# TRACKING SYSTEM DESIGN FOR A PRODUCTION WAREHOUSE OF AUTOMOBILE CONDENSERS

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เพื่อที่จะอยู่รอดในสภาวะตลาดที่มีการแข่งขันสูง บริษัทต่างๆ จำเป็นต้องมีการพัฒนา และปรับปรุงไม่เพียงแต่ประสิทธิภาพการดำเนินงานหลักของบริษัทเพียงเท่านั้น หากแต่ต้องรวมไปถึงประสิทธิภาพการทำงานในส่วนงานสนับสนุนอื่นๆ ด้วย ด้วยเหตุดังกล่าว วิทยานิพนธ์ฉบับนี้จึงได้ถูกจัดทำขึ้น โดยมุ่งเน้นไปที่การค้นหาวิธีการปรับปรุง และพัฒนาประสิทธิภาพงานคลังสินค้าของโรงงานผลิตเครื่องควบแน่นรถยนต์แห่งหนึ่งในประเทศไทย ด้วยการนำเอาเทคโนโลยีการติดตามด้วยคลื่นความถี่วิทยุมาประยุกต์ใช้ในการจัดการสินค้าสำเร็จรูป

เทคโนโลยีการติดตามด้วยคลื่นความถี่วิทยุนี้ ถูกนำขึ้นมาพิจารณาเพื่อแก้ไขปัญหาการดำเนินงานในคลังสินค้าตัวอย่างต่างๆ ในปัจจุบัน อันประกอบไปด้วย จำนวนสินค้าคงคลังคลาดเคลื่อน สินค้าถูกวางไว้ผิดตำแหน่ง และการส่งสินค้าผิดพลาด ผู้วิจัยพบว่า สาเหตุสำคัญที่ทำให้เกิดความผิดพลาดเหล่านี้ เกิดจากข้อมูลคลังสินค้าที่ขาดความแม่นยำ และรูปแบบการดำเนินการในปัจจุบันซึ่งพึ่งพิงแรงงานคนเป็นส่วนใหญ่ เพื่อลดความผิดพลาดดังกล่าว ผู้วิจัยจึงได้ทำการศึกษาถึงประโยชน์ และข้อจำกัดต่างๆ ของการนำเอาเทคโนโลยีดังกล่าวมาประยุกต์ใช้ในส่วนงานคลังสินค้า และการดำเนินงานทางกายภาพอื่นๆ ของหน่วยงานที่เกี่ยวข้องกับงานดังกล่าว

เพื่อให้บรรลุเป้าหมายข้างต้น ผู้วิจัย และบริษัทกรณีศึกษาจำเป็นต้องมีความเข้าใจไม่เพียงแต่ตัวเทคโนโลยีการติดตามด้วยคลื่นความถี่วิทยุ หากแต่ยังต้องทราบถึงแนวทางการผสานรวมเทคโนโลยีดังกล่าวเข้ากับการปฏิบัติงานในคลังสินค้าตัวอย่างด้วย ทั้งนี้ ผู้วิจัยสามารถทำการออกแบบระบบการติดตามด้วยคลื่นความถี่วิทยุสำหรับบริษัทกรณีศึกษาได้ โดยผู้วิจัยได้ทำการวิเคราะห์ทั้งในเชิงเทคนิค และเชิงการเงินของโครงการ ซึ่งผู้วิจัยพบว่า หากมีการนำเอาเทคโนโลยีการติดตามด้วยคลื่นความถี่วิทยุมาใช้ในงานคลังสินค้าของบริษัทกรณีศึกษาจะช่วยลดระยะเวลาในการทำงานรวมลดได้ประมาณ 50% ในขณะที่ค่าใช้จ่ายด้านแรงงาจะลดลงได้สูงสุดถึง 15% สำหรับระยะเวลาคืนทุนของการโครงการนี้ คาดว่าอยู่ที่ 8 ปี แต่ระยะเวลาดังกล่าวอาจเร็วกว่าที่คาดการณ์ไว้ ขึ้นอยู่กับราคาของอุปกรณ์ตัวรับสัญญาณคลื่นความถี่ ซึ่งมีแนวโน้มลดลงอย่างต่อเนื่อง



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In order to survive in a harshly competitive market, a company needs to enhance not only its core operational efficiency but also the performance of other business functions, including the supportive ones. As such, in this thesis, we will explore how we could improve the performance of one important supportive operation in a Thai automobile condenser manufacturer, namely the warehousing process, using RFID tracking technology.

RFID tracking technology is brought into consideration by the company's management team due to its current warehousing issues, including inventory mismatch, inventory misplacement, and faulty delivery. We found that the root cause of these problems was stemming from inventory information inaccuracy as most of its operations was manually operated. Based on this observation, we thence explore how such a technology could be exploited so that inventory information, as well as other related physical operations, could be improved.

In order to achieve such a goal, we need to fully understand not only the RFID technology - its capability and limitation - but also the integration between the underlying technology and the current warehousing operations. Eventually, we have been able to design an RFID tracking system applicable for the case study company taking both technicality and financial analysis into consideration. Based on our preliminary calculation, overall lead time could be approximately reduced by 50%, while total labour cost could be potentially reduced up to 15%. The payback period of the investment is also projected at 8 years, but it could be sooner depending on tag prices, which seem to be decreasing over time.



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Kittisak Lertkajornkitti

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# 1 Introduction

Many businesses have established each year causing the increment in the level of market competition. Thus, the current incumbents must be prepared by strengthening their capability and performance. To be able to successfully compete with other rivals, a company must efficiently reduce losses occurred throughout the company's supply chain. The effective supply chain can significantly assist and allow quantitative and qualitative information to be accurately transferred across the firm. In the business process, many losses may occur due to an inappropriate design in information, documentation, and communication systems. Those processes must be systematically managed and controlled in order to reduce errors and costs which have a strong impact to the firm's profitability.

In manufacturing firms, production is the most concerned process compared to other processes in term of cost, however, to achieve more competitive advantage, the entire supply chain should be thoroughly analysed and managed in order to efficiently reduce losses in the system. A warehousing process is one of the most significant process in the supply chain, however, the process is usually neglected by most of manufacturing companies. During the operation, several factors such as communication, documentation, human resource, space capacity, and policy are important to be effectively managed in order to avoid unwanted losses and difficulties that can cause damage to the company's performance.

Many companies use a traditional warehouse process to manage their inventory which consists of four significant processes, namely receiving, putaway, picking, and shipping. In each process, high amount of information together with the physical operation are parallelly transferred across each other, therefore, a sophisticated architecture in control system has to be rigorously researched and implemented. Moreover, these operations require an intimate and dynamic management with a continuous improvement to achieve an effective and sustainable warehousing, however, most of manufacturing firms are lack of required knowledge on analysing, evaluating, and identifying the existing problems.

In the study, the important linkage of information and operation flows in warehouse management is introduced. A tracking system design is conducted based on the current operation and working environment of a company's warehouse.

## 1.1 Background



The research is conducted based on a case study of a company, namely Company X, the company is a manufacturing firm in Thailand, producing an automotive cooling system and distributing to domestic and international market. The company mainly manufactures condenser and evaporator for passenger cars, see figure 1. The company has more than 2,000 product models ready for production. The main material used in production is aluminium, which is the most common material used in automotive industry. The total area of the production warehouse is more than 8,000 sq.m., containing more than 200,000 units of finished goods in stock, see figure 2 for the layout of Company X’s warehouse. There are currently 20 operators, and one manager working in the warehouse.


