An RFID and sensor technology-based warehouse center: assessment of new model on a superstore in China

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Abstract

Purpose – Large supermarkets, chain stores and enterprises with large-scale warehousing put forward higher standards and requirements for the automation and informatization of warehouses. As one of the fast-growing commercial supermarkets in China, the traditional warehouse management mode has restricted the rapid development of Yonghui Superstores to a certain extent. The purpose of this paper is to find out how the existing warehouse mode can be changed and to solve the existing problems of warehouse management of Yonghui Superstores.

Design/methodology/approach – This research puts forward construction of warehouse center, which is based on radio frequency identification (RFID) and sensor technology, then designs the model for receiving, storage, operations management, distribution and outbound to solve the existing problems of warehouse management of Yonghui Superstores.

Findings – What technologies should be adopted to meet storage requirements? How to monitor the storage environment in real time and improve the operation and management level of the warehouse? This study found that building a warehouse center based on RFID and sensor technology was a good solution.

Research limitations/implications – The Yonghui Superstores warehouse center model lacks corresponding simulation experiments, and the investment and income are difficult to estimate quantitatively.

Practical implications – This paper has designed and discussed the warehouse center model based on RFID and sensor technology, which provides a few references for the actual investment and construction of a warehouse center. In addition, the warehouse center model has strong generalized applicability and could be widely used in various enterprises.

Social implications – The warehouse center could improve the warehouse management level of Yonghui Superstores and change the traditional warehouse management mode. To some extent, it improves the enterprise flexibility of the market, which will be of great significance to improve business efficiency and enhance brand image and competitiveness.

Originality/value – This study takes Yonghui Superstores as a case to analyze the problems of warehousing management in detail and then designs a warehouse center based on RFID and sensor technology. The study discusses the location and distribution, software and hardware selection, benefits evaluation, significances and return on investment, which makes the warehouse center model versatile, technically feasible and economically applicable.

Keywords RFID, Sensor, Model, Warehouse center, Yonghui Superstores

Paper type Case study

1. Introduction

Warehouse management plays a role in the storage and exchange of goods, which includes receiving the goods from suppliers, storing the goods until they are required, picking the goods when they are required and transporting the goods to distributors or retailers (Tompkins and Smith, 1998; Keller and Keller, 2014). Warehouse management is an important part of the goods supply chain, which in turn is an important link to connect manufacturers, distributors, retailers and consumers. Objects of warehouse management include finished goods, raw materials and semi-finished

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goods. Warehouse management records detailed stored information of goods, including stock status, shipping status, market flow and other related information. It plays an important guiding role in production, supply, sales and decision-making. Meanwhile, it affects the enterprises' production, operation and development.

Traditional warehouse management mainly relies on manual management or semi-automatic management. Generally, warehouse conditions are relatively simple, lacking effective environmental monitoring equipment and storage environment such as temperature and humidity, which cannot be guaranteed. Expired, deteriorated, damaged and other conditions of goods occur from time to time, which can easily cause economic losses to enterprises.

The warehouse staff manages the goods by using handheld laser scanning equipment and barcode technology. Barcode technology has been developed for many years. Owing to its mature technology and low cost, it has been widely used in warehousing management of commodities. In small supermarkets, stores and goods with low requirements for storage condition, the basic storage environment and barcode technology could meet the storage requirements of the goods. However, for large supermarkets, chain stores and enterprises with large-scale warehousing needed, the general storage environment has been unable to meet the warehousing requirements of commodities and the higher standards and requirements for the storage environment and technical level, which have been put forward.

Large warehousing enterprises have a higher level of requirements for the automation and informatization of warehouses. Warehousing management is not simple commodity storage, but comprehensive management of information on goods inbound and outbound of the warehouse, storage, circulation and other links. Large warehousing enterprises require monitoring of commodity storage environment in real time, automatically adjusting the storage environment to ensure the best storage conditions for the goods. Inbound, outbound, weighing, stocktaking and other business could be automatically controlled and product information could be collected in real time.

Modern large warehousing enterprises have put forward higher requirements for warehouse construction. What technologies should be adopted to meet the storage requirements? How to monitor the storage environment? How do the warehouse operation and management? What hardware and software equipment do we need for warehouse center construction? How to achieve investment and profit? How should the location of warehouse construction be selected? These problems are issues that need to be considered in the construction of a warehouse center.

The development of information technology, especially radio frequency identification (RFID) and sensor technology, it provides a new solution for warehouse center construction. How to use the technical advantages and characteristics of RFID and sensor technology to achieve the construction of a warehouse center to meet the large-scale warehousing needs of commodities is the main problem to be solved in this article.

2. Literature review

At present, a number of scholars are studying in warehouse management. Van den Berg and Zijm (1999) analyzed the issues of the warehouse system and warehouse management, including the design, planning and control of the warehouse system. Saleheen *et al.* (2014) conducted a study on the retail supermarket in Bangladesh, elaborated the important role of warehouse management in the retail supply chain. Gu *et al.* (2007) analyzed the problems of warehouse operation planning such as receiving, storage, ordering and transportation and then summarized the related decision models and solution algorithms. Atieh *et al.* (2016) studied the warehouse of a telecom service provider in Jordan to evaluate the impact of an automated warehouse management system to supply chain performance. Alamri and Syntetos (2018) put forward the inventory management mode of allocation-in-fraction-out (AIFO) based on the principle of LIFO and "First In First Out" (FIFO). Sulírová *et al.* (2017) compared different types of warehouse and inventory management techniques to address the problems of transportation, handling and storage of materials. Alawneh and Zhang (2018) studied the dual-channel inventory management method to improve the flexibility of warehousing and supply chains. Current research on warehouse management has analyzed the key business links involved in inventory management and the impact on the logistics and supply chain of the commodity, which further illustrated the importance of strengthening warehouse management.

Information technology, especially RFID and sensor technology, it provides new ideas for warehouse management. At present, many scholars have studied the application of RFID and sensor technology in warehouse management. Feng *et al.* (2014) studied how Wal-Mart inspires suppliers to adopt RFID technology based on the theory of principal-agent and analyzed the key influencing factors and existing problems. Wang *et al.* (2010) designed an automated warehouse system based on RFID technology to meet the demand for online shopping makes fast delivery of customers in British. Manthou and Vlachopoulou (2001) designed the framework and model of the inventory and marketing system using barcode technology to improve inventory accuracy and customer service. Li *et al.* (2010) conducted a study on real-time tracking of supermarket commodity information and code reading by Internet of Things (IoT) technology to solve the problem of shortage and excess of fresh products. Ma *et al.* (2015) take warehouse supermarkets as an example to verify the impact of big data and mobile Internet technology in the supply chain. Reaidy *et al.* (2015) proposed a collaborative warehouse order system based on RFID technology, intelligent environment and multi-agent systems. Lian *et al.* (2007) constructed the software and hardware of a logistics warehouse system based on RFID technology. Tan (2008) designed the logistics system based on RFID and introduced the working principle and management model in details. Xu *et al.* (2013) designed and developed the warehouse management system based on RFID and dynamic inventory SKU. Lou *et al.* (2011) discussed the characteristics of IoT and related support technologies and then explored the supply chain management system based on IoT. Fosso Wamba *et al.* (2016) studied the technical, organization, environment and management characteristics of SMEs based on RFID technology. Gajzler (2015) explored the technical and management issues of the infrastructure construction of warehouse system from the perspective of the construction of

large-scale warehouse facilities. Scott (2018) found that the warehousing business of multinational freight companies has some deficiencies in information sharing and proposed using RFID and sensor network to achieve information sharing in a warehouse. Borstell *et al.* (2014) proposed a pallet monitoring system that combines vehicle positioning, RFID identification and depth sensors to collect and monitor information such as pallet position and storage time. These studies have carried on the detailed analysis of information technology, especially the application and the solution of RFID and sensor technology in warehouse management, which provides some references for the construction of warehouse center based on RFID and sensor technology.

