. database systems might need updating due to the increased lookups generated. Equally the costs for creating a link between the existing data-systems, typically ERP-systems, are often overlooked as an expense when planning the RFID implementation. Finally it is important to look at the costs for planning the implementation and training the personnel that are going to use the equipment. Here is a look at some of the different issues regarding cost.

Tags and readers

There exists a wide diversity of tags and readers with prices ranging from somewhere under 10 cents to well over a 100$ for tags and several thousand dollars for some readers. The standard set by Auto-ID Center for its Electronic Product Code states that the goal is to make cheap tags and readers, the elusive mark being 5 cents for tags and 100 dollars for the reader. Auto-ID Center's sponsors and partners, Alien Technology and ThingMagic, designing tags and readers respectively, have already come close. In a much publicized story Gillette ordered 500 million tags from Alien Technology. Though no one will reveal the price per tag Gillette's VP Dick Cantwell says in an interview with RFID Journal: "I can say publicly that the cost of the tags is well under ten cents."[22]. About the possibility for the 5 cent price mark he says: "[…] the Auto-ID Center vision for a five cent tags is very much on the pathway that we've established with Alien. And we're looking at add-on capability through printing and packaging to take the cost still lower by 20 to 40 percent by integrating the chip right into the printing on our packaging."[23]. ThingMagic, who

The cost of deploying
[Peter Abell, Research Director, Retail Industry Service, AMR Research] [..] gave some rough numbers on the cost of deploying the technology:
--$2 million per warehouse, including hardware, software and systems integration.
--$1 to $2 million per manufacturing plant
--$10 million for headquarter systems
--7 to 20 cents per RFID tag.

He said 50 to 70 percent of the ongoing costs would be from the tags and that there would probably be pass-through costs for several years. But he added that eventually, the technology would enable manufacturers and retailers to sell goods at a lower cost. He spelled out some of the supply chain benefits of item-level tracking:
--20 percent labor savings because you don't have [to] verify picked items or goods shipped or received.
--25 percent reduction in inventory because of better visibility across the network and in the back of the store.
--Increased sales of 3 to 4 percent from reduced out of stocks on promotional items, but also in the warehouse, and backroom.
Source:
www.rfidjournal.com/article/view/484

recently teamed up with Intel in order to develop their low-cost reader[24], says that by looking at devices with similar complexity, e.g. a typical 802.11 access point, one can assess the projected cost[25]. Access points sells for around a 100$ (PSData.no sells access points for NOK 580,- excl. VAT[26]). According to RFID Journal, Auto-ID Center white papers say that readers will fall dramatically in price when the number of readers sold rises. If 100 000 readers are produced, the price would be around 500$, but as the sales increase to 2 million the cost of the readers would fall to 70$[27]. Note that the stated goal of Auto-ID Center has most relevance for companies working within retailing, from manufacturer to logistics to retailing. Some specialized businesses might benefit from looking at other solutions and standards. E.g. Marathon Oil uses RFID for drilling oil. They have attached readers costing upwards of 3000$ to perforating guns and isolation valves which is lowered into the well. By using an RFID-tag they can accurately decide at what depths they should perforate the inner walls of the well. The tags and readers must withstand temperatures up to 300 degrees Fahrenheit (approx. 150 degrees Celsius) and pressures up to 15000 pounds per square inch (approx. 103 MPa). Because of this, the price is high compared to what would be used in a typical retail-setting. The bottom line is to calculate the cost of the equipment needed to get the job done, and then evaluate if there is a potential return of investment.

Infrastructure for signals

After the readers and tags are placed there is a need to get the signals from the readers to the servers that will handle the data. If the readers haven't got built-in networking hardware it is often linked through with e.g. a RS-232 coupling. The network could be a regular WLAN hooked up to proprietary servers or a public server, such as Auto-ID Center's PML-servers placed on the Internet. This would be a typical setup for a distribution center or manufacturers storage-facility. If the company already has set up a WLAN it may not be necessary to upgrade this. A regular 802.11 setup is fine. According to RFID Journal the traffic over the net is increased some 30%[28]. In addition some logistical-companies set up their trucks and trailers with readers. These might send their data with GSM-/GPRS-technology.

Infrastructure for data-handling

An RFID system produces vast amounts of data which needs to be interpreted in some way. This demands high powered servers capable of handling the massive flow of data. Says RFID Journal: "Some companies say they had to upgrade servers in the warehouse and add storage capacity, but the costs were not extravagant."[29]

Linking with existing systems

Most companies have existing systems that needs to be linked to the RFID information. ERP-(Enterprise Resource Planning) systems is a common household item in any business structure. Large

ERP-providers, like SAP, recently announced that they will release an RFID package to help companies use the RFID data their new systems provide[30]. This linking can be costly to develop in-house. Boeing got firsthand experience with this as they installed an RFID-system in their facility in Wichita, Kansas. They hired a major IT consulting firm to integrate the RFID data with their legacy systems. It backed out claiming it couldn't deliver on time. Boeing put two of their own people on the job that spent five months doing the coding, and this was only for the first phase of the project.[31]

Planning and training

There are many pitfalls during the installment of an RFID system. There are different standards that adhere to different frequencies, to check for interference sources on the install site or that the existing infrastructure can handle the added strain or need to be updated. In short many, many technical questions that need to be answered before installing the system. Some say that one of the critical issues regarding RFID is the lack of qualified personnel. Especially the fickleness of radio waves is hard to predict, so it is unlikely that "of the shelves"-systems that companies can install themselves, will be available anytime soon. In this context it is worth mentioning that Checkpoint Systems recently announced their fixed price EPC pilot network, ranging from $45,000 to $145,000[32]. They even give insurance about the feasibility of the system: "Customers can be certain the pilot will work, otherwise they don't have to pay." [ibid]

What it boils down to is that planning is crucial. Some companies installs the system bit by bit, and thus might further down the road find out that the system doesn't meet future demands. In some larger companies it might even be installed systems that don't work together, just because the various departments have different needs. RFID Journal"[…] knows of one company that spent $5 million on hardware and $15 million to support it because the systems weren't in place from the beginning."[33]

Also it is often necessary to retrain those who will use the equipment. Sometimes the installment requires a change in working procedures. When Procter & Gamble reorganized a manufacturing plant in Spain the forklift drivers were taught how to use the installed computers to find the right pallets and how to react to alerts from the system.

Advantages and disadvantages

The primary benefits of RFID are:

- Removing of clerical errors in recording data
- Reliable operation in a harsh environments (e.g. wet, dusty, dirty conditions; corrosive environments; or applications where vibrations and shocks are possible)
- Faster data collection, Non-contact operation.
- Freedom from line-of-sight constraints (transponders can be read irrespective of orientation; through paint, even through non-ferrous solids)

- Reduction in labour and paperwork required to process data.

There are many advantages when RFID technology is implemented in a company, like:

- Realise major gains in labour efficiency and productivity;
- Automate many manufacturing, assembly and quality control processes;
- Reduce waste and keep inventory levels at a minimum;
- Increase customer satisfaction;
- Improve profitability.

There are also a number of possible disadvantages related to the use of RFID technology.

- Privacy. Several people and organizations have expressed vocal concerns over the possible misuse of RFID tags for identification of customers. This represents a public relation problem that has to be overcome before widespread use of RFID can be a reality. A website that has become the gathering point for many of these opponents is www.nocards.org
- Security. When a tag is read, there is a possibility that someone with malicious intent may overhear the data being sent. Therefore, it is not recommended to store excessive amounts of data on the tag. For more, see ”Security”.
- Cost. Both the tags and the reader cost money. In addition, there may be substantial redesign required in the infrastructure. This has to be weighed against the possible savings when implementing RFID. For more, see “The Cost of RFID”.
- RFID is a relatively new technology, so it may be said that is hasn't been thoroughly tested yet. This may make someone hesitant about implementing it, but there has been a substantial amount of pilot projects within the retail industry and they have all responded positively.
- The way RFID works still demands that alternative ways of getting the information is available. A barcode could, in comparison, still be ‘read’ by looking at the plaintext numbers below the code, even if the reader itself stopped working. If an RFID reader stopped working a human should be able to draw out some sort of analogue information.
- RFID has trouble reading through conductive materials, such as metal. This can be somewhat alleviated by careful placement of the tag. For instance can an RFID tag be placed on aluminium foil packaged goods, e.g. potato chip bags, in such a way that the packaging functions as an antenna.

RFID is also plagued with competing standards (esp. ISO/EPC), so a company may decide to wait this until this has been resolved. However, if the company is going to implement a closed-loop solution, this is not a problem. For more, see “RFID Standards”.

