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ORIGINAL ARTICLE

Warehouse management with lean and RFID application: a case study

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Abstract This research presents the integration of lean production and radiofrequency identification (RFID) technology to improve the efficiency and effectiveness of warehouse management. More than ten million parts belonging to around 10,000 types in a distribution center were involved in this study. There are more than 10,000 storage and retrieval operations for hundreds of part types on a daily basis. Value stream mapping was used to draw current state mapping and future state mapping (with lean management and RFID) with material flow, information flow, and time flow. Preliminary experiments showed that the average reading rate of electric forklift and hydraulic cart are 99.3 and 99.1 % by fixed ultra-high frequency RFID readers with antenna installed at the receiving/shipping dock and passive tags mounted on box/pallet. The processing time of data transmitting to warehouse management system at receiving and shipping docks was reduced by 99 and 89 %, respectively. The total operation time from current stage to future stage with only lean can be saved by 79 %. With further integration of RFID to lean, the total operation time can be saved by 87 %. Moreover, performance on saving total operation time can be enhanced to 91 % with cross-docking. The benefit of using RFID in the warehouse management is realized and promoted.

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1 Introduction

The term "Lean Production" was first introduced in the book "The machine that changed the World" in 1990. Since then, many enterprises applied lean production to improve the productivity and competitiveness against the global competition and economy decline over the past decades. Derived from Toyota Production System, lean production enables production system and warehouse to integrate different tools to eliminate waste and create value, leading to the improvement in quality and the reduction of cost, lead time, inventory, and equipment downtime.

Radiofrequency identification (RFID) uses radio waves to exchange data between a reader and electronic tags attached on objects. The data on the tags can be read and written to facilitate the identification and tracking of the objects. Promoted by the U.S. Department of Defense and the world's largest retailer Wal-Mart, RFID has become an effective way to track the goods throughout the supply chain and one of the most promising new technologies influencing the operations in production, warehousing, and distribution sectors in recent years.

The distribution center under this study stores more than ten million parts belonging to about 10,000 types stored in ten warehouses. There are more than 10,000 storage and retrieval operations for hundreds of part types on a daily basis. Due to the increase in volume and variety of storage and retrieval demands, a warehouse management system (WMS) with better effectiveness and efficiency is required. Therefore, both lean management and RFID are adopted in the operation improvement. This study presents the application of lean management and RFID to improve the logistics efficiency in the distribution center.

Preliminary experiments showed that about 99.2 % average read rate was achieved with a fixed ultrahigh frequency (UHF) RFID reader and four antennas installed at a receiving/shipping dock and UHF passive tags mounted on cartons or pallets. The benefit of using RFID in the warehouse management is analyzed and promoted, e.g., decreasing data process time and labor cost.

The remaining of the paper is organized as follows. Section 2 presents a review of relevant literature. Section 3 analyses the warehouse operations without RFID. Section 4 discusses the redesign of a new process in the warehouse operations with lean and RFID. Section 5 evaluates the efficiency improvement, while the last section, Section 6, draws conclusions and proposes future research directions.

2 Literature review

RFID technology and its application in warehouse management are first reviewed. The literature related to lean production and value stream mapping are then investigated.

2.1 RFID application in warehouse management

RFID has become a critical technology for efficiency and effectiveness improvement in production, logistics, and supply chain management. RFID can identify, classify, and manage the flow of materials and information throughout the supply chain wirelessly without human intervention in order to avoid human error. Information of an object's current location, condition, and history can be stored and retrieved on a real-time basis, giving better visibility for decision making.

In its basic form, a typical RFID system has two major components, a reader (also called an interrogator) and tags (also called transponders). A tag consists of a microchip storing identification data with two typical types: (1) passive, without any power source and (2) active, with a power source. When a part with an RFID tag passes within the range of the reader, the information in tag is received by the reader. The reader then sends the information to a computer or backend application system to figure out the identity with the signals. Nearly all RFID systems operate on one of the following four frequency bands: low frequency (LF), high frequency (HF), UHF, and microwave [1]. This study uses passive tags and UHF readers.

Coyle et al. [2] pointed that the main warehousing operations consist of inventory storage, order product mixing, cross-docking, and customer service. The most important of them is inventory management, including storage/retrieval management and inventory control. The progress through RFID can be observed in different types of supply chains such as warehouse management, transportation management, production scheduling, order management, inventory management, and asset management systems [3]. In supply chain management, the product information that can be captured by the RFID system includes instance data (e.g., dates of manufacture and expiration), historical data (e.g., departure and arrival times), product group data (e.g., description, dimensions, and selling units), and commercial entity data (e.g., address and telephone number) [1].

Saygin [4] compared the inventory models that use RFID data on the basis of service level, cost, inventory and waste reduction, and decision-making complexity. A comparative analysis of the models was presented in a simulation environment, which also demonstrated the overall benefits and effectiveness of RFID technologies in providing low-cost manufacturing solutions, reduced inventory levels, and lower overall waste. Zhou et al. [5] developed an RFID-based remote monitoring system for enterprise internal production management. They concluded that the developed system can lead to enterprise inventory visibility, which, in turn, leads to reduced costs, improved customer service, increase of inventory accuracy, and decrease of lead time variability.

Ngai et al. [6] presented the findings of a case study on the development of an RFID prototype system that was integrated with mobile commerce in a container depot. Their proposed system architecture aimed to keep track of the locations of stackers and containers, provide greater visibility of the operations data, and improve the control processes. Wamba et al. [7] analyzed the impacts of integrating RFID technologies and electronic product code (EPC) network on mobile business to business e-commerce. They noted that RFID adoption forces supply chain actors to change their business processes through automated activities, a high-level information sharing, and a better synchronization between supply chain actors.

Wamba et al. [8] focused on RFID technologies in the picking and shipping process of one warehouse in a third-party logistics company. They showed that RFID technologies can support the redesign of business processes and improve data quality, real-time data collection, synchronization, and information sharing between actors. Huang et al. [9] applied RFID-based wireless manufacturing to manage job-shop work-in-process inventories. The results showed that RFID technology replaced the manual data capturing system by an automatic data collection system with real-time communication and interaction with various decision support systems. Nonvalue adding data collection activities are eliminated.

