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A RFID-based Intelligent Warehouse Management System Design and Implementation

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***Abstract*—A RFID-based intelligent warehouse management system (RFID-IWMS) is proposed in this paper. The RFID-IWMS helps to achieve better inventory control, as well as to improve operation efficiency. To this purpose, it automates the manual warehouse operation and provides tight integration with current warehouse management system (WMS). In this system, RFID tags are embedded in the pallets and shelves. In addition, forklifts are equipped with intelligent terminal as well as RFID reader and antenna to support automatic data scanning and storage location checking. Moreover, a middle layer software component is design to facilitate the communication between WMS, portable terminals and forklift terminals through wireless LAN. Besides, it also supports additional powerful functions such as forklift scheduling, picking sequence management and 3D shelves monitoring. The design of the system makes full use of the existing equipments and facilities and has the feature of low cost and quick in-action. Through real working practice in the distribution center of Bailian Group, the system is proved to be feasible in the aspects of both technology and cost.**

Keywords: RFID; intelligent warehouse; forklift schedualing and tracking; warehouse management system(WMS)

I. INTRODUCTION

According to the Retail Industry Forecast Report released by the State Information Center, in 2005 to 2010, China's retail industry has enjoyed a steady growth at the rate of 8% - 10%. In 2020, total retail sales of consumer goods will exceed 20 trillion Yuan. Moreover, the progressively liberalization of the retail industry to foreign investment intensifies the competition in the retail industry. As a result, the competition has transferred from a single company to the whole supply chain and the efficiency play a vital role.

Roughly, the circulation of retail commodity is like suppliers - distributor warehouses or distribution center - retail stores. Among this, a warehouse is an essential link between the upstream and downstream entities, so its performance is critical. In the contract, most of the warehouse operations are either labor or capital-intensive. Normally, warehouse management system (WMS) was widely adopted for collecting data of warehouse in order to optimize the operation and management. However, the current WMSs have an obvious weakness in the terminal data gathering because they contain no feature of real-time and automatic data retrieval. Instead, WMSs rely heavily on warehouse staff to input operational information manually or through bar-code system. Hence, incorrect information is inevitable because human error is account for around 80% of incorrect information. The efficiency of the warehouse is unsatisfied. As a result, these practical problems and hot issue are increasingly becoming the bottleneck of the business and reduce the advantage of economies of scale. Moreover, it is difficult to formulate reliable material handling solutions to handle different orders either by warehouse staff or through WMSs. Therefore, it is essential to propose an intelligent system with real-time and automatic data synchronization features to combine the logistic operation and the WMSs together.

In fact, various technologies have been adopted to improve the performance of the warehouse. From the aspect of business, whatever technology ultimately become popular in warehouse management, there is no question that higher efficiency and lower cost are urgently needed. Among all the technologies, Radio Frequency Identification(RFID) is thought to be the most promising one. Because RFID technolgy meets the two main demands (efficiency and cost-effective) with the advantage of mini-size, strong penetrability, wireless readability, shape diversity, reusability and comparatively low-cost. Compared with high investment and operation cost of the automated warehouse, the application of RFID technology make full use of the existing equipments and facilities and has the feature of low cost and quick in-action. RFID is not the only technology that is pushing the evolution of warehouse management systems. Optimization tools that maximize warehousing operations are another technological addition to WMS. These are tools that are specifically designed to take a look at a warehouse or distribution business and discover which operations are most effective and least effective.

In this paper, the design of the RFID-based intelligent warehouse management system (RFID-IWMS) is described. Overall, specific to the current problems, our design has adopted the intelligent RFID approach in the labor-intensive operations and integrate it with the current WMS. RFID-IWMS can achieve the effective management of warehouse space, automatic recognition and tracking of goods in overall process and the real-time data synchronization between warehouse operation and WMS. As a result, the efficiency of warehouse operation and management is increased remarkably and human errors are have been reduced by 90% percentage.