RFID in the construction industry

A major challenge for any business is to identify what investments in IT can bring back in the shape of return of investment or other benefits. This is especially true for the construction industry which could be due to its structure, fragmentation and under financing. Construction projects are conglomerated by a great many different actors; architects, entrepreneurs of different professions, logistical firms, material wholesalers and manufacturers. This makes construction organisations slow to plan IT investments and IT expenditure is significantly lower than for other businesses. [Andresen et al, 2000.]

In addition there are technical difficulties with implementing a wireless technology like RFID on a construction site. The constantly changing site means that there probably cannot be any fixed emplacement of readers. Wireless technologies also respond with disfavour to obstacles, in particular metal, of which there is in abundance of on a construction site. The research being done for this thesis has revealed two business cases where RFID was used in the construction industry. The first was in relation with the testing of concrete used in construction. Samples of concrete were previously labelled with barcodes and a set of documents followed each sample with detailed information. These were frequently victim to tearing and human errors which often delayed construction projects. BuildNow, a Singaporean company, uses RFID tags which are embedded into the sample and the information is written directly to the tag. This ensures that the information is complete at arrival at the test centre and that human errors are almost eradicated[34]. The other business case dealt with the tracking of spools. Fluor Construction, one of the world's largest, publicly owned engineering, procurement, construction and maintenance companies, set up an RFID trial with Shaw Industries, who made the spools and Fiatech, a non-profit consortium of construction companies, material

The problem with Smart Chip technology in the construction industry
Smart Chip technology - whether in the form of RFID for auto identification, smart cards for secure business transactions, or miniature GPS receivers for cell phone localization - exists now and is providing real ROI in numerous industries. Many people perceive potentially valuable construction applications for the technology, but implementation in construction to date has been limited. The primary reasons for slow construction industry implementation are:

1. Chip Economics. Chip development (design and production set up) has a relatively high fixed up-front cost. Developers need to perceive a large potential market in order to develop application specific chips. The construction industry is a large enough market to support such development, but individual construction related companies are not.
2. Technical and economic feasibility for users. For the reasons above, chip suppliers have not developed and marketed chips for construction and there are few examples of chip technology used successfully in construction applications. Similarly, because of the construction industry's historical reluctance to adopt new technologies, suppliers are slow to translate existing smart chip products to the construction market. Finally, both the technical feasibility in a construction/plant environment and the potential economic benefits of smart chip technology in construction/operating work processes are unproven.

As a result, the technology is underutilized in construction applications and many potential benefits are not realized by individual companies and by construction industry as a whole.
Source: www.fiatech.org/projects/ijs/Desc.htm

suppliers and academics focused on speeding the development and deployment of technologies in the construction industry. The trial used active RFID tags for tagging individual spools and reading them by stopping the truck briefly under a specially designed portal. They got a 100 percent tag read during the trial and verified that active tags did indeed work, even though the tagged items were made of metal and the environment filled with metallic objects[35].

Summary

As can be seen there is a multitude of factors to take into account when looking at implementing RFID technology. One of any company's primary concerns is the competing standards, though this may be rectified with EPCglobal's new generation 2 tags. If ISO and EPCglobal can agree upon mutual ground one hurdle may be crossed and a global standard that meet industry demands may be put forth. It seems that with the embrace of RFID from major actors in the market, Wal-Mart and Department of Defense in the USA and Metro AG, Tesco and Marks & Spencer in Europe, the adoption rate of other companies is imminent. The cost for implementation can seem prohibitive for some, especially since some gains may be difficult to quantify.

RFID has many potential uses beyond being a mere replacement for barcodes to be used in the chain of supply. Because of the integral security it is possible to make RFID tags a proof of authenticity, provided RFID manufacturers can make these tamperproof. Because of the ability to read many tags, without having a line of sight, receiving goods and taking inventory can be automated to a high degree. The information loaded is already in digital form and can be hooked up to the company's back office systems. Some suppliers of such systems are already integrating RFID obtained information into their software, one of these is SAP.

The construction industry sets harsh demands on any equipment set to work on a site. This is due to the rough conditions present. Wireless equipment will be seriously hampered by the presence of many metallic and dense obstructions, so any implementation project needs to make sure their system demands are met.

Logistical processes on construction sites.

Introduction

This chapter will look at logistics in general and in particular the problems with construction site logistics and a subchapter dwelling on the logistics of doors and windows. Finally there will be a summary from a test project that was made at Sophiehaven in Denmark where there was a heavy emphasis on the planning of logistics and its implications on cost and progress and some views from the building of Arendal cultural centre based on an interview with that projects acquisition manager.

Logistics in general

Logistics was first attached to military operations where it tied into the feeding of soldiers. The navy developed early the planning required for maintaining the ship between harbours. The army too had a need for planning how to move their troops between battles. This need has extended into civilian life, especially today where cost efficiency is life or death for competing companies.

One definition of logistics is "handling an operation that involves providing labour and materials be supplied as needed". [36] Another way to look at it is from the commercial point of view; The Seven R's of Logistics; delivering the Right product in the Right quantity and the Right condition, at the Right place, at the Right time, for the Right customer at the Right cost[37]. The Council of Logistics Management defines it as: "[...] that part of Supply Chain Management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements. […]"[38]

Construction site logistics

Logistics on a construction site is by the nature of the site a very dynamic process. Even though the process of building a new structure is quite linear, the building site goes through many phases during the construction. During the planning it is necessary to analyze these different phases as they influence how deliveries can be made.

A walkthrough the processes of a construction are roughly as follows. The building owner looks for an architect for visualizing his ideas and to see of the basic premises of the building is possible to implement. A functional description of the building is made and an invitation to tender is sent out. Construction firms typically give their bid and the building owner picks out the offer that seems most favourable to him. The winning construction firm, if the contract practice sets them as the main contractor, looks for consultants and sub contractors that complement the expertise they have in-house. Then all the necessary official forms and applications need to be filled out. A prioritized list over the trade workers and a progress plan is set up. Then the physical work begins in earnest.

First the excavation work is started, followed by the concrete work. This might be in combination with steel work. After this the roof is set and the carpenters work to seal up the building so that it can start to dry up. To seal up the building the windows are inserted, while still using temporary doors. When the outer shell is closed up the work starts on the inside. Interior walls are set up in parallel with ventilation, plumbing and electrical work, which is defined as the technical trades. Finally this is rounded off with flooring and paint work. If the contract includes furnishing this is done last[39].

Different sites have different variables that influence logistics. How much space is there to store goods? Is the storage space long term or short, i.e. can the goods be stored over a long or short period of time before it has to move? What size vehicles can access the site, both due to the site itself and due to its surroundings, e.g. if the site is located within a village with narrow streets? What kind of offloading equipment is available?

The stream of materials is planned to arrive at the moment it is needed, the so called Just In Time (JIT)-method. This is mainly to avoid overcrowding the site with materials but also because some materials might be damaged by being stored. This is especially important for breakable items such as windows.

In addition there is a conflict of interests present when studying the logistical procedures on construction sites. The construction industry is presented as one of the industries that implements new procedures and technologies the slowest. A single project might include many subcontractors where all of them have different ways of doing their job. Even when there is one main contractor who are responsible it is often thought that any problem subcontractors run into will be their own[40]. In addition, subcontractors have their own budgets for their part of the project. One of the reasons why this occurs may be that the construction industry is one of the most traditional and conservative industries in their operation.

> "Building a building is not like building a plane or a computer. Boeing or Dell will build everything on a computer before anything is done in the physical world. On a building site, everything is pieced together from drawings and specs. And because you have so many different groups of people collaborating on projects, inefficiencies tend to be fairly high."
> Tim Mitchell, CMD Group's director of editorial development.
> Source:
> www.bizjournals.com/atlanta/stories/2000/09/04/focus13.html

The logistics of doors and windows

As the thesis emphasises the tracking of doors and windows, as described under the introductory chapter, this subchapter will look at how the process of ordering doors and windows occur.

> **NOBB for the building industry**
> The NOBB-register was established in 1993 through a cooperation between Trelast- og Byggevarehandelens Fellesorganisasjon (TBF) and Norsk Byggtjeneste. NOBB is a database for the building industry with article and price information. This was based on the desire to simplify and increase the efficiency of the information the suppliers gave to its customers. The register contains the following main areas of interest: A common article numbering and article group system, a unified price updating system, access to updated article information, electronic commerce, technical and commercial information about products, adaptation for ordering and storage systems in addition to integration for spreadsheets and calculation systems.
> Source: www.ean.no (translated from Norwegian)

During the construction phase the architects use catalogues over different building materials. In Norway this could be Norsk Varedatabase ODA as[41] which contains more than 350 000 products from over 470 information sources. These products are given unique NOBB (Norsk Byggevarebase) numbers which identifies the different articles. This gives a list of materials which is to be ordered. The building owner will then send out an invitation to tender and subsequently pick the best offer. There are many different types of contract practices, but one that is often used is by a main contractor that hires sub-contractors to do the work that they themselves do not cover. The main contractor checks the building specifications and orders the necessary materials. Most of these are ordered as bulk items in large quanta, not so with doors and windows.