*Figure 1 - Shows the example of Company X's products*

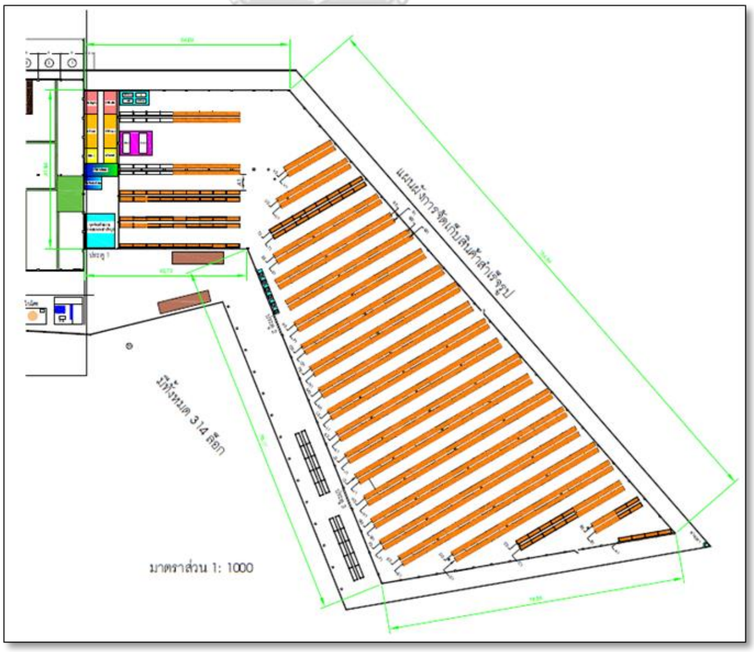


*Figure 2 - Shows the Layout of Compay X's Warehouse*

The company has encountered with recurrent errors in warehouse management, especially in inventory information that can cause critical impacts to the entire supply chain. In recent years, the company had paid extra costs in air freight shipping due to wrong model and wrong quantity (shortage) of products being shipped, losing in the total of more than 0.5 million Thai Baht in air freight shipping cost during 2017-2019. Therefore, the inaccuracy in warehousing data are the main issue causing the loss in profit.

Moreover, when inventory data is deviated from the actual goods in stock, the production will mistakenly plan resources based on the data obtained from the system. Thus, the resources such as material, labour, and operation costs will be miscalculated, which probably cause increment in the total production cost. Ineffective in production planning can cause overproduction and/or underproduction of finished goods, and may cause negative impacts to the related business functions. For instance, overproduction can increase in the level of inventory, causing insufficient in warehouse space; also, underproduction of goods can decrease the company's revenue due to the loss in sales opportunity.



(Currency conversion rate: 1GBP = 40THB)

The company has planned to register into the stock exchange of Thailand years ago; however, the financial reports have not been approved due to the errors in inventory controls. Thus, once the company has successfully registered and be listed in the stock market, there might be a chance of delays in financial report submission due to the large amount of discrepancy in inventory data which required lots of time for the inventory adjustments. As a result, investors may lose their confidences buying stocks, instead they may panically sell their stocks, leading to a significant decrease in the stock price.

In the current operation, the company uses a manual operation for stock data collection, which requires warehouse operators to manually key in the stock data such as quantity and location into an ERP system, Enterprise Resource Planning software. The firm has concerned that the discrepancy in inventory data is caused by the manual information input operation. Therefore, to achieve higher accuracy in stock data and to prevent the problem from recurrence, new design in flow of information and operation, and specific knowledge and technology should be thoroughly developed.



The company has encountered persistent difficulties in warehousing operations, including data tracking, stocking, picking, and shipping accuracy. The warehouse has a limited space and currently been fully occupied with stocks, causing potential risks or errors in storing, order picking, and shipping operations. Thus, designing information and operational flows, and creating strategic planning and management would optimise the warehouse capacity and efficiency for obtaining maximum profitability by minimizing the potential costs.

*The Current Information and Operation Flows*

According to the case study of the Company X, the company's warehouse operation associates with two main departments including production and sales. The information and operation flows of the warehouse begin from the production site, process through the warehouse, wait for order allocation from sales department, and then prepare for the shipment. The information is transferred, managed, and controlled through ERP system. Once the product is moved from a process to another process, the product information such as product quantity, location, and other product details are captured, collected, and input into the system by manual key-in operation. The data key-in computers are located at the end of each process to receive product information from the previous process and to transfer to the next process.

The company currently uses whiteboards, papers, and a computer software, Excel spreadsheet to daily monitor, record and update the stock quantity and location in additional to the ERP system. However, these additional operations can cause a discrepancy in the inventory information since there are many recorded data sources and possible delays in data updating. Since the manual operation is lack of information accuracy, time-consumed, and delay in stock updating, therefore, the errors in inventory data can cause mistakes to the production planning, leading to the possible loss in profitability.

## 1.2 Research objective

The objective of the research is to design a tracking system for reducing the errors and increasing the operations efficiency in a production warehouse of automotive condensers.

## 1.3 Scope of the study

The research focuses on the design and selection of the RFID system based on the capability and limitation of the technology. The study compares the advantages and disadvantages of similar types of RFID systems based on the specific business requirements and the limitation of the current warehouse operations and infrastructure. Return on investment (ROI) is analysed in order to evaluate and justify the RFID implementation; total investment costs, additional annual costs and maintenance costs are calculated.

# 2 Literature Review

Warehouse can be divided into two main types, i.e., production warehouse and distribution centre, more specifically, they can be classified by their roles in the supply chain as raw material warehouse, work-in-process warehouse, finished goods warehouse (for production warehouse), and distribution warehouse, fulfilment warehouse, local warehouse, and value-added service warehouse (for distribution centre) (Frazelle, 2001). Each type of warehouses has some different in processes, however, most of them share similar patterns of operations and material flow, i.e., receiving, put-away, order picking, sorting, packing, and shipping (Tompkins, et al., 2011).

Warehousing can cost up to five per cent of cost of sales in an organization (Hwang & Cho, 2006). Moreover, as the current business environment is intensely competitive, companies must concentrate on cost reduction in all business aspects, hence, minimizing warehousing cost has become a critical business issue. A technological approach called Warehouse Management System (WMS) has been developed to cope with these challenges.



Many companies have considered whether to invest in warehouse management system (WMS), warehouse control system (WCS), or warehouse execution system (WES). These management software systems are developed specially for warehouse management; however, those software systems have some overlapped functions across each other. Therefore, investigating the specific functionalities of each system in detail will allow companies to successfully determine which functions are the best fit for their requirements.

Warehouse management system (WMS) is a specialized business solution software which controls the overall flow of inventory moving in and out of a company's warehouse or distribution centre. A WMS manages all functions of inventory from receipt to shipping, including receiving, put away, replenishing, picking, shipping, and ability of tracking and tracing inventory by integrating with warehouse-related technology equipment. Although WMS supports many warehousing functions, however, there are some functions WMS is not compatible such as machine controlling (PLCs, programmable logic controller), and any other automation system.

WMS is a computer software used to manage and control the movement and storage of products in a warehouse. Based on warehouse control system, WMS can be distinguished into three types, including Basic WMS, Advanced WMS, and Complex WMS. Basic WMS is a software system that supports only stock and location control, while Advanced WMS is eligible to plan resources and activities integrating to the flow of goods in the warehouse, and Complex WMS provides information for each product in terms of location and destination including, tracking and tracing, planning, execution, and control for optimising the warehouse operations (Faber, et al., 2002).



Warehouse control system (WCS) is a warehouse solution software which controls the material handling equipment in real-time. WCS provides a uniform interface to many types of automated equipment such as AS/RS (Automated storage and retrieval system), conveyors, carrousels, sorters, and palletizers. The software is able to support real-time information transfers in communication, command processing, and discrete equipment signals which enable the warehouse system to maintain at its maximum efficiency. However, most of WCS is lack of ability to interface with enterprise resource planning (ERP) system, and also lack of advanced WMS functionality (enVista Thought Leadership, 2017).

Warehouse execution system (WES) is a newer warehouse solution software. WES software is developed from WCS-based software by including basic WMS functionality into the existing WCS, thus, WES is considered as a light version of a WMS with fully controls functionality. For some small and mid-sized businesses, a WES is enough. However, for a larger and more complex business, a more advanced inventory management system may be required, which is available only in a WMS software, see figure 3 for overlapping of the software functions between WMS, WCS, and WES (enVista Thought Leadership, 2017).

