Research article

RFID-enabled supply chain systems with computer simulation

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Abstract
Purpose – The purpose of this paper is to review key points about the radio frequency identification (RFID) and the fundamental concepts of supply chain management (SCM). To understand important supply chain (SC) strategies for a complete success, main strategies are identified. Some applications of RFID in SC are briefly reviewed and three large cases of RFID implementation in SC are discussed.
Design/methodology/approach – Provides key elements of SCM, a brief background on RFID, and the integration of SC and RFID to generate new systems with higher level of profitability and efficiency. Three cases using computer simulation techniques for system evaluation are reviewed.
Findings – The paper finds that to make the SCM functional and successfully operational, management must be committed to high standard of performance including competitive lead times to customers, significantly reduced inventories, world-class product quality, and reduced process and product complexity.
Originality/value – Owing to the fact that a better management of a production system is related to the full understanding of the technologies implemented and the system under consideration, sufficient background on the RFID technology is provided and a SCM system including its appropriate strategies are discussed.

Keywords Supply chain management, Productivity rate, Radiofrequencies, Tagging, Codes, Simulation

Paper type Research paper

1. Introduction

Radio frequency identification (RFID) is in its first stages of the development and usage. Its complete benefits will excel and shine some years in the future. The implementation of RFID basic structures is accounted as its first critical step. This, by itself, is the main driver and the essential key for its acceptance. An RFID system is comprised of tags, a reader that can read data from the tag, antenna and the hardware and software. The main reason for setting up an RFID system is to collect desirable data from a moving object or a fixed one. Although, there is piling news against the security for this technology and the privacy that it accounts for recent expert reports indicate that, during the past year, about one billion RFID tags are produced and implemented all around the world.

RFID has been identified as one of the ten greatest contributory technologies of the twenty-first century. This technology has found a rapidly growing market, with the global sales expected to top $7 billion by year 2008 (Chao *et al.*, 2007). Companies lined up to use RFID and do employ experts to improve the efficiency of their operations to gain competitive advantages over time. Manufacturers can use RFID solutions to reduce operating costs through decreasing the labor costs, and claims and returns. This will help them to increase the operating incomes. They also can reduce the working capital by enabling reductions in inventory and lowering the inventory write-off from the return goods and those items that are un-saleable at the end. Main benefits of RFID can be listed as (www.rfidbase.com):

- improving the speed and accuracy for tracking pallets, boxes and containers;
- helping to reduce stock levels;
- helping to reduce operating costs;
- improving the management of inventory;
- improving efficiency in work-in-process (WIP) reporting; and
- improving inventory visibility to feed JIT systems.

The introduction of RFID technologies has brought much debate and speculation about its potential impacts. A study conducted by the University of Texas at Austin and sponsored by NXP shows the financial impacts of RFID in the US healthcare and retail stores. The key finding of this study can be summarized as follows (www.rfidbase.com):

- companies in the retail and healthcare sectors have experienced, to date, a 900 per cent rate of return on their RFID investments;
- current adoption levels of RFID at the pallet and item levels in retail currently derive $12.05 billion in benefits from existing RFID applications;
- retail consumers see a $2.63 billion annual cost savings benefit;

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- total benefits accruing to healthcare industry manufacturers, distributors, and hospitals is equal to $45.9 billion; and
- improved patient care from RFID deployment is valued at $30.72 billion.

Benefits to the healthcare consumer, through enhanced patient care, is estimated at $165.12 billion.

The main objective of this paper is to review some key points about RFID and to present some of its applications in supply chain management (SCM). The plan for this paper is as follows: Section 2 discusses the trend. Section 3 gives a brief discussion on supply chain (SC). RFID applications are discussed in Section 4. RFID enabled SC systems are discussed in Section 5. Cases 1, 2, and 3 are discussed in sub-Sections 5.1, 5.2, and 5.3, respectively. The paper conclusion is given in Section 6.

2. The trend

RFID is a method for sending and receiving data without any contacts occurs between the interrogators and tags using electromagnetic waves (Anonymous, 2004). RFID tags can hold more information than data carrier systems such as bar code system. OMRON has announced that it will get into the RFID technology by year 2005. The technology is called "Jomful". OMRON produces two types of RFID tags with 13.56 MHz and 850-960 MHz (Anonymous, 2005c). The company had received a patent for "Jomful" in the USA, Europe, Korea, Taiwan, and Japan (Anonymous, 2005c). Revenue for RFID products is predicted to grow steadily over the next six years and shown by Figure 1. It is expected to reach US$ 4 billion per year by 2008 (Alexander Resources, 2004).