At the same time, many scholars have studied the changes brought by RFID, sensor and other information technologies in warehouse management. Liu *et al.* (2006) verified that the application of RFID technology could increase the usage rate of warehouse space and improved the business speed, reducing the work error and operating costs. Chen *et al.* (2013) proposed a warehouse management system based on RFID technology and verified that RFID could improve the efficiency of warehouse management. Ma and Liu (2011) established a warehouse management system based on Wi-Fi and real-time location technology to reduce the inventory and cost of enterprises and then improve the turnover. Ustundag and Tanyas (2009) calculated the expected benefits of supply chain management in terms of efficiency accuracy, visibility and safety through simulation the model of integrated RFID technology. Sarac *et al.* (2010) analyzed the impact of RFID technology on supply chain performance in terms of the model, simulation, case study, experiment and ROI. Tajima (2007) studied the sustainable competitive advantages of RFID technology in supply chain management and constructed the strategic theoretical value. Michael and McCathie (2005) explored the pros and cons of RFID technology in supply chain management. Shih and Wang (2016) proposed a cold chain system based on time-temperature indicator (TTI) that uses wireless sensors to collect temperature data, and the experiment showed that cold chain systems could increase rice sales, create jobs and reduce energy costs. Diete *et al.* (2016) proposed a system that combines ultrasonic, pressure, video and inertial sensors and then integrated them into smart glasses and wristbands to enhance the system's identification and monitoring capability, enabling the identification and selection of goods in logistics orders. The application of RFID and sensor technology could improve the efficiency of warehousing enterprises, lower inventory backlog and reduce enterprise costs. Current researches on the improvement of warehouse management with RFID and sensor technology further confirm the importance of RFID and sensor technology.

In addition, some scholars have studied the actual application of RFID, sensor and other information technology in warehouse management by case study. Poon *et al.* (2009) proposed that using RFID technology to collect and share warehouse data to analyze the problems of inventory management systems and verified it by case study. García *et al.* (2007) designed a multi-level agent system based on RFID technology to control the large-scale electronic retailer "Group Lo Monaco" in Spain. Bottani and Rizzi (2008) surveyed manufacturers, distributors and retailers by means of questionnaires to assess the impact of RFID technology and EPC on the FMCG supply chain. Delen *et al.* (2007) analyzed the entire physical layout of RFID reader from the distribution center to the retailer and verified the value of RFID technology for the entire supply chain. Bertolini *et al.* (2013) explored how RFID technology can improve the implementation of the FIFO policy for the storage of fresh products in large-scale retail channels. Yan and Huang (2008) proposed a product lifecycle monitoring information system based on RFID technology to solve the security and monitoring problems of mobile phones. Pero and Rossi (2014) studied the innovative system based on RFID, Wi-Fi and customer-accessible WEB programs and then analyzed its application in an Italian company. Wamba *et al.* (2008) analyzed the impact of RFID-EPC network on mobile B2B e-commerce, then tested and evaluated the application scenarios in the pilot project. Boeck and Fosso Wamba (2008) analyzed the impact of RFID technology on the supplier-buyer relationship in the supply chain of the retail industry by case study. Muthukumar *et al.* (2018) proposed a sensor-based warehouse system to monitor the temperature, humidity, gas and other data in the warehouse, to control the waste of food effectively. Jiang *et al.* (2015) proposed a cotton warehouse fire alarm system based on IoT and used ZigBee wireless sensor network for data acquisition and transmission to control the fire effectively. Trebar (2015) proposed using RFID and temperature sensor to monitor the activity and real-time temperature of perishable food in the logistics process to meet the requirements of cold chain transportation. The case study confirms the feasibility and effectiveness of information technology, especially RFID technology in the field of warehouse management, and it further illustrates the application prospect of RFID technology.

In conclusion, we analyzed the research status of warehouse management and RFID technology in the application of warehouse and supply chain management, which provided the theoretical basis and some references for RFID and sensor technology in the construction of warehouse center.

3. Case study

Case study is a way of combining technical models with reality. At the same time, it is an intuitive method to verify the proposed solution. In view of the problems existing in the current warehousing management, this article takes Yonghui Superstores as an example and combines the actual situation to analyze the problems and solutions, which provides some references for the construction of warehousing center.

3.1 Background

Founded in 2001, Yonghui Superstores is one of the top 500 enterprises in China and is a national "circulation" and "agricultural industrialization" enterprise. After more than ten years of development, Yonghui has developed into a large group enterprise integrating retailing, modern logistics, modern agriculture, food industry and industrial development. Yonghui has developed more than 580 supermarket chains in

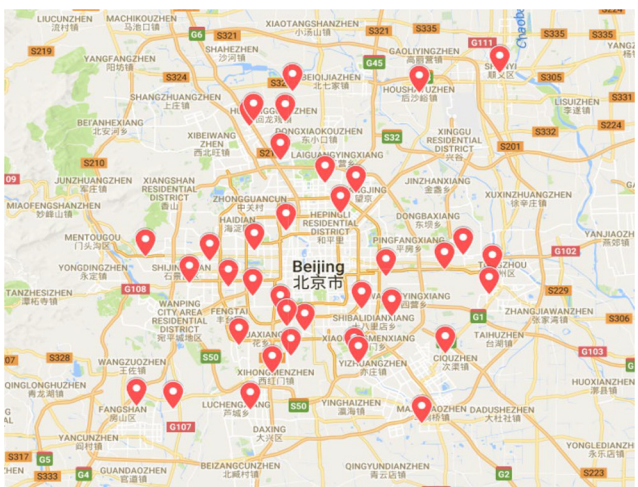
19 provinces and cities in China and its business area over 5 million square meters (YongHui superstores official website, 2016). Yonghui currently has 37 stores in Beijing and the specific distribution as showed in Figure 1:

The number of Yonghui Superstores in each district in Beijing is shown in Table I, and there are eight stores in Chaoyang District, four stores in Haidian District, seven stores in Fengtai District, two stores in Shijingshan District, four stores in Daxing District, four stores in Tongzhou District, four stores in Changping District, two stores in Fangshan District, two stores in Shunyi District; and the number of Yonghui Superstores in Dongcheng District, Xicheng District, Mentougou District, Pingu District, Huairou District, Miyun District and Yanqing District is 0 each.

After statistical analysis of 37 Yonghui Superstores, the proportion of Yonghui Superstores in each district in Beijing is shown in Figure 2. Among them, the Chaoyang District is 22 per cent and Fengtai District is 19 per cent, whereas the Haidian, Daxing, Tongzhou and Changping districts were all 11 per cent. The Shijingshan, Fangshan and Shunyi districts were all 5 per cent, but the Dongcheng, Xicheng, Mentougou, Pinggu, Huairou, Miyun and Yanqing districts were all 0.

