RFID BI mobility and producer to consumer traceability architecture

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Abstract: Radio frequency identifier (RFID) emerged in 2000 an intelligent remote object identification. RFID helps tracking object position and relevant information using radio frequency technology (Bouet and dos Santos, 2008; Pais, 2010). Its application in industries, highly increases the inventory management consistency and accuracy, by capturing in real-time observed object attributes for traceability and quality control purpose. In order to provide traceability and quality control services, RFID applications should offer two main services: business intelligence (BI) and mobility management. The RFID BI provides production traceability services (QoS metrics related to manufacturing processes). And RFID mobility service maintains accurate RFID tag location. In this paper, a generic RFID BI mobility' data model is defined. In the proposed data model, RFID product information generated by a supply chain organisation is translated or migrated from a producer to a consumer. This migration generates two distinct types of RFID mobility: internal (inside buildings) and external.

Keywords: mobility management; radio frequency identifier; RFID; business intelligence; BI; data models; business processes; QoS; mobile networks; position system; GPS; events; mobility subscription.

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1 Introduction

One main reason of radio frequency identifier (RFID) adoption by big industries (Wal-Mart, Costco, Coca-Cola, etc.) (Melski et al., 2007) is its contribution to the overall inventory management and object location management improvement. In reality, RFID infrastructure deployment in a supply chain industry reduces human errors in the inventory management by using a remote reading technology (radio frequency).

To improve the inventory management, a set of servers and mobile network elements are used to construct the RFID infrastructure (Figure 1). RFID architectures are generally 3-tier architecture oriented, where the business intelligence (BI) RFID server is a middleware server (Al-Kassab et al., 2013; Floerkemeier et al., 2007; Wang et al., 2008; Shah and Murtaza, 2008). The BI RFID server decouples the RFID raw data coming from RFID readers to data required by existing applications systems of an organisation. The RFID raw data are RFID data sent by a producer to a consumer. These raw data must contain adequate or a large set of product information to be able to answer user requests.

For example, an end user may want to know the product manufacturer, the product lot identifier, when and where the product was made, where the product is currently located, what is the product unit cost, how many products have been sold per location and per month. To respond to these questions (or combination of these questions) and for performance analysis, the BI RFID middleware must provide a BI RFID mobility data model that tracks and manages RFID data and answers consumer or producer inquiries.

In this paper, a RFID BI mobility data model that aims to respond to those questions is described. The proposed BI RFID mobility data model resolves the RFID location and product information tracking. In reality, in terms of information flow, the BI RFID mobility data model acts as a displacement vector of BI RFID data from the producer to the consumer system.

The paper is organised as follows: we first introduce the related work on the RFID middleware. Then, we explain the proposed BI RFID mobility model. After, we discuss about the RFID business processes of a manufacturing organisation. Next, we described the proposed RFID data model. And finally, is the conclusion of this paper that resumes the proposal.

2 Related works

Works in BI RFID can be classified in three main categories: optimising collected data volume, RFID external mobility models, and business enhanced.

Optimising collected data volume research is very important in RFID management as the product data volume grows exponentially when recorded at RFID granularity level (Melski et al., 2007; Gonzalez et al., 2006). In Melski et al. (2007), the authors suggest a data compression approach. The compression approach consists first of knowing the organisation processes, then installing point of collections (RFID readers) only where they are necessaries and by saving only important data which means some internal mobility may be skipped. Gonzalez et al. (2006) suggest RFID Cuboid data model approach that uses three tables: the information, stay and map. The information table acts as a RFID product dimension table where information related to a product is bound to RFID code. The stay table captures an RFID movement within an organisation building and the map table contains an aggregation of RFID relationships (for example, RFID container). Both papers (Melski et al., 2007; Gonzalez et al., 2006) do not handle continuously RFID external mobility, but Melski et al. (2007) propose fixed check point areas to get the current position of RFID object.

