Life-cycle covering traceability and information management for electronic product using rfid

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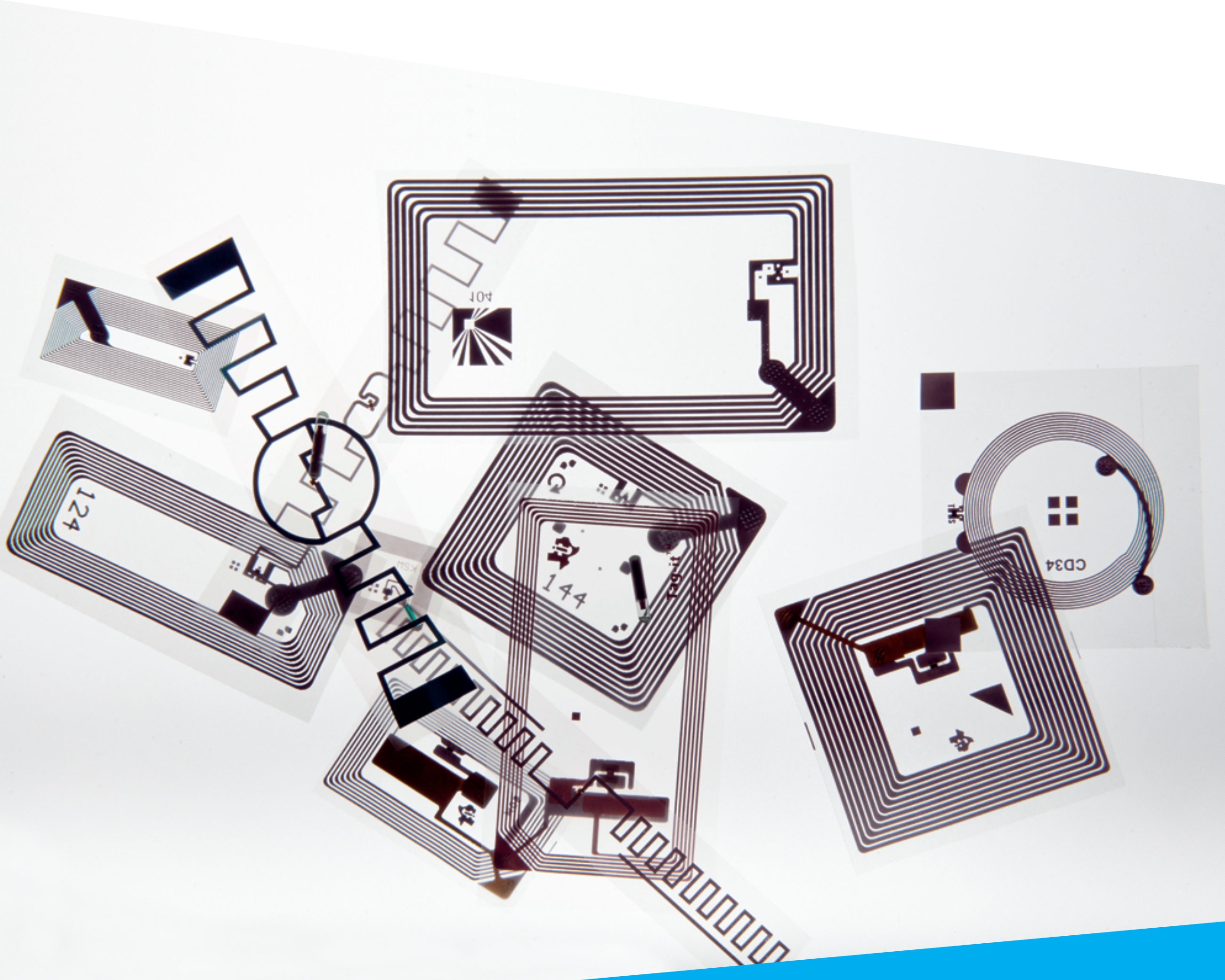

MAMK
University of Applied Sciences

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ABSTRACT

Radio frequency identification (RFID) is automatic object identification technology based on radio waves, and it has been seen as a promising technology to automate identification and control of items in manufacturing. RFID has been used in a wide scale of applications from simple tracking solutions to complicated systems for managing the entire supply chain. ERFID (Elektroniikkatuotteen elinkaaren kattava jäljitettävyys ja tiedonhallinta RFID-tekniikan avulla - Life-cycle covering traceability and information management for electronic product using RFID) project was set up to improve product traceability in the electronics industry using this technology. Because the lifecycle of a product involves the whole chain of design, manufacturing, supply chain, use, and disposal of product, the two main contributions of this research and its results are 1) to test and experience the applicability of RFID technology to the improvement of different manufacturing operations, and 2) to advance the use of RFID in the product lifecycle management of electronic products. Both practical research and review of existing research results were performed in the project to achieve these goals. A number of practical tests were conducted both in laboratory and factory environments to test the practical applicability of the technology to different manufacturing and lifecycle traceability problems. The results of this research are promising and they have shown that RFID technology has an increasing potential in existing and novel applications which can improve the efficiency and effectiveness of manufacturing and lifecycle management, but also drawbacks, restrictions, and important things to be considered when using the technology were noticed. Therefore, one of the main findings of the research is that a thorough testing period is always needed before implementing the technology in a larger scale. Moreover, also other important issues to be noted when implementing the technology in a factory are discussed in this report, as well as suggestions on using RFID in lifecycle covering data management.

Keywords: RFID, traceability, product life-cycle management

TIIVISTELMÄ

Radiotaajuista etätunnistustekniikkaa (Radio frequency identification, RFID) voidaan käyttää kohteiden automaattiseen tunnistamiseen radioaaltojen avulla, ja sitä on pidetty lupaavana teknologiana tuotteiden ja puolivalmisteiden tunnistamiseen ja hallintaan myös kappaletavaratuotannossa. RFID-tekniikkaa on käytetty teollisuudessa monenlaisissa sovelluksissa yksinkertaisista tunnistusratkaisuista aina monimutkaisiin tuotteiden jakeluketjujen hallintajärjestelmiin. ERFID-projektin (Elektroniikkatuotteen elinkaaren kattava jäljitettävyys ja tiedonhallinta RFID-tekniikan avulla) tavoitteena oli tuotekohtaisen jäljitettävyyden parantaminen elektroniikkateollisuudessa kyseisen tekniikan avulla. Koska tuotteen elinkaari käsittää suunnittelun, tuotannon, jakelun, käytön ja käytöstä poistamisen, hankkeessa saavutettujen tulosten vaikuttavuus on kaksitahoinen: 1) saavutettiin kokemuksia RFID-tekniikan soveltuvuudesta erilaisten elektroniikan tuotantoprosessien hallinnan parantamisessa, ja 2) luotiin ideoita RFID-tekniikan käytöstä elektroniikkatuotteen elinkaaren kattavan tiedonhallinnan apuvälineenä ja selvitettiin sen soveltuvuutta siihen. Tulosten saavuttamiseksi sekä tehtiin käytännönläheistä testausta ja luotiin testiympäristöjä että käytiin läpi jo olemassa olevaa tutkimusmateriaalia. Käytännön testejä tehtiin sekä laboratorio-olosuhteissa että todellisissa tuotantoympäristöissä, jotta saatiin mahdollisimman paljon käytännön kokemuksia tekniikan soveltuvuudesta erilaisiin tunnistussovelluksiin tuotannossa ja elinkaaren aikana. Tutkimuksen tulokset ovat lupaavia ja ne osoittavat, että RFID-tekniikalla on potentiaalia toimia tuotannon tehostajana ja elinkaarisovellusten pohjana, mutta tutkimuksessa tulivat hyvin esille myös tekniikan asettamat rajoitteet ja seikat, jotka täytyy huomioida kun sitä ollaan ottamassa käyttöön. Yksi tutkimuksen tärkeimmistä tuloksista onkin se, että kunnollinen testausjakso on aina järjestettävä ennen RFID-tekniikan integroimasta tuotantoon. Raportissa käydään läpi myös muita tärkeitä seikkoja, jotka on huomioitava otettaessa tekniikkaa käyttöön teollisuudessa, sekä myös ajatuksia RFID:n käytöstä elinkaarisovellusten ydinteknologiana.

Asiasanat: RFID, jäljitettävyys, tuotteen elinkaaren kattava tiedonhallinta

PREFACE

The ERFID (Elektroniikkatuotteen elinkaaren kattava jäljitettävyys ja tiedonhallinta RFID-tekniikan avulla - Life-cycle covering traceability and information management for electronic product using RFID) project results bring further information on potential, usability and costs concerning the life-cycle covering traceability of electronic products. The research project was organised in co-operation between Mikkeli University of Applied Sciences (MAMK) and University of Eastern Finland (UEF). Behalf of MAMK the project was implemented at Elektroniikan 3K-tehdas (Electronics 3K Factory) in Savonlinna. Company participants in the project were satisfied with the project findings.

By publishing the project final report in Publications series the information is spread out and shared more widely among the Finnish electronics manufacturing branch and other parties involved in product manufacturing industry, product traceability or RFID technology. The research project is a good example of networking between MAMK, UEF and Elektroniikan 3K-tehdas on research, development and innovation sector.

The ERFID project was funded by the Finnish Funding Agency for Technology and Innovation (TEKES), the European Regional Development Fund (ERDF), Control Express Finland Oy, Genelec Oy and Kemppi Oy. The project was organized during 1st May 2010 - 30th April 2014.

The writers

26th May 2014

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1 INTRODUCTION

Today, new promising technologies for improving the management of manufactured products and manufacturing processes are being intensively sought for. Radio frequency identification (RFID) can potentially assist in enhancing the efficiency of manufacturing by reorganizing and optimizing internal operations, including purchasing, warehousing, management, and distribution of materials in the production, as well as in external supply chain management. RFID enables the identification of individual objects (i.e. products) automatically and wirelessly, so it has an increasing potential in a variety of applications which could make manufacturing more productive and easier to manage.

These days, the manufacturers are willing to improve their business efficiency by reorganizing and optimizing internal business operations, such as purchasing, warehousing, management and distribution of materials in the production, and external supply chain management. In the future it will be vital to be able to monitor and control these operations, but it seems that the technology used conventionally for this have certain restrictions which make it difficult to enhance these operations.