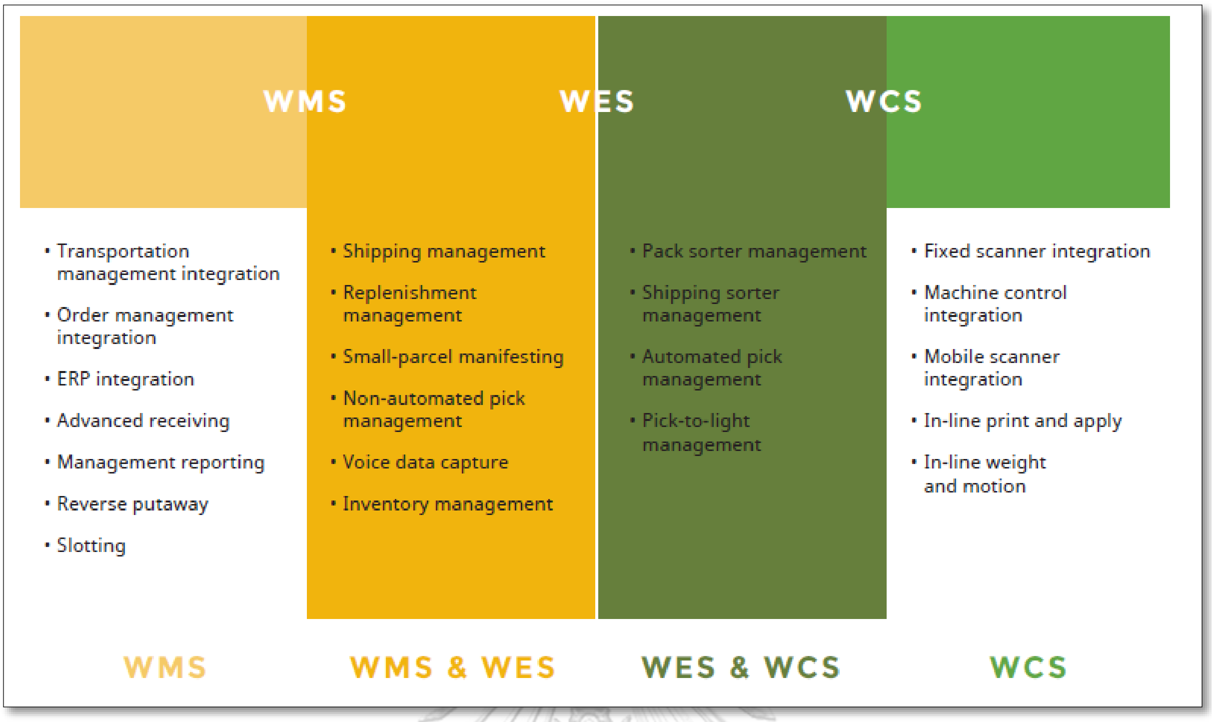


*Figure 3 - Shows the Overlapping of the software functions between WMS, WCS, and WES, (enVista Thought Leadership, 2017)*

Back to early 2000s, all software applications related to the supply chain management are ready-made package which are targeted for dealing with common logistics tasks. As these software applications are mass-customised products (neglecting the specific requirements of a certain business sector), it causes the software applications to be vulnerable and problematic. Thus, to solve the issue, many firms use mix packages software to manage their businesses (Helo & Szekely, 2005).

In a supply chain, the information data is transferred or exchanged across the organizations through management systems, such as Enterprise Resource Planning (ERP), Warehouse Management System (WMS), Transportation Management System (TMS), and Supply Chain Management System (SCM) to support and optimise the logistics processes, including planning, and forecasting from within a single supply chain member to the entire supply chain network (Nettstrater, et al., 2015). In figure 4, shows the connection and information flow between ERP, WMS, TMS, and SCM management systems.

Recently, the information management systems, and especially the warehouse management system (WMS) have been developed to support the integration of advanced functionalities for a more complex warehouse. The software developers of WMS have extended the scope of their software to integrate the core functions with other related operational functions, such as the support of resource planning, billing, value added services, and vendor managed inventories for obtaining the maximum benefits (see figure 5) (Nettstrater, et al., 2015).

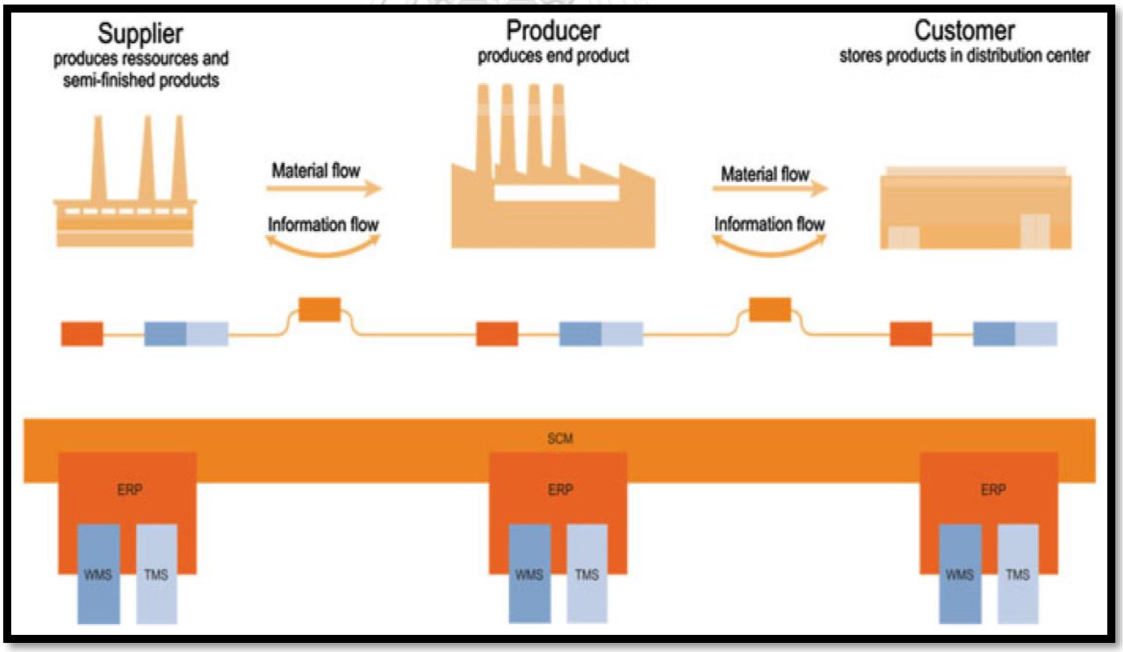


*Figure 4 - Shows the connection and information flow between ERP, WMS, TMS, and SCM.*
*Source: (Nettstrater, et al., 2015)*

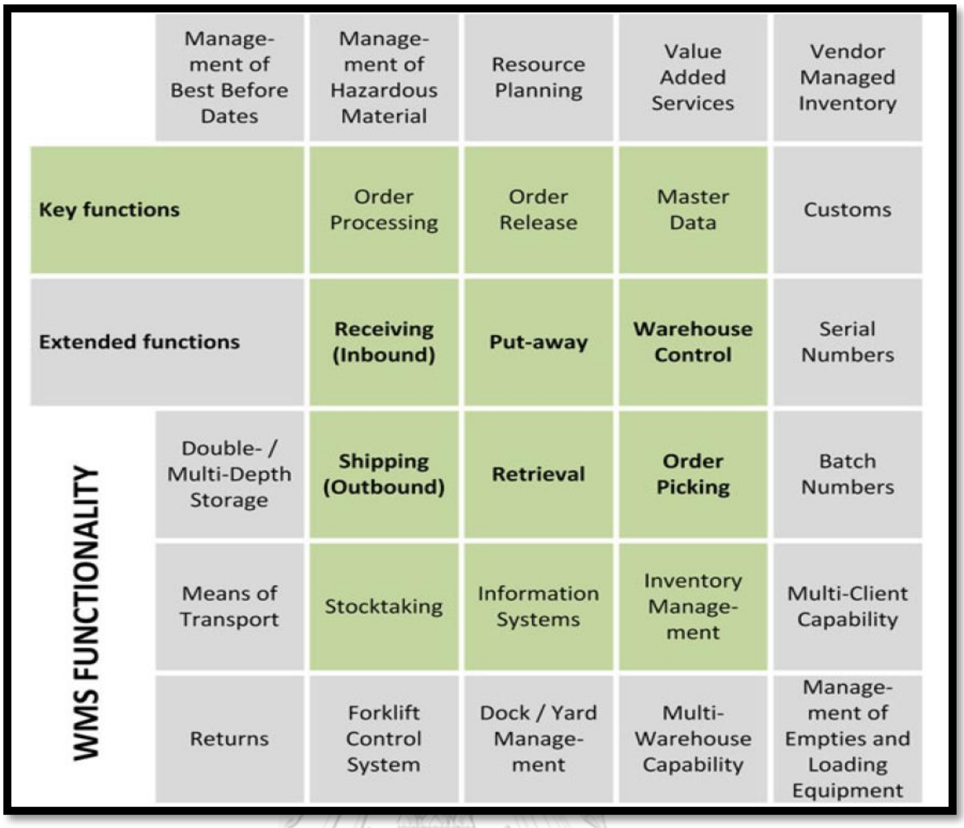


*Figure 5 - Shows the Core and Extended Functionality of Advanced WMS, Source: (Nettstrater, et al., 2015)*

To implement the WMS into the existing management system, it requires a specific knowledge and understandings of the overall flow of information and operations throughout the company's supply chain. The required knowledge allows the company to be able to specifically develop the most suitable system flow designs based on the company's resources.

