Research Article

Survey of RFID-IoT in Supply Chain Management

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Abstract: Radio frequency identification (RFID) has been identified as one of the emerging technologies in supply chain management. With the integration of RFID with internet of things (IoT), called RFID-IoT has bring the advancement of support chain management (SCM) to the automated sensing, pervasive computing and ubiquitous data access by manufacturer, distributor, retailer and even consumer. This paper intended to introduce the concept of RFID-IoT technology in SCM, recent application in SCM such as identification, monitoring, process enhancement, logistic tracking, product quality and analyze the current challenges and future potential of RFID-IoT technology. In future, RFID-IoT is expected to be integrated with other technologies to produce a comprehensive solution in SCM**.**

Keywords: RFID, IoT and Supply Chain

1. Introduction

For over 50 years, Radio Frequency Identification (RFID) has emerged on proposing various application solution in healthcare, defence and security, environment, agriculture, and supply chain management (SCM). RFID is a technology which can detect unique identifier from a range of distance via a radio signal. Conventionally, RFID acts like other sensors as a system input for multi sensing, localization, and remote monitoring by generate and receive electromagnetic fields from RFID reader to RFID tag. Generally, it served as detection and identification purpose. The beneficial of RFID is it links between physical space and information space and discover the binding between physical space object and information space object (Cao & Zhang, 2016). RFID-IoT is considered an enhancement technology over barcode. Unlike barcode which need to align with the sight, RFID has automated sensing and identification technology up to certain distance range. RFID has improved the traceability of objects, processes, and stages in many industries.

The advanced identification of RFID and pervasive computing of WSN had encouraged the emergence of Internet of Things (IoT) technology. The basic purpose of IoT is to make a big network by combination of various collection of sensor devices such as RFID, Global Positioning System (GPS) and network to provide information sharing in global. The core technologies of IoT referred to RFID and WSN where RFID transforms physical objects and environment into digital data and WSN provides distributed and pervasive wireless system. Besides, the outstanding sensing ability of RFID and high ubiquitous ability of WSN are merged to provide a worldwide interconnected objects where each of them can be discovered and used as a resource under IoT network. This concept named as RFID-IoT. RFID-IoT has increased devices interoperability from various applications and it leads the revolution of industry especially in SCM.

SCM comprises many key processes. It starts from raw materials, suppliers, organizations, to consumers management through a system. The system is built to support business strategy to achieve profitable benefits to the stakeholders (Ali, 2008). RFID-IoT plays a critical role in helping supply chains in collecting, identifying, improving, and optimizing supply chain processes under dynamic environments. Besides that, RFID-IoT also enables the intra-connection between the devices and inter-connection between environment and humans. Fig 1 shows that the number of RFID-IoT articles from Year 2010 to 2019 according to Google Scholar searches. Fig 1 showed that the number of articles remains in a big amount which is more than 1000 since Year 2015 and it is still increased drastically. Most of the RFID-IoT articles focused in several major areas such as manufacturing, shipping and distribution, inventory, and retail. The increasing of published articles in recent years indicates the potential of research on RFID-IoT in supply chain.

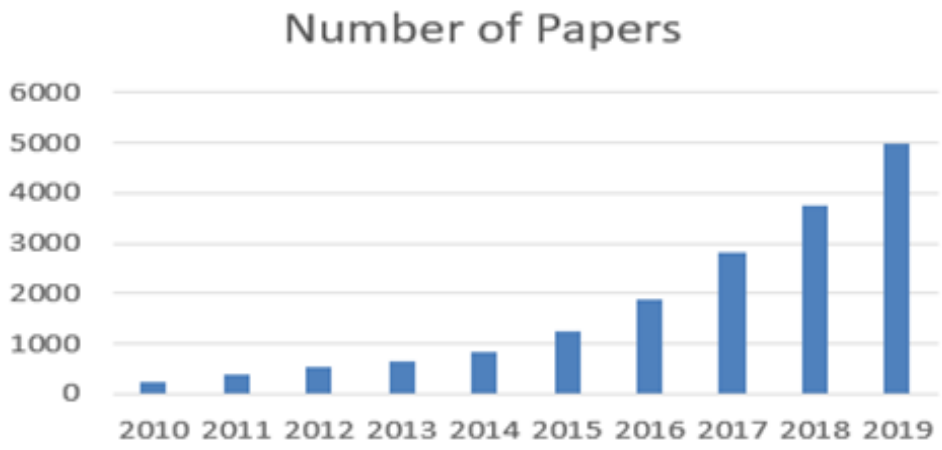

Figure 1. Number of RFID-IoT articles by year

This paper focuses on the literature of RFID-IoT in supply chain operations by introducing the background of RFID-IoT technology, giving useful insights into the anatomy of the previous proposed methods, revealing current limitations and future potential works. Since these solutions had existed over a decade, a review from previous proposals would need to be addressed to provide a knowledge base overview of the technology for researchers and practitioners. The aim of this paper is as follows:

1. To understand how much RFID-IoT technology has advanced in SCM in term of effectiveness, interoperability, scalability, and compatibility.
2. To understand what are the challenges that faced by current approaches in SCM.
3. To discuss what can be expected in future development of RFID-IoT technology.

The paper is organized as follows. Section II gives a brief introduction of RFID-IoT technology before Section III starts to discuss about RFID-IoT methodology in supply chain management. Next, Section IV presents discussion on current limitation of RFID-IoT applications, followed by future potential and direction of RFID-IoT technology in SCM. Lastly, the final section of the paper concludes the paper and gives a summary of this review paper.

2. Brief Introduction of RFID-IoT in SCM

A RFID is a non-contact and automatic identification device that use electromagnetic signal to detect, track and identify a variety of objects including components, vehicles, goods, work force, and other assets. Generally, RFID consists of three major parts which are RFID tag, RFID reader and back-end database which stores the Unique Identification (UI) of each tagged object. RFID tag can be divided into two types. One is called passive tag and the other tag is called active tag. Active tag usually needs to be powered up by its own power source (e.g. battery). On the other hand, power source is not needed by passive tag. This is because passive tag relies on the electromagnetic energy transmitted by RFID's reader. As a comparison, active tag has bigger transmission range than passive tag. Both tags have different usages. Active tag can track objects in real-time location by continuously sending their signal to the reader. Meanwhile, passive tag is used with many tagged objects to provide a more economical deployment cost. This is because passive tag has lower price point and provide the similar data density as active tag. Data density is important to visualize the data and provide useful information to the user.

The read range of RFID reader depends on its operation frequency. It can be divided into four major categories which are low frequency, high frequency, ultra-high frequency, and microwave signal. RFID has a similar function on barcode in that it stores unique serial number for tracking product information on a microchip. However, unlike barcode technology, RFID is able to identify individual product with its own serial code by using radio waves (Attaran, 2007). Besides that, RFID also capable to store more data compared to barcode. WSN is required to deploy RFID seamlessly. The integration of WSN brings RFID technology to a scalable, portable, short deployment time and cost-effective solutions as compared to wired network (Noel et al., 2017). Both RFID and WSN are two significant enabling technologies of IoT.

With the combination of miniaturized, easily accessible, and economic development of embedded devices such as RFID, it has inspired the development of IoT technology. IoT is a network infrastructure which links

physical and virtual objects through data collection, data ingestion and communication technology (Ibrahim, 2018). IoT has made the devices to be remotely accessible to the user. IoT system includes three major layers which are perception layer, network layer and application layer.

In SCM, RFID-IoT plays the main role in identifying reliable data automatically and extend communications through internet to show the status of material, stock, equipment, machine, and manpower. With implementation of RFID-IoT, the users can monitor and supervise every process, stage and product in real time and give responsive feedback according to their current situation. This has effectively improved the circulation in supply chain and lower down the unnecessary cost and lost. For example, it can reduce chances of out of resources such as raw materials, logistic vehicles, and workers. One of the major problems in SCM is the process completed in each stage is not able to be combined and integrated together. Therefore, it is hard to calculate cost estimation and time consumption. While RFID-IoT offer the combination of intra-connection and interconnection between machine, process, stage and environment without manual intervention, RFID-IoT technology allows information exchange over internet and improve visibility throughout the entire supply chain in order to achieve an effective workflow in the system. It can be simplified into four major stages which are manufacturing, shipping and distribution, inventory tracking and retail tracking [6]. It is shown in Fig 2. This study will discuss further on recent articles focus on the usage of RFID-IoT in these four major fields.