Poon et al. [10] formulated WMSs for handling warehouse resources and monitoring warehouse operations. The system adopted RFID technology to facilitate the collection and sharing of data in a warehouse. Wang et al. [11] illustrated that RFID-based digital WMS helping a warehouse in improving operation efficiency, utilization of warehouse capacity, and inventory accuracy as well as reducing manpower and loading time. Kumar and Chan [12] indicated that the application of RFID improved not only the utilization of warehouse recourses but also the work efficiency of the system. Wang et al. [13] presented that using RFID techniques can improve accuracy of the object tracking and lead time for preparing the robot's arm tooling that in turn effectively improve the manufacturing processes.

2.2 Lean production and value stream mapping in warehouse management

Lean production was originated from Toyota with the name "Toyota Production System (TPS)" or "just-in-time (JIT)", or "pull-system." On the basis of continuous improvement and the philosophy of doing more with less, lean production focuses on waste identification and elimination by allowing only the minimum amount of processing time, lot size, production resources, material, inventory, and cost.

In recent years, value stream mapping (VSM) has emerged as the preferred way to implement lean production by mapping a productive process and identifying waste for improvement. VSM is a simple but powerful tool using pencil and paper as well as a predefined set of standardized icons [14, 15]. VSM can be used to identify the waste and then eliminate the waste, so that the efficiency and productivity can be improved. In addition, Singh et al. [16] also indicated that vast literature on value stream mapping and its growing adaptation in developed and developing countries indicated the interest shown in this area by researchers and practitioners.

A particular product or product family needs to be first identified as the target for improvement. A current state map is then drawn that is a snapshot capturing how things are currently being done. This is accomplished while walking along the actual process and identifying the waste and weaknesses along the routine. Wastes are then analyzed and eliminated by rationalization and/or the application of RFID. Finally, a future state map is developed as a picture of how the system should be done after removing the waste and inefficiency. Future state map becomes the basis for making the necessary changes to the system.

Brintrup et al. [17] identified how RFID can serve as a vehicle to reduce TPS seven wastes of manufacturing and outlined a new value-driven opportunity analysis toolset to achieve leaner manufacturing. The toolset identified where RFID can bring value through automated data collection, the conformance of data dependencies, and improvements in visibility. Gopakumar et al. [18] used a discrete event simulation method to model the current system's functioning and to identify operational inefficiencies which were quantified through a detailed VSM exercise at a large food distribution center. This article presented that the simulation model can help visualize the benefits that would accrue through the use of lean principles to reduce the nonvalue added time in warehouse operations.

Gu et al. [19] presented a comprehensive review showing that market competition requires continuous improvement in the design and operation of production distribution networks, in turn requiring higher performance from warehouses. The adoption of new management philosophies such as lean production also brings new challenges for warehouse systems, including tighter inventory control, shorter response time, and a greater product variety. The widespread implementation of new information technologies, such as bar coding, RFID, and WMS, provides new opportunities to improve warehouse operations. Malta and Cunha [20] indicated the maximization of customer value by reducing waste in the operations is the objective of continuous improvement processes embedded in lean management principles. Their implementation promised significant improvements in productivity, quality, and delivery, which should result in substantial cost savings. Kilic et al. [21] indicated that material handling is one of the most important issues that should be taken into account for eliminating waste and reducing the cost. According to lean production concepts, they developed distribution models in plants to minimize the number of vehicles and the distance traversed.

3 Warehouse operations with neither lean nor RFID

3.1 Background

The distribution center under this study provides repair parts to more than 15 primary customers on a daily basis. It stores more than ten million parts belonging to about 10,000 types stored in ten warehouses. There are more than 10,000

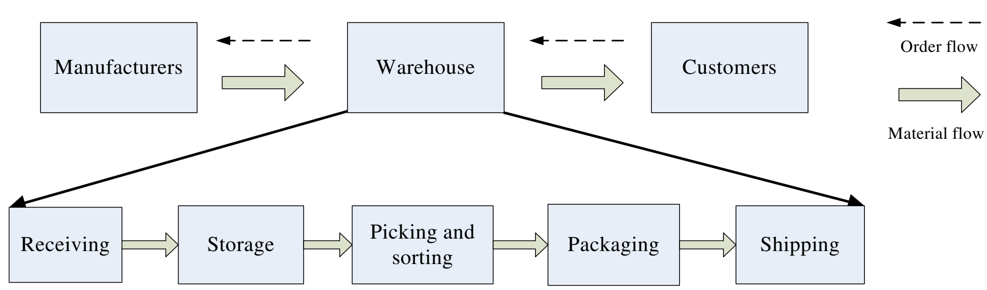
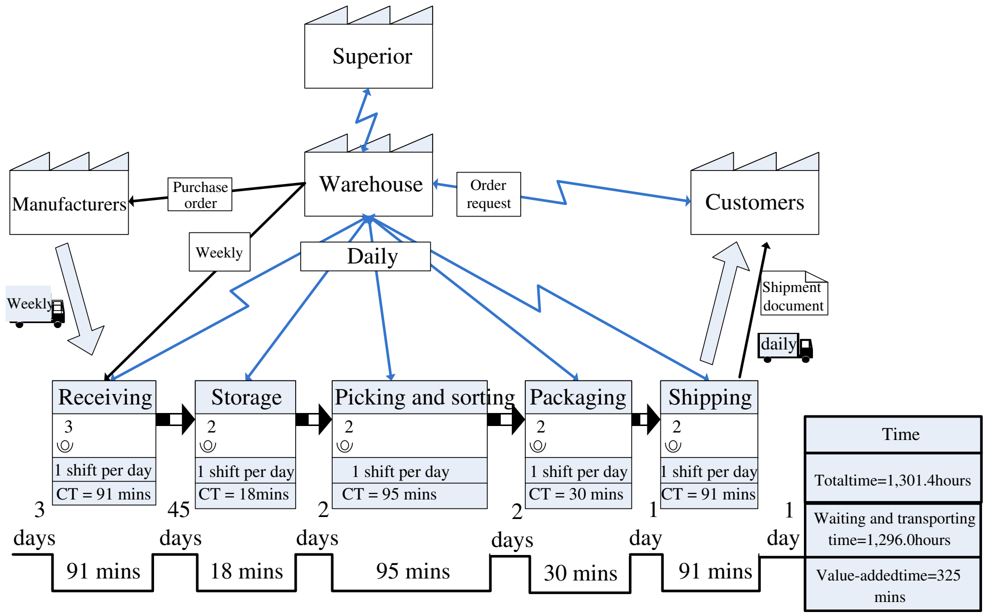