Some researches are relative to RFID external mobility (Vaghela and Mahalle, 2012; Singhal and Gujral, 2012). Vaghela and Mahalle (2012) propose an external mobility model that uses the same principles as the mobile IP protocol. In this model, each access network has routers with RFID reader capability, a RFID agent, a home agent as well as a foreign agent to handle the mobility of an RFID object from home access network to a foreign access network. A RFID agent allows the RFID object to have a dynamic identity code which incorporates the IP address of the access network it is visiting. In Singhal and Gujral (2012), RFID external mobility uses the global system for mobile (GSM) topology model. The paper presents an architecture capable to monitor the attendance of students in a classroom. In this architecture, presumptions are that each student has a mobile phone in which RFID tag has been attached. And in each classroom, RFID reader has been installed at the main entry door. Then, as the student mobile phone get in the classroom, the RFID tag is read and relevant data about the concerned student are recorded in an attendance database. GSM module SIM300 has been used for simulations.

The business enhanced RFID research is new area of research that focus to enhanced business using RFID (Al-Kassab et al., 2013; Floerkemeier et al., 2007; Bottani, 2008; Herschel and Rafferty, 2012; Wang et al., 2008; Shah and Murtaza, 2008). Solutions proposed are either middleware and/or BI systems that add to legacy applications product/object data granularity at RFID level. In these papers, middleware systems are acting as a data warehouse and electronic product code information system (EPCIS) standard is used as the framework standard to define their design principles. Researches (Al-Kassab et al., 2013; Floerkemeier et al., 2007; Bottani, 2008) propose BI solutions that are not taking in account enterprise business processes and their dependencies to RFID information. Proposed architecture is based on few processes as inventory and/or stock.

None of related works determine the business processes of an organisation, their dependencies to RFID product, mobility event subscription within organisation departments when the product change location areas, flexibility (GPS and 3G/4G mobile networks) in RFID external mobility models and enhancement of current enterprise applications that are impacted by the RFID product granularity.

3 RFID BI systems architecture

The proposed RFID BI systems architecture (Figure 1) is made of the following architecture main components:

- RFID products
- RFID location events collector
- RFID middleware
- location server (LCS)
- enterprise application systems

- mobility event subscribers
- BI RFID system.

RFID products are items that have been tagged with RFID capabilities and that belong to a specific company. Each RFID product has a unique electronic product code (EPC) (Bouet and dos Santos, 2008; Pais, 2010). A RFID product may be a container of other RFID products. A company A may acquire RFID products from a company B or sell its products to a company B. A RFID product during its life cycle may change location during its transportation from seller to buyer (external mobility) or inside organisation buildings moving from one physical area to another (internal mobility). This mobility of a RFID product in organisation depends generally of the product business process flow implemented.

RFID location events collector system is made of global position systems (GPSs) and RFID readers. GPS system is incorporated in the transportation vehicle to identify the specific geographical position of RFID products that have been loaded in the car. The RFID product position tracking service during the product transportation is called *RFID external mobility event* in this architecture. RFID readers are devices that remotely read the information stored in RFID tags/smart cards, then transmit these information to the RFID middleware for processing purpose. The RFID tags may be passive or active. Passive RFID tags have no internal power source and are powered by the electromagnetic energy transmitted from an RFID reader. Active RFID tags use battery-powered that continuously broadcast their own signal. Inside an organisation, the RFID product may move from one physical area to another. A physical area is modelled with one entry RFID reader and one exit RFID reader.

RFID middleware system acts as an intermediate system that gets the RFID internal mobility location from RFID location events collector system and RFID external mobility location from LCS system. Then, the RFID middleware system data are extracted and enhanced with business data, then loaded in the BI RFID system.