An example of a challenging operational field is shop-floor management, in which manufacturing companies usually confront many challenges such as information gaps between individual manufacturing units and poor visualization of production stages, work-in-progress, and the state of the warehouse. The principal reasons for this are the lacks of competent technologies to acquire manufacturing data and software which is able to support online shop-floor management. Therefore, novel technologies have been recently sought for to fill this gap, and RFID can be considered as one of the most promising ones.

1.1 Basics of radio frequency identification (RFID)

Radio frequency identification (RFID) is an automatic object identification and data collection technology based on radio waves. It is a promising technology with full benefits to be emerged to all industries in the future. Generally speaking, the use of RFID technology is supposed to increase in manufacturing, when it comes to assuring the traceability of both work-in-process and final products, as well as manufacturing materials and tools, for example.

RFID involves a RF transmitter/receiver pair, where one (tag) transmits its identity to the other (tag reader) (Brusey and McFarlane, 2011). In addition, the technology usually includes an information management system for processing and transferring the produced data. For a more detailed description on the technology, the reader may refer to Lehpamer (2007) or Ranky (2006).

The main parts of a RFID-based information management system include :

- Tag which is attached to a product to identify it. The microcircuit of the tag includes a unique code and/or other information.
- Tag reader (manual or gate). The information of the tag can be read and possibly altered using the reader. The reader has an antenna that emits radio waves, and the tag responds by sending back its data.
- The reader is connected to an information management system, which can be used to process the information included to the tag.

The information management system generally includes a server connected to a database, and system management software with a connection to background programs such as Enterprise Resource Planning (ERP). The end-users have an access to the database via a graphical user interface, which enables flexible use of information for various purposes.

1.2 RFID software

The main software components of RFID-based information management system include middleware, application software, databases, possible background systems such as enterprise resource planning, and the necessary infrastructure for information transfer. The main tasks of these are:

- Middleware: system management and arrangement of communication interfaces
- Application software: extraction of information from the database, controlling purposes etc.
- Database application: offers a record of the events collected by RFID and possibly the data connected with individual tag codes and runs on ordinary PCs or a server (e.g. Oracle, SQL, Postgres, MySQL).

The information flows in such a system are as follows. The tag communicates with the reader, which is connected to the main information server or, in a simplest case, straight to a user PC with appropriate application software. Generally the user can also manipulate the readers via the user PC. Usually some filtering is needed before transmitting the data, however, which necessitates the existence of a piece of software between the reader and the server.

This piece of software is often called middleware. This software component connects the RFID reader to the other software components in an ICT system and also filters the data before it is transmitted forward (Sørensen, Christiansson, and Svidt, 2010). In its simplest form, RFID middleware is a software layer residing between the RFID hardware and the existing back-end system or application software. The middleware software is usually located on ordinary PCs or servers and provides an interface for many sensor technologies, which enables cross-platform hardware integration (Chen, Tu, and Jwo, 2010).

1.3 RFID – a solution for the problem of traceability?

RFID technology seems to have an increasing potential in various applications that can make manufacturing more efficient and more productive, and there is also recent evidence on that. It has been shown that the information generated by RFID can be used for reducing inventory levels, cut down lead times, and facilitate enterprise-wide operational visibility throughout the entire product lifecycle (Huang et al., 2012a). Moreover, Mehrjerdi (2011) has listed almost 80 benefits of RFID based upon ten case studies already reported in the literature. Additionally, Zelbst et al. (2012) have studied the impacts of RFID on manufacturing efficiency and effectiveness, concentrating on such firms in the manufacturing sector which have been at their growth stage of adopting the technology. The authors provided empirical evidence of the role of RFID technology in increasing the efficiency and effectiveness of manufacturing, and in improving customer satisfaction and organizational performance.

At the beginning of the ERFID project, potential benefits that might be achieved by implementing RFID technology in manufacturing were listed by the project partners. They included:

- Product traceability
  - reduction of manual work used for collecting manufacturing data
  - automation of production control and making it real-time
  - exact and comprehensive production monitoring without massive amount of work

  - a part of the work currently put on reading bar codes is released for other purposes
  - reliability of collected information is more reliable, because less data is collected manually
- Authentication of final products and prevention of counterfeiting
  - original branded products are easier to authenticate using RFID
  - it is more difficult to manufacture counterfeits
- Traceability of materials and parts
  - automated maintenance, monitoring and control of warehouse
  - possibility to develop and offer additional services on the retail and end-user level
- Improvement of supply chain and lifecycle management
  - accelerating and facilitating the loading of goods
  - checking the contents of leaving deliveries fast
  - automated error checking and decreasing the number of errors
  - automated documentation of delivered products
  - tracing and updating of maintenance history
  - detection of counterfeits in maintenance or repair (especially products with warranty)
  - identification of original, branded products and connecting them with production-related data
  - automated outsourcing of right spare parts
  - enables feedback from maintenance to production

On the other hand, it was noticed at the early stages of the project that there are also drawbacks which have more or less restricted the implementation of RFID technology when looking at the issue from a wider viewpoint. The most important of these include certain technological issues, privacy and security issues (Nambiar, 2009), and standardization issues (Xiao et al., 2007). Although worldwide efforts have been put to develop standards for RFID development and deployment, the achievement of the potential benefits of RFID in manufacturing has been, unfortunately, slower than expected (Huang et al., 2012a).

1.4 Scope and contribution of the research

The scope of this research was to study the use of RFID technology in the lifecycle management electronic products. Because the lifecycle of a product involves the whole chain of design, manufacturing, supply chain, use, and disposal, the two main contributions of this research and its results are thus on one hand to test the applicability and study the potentiality of RFID technology in the improvement of different manufacturing operations, and on the other hand to advance the use of RFID in the product lifecycle management. Both practical research and review of existing research results were performed in the project to achieve these goals.

2 RFID-BASED SYSTEM FOR TRACING ITEMS I MANUFACTURING

It is always important to test the new technology, both hardware and software, in real manufacturing conditions. Therefore, a RFID-based demo system was constructed in the ERFID project. Only a general overview of the system is given here. For more detailed information, the reader may refer to the test report.

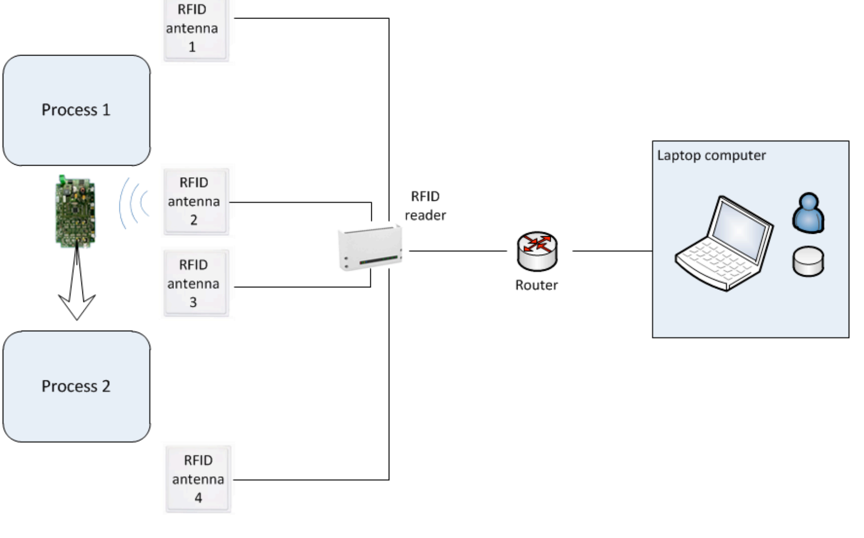

FIGURE 2.1. The principles of the RFID demo implementation. The RFID reader software, database and management GUI have been installed to the laptop computer.

The principles of the field system developed are shown in *Figure 2.1*. The main parts are RFID reader, four antennas, and a laptop computer to which the necessary software modules have been installed.

2.1 Hardware specification

The hardware of the demo system developed includes:

- ***a.*** ***RFID tags*** attached to the electronics products
  Electronics products: 1) assembled test PCBs with a Murata Magicstrap RFID surface mount component, and 2) welding machine components with Murata Magicstrap components and encased RFID tags designed for metal surfaces (Steelwave Micro, Confidex).
- ***b.*** ***Antennas***
  Long-range, mid-range and low-range antennas manufactured by Feig Gmbh and Kathrein GmbH were used in demos. The antennas were situated in predefined stages along the production line to record corresponding periods of time.
- ***c.*** ***RFID reader*** and peripherals
  Model: FEIG Electronic OBID i-scan ISC.LRU3000, with ports for four separate antennas. In addition, a hand-held reader (Kenetics Volaré usb-stick reader) was tested. The antennas were attached to the reader with RF-cables, and the reader was attached to a laptop computer with windows 7 via a wlan router.
- ***d.*** ***Laptop computer*** with embedded software modules

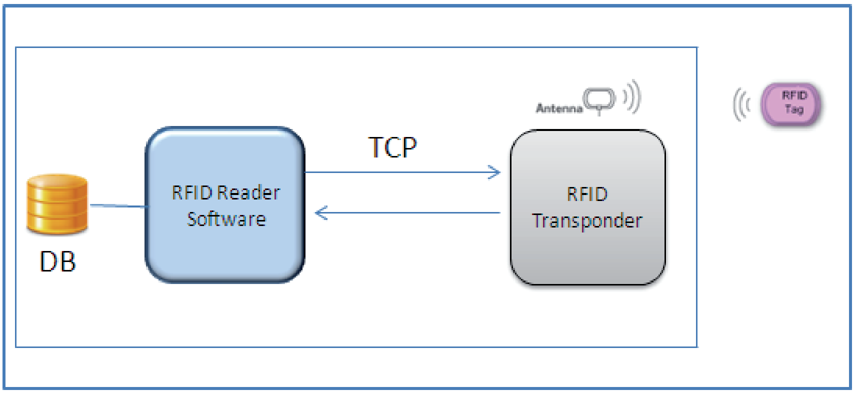

FIGURE 2.2. Communication between RFID Reader Software and RFID Transponder.