Fig. 1 Current operation process in the warehouse

Fig. 2 Current state map of the warehouse



storage and retrieval operations for hundreds of part types every day. Customer demands are supplied from the inventory in the warehouses. When the inventory level is less than the reorder point (taking into account the safety stock and the average and variation of demands), it triggers the warehouse to place purchasing orders (PO) to the manufacturers. In this sense, as shown in Fig. 1, the order (i.e., information) flows from customers backward to warehouse and then to manufacturers, and the material flows in the reverse direction from manufacturers forward to warehouse and then to customers. Each warehouse has the following operations: receiving, storage, picking and sorting, packaging, and shipping. The distribution center has a WMS using bar code to track the pallets, cases, and items.

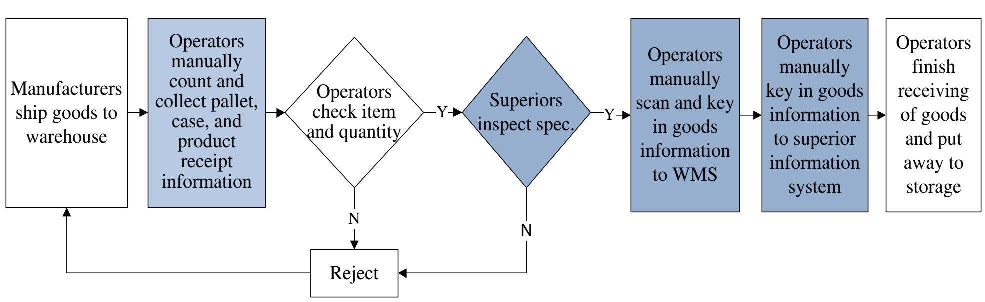
3.2 Current state map and processes (as-is) analysis

In order to identify the operation's problems and bottleneck in this distribution center, a value stream mapping technique is used to draw current state mapping with material, information, and time flow, as shown in Fig. 2. It takes a total time of 1,301.4 h (approximately 54.2 days) from goods receiving to goods shipping. The waiting time and transportation time in this process is about 1,296.0 h, but the value-added time is only about 5.4 h. In the current operation, both waiting time and transportation time are too long. Moreover, the storage, retrieval, and shipping operations are also inefficient. The parts are moved using forklifts and tracked using bar code technique in the warehouse. All goods are stored and retrieved in storage racks manually. Some of the operations in the process are either not necessary or with insufficient value adding. Typical TPS seven wastes are investigated in the warehouses: overproduction, waiting, transport, inventory, overprocessing, motion, and defects. Two major wastes were identified and needed to be reduced or eliminated: waiting and unnecessary motion. In summary, current warehouse operation is inefficient because of poor management and slow manual operations resulting in low throughput, long lead time, and high labor cost.

3.2.1 Analysis of current processes of receiving and storage

Manufacturers produce parts according to the PO from the warehouse and deliver goods to the warehouse for replenishment. There are three operators in receiving dock executing receiving operation. When purchased goods are delivered, operators conduct first phase check for the quantity and item identification numbers. The entire batch of

Fig. 3 Current receiving and storage process: as-is model



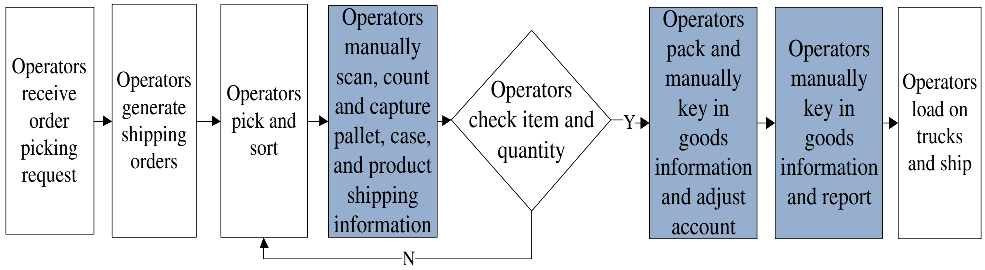


Fig. 4 Current picking, sorting, packaging, and shipping process: as-is model

goods are rejected, if either quantity or identification number does not meet the order requirement. If these goods are in compliance with order requirements, they would be moved to a temporary area and wait for the next phase technical inspection of specifications by superiors. Once passing the specification inspection, the goods are accepted and put away into storage area. Currently, warehouse operators need to sequentially scan the bar code on each part in order to confirm the type and quantity. They also need to key in the data into the local WMS and key in these data again to the superior's information system to update the inventory level. With the update from the superior's information system, the superiors need to personally come to the distribution center to confirm the product specification. The receiving and storage processes are shown in Fig. 3. The duration of working time of receiving and storage processes depend on the quality and quantity of the delivery order, the time for bar code scanning (that depends on the operator skill), the quantity of data to WMS, the transportation time of parts from receiving station to storage racks, the time to load the parts to racks, and mostly the time waiting for superiors to inspect and approve the specification.

According to Fig. 2, after the parts are shipped to the receiving dock, it takes an average of 45 days of waiting before the final acceptance. This includes about 26 days waiting for the specification inspection and about 19 days waiting for inspection report. The actual inspection time is less than 1 day. As supplier's delivery date has high variation, the superior inspectors are dispatched to come to the warehouse after the parts are actually in the warehouse. As these inspectors need to plan the schedule to travel from headquarter located in different cities to this warehouse for specification inspection, much time is wasted in the traveling and waiting. With a slow manual process, the waiting time becomes even longer when multiple order deliveries are happening in a short period of time. Furthermore, the inspection report requires the approval from the headquarter and the warehouse needs to send the report out and wait for the approval to accept the goods and store them in the warehouse. As many parts are waiting for the inspection reports, the warehouse's temporary storage area becomes very crowded and the operators need to temporarily move around the parts so that the inbound goods can be received and temporarily stored at the receiving station for the first phase inspection. There obviously exists space of improvement for the congested temporary storage space, the long waiting time, and inefficient operations and communication here.