These are often given unique numbers that signifies where in the building the door/window will go. This practice is more prevalent on doors than on windows due to that these are less unique than doors. A door will often include hinges and locks so that it is critical that it is placed in the right spot, within a row of identical windows this is not often the case.

The order is often written as an Excel-document, which specifies the particular doors/windows that is to be ordered. The order is sent to the manufacturer (doors and windows are seldom bought through a whole seller) with instructions on how the order is to be delivered. This includes any special packaging, e.g. that all doors for a certain building section on a certain floor is placed on the same pallet, and by a certain delivery schedule.

At the manufacturer the production is started as most doors and windows are made specifically for a certain order. This means that there are very seldom stocks of materials to use and the production and delivery time is about 8 weeks. Each door/window is marked with a label that specifies its unique number. The items are packed, hopefully in concordance with the order specifications. With both doors and windows packing means that they are stacked on pallets, cross braced, screwed together and wrapped in cardboard and plastic. Finally the pallets are marked as to which building section/floor it belongs to, this is often done with a large felt pen on the outside of the wrappings or on a wooden beam/cross brace. At last it is shipped off to the construction site.

Here it is received by the contractors that are in charge of mounting them. The delivery is accompanied by a consignment note that indicates the contents. Though it is a best practice to actually check the papers up against the actual content this is often neglected. The labels that identify the individual item are most often not visible from outside the packaging. Removing the packaging is time consuming and unwanted since it makes it difficult to transport the pallet to its mounting place. So often the pallets are transported directly into the building.

If there are any errors in the delivery it will be noticed by the team that mounts it. This could cause confusion since a door/window that is absent is often thought to be present at some other place on the site. An ensuing search occurs that goes through the other pallets that are delivered at the site. If the missing items still is not found the manufacturer is notified and they check their papers. Just the initial confusion often goes into 10 hours or more, and the whole process could take 3-4 days.

Case study - Sophiehaven

The completed Sophiehaven (www.projekt-hus.dk)

There are some interest in the study of logistical procedures on construction sites and their influence on the whole building project. In Denmark there was staged a large scale test for evaluating the effect that better control over logistics might incur on a building project. The test was set on a large housing project called Sophiehaven, and many of the Denmark's largest contractors actively participated in the study. The results of this project were published in two reports, Byggelogisitik I [Building logistics], in March 1993 and Byggelogistik II, in January 1994, of which this thesis has studied the first report[42] , in addition to a report made by the "By- og Boligministeriets" development project "PROJEKT HUS"[43], which analyzed the Sophiehaven project. The project looked at many problems identified at earlier building projects concerning logistics and tried to remedy these. Some of the areas they looked at were:

- How to include all parties in the early stages of planning. Prior to this project the norm was that only the architect and the owner of the building were involved from the start. This was not fortunate when many decisions being made at this stage influenced how the flow of materials would be through the whole project. When nearly all parties were included at Sophiehaven everyone could make comments on how their work was affected by different issues like site layout, building stage planning, choice of materials and delivery schedule.
- How different aspects of the building industry's customs affects logistics. As an example it was revealed that some entrepreneur's payment policy influenced the measurements set into effect for increasing efficiency. Specifically the plumbers were reluctant to getting the materials placed at the location it was to be installed since their pay included the job of transporting it up themselves.
- The problem of how investments made in the building industry could have its pay-off in an entirely different sector. This does not suit the fragmented type of projects where different entrepreneurs fight for their piece of the collective budget. I.e. the carpenters will be reluctant

to invest from their budget on something that the concrete worker will benefit from without a similar investment.

- How the industry's acquisition decisions were made by getting the right materials for the lowest price and not the best delivery to the best price, this in spite of the fact that the actual cost of the material amounts to less than half than that of the delivery. This could seriously affect how the progress on site developed and could cause unnecessary loss and waste. By paying a somewhat higher price for the delivery one could get an arrangement that was more suited for Just In Time-production.

According to the Sophiehaven project there exist nine definite symptoms to insufficient materials management:

1. Much local transportation on site.
2. Large stocks of materials on site.
3. Waste of materials.
4. Loss of materials.
5. Lack of materials.
6. Incorrect deliveries.
7. Much returned goods.
8. Breakage.
9. Damage after installation.

These symptoms do not appear independently of each other. As an example the symptom 'Much local transportation on site' can have the following causes:

- Insufficient planning.
- Insufficient delivery planning.
- Insufficient placement planning.
- Insufficient respect for placement planning.
- Insufficient placement control.

A simple count of the errors that occurs the most reveals this list:

- Insufficient work planning.
- Insufficient delivery planning.
- Bulk purchase discounts.
- Project errors.
- Other human errors.

About 30 % of these could of the problems be ascribed to the contractors, 15-20 % to the suppliers and 10-15 % to the project administration. The rest was ascribed to others, amongst these the transportation companies.

The Sophiehaven project then set out five suggestions for better facilitating the material management:

1. Project materials and documents.
2. Setting of prices.
3. Improved lateral cooperation.
4. Alternative forms of delivery.
5. Shared material management.

The project then constrained itself to focusing on the practical cooperation during the building and to improve the material management. These were realized through the creation of a common material manager, across the different entrepreneurial trades, which proved highly successful and by concentrating the material delivery to procedural dependent rather than supplier dependent. This was implemented by creating ‘units’. Anything that needed secondary items for mounting was to have these attached to the main object at delivery. E.g. a door would need screws, locks, handles, hinges, mountings and fittings. By creating such a unit a worker could be sure that everything needed for the mounting would be present.

A summary of the project showed that:

- There was spent less man hours than budgeted.
- The material management led to a steadier supply with fewer errors.
- Loss and waste was less than expected.
- Building time was reduced by a month.
- The common material manager was a great help in the administration of the material flow.

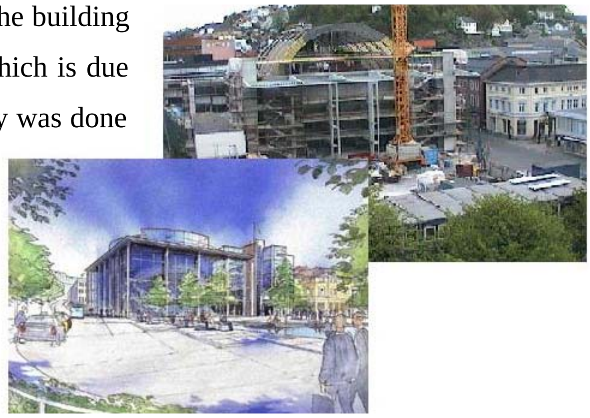
In the analysis of the deliveries made during the building it was revealed that 45 % of them had an incident that led to extra expenses. About 65 % of these were due to extra deliveries caused by insufficient material planning from entrepreneurs. About 25 % were due to extra deliveries caused by out of stock materials, back orders or material deficiencies.

The analysis showed further that about 45 % of the total costs from the incidents could be traced to suppliers and about 30 % to entrepreneurial errors. The remaining 25 % were due to project modifications, theft, vandalism, and so on.

In conclusion of the study it was indicated a prudent expenditure cut to building expenses within the reaches of 5 %, which was more than the expected net profit for the similar projects. In the longer term, when the methods are more familiar, a net profit of 10-15 % is not unthinkable.

Case study – Arendal Cultural Centre

During the thesis a partial case study was done of the building of the new cultural centre in Arendal, Norway, which is due to be finished in the first quarter of 2005. The study was done by a tour of the site and an interview conducted with the project engineer and acquisition manager Ole Morten Sundsdal. (A transcript of the interview, in Norwegian, can be found on the accompanying CD.) The focus of the study was on the logistics of doors and windows.



Arendal culture centre. (web2.sor.no/webcam and www.myol.no)

The building is a combined cultural centre and city council administration building, where the building owner is Stiftelsen Arendal byselskap. The building will, upon its completion in 2005, have a total floor space of 11.600 m^2 and house a theatre hall, conference rooms, office spaces and a canteen. Its budget is scheduled to be 317 million NOK. The building contract was given to the KRS-group, which is a collaboration between the Norwegian building companies Kruse-Smith, Br. Reme and Selmer Skanska. The work started in last quarter of 2002.

The ordering of the doors and windows were described in Excel documents that were sent to the manufacturers. The doors had one row for each unit as these were unique and the windows were ordered as sets of specific types. The doors were marked with a unique number e.g. 001.2.1.2, which signifies door number 001.1, to be mounted on the ground floor and in building section 2 (the windows were only marked for type and which floor they were to be mounted in). This number is put on each door and each casing. The manufacturer then packs the doors going to the same section on the same floor on the same pallet. This pallet would then be clearly marked for going to this exact location. The pallet will be placed according to its marking upon delivery. The delivery was usually by trucks with a soft top trucks and offloaded with the on site construction crane. It would be received by the person in charge of the specific trade. For KRS the wooden and steel doors and the windows would be the responsibility of the carpentry trade, thereby the carpentry foreman. Then the carpenter doing the mounting will search for the door marked with the specification set on his drawing and mount that door.

