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Mo, J., & Lorchirachoonkul, W. (2012). Extended system design for RFID enabled supply chains with non-RFID technologies. *International Journal of Business Information Systems*, 10(3), 348–368.

<https://doi.org/10.1504/IJBIS.2012.047535>

Document Version: Accepted Manuscript

Published Version: <https://doi.org/10.1504/IJBIS.2012.047535>

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Citation:

Mo, J and Lorchirachoonkul, W 2012, 'Extended system design for RFID enabled supply chains with non-RFID technologies', *International Journal of Business Information Systems*, vol. 10, no. 3, pp. 348-368.

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<http://dx.doi.org/10.1504/IJBIS.2012.047535>

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Extended system design for RFID enabled supply chains with non-RFID technologies

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Abstract: Currently, the coordination between supply chain participants is normally organised via a scan packing system and communicated through electronic data interchange technology. However, the scan pack process is costly and time consuming. Using the electronic product code technology defined by EPCglobal, two national demonstrator projects have been developed to explore the suitability of RFID to the fast moving consumer goods supply chain. The projects show that two major issues must be addressed for RFID technology to be used effectively in global supply chains. First, small and medium enterprises using different RFID standards are unable to participate. Second, RFID IT infrastructures are rigid and costly. This paper examines the capability of two new mobile technologies in relation to current RFID system designs and experiences in the national projects. An extended RFID system is proposed to enable these non-RFID technologies to be used in conjunction with EPC-based systems so that links to non-RFID sites can be established and the cost of system implementation can be more affordable.

Keywords: electronic product code; EPC; radio frequency identification; RFID; national demonstrator projects; NDP; mobile servers; geo-fence; QR code; supply chains system integration; supply chain IT infrastructure.

Reference to this paper should be made as follows: Mo, J.P.T. and Lorchirachoonkul, W. (xxxx) 'Extended system design for RFID enabled supply chains with non-RFID technologies', *Int. J. Business Information Systems*, Vol. X, No. Y, pp.000–000.

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William Lorchirachoonkul is currently the IT Director of Openlogix Pty Ltd. He has been the IT Manager for several large logistics and container companies managing national company networks. He is also a PhD candidate at RMIT University. His current research topic includes, virtualisation model, cloud computing, and ubiquitous systems.

1 Introduction

The need for organising business on a global basis has increased supply chain activities in recent years substantially (Chauhan and Proth, 2005). A manufacturing-based supply chain contains a broad spectrum of partners including manufacturers, third party logistics (3PL), distributors, retailers and has significant uncertainty in its operations (Cucchiella et al., 2008). Such supply chains need to be coordinated by the barcode-based ‘scan pack’ technology (Pawar and Driva, 2000) and good IT infrastructure (Maad and Coghlan, 2010). However, the scan pack process is very labour intensive and time consuming. It requires both sides of the communication parties to scan and verify a number of packaging information. Since most scan pack systems are standalone applications, it has been an integration issue to most enterprise management systems and ERP implementations (Power and Sohal, 2002; Motwani et al., 2005). Scan pack supply chain information infrastructure is built on barcode identification technology, which has inherent deficiencies such as inability to identify individual items. With the trend of globalisation and customer expectation, goods are required to be identified in small batches or in some cases, individually for quality control and market segmentation. Unfortunately, there is no universally agreed system architecture of structuring these information among the stakeholders for secured access by the authorised parties.

Recently, radio frequency identification (RFID) technology is being applied to supply chain management (SCM) with passive RFID being the low cost option for replacing bar coding. Although some preliminary assessments of the economical impact of RFID have been made (Bottani and Rizzi, 2008), documentation of true benefits in real industrial environment is scarce. Pioneering companies are left with a risky decision: “When to roll out RFID technology in their supply chain?” To investigate the potential of passive RFID technology applied to fast moving consumer goods (FMCG) supply chain, two national demonstrator projects (NDP) were conducted in Australia to investigate the effectiveness of using electronic product code (EPC) to improve business efficiency (Mo et al., 2009c). EPC is an identification standard administered by EPCglobal (<http://www.epcglobalinc.org/>) using a specific type of passive RFID (EPCglobal Inc., 2005). Likewise, the European project, ‘Building radio frequency identification solutions for the global environment’ (BRIDGE) (<http://www.bridgeproject.eu/index.php/mainpage/en/>) was developed to resolve barriers to the implementation of the EPCglobal network in high value supply chains such as pharmaceutical industry (Danel, 2009). Standardisation of EPC network requirements helped the initial system design and preparation but major portion of the effort in these projects was to deal with incompatibility among enterprise systems in the supply chain.

Therefore, on one side, implementing RFID technology has obvious competitive advantage over existing competitors. On the contrary, potential increase in productivity is heavily offset by huge capital expenses on assets which may be out of date in a few

months' time. Smart et al. (2010) identified the different types of adoption costs faced by organisations involved in the adoption of RFID within supply networks, and created a generic theoretical framework of costs associated with process innovation adoption to the case of RFID technology. Apart from costs of development, switching, capital and implementation, ethical costs associated with privacy and health issues were also significant. As a consequence, small and medium enterprises (SME), which do not have the same level of resources as large multinational corporations, simply wait until such time that they feel the technology is mature and stable enough to be integrated to their existing operation. Ironically, large organisations, which embrace RFID technology, will need to communicate with SME that may not choose to implement RFID due to resource constraints. In the 3PL environment, where a warehouse can represent different suppliers and customers, after the RFID tags are read and filtered by the middleware, a set of queries can be sent to multiple EPCIS at the same time to query an order that consists of multiple tags. However, if one of the links is broken due to system response, connectivity, security or other reasons, that request may not be executed. If the result of that particular query is required to trigger an event or change of ownership, we may end up with a potential dead-lock. Since there is no other physical way in that the RFID tags can be read or updated in these parts of the supply chain, the traceability of the product is either disrupted or lost completely.

This paper consolidates the experience in the two national projects and identifies the gaps between enterprise systems for implementation of RFID enabled supply chains. Two new non-RFID goods track and trace technologies that can provide the missing links between broken supply chain segments are introduced. To accommodate these new technologies, an extended IT infrastructure model is developed to integrate both RFID and non-RFID technologies as a coherent supply chain system.