Furthermore, goods entrance and departure points are in the same area in the warehouse, and the locations of goods storage are not fixed. The warehouse operators store goods based on the stock number and assign the storage location

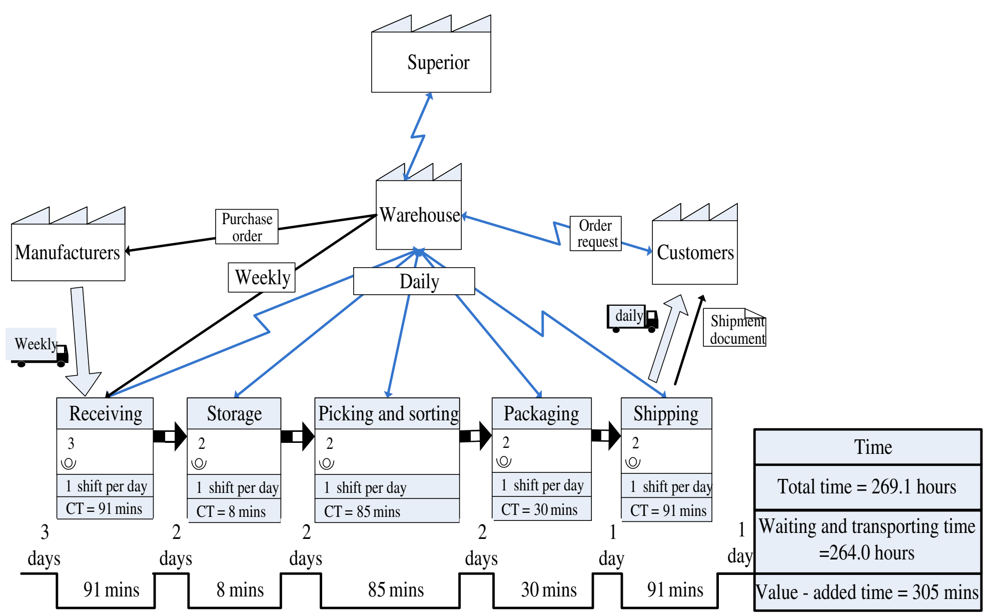


Fig. 5 Future value stream map with lean management

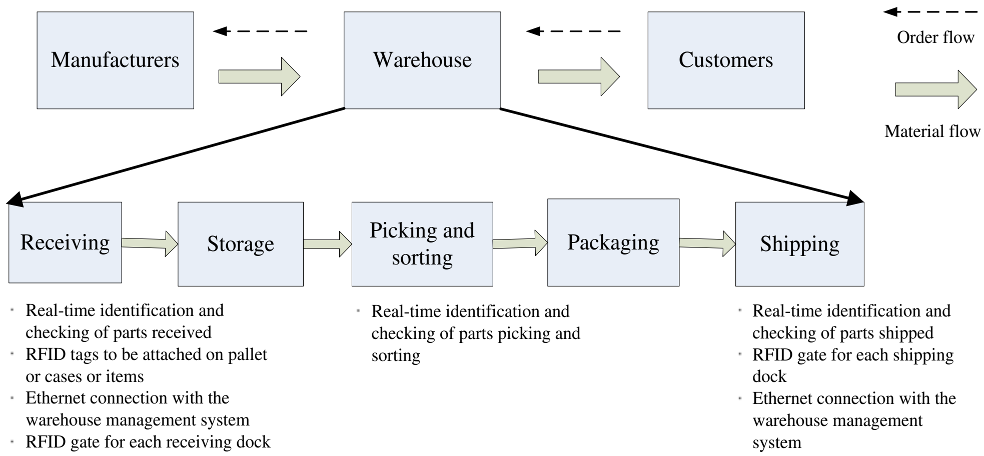


Fig. 6 The reengineered operation process in warehouse management

based on their memories and experiences. As the storage racks for high-demand, high-priority goods often run out of stock, their storage location need to be changed frequently. As a result, these goods might be stored at farther location to the warehouse entrance and departure area, and this increases the transportation distance and cost in storage and retrieval processes. The above problems lead to low efficiency in warehouse operations.

It takes an average of 91 and 18 min to receive one type of goods and to store a part to the storage rack, respectively, with the time measurement by stopwatch. The receiving process can be improved in the following three directions: first, the change of storage policy from random location to fixed location; second, the adoption of new technology to check quantity currently done by bar code scanning; and third, the improvement of data input and transfer. Figure 3 shows the bottleneck operation and key improvement steps in the blocks with dark background.

3.2.2 Analysis of current processes of picking, sorting, packaging, and shipping

The warehouse operation is labor intensive, especially in order picking. There are six operators in charge of order picking, sorting, packaging, and shipping processes. The operator picks up goods according to the pick list generated from the WMS by using discrete order picking method (i.e., one order-picker picks up one order and one goods at a time). The order pickers travel to the physical location of goods, verify the item and quantity, and retrieve the goods. Prior to consolidating bulk goods into containers, the operators must scan the bar code on goods and boxes one by one to confirm the quantity and then manually key in the data collected from bar code reader to WMS to update the inventory on hand.

After the completion of picking and sorting, the operators have to confirm again the completion of the order picking of all items and packaging in the containers and then move them to the temporary storage area waiting for trucks and shipment. When the containers are shipped out from the temporary storage area, the operators also need to key in the data again to the superior's information system to update the inventory level.

The location of storage racks for high-demand, high-priority goods, and its distance to the warehouse entrance and departure area are the factors affecting the efficiency of order picking. Shorter travel time and lower cost are needed with the better plan considering the material storage by popularity. It takes an average of 99.6 h to process one type of goods with picking, sorting, packaging, and shipping, with the time measurement by stopwatch. Figure 4 shows the bottleneck operation and key improvement steps in the blocks with dark background.

