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The role of radio frequency identification (RFID) technologies in the textiles and fashion supply chain: an overview

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DOI: 10.1533/9780857098115.1

Abstract: Barcode and radio frequency identification (RFID) technology have been widely applied in automatic identification and tracking throughout the textiles and fashion supply chain. This chapter will first compare the differences between these technologies and discuss how RFID technology can perform better than barcode technology in various aspects. The fundamentals of RFID technology, the architecture of an RFID system and an overview of the application of RFID technology in the textiles and fashion supply chain will be described.

Key words: barcode, radio frequency identification (RFID), system architecture, textiles and fashion supply chain.

1.1 Introduction

The apparel industry is one of the most important sectors of the economy, creating jobs and products that meet fundamental human needs. The supply chain of the apparel industry is highly complex due to a number of distinct industrial features, which include short product life-cycles, a wide product range and volatile customer demand. It is becoming an increasing trend to employ radio frequency identification (RFID) technology to identify and track individual products in the apparel supply chain.

A supply chain is a set of policies, processes, management actions, and technologies that collectively forecast, acquire and deliver products and services to meet the identified needs of a company and/or customer (Shepard, 2005). Supply chain management (SCM) is the management of a network of interconnected business processes involved in a supply chain for the purpose of creating value for customers and stakeholders. It spans all movement and storage of raw materials, work-in-process inventory and finished goods. Effective SCM is crucial to lower operating costs and improve the competitiveness of businesses. Good SCM depends on the availability of accurate and timely data about various activities in the supply chain. These include progress in meeting production schedules, current inventory levels and the location of material. Data acquisition is thus crucial. For example, early detection of a shipment delay by rail may mean that it can still make its deadline by trucking it, while later detection of this problem may mean that some critical parts may have to be delivered by air, a much more expensive option.

In recent years, automatic identification systems have become popular in many manufacturing and service industries as well as the logistics industry, which aim to improve data acquisition processes and to capture data in a more timely and accurate manner. This in turn gives management and decision-makers more time to recognize potential problems and make efficient decisions. The application of automatic identification systems involves a broad range of supply chain operations, such as:

- item identification and tracking;
- manufacturing;
- retailing;
- transportation;
- warehousing; and
- payment transactions.

Technologies such as barcode, RFID, signature capture and magnetic stripe, the former two being most commonly used in logistics and SCM, are indeed already in use.

1.2 From barcode to RFID technology

A barcode is an optical machine-readable representation of data relating to the object to which it is attached. The invention of the barcode is usually credited to two graduate students at Drexel Institute of Technology, Norman Joseph Woodland and Bernard Silver, who pioneered the concept and filed the first patent on barcode technology on 20 October 1949. The first application of industrial barcode technology was in the labeling of railroad cars in the 1960s, but it was not commercially successful until the now ubiquitous Universal Product Code (UPC) barcode. This was developed and used to automate the grocery checkout process, the first occasion of which has been credited on a packet of chewing gum in Troy, Ohio, in 1974. The successful application of barcode technology revolutionized inventory tracking and management in the retail industry.

Nowadays, barcodes are used almost universally. Airlines rely on barcodes to track passenger luggage to reduce the chance of loss. Warehouses rely on them to track the movements of materials and parts. The express industry relies on them to track mails and parcels. Barcodes are attached to each book to make the borrowing, returning and stocktaking of books easier and faster. Researchers have also looked into insects' mating habits, such as by placing tiny barcodes on individual bees. NASA depends on barcodes to monitor thousands of heat tiles that need to be replaced after every space shuttle trip. Barcodes even appear on humans! Stamping barcodes onto fashion models helps designers to coordinate their fashion shows.

Many different types of barcode technologies have been developed since the emergence of the UPC barcode, which can be classified mainly into two categories:

1. linear barcode;
2. two-dimensional (2D) barcode.

Each category comprises multiple barcode types. The linear barcode is made up of parallel lines and spaces of various widths that create specific patterns, which typically encodes alpha-numerical strings up to maximum of about 20 characters. The 2D barcode is made up of rectangles, dots, hexagons and other geometric patterns in two dimensions, which can represent more data per unit area than the linear barcode.

Although it is well developed and its applications are wide-ranging, barcode technology does have some limitations. For example, we are not able to change the data on a barcode once it is printed. In addition, barcode scanning devices are designed to operate over short distances. It is these limitations which RFID technology is capable of overcoming.