2.2 Software description

RFID software is designed to follow the flow of manufacture process at the electronics plant, in which RFID tags are attached to electronics components. FEIG RFID Reader is used to read the tags as the products go through manufacture line. Software consists of server and client parts. Server part (RFID Reader software) connects through TCP to FEIG RFID Reader and reads the items in Buffered Read Mode in fixed-time intervals. It performs data processing and saves data in a database. Client part (RFID Analyzing software) retrieves data from the database and presents results to user queries.
The software modules of the RFID demo system and their tasks are:

tr_type	idd_type	serial_number	antenna	timestamp
132	0	300000e200600303a0de40000000	3	2012-10-09 14:54:32
132	0	300000e200600303a0de40000000	4	2012-10-09 14:56:20
132	0	300000e200600303a0e856000000	3	2012-10-09 15:25:12
132	0	300000e200600303a0e856000000	4	2012-10-09 14:51:39
132	0	300000e200600303a0e876000000	1	2012-10-09 14:52:47
132	0	300000e200600303a0e876000000	2	2012-10-09 14:54:07
132	0	300000e200600303a0e876000000	3	2012-10-09 14:54:30
132	0	300000e200600303a0e876000000	4	2012-10-09 14:56:18
132	0	300000e200600303a10922000000	1	2012-10-09 14:52:46
132	0	300000e200600303a10922000000	2	2012-10-09 14:54:01
132	0	300000e200600303a10922000000	3	2012-10-09 14:54:38
132	0	300000e200600303a10922000000	4	2012-10-09 14:56:18
132	0	300000e200600303a10abc000000	1	2012-10-09 14:52:46
132	0	300000e200600303a10abc000000	2	2012-10-09 14:54:09
132	0	300000e200600303a10abc000000	3	2012-10-09 14:54:41
132	0	300000e200600303a10abc000000	4	2012-10-09 14:56:21

FIGURE 2.3. An example of a MySQL database with collected reading events.

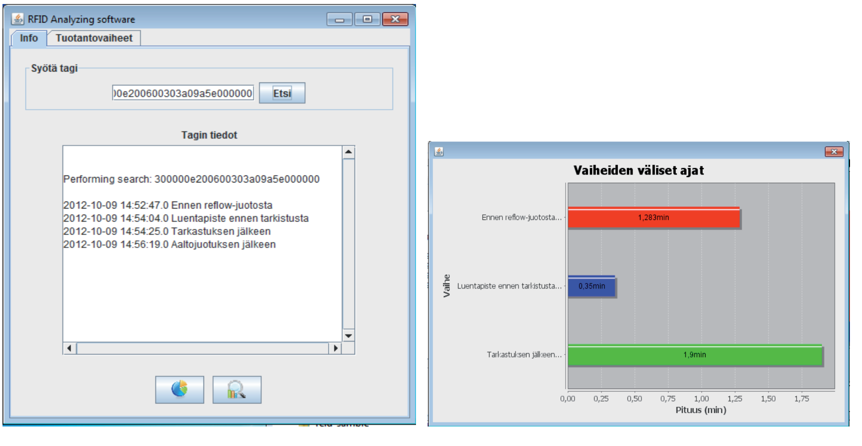

FIGURE 2.4. GUI of the RFID management software. On the left: searching for an individual tag and its timestamps at different stages. On the right: a chart showing the average duration of different manufacturing stages.

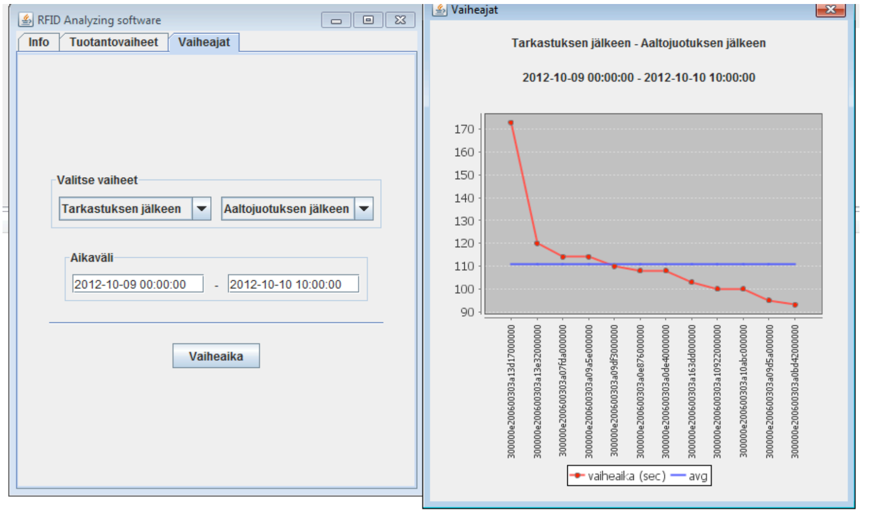

FIGURE 2.5. On the left: selecting a manufacturing stage for presenting statistics information on processing times. On the right: a graph presenting the trend of cycle times of individual products in the selected unit process.

a. Reader software: gets a list consisting of recorded RFID tags from the reader and adds the physical location and timestamp of a detected event to the database.
b. Database: MySQL database to which the reading events are collected (See *Figure 2.3*).
c. Graphical user interface and client software: the software for managing the contents of the database (See *Figure 2.4*). GUI gets the tag and event information from the database. GUI can also be used for monitoring individual products (i.e. tags) and their timestamps at different stages of production, and the time elapsed between the reading events (See *Figure 2.5*).

3 OFF-SITE TESTING OF RFID TECHNOLOGY

In addition to factory tests accomplished on electronics manufacturing lines in real factory environment, off-site testing was carried out. This off-site testing included testing of RFID durability at different environmental conditions, data retention tests and evaluating hand held RFID readers.

3.1 Durability

The durability of RFID tags against different environmental conditions was tested by several test experiments. In addition to label type tags, Murata Magicstrap chips soldered on a printed circuit board (PCB) were tested. The RFID test labels used in the tests included labels with paper substrate, polyethylene terephthalate (PET) substrate and Kapton ® (polyimide) substrate, as well as 3D resin domed stickers.

Random, repeated dropping test for RFID tags was executed by a dropping tumbler. The test tags attached to test units were dropped down 600 times from a one meters height. Most of the tags worked after the dropping test. Some of the heavier 3D domed RFID sticker tags had loosened from the plastic test unit, which means that the tag adhesive was inadequate to keep the tag attached.

In an industrial environment it is possible that dirt and soil etc. accumulate to objects like RFID tags. This dirt was simulated by covering RFID labels with motor oil and by scattering iron chips on RFID tags. It was noted that the tags could be read through oil. Moreover, tags covered by a layer of iron chips were also readable. In addition, small amounts of dirt did not seem to have effect on the reading range. RFID labels did not dissolve in motor oil immediately, but it is likely that motor oil could harm normal label material during a longer exposure. When motor oil resistance is needed, special motor oil resistant label substrate material should therefore be chosen.

It was also noted that exposure to strong UV light (400 W, 1 hour) induced yellowing on paper and PET (polyethylene terephthalate) film, which were used as substrate material in the RFID labels. The RFID chip itself did not get damaged by the UV radiation.

Temperature and moisture resistance of RFID tags were tested in two ways. A five day long humidity-temperature test (85% RH, 85 °C) was accomplished for the RFID test tags, and every test sample worked after the test. A more challenging test was to put test tags through a reflow oven, the maximum peak temperature of which is 250 °C. It was noticed that RFID chips can handle a short time exposure to 250 °C temperature, which is needed to solder electronic components on the printed circuit board. However, the RFID label substrate made of paper turned yellow during the reflow cycle, and PET type film substrate even melted during the reflow cycle. The only RFID label substrate type, which actually survived in the reflow oven, was Kapton® (polyimide) type RFID substrate. Therefore, if a RFID substrate material for high temperatures is needed, the polyimide film is a good choice.

Powerful magnetic fields often exist around the machines and devices used in the industry. For example welding machines and large electric generators may produce strong magnetic fields. A concern was raised that strong magnetic fields emitted from industrial electrical equipment could disturb the RFID memory function or even erase the RFID memory. To test the vulnerability of RFID memories to magnetic fields, a plastic bag containing RFID tags were placed on the surface of a welding station for three weeks. This welding station is known from the fact that a wrist watch of a welder often interferes with magnetic fields of this welding station. However, after three weeks exposure to magnetic fields of this welding station the RFID-tags were intact and readable. The RFID identification code in RFID tags was remained unaltered during the three weeks' storing under the influence of strong magnetic fields.

In summary, a conclusion that can be drawn from the environmental test results was that the RFID chip itself survives well in harsh environments. Nevertheless, the interconnection between chip and antenna and the RFID substrate material are more prone to damages.

3.2 Assembled RFID chips

The possibility of using PCB-copper plane as an antenna is an interesting and attractive thought. Murata Manufacturing co., ltd. has developed a chip that can be easily assembled to a PCB and is fully compatible with reflow soldering (See *Figure 3.1*). There are four different chips available for differently sized antenna designs.

Using a larger antenna design or a larger PCB usually means a longer reading range. According to tests, the 5x5mm antenna design had the shortest reading range. The following RFID-readers were used to test the read range of each PCB: the Volare UHF USB reader with integrated antenna and the Feig LRU 3500 reader with Feig 270x270mm antenna.

The main conclusion to be reached here is that assembled, soldered Magicstrap components seem to work, and other components assembled on the same PCB do not seem to lower the read range.

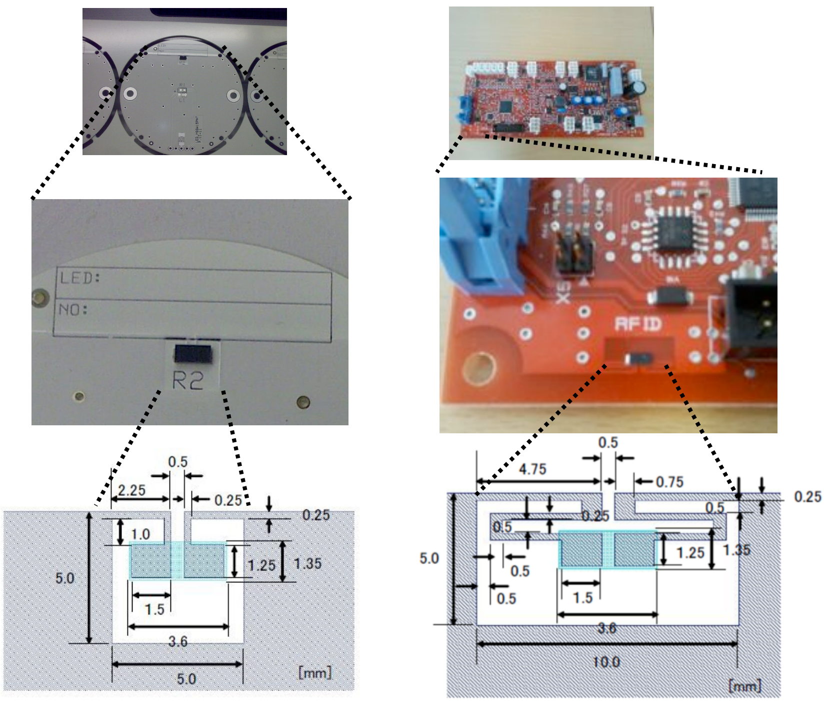

FIGURE 3.1. Murata Magicstrap RFID-chips assembled on PCBs. On the left: Murata Magicstrap version Type 1, product code LXMS31ACNA–009 5x5mm antenna pattern. On the right: Murata Magicstrap version Type 2, product code LXMS31ACNA-010 5x10mm antenna pattern.