4 Warehouse operations with lean and RFID

4.1 Warehouse operations with lean management

In order to conduct reengineering to the process to a continuous flow with less congestion, waiting, and idleness, current waste on labor, time, and space need to be eliminated. First of all, the warehouse operator has to plan the receiving schedule

Fig. 7 RFID equipment used in this study

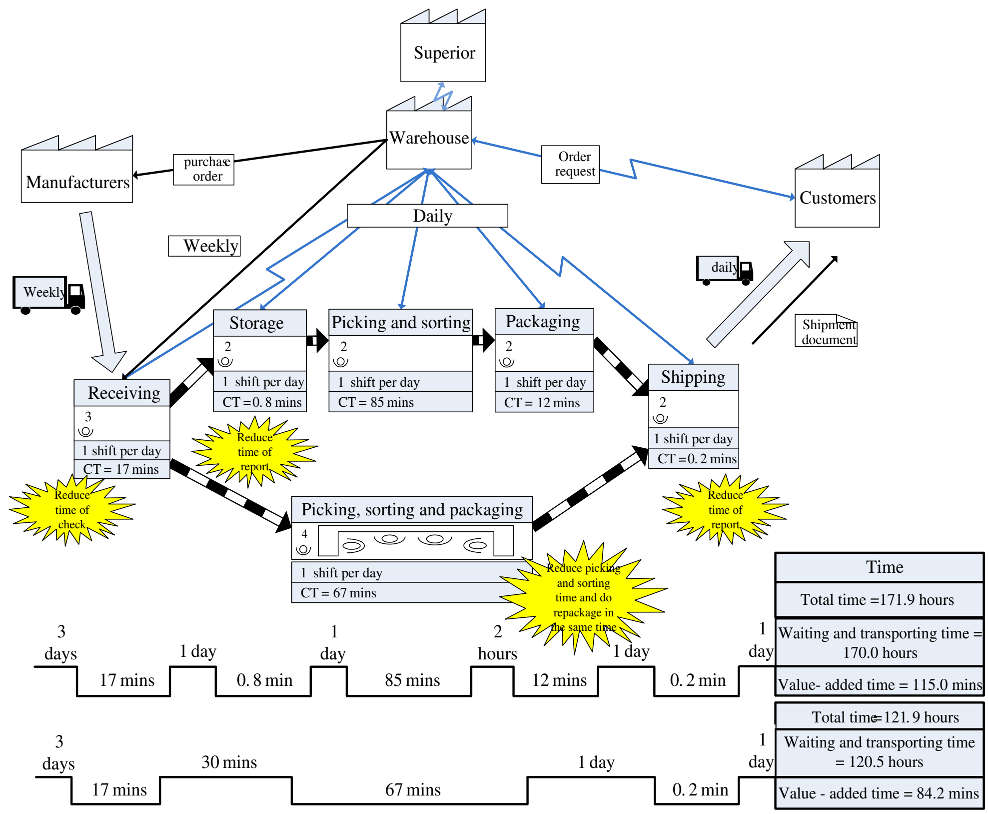


Fig. 8 The future value stream map with lean and RFID

and delivery time according to the agreement with suppliers. If the suppliers can deliver the goods in accordance, the superior's inspector can arrange the inspection schedule in advance and execute inspection on schedule. Furthermore, in order to balance the operator workload, operators' capacity requirement planning is conducted with certain capacity buffer reserved for the flexibility. Thus, when goods are shipped to the warehouse, receiving and inspection operations can be performed on schedule. Besides, the warehouse's superior can simplify the inspection document format and the approval procedure. After the inspector completes the inspection procedure and records the inspection result, the document can be approved and sent back to the warehouse on next day. Once the above operation processes are amended, the time for goods acceptance and storage to the warehouse can be shortened from 45 to 2 days.

Furthermore, the warehouse operators adjust the storage policy from random location to fixed location. Top 100 high-demand or high-priority goods are chosen, and their storage locations are positioned, fixed, and concentrated, so they are close to the entrance and departure area. The average storage and picking time can be slashed by 10 min after the adjustment. Figure 5 shows the future value stream map after adjusting the process. The time of operational process, storage, and picking is reduced from 54.2 to 11.2 days, from 18 to 8 min, and from 95 to 85 min, respectively.

4.2 Warehouse operations with lean management and RFID application

RFID is integrated with lean management in warehouse management in this case study. Process redesign is needed and "To-Be" scenario is developed. When implementing the RFID system, an RFID reader is installed at the receiving and shipping dock to automatically capture the identities and data of RFID tags attached to the cartons and pallets. In the current receiving, picking, and shipping process, there are procedures required to be simplified or modified to improve the efficiency.

Table 1 Total time comparison (in hours)

Item	With neither lean nor RFID	With lean	With lean and RFID	
			Regular	Cross-docking
Total time	1,301.4	269.1	171.9	121.9
Time saving		79 %	87 %	91 %

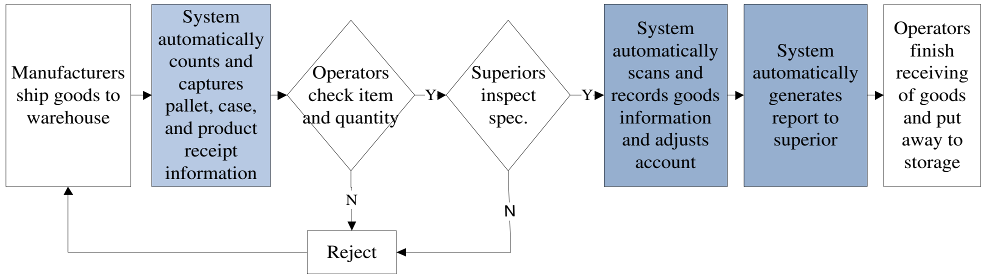


Fig. 9 To-be receiving and storage processes

The reengineering operation process at the warehouse with pallet/case level tagging is shown in Fig. 6. The pallets/cases are identified through RFID reusable tags. Each receiving and shipping dock is equipped by an RFID reader that acts as a portal. EPC codes of pallets/cases can be read and the information is transmitted to WMS through Ethernet network on a real-time basis. The data was manually collected by operators using traditional bar code, while it is automatically collected by the RFID system now.

4.2.1 Selection and installation of RFID equipment

Typical RFID frequencies available in markets include LF, HF, and UHF. In order to facilitate receiving and shipping process in the distribution center and supply chain, long-range RFID for a read range of up to several meters is required. UHF RFID equipment operating between 922 and 928 MHz ranges is adopted in this study, including fixed reader, handy reader, and passive tag, as shown in Fig. 7. Fixed RFID reader and antennas are installed at receiving and shipping door, where two antennas are installed at each side of the door, 3 m in distance facing each other.

