

Helsinki University of Technology Laboratory of Industrial Management
Doctoral dissertation series 2005/2
Espoo 2005

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**FORWARDER INDEPENDENT TRACKING SYSTEMS –
PROBLEM DESCRIPTION AND SOLUTION DESIGN PROPOSAL**

Dissertation for the degree of Doctor of Science in Technology to be presented with due permission of the Department of Industrial Engineering and Management, Helsinki University of Technology, for public examination and debate in lecture hall TU2 at Helsinki University of Technology (Espoo, Finland), on the 12th of August, 2005, at 12 o'clock noon.

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ISBN 951-22-7764-6

ISBN 951-22-7765-4 (online)

ISSN 1459-8051

ISSN 1795-2441 (online)

URL: <http://lib.tkk.fi/Diss/2005/isbn9512277654/>

Monikko Oy

Espoo 2005

ABSTRACT

This thesis provides a concise review of previous literature discussing tracking and expands on it based on empirical observations and proposed solution design. The aim of the thesis is to describe why tracking has become an increasingly important area in logistics management, identify the key problems with current designs of tracking systems, and develop and test a solution proposal that addresses the identified problems.

Current tracking systems are difficult to set up in short-term multi-company networks. This is a problem for example in project-oriented industries and when utilising spot markets for logistics services.

The proposed Forwarder Independent Tracking (FIT) solution concept was developed and tested in four case studies, two of which included a pilot implementation. The main data collection methods of the case studies have been active involvement in the planning and the carrying out of the pilot implementations, acting as a helpdesk in the pilots, observation, constant contact with key personnel of the case companies, and semi structured interviews.

The studies show that FIT can be used to produce and disseminate reliable tracking and inventory transparency data in short-term multi-company distribution networks. Tracking systems built according to the FIT solution concept offer a possibility to gather tracking information from logistics service providers without a priori integration. The FIT solution concept also provides logistics companies currently without tracking systems (e.g. small, local companies) a possibility to offer tracking information to their customers. The thesis concludes that owing to these properties, the proposed FIT solution concept can have a high significance also in stable distribution networks.

The thesis also examines when Radio Frequency Identification (RFID) technology offers the most benefits in tracking, and concludes that the benefits are linked to the efficiency and security of physical identification, and that RFID is not needed for implementing the FIT concept.

ACKNOWLEDGEMENTS

This thesis report summarises some of the results achieved during my five-year career as a researcher at the Helsinki University of Technology. The research has been conducted in the collaborative environment of our research group (the logistics research group (LRG)). Many people have contributed to the research process at different stages and I am not able to name them all but am very thankful to each and every one of them.

First, I would like to thank the supervisor of the thesis, Professor Kari Tanskanen, and the instructor Academy Research Fellow Jan Holmström. Primarily for their input on the thesis, but also because as the heads of our research group they have been able to create a good atmosphere for research and have ensured stable base funding for our group. The National Technology Agency (TEKES) has also had a big impact on our research group, as it has been the primary financier of LRG at least throughout my research career, which I gratefully acknowledge.

I am also very grateful to the pre-examiners of the thesis Professor Thomas Vollmann and Dr. Ilkka Töyrylä. Your comments helped to improve the thesis, and your ability to write the pre-examination reports on quite a tight schedule gave me a chance to graduate before turning 30 – thank you.

A great amount of teamwork has been carried out throughout my research career. Timo Ala-Risku – the other integral part of the easygoing but effective “tutkimustiimi Kärppä ja Tipu” – has had a major role in several of the case studies as well as in many of the papers included in the thesis. Thank you Timo, it has been both fruitful and a great deal of fun to work with you. Also Dr. Kary Främling has had an integral role in the progress of our research related to tracking. Without his ideas and hard work in developing the Dialog system and conducting the pilot installations, the thesis could not have materialised in its current form. Thank you Kary, I am very grateful for your effort. Also the other members of our research group have been very helpful during the progress of research by commenting papers in different stages of finalisation, and in all ways creating a forward-going, pro-research environment. For example, Johanna Småros has provided some pertinent comments on key moments – especially as the reigning European champion of ECR, when I was writing a paper of the Sainsbury’s RFID trial

for the ECR Academic Award competition back in early spring 2002. For all the help I have received, I just hope that I have been and will be able to contribute back to our little research community even nearly to the same extent.

Applied research in the form presented in this thesis would be impossible without capable and motivated people in the case companies. I am very grateful to all the people in the case companies who have found the time to participate in our research. I owe special thanks to Markku Henttinen, whose infectious enthusiasm has spurred the motivation of us researchers in several occasions, Jukka Lankinen, who numerous times has spent great effort in collecting the data needed for our analyses, and Timo Hämäläinen and Jari Collin, for their effort in carrying through and facilitating our up to date biggest pilot implementation.

I am also very grateful for all the private foundations that have participated in the funding of my postgraduate studies: Tekniikan edistämissäätiö, Kuorma-autoliikenteen Volvo-säätiö, Päijät-Hämeen rahasto, Emil Aaltosen Säätiö, Ella ja Georg Ehrnroothin säätiö, Marcus Wallenbergin säätiö, Heikki ja Hilma Honkasen säätiö, and Huonekalurahasto. The grants have enabled strict focus on the academic work and have been a key resource in ensuring successful postgraduate studies.

Finally, I would like to thank my fiancée Laura for holding up the home front. Lets just hope that our common projects in the personal front will have as fruitful outcome as my research endeavours.

Espoo 29th June 2005

Mikko Kärkkäinen

This doctoral thesis in an article dissertation that comprises six separate publications and this compendium of these publications summarising the objectives, methods and results of the research.

The separate publications included in this thesis are the following (in chronological order):

- Paper I Kärkkäinen, M. and Holmström, J., (2002), “Wireless product identification: Enabler for handling efficiency, customisation, and information sharing”, *Supply Chain Management: An International Journal*, Vol. 7, No. 4, pp. 242–252.
- Paper II Kärkkäinen, M., Holmström, J., Främling, K., and Artto, K., (2003), “Intelligent products – a step towards a more effective project delivery chain”, *Computers in Industry*, Vol. 50, No. 2, pp. 141–151.
- Paper III Kärkkäinen, M., (2003), “Increasing efficiency in the perishable goods supply chain with RFID tagging”, *International Journal of Retail & Distribution Management*, Vol. 31, No. 10, pp. 529–536.
- Paper IV Kärkkäinen, M., Ala-Risku, T., and Främling, K., (2004), “Efficient tracking in short-term multi-company networks”, *International Journal of Physical Distribution & Logistics Management*, Vol. 34, No. 7., pp. 545–564.
- Paper V Ala-Risku, T. and Kärkkäinen, M., (2005), “Material delivery problems in construction projects: A possible solution”, *International Journal of Production Economics*, in press
- Paper VI Kärkkäinen, M. and Ala-Risku, T., (2005), “Tracking based material flow transparency for small and medium sized enterprises”, *working paper*

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1 Introduction

1.1 Background and motivation

Tracking is the process of gathering and presenting information on the location of delivery items in a distribution network or supply chain (Deschner et al., 1998). Lee and Billington (1992) were among the first to recognise the importance of tracking, when in 1992 they presented the lack of capability of informing customers on the progress of their orders as one of the most severe pitfalls of supply chain management (SCM). Early 1990s were an important period for the development of tracking applications also in practice. At that time, FedEx built the first large-scale shipment tracking system and started offering tracking as a value added service for its customers (Janah and Wilder, 1997; Tausz, 1994). Since then the development has been rapid. Well functioning and accessible tracking services are currently demanded by most customers and they have evolved to be an industry norm in logistics service provision – tracking is considered as a market qualifier in more advanced logistics services (Ciuba, 2004; Day, 1991; Jakobs et al., 2001; Willesdorf, 1991; Williams and Tao, 1998). This constitutes a remarkable development both in the provision and demand for tracking services, and it has taken place in just over a decade.

This development has lead to the current situation, where major logistics companies continuously invest considerable sums in providing tracking services to their customers (Booker, 1999; Coia, 2001; King, 1999; Whiting, 2003). This is a necessity, as the accessibility of delivery status at any time and the immediate notification of delays or other delivery problems are regarded as basic information needs in the logistics chain (Loebbecke and Powell, 1998).

Traditionally tracking has been considered a separate function related mostly to controlling individual shipments, and without clear linkages to logistics management in general. However, besides its role in providing information on shipment status, tracking can also have an impact on supply chain management as it provides the possibility of creating visibility or transparency to the material flowing in the supply chain. A comprehensive tracking system, for example, enables a company to monitor the arrival

of critical components and plan its operation based on the estimated arrival of them (Biddle, 2004). Several authors have stated material flow transparency, i.e. the visibility to inventories and deliveries in the whole supply chain, to be an imperative requirement for successful supply chain management, and it has been associated with significant supply chain efficiency improvements in several studies (Ballard, 1996; Clarke, 1998; Gunasekaran and Ngai, 2004; Lee and Billington, 1992; White and Pearson, 2001). The possibilities of tracking in aiding the establishment of a transparent supply chain thus signify great potential impacts for supply chain management.

1.2 The aim of the thesis

Regardless of the recognised importance of tracking, the body of literature discussing tracking and its role in logistics management has remained ambiguous and unstructured, and most of the contributions have been aimed solely at the practitioner audience. This thesis contributes to the logistics literature by providing a concise review of previous literature discussing tracking and expanding the literature based on empirically founded new knowledge. The aim of this thesis is to describe why tracking has become an increasingly important area in logistics management, identify the key problems with current designs of tracking systems, and develop and test a solution proposal that addresses the identified problems.

1.3 Structure of the study

This doctoral thesis consists of separate publications and this summarising paper. The thesis proceeds as follows: In the second chapter we will review existing literature on shipment tracking. We will define tracking, review the presented rationales for using tracking systems, discuss the functionality and key characteristics of tracking systems, and outline the shortcomings and open issues in previous literature. In the third chapter we will present the research questions of the study and discuss the relation of the separate publications to the research questions.

Research design and methods will be presented in the fourth chapter. The fifth chapter presents the results of the research. Conclusions are drawn in the sixth chapter. There we summarise the main results of this thesis and discuss its contribution to previous literature. We also perform an evaluation of the research. The seventh chapter is reserved for discussion and outlining directions for further research. The separate publications included in this thesis are located at the end.

2 Literature review

Previous literature on tracking and the systems used in tracking are reviewed in this chapter. Section 2.1 discusses the definition of tracking, and the relation of tracking to tracing and traceability. The rationale for tracking is discussed in section 2.2. In section 2.3, the basic functionality of tracking systems is reviewed, the most important characteristics of tracking systems are presented and a review of a selection of currently used tracking systems is performed. Section 2.5 discusses the limitations of previous solution designs and literature: the difficulties of using tracking systems in short-term multi-company networks and the problems associated with identification technology selection.

2.1 The definition of tracking and its relation to traceability

A clear definition of tracking cannot be found in the logistics literature, even though the term is a relevant and important one (Stefansson and Tilanus, 2001; van Dorp, 2002). In particular, tracking has invariably been associated with tracing, to form the commonly adopted concept of tracking and tracing (van Hoek, 2002; Huvio et al., 2002).

When considering tracking and tracing as independent terms, tracking is usually perceived as the following of the location of an entity in transit (storing information), while tracing is defined as locating the entity when needed (retrieving the stored information) (Bingham and Pezzini, 1990; CIES, 2004; Mousavi et al., 2002; Stefansson and Tilanus, 2001). They thus form a clearly complementary pair (Stefansson and Tilanus, 2001), and it would be against common sense to implement the other functionality while deciding to omit the implementation of the other. Therefore, for the sake of clarity, the term tracking is in this thesis used to stand for both the gathering of data on entities in transit and the processing of that data to useful information.

The concept of tracking and tracing has further been associated with traceability (Jansen-Vullers et al., 2003; CIES, 2004), and some authors also use these terms quite interchangeably (see e.g. van Dorp, 2002; van Dorp, 2003). It is also important to distinguish tracking from traceability, as traceability encompasses storing the whole relevant history of products, including the origin of product components (Liddell and Bailey, 2001; Töyrylä, 1999; Wilson and Clarke, 1998).

Traceability is actually often seen as consisting of two distinct parts: 1) following the location and progress of an entity in the distribution chain and 2) registering of parts, processes, batches and materials used in production by lot or serial number (Jansen-Vullers et al., 2003). De Broses (2004) named and described these distinct aspects of traceability in a way that clearly illustrates their difference and the relationship between tracking and traceability: 1) logistical traceability (i.e. tracking the location and progress of products) and 2) qualitative traceability (i.e. associating any additional information to the products).

The definition of de Broses (2004) also clearly positions tracking to the field of logistics and distribution. Traceability, however, has to be ensured in any parts of the value adding processes and there are several critical traceability points, i.e. points where materials are portioned, divided, mixed, separated, formed, cooked, turned, bored or wrapped, in any production process (Wall, 1995). Traceability data is also used in a wide range of applications. Besides logistics applications, traceability data is used for recall applications, product-liability-prevention applications, quality- and process-improvement applications, proof-of-quality and proof-of-origin applications, security applications, after-sales applications, and accounting applications (Töyrylä, 1999).

However, it is important to recognise that tracking is present in traceability, as some contributions to traceability literature do give insights also in consideration to tracking. Therefore, literature on traceability was also reviewed for this thesis and cited where appropriate. For example Töyrylä (1999), in his doctoral thesis on traceability discusses tracking related issues related in several occasions.

2.2 The reasons for building tracking systems

Previous literature has identified four main reasons for conducting tracking and building tracking systems: 1) the use of tracking information for real-time co-ordination of goods in transit, 2) the generation of exception notices based on tracking information, 3) the use of tracking in increasing the efficiency of administrative processes, and 4) the use of tracking information in developing logistics management metrics and analyses.

2.2.1 Tracking systems in logistics co-ordination

Stefansson and Tilanus (2001) state that tracking systems are needed for co-ordinating logistics, because they form the link between the information systems and the physical reality (the material flow) in the supply network. Harris (1999) has further claimed that efficient co-ordination of logistic flows would be difficult to achieve without tracking systems linking the information systems and the physical material flow. Several other authors have complied with the idea by noting that many logistics services, for example multi-modal transport and merge-in-transit, would be extremely difficult to produce without tracking systems (McLeod, 1999; Samuelsson *et al.*, 2002; Kärkkäinen *et al.*, 2003a; Ala-Risku *et al.*, 2003; Giannopoulos, 2003). Previous literature thus clearly agrees that tracking is needed for co-ordinating shipments in transit.

2.2.2 Generation of exception notices based on tracking information

Tracking can also enable quick detection of and reaction to unexpected events, as it enables linking the status of the tracked entities to other information in information systems (Stefansson and Tilanus, 2001; Töyrylä, 1999). In this sense tracking can be seen as a key enabler for supply chain event management (SCEM), the aim of which is to detect exceptions in operative processes and create alerts from these exceptions (see e.g. Otto, 2004).

This potential reaction is important for operational efficiency – exceptional situations can be resolved before they cause significant problems; or at the very least the damage can be minimised (Willesdorf, 1991; Stefansson and Tilanus, 2001). Stefansson and Tilanus (2001) present that tracking systems can be used to follow and ensure that deliveries progress according to their distribution schedule, and exception messages can be created if a delivery arrives at some checkpoint late or before the due time. Garstone (1995) has regarded this possibility of notifying of delivery exceptions as a key service component for the transportation industry to meet the requirements of manufacturing when adopting just-in-time operations. The literature is, however, unclear on how this information on delivery exception can be utilised in operations. This raises an important further question; are there any good standard actions to be taken in any specific industries?

Töyrylä (1999) presented that tracking information can also be used to monitor the time that specific material lots have resided in inventory. This information on material dwell-times can then be used to detect items that have exceeded their maximum allowed time in the inventory. He further explained that if the expiration date of the lots is linked to the lot information, notices of stored goods nearing their expiration can also be generated. The case study companies of Töyrylä (ibid) reported that the applications had helped them reduce waste associated with the expiration of products and raw materials. These findings are important and potentially far-reaching, but are not supported by other studies. Therefore, research validating these findings would be a valuable addition to the body of literature.

2.2.3 Tracking in developing more efficient administrative processes

Tracking is also reported to have potential in increasing the effectiveness of administrative processes. It can help in introducing paperless and less paper systems, and can therefore improve information accuracy and help reduce waste (Florence and Queree, 1993). Stefansson and Tilanus (2001) state that tracking information can, for example, serve as a basis for automated payments to haulers. However, previous literature does not present any empirical (nor analytical) validation for their arguments on the support of tracking for administrative processes.