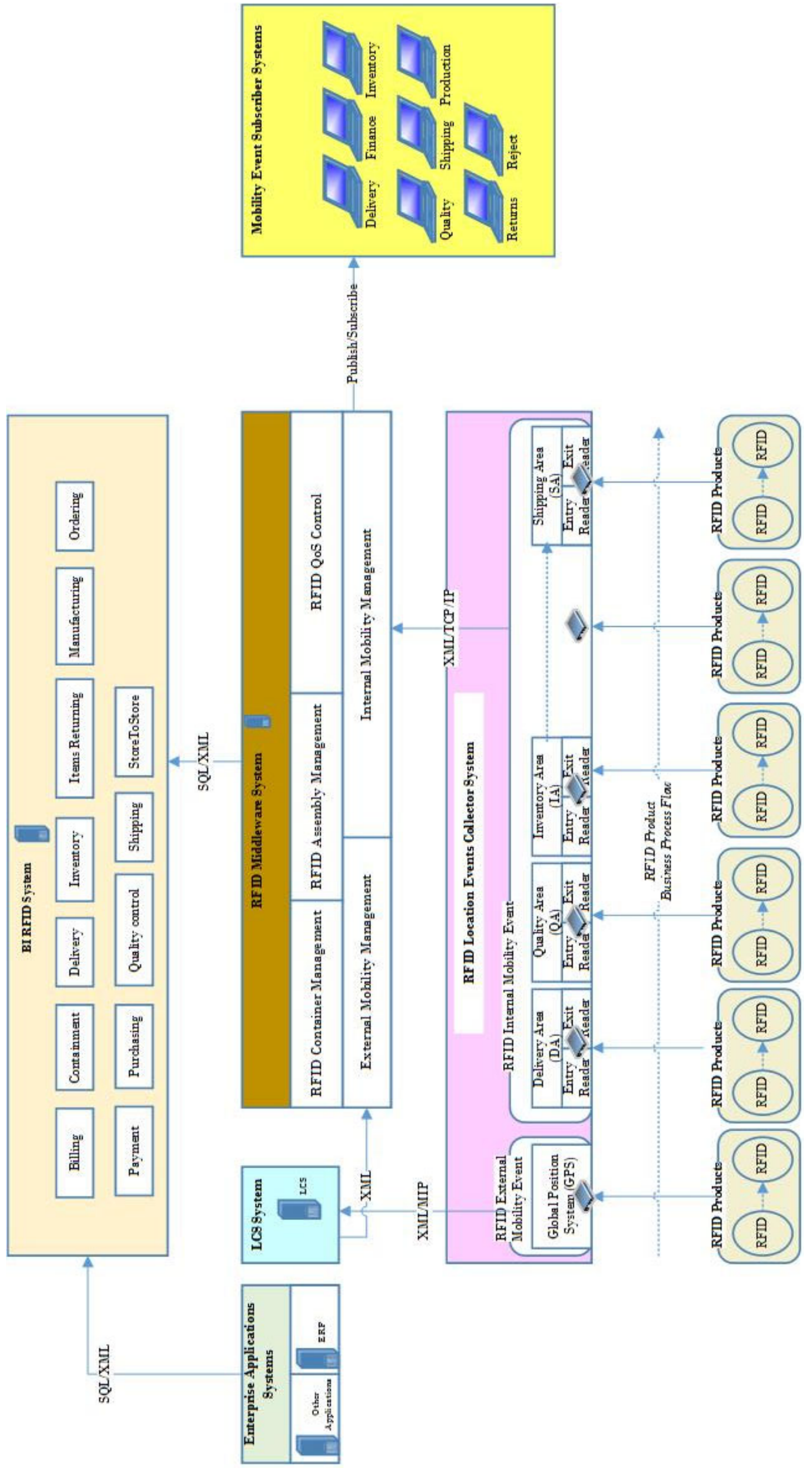
LCS is a system that collects in a given frequency the geographical position of RFID object. The object position is obtained through the RFID external mobility location module. The RFID middleware system subscribes and gets from the LCS the RFID geographical position when products stored in transportation vehicle are in wide area mobility.

Enterprise application systems is the set of systems related to manufacturing/supply processes where business data are extracted, enhanced with RFID middleware data and loaded in the BI RFID system.

Mobility event subscribers systems are business department systems that are interested in the RFID internal mobility from one physical area to another. When the RFID internal mobility event did occur the subscribers are notified by adding the requested data in their queues. Data message recorded have the same data structure as the *InternalMobility* entity.

RFID BI system is a business system that uses historical data at RFID (EPC) granularity for reporting and analysis purpose. Data in this system are modelled in a star schema then saved through an OLAP (ROLAP/MOLAP/HOLAP) database engine.