Gunasekaran et al. (1999) examined that integrating the information flow with the physical or operation flow helps optimise the overall process time in a warehouse, however, if there are some gaps or errors between the flows, it will lead to bottleneck and poor customer service level.

Moreover, Wattky & Neubert (2004) also state that the information flow between supply chain partners is recognised to be a strategic activity that enhances supply chain performance and enables a company to achieve competitive advantage. Therefore, the link of information flow and operation flow can be considered as a key determinant of a company's management performance. However, Ramaa et al. (2012) mention that if a company only implements WMS without changing any processes, it does not lead to cost reduction or efficiency improvement, it will just minimise errors caused from human factors.

Gunasekaran et al. (1999) state that warehouse operations can be improved by using barcode technology in the conjunction with software information systems to provide accurate data collection. In addition, Brewer et al. (1999) study the intelligent tracking technologies in manufacturing and throughout the supply chain such as global positioning systems (GPS), geographic information systems (GIS), and especially radio frequency identification (RFID) to provide real-time information and to support logistic execution.



Even though the advantages of RFID technology have been evidenced in laboratory testing and experimental trials in many companies (Angeles, 2005), there are several barriers to RFID implementation, including undefined specific standards platform, high RFID tag cost, and cost/performance trade-offs (Clarke, et al., 2005). Thus, RFID and its predecessor, barcode technologies are still coexisted in term of usage in most of the warehouses since the barcode technology has been significantly invested by companies around the world (Ross, et al., 2009), and also, accepted as the standard for automatic identification (Auto ID) employed in the warehouse (McFarlane & Sheffi, 2003).

RFID technology is adopted in many logistics applications especially in goods tracking. The process of tracking and tracing of RFID technology begins from the tagging of products at manufacturer (upstream level). The manufacturer stores data of the product information into RFID tag attached to the finished products, the tagged products are then delivered to warehouse, and lastly to retailer (downstream level); the RFID system in logistics application is implemented to enhance operational performance and to improve customer satisfaction (Chung, et al., 2017). In Figure 6, shows the example of information and operation flows configuration in a typical warehouse when applying RFID technology (Chen, et al., 2013).

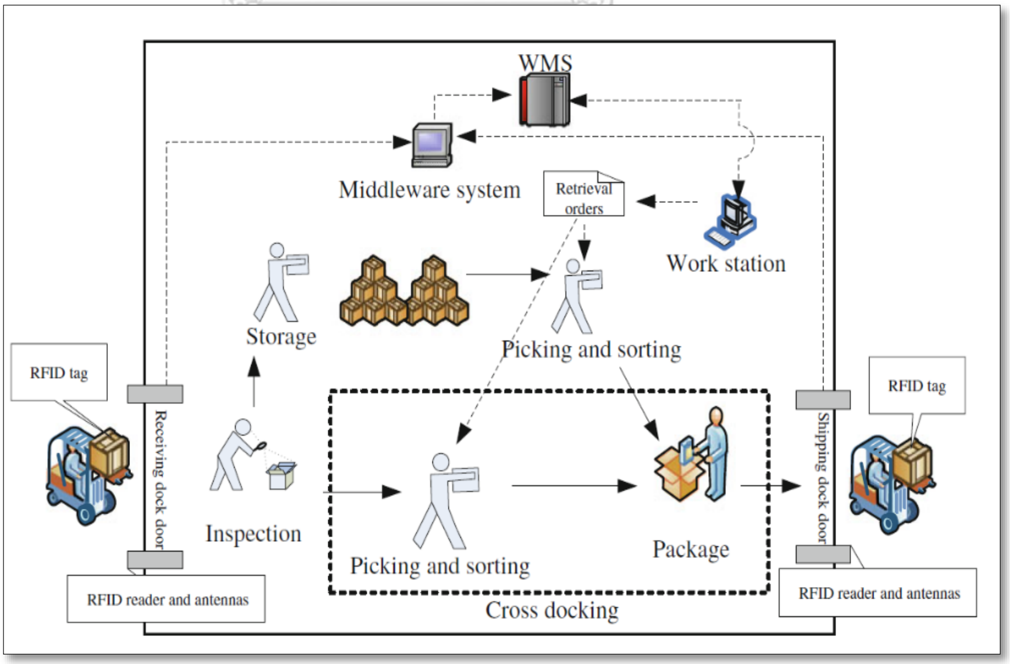


*Figure 6 - Example of information and operation flows in a warehouse with RFID, Source: (Chen, et al., 2013)*

Lefebvre et al. (2006) identified that RFID technology can provide significant improvements in each of the warehousing process; e.g., in order picking process is time-consuming, and subjected to human errors, RFID can provide automated verification activities and simplify the process, therefore, making it more efficient. The use of RFID implies the optimization of processes, allowing the elimination of manual and visual verification of each product received, thus, the errors due to human factor can be avoided (Castro & Wamba, 2007). RFID technology can be applied to reduce the paperwork and increase productivity and information accuracy by transferring information via RFID tags and readers and storing the data into the WMS systems (Srivastava, 2004).

Even though, RFID technology can provide lots of beneficial tracking information for all functions in the supply chain, thereby, enhancing process visibility; however, there are some limitation to the technology as Clarke et al. (2005) investigated that the product material density and physical orientations of tags attached to products affect the penetration performance of RFID. Therefore, the implementers must clearly understand the physical properties of tag orientation and the limitation of the technology, so that they can effectively design or develop the most suitable operation flow for specific requirements, allowing the system to achieve the maximum benefits.

# 3 Methodology

To determine whether to invest in the tracking technologies for the given company, there are significant factors, mainly associated with technological, financial, human, and managerial aspects that needed to be thoroughly investigated (Moretti, et al., 2019), (Wei, et al., 2015), (Osyk, et al., 2012). The research model is conducted by determining the potential advantages, investment costs, return on investment (ROI), and possible difficulties in the technology implementation.

In figure 7 shows the proposed design framework for RFID tracking system. The design and implementation of an RFID system is a complex task which requires both high-level of technical and non-technical skills to resolve the issues during the implementation. In this section, activities and concerning issues are described and discussed in each stage of the framework.

The proposed tracking system design framework consists of the following five significant stages:

- *Stage 1: Identification of the Existing Gaps and Problems (AS-IS)*
- *Stage 2: Study of the Warehouse Tracking Technology*
- *Stage 3: Hardware Adoption and Selection*
- *Stage 4: Process Redesign (TO-BE)*
- *Stage 5: Cost Reduction and Investment Analysis*

