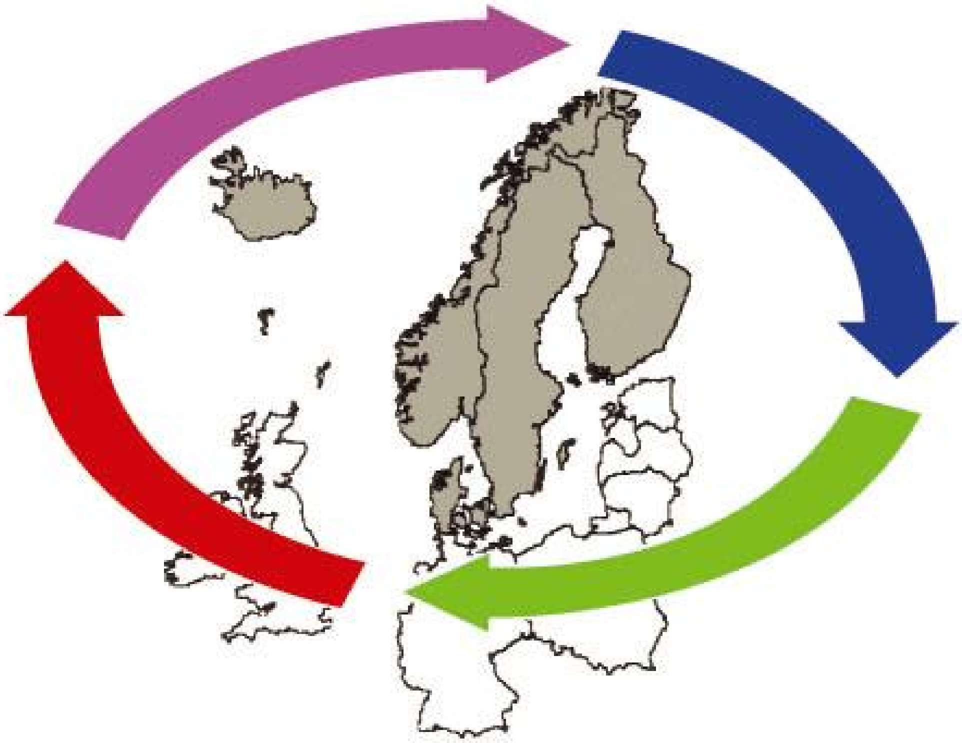

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POSITIONING TECHNOLOGIES IN PRODUCT TRACKING

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ABSTRACT

Purpose of this paper

The aim of this paper is to find ways to improve supply chain coordination by evaluating the suitability of different positioning technologies to product tracking in supply chains.

Design/methodology/approach

Based on a literature review, suitability of different positioning technologies to product tracking in supply chains was evaluated.

Findings

Positioning technologies can be divided into three groups: satellite positioning, network-based positioning and local positioning. Satellite positioning is best suited for tracking of transport equipment and large-sized units (e.g. containers) when a real-time monitoring is needed. Network-based positioning can be used mainly in the applications where individual location requests are sufficient. Local positioning technologies extend positioning to indoors (e.g. warehouses) and provide even centimetre-level position accuracy. By using identification technologies, even product units can be tracked rather inexpensively. Because of a wide range of actors, interfaces and standards, a common tracking solution that covers the whole supply chain is seldom implemented. The challenge is to provide the information in a common and easily available and applicable form.

Research limitations/implications (if applicable)

The paper evaluates only a part of the existing positioning technologies. Further studies are needed to gain more extensive perspective on this topic.

Practical implications (if applicable)

Companies can utilize the results to get information about existing product tracking technologies and to analyze the suitability of these technologies to their own operations.

What is original/value of paper

The paper provides valuable information to support the improvement of supply chain co-ordination by means of product tracking and related positioning technologies. It also gives a framework for further analysis of other positioning technologies.

Keywords: Tracking and tracing, Satellite positioning, Network-based positioning, Local positioning, Information exchange, Supply chain management

1. INTRODUCTION

Information sharing is a key component for successful supply chains. It provides the basis for the controlling of logistics-related operations and for the seamless supply chain integration (Tapaninen et al., 2010). Information in the supply chains is used to prevent uncertainty that is related to lead times, capacity availability and product quality (Ketzenberg et al., 2006). Information sharing improves supply chain coordination, reduces a bullwhip effect, decreases supply chain costs, and makes it possible to respond to changing customer needs more quickly (Ketzenberg et al., 2006; Li and Lin, 2006). Information shared in the supply chain has to be of good quality. This contains aspects such as accuracy, adequacy, completeness, credibility, accessibility, compatibility between users and timeliness (Monczka et al., 1998). The most gain from information sharing is achieved when every actor in the supply chain contributes to information exchange and a full transparency in the chain can be attained. Any bottlenecks in information exchange are reflected to the whole supply chain (Inkinen et al., 2009).