2.2.4 Tracking information as a basis for logistical metrics and analyses

Tracking has been presented as a potential source of meaningful measurement data. The collected data can provide important and relevant input into management information systems and help in finding out where costs are incurred as well as where profits are made. It can also be helpful in verifying that the quality of the process remains acceptable. (Florence and Queree, 1993; Stefansson and Tilanus, 2001)

Töyrylä (1999) has described the potential of item-level time-location data recorded at a varying number of control points, i.e. tracking data, on the generation of logistics metrics, in more detail. He reported that companies have been able to generate internal lead-time metrics and on-time delivery rate metrics with tracking data. In one of the cases in his study, tracking data was occasionally used to map the material flows within the manufacturing process. Töyrylä (ibid), however, does not discuss what information has to be linked to the tracking data in order to generate the discussed metrics and the results are not supported in the literature by other findings. Furthermore, tracking data can be used for security related analyses. For example, two companies in Töyrylä's (ibid.) study used tracking data to identify the points in the material flow where losses were taking place.

2.3 The functionality and key characteristics of tracking systems

In this section, we will first present the basic functionality of tracking systems. Then we will discuss the key features that tracking systems incorporate, and finally we will review and analyse existing tracking systems.

2.3.1 The basics of tracking systems

Tracking systems are based on check-points that register the movements of the tracked items. When a tracked item (e.g. a shipment) arrives at a checkpoint (a predefined point in the distribution network) the arrival is registered and a message regarding the arrival is sent to a tracking database. (Loebbecke and Powell, 1998; Stefansson and Tilanus, 2001; Tausz, 1994) These messages invariably contain three basic attributes: the

identity of the entity at the checkpoint, the location of the checkpoint, and the time of the arrival of the entity (Stefansson and Tilanus, 2001), to which we later refer to as the basic tracking attributes. However, additional attributes (e.g. the quality of products in the case of perishables) concerning the tracked item may also be recorded. The last location (and the time of pass) of the tracked item can then be interrogated from the tracking database.

The most common method of registering the pass of a checkpoint is to use some automatic identification technology to read a code from the tracked consignment, but some tracking systems are based on warehouse transactions or logistics documents, for example customs clearing documents (Shah, 2001; Loebbecke and Powell, 1998; Stefansson and Tilanus, 2001). In some less common, steadily increasing instances, an entity is continuously tracked in the supply network (for example GPS location of a truck or a marine container). However, since the continuously tracked entity is usually a transport instrument containing several consignments, it can, from a tracking system perspective, be regarded as a moving checkpoint. (Anon., 1996; Bodamer, 2002; Whiting, 2003)

The basic functionality and the building blocks of tracking systems are illustrated in Figure 1.

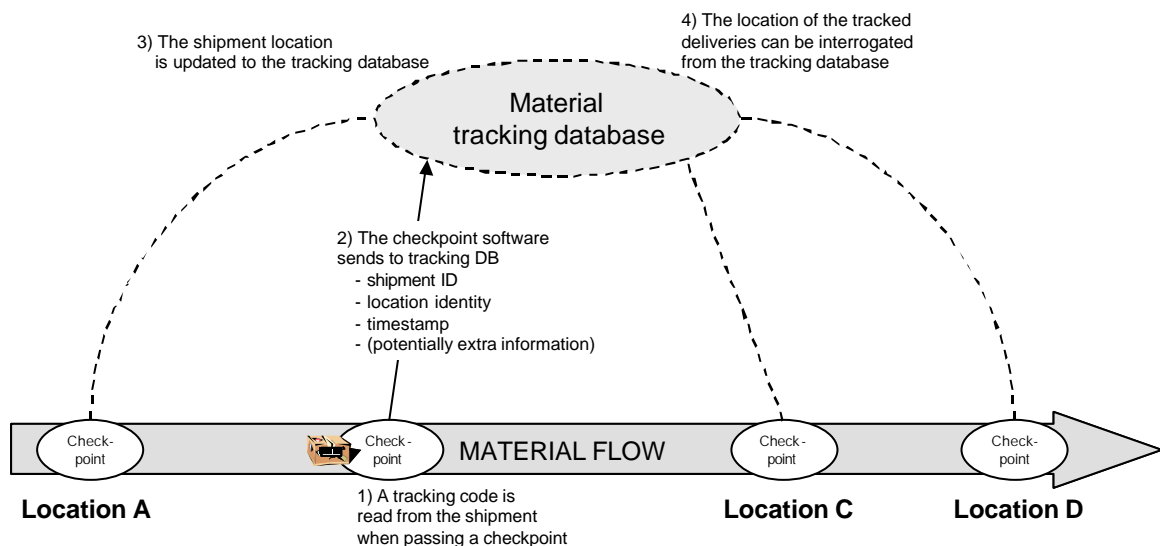


Figure 1 The basic components and functionality of tracking systems

2.3.2 Key features of tracking systems

Tracking systems are utilised both inside single organisations and now, due to the shift of the focus of logistics management from solely inside one enterprise to multi-company supply chains, also in multi-company setting. When operating tracking systems in multiple company networks, different parties of the supply network need to determine the requirements and attributes for tracking systems co-operatively due to the cross-company nature of supply network processes (van Dorp, 2002).

For tracking systems to be functional, the parties (be that within one company or between several companies) using the system need to agree on six key issues (compiled from: Stefansson and Tilanus, 2001; van Dorp, 2002; Giannopoulos, 2003):

- 1) the operational scope of the system
- 2) the goods identification technology used in tracking
- 3) the coding of the tracked items
- 4) the content of the exchanged tracking information
- 5) the information architecture used in the tracking application
- 6) the ways of accessing the tracking information

Next, each of these attributes will be reviewed in more detail.

The most important issue of tracking systems in multi-company networks is the **operational scope of the system** (van Dorp, 2002). The operational scope refers to the span and range of gathering the tracking information, i.e. is the tracking information gathered only from goods handled by a single company, or are several companies (both LSP's and customers) in the same supply network able to provide tracking information to the system. The main practices in current systems are: 1) the system is operated by one logistics service provider 2) the system is operated by an independent tracking

service provider (therefore it can be utilised while the goods are handled by different LSP's) 3) the system can be operated by several different companies that use some specific workstations or software at the checkpoints.

At each checkpoint of the tracking system, specific equipment is required for reading the identifiers – it is imperative that the necessary equipment is available everywhere so that the tracked item can be identified at all checkpoints. Therefore, **the identification technologies** utilised in the tracking system have to be agreed on (Stefansson and Tilanus, 2001; van Dorp, 2002). There may also be an agreement to utilise several technologies (e.g. manually read tracking codes, bar coding, and radio frequency identification) within one tracking system, but this demands applying several identifiers based on different identification technologies to the tracked entity.

The tracking information regarding the tracked entities is gathered using specific identities (i.e. **tracking codes**) for the tracked items (van Dorp, 2002). The reporting of the tracking information is also usually based primarily on these codes. The identities can be service provider specific or delivery numbers/codes, customer order numbers, or other codes specified by the customer.

Tracking systems can also differ in the **information content** of their tracking messages. As stated earlier, tracking systems may record only the identity of the tracked item, the location of the checkpoint, the arrival time of the item, or append these pieces of information with additional attributes (Stefansson and Tilanus, 2001). The transmittal of additional information can be a relatively simple and valuable means to gain feedback information from the supply network. For example, if the quality of the consignment has suffered during transportation (observable damage or improper temperature conditions), appropriate action can be taken. However, in order to be continuously taken use of, the types of additional information transmitted in the tracking messages have to be defined.

The information architecture of a tracking system is important as it greatly influences how accessibility can be built to the tracking information. There are two basic possibilities for **information architecture** in tracking systems (applied from Stefansson and Tilanus (2001)):

- The tracking system can send the tracking information to each participant of the transport chain, who store the tracking data in their own information system. Such information systems can contain both tracking information that is received directly from the company's own operations and information brought from a tracking system by another network party.
- The tracking information is gathered to a central information system containing all the tracking data. Other network members can obtain tracking information from there by manual information requests (by telephone or over a www-connection), or retrieve the information to their systems by the means of systems integration or system-to-system messaging. This central system is usually operated by the provider of the tracking service, but it could also be operated by a specific third party IT provider, or a powerful supply network participant.

When considering the **accessibility of the information**, it is typically most convenient for a company to have the tracking information in its own systems as it can then be compared to other, often company specific, information (such as planned delivery dates or project construction schedules). Another convenient alternative is to have the information accessible through automatically performed queries, which demand configuring EDI or XML message interfaces with the central tracking system (Deschner et al., 1998). Manually performed queries (be they telephone or www-based queries) do not enable automatic follow-up of the deliveries, they are costly and error-prone, yet are commonly used as they do not cause any set-up costs. When automated data transfer methods are used, it must be ensured that the system receiving the tracking information understands at least all the basic pieces of tracking information: what is the tracked item, what is the location the item has reached and what is the time of the pass.

2.3.3 Characteristics of current tracking systems

A review of a selection of current tracking systems classified with the above criteria is presented in Table 1. The review includes systems that are described in published articles, complemented with systems that could be described based on interview data. The information for systems 1 to 3 was drawn from Stefansson and Tilanus (2001). The information on system 4 is derived from Shah, (2001); Janah and Wilder, (2001); and FedEx, (2005). System 5 is presented in Loebbecke and Powell, (1998). Information on

system 6 is gathered from Dierkx, (2000); Lambright, (2002); and Savi Technology, (2002). Finally, information on systems 7 to 9 was gathered in semi-structured interviews with representatives of tracking system operators. For system 7, the director of business development (Kullström, 2003), for system 8 a development manager (Sundelin, 2003), and for system 9 the business development manager and managing director (Mäkinen and Mäkinen, 2003) were interviewed.

Table 1 Summary of a review of current tracking systems

	Operational scope of system	Identification technology	Item coding	Information content	Information architecture	Accessibility of information
1. International road haulier (Scansped)	The LSP operates the system	Manual	Proprietary tracking number	Manual data handling, therefore flexible content	Report sheets of specific shipments that are tracked are faxed to central administration	Manually constructed reports from tracked deliveries
2. International shipping agent (Wilson)	Documents from carriers are used for tracking	This system reacts to documents generated in the delivery chain	Proprietary tracking number	Basic tracking attributes	Centralised at service provider	www-query or EDI link
3. Express parcel service (DHL)	The LSP operates the system	Bar code	Proprietary tracking number	Basic tracking attributes	Centralised to the LSP	Telephone and www-query, or EDI or systems integration
4. Express parcel service (FedEx)	The LSP operates the system	Bar code	Proprietary tracking number, alternative (order numbers) references possible	Basic attributes, supplementary information possible	Centralised to the LSP	www-query, e-mail query, or systems integration
5. Tracking service provider (TRANSPOTRACK)	The system can be operated by different companies if they install a proprietary checkpoint PC in their premises	Bar code	Proprietary tracking number	Basic attributes, supplementary information possible	Centralised to the tracking service provider	Systems workstations at the customers' premises.
6. Tracking service provider (Savi Technologies)	The tracking service provider operates the system	Several different technologies (e.g. bar code and RFID)	Proprietary conveyance tracking numbers	Basic attributes, supplementary information possible	Centralised to the tracking service provider	www-query, systems workstations, XML messages, or systems integration
7. International road haulier (Schenker)	The LSP operates the system	Bar code	Proprietary delivery number	Basic attributes, supplementary information possible	Centralised to the LSP	www-query
8. National parcel service (Finnish Postal Service)	The LSP operates the system	Bar code	Proprietary tracking number	Basic tracking attributes	Centralised to the LSP	www-query
9. National car transport provider (SE-Mäkinen)	The LSP operates the system	The checks are reported manually through on-board computers (large distribution units, i.e. cars)	Manufacturer allocated vehicle serial number, alternative references possible	Basic attributes, supplementary information possible	Centralised to the LSP	www-query or file transfer

Some general characteristics of current tracking systems can be lined out from Table 1.

The systems usually operate only within the boundaries of a single company. The collection of the tracking data is restricted to a single logistics- or tracking service provider in all instances but one.

The predominant choice of identification technology is bar coding, which was solely utilised in five of the nine reviewed systems. Two systems are based on manual registration, one system utilises logistics documents, and the system of one tracking service provider supports other technologies (e.g. RFID) in addition to bar codes.

The systems utilise mostly proprietary tracking numbers defined by the company operating the system, which was the case with all but one tracking system that relied on manufacturer allocated product numbers. However, alternative references for data retrieval were enabled in some systems.

Current tracking systems are based on information architecture where the tracking information is centralised to the provider of the tracking service. This was evident in all cases.

The predominantly used methods for accessing the tracking information are manual queries (using a www-site, telephone or e-mail). Five of the nine tracking service providers also offered systems interfaces for integrating with the tracking system. The characteristics of current tracking systems are summarised in Table 2.

Table 2 The characteristics of predominant tracking systems

	Operational scope of the system	Identification technology	Item coding	Information content	Information architecture	Accessibility of information
Predominant tracking systems	LSP handling the shipments operates the system	Bar code (sometimes manual or RFID)	Proprietary tracking number	Basic tracking attributes (supplementary information)	Centralised to the LSP (tracking service provider)	www-query, EDI-link, systems integration

2.3.4 Tracking systems in multi-company networks

As discovered in the previous sub-section, most of the current tracking systems operate only within a single company. However, in large supply networks there are often several forwarders for a single transport and thus the users of the tracking information have to retrieve the information from several separate single company focused tracking systems (Deschner et al., 1998). In these situations the customer companies of logistics or tracking service providers have two possibilities for accessing the tracking information in each of the different systems: using manual queries or integrating their information systems with the tracking system.

Either way of information retrieval is problematic in multi-company networks, as each systems operator usually uses their own proprietary tracking numbers (Deschner et al., 1998; Li and Shu, 2003). Therefore the users of the tracking information need to administer which tracking code to use depending on which forwarder is responsible of the transport at any given moment when utilising manual tracking information access. The proprietary coding also makes systems integration significantly more difficult, as the tracking codes of the customer's system and all the tracking systems integrated with the customer's system have to be aligned for the systems integration to be successful.

Even if the problems generated by the proprietary coding are overcome, manual information access provides only limited functionality and is time-consuming. In www-based queries, one can retrieve and interrogate the tracking information of a consignment by giving tracking and authorisation codes on the web page of the provider of the tracking service (usually a LSP). However, due to the costs and error-prone nature of manual work, it is not a feasible option if there is a significant number of shipments that need to be tracked. Manual queries do not work, for example, in international investment project deliveries, as there are several thousands of project components that need to be monitored (Halmeperu and Nystén, 2003; Harju-Jeanty and Jäntti, 2004).

In stable and large-volume relationships the customer can invest in systems integration with the provider of the tracking service. The integration challenges caused by several forwarders and proprietary coding can be overcome with increased integration efforts. Two different solutions have been proposed in previous literature to address these challenges of tracking in multi-company networks (Deschner et al., 1998; Li and Shue, 2003).

Deschner et al. (1998) have developed an agent based tracking information retrieval infrastructure with the aim of aiding the use of tracking systems in multi-company supply networks. The main idea of the system is to, in most cases, leave the tracking information to reside on the forwarders' information systems and use software agents to collect the tracking information from the forwarder systems when needed. The Deschner et al. (1998) solution encompasses an exchange of EDIFACT messages

between the forwarders included in a transport and the customer of the tracking services for synchronising the tracking codes used by each party.

Li and Shue (2003), on the other hand, have developed an infomediary infrastructure for air cargo tracking. The aim of the proposed system is to get all air cargo transporters to integrate their system with the infomediary, which can then act as a connection point for the customers of the tracking systems. This proposed system is, however, aimed only for tracking airfreight and is thus not applicable to all areas.

2.4 Problem description: Difficulties and open issues with current tracking systems

In this section we will discuss the difficulties and open issues within current tracking systems. First, we will address the difficulties of applying current tracking systems in short-term multi-company supply networks. Second, we will discuss the issue of identification technology selection in tracking systems, we will review literature discussing when to utilise RFID rather than the currently predominant bar coding in particular.

2.4.1 Tracking systems in short-term supply networks

In this we use the term short-term supply network to refer to any temporally existing distribution structure. For example, the distribution organisations of investment project deliveries can be classified as short-term supply networks as they typically exist only for the duration of single project. Also any other logistics structure with temporary relationships, such as a distribution organisation utilising logistics service providers picked with spot trade, can be labelled as short-term networks.

Companies operating in short-term multi-company networks experience significant problems with the predominant tracking systems aimed for use within a single company. This is because both potential methods for retrieving tracking information (manual inquiries and system integration) are unfeasible in short-term environments.

Manual inquiries are unfeasible in short-term networks primarily due to the reasons of low efficiency as presented in sub-section 2.3.4. Also, the administration of which tracking system and code to use at different times is invariably even more complicated in short-term than long-lasting networks.

However, in contrary to the situation in long-term partnerships, systems integration is not a viable option when operating in short-term supply networks. For example, in project-oriented industries the span the existence of the supply networks is often restricted to a single project (Dainty et al., 2001). Thus, it is usually unfeasible for the companies to engage in business-to-business application integration to get the tracking information automatically, as integrating with all the relevant tracking systems would consume vast amounts of time and IT resources (Linthicum, 2001; Wilde, 1997). Therefore, it would be difficult to recover a viable payback for the investment during the lifetime of the supply network. As a result, companies operating in short-term supply-networks are often reluctant to invest in systems integration (Cheng et al., 2001).