FIGURE 3.2. Left to right: Volare UHF USB reader stick (with an internal antenna), Feig LRU 3500 reader, Feig 270/270mm antenna.

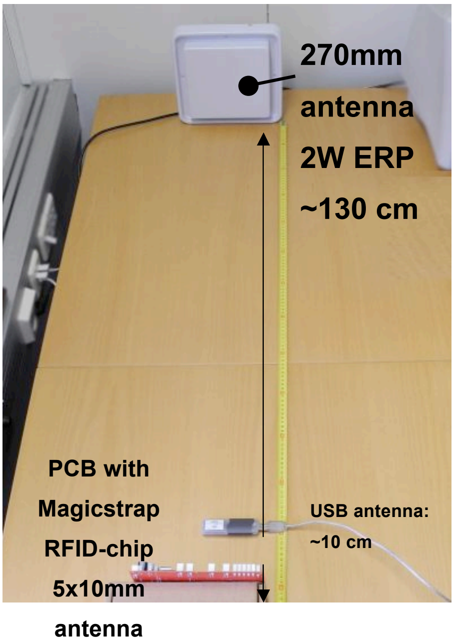

FIGURE 3.3. The read range of the larger PCB with the larger (5x10mm) antenna pattern.

3.3 Data retention

The ability of a RFID tag to retain its data is an essential property when considering the life-cycle covering RFID traceability of products. RFID memories contain typically an EEPROM (Electronically Erasable Programmable ROM) type non volatile memory. EEPROMs can usually handle tens or hundreds of thousands of rewriting/reprogramming cycles. For RFID purposes numerous reprogramming cycles are generally not needed, because a RFID tag is written usually only a few times or only once. That is the difference between the RFID use and other applications of non volatile memories. Data retention means the ability of the RFID memory to retain data over time. RFID chip manufacturers declare nowadays long data retention times, for example ten, twenty or even fifty years of data retention (See *Table 3.1*).

Different types of non volatile memories may behave differently under different circumstances. Discovering the worst possible environmental conditions (where the RFID memories should be tested) is difficult. Based on the literature (Sikora et al., and standards JESD22-A117 and JESD47H)), data retention tests are often performed at elevated temperatures, for example at 55 ºC, 85ºC or 125 ºC for 100 h or 1000 h. The increased temperature will accelerate most defect mechanisms. However, there are some defect mechanisms which occur only at low temperatures. Thus, all defect mechanisms can not be revealed using only high test temperatures.

Long term high temperature test was performed for RFID memories. The tested RFID memory was Murata Magicstrap containing the RFID chip G2XM manufactured by NXP Semiconductors. The chips were stored at 55 ºC and 85 ºC temperatures for 10 000 hours. The RFID identification information was read by a RFID reader for every 1000 hours. The data in the RFID remained unaltered for 10 000 hours. According to test results it seems that RFID chip memories are not vulnerable for high temperatures like 55 ºC or 85 ºC.

TABLE 3.1. RFID chip properties including the declared data retention.

Manuf	Chip	Memory Size [bits]	Write rate [tags/ sec]	Data retention	Operating temp [ºC]	Memory type
Alien	Higgs 2 Higgs 3	EPC: 96 User: 512 Unique 64 bits TID: opt Password: 32		50 years (Higgs 3), 10 years at 25 C (Higgs 2)	[-50,+85]	Eeprom
Impinj	Monza 3 Monza 4 Monza 5	EPC: 96 or 496 User: 32, 128 or 512 Unique TID: opt Password: 32	15, 20 or 50 tags/ sec	50 years	[-40,+85]	Eeprom
NXP	G2iL G2XM G2XL	User: 512 EPC: 128 or 240 Unique 64 bits TID: yes Password: 32		20 years (< 55C)	[-40, +85]	Eeprom

3.4 Hand-held readers

Two hand-held readers of different sizes were compared to see the differences in read-ranges and general usability (See *Table 3.2* for details). The both hand-held readers are manufactured by Nordic ID.

Nordic ID Morphic UHF RFID Cross Dipole (See *Figure 3.4*) is the smaller one of the tested hand-held readers with 0,5W RF power, and it is the smallest 0.5W UHF RFID handheld computer. The manufacturer declares that the maximum read range is 2.5m and the read speed is up to 150 tags per second. It has a 2.2 inch resistive touch screen. Other features include 3G, GPS, WLAN, Bluetooth, USB, Ethernet, and 2D-barcode.

FIGURE 3.4. Nordic ID Morphic UHF RFID Cross Dipole

The larger one of the tested hand-held readers is Nordic ID Merlin UHF RFID Cross Dipole (See *Figure 3.5*). It had larger 3.5 inch resistive touch screen and larger antenna. It has 1W of RF-power, and the manufacturer promises maximum read range of 5m and a typical read speed of 150 tags per second. Other features include 3G, GPS, WLAN, Bluetooth, USB, Ethernet, and 2D-barcode.

FIGURE 3.5. Nordic ID Merlin UHF RFID Cross Dipole

Some reading ranges detected in tests for different types of RFID tags are listed in *Table 3.3*. It can be seen that in practical use the actual read range is usually much smaller than that declared by the manufacturer.

TABLE 3.2. Reading range of different RFID-tags

RFID reader	Nordic Id –Morphic 	Nordic Id – Merlin 
Speed	Reads over 50 tags/sec	Reads over 50 tags/sec
Ergonomy	Easy to hold, screen too small	A little bit heavy to carry, screen size ok.
Operating system	WinCE 6.0, text size too small	WinCE 6.0
Antenna	360° - most sensitive to front/back direction	360° - most sensitive to front/ back direction
Output power adjustment	8mW-500mW, 19 steps	8mW-500mW, 19 steps
Weight	230g	770g
Max reading range	Datasheet: 2,5m Actual: 2,5m	Datasheet: 5m Actual: 3m
Screen size	2.2"	3.5"

TABLE 3.3. Read ranges of the tested hand-held readers for different RFID-tags

Reader/out-put power	Morphic/500mW	Morphic/8mW	Merlin/500mW	Merlin/8mW
Dogbone	2,5m	30cm	3m	1,7m
Murata chip on a large PBC	30cm	3cm	40cm	5cm
Murata chip on a small PCB	15cm	1cm	20cm	1-2cm
Steelwave Micro	30cm	10cm	50cm	20cm
Squiglette	20cm	3cm	30cm	5cm

4 FACTORY TESTS

Factory tests were conducted to examine the applicability of the technology in real manufacturing environments. The purpose of testing was to answer the following questions:

- Is the functionality of the RFID devices and software adequate in a real electronics manufacturing environment?
- Can individual products be identified using the system?
- Can through-put times of individual products be monitored automatically and in real time?
- Can stage-specific cycle and waiting times of individual products be monitored automatically and in real time?
- What are the main problems in practice and the main ideas for future development?

4.1 Test arrangements

The factory tests were conducted in two separate manufacturing environments: 1) in the test environment of the 3K Factory of Electronics (See *Figure 4.1*) and 2) in the manufacturing premises of Kemppi Ltd in Lahti, Finland.

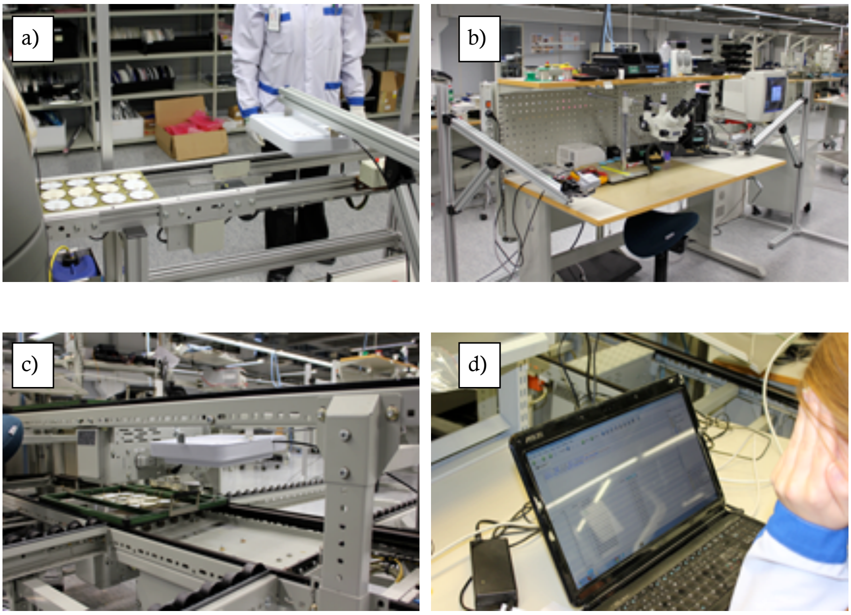

FIGURE 4 .1. Examples of RFID working points. a) the 1st reading point before reflow soldering, b) the 2nd and 3rd reading points before and after the inspection and repair stage, c) 4th reading point after wave soldering, d) system management PC.

4.2 Location of tag in the product

It was assumed that the spot, where a tag is located in the product, has a remarkable influence on the reading efficiency. If the tag location is open to a reader, it was assumed to be likely, that the reader will detect the tag. During test experiments, it was noticed that a tag located especially in the corner of metal housing (see in *Figure 4.2. b*) of a product was difficult to get detected. Reading problems often occurred also, if a metal plate was situated between a tag and a reader or if parallel printed circuit boards were close to each other.