Yonghui Superstores are distributed in the urban and suburban areas of Beijing and are rarely distributed in remote suburbs. Although there are stores of layouts in each area, there is a lack of large logistics warehouse center to be responsible for the allocation of goods. The storage of goods, management of suppliers, goods allocation and other issues are highlighted. As one of the fast-growing commercial supermarkets in China, Yonghui Superstores has strong representativeness.

Figure 1 The distribution of Yonghui Superstores in Beijing

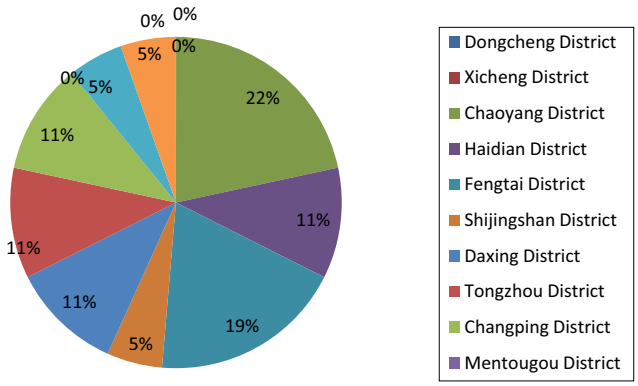


Source: Google Map

Table I The number of Yonghui Superstores in each district in Beijing

District	Number	District	Number
Dongcheng District	0	Changping District	4
Xicheng District	0	Mentougou District	0
Chaoyang District	8	Fangshan District	2
Haidian District	4	Shunyi District	2
Fengtai District	7	Pinggu District	0
Shijingshan District	2	Huairou District	0
Daxing District	4	Miyun District	0
Tongzhou District	4	Yanqing District	0

Figure 2 The proportion of Yonghui Superstores in each district



3.2 Problems

Through analyzing the operation of Yonghui Superstores, the following problems mainly exist in the warehousing management of commodity at present:

- *Lack of large-scale warehouse centers*: The current business model of Yonghui Superstores is direct delivery to the stores by the suppliers, and the internal warehouse of each store is responsible for the storage and internal deployment of the goods. However, with the expansion of the business scale and the increase in the number of stores, the current business model has shown some shortcomings.
- *Limited storage conditions*: The storage facilities are simple and lack effective environmental monitoring equipment. The storage environments such as temperature, humidity and pressure cannot be monitored in real time. Some of the goods that require higher storage conditions are prone to deteriorate, expire and get damaged, resulting in economic losses to the suppliers and the supermarkets.
- *Low level of automation, mainly relying on manual operation*: At present, commodity storage mainly relies on the internal warehouse of the store. The daily operation and management of warehouses are operated by manpower, with low efficiency and high error rate. Goods information, such as sales, storage and wastage, is gathered through the barcode technology, which cannot be mastered in real time, and the level of automation is quite low.
- *Limited management level of goods procurement and delivery*: Yonghui Superstores have 37 stores and are situated in different areas in Beijing. Suppliers can only distribute goods respectively according to the demand of each store. Long delivery time, long distance and high transport cost, the goods cannot be distributed uniformly. As the commodity information cannot be collected and tracked in real time, the procurement plan and demand situation do not match. To a certain extent, the timeliness and accuracy of goods procurement have been affected and

then it disturbed the daily work plan of the procurement department.

These problems existing in warehousing management of Yonghui Superstores have restricted the rapid development of Yonghui Superstores to a certain extent. How to solve these problems? What technologies should we adopt to improve warehousing management of Yonghui Superstores? How to monitor the storage environment of Yonghui Superstores in real time and improve the operation and management level of the warehouse? This paper proposes establishing a large warehouse center with RFID and sensor technology to address these issues. But what hardware and software facilities do we need for warehouse construction? How should the location of warehouse construction be selected? These problems are issues that need to be considered in the construction of a warehouse center. How to solve these problems is the focus of this paper.

4. Key technology

4.1 Radio frequency identification technology

Radio frequency identification (RFID) technology is an automatic contactless identification technology, whose basic principle is to use the radio frequency signals and its spatial coupling, transmission characteristics to identify the static or moving items automatically (Finkenzeller, 2010; Roberts, 2006). The identification can be done in a variety of harsh environments without human intervention. The RFID system is mainly composed of RFID tags, RFID readers and antennas (Finkenzeller, 2010; Roberts, 2006).

The RFID tag is characterized by fast read and write, high security for data, easy to use and diversified package forms. It can be adapted to the bad environment and can also be easily embedded or attached to the different types of products. Table II shows several common passive electronic tags that are used in diverse fields (Finkenzeller, 2010; Banks *et al.*, 2007).

According to the practical requirements, we need to use the HF 13.56MHz passive electronic tag, which is lightweight, has a small size, large storage information, long life and low cost and has been widely used in practical engineering. The technical characteristics of RFID tag have enabled it to be stably applied in goods warehouse management and it has extensive application prospects.

4.2 Sensor technology

A sensor is a physical device which can detect external information and then convert the detection information into a usable signal according to a certain law (Grattan, 1999; Wilson, 2004). It is mainly composed of a sensing element, a switching element and a corresponding switching circuit (Grattan, 1999; Wilson, 2004) . In addition to the information sensing, signal output and other functions of traditional sensors, wireless sensor network (WSN) also has the functions of collaboration, computation and communication (Wilson, 2004).

There are many kinds of sensors, which are mainly divided into photosensitive sensors, acoustic sensors, gas sensors, chemical sensors, pressure sensors, temperature sensors and fluid sensors. according to their functions (White, 1987; Grattan and Meggitt, 1999; Wilson, 2004). With mature technology and low cost, it has been widely used in various fields. Its technical advantages and application experience are conducive to its development and application in the field of commodity logistics and warehousing management.

In this study, we mainly use temperature sensors, pressure sensors, humidity sensors, smoke sensors, laser-ranging sensors, vision localization sensors and photoelectric sensors to monitor the storage environment according to the needs of the construction of warehousing center. The specific functions are as for Table III (White, 1987; Juds, 1988; Grattan and Meggitt, 1999; Wilson, 2004).

All kinds of sensors are mainly used to monitor the storage environment of goods in real time. Temperature sensors, humidity sensors and smoke sensors are used to monitor, collect and transmit the data of temperature, humidity and smoke in the warehouse to ensure that the storage environment meets the appropriate standards. Pressure sensor is mainly used for weighing the goods; photoelectric sensors are mainly used for monitoring the position of stacker, goods and storage position; laser-ranging sensors are mainly used for monitoring the clearance of goods; and vision localization sensors are mainly used for the precise position of goods and controlling the AGV trolley in real time.

With the development of sensor technology, it has a very mature application in corresponding fields. This paper makes a detailed classification and analysis of its role in the field of warehouse management, combining with the technical characteristics and advantages of all kinds of sensors and applies it to design the warehouse center model, reasonable sensor node layout and combines with all kinds of sensors to achieve the environmental monitoring and operation control of warehouse center. For the convenience of identification, it is identified (Figure 3).

Through the analysis of the characteristics and advantages of RFID and sensor technology, we could make a reasonable layout of the design of the warehouse center model. We give full play to the technical characteristics of RFID and sensor, effectively solve the existing problems in warehouse management to achieve the precise management of goods and improve the warehouse management level of the enterprise.