The integration approach proposed by Deschner et al. (1998) does not help to solve the problems experienced in short-term networks, as it demands severe interface development efforts for the EDIFACT messages for synchronising the tracking codes of each integrated party. The Li and Shu (2003) solution, on the other hand, is restricted to air cargo tracking and therefore fails to serve as a complete solution. Furthermore, neither solution takes into account the fact that in many supply networks there still are logistics operators that currently do not yet possess tracking systems. This is, for example, a reality when mechanical engineering projects are delivered to remote locations, where the final mail operators are usually small local transport service providers (Halmeपुरo and Nystén, 2003).

Due to the ill fit of manual queries and systems integration as methods for information access and the limits of proposed solutions in current literature, it can be argued that existing tracking solutions are difficult to apply in short-term multi-company networks. For example, the tracking of mechanical engineering industry project deliveries is currently based primarily on manual monitoring and visual inspection at the site, because of the existing systems' poor fit to the industry (Halmeपुरo and Nystén, 2003).

2.4.2 Identification technology selection in tracking

In their review of tracking applications, Stefansson and Tilanus (2001) find bar coding to be the most commonly used identification technology in tracking. They also state that technology advances and price cuts on radio frequency identification (RFID) will potentially lead to its large-scale adoption. RFID systems are constructed from electronic devices called transponders, more commonly known as tags, which are attached to the items to be identified, and reading units, often called readers. RFID readers communicate with the tags via electromagnetic waves on different frequencies. For a more detailed technical description of RFID technology and its potential application areas see for example Finkenzeller (2000) or Kärkkäinen et al. (2001).

McFarlane and Sheffi (2003) agree with the views of Stefansson and Tilanus (2001) and present that RFID will enable more efficient and widely applicable tracking services. Furthermore, there is a large body of more practitioner oriented literature discussing the potential of utilising RFID in tracking and its great strengths related to bar coding (see e.g. Burnell, 1999; Burnell, 2000; Bushnell 2000; Gould, 2000; Kärkkäinen and Ala-Risku, 2003a; Moore, 1999a). The authors commonly argue that RFID technology is superior to bar coding in tracking applications, as RFID identifiers do not require a line of sight between tags and the reader in order to be read as tags can be read through non-metallic materials, and because tens of tags can be read simultaneously.

However, the whole reasonability of utilising RFID in tracking is clearly questioned in some articles. These RFID critics state that the technology is too expensive and that it is unlikely that the investment will pay off (Burnell, 1999; Riso, 2001). Additionally, critics often indicate that RFID is an over-marketed, hyped, technology and that the existing bar code based systems already provide most of the needed functionality (Burnell, 1999).

Therefore, it is clear that there is contradiction among opinions presented in current literature. Furthermore, previous literature does not provide any frameworks or guidelines for analysis on where or when RFID should be utilised. Lacefield (2004) has presented the clearest guidelines by simply stating that companies have to ask themselves: “Do we have a problem? Can an RFID solution reliably solve the problem? And, is there an easier and/or cheaper solution?” These contradictory opinions on whether RFID technology should be applied in tracking and the lack of guidelines on where RFID has most potential form a clear weakness in the current body of literature.

2.5 Conclusions of the literature review

Even though there clearly is a vivid body of literature discussing tracking and the systems used in tracking, some clear shortcomings can be pointed out on the current knowledge on tracking. First, previous literature is ambiguous in describing in what ways the delivery exceptions can be reacted to. Second, while Töyrylä (1999) successfully presents logistical metrics that are possible to generate based on tracking information, he does not describe how to generate the metrics in practice. Furthermore, he does not specify what additional information is required for generating the metrics. The findings of Töyrylä (ibid) on the use of expiration dates on material flow control are interesting but lack support from other studies.

Second, there are two distinct shortcomings or open issues in current tracking systems and the literature describing them. First, the current tracking systems are not suitable for use in short-term multi-company networks and second, previous literature presents opposite opinions on whether RFID would be feasible as the identification technology in tracking systems rather than bar coding. Furthermore, no guidelines on when RFID would offer the biggest benefits are offered.

3 Research questions

The aim of this thesis is to describe why tracking has become an increasingly important area in logistics management, identify the key problems with current designs of tracking systems, and develop and test a solution proposal that addresses the identified problems. Based on the identified shortcomings in previous literature and current tracking systems, the following explicit research questions were defined.

First, some weaknesses were identified in previous literature in the description of the benefits achievable with tracking. Furthermore, the lack of previous empirical results covering some of the identified benefits, and the wideness of potential uses of tracking systems and information justify explorative research on the reasons of using tracking systems and gathering tracking information. Therefore we can formulate the first research question (research question 1) of the thesis as:

“What can be obtained by using tracking systems and tracking information?”

The second identified shortcoming in the previous literature was the inability to use the existing tracking systems in short-term multi-company supply networks and the lack of solution proposals addressing the challenges of short-term environments. The second research question (research question 2) of the thesis is thus formulated as:

“How to design tracking systems applicable to short-term multi-company networks?”

The answer to this question is forwarder independent tracking (FIT) solution concept describing system attributes required for successful application of tracking systems in short-term multi-company supply networks.

Exploring research question 1 revealed that one of the most significant benefits of tracking information is its potential of increasing material flow transparency in supply chains. During this study, we observed that tracking systems constructed according to the proposed FIT solution concept enable generating transparency to materials both in-transit and residing in inventories. We call the procedure of generating transparency with tracking systems the tracking-based approach to increase material flow

transparency. However, as is the case with any solution, this procedure is unlikely to be the most suitable solution in all business environments and its value is increased if its feasibility area becomes better known. Therefore we posed a third research question (research question 3) for the thesis:

“How does operational environment affect the applicability of the tracking-based approach to increase material flow transparency?”

The existing literature presents contradictory views on whether RFID technology should be utilised in tracking. The current body of literature also fails to explicate in which situations RFID technology offer the most benefits over bar coding. Therefore, there is a clear need for research on when to apply RFID technology in tracking. The fourth research question (research question 4) of the thesis is thus:

“Under what circumstances does RFID technology offer the most benefits in tracking?”

The research aims at finding out when RFID offers the most benefits rather than conducting more straightforward cost/benefit estimations. This is because the cost of RFID is decreasing even though the basic functionality of the technology remains the same. Therefore, the results of the cost/benefits estimations would change as the technology matures, but the areas where it offers the most benefits will remain static if no major changes on the functionality of the technology occur.

4 Research design and methods

In this chapter we will first discuss the research approach selected for this thesis (section 4.1). In section 4.2 we present the progress of research in this thesis study. The data collection methods used in the study are presented in section 4.3. In section 4.4 we present the relation of the separate publications to the research questions of the study, and section 4.5 contains a few words on the motivation of preparing this dissertation in the form of a bundled thesis.

4.1 The research approach

Logistics clearly belongs to applied sciences, which are categorised by the pursuit of knowledge with the aim of obtaining a specific goal, i.e. its aim is to develop knowledge that has the specific purpose of increasing the effectiveness of some human activity (Niiniluoto, 1993). Furthermore, many studies in the field of logistics are design research by their nature; they are concerned with developing the design of application or processes, i.e. they do not only aim to establish how things are, but how things ought to be in order to attain the desired goals (Niiniluoto, 1993; Simon, 1996).

Design research is important in logistics, as it aims to provide novel, practicable leading edge solutions. The development of practically applicable leading edge solutions by logistics researchers has been called for by the leading authorities of the field, as the research community continually has to justify itself also to the practitioner audience providing the research data and in the end financing most research (Christopher, 2002; Fearn, 2002; Lambert, 2002). Therefore, the results of logistics research should be judged not only based on their correctness, informativeness, and truthlikeness, but also based on their practical relevance and applicability (Benbasat and Zmud, 1999; Niiniluoto, 1993; Kasanen et al., 1993).

The aim of this thesis is to describe why tracking has become an increasingly important area in logistics management, identify the key problems with current designs of tracking systems, and develop and test a solution proposal that addresses the identified problems. In the development of the solution proposal, the research reported in this thesis has followed the example of “Innovation Action Research” (Kaplan, 1998). The aim of innovation action research (IAR) is to give researchers a structure for developing relevant new knowledge on different fields of management research. It offers guidelines for developing new solutions that alter existing practice and testing the feasibility and properties of the innovations (Kaplan, 1998). In the terminology of Simon (1996) the framework is an example of procedural rationality – a procedure for problem solving when some of the issues surrounding the problem and the potential solution are not clear from the beginning. Therefore, the IAR approach supports the aims of this thesis research extremely well.

The flow of research in innovation action research is to initially document major limitations in a contemporary practice, identify a new concept to overcome the limitations, and to continually apply and improve the concept through publication, teaching and active intervention in companies. Kaplan (1998) specifically emphasises that installations of the proposed solution model are needed for the researchers to understand the problem and all the practical issues it encompasses more deeply. As the collection of empirical data in IAR is mainly carried out with case studies, the approach is well in line with Meredith’s (1998) views of methodological selection in operations management theory building. The flow of innovation action research is illustrated in Figure 2.

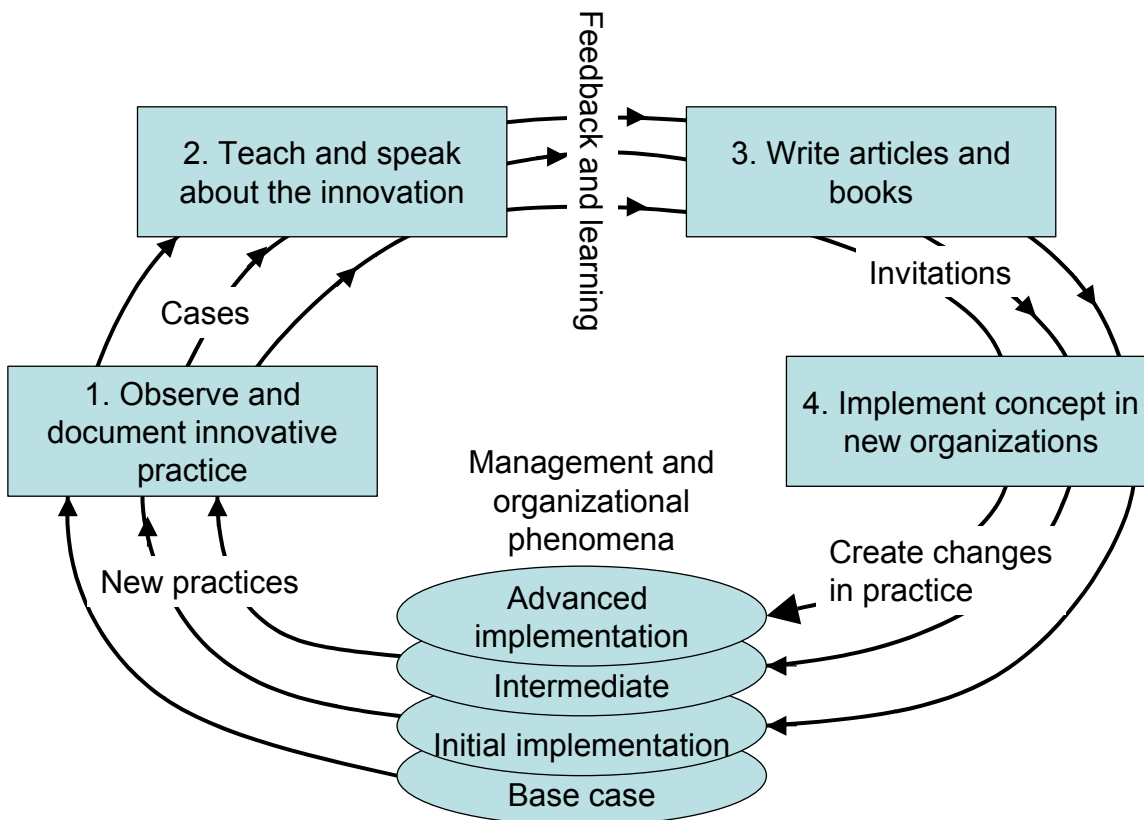


Figure 2 The flow of innovation action research (Kaplan, 1998)

Other authors have presented approaches for design research in other fields of management research. Kasanen et al. (1993) have proposed a “constructive approach” for management accounting research. They propose the following six-phase research process: 1) find a practically relevant problem, 2) obtain a general and comprehensive understanding of the topic, 3) innovate, i.e. construct a solution idea, 4) demonstrate that the solution works, 5) show the theoretical connections and the research contribution of the solution concept, and 6) examine the scope of applicability of the solution. The research process of constructive research closely resembles that of IAR. The main difference between the approaches is that the constructive approach emphasises the active innovation of the solution concept by the researcher, whereas IAR considers that the solution concept can be found or borrowed from already existing practical applications and then developed further.

In the field of Information Systems research, Benbasat and Zmud (1999) are on the same lines with IAR and the constructive approach in research problem identification. They recommend that researchers look to practice and especially the problems encountered in practice to identify research topics and examine literature only after commitment to a specific topic has been made. Furthermore, Mahoney and Sanchez (2004) propose a similar approach for strategic management research. They state that strategy researchers should present their theories for potential application to managers, observe how the proposed theories function in practice, and update the theories based on the findings. When a researcher is engaged in discussing and observing the practical implementation of a strategy theory she is engaged in a double-loop learning where she supplies insights, relationships and theory to the practitioner, and receives information on the practical relevance and applicability of the theory. This interaction is beneficial from both the practitioners' and researcher' point of view.

The weakness of the IAR approach is the lack of guidelines on how to evaluate the research. Even though he has applied the research approach with apparent success, Kaplan (1998) acknowledges that the IAR framework does not provide clear guidelines for evaluating the outcomes of the research. In presenting IAR, Kaplan (*ibid*) states that most traditional ways of evaluating the findings, e.g. surveys on the success of implementers of the proposed design, should not be applied in the purpose of estimating the feasibility of developed operating models, but does not present any formal evaluation framework to be utilised. Furthermore, he admits personally conducting only continuous informal evaluation of the design proposal developed in the research (*ibid*).

However, the IAR model has feedback loops to increase and ensure both the practical and scientific relevance and validity of the results. The practical feedback loop consists of discussion with practitioners and even more importantly of implementations of the proposed solution design. The scientific feedback loop consists of presenting the results and its research basis on international scientific conferences and journal articles. The responses of the research community help to develop and ensure the scientific relevance, validity and general applicability of the research. These feedback loops closely resemble the double-loop learning of strategy researcher as proposed by Mahoney and Sanchez (2004). Even though the primary function of these feedback

loops is aiding the development of the proposed solution designs, we argue that their results can also be used in the evaluation of the success of the research. This issue is further discussed in section 6.2, evaluation of the thesis.

4.2 The progress of research

The majority of the research in this thesis study has been performed in an IAR stream examining how to build tracking systems for short-term multi-company supply networks and how to utilise those systems. This research stream has provided most of the results related to research questions 1, 2 and 3. The thesis study also incorporates two separate studies examining the utility of RFID technology in tracking and thus contributing mainly to research question 4.

This thesis research was initiated with the RFID studies. However, here the parts of the thesis research are reported in the order of their importance, and therefore the main research stream is discussed first.

The main research stream has developed a solution concept for tracking in short-term supply networks, and a tracking-based approach for generating material flow transparency. These have been tested in two successive implementations and their feasibility and applicability area has been studied in two further case studies. The flow of this research stream has been the following:

- 1) The research stream was initialised with a problem description and rough first illustration of the solution proposal, which was constructed based on conceptual analysis and unstructured discussion with companies supplying goods to international investment projects. This stage of research was performed in the spring and summer of 2001, and its results are reported in Paper II.

- 2) The operating principles of current tracking systems were studied in a literature review; and a technical solution for tracking in multi-company networks was developed in co-operation with companies from project-oriented mechanical engineering industry. The tracking system was developed by Dr. Främling and the specification of the system are initially published in Främling (2002). The system is presented in more detail and in a more general form in Kärkkäinen et al. (2003b). The systems development was carried out in the autumn 2001.
- 3) A pilot installation with the tracking system was performed with an original equipment manufacturer (OEM) delivering sub-solutions to heavy industry investment projects, and its subcontractor. This pilot was performed to validate the developed tracking system. The experiences gathered in the pilot installation, previous knowledge, and a thorough literature review on current tracking systems were used to refine the tracking approach to a specific solution concept of forwarder independent tracking (FIT). The solution concept for tracking in short-term networks and experiences from the first pilot installation are reported in Paper IV. This pilot installation was performed in the spring 2002.
- 4) A case study was conducted in a furniture industry supply network including a large retailer and three SME suppliers. This study was undertaken to examine the feasibility and potential benefits of the proposed solution concept in consumer goods supply chains. During this study, we discovered how the proposed FIT solution concept can be used for generating inventory transparency. We refer to this procedure of generating inventory transparency as tracking-based approach for generating inventory transparency. Data from this case study is used in Paper VI. This case study was conducted the summer and autumn of 2003.
- 5) A pilot installation testing the tracking-based approach for generating inventory transparency was conducted in a telecommunication network installation project. In this pilot, Främling's tracking system was used to create inventory transparency to six installation warehouses. Data from this case study with the pilot is used in Papers V and VI. The pilot installation was initiated in the late autumn 2003 and was carried on till the autumn of 2004.