Figure 1 RFID BI systems architecture (see online version for colours)



4 RFID mobility concepts

In the production supply\manufacturing chain, two kinds of RFID mobility are used: external mobility and internal mobility. The external RFID mobility tracks the position of a roaming RFID product using wireless technologies and infrastructure equipment such as RFID readers, mobile networks (UMTS, 3G, 4G, WIMAX, etc.), and LCS which manages and controls the RFID object location.

When RFID products are roaming in a proprietary local area network (WLAN), their position management will be within the organisation building. In this case, the term BI RFID internal mobility is used to materialise the product mobility and its attributes tracking.

The RFID position' calculation in case of external mobility is realised either through GPS or the real-time location system (RTLS) protocol solution (Bouet and dos Santos, 2008). The RTLS protocol uses network location-based method as enhanced observed time difference (EOTD) (Kohli and Potgantwar, 2016) that helps tracking an object position using at least three network access resources. This method is also known in the literature as the triangulation method. The RTLS is generally used when the position accuracy (measure incertitude within 5 cm–30 cm) is required to calculate the object position. However, for internal mobility (inside a building), the RFID reader' symbolic location is largely sufficient for the RFID product location management. In this paper, GPS and a symbolic location methodologies are used to obtain the RFID position in case of external and internal mobility respectively.

4.1 RFID mobility events

Let consider a production supply\manufacturing enterprise model as a black box with two main gates for RFID product flow: entry and exit gates. Each of these gates has a RFID reader that captures the entry or exit mobility events of RFID products.

In case of external mobility (Table 1), an entry event occurs when a RFID product moves from transporter area (TA) to the delivery area (DA). In case a product must be transported to a client location, the product is kept first in the shipment area (SA). The exit event occurs when the RFID product moves from the SA to a TA.

Inside an organisation, a RFID product may be transformed and/or moved from one room area to another for quality control, storage or transformation services. Depending of the organisation, the internal mobility events flow may vary. In Table 2, a summary of different internal mobility combinations an enterprise may implement are considered.

In Table 2, DA stands for delivery area, IA for inventory area, PA for production area, QA for quality control area, RJA for reject area, RA for return area, and SA for shipping area.

Table 1 External mobility events

External mobility		
Event	*Area changes*	
Entry	TA	DA
Exit	SA	TA

Table 2 Internal mobility area transitions (see online version for colours)

Internal mobility							
Area1	*Area2*	*Area3*	*Area4*	*Area5*	*Area6*	*Area7*	*Area8*
DA	QA	IA	PA	SA			
				QA	IA	SA	
					SA		
					RJA		
			SA				
		RA	SA				
	IA	QA	IA	PA	SA		
					QA	IA	SA
						SA	
						RJA	
				SA			
			RA	SA			
		PA	SA				
			QA	IA	SA		
				SA			
				RJA			
		SA					

4.2 *Mobility event subscription*

Inside an organisation, to plan their upcoming activities, some department services may subscribe to RFID Product mobility events in case the product changes location areas. In our mobility data model proposal, adjacent location area services of an implemented product mobility flow are eligible to receive a mobility event notification. Other department services that are not part of the product mobility flow as Finances may subscribe to a mobility event too. For example, considering Table 2, in case a RFID product moves in the area 1 (DA), the QA and/or IA adjacent department services will be informed. Thus, these notified departments may start planning their related activities.

Table 3 Mobility event subscription

Subscribed event notification from $area_i$ *to* $area_{(i+1)}$			
Current area	*Target queue selection*	*Department service queue (DSQ) of* $area_i$ *to* $area_{(i+1)}$	*Target area*
$area_i$	Queue criteria 1	DSQ1	$area_{i+1}$
$area_i$	Queue criteria 2	DSQ2	$area_{i+1}$

For each mobility event, adjacent department services must subscribe to listen to the concerned mobility topic event. Many department services may listen to the same mobility topic event, then update or plan their activities adequately. For example, in an organisation, the quality department service and inventory department service may be interested at the mobility topic event from area 1 to area 2. The quality department service may be interested on products that move in area 1 and that have a unit price greater or equal to $500 and as of the inventory department service, it is interested to the negation of proposed statement meaning products that have unit price less than $500.