To this purpose, the innovations and improvements come in three main areas. Firstly, in our design, considering

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practicality and operability, the tags are placed in the pallet as well as the entry of every rack of the shelf. Racks are the minimum storage units of distribution centre. The RFID-pasted racks have the ability of active response by means of recognizing the entering and leaving of the goods automatically and offering a function of storage location checking and error-warning. In addition, the tags of pallets and racks are combined together to increase the efficiency of stock-taking. Furthermore, a set of RFID reading performance test is performed. Based on the results, the most suitable location for the installation of the RFID devices are determined. Secondly, the mast of forklift was also modified to accommodate the RFID reader and antenna. The reader in the forklift is connected to a dedicated vehicle-mounted terminal which is able to communicate with WMS through the wireless network. In this way, the intelligent terminal is capable of scanning the data of the wanted goods efficiently, finding the right storage location and providing error-warning when miss-allocation happened. While completion, the terminal will perform real-time data synchronization with WMS. Thirdly, a RFID middleware is proposed to facilitate the communication and process of mass RFID data among RFID devices, portable and forklift terminals as well as WMS system. It also supports additional powerful functions such as locating and scheduling of forklifts, remote and centralized management of multi-warehouse, three-dimensional monitoring of goods shelves. On that basis, an order-picking model is constructed by mathematic algorithms to generate the shortest pickup sequence for the appropriate forklifts. In doing this, the objectives of maximizing the productivity of warehouse and minimizing the operation costs in a warehouse are achieved.

The paper is divided into five sections. Section 1 is the introduction. Section 2 presents related literature reviews on current RFID application in warehouse management. Section 3 explains the design methodology of RFID-IWMS. While in Section 4, result and discussion are presented to illustrate the improvement in productivity of warehouse management with the help of RFID technology. Finally, a conclusion about the application of RFID technology is drawn and suggestions for future work are made.

II. Literature Review

In the retail industry, a warehouse is a critical component for linking the upstream and downstream. Today the intensified competition calls higher requirement of the warehouse management system. Currently, warehouse management system (WMS) has been widely adopted for handling warehouse resources and monitoring warehouse operations. However, currently WMSs rely heavily on the traditional bar-code system to get the information from boxes, pallets and racks. Disadvantages of bar-code-based approaches include that drivers have to leave their truck and scan bar-code labels manually. Bar-code labels may become unreadable because of soiling or damage. Furthermore, it is not possible to edit data on the bar-code labels [1]. In addition, the data collection of bar-code system is lacking in real-time information sharing ability. Therefore, WMSs are incapable of capturing real-time information or visualizing the actual inventory status of warehouse [2].

In recent years, RFID technology has become popular in the business application, especially in the logistic and supply chain management. This technology has been widely adopted in different business operations to identify, locate and track people, animals or assets [3]. By using the RFID technology, the requirement of automated data capture can be achieved. The remarkable improvement in the productivity and efficiency overwhelms the relatively high cost, compared to the traditional bar-code technology. As a result, enterprises are willing to using such technology in the working practice [4]. However, the importance of integration between the RFID data capture and background systems, such as WMSs, is still neglected. This highlights the need to develop middleware integrated with RFID technology to support the intelligent management of warehouses.

The systems mentioned in [2] and [3] are an idealization which are too complex to be implemented. If it is possible to be applied, it will be quite expensive and time demanding. But in the RFID-IWMS, it focuses on the key shortcomings of current warehouse system. It is practical, simple and comparatively much cheaper. Different from the system mentioned in [4], our system provides a close integration with the background WMS. This dramatically increases the level of management of the warehouse. For example, getting KPI (Key Performance Index) data is easier. Compared with the existing RFID warehouse management, for example, Wal-Mart, our system can make full use of current facilities, so it has the feature of quick in-action and cheap. In China, most of the companies in logistic industry are medium-sized and small enterprises, so these features are very attractive for them.