Since doors and windows are amongst those items that are preferred in a Just In Time-delivery schedule these are not stored for any amount of time on the site. They are ordered for delivery as near to mounting time, and placed as near to the mounting place, as possible. Certain other items might for convenience or economic feasibility be ordered in large quanta and either is stored on site or in a third party warehouse. Such items might be steel-stanchions and plaster-plates. The steel stanchions are placed on site and in any convenient spot as these are very light, easy to transport and can be exposed to weather. Plaster plates are large, heavy and fragile; these are preferably stored as close to the mounting as possible, with any surplus material stored in a warehouse off site.

The actual amount of errors made by the manufacturer during packaging is varying from different manufactures and the progress of the project. The first delivery has a tendency to be hurried together. The pallets are filled with whatever fits and shipped off. This means there is a lot of work figuring out what is what on site. What KRS typically does is to send the manufacturer an invoice on the hours they spent on straightening the order out. This means that the second delivery is often to the specifications. Then after a while the manufacturer lax off and the process starts over again. Acquisition manager Sundsdal says: "[…] there are often mistakes."

The labels that shows what specific doors or windows that are placed on a pallet are not readily visible. This means that when they arrive and the carpentry foreman should do an initial inspection there is seldom time to remove the wrappings and study the individual items label. The pallets are placed inside the building unchecked.

Errors that could occur would be:

- Missing items
- Wrongly stacked ordered items
- Non-ordered items
- Faulty items

Missing items could be that the order was for 10 windows and only 9 arrived. Wrongly stacked ordered items could be that a window destined for section 3 on the second floor was packed with the pallet for section 1 on the ground floor. Non-ordered items could be to receive a window of a type that cannot be used in the project. These three errors could often be interlocked. It would be fairly easy to spot that there was one item missing from a given pallet. But if this item was replaced with a non-ordered item or a wrongly stacked item it would not be as easily discovered. This is most often revealed at the mounting site when the items are unpacked. The problem that arises is: where is the window? Is it on another pallet on some other location on site or is it still at the factory or maybe not even made yet? The carpenters are running all over the site looking for the window and the factory might be contacted. Any non-ordered or faulty items will have to be repacked and shipped back. Such commotion might take 3-4 days of work. The team that was ready to mount the windows would have to be reorganized to other tasks. Given that each worker cost 270 NOK an hour means that the costs mount up pretty fast.

Faulty items are those items that are of the right type, but have some sort of error. During the building of the cultural centre they received some windows which were of the right type but had glass of the wrong colour. The carpenter who mounted them saw that they were of the right type and was unaware of the faulty colour. This particular error was of little consequence since the glass is easily replaced, even if the window is mounted in the wall. According to Sundsdal it would have been much more serious if the window casement had been enamelled in the wrong colour. This would mean that the window would have had to be mounted to get the building sealed and then removed from the wall and replaced by another when replacement windows were ready. For doors this was especially critical as doors have a delivery time on eight weeks.

On all of these incidences it would be fortunate to have some sort of aid in doing an initial inspection. Sundsdal says that initial inspection could avoid critical errors, especially towards the end of the project phase when the building is to be handed over. It is at these times that the 3-4 days of work could be of most help. But also for convenience sake, e.g. if a window weighing 200 kilos was placed deep inside the building on the third floor by mistake, could it be fortunate to have better tools to identify the contents of a specific delivery. The problem with the initial inspection is the aforementioned time consuming task of visually identifying individual items within the wrappings on a pallet against the list of contents accompanying it.

Summary

Logistics, the process of making sure that labour and materials are at the right place at the right time, is a vital part of any construction project. On a construction site, logistics is by its very nature an extremely dynamic process as different kinds of materials arrive and the site evolves into a finished building. The logistics of doors and windows is a specialised case that the thesis looks into in greater detail.

Doors and windows are often specially made for each project, which means that there seldom is a stock to take from, and the delivery time is about 8 weeks. Once on the construction site, they are received by the contractors in charge of installing them. Errors in delivery are often not discovered until they are about to be installed, at which time the item may have to be shipped back to the manufacturer, possibly causing major delays.

The Sophiehaven project in Denmark was a project that studied the procedures that happen on construction sites including many of Denmark's largest contractors. Many changes were implemented in the logistical processes so that any results could be measured. The conclusion was that a greater emphasis on logistical planning could cut down on the work costs and expenses.

An interview with Ole Morten Sundsdal, project engineer and acquisition manager at the Arendal Cultural Centre building project is also detailed in this chapter. It looked into the logistical processes on the construction site, in particular the processes connected to doors and windows.

The theory of contextual design

Introduction

One of the problems facing software developers is that many systems are designed from a technical point of view. The focus of the system design is on what will and what will not work within the technical constraints. Often the developers make guesswork out of important questions regarding how the users will perceive the usefulness of the system. Contextual Design is a methodology for designing systems. The methodology was developed by Hugh Beyer and Karen Holzblatt (who formed a company called InContext, http://www.incent.com/), and is described in detail in the book Contextual Design: Defining Customer-centered Systems.

In this system the authors focuses on the cooperative design process between the users and the developers. Both sides can learn from the other in what will make the optimal system. Holzblatt explains that what the users wants is not necessarily what they describe. If she told a carpenter that she wanted a window in her den it is easily understood by the carpenter, but if what she really wanted was a lot of light and to see the garden then some care must be put into the design and choice of window type. Adversely if she wanted a buffet in her basement at a particular place, the carpenter might inform her that from his experience her choice of location is not good because of the many support beams located there.

A short review of the contextual design process

The method is heavily user-centred. The design method can be described roughly as "observe the users, draw conclusions, and make a new system based on the observations and your ideas".

Here is a more detailed look at the different phases of the process:

Contextual Inquiry

The designers go to watch the customers to do the job with their current systems, write down everything noteworthy, and ask if they're unsure. This phase also includes a full interview of the customer. The primary goal, of course, is to understand what the user is doing, why the user is doing that, and what they think they should be doing.

Interpretation session

So now you have a view of what the customer has done. It's time to make some sort of sense of it all. All points of the work that the interviewers have noted and all insights are considered.

Work modelling and consolidation

This is the phase where the team draws diagrams, all sorts of diagrams, starting from physical models of the workspace and ending with cultural models. After this, the diagrams that model single specific customers are merged into consolidated diagrams that describe what all users generally do.

Work redesign through visioning and storyboarding

This is where people throw together new ideas of the work, and create storyboards of what they thought would be good models of work. This is the time of redesign and invention.

User Environment Design

This is where the model of the new system is starting to look like what it will become. Here, the system is modelled so that the new patterns of the work and the new user interface are shown.

Mock-up and prototype

Now we have a design - so it's time to make prototypes. Paper prototypes are good for this. Once you have made the prototype, it's again time to go to the customers and show the prototype to them, and hear what they have to say about it (and possibly make changes).

Compared to other design methods, contextual design is very time-consuming, but it has good guarantee that you get a system that fits the customer's needs.

Summary

As can be seen contextual design can be a very powerful tool for developing systems. Especially for technical oriented developers it is easy to get lost in the technology and lose sight of the main goal; making a system that the end user can use effectively.

During this thesis the use of contextual design was cut short by the lack of a viable arena to apply the theory on. This means that, while the thesis tries to design with regards to the end user it is not by actual applying contextual design to the prototype development.

Possible points of improvement by using RFID

Introduction

There are many processes being done at a construction site, and some of these could be alleviated by the introduction of RFID technology. This chapter will try to look at some potential processes that will be tried implemented during the course of this thesis. There are huge amounts of different items that are tracked during the project of constructing a new building. There are papers, building materials, tools, vehicles and people. All of these could be tracked by using RFID technology and all of these are essential for the execution of a successful building project. The time range might be from the start of the project, when the building only exists on paper, to the long afterlife when a carpenter might want to know the exact type of a certain window due for replacement after 10 years of faithful service.

This chapter will take into account the lessons learned from the previous chapters and try to describe the ideal process of the logistics of doors and windows. This is despite of the fact that this thesis did not perform an ethnographic study of an actual construction site. The thesis then moves on to draw out the main parts of the ideal process and make one that is deemed capable of implementation.

The ideal process

The ideal process is the process that first and foremost makes the number of errors as negligible as possible. It should aim to satisfy the needs and views of the end users. It should also seek to envisage the whole process, not just the immediate need, but also it’s surrounding tasks.