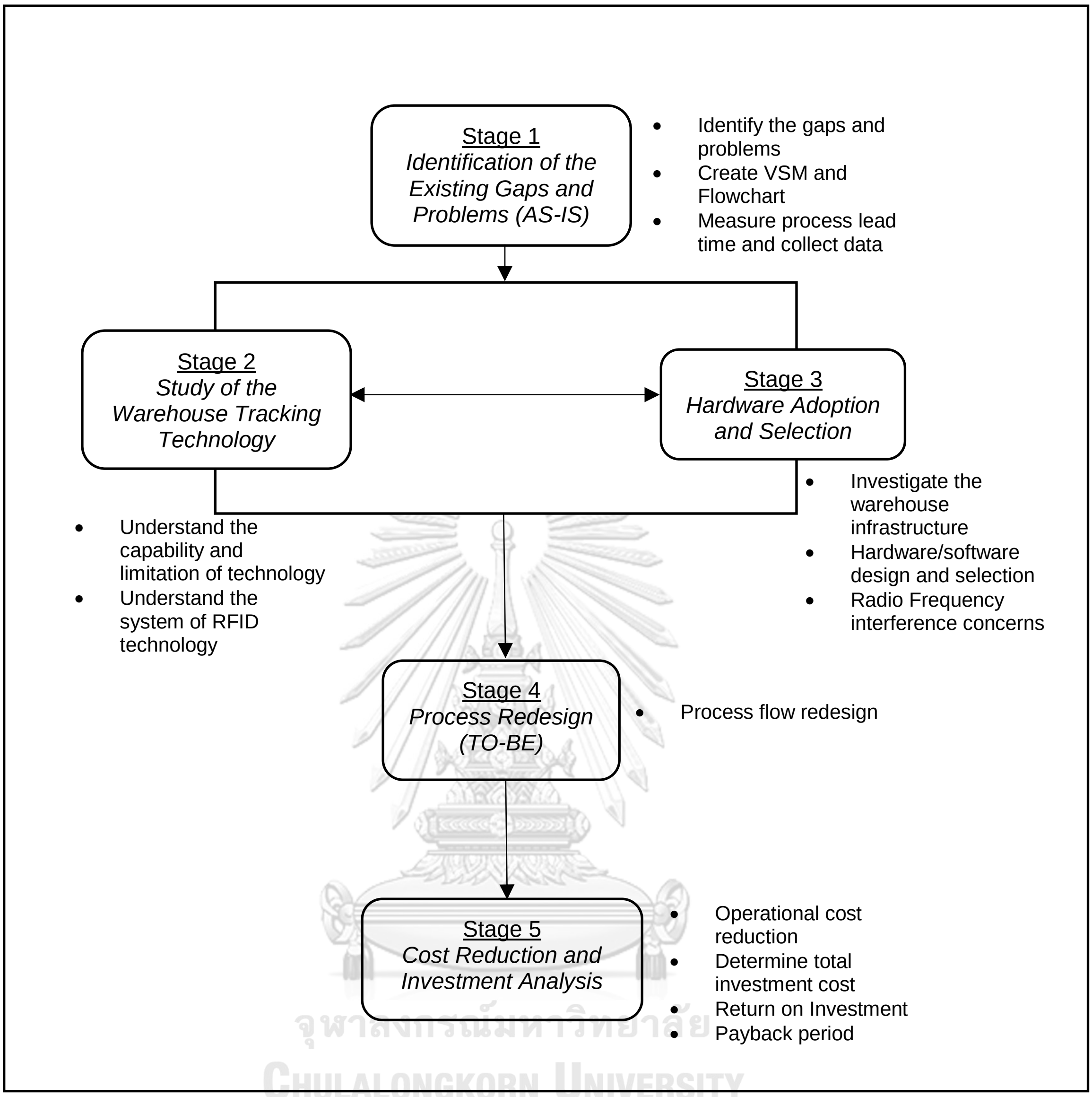




*Figure 7 - Shows the Proposed Design Framwork for RFID Tracking System*

*Stage 1: Identification of the Existing Gaps and Problems (AS-IS)*

To effectively solve the existing problems, a company must identify any gaps and potential problems in the existing operations through field studies, such as interviewing and observation. Based on the field studies, warehousing data such as material flow, information flow, and process time flow are needed to be collected for creating value stream map and process flowchart.

Value steam map and process flowchart are created for observing the overview of the related business functions and also, for investigating the current warehousing operations, including, cycle time, manpower, waiting time, and value-added time in each process to determine the bottlenecks or any potential problems in the processes.

Warehousing data such as inventory data and cost reports are significant for identifying the most severe problems affecting to the company's performance and profitability, so that the company could effectively prioritize which areas are the most critical and needed to be promptly resolved.

*<u>Stage 2: Study of the Warehouse Tracking Technology</u>*

After the potential problems of the existing operations are identified, next, the company must understand the principle of the adopting technology including capability and limitation of the tracking system in order to determine whether the tracking system is suitable for the business requirement or not.



The most advanced warehouse tracking system is relied on the adoption of radio frequency signal as a medium for exchanging information wirelessly, namely radio frequency identification (RFID). The RFID system captures, processes, records, and updates tracking information of goods moving in and out of the warehouse.

However, the RFID system uses radio signal to capture and wirelessly transfer product information from receiving tags attached on a product to be recorded into the WMS database. Thus, material of the finished products, orientation of tag antenna, and collision in radio wave transmission are needed to be concerned as those factors could negatively affect the quality of the transmitting signals, which can cause errors in the inventory data. Therefore, the company should thoroughly understand the system of the technology in order to effectively implement the technology into the existing operations.

*Stage 3: Hardware Adoption and Selection*

Due to the fact that RFID system implementation relies on the surrounding environment in which the system is implemented, the company must consider on the environmental factors when selecting the RFID equipment. The radio frequency selection, the type and location of the readers and the tags, and orientation design of the equipment all depend on the environment settings; thus, at this stage, warehouse infrastructure analysis together with the hardware/software design and selection are needed to be thoroughly investigated.

1. *Warehouse infrastructures analysis*



The warehouse infrastructure analysis is conducted to determine whether the environment suits an RFID system. The physical environment in term of surrounding materials should be considered. It is significant to examine any radio signals reflecting and refracting materials that will cause interference to the quality of transmitting radio signals. The sources of interference include all kind of metal materials such as metal rack, wall of the building, and the material of the finished goods. The design of the RFID solution must consider on the effect of the radio frequency interference to ensure that the performance of the system is at the highest level.

The performance of the transmitted signal of RFID system is depended on the type of the material that the receiving tag is attached to. For instance, if the surface of the tagged object is made of metal, then the radio signal will be reflected and degraded, causing the chance of errors in signal readings of the readers. To solve such problems, the RFID tag should be customised and coated with an insulator case in order to avoid the direct contact from the metal surface.

2. Hardware/Software design and selection

The objective of this step is to suggest a detailed design for the RFID hardware and software, and to explain how to select the most appropriate specification and configuration of the implementing RFID system as follows:



- The desired read range and read reliability of the readers should be designed based on the specific operations and environment; for example, if the finished goods are tightly packed with a large quantity of goods, then the system would require a longer read range and more read reliability. Thus, this will affect the selection of the reader and antenna at each read point.

- Selection of the tags (active, semi-passive, passive), tag orientation, and tag placement are needed to be designed specifically for the cartons, cases, and pallet rack. Different type of tag may be selected for different cartons, cases, and pallet rack.
- Communication network of the RFID system should consider on how the readers will connect to the intranet network, including system installation, network design, and network equipment. In addition, in order to effectively select the most appropriate wireless equipment, a site survey or a software simulation of the wireless network can be provided by the technology suppliers.
- Software system can be customised based on the business requirement; software architecture and type of software can be freely designed and selected.



*Stage 4: Process Redesign (TO-BE)*

After the implementation of the proposed RFID system designs, the current business process flows have to be redesigned; some procedures in the existing operations may be modified, and the new procedures may be added to enhance the quality of the existing operations. Since the manual process of counting and paperwork can be eliminated, instead, the RFID system will be replaced causing the process changes to the warehouse operations. Therefore, in each warehousing process, the process flows must be thoroughly revised in order for the warehousing operators to correctly work with the new system.

*Stage 5: Cost Reduction and Investment Analysis*

At the final stage, the benefits of the proposed RFID implementation will be evaluated in the form of the potential cost reduction of the warehousing operations. Lead time in each process can be significantly reduced due to the elimination of some processes such as counting and paperwork, thus, as a result, operational cost and consumable resources cost can also be reduced. These cost reduction results will be further used for the investment analysis to determine the potential payback period of the investment. The return on investment can be calculated by the total investment costs and the potential operational costs reduction.

## 3.1 Stage 1: Identification of the Existing Gaps and Problems (AS-IS)

The objective of this process of investigation is to clearly understand the existing operations of warehousing system. Value stream map (VSM) is created to identify and analyse the existing operation issues, such as bottleneck in the warehousing operations by using information, material, and time flows. The current state map (as-is) is created to understand the process time flows for developing the higher-efficient future state map (to-be). In Figure 8, shows the current VSM of the warehouse operation of Company X (as-is).