The tracking of shipments, materials and products has been recognized as an important tool for improving supply chain operations (Holmström et al., 2010). The complete transparency of products in a supply chain can be ensured only by tracking such information in a timely manner (Woo et al., 2009). From the product tracking perspective transparency means that the information about the location and the availability of transport equipment, transport units or product units is available for different actors anywhere and anytime, in optimal case through the whole supply chain (Pulli et al., 2009). The product tracking and the information it provide can be used, for example, in real-time co-ordination of deliveries, in the generation of exception notices and in developing logistics management metrics and analyses (Kärkkäinen, 2005). From a technical perspective, product tracking solutions can be implemented in many ways. In order to gain best benefit from product tracking in supply chains, logistics companies should be aware of existing tracking technologies and their characteristics. In this paper, an overview of existing positioning technologies is presented and the suitability of these technologies to product tracking in logistics is evaluated.

2. PAPER'S OBJECTIVES, METHODOLOGY AND STRUCTURE

The aim of this paper is to find ways to improve supply chain coordination by evaluating the suitability of different positioning technologies to product tracking in supply chains. Before the evaluation was carried out, the basic characteristics of product tracking in logistics were clarified and an overview of existing positioning technologies was made in order to find out issues and technological features that should be taken into consideration in the evaluation.

Also a framework with several attributes of analysing positioning technologies is presented. The objective of the paper is to answer the following research question:

- What kind of positioning technologies exist and how do these technologies suit for product tracking in supply chains?

To find out the basics of product tracking and positioning technologies, a literature review was conducted. The review is based on a number of different sources including scientific journal articles, conference articles, research reports and books. The source material was mainly searched online using academic databases and search engines (e.g. CiteSeerX, Google Scholar, IEEE Xplore and SpringerLink) as well as Google Web Search. The books were searched both in electronic databases and traditional libraries. Both Finnish and English literature was used in the study. The typical keywords that were used in the search of source material were tracking, tracing, positioning, identification, supply chain management, logistics, transportation, information exchange/sharing/system/technology, satellite positioning, network-based positioning, local positioning and their combinations. Since only a limited number of comprehensive studies about positioning technologies were found, more information about each technology was searched by using the name of each technology (e.g. barcode, RFID, GPS and WLAN). On the basis of the literature review, an evaluation of the suitability of the different positioning technologies to product tracking in supply chains was made.

The structure of the paper is as follows. First, sections 3 and 4 introduce the results of the literature review. In section 3, the basic principles of product tracking in logistics are presented. In section 4, the existing positioning technologies are overviewed. Because the number of existing technologies is quite large, the most commonly used and best-known technologies are presented in the paper. In section 5, a framework for analysing various positioning technologies in supply chains is presented and suitability of the positioning technologies is evaluated based on the literature review. In section 6, the results of the paper are concluded and discussed.

3. PRODUCT TRACKING IN LOGISTICS

A clear definition for tracking and tracing does not exist in the logistics literature (e.g. CIES, 2005; Kelepouris et al. 2006; Stefansson and Tilanus, 2000). When they are considered as independent terms, tracking is usually defined as following the location of an entity on its way from origin to destination and storing tracking data to an information system, while tracing is understood as locating the entity when needed by using the stored information (e.g. CIES, 2005; Kärkkäinen, 2005). These definitions clearly show that tracking and tracing are closely linked together (Stefansson and Tilanus, 2000) and therefore both aspects should be taken into account when implementing solutions for monitoring of shipments (Kärkkäinen, 2005). In this paper, the term *product tracking* is used to cover both tracking and tracing aspects.

3.1. Benefits of product tracking

Globalisation, increased customer needs and intensified general supervision have emphasized the importance of trackability and traceability of shipments (Sallanniemi et al., 2004). Kärkkäinen (2005) identified four main reasons for conducting product tracking and for building tracking systems. First, a tracking system can be used in logistics co-ordination since it forms the link between the information systems and the material flow in the supply network. Second, tracking can enable quick detection and reaction to unexpected events making it possible to generate exception notices for different parties of the supply chain. Third, tracking can be used to increase the efficiency of administrative processes. Tracking information can help in introducing paperless, less paper consuming or even automated systems which may improve information accuracy and reduce waste. Fourth, tracking information can be used as a basis for logistical metrics and analyses (Kärkkäinen, 2005; Stefansson and Tilanus, 2000).

3.2. Basic principles of product tracking systems

A tracking system can provide two kinds of information: symbolic and physical. In symbolic location systems tracking is done at discrete times and places (Hightower and Borriello, 2001). When a tracked item arrives at a predefined control point located in the supply chain, the arrival is registered and a message regarding the arrival is sent to a tracking database (Kärkkäinen, 2005; Stefansson and Tilanus, 2000). These messages typically contain three basic attributes: the identity of the entity, the current location of the entity and the time of the arrival of the entity. Additional attributes concerning the tracked item (e.g. quality and quantity of items) may also be recorded (Stefansson and Tilanus, 2000). On the basis of these attributes the last location and the time of pass of the tracked item can be explored (Kärkkäinen, 2005) and the arrival and departure of the item can be planned and/or forecasted (Tilanus, 1997). By comparing the time of pass and the forecast, the tracking system can detect possible conflicts and take necessary informative actions (e.g. generate exception notice) (Tilanus, 1997). A tracking system that provides symbolic position information is usually implemented by using barcodes, RFID tags or just simply entering tracking data manually to the tracking database (CIES, 2005; Stefansson and Tilanus, 2000).