Although RFID technology has been around since 1960 the use of RFID in SCM is new. The world largest retailers, including Wal-Mart in the USA, Metro Group in Germany, Marks & Spencer in the UK mandated the use of RFID in tracking supplies (Roberti, 2003). In 2004, the United State Department of Defense (DoD) also became another strong supported of this technology. It was March 2005 that more than 104 Wal-Mart stores have been equipped with the RFID systems. By that time 36 of Sam's Clubs and three of Wal-Mart's distribution centers (Sullivan and Dunn, 2004; Sullivan, 2005) were also equipped with this technology. By 2006, Insight forecasted that tagging will be well on its way to becoming a common place within SCs, including among smaller retailers and suppliers, with an expected tag price of 1-2 US¢. Insight research expected that tagging at the item level to be widespread, virtually replacing bar coding (Anonymous, 2006). The pace of RFID adoption is estimated by Collins (2003) and the risk of RFID was studied by Rappold (2003).

Figure 2 shows that since 2000 the trend on RFID research by active researchers is increasing and expected to continue for the coming decade similarly (Chao *et al.*, 2007). Table I lists the top eight countries in the world that have produced articles in the field of RFID.

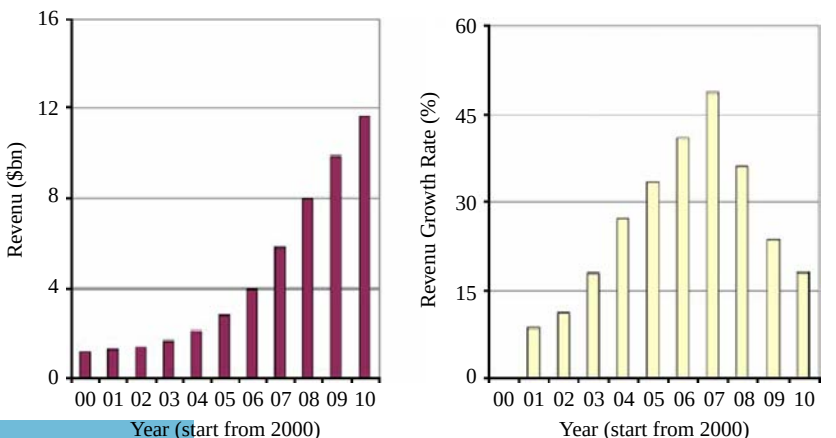
3. Supply chain

SCM is a link between planning and control of the supply process and corporate competitiveness. SCM is an effort to win economic advantage by expert deployment of SC resources. In simplest terms, an integrated SC is a connected series of organizations, resources and activities involved in the creation and delivery of value in the form of finished products and services to end customers. Management of a SC involves the integration of all decisions that affect the design and flow of purchased items/materials/services into and through a corporate entity to finished products.

A research conducted by AMR indicates that early adopters of RFID can cut SC costs by about 3-5 per cent (Anonymous, 2005a). The same study points out that these users of RFID can reduce costs by about 2-7 per cent. Generally speaking, RFID can have a huge impact on the entire SC processes. Hence, it is important for the big SC players to learn about this technology and to take its effectiveness into consideration. Companies considered to be the best in the class for their SC performance must be able to operate their network efficiently at 4-7 per cent of revenue less than the average company in their industry. Main strategies used with SCM are:

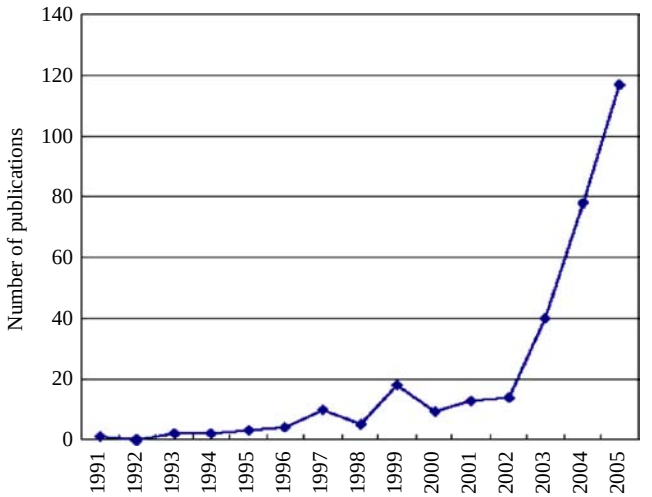
- competitive strategy;
- product development strategy;
- marketing and sale strategy;
- SC strategy;
- strategic fit;

Figure 1 Total RFID base applications market – worldwide revenue forecasts, 2000-2010



Source: Frost & Sullivan (2004)

Figure 2 Total articles published on RFID from 1991 to 2005



Source: Chao *et al*. (2007)

Table I Top eight countries doing research on RFID

Row	Country	Number of published articles
1	USA	84
2	Japan	21
3	Germany	17
4	Switzerland	15
5	South Korea	14
6	Canada	11
7	UK	9
8	Finland	8

Source: Chao *et al.* (2007)

- global freight management strategy;
- customer focus strategy; and
- strategic sourcing.