2 Review of RFID infrastructure

RFID was first conceived in World War II. Research and development in the late 1990s showed that it was one of the most promising technological innovations, with the potential to increase supply chain visibility and improve process efficiency (Roberts, 2006). However, it is not until mid 2000 that its wider application became acceptable to supply chains. RFID has inherent problems as a reliable identification technology. Zhou (2009) modelled item-level information visibility through reduced randomness, scale of the information system, distribution, control variables and production functions. In order to establish a business case for RFID deployment, Lin (2009) applied the fuzzy Delphi and fuzzy analytic hierarchy process methods to develop a framework for the development of RFID technology, which included the hierarchy of factors, structural procedure, and sequence of adoption. To improve tag performance, Yoon et al. (2008) modified the tag information reading mechanisms. The experimental results showed that when the new mechanisms were applied and the initial number of slots was chosen appropriately, the performance of the modified tag collection algorithm was greatly enhanced compared with the standard tag collection algorithm. In view of the security and privacy issues in RFID, Solanas et al. (2007) designed a cell-based architecture with a specialised protocol by which the tag readers cooperated in order to conduct tag identification in a private and scalable way. Lyu et al. (2009) utilised RFID with a quality assurance system to detect, and prevent quality problems by allowing onsite staff to

monitor complicated variations in production process and handle possible abnormalities simultaneously. Wang et al. (2010) studied 133 manufacturers in Taiwan and developed a range of determinants for RFID adoption in the manufacturing industry. These efforts generated crucial engineering knowledge assisting supply chains to develop RFID systems for their particular environment.

Earlier applications of RFID to supply chains were focused on warehouse management. Chow et al. (2006) designed a resource management system that integrated RFID, case-based reasoning technique and programming model for forklift route optimisation. The system increased operational efficiency by retrieving and analysing useful knowledge from a case-based data warehouse solutions. Poon et al. (2009) introduced RFID into bar-code-based or manual-based warehouse management systems, and tried to solve problems in daily operations of inventory level, locations of forklifts and stock keeping units. The result was promising but there were issues in the range of readers. Szmerekovsky and Zhang (2008) studied the affect of manufacturers and retailers attaching RFID tags at the item level in a vendor managed inventory system. Although the outcome was limited by only one manufacturer and one retailer, they were able to show the importance of shelf space availability and tag costs in RFID adoption.

As the scope of RFID application is extended, the issue of infrastructure support between organisations within supply chains becomes imminent. Movahedi et al. (2007) proposed the concept of quality in supply chain as an important organisational enhancement requirement in order to increase competitive advantage through optimising efficient SCM. A key element of this strategy was the use of advanced communication technologies and technological tools such as e-marketplaces (EM) and RFID. Li et al. (2009) investigated the relationship of three factors in SCM: IT implementation, supply chain integration, and supply chain performance. They found that IT implementation had no direct effect on supply chain performance. Instead, performance was enhanced through supply chain integration. Their findings highlight the importance of RFID infrastructure design while RFID implementation is an enabler of good supply chain performance. Further evidence could be seen from Ngai et al. (2007) who studied the development of RFID prototype system that integrated mobile commerce in a container depot. The system tracked locations of stackers and containers and provided greater visibility of the operations data. The study showed that the benefit of using RFID was to improve control processes in the container depot. In the grocery industry, Martínez-Sala et al. (2009) embedded an active RFID data tag to a returnable packaging and transport unit in order to improve efficiency and even form an intelligent supply chain.

RFID enabled supply chain is not limited to commodity goods. Wu et al. (2006) explored the challenges and obstacles to RFID's quick adoption, the potential resolutions and approaches to the challenges, and the migration strategies to expand the RFID industry. Véronneau and Roy (2009) explored the potential contribution of RFID and other technologies to the efficiency of a cruise corporation's service supply chain. The main finding of their research was that RFID could not achieve direct gains significant enough on a pallet-level-tagging deployment to justify the expenditure. Lee et al. (2008) drew observations from three case studies in the service sector, and developed a customer-facing model, which enhanced customers' value perceptions in order to strengthen customer loyalty.

However, expensive IT infrastructure and uncertain return on investment are the biggest concerns for many supply chain practitioners. Ustundag and Tanyas (2009) used a simulation model to calculate the expected benefits of RFID on a three-echelon supply

chain obtained through performance increases in efficiency, accuracy, visibility, and security level. Their study investigated how the product value, lead time, and demand uncertainty affect the performance of the integrated RFID supply chain in terms of cost factors at the echelon level. Angeles (2009) conducted a questionnaire-based survey and hypothesised from the collected data that supply chain managers planning to deploy RFID systems were alerted to the criticality of IT infrastructure issues as they braced for a likely widespread implementation of RFID in their supply chains. Wang et al. (2007) developed a SCM system with links to a personal digital assistant (PDA) as a construction management portal. The advantage of the system was not only in improving work efficiency for on-site engineers, but also in providing dynamic operation management to enable project participants to control the whole project.

There are significant costs when adopting RFID into the supply chain. Kim and Sohn (2009) proposed a cost of ownership model for RFID logistics system and analysed the effect on profit of various parameter settings in order to support the decision making process of infrastructure construction. Whitaker et al. (2007) found that RFID implementation spending and partner mandate were associated with an expectation of early return on RFID investment. They found that firms with broad IT application deployment and a critical mass of RFID implementation spending had better chance to achieve early returns. Wamba et al. (2008) tested the EPC network in a pilot project and concluded that while the technology could improve the supply chain processes, it would require a higher level of information sharing/synchronisation between supply chain members in a wider strategy. Memon et al. (2010) attempted to use sensor network with RFID to track vehicles but there were network restrictions and cost issues. Tseng et al. (2008) proposed a framework for evaluating the business value of RFID technology. They drew on the experience of five early adopters from the Taiwan healthcare industry and formulated the framework as a set of propositions based on literature, case studies and intuition. The high cost of infrastructure prohibits RFID's application on a wider network.