- 6) A delivery management model utilising the tracking-based approach for generating material flow transparency was developed for construction projects. The developed model is presented in Paper V. This delivery model was developed in the spring 2003.
- 7) A case study including an equipment manufacturer, its supplier and a project contractor was conducted in a mechanical engineering supply chain to further examine the feasibility and potential implications of the proposed FIT solution concept and the tracking-based approach for generating transparency in investment project deliveries. The companies in this case study are different from the companies in the first pilot implementation. Findings from this case are used in Paper VI. This case study was conducted in the autumn 2004.
- 8) The potential of using the tracking-based approach for generating transparency in supply chains with small and medium-sized companies as well as the factors affecting the applicability of the tracking-based approach was analysed based on the furniture, telecom, and mechanical engineering industry cases. The results of this analysis are presented in Paper VI. This analysis was performed in the late autumn 2004.

The research focusing on the potential of RFID technology in tracking consist of two studies:

- 1) A study reviewing published case studies of RFID applications. A model classifying the benefits achievable with wireless identification technology was developed based on the cases. The classification model is presented in Paper I. This study was conducted in the summer 2000.
- 2) A case study of RFID based on tracking in the grocery industry. Findings from this case study are presented in Paper III. The case study was conducted in the autumn 2001.

4.3 The data collection methods

The data collection methods utilised in the research are presented in this section. We will first review the data collection methods in the studies included in the main IAR cycle developing tracking tools and their utilisation methods for short-term supply networks, after which we will move to presenting data collection methods in the studies in the RFID stream.

Paper II is based on conceptual analysis and unstructured discussion with companies supplying goods to international investment projects. Therefore, no specific data collection methods were utilised.

The empirical research in the main IAR research stream consists of four case studies, two of which have incorporated a pilot implementation.

The first case study was performed with a supplier delivering components to investment projects and included a pilot implementation which was used to verify the concept of forwarder independent tracking (this solution concept will be described in more detail in the results chapter). As Paper IV states, the principal information gathering methods in the pilot implementation were active involvement, observation, and constant contact with key personnel of the OEM company and its subcontractor. Additionally, interviews were conducted with management personnel who were not directly involved in the installation. Triangulation or other means of data validation were not used, as the aim of the case was to act as a proof-of-concept for the proposed solution concept, not to provide empirical data on company operations. Dr. Främling has been primarily responsible for the data collection in this case study.

After the first pilot installation we (the applicant and Mr. Ala-Risku) started a case study with the aim of studying the feasibility of utilising the proposed solution concept in the furniture industry. This case is used in Paper VI, where the used data collection methods are used not well described due to space. The case consisted of two furniture retail chains, their common distribution organisation and three supplier companies. The main data collection method was semi-structured interviews (the list of interviewees and the interview dates is presented in Appendix A). Additional data was gathered with

active participation in the joint supply chain development meetings of the case companies, and direct observation of operations at two of the three suppliers and the two retail chains. The researchers also gained valuable insights on the applicability of the proposed concepts in a reporting workshop of the findings.

In gathering the data, we tried to ensure the reliability of the collected information by the following generic practices:

- We took especial care when making interpretations from the answers of the interviewees, and interpretations made from the interviewees' responses were cross-checked between the interviewers to guard from subjective bias. Cross-checking has been possible, as there usually were two interviewers present in the interviews.
- We tried to avoid the subjective perception from the side of the informant by using several informants whenever possible. Also the information acquired with the other data collection methods was compared with interview findings when possible.
- To ensure the transparency of the research and enable re-analysing the findings, we have written discussion memorandums based on the interviews. The memos have been stored in a case study database along with the used interview questions for easy future access.
- We have tried to ensure the completeness of the information by re-contacting the interviewees in the case of missing information or additional information requirements. In instances where the original informant was not able to fill our information needs, we were directed to additional respondents.

After the furniture case study we started another case study, the aim of which was to evaluate the feasibility of using the forwarder independent tracking solution concept for developing inventory transparency in telecommunications network equipment deliveries. This case study also incorporated a pilot implementation. Material gathered in this case study is used in Papers V and VI.

The main data collection method in this case was active participation in the planning of the pilot, in the development of a business case for the pilot and in actual piloting. The researchers were responsible for the development of the piloted transparency approach, participated actively in the planning of the implementation, prepared all education and instruction material related to the pilot and were responsible for holding the educating session for the personnel implementing and using the software at the pilot locations. Furthermore, once the pilot was in progress, the researchers acted as a helpdesk for the companies installing and using the systems. After the initial implementation, the researchers remained in close contact with the company representatives responsible for the pilot and received first hand knowledge on the progress and impacts of the pilot.

In addition to the active participation, semi-structured interviews were conducted with seven different respondents from three different organisational areas of the case company. In conducting interviews and documenting research data gathered in the whole case study, the same quality assurance guidelines were followed as in the furniture case.

The final case study in this research stream was conducted in the supply chain of project oriented machinery products. In this case study, representatives from an equipment manufacturer (one respondent), its SME supplier (one respondent), and a project contractor (two respondents) were interviewed. The interviewees, their organisational positions and the dates of the interviews in this case are listed in Appendix B. Semi-structured interviews were used for data collection. In the interviews we first discussed the perception that the respondent's organisation had on material flow transparency, and the current pressures, possibilities and plans for developing transparency. After this, we presented the proposed transparency approach and the respondents were asked to describe their perception on its implications on their organisation and the supply chain and compare it with their prevalent or planned transparency solutions. Additionally, the researchers accessed the companies' www-pages before interview to familiarise themselves with the companies and their operations. The quality assurance methods described in the furniture case were also utilised in this case study, with the exception of more restricted sources of information.

The research stream focusing on the potential of RFID in tracking consists of two studies. The first study presents a classification framework of RFID benefits. The framework is based on published case studies as proposed by Lewis (1998), and no additional empirical data was utilised in building the framework. The original publications are reported with the case descriptions in Paper I. The publications reviewed for the paper were acquired mainly from ABI Inform database by reviewing all material that was found with the search-key “RIFD” in full text of the article.

The case study of RFID tracking in the grocery industry (reported in Paper III) is based on a semi-structure interview and information acquired from published documents. Extra information needs detected when writing the case study report were fulfilled with additional contact with the interviewee. The resulting case description was validated with the informant. The used interview questions are reported in Paper III.

The information collection methods for gathering the empirical data of the thesis are summarised in Table 3.

Table 3 The data collection methods for the empirical data

Research phase	Data collection methods	Reliability assurance methods	Included in papers
Pilot installation in mechanical engineering industry	Active involvement, observation, interviews		Paper IV, Paper VI
Case study on the furniture industry	Interviews, participation in meetings, observation, results workshop	Multiple interviewers, multiple data sources, case database, re-contact and additional respondents when needed	Paper VI
Pilot installation in telecommunication network equipment deliveries	Active participation (in planning and carrying through the pilot), observation, interviews	Multiple information collectors, multiple data sources, case database, additional informants or queries when needed	Paper V, Paper VI
Case study in the supply chain of mechanical engineering projects	Interviews, www-pages	Multiple information collectors, case database, additional contact when needed	Paper VI
Published cases of RFID applications	Article database searches	Transparency to data provided by identifying the original sources in the paper	Paper I
A case study of RFID tracking in the grocery industry	Semi-structured interview, review of published documents	Extra information needs fulfilled with additional contact, the case report validated with the respondent	Paper III

4.4 The relation of the separate publications to the research questions

In this section we describe the separate publications included in the thesis briefly, discuss their contribution to answering the research questions and, in the cases of a joint publications, present the role of the applicant in the paper.

Paper I presents a framework that classifies the benefits achievable with wireless product identification technology to handling efficiency, efficient customisation, and effective information sharing. This framework can be used in analysing when RFID technology should be utilised, and therefore the paper makes a clear contribution to *research question 4*.

The applicant has been primarily responsible for writing the paper. Dr. Holmström had a significant role in defining the structure of the paper, and a noteworthy role in finalising the paper.

Paper II investigates how the logistic challenges of international projects can be solved with an effective tracking solution. The paper thus contributes to *research question 1*. The paper also outlines basic requirements of a tracking system that could be utilised in a project delivery chain and lays the framework for the proposed solution concept and thus contributes to *research question 2*.

The applicant is the main contributor in the paper. He has designed the structure and flow of the paper, and he has been primarily responsible for the overall writing of the paper. Dr. Holmström has contributed to the structure of the paper, and he was involved in finalising the paper and its overall analysis. Dr. Främpling has built the actual system described in the paper, provided the software technology related understanding for the paper, and has strongly contributed to the parts of the paper discussing software technology aspects. Professor Artto has brought project management insight to the paper.

Paper III deals with the benefits of RFID based tracking in a short shelf life product supply chain. The paper discusses the benefits achieved with tracking, contributing to *research question 1*, as well as the rationale of utilising RFID, thus also contributing to *research question 4*.

Paper IV examines how to construct tracking systems applicable to short-term multi-company networks and proposes a forwarder independent tracking (FIT) solution concept to overcome the challenges in this difficult environment. Therefore the paper makes a strong contribution to *research question 2*. The paper also briefly discusses the identification technology selection made in the pilot installation, and therefore has a minor contribution to *research question 4*.

The applicant has been primarily responsible for designing and writing the paper, the literature review and research design sections have been completely written by the applicant and he has had the biggest role also in other sections. Mr. Ala-Risku has contributed especially to the definition of the proposed tracking approach and to finalisation of the paper. Dr. Främling has designed and programmed the demonstration system presented in the paper, and conducted the case study reported in the paper.

Paper V presents how tracking information can be utilised in increasing the efficiency of the material delivery process of construction projects. The paper therefore has a strong contribution to *research question 1*. The paper also presents guidelines on how inventory transparency can be built with tracking systems built according the FIT solution concept and highlights construction projects as one of the prime targets for this tracking-based approach for transparency, and therefore contributes to *research question 3*.

Mr. Ala-Risku has been the primary contributor to the paper, and has been responsible for the literature review of the paper in particular. The applicant has contributed mainly to the design of the flow of the paper and to the writing of the results section of the paper. The data collection and the development of the model presented in the paper have been conducted co-operatively by Mr. Ala-Risku and the applicant. Dr. Främling has developed the tracking system used in the pilot installation and has provided technical expertise for the pilot.

Paper VI investigates the applicability of the proposed tracking-based approach for generating material flow transparency for supply chains with small and medium-sized enterprises, and the effect of operational environment on the applicability of the approach. The paper presents how tracking can increase material flow transparency, and thus contributes to *research question 1*. However, the paper also gives a clear description of how to utilise the FIT solution concept for generating material flow transparency and discusses the characteristics of business environment that affecting the applicability of this proposed approach for generating transparency. Thus, the main contribution of the paper is to *research question 3*.

The applicant has been primarily responsible for designing and writing the paper. Mr. Ala-Risku has contributed especially to the final formulation of the paper. The data collection of the study has been performed collaboratively by the applicant and Mr. Ala-Risku. Dr. Främling has developed the tracking system used in the pilot installations and has been responsible for the technical expertise required in the pilots.

The relations between the research questions and the separate publications are illustrated in Table 4, where an “X” represents a strong contribution to the research question expressed in that column and “(X)” stands for a weaker contribution. For benefit of the readability of Table 4, the separate publications included in the thesis are presented again in Table 5.

Table 4 The relation of the research questions and the separate publications

	Research question 1: “What can be obtained by using tracking systems and tracking information?”	Research question 2: “How to design tracking systems applicable to short-term multi-company networks?”	Research question 3: “How does operational environment affect the applicability of the tracking-based approach to increase material flow transparency?”	Research question 4: “Under what circumstances does RFID technology offer the most benefits in tracking?”
Paper I				X
Paper II	X	(X)		
Paper III	X			X
Paper IV		X		(X)
Paper V	X		(X)	
Paper VI	(X)		X	

Table 5 The separate publications included in the thesis

Paper I	Kärkkäinen, M. and Holmström, J., (2002), “Wireless product identification: Enabler for handling efficiency, customisation, and information sharing”, <i>Supply Chain Management: An International Journal</i> , Vol. 7, No. 4, pp. 242–252.
Paper II	Kärkkäinen, M., Holmström, J., Främling, K., and Artto, K., (2003), “Intelligent products – a step towards a more effective project delivery chain”, <i>Computers in Industry</i> , Vol. 50, No. 2, pp. 141–151.
Paper III	Kärkkäinen, M., (2003), “Increasing efficiency in the perishable goods supply chain with RFID tagging”, <i>International Journal of Retail & Distribution Management</i> , Vol. 31, No. 10, pp. 529–536.
Paper IV	Kärkkäinen, M., Ala-Risku, T., and Främling, K., (2004), “Efficient tracking in short-term multi-company networks”, <i>International Journal of Physical Distribution & Logistics Management</i> , Vol. 34, No. 7., pp. 545–564
Paper V	Ala-Risku, T. and Kärkkäinen, M., (2005), “Material delivery problems in construction projects: A possible solution”, <i>International Journal of Production Economics</i> , in press
Paper VI	Kärkkäinen, M. and Ala-Risku, T., (2004), “Tracking based material flow transparency for small and medium sized enterprises”, <i>working paper</i>

4.5 Why a bundled thesis was chosen for this dissertation

The existence of previously published articles made a bundled thesis a natural choice for reporting this thesis research. Publication efforts during the thesis research can be valuable even if one is not aiming to write a bundled dissertation. Three distinct reasons motivated the applicant to start publication efforts early:

- 1) Rapid publication of results enables getting quick feedback on the research ideas from the research community. The editors and referees of international journals are esteemed experts in their field. Thus, by submitting results to journals one can get valuable further insights and find the weak points in one's reasoning earlier. It increases the quality of the findings.
- 2) By publishing early, it is easier to discover similar or closely related research performed elsewhere. This can lead to interesting collaborations, the discovery of new viewpoints or further validity of results from similar results in other studies.
- 3) It is easier to find a good focus for an article than a thesis. One can quicker get on with improving and building on previous results.

5 Results

The results of this doctoral study are presented in this chapter. In section 5.1 we will discuss what can be obtained by using tracking, then in section 5.2 review results on how to construct a tracking system for short-term distribution networks. The applicability area of the tracking based approach for creating material flow transparency is discussed in section 5.3. In section 5.4 we will discuss circumstances in which RFID technology has the most potential as the identification technology for tracking.

5.1 What can be obtained by using tracking

The first research question of this thesis is: “What can be obtained by using tracking systems and tracking information?”

The reasons for gathering tracking information are discussed Papers II, III, V, and VI included in the thesis. This section is divided into two parts: in the first part we review the results presented in the separate publications and in the second part these results are re-grouped and summarised.

5.1.1 The results presented in the papers

Material deliveries to installation projects are time-critical. The challenge of delivering project material is to time the deliveries in an uncertain environment to arrive late enough not to cause severe storage problems, but in time so as not to hinder the carrying through of the project. (Paper II)

Paper II presents how the problems with the time criticality of the delivery of project materials would be relieved if the project contractor had the capability of tracking deliveries to gain knowledge of their delayed arrival (or, even better, if the contractor could get a proactive announcement of a delay). This would enable the project plan to be updated by taking into account the delay of that particular delivery. Thus, the drawbacks of delayed shipments could be greatly reduced. With assurance on the notification of potential delays, shipments could also potentially be sent with a smaller

safety-margin, which would result in shorter lead-times and less trouble with storage and security on the project site. The paper thus agrees with previous literature that tracking can be valuable, as it provides knowledge of unexpected events in the delivery process, and enables reacting to them before they cause significant harm. The paper expands previous literature by presenting the updating of a project plan as one potential model of reacting to detected delays of material deliveries.

Paper III presents a case study of RFID based tracking on the short shelf life goods supply chain. The development of the tracking methodology was initiated on the basis of a vision of an information enriched supply chain, where all disruptions could quickly be dealt with prior to causing major problems, which is well in line with earlier tracking literature. Two more practical goals were assigned with the tracking trial:

- Reducing labour associated with stock counting and rotation monitoring in stores
- Reducing spoilage in the supply chain

The term rotation monitoring stands for the monitoring of the replenishment process to ensure that perishable items are replenished to the shelves according to their remaining shelf-life.

Paper III describes how the retail chain initiated a trial utilising RFID technology to gather comprehensive tracking information from the supply chain and from the stores in particular. Based on the experiences of the trial the retailer estimated that, with comprehensive tracking information, it could achieve significant savings on depot inventory control, store replenishment productivity, and by eliminating stock-loss due to spoilage. The estimated savings result from better knowledge on where material resides in the supply chain, and the possibility to move additional information (i.e. the use-by dates of products) within the tracking application. The paper thus tightly associates tracking with the monitoring of inventory levels in the supply chain. The paper further presents how the use-by dates can be effectively used to reduce the spoilage problem in the supply chain considerably and thus gives verification to the findings of Töyrylä (1999) on the potential of using material expiration dates for developing more effective material flow control.