Passive tags are mounted on pallets or cartons. A tag consists of a chip used to store the identifying bit sequence and an antenna used to communicate with the reader. The assembled chip and antenna of this passive tag sits on a 3×5 in. a piece of material with a peel-and-stick adhesive backing. Multiple parts are stored in a carton which is packed on a pallet. One tag is used for one part of each type.

The information stored inside the tag is coding based on 16 bits of ASCII and each category can store 0~9 numbers and alphabetical A~F for English RFID. The RFID tag used in this study has a storage capacity of 12 bytes sufficient for storing 24 ASCII codes. The information stored in tag is a combination of part identification number, type, quantity, and adjustment date.

4.2.2 Testing of RFID reading rate

One RFID reader can simultaneously read multiple tags mounted on cartons and pallets, and this is one of the major advantages of RFID application. However, this is also a major challenge in RFID application, as there is no guarantee of 100 % reading rate due to radiofrequency interference and metal shielding.

Having set up the RFID reader, the testing of reading rate of RFID reader is implemented. Different scenarios are planned and tested. For example, in one scenario, a total of 30 tags were tested for one pallet carrying four boxes with 2, 4, 5, and 19 different items, respectively. One tag is for one item and each item's tag is mounted outside the box with this item. As another example, an RFID tag is mounted on a pallet with multiple boxes of the same parts on it. Electric forklift and hydraulic cart are used to move the pallet for testing in the shipping process from suppliers to the warehouse and also from warehouse to customers. Fifteen tests are conducted for the reading rate. The average reading rate of electric forklift and hydraulic cart are 99.3 and 99.1 %, respectively. One hundred percent reading rate is achieved for tags mounted only on the pallets.

4.2.3 Simulation with RFID system in warehouse

This section presents the simulation with RFID system in receiving and shipping processes in warehouse.

Warehouse receiving process Items with the high-demand, high-priority, and large quantity are first selected as the main objects for RFID implementation test. The receiving steps with RFID are explained as follows:

- Suppliers ship the goods to the warehouse with pallets.
- The operator drives electric forklift to unload pallets and pass through the receiving dock. The tags on pallets

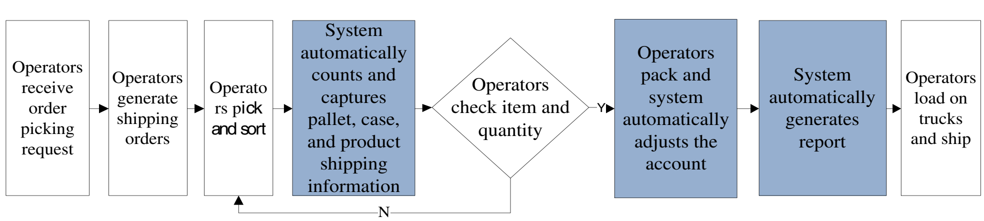


Fig. 10 To-be picking, sorting, packaging, and shipping processes

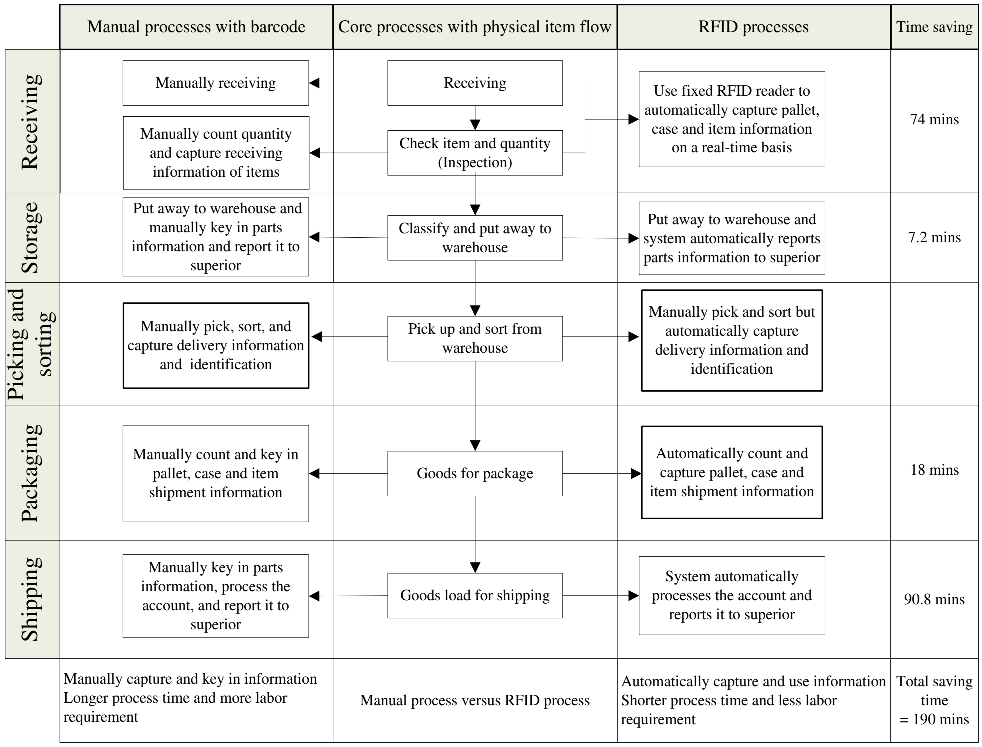


Fig. 11 The operation process analysis categorized by process type and data capturing method

and/or boxes would be read by the fixed RFID reader for recording part identification number, type, quantity, and the information is transmitted to WMS synchronously.

- After the fixed RFID reader finishes reading all pallet tags and verifying quantity, the accepted information would be transmitted to the WMS and also to superior automatically.

Through above steps, when the RFID technology is used in the receiving process, manual activities such as counting and data input are omitted.

Simulation test using RFID showed that the average process time of receiving check for each pallet and each item can be improved from 7.13 to 1.32 min (an improvement of 82 %) and from 1.26 to 0.23 s (an improvement of 82 %), respectively. Furthermore, the report preparation and uploading time in receiving process is measured. It took less than 1 s for the fixed RFID reader to read the data from the tag and transmit them to the WMS synchronously, resulting in an improvement of 99 %.