RFID is a generic term used to describe technologies that involve the use of a wireless non-contact system. This utilizes radio waves to transfer data from an RFID tag attached to an object, for the purposes of automatic identification and tracking. Unlike barcode technology, RFID tags can be read from up to tens of meters away and beyond the lines of sight of the reader. Although the history of radio frequency engineering can be traced back to 1864, when James Clerk Maxwell predicted the existence of electromagnetic waves through his famous equations, RFID was not invented until 60 years later. The first RFID application was developed in conjunction with radar technology for the Identification Friend or Foe (IFF) system used during World War II. The IFF system was developed in a secret British project led by Scottish inventor and physicist Sir Robert Alexander Watson-Watt. In this system, active and battery-powered RFID tags were placed on each British plane. When planes received radio frequency signals from radar stations on the ground, they broadcast signals back in the opposite direction which identified the plane as friendly. A passive radio transponder with memory, invented by Mario W. Cardullo and patented on 23 January 1973, is usually viewed as the first patent for an RFID tag. However, the first patent to be associated with the abbreviation RFID would not appear for a further ten years, this being granted to Charles Walton.

The applications of RFID technology have increased rapidly since its emergence. Nowadays, RFID can be used almost anywhere where a unique identification system is needed. The major areas of RFID applications involve:

- access control;
- personnel and product identification;
- fleet management;
- vehicle identification;
- production line monitoring;

- passport security;
- mail and shipping; and
- baggage handling.

1.3 Comparing barcode and RFID technologies

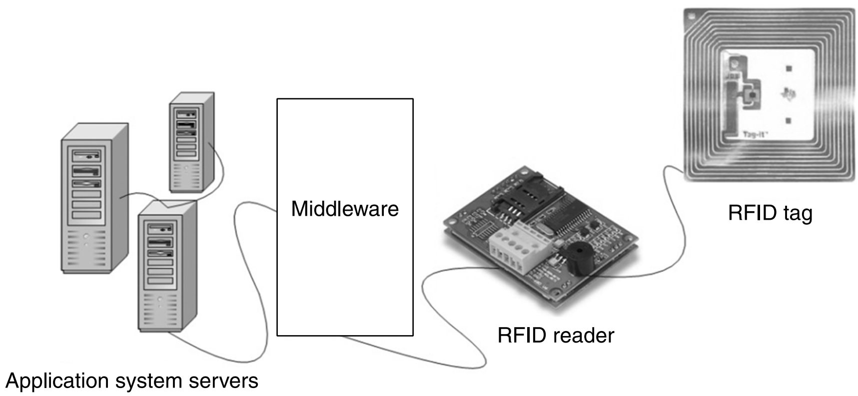
Both barcode and RFID technologies are used widely for automatic identification and tracking, and each fulfills this function efficiently and reliably. However, there exist significant differences between these two technologies:

- Barcode technology works by scanning a printed barcode label with barcode readers such as an optical laser, while RFID scans a tag using radio frequency signals. Barcodes do not work well in environments where barcode labels are prone to being wrinkled, dirty or smudged. These are common problems because the barcode labels have to be exposed on the outside of the product. However, RFID technology can perform well in these environments because RFID tags can be implanted within the product itself. This means the electronic components of RFID tags are better protected and can therefore offer greater ruggedness and reusability.
- Barcode readers require labels to be in their optical line-of-sight, something that is not required of RFID readers. This makes reading RFID barcodes much less time-consuming, as the scanners do not have to be individually positioned to scan each label in turn; rather an RFID reader can read tens of RFID tags in its scanning area simultaneously, speeding up the process considerably.
- Barcode labels can only be read at a limited distance, typically no more than 15 ft. In contrast, RFID scanners can read tags at up to 300 ft.
- It is impossible to alter the information in a barcode label once it is printed out. However, the RFID reader can communicate with RFID tags and alter the information in each rewritable tag. In addition, an RFID tag can store much more information than a barcode.
- Barcodes can be replicated or counterfeited with ease, while RFID tags are much more secure due to their greater complexity.

Although this comparison primarily focuses on the advantages of RFID over barcodes, the use of both technologies is not mutually exclusive. It is not expected that one will simply replace the other, but rather both may work in tandem in different marketing areas. In some respects, barcodes have advantages over RFID. For example, compared with RFID, barcode technology is easier to use and more affordable.

