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RFID-enabled Supply Chain Traceability: Existing Methods, Applications and Challenges

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1. Introduction

Radio Frequency Identification (RFID) technology promises to revolutionize various areas in supply chain. Recently, many researchers have investigated on how to improve the ability to track and trace a specific product along the supply chain in terms of both effectiveness and efficiency with the help of this technology. To enable traceability over the entire lifecycle a robust and seamless traceability system has to be constructed. This requires for the following three elements: (1) data model and storage scheme that allows unique identification and scalable database, (2) system framework which enables to share the traceability data between trading partners while maintaining a sovereignty over what is shared and with whom, and (3) a tracing mechanism in order to achieve end-to-end traceability and to provide the history information of products in question.

Along with the studies addressing the requirements and design of traceability system architecture, applications in the real environment have also been reported. Due to the strong regulation in EU which states that food business operators shall be able to identify any person who supplied them and any business which takes food from them, RFID-enabled traceability systems are well implemented in the food supply chain. However, there exist other industries adopting RFID to enhance traceability such as pharmaceutical and aviation and even in the continuous process industry like iron ore refining.

Despite the promising nature of RFID in tracking, there are several challenges to be addressed. Since an RFID tag does not require line-of-sight, multiple tags can be read simultaneously but also tag collisions may occur. Therefore there is no guarantee that a tag will be continuously detected on consecutive scans. Moreover, the use of RFID tags can be of serious threat to the privacy of information. This may facilitate the espionage of unauthorized personnel.

In this chapter, we analyze the main issues of RFID-enabled traceability along the supply chain mentioned above: existing methods, applications and future challenges. Section 2 starts with pointing out the characteristics of RFID data and the requirements for RFID-enabled traceability. Subsequently, we introduce data types, storage schemes and system frameworks proposed in the existing literatures. Then, we discuss tracing methods based on the traceability system architecture. Section 3 presents current applications in real settings of both discrete and continuous production. We also discuss challenges that are preventing companies from adopting RFID for their traceability solutions in section 4. Finally, we conclude our study in section 5.

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2. System architecture

Traceability, according to ISO standard (ISO, 1995), is the ability to trace the history, application or location of an entity, by means of recorded identifications. It also may be defined in general as the "ability to trace and follow any product through all stages of production, processing and distribution (EC, 2002)." Traceability itself can be divided into three types (Perez-Aloe *et al.*, 2007): (1) Back traceability (supplier traceability) (2) Internal traceability (process traceability) (3) Forward traceability (client traceability). Having the end-to-end traceability encompasses all three types of traceability and since traceability is defined over every stages of a supply chain, several researchers pointed out various elements that should be taken into account. Bechini *et al.* (2005) posited that traceability systems are constituted by three elements: (1) univocal identification of units/batches (or lots) of every product components, (2) information collection about time and location for every batch transfer/transformation, and (3) a method to relate this kind of data. Similarly, Jansen-Vullers *et al.* (2003) suggest the four elements of traceability in order to manage information on manufacture: (1) physical lot integrity, which determines the traceability resolution, (2) collection of tracing and process data, (3) product identification and process linking, and (4) reporting/system data retrieval.

In practice, traceability systems should be able to store information and show the path of a particular item/part of interest along the whole supply chain from the supplier to the retailer and eventually to the customer. Throughout this process, secure, reliable and automatic product identification is crucial to provide effective and efficient traceability. Barcode technology, in the past, has been used for the identification of products. However, in order to meet the traceability requirements pronounced by the governments, a new technology that allows automated recording of information was needed.

Today, in this spirit, new opportunities for traceability come from the RFID technology. Unlike barcode technology, RFID has several advantages such as multiple reading at a rate of 1000 tags per second that makes it not only a feasible and cost-effective candidate for object identification but also a significant tool to provide visibility along different stages of the supply chain. A typical RFID system is made up of: a reader, which forms an electromagnetic field, and some passive tags without a power supply. They can be read only if they are in the vicinity of a reader which supplies the power required (Bernardi *et al.*, 2007). Every RFID tag has a unique identification number and, depending on the type, it can have a rewritable memory (Gandino *et al.*, 2007).

2.1 Requirements for RFID-enabled traceability

Given the increasing importance of RFID as a means to monitor and manage products for traceability, it has been extensively used for a diversity of applications. For RFID to be used in traceability systems the characteristics of RFID data should be considered in advance. Lee & Park (2008) pointed out two peculiar characteristics of RFID data which are:

- *Dynamic*: Not only the word dynamic means that data changes over time but it also imposes the concept of the item being merged with other subparts and being divided into several components through the production process.
- *Procedural*: Items will leave a trail of data as they pass through several different locations. As an object is equipped with a tag, when it passes by the interrogation zone of a reader it will send information messages to the interrogator. This process will make

the identification of a tag for the reader at every location creating a consistent path of the object.

Along with this particular elements RFID data possesses there are a number of requirements that ought to be respected for the construction of RFID traceability system. Identifying the requirements is important for the data model and storage scheme on which the system is based as it reveals the information needs that the model should meet. Although the requirements might slightly differ based on which application the RFID technology is used, the common requirements can be inferred from the ones that can be applied to the food supply chain (Kelepouris *et al.*, 2007) and are as follows:

- *Item identification*: Many researchers agree that all traceable items in the supply chain should be uniquely identified (Jansen-Vuller *et al.*, 2003; Moe, 1998; van Dorp, 2003). The item identification should be consistent for all partners in the chain. In a different case, data synchronization should take place, which results in significant cost increase and poor data quality.
- *Bill of lots – batch distribution*: For the production process that is concerned with a sequence of activities transforming a listing of raw materials, parts, intermediaries and subassemblies into a particular end item, a complete BOL that contributed to the composition of a product batch must be registered in order to support full traceability. If a supply chain is consisted of stages in which the product is not subject to any transformations, then the BOL need not be registered. However, the registration of the distribution of the batches in items, cases or pallets is mandatory.
- *Operations and capacity units*: Traceability requires the recording of both the variables and their values under which the operation took place.
- *Item Observation*: Apart from the information regarding product composition, information representing product location throughout the chain should also be recorded.