III. System Design and Architecture

A. System and Network Architecture

The components of the system consist of: RFID hardware, middleware software, wireless local area network (WLAN), intelligent vehicle-mounted terminals and RFID data flow hub processor as well. The RFID hardware includes: RFID tags, antennas, fixed and portable readers. The middle layer software has three parts which are storage and distribution management system, 3D shelf monitoring and the interface with WMS and ERP (Enterprise Resource Planning). The storage and distribution management system plays an important role in the background control. It has three parts which are Digital Shelf Management System, Forklift Locating System and Forklift Scheduling system.

The RFID data flow hub processor is mainly used to classify, filter, and pre-process RFID data flow. It provides a uniform and centralized data source to the other systems. Moreover, in the future, the hub processor can be extended to support local EPCIS (Electronic Product Code Information Services) of the Internet of Things. The design of the system follows the ISO standard of the RFID industry which has the ability to support the future Internet of Things.

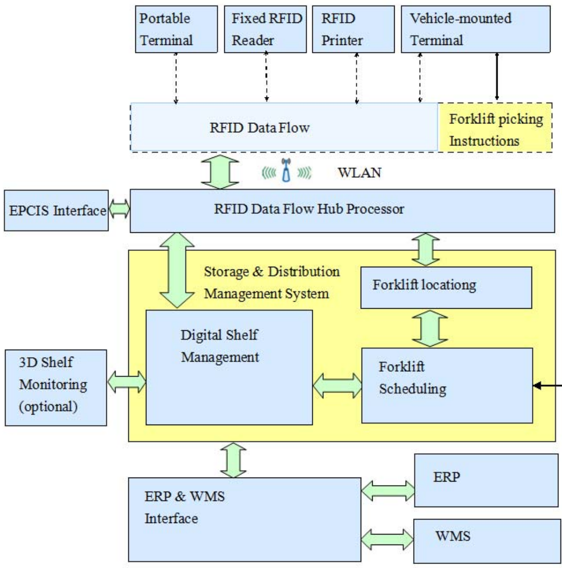

Figure 1. System architecture of RFID-IWMS.

B. Portable RFID terminal

The portable RFID terminal adopted in RFID-IWMS has all the function of common RF handheld terminal. In addition, it also supports the reading and writing of RFID tag. In this design, the goods information is bounded to RFID tag in the pallet. Through reading and writing the RFID tag, the warehouse staff can avoid the manual record. Furthermore, the information could be sent to the storage and distribution management system synchronously while reading and writing. Fig. 2 shows the portable RFID terminal and the software interface.

Figure 2. Illustration of portable RFID terminal.

C. Digital pallet and shelf

As mentioned above, considering practicality and operability, tags are placed in the pallet level as well as the entry of every rack of the shelf, see Fig. 3. The pallet embedded with an RFID tag is called a digital pallet. The tag records all the related information of the products on it, such as amount, name, production date, etc. The status of a digital pallet may be full, half or empty. A shelf has a certain number of racks, a rack is a minimum storage space identified by a ID number, namely, rack ID (RID), which is bound to the tag ID (TID) of the digital pallet placed on it. Similar to a digital pallet, the status of a rack could be full or empty.

In the real application environment, large capacity and durable RFID tags are employed in the pallets and shelves. Through binding the tags of the rack and the digital pallet placed on it, the efficiency of stock-taking enjoys a great increase.