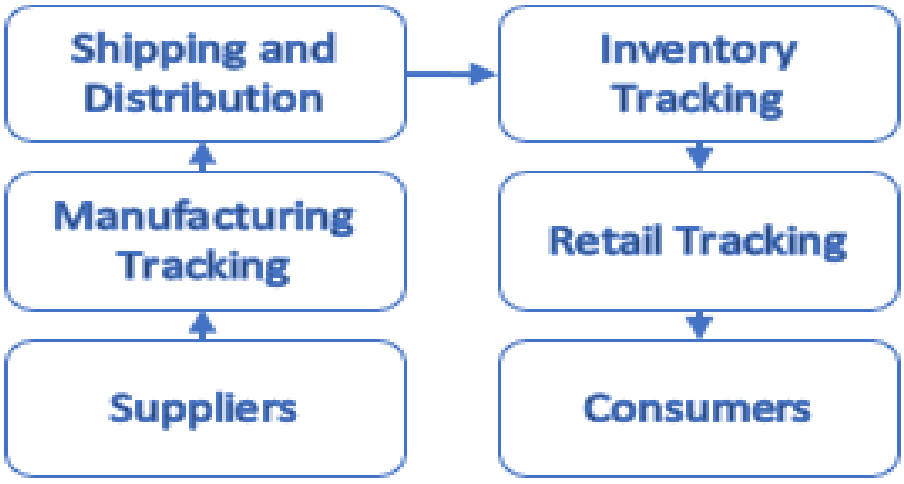

Figure 2. An example of RFID-IoT implementation in supply chain system

3. RFID-IoT System in Supply Chain Management

RFID is a non-contact and automatic identification device that consumes low power energy and cost. The extensive range of potential applications in SCM is growing around the world owing to its prominent capability. Moreover, with the integration of IoT technology, it is possible to collect and share the data through internet. IoT plays an important role to achieve a seamless, interoperable, and securely connection RFID-IoT system. It brings a lot of potential applications in numerous disciplines in supply chain.

From Fig 2, the developed supply chain systems by RFID-IoT are divided into four main categories which are manufacturing tracking, shipping and distribution, inventory tracking and retail tracking. In order to provide an insight for the readers to assess the value of result of RFID-IoT in SCM, scientific articles are analyzed to understand its methodology, and applications in supply chain based on the abovementioned four categories.

3.1 Manufacturing Tracking

There are number of literatures reviewed about manufacturing using RFID-IoT in supply chain. By using network of sensors to collect manufacturing data, RFID-IoT is expected to give valuable data insight to increase the efficiency in product manufacturing.

In this article (Zhang et al., 2015), the authors proposed an active material handling strategy including designing an intelligent trolley and workflow based on real-time navigation. The objective of this work is to reduce the move task deviation or errors. The proposed strategy is optimized by active sensing capability from RFID, interactive and navigation of the process flow in material handing with the integration of IoT technology.

This method also allows intra-connection between machine to machine (M2M). With the proposed optimized strategy, the efficiency of bulk tracing and tracking was improved. This is because the error of handling is decreased by automating the workflow of material handling task with real-time navigation. The overall transport cost is also reduced to meet the requirement of large-scale manufacturing using RFID-IoT technology.

Other than that, an automated identification, traceability and tracking of automotive parts are always requested to reduce the downtime cost. The purpose of this is to rectify the processing defect and product recall. Using innovative embedded design of RFID in bolt, Segura Velandia et al. (Segura Velandia et al., 2016) designed crankshaft tracking system in their manufacturing, assembly, and retail processes. To increase the success rate, the designed system needs to monitor the crankshaft state under harsh operating conditions. Essentially, the proposed method focuses on designing a low-cost UHF RFID passive tag and optimized reader antenna infrastructure which are robust in metal environments. Moreover, the designed RFID bolt is removable and reusable to other similar engine components. The data of manufacturing, assembly, environment, and service are captured in real time and stored on local server using IoT technology. The paper claimed that the proposed RFID-IoT system has the advantage in cost compare to the relatively high cost of camera-based systems in manufacturing and assembling crankshaft.

The quality and safety of the used material are one of the focus in manufacturing. With the demanding on better quality of material and safety, it is necessary to obtain the material data such as description and non-compatible ingredients before ship to other distributors. Doinea et al. used IoT sensors such as RFID and Near-Field Contact (NFC) to monitor the food production ecosystem starting from seeds, fertilizer provider, food additives and food ingredients (Doinea et al., 2015). IoT technology made the traceability of raw materials become easier, automatic, effective, and real-time collection. This has greatly improved the product quality and safety. Data collected will be used to ensure the right quantity of ingredient properties including chemical composition as labelled in the food product.