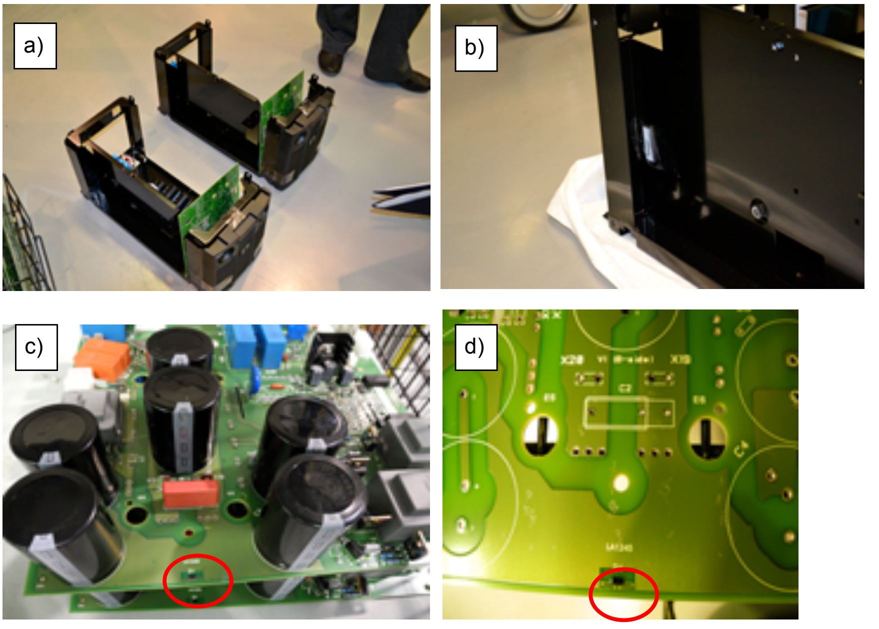

FIGURE 4.2. Product examples. (a) Metal housings with printed circuit boards. (b) tag located in a corner of a metal housing, (c) and (d) printed circuit board with a RFID chip surrounded by a red circle.

4.3 Effect of antenna range and power

The influence of an antenna power was studied by regulating the power of long read range antenna. By increasing the antenna power, the reading was easier, because tags were read with higher likelihood. The disadvantage of high antenna power is that the probability of false readings increases.

Also mid range reader was tested on an assembly line, but this mid range antenna could not be located near enough the products to be read. Because of too long distance, typically some of the products were not read. On the other hand, false readings with this mid range antenna were unlikely. If the mid range antenna could be located close enough to products on a assembly line, the mid range antenna read range is enough to get products read. If a long range antenna is in use, false readings from other products must be prevented. Tag containing products, which are not meant to be read, should not be allowed to pass the long range reader in the nearby. Or false readings should be prevented by other means. False readings may be a problem if different tags with different read ranges are in use in the same production hall. If tags with short read ranges are wanted to be read, also tags with longer read ranges are easily read even if the longer read range tags are located more far away. Read range can be limited also by physical read barriers.

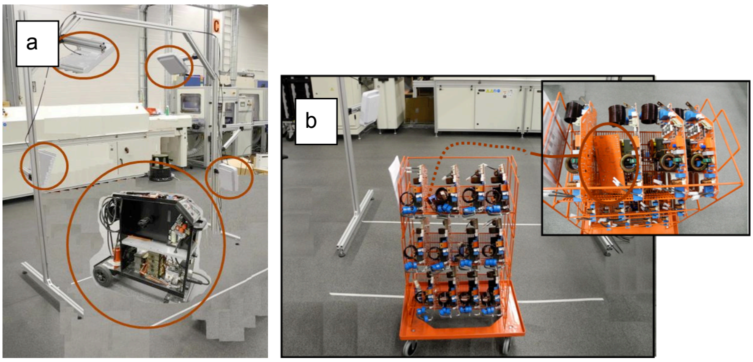

FIGURE 4.3. Port type reader was used to read tags placed inside a welding machine (a) and in a PCB rack (b).

4.4 Identification of multiple tags

A port type reader was used to test the reading of multiple tags simultaneously (see in *Figure 4.3*). Tags were placed at different spots of welding machine and printed circuit board (PCB) rack. The port type reader consisted of four long range reader antennas. The port reader could read all or almost all tags placed in the welding machine and in the PCB rack.

4.5 Summary

During the field tests it was noticed that the hardware and software functioned well. Software including the reader software, database, database connection and graphical user interface worked without problems during the last test period.

It was also noted that the identification of individual products was possible using the system. By placing the antennas to right locations it was possible to monitor the through-put times of products in almost real time, as well as cycle times of unit processes.

The main problems and targets of development identified during the factory tests are as follows:

- Dead angles: some specific spots in a product or in a panel of PCBs may remain systematically unreadable. *Solutions*: correct and exact placement of tags and antennas.
- Blind spots for tags were located systematically in places such as inside the metallic frame, behind the PCB, behind the product with respect to antenna etc. *Solution*: correct placement of tags and antennas.
- Metallic surfaces (e.g. copper) may distract reading. *Solution*: Avoid placing tags near/behind metallic surfaces.
- Reading efficiency can be improved by increasing the antenna power, but the risk for reading wrong tags near the reading spot also increases. It is also important to remember that there is legislation which restricts the power. *Solutions*: antenna power can be increased to a certain extent, but it is probably better to optimize placement of antennas or add antennas to the difficult reading spot to increase reading efficiency.
- Incorrect reading events are possible. *Solutions*: primarily the reading sector of antennas has to be controlled carefully by adjusting power (particularly long-range antennas) and/or by using physical structures which restrict the progressing of signals in appropriate places. Selecting the right technology (antenna type) is likewise important. By means of programming the prevention of incorrect reading events is much more difficult to handle perfectly.
- Reflection of the signal from production structures is also possible, for which wrong events may be read from further. *Solutions*: careful placement of antennas with respect to other structures and proper testing of as many scenarios as possible. Selecting the right technology (antenna type). A possibility of removing erroneous events from the database should be made possible, and the management of the database should be restricted by access rights of different levels. Advanced computer programs could be used for filtering reading events or serve as decision support systems for detecting erroneous events.
- How to monitor all cycle and waiting times as accurately as possible? *Solutions*: an adequate number accurate placement of antennas. Selecting the right technology according to each manufacturing stage (reader type, antenna type). Training and proper instructions for workers using manual RFID readers.
- Treatment of reading events may prove to be problematic when the product remains within the reading range during idle times, so that it is read several times. *Solution*: It is possible to manage reading events by software, e.g. by recording only the first event of the tag into the database, or by updating the record regularly at specified time intervals.
- There are many possibilities to use collected data in the improvement of production efficiency, e.g. analysis, online monitoring and reporting of cycle and through-put times, traceability of manufacturing stages of individual products and so on.

5 IMPLEMENTATION OF RFID IN A FACTORY

5.1 General

The primary questions considering the implementation of RFID technology on the factory level are probable to deal with hardware and software instruments and their integration to existing systems. Before the implementation is started, perhaps the most interesting questions are the system cost and repayment period. Some approximate numbers for costs are given here, but it should be kept in mind that the total cost depends largely on the special features of the case concerned such as the extent of application, number of reading points needed, number of tags, the type of readers, and the software needed etc. Furthermore, the architectures, infrastructures and frameworks presented in this report are tentative examples of how the implementation could be performed in reality. RFID system design is always case-specific and the specifications should be defined according to special features of each target.

At least four fundamental questions require answers before the implementation can be started. The first question encountered is often the technology, which is referred to as hardware in this report. The hardware includes, not only the RFID tags and readers, but also computers and servers needed to collect and store the data provided by the sensor technology. The second question is the software needed to process the data and information provided by the technology to a form that can be utilized on the different organizational levels of the factory. The software include, not only the application software to monitor process variables such as through-put times based on the data, but also the invisible modules that manage the entire system and databases, and perform communication between the different interfaces.

The third question is the infrastructure, which ensures transferring the produced data and information between different hardware and software modules. The hardware, software and infrastructure altogether form the information management system. The fourth and perhaps the most important question is the money. Although it may be difficult to answer, it would be interesting to know, on the current level of costs, some suggestive numbers of the amount of Euros needed for the implementation and integration of RFID to existing systems. This would enable estimating the repayment period of the system.

5.2 RFID integration process

It is quite usual to outsource the implementation of an RFID system to a professional service partner to reduce problems and exposure to risks. This is because especially the integration of RFID with other systems requires a comprehensive knowledge of different systems. Whatever the instance is that is taking care of the implementation, it is always recommended to accomplish RFID installation in phases using a test or pilot site (Jabbar & Jeong, 2010).

The process of implementing an RFID system according to Jabbar & Jeong (2010) is presented in *Figure 5.1*. First, business and feasibility analyses should be conducted to find out the cost-effectiveness and profitability of the system in the environment concerned, followed by the process and site analyses with small-scale tests. Meanwhile, the requirements and specifications for the different system components are obtained. After the requirements are defined and plans are ready, hardware can be purchased, system installed and staff trained.

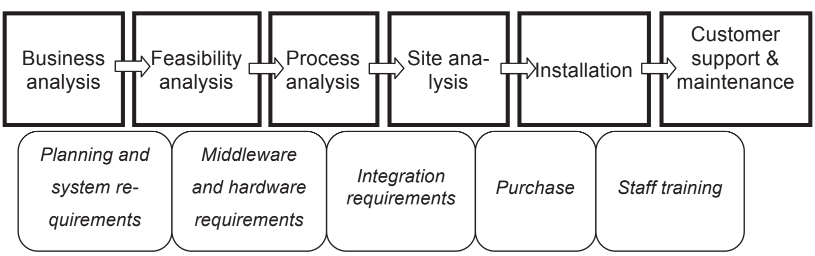

FIGURE 5.1. Process of implementing and integrating RFID (modified from Jabbar & Jeong, 2010).

Some of the most important technical issues to be considered during the integration process include:

- Diagnosing the RF environment and possible problems
- Installation of readers and other hardware
- Testing the tag performance in the final environment/in an environment similar to the final environment
- Design of the information management system
- Design of the data storage systems

5.3 Cost issues

Estimating the cost of RFID system integration is difficult, because the costs depend largely on the extent of application, number of reading points needed, number of tags, the type of readers, and the software needed. The current price of individual tags is relatively low, but major investments may be necessary to integrate RFID to existing IT infrastructure and enterprise software. In addition, the investment cost from RFID readers can prove to be significant if the number of reading points needed is high. Costs of implementing an RFID system include (suggestive numbers at the time of writing this report):

- Tags 0.06 – 5 € per each (those used in logistics: 0.06 – 0.20 €) (3k-Factory of Electronics, 2011)
- Readers ~400 – 3 000 € per each + antennas ~100 – 1 000 € per each + possible manual readers ~ from 500 € each (3k-Factory of Electronics, 2011)
- Computers, servers and auxiliary: from 1 000 €
- Middleware 2 000 – 200 000 € (depends largely on the number of interfaces; also free open source applications exist) (Source: RFID-lab)
- Application software: from 0 to 10s k€ (depends largely on the extent of functionality)
- Database application: from 0 to 10s k€
- Integration work (bought service/own work), k€ – 10s k€ (Source: Vilant Systems Oy)
- Possible changes in existing background systems such as ERP (software supplier/consult), from some k€s
- Possible modification of production systems and product layout changes (e.g. due to soldering of RFID chip), from some k€s
- System support, maintenance and updating (bought service & own work, as agreed)
- Staff training (training personnel, workers' absence from production), depends largely on the scale of the system

Based on these numbers it can be easily seen that presumably the hardware cost of the system will be a relatively small part of the total cost, depending of course on the scale in which the system is implemented.