The literature review shows that successful RFID adoption relies on good infrastructure design of the application environment in which the RFID system is deployed. Two particular issues are observed. First, the cost models for evaluating business case for RFID deployment are based on the notion that RFID is available anywhere in the supply chain. Since the issue of broken communication path in the supply chain due to incompatibility or malfunctioning issues is ignored, performance of RFID systems in practice can never achieve the expected level of revenue. Second, existing RFID infrastructures are rigid and costly. A high cost base makes RFID investment almost impossible to be justified. Gunasekaran and McGaughey (2009) presented a framework to assist wireless networks to be used in mobile commerce. Recently, the viability of mobile commerce was studied with promising results using enhanced network messaging services (Samanta et al., 2010). This paper is motivated by these researches to propose the use of new mobile technologies that extend RFID system infrastructure to cater for these two issues.

3 New mobile technologies

The main problem of global RFID deployment is the lack of visibility beyond physical boundaries of organisations. Existing frameworks such as EPC are based upon physical

RFID tags being read by RFID readers which reside over a gate or doorway. As products containing RFID tags move across the RFID readers, the location of the products is confirmed. This feature is very useful for traceability in a warehouse operation environment, but it becomes ineffective when products move across two trading parties. We introduce the concept of mobile servers, which integrate with QR code and geo-fence, to fill the gap.

3.1 Mobile servers

Since new electronic identification technologies are always evolving, it is almost impossible to specify a single operating standard in today's supply chain environment. As the global economic crisis spreads and our credit market tightens, fewer organisations are willing to invest on such evolving technologies, despite the benefits gained from increased efficiency. The risk of their network infrastructures being out of date and unable to keep up with newer standard simply outweighs the benefit that the technologies offer. To circumvent these problems of managing existing IT infrastructures, the use of wireless technologies is imminent (Stormer, 2006).

Equipped with improved wireless connectivity, mobile devices can be integrated with existing distributed applications frameworks (Figure 1). Lavi et al. (2005) introduced a mobility and group management architecture, enabling real-time collaborative group applications such as push-to-talk for mobile users and multicast overlay for data delivery. Baousis et al. (2009) proposed distributed, adaptive routing schemes on mobile agents to overcome risks like load oscillations. Tacconi et al. (2010) proposed a system architecture for enabling mobile nodes to query a deployed wireless sensor network in an intelligent transportation system scenario. Using three different types of mobile nodes: mobile sinks (i.e., the moving nodes), vice-sinks and ordinary sensor nodes, they showed that their proposed solutions enabled the introduction of novel intelligent transportation system applications. As mobile devices such as mobile phones or smart phones become more sophisticated, manufacturers allow more functionality to be included on their operating systems. Implementation of the mobile server concept has become easy.

Mobile servers need a data scheme to work on. QR code was developed by a Japanese corporation Denso-Wave in 1994 (<http://www.denso-wave.com/qrcode/index-e.html>) and it has been widely used in Japan. QR code is essentially two dimensional barcode, which can be decoded by filtering the pixel of the image. Therefore, it can be easily decoded with an image taken by a digital camera. The main drive for developing QR code was for high speed, fast moving scanning application, such as those used in manufacturing industries. QR code was used for tracking parts in vehicle manufacturing initially. Figure 2 shows tests on capability of the QR code technology handling multi-scan requirements and reading distorted or damaged labels. The code is now accepted by ISO in much broader context, including both commercial tracking application and convenience-oriented application aimed at mobile phone users (ISO/IEC, 2006).

At the moment, apart from normal desktop and laptop computers, most mobile phones have an in-built camera which can read the QR code, and decode it with free software inside the phone. Decoded data can be linked either to a website, or stored somewhere in a server. Typical mobile phones such as Apple iPhone and most Nokia phones have been proved to work seamlessly with this code.

Figure 1 Connectivity and applications on mobile devices (see online version for colours)

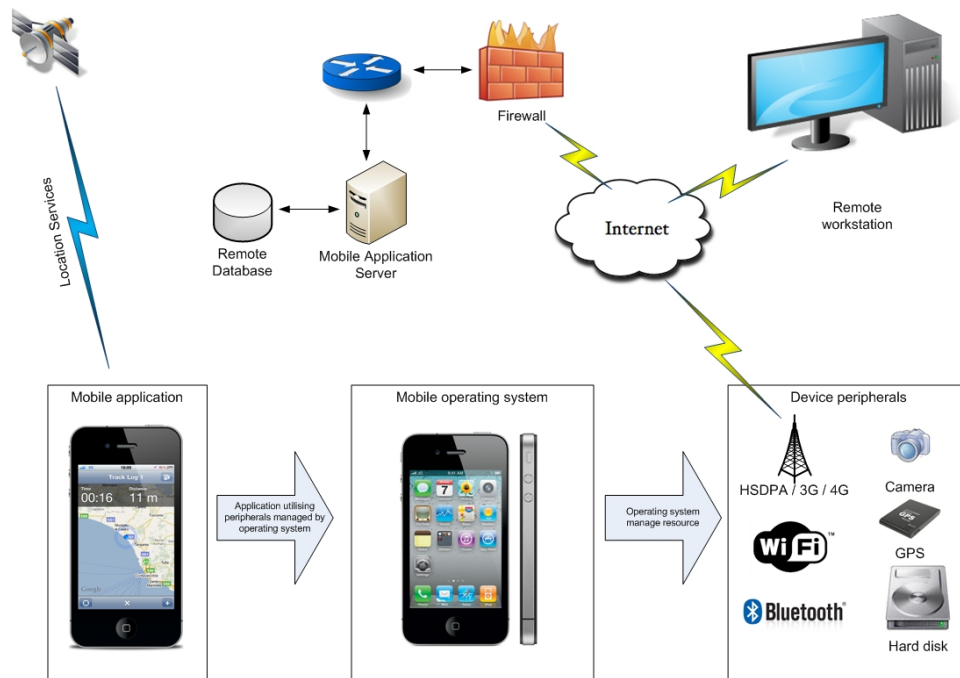


Figure 2 Demonstration of QR code technology for multi and distortion tolerant scanning, (a) multi-QR code tags are recognised in one shot (b) distorted QR code tag can be decoded (see online version for colours)