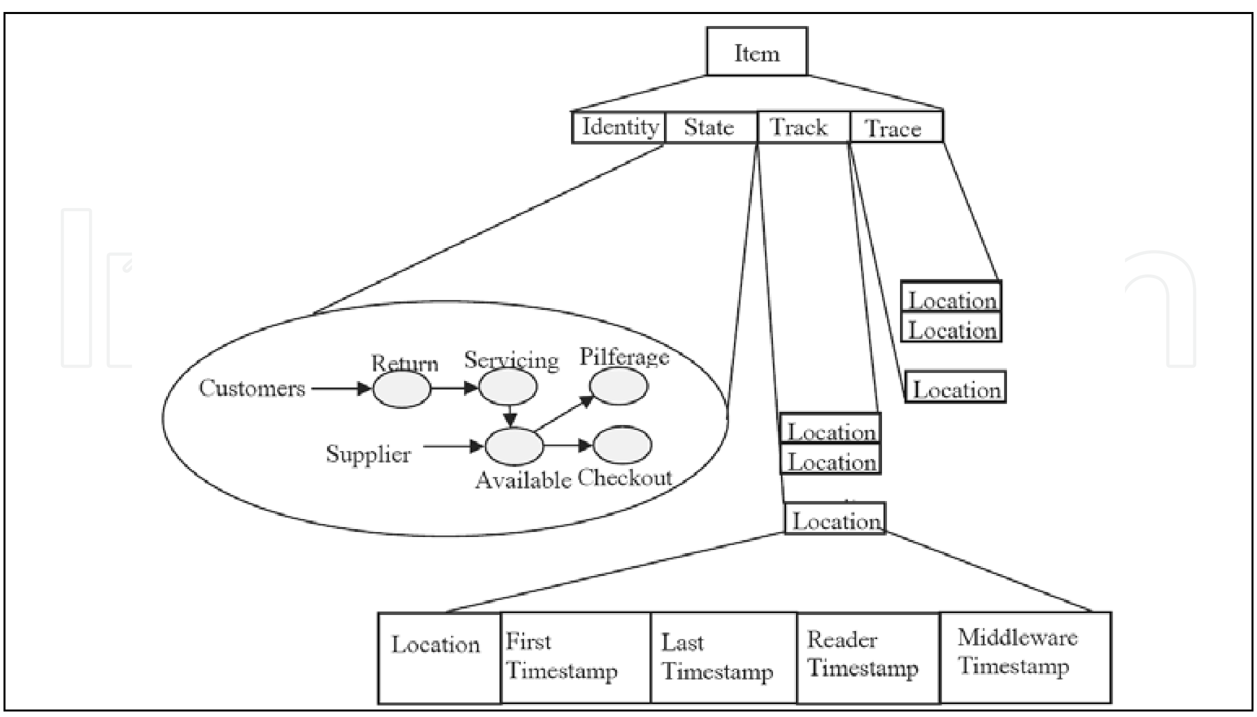

Fig. 1. A schematic view of item record (Gan *et al.*, 2006)

2.2 Data model and storage scheme

Taking these characteristics and requirements into account, data model as well as storage scheme can be built. A data model is essential in that it efficiently models different collection of identifiers that typically occur in item-tracking applications. Numerous researchers have proposed various data models for tracking items. A simple approach is to capture the identity code by RFID readers at both source and destination locations as item moves from one interrogation zone to another. A reader normally records the time of identifying the code based on its internal clock. Fig. 1 illustrates a schematic view of an item record in the database (Gan *et al.*, 2006). Each item record includes an identity code field, a state field, a track record pointer and a trace record pointer. The state field includes several values (e.g., Available, Checkout, Pilferage, Checkin, Return and Servicing) that commonly occur along the supply chain. The track record updates the timestamp fields of the specific location record with the most recent timestamps but if an item visits the same location several times it is not added. On the other hand, the trace record stores every location visited by each item up to the present location in order to trace the history locations.

Another approach came from the key observation that although individual items need to be tracked, they can be tracked more efficiently by tracking the groups to which they belong (Hu *et al.*, 2005). For example, a group can have several items in the same proximity (e.g., items of an identical product). One alternative to tracking a group of identifiers is to maintain an item count for the group, where the count can be viewed as a transformation obtained from an identifier collection (Hu *et al.*, 2005). However, in combining this approach with RFID, there are issues to be addressed.

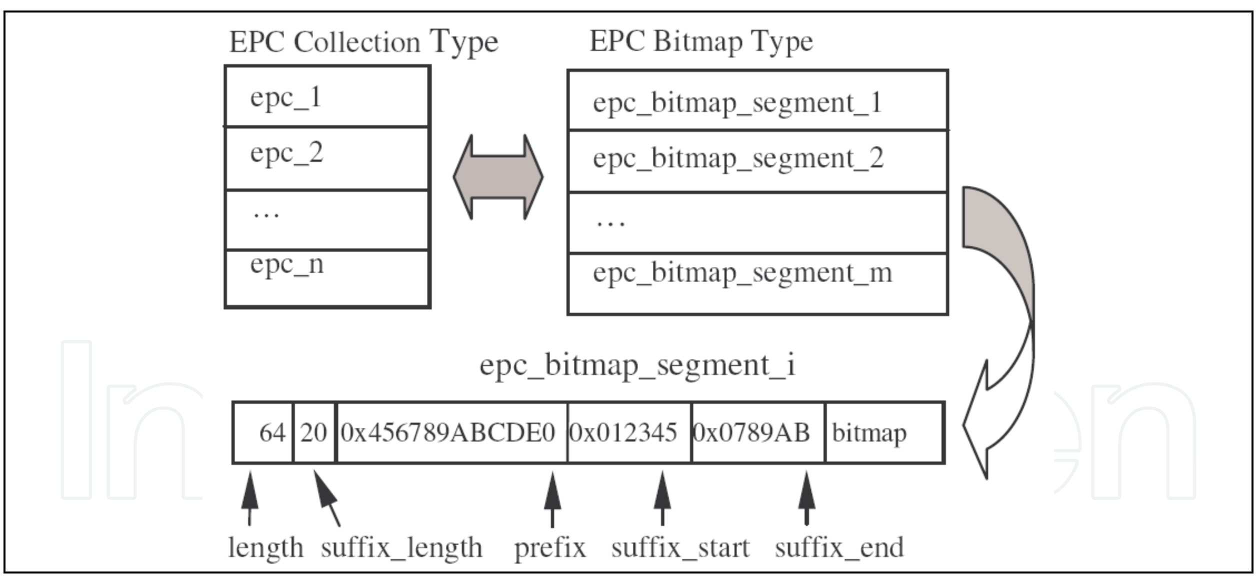

Fig. 2. EPC collection datatype and bitmap datatype (Hu *et al.*, 2005)

In this sense, Hu *et al.* (2005) proposed a bitmap datatype that compactly represents a collection of RFIDs, that is, their EPCs. The Electronic Product Code (EPC) is a simple naming scheme that uniquely identifies objects (items, cases, pallets, locations, etc.). Like many numbering schemes used in practice, the EPC can be divided into digits that identify the manufacturer and product type as well as the unique item within a group by using extra digits or a serial number (Engels, 2003). An EPC code generally contains (Brock & Cummins, 2003):

- *Header*, which identifies the length, type, structure, version and generation of EPC.
- *Manager number*, which identifies an organizational entity.
- *Object Class*, which identifies a "class", or type of thing.
- *Serial number*, the specific instance of the Object Class being tagged.

Hu *et al.* (2005) defined a new *epc_bitmap_segment* type to represent a collection of EPCs, which share a common *epc_prefix*. This type can be used to represent different classes of EPCs (i.e., 64, 96, and 256 bit) since the individual attributes within the epc_bitmap_segment type capture EPC type specification information (EPC length, EPC prefix length, EPC suffix length, etc.). Fig. 2 shows that the epc_bitmap_segment type is used to model a collection of EPCs that generates closely together. Additionally, a multiset type called epc_bitmap is defined that can hold collections of bitmap segments in order to model a collection of EPCs that can be arbitrarily dispersed.