Estimating the repayment period of the system can be even more difficult. Factors possibly improved by the RFID system and affecting the return on investment include:

- Automation of material flows
- Reduction of material loss
- Avoiding errors in delivery and shipping
- Real-time monitoring of material flows
- Real-time monitoring of stock => smaller stocks, faster inventories
- Automation, monitoring and control of production
- Control of supply chain (subcontractors)
- Prevention of counterfeiting
- Lifecycle covering monitoring of products

In other words, the financial benefits may be enormous, but another interesting question is what would the repayment period be. Ivantysynova et al. (2009) have discussed the RFID investment decision more deeply and brought up some RFID evaluation methods presented in the literature which can assist in making the decision.

5.4 Selecting the right technology

5.4.1 RFID or barcode?

Some features of RFID and barcode technologies are compared in *Table 5.1*. As can be seen, RFID outperforms the barcode in many ways; only the cost issue is a benefit for the barcode technology. However, there are some aspects which can make the barcode a preferable choice in many cases. First of all, total investment cost is one of these. As the infrastructure, interfaces, links to ERP, and know-how for barcode technology already exist in most factories, the other benefits gained by RFID have to be significant and the return on investment has to be calculated properly before the technology is switched. Thus, when RFID is implemented, it is quite typical to use both technologies as parallel systems.
Second, if the manufacturing process consists of several manual processing stages, the benefit from using RFID is not so significant, as the worker has to handle a manual reader nonetheless. Therefore, RFID may be the primary choice of highly automated factories at the first stage. Furthermore, the lifespan and durability issues may not be considered important advantages if lifecycle covering traceability is not pursued.

TABLE 5.1. Comparison of RFID and barcode technologies (modified from Stankovski et al. [2009]).

Feature	RFID tag	Rate	Barcode	Rate
Traceability	The combination of unique identification code, user data, serial number and on-board memory makes it possible to track, recall or document the life span of a single item.	5	Bar code is limited to an entire class of products. It is not feasible to recall track or document a single item.	3
Dynamic updating	Tags are rewritable and offer a memory to retain information. This feature may be used to store a calibration history, preventive maintenance, etc. Updates may be made automatically without human intervention.	5	Once a bar code is printed it remains constant. The code and the process of attaching the bar code are not supportive of real time updates.	1
Lifespan	Tags have no moving parts and are embedded in protective material for an indestructible case and multi-year lifespan.	5	Bar codes have unlimited shelf life but are subject to degradation with handling.	2
Counter-feiting	Tags are produced with a UIC or serial number from the manufacturer. This is embedded digitally on the microchip and may not be changed, which makes them resistant to counterfeiting.	5	Bar codes may easily be duplicated and attached to products and are easily counterfeited.	1
Scanning	Offers a range from inches to hundreds of feet and does not require line of sight.		Offers a range over inches and requires line of sight to read the code.	4
Cost	High volume tags are currently about 50 cents (in 2009!).	1	This is a clear advantage since they cost about 1 cent.	5
Reusability	Yes	5	No	1
Durability	Tags may be placed in extreme environments and are very robust to handling.	5	Bar codes cannot be read if they are dirty or damaged.	3
SUM		***36***		***20***

5.4.2 Issues to be considered when using RFID

When applying RFID, the first thing is to decide the frequency band according to the application. Of the different radio frequency bands available, the ultra-high-frequency (UHF) technology was in focus in this research, when suitable technology for the life-cycle covering traceability of electronic products was being searched for. The European UHF frequency band 865–868 MHz was used in the factory tests. In off-site testing also the HF technology (13.56 MHz) was tested.

The reading range of the HF technology is much shorter compared to UHF tags, as some UHF tags can be read from a distance of over 10 m. The typical reading ranges of HF tags are between 5 and 50 centimeters. HF tags that are not located within the desired reading range will not be read, because reading ranges of HF technology are relatively short. Limiting the reading range of HF tags was discovered to be effortless.

HF technology was noticed to be sensitive to metal objects located nearby. The HF technology RFID reader must be tuned according to its environment, and if some changes occur in the environment, the reader must be tuned again. For example, a printed circuit board contains metal, and it is possible that the HF reader needs tuning, when a printed circuit board enters its reading range. Although HF readers may have an auto tuning property, which performs tuning automatically, HF technology may not be the best choice if the environment contains moving metal parts and tuning is therefore needed regularly.

The UHF technology was discovered to have long reading ranges, 10 meters or even more for the best UHF tags. This long a reading range is sufficient for many applications. The disadvantage of a long reading range is that the tags located further than the desired reading range may be detected and read; especially this concerns cases in which tags having different reading ranges are in use for some reason. If a tag having a short reading range is wanted to be read, one must use high antenna power. But using a high antenna power means that a tag having a long reading range can be read, although it is located far away from the reader antenna and it is not supposed to be read. Detection of these unwanted tags must be prevented by antenna orientation, antenna power, physical barriers, or through a software system.

6 LIFE-CYCLE MANAGEMENT OF ELECTRONIC PRODUCTS USING RFID

Collecting and storing different pieces of information regarding its manufacturing, delivery, daily use etc. during its life would offer several benefits in the management of electronic products. Moreover, European legislation, i.e. the so called WEEE-Directive (Waste Electrical and Electronic Equipment), has forced the electronic manufacturers to introduce new concepts for the recycling of WEEE (Kurk & Eagan, 2008), and product lifecycle management is nowadays considered an important issue.

Product lifecycle management (PLM) is a business activity of managing a company's products all the way across their lifecycle in the most effective way (Stark, 2006), and lately it has emerged as the most popular approach towards the product management both inside the company and in the company's value chain (Cao et al., 2009). PLM systems are usually computer-based information systems which are designed to assist the organization's PLM strategy (Cao et al., 2009). However, existing PLM software solutions today do not support product tracking comprehensively, but rather data exchange within the company (Lazarevic et al., 2011). In other words, PLM is considered a rather restricted methodology when it comes to lifecycle management after the product has left the factory.

A general framework of a system for collecting and using product lifecycle information and some examples on using this kind of data are presented in *Figure 6.1*. As mentioned, during manufacturing an identification system integrated to a lifecycle information database could be of help in many operations of warehousing, process management, and tool control. Automating the control of product deliveries would be useful for manufacturers, distributors, retailers, and other operators in the supply chain. During transport, automated identification technology could assist in customs operations or prevent thefts, for example.

After the product has been delivered to its end-user, use-related information could be collected which might be useful if the product arrives in maintenance or repair at some stage. If the user is identifiable by the product, the user might get access to some tailored services in the internet, for example. In the service, branded products could be recognized from pirate products, and warranties could be validated automatically. Right spare parts could be ordered in advance by using manufacturing information located in the database, and also correct working instructions could be made available. When the product is being disposed of, it would be useful for the recycler to gain access to product-specific life cycle information in order to support the decisions concerning which level of recycling is most cost and environmentally effective for the product (Bindel et al., 2010).

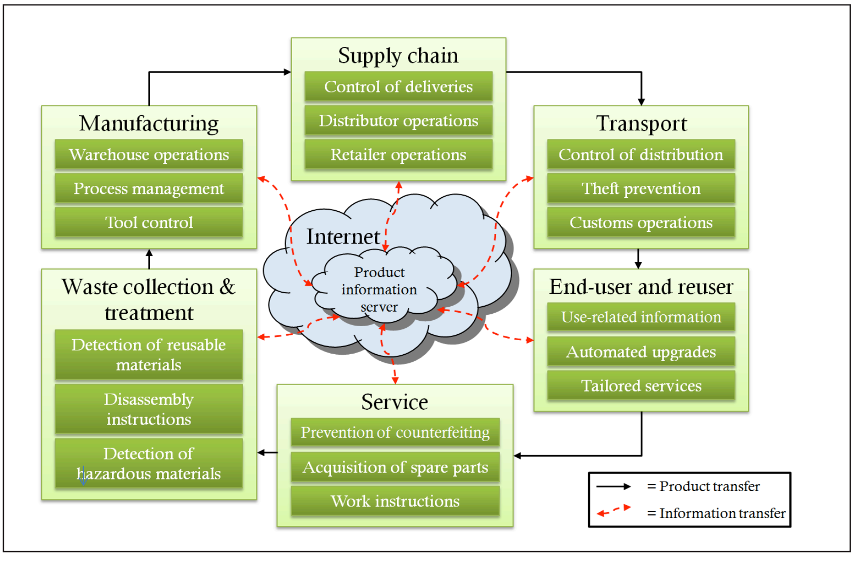

FIGURE 6.1. Some examples of recording and utilizing product lifecycle information at different stages using a remote server via the internet.

6.1 RFID in the lifecycle management of electronic products

As many branches of manufacturing, also electronics industry could benefit from RFID technology. Bindel et al. (2010) presented an interesting framework to provide a new lifecycle monitoring system for electronic manufacturing with embedded RFID components. In the presented system the printed circuit board can be uniquely identified by its serial number after embedding the component and integrating it with supporting systems. After this, process information and use profiles can be stored either on the tag or the board could be linked to a distributed database system which is interfaced with the company's ERP or MES systems (Bindel et al., 2010).

Some ideas on using a RFID chip embedded to a printed circuit board to assist in different manufacturing operations are presented in *Figure 6.2*. A PCB could be assigned an ID number which could be used instead of a barcode label, although starting from the very beginning of the manufacturing process unlike the barcode. The RFID chip would be traceable right after it is taken out of the warehouse and connected with the product.