In this study (Li et al., 2017), this work has developed an economical and effective solution on trace and track the prepackaged food in real time situation using RFID and QR code technology. This sensory technology combination is selected by considering the implementation cost in large scale manufacturing. Other than number counting, the proposed system is also able to detect excessive additive, unhealthy ingredient, and expired date of the food. A validation and warning alert is also employed to identify the root cause and facilitates timely response especially when the food quality and safety issue happens.

3.2 Shipping and Distribution Tracking

There is a vast amount of literature on product shipping and distribution tracking in supply chain. It starts tracking from supplier to end user. These studies focused on vehicle management, asset, and resource management, estimate dispatch and arrival time based on real-time information streaming.

Qiu et al. (Qiu et al., 2015) discussed about the importance of real-time information in improving logistic visibility and transparency. As an example, vehicle management on dispatch and pick up orders in industrial park. The focus of this paper is logistic management in supply hub where warehouse housing and transportation services are offered to multiple manufacturers. To detect and share all physical assets and business services, RFID and IoT technology are integrated to generate an end to end system infrastructure. The concept of the infrastructure emphasizes on easy deployment, simple-to-use mechanism, access flexibility and simple data format such as Extensible Markup Language (XML).

In this study (Wu et al., 2011), the researchers proposed an inland shipping management information system (ISMIS) to improve the inland shipping management. ISMIS takes advantage of WSN technology and core technologies including RFID, IoT and cloud computing to provide a real-time information of vessel state, environment state, bridge information and traffic state in inland waterways. This design has increased the efficiency of management by lowering down information barrier, latency and increasing data transparency.

Other than mobile app, Ding et al. (Ding et al., 2018) presented a comprehensive solution from outsourcing manufacturing to retail transportation based on web application. The proposed system named RFID-enabled social manufacturing system (RFID-SMS). This approach is able to integrate real-time production and transportation data to provide a better decision support tools on product schedule, dispatch and delivery time and order management. Other than that, a meta-heuristic method named improved teaching-learning based optimization (TLBO) was proposed to minimize the production cost and transportation cost.

3.3 Inventory Tracking

The literature to date provides a wide range of RFID-IoT applications in inventory tracking. This has included product identification and tracking, equipment maintenance date, environment identification and manpower tracking.

In this study (Tejesh & Neeraja, 2018), the authors developed a real-time indoor warehouse inventory system to identify and monitor the product. The purpose of this approach is to achieve high effective and efficiency inventory management. Instead of using barcode, RFID technology is chosen because of its robustness and flexibility in identification. It is expected to be apply on large scale production. The type of tag involved is only passive tag as the authors claimed that passive tags have less interference effect and lower maintenance cost as it attached to any physical objects in real application. Besides that, open source IoT platform like NodeMcu and Wi-Fi module like ESP8266-01 is employed together with Raspberry Pi 3 to facilitate the sensor connection capability. Based on the presented prototype, the proposed system is able to show the product details such as tag number, storeroom location, time and description in a formatted table. The solution is simple and effective in solving inventory inaccuracy problem.

The authors (Abdelkrim et al., 2018) proposed a novel storage utilization system to place the product in a safer manage way. The stored products are divided into seven categories such as flammable, explosive, oxidizing, health hazardous, toxic, harmful, and corrosive based on their chemical substances. After categorization, the product also classified accordingly to set of compatibility rules. For example, flammable and harmful product are compatible to be stored together. A mathematical representation based on product class and compatibility was presented. Specifically, this solution is vital to store danger and hazard products in inventory. Besides, a communication conceptual model which utilized RFID and IoT technology is employed to cover object to object, object to human and object to environment. The objective is to create interconnection between product and shelves within inventory area. This solution not only ensure safety of product and people, it also increases the product-based storage efficiency by minimizing the required time for storage.

Zhou et al. (Zhou et al., 2017) proposed a feasible solution in inventory by introducing movable shelves as trackable items. By using RFID to trace the shelves location and IoT to stream the date to the server in real-time, an optimal inventory environment was formed. By calculating the inventory capacity and detecting the location, the system allows any item to drop off and pick up based on the demand as long as it happens between the coverage area. With the feasibility of the method it can reduce the inventory inaccuracy, trip costs and lead time for single trip demand in the same inventory. The main objective of the approach is to solve the difficulty in managing large complex operational inventory and warehouse.