The above scheme is suitable for applications that maintain summary information at periodic intervals such as retail store management, supply chain management (SCM), and asset management (Hu *et al.*, 2005). However, for the method to be exploited in other areas, it should be modified or used with other supplementary schemes.

In addition to providing the means to identify information about lots (or products), a data model should also be able to represent activities or processes (Kim *et al.*, 1995). Fig. 3 designates that the lot behaviour can be modelled by the following six activity patterns using UML (Unified Modelling Language) diagram (Ministry of Agriculture, Forestry and Fisheries of Japan, 2003):

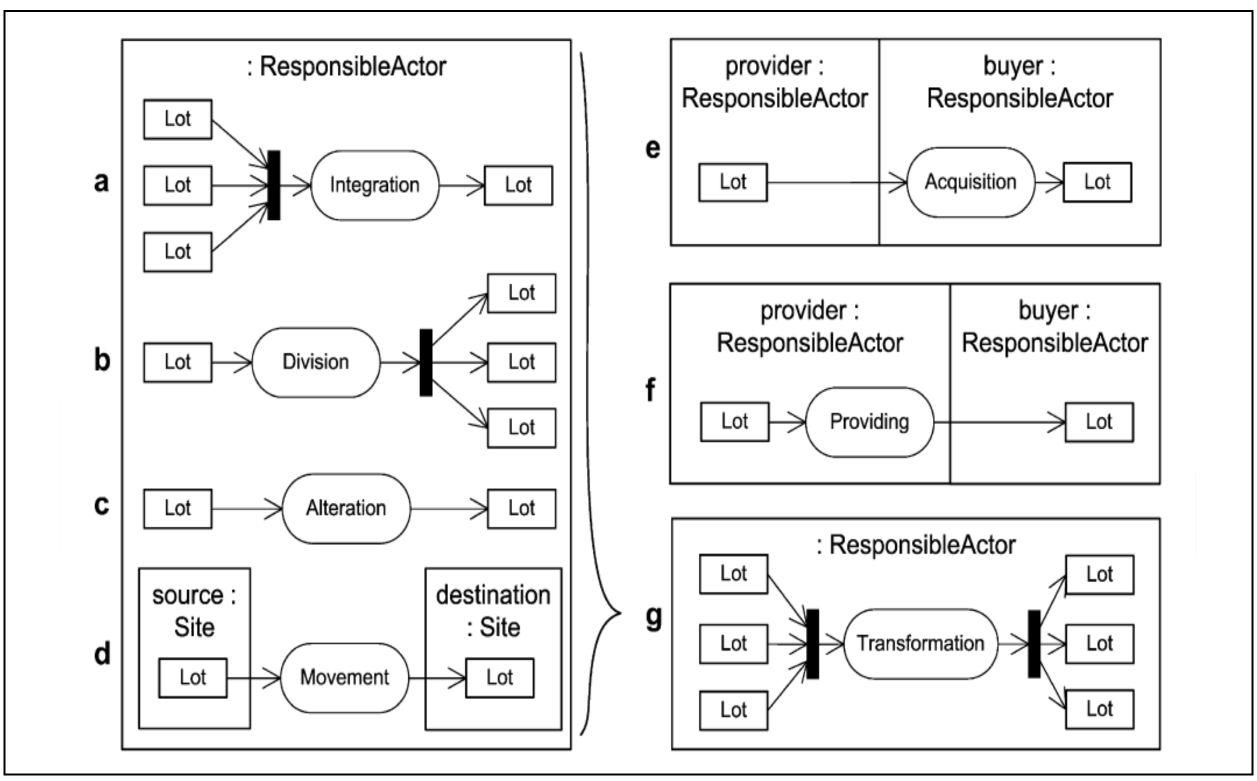

Fig. 3. Basic behavioural patterns of a lot (Bechini *et al.*, 2008)

1. *Lot integration* (e.g., mixing and packing): A number of lots are integrated into a single lot. The responsible actor of the lot creates an association between the pre-integration lots and the post-integration lot.

2. *Lot division* (e.g., cutting and splitting): A lot is divided into a number of lots. The responsible actor of the lot creates an association between the pre-division lot and the post-division lots and vice versa.
3. *Lot alteration* (e.g., heating and drilling): A new lot is generated from a lot by an alteration activity. The responsible actor of the lot creates an association between the pre-alteration lot and the post-alteration lot, and vice versa.
4. *Lot movement*: A lot is moved from one location to another under the same responsible actor. Since a lot can be associated with a unique site, the responsible actor has to create a new lot with a new identifier.
5. *Lot acquisition*: An actor of the supply chain acquires a lot from another actor. This association allows implementing the tracing process and therefore determining origin and characteristics of a particular product.
6. *Lot providing*: An actor provides another actor with a lot. This association allows implementing the tracking process and hence following the downstream path of a product along the supply chain.