Symbolic location systems typically provide only very coarse-grained position information about movements of the tracked items, and therefore, the tracking information is seldom real-time (Hightower and Borriello, 2001). If precise and real time position information is needed, tracking must be implemented by using a physical-positioning system (Hightower and Borriello, 2001; Kärkkäinen, 2005). In this case, the tracking data of a tracked item is sent and stored to a tracking database on a continuous basis, and thus, movements of the tracked items can be monitored in real-time. The continuous tracking applications are usually implemented by using satellite positioning technologies (Kärkkäinen, 2005; Stefansson and Tilanus 2000).

3.3. Levels of product tracking

Product tracking can be implemented in different hierarchical packaging levels. Stefansson and Tilanus (2000) listed several examples of trackable packaging levels: 1) the product units themselves that travel from A to B, 2) a box, containing several product units, 3) a large box, containing several small boxes, 4) a pallet, loaded with boxes, 5) a container, loaded with pallets, 6) a shuttle train, loaded with containers, and 7) several boxes, pallets or containers together making up a shipment from shipper to receiver. The packaging level has a direct impact on the way the tracking system can be implemented and operated.

According to van Dorp (2002) product tracking can be viewed in four perspectives: in a company perspective, in a multi-site perspective, in a supply chain perspective and in an external environment perspective taking into account requirements set by authorities, governing bodies or branch organisations. The best benefit of product tracking is achieved when it is implemented through a whole supply chain (Hinkka et al., 2010). However, there are many challenges in developing supply chain wide tracking solutions. They are usually expensive to build, equal sharing of costs and benefits between various actors is difficult, the integration of practices and interfaces between different parties is challenging and so on (e.g. CIES, 2005; Hinkka et al., 2010).

4. POSITIONING TECHNOLOGIES

According to Rainio (2003) positioning methods can be divided into three main groups: satellite positioning, network-based positioning and local positioning. Each of these groups consists of different positioning technologies that differ from each other mainly in the terms of technical implementation, operational environment and position accuracy. These attributes set conditions for the applications in which each positioning technology can be utilised. Figure 4.1 illustrates the operational environment and position accuracy of different positioning technologies and methods.

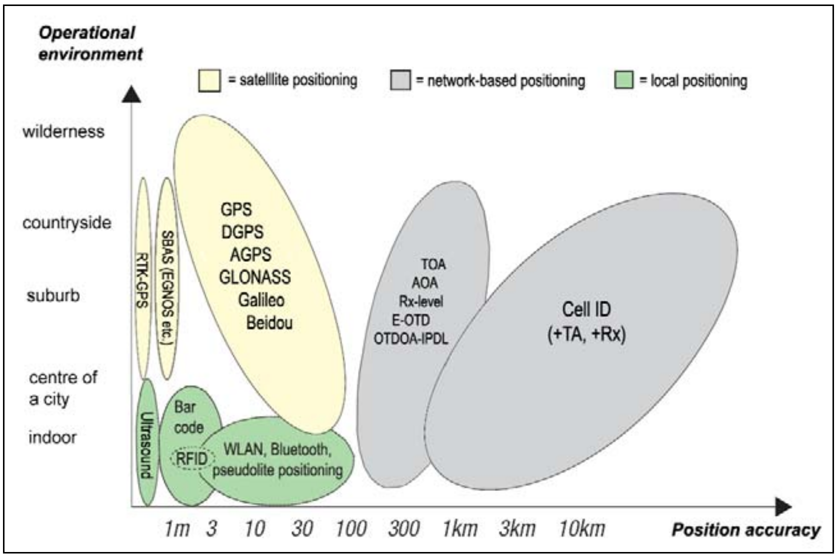

Figure 4.1 Operational environment and position accuracy of different positioning technologies. (Rainio, 2003 edited by authors)

4.1. Satellite positioning

Satellite positioning is based on receiving orbit and time information signals transmitted by positioning satellites revolving around the Earth and calculating the location of the satellite receivers located on the Earth based on the distances of the satellites (Daly, 1991). There are four Global Navigation Satellite Systems (GNSS) in use or under development: GPS developed by the USA, GLONASS developed by the Soviet Union/Russia, Galileo developed by the European Union and Beidou 2/Compass developed by the People's Republic of China. At the moment, the GPS is the predominant and the only fully-functional satellite positioning system (Kaplan and Hegarty, 2006). In addition to the GNSS systems, there are regional satellite systems (e.g. India’s IRNSS and Japan’s QZSS) and satellite-based augmentation systems (SBAS) (e.g. EU’s EGNOS and India’s GAGAN). There are also different kinds of satellite-based methods and system extensions (e.g AGPS, DGPS and pseudolite positioning) that can be used to improve the accuracy and reliability of GNSS positioning (Airos et al., 2007;

Kaplan and Hegarty, 2006). Key features of the main satellite-based positioning technologies are compared in table 4.1.