To ensure optimum performance, companies must work to reduce costs, accelerate operations, and improve quality both in their own processes and in their partner organizations. By gaining cross-company visibility and control, companies can identify and pursue opportunities for SC improvements. The Global Supply Chain Forum identified eight key processes that drive SC efficiencies:

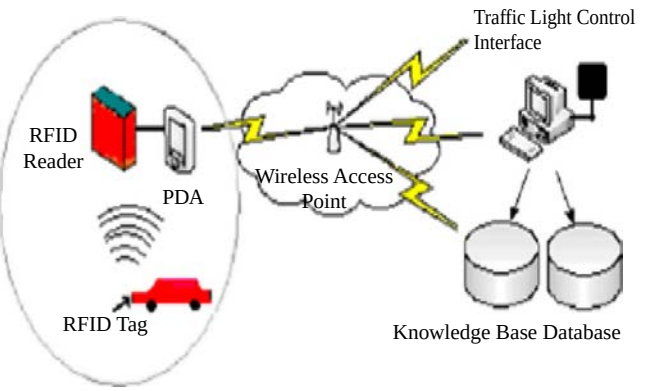
1 customer relationship management;
2 customer service management;
3 demand management;
4 order fulfillment;
5 manufacturing flow management;
6 supplier relationship management;
7 product development and commercialization; and
8 returns management.

4. RFID applications

It is important for business and social science researchers to understand RFID, because it is likely to have a profound impact on how firms compete globally, especially in terms of SCM (Ngai *et al.*, 2007c). About 97 per cent of pallets sent to Iraq have been shipped with RFID tags (Barlas, 2005). The largest area of adoption has been in retail industry (IDTechEx, 2006), and approximately 1,500 RFID patents have been issued since 1997 (Read, 2005). This technology can save billion of dollars for the world businesses specially the first world countries that are ready to implement that. Various countries have started to use RFID in different forms and shapes. RFID is used to develop intelligent highways (Legg, 1994), distribute products (Schneiderman, 1995), and transport construction materials (Naresh and Jahern, 1997). It is used in the US army (Anonymous, 1997), in manufacturing systems to monitor the factory level (Labs, 1998), in US postal services (Heftman, 1998), to transport passenger's luggage by Airline industry (Goldberg, 1999), to monitor the sugar cane farms by farmers (Anonymous, 1999), for soil monitoring purposes (Hamrita and Hoffacker, 2005), in agriculture and food industry (Wang *et al.*, 2006), in SCM (Lin *et al.*, 2006; Naim *et al.*, 2002), in service sector (Lee *et al.*, 2007), for product design (Repo *et al.*, 2005), in book industry (Hicks, 1999), in museum for tracking visitors (His and Fait, 2005), in oil refinery (Bacheldor, 2007), in managing restaurant (Ngai *et al.*, 2007a), in parking management (O'Conner, 2007), in SC systems with mobile monitoring capability (Ngai *et al.*, 2007b; Wamba *et al.*, 2006, 2008), in retail systems (Kourouthanassis and Roussos, 2003), in retail grocery sector (Hingley *et al.*, 2007; Reyes *et al.*, 2006), for monitoring patients with diet problem (Hall and Hampl, 2004), in automobile industry (Fleisch and Strassner, 2003; Ford Cuautitlan, 2003), in pharmacy industry (Anonymous, 2005b), for hospital social impacts assessment (Fisher and Monahan, 2008), in investment (Uckun *et al.*, 2008), in logistic management (Chow *et al.*, 2007; Estefania *et al.*, 2007), in enterprises (Liard, 2005), and for monitoring and tracking live animals (Wismans, 1999). Temporal management of RFID data are discussed by Wang and Liu (2005), and dynamic data-drive application systems is discussed by Kima and Heller (2006). RFID guide is discussed in Bhuptani and Moradpour (2005), and emerging RFID technology roadmap is discussed by Vermesan *et al.* (2007).

Wen (2008) has proposed a dynamic and automatic traffic light control expert system (DATLCES) for solving the road congestion problem. The framework is comprised of six sub-models coded in Arena to be simulated to help analyzing the problem. This DATLCES is composed of seven elements as such as: a RFID reader, an active RFID tag, a personal digital assistants, a wireless network, a database, a knowledge base, and a backend server. These pieces are shown in Figure 3.

Figure 3 A framework for DATLCES



Source: Wen (2008)

Wamba *et al.* (2006, 2008) provided insights on the RFID technology and the electronic product code (EPC) network by investigating their impacts on mobile B2B-eCommerce. Based upon the empirical data gathered from the interrelated firms in a SC, several scenarios that integrate RFID and EPC networks are tested and evaluated. The results indicate that the business approach seems appropriate to capture the potential of integrated RFID–EPC network systems and that such systems can improve shipping, receiving, and put-away processes.

Bottani and Rizzi (2008) have discussed on the "Economical assessment of the impact of RFID technology and EPC system on the fast-moving consumer goods supply chain". They described a research that aims to quantitatively assess the impacts of RFID technology and (EPC) systems on the main processes of the fast-moving consumer goods (FMCG) SC. A three-tier SC that is composed of manufacturers, distributors, and retailers is examined, and the results of the feasibility study show that RFID and EPC implementation is still not profitable for all of the tiers in the chain.