5. Proposal of a radio frequency identification/ sensor-based system model

Warehouse center model of Yonghui Superstores is mainly composed of receiving, storage, operations management,

Table II Classification table of passive RFID tags

Category	Frequency band	Memory capacity	R-W distance	Price
LF	120-150 KHz	128-512 byte	10 cm	Cheap
HF	13.56 MHz	128-8 K	10 cm-1 m	Medium
UHF	433,868-928 MHz	64 K	1-100 m	Expensive

Table III Function classification of sensors

Category	Main functions
Temperature sensors	Monitor the temperature of the warehouse
Pressure sensors	Sensor arrangement for the weighing system
Humidity sensors	Monitor the humidity of warehouse
Smoke sensors	Monitor the smoke of warehouse
Photoelectric sensors	Monitor the position of the stacker, goods, storage position, etc.
Laser-ranging sensors	Monitor the clearance of goods
Vision localization sensors	Accurate positioning of goods, AGV trolley navigation, positioning and control
WSN	Distributed WSN nodes

Figure 3 Identification of sensors

Category	Identification	Category	Identification
Temperature Sensors		Photoelectric Sensors	
Pressure Sensors		Laser-Ranging-Sensor	
Humidity Sensors		Vision Localization Sensors	
Smoke Sensors		RFID reader	
Camera		GPS	

distribution and outbound. The warehouse center model based on RFID and sensor technology optimizes the business process and brought new changes in technology and management.

5.1 Warehouse center model of Yonghui Superstores

As shown in Figure 4 (Tan *et al.*, 2013; Liu, 2013), the warehouse center model of Yonghui Superstores mainly includes three modules: the first module includes unloading, weighing, quality inspection, affixing RFID tag and writing data; the second module includes goods inbound, storage, stocktaking and other links; the third module includes distribution of the goods, outbound, logistics transportation and other links.

Module 1: This module is primarily some preparatory work before the goods are stored, and it includes the following aspects:

- *Unloading*: Suppliers arrange the goods according to the order, transport goods to warehouse center and place the goods in the designated unloading area.
- *Quality inspection*: Before the storage, the goods need to be inspected for quality. For a larger number of batches of goods, determine the product quality into the warehouse by the sampling.
- *Pasting the RFID tags*: Pasting of tag is usually in the form of a tray or standard package so that it is easy to manage.
- *Weighing*: For products that need to be measured by weight, their weights need to be determined before entering the warehouse.
- *Writing data for RFID tags*: After the above four steps, the RFID reader installed in the quality inspection area will write the related goods quality inspection data into the RFID tags.

Module 2: This module is mainly the internal business of the warehouse, including the three major business of inbound, storage and stocktaking:

- *Inbound*: When information is written into RFID tags pasted on the goods, the forklifts carry the goods into the warehouse, and then the system automatically distributes according to the goods information and sends the instructions to the forklift.
- *Storage*: The forklift truck handles the goods into the warehouse after receiving the position instruction and the RFID reader automatically uploads and updates the data.
- *Stocktaking*: According to the stocktaking need, the fixed RFID reader and handheld RFID reader arranged in the warehouse can achieve the single, multiple and full stocktaking for one or more goods.

Module 3: This module mainly includes goods distribution, outbound, logistics transportation and other business processes:

- *Distribution of goods*: The warehouse center will send distribution orders after receiving the order of the supermarket stores in the area, and the warehouse dispatcher carries out the distribution according to the delivery manifest.
- *Outbound*: When the goods are out of the warehouse, the RFID reader at the entrance of the warehouse will automatically read the outbound goods information and check it with the warehouse data center. If the data are correct, the goods are allowable outbound and the data is automatically updated.
- *Logistics transportation*: Goods information will be checked again before loading. If the information is correct, it will be loaded and transported. At the same time, RFID tags will be recycled at the same time.

5.2 Receiving model

The receiving link is a very important part of warehouse management, as shown in Figure 5, the receiving model mainly contains the following three aspects.

5.2.1 Procurement order and arrangement of the source of goods

The warehouse center sets the corresponding stock alarm value according to the sales situation of the goods and makes the procurement plan according to the goods stock situation after stocktaking. The supplier accepts the order and provides the goods. At the same time, the procurement department will make new procurement plan depending on the market demand.

For fixed suppliers, procurement department can direct online order for procurement, for the new goods or similar goods needed to find new suppliers, it can adopt the bidding or offline procurement. The supplier should provide detailed product information to the warehouse center, including product name, raw materials, manufacturers, origin, date of production, implementation standards, production standards and so on, to write the good data to RFID tags.

5.2.2 Unloading and inspection, pasting the tag and writing the data

When the product is delivered to the unloading area, it is unloaded as required. After completion of unloading, quality inspection of the product should be performed (the same batch of products can be sampled) to ensure that the product meets the quality standards.

Figure 4 Warehouse center model

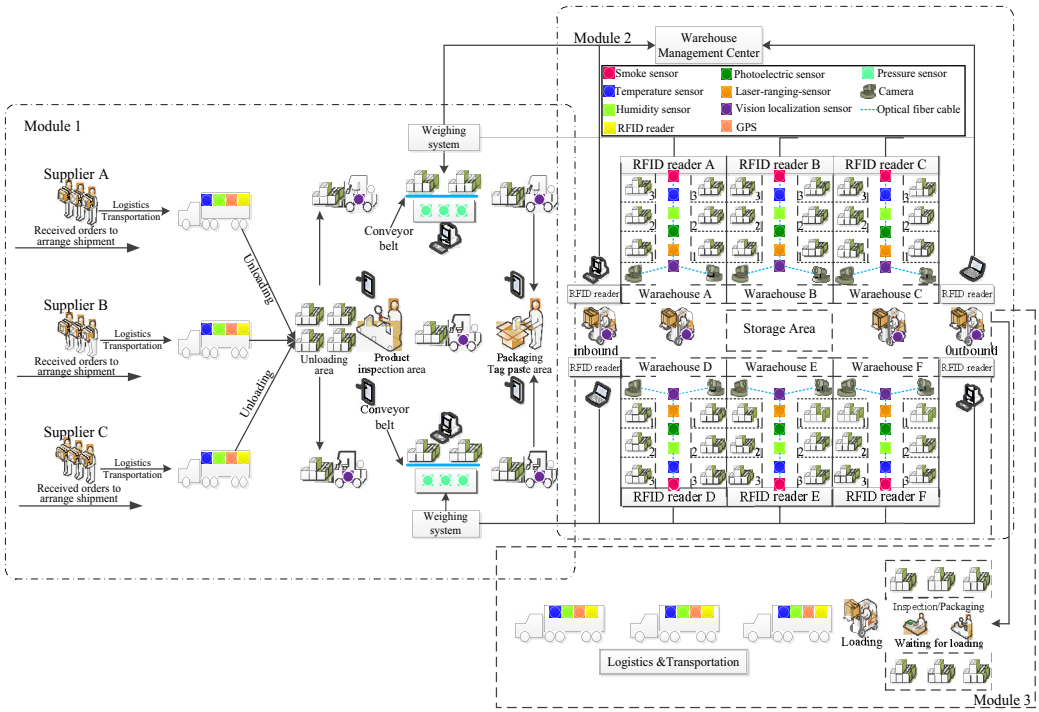
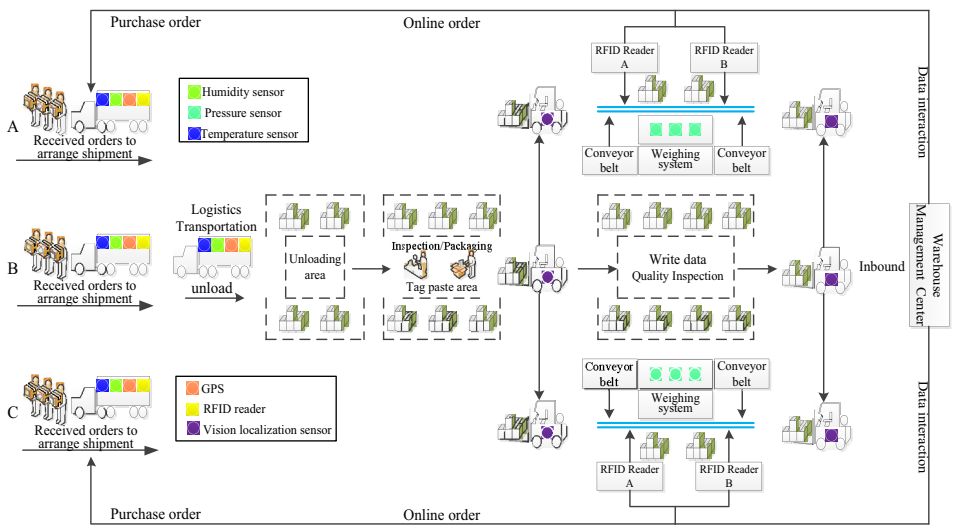