Table 4.1 Key features of the main satellite-based positioning technologies. (Potinkara, 2004; Spatial Source, 2010)

Technology	Dependencies	Range	Civil accuracy	Response time	Satellites required	Need for accessories
GPS	USA	Global	10 m	20–60 s	> 3–4	No
GLONASS	Russia	Global	57–70 m	20–60 s	> 3–4	No
Galileo	Europe	Global	4–15 m	N/A	> 3–4	No
Beidou 2	China	Global	10 m	N/A	> 3–4	N/A
A-GPS	Mobile network	Mobile network	20 m	N/A	> 3–4	No
DGPS	Base station, price	200 km	0,01–5 m	20–60 s	> 3–4 + base station	Yes / No (worse accuracy)
RTK-GPS	Base station	6 km	0,001–1 m	60 s	> 4–5 + base station	Yes
EGNOS	No	Europe	1–2 m	6 s	3 GEO satellites	No
SISNeT	Internet connection	Europe	1–2 m	6 s	No	Yes / No (Internet connection is required)

4.2. Network-based positioning

Network-based positioning is premised on mobile phone networks (e.g. a GSM network) (Syrjärinne, 2001). The data terminal unit (e.g. a mobile phone) always belongs to a coverage area of a cell and a base station, which allows to clarify the location of the data terminal unit on a coarse-level (Rainio, 2003). The most simple network-based positioning methods (e.g. Cell ID) make it possible to define the location of the data terminal unit with the accuracy of the service area of the base station (Deblauwe, 2008). More advanced methods are based on the measurement of receiving level of the signals (Rx-level), angle/direction of arrival of the signals (e.g. AOA and DOA) or travel times of the signals (e.g. TOA, TDOA, E-OTD, AFLT and OTDOA-IPDL) (Arokoski et al., 2002; Deblauwe, 2008; Rainio, 2003). Key features of the typical network-based positioning technologies are compared in table 4.2.

Table 4.2 Key features of the typical network-based positioning methods. (Arokoski et al., 2002; Brimicombe and Chao, 2009; Laitinen, 2006; Syrjärinne, 2001)

Method	Position accuracy		Advantages	Drawbacks
Cell ID	0,2–35 km	Depends on the cell size: urban areas usually have smaller cells than rural areas.	Does not require changes to network or data terminal units (DTU).	Position accuracy varies depending on a cell size.
Cell ID + Timing Advance	0,2–10 km	Error margin is greater when the distance between data terminal unit and base station increases.	Improves the accuracy of Cell ID. Does not require changes to network or DTUs.	Position accuracy varies depending on the cell size and the distance between DTU and base station.
Rx-level	150 m	More accurate in rural areas than Cell ID.	Does not require changes to a network or DTUs.	Three base stations are required. Sensitive to errors.
AOA (Angle of Arrival)	100–1000 m	Error margin is greater when the distance between DTU and base station increases.	Accuracy is quite good in an appropriate environment. Does not require changes to DTUs.	Line of sight is needed and thus it is sensitive to errors. Does not suit well to urban areas. Changes to network are required. Burdens the network.
TOA (Time of Arrival)	125–200 m	Accuracy can be higher within areas of low multi-path effect.	Does not require changes to DTUs.	Changes to network are required. Three base stations and accurate time synchronization between base stations are required. Burdens the network.
E-OTD (Enhanced Observed Time Difference)	50–150 m	–	Accuracy is quite good. Short response time. Does not burden a network as much as TOA and AOA.	Changes to network are required. Changes to DTU may be needed. Three base stations are required.
OTDOA-IPDL	10–200 m	In urban areas, position accuracy may be deteriorated due to signal attenuation and reflection.	Future technology that operates in a 3G network.	Three base stations and a 3G DTU are required.

4.3. Local positioning

Local positioning refers to technology that provides location information within a restricted area based on the transmission of short-distance signals (Kotanen et al., 2003). Local positioning systems can be used both outdoors and indoors, and they can provide metre-level or even centimetre-level position accuracy (Rainio, 2003). Local positioning methods can be divided into identification technologies and actual local positioning technologies.

4.3.1. Identification technologies

Identification technologies are not usually understood as actual positioning technologies but they can be used to determine the location of desired objects in a certain place during a certain time. Therefore, identification technologies do not usually provide real-time position information but the position data they are providing is symbolic position information.

The most important identification technologies that are used in the logistics are barcode and RFID technology. **A barcode** is an optical machine-readable representation of information which can contain, for example, certain data on certain products. It is a standardized and inexpensive technology that has contributed to global expansion of technology (Raj, 2001). **RFID (Radio Frequency IDentification)** is a generic term for technologies that use radio waves to identify objects. The main purpose of a RFID system is to enable data to be transmitted between a RFID tag and a RFID reader, and processed according to the needs of a certain application (Finkenzeller, 2004). The reading distance of RFID tags varies from a few to even 100 metres depending mainly on the frequency range (LF, HF, UHF or MF) being used and on the type of the tag (passive or active). The reading speed of RFID identifiers is rather fast making it possible to read multiple tags simultaneously and to automate different processes (Arendarenko, 2009; Wyld, 2006). These two technologies are compared in Table 4.3.