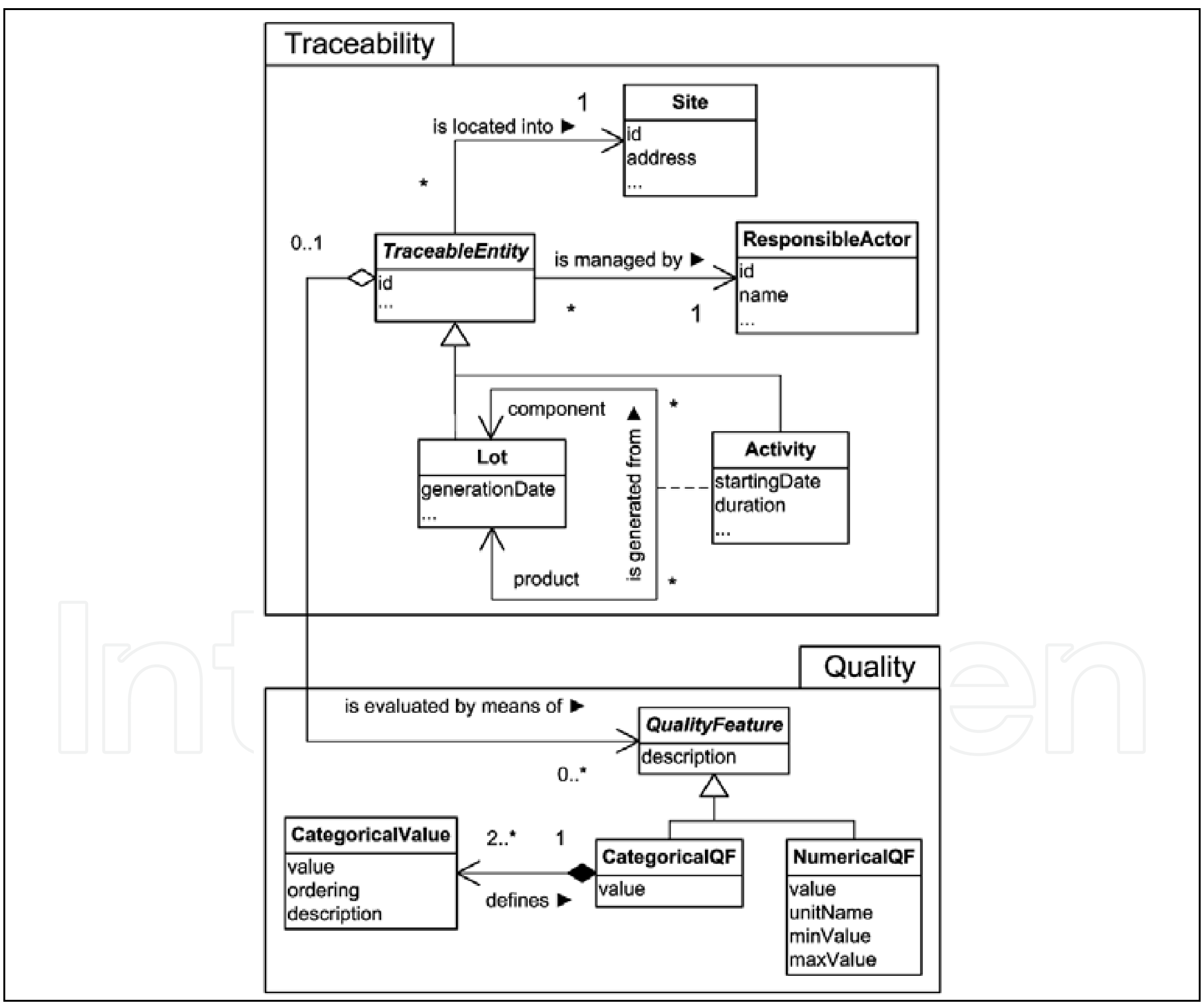

Fig. 4. UML class diagram of the traceability model (Bechini *et al.*, 2008)

Quality is also recommendable to be taken explicitly into account in the data model. The data model shown in Fig. 4 uses UML to reflect these requirements (Bechini *et al.*, 2008).

Here, classes are grouped into two packages: *Traceability* and *Quality*. The entities that allow tracing and tracking the product path is contained in the former while, in the latter, the information related to lot quality is included. The Quality package contains the abstract class *Quality Feature* (QF), which includes a description of the feature itself and a collection of methods to set and retrieve its values of either categorical (*CategoricalQF*) or numerical (*NumericalQF*).

2.3 System framework

Using the above models, the overall system framework should be constructed. The system architecture may vary based on which data model and, especially, standard it uses. Among the organizations that provide standardization of the RFID network, EPCglobal is the leading consortium which defines standards to enable data sharing of electronic product code related information within and between enterprises.

The EPCglobal Network (Fig. 5) promises a scalable, secure and easy to use architecture in which mechanisms to query traceable data are included. It describes components and interfaces for the RFID data interchange between servers called EPCIS (EPC Information Service) that contain information related to items identified by EPC numbers (EPCglobal, 2006). Each EPCIS contains the read time (at the reader location), capture time (at the EPCIS), reader location, action, and several optional attributes of all the EPCs of interest which can be specifically defined by companies (e.g., manufacturers). The standardization of the interface encourages the partners to provide vendor-specific implementations, which increase the scope of the traceability along the supply chain.

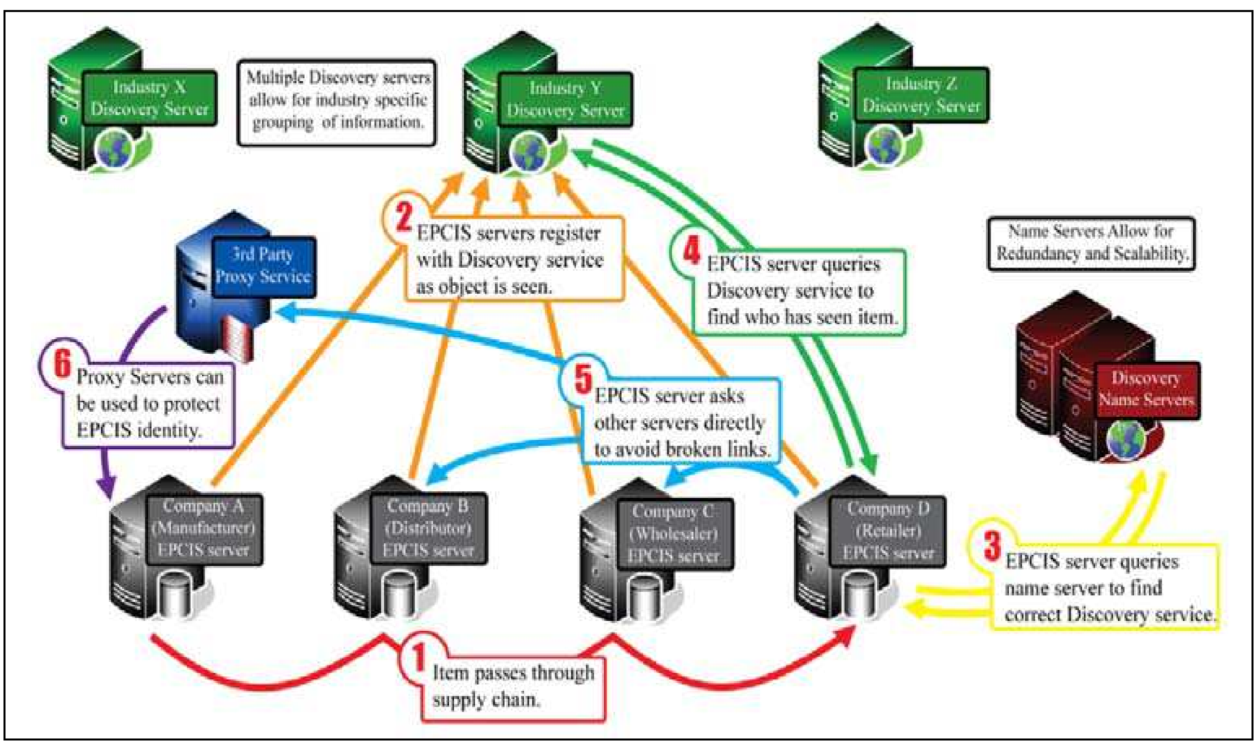

Fig. 5. EPCglobal network architecture (Beier *et al.*, 2006)

In the EPCglobal Network, Discovery Services are the core components to provide traceability by simplifying the data exchange process and by offering trading partners the ability to find all parties who had the possession of a given product and to share RFID events about that product (Beier *et al.*, 2006). As an instantiation of Discovery Services, EPCglobal proposed an Object Name Service which is based on the idea of what Domain Name Service is to the Internet (EPCglobal, 2005). However, unlike the Internet where domain addresses are freely available to anyone, EPC-related information need to have a privacy protection and so be shared selectively by the partners' agreement.

Discovery Services are consisted of a database and a set of web services interfaces (EPCglobal, 2006). The web service interfaces will allow an authorized firm to register EPCs and EPCIS URL links when the company has manufactured or been supplied with a new product. Then, authorized companies may be allowed to retrieve links to all EPCIS servers that contain events for a specific EPC (Beier *et al.*, 2006). The record attributes that Discovery Services store are as follows (Beier *et al.*, 2006):

- *EPC number* of the item
- *URL* of the EPCIS that submitted this record to indicate that it had a custody of the item
- *certificate* of the company whose EPCIS submitted the record
- *visibility*, a flag indicating if this record can be shared with anybody or merely with parties who submitted records about the same EPC
- *timestamp* when this record was inserted

2.4 Tracing methods

Several researchers proposed detailed mechanisms for traceability that take into account more specific characteristics occurring in every nodes of the supply chain. For their practicality, these approaches have the advantage over a general one and can be a promising candidate for being included in future standards.

