# A Supply Chain Perspective of RFID Systems

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*Abstract*—Radio Frequency Identification (RFID) initially introduced during WW-II, has revolutionized the world with its numerous benefits and plethora of implementations in diverse areas ranging from manufacturing to agriculture to healthcare to hotel management. This work reviews the current research in this area with emphasis on applications for supply chain management and to develop a taxonomic framework to classify literature which will enable swift and easy content analysis and also help identify areas for future research.

*Keywords*—RFID, supply chain, applications, classification framework.

## I. Introduction

RADIO Frequency Identification (RFID), a technology that originated during World War - II [1], facilitates automatic identification usings *tags* and *readers*. In recent years, RFID systems have seen a proliferation in the number of applications and have been successfully applied to the areas as diverse as transportation, health-care, agriculture, and hospitality industry to name a few.

Research in this field can be broadly categorized into two groups viz. improvements in the technology such as improving tag readers [2] and developing tags that adhere to multiple substrates and function under extreme conditions of temperature and humidity [3], [4], and application of the latest technology to achieve various objectives such as improving traceability [5] and efficiencies [6], eliminating inventory inaccuracies [7]–[9], and real-time monitoring of system behavior (especially critical in healthcare [10]–[13]) to name a few. The reader is directed to [14] for a more detailed list of applications of RFID systems.

This work seeks to review the current research in this field and to develop a taxonomic framework to classify literature which will enable swift and easy content analysis and also help identify areas for future research. Section II looks into the basic concepts involved in RFID systems. Section III elaborates on the proposed framework for categorizing literature in the realm of RFID. Section IV presents the conclusions and possible directions of future work.

## II. Basics

RFID technology comprises *tags* which store and transmit data using radio waves and *readers* which communicate with different tags and relay collected data to a *back-end server* for further processing. RFID systems may be employed [1] for automatic *identification*, *monitoring*, *authentication* and *alerting* through this exchange of data between the tag and the reader. The process is automatic and functions well even when the tag and the reader are not in direct view of each other.

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The tags and readers have a *challenge-response* mechanism [15] which works much like the security question that many websites have the users complete in order to authenticate the user. This allows for the tags to authenticate the reader and ensures that data is inaccessible to unauthorized readers.

RFID tags have often been compared to barcodes, the predecessor and relatively inexpensive technology. However, the barcode and scanner have to be in direct line of sight for them to recognize each other and the items have to be physically moved against the scanner for data collection. Cronin [16] compares RFID with barcodes in more detail. An excellent summary of the research in this area from 1995 to 2005 can be found at [17]. More details about the technology and the classification schemes can be found at [18], [19].

## III. Research Framework

Although RFID systems have been around since WW-II, implementations specific for supply chain management are a recent development. In this framework, the existing literature has been categorized into conceptual areas and application with emphasis on supply chain management. The conceptual areas include *challenges and architecture*, and *feasibility and viability*, *information systems*. Applications have been categorized into 3 areas viz. *agri-food sector*, *manufacturing operations*, and *production planning*. Table I summarizes the findings of this work.

### A. Challenges and Architecture

With suppliers distributed across the globe, it becomes imperative for companies to reduce the inefficiencies in their supply chain, be it that of automotive parts, construction components, fresh-produce or meat, in order to stay competitive. RFID systems provide improved traceability and end-to-end visibility of products and components over the entire supply chain.

Ju et al. [20] suggest that it is imperative that all the players in the supply chain communicate and agree on standards for data, hardware, software and network protocols in order to reap benefits from a RFID system. Lee et al. [5] propose a step-by-step methodology for implementing a RFID-based system which provides end-to-end traceability through the entire supply chain.

Yan et al. [21] develop a systems design to facilitate implementation of RFID systems in the supply chain for the apparel industry which would lead to a comprehensive tracking management system. Yue et al. [22] propose a framework for implementing RFID in a pharmaceutical supply chain and identify critical success factors (CSF) which would help serve as a blueprint for companies interested in implementing RFID systems. Cheung et al. [23] look at the impact that RFID

TABLE I
TAXONOMIC FRAMEWORK

| Challenges and Architecture | Feasibility and Viability | Information Systems |
|---|---|---|
| [5], [20]–[28] | [29]–[35] | [36]–[40] |
| **Applications** | | |
| **Agri-food sector** | **Production Operations** | **Inventory Planning** |
| [41]–[50] | [6], [51]–[59] | [8], [9], [60]–[62] |

systems have on the logistics strategy and how it aids in the decision-making process.