If the ID number could be connected with product information in a database, changing the manufacturing machines such as the placement programs of pick and place machines or soldering profiles automatically would be one possibility. In addition, a worker could get his specific work instructions and information on different working stages automatically from the database at the moment when the product arrives at his working point. On the other hand, production-related information such as worker IDs or process parameters (soldering temperatures, materials and substances used etc.) could be transferred automatically to the database. The status of each individual product, as well as average cycle times of single unit processes, would be updated regularly, and this information would be available for managers and other staff online, and production bottlenecks could be visible all the time.

Furthermore, rework information and any measurements conducted during the manufacturing process such as test results could be connected with individual products and transferred to the database automatically. In the delivery zone, the true benefits of RFID could be realized if all tagged products on a pallet could be accurately read at one time, which in fact was observed to be possible in this research. Also automated documentation of deliveries and error prevention in record keeping would be a major benefit. Sales department could be provided with real-time information on the state of the stock.

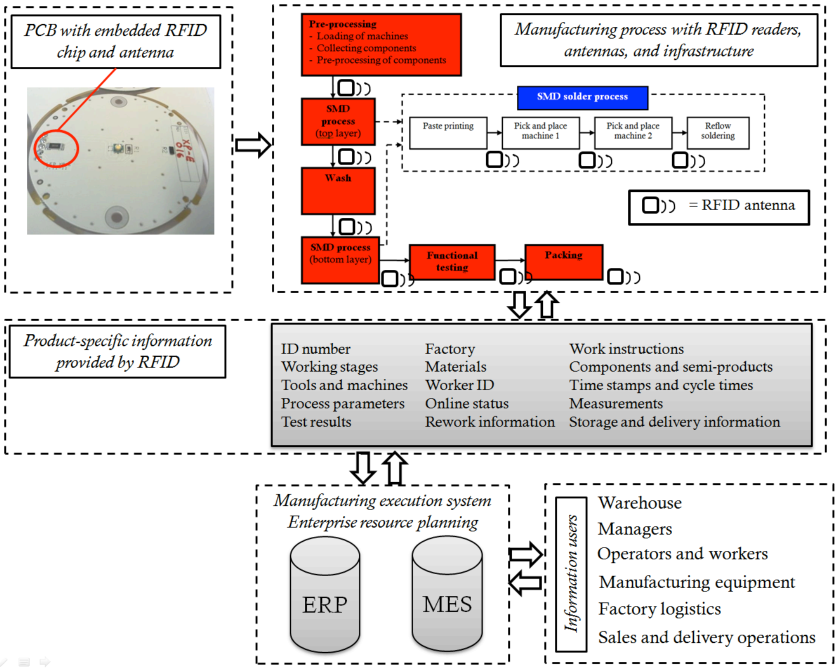

FIGURE 6.2. Some ideas on using an embedded RFID component to assist in different factory operations in the electronics industry. Information flows are marked with arrows.

6.2 Technological challenges

Lifecycle management necessitates that RFID devices work properly during the product lifecycle, which requires adequate performance from them. At the moment there are certain incompatibility issues with regard to read range, reliability and lifespan of RFID devices. (Cao et al., 2009).

6.2.1 Readability of tags

As our results have shown, radio frequency waves cannot penetrate into metals, which can make it difficult to read tags placed on metal surfaces. In addition, water and other liquids absorb RF waves, which reduces the read range to a great extent, and there are also dielectric materials and environmental conditions may reduce the efficiency of antenna and shorten the reading distance (Singh et al., 2009). Especially when reading multiple products loaded on a pallet, factors such as product-package type, tag location, tag type, pallet pattern and speed through a portal have a significant effect on the read rate for case level tagging, as has been shown by Singh et al. (2009), so each case has to be optimized separately.

The results presented in the literature are supported by those of this research. The results are also encouraging, because it seems that these difficulties can be overcome. The gate reader consisting of four long-range antennas which was used in the tests was able to detect almost all of the tags on a pallet, even most of those located in difficult spots and in metallic structures.

6.2.2 Durability of tags

Resistance to time and varying environmental conditions is naturally of primary concern when designing lifecycle applications using RFID tags. The tags have to survive years and even dozens of years in conditions that depend largely on the product.

As observed during the environmental tests, it seems that the RFID chip itself may survive well in harsh environments. Nevertheless, the interconnection between chip and antenna and the RFID substrate material are more prone to damages. In general, RFID labels are less durable than RFID chips. If a RFID substrate material for high temperatures is needed, the polyimide film is a good choice.

6.2.3 Data retention

Data retention means the ability of the RFID memory to retain data over time. As mentioned, the ability of a RFID tag to retain its data is an essential property when considering the life-cycle covering RFID traceability of products. Today's RFID chip manufacturers declare data retention times as long as twenty or even fifty years (See *Table 3.1*).

RFID memories contain typically an Electronically Erasable Programmable ROM type non volatile memory, which can handle tens or hundreds of thousands of rewriting/reprogramming cycles. This is enough for most RFID manufacturing applications. Nonetheless, environmental factors such as temperature may affect the performance of the memory and inflict damaging. According to tests performed in this project it seems that tested RFID chip memories are not vulnerable for higher temperatures such as 55 °C or 85 °C.

6.2.4 Data storing

Management of lifecycle information using RFID technology has its limitations. One of these is that the tag memory capacity is limited, so only a limited amount of data can be stored on the tag. In case of complex products that go through numerous phases of life cycle, there is a need for a large amount of information that cannot be written on the tag, but has to be stored in a database instead (Stankovski et al., 2009). As long as the memory capacity of tags remains limited, this is the only reasonable option in any large-scale lifecycle application.

When establishing and utilizing external databases, a couple of questions require answering. Who upkeeps the database, who pays the investment and maintenance costs, and who will be granted access to it? The question of cost is perhaps the easiest one, because including it to the product price would perhaps be the only reasonable option, but in the tightening markets the increased price should be realized as a consumer benefit to hold the achieved market sector. Perhaps some part of the system cost could be collected from the users of the database, in the form of added value services, for example. The up keeper of the database could be the manufacturing company itself or a third party, who would concentrate on information management business.

7 MARKET REVIEW OF RECENT TRENDS IN RFID IMPLEMENTATION

7.1 Background to the market review

During the ERFID project implementation, it was noted that RFID has not been adopted as widely and fast as it was expected. An example on this is that bar codes are still used by shops instead of that customers would just push shopping carts through cash system and the purchases would be automatically recorded and charged. RFID tracing has several benefits over other identification systems. RFID tag can be read without line of sight, tag is rewritable (a dynamic data carrier), reusable and RFIG tags can be used as tools for anti-counterfeiting. There are two principal reasons for not choosing RFID.

First, RFID technology expenses may result in choosing some other technology. In certain cases even 9 euro cents may be too much, when a barcode may cost only the price of the ink. Both RFID and bar code systems need equipment and software to work. For example suitable middleware software is needed to supply data read by RFID readers to existing enterprise resource planning (ERP) systems. It is possible that as a newer technology, for RFID technology has not had been so many system integrators in certain business areas, and it is possible that much must have been done from the scratch. Starting from the very beginning may guarantee that a desired tracking system is generated, but expenses may be more than if an existing system could be selected. Recently more RFID system interrogators have started business in different fields.

The second reason for choosing some other tracking method than RFID are the reliability issues. 100% reading certainty is not always achieved. All tags, which are present, are not always found because of dead angles. Products which are not meant to be read may be read because of signal reflections. Reading reliability can be improved by several methods like recording into the system some information about how many or what items should be read to detect missing or unwanted extra items.

In addition to cost and read reliability issues, some other factors may affect selecting the tracking method. In consumer products RFID identification may be seen as a threat to personal privacy, if the consumer product end user does not remove RFID tag from the product after purchase. It is also predicted RFID tags could be used to propagate computer viruses (Mannila 2006). Based on the observed delay in RFID technology adopting this market review of recent trends in RFID implementation and alternative methods for product identification and tracing was seen useful. The RFID application part of this review is focused on Finnish industry. Mika Liukkonen (2012) has compiled a report of worldwide RFID applications in manufacturing industry.

7.2 Recent trends in RFID implementation

Although retail shop purchases are not yet recorded or charged automatically by RFID, a form of radio frequency identification called near field communication (NFC) is coming into use in retail stores. NFC operates at 13.56 MHz and is an extension of High Frequency (HF) RFID technology. The read range of NFC technology is limited in to some centimeters when UHF technology read range may be over 10 m. UHF technology was utilized in the ERFID project when UHF RFID chip was integrated into the printed circuit board. The short read range of NFC 13.56 MHz technology is suitable for payment applications for safety reasons. NFC Payment terminals at retail shops accept contactless payment, when purchases are paid by a NFC enabled payment card. In contactless payment the payment card is passed close to the card reader, after which the transaction is processed in less than a second (Luottokunta 2014). The customer does not have to insert the card in the terminal nor key in a PIN code. The PIN code may not be asked for purchases worth below 25 eur. In the future, mobile phone can be used for paying the purchases (Luottokunta 2014).

Several Finnish manufacturing companies have adopted or tested RFID technology as can be seen in tables 7.1A and 7.1B. The table 7.1A lists companies tagging the product or production material itself and table 7.1B lists companies, which use RFID in asset tracking purposes or logistical applications (eg. trolleys, roll gages or containers are tagged). For example logistics trolley tracing can be implemented by so called 'smart wheels' of a trolley. RFID wheels (castors) used in trolleys are manufactured by for example a Finnish company Manner Oy (Manner Oy). The payback time of logistics RFID applications like logistics trolley tracking or other asset tracking may be shorter than production item level tracking (Hinkka 2012). Power and automation equipment company ABB was a forerunner when it employed RFID technology in product shipping processes at Helsinki factory in year 2006 (Wessel 2009) and later RFID was employed in material reception with Kanban based reorder triggering system (Vilant systems Oy a).

In typical RFID adoption cases different types of RFID labels or tags are in use. No such industrial examples were found in which RFID chip would be integrated into the PCB board and the PCB ground would have been used as an RFID antenna. From the world-wide point of view, such applications probably do exist, but apparently RFID integration into PCB is not widely in use. Based on the ERFID project results, it is supposed that PCB integrated RFID tracking will increase, because it was shown that the integration works.

TABLE 7.1A. Finnish RFID adoptions and pilot testings, where product or material itself is tagged.