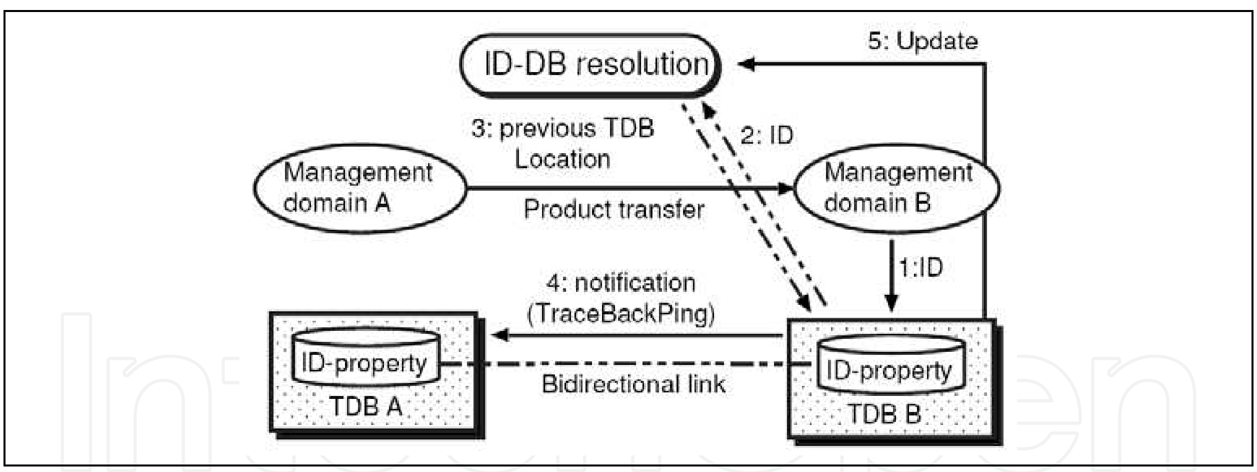

Fig. 6. TraceBack mechanism for traceability systems (Shirou *et al.*, 2007)

To be used in real applications, tracing methods should consider the peculiar characteristics of items as they traverse down the supply chain. Specifically, they must be able to track and trace not only the end items but also the components that compose them. Shirou *et al.* (2007) proposed a mechanism called "*TraceBack*" for traceability systems which uses a TDB (Traceability DataBase) and provides a tracing mechanism that are capable to reflect the product 'merge and division' mentioned above. TraceBack mechanism (Fig. 6) can be illustrated as the following flow of messages (Shirou *et al.*, 2007):

1. When the Management domain B receives the product, the TDB B in the Management domain B receives the ID of that product using an RFID reader.

2. The TDB B sends a query to the ID-DB (A mechanism which is used in the models proposed by standardization groups such as EPCglobal to find the database matching a specific ID) resolution mechanism to get the previous TDB location.
3. The ID-DB resolution mechanism sends back the last TDB location (TDB A).
4. The TDB B sends notification to the TDB A and creates a link to the TDB A. The TDB A receives the notification and creates a link to the TDB B.
5. The TDB B updates the location of the product in the ID-DB resolution mechanism.

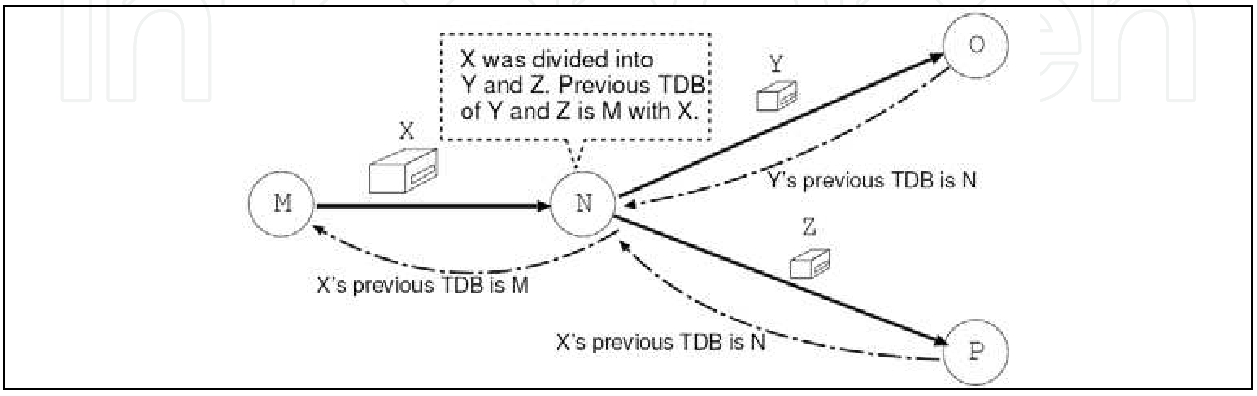

Fig. 7. Tracing mechanism for product division (Shirou *et al.*, 2007)