For the logistics of doors and windows the ideal process would be something as follows:

1. The building owner issues an architect with the specifications of the building. This specification document is labelled with an RFID tag, and uses an Electronic Data Interchange (EDI) system to verify that this is the latest version at key points.
2. The architect uses 3D CAD system to design the building, using a common database of building items to identify the best materials for this particular design.
3. The architect’s design is transformed into building drawings and a list of materials needed. These are given to potential contractors as invitations for tender is sent out.
4. The contractors use the electronic documents to estimate their bid. Later the winning contractor will use the document to order the needed materials.
5. The producers receive the order documents, which contains all the information needed to get the production going. The order documents contain any special considerations that are to be

used, be it special packaging, delivery scheduling, colour specifications or other information relevant to the order.

6. The producer packs the order according to the specifications set by the contractor. RFID tags retain the information about what has been done and what the next step is. The producer sends an electronic shipping document to the contractor specifying what is in each shipment. This document can also contain information on how the production is progressing on the remaining order.
7. Upon delivery the contractor uses the electronic document as basis for the initial inspection of the shipment. An RFID reader scans the items automatically upon delivery and notifies any interested parties of any anomalies.
8. If the shipment clears the initial inspection the system automatically administrate the billing procedure. The necessary information is transferred into the contractors back office systems.
9. As time goes by, any service being done on the building can use the information in the RFID tags as needed. E.g. can a carpenter, that must change a 10 year broken window, check the specific type and make of this window and order a new one.

The implementable process

The above described process delves deep into the processes that are done at several levels. This includes the building owner, the architect, the contractor, the producer and any links between. This makes it quite improbable to implement a full solution given the premises of this thesis. Instead the thesis focuses on a solution that tries to implement parts of the ideal process but still tries to use the inherent possibilities of RFID. This solution should be as independent of other actors as possible and focus solely on the construction site processes. Some considerations to a few minor requirements could be necessary to implement the solution fully. These requirements should exclude major alterations to other parties' processes.

The process that would be tried implemented as a prototype would follow these guidelines:

1. The contractors would send an order sheet, typically in Excel format to the producer, with information on which units were to be packed together and when these would be delivered.
2. The producers, which in our case already used RFID tags in the production line, marked the order with the serial number for each individual item and send it as a shipping document to the contractor. In addition, for ease of use, the producer writes the number of items on each pallet to each tag on that pallet. This ensures that all tags are read later in the process.
3. When the shipment arrives at the building site, the contractor uses a RFID reading device to scan the pallets. The contents are checked up against the shipping document provided by the producer. If the pallet checks out fine, the manager responsible for doing the inspection gets a notification and the pallet is placed in its appropriate place. Should the pallet contain any

> errors, the manager will be notified about the nature of the error. This could be that there are fewer items on the pallet than the tags tells, that there are more items than expected or that items are misplaced on a certain pallet. This can now be dealt with immediately instead of later, deep inside the building.’

Some requirements are critical. If the producer cannot guarantee for the accuracy of linking the tag against the correct item, the whole point of tagging becomes a moot point. E.g. if the tag says that this door should be of type V1 and the door is actually of type V3 then it is impossible to use the information later in the process. It is also wanted, but not imperative, that the items are stacked in such a fashion that the placement of the tags is consistent.

Placement of tags in doors from Swedoor AB

Summary

This chapter has looked at how an ideal process could have been designed. Then, by looking at how a more realistic scenario could be presented, it set up the premises for how the specifications for the prototype should be evaluated.

There are more possibilities for RFID than mentioned here, but that would be outside the scope of this thesis.

Prototype

Introduction

During this thesis project one of the end products would be a prototype which would make it possible to test the theory mentioned above. The planning of the prototype started in January, though the actual software development on the physical hardware started in late April, when the equipment arrived.

Specifications of the prototype

The task at hand called for hardware that could in some way ease the logistics on a construction site. Since the task was still quite widely defined, e.g. there is no mention to which particular logistic process to support, it was imperative that the equipment specifications were equally widely defined. Early on in the project there were stated some demands that the actual equipment and its deployment must meet on a given site:

1. Mobility: The equipment needed to be fairly mobile, in other words it cannot be a fixed emplacement. This is because of the nature of a construction site. It is always dynamically changing and the equipment might be wanted elsewhere when the building project was concluded.
2. Penetrability: Due to the many probable obstructions on site, consisting of everything from people, machines, concrete, metal, plastic and wood, it was important that thought was given on how to reliably read tags with radio waves. As a rule of thumb low frequencies better penetrates obstructive material than higher frequencies, but none of these fare well against metal in any form. Higher frequencies have longer range if unobstructed.
3. Durability: Construction sites are messy places were the people working there are doing very manual labour, often in bad weather, hot or cold. This puts a demand on the hardware to be resistant to water, shocks, dust and temperature.
4. Usability: Ease of use is important if the equipment is to be taken into general use. The goal is to make the identification as automatic as possible, with as little human interaction as possible involved. This ensures higher reliability, but puts a higher demand on the systems methods of dealing with errors.
5. Compatibility: The hardware needed to be compatible with any existing systems. One of the reasons the project was defined in the first place was that Selvaag noticed that several of their manufacturers used RFID in their production line. The thought was to use these existing tags for in their own building projects. But this also means that one is at the mercy of whatever type of hardware that the original manufacturer used. What is suited at the production line might not be the best choice for use on a construction site.

6. Cost: Implementing RFID can be a costly adventure. Some thought would have to go into weighing the cost of a prototype against the probable cost savings possible through its implementation. This would imply studying the existing processes, finding what the prototype might do to the effectiveness of the chosen processes and finding how this might affect the cost of the process, if possible. This might be difficult to do, since processes often overlap and in addition it might not be a direct link between cause and effect, i.e. increased efficiency in one process might only be cost effective in an entirely other process.

Having set these demands the choice fairly quickly was set on three possible uses of RFID technology and on how it would have to be deployed.

1. A portal where the trucks delivering materials to the site had to drive through. The material loaded on the truck would be registered and any abnormalities would put to the attention of a supervisor.
2. A smaller portal where all the material being loaded of the trucks, had to be passed through. For most purposes, it would be the same as above.
3. A hand held scanner that could be used to manually scan the material, either on the truck or on the ground after being offloaded.

Of these three the first option has the most versatility and least human interaction. If the portal were set at the entrance of the site, provided they had only one, one could be certain that all materials had to pass through the checkpoint. The problem with this solution is the penetrability of radio waves. Materials delivered at the site will often be packed in containers or other metal obstructions. This would seriously hamper ranges or even cut off readability entirely. In addition it is difficult to read entire stacks of tagged items without knowing exactly how many tags one is looking for. For this solution to be reliable one would have to mark the shipment with the number of items present and in addition one would have to somehow make the tags ‘visible’ outside the metal. One way of doing this is to use a hierarchical system where individual items are tagged, then each pallet is tagged and the information on what is on the pallet is tied to this pallet-tag. Then one could tag the containers or vehicle in a similar fashion. So when a particular container is driven through the portal the container tag reports itself and the rest of the load is derived from this tag. This in turn would mean a closer cooperation with the supplier as they would have to do the work of tagging the pallets and containers. It would mean that some RFID equipment would have to be placed at the supplier and any middle brokers. The involvement of the suppliers is probably wanted in a large degree, but to make the prototype as ‘do-able’ as possible it is tried to be on a non- or low-reliance to other parties in this particular thesis.

The second option has basically the same pros and cons as the first, but in addition there are other issues. Though the material will be outside the container or vehicle shell it might still be packaged in such a way that reading the tags is difficult. The same goes with the actual number of tags present on the pallet or in the package. On top of this it is now necessary to physically move the materials through the portal. This would be easiest to do while the material is offloaded from the vehicle. But this poses another problem. There are many ways to offload a vehicle, often a crane might be involved or it might be manually. Are the materials bulky and difficult to handle? Are the materials going in on the ground floor or the fourth? The size might be highly different for different classes of material too. All in all it is very difficult to make one portal that might satisfy the endless types of materials.

The third option, the handheld scanner, is very dependent on the person who is operating it. Because of the nature of handheld readers the read range is shortened considerably. A range of about 10 cm is not uncommon. Due to the battery driven state the reader cannot induce enough power in the tag to give a longer range. This means that special care must be taken when using this type of reader to be certain that all tags belonging to a shipment is properly scanned. This could be remedied by inserting the number of tags to be found in a specific shipment, e.g. one pallet, into every tag that belongs to that shipment. I.e. if a pallet contains ten items then each tag should contain their own serial number and in addition the number ten to signify that it is part of a ten piece pallet.

The ideal case would be a way to let the reader check up on the actual order/shipment documents that are available, if they are in digital form. These could be put on a central server so that the reader automatically checked up on these documents when a shipment arrived. If these documents contained a reference to the serial number of a given item this could be used to list which items have arrived. This is somewhat akin to how the EPC system is designed. Where there to be any change in the documents the reader would get the latest edition anyway. There should though be a form of redundancy in the system such that if the link between the reader and the server went down, the reader might still perform its task, even though it might be with a more uncertain information value.