Paper V discusses the potential of utilising tracking for generating inventory transparency for project supply chains. The transparency is needed for providing project management with reliable information on the material availability for project tasks. However, the paper states that it is difficult to create transparency to the materials in construction project supply chains, whether the inventory is located at the site or elsewhere in the supply chain. This is because the materials on a site are often not registered in any inventory control system, but are only visually controlled (Halmepuro and Nysten, 2003; ISI Industry Software, 2003). In some cases, site inventories are monitored with a spreadsheet application, but the inventory records tend to be flawed due to manual processes and inconsistent registering of the material movements (Harju-Jeanty and Jäntti, 2004).

Paper V presents how tracking systems can be used for creating inventory transparency and thus to solve the problem. The paper continues that transparency is especially difficult to achieve in site inventories and other short-term storages with traditional solutions. Short-term storages are also the most critical inventories for material constraint analysis in project management. Therefore, generating transparency with tracking to these locations can offer significant benefits. However, the tracking can naturally be used for creating transparency to inventories located in any other part of the supply network (e.g. at the suppliers or sub-suppliers).

The requirement for creating inventory transparency with tracking is that the incoming shipments (materials received at the site / warehouse) and outgoing materials (materials installed / sent from the warehouse) of a supply chain location are continuously tracked (Kärkkäinen and Ala-Risku, 2003b). Therefore, deliveries have to be equipped with an identifying code (e.g. a tracking code, order number or a delivery number), which can be used to link the shipment that arrived to the materials it contains. These codes are registered with a tracking system when packages arrive at or are taken out of a given storage location. The tracking software then conveys the tracking code, the location of the inventory and the time of the read to a tracking database. For creating information on the inventory levels, the codes in the tracking database have to be linked also with the material contents of the shipments.

The resulting inventory information can be used for material constraint analysis of the project management. For determining project task level materials availability a link between the materials tasks and the material needs of each task is also required. The materials needed for a task can be thought of as a bill of materials (BOM) for a task.

Paper V further presents how creating inventory transparency based on shipment tracking information also enables interrogating the following information from the tracking databases:

- What is the location of the different goods needed for a certain project task
- What materials are at a given location (e.g. site inventory or intermediate storage inventory)
- What is the location of a certain shipment
- What are the dwell times of materials in a specific location

This information is sufficient for checking the availability of material for the project tasks and it can also be used to optimise inventory allocation in the supply chain.

Paper V furthermore shows that when database tables containing the delivery dates promised by the suppliers, the ordering date and shipping date are connected to the tracking database, the following performance metrics can also be generated:

- The on-time delivery rate of a supplier
- The lead-time of orders (from ordering to the receiving of the goods)
- The lead-time of deliveries (from the dispatch to the receiving of the delivery)
- If the packages are traced in several locations the de-constructed lead-times can be used for performance analysis of the supply chain (Jahnukainen et al., 1995).

Therefore Paper V makes a contribution to previous literature by presenting how tracking information can be used for inventory monitoring and transparency, and also by describing how the material flow transparency information can be used for more efficient project management. Furthermore, the paper presents findings that support the results of Töyrylä (1999) on what metrics can be generated with tracking information, and makes an additional contribution to increasing the practical applicability of the

results by presenting what additional information is needed for the development of the metrics.

Paper VI recaptures how tracking systems can be used to build material flow transparency in the supply chain, both goods in transit and material residing in supply chain warehouses, with focus on the use and utility of tracking systems built according to the forwarder independent tracking solution concept. The paper thus contributes to the first research question by describing how material flow transparency can be built with tracking systems in a more concise manner.

5.1.2 Concluding remarks on the findings

This thesis makes four distinct contributions to previous literature related to the first research question: “What can be obtained by using tracking systems and tracking information?”

First, the thesis describes how the main benefit of tracking systems and information enhanced transparency to the material flows in the supply chain, to both goods in transit and material residing in supply chain inventories. The relation of tracking and material flow transparency was first identified in Paper III. The requirements for inventory monitoring based on tracking systems were presented in more detail in Paper V, and Paper VI presented in a concise manner how tracking can be used to build transparency to material both in transit and residing in supply chain warehouses.

Second, the thesis presents ways in which tracking information can be utilised in project-oriented industries. Paper II described how the tracking of material shipments in transit can be used in updating the project plan, and Paper V described how inventory transparency achieved with tracking systems can be used in building a feasible near-term project operations plan.

Third, Paper V validates the findings of Töyrylä (1999) by presenting further results on what logistics metrics can be developed based on tracking information and further validation is provided in (Kärkkäinen et al., 2004). Paper V also describes what additional information is needed for developing the metrics and thus enhances the

practical applicability of the results of Töyrylä (ibid). It is important to notice that the final use of the tracking information has an impact on the way in which the final user of the tracking information will need to access the information. If only the status of a system on a specific moment is of interest, then it is enough for the user of the tracking information to be linked with the provider of the service, and access the information when needed. If pro-active alerts of potential problems are sought for, the tracking database should be integrated with a system containing the original distribution timetables and the logic for alerts. And, if logistics measures (such as delivery reliability) based on historic data as are to be generated the tracking information should be collected or linked to a reporting database or system of the customer.

Fourth, the thesis presents findings on how additional information linked to the basic tracking information can be used to achieve further benefits. Paper III presents how the use-by dates can effectively be used to reduce the spoilage problem in the supply chain considerably and thus this thesis supports the findings of Töyrylä (1999) on the usefulness of using material expiration dates in lot level logistics control. Further research in Kärkkäinen et al. (2004) reports achievable benefits when incorporating information of the materials carried in the packages to the tracking systems aimed for controlling the rotation of the reusable packages themselves.

5.2 How to construct tracking systems for short-term networks

The second research question of this thesis is: “How to design tracking systems applicable to short-term multi-company networks?”

This research question is addressed in Paper II to some extent, but it is mainly dealt with in Paper IV. As Paper II presents earlier understanding of the same issues as discussed in Paper IV, material for this section is drawn mostly from Paper IV as the ideas are further developed and presented in a better-organized way there.

Paper IV proposes a solution concept called forwarder independent tracking (FIT) as a solution for the difficulties of tracking in short-term multi-company supply networks. Next we will present the description of FIT from Paper IV.

The aim of forwarder independent tracking is to produce and disseminate reliable tracking data from deliveries that are handled in short-term multi-company distribution networks. Tracking systems built according to the FIT concept should enable tracking data to be gathered independent of the company handling the goods, with the resulting location information being readily available in the systems of all those companies requiring it.

As presented in sub-section 2.4.1, it is not feasible to integrate the tracking systems of the logistics service providers to a company's own information system when operating in short term supply networks. In many instances, for example when delivering components to international investment projects, the only alternative is then to rely on manual information requests from the tracking systems of the logistics service providers taking part in the delivery of the goods. This method of operating is illustrated in Figure 3. In the Figure the tracking customer refers to the organisation requiring the tracking information. This can be the sender or recipient of the delivery, or when considering project deliveries, the contractor responsible of the timely installation of the ordered goods.

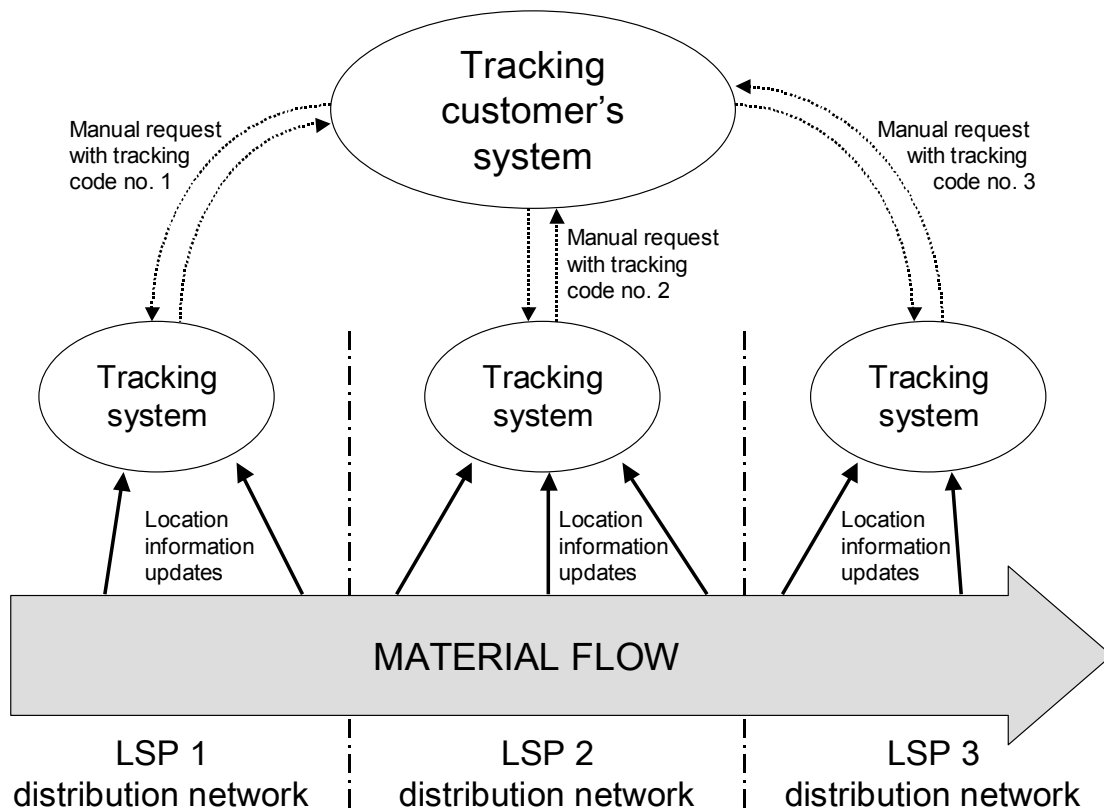


Figure 3 Retrieving tracking information with manual information requests

During the research process, it was identified that the combination of distributed programming and peer-to-peer information sharing allowed developing a new kind of solution to the problems experienced with current tracking systems in a multi-company setting. The problem of acquiring tracking information outside company boundaries could be solved with lean software components by combining these two approaches, as already presented in Paper II.

For the solution concept to have universal application, it was imperative that any given company would be able to receive tracking information concerning their own shipments regardless of the logistics service provider(s) used, Paper IV continues. Another prerequisite for the solution was the possibility of disseminating the tracking information to a project co-ordinator or to a forwarder responsible for the total delivery of the project. This meant that any logistics service provider should be able to offer the tracking information automatically to any of its customers, or their customers' customers.

Each shipment should therefore be able to provide two pieces of information: 1) “which shipment am I?” and 2) “who is interested in me?”. So, according to the forwarder independent tracking concept, each shipment is given an identification code that reveals both the identity of the shipment, and directly tells where the tracking information should be sent. These pieces of information enable logistic service providers (LSP) to gather and spread tracking data. The information system receiving the tracking message has also to be able to identify the location the tracked entity has reached and the time of arrival.

In FIT-type systems, the tracking information can be gathered from both new checkpoints that are installed in the handling locations and the existing tracking systems of the logistics service providers. The idea of FIT solution concept is illustrated in Figure 4.

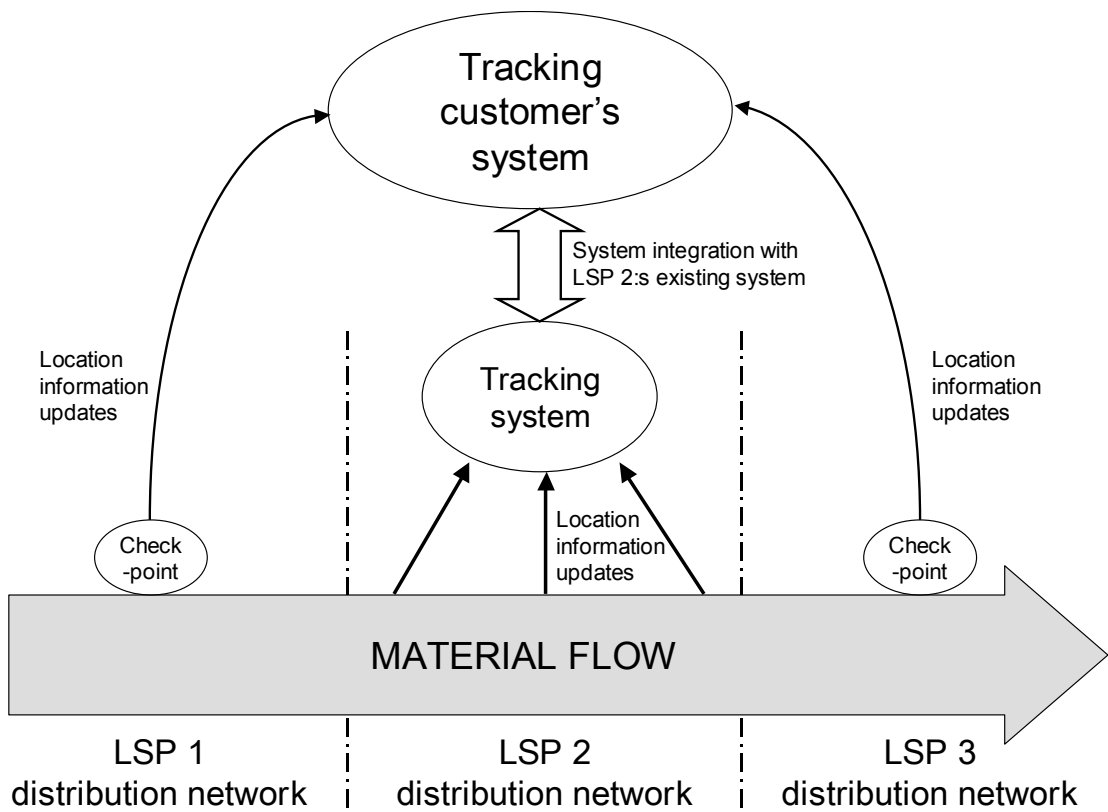


Figure 4 The operating model of tracking system complying with the FIT solution concept (Paper IV)

The practical requirements for incorporating a new LSP to a FIT-type system differ depending on whether an LSP has, or has not, an extensive tracking system (cf. LSP 2 and LSP 3 in Figure 4) and the life-span of the distribution network. If the LSP has an existing tracking system and the business relationship is long-term, then systems integration is a good option for retrieving tracking information from that LSP's tracking system. When tracking is needed for locations or partners without sufficient systems, or the need from tracking information is temporary, new checkpoints should be installed.

As new checkpoints are often needed in a short-term distribution network, the checkpoint solutions of FIT-type tracking systems should be relatively easy to distribute and be quick to install. One solution, fulfilling the distribution requirements, is a file downloadable from the Internet. The installation time for appropriate components should be short even for the less experienced personnel. These kinds of lightweight checkpoints enable a scalable tracking network to be adjusted according to transforming distribution requirements.

Logistics service providers currently operating their own tracking systems should not always have to install new checkpoints. The alternative solution is to re-direct information generated by their tracking systems to the interested party with an integrating middleware component of a FIT-type system. In such cases, the compatibility of data formats of tracking messages with the recipients information systems must be ensured, as is always the case when integrating information systems. The integration efforts are justified when continuous high volume business between the partners can be expected. In instances where integration is deemed desirable the solutions presented by Deschner et al. (1998) and Li and Shu (2003), can be included in the set of potential integration tools.

The aim of the FIT solution concept is to utilise existing solutions and provide means for efficient tracking in supply networks crossing the boundaries of several traditional tracking systems. Therefore it differs from traditional systems with strictly proprietary coding and information management practices.

The basic requirements for tracking systems complying with the FIT solution concept are summarised in Table 6.

Table 6 The basic requirements for tracking systems complying with the FIT solution concept (Paper IV)

	Operational scope of the system	Identification technology	Item coding	Information content	Information architecture	Accessibility of information
Forwarder Independent Tracking -systems	The system can be easily operated by all LSP's even in short-term networks	Should support several technologies	Identifies the item and the recipient of the information	Basic attributes, preferably possibility for supplementary information	Can in principle be centralised to service provider or distributed to the users of the tracking data	The data should be directly available on the systems of the parties needing the tracking data

Paper IV also presents a demonstration system complying with the FIT guidelines. This demonstration system was used to assess the practical feasibility of the FIT solution concept. Several key characteristics of the demonstration system were presented already in Paper II. Next we will review how Paper IV describes the demonstration system of the FIT solution concept.

To incorporate the two distinct pieces of information needed for identifying packages in FIT systems: the identity of the shipment and the identity of the recipient of the tracking information, the notation ID@URI was used in the demonstration solution. In this notation the ID stands for an identity code of the consignment, and URI stands for the uniform resource identifier (i.e. Internet address) of the computer to which the tracking messages should be sent. Because all URI's are unique by their definition, the ID parts of codes connected to different URI's can be identical without problems of dual codes. This gives the owner of the URI freedom to define their ID-coding scheme, without the need of co-ordinating the efforts between different parties creating codes. Therefore, ID@URI-coding enables multi-company applications without the need for standardising and allocating codes for shipments.