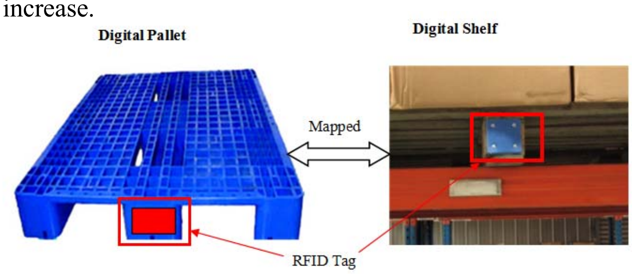

Figure 3. Illustration of digital pallet and digital shelf

D. RFID-enhanced Forklift

Forklift is one of the major tools in warehouse used for tasks including goods handling, grounding, and undercarriage. Its working performance has direct impact on the overall operational efficiency of a warehouse. Although supporting devices like bar-code readers are widely used, the driver is inevitably required to leave their forklifts, scan bar-code labels and input data manually for further processing by WMS system. Without the real-time integration, the data can also become inconsistent, because information and goods are physically separated. With forklift trucks equipped with RFID and WLAN systems, these failures can be avoided.

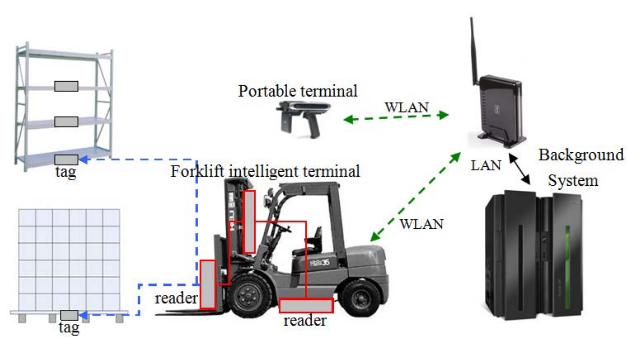

Figure 4. Illustration of RFID-enhanced forklift.

In RFID-IWMS, an intelligent terminal is developed to combine the RFID devices, forklifts and middle layer control system (Storage and Distribution Management System) together. Firstly, forklifts are modified and equipped with RFID identification units and data preprocessing units. For each forklift, two antennas and readers are installed as RFID identification units. One antenna is set up on the front of the fork head, perpendicular to the floor, and is used for detecting the tags on pallets and shelves. The other is installed under the forklift, parallel to the floor, and is responsible for detecting the RFID tags on the warehouse floor and on the dispatch area. The vehicle-mounted computer in each forklift, serving as the data preprocessing unit, exchanges data with background information system via the WLAN Fig. 4 shows the system structure.

Forklift drivers receive instructions and information about origin and destination of the goods to be transported from the Storage and Distribution Management System. The integrated RFID reader accelerates the reading and transmission of goods information and it will also allow forklift drivers to focus on driving without any other intervention. When reading is needed, the terminal turns the reader on. Different algorithms are adopted to avoid the multiple reading. For example, if more than one pallet tag is read, antenna power will be reduced to a certain value until one tag is read.

The Forklift Scheduling System receives orders from WMS system and stores them in a queue. The queue is managed by a forklift tasking module. Orders are sent to the appropriate forklift ensure the shortest order-picking path. An RFID tag with a unique ID is fixed on each pallet. When a forklift moves the pallet, the antenna on the fork head will detect the pallet's tag. In this way, the system can access the cargo information from the background information database immediately. It's an efficient way to manage a great number of pallets in warehouse. When the rack location is wrong, the forklift terminal will display a "wrong rack" warning, shown as Fig. 5 below.

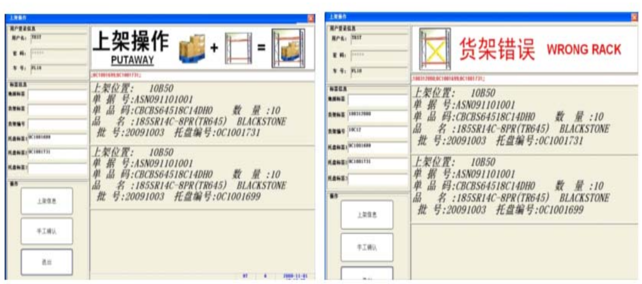

Figure 5. Screen shot of correct and wrong storage operation

As soon as the operation is completed, the Storage and Distribution Management System will receive message from the forklift intelligent terminal and the state of the goods will be updated immediately. This feature is used to join the flow of goods and the flow of information. The overall procedure is showed as Fig. 6 below.