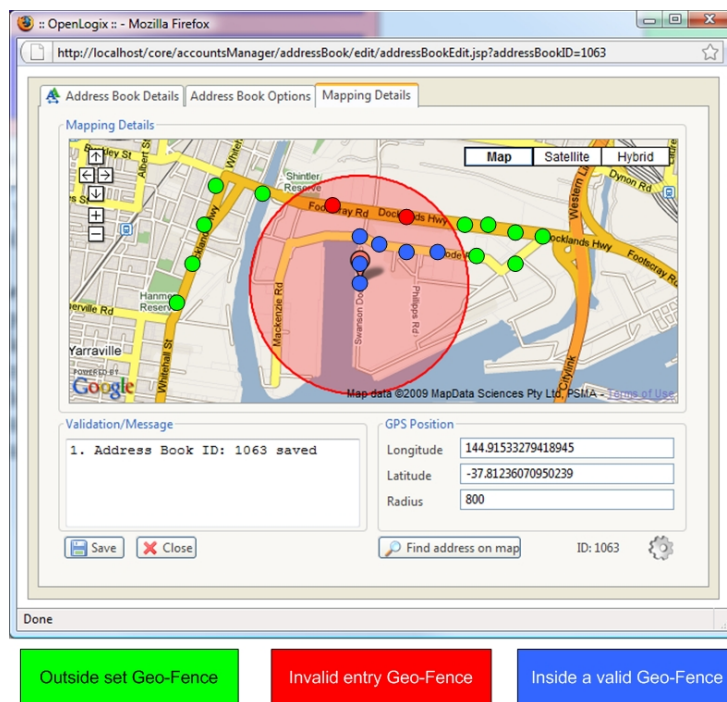
3.2 Geo-fence

One of the most widely used mobile devices in vehicle tracking is global positioning system (GPS) (Hamilton, 1993; Lu et al., 2007). Using a client-server concept, Rizos (2007) demonstrated a real time kinematic model of GPS service that provides the user's coordinates. These developments have been applied in most fleet management system (FMS) for the last decade.

To utilise GPS for RFID application, the mobile device can be configured to define a virtual boundary on the GPS map called 'geo-fence'. The mobile device keeps track of the GPS coordinates against the defined geo-fence. When a vehicle enters the valid geo-fence zone, an arrival timestamp is stored and an event can be triggered that leads to a set of predefined tasks to be actioned, such as registering arrival of a consignment. When the vehicle leaves the virtual geo-fence, the departure time is recorded and the onsite loading time is calculated.

In Figure 3, the geo-fence is represented as a circular boundary (in fact, the boundary can be any shape) that overlaps a small section of a major highway which the vehicle will need to pass in order to gain access to the actual pickup or delivery address. In order to validate that a vehicle is in fact on the actual delivery point and not just passing by, the system will need to check that the last n positions (where n is a set number depending on the boundary) are all within the defined geo-fence in a preset time condition. The shape of the geo-fence can vary depending on the need.

Figure 3 Circular geo-fence detection process (see online version for colours)



The mobile device equipped with the geo-fence capability can then act as a mobile server in conjunction with FMS to keep track of the movement of a group of RFID-enabled consignments outside the company's physical boundary.

Existing telecommunication systems generally have sufficient speed and coverage to support lower level data transmission requirements. The obstacle is basically cost of accessing these networks. To use these mobile devices in a supply chain, IT infrastructure of supply chain companies must be re-designed to cope with the mobility and volatility (in terms of connectivity and security) that these mobile devices bring.

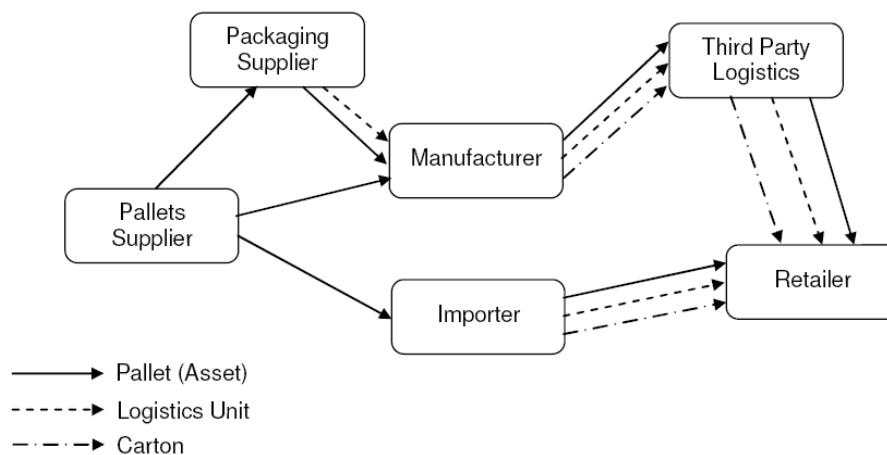
4 The national RFID pilot projects

The national RFID pilot projects were developed to assist supply chain companies to accumulate operating performance data of an RFID enabled supply chain in a real business environment so that they can use the data to justify their own business case for adopting EPC system. In a subsequent simulation analysis, it was shown that the new RFID-based business process could bring a labour saving of \$0.2 M per year, just on the nine products that EPC was applied (Mo, 2009). Given that there were savings in inventory, error elimination, processing time and other advantages, enormous benefits could be achieved if the process was rolled out to other products. However, due to the two issues discussed in Section 2, the RFID system needs further enhancement to extend to non-RFID enabled participants of the supply chain using the mobile technologies described in Section 3.

4.1 The national EPC network demonstrator project

The national EPC network demonstrator project (NDP) aimed to identify the business benefits of sharing information securely using the EPC network in a FMCG supply chain (GS1 Australia, CSIRO, 2006). Using the EPCglobal model, the partners set up a mini supply chain with several distribution points where EPC network system was installed (Figure 4).