Having settled for a central server with the necessary documentation available in digital form, the need to transfer the information to and from the reader makes itself apparent. There are several types of data transfer available, all depending on which type of reader implementation is chosen. For the first option, the portal could be fairly fixed to one location. This means that there is a possibility to use cabling to transfer the data to and from it. This might be perilous though, given the heavy traffic going on within the site. The cable would have to be very well protected so that it is not cut during construction. Option two would have to be more mobile than the first and as such a cable is not advisable. It could be done, but this cable would be even more susceptible to damage, given its more central position. The handheld reader would of course be nearly useless if tied to a cabled solution.

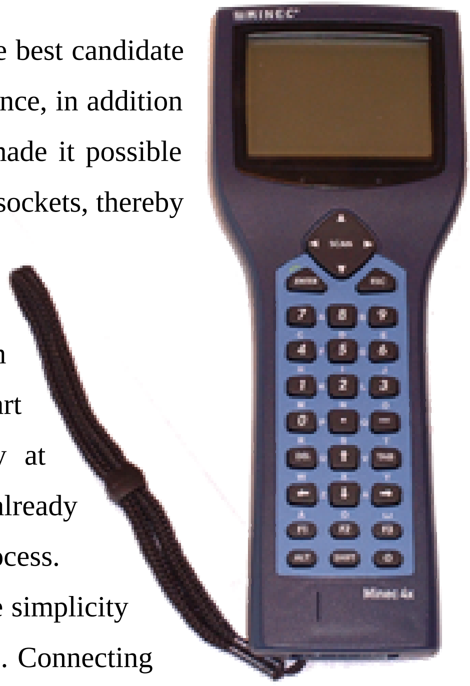
The best solution would probably be some sort of wireless connection between the reader and a node which was connected to the internet or the server. Having the server placed on the Internet would mean that it was accessible from several sites and as such be more versatile. When it comes to wireless connections there are a host of different technologies to choose from. Some of the more interesting examples are: WLAN, based on the 802.11x series, Bluetooth and the GSM network.

As earlier mentioned wireless technologies have difficulties with operating successfully within the cluttered space of a building site. The most notable drop in efficiency would be on the range of the device. With WLAN having about a 100m range and Bluetooth having about 10m, the choice between these two is fairly simple; WLAN is better suited for this purpose. But construction sites are often large in size, and a 100m is not that much, especially if it is shortened by obstacles. It could be remedied by strategically placing antennas around the site, but this can be costly and unsuited for the dynamic nature of a site. The GSM network is also hampered by the presence of obstacles, but not in the same degree as the other two. Most cellular phones can get a fair connection almost anywhere within a building, and so within a construction site. With the addition of the GPRS technology, where one is only charged for the amount of data loaded through the net, this is a viable option for data transfer.

Development of the prototype

With the above specifications in mind, it was decided to develop a solution involving a handheld scanner that would communicate with a server, which in turn was connected to a Microsoft Excel Workbook containing the ID numbers of the incoming materials. The scanner would read the number on the tag and send it to the server, which in turn would check the number against the workbook and give an *OK* or *Not OK* message back to the scanner while at the same time logging the materials' arrival.

As the prototype was originally planned to be developed to cooperate with Selvaag's existing systems, and it was planned that the thesis would focus on doors and windows, it was decided to make the prototype able to read the tags already present in the doors from Swedoor. Sweedor gets all their equipment from Datalogic, and it was decided to look at Datalogic's equipment when the time came to order. It was also decided to use a handheld scanner, because of price, ease of use and storage. In addition, if a handheld scanner was used, it would have little to none impact on the processes of the manufacturers, as (for doors and windows) the tags were already present.



The Minec 4x handheld scanner from Datalogic looked like the best candidate for the specification. It boasted a 10-centimetres scanning distance, in addition to both WLAN and GPRS connectivity. WLAN and GPRS made it possible for the scanner to connect to the server over standard Berkeley sockets, thereby simplifying the connection process. It was also decided to use the same tags as Swedoor AB use in their production process (LRP125HT-FLX, also from Dalalogic), since it was a request at the start of the thesis that we looked specifically at doors and windows, and Swedoor already use RFID tags in their production process.

The server was programmed in Microsoft Visual C#, due to the simplicity of the language and the ease of setting up the network sockets. Connecting to the Excel Workbook also turned out to be easy with the use of ADO.NET. The only problem is that this demands the workbook to be formatted in a special way so that it can be read with standard SQL commands.

The Minec 4x comes with Windows CE installed, and can be programmed in Microsoft eMbedded Visual Basic or Microsoft eMbedded Visual C++. In order to keep the program as simple and readable as possible, it was decided to do the programming in VB.

In order to make the GSM/GPRS work, a SIM-card must be installed. Since there is no option to input a PIN, this must be disabled on the card before inserting it into the scanner. (Details on how to insert the SIM-card is in the user manual). To set up a GPRS connection you either have to set up a dial-up connection through the Control Panel on the device or use AT commands directly to the Siemens MC45 GSM module. Depending on your network provider, the number to dial is either **98*1#* or **99***1#* .The full AT Command used to create the PDP Context is:

```
AT+CGDCONT=[<cid>[<PDP_type>[,<APN>[,<PDP_addr>]]]]
```

where cid is PDP Context Identifier (1 or 2), PDP_type is the data protocol (IP), APN is the Access point name and PDP_addr is the address of the protocol (PDP_type) that identifies the device. APN and PDP_addr are different from network provider to network provider, so it will be dependent on the SIM-card inserted.

All commands to the RFID module are done via a DLL-file that has to be called from the program. Use of this DLL is documented in the Programmer's Guide that came with the reader.

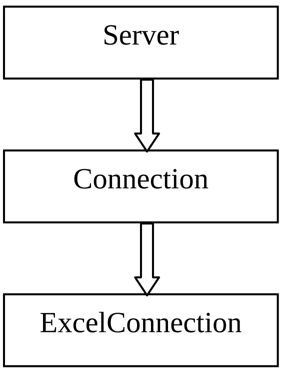
Development of the prototype was delayed due to a communication failure at Datalogic. Instead of the high-frequency reader that was ordered, a prototype of a low-frequency reader was sent. Further delays came when it was discovered that the included development tools were old and incompatible with visual basic and a new version had to be requested.

It was also not possible to program the reader for use with a CF WLAN card, as the card never arrived from the store where it was ordered. The store finally reported that they wouldn't get the card until June 6th, which was past the project's deadline.

When the reader finally arrived, it was discovered that the 10cm reading distance was exaggerated, as we never managed to scan a tag that was further away than 3.5 cm. It was reported from Datalogic that tags with larger antennae might be read at greater distances.

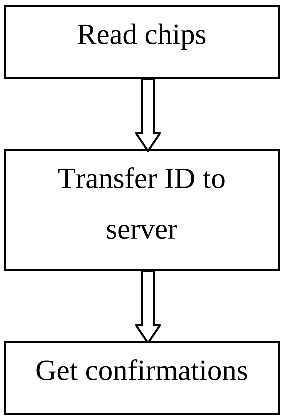
The final prototype

The Server



The prototype consists of two parts, a server and a client, both relatively simple programs. From the beginning, it was requested that the server logged all incoming tags in an Excel Worksheet, so the server was developed with that in mind. When the server starts, it listens on port 20001 for incoming connections. If a connection is established, a simple handshake takes place. The server then receives the tags' id-numbers, each 44 bytes long. The id-numbers is converted to hexadecimal, since the data on the chips might not be otherwise readable by humans (or Excel), and then put into the document via ADO.Net. The server then sends confirmations and tells the operator where the doors should be placed. (This data is read out from the same Excel Worksheet.). Finally, the connection between the server and the client is dropped.

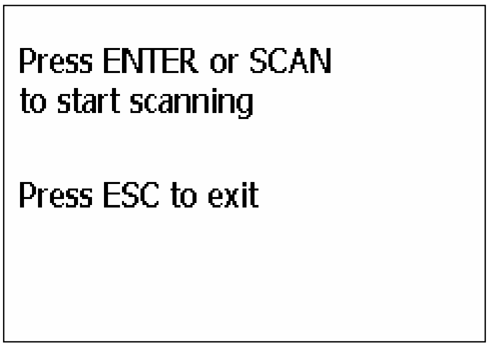
The Client



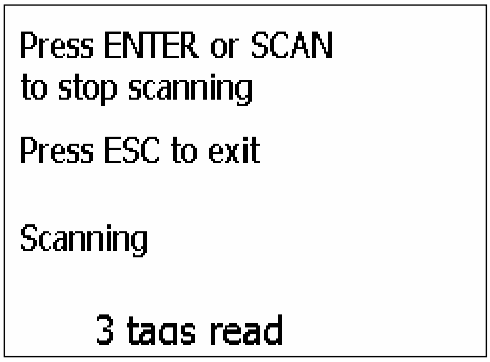
The goal with the client was to keep the interface as simple as possible. On any given screen, the operator has only two choices, to go further in the process (left), or to exit the program. This reduces the risk of user failure, and makes the training of the operators quicker and easier. The client will read the tags, then stop, so that the user can set up the connection that will be used for transmission of the ID's. The reason for this break is that the RFID module and the onboard GSM unit use the same COM-port (COM#1), and if the GSM is in use, all system calls that is directed to the module is being sent to the modem instead, which of course precludes the unit from working.