1.4 RFID technology

To fully utilize RFID technology in apparel supply chain operations, practitioners must understand the fundamentals of RFID technology clearly. To this end, the



1.1 Architecture of an RFID system.

following section will outline the basics in order that the potential benefits of the technology may be fully understood. An RFID system usually consists of the three components shown in Fig. 1.1, which include:

1. RFID tags;
2. RFID readers;
3. middleware.

The RFID tag is attached to the item that is to be identified or tracked within the supply chain by the RFID system. The RFID reader provides multiple functions such as:

- powering and identifying RFID tags;
- reading (writing) data from (TO) tags; and
- communicating with the middleware.

The middleware can receive data from the RFID reader, and enter it into a database, as well as provide access to it. The communication mechanism between tag and reader is essential to the development of RFID systems.

1.4.1 RFID tags

RFID tags are the heart of the RFID system, which stores the information that describes the item being tracked. They come in a variety of shapes, sizes and capabilities. In general, an RFID tag is made up of three essential components, including:

1. *Antenna*: An antenna is responsible for transmitting and receiving radio waves between RFID tags and readers. It is an electrical device that converts electric currents into radio waves, and vice versa. In certain situations, an antenna can

collect enough radio waves to power the tag's other components without a battery. There exist various antennas with different shapes and sizes in the case of RFID.

2. *Integrated circuit*: The integrated circuit (IC) component is the brains of RFID tag. It is actually a simple microprocessor. For many tags, the purpose of IC is to transmit the tag's unique identifier. However, the IC also acts as the main controller if the tag includes some peripheral components, which is responsible for collecting any extra information and transmitting it along with the tag's identifier. Some ICs can store as much as 2 kilobytes of data. In addition, the IC is responsible for ensuring that tags do not transmit their information at the wrong time by using an appropriate transmission algorithm, which ensures that the tag transmits either in the proper time slot or at random intervals.
3. *Printed circuit board*: The printed circuit board is the material that holds the tag together. This can exist in various shapes and sizes as well as different types of materials including glass tubes, molded styrene or epoxy resin, etc. For example, tags that are used for tracking fabrics on a shop floor, where extremely high temperatures and humidity may be encountered, would tend to be very rigid and placed inside a protective enclosure. In contrast, RFID tags which track fabrics in warehouses, where such conditions are less extreme, require greater flexibility so that they can bend with the fabric. It should be pointed out that printed circuit boards cannot be made from some types of material due to their adverse effect on the readability of RFID tags. These include metal, liquid and other particularly dense materials.

RFID tags can be classified into two categories: passive tags and active tags. Passive tags do not have a dedicated power supply. Their operating powers are derived from the electrical field generated by the RFID reader. Consequently, passive tags cannot work unless they are placed near to the reader (usually within a few centimeters). RFID tags are usually very small and can be installed unobtrusively because they do not contain an internal power supply. Some are as light, or even lighter, than barcoded labels.

In contrast, active tags have their own power supply inside, usually in the form of a battery. They have significantly greater read range than passive tags and unlike passive tags, can be read through materials that are usually impenetrable to radio waves. However, active tags are much greater in size as well as expensive due to their more complex circuitry.

The choice between a passive or an active tag is purely dependent upon the application for which it will be used. Passive tags are usually utilized in situations where tag cost is a main concern, such as for production data capture in apparel sewing lines, where the tag can be placed near to the reader for fuel dispensing, for example. Active tags would be used in cases where the cost, size and battery life-span of the tag are less important concerns, as well as when tags need to be used at a greater distance. An example of this may be in areas such as toll-paying and shipping container identification.

1.4.2 RFID readers

To retrieve the data stored on an RFID tag, an RFID reader is required. A typical RFID reader is a component that has one or more antennas that emit radio waves and receive signals back from the tag. The RFID reader is responsible for orchestrating the communication between itself and RFID tags in its read range, which decodes the data encoded in the tag's IC and passes the data to the middleware for further processing. RFID readers can be classified into the following four categories:

1. *Handheld reader*: The handheld reader combines the power of a mobile device with wireless networking and multi-protocol RFID capabilities, which acts like a handheld barcode scanner.
2. *Vehicle-mount reader*: This is a reader embedded into mobile devices such as trucks and forklifts, which has the convenience of hands-free scanning with little or no human intervention.
3. *Fixed reader*: This is mounted in a fixed position to read tags automatically as items pass by or near them, which can help reduce the communications burden on your network or servers.
4. *Hybrid reader*: Each of the three readers described above is dedicated to reading either passive or active tags. The hybrid reader is designed to be able to switch between both passive and active modes in order to read both types of tags.