Table 4.3 Comparison of barcode and RFID technology. (Arendarenko, 2009; Wyld, 2006)

	Barcode	RFID
Reliability of reading	Practically 100 %.	50–100 % depending on the application.
Reading distance	Up to 4 metres but usually less than 1 metre.	Typically a few metres but may be even 100 m.
Readability	A line of sight is required.	Does not require a line of sight and can penetrate obstacles.
Reading speed	Low. Only one tag can be read at a time and often manually.	High. Even over 100 tags can be read simultaneously and automatic reading is possible.
Data content	Typically restricted to a few tens of characters at maximum. Only reading is possible.	Several thousands of characters. Easily rewritable.
Durability of tags	Low. Tags can be damaged or removed easily. If tags become greasy or dirty, they cannot be read at all. Barcodes are often disposable.	High. Less sensitive to environment. Lifetime of RFID tags can be even several years. RFID tags are reusable.
Security	Easy to copy and counterfeit.	Difficult to copy and counterfeit.
Price	Low.	High.

4.3.2. Actual local positioning technologies

The most common actual local positioning technologies are Bluetooth, IrDA, pseudolites, ultrasonic-based technology and WLAN. In the following, the key features of these technologies are described and compared (see table 4.4) from a positioning perspective.

Bluetooth is a low cost, low power short-range radio technology operating with a license-free 2.4 GHz frequency band. Bluetooth can operate without a line of sight, even through the obstacles. The range of Bluetooth is application specific but it typically varies between 10 and

100 metres depending on the Bluetooth device class (Bluetooth SIG, 2010). Accuracy of Bluetooth positioning is usually a few metres but it may be even better in a favourable environment (Behzadan et al., 2008; Kotanen et al., 2003).

Infrared technology (IrDA) is a point-to-point, narrow angle (30° cone), ad-hoc data transmission standard designed to operate over a distance of 0 to 1 metre and at speeds of 9600 bps to 16 Mbps by using infrared waves (Infrared Data Association, 2011). The accuracy of IrDA positioning is high (usually centimetre-level) but the technology suffers a line of sight issues and its operating range is very short (Hallberg and Nilsson, 2002).

Pseudolite positioning is based on the pseudo-satellites or pseudolites. Pseudolites (PLs) are ground-based satellite-like transmitters that can generate and transmit GPS-like ranging signals to improve outdoor GPS availability or even entirely replace the GPS constellation for indoor applications (Toth et al., 2003). The range of a pseudolite positioning varies from a few metres to a few kilometres (Chen and Kuittinen, 2007) and its positioning accuracy can be even centimetre-level (Cobb, 1997).

Ultrasonic waves (sound with frequencies above 20 kHz) can also be used for positioning purposes (Rainio, 2003). Ultrasonic positioning systems are usually based on a calculation of distances or distance differences by measuring ultrasound time of flight (TOF) between transmitter(s) and receiver(s) (Dijk et al., 2004). Ultrasonic positioning can offer very high accuracy (even millimetre-level) (Hazas and Ward, 2002; Rainio, 2003) but it has a limited operating range (usually a few metres) (Dijk et al., 2004).

WLAN (Wireless Local Area Network) is designed for communication but it can also be used for positioning purposes (Li et al., 2005). The range of a typical WLAN node is about 100 metres (Behzadan, 2008). The coverage area can be extended by adding WLAN access points. WLAN can operate without a line of sight (Khoury and Kamat, 2009). The accuracy of WLAN positioning usually varies between 1 and 20 metres depending on the densities and ranges of access points and on the positioning algorithm used (Reyero and Delisle, 2008).

Table 4.4 Comparison of the local positioning technologies.

Technology	Accuracy	Range	Advantages	Drawbacks
Bluetooth	Up to 1 m.	10–100 m, can be extended by using multiple receivers.	- no need for a line of sight - can penetrate solid objects - quite good operating range - low power consumption - multipoint connection	- low data rate - uses a crowded frequency band - easier to eavesdrop than IrDA because of the greater range and radio frequency
IrDA	Centimetre-level.	Typically 0–2 m.	- universality and wide distribution - good software and hardware support - low power consumption - inexpensiveness and good security - high position accuracy	- the need for a line of sight - very short operating range - point-to-point connection only
Pseudolites	Even centimetre-level.	From a few metres to a few kilometres.	- high position accuracy - enables fairly high operating range	- several pseudolites are needed to ensure sufficient position accuracy
Ultrasonic	Centimetre-level	A few metres.	- very high position accuracy	- short operating range - usually requires large number of receivers and their placements need quite sensitive alignment - usually expensive to implement
WLAN	1–20 m, depending on the used positioning algorithm.	100 m, can be extended by adding access points.	- high operating range and data rate - no need for a line of sight - can penetrate solid objects - can also be used for communication purposes	- quite low position accuracy - fairly high power consumption

Data sources: Arokoski et al., 2002; Behzadan et al., 2008; Bluetooth SIG, 2010; Chen and Kuittinen, 2007; Cobb, 1997; Dijk et al., 2004; Hallberg and Nilsson, 2002; Hazas and Ward, 2002; Infrared Data Association, 2011; Khoury and Kamat, 2009; Reyero and Delisle, 2008.