Figure 4 NDP mini supply chain



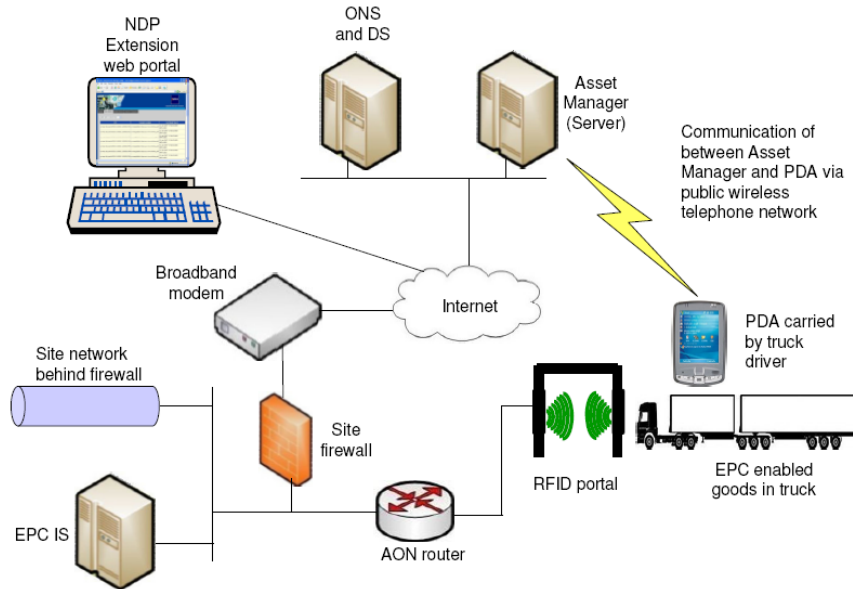
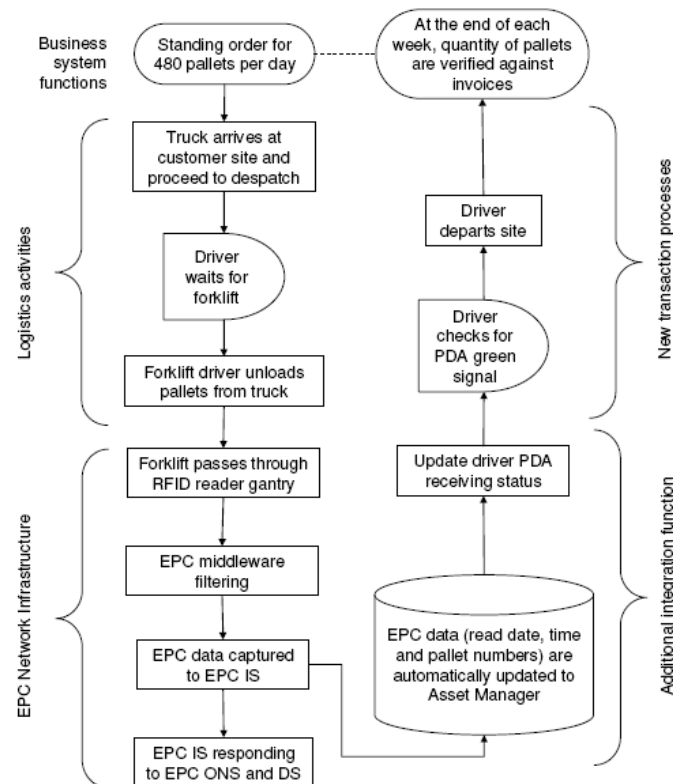
There were three types of materials transacted in the supply chain. All items in Figure 4 were allocated a unique global EPC by GS1: pallets were identified by global returnable asset identifier (GRAI), logistics units were identified as serial shipment container code (SSCC) and cartons were identified by serial global trade item number (SGTIN). The EPCglobal model defined one authoritative registry of numbers that could be queried for links to access detail information from the EPC network. The transactions in the supply were real business activities. Usually, a purchase order was issued by the retailer who triggered the movement of goods among the partners, such as ordering cartons from the packaging supplier, the manufacturer and the importer. When a given tag was detected at the transaction points, instead of having each company storing this information and communicating to the next partner, the EPC network system searched information through the IT infrastructure.

This NDP used the full stack of EPC network protocol enabling inter-organisational transactions and SCM. In order to share information securely among the partners, the NDP IT architecture (shown as part of Figure 7) had several layers of controls. First, EPC data captured at the read points were filtered by middleware layer and stored in the EPC information server (EPC IS) within partners' firewall. When information about an EPC was required, the partner would first login the portal and authenticated the identity by a username and password pair control. Once logged in, the partner could issue a request for information by the EPC as the search key. The EPC discovery services and root ONS would work together to direct that request to the appropriate EPC IS where the EPC information could be found. All transaction and product information including data about the product, containment (content), history (track and trace) information can be accessed. This data sharing capability was the biggest advantage of the NDP which demonstrated the data transparency about the traded items. Detailed transaction data such as location and time about an item (e.g., a shipment on pallet) were immediately available to other partners once the information was available at the local EPC IS.

4.2 *The NDP extension*

The 'national EPC network demonstration business information integration' (NDP extension) was the extension of NDP investigating how EPC information could drive business transactions in hiring of pallets (the asset) to achieve paperless (electronic) proof of delivery (Mo et al., 2009a). As assets moved between trading partners, irregularities were often ignore on the spot, but they were difficult to reconcile at a later date. The errors were not found until the statement was available several weeks later. The trading partners found the discrepancy difficult to be resolved due to lack of supporting paperwork. Since there were millions of pallets in circulation throughout the world, the loss could be enormous.

In the NDP Extension, six sites in two states: New South Wales and Victoria, were installed with the EPC hardware and network infrastructure. Based on the EPC IT infrastructure, the consortium developed additional processes as shown in Figure 5 to achieve electronic proof of delivery. In order to integrate the business requirements, the server software called 'asset manager' communicated with a client programme on the driver's PDA to provide the driver with feedback on the success of delivery (i.e., green signal) before leaving the customer's site.