Figure 5 Receiving model of warehouse center



After product inspection is completed, the product is sorted and affixed with RFID tag (Note: The label should be designed to be easily affixed and recycled). Generally, the tag is pasted on the box or tray as a unit so that it is easy to manage. After the tag is posted, it should be initialized uniformly. Combining the bar code of the goods packaging and the data information provided by the supplier, use fixed RFID reader or handheld RFID reader to write the product data into the RFID tag.

5.2.3 Quality inspection

The quality inspection process is mainly to check the quantity and tag information of the goods by means of fixed RFID reader or handheld RFID reader in the quality inspection area to ensure that the tag data is consistent with the supplier's supply data and procurement data and is allowed to be stored after confirmation. If there any error, an alert will be issued and further verification will be required before it can be put into storage.

5.3 Storage model

When the quality inspection is completed, the forklift carries the goods into the warehouse. As shown in Figure 6, the storage model mainly includes the following two aspects.

5.3.1 Inbound

The RFID reader will automatically read the RFID tag information on the product packaging and upload the information to the warehouse database when the forklift carries the goods to the scope of reading and writing.

The warehouse database will automatically assign the location and check the uploaded RFID tag information. If it is correct, the information of the goods will be writing to the RFID tag on the outer package of the product through the RFID reader of the warehouse gate. Then, the forklift will be issued into the warehouse instruction. (Note: The data of warehouse center are provided by the weighing system, the product inspection system and the storage system).

5.3.2 Entering the storage position

The goods will be transported to the designated location after the forklift gets the store instruction. At the same time, the information of inbound goods is uploaded to the warehouse database for confirmation. If confirmation is correct, the forklift is permitted inbound. Then the RFID reader inside the warehouse will automatically read and write information on the packaging of goods and upload to the database. The database of Yonghui warehouse center automatically changes the data of goods based on the upload data information and complete the inbound process.

5.4 Operation business model

Goods operation is the core of warehouse management. As shown in Figure 7, the operations business model mainly involves two tasks: stocktaking and daily management.

1 *Stocktaking*: The control state of storage is very important to goods procurement plan. The stocktaking of goods can be performed using fixed RFID reader and handheld RFID reader. The RFID reader can automatically read the tag pasted on the packaging of goods to get the information and compare the database of Yonghui warehouse center to complete stocktaking. It is easily and efficiently to conduct single, multiple and full stocktaking for one or more goods by means of fixed and handheld RFID reader.

2 *Daily management*: The daily management of goods includes warehouse cleaning, environmental monitoring, goods wastage and so on. The aim of daily management is to ensure appropriate storage environment. Various sensors arranged in the warehouse could monitor the storage environment of goods in real time. The temperature, humidity, smoke and other sensors makes the storage environment more stable and safe; the pressure sensors make the weighing business more accurate; the photoelectric sensors, visual positioning sensors and laser-ranging sensors could monitor the position of stacker and goods and storage position and control the AGV trolley in real time, which ensure the rational usage of resources and keep the storage environment within a reasonable range to meet the corresponding standards and the wastage is effectively reduced. Once an exception occurs, the warehouse can be adjusted in time to reduce economic losses.