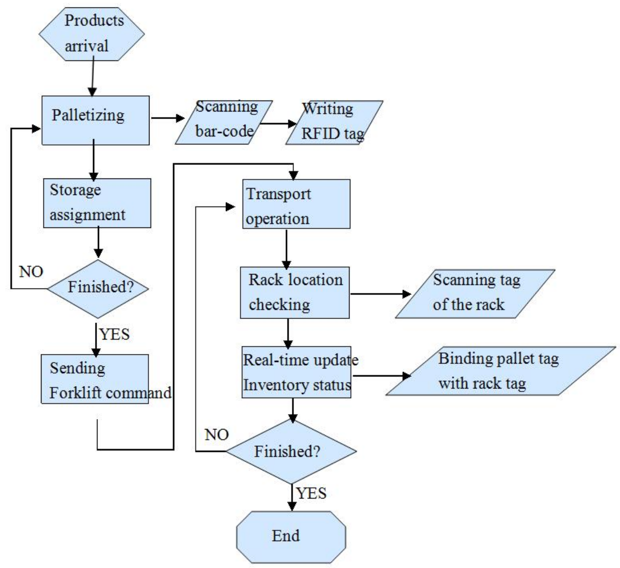

Figure 6. Flow chart of storage procedure

E. Coding scheme

EPC CLASS-1 GEN2 standard passive tags are adopted in this project. The tag has storage capacity of 96-bits and is defined by EPCglobal tag data standards version 1.3. The first 8-bits are the Header, set to the fixed value 0x35. The following 28-bits is the General Manager Number, allocated by EPCglobal to identify a company, manager, or organization, and the test code 0x0024ABD, provided by VeriSign, is temporarily employed as the General Manager Number. The next 24-bits are Object Class, used by an EPC managing entity to identify class or "type" of thing. Currently, three objects need to be differentiated in a system, namely Floor ID (0x000065), Rack ID (0x000066), and Pallet ID (0x000067). The last 36-bits are Serial Number, which is unique within each object class. The detailed definition can be seen from table 1 below.

TABLE I. THE DETAILED DEFINITION OF CODING SCHEME

<table>
<tr><th>Tag Type</th><th>Floor Tag</th><th>Pallet Tag</th><th colspan="2">Rack Tag</th></tr>
<tr><td>1 ~ 8 bits</td><td colspan="4">Header(0x35)</td></tr>
<tr><td>9 ~ 36 bits</td><td colspan="4">GeneralManager Number(0x0024ABD)</td></tr>
<tr><td>37 ~ 60 bits</td><td>Floor ID (0x000065)</td><td>Pallet ID (0x000067)</td><td colspan="2">Rack ID (0x000066)</td></tr>
<tr><td>61 ~ 68 bits</td><td colspan="4">Distribution Center Code</td></tr>
<tr><td>69 ~ 76 bits</td><td>Warehouse Number</td><td>Pallet Model</td><td colspan="2">Passage Number</td></tr>
<tr><td rowspan="3">77 ~ 96 bits</td><td rowspan="3">Floor Location ID</td><td rowspan="3">Pallet Number</td><td>77~88bits</td><td>ShelfColu mn Number</td></tr>
<tr><td>89~93bits</td><td>ShelfLevel Number</td></tr>
<tr><td>94~96bits</td><td>Rack Grid Number</td></tr>
</table>

F. RFID & WMS Integration

All management modules mentioned above must be integrated with the correspondent data and functions of the original WMS so as to maximize the efficiency of the RFID system. Since the original WMS has already included pallet and rack management modules, the software development shall leverage these existed modules and be focused on RFID control system. Besides, in the original WMS system, all pallets are managed by provisional VPID (Virtual Pallet ID), which is unable to identify a particular pallet. In order to solve this problem, a mapping table of the relation between the VPID of the original WMS and the PID (Pallet ID) of each pallet tag shall be introduced to the new system. Besides, the face that the RID (Rack ID) of each rack tag is consistent with that of the original WMS enables the new system to inherit the rack management module from the original WMS directly.