3.4 Retail Tracking

The retail sector is highly competitive. This sector requires not only efficiency in business operation but also innovation in technology. Since RFID-IoT became more advance and mature, it has been adopted across multiple consumer applications in retail to avoid counterfeit items and enhance the customer purchasing experience such as provide real-time product information update and faster checkout.

Xiao et al. (Xiao et al., 2018) tackled on a low-cost UHF RFID reader design using printing electronics technology. By formulating high conductive ink for screen printing, a high-quality RFID's antenna was developed and investigated to closely matching their application performance to conventional chemical etching method particularly in an interference situation such as metal shelves. From the presented result, the new UHF RFID reader is intended to be used in commercial to reduce the implementation cost of RFID in large retail shop.

Verdouw et al. (Verdouw et al., 2016) suggested retailers should provide product information to the consumer at their most convenient way. The authors developed an application named Product Information App (PIA) to allow the consumer to search the up-to-date product information in food supply chain (i.e. fresh fish). In addition, PIA also helps the retailers to compute the cost operation of the product in a more defined quantitative analysis. As addressed in this paper, the development of application is still at the early stage and it still needs time to bring the solution broadly affordable for every retailer especially for Small-Medium Enterprise (SMEs).

Other than application-based, a mutual authentication protocol between IoT devices especially RFID reader and tag in RFID-IoT security mechanism was presented (Tewari & Gupta, 2017). As this work used basic operation such as bitwise for authentication purpose, it has advantages of low computation, storage, and

communication cost. This ultra-lightweight authentication protocol was proven to have high efficiency and safety factor for passive tags as it can automate project tasks under limited resources.

In order to enhance customer's purchasing experience in retail store, a recent article studied on smart retailing using RFID-IoT was proposed (Kalange et al., 2017). In this paper, the proposed system solved the real-life shopping problem using customized RFID sensors, gateway, cloud and mobile device technology. A more user-friendly and interactive android application was presented to provide a real-time shopping experience and guidance for product list, information, promotion, location, and availability. From the aspect of retailer, the proposed system increases the efficiency of the storeowner in economic manner as well as all operation is conducted and connected automatically.

The summary of research works and application of RFID-IoT technology in supply chain has tabulated in Table 1. It can be seen that all the previous studies are evaluated based on multiple criteria such as networked sensors, data interoperability, multi-scale system integration, scalable and multi-level cyber security, intelligent automation, prediction and recommendation system and cost effective.

Table 1. Summary of Research Works and Application of RFID-IoT in Supply Chain

Article	Networked sensors	Data interoperability	Multi-scale system integration	Scalable and multi-level cyber security	Intelligent automation	Prediction and recommendation system	Cost effective
(Zhang et al., 2015)	/	/			/		
(Segura Velandia et al., 2016)	/				/		/
(Doinea et al., 2015)	/	/			/		/
(Li et al., 2017)	/	/					/
(Qiu et al., 2015)	/	/	/	/	/		
(Wu et al., 2011)	/	/	/	/			/
(Ding et al., 2018)	/	/	/		/		/
(Tejesh & Neeraja, 2018)	/						/
(Abdelkrim et al., 2018)	/	/			/	/	/
(Zhou et al., 2017)	/	/			/		
(Xiao et al., 2018)	/						/
(Verdouw et al., 2016)	/	/					
(Tewari & Gupta, 2017)	/	/		/			/
(Kalange et al., 2017)	/		/	/			/

4. Current Challenge and Future Potential of RFID-IoT

Modern supply chains have evolved from trace and track to highly complex value networks problem to allow connection between environment to machine, machine to machine, and machine to human. The technology has become a vital source of competitive advantages among suppliers, distributors, manufacturers, and retailers. However, it also creates a challenging task to form a feasible and versatile SCM system. This system is expected to be capable to verify raw materials, store the product in a limited space in inventory, maintain the visibility of the product along the chain and enhance the customer experience in retail shop. In the following paragraphs, numerous challenges encountered by current literatures are highlighted. A RFID-IoT system includes RFID and IoT technology emphasize connection of all components based on sensors, cheaper processors, and ubiquitous computing. Improvement of the technology from the aspect of hardware is desired to increase its reliability and

minimize the deficiencies during trace and track the product. It is expected more innovative designs especially in RFID tag and reader with higher sensitivity, feasibility and adaptability will be published in the future. The design of hardware is preferred in miniature, low energy consumption, embedded and easy to implement with other technologies. Besides that, lack of seamless and compatibility to integrate between the current existing system and the newly developed system has been one of targeted issues.