Figure 6 Storage model of warehouse center

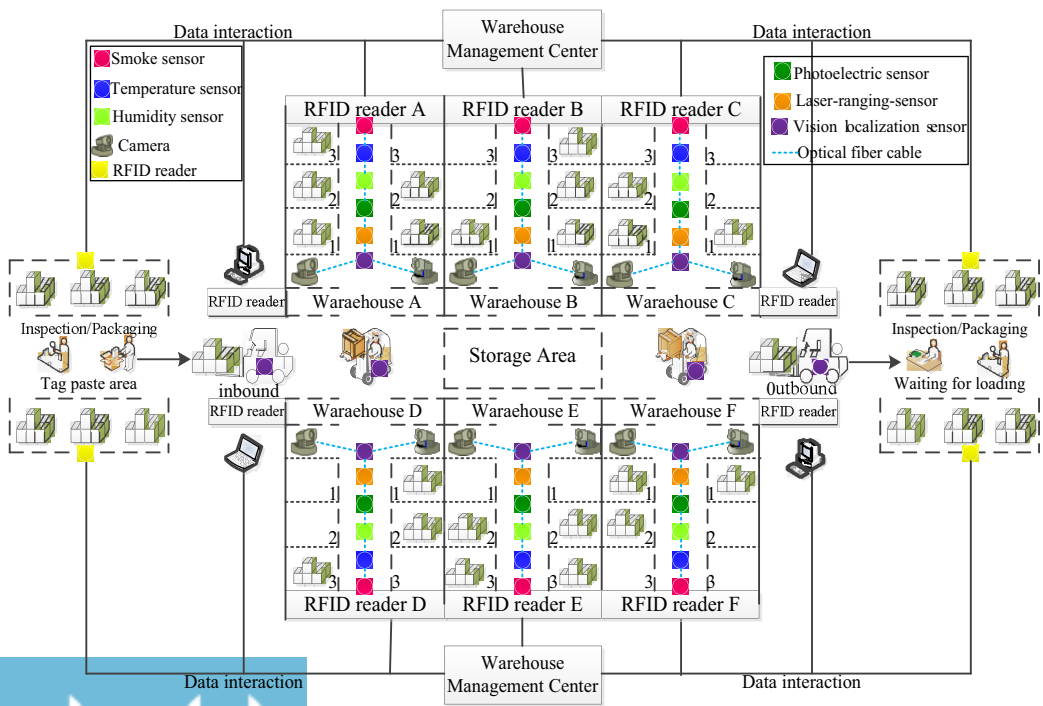
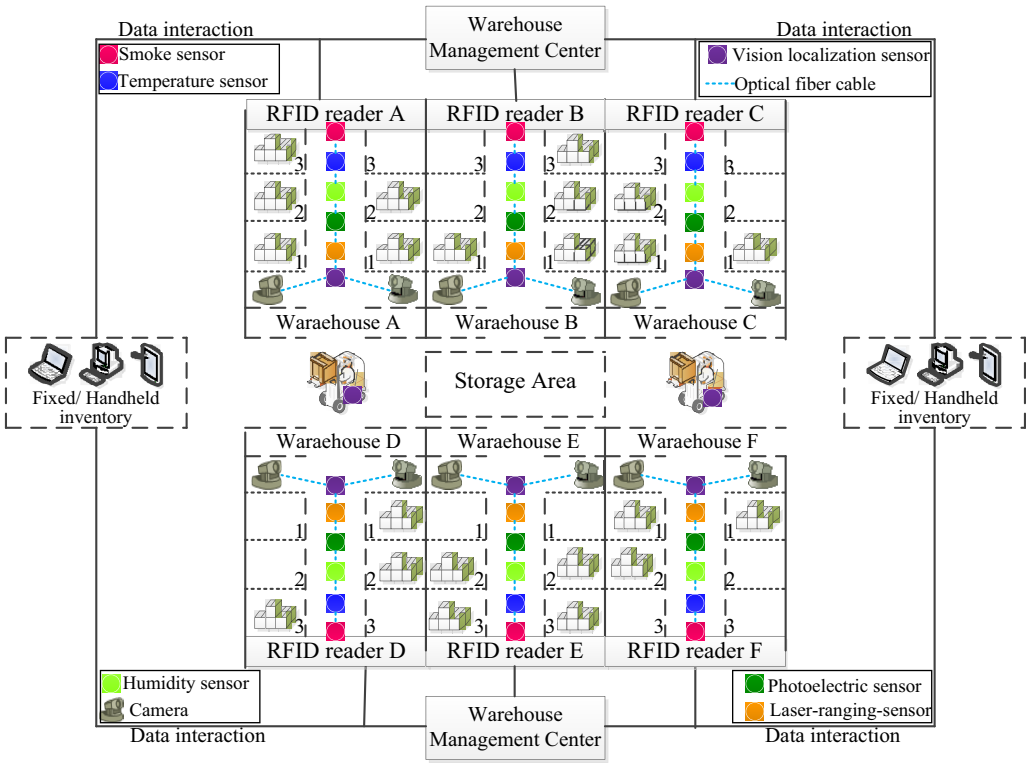


Figure 7 Operation business model of warehouse center



Through the management of warehouse center, the state of the storage, inventory and wastage can be monitored in real time so that the warehouse management staff can quickly and accurately deal with the needs of Yonghui Superstores and warehouse procurement.

5.5 Distribution and outbound model

Distribution and outbound are the last part of the warehouse center management, as shown in Figure 8 (Liu and Yao, 2017), the process mainly involves four aspects: distribution, outbound, tag recycling and transportation:

1 *Distribution*: After the Yonghui Superstores' orders arrive at the warehouse center, warehouse server automatically analyzes order by the warehouse database, at the same time, which controls the RFID reader and would read the goods information, calculate the goods position based on the analysis for orders and generate a distribution order. After the distribution instruction is generated, the warehouse server will send the distribution order to the forklift, and the forklift will go to the corresponding goods position and carry the goods after receiving the order. If there is no error, the products will be delivered out of the position.
2 *Outbound*: When the forklift carry out the goods through the export, the RFID reader will automatically read the RFID tag information on the product packaging, at the same time the data will be uploaded to the warehouse database, then the warehouse center checks the order information with the warehouse database to make sure no errors are included in the product name, brand, quantity, specifications and manufacturers. Warehouse database updates the store information according to the goods outbound automatically.
3 *RFID tag recycling*: After the goods is outbound, the RFID tags and trays must be recycled by special personnel, then complete the RFID tags recycling process through the procedure of recycling, registration, check, initialization and so on.
4 *Logistics and transportation*: After a series of procedures, the goods began to load. Before loading, the related information about the product's varieties, quantity, grade and other information will be checked to ensure data complying with the order. After confirming the data, the goods will be taken to the Yonghui Superstores.

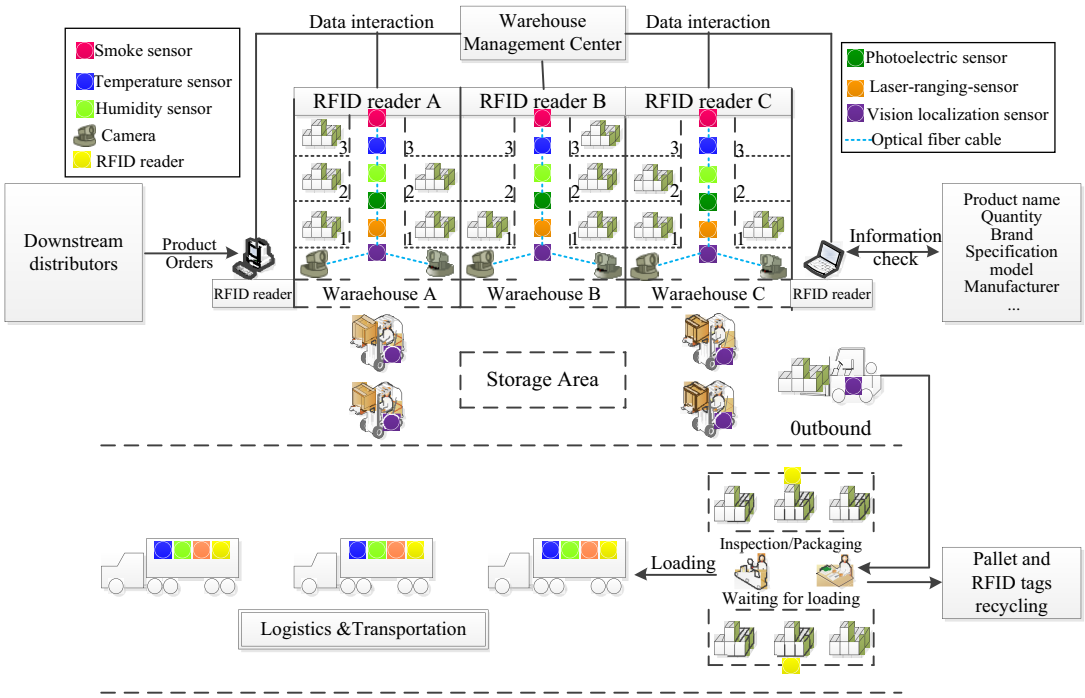
Warehouse center model of Yonghui Superstores used RFID and sensor technology to optimize the entire business, which will change the traditional methods of warehouse management and simplify the business processes and improve business efficiency and management level.