Wang *et al.* (2007b) simulated the impact of an RFID system on the inventory replenishment of the thin film transistor liquid crystal display (TFT-LCD) SC in Taiwan, and examined global operations and logistics through a case study of a well-known LCD monitor manufacturer. The results of the experiment show that an RFID-enabled pull-based SC (RPSC) can be effectively achieved with a 6.19 per cent decrease in the total inventory cost and a 7.60 per cent increase in the inventory turnover rate.

Jedermann *et al.* (2006) have used new sensor, communication and software technologies to expand the facilities of tracking and tracing systems for food transports. An embedded assessing unit detects from sensor data collected by a wireless network potential risks for the freight quality. The proposed system autonomously configures itself to a product specific supervision task based on data scanned by an RFID reader during freight loading.

Wang *et al.* (2007b) conducted a research that is based on the case of a real-world company and the pull-based demand driven supply network environment, establishing a RFID-enabled and a non-RFID-enabled TFT-LCD SC, embedded with automatic replenishment simulation systems to analyze and compare the degree of improvement in the key performance indicators of total inventory cost and inventory turnover rate. The simulation system proves its effectiveness through stability test, time phase relationship test, and integration test. After nearly 2,500 runs of experiment, authors found that there is more decrease in total inventory cost and more increase in inventory turnover rate of the RPSC than the non-RPSC. They also found that due to the existence of WIP, on-hand units, the degree of improvement in the bullwhip effect on tiers with production plants is limited.

Estefania *et al.* (2007) have discussed the enabling of technologies for developing a flexible tag microlab for food monitoring during the logistic chain. The realization of the system includes the integration of physical and chemical sensors with RFID communication capabilities.

Lee *et al.* (2007) have discussed in their article titled "Radio frequency identification (RFID) implementations in the service sector: a customer-facing diffusion model" on three cost-conscious businesses having focused on using RFID systems to enhance the efficiency in the supply management/logistics process. These firms go through an implementation process that focuses on the supplier-facing and back-office operations. Drawing from observations from three case studies in the service sector, they developed a complimentary customer-facing model, which focuses the diffusion of RFID as originating from those activities associated with the delivery of the actual service offering.

Wang *et al.* (2007a) developed a mobile construction RFID-based dynamic supply chain management (M-ConRDSCM) system to improve efficiency and cost effectiveness of project control, improve practical communication among participants, and increase flexibility in terms of project delivery and response times. As a basis for the case study a high-tech factory building project in Taiwan is used.

5. RFID-enabled supply chain systems

This section is devoted to the review of SC cases presented in the literature that have been solved by computer simulation techniques for analysis purposes. The cases are:

1 the impacts of RFID on inventory replenishment (Wang *et al.*, 2007b);
2 monitoring the states of the SC (Kim *et al.*, 2007);
3 delivering chain performance (Kim *et al.*, 2008);
4 mobile construction RFID-based dynamic SCM Wang *et al.* (2007a);
5 using RFID systems to enhance efficiency in supply management/logistics process Karkkainen (2003); and
6 economical assessment of the impact of RFID technology and EPC system on the FMCG SC (Bottani and Rizzi, 2008).

Li and Visich (2006) compiled a list of 39 benefits across the SC. Upon the examination of Li and Visich's list and other RFID overview papers, this paper identified 15 distinct types of benefits by minimizing overlap and excluding secondary benefits (Tajima, 2007). Figure 4 shows how these 15 benefits are classified into two categories of:

1 realized benefits throughout the SC; and
2 realized benefits by major SC participants.

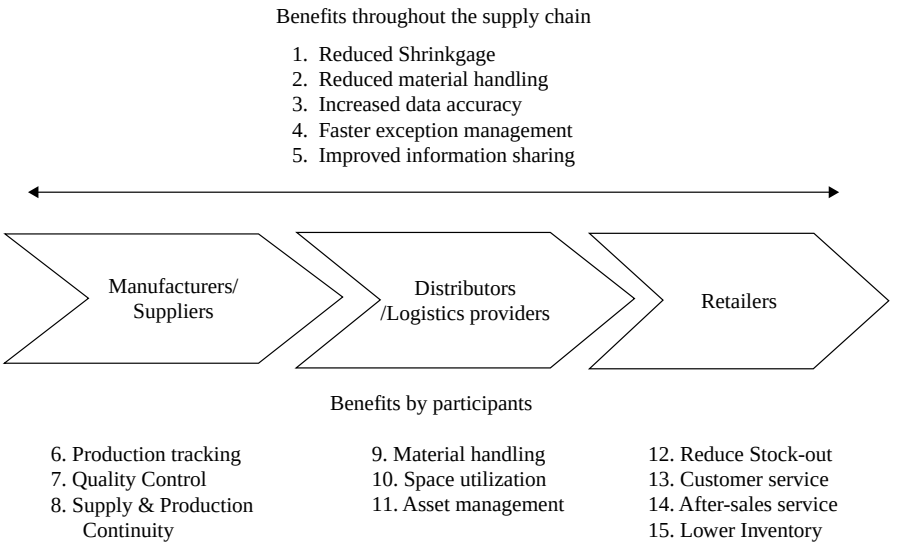
Each benefit type is briefly described in Table II (Tajima, 2007).