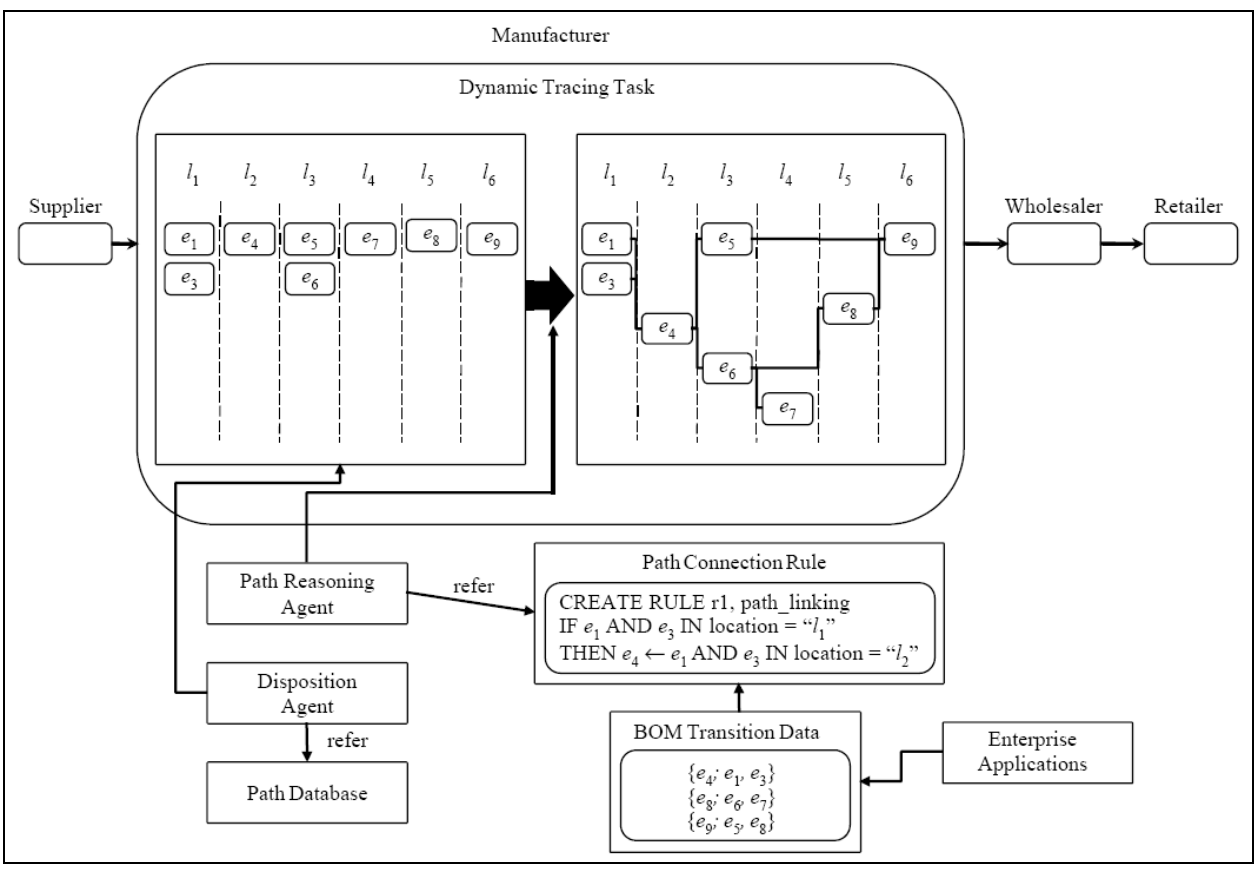

Fig. 8. An example of DTTM (Lee & Park, 2008)

Based on this model they suggested a mechanism regarding "divide and construct" of a product. Fig. 7 shows how this works for a product division (Shirou *et al.*, 2007). In this figure, product X is divided into product Y and Z. In this special case, TDB_N knows that product X was divided into two parts and transferred to TDB_O and TDB_P. After TDB_N receives a link message on Y and Z, TDB_N makes a response with link information on X. From this, the message sender can track product Y and Z correctly.

Lee & Park (2008) proposed a different model, DTTM (Dynamic Tracing Task Model) to get a full end-to-end traceability. The motive for their model and the previous one is almost the same in that they both did not disregard the critical feature of product "merge and split" process occurring in the supply chain. Fig. 8 shows an example of DTTM procedure. The distinctive advantage of this approach is that it uses the existing BOM (Bill of Material) for the tracing mechanism which can be adopted in an efficient way because of the fact that firms already have this information in their enterprise applications (ERP, SCM etc.). This will not only save the implementing cost of an RFID traceability system but also the effort and burden of changing the legacy system to adapt to it.

With the data model, system framework and tracing methods, managers who are in charge of tracking and tracing now have the ability to specify queries across the entire network. To illustrate traceability query execution in a network, a relational model is needed. Agrawal *et al.* (2006) called their relational model as the *global schema* (Fig. 9) and assumed that every participant in the supply chain has access to this information. This model allows organizations to make a query without knowing where and how data has been stored in the past. Physically, the global relations *Observed*, *ObsPropertySet*, *Assembled*, *AsmPropertySet*, *Disassembled*, *DsmPropertySet* are partitioned horizontally such that each partition belongs exclusively to each organization, and the attributes *parent* and *child* are object identifiers (*oids*) and the attribute *ts* is a timestamp (Agrawal *et al.*, 2006). As an example of traceability queries, a recall query has the following general form expressed in relational algebra (Agrawal *et al.*, 2006):

$$Qr: \pi_{lid}(max_{ts}(\sigma_{oid=o}(Observed)))$$

Recall queries are used to detect the current location of an object. They need to be executed at each node where there is an entry with *oid=o* in the respective partition of the relation *Observed* (Agrawal *et al.*, 2006).

Property(name)
Organization(gid)
OrgPropertySet(gid, propertyName, value)
Location(lid, parentLid, gid)
LocPropertySet(lid, propertyName, value)
Object(oid)
ObjPropertySet(oid, propertyName, value)
Observed(oid, lid, ts)
ObsPropertySet(oid, lid, ts, propertyName, value)
Assembled(parent, child, ts)
AsmPropertySet(parent, child, ts, propertyName, value)
Disassembled(parent, child, ts)
DsmPropertySet(parent, child, ts, propertyName, value)

Fig. 9. Relational schema (Agrawal *et al.*, 2006)

3. Applications

3.1 Food supply chain

In many countries traceability systems are mandatory for enterprises in the food chain. Based on the EU requirement, food business operators shall register the origin and the destination of the alimentary commodities they manage, and they shall label food to facilitate its tracking process (EC, 2002).
In the Italian cheese (Parmigiano Reggiano) supply chain several actors are involved including milk farm, dairy processors, and warehouses. The first step in this Parmigiano Reggiano traceability process is the identification of the characteristics of product in its different aspects along the entire supply chain (Regattieri *et al.*, 2007). The relevant information (such as cooking boiler temperature, humidity, and fodder batch code) is collected automatically using sensors, PLCs and barcodes but a sensor-augemented-RFID tag can also be used (Fig. 10).

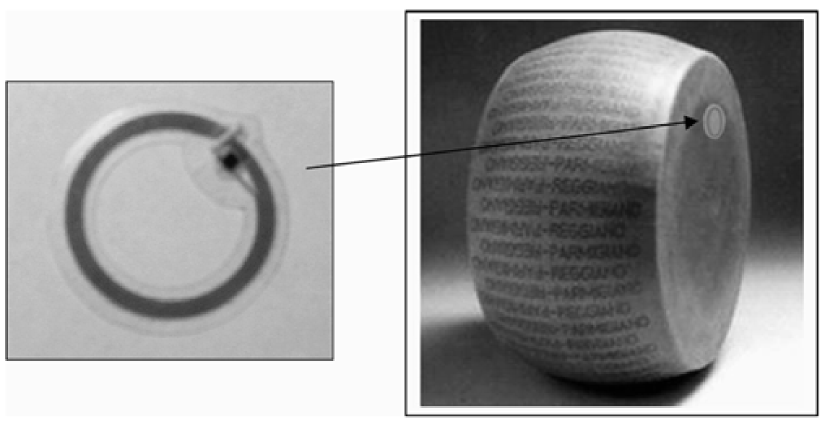

Fig. 10. A tag applied to cheese (Regattieri *et al.*, 2007)

Fig. 11. MTs at warehouses and Exposition in a supermarket (Martinez-Sala *et al.*, 2009)

Martinez-Sala *et al.* (2009), in their paper, showed the work developed in collaboration with a Spanish company ECOMOVISTAND in order to turn the MT (an innovative and ecological packaging and transport unit) into an intelligent product platform by embedding active RFID tags. MT is mainly made of last generation plastics with high mechanical endurance and an expected lifespan of more than 10 years. In their solution, an active RFID is the core element to achieve the business needs. MTs can be tracked by attaching an RFID tag. The RFID constraints posed by the ECOMOVISTAND business model is as follows (Martinez-Sala *et al.*, 2009):

- *Long range readings*. MTs are carried by forklifts and moved through large, open warehouses and dock gates (Fig. 11). Besides this capability is key to future service extensions, such as smart shelves (Fig. 11)
- *Monitoring of perishable goods*.
- *Full read/write capabilities*.
- *Ensuring reader a seamless integration into the customers facilities with minimum impact to their information systems.*

Depending on the type of RFID tags used (e.g., passive or active) the capabilities it can provide in the food supply chain may differ. Thus, companies in the network should collaborate in order to make the RFID system properly implemented.