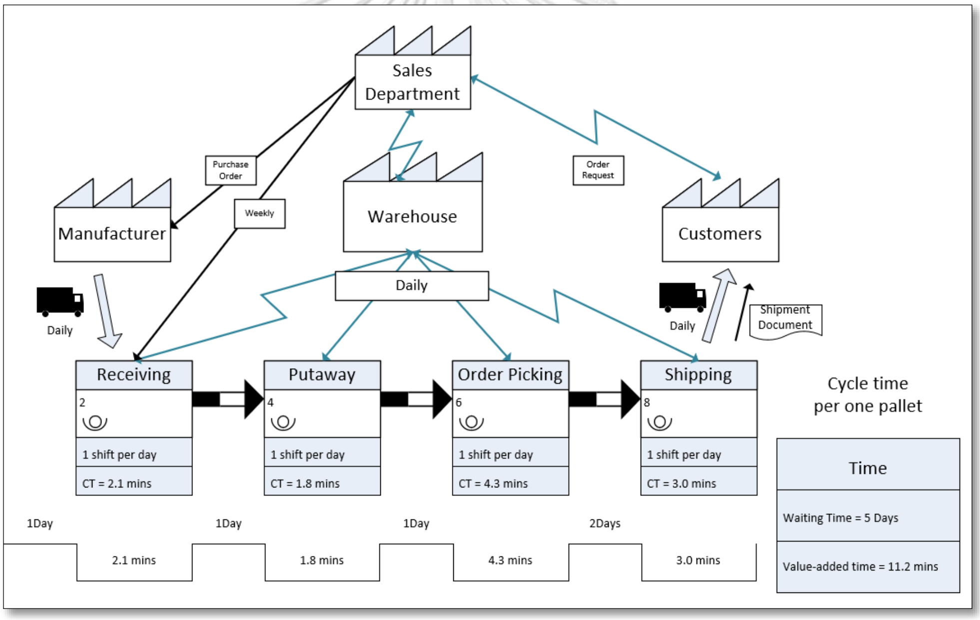


*Figure 8 - Shows the Current VSM of the Company X. (as-is)*

According to the Company X's VSM, the overall operation process is started from the order information from sales department and customer. When a customer places an order, sales staff will check the product availability together with warehouse staff. If the products are not available in stock, the sales staff will request for a new production. After the products is manufactured, the finished product (FG) will be transferred to the warehouse for storage (receiving and putaway) and waiting for shipping arrangement confirmation from sales department. Once the shipping schedule is confirmed, warehouse staff will conduct order picking and prepare for shipment to be delivered to the customer.

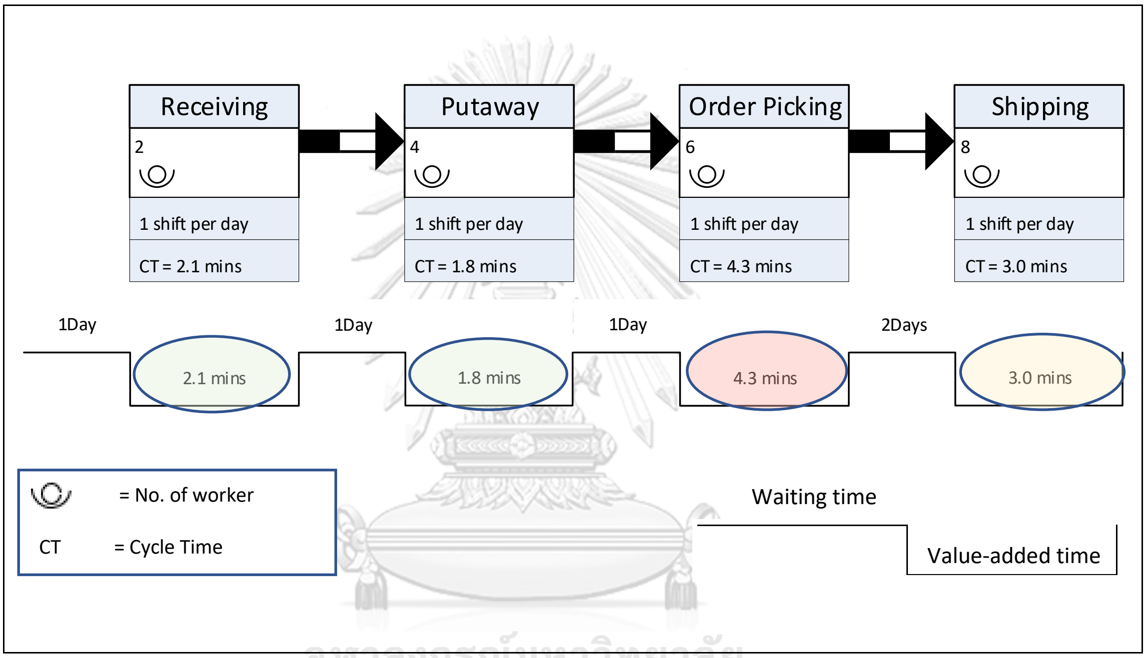


*Figure 9 – Shows the cycle time bottlenecks in the warehousing operations.*



According to figure 9, the order picking process shows the highest cycle time of 4.3 mins comparing to the other processes in series. Hence, the order picking can be considered as the bottleneck process which has to be effectively solved in order to reduce and enhance the overall warehousing cycle time.

Moreover, warehouse operation flowchart is also created to clearly understand the operation and information flows that are exchanged among four business departments including production, quality assurance (QA), warehouse, and sales. The current warehouse operation flowchart is shown in figure 8. The starting point of the flowchart begin from the production site (1) by moving finished goods to handover area (receiving area) and conduct a quality check process by QA before sending and receiving goods into the warehouse. Warehouse receive FG at handover area, (4. Receiving), and move the pallet to the assigned stock location, (5. Putaway). Once sales department send an order allocation for order picking, warehouse then conduct an order picking process, (7, 8, 8.1 (optional), 9, 10, and 11), and then prepare for shipping arrangement (13) as shown in figure 10.

Refer to the current VSM, the order picking process is considered as the bottleneck of the warehousing operations. Moreover, the warehouse operation flowchart in figure 11 provides more visibility of the bottleneck subprocess. Therefore, investigating into the current information and operation flows, cycle time, value-added and non-value-added time would strongly support in designing more efficient process flows and allow for evaluating cost and benefit when implementing new technologies.