The client has only three commands that it can send to the reader:

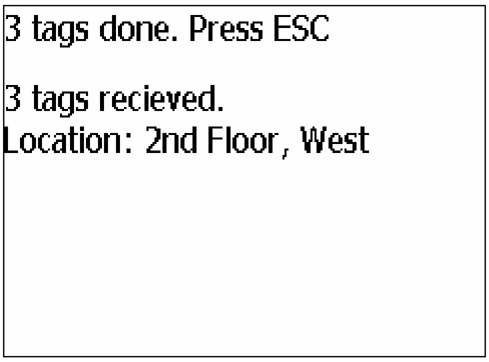
- `RFIDSTART`: This is the command used in the handshake.
- `RFDATA`: This is followed by the 44 bytes long ID which in turn is put into the Excel Worksheet by the server. The reason for this command to be shorter than the others is that the Scanner can't handle strings that are longer than 50 bytes.
- `RFID_END00`: This is the last command being sent by the scanner. The Server will, on receiving this command, process the data, send confirmations and close the connection.



Screenshot 1: The opening screen



Screenshot 2: This is shown while scanning



Screenshot 3: Scanning is complete and confirmations are received

Testing of the Prototype

Even though the opportunity to test the prototype on a construction site did not come through, a few tests were performed with the prototype.

One of the most important tests was reading distance. It was tested with various materials between the reader and the tag. Reading distance through different nonconductive materials (air, wood, plastic or paper) was all in the vicinity of 3-3.5 cm, which was far below the 10cm that was promised. If the tag was behind metals, reading was impossible, as was expected. More surprising was that if the tag was in close contact with metal (e.g. it was placed on a coin), reading was also impossible.

A test of the GSM unit was also performed. The GSM unit (Siemens MC45) seems to function as well as other cellular telephones, in terms of coverage and signal strength. A surprising side effect of using the GSM unit is that the display goes black at random intervals as all the pixels are lit.

Summary

From the start, the thesis was supposed to include the development of a prototype that could be tested and evaluated, if possible on a construction site. Unfortunately, this was not possible, as our contact within the construction company was otherwise occupied. Different solutions for the prototype were considered, but the decision was to develop a solution involving a handheld scanner that communicated with a server over the GSM network, in accordance to the specifications set in this chapter. When the unit arrived and was tested, it was discovered that the reading distance of the scanner was too short to use reliably on a construction site, and other solutions should be considered instead.

Integration with existing systems

Introduction

RFID technology will by its nature generate a lot of data. This data consist of information that the company implementing the system probably would want to make use of. It is easy to fall into the trap of just looking at the immediate need, forgetting the possibilities surrounding it. This chapter will only scratch at the surface of the possibilities that data integration could provide, this is largely caused by downgrading the focus on this topic as described in the chapter two.

RFID and software integration

In the December 2002 issue of RFID Journal, AMR Research claimed that only 1 % of 550 RFID companies offered RFID enabled software applications. Bruce Richardson AMR's senior VP said: "I had a logistics vendor in yesterday, and I asked them about RFID, and they said they are watching it. I don't understand that because this is going to have a dramatic impact [on business]."[44] The notable exception to this disinclination to explore RFID was one of the worlds leading software developers for the Enterprise Resource Planning (ERP) market, SAP.

Today the problem is that there exist few software packages that fully integrate the real time data streaming from RFID. According to Saket Batra, who is a research analyst at KeyTone Technologies, there are two types of systems integration options available. The first are those solutions that are supplied by the hardware vendors who make home-grown software that connects the existing back-end systems with their hardware. The problem, still according to Batra, is that this solution is hard to upgrade if new software is added to the back-end system. The other type is middleware solutions that integrate RFID with the existing IT infrastructure. These are often expensive, both in purchase and support.

Batra continues to explain that the best solution is for existing ERP producers to integrate RFID support into their current portfolio. This will pay off twice as no third parties gets to disrupt a functional backend system and the primary and recurrent costs will be reduced. Major ERP system developers as the aforementioned SAP and Oracle have started to offer RFID enabled backend systems. Another major software actor, Microsoft, launched a pilot project for their middleware for their Axapta warehouse management system in December 2003.

Summary

This chapter has taken a brief look at how RFID can and must be implemented within the company's backend systems, should the full potential of the technology be used. Some of the major companies involved in Supply Chain Management (SCM) and ERP systems are involved in getting the RFID technology out so that companies can start reaping the benefits of RFID. This integration is an essential part of RFID adoption within any industry.

Results

Introduction

During the course of this thesis, there has been a review of the constantly evolving RFID technology, a look at the construction industry and a brief review of the contextual design method before it tries to summarize by looking at how the RFID technology can be used to make the logistical procedures of doors and windows more efficient. Then follows a suggestion to how this might be implemented in a prototype, with an evaluation of the system criteria needed for such a prototype. Finally there is a short look at how and why the industry should consider the whole structural process rather than looking for a quick fix to an immediate problem. This chapter will try to summarize the important lessons that can be gleaned from the above mentioned material. It feels natural to divide the results into RFID related and construction industry related results.

RFID related results

During the literature study and the physical implementation and testing of the prototype some lessons could be learned. There are some technical and organizational limitations to the RFID technology that will affect how it can be implemented on a construction site.

- At the present, there is a lack of a global standard that have incorporated the needs of the construction industry. This includes standards in numbering systems and research into the specific requirements of construction sites for the air interface.
- RFID has difficulties with penetrating conductive materials, such as metals. Such materials are often in abundance on construction sites.
- The read range for RFID readers varies greatly.
- RFID does not need line of sight, which greatly eases the reading of packaged goods.
- The technology is still immature. Extensive testing and implementation has not been in widespread use, though there is some research concerning the retail industry.
- Studies show that RFID is best utilized if the whole organizational structure is evaluated concurrently. RFID technology may require large organizational restructuring, and implementation must be planned carefully.
- The price of RFID is still high if not used with discretion, i.e. do not tag one dollar items with 50 cent tags, though it could be reasonable to tag a tool worth thousands of dollars with a $100 tag. In the retail industry there has been some attention to driving the prices down, amongst others from EPCglobal.
- Readers come in many shapes and sizes, from small handheld devices to large fixed installations. All of these have pros and cons that need to be considered before deployment.

- Because of the problems of manufacturing tags and writing the proper information on them, including any encryption, tags can be used as proof of authenticity for the tagged item.

Construction industry related results

Some of the greatest changes to a business that implements RFID technology are not within its technological structure, but the organizational. The construction industry has some elements that are unique. Some of the results that can be extracted from the previous chapters are detailed below.

- It is difficult to quantify the actual return of investment (ROI) with any new technology. Sometimes it can only be deduced when thorough analysis of the entire process has been performed. The ROI, if any, can appear as an unplanned consequence in an entirely different process than the one it was implemented in.
- The construction industry is highly fragmented. Both in its structural hierarchy and its business models. Within a project a subcontractor will often work on a totally separate budget than the main contractor. He is just paid to do a job and when it is finished, the main contractor is done with him.
- The construction industry is known to be very slow to adopt new technology. This can be due to their fragmented structure, but also because the industry is very traditional.
- Pilot projects like Sophiehaven shows that there is great potential in focusing on greater integration between the different specialised departments within the industry.

Summary

This chapter has summarized the results that are extracted from the work with the thesis. It looked at two distinct types of results, those concerning the technology and those concerning the organizational structure within the industry. These views will be discussed in the following chapter.

Discussion

Introduction

In the work description two questions that needed answer was mentioned:

1. The feasibility of using RFID on constructions sites. This is because construction sites are often quite unsuited for wireless technology. They are often widely spaced, with concrete and metal obstructions and in addition filled with noise and interference from vehicles and construction-machines.
2. The cost-effect of using RFID. Are there any real problems on-site that can justify the expense of the technology employment? Where are the possible savings located? In reducing errors, in increased work efficiency or in tying up back-office systems to the technology?

During this chapter the results presented previously will be measured up against these questions. Finally, a short look at alternative solutions and a review of suggested further work rounds off this chapter.