6. Discussion

In view of the problems existing in the warehouse management of Yonghui Superstores, this article mainly discusses and analyzes the warehouse center based on RFID and sensor technology from the following aspects:

- location and distribution of warehouse center;
- software and hardware equipment required for the construction of a warehouse center;
- benefits from the warehouse center;
- return on investment (ROI) of warehouse center; and

Figure 8 Distribution and outbound model of warehouse center

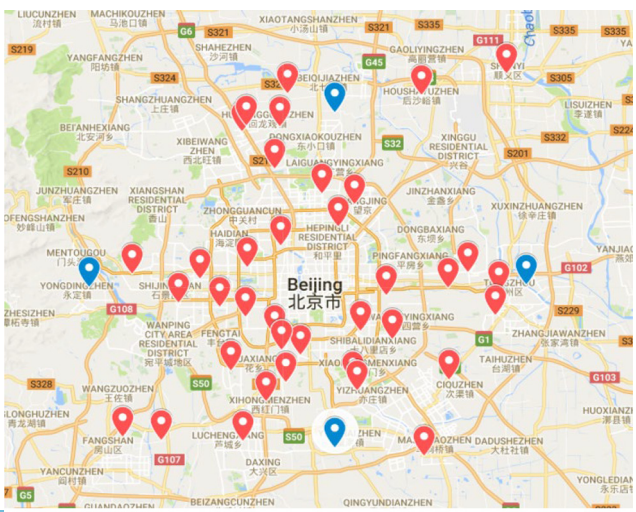


- significance of warehouse center construction, which provide references for the investment and construction of a warehouse center.

6.1 Discussion of location and distribution

As shown in Figure 9, the red mark represents Yonghui Superstores, and the blue mark represents the warehouse center. The topographic map of Beijing is a circular distribution. Current stores of Yonghui Superstores are mainly distributed between the third, fourth and fifth rings. The map shows in the topographic distribution of the four directions of the east, west, south and north.

Figure 9 Warehouse center distribution model



Source: Google map

According to the development of Yonghui Superstores and topographical distribution, warehouse centers should be set in the four directions (east, west, south and north) to meet the goods supply needs of each store. As shown in Figure 9, the warehouse center can be set up in the East-Yongshun Town, Tongzhou District; West-Yongding Town, Mentougou District; South-Yinghai Town, Daxing District; North-Beiqijia Town, Changping District. These warehouse centers can cover all of Yonghui Superstores.

However, in the real world, setting up the warehouse center needs to integrate factors such as store requirements, transportation routes, number of stores and the size of the warehouse center. Because of the large size of the warehouse center, the cost of the construction must also be considered, including rent, infrastructure construction, the cost of software and hardware equipment, manpower and material costs and other factors. On the basis of the comprehensive assessment, decide whether or not to establish the warehouse center, where and how large-scale should be built.

6.2 Discussion of hardware and software required

As shown in Table IV, investment and construction of Yonghui Superstores warehouse center mainly involve hardware system, software system and business system:

- *Hardware system*: The investment of hardware system includes construction of RFID system, sensor system, weighing system, power system, monitoring system, network system, transportation system, warehouse equipment and MIS server room.
- *Software system*: The investment of software system includes construction of the OA system, middleware system, database system, WMS, VMI, interface system, system integration, system maintenance and TMS.
- *Business system*: The investment in the business system mainly includes infrastructure construction, warehouse

Table IV Hardware and software required of warehouse center

System name	System module
Hardware system	
RFID system	RFID reader/tags/antennas
Sensor system	Temperature, humidity, pressure, smoke, etc.
Weighing system	Pressure sensor, conveyor belt, etc.
Power system	Cabling and connectors, UPS, etc.
Monitoring system	Camera, storage device, video matrix, etc.
Network system	Optical cable, network devices, etc.
Warehouse equipment	Forklift, pallets, shelves, conveyors, AS/RS, etc.
MIS server room	Computers, printers, air conditioners, RAID, etc.
Transportation system	Truck, GPS, etc.
Software system	
OA	Personnel management, Document flow, etc.
Middleware system	Web servers, Transaction monitors, etc.
Database system	SQL Server, Oracle, etc.
WMS	Inbound, outbound, inventory management, etc.
VMI	Supplier qualification, CRM, etc.
Interface system	Interface protocol, peripheral equipment, etc.
System integration	Application module, equipment system integration
System maintenance	Module development, system update, etc.
TMS	Path planning, tracking, etc.
Business system	
Infrastructure construction	Materials expenses, equipment charges, etc.
Warehouse rental	Land rent, land taxes and fees
Employee salary	Manager, official, technicist, driver, etc.
Operating expenses	Water fee, power rate, property fee, garbage fee, etc.

Source: Leung *et al.* (2007)

rental and employee salary; operating expenses, such as water, electricity, electricity and waste disposal.

Through analysis of the hardware systems, software systems and business system related business modules required by Yonghui Superstores warehouse center, it provides some references for the investment and construction of the warehouse center and the capital budget.

6.3 Discussion of benefits from warehouse center

As shown in Table V, the benefits of investment and construction in Yonghui Superstores warehouse Center mainly include revenue, operating profit and capital efficiency:

- *Revenue*: The revenue mainly comes from the rental savings from the reduction in the storage area of Yonghui Superstores, the sales revenue from the increase in business area, turnover income from inventory funds and improved visibility of stocks.
- *Operating margin*: Operating margin mainly includes the cost of goods sold and operating expenses. The application of RFID and sensor technology can reduce the wastage of goods, prevent counterfeit products and theft and avoid the low price brought by mass procurement, which effectively reduces the cost of goods sold. At the same time, the reduction in manpower, material resources and transportation costs, as well as the reduction in inventory, have reduced Yonghui Superstores' operating expenses.
- *Capital efficiency*: Capital efficiency mainly includes two aspects: fixed asset and stock capital. The fixed asset includes reduced capital investment in barcode equipment, manual weighing equipment and ordinary shelves. Stock capital includes the reduction of safety stock, shorten delivery time and turnaround time and so on.

6.4 Discussion of return on investment (ROI)

ROI refers to the economic return that the enterprise obtains through investment. ROI can be calculated by the following formula (Sarac *et al.*, 2010):

$$\text{ROI 1} = \frac{\text{Annual profit or Annual average profit}}{\text{Total investment}} \times 100\,\text{per cent}$$

Yonghui Superstores can increase ROI through reduce the cost of sales, enhance the profitability of goods and improve the efficiency of asset usage. However, ROI 1 is only applicable to evaluate the ROI in a fixed year. In the real world, there may be more influential factors. Owing to the long operating cycle of the warehouse center, the ROI must take into account the time value. Banks *et al.* (2007) proposed a calculation formula for ROI based on the time value of the fund:

$$\text{ROI 2} = \left(\frac{\sum_{t=1}^{n} \frac{V_t}{(1+D)^t} - V_i}{V_i} \right) * 100\%$$

Table V Benefits from the warehouse center

Revenue	Rental income from the reduction of stores warehouse area
	Improved visibility of stocks
	Cash turnover income from reduced inventory funds
	Income from the increase in business area
Operating margin	
Cost of goods sold	Reduced wastage of goods
	Accurate procurement, adequate supply of goods to bring sales revenue
	Reduced goods shrinkage rate
	Reduced product expiration
	Reduced deductions
	Product price advantage brought by mass procurement
	Anti-counterfeiting/anti-theft, reduced intangible loss
Operating expenses	Reduced labor and material costs
	Reduced pressure on inventory funds
	Reduced transportation costs
	Accelerate product circulation time
Capital Efficiency	
Fixed asset	Reduced investment in barcode equipment
	Reduced investment in manual weighing equipment
	Reduced capital investment in ordinary shelves
Stock capital	Improved inventory accuracy and reduced safety stock
	Shortened delivery time
	Shortened inventory turnaround time

Source: Banks *et al.* (2007)

In this formula, t represents the time period, n represents the number of periods, V_i represents the investment of Yonghui Superstores warehouse center, V_t is the monetary yielded by Yonghui Superstores warehouse center at the end of time period t, and D represents the discount rate for the time value of funds (Banks *et al.*, 2007; Sarac *et al.*, 2010).