5. EVALUATION OF POSITIONING TECHNOLOGIES' SUITABILITY TO PRODUCT TRACKING

Many studies (e.g. Hightower and Borriello, 2001; Kaemarungsi, 2005; Potinkara, 2004) have described attributes that must be taken into consideration when selecting a positioning technology. During this study, different attributes were examined and six of them were seen as the most important factors from the viewpoint of product tracking in supply chains. These six attributes were chosen to evaluate the suitability of satellite positioning, network-based positioning and local positioning technologies to product tracking in supply chains. The selected attributes are found in most studies when different positioning technologies have been compared. The selected attributes are presented and described in table 5.1.

Table 5.1 Main attributes of positioning systems from a viewpoint of product tracking. (e.g. Hightower and Borriello, 2001; Kaemarungsi, 2005; Potinkara, 2004)

Attribute	Description
Physical position versus symbolic location	Physical-positioning technologies provide exact information whereas symbolic location technologies provide suggestive information about movements of the tracked items.
Coverage area	Coverage area is the area within which signals can be received in an acceptable quality.
Accuracy	Position accuracy describes the probable difference between a calculated point position and the true point position.
Scalability	Scalability describes ability of a positioning system to evolve with increasing requirements.
Cost	Cost of a positioning system may include installation, infrastructure, and usage costs.
Sensitivity	Describes sensitivity of a positioning technology to an environment and different conditions.

5.1. Suitability of satellite positioning to product tracking

Physical position versus symbolic location: Satellite positioning is a physical-positioning technology that can provide continuous and real-time tracking information about the movements and conditions of shipments. Real-time tracking information makes it possible to detect and correct exceptions during a shipment with a minimum delay. Hence, satellite positioning is particularly appropriate for tracking of shipments that need very smooth flow through a supply chain (e.g. valuable products, project cargos and groceries). The planning of companies' operations is also much easier when exact locations of the shipments are known. Continuously stored tracking information can be used to find out and remove possible bottlenecks in the supply chain, and thus, to enhance the flow of shipments from origin to destination.

Coverage area: Satellite positioning can be used on a global level with GNSS technologies (e.g. GPS). Therefore, satellite positioning enables shipments to be tracked and traced through global supply chains. At the same time, satellite tracking system will benefit a variety of actors through a supply chain. Indoor positioning does not usually work with GNSS technologies alone but AGPS, DGPS, pseudolites and other satellite-based enhancement technologies can be used to improve the coverage area of satellite positioning and to extend satellite positioning into indoor environments (e.g. positioning an item on the warehouse).

Accuracy: The position accuracy of the GNSS systems (a few metres to dozens of metres) is sufficient for most product tracking purposes (e.g. tracking and tracing movements of a container from a consigner to a consignee). The accuracy of satellite positioning can be improved with satellite-based enhancement technologies (e.g. AGPS, DGPS and pseudolites) by which even centimetre-level position accuracy can be achieved.

Cost: The basic infrastructure for satellite positioning is already in place and available for everyone. However, cost of satellite receivers that must be installed to all tracked items is considerably high. The usage costs of satellite-based tracking are also rather high. Further, utilisation of satellite positioning in product tracking often requires high investments to companies' back end systems.

Scalability: Satellite positioning system can serve an unlimited number of receivers worldwide with the existing and available-to-all satellite infrastructure. However, scalability of satellite tracking system is rather low mainly due to the high cost of satellite receiver systems. Therefore, the satellite-based tracking system is best suitable for tracking of full load transports (e.g. containers or trailers) and less suitable for tracking of product units.

Sensitivity: The signals received from the satellites are very weak and thus sensitive to interference. Different kinds of obstacles and materials may even prevent the use of satellite positioning completely. GNSS technologies usually work very poorly or do not work at all in indoor environments. Reliability and coverage area of satellite positioning can be improved by using enhancement technologies such as AGPS, DGPS or pseudolites.

5.2. Suitability of network-based positioning to product tracking

Physical position versus symbolic location: Since network-based positioning consumes rather lot of resources of the network, a continuous and real-time commercial positioning service is practically impossible to be implemented with network-based technologies. Network-based positioning can be used mainly in applications where single location requests are sufficient. The location data produced by network-based positioning is close to precise and up-to-date only when a single location request is sent and the location data is received. Therefore, network-based positioning can be considered as symbolic location technology.

Coverage area: The cell sizes in cellular networks vary from hundreds of metres to a few dozen of kilometres. The cellular network covers most parts of the globe but there are still areas that are not covered. Cellular networks can operate both in outdoor and indoor.

Accuracy: The accuracy of network-based positioning varies from dozens of metres to dozens of kilometres depending on the used technology, concentration of base stations and conditions of use. The present network-based technologies alone are not usually suitable for product tracking applications that require exact position accuracy.