Visich et al. [24] identify some of the challenges involved in implementing RFID systems in a manufacturing supply chain and propose strategies that would help in implementation. Other researchers [25]–[27] also look into the benefits and challenges associated with the implementation of RFID for an efficient supply chain management.

Reverse logistics deals with the flow of components back from the customer to the manufacturer as may be the case when components are being recycled. There may be collection centers where customers return their used products. Lee et al. [28] suggest the use of RFID system to collect data pertaining to the returned goods which can then be used to determine collection vehicle schedules and also alert the manufacturer about the incoming load.

### B. Feasibility and Viability

RFID systems provide improved traceability and end-to-end visibility of products and components over the entire supply chain. However, it is important to determine if it is economically viable and practically feasible for each specific case. Decker et al. [29] develop a cost model that helps companies determine which of the technologies that make components “smart items” viz. barcodes, RFID tags, wireless sensor networks would be beneficial given its particular parameters. Hardgrave et al. [30] demonstrate using Walmart as an example that RFID systems do improve the inventory inaccuracies that plague supply chain management systems.

Uckun et al. [31] determine optimum investment levels for RFID systems in order to maximize profits by eliminating inventory inaccuracies. Inaba [32] develop a prototype system using RFID system that help reduce inventory inaccuracies in the supply chain and improves inventory turnover rate. The system also allows for efficient customer relationship management (CRM) by monitoring customer spending and rewarding loyal and returning customers with discounts.

Mehrjerdi et al. [33] discuss how supply chain management can benefit from RFID systems. The authors lists some of the benefits in the areas of production and quality control, material handling, inventory control, and space utilization to name a few. Based on a survey of fast moving consumer goods (FMCG) industries, Madlberger [34] concludes that the apprehension of its perceived benefits and the anticipated expenses are significant factors that influence a organization’s reluctance to implement RFID systems. Bottani et al. [35] conclude that a RFID-based system does have the potential to reduce losses due to unavailability of fast moving consumer goods based on the results of analytical models developed by the authors.

### C. Information Systems

In order to utilize the benefits of RFID systems to the fullest, it is imperative that these systems be integrated into the information infrastructure and network architecture of the organization. Tan et al. [36] propose a framework for implementing RFID systems in a logistics supply chain environment. The authors also develop a web-based system for information sharing across the different partners in the supply chain.

Choy et al. [37] develop an interactive database management system to facilitate easy retrieval of information regarding resources in its supply chain which is captured real-time using RFID technology. Angeles [38] looks at the information system requirements for companies that use RFID systems to facilitate efficient supply chain management and the challenges involved in data integration.

Bi et al. [39] propose a RFID-based web-enhanced system for identifying and locating suppliers on the supplier network of a company. This helps companies identify their suppliers’ supplier and buyers’ buyers all the way to the final branch on the supplier network. Warehouse is an integral part of the supply chain. Hence, it becomes imperative that the resources such as pallets, fork lifts etc. are efficiently utilized. Poon et al. [40] propose a logistics warehouse management system based on RFIDs to facilitate easy data collection and sharing.

### D. Argi-Food Sector

Due to the perishable nature of products and due to the health risks involved, end-to-end traceability becomes significant in the agri-food sector. Yan et al. [41] propose a meat supply chain surveillance system based on RFID tags to improve traceability of pork meat thus reduce health risks to customers in the event of a disease outbreak.

Amador et al. [42] propose the use of RFID tags for real-time tracking of temperature of pineapples all along its supply chain. The authors show that since RFID tags facilitate easy data collection at any point in the supply chain, they are superior to conventional tags. The authors also explore the feasibility of RFID tags with probes since probes provide a more accurate reading of the temperature.

Abad et al. [43] demonstrate the application of RFID tags in a fresh fish logistics chain. RFID tags are advantageous since they improve the traceability, reduce time required for data collection, can withstand temperature and humidity and finally can be re-used. A web-based traceability system based on RFID tags for tracking fresh fish is proposed by Hsu et al. [44].