4.3 Location area abstraction

A location area is a logical area where a product may stay for a specific duration. The product mobility flow in a location has two main events: *in* and *out*. To detect a mobility flow event, a location area must be associated with one or many RFID readers that captures the occurred mobility event. A set of RFID readers will be used for a mobility ‘in’ event and a distinct other set of RFID readers are used for a mobility ‘out’ event of a specific location area.

Depending of each organisation and of its implemented manufacturing product mobility flow process, a logical area may be bound to one or many physical location areas.

5 RFID middleware system

The RFID middleware system offers different RFID data granularities that enhance the enterprise applications and reporting applications. In this proposal, the RFID middleware has five main service components: external mobility management, internal mobility management, RFID container management, RFID assembly management, and RFID QoS control management. In the following sections, proposed data models of all RFID middleware services are described.

5.1 Internal RFID mobility data model

The internal RFID mobility data model involves five main data entities: InternalMobility, location, reader, EventType, and RFIDProduct.

The InternalMobility entity is a transactional dataset that captures RFID mobility data values generated from the internal mobility events flow inside an organisation. The location entity is used to capture physical location areas the RFID flows in or out. The reader entity identifies the RFID reader device. Using wireless technologies, the RFID reader reads product with RFID tag from distance (up to 30 metres for passive RFID and up to 500 metres for active RFID). The EventType entity acts as a lookup table that records ‘in’ or ‘out’ mobility event of an RFID product. This mobility event occurs when a RFID product gets in or out of a location area. RFIDProduct entity is the smallest granularity data entity that identifies uniqueness of a product or a products container.

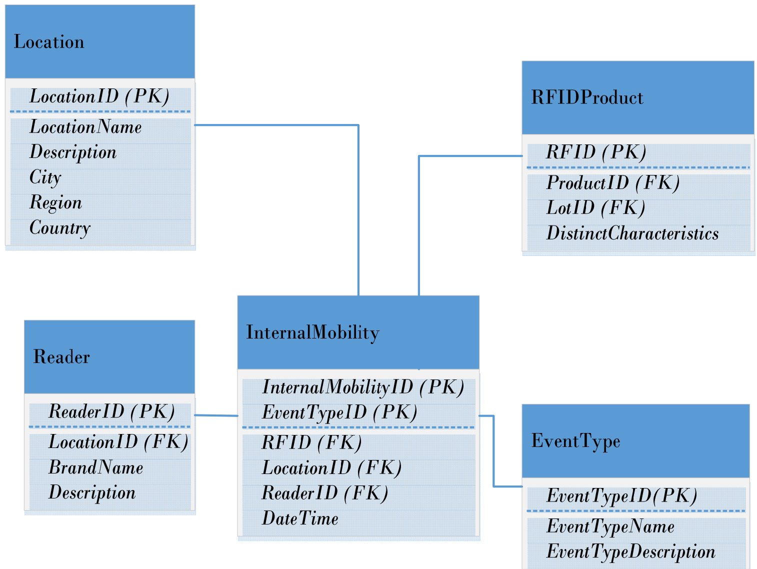


Figure 2 Internal mobility data model (see online version for colours)