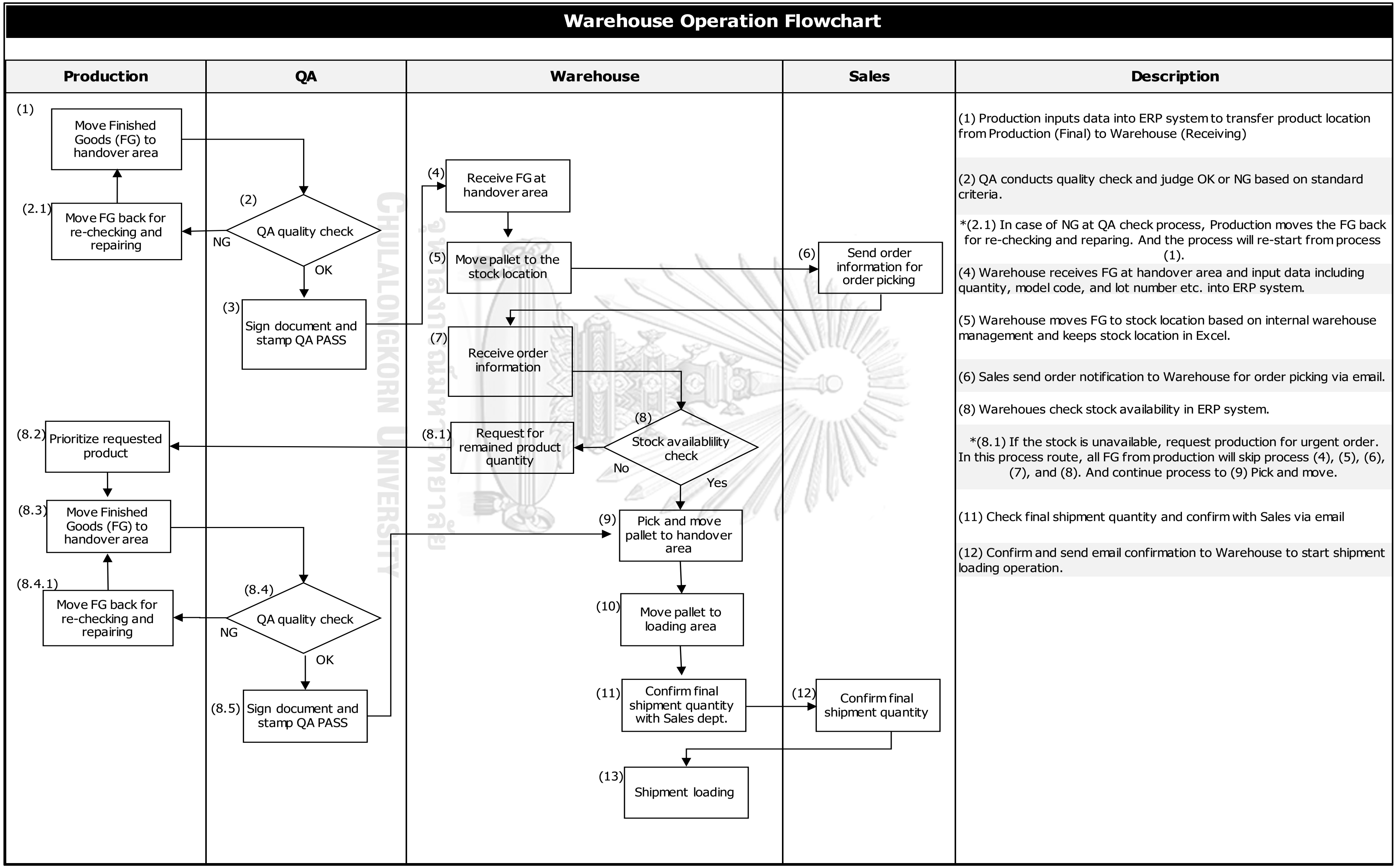


*Figure 10 - Shows the Current Warehouse Operation Flowchart*

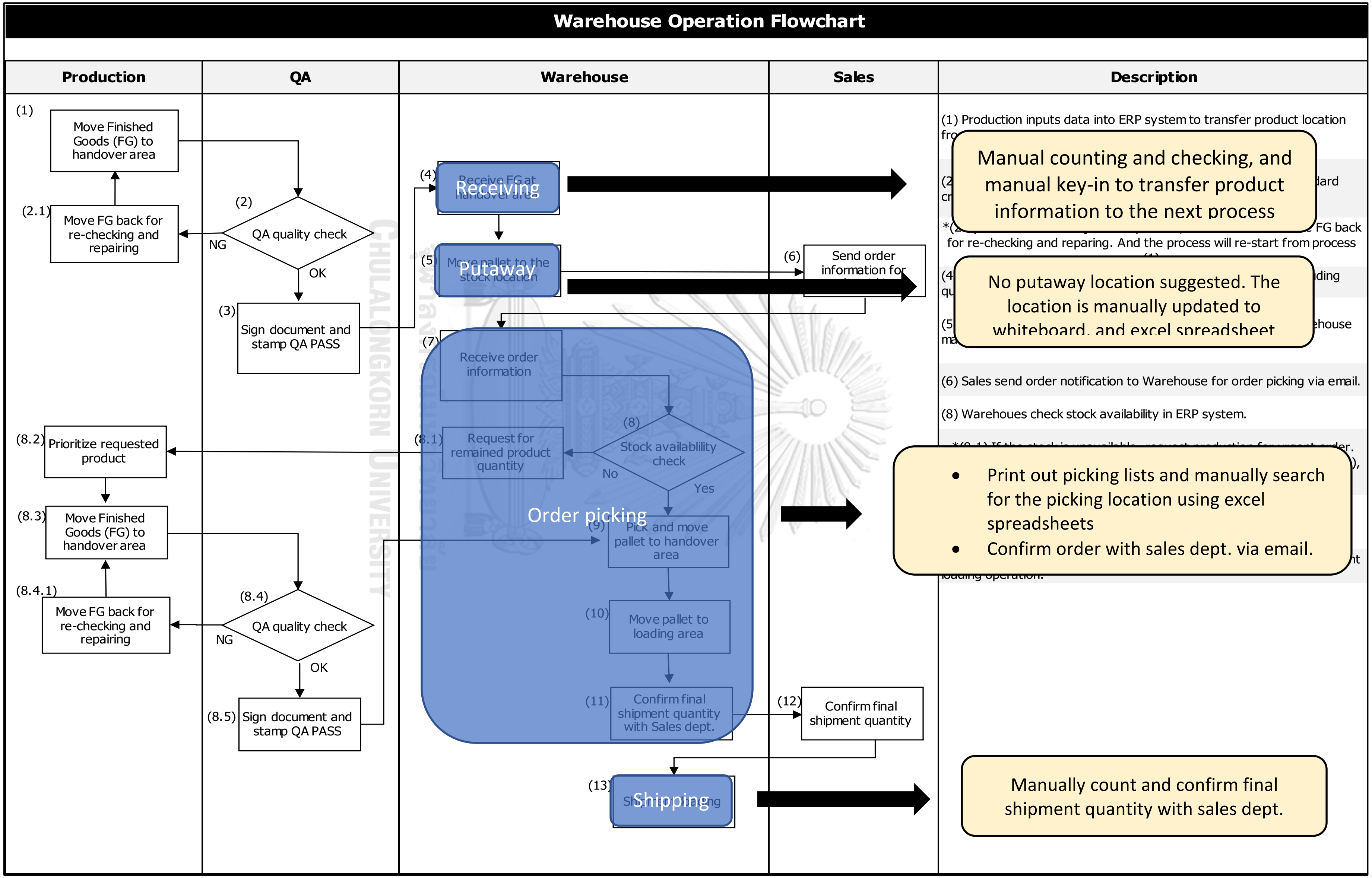


*Figure 11 - Shows the Current Warehouse Operation Flowchart with Warehousing Process Label (AS-IS)*

According to figure 11, in receiving process, errors due to manual operation such as wrong quantity receiving, and delay in key-in process from previous operation can cause significant impacts to the business. In the current operation, carton boxes of finished goods are stacked on a pallet with different orientations which is difficult to identify each carton box, causing an operator to possibly miscount the quantity of the products, see figure 10. Moreover, in key-in process, when the product information has not yet transferred from the previous operation (final production), then, the receiving process cannot proceed or confirm the goods receipt process, which cause errors and delays.

In putaway process, after the receiving process, the pallets of goods are moved to the location based on alphabetically order of model numbers. After the finished moving, the putaway operator writes down the model number and location of the goods on a piece of paper, and also, update on the whiteboard that located at each row of the pallet racks. Another operator will collect the information from either whiteboard or paper to update on the Excel spreadsheet. However, since there are many sources of information and different operators processing, those manual operations can cause errors and delays in information updates (figure 12).



*Figure 12 - Shows the Process of Receiving and Putaway in the Current Operation (manual)*

The most crucial warehousing activities are generally performed during order picking process which consists of subprocesses such as receiving information, checking and searching, picking, and confirming. Battini et al. (2015) mentioned that during the picking process different kinds of errors can occur, which considering the negative impact of the entire process. The process errors can be divided into two types, i.e. 'detectable error' and 'propagating error'. The detectable error can easily be detected and prevented by item confirmation process; the process immediately notifies the operators and allow the errors to be rectified. However, the propagating error is a hidden error, difficult to identify, and leading to further work at the end of the picking operation (Grosse, et al., 2013), see table 1.

*Table 1 - Shows the common errors occurred during an order picking process [modified: (Battini, et al., 2015)]*

| Type | Operator Picking Error | Immediate Correction | Corrective Action |
|---|---|---|---|
| Detectable | 1) Right item picked but wrong item confirmed | Yes | Confirm the right picked item |
| | 2) Wrong item picked and wrong item confirmed | Yes | Pick the right item and reconfirm |
| Propagating | 3) Wrong item picked but right item confirmed | No; (error found at the end of the process) | Pick the right item and reconfirm (additional work required) |
| | 4) Wrong quantity picked but right quantity confirmed | No; (error found at the end of the process) | Pick the right quantity and reconfirm (additional work required) |

According to table 1 shows the four most common errors occurred during the order picking process, as mentioned in several journals, and also validated by practical experienced authors (Poon, et al., 2009); (Battini, et al., 2015). For detectable error type, both errors (1 and 2) are mistakenly identified as “wrong item” after a physical picking, then, the items are returned back for another recheck loop, hence the errors are detectable and able to be rectify during the picking process. However, for propagating error type, the errors (3 and 4) are also mistakenly identified as “correct item” after a physical picking, then, the items are then released to another process, thus, in this type of error, an additional work are required since the item are already passed through the normal process.

In shipping process, final product quantity and final shipping destination are confirmed in this process. The shipping operator communicate with sales department via e-mail to confirm the final shipment including, model codes, final shipping quantity, shipping marks, and transportation units; however, many documents and information data at this stage are quite complicated and needed to be thoroughly checked to ensure that the right quantity and model of goods are delivered to the right destination.