Gandino et al. [45] propose a framework to improve traceability in the agri-food sector and show that by implementing RFID systems, agri-food businesses increase their automation levels and improve their efficiencies. Geng et al. [46] develop a dairy-cattle identification system based on RFID tags that can be read over eight meters thus digitizing the dairy farm production and facilitating precision cattle breeding.

Reiners et al. [47]incorporate RFID tags into the eartags of piglets and use readers aimed at improving the identification accuracy and identification rate. Shanahan et al. [48] propose an integrated traceability system based on RFID tags and biometric data to enhance the traceability of beef through its value stream thus improving customer confidence. Jedermann et al. [49] develop miniaturized RFID-based temperature loggers to monitor temperature variations in perishable food as they are transported from the farm to the grocery stores. The authors conclude that these miniature tags help better control the damage to perishable food along the transport chain.

Martinez-Sala et al. [50] develop an active product platform by integrating the special packing and transport unit with embedded RFID tags. This packing and transport unit can be used during the entire supply chain right from the packing stage at the producer to display stands at the grocery store. Since these units are reusable and have to be returned, it is imperative to track the location of these units as they travel through the supply chain. The RFID tags also enable to provide more value-added services to customers of this fresh-produce company.

### *E. Production Operations*

With cut-throat competition and manufacturers trying to squeeze value out of every proverbial penny, it becomes imperative to investigate potential improvements that can be achieved in the company's operations using RFID systems. Based on survey and analysis of fast moving consumer goods (FMCG) companies, Bottani et al. [51] suggest that a pallet-level identification using RFID tags is beneficial to all parties in a 3-tier supply chain with a manufacturer, distributors and retailers.

Kim et al. [52] develop a location identification system that helps in locating vehicles on a shipping yard of a automotive assembly plant thus improving the delivery performance. Kovavisaruch et al. [55] propose the use of a RFID-based system for a cargo transportation company to monitor the health of tires and their history of rethreading since tires contribute to a significant portion of the operating expenses. Hua et al. [54] develop a real-time manufacturing execution system for a textile-based company that enables the shop-floor personnel to make immediate decisions pertaining to production.

Xianwen et al. [56] develop a monitoring system for containers using RFID and electronic data interchange (EDI) that improves container utilizations by reducing the data entry times. Keeping track of the availability of parts in a automotive plant that provides customizable products can be quite daunting if the task needs to be done manually. A RFID-enhanced communication system has been developed by Mourtzis et al. [57] that provides real-time information of parts availability. A similar web-enhanced communication system has been developed by Sawyer [58] to monitor the location of components during the construction of a football stadium.

Wang et al. [59] help a LCD manufacturing company improve its inventory turnover and reduce the inventory holding costs through the use of a RFID-based system for automatic replenishment of inventory in its supply chain. Guo et al. [53] employ RFID tags to capture the movement of parts which helps in scheduling of production in a flexible assembly line with flexible operator assignments. Liu et al. [6] achieve increased production efficiencies at a integrated circuit packaging house by using a RFID system that integrates with the Enterprise Resource Planning (ERP) software.

### *F. Inventory Planning*

Lean principles encourage companies to minimize their inventory as much as possible. Rekik et al. [8], [9] use RFID tags to control inventory inaccuracies due to misplacement and theft in retail stores. The authors compare three analytical models viz. the inaccuracies are ignored, the misplacement and theft errors are incorporated into the inventory control mechanism, and RFID tags are used to control the errors.

Zhou et al. [60] propose a manufacturing data tracking system that utilizes RFID tags to facilitate real-time monitoring of production in a manufacturing plant. Zhou et al. [61] show through analytical models that item-level visibility and traceability through RFID tags help reduce uncertainties in inventory levels. Szmerekovsky et al. [62] compare a RFID-based continuous review policy with a non-RFID-based periodic review policy and conclude that the RFID-based system fares better especially when the cost of tags is shared between the manufacturer and the retailer.

## IV. Conclusions and Future Work

Identified as one of the greatest contributions of the twenty-first century [33], RFID systems facilitate automatic and remote identification of components thus improving visibility and inventory accuracies in the supply chain. Due to its multitude benefits, research in this area has been extremely prolific. Implementations have also been growing at a remarkable pace. However, in order to be fully utilized in a supply chain where there are many organizations involved, it is imperative to develop uniform standards for both hardware and software so that these various systems can seamlessly interact and communicate with each other. It is also important to ensure the feasibility and economic viability of these systems before embarking upon the implementation journey.

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