Figure 5 Asset manager network for electronic proof of delivery (see online version for colours)**Figure 6** EPC enabled pallet receiving process in NDP extension

The 'asset manager' was a routing server programme hosted on the telecommunication partner's server. The corresponding client software was developed and installed on the driver's PDA. Pallets are 'read' when leaving the manufacturer's service centre and on entry into the customer's warehouse. Figure 6 shows the pallet receiving process using asset manager's network. When EPC data was captured at the customer's RFID portal, the data was sent to the 'asset manager' which automatically updated the PDA with pallet delivery confirmations (including date, time and specific pallet numbers) via the telecommunication partner's public wireless telephone network.

The NDP extension has shown that the normal EPC system cannot complete electronic proof of delivery in a business transaction. A mobile client has been used to supplement this functionality.

4.3 Lessons from the two national projects

The two national projects had similar mission, i.e., to test ability of the EPCglobal compliant network in facilitating sharing of RFID and related metadata for FMCG supply chains. This fundamental requirement drove a number of similarities in IT infrastructure. One of the similarities was to use fixed IP address for the servers. This requirement was based on a rigid server structure, which assumed a non-interrupted channel. However, the requirement of fixed IP address was proved to be a difficult IT management issue. The site IT managers regarded the assignment of a fixed IP address as a compromise to the security of the private networks. Since the projects were still exploratory, existing networks and business processes should not be put at risk. At the end, a separate cable was installed to every RFID test site from the public internet network and the fixed IP address was provided by the internet service providers on special subscription.

The national pilot projects showed gaps in the systems and processes of existing RFID-based networks:

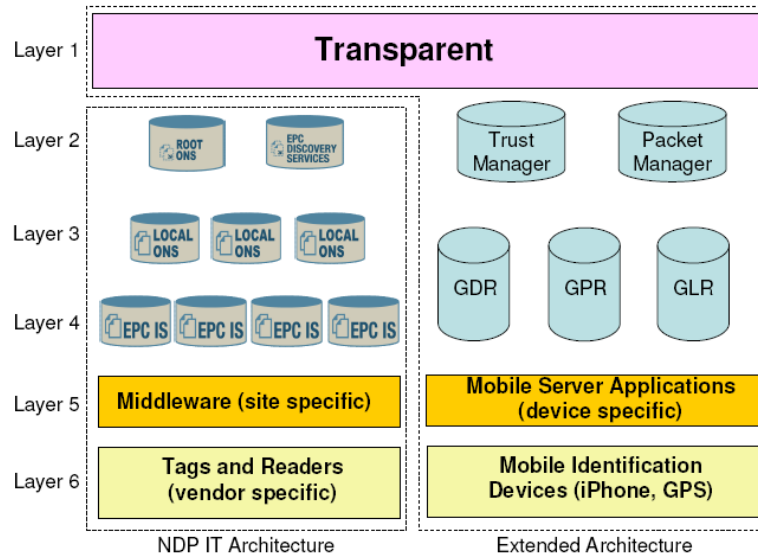
- a Partners of the supply chain change frequently. The rigidity of EPC IT infrastructure requirements discourages changes in partners.
- b In a global supply chain, companies from several countries are involved. It is not possible to guarantee that all companies use the same RFID standard and systems. Companies without EPC IT infrastructure are still operating in the EPC enabled supply chain but they are unable to provide EPC information on their sites.
- c The EPC IT infrastructure was only available in the premises of the partners. Once the goods left the premise, the traceability is lost. This has resulted in an observation that an item went missing for 28 days in transition between Sydney and Melbourne (usually one day trip).
- d The routes for physical goods movement are predominately one way in the national projects. In a more sophisticated global environment, goods and parts can move in any direction. The EPC processes in the national projects did not handle reverse logistics.

These issues have been raised as an enterprise architecture research investigation with emphasis on identification of system functionality (Mo et al., 2009b). However, there is no ready made solution for handling non-RFID compliant segments of the supply chain network.

5 Design of extended system

We propose an extended IT system layer code name ‘transparent’ that interacts with the existing RFID framework (Figure 7). The primary objective of transparent is to enable mobile technologies, such as mobile server and GPS as alternative medium in data collaboration amongst various RFID network. To ensure that the traceability of the RFID tags remain intact, even when there is a disjoint section in the supply chain, where RFID technologies may not be accessible to the sending or receiving parties, transparent uses mobile technologies to emulate non-RFID components of the RFID infrastructure, thus providing an affordable alternative interface that would then be feedback to the RFID physical networks.

Figure 7 Architecture of extended system (see online version for colours)



5.1 Integration with mobile devices

For warehouse and entry portal applications, a digital camera similar to the quality of a webcam can be used to capture the tag. The information can be encoded by the computer for onward passing to onsite EPC-IS. Alternatively, if the application requires mobility, mobile devices with in-built camera can be configured as mobile servers to scan QR code enabled items. Since QR code is basically a picture shot, the scanning process for QR code is very simple and can be operated by any warehouse staff. The mobile server will then decode the information immediately and appropriate actions can be triggered. In a supply chain environment, information such as product code, serial number and production date can be encoded using QR code. The content of the encoded message can be stored as text format which can then be parsed using a delimiter to extract the field content. It is important to acknowledge that if data are stored in this manner, an agreed field format between the recipient and sender must be established. For this reason, it is a common practice to encode only the URL link as pointer to a particular web portal, where