3.2 Air baggage handling

RFID technology can also be used to enhance the ability for baggage tracking, dispatching and conveyance inside the airport. Due to the management efficiency and user satisfaction, RFID was deployed in the Beijing Capital International Airport (BCIA), the largest and most important airport in China.

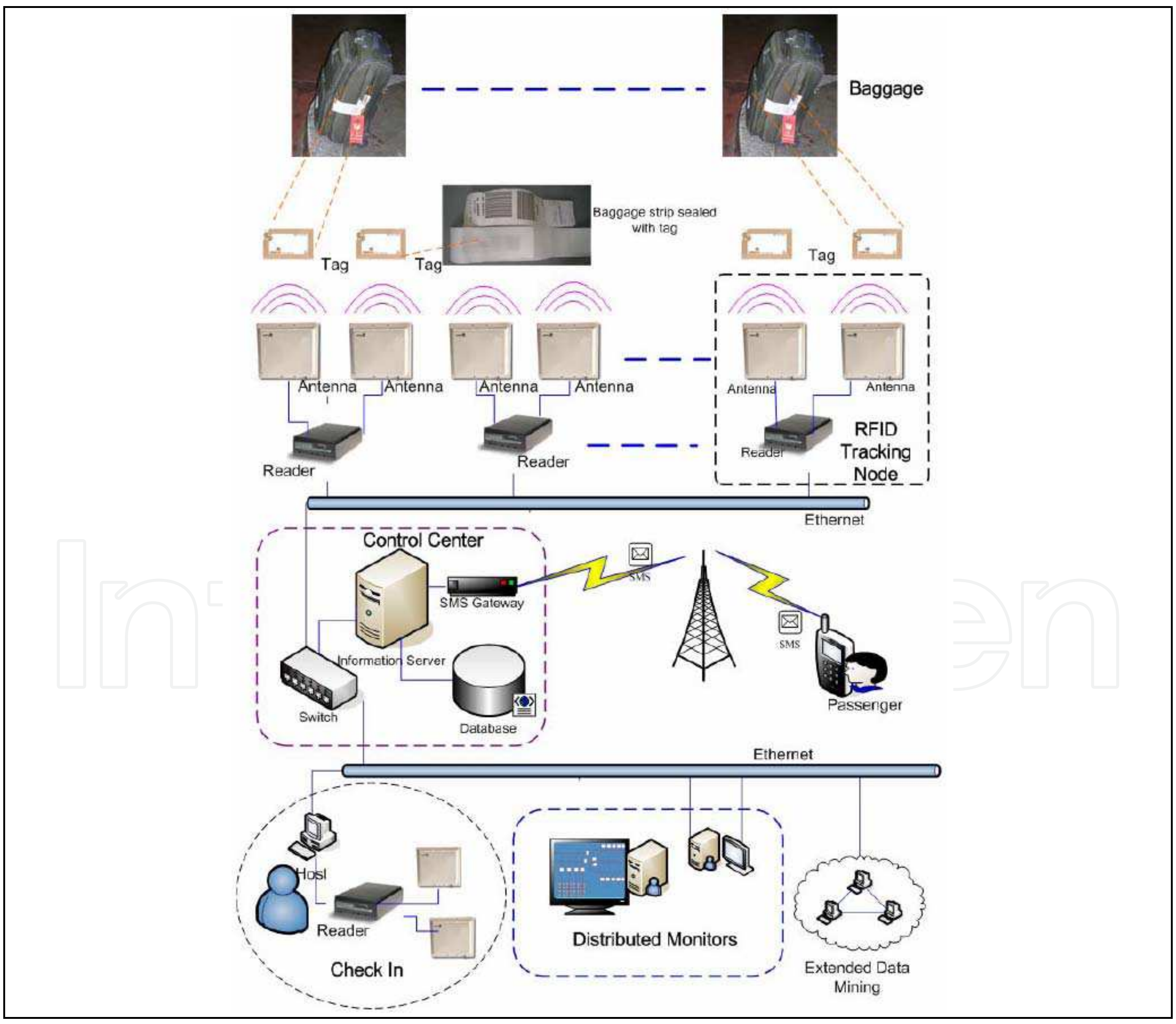

Fig. 12. RFID-based traceable air baggage handling system topology (Zhang *et al.*, 2008)

The system (Fig. 12) was developed by Zhang *et al.* (2008), which was expected to resolve the problems including delayed, lost, stolen, and not-located baggage. Their approach exploits not only RFID but also the existing barcode-based automated handling systems with less efforts and investments. The functionality of each component can be summarized as follows (Zhang *et al.*, 2008):

- *RFID tracking node* is consisted of one TCP/IP supported reader and a couple of fixed antennae transmitting RF signal
- *Control center* takes charge for the coordination of large-scale and heterogeneous readers
- *Information server* supplies the service interfaces and APIs to human interaction related applications by means of Web Services
- *Distributed Monitors* display the query results in the form of GIS map

The application was implemented inside the Airport Terminal 2. The LED screen was installed above each conveyor exit and it displays the amount of the sorted and sorting baggage of the flight. According to the statistics from Air China between March 19, 2005 and April 18, 2006, RFID saved costs related to lost baggage, baggage damage, and temporary costs. Also it has been expected to save the industry US $760 million annually upon full implementation. Moreover, the processing cost has been decreased due to the boosted productivity with a more automatic workflow provided by RFID (Zhang *et al.*, 2008).

3.3 Iron ore distribution chain

Traceability is common in part production and often easy to achieve by using RFID. However, obtaining traceability information in continuous processes implies many challenges. In a continuous process, the products are gradually refined through a series of operations and there are no natural product lots (Fransoo & Rutten, 1994; Dennis & Meredith, 2000). Moreover, the physical characteristics of the material are often changed during the refinement process, which also makes it difficult to place the definition of a unit of measure (Fransoo & Rutten, 1994). Due to these characteristics, RFID alone cannot give the ability to trace in the continuous process. Instead, various tracer methods (e.g., off-line methods or on-line methods) are used to support the whole distribution chain of a flow process.