Cost: Network-based positioning is based on the existing cellular network that is available for everyone, and thus, there is no need for fixed location antennas to be installed. However, some of the network-based methods (e.g. AOA, TOA and E-OTD) may require changes to a network and/or locatable device. The locatable device can as its simplest be a regular mobile phone. The usage costs of network-based tracking are lower than satellite-based tracking mainly because the tracking data in cellular networks is sent in an ad-hoc principle. Acquisition costs of a network-based tracking system are also lower than in a satellite-based tracking system.

Scalability: Network-based positioning suffers the same kinds of scalability problems as satellite positioning. The cost of cellular devices is rather high, and thus, network-based positioning is best suitable for tracking of large-sized units and less suitable for tracking of product units. Since the tracking data in cellular networks is sent in the ad-hoc principle, the amount of tracking data is smaller and easier to handle compared to the satellite systems.

Sensitivity: Network-based positioning is less sensitive to environment and other conditions than satellite positioning. Network-based positioning can be used both in outdoor and indoor.

5.3. Suitability of local positioning to product tracking

Physical position versus symbolic location: Local positioning technologies contain both physical-positioning and symbolic location technologies. Identification technologies (e.g. barcodes and RFID) provide symbolic location information since tracking is in most cases done at discrete times and places. Actual local positioning technologies (e.g. Bluetooth, IrDA, pseudolites, ultrasonic and WLAN) can be considered as physical-positioning technologies since they can provide precise and real-time location data on a continuous basis.

Coverage area: Local positioning technologies can usually operate both outdoors and indoors. The range of identification technologies varies from centimetre-level (e.g. some barcodes) to 100 metres (e.g. some UHF active RFID tags). By adding identification points across the supply chain, items can be tracked at coarse-level through the whole chain. Actual local positioning technologies can operate only in a restricted area. Bluetooth, pseudolites and WLAN are best suitable for actual local positioning since their operating range can be rather high (tens to hundreds of metres or even kilometres). Such a range is often sufficient to cover a warehouse area or even a whole terminal. Infrared and ultrasonic technologies are usable only in very short-range tracking applications due to their low range (only a few metres).

Accuracy: Since tracking with the identification technologies is done at discrete times and places, the location of the tracked items can be defined only at very coarse-level such as “the shipment is located between the factory and the distribution centre”. Yet, this level of accuracy is often sufficient for product tracking purposes. The accuracy of actual local positioning technologies typically varies from centimetre-level (IrDA and ultrasonic) to metre-level (Bluetooth, pseudolites and WLAN). Such accuracy allows precise positioning of a container, a pallet or even a product unit in a restricted area such as an outdoor or indoor warehouse.

Cost: Barcode tags are very cheap. The prices of RFID tags are nowadays also at a reasonable level but they are still more expensive than barcodes. However, the labor costs of using barcode technology are often higher compared to RFID technology since the scanning of barcodes is usually done manually while the scanning process can be automated with RFID technology. Compared to a satellite tracking system, the initial costs of an RFID tracking system may be higher since the identification points have to be installed in every location where the items are wanted to be identified. Instead, adding new tracked items in the RFID tracking system is usually much more inexpensive compared to the satellite tracking system.

The cost of the tracking systems that are implemented by using actual local positioning technologies (e.g. Bluetooth, pseudolites or WLAN) is highly application dependent. It can be roughly stated that the larger the covered area, the higher the cost of a tracking system usually is. From technological point of view, infrared and Bluetooth technologies are rather low-cost whereas pseudolite and ultrasonic technologies are usually expensive. WLAN positioning systems are often cost-effective to implement since WLAN networks are widespread and positioning systems can be built on top of existing networks.

Scalability: The scalability of barcode and RFID technologies can be considered good or even excellent. Once a basic infrastructure for a tracking application is built, new locatable items can be added easily and at low cost as a part of the tracking system. Due to the inexpensiveness of the tags, barcodes and RFID are well-suitable for tracking of product units (even large amounts). They can be used to track full and partial load transports as well.

The scalability of actual local positioning technologies is much lower compared to barcode and RFID technologies. They work only in a restricted area and the tracking infrastructure for these technologies usually has to be planned and built case by case. Because of the rather low range of local positioning technologies, base stations have to be installed quite densely if larger areas need to be covered. Since all tracked items must be equipped with a locatable device and the prices of the local positioning devices are rather high, the scalability of actual local positioning technologies suffers.

Sensitivity: Barcodes are sensitive to environment. Barcodes require a line of sight to operate and they become unreadable if they are greasy or dirty. Unlike barcodes, RFID tags do not require a line of sight and they can be read through obstacles. RFID tags (even hundreds at a time) can be read, for example, inside a carton, box or other container, which makes it possible to implement highly automated tracking applications. RFID tags are also less sensitive to adverse conditions (e.g. dirt, chemicals and physical damage) than barcodes.