Many proposed systems are deployed in large scale production system. However, the maintenance of the system pipeline, network architecture and data management are hard, and it causes the plausibility to redesign the whole architecture. A lot of resources, time and cost were wasted. At the same time, with the increase of IoT devices, it remains a big challenge to develop a system infrastructure which can manage massive data within a same network. Large amount of data transmission can cause system delay, communication error and conflict between the users. The challenge has become more difficult when most of the data are collected in real time by the connected devices. Once data is collected, the process of analyzing the data including data validation, cleaning, mining, exploring, and loading requires highly skillful workers and powerful computing hardware such as Computer Processing Unit (CPU) or Graphic Processing Unit (GPU).

The development of RFID-IoT system infrastructure will embrace the requirement of standardization of IoT protocols such as identification, data format, security, communication, and network standards. These standards are issued by International Organization for Standardization (ISO) for RFID applications, such as animal tracking (ISO 11784 and 11785), contactless payments (ISO 14443), performance (ISO 18046) of RFID tags and readers and others (Lim et al., 2013). Notice that, the standardization of RFID applications is still varied from country to country owing to the lack of government regulations and global collaboration.

While considering technical issue and standardization of RFID-IoT, security and privacy protection issue also been raised by many academicians and practitioners. The wireless connection between RFID readers and tags are subjected to security attacks such as interception, modification and wrongly synchronization (Fan et al., 2020). The unverified and unauthorized tags or readers should be prevented to have secure and stable security system. It is suggested to have reliable and lightweight RFID-IoT authorization module for every developed system.

The findings from literature reviews show that most of the system aims to have practical implementation of a solution with sensing capability that allows information transfer through IoT approach. The current implementation of system relies on multiple technologies which causes the increasing of the cost development of the system infrastructure. In addition, the cost of operation and adoption of new system is increased owing to the incompatibility and feasibility to the existing systems. A smooth and feasible project workflow with a lot of coordination efforts is needed to ensure the efficiency of the resource arrangement while maintain the overall cost in supply chain.

The rise of RFID-IoT has explored the potential of the technology to resolve many issues such as fast changing in orders and customer requirements in supply chain. The benefits of RFID-IoT adoption are likely affected by factors such as company size, product profit, cost of the middleware and hardware and others. Therefore, it is necessary to have justification of Return of Interest (ROI). It should be done based on quantifying all the key factors to help the company to examine the achievable profit and compare it against the cost of adoption to make a wiser decision.

To increase the efficiency from aspects of resource and cost, there is a need to further analyze the collected data. Although several studies have proposed RFID-IoT data processing and sharing solutions in supply chain, cost of computing and efficiency of storage are always neglected (Hu et al., 2014; Wang et al., 2014). Fortunately, with the emergence of cloud technology in these days, cloud provides an accessible platform of on-demand computing microservices especially on data exchanging and integration with other system in lower cost. Instead of developing own system infrastructure from scratch, developers can deploy their application by "renting" the technology from cloud service provider. This helps to save the cost of development from software, hardware, and manpower resources. Furthermore, developer also can save high maintenance fees as many services are handled by cloud provider and it can be customized based on your need. Additionally, cloud service provider such as Google Cloud Platform offers "pay-as-you-go" without any up-front and termination fees. This has encouraged the fast development of Proof of Concept in many applications using minimal cost and resources.

5. Conclusion

The implementation of RFID with IoT technology has automated many applications equipped with sensing, identification, processing, communication, network capabilities. This paper reviews the recent researches on

RFID-IoT in SCM. It starts by introducing RFID, WSN and IoT technology and discuss the fundamental use of RFID-IoT technology in supply chain management in the past decade. Next, a brief introduction of RFID and IoT technology is explained before their application in SCM is discussed thoroughly. Then, the current challenges and potential future works are presented. It is concluded that if RFID-IoT is implemented with more technologies, it will bring a big impact to SCM in the future.

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