In some situations the ID@URI may not be used as the only identification code for the tracked product. For example, existing project management systems usually identify deliveries in their own way, for instance by project and item number. Therefore, to ease the use of the system in the operations of several companies, the system incorporates a functionality of mapping the ID@URI codes to company internal codes. This enables the use of the system with the current internal coding in a company.

The application was developed around two software components. The first is a client agent, which is needed at each checkpoint where shipments are tracked. The second component is a server agent residing at the computer specified by the URI-part of the identity. It receives tracking messages from the client agents and forwards the tracking information to the in-house tracking system of the company.

The basic operational principle of the system is that when a delivery arrives at a checkpoint, its tracking code is read to the client component. The client then communicates the identity of the checkpoint, the tracking code of the consignment and the time of the reading operation to the server. The server compares the tracking code to the shipment identity used in the in-house tracking system of the case company, and subsequently up-dates the information in the tracking system.

These client and server components are *lean* (123 and 39 kilobytes respectively), *quick to install*, and *platform-independent* as they are programmed using Java programming language. Both the leanness and quick installation are important for effective forwarder independent tracking solutions. Leanness is important, as it enables distributing the components efficiently via the Internet. The components can be downloaded via the Internet (even over a GSM-data connection), or distributed as e-mail attachments. The installation of the components typically takes only a few minutes, which enables efficient set-up of the system; and, thus allows using the system for temporary distribution networks. Platform independence of Java-based components helps to keep the system accessible to all companies in the distribution network.

The recipient's information system can identify the tracked shipment based on its ID@URI code. Separate measures have to be taken to identify the location of the checkpoints. Two different approaches can be used to manage the checkpoint identities:

- 1) The recipient of the information manages the identities when it organises the distribution of the checkpoint software. The software can be distributed with the identities via e-mail, or when using www-downloads, the checkpoint personnel can be forced to register the identity and location of the checkpoint when downloading the software. This, however, leads to several overlapping proprietary tracking networks if several companies wish to track their shipments at the same location. Although the

leanness of the software makes it possible to operate several tracking networks with different software components at a single checkpoint, it demands extra operative effort at the checkpoint.

2) The checkpoints have globally unique identities based on a standardised notation. The authors propose a notation of the form `LocationID@URI` for the checkpoint location identities. The `LocationID` is the identity of an individual checkpoint, and the company operating the checkpoint allocates it. The `URI` is the Internet address of the operator's server containing exact information (e.g. postal address, operating hours, handling equipment) on the individual checkpoints. This enables the system to remain scalable, as all checkpoint identities are globally unique and companies operating the checkpoints can use the same software components with all their customers.

When using the `LocationID@URI` notation, the management of information related to checkpoint identities can be implemented with the demonstration system, as the client components of the software can be used also for retrieving information from databases connected to a server component. The practical solution requires that a company operating checkpoints in the tracking network stores the checkpoint identities and the related information on a database table and installs a server component connected to the database. The companies receiving tracking information can then use a client component to query the database for information regarding specific checkpoint identities (Kärkkäinen et al., 2003b).

The format of the timestamp has been solved in a trivial manner. The server component takes a Java Database (JDBC) connection to the database in which the tracking information is stored and inserts the information with a standard SQL insert. Therefore, the timestamp generated by the client takes the format used in the tracking database when inserted in it

The demonstration system in itself does not depend on the identification technology used on the tracked consignments. The system can be used with all available techniques for automatic identification if the technology supports the `ID@URI` notation. In practice, drivers for bar code and radio frequency identification (RFID) readers are

installed and the system also supports manual data input if no automated means are available.

The key features of the demonstration system are summarised Table 7. Furthermore, the table recaptures the key issues of predominant tracking systems and the FIT solution concept to ease their comparison.

Table 7 The key factors of predominant tracking systems, the FIT solution concept, and the demonstration system (Paper IV)

	Operational scope of the system	Identification technology	Item coding	Information content	Information architecture	Accessibility of information
Predominant tracking systems	LSP handling the shipments operates the system	Bar code (sometimes manual or RFID)	Proprietary tracking number	Basic tracking attributes (supplementary information)	Centralised to the LSP (tracking service provider)	www-query, EDI-link, systems integration
Forwarder Independent Tracking -systems	The system can be easily operated by all LSP's even in short-term networks	Should support several ID technologies	Identifies the item and the recipient of the information	Basic attributes, preferably possibility for supplementary information	Can in principle be centralised to service provider or distributed to the users of the tracking data	The data should be directly available on the systems of the parties needing the tracking data
The FIT demonstration system	Any company that downloads the client over the Internet can use the system	Bar code, RFID and manual data input supported	ID@URI code specified by the user of information	Basic + comment field with free text	Distributed to the users of the tracking data	Data resides in the systems of the companies requiring the data

To further test the practical applicability of the forwarder independent tracking concept, an industrial pilot installation was undertaken with the demonstration system. The pilot was performed with an original equipment manufacturer (OEM) delivering sub-solutions to heavy industry investment projects, and its subcontractor. (Paper IV)

The pilot installation received positive feedback. The installation of the components proved efficient and the system operated to specification. No discrepancies were encountered during the one-month time span of the pilot. Furthermore, the personnel involved had no significant difficulties when using the system. The case company considered the system very efficient and it decided to apply a system with FIT principles also in the future. The development and maintenance of the system at the case company has since been transferred to a commercial software vendor, and it has since been used in an intercontinental project delivery during 2002 (ISI Industry Software, 2003; Peltonen, 2002).

Thus, Paper IV, and therefore this thesis, contributes to the previous literature by presenting a solution concept that can be used for designing tracking systems to gather and convey tracking information in short-term multi-company supply networks. The concept is validated with a pilot implementation conducted with a demonstration software built according to the guidelines of the solution concept. The proposed solution concept is novel and clearly different from the predominant tracking approaches. Furthermore, the proposed solution concept can act as a valuable complement when utilising the solutions of Deschner et al. (1998) and Li and Shue (2003) for integrating existing tracking systems by also enabling the gathering of tracking information from supply chain locations not covered by the span of monitoring of the tracking systems to be integrated.

5.3 The applicability area of the tracking-based transparency approach

The third research question of this thesis is: “How does operational environment affect the applicability of the tracking-based approach to increase material flow transparency?”

This research question is addressed mainly in Paper VI, and to a lesser extent in Papers II and V.

Section 5.1 presented how tracking systems and information can bring benefits by increasing the material flow transparency in the supply chain, the basic requirements for this transparency were also reviewed. Paper VI further presents how tracking systems complying with the FIT solution concept can be used for establishing material flow transparency in all parts of a supply chain. As a summary, FIT-type tracking systems enable visibility to goods in transit due to their potential of creating comprehensive tracking networks and the checkpoints of FIT-type systems can easily be installed at different storage locations of a supply chain and thus also enable visibility to material in supply chain inventories. (Paper VI).

When building inventory transparency with FIT systems, checkpoints that track all in- and out-going material of a warehouse or a specific inventory area are installed. It is

then possible to find out what shipments are currently in the inventory location by interrogating the tracking database, as illustrated in Figure 5. For establishing stock keeping unit (SKU) -level inventory transparency, information of the content of the shipments is also needed (Ala-Risku and Kärkkäinen, 2004). The inventory levels for each SKU can be calculated by counting the number of the SKU in each shipment in that storage location. Correspondingly, the inventory value for that location can be calculated by summing up the values of shipments residing in that location. This procedure of building transparency with tracking is further referred to as the tracking-based approach to increase material flow transparency.

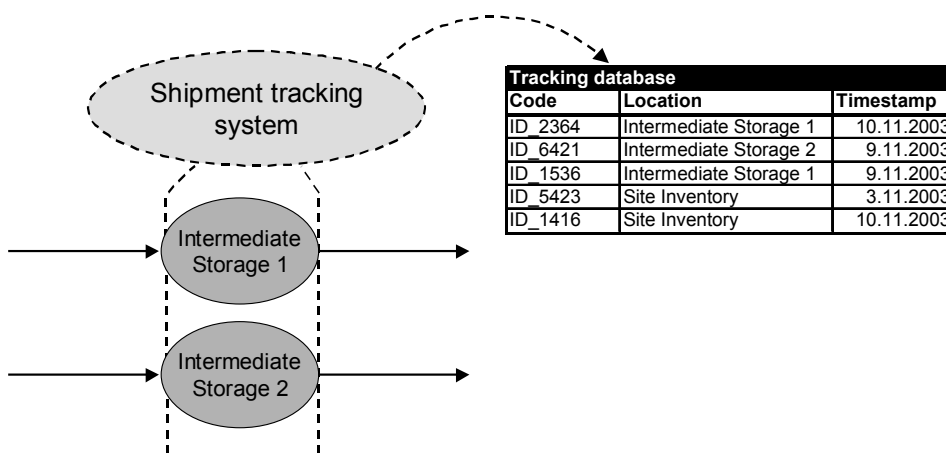


Figure 5 Inventory transparency created with a tracking tool (Paper V)

Paper VI examines the potential of utilising the tracking-based transparency approach in supply chains with small and medium-sized enterprises (SMEs). This is an important topic of research as transparency solutions have not been implemented by SMEs due to: 1) the high investment usually needed in the currently the available options, 2) the demand for sophisticated internal systems by most transparency solutions, 3) the need of IT resources and expertise in the installation and maintenance of most available options, and 4) the applicability of most available solutions with communication only with a single partner. (Compiled from Eagan et al., 2003; Levy et al., 2002; McLaren et al., 2002; Morrell and Ezingard, 2002; Patterson et al., 2003; Stefansson, 2002.)

Paper VI states that these difficulties that SMEs experience with information technology solutions can be avoided with the tracking-based approach for generating transparency. The paper draws on pilot installation and case study material for its analysis and

concludes that the tracking-based approach can be implemented with very little investment requirements, is applicable with low end systems and actually does not require any existing inventory monitoring systems to already be in place, has minimal requirements for installation and maintenance and is scalable for use with several partners. Therefore, based on the findings of Paper VI, it can be stated that the tracking-based approach for developing material flow transparency is feasible also in supply chains including SMEs. Therefore, the potential existence of SMEs in the supply network does not affect the applicability of the approach.

Paper VI also identifies several environmental factors contributing to the applicability of the tracking-based approach for generating transparency. The applicability factors of the proposed approach are summarised in Table 8. It has to be noted that the presented results are gathered from three case studies, and therefore do not form a comprehensive representation on how different environmental factors affect the applicability of the proposed approach.

Table 8 Environmental factors contributing to the applicability of the proposed transparency approach (Paper VI)

Environmental factors with positive contribution to applicability	Environmental factors with negative contribution to applicability
+ Short-term transparency requirements: <ul style="list-style-type: none"> ○ Transparency to a temporary storage location or distribution partner ○ Temporarily increased need for transparency (e.g. promotions and product introductions) 	- Well working current internal systems and high efficiency requirements in the supply chain
+ Supply chain locations or distribution partners currently lacking internal solutions	- The integration of current systems can be seen as an investment in a long-term relationship
+ Delivery item level measurement and control desirable in the supply chain	- High volume operations where packages are dismantled and repacked

We will next review the factors in more detail, first discussing the factors that make the approach attractive, and then moving to the factors that undermine its practicability.

Paper VI states that supply chain environments that profit the most from the tracking approach are characterised by short-term demand for additional transparency, supply chain locations with no existing inventory management systems and situations where delivery items are already assigned to end user demand.

The first issue concerning the applicability of the approach was the time-span of the transparency requirement, which was brought up in all the three case studies in Paper VI. The features making the approach attractive for short-term need are low investment cost and speedy implementation. Paper VI further identifies two distinct categories of temporary transparency need: 1) developing transparency to storage locations that exist or are included in the supply chain only temporarily, 2) temporary transparency demand due to infrequent and complex situations demanding increased supply chain visibility, such as promotions, product introductions, product ramp-down or when incorporating a new partner to the supply chain.

The second aspect, which was very clearly present in two of the cases in Paper VI, is the suitability of the tracking-based transparency approach for supply chain locations without existing inventory management applications. The approach does not require the existence of any previous applications; instead, it can actually provide a simple inventory monitoring system for the storage operator in addition to the transparency for the supply chain. This is important, as inventory has to be monitored in all parts of the supply chain (Ballard, 1996). The fit of the tracking-based approach for storages currently lacking inventory management systems is supported by Paper V, which presents the tracking-based approach as a solution especially for inventories at the project site and other short-term storages in the project supply chain, often currently operated by manual inventory control practices.

Third, Paper VI suggests that the tracking-based transparency approach is well suited for supply chains where delivery items are designated for a specific end use or user and thus require delivery item level control in the supply chain. In the telecommunication equipment delivery case of Paper VI, the delivery items are, as a rule, pre-assembled installation packages for a single project task. In this case, an interviewee from project management operations regarded the dwell times of individual delivery items as a far more important metrics for controlling and developing operations than inventory levels

of stock-keeping-units (SKUs) or inventory value. He argued that as the project operations are carried out with installation packages, not SKUs, the distribution process should also be controlled and measured on the delivery item level to ensure effective support to the installation project.

This finding is supported in Paper II, which presents that a large part of the material installed in investment project sites are customised “product individuals”, i.e. products that (whether customised or mass-produced) have a specific, clearly defined place in the resulting construction, are identifiable at individual item level and have to be handled as individuals. Product individuals have to be treated in an individualised manner throughout the supply chain. Their specification, quantity and delivery time are defined in the project plan. (Paper II). Therefore, tracking-based material control is required, as a large deal of material in investment projects cannot be controlled just by keeping account of materials as SKUs.

In Paper VI, the following environmental factors were identified to limit the applicability of the tracking-based transparency approach: strict requirements for efficient material handling and the existence of adequate information systems in the facilities, long-term partnerships with large partners that support integration efforts and high volume warehouse operations with dismantling of received delivery packages and re-packaging items for dispatch.

One interviewee in the furniture case of Paper VI pointed out that if not integrated to internal systems, the tracking-based transparency approach can introduce a new manual work phase to the material handling processes. If a company already has sufficient internal material control systems, the costs of using the approach may in the long run exceed the costs of integrating current systems with its partners. Therefore, in cases of high operational efficiency requirements and existing inventory systems, the applicability of the approach needs to be studied on a case by case basis.

Paper VI also states that building transparency by integrating current systems may also be appealing if more wide-ranging solutions are desired. For example, in the furniture case the retailer organisation started to offer a flexible integration module to its suppliers while the study was in progress (Paper VI). All three SMEs accepted the offer,

as the retailer agreed to deal with all needed data conversions. The investment to the retailer's transparency solution can be considered natural for the supplier companies, as the retailer is a major customer for each of the suppliers and the companies have agreed on building a long-term partnership with each other. Therefore, even the supplier companies expect the systems investment to be beneficial in the long run. In this instance, the investment is rather to the mutual relationship, not mere data exchange, which may in some situations be strategically desirable.

One supplier in the furniture case of Paper VI currently uses a tracking-based internal inventory control application. However, it is clear that the tracking-based approach is most useful when the contents of the transport packages are not unpacked and repacked. The unpacking and re-packing of goods can of course be managed with the tracking-based system, for example by using the composite container methodology applied from object-oriented programming as presented by Främling et al. (2004). However, the recording of all unpacking and packing operations individually can undermine the efficiency of warehouse operations. Therefore, the proposed approach cannot be considered feasible for traditional large volume distribution warehouses unless the recording of all the material handling activities can be truly automated for example with RFID technology. On the furniture suppliers case the approach is feasible as it always packages only one final product per a package.

Based on the analysis in Papers VI, V, and II we can conclude that the tracking-based material flow transparency approach is likely to be a good solution in supply chains with temporary transparency needs, limited information systems, and a need for delivery item level logistics control. The findings of Paper VI suggest that the suitability of tracking-based approach is questionable in environments with strict efficiency requirements and adequate internal control systems in place, long term relationships, and large scale SKU-level warehouse operations. Based on Paper VI we can also conclude that the size, investment possibility, and level of IT expertise of an organisation do not play a major role on its possibility of taking the tracking-based transparency approach in use. As the results are based on three case studies, they can not be considered a comprehensive representation on how different environmental factors affect the applicability of the proposed approach. However, the results offer help

in understanding in which situations the tracking based approach for creating transparency can be beneficial to companies, and where its feasibility is questionable.

Even though the research related to research question 3 has specifically focused on the applicability area of generating inventory transparency with FIT-type tracking systems, most of the findings are not FIT specific. Generally, other tracking systems can also be used for generating transparency in short-term or low-volume business relationships, depending on their technical set-up. For example, the challenges related to sender-specific tracking coding are reduced if checkpoints of individual tracking systems can be quickly and easily taken into use. In such cases several systems can be used in parallel. However, operating several systems and selecting the appropriate one for each package can decrease operational efficiency at the sorting and inventory locations, and is a potential source for errors. Of course, these problems are minimised if the warehouse or sorting location handles the goods of only one partner.

The findings related to research question 3 have interesting implications on a proposed empirical theory linking warehouse complexity, warehouse control, and warehouse management systems (Faber et al., 2002). The proposed theory states that the number of orderlines processed per day and the number of SKUs in the warehouse are the two main variables determining warehouse complexity. An increase in the value of these variables increases warehouse control complexity, and thus increases the likelihood of needing a custom made warehouse management software.