As mentioned, the system can get the position coordinates of a forklift according to the information of floor tags via the antenna under the forklift. However, considering that metals have shielding effect over RF signals, the installation position and angle of the antenna will impact its read range, and a relatively wide read range is required for avoiding missing crucial data. Therefore in actual operation, repeated field testing had been conducted to identify the best solution.

G. Forklift location tracking and task scheduling

Meanwhile, for the sake of locating forklifts, the whole warehouse passage area is divided into 1m×1m grids, with an RFID tag placed on each intersection of grid lines. And the coding information of these tags is associated with the actual position(x, y) in the warehouse. With the help of the antenna set at the bottom of each forklift, the real time location information of a specific forklift can be acquired from the tags nearby, so as to pinpoint the exact position coordinates. Besides, with the update of position coordinates in real time, the tracing and optimizing of forklift routes can be realized. Also it enables the system to send out timely warning upon detecting forklift driver's mistakes. Fig. 7 shows forklift locating scheme.

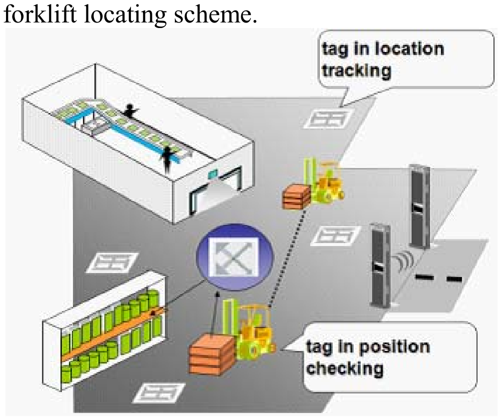

Figure 7. Illustration of forklift locating scheme

Similar with pallet, every rack in dispatch area and storage area is marked by a RFID tag. Consequently, when a forklift drives into the dispatch area or when the fork head of a forklift moves between the levels of a shelf, the antenna on the fork head can detect the tag on the rack and obtain the cargo information automatically. Thereby, a three-dimensional rack management in both dispatch and storage area is achieved.

On the premise of having achieved locating and tracking forklifts, route scheduling and verification can be realized. According to the construction layout and shelves placement of a warehouse, an algorithm is programmed to identify the shortest route for each action, by collecting the data of a sequence of coordinates which constitute the shortest route from the forklift's present location to the operation spot.

Besides, the system will also compare the real-time route with the shortest path provided by the algorithm. Therefore, in the case of any deviation, the system will send the forklift driver a warming, so as to ensure the working efficiency while reducing human errors. The specific system interface is shown in Fig. 8 below.

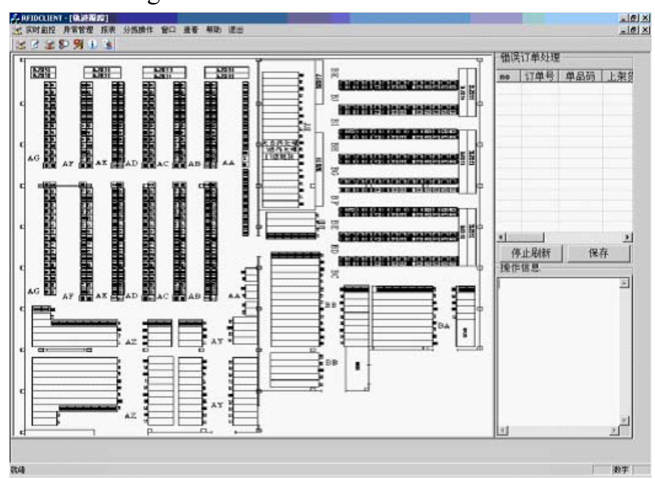

Figure 8. The screen shot of location tracking

The algorithm is shown as follows:
$S_s(x_s, y_s)$, starting point of the route sequence.
$S_e(x_e, y_e)$, end point of the route sequence.
F_s, the selected forklift which is nearest to the operation spot.
ay_i, y-axis coordinate of an aisle i which is parallel to the y-axis.