RFID readers must be capable of detecting minute changes, through their antennas, in the electromagnetic field which they generate. This is the way in which the tags communicate with the reader. The RFID reader emits radio waves in ranges of anywhere from 1 inch to 100 ft or more, depending upon its power output and the radio frequency used. In passive mode, the RFID reader creates a radio frequency field when it is turned on. RFID tags are activated if they are detected by a reader. These tags do not require battery power and they draw their energy from the radio frequency field. In the active mode, the RFID reader switches to the read mode and interrogates active tags when they come within its range.

1.4.3 Tag and reader communication

The communication between RFID tags and readers usually happens on the following radio frequency bands:

- *Low frequency* (*LF*): This comprises of electromagnetic waves which emit radio frequencies of between 30 and 300 KHz. These are generally used in passive tags and in short-range applications, such as cutting component identification in sewing assembly lines and anti-theft systems in automobiles. LF RFID systems typically operate between 125 and 134 KHz and between 140 and 148.5 KHz. These systems provide a shorter read range (<0.5 m or 1.5 ft) and slower read speed than the higher frequencies. However, compared to any of higher frequency systems, LF systems have the strongest performance in the reading of tags which are attached to objects with water or metal content.

- *High frequency* (*HF*): This consists of radio frequencies in the range of 3 to 30 MHz. These are widely used in smart card and smart label applications, such as baggage tracking or small product labeling. HF RFID systems typically operate at 13.56 MHz, which have a greater read range and higher read speed than LF systems. Their typical read ranges are less than 1 m (3 ft), and they have a diminished ability to read tags on objects with a higher water or metal content compared with LF systems.
- *Ultra high frequency* (*UHF*): This refers to radio frequencies in the range of 300 MHz to 3 GHz, which are primarily used in highway toll-collection applications. Typically UHF RFID systems operate between 868 and 928 MHz, such as 868 MHz in Europe and 915 MHz in North America. The UHF system's read range is up to 3 m (9.5 ft) and the data transfer rate is faster than HF systems. Its ability to read tags on objects with water or metal content is superior to both HF and LF systems.

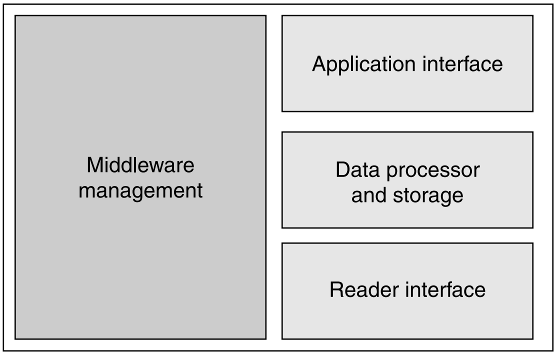
In summary, higher frequency systems require higher power and are somewhat more expensive than their lower-frequency counterparts. They support greater read distances as well as higher data transmission rates, and are more orientation-sensitive. Higher-frequency systems are less capable of penetrating metallic surfaces but are less prone to noise interference than are lower-frequency systems.

1.4.4 Middleware

Middleware is a key component for managing the flow of information between tag readers and application systems. To quantify the data, RFID systems must first collect it in an application system (software). RFID middleware applies filtering and formatting to data captured by a reader, and provides this processed data to back-end application systems.

Broadly speaking, the middleware refers to software or devices that connect the RFID hardware and the RFID application systems. The general architecture of the middleware component is composed of four layers (Fig. 1.2):

1. *Reader interface*: This is the lowest layer of the middleware component, and is that which handles the interaction with the RFID hardware. It maintains the drivers of all the devices supported by the RFID system, and manages all hardware-related parameters such as reader protocol, air interface and host-side communication.
2. *Data processor and storage*: This layer is responsible for processing and storing the raw data coming from the readers. Examples of processing logic implemented by this layer include data filtering, aggregation and transformation. If necessary, this layer can handle the data level events associated with a specific application.