The results of this study suggest an amendment to the theoretical framework. The primary feasibility case of the tracking-based approach – a situation where dedicated packages are handled in a warehouse without dismantling them – can be thought of as a situation with an unlimited number of SKUs (often somewhat similar in physical characteristics) operated with standard control and handling procedures. However, the packages have to be individually controlled, their information can not be pooled in information systems by handling them only in quantities of a certain SKU. The set-up demands individual package level information management and operations control and traditional warehouse control methods (such as the ABC classification based on transaction volumes) are totally inapplicable in such situations. The findings of this

research thus suggest that an amendment to the proposed theory of Faber et al. (2002) is needed.

5.4 When to utilise RFID technology in tracking

The fourth research question of this thesis is: “Under what circumstances does RFID technology offer the most benefits in tracking?”

The factors affecting the benefits of RFID over bar coding as the identification technology for tracking applications are addressed in Papers I and III, and to a lesser extent in Paper IV.

This section is organised as follows: first, we will present a classification of the benefits achievable with automatic identification technology based on Paper I. Then we will discuss the role of RFID in achieving these benefits based on Paper III and complementary literature. Finally, we will form a proposal presenting in which situations should RFID technology be applied in tracking based mostly on Papers III and IV.

5.4.1 The benefits achievable with automatic identification

Paper I presents the concept of item level supply chain management as a goal in which the potential benefits of automatic identification have been achieved. In the paper the benefits achievable with automatic identification technologies are classified as efficient handling, efficient customisation and effective information sharing enabled by the identification technology.

Paper I states that in order to achieve greater velocity in distribution, distribution centres have to be extremely effective in handling and sorting shipments. British Airways (Nelms, 1999) and Lynx Express (Anon., 2000) have successfully used wireless identification technology to achieve significantly faster and more accurate sorting and distribution.

According to Paper I, the challenge of being able to produce customised products efficiently, even at item level customisation, is easier to solve when products can be identified on single product level. For example, QSC-Audio Products has built a smart conveyerised assembly system using radio frequency identification (RFID) technology. This system enables the company to build to order with mass production efficiency. RFID tags are used to identify the products on the assembly line and the configuration of a particular product to be assembled is attached to its identity. (Feare, 2000)

Paper I also states that the problems in the sharing of operational information linked to small, customised deliveries across company boundaries are solved if all the necessary information about handling a product is attached to the product and is attainable in an effortless (automatically readable) way. For example, EDI messages can be stored in identifiers attached to deliveries (Johnston and Yap, 1998). Besides solving the problems of linking material and information flows together, the communication of operational information with the deliveries themselves decreases the need to integrate information systems in order to build effective processes between companies. The possibility to use identifiers to carry operational information in systems readable form enables supply chain partners to automate processes without systems integration. Therefore, it is also possible to use short-time partnerships more effectively.

As the examples indicate, item level supply chain management is a solution to the handling, customisation and the information sharing challenges in supply chain management. The enabling steps to item level supply chain management are illustrated in Figure 6. Handling efficiency is the basis on which item level supply chain management is built on. It can be achieved when products are identified without a need to handle them physically. Automatic identification in single item level enables efficient customisation. In efficient customisation products or deliveries are efficiently processed and handled in small batches. Effective information sharing enables efficient handling and customisation even in dynamic inter-company networks. The key to effective information sharing is attaching the control attributes to the product so that they are globally available without prior arrangement. (Paper I)

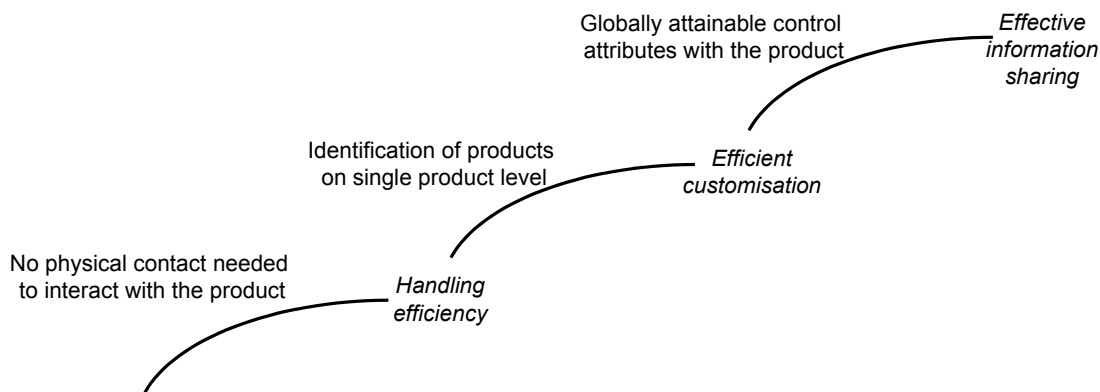


Figure 6 The enabling steps of item level supply chain management (Paper I)

Greater handling efficiency can be achieved if the need to handle the product in order to identify it is eliminated. Wireless product identification technologies can be applied to enable interaction with the product without physical contact (Paper I).

Paper I continues that most commonly used wireless identification technology is based on Radio Frequency Identification (RFID) tags. It can fulfil the requirements of item level supply chain management with acceptable costs. Products can be identified effortlessly because RFID tags do not require line of sight in order to be read, they can be read through non metallic materials and tens of tags can be read simultaneously (Jones, L., 1999; Boxall, 2000; Mumby, 2004; Rafsec, 2005; Robson, 2004). The tags are also resistant to temperature and other environmental factors and can be read and written at least hundred of thousands of times and can therefore have a life span of over ten years in continuous use (DeJong, 1998; Mumby, 2004). The read/write capability of RFID tags also enables changing the product information during processing (i.e. re-routing and price-changes). Other technologies that could be used are Bluetooth chips for expensive equipment and Global Positioning Systems (GPS) could be utilised for very large items such as containers even though it is not in itself an identification technology.

Paper I states that in order to be able to practice efficient customisation, products have to be identified at single product level. Then it is possible to control items individually in all parts of the supply chain, e.g. in manufacturing and distribution, which provides the ability to offer customised products and services for the customers (Töyrylä, 1999).

The identity of the product is stored in the tag by using the RFID technology. Common RFID tags provide from 256 bits to several kilobytes of read/write memory (Finkenzeller, 2000; Gould, 2000; Mumby, 2004; Robson, 2004), which would be more than enough to give each individual product an identity of its own.

Further, Paper I presents that effective information sharing can be achieved if supply chain execution data, e.g. how the product is to be handled and where it is to be delivered, is communicated with the product in a machine-readable way. Then, the synchronisation of the information and the physical objects can be assured (Johnston and Yap, 1998). Paper-based processes can also be eliminated without the need to integrate IT-systems. This also enables efficient processes in short-term relationships. When using RFID technology, the control attributes of the item can be stored in the tag's memory or it can contain a reference to a network address where the information about the product is stored, so the control attributes are attainable at any given place (Ashton, 2000; Stebbins, 2000). When using the network address the product's information is also attainable at all times if the product's network address is known.

5.4.2 The role of RFID in realising the benefits

In Paper III, the case retailer decided to go forward with developing an RFID based tracking model for chilled goods because bar code based tracking methods were difficult to apply particularly in stores. In the case of Paper III, it was evident that bar code based practices of inventory management within the store environment are labour intensive, difficult, and prone to errors. This is due to the amount of effort in tracking all the movements of products with bar code based solutions. Furthermore, the store environment presents the biggest logistics challenges in the grocery supply chain, and thus the case company wanted to examine technologies potentially aiding the problems of tracking inside stores.

Paper III states that the most important issues in RFID functionality from the retail viewpoint were the possibility of batch reading and that no line of sight is needed to read the tags. These enable the reading of tags in product crates without a need for separate handling. This was considered especially important in retail store environment where the development efforts were focused.

Therefore, in the case of Paper III, RFID technology development was initiated simply because it enabled more efficient capture of the tracking information – handling efficiency. This notion of utilising RFID in the retail supply chain for increased handling efficiency is supported by the aims of the development efforts of Tesco and WalMart, who are testing and employing read-only RFID technology primarily to enable more efficient data capture from the material flow (Cobain, 2004; Puckett, 2004). Tesco even calls the technology Radio Barcodes in order to easier focus on the issues they are after and to avoid the complicated hype and fuss around RFID technology (Cobain, 2004). The director of information technology at WalMart also pointed out in a recent conference that due to the large volume of material moved they do not have the possibility of tracking the material transfers between store backroom and sales area with bar coding (Puckett, 2004). Therefore, in some instances RFID technology is needed for tracking due to the unfeasibility of capturing the tracking information from the material flow with bar code based solutions.

Besides the volume of transferred goods, the handling environment can sometimes render bar coding useless and therefore RFID can be a good solution for tracking. In the case presented in Paper IV, the company decided to use RFID technology for identifying the deliveries regardless of the associated costs primarily due to the risk of losing the readability of bar codes to dirt and wearing in the harsh environments encountered in a mechanical engineering industry supply chain. However, RFID technology is not the only solution for environments where bar coding is not applicable for some reason. Other alternative technologies are, for example, vision recognition and contact memory. For further discussion on the identification technologies see (Kärkkäinen et al., 2001; Moore, 1999b).

The customisation benefits presented in Paper I are not in any way RFID dependant. Bar coding can be easily utilised in very many instances to give items a unique identity that can be used to control and handle the item as an individual. The question, which technology to choose, should be thought of as a selection of the most effective identification technology for that application and environment in question. For example, all the customisation examples in Paper I could also have been carried through with bar

code technology, but the companies have estimated RFID to be more cost effective in their operations.

RFID is not required for the effective information transfer based on identification technology. Here we discuss the two potential information transfer methods: information programmed directly to the identifier and using a code stored at the identifier as a reference to information stored in databases (Paper I).

For transmitting information in the identifier, bar coding can be utilised just as RFID. For example, Johnston and Yap (1998) used two-dimensional bar codes, not RFID, for transmitting EDIFACT advanced shipping notices. Actually, transmitting information in bar codes is in many cases easier compared to transmitting information in RFID tags due to the much greater information storage capacity of two-dimensional bar codes than common RFID tags. Common two-dimensional bar codes can carry 2 000 ASCII characters or more (Kärkkäinen et al., 2001), which is enough for e.g. storing EDIFACT messages as the above example points out. RFID tags with read/write data storing capability currently usually have a memory size of 256 bits. For example, the most recent large-scale RFID adoptions with read/write memory (CHEPs launch of its service of renting RFID tagged pallets, and Marks and Spencer's equipping its reusable delivery crates with RFID tags) have both utilised tags with 256 bits of memory (Mumby, 2004; Robson, 2004). This 256 bits of memory is enough for encoding only 32 ASCII characters. Therefore the information to be stored to RFID tags has to be strictly limited or very tightly structured so that information can be encoded with few characters.

The strength of RFID is of course its potential capability for read/write memory, which enables the information on the tag to be appended and changed. However, in practice the information that can be programmed to RFID tags is highly limited and therefore tags cannot be used e.g. as traceability databases collecting all relevant operations performed to the items they are attached to. Furthermore, a database residing on a tag is accessible only when in the vicinity of the tag, and therefore its utility is decreased as it is not readily available for most relevant traceability operations (Töyrylä, 1999).

RFID technology is also presented as a vehicle for linking information stored in databases to individual items, thus creating intelligent products or the Internet of things (see e.g. Ashton, 2000; McFarlane et al., 2002; McFarlane and Sheffi, 2003; Wong et al., 2002). However, the same referencing can also be performed with bar codes, as is clearly presented for example in Kärkkäinen et al. (2003b). Again, when selecting which identification technology to use as the reference for information in databases, one should consider the effectiveness of the identification situation itself.

In the identification situation itself RFID has some distinct advantages that can in some cases enable overcoming the additional costs. The potential of totally automating the identification and performing automatic inventory counts enables building more robust processes and new types of replenishment services (Småros and Holmström, 2000). RFID has other distinct benefits besides the efficiency of identification; it is almost impossible to copy or forge RFID tags, so the information in the database is only handed out to or updated by a party with the original identifier, and encryption technologies can also be incorporated in the RFID reading process to further enhance security when needed (Finkenzeller, 2000).

5.4.3 The most potential RFID application areas

When separating the facts from the myth and hype and considering the choice of identification technology from the identification event point of view, we can identify four specific situations where RFID especially provides value.

First, RFID has good potential in tracking in situations where tracking is deemed important, but the gathering of the tracking information has to be very efficient for feasible operations. This situation is present in many high volume environments, such as in grocery supply chains or express parcel logistics. The need for RFID is the most severe, if it is not possible to use conveyers or sorting belts on which the items can be automatically identified with bar coding. This is the case for example in stores (Paper III) and any other supply chain location with space limitations, and in temporary or transferring handling locations often present for example in military logistics (Dierkx, 2000; Lambright, 2002; Songini, 2004).

Second, RFID has of course very good potential in environments where bar coding based solutions have difficulties in identification performance, be that due to extreme temperatures, dirt or physical wearing of the identifiers (Paper IV).

Third, RFID provides value in safety-oriented tracking owing to its very good read rate and the hard copying and fortifying of tags, as well as the possibility of encryption. This benefit is present whether there is a need to reduce theft or shrinkage of valuable goods or prevent terrorism (Cobain, 2004; Croft, 2004; Lambright, 2002; Songini, 2004).

Fourth, RFID provides value when the relatively limited data carrying capacity it provides can be turned to good use. This potential was present for example in the case of Paper III, where only the description and quantity of products in the crate, the use-by date of these products and the crate's id-number were programmed to the tags attached to the crates. The case presented how spoilage can be reduced when the use-by dates of products are easily and comprehensively obtained from the goods handled in the supply chain. Great benefits can therefore be accomplished with limited information content. Marks and Spencer has a similar set-up in its RFID based operations, which are planned for full roll out in the spring of 2005 (Mumby, 2004).

The information on product content and the use-by date of products on a transport crate can of course also be transferred in bar codes, as is the current practice for example at Mark and Spencer's (Mumby, 2004) and Sainsbury's (Paper III). However, when information is carried in such reusable transport packages, the possibilities of the read/write memory of RFID can be truly utilised. The information to be carried can be reprogrammed to the tags on each round, and the task of attaching new bar code labels can be avoided. It has even been calculated that this can in many instances be a more cost efficient alternative of attaching the information to reusable crates than attaching new bar code labels to the crates on each round of use (Albright, 2002; Mumby, 2004). Kärkkäinen et al. (2004) are on the same lines by stating that when using identifiers on the reusable packages, it is possible to start utilising more expensive automatic identification technologies, as the same identifiers are used in several use cycles.

Therefore, we can conclude that the potential benefits of utilising RFID in tracking are the highest in situations where the tracking information has to be efficiently gathered from the material flow (i.e. handling efficiency is important), bar coding can not be utilised due to environmental or safety considerations and when the limited capability of storing read/write information on the tag can be efficiently utilised. The prime example of an application in the last category is the use of RFID in the tracking of reusable transport packages.

6 Conclusions

In this chapter, we first present the most important findings related to each research question and discuss how they contribute to previous literature in section 6.1. Then in section 6.2 we discuss the implications and linkages of these findings. Section 6.3 focuses on the evaluation of the thesis research.

6.1 Contribution of the thesis to prior literature

This thesis contributes to prior research literature by providing information for answering the four research questions of the study.

In relation to the first research question: “What can be obtained by using tracking systems and tracking information?”, the thesis makes four distinct contributions: 1) the thesis describes the potential of tracking for the purposes inventory monitoring and material flow transparency in the supply chain and the requirements for utilising tracking in establishing transparency, 2) presents specific ways of utilising tracking information in project-oriented industries, 3) validates prior literature on using tracking information for developing logistics metrics by further results and describes what additional information is needed for developing the metrics, thus enhancing the practical applicability of the results, and 4) it presents findings on how additional information linked to the basic tracking information can be used to develop further benefits.

For answering second research question: “How to design tracking systems applicable to short-term multi-company networks?”, the thesis adds to previous literature by proposing a novel solution concept for solving the challenges of tracking in short-term multi-company networks. The proposed solution concept is validated by a pilot installation with a demonstration system constructed by the guidelines of the solution concept.

In answering the third research question “How does operational environment affect the applicability of the tracking-based approach to increase material flow transparency?” the link between tracking and material flow transparency is examined further. The

question is answered by mapping out environmental characteristics that affect the applicability of the tracking-based approach for generating transparency. The tracking-based approach is likely to be a viable solution in environments with temporary transparency needs, limited information systems, and need for delivery item level logistics control. The feasibility of the approach was found questionable in environments with strict efficiency requirements and adequate internal control systems, long-term relationships and large-scale SKU-level warehouse operations. Company size, the availability of capital for systems investments and the level of IT expertise of an organisation do not seem to play a major role in the possibility of taking the tracking-based approach into use. These results do not form a comprehensive representation on how different environmental factors affect the applicability of the proposed approach, but give significant aid on determining the feasibility area of the proposed transparency approach.