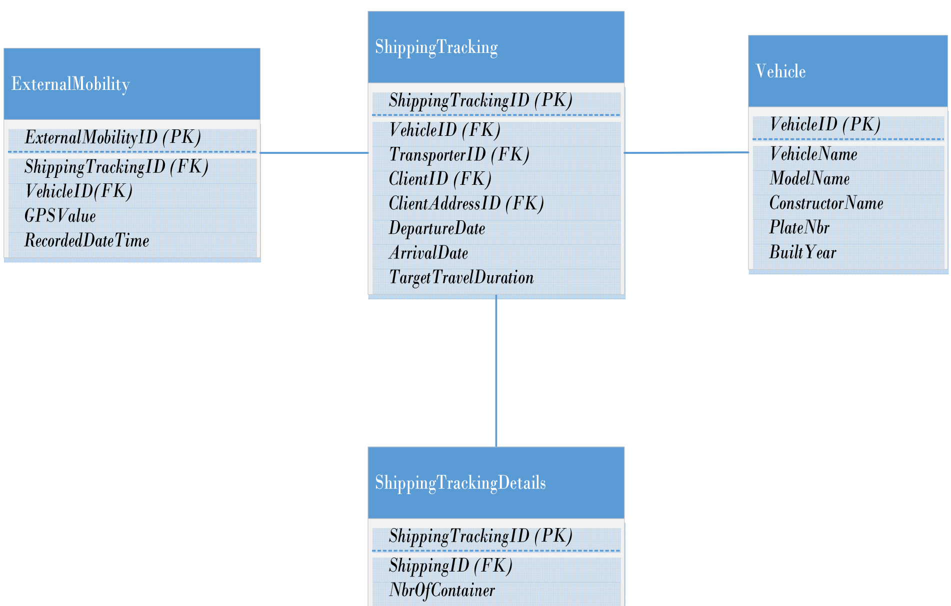


Figure 3 External mobility data model (see online version for colours)

5.2 External RFID mobility data model

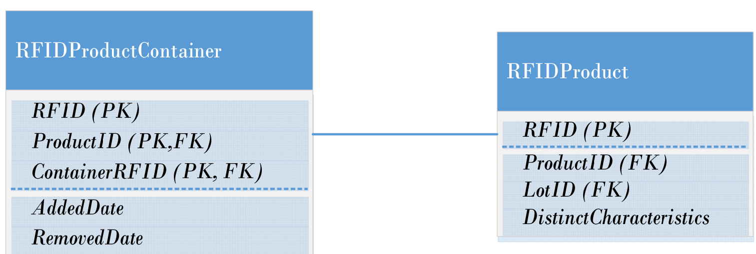
The external RFID mobility data model involves four main data entities: ExternalMobility, ShippingTracking, ShipingTrackingDetails, and vehicle.

The ExternalMobility entity is a transactional dataset that captures the position of a vehicle transporting RFID products from a supplier to a customer. The vehicle position values are generated by a GPS device incorporated in the vehicle. The GPS position value is sent to the LCS periodically. The frequency update of the vehicle position may vary depending of the product sensibility. The ShippingTracking entity captures shipping vehicle identification as well as client identification, destination address, vehicle departure and arrival dates. Its ShippingTrackingDetails entity records the shipping identification and number of related containers. The vehicle entity contains detailed information about the used vehicle during the product transportation.

5.3 RFID container data model

The RFID container data model uses two main data entities at RFID granularity level: RFIDProductContainer and RFIDProduct. RFIDProductContainer is an entity that contains RFID, product and container related information. RFIDProduct is an entity that has RFID and product and lot identification.

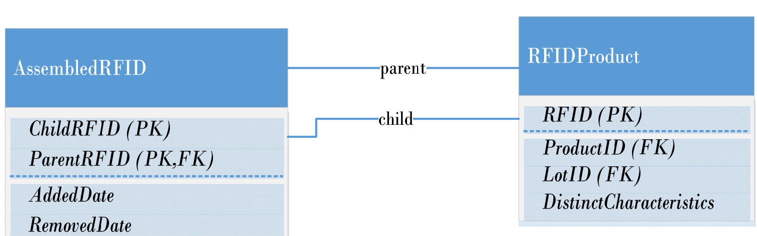
Figure 4 RFID container data model (see online version for colours)



5.4 RFID assembly data model

The RFID assembly data model uses two main data entities at RFID granularity level: AssembledRFID and RFIDProduct. AssembledRFID is an entity that maintains relationship of child RFIDProduct incorporated in a parent RFIDProduct.

Figure 5 Assembled RFID product data model (see online version for colours)



5.5 RFID QoS control data model

The RFID QoS control data model has two main data entities at RFID granularity level: QoSControlRFIDProduct and RFIDProduct. QoSControlRFIDProduct is an entity that keeps QoS control information, rejected reason and related product RFID identification.