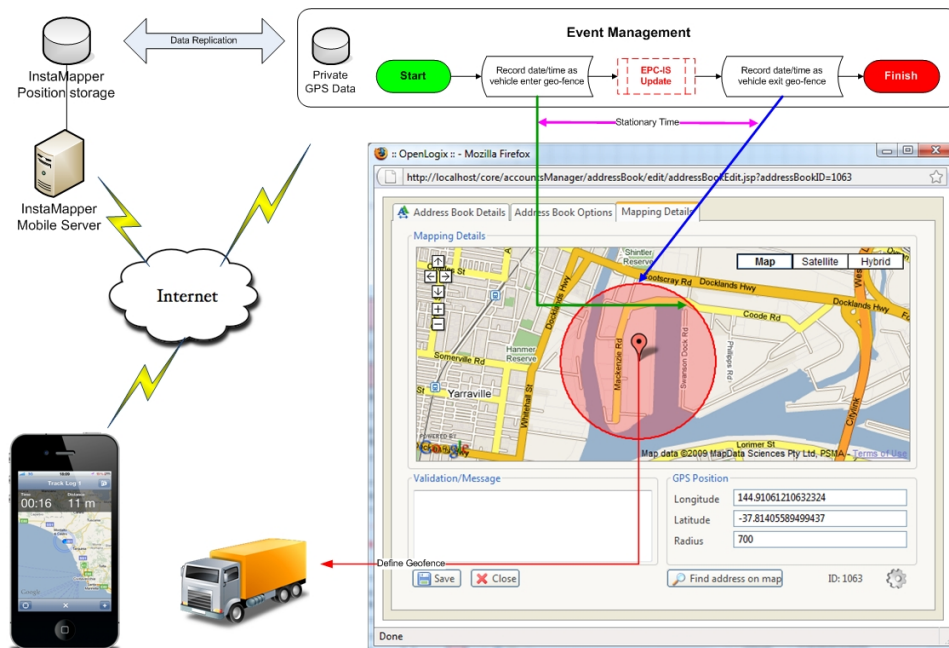
detailed information can be retrieved externally. Since the information is stored externally, security and updating can be done any time.

5.2 Integration with geo-fence

GPS devices are dumb devices that can only receive GPS signals for information of the driver. In order to return GPS coordinates to the FMS, a PDA with GPS capability is configured to transmit location information at set time intervals (e.g., every 2 minutes). If the vehicle is in an area that mobile reception is not available, the coordinates and timestamps are stored inside the PDA until such time that mobile reception is re-established. The geo-fence mobile server can filter out any invalid signal and feed useful information to an event manager, which can trigger pre-defined process when the event profile is detected.

In Figure 8, the mobile geo-fence server keeps track of the GPS coordinates against the defined 'geo-fence' zone. As the vehicle enters or leaves the 'geo-fence' zone, time and location data are captured and filtered according to defined FMS rules. If the loading time exceeds that allowed in the customer's service level agreement (SLA), additional charges can be added and the billing system is triggered.

Figure 8 Integration of geo fence with FMS module (see online version for colours)



It is noted that the actual arrival timestamp will be the time that the system detects that the vehicle enters the 'geo-fence' zone. This is dependent on the size of the 'geo-fence' (i.e., the logical radius or shape of zone polygon) and GPS update interval. Therefore, it will never be as accurate as if the tag were scanned physically by a reader. However, it is very cost effective to have the geo-fence as a virtual gate, since the only capital cost

involved will be the GPS on PDA which is now a standard tool in most logistics operation.

5.3 Registers

Part of the extended system is a group of global registers that keep track of objects in the supply chain. It is necessary to note that objects may exist in multiple instances amongst different systems and platforms. The global registers are reflecting the functionality of the layer 3 and 4 functionality of the EPC system.

- a *Global device register (GDR)*: Used to maintain instance of physical device, such as smart phone and GPS devices. Each GDR are given a unique identifier. They are constantly being monitored against other GDRs and GLRs. Events are raised if a GDR meet a predefined condition, e.g., with a GDR enter into a predefined geo-fence at a specific time.
- b *Global package register (GPR)*: Key function is to track and manage packages within the transparent realm. This includes logistic units, which can travel between trading partners and internal branches. Manufacturers, importer, distributors and direct customers can extract detailed tracking information, even if the logistic unit was managed by multiple 3PL providers.
- c *Global location register (GLR)*: Used to identify multiple locations that could reside within the same geo-fence. Each location, such as warehouse location is given a unique GLR number. This will enable transparent to uniquely identify location's address rather than just depending on the geo-fence alone. This is very useful when delivering into an office building, where the same geo-fence is shared with many addresses.

These registers are used by two server processes: trust manager and packet manager that communicate with the transparent layer.

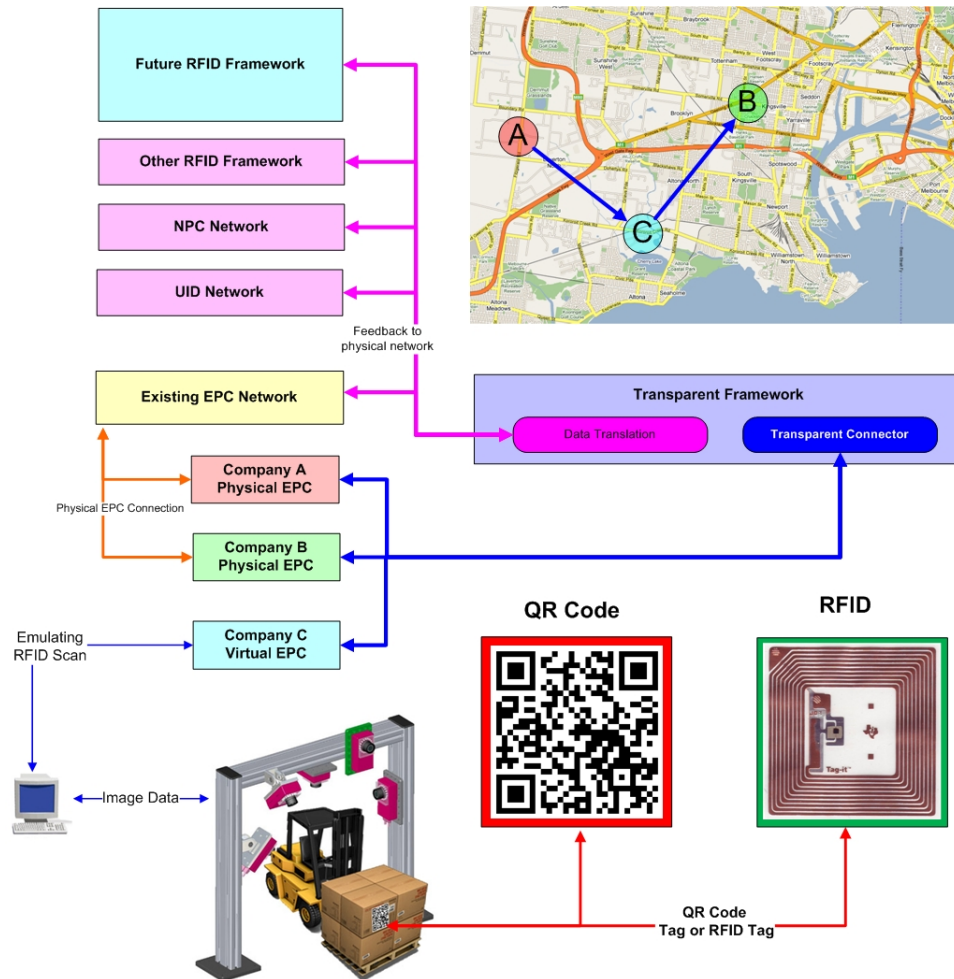
The trust manager manages the security profile of each trading partners. It will also store the environment profile of each trading partners and their inter-relationship. The packet manager generates data packet which are sent and received via transparent connectors. It also contains the type of interface which describes the environment and configuration of each trading partners via the trust manager. The framework therefore has the capability of integrating a number of RFID and non-RFID devices into a track and trace system that does not depend on the compatibility of individual devices in the system. The framework itself has built in components that handle irregularities and exceptions in a consistent manner.