- Step 1: Determine the starting point and the end point of pick-up sequence. With the locations of the forklift $F_i(x_i, y_i)$ and the operation spot $O_t(x_t, y_t)$ identified by the system, the starting point of the pick-up sequence $S_s(x_s, y_s)$ is set to the initial position of F_s, which is calculated according to the shortest distance between F_i and O_t(i.e. $min\sqrt{(x_i - x_t)^2 + (y_i - y_t)^2}$), while the end point of the pick-up sequence $S_e(x_e, y_e)$ is set to O_t.
- Step 2: Find the shortest path between S_s and S_e. In this step, the shortest path between S_s and S_e is formulated by different situations. The layout of the warehouse can be seen in Fig. 9, with shelves placed parallel to the y-axis. If $x_s = x_e$, the pick-up sequence is $S_s \rightarrow S_e$. The selected forklift F_s shall move from y_s to y_e along the path parallel to y-axis. If $x_s \neq x_e$, F_s shall first move from S_s until $x_s = x_e$. However, since a forklift can't move across a shelf, F_s shall move along the direction parallel to y-axis to an aisle perpendicular to the shelf.

For this purpose, two coordinates, namely ay_i and ay_{i+1} (where i and $i+1$ are two y-axis aisles next to the starting point and $ay_i < ay_{i+1}$) shall be calculated by the system. Then if $y_e \geq ay_i + (ay_{i+1} - y_s)$, two points (x_s, ay_{i+1}) and (x_e, ay_{i+1}) shall be inserted into the pick-up sequence, which shall be refined as $S_s \rightarrow (x_s, ay_{i+1}) \rightarrow (x_e, ay_{i+1}) \rightarrow S_e$. Otherwise if $y_e < ay_i + (ay_{i+1} - y_s)$, two points (x_s, ay_i) and (x_e, ay_i) shall be inserted into the pick-up sequence, which shall be refined as $S_s \rightarrow (x_s, ay_i) \rightarrow (x_e, ay_i) \rightarrow S_e$.

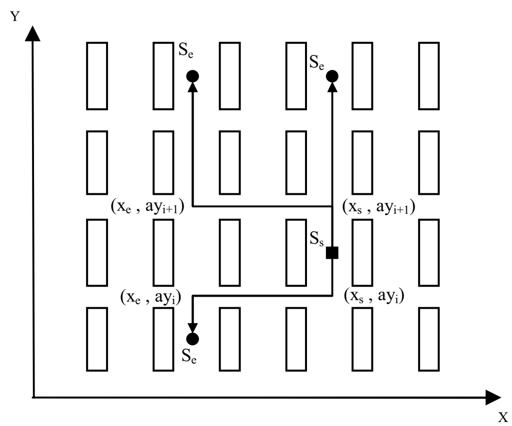

Figure 9. Example of path finding algorithm

In addition to the shortest path algorithm, an order-sequence model is also constructed by mathematic algorithms to generate the shortest pickup sequence for the appropriate forklifts. Besides, the system will also compare the real-time route with the shortest path provided by the algorithm. Therefore, in the case of any deviation, the system will send the forklift driver a warming, so as to ensure the working efficiency while reducing human errors.

IV. RESULTS AND DISCUSSION

The system described in this paper has been successfully implemented in the distribution center of Bailian Group. Bailian Group is one of the biggest retail companies in China. The distribution center of Bailian has two warehouses, 2,500 goods shelves and 3,500 pallets with the area of 6,000m^2. Up to now, RFID-IWMS has been running for two years and enjoys an average throughput of 100,000 boxes of goods every day. The technology has proved a stable and reliable approach.