Through the ROI analysis assess the Yonghui Superstores warehouse center construction whether necessary. If the ROI is high, it means that the project has strong profitability and is suitable for investment construction. If the ROI is low or negative, the project needs to be re-assessed to consider the necessity of investment.

Through analysis of ROI, the risk of investment that construction of Yonghui warehouse center will be reduced and provided some references for the investment and construction of projects in real situations.

6.5 Discussion of the significance of warehouse center construction

Yonghui warehouse center model has comprehensively designed from the aspects of inbound, operations management, distribution and outbound based on RFID and sensor technology, which simplify the business process and improve work efficiency. It can effectively solve the problems existing in warehouse management of Yonghui Superstores. Construction of a warehouse center has important management significance and economic significance for the development of the enterprise.

6.5.1 Significance of management and operation

Construction of a warehouse center based on RFID and sensor technology is technically feasible and has strong practicability, compared with the traditional warehouse model. Through implementation and construction of the warehouse center, improvements will be made as follows:

- *Change in the traditional mode of warehouse management*: The traditional mode of warehouse management mainly relies on manual operation. Through implementation and construction of the warehouse center, the loading, unloading, stocktaking, scheduling, distribution and other business processes to achieve automation and intelligent. To some extent, it has also reduced the investment of manpower and material resources for an enterprise. At the same time, it not only improves work efficiency but also changes the situation of low efficiency and higher fault rate relying on manual operation in the past.
- *Stocktaking more convenient with application of RFID technology*: The stocktaking of goods could be performed using fixed RFID reader and handheld RFID reader. It is easily and efficiently to conduct single, multiple and full stocktaking for one or more goods through RFID reader automatic read the tag pasted on the packaging of goods to get the information, which improves the situation of time-consuming, laborious and high error rate in the past relying on manual. The warehouse management staff could master the situation of inventory goods in real time, which has great significance to optimize the inventory and store position rationally and then realizes the rational usage of resources.
- *Real-time control of inventory information*: Storage information could be updated in real-time, which improves the real-time and dynamic nature of inventory data and realizes the visual management of inventory goods. In addition, it makes the logistics and information flow of enterprises more accurate, which is more conducive to the production and sales of enterprises.

- *Real-time monitoring of the storage environment*: The temperature, humidity, smoke and other sensors make the storage environment more stable and safe and avoid mildew and deterioration of the goods caused by excessive or too low temperature or humidity in the past, which reduces the loss of the goods. Pressure sensors make the weighing business more accurate to avoid the inefficiencies and high error rates caused by manual operations. The photoelectric sensors could achieve the position of stacker, goods and storage position monitoring in real time; the laser-ranging-sensor could monitor the clearance of goods; the visual positioning sensors could realize precise positioning of goods, control of AGV trolley in real time, which ensure the rational usage of resources.
- *More accurate procurement and delivery plan*: Yonghui's every store does not need to store as many goods as before. They only need to store a small amount of daily sales products, then the inventory pressure is effectively reduced and achieving zero inventory management. Each store will send the demand for goods to the warehouse center, the storage and deployment will be handled by the warehouse center. The warehouse center will formulate a unified procurement plan based on the sales and inventory of the goods.
- *Improved efficiency of communication between supplier and supermarket*: The situation of suppliers needs to face many stores' orders has changed and only need to directly connect with the Yonghui warehouse center. Data of goods are sharing, goods' information of order processing, storage, sales, wastage, financial settlement can inquiry in real-time.

6.5.2 Significance of economic

Through implementation and construction of the warehouse center, economic benefits will be made as follows:

- *Renting of RFID tags and read-write devices*: It eliminates the large purchasing cost; moreover, it could be repeatedly erased and used to reduce the actual use costs.
- *One-time investment, no need to re-invest*: Sensors and other hardware devices are a one-time investment, which not needs to re-invest and has a long service life and a long ROI.
- *Reduced cost of goods distribution*: Changing the situation in which suppliers need to distribute goods to each store separately, the suppliers only need to deliver the goods to the warehouse center according to the order, and all product distribution are arranged by the warehouse center. Therefore, there are lower distribution costs, more efficient and convenient goods circulation.
- *Customized development to reduce costs*: Warehouse center could be developed selectively according to the scale of the location. The hardware and software system could customize development of functional modules according to the requirements and pay for the development and maintenance costs according to the system module, thus avoiding the waste of resources brought about by the introduction of the whole system in the past.
- *Acceleration of capital turnover*: The goods inventory information could be mastered in real time and the goods inventory could be adjusted according to actual needs, which avoiding the shortage of products with large demand, the unsalable and loss of products with a small demand, resulting in capital occupation and poor circulation.
- *Enhanced brand value of enterprise*: Automation and intellectualization of warehousing business reduce the investment of human resources, standardize the operation of business processes, improve work efficiency and create better economic benefits and brand value for enterprises.

Warehouse center based on RFID and sensor technology could improve the warehouse management level of Yonghui Superstores and change the traditional warehouse management mode. To some extent, it reduces warehouse management costs and inventory losses for the enterprise, improves inventory turnover and saves time efficiently. Also to a certain extent, it improves the enterprise flexibility to the market, without doubt, this will be of great significance to improve business efficiency and enhance the brand image and competitiveness.

7. Conclusion

In this study, we mainly carried out the following works:

- We analyzed the present situation and existing problems of warehouse management and then put forward constructing a warehouse center to meet large-scale warehousing needs.
- We detailed and analyzed the problems that need to be considered in the construction of a warehouse center, including technologies, location, hardware and software, operation and management and ROI.
- We analyzed the current situation and problems of warehouse management in Yonghui Superstores and made clear the problems needed to be solved on the basis of the second work.
- We put forward the warehouse center model of Yonghui Superstores and designed the model based on receiving, inbound, operations management, distribution and outbound based on RFID and sensor technology.
- We described and analyzed the application of RFID and sensor technology in warehouse management business in detail.
- In view of the problems that needed to be solved in the construction of Yonghui Superstores warehouse center in the third work, we discussed it from the point of view of five aspects – location and distribution, software and hardware, benefits, ROI and significance of warehouse center construction – which provided references for the construction of Yonghui Superstores warehouse center in the real world.

Warehouse center based on RFID and sensor technology could improve the warehouse management level of Yonghui Superstores and reduce the cost of warehouse management, it has great significance to improve business efficiency and enhance the brand image and competitiveness. Our research work provides some references for the construction decision of Yonghui Superstores warehouse center.

However, there are some limitations in this study:

- The model of the warehouse center lacks corresponding simulation experiments.
- It is difficult to estimate the detailed investment and income of Yonghui Superstores warehouse center because of the lack of specific and effective data.

The shortcomings of the current research are also the focus of future research directions. We need to solve these shortcomings to achieve deeper research in warehouse management.

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