Research to assess the impacts of RFID on SC systems is scarce. This is a step towards filling this gap by studying cases and deriving results from our findings. To do that, we review three cases from the literature and show how RFID can have a big impact on the SC and create business value for that.

5.1 Case 1

Wang *et al.* (2007) have analyzed the simulated impact of RFID technology on the inventory replenishment of the thin film TFT-LCD SC in Taiwan. This is a multi-agents-based SC model that is a combination of different agents designed for the operational process and functional requirements of every tier. The conceptual flowchart of RFID/EPC SC application is shown in Figure 5. When loads are put into the trucks and sent to the warehouses, the antenna of the RFID system will read the EPC tag on cases, retrieve the embedded information, and transform the data format. Through the internet connection, transactions of stocks can be monitored at any time

Figure 4 Benefits throughout the SCM



Source: Tajima (2007)

(Wang *et al.*, 2007b). The structure of multi-agents embedded with the RFID/EPC system has been designed as shown in Figure 6. As can be seen the structure of the SC is divided into three parts of:

1 SC planning agent;
2 units control agent; and
3 executive operation agent.

The SC model that was developed is a pull-based multi agent simulated using AnyLogic software. To test the impacts of RFID, authors have taken an automatic inventory replenishment function using (s, S) policy into consideration. Once the results were compared it was noticed that the RPSC can decrease 6.19 per cent total inventory cost and increase inventory turnover rate by 7.60 per cent.

5.2 Case 2

Kim *et al.* (2007) have proposed a research on SC using RFID technology to monitor the states of SC system real time. A methodology is suggested to transform the state vectors obtained from RFID into bi-directional cause-effect knowledge for the management of dynamic SC (Kim *et al.*, 2007). This research was aimed to mine bidirectional cause-effect knowledge from the state data. To do so, authors has discussed following steps:

1 a fuzzy cognitive map (FCM) model of SC is developed;
2 the weight matrix of the FCM model is discovered using the past data and genetic algorithm;
3 through the detection of a sudden change in certain state, its cause is sought from the past state data throughout backward analysis; and
4 computer simulation was used to show the performance of the forward-backward analysis methodology.

In this research, the state of the SC is divided into three cases of:

1 external states;
2 policy states; and
3 internal states.

The SC considered here is a three stage SC comprised of a supplier, a manufacturer, and a retailer. Figure 7 shows the cognition map of the SC having three external states, three policy states and 12 internal states (Kim *et al.*, 2007). Notice that the edges show causal direction. Internal states can be observed through RFID information system (Kim *et al.*, 2007). The "Mfg inventory level" is an internal state. The increase in the "Mfg inventory level" points to this fact that less products needs to be produced which causes the "Mfg production rate" to go down. From here the impacts on the "Mfg work in process", "Mfg inventory level" and "Mfg production rate" can be seen.

The forward analysis method showed an average of 86 per cent accuracy with fuzzication and an average of 76 per cent was obtained by the backward analysis method. The accuracy of the backward analysis is 83 per cent without fuzzication.

5.3 Case 3

Kim *et al.* (2008) have proposed a location-enabled RFID tracking of vehicles in a shipping yard of an automotive assembly plant. It is considered as a starting point of outbound logistics, which holds finished vehicles temporarily until their shipment. In shipping yards, various dynamically changing events and operations associated with vehicle movements, deployments and shipments may occur. In this paper, authors have used a comprehensive simulation framework that can simulate the real operations of the yard. A value proposition of the real-time information of the RFID tracking system using simulation is used.

With the emergence of RFID, location tracking technology allows detecting the presence and location of entities using RFID tags (Turner, 2004). The location tracking system with a real time database provides a means to achieve better decision making by optimizing related business processes (Datta and Viguier, 2000).

Most of the well-known problems for yard managers are (Kim *et al.*, 2008):