In the traditional way, the bar-code based system is lack of the integration with the WMSs. As a result, it is hard to get KPI (Key Performance Index) data of warehouse operation. The application of RFID-IWMS also benefits the management of warehouse. It enjoys a remarkable achievement. According to the statistic data provided by the user of the RFID-IWMS, based on the existing criteria, the accuracy rate of receiving and shelf storage reach over 99.9%. And time is shorted by 71% compared to the traditional way (bar-code based system). The acceleration rate of speed in order-picking is 195%. In addition, the efficiency of stock-taking increased by 40% (average operation number per minute). Using RFID technology, the condition of the warehouse is more visible and transparent. As a result, the average out of stock is decreased. Table 2 shows the comparison of productivity with RFID technology and traditional way.

TABLE II. THE COMPARISON WITH RFID TECHNOLOGY AND TRADITION WAY

	Avg time of receiving (minutes per note)	**Avg time of receiving (minutes per pallet)**	**Avg Time of picking (minutes per pallet)**
Tradition technology	12.93	3.3	2.42
RFID	7.52	2	0.82
Efficiency improvement (%)	71%	65%	195%

From the aspect of Return on Investment Analysis, the investment of upgrading a warehouse with an area of 6000m^2 is 1,250,000 yuan. The Investment covers RFID hardware (e.g. digit-labels, antennas and readers), upgrading the forklifts, software development and integration, network infrastructure and human cost as well. The commercial benefit includes reduce of human labor, increase of utilization ratio and throughput of the warehouse. Compared with the current warehouse which has the same area without the RFID systems, the cost saving of RFID-IWMS is around 550,000 yuan per year. Through evaluation, it will take 2.3 years to recoup the investment. Correspondingly, the investment of 24,000m^2 is 2,700,000 yuan and the time is 1.2 years.

According to the preliminary statistics, the successful implementation of this system has a huge revolutionary impact on the business model and operation procedure of warehouse management. Consider the cost of designing, building and managing a warehouse of 6000m^2 with RFID intelligent system, the saving of management will be above 2,000,000 yuan. At the current scale of 10 warehouses, the annual saving of the distribution center will be over 20,000,000 yuan.

From the economic aspects, the economic benefit comes from the cost saving which is estimated up to 50,000,000 yuan within the future five years.

V. CONCLUSION AND FUTURE WORKS

In this paper, a RFID-enabled intelligent warehouse management system is proposed for improving the performance of the warehouse. By automating the manual operation, close integration with current WMS, supporting forklift task scheduling and innovative 3-dimensional shelf monitoring, the efficiency and accuracy of the warehouse is increased remarkably.

The capabilities of the system are demonstrated in the successful case of Bailian Group. The value of RFID-based intelligent warehouse comes from four aspects: (1) An improvement of service standard of the warehouse; (2) A reduction of the cost of warehouse operation; (3) An improvement in the accuracy of stock control; (4) An enhancement of inventory turnover and visibility. The application of RFID technology makes full use of the existing equipments and facilities and has the feature of low cost and quick in-action. The feasibility of the system in real working practice is proved by the successful real-world working practice.

Nevertheless, there is still room for future improvement. Three areas could be considered in future work for improving or extending the existing system. Firstly, in the proposed system, quite a lot of additional hardware and software components are needed to upgrade the current system. The system will become widely accepted only if users can exchange system components freely and the overall system is as simple as possible. So hardware interfaces and software interfaces should be well defined. Secondly, future RFID tags will have more user memory with a affordable price, as well as the possibility to pre-process data on the label. The application of RFID tags could be transferred from the current pallet level to packing box level or Item level. Thirdly, people are more conscious of the performances of the whole supply chain. In the future, RFID technology will popularize in different parties, such as production, distribution and retail. The flexibility of the current system should be improved to fit the whole supply chain network. The function of tracing and tracking key logistic data should also be considered especially in the food industry.

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