Feasibility

The lack of a standard that specifically addresses the needs of the construction industry may or may not be essential for the adoption of RFID on construction sites. With regards to numbering there are many proprietary numbering systems that deals with building materials like NOBB in Norway, though the IFC could, if widely adopted, be used as a basis for identification. The EPC standard, now widely adopted across the retail industry, could theoretically be used. But if the construction industry does not want this numbering system as a basis, then any generic numbering system could be used to uniquely separate items while using the IFC, as reference written to the tag. As to the air interface, the number of possibilities within the different frequencies alone is staggering. First and foremost there should be done some research into which frequency range that functions best within the constraints of a construction site. This would set a technical recommendation. But there is a massive development within the HF-range (especially 13.56 MHz) and UHF-range (especially 850-900 MHz) in the retail industry, which could prove to be critical for adoption in other industries, even if it is shown to be substandard to their need, as it drives the price down and spawns (more-or-less) ready-to-install systems.

RFID has some innate abilities that affect its capability to function on a construction site. Since RFID works by propagating radio waves, it means that metal and other conductive material may seriously hamper its operability. A construction site is also filled with interference from construction machines. All in all, the environment is not ideal for an application that relies on wireless technology. But with careful planning such employment may be possible. As mentioned above there should be conducted some research as to which frequency range would be best suited for a construction site.

Another innate ability is the range of which it is possible to read a tag. With the prototype developed for this thesis, this range was restricted to around 3 cm. This is far too short to be of any practical use as most tags would be inside packaging. If the stated range of 10 cm was upheld, this device would have far greater potential, at least for the specialised area of work that it was meant for, though the range is still somewhat on the short side. It is also this ability to read through packaging that makes RFID so interesting, because this would mean that the contents can be verified without removing the wrappings. This is of particular interest for the specific problem that this thesis takes a look at, an initial inspection of doors and windows; because one of the main gripes is that the identifying labels are placed inside wrappings that are unfavourable to remove. A dismantlement of the packaging makes it troublesome to move the pallet afterwards.

RFID is still deemed expensive, and with some justification. The tags are still fairly high priced, except to very large orders like that of Gillette and their 500 million tags, and readers even more expensive, especially if one needs special requirements. One of the few cases that involve use of RFID in the construction industry used active tags to make the system more robust to its metal environment and this would drive the price further up.

The RFID technology is still immature. Even though there are being done a lot of testing and pilot projects in the retail industry there are many points that need addressing before it can be considered a household item. In addition, the technology is best utilized if implemented across the business structure. In this thesis it would mean that it would not be enough to implement the technology just to simplify the initial inspection process, as the information from RFID could be used in other processes, e.g. for automatic billing procedures and inventory checks. It is still recommended to focus on one process first and build on the experiences from this endeavour. The main point is not to be content with the single process.

There are two main problems with introducing any technology into the construction industry. The first is that this industry is well known to be very traditionalist and conservative in their operation. Many contractor firms started out as family businesses and normally work with fairly low tech tools with little involvement across the horizontal business branch. This is about to change, as there are some effort being done, both internationally and nationally that address this shortcoming.

The other is the fragmentation of the industry. When a main contractor hires a subcontractor the subcontractor works as separate entity within the project. He has his own budget and schedule, even though these have to coincide with the main contractors plans. And there even seems like there is a true ‘us and them’ feeling between these two even if they work against the same goal. During the interview with the acquisition manager in Arendal he mentioned that any problem the subcontractor ran into it would be the subcontractors’ problem, the main contractor tried to stay out of it. Of course, this was long as the job was done. This does not contain itself to the contractors either; some investments might be better put at some producer of material than on the construction site. But who should pay the bill for this investment, should the contractor pay for some of it as it would benefit him too?

This attitude makes it very hard to introduce new technology as the effect of the technology might not present itself in the place where it was introduced. It seems unlikely that a subcontractor would spend anything from their budget on something that another subcontractor will benefit of without spending the same amount themselves. This is especially true when considering it is difficult to quantify the return of investment on new technology.

For this to happen one needs pilot projects that includes the whole lateral business structure where everyone is focused on a common goal. A project like that of Sophiehaven, tested out with the introduction of RFID in some of the processes could yield interesting results.

Another way of looking at it would be to see if the technology should be implemented at the construction site at all. E.g. if Swedoor were to integrate their RFID technology with a system for quality assurance of the packing of pallets, then the whole problem assessment for initial inspection controls would be a moot point. There is hardly any point in checking the pallets for errors if they occur very seldom.

Cost-effectiveness

As already mentioned it is difficult to accurately quantify the return of investment from technological introductions. But the estimates taken from several test pilots concerning RFID shows that there is great potential for ROI, but these projects are mainly done for the retail industry. This thesis does not have enough insight into these differences to make a judgement as to the comparability between retail and construction industry.

Of the few studies that look into the savings that might come from making the construction site logistics more efficient is the Sophiehaven project. And this looks at it from the perspective of integrating the different actors present within a project in a larger degree than done before. This project showed that there is great potential in doing this, for this project alone it ran into some 5 % of the work costs, which is in the region of the expected total profit for similar building projects. The Sophiehaven report even states that it might give profits of 10-15 %, which is quite substantial.

At Arendal Cultural Centre the acquisition manager said that the potential gain from supporting the initial inspection process was difficult to estimate, but that errors occur often and that much time is spent on such incidents when they occur. He mentioned that incidents quickly took many hours and that figuring out the whole process of erroneously deliveries could take 3-4 days. When one man hour costs 270 NOK it does not take long to build up substantial amounts of money.

Alternative solutions to RFID

Strictly speaking, there could be alternatives to fixing the definite problem that this thesis looks at. If the focus was strictly on initial inspection on doors and windows and the main problem for this not being done at the site was that the labels was not visible from outside the packaging, then this could be resolved in other ways. First of all is that if the producer increases its quality assurance to its packaging before shipping the pallets, then the initial inspection could be pointless (barring administrative purposes, which could be fulfilled by checking off the windows as they are mounted).

Or the producers could make the labels accessible from outside the packaging by re-evaluating the way they were placed. If the workers would bother with inspecting the pallet anyways would be another matter as it still involves reading of numbers and cross-referencing it with the shipping document. Of course were the labels visible then a barcode reader might be a possibility, but once again is the construction industry a fairly dirty and rough environment and visibility might be reduced as a result of this. This again could make manual reading impossible to of course.

Further work

There are especially five things that should have been done in regards to this thesis. An actual experience on a construction site might give insight into the processes that are not accessible from literature study. This would also have given an opportunity to perform a contextual study which would have given insight into what was wanted from the actual actors themselves.

Secondly, it could have been interesting to look at the economic side in greater detail. One relatively simple way of deducing some immediate cost-effects would be to use the incidents reports from a few projects and see how many there were that were linked to the problems stated in this thesis.

Thirdly, to evaluate the specific needs on a construction site with regards to noise, interference, range and penetrability for several RFID frequencies. This report uses equipment that was commercially available, not necessarily because it was optimized for this purpose. As it turned out the equipment was poorly suited for use it was intended.

In the same regard, it proves that it is extremely important to state the requirements of the equipment to the manufacturer and then preferably perform an actual equipment check either on site or in similar conditions before settling on equipment of a certain type and make.

Finally, when the prototype is done it would have been nice to have performed a field test of the whole system, preferably with or by the persons who would have used the equipment on the site.

Conclusion

Is it possible to use RFID in support of construction site logistics with the technology and business structures that exists today? It is absolutely possible to make working prototypes that addresses many needs in the supply chain of the construction industry. But it is not feasible or credible to envisage a large scale implementation of RFID technology on construction sites today. The road for RFID adoption would more likely be with smaller pilot projects that test the grounds of what is and what is not possible. This would probably be best done in conjunction with an international body to ensure that the whole business strives towards the same goal. There are signs that the industry is slightly converging on the importance of acceptance for international standards.

If the construction industry could get large actors in the construction market to support and even demand the use of RFID, as the retail businesses have their Wal-Mart, it would be more likely to cause some stirring within the industry. As Wal-Mart demands that all links in the chain adhere to the standard of their choice, so should the driving force in the construction industry demand that the manufacturers and logistical firms use the technology too. The problem is the ‘standard of choice’. This is where the smaller pilot projects plays it part.

As for the economic side there is evidence from pilot projects that RFID could be cost-effective to employ, but as these are founded in the retail business, their applicability for construction is uncertain.

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Contents of the accompanying CD

Source code of the prototype
Documentation for the Minec 4x
API for the Minec 4x, including the new API; has to be installed on top of the old.
A literature study done in cooperation with another group, the results of which are integrated in this thesis.
Interview with Ole Morten Sundsdal, Aquistion manager at KRS in Arendal (in Norwegian)
Interview with Arve Engebretsen, daily manager at Montér, Grimstad (in Norwegian).

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