The fourth research question: “Under what circumstances does RFID technology offer the most benefits in tracking?” is answered by concluding that RFID technology offers most benefits in situations where its true advantages – related directly to the event of identification of the item – can be taken use of. Such circumstances are present, for example, in environments where tracking is deemed important and identities of delivery items have to be very efficiently retrieved from the material flow for tracking to be feasible, where there are safety concerns to be addressed, or bar coding is unfeasible due to the characteristics of the physical environment. RFID can also provide significant value in environments where the limited read/write data carrying capacity it provides can be successfully used. Examples of such environments are the distribution of perishable goods, where adding the use-by date of the goods can provide significant benefits and the identification of reusable transport packages where the material content of the packages (and potential additional information) can be programmed to the tags on each round of using the package. These guidelines can be considered as a contribution, as previous literature did not include any clear guidelines, but presented contradictory viewpoints on whether and when RFID technology should be utilised in tracking.

6.2 Managerial implications

In this section we analyse the findings of the research questions concurrently and discuss the implications of the findings. When we examine the findings of research questions 1, 2, and 3 we can identify significant potential effects on the dynamics of logistics service markets.

Findings related to research question 1 outline how tracking systems and tracking information can be used to increase the efficiency of logistics service provision as well as the value of the service for customers. The big potential of tracking is also apparent in the trends of the industry. Major logistics companies continuously spend millions in developing and retaining capacity for tracking goods transported in their distribution networks. The customer value of reliable tracking information is also apparent in the actions of several major producer companies at least in the high tech sector. The quest of building a global distribution network with only a few selected LSP's is by a great deal motivated by establishing reliable visibility to the material flow. If a global visibility to the transported material is sought for, then reliance on only a few large LSP's is a logical choice with the predominant design of tracking systems. The large LSP's are natural partners as they have sufficient resources for developing their tracking systems, and the number of partners has to be restricted due to the amount of effort in systems integration with each of the partners. In many instances this reliance on a few large companies with good tracking systems can lead to a distribution network with reduced distribution effectiveness in some areas as well as increased costs. Therefore tracking systems can be seen as a technological driver that affects the market structure of logistics service provision.

A change in the basic solution design of tracking systems can alter the way in which they affect the development of the market of logistics services. The research related to research question 2 has focused on the development of tracking solutions for short-term distribution networks, and deliveries in project-oriented industries are cited as the prime example of such short-term networks. However the proposed solution concept of Forwarder Independent Tracking (FIT) has two characteristics that make it very relevant also when building logistics networks for more stable distribution needs. First, FIT offers a possibility for gathering tracking information from an LSP without arduous

integration effort. Second, the FIT solution concept would enable logistics companies currently without tracking systems (e.g. small, local companies) to offer comprehensive tracking information to their customers.

These aspects of the FIT solution concept could have a major impact on the structure of the markets of logistics services, if the concept grows more popular. First, easier integration with the tracking systems of several LSP's would reduce the pressure of reducing logistics partners. Also, the system would also potentially reduce the importance of tracking systems integration as a factor of customer lock-in. Second, tracking systems would not act as a differentiator in the market for logistics services. This could potentially increase the feasibility of acquiring logistics services with spot trade and even increase the feasibility and popularity of transportation marketplaces. Third, reduced effort in adding a new company to the distribution network and the reduced cost of offering tracking services could potentially lead to the emergence of strong local distribution companies. These local companies could have a very high market share in a distinct geographical area, and could be directly utilized by end customers strongly present on that area. However, the local companies would also be good partners for several larger LSP's not willing to invest in building a comprehensive distribution network in that area. The same local company could in principle serve several global service providers, as it would be relatively simple to convey the gathered tracking information to each one of them. The inclusion of the same local distribution partners in the networks of several global LSP's without a sacrifice in the quality of the service could lead to an increase in the total efficiency of logistics services.

The findings related to research question 3 suggest that in addition to having an impact on the markets of logistics services, the FIT solution concept can affect also supply networks with warehousing and production. This is because FIT can be used to establish visibility to goods stored or processed within the facilities of organizations participating in the supply network with relatively little integration effort. Therefore, it removes some information systems related obstacles from the use of temporary supply network partners. Thus, it potentially has the same kinds of affects as industry-wide standardization efforts such as RosettaNet.

The findings related to research question 4 suggest that, at least in the short-term, RFID will potentially be the most beneficial in enduring high volume distribution networks. The high volume of operations enable taking full use of RFID's potential in increasing the efficiency of handling, and enduring supply chain relationships provide a stable basis on which to build operations, so that investment in tags and readers can be justified. Furthermore, the stability of relationships in the supply network eases the introduction of reusable packaging, and the value of RFID is very high when applied to reusable packaging. Therefore as the primary feasibility area of RFID seems to greatly differ from the primary applicability area of FIT, it is very likely that large-scale implementations of RFID will first be performed with conventional tracking systems, and RFID will not be widely utilized in FIT systems.

6.3 Evaluation of the thesis

This thesis has utilised the Innovation Action Research (IAR) -framework as a guideline for carrying out the research. The IAR approach does not incorporate a formal framework for evaluating the success of the research. There are also very few other formal frameworks for evaluating the success of design research. Kasanen et al. (1993) present that the success of design research should be evaluated based on the following aspects: 1) are companies willing to take the proposed design into use and 2) whether measurable benefits can be obtained with the design. They further present a set of three different market tests for measuring the success of the resulting design on these two dimensions: 1) weak market test (has any responsible manager applied the design), 2) semi-strong market test (has the design become widely adopted), and 3) strong market test (have the users of the design systematically achieved better financial results than others).

The presented market tests can be very useful in estimating the relevance and applicability of the results, but it is also evident that a considerable time is needed for companies to take a researcher's design proposal into operative use, i.e. for the requirements of the market-tests to be filled. It cannot be considered a reasonable requirement for a thesis project that develops a novel solution design to ensure that the results of the research are also put into large-scale use by the industry.

However, as already briefly presented in section 4.1 the IAR approach incorporates feedback-loops for ensuring and increasing the practical and scientific validity and relevance of the results. The feedback loops of the IAR cycle closely resemble the double-loop learning procedures suggested by Mahoney and Sanchez (2004). The feedback loops of the IAR approach are illustrated in Figure 7. The practical feedback loop consists of discussing the target problem and proposed solution design with managers of companies where the problem should be present and should also incorporate implementations of the proposed solution design. The scientific feedback loop consists of presenting the results in scientific conferences and journals.

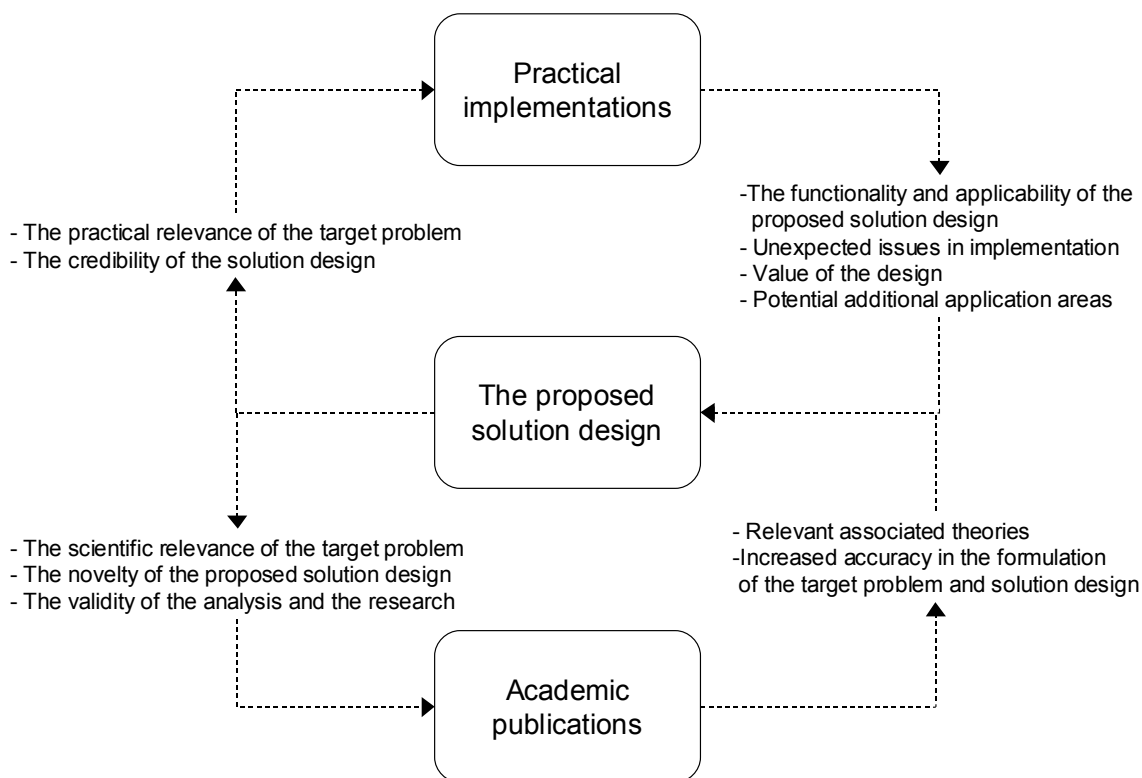


Figure 7 The feedback loops of Innovation Action Research (applied from Kaplan, 1998)

The practical feedback loop is needed to ensure the relevance of the target problem and to assess the credibility of the proposed solution design – is the proposed solution and the logic of the solution believable to the industry experts. The problem has to be relevant and the proposed solution has to have some credibility for companies to invest their resources for (pilot) implementations of the system. The discussions with management and practical implementations also give relevant feedback on the

functionality and applicability of the proposed solution design, reveal unexpected issues or problems in the implementation of the proposed solution design, can help in establishing the value of the solution design, and the implementations can even reveal new application areas for the solution concept.

Continuous publication of the research results helps to ensure the scientific relevance of the research and the novelty of the proposed solution design. The referee process also often forces to clarify the representation of the target problem and proposed solution. Also, the validity of the analysis and research, which serve as the basis of the solution proposal are reviewed in the referee process. The conference presentations and published articles can also give the researcher information on previously unfamiliar management theories, for example from a different field of research, that potentially can be linked to the problem or proposed solution design.

The above described feedback loops can be used for continuous informal assessment and direction of the research (Kaplan 1998). However, the feedback loops can be used also for formal assessment of the results, if evaluation criteria can be set. Especially the clarity of the representation of results, the validity of research, as well as the practical relevance and applicability of the findings can be assessed with the above described feedback loops. More formal evaluation helps to overcome the weakness of the IAR approach. However, as Kaplan does not present any criteria for evaluating the research, applicable evaluation criteria have to be sought from other sources.

Different authors have proposed different criteria for evaluating design research. Niiniluoto (1993) considers that the results of applied science should be assessed by their correctness, informativeness, and truthlikeness as all sciences, but also based on their practical applicability. Benbasat and Zmud (1999) propose that the results of design science should be above all practically relevant. The practical relevance comprises the practical importance of the target problem, the utility of the proposed solutions, timeliness of the problem and proposed solution (i.e. focusing on current problems and technologies), and accessibility of the results (i.e. the results are presented in a way understandable also to practitioners). Holmström et al. (2004), are on the same lines as they propose design research to be evaluated based on the novelty, relevance, functionality, and optimality of the proposed solution designs.

The scientific relevance (i.e. novelty) and validity (correctness, informativeness, and truthlikeness) of the results of this thesis research can be evaluated based on the lack of previous literature on the topics, and the success of publishing the results in peer reviewed journals. The accessibility of the results can be evaluated based on the published papers, i.e. can the separate publications and this compendium be considered understandable also to practitioner-oriented readers? The practical relevance of the target problem and proposed solution designs, and applicability of the results can be assessed based on the success of getting companies to submit resources to live pilots of the proposed solution designs. Furthermore, the functionality of the solution designs was demonstrated in the successful implementation trials.

7 Discussion and further research

The aim of this thesis is to describe why tracking has become an increasingly important area in logistics management, identify the key problems with current designs of tracking systems, and develop and test a solution proposal that addresses the identified problems. The thesis has been able to establish a classification on what can be obtained from tracking, develop a solution concept for tracking in short-term multi-company networks and outline its applicability area, and examine the applicability of RFID technology in tracking.

In this chapter, we will discuss how the results of this thesis affect logistics management in a greater extent, and what kind of further research possibilities were identified during this thesis study.

First, the thesis brings forth the potential need of a tracking-based control logic in some types of supply chains. The comments in the telecom case of Paper VI raise a question on the whole applicability of traditional logistics control and measurement methods for monitoring the delivery process in project-oriented business. The traditional material flow control metrics proposed in supply chain management literature are based on aggregate information with supply chain location focus (e.g. inventory rotation, delivery reliability or average delivery lead time of specific supply chain phases) (see e.g. Bolstorff and Rosenbaum pp. 49-54, 2003). The findings in this research (primarily from the telecom and machinery cases) suggest that this viewpoint might not be sufficient or optimal for controlling project-oriented operations. Rather, the monitoring and control should focus on the progress of individual shipments. In his thesis, Töyrylä (1999) also reported similar findings when he reported that one case study followed the inventory dwell-times of individual material lots instead of focusing on inventory value and rotation metrics.

The tracking-based control approach differs greatly from the traditional way of controlling material-flow. The focus would no longer be on the effectiveness of supply chain phases or even the whole supply chain, but on the flow of individual products or material lots and their effective control. In principle, this new way of control should suit the project equipment delivery process very well, as it has to aim on timely and reliable delivery of specific products or lots and be able to report any possible delays instantly. Exploring the true applicability of traditional logistics management methods for controlling project equipment deliveries and potentially developing new tracking-based possibilities forms one stream of further research stemming from this thesis study. This stream of further research has already been initiated in the Cyclog research project conducted at the Helsinki University of Technology and within the project there are two ongoing case studies focusing on the topic.

The thesis also presents the solution concept of forwarder independent tracking (FIT). The solution concept can be considered important as it significantly eases the implementation of tracking based control in a multi-company setting. It presents a model for designing tracking systems for multi-company setting and also provides guidelines for unambiguous referral to the tracked entities in a multi-organisational network. As presented in Papers V and VI, FIT-type tracking systems can also be used to establish inventory transparency and other metrics in multi-company supply chains operating with traditional control logic. Thus, the results have great potential utility for all kinds of multi-company supply chains, as material flow transparency is considered one of the most important aspects of successful supply chain management (Ballard, 1996; Clarke, 1998; Gunasekaran and Ngai, 2004; Lee and Billington, 1992; White and Pearson, 2001)

Increasing the amount of empirical research material on the applicability and implications of the FIT concept is another area in the need of future research. Fortunately, there are now also some commercial providers of tracking services corresponding with the principles of the FIT solution concept (ISI Industry Software, 2005; LogiNets, 2005; Stockway, 2005), which enables the researchers to perform case studies on installations with commercial software. This can significantly reduce the effort needed from researchers compared to researcher led pilot installations.

Furthermore, commercial providers, due to secured maintenance and development of the solution, potentially enable studying the concepts in real-life operations, not just in the piloting phase. Structured interviews and potentially even surveys could also be used to further examine the applicability area of FIT.

The telecom and machinery cases in Paper VI and the analysis of the challenges of project management in Paper V also brought forth the existence of temporary storage locations in the cases. This is an interesting discovery as the literature discussing facility (warehouse or depot) location problems traditionally deals with the tradeoffs between fixed warehouse location costs and variable transportation costs (see e.g. de la Fuente and Lozano, 1998). Therefore, the whole phenomenon of temporary storage locations could provide a fruitful area for further research with a significant contribution to the logistics literature. There are several potential interesting research questions linked to the temporary storage locations, for example: where do they exist and why are they used, what is their economic impact, in what situations should they be used, and how should they be controlled?

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Appendices

Appendix A The informants in the furniture case

Organisation	Interviewee
Retailers' distribution organisation	Several interviews and discussions with the logistics management (logistics director and development manager)
Retailers' distribution organisation	Interviews with systems development representatives (IT director (three interviews) and IT manager)
Supplier A (sofa supplier)	Quality manager (4.6. 2003)
Supplier B (shelve supplier)	Managing director (10.6. 2003)
Supplier B's information system supplier	Phone interview with the managing director (2.9. 2003)
Supplier C (shelves supplier)	Phone interview managing director (8.9. 2003)
Retail chain A	Phone interview with store manager and regional manager (15.9. 2003)
Retail chain A	Phone Interview with another store manager (22.9. 2003)
Retail chain A	Product line manager (sofas) (3.9. 2003)
Retail chain B	Manager of impot/export warehouse's (18.6. 2003)
Retail chain B	Store manager (24.6. 2003)
Final mile distribution company of both retail chains	Phone interview managing director (16.9. 2003)

Appendix B The informants in the machinery case

Organisation	Interviewee
Project equipment manager	Development manager (31.3.2004)
Component supplier	Factory manager (29.5.2004)
Project contractor	Senior project manager (5.10.2004) Purchasing manager (5.10.2004)