Table II A brief description of 15 benefits

List of benefits	A brief description
Reduced shrinkage	Misplacement, spoilage, shoplifting, and organized retail crimes
Reduced material handling	Reduced material handling leads to lower labor cost and increased productivity
Increased data accuracy	Accurate information has great potential to improve the quality of management decisions
Faster exception management	RFID can automate some aspects of exception management, such as invoice reconciliation, shipment data adjustment, and the sending of alerts
Improved information sharing	Data sharing, such as exchanging electronic bills, could be automated with the use of RFID and automation would consequently reduce the manual tracking of paper trails
Production tracking	RFID could enable tracking of raw materials, WIP inventory, finished products, and even assembly status during production
Quality control	RFID could be used to ensure quality control during production
Supply and production continuity	By improving material tracking through the manufacturing process, RFID could ensure continuity in production and supply availability
Material handling	The impact of reduced material handling is particularly significant for warehousing operations since 50-80 per cent of the cost is in labor associated with material handling
Space utilization	RFID could provide flexible space allocation by reducing product incompatibility problems
Asset management	Better tracking of reusable assets consequently leads to better asset utilization, better shipment consolidation, reduces fuel expenditure for trucking, improved reverse logistics, and lower capital costs
Reduced stock-outs	By increasing accuracy in finished good inventories, RFID could help reduce stock-outs and subsequently reduce lost sales
Customer service	RFID could help improve customer service in several ways. At Gap, the use of RFID freed staff from counting inventory and dealing with stock-outs, and hence, increased staff availability for customer assistance
After sales service	RFID could efficiently respond to recalls by isolating bad batches of goods and improve warranty processing and returns handling by efficiently retrieving information such as warranty details, service history, and goods authentication
Lower inventory	By improving inventory data and reducing stock-outs, RFID could reduce safety stock

Source: Tajima (2007)

- non-existing vehicles could be included in the load;
- wrong vehicles may be loaded onto trucks;
- some vehicles may stay in the shipping yard for a long period; and
- load makeup efficiency is not optimal.

Most of these problems are caused by the lack of information or inaccuracy of the data on hand. To resolve such problems one needs to utilize RFID to get on time and accurate data. The RFID information system can provide the locations of every vehicle in real time enable manager to make a better plan for the loading. To make sure that the tracking of vehicles has a reading success rate of close to 100 per cent an active RFID system should be taken into consideration. Otherwise, when the application environment is filled with interferences the rate of misreading increases for the passive RFID tag system.

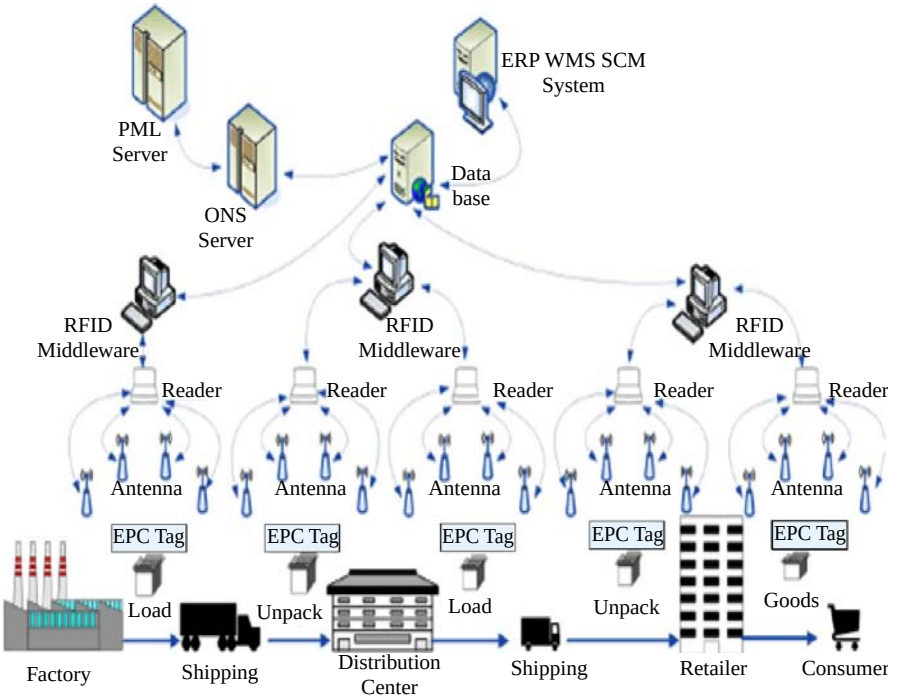
The simulation system used here is composed of two components of simulator and planner. The simulator task is simulating the real shipping yard environment relating to the deployment and shipment of the finished vehicles. The planner has two planning algorithm: one is for the deployment and the other is for load makeup. The result from this study indicates that the RFID tracking system applied to the current practice model can improve customer satisfaction and decrease labor cost thus leading to profit increase. Need to be said that the RFID-based information systems driven by intelligent algorithms can innovate SC operations with timely information and better decision support. Figure 8 shows the shipping yard layout and vehicle flow used in this study.

6. Discussion and conclusion

RFID is an emerging technology with full benefits to be emerged in several years to all industries worldwide. It will bring a good opportunity for improving SC efficiency and hence to enhance the profitability level of the organization. With RFID used in the mobile SC, management can trace and track goods, products, services in various stages of the SC. With this technology, we can find the bottlenecks in SC and find real time solutions and manage the work. Therefore, we may never see insufficient inventory, incorrect shipments, missed delivery deadlines, and interrupted production. This technology can provide a convenient and highly accurate means of capturing data on the goods moving. RFID simplifies the checking and monitoring of tasks, and provide up-to-date information on process status, enabling us to react swiftly to unforeseen events. These capabilities are exactly what we need to create and manage a sophisticated, adaptive supply network.