Company	Case
Assistor Oy	vehicle tracking, vehicle importing (Lahti 2007)
Fenestra Oy	window manufacturing (Brunström 2008)
Finnpark Tekniikka Oy	vehicle identification in parking garages (Finnpark Tekniikka Oy)
Honkarakenne Oyj	wooden log identification (Finn ID Oy)
Incap Furniture LTD	tests at furniture industry
Isku-Yhtymä Ltd	tests at furniture industry
Kari-Finn Oy	product identification, float sensor assembly line
Manner Oy	manufacturing of RFID trolley castors
Martela Ltd	tests at furniture industry
Metso Paper	automatic inventory of paper machine spare parts (Vilant Systems Oy b)
Metsä Fibre	pulp identifying
Naisten Pukutehdas Oy / NP Collection Oy	garment tagging
Nokian renkaat Oy	tracking the components of the tires (Swedberg 2008)
Novart Oy	tests at furniture industry
Tiehallinto	vehicle tracking on ferries
Valmet Automotive	car chassis identification

TABLE 7.1B. Finnish logistical RFID adoptions (parcels, containers, trolleys, railway wagons etc are tagged).

Company	Case
ABB Group	product shipping (parcel tagging) (Wessel 2009) material receiving (Vilant Systems a)
Comforta Oy	logistics trolley tracing (Top Tunniste Oy c)
Ekokem Oy	RFID forklift truck manufactured by VTT and Rocla
Encore Ympäristöpalvelu Oy	waste container tracing
Ferrometal Oy	kanban box shelf system
Finland Post	piloting of tracking and managing re-useable assets (roll gages) (Itella Oyj)
Lassila & Tikanoja	glass bottle container tracing
Plandent	consumables inventory level controlling, Kanban inventory system
Stora Enso	Intelligent packaging, PackAgent (Collins 2005)
Stora Enso/VR Yhtymä Oy (VR Transpoint)	- locomotive and railway wagon identification (Vr Cargo) - railway wagon identification, wagons carry wooden logs (Collins 2005)
Sukkamestarit Oy	sock manufacturing, production batch tracing (work order sack tracing)
Turku University Hospital	shelf trolley identification of hospital instruments (Aksulit Oy b)
Orion Oy	testing of ensuring consumer drug package authenticity (Kemppainen 2006)
Rautaruukki Oy	cargo cassette identification and tracking provided by Identoi Ltd (Identoi Ltd))
Valio Oy	- cheese molds identification (Top Tunniste b) - logistics trolley tracing by smart wheels (Aksulit Oy a)
Valtra Oy	RFID enabled forklift trucks (Vilant Systems c)
Valtra Oy / Ferrometal Oy	smart shelf system (Vilant systems a)
Würth Oy	automatic picking line

7.3 Alternative methods for product identification and tracing

Instead of radio frequency technology, identification may be carried out for example by labelling or marking the PCB itself. Automated identification of these markings can be executed by machine vision systems. The identification code may be alphanumeric text or bar code. Bar codes may be linear, one-dimensional 1D bar code and matrix two dimensional 2D barcodes. Datamatrix and QR code are examples of 2D bar codes. 2D bar codes may represent more data per unit area than 1D bar codes. 2D bar codes contain built-in techniques, which allow recovering the code message even if the mark is damaged as much as 20% of the symbol (Stevenson 2005).

In addition to RFID and bar code identification, a digital watermark is suggested to be an alternative for data management. Digital watermarking is a technology, in which data that cannot be detected by human eye is embedded into digital data. The digital data may be an image, for example. Data addition is done by utilizing redundancy in this digital data. The values of the pixels across the entire image may be changed slightly and data, which the user cannot normally see, is stored in the image in addition to the usual image data. Currently, there are no examples of digital watermarking information used on anything other than digital content data (like DVD and CD data) and paper media. One challenge for digital watermarking is its compatibility with reading devices. Digital watermarking could be used for enforcing copyright and for certifying originality (Hirakawa and Iijima 2009).

On printed circuit board surface, the identification code may be added by labelling, printing, engraving (dot pin marking) or laser marking. Label applicators may be used for automation of label adding. Inkjet printers can be used for adding the code direct on PCB surface. The colour of inkjet printing can be chosen to achieve the maximum contrast between the PCB surface and the code notation. Inkjet printer is somewhat cheaper equipment compared to laser equipment; inkjet printers suitable for printed circuit board marking may cost 5 000 – 12 000 eur (Hämäläinen 2014). Nowadays, also printed board manufacturers may use ink jet printing instead of earlier used silk screen printing for adding component legends and other notations on the PCB surface. PCB manufactures use etch resistive inks. With laser equipment the imprint is more accurate compared to inkjet printing, where printer's imprint consists of small dots. Nevertheless, also 2D codes can be printed also by inkjet printers.

There are several laser marking systems, but most common laser marking systems are CO2 laser marking and fiber laser marking systems. CO2 laser is suitable for plastic materials like printed circuit boards. Fibre lasers are suitable for metal surfaces. Laser marking is fast and accurate. When writing alphanumeric data, it is possible the PCB conveyor does not have to stop while writing. Writing more complex 2D codes need of stop of some seconds. The disadvantage of laser marking of PCBs is that bar codes marked by laser may not be readable by normal bar code readers, if the contrast between the marks and the background surface is not sufficient (Hämäläinen 2014, Häyhä 2014). The laser must be adjusted for every material in use. There are different FR4 materials on the market. If the laser marked bar codes are readable, when a certain PCB material from a certain manufacturer is in use, the laser settings may need adjusting, if the PCB manufacturer is changed. It is possible certain bar code readers do not read laser marked bar codes because of the lack of sufficient contrast. 2D code readability from the PCB surface can be optimised by using white silk-screened ink block as background to the code. This technique is especially suitable in cases where board material is not suitable for laser marking, such as ceramic substrates (Stevenson 2005).

CO2 laser equipment itself costs between 15 000 – 30000 eur (Häyhä 2014), while fiber laser equipment is more expensive. In addition to laser equipment itself, different shields are usually installed around the laser equipment for protecting human beings laser radiation and laser radiation reflections. In addition to shields, laser marking station can be build up. On a laser marking station printed circuit boards travel on a conveyor and are both recognised and marked automatically. Laser marking stations features may include fiducial check and be fully compatible with SMEMA and GEM standards, which are common interface standards at printed circuits production lines. The price of laser marking station may be twice or more as much as laser marking equipment itself. In addition to laser marking equipment also bar code readers need to be purchased, if bar code identification is wanted to be implemented. Laser marking stations suitable for PCB marking are manufactured for example by IPTE Factory Automation from Belgium and multinational, automated production systems manufacturer Nutek Ltd.

8 CONCLUSIONS

In order to improve the efficiency of current shop floor production systems in discrete manufacturing, supervisory control of the processes involved should be accurate enough so that the state of every product could be tracked online and their operation could be scheduled correctly. Radio frequency identification is a promising technology for wireless tracking of individual objects. It also seems that the whole gamut of applications is extremely wide. The automotive and electronics industries have been using RFID for many years and other manufacturing industries seem now to be recognizing the fact that RFID can improve their operations as well.

This research has shown that RFID technology has much potential in existing and novel applications which can improve the efficiency and effectiveness of manufacturing. On the other hand, there are also drawbacks which seem to restrict the implementation of RFID technology at the moment. At least four fundamental questions require answers before the implementation can be started on a larger scale. The first question often encountered is the technology, which can be referred to as hardware, and its cost. The hardware includes, not only the RFID tags and readers, but also computers and servers needed to collect and store the data provided by the sensor technology. On the other hand, if the product is relatively cheap, the tag price should be small enough to avoid reduction of competitiveness in the market.

The second question is the software needed to process the data and information provided by the technology to a form that can be utilized on the different organizational levels of the factory. The software include, not only the application software to monitor process variables such as through-put times based on the data, but also the invisible modules that manage the entire system and databases, and perform communication between the different interfaces. The third question is the construction of infrastructure, which ensures transferring the produced data and information between different hardware and software modules. The hardware, software and infrastructure altogether form the information management system.

The fourth and perhaps the most important question is the money, i.e. the overall cost of the system compared to the achieved profit. Before the implementation, the most interesting, important, and difficult questions are the system cost and the repayment period. Although it may be difficult to answer, the return-on-investment has to be calculated as accurately as possible before integrating RFID into production. Some approximate numbers have been presented in the literature and in this report, but it should be kept in mind that the total cost depends largely on the special features of the case concerned such as the extent of application, number of reading points needed, number of tags, the type of readers, and the software needed etc.

Despite these difficulties, many manufacturers have already implemented RFID, which suggests that the technology has at least partly claimed its place in the management of manufacturing. In this research, a number of practical tests were conducted both in laboratory and factory environments to experience the practical applicability of the technology to different manufacturing and lifecycle traceability problems. The results of this research are promising and they show that RFID technology has an increasing potential in existing and novel applications which can improve the efficiency and effectiveness of manufacturing and lifecycle management, but also drawbacks, restrictions, and important things to be considered when using the technology were noticed. Therefore, one of the main findings of the research is that a thorough testing period is always needed before implementing the technology in a larger scale.

RFID costs are decreasing fast, and this applies both to the cost of equipment and to costs of tags. As the technology will continue to evolve at the meantime, it is easy to see that the total number of RFID applications will continue to increase. As the cost of technology continues to fall, it is easier for manufacturers to find profit in implementing RFID in their production and supply chain. Therefore, it is presumable that also cheaper consumer products will be provided with RFID tags in the future, if only the return on investment turns out to be reasonable.

Moreover, as electronic components, including RFID chips and antennas, continue to reduce in size, it is possible to include the technology to smaller products than before. Printed circuit board, in which the design space is always restricted, is a good example on this. In the future it will be less costly to solder small RFID chips to PCBs, which makes the technology more attractive among the electronics manufacturers, and especially among their customers. This opens new possibilities for using the technology in the manufacturing and supply chain of a large variety of products.

In the future, it is probable that the so called intelligent applications such as those based on agent technology will become more abundant also in real-life manufacturing applications. This means that the manufactured products are able to act as intelligent agents, can communicate with the production equipment, provide information on their own state, and can even control the timing and settings of the process equipment. This can increase the flexibility of the production, but before they are implemented on a larger scale, a lot of product development has to be performed. Furthermore, it is probable that these so called intelligent applications and their maintenance will be offered as a service provided by another company, which is specialized in providing these challenging, tailored solutions.

Life-cycle applications offer another potential future direction for RFID in manufacturing. Improvement of the visibility throughout the lifecycle of products is vital in the future especially for companies making products of higher value. It is presumable that embedding RFID in products could reduce the lifecycle costs of manufactured products by increasing detectability, traceability, and controllability of manufacturing and distribution of products. Life-cycle management applications also offer another possible form of business for service providers specialized in RFID solutions.

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ATTACHMENT I

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