IrDA and ultrasonic technologies are sensitive to environment. They usually cannot operate without a line of sight and various obstacles may prevent the use of these technologies completely. Bluetooth, pseudolites and WLAN are less sensitive to environmental issues. They can operate without a line of sight and penetrate obstacles. The obstacles and poor weather conditions may, however, reduce the accuracy and range of these technologies.

5.4. Summary of the evaluation

Table 5.2 represents the comparison of satellite positioning (GNSS), network-based positioning and local positioning from product tracking perspective. It should be emphasized that each of these three position technology groups includes many different positioning/identification technologies, and therefore, the presented comparison is only relative.

Table 5.2 Comparison of the positioning technologies from a viewpoint of product tracking.

Evaluated attribute	Satellite positioning	Network-based positioning	Local positioning
Physical position versus symbolic location	physical position	symbolic location	1) symbolic location 2) physical position
Coverage area	global, does not usually operate indoors	nearly global, operate also indoors	1) low range but even the whole supply chain can be covered by using multiple control points 2) operate only in a restricted area
Accuracy	medium to high	low to medium	1) coarse-level 2) high to excellent
Scalability	low	rather low	1) high to excellent 2) low to medium
Cost	high	medium	1) low (tags), medium to high (infrastructure) 2) low (Bluetooth and IrDA), medium (WLAN), high (pseudo-lites and ultrasonic)
Sensitivity	high	medium	1) high (barcodes), low (RFID) 2) high (IrDA and ultrasonic), low to medium (Bluetooth, pseudolites and WLAN)

1) = identification technologies (barcode and RFID)
2) = actual positioning technologies (Bluetooth, IrDA, pseudolites, ultrasonic and WLAN)

6. CONCLUSIONS

Kärkkäinen (2005) provides four reasons how product tracking increases efficiency of supply chains: 1) a tracking system forms the link between the information systems and the material flow in the supply network, 2) tracking enables quick reaction to unexpected events, 3) tracking increasing the efficiency of administrative processes and 4) tracking data can be used a basis for logistical metrics and analyses. To gain best benefit from product tracking in supply chains, logistics companies should be aware of existing tracking technologies and their characteristics. This paper introduces basics of the main existing positioning technologies. Further, the suitability of these technologies to the product tracking in supply chains is evaluated based on six attributes: physical positioning vs. symbolic location, coverage area, accuracy, scalability, cost and sensitivity.

Satellite positioning (e.g. GPS) is, in practice, the only positioning technology that makes it possible to track and trace shipments at the same time in a global and real-time level on a continuous basis. Thanks to real-time position information, the progress of shipments can be monitored very closely, and possible exceptions can be detected and corrected with a minimum delay. The metre-level accuracy of satellite positioning is sufficient for most product tracking purposes. The disadvantages of satellite positioning are inability to operate indoors, high cost of the satellite tracking systems and low scalability. Satellite positioning is best suited for the tracking of transport equipment and large-sized units (e.g. containers) when a continuous, real-time and long-range (even supply chain wide) tracking is needed. Satellite-based enhancement technologies, such as AGPS, DGPS or pseudolites, can extend satellite positioning to indoors, and improve accuracy and reliability of the satellite positioning.

Network-based positioning consumes rather a lot of network resources, and thus, a continuous and real-time commercial positioning service is practically impossible to implement. Network-based positioning can be used mainly in the applications where single location requests are sufficient. Because of the rather poor and varying accuracy, present network-based positioning technologies alone are not usually suitable for product tracking applications that require absolute position accuracy. Network-based positioning can be used, for example, as a complementary and supportive technology together with the satellite positioning.

Local positioning technologies can extend positioning to indoors (e.g. warehouses) and provide even centimetre-level position accuracy both in indoors and outdoors. Such accuracy makes it possible to define an exact location of a container, a pallet or even a product unit in a restricted area such as an outdoor or indoor warehouse. Bluetooth, pseudolites and WLAN are best suitable for actual local positioning since their operating range is rather high compared to infrared and ultrasonic technologies. When a product tracking is examined from the supply chain wide perspective, the role of actual local positioning technologies is somewhat insignificant since they operate only in a restricted area. By using identification technologies (e.g. barcodes or RFID), supply chain wide tracking solutions can be implemented and even product units can be tracked rather inexpensively. The identification technologies usually provide only very coarse-level information about movements of the tracked items since tracking is done at discrete times and places.

As the evaluation presented in the paper revealed, each positioning and identification technology has its own advantages and disadvantages. The nature of the shipment itself is the key factor in determining which positioning/identification technology should be considered. In an ideal situation, several positioning and identification technologies would be utilised at the same time to guarantee a seamless tracking of the shipments through the whole supply chains.

However, there is seldom need for this kind of tracking solutions since in the most cases coarse-level position information about movements of the tracked items is sufficient enough. This paper showed that the technical capabilities for implementing of advanced product tracking solutions indeed already exist. Because of a wide range of actors, interfaces and standards, a common product tracking solution that covers the whole supply chain is, however, seldom implemented. The biggest challenge is to provide the information in a common and easily available and applicable form.

The paper evaluates only a part of the existing positioning technologies. Further studies are needed to gain more extensive perspective on this topic.

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