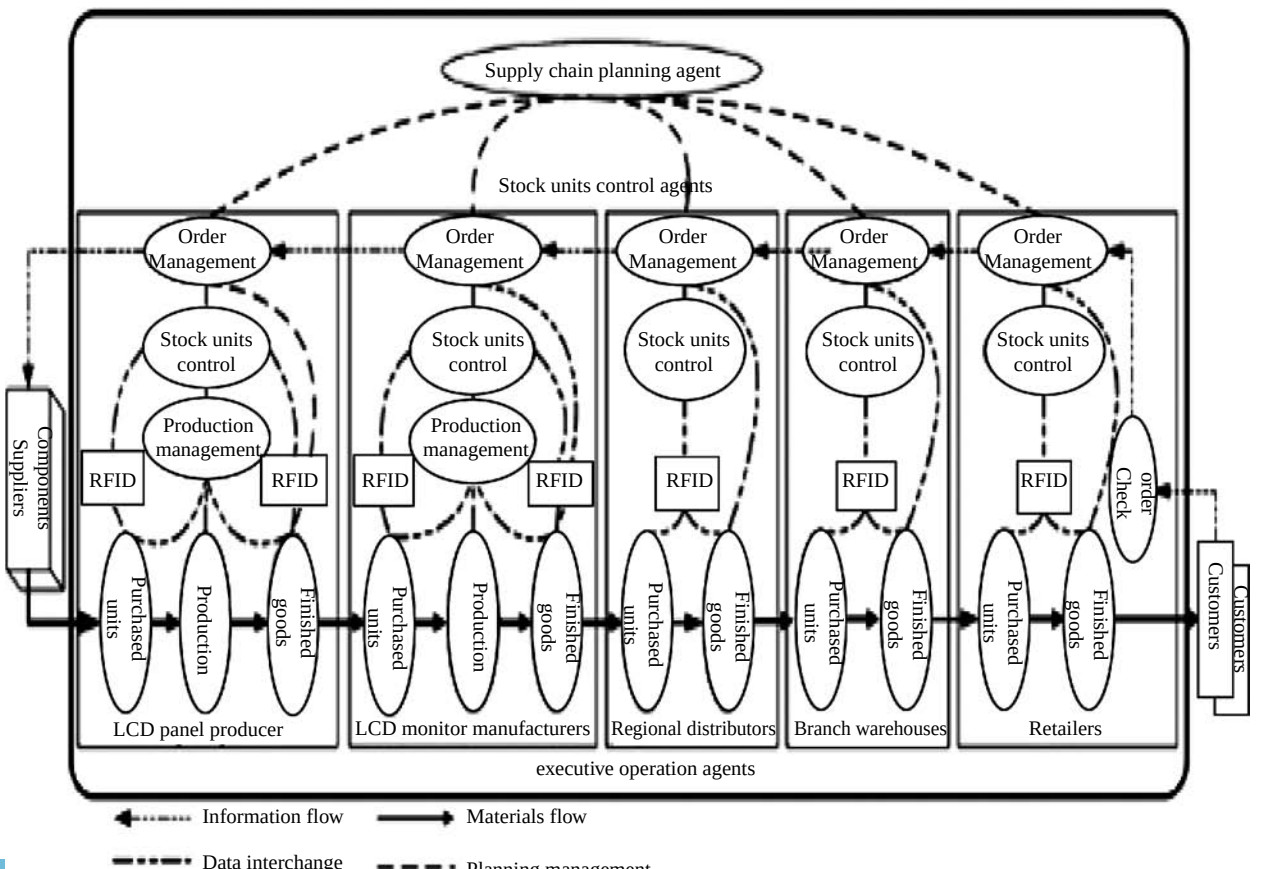
In this paper, author reviewed key points about the RFID and the fundamental concepts of SCM. To understand the importance of SC, main strategies are identified. Some applications of RFID in SC are briefly reviewed and three large cases of RFID implementation in SC are discussed. In one case, it was found that once the results were compared the RPSC was able to decrease total inventory cost by 6.19 per cent and increase inventory turnover rate by 7.60 per cent (Wang *et al.*, 2007b). In a three stages SC (Kim *et al.*, 2007), the forward analysis method showed that an average of 86 per cent accuracy with fuzzification and an average of 76 per cent with the backward analysis method have been obtained. The accuracy of the backward analysis is 83 per cent without fuzzification.