Figure 6 RFID QoS control data model (see online version for colours)

6 BI RFID system

The BI RFID system allows an organisation to produce information reporting and data analysis at RFID granularity level. It takes advantage of the useful information coming from the RFID middleware system, then merges them with the relevant business data of the enterprise applications. For example, if we do focus on enterprise resource planning (ERP) application of a manufacturing/supply chain company, main business processes covered by this system are: purchasing, ordering, shipping, QoS controlling, manufacturing, inventorying, billing and payment. To be effective on their daily activities, organisations aim to measure their business processes performances in real-time, daily, weekly, monthly, quarterly, semesterly or yearly based to measure performances of their business functions versus the objectives. The BI RFID system is the system that supports organisations to measure their business performances and generate reports at the lowest product dimension hierarchy (RFID level). Using this lowest product granularity level, reporting applications can narrow performance metrics of an organisation to specific RFID items of a given product (for example, RFID item list of Samsung Galaxy 8 product returned to the supplier. Assumption is that each Samsung Galaxy 8 product has a unique RFID identifier).

6.1 Added values of BI RFID

The BI RFID system allows manufacturing organisations to address more BI questions than a traditional BI system. In addition on questions of who (to get clients, employees, suppliers, transporters), what (to get products), when (to get the transaction date/time), where (to get the location where a transaction/event occurs), the BI RFID system helps to answer question as which subset of a specific product was involved in a transaction. Specific questions as: which subset of product ‘A’ set has been shipped to customer ‘X’? Which subset of product ‘A’ set has been rejected by the quality control? Which subset of product 'A' set has been delivered and that is part of purchase 'Y'? These questions act as filters on product 'A' metrics granularity to get only relevant information of a specific RFID items of product 'A' set that fulfil the answer.

Using RFID granularity level in BI system optimises accuracy of an information request, reduces cost of data research by focusing only on items set of a specific product that is concerned, improves query execution time performance as used datasets are filtered and security is applied at a lowest RFID product granularity level. The RFID external mobility tracks and improves client satisfaction by offering frequent updates of bought products geographical position during their transportation from a supplier to a customer. And the RFID internal mobility optimises task work planning efficiency and improves work control accuracy by determining on which specific subset items of a given product an employee did work on. RFID granularity associated with manufacturing business subjects improves the global traceability transparency of an item by identifying if requested, the used components and/or assembled items that have been included to get a finished product.

6.2 BI RFID services

BI services bind descriptive information required from data entities to the performance measures of a department service or organisation service. Those services are segmented in subject areas, then modelled in star schema design (dimensional model) in the goal to offer non-technical users and knowledgeable IT persons, capabilities of making data analysis and creating queries or reports that produce predictable results.

In the current architecture, the RFID BI layer of manufacturing or supply chain company ten main BI services: billing, delivery, inventory, manufacturing, ordering, payment, purchasing, returning items, and shipping. Almost all manufacturing ERP applications implement those services. These services are tightly coupled with RFID middleware services (internal mobility, external mobility, RFID containment, RFID assembly, and RFID QoS control), then enhanced with RFID capabilities data and uploaded in BI RFID system.

Detailed service description and its transformation in multidimensional models will be described in the next paper.

7 Conclusions

In the current century, information change in some organisation is in order of seconds, minutes, hours or days. Considering this factor, it is very challenging at enterprise level to maintain services offered with precision, integrity or in conformance of required QoS. The RFID BI mobility architecture proposed helps manufacturing or supply organisation solving this challenge with services that track product mobility and enhance product management with RFID capabilities as well as reporting services with predictable results for decision support that are objectives aligned.

In this paper, a RFID location event collector system with two mobility modules has been proposed: *RFID internal mobility* and *RFID external mobility* that tracks RFID product mobility inside and outside an organisation respectively. The proposed architecture allows to existing applications to take integrate RFID granularity information to applications that have product as finest granularity. This integration is achieved through the RFID middleware system which maintains and share the RFID product related information with other legacy enterprise applications.

Next work will consist to implement and evaluate the proposed RFID BI system services and their transformation to multidimensional data model for reporting services purpose.

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