1.2 General architecture of a middleware component.

3. *Application interface*: The application interface layer provides the application with a program with which it can access, communicate and configure the middleware component. It integrates the application systems with the middleware by converting the requests from application systems to applicable middleware commands.
4. *Middleware management*: This layer is responsible for managing the configuration of the middleware component, which provides the following functions:

   – add, configure and modify connected RFID readers;
   – modify application level parameters such as filters, and duplicate removal timing windows;
   – add and remove services supported by the RFID middleware.

   By using the middleware component, the following advantages can be obtained:

   – The details of RFID hardware are hidden from the application systems.
   – Raw data from RFID readers can be processed before being passed as aggregated events to the application systems. Standardization is provided to handle the huge amount of raw data.
   – An effective method is provided to manage RFID readers and query the RFID data.
   – It can provide the user with an interface that allows the set-up and reconfiguration of the RFID devices.

1.5 RFID applications in the fashion supply chain

The apparel industry has been regarded generally as lagging behind other industries such as electronics and automotive industries in regards to the utilization of innovative technologies. However, with the emergence and popularity of RFID technology, a number of apparel enterprises seized the development opportunity of this technology quickly and utilized it to enhance their competitive edge. RFID technology has now been widely applied throughout the apparel industry, ranging from fashion retailers to department stores to logistics service providers (Moon and Ngai, 2008).

As an example, in the tracking of rental uniform items, in 2002 a German company invented two types of new washable RFID tags to target the apparel and uniform rental markets in the United States (Anon, 2002). In 2008, American Apparel implemented item-level RFID tagging and product tracking (O'Connor, 2008). Kaufhof and Marks & Spencer started their RFID activities in 2003 and in 2004, respectively, by using item-level RFID tags on individual items of clothing (Collins, 2006; Loebbecke and Huyskens, 2008). Christophe Cavailles, director of DHL Solutions Fashion, also stated that RFID was well suited to reducing the complexity of the inventory and delivery checking involved in the apparel supply chain (Ilic, 2004). Legnani *et al*. (2010) have pointed out that the apparel industry, characterized by short life-cycles, quick-response production, fast distribution, erratic customer demands and impulsive purchasing, is one of the sectors which can most extensively benefit from the RFID technology.

RFID technology has also been widely used to develop real-time production data capture systems. This is used whilst collecting production data from sewing assembly lines and other departments in apparel manufacturing (Guo, 2008). Guo *et al*. (2009) integrated the RFID-based data capture system with an artificial intelligent algorithm to provide effective production decisions for apparel manufacturers. Ngai *et al*. (2009) utilized a case study approach to explore the adoption of RFID-based information systems in apparel manufacturing, and identified various strategies for the successful application of the technology in apparel manufacturing. Choy *et al*. (2009) developed a sample management system by integrating RFID technology and a case-based reasoning technique. To manage the iterative process for evaluating fabric swatches in the development of new apparel products, RFID technology is utilized to provide real-time swatch tracking and accurate fabric status updates within a fabric sample storeroom.

Madhani (2011) pointed out that fashion retailing may greatly benefit from the application of RFID technology. He proposed a marketing value-added framework by using the item-level tagging of RFID in order to help fashion retailers achieve overall business excellence. Wong *et al*. (2006) employed RFID technology to assist businesses in checking the apparels' authenticity. This involved using passive RFID tags to identify cloned RFID tags. Moon and Ngai (2008) proposed a four-point plan for an RFID-based framework, which would improve the business values of fashion retailers. In this framework, RFID-based decision-making solutions create business values for fashion retailers through improving responsiveness, relatedness and refinement. Hwang and Rho (2008) proposed an RFID system for centralized reverse SCM. This employed the RFID-based smart shelf/fitting room and inbound/outbound facilities to collect data and generate useful information, such as attractiveness of product and product return type. Al-Kassab (2010) examined the business value of RFID technology in apparel retailing by conducting a case study at Galeria Kaufhof, one of the largest department store chains in Europe, and pointed out RFID technology's usefulness in discovering process inefficiencies, cutting costs and improving the quality of service.

Some researchers have demonstrated the useful application of RFID technology in other aspects of the apparel supply chain, with the exception of apparel retailing and manufacturing. Wong *et al*. (2006) investigated the information flow by means of RFID-based data throughout the apparel supply chain. For this, he used an entity relation diagram to observe the relationship between each of its members in the supply chain. Bottani *et al*. (2009) examined the impact of RFID technology on logistical processes in the fashion retail supply chain by using quantitative assessments. This study concluded that RFID technology has the potential to generate improved revenues for the fashion supply chain.

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