Figure 5 Conceptual framework of RFID/EPC in SCM



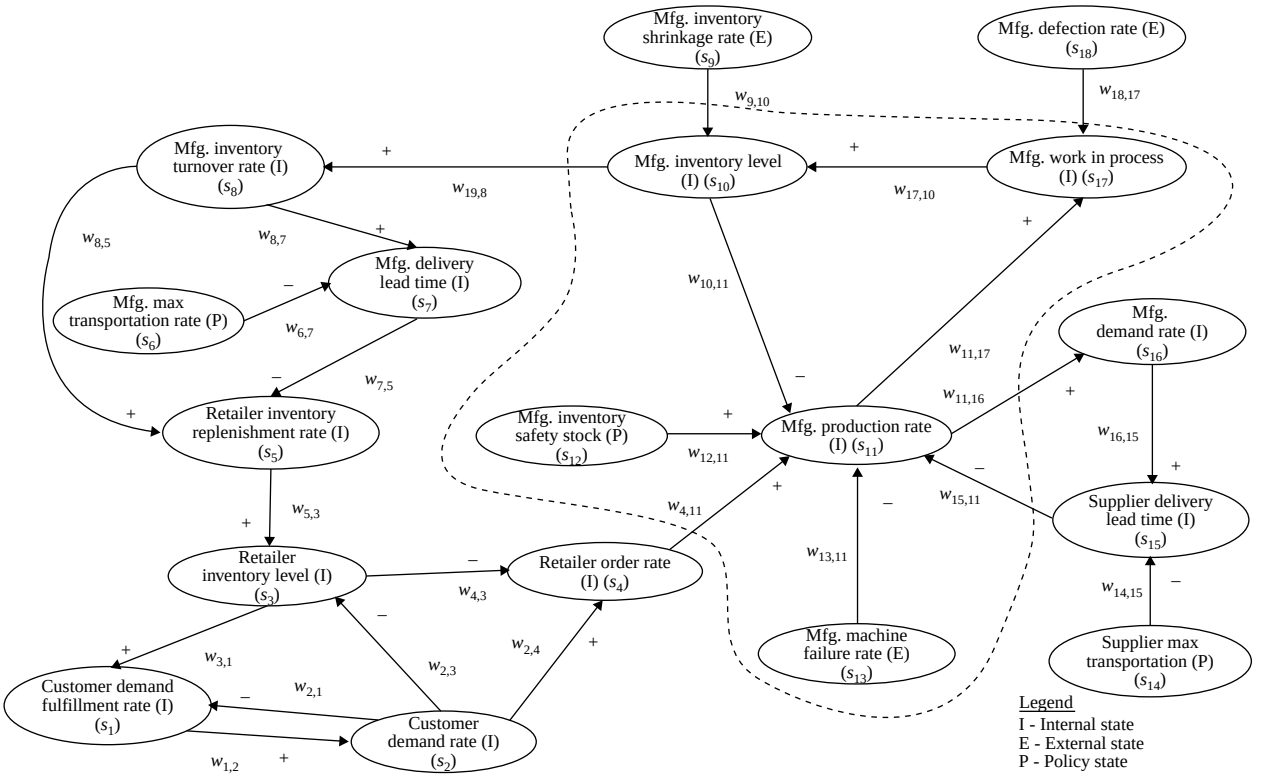
Source: Wang, S.-J. *et al*. (2007b)

Figure 6 Multi agent structures of RPSC



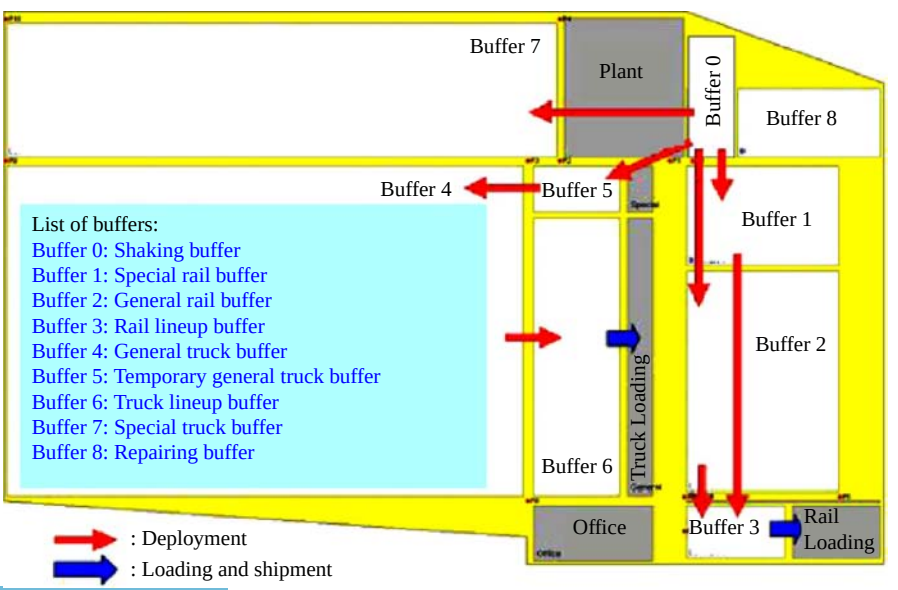
Source: Wang *et al*. (2007b)

Figure 7 Cognitive map of three stages SC



Source: Kim *et al*. (2007)

Figure 8 Shipping yard layout and vehicle flow



Source: Kim *et al*. (2007)

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