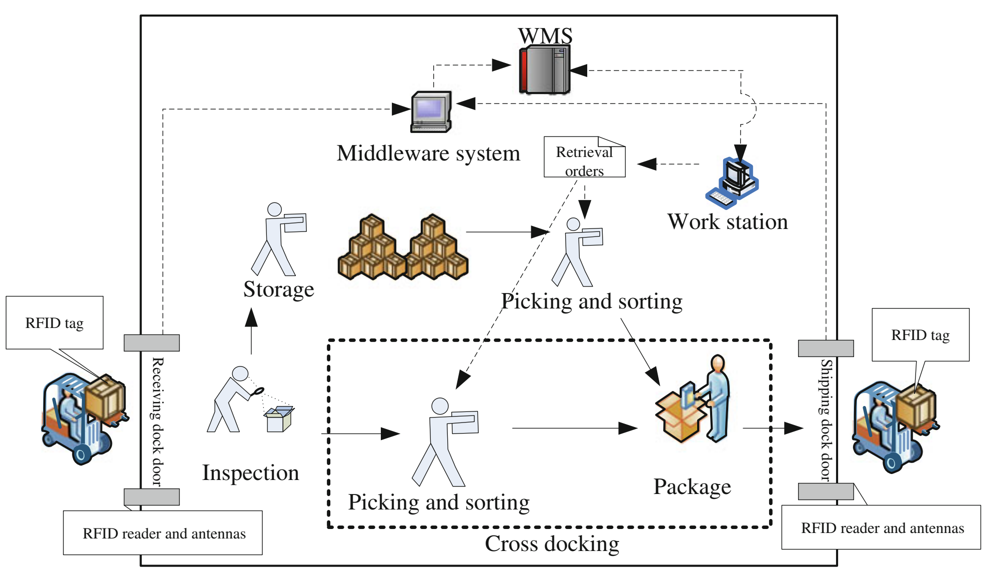


Fig. 12 Final warehouse configuration after applying RFID technology

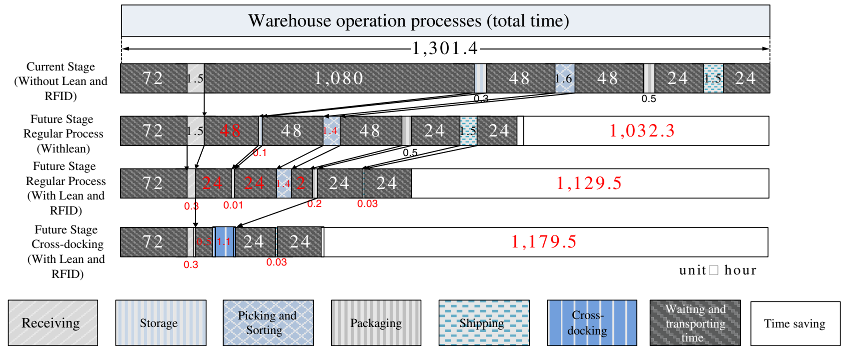


Fig. 13 The comparison of total warehouse operation time (in functions) of four scenarios, current stage (without lean and RFID), future stage with only lean, future stage with both lean and RFID, and future stage with lean, RFID, and cross-docking (in hours)

Warehouse shipping process The warehouse shipping process consists of the steps described as following:

- The operator uses forklift to load the boxes to pallets, seal the boxes on the pallet with plastic films and then store them at the shipping area. By passing through the fixed RFID reader, the information in the tags is read, compared, recorded, and finally transmitted to the WMS.
- Once tags' data are read by the fixed RFID reader, the information is transmitted to the WMS and the reporting procedure is completed simultaneously.
- One digit is used for confirming if the information of one tag is read. "0" is set for unread and "1" as read. This mechanism can avoid multiple reading in the shipping process. Double checking can be done by handy reader.

When RFID technology is applied to the shipping process, it changes the report key-in process from manual to automatic. It took less than 1 s for the fixed RFID reader to read the data from the tag on pallet or carton and transmit them to the WMS immediately, resulting in an improvement of 89 %.

4.2.4 *The future state (to-be) map*

Figure 8 shows the future state map with the integration of lean management and RFID technology in the new procedure. The total operation time was 269.1 h with only lean management that can be reduced to 171.9 with both lean management and RFID application, with a saving of 97.2 h. It is noted that, with the application of RFID to facilitate the real-time data transmission to the WMS and the real-time reporting to superior information system for quick approval, it becomes feasible to implement cross-docking that was not possible before. With cross-docking, after finishing the goods receiving in the incoming process, the operators can pick, pack, and ship out the goods on the dock for the outbound process without moving them to the rack/storage area. Thus, total operation time can be further reduced from 171.9 to 121.9 h, with a further saving of 50.0 h.

Table 1 presents the total time comparison. When the warehouse operator applied lean management to eliminate waiting time and unnecessary motion, the total operation time was reduced from 1301.4 to 269.1 h (with an improvement of 79 %). Furthermore, when the warehouse applied RFID technology, the total operation time can be reduced to 171.9 h (with an improvement of 87 %). With cross-docking operation on the basis of real-time data communication with RFID, the total operation can be further reduced to 121.9 h (with an improvement of 91 %).