5.4 Implementation

Figure 9 demonstrates how the extended model is implemented for different companies interacting with transparent framework. Each organisation operates their own proprietary enterprise resource planning (ERP) solutions which are hidden away behind their firewall. Using transparent connector, the supply chain partners establish a connection to the transparent framework. Companies A and B are established trading partners and are member of the EPC network. Company C is company A's outsource logistics provider and does not have any RFID infrastructure. Company C's primary role is to facilitate pick

and transport service on behalf of company A. This service is triggered by company B's pre-order advice (POA) to company A. Since company C is not a member of the EPCglobal network, any activities handled by company C will not be visible to company A and B. Thus, the performance of the supply chain is heavily degraded, especially in a just-in-time (JIT) operation, where lead time and inventory records are critical.

Figure 9 Implementation of transparent framework incorporating RFID and non-RFID networks (see online version for colours)



In our proposed model, transparent connector synchronises the activities of physical EPCglobal network from company A and B. At the same time, transparent synchronises events generated from company C's virtual EPC network back to the physical EPC network of companies A and B. It is also important to note that company C may also service orders for other company A's customers that are not member of EPC network or belong to other RFID network, as long as those customers are a part of transparent framework subset where they may not have transparent connector installed, but exist in the GLR. Events generated from GLR will still be visible to company A via transparent

network, thus improving the visibility and traceability of the overall supply chain between all parties.

The extended system has been tested in a local logistics company managing movement of containers between ports and warehouses. The customer, who is a manufacturer of canned and processed food located at an offshore facility, uploads their bill of landings (BOL) into transparent to initialise the ordering process and the registers. The order details are then routed by transparent into the local logistics company database, where a link to the FMS is made. The FMS constantly monitors the voyage data published from the stevedore companies. Once the vessel arrives into the local ports, the logistics company then communicates with the stevedore and requests a timeslot to pick up the container. A driver, vehicle and trailer are allocated and the information is returned to the stevedore company for security verification.

At this point, geo-fence is activated and communicates with the FMS to create a relationship between the manufacturer's BOL and registered assets in transparent. The system then waits for the respective GDRs to enter the specified geo-fence at certain time windows. When the condition is reached, the FMS sends a message back to transparent updating the tracking status of the order, which is visible to everyone in the supply chain. Once the container arrives at the local depot, it is then unpacked, palletised and a QR code is attached to each pallet. An event is raised by a mobile server when a QR code is read by cameras at the dispatch area. Transparent is notified as the shipping container leaves the local port. Since the retailer is part of the RFID network that transparent interfaces with, an advance shipping notification (ASN) message is sent to their enterprise system alerting them of arrival of the shipment. From this point onwards, transparent takes control of goods tracking and communicates with the retailer's RFID system when the consignments are finally delivered.

6 Conclusions

In this paper, the use of non-RFID technologies in a RFID environment is explored. This research is based on the experience of two RFID pilot projects in Australia that aimed to demonstrate the application of EPC-based networks for supporting global supply chains. Some of the major pitfalls in these pilots are identified including potential risks of broken link, data dead lock and high cost of RFID system implementation. From these RFID pilot projects and motivated by recent researches in wireless IT infrastructure developments, mobile client devices have been proved useful in providing feedback to the personnel on site to complete the business transaction by electronic proof of delivery.

With new developments in wireless technologies, it is now possible to incorporate more intelligence in mobile devices for managing movement of goods, making on the spot decisions and communicating with different types of servers as required. The concepts of mobile servers and geo-fence are introduced in this paper. Both application concepts make use of the application programming interface capability of contemporary mobile devices such as iPhone and PDA to add new tracking capabilities to the RFID IT infrastructure. For mobile servers such as iPhone and webcam, QR code is used to supplement the deficiency of RFID data networks at locations where RFID IT infrastructure is unavailable. QR code has robust performance over other forms of data labelling. In addition, for tracking movement of consignments and other large items,

PDA's are configured as geo-fence servers and can be used to capture location information of logistic units.

These new mobile technologies require an integrated system to tie them together in a meaningful way. We propose an extended information system architecture with an additional layer providing a seamless communication channel between dissimilar devices. The key feature of transparent framework is the establishment of three registers that work in parallel with the EPC layers so that goods information can be reconciled seamlessly via the transparent framework. With these new developments, supply chain participants without RFID capabilities can participate in the global supply chain without the risk of broken information link at reasonable costs. Future research will be required to extend this capability to global destinations where other RFID coding schemes are used.

Acknowledgements

The authors would like to thank the support of the two national projects, NDP and NDP Extension by the Australian Government through two research grants from the Information Technology Online (ITOL) programme managed by the Department of Communications, Information Technology, and the Arts. The authors would also like to thank the reviewers for their constructive and helpful comments.

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