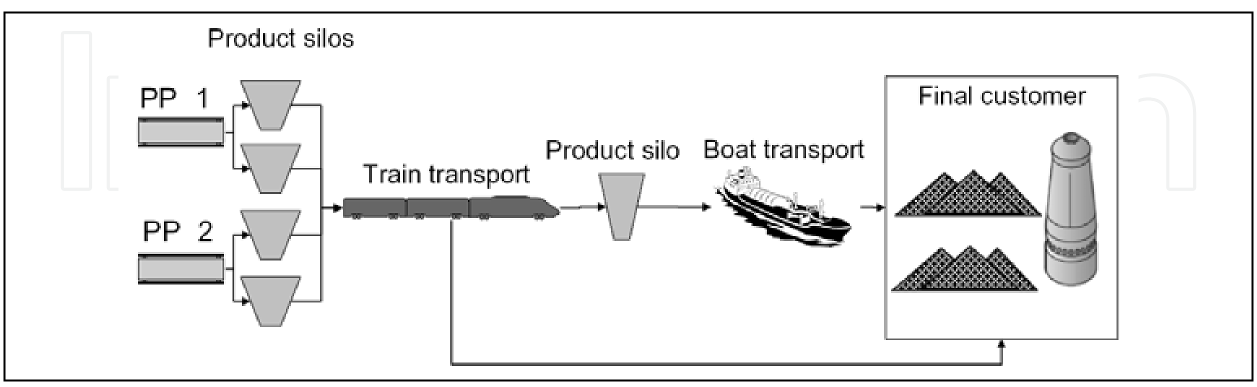

Fig. 13. Flow chart of the iron ore pellets distribution chain (Kvarnstrom & Oghazi, 2008)

Nevertheless, RFID may be very promising in one part of the whole supply chain, the distribution chain. Fig. 13 shows a flow chart of the distribution chain for iron ore pellets produced in Malmberget, Sweden. Together with traceable unit method which creates virtual batches by dropping some type of marker in the material flow with regular intervals, RFID offers the possibility to measure precise residence time in the process. The RFID tags would be used as the start and the end points of each batch. And process data can then be linked to a virtual production batch (Kvarnstrom & Oghazi, 2008). From the test results in the iron ore distribution chain, in order to achieve a sufficient read rate (more than 50%), it is necessary to use RFID tags that are larger that the pellets (Kvarnstrom & Oghazi, 2008). However, they proved that their technique may be used to create traceability in the continuous process chain.

4. Challenges

There are several challenges in deploying RFID for traceability. One of the main challenges comes from the inherent technical nature of RFID. RFID tags may collide with each other when multiple tags try to respond to the reader simultaneously. Thus, there is no guarantee that a tag will be continuously detected on consecutive scans (Floerkemeier & Lampe, 2005). Given the fact that it does not provide 100% read rate, most of the data models and tracing mechanisms to provide an efficient way for traceability would almost be useless. However, lots of efforts poured by engineers have increased the level to almost 99% and in the near future the technology will be matured to the level of the existing barcode system which has no problem of reading items.

RFID tags are subject to price and size constraints. Although the tag price is continuously decreasing companies are hesitant to use RFID because of the price disadvantage over barcode. Since tags derive energy from readers (in the case of passive tags) their communication bandwidth is limited (Zarolostas *et al.*, 2007). In addition, due to their small size requirements, tags have limited memory which indicates that the stored information on tags is also limited (Sarma *et al.*, 2001).

Another important facet of RFID-enabled traceability is that the amount of information generated by the infrastructures as items pass through the supply chain is vast. This leads to the need of heavy filtering and aggregation so as to generate meaningful events or information that could impact the operational procedures and business strategy (Zarolostas *et al.*, 2007). Middleware which is responsible for this filtering should be carefully designed so that the trade-offs between communication overhead and processing capabilities have the desirable value to the firms.

As each node in the network would implement the system produced by different RFID vendors the information flow is likely to be heterogeneous. One solution to this problem might be the establishment of standards. However, the standardization of RFID in all aspects is still in progress. Therefore researchers are trying to propose methods that can seamlessly make various types of information interoperable. Also two groups, EPCglobal and ISO are the leading organizations that are expected to establish the de facto standards for RFID, so most of the vendors make their products in accordance to the standards they provide.

Since traceability can only be obtained through all the participants' cooperation along the supply chain, privacy issues have been reported by several practitioners and governments. In US, many organizations, such as Consumer Privacy and Civil Liberties Organizations, are requesting attention to privacy threats (Privacy Rights Clearinghouse, 2003). In Canada, the Annual Report to Parliament 2005 of the Privacy Commissioner underlines the importance to make sure that RFID does not harass informational privacy rights (Privacy Commissioner of Canada, 2005). In European Union, the national authorities established guidelines needed for a safe use of RFID in compliance with the Working Document adopted by 2005 by the European Data Protection Working Party (Data Protection Working Party, 2005). Due to the privacy threats made by RFID (e.g., personal belongings monitoring and industrial espionage) many solutions have been analyzed (Bernardi et al., 2007):

- *Killing the tag*: a command that kills the tag at the POS (point-of-sale)
- *Using passwords or encryption*: To avoid unauthorized readings of tags (Weis *et al*., 2003)
- *Changing tag ID*: Using different IDs makes difficult to recognize a tag (Juels, 2004)
- *Blocking the anti-collision system of the reader*: A special tag stops the correct functioning of the reader (Juels *et al*., 2003)

Recently, researchers are considering RFID as a device to develop "intelligent" products, and when combined with other sensors, it is expected to provide capabilities far beyond mere identification function of today's RFID (Zuehlke, 2008). This means that they record all pertinent product and operating data and exchange this information with all participants as well as other products and environments to enable the so-called "Internet of things." However, to make this feasible, the memory capacity of an RFID chip should be large enough and this will incur more cost. Thus, in designing tags for the future scenario, an efficient storage scheme should not be overlooked.

5. Conclusion

RFID technology gives several advantages for enterprises to effectively operate their daily operations (Lee & Park, 2008). One of the benefits is the product traceability. If a product can be tracked and/or traced, product recall, product pedigree analysis and consumer visibility can be improved. Design and implementation of traceability systems need preliminary investigations to point out not just requirements but also problems and solutions at different abstraction levels (Bechini *et al*., 2008). In order to achieve coordination along the supply network, appropriate and widely accepted data models and system framework should be constructed before the actual tracing query is made.

In spite of the promising nature of RFID, numerous applications in the actual supply chain has not been reported. Only few pilot studies as well as experimental tests have been proved that RFID would be a successful tool to enable supply chain traceability. The reasons why companies are yet reluctant to have confidence in adopting the technology to gain their product visibility may be attributed to the several challenges such as lack of standards, immaturity of RFID, and privacy issues.

Researchers as well as practitioners are proposing methodologies that address those current problems. Also more and more opportunities from RFID are being investigated. Thus in spite of the obstacles facing RFID, the fact that the technology promises to revolutionize the way we track items in the supply chain will not likely to change.

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Sustainable Radio Frequency Identification Solutions

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Radio frequency identification (RFID) is a fascinating, fast developing and multidisciplinary domain with emerging technologies and applications. It is characterized by a variety of research topics, analytical methods, models, protocols, design principles and processing software. With a relatively large range of applications, RFID enjoys extensive investor confidence and is poised for growth. A number of RFID applications proposed or already used in technical and scientific fields are described in this book. Sustainable Radio Frequency Identification Solutions comprises 19 chapters written by RFID experts from all over the world. In investigating RFID solutions experts reveal some of the real-life issues and challenges in implementing RFID.

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