4.3 Analysis of future processes and comparison of bar code and RFID process

Figure 9 shows the future receiving and storage process in the RFID enabled-supply chain system, while Fig. 10 shows the future picking, sorting, packaging, and shipping process. These two to-be processes are for the comparison with the two as-is processes shown in Figs. 3 and 4. The blocks with dark background in Figs. 9 and 10 represent the procedures that were simplified or improved, in order to provide better efficiency and quality of the as-is processes in Figs. 3 and 4, respectively. The primarily change is the information flow resulted from the different between bar code and RFID. The main improvement using RFID is to provide better visibility and real-time

Table 2 The comparison of total warehouse operation time (in value-added time and nonvalue-added time) of four scenarios, current stage (without lean and RFID), future stage with only lean, future stage with both lean and RFID, and future stage with lean, RFID, and cross-docking (in hours)

Item	Current stage (without lean and RFID)	Future stage (with lean)	Future stage (with lean and RFID)	
			Regular	Cross-docking
Total	1,301.4	269.1	171.9	121.9
Nonvalue-added	1,296.0	264.0	170.0	120.5
Value added	5.4	5.1	1.9	1.4

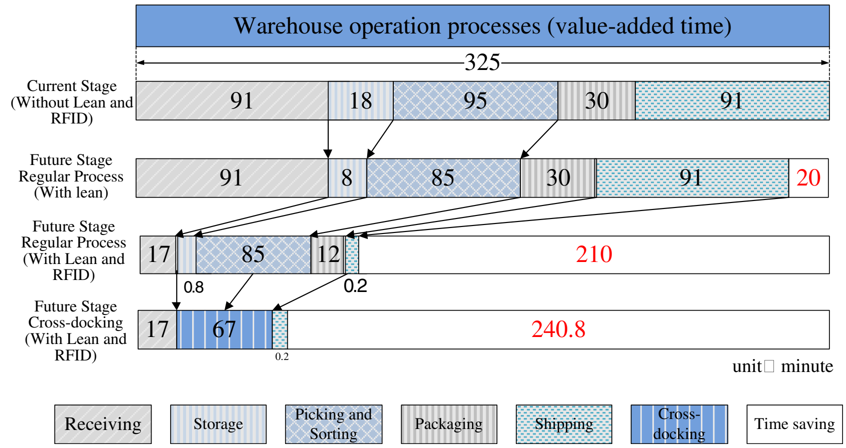


Fig. 14 Performance improvement in value-added time in four scenarios (in minutes)

information communication, leading to the improvement of the efficiency and effectiveness of warehouse management.

There are many manual operations with human touch points at the as-is warehousing processes. From Figs. 9 and 10, it is observed that the RFID technology not only decreases the number of human touch points but also speed up operation processes. Therefore, the warehouse operation can increase efficiency because of the reduction of manual process time and the elimination of potential human errors. These result in higher throughput and lower labor cost.

Major difference in the characteristics between the traditional bar code and the modern RFID includes business process automation and data quality. In the traditional bar code process, the data are manually collected due to the inconsistency of bar code size, the location of bar code on the box, and the size and shape of box storing items. The operator has to work hard on manually scanning of every bar code symbol and counting every item. In contrast with RFID, the data are rapidly and automatically captured through the RFID readers and tags with less labor usage and less operation time. Furthermore, the RFID tags are capable of carrying more information compared to bar code. This greater capacity allows the storing of additional information such as location, history, and destination data. The quality of these data is higher in terms of application into various kinds of enterprise applications, such as real-time goods visibility or goods track and trace system. Figure 11 illustrates the process analysis comparing bar code and RFID. It can be observed that RFID process time is less than bar code process by 190 min.

5 Evaluating the efficiency improvement

In this study, RFID is integrated with lean management in warehouse operation. RFID reader and antennas were installed at warehouse receiving and shipping dock doors to automatically capture the identities and data of RFID tags attached on the pallets/cases. EPC codes of pallets/cases can be read and the information is transmitted to WMS through Ethernet network on a real time basis (as shown in Fig. 12). Simulation of operations with RFID system was implemented. The performance improvement is analyzed as follows.

Figure 13 demonstrates the comparison of total warehouse operation time of four scenarios, current stage (without lean and RFID), future stage with only lean, future stage with both slean and RFID, and future stage with lean, RFID, and cross-docking. From current stage to future stage with only lean, much waiting time and unnecessary operator moving time are eliminated leading to a reduction of 1,032.3 h (79.3 %). With further integration of RFID to lean, additional 97.2 h is saved (7.5 %). Finally, on the basis of RFID technology integrating to WMS supporting real-time information, cross-docking operation can save additional 50 h (3.8 %). The final scenario with lean, RFID, and cross-docking uses only 9 % of the original total warehouse operation time (from 1,301.4 to 121.9 h), with 90.6 % saving!

Table 2 illustrates the improvement of total warehouse operation time of four scenarios, from the viewpoint of value-added and none value-added time. The value-added time in Table 2 consists of receiving, storage, picking and sorting, packaging, shipping, and cross-docking in Fig. 13. After the reengineering, the value-added time can be reduced from 5.4 to 5.1, 1.9, and finally to 1.4 h in the four scenarios. The final value-added time is only 25.9 % of the original version. Furthermore, the none value-added time can be

Table 3 Improvement in receiving, storage, packing, shipping process time (in minutes)

Item	Without lean and RFID	With lean, RFID, and cross-docking	Rate of improvement (%)
Receiving time	91	17	81.3
Storage time	18	1	95.6
Packaging time	30	12	60.0
Shipping time	91	0.2	99.8

reduced from 1,296.0 to 264.0, 170.0, and finally to 120.5 h. The final nonvalue-added time is only 9.3 % of the original version. In summary, saving of 74.1 % and 90.7 % on value-added time and nonvalue-added time are achieved, respectively.

Figure 14 and Table 3 present the performance improvement in value-added time in these four scenarios. It is observed that much improvement is reached in all receiving, storage, packaging, shipping time with saving rates of 81.3, 95.6, 60.0, and 99.8 %, respectively.

6 Concluding remarks and future research

This study applied VSM to analyze the receiving, storage, picking and sorting, packaging, and shipping operations in a distribution center. Inefficient and ineffective operations were identified and lean management concept was used to eliminate wastes. RFID technology was also introduced to reach further improvement. Operation processes are reengineered and changed due to the application to lean management and RFID.

Preliminary results of this case study revealed the benefit of the RFID technology application to the logistics operations in warehouse. The processing time of data transmitting to WMS at receiving and shipping docks was reduced by 99 and 89 %, respectively. The total operation time from current stage to future stage with only lean can be saved by 79 %. With further integration of RFID to lean, the total operation time can be saved by 87 %. Moreover, performance on saving total operation time can be enhanced to 91 % with cross-docking.

This case can be a benchmarking and reference model for further promotion of efficiency improvement in logistics system using better management philosophy and modern technology. This study can be extended to inventory management in order to increase the visibility of stored goods. It is critical to apply RFID to the warehouses of upstream and downstream in the supply chain for the integration of material management. Applying RFID to transportation system to increase the traceability of deliveries is also of interests.

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