In addition, the company has a periodic inventory cycle count each quarter. According to the previous year historical data from Q4/2018 to Q3/2019, the data in table 2 shows that the stock inventory is inaccurate with the average percentage error of 2.4% (or 5,126 units) in each quarter. Even though, the number seems to be very small compared to the average of the total inventory count of 212,787 units each quarter, however, the unit cost is relatively high (800 baht per unit in average), which is approximately 4 million Thai Baht in the inventory value. Therefore, in order to prevent any potential losses, the inventory information has to be systematically managed and controlled.

*Table 2 - Shows the Historical data of Stock Cycle Count (Q4/2018-Q3/2019)*

| | Stock Count Discrepancy | |
|---|---|---|
| | Total Unit in Stock | Discrepancy (Units) |
| Q4/2018 | 198745 | 3452 |
| Q1/2019 | 237650 | 8521 |
| Q2/2019 | 213211 | 5745 |
| Q3/2019 | 201543 | 2784 |
| | | |
| Average | 212787 | 5126 |
| %Error | | 2.4% |
| Inventory Value | ฿ 170,229,800.00 | ฿ 4,100,400.00 |

Typically, manual tracking system has higher occurrence of human errors in reading and recording the logistics information of the transport goods. Common human errors in manual tracking system include inaccurate quantity and loss tracking on location of transport goods; which can negatively affect the overall logistics cycle time and costs. In addition, the inefficiency in manual tracking system is caused from inconsistency of worker performance; worker’s fatigue from long working hours, high workload, and large amount of information that needed to be managed can cause the errors (Jamaludin, et al., 2018).

## 3.2 Stage 2: Study of the Warehouse Tracking Technology

The tracking technologies are investigated based on Company X's resources and constraints. The operational costs such as direct labour cost, breakdown processing cost, and resource utilisation are collected and analysed to determine the most appropriate warehousing configurations for the specific conditions. The first step is to understand the capability and limitation of warehousing technologies, including RFID technology, barcode technology, wireless communication, and other related technological equipment.

### 3.2.1 Tracking Technology

Transferring or picking goods in manual warehouse operation is considered one of the most crucial warehouse activities, thus, over the years many warehouse technologies have been developed to support and control the information and operation flows of the process (Tompkins, et al., 2011). A handheld barcode scanner is one of the first devices adopted to support the warehouse tracking process. Product information such as stock keeping units (SKU) or stock location is attached in the form of barcode that can be scanned by using the handheld scanner; and the information is recorded into the warehouse information system (Battini, et al., 2015).

However, the barcode technology also has its limitations such as need of line of sight, short detection range, low reading rate, and easy to be damaged or removed; thus, due to its disadvantages, it could be seen that the barcode technology has been replaced by more advanced technology called radio frequency identification (RFID) and being developed for product tagging, and inventory controlling in warehouse applications (Lim, et al., 2013) (Liu, et al., 2006).

RFID has achieved great success in various logistics applications, such as livestock tracking, airline baggage, building access, and especially warehouse management, i.e., case, pallet, truck, and trailer tracking (Yatinkumar, 2017). See table 3 for Barcode and RFID technologies comparison and see figure 13 for example of barcode and RFID tag.

*Table 3 - Shows the difference of Barcode and RFID technologies*

| | **Barcode** | **RFID** |
|---|---|---|
| Technology | Optical (Laser) | Radio Frequency (RF) |
| Read Range | Several centimeters up to several meters | Passive UHF:<br>Up to 12 meters (Fixed readers)<br>Up to 6 meters (Handheld readers) |
| Read Rate | Low - one tag at a time | High - Multiple (up-to 100+) tags at a time |
| Read/write Capability | Read-only | Read, write, modify, and trigger |
| Interference | Easily damaged or removed | Some frequencies cannot pass through certain metals or liquids |
| Cost/tag | Low – Thai Baht 0.20 - 1.00 | High – Thai Baht 1.20-5.00 (depends on quantity) |


*Figure 13 - Shows the example of Barcode and RFID tag*

A typical RFID tracking system consists of four main components, including an interrogator (reader), a transponder (tag), antennas, and a host computer (Chung, et al., 2017). There are three types of RFID tags including active, passive, and semi-passive; active tag has batteries on-board and can transmit signals on its own. Passive and semi-passive tags require source of energy to engage in communication; semi-passive tag has a battery on-board, but it is only used for on-board computations (Bolotnyy & Robins, 2007), see figure 14.

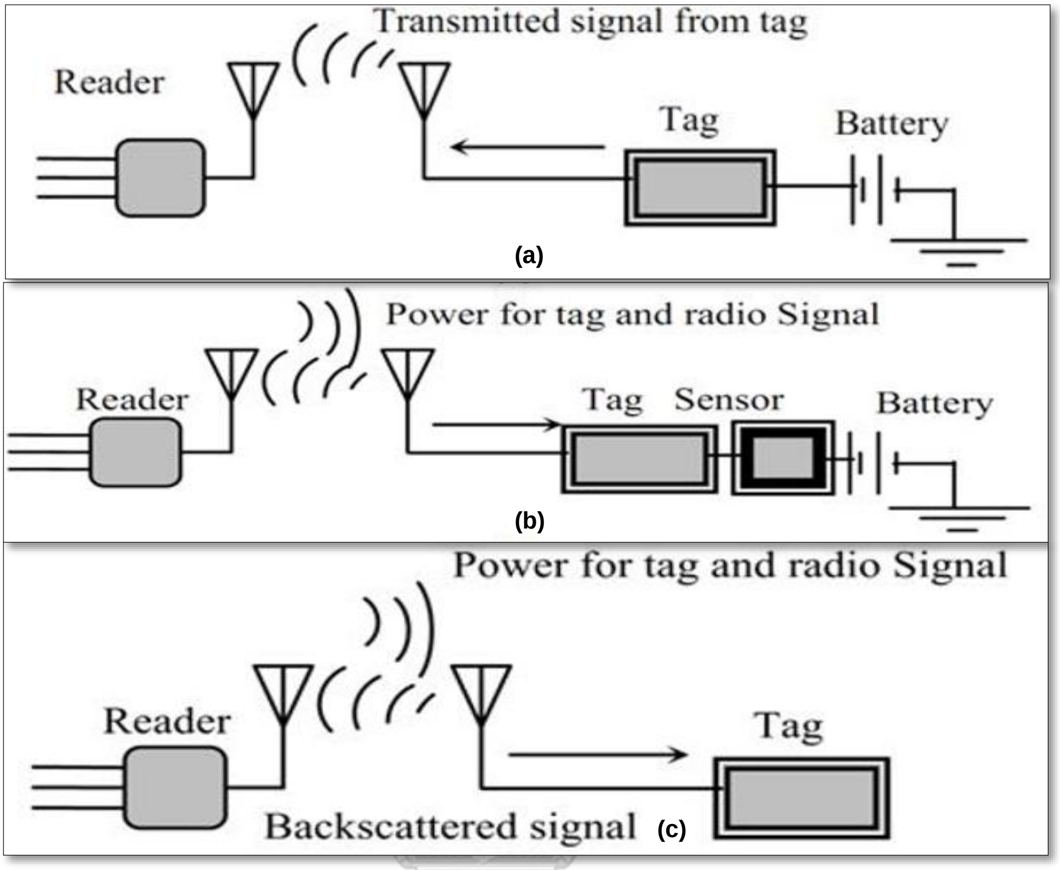


*Figure 14 - Shows the overview of an RFID tracking system*
*(a) Active Tag, (b) Semi-Passive Tag, and (c) Passive Tag (Khan, et al., 2009)*



RFID reader and tag can operate in three different frequencies, i.e. low frequency (LF; 125-134 KHz), high frequency (HF; 13.56 MHz), and ultra-high frequency (UHF; 850-950 MHz). In table 4, each RFID frequency is adopted in different applications due to the limitation of its frequency range capability. According to the case study, ultra-high frequency (UHF) is the most suitable frequency range for the company’s requirements of warehouse management in case and pallet tracking.

*Table 4 - Shows technical specification of each frequency type of RFID tag*

| Description | Low Frequency (LF) | High Frequency (HF) | Ultra-High Frequency (UHF) |
|---|---|---|---|
| Frequency range | 125-134 KHz | 13.56 MHz | 850-950 MHz |
| Tag type | Passive | Passive | Active and passive |
| Read range | 0-0.5m | <1.5m | Active= up to 100m, Passive = up to 3-5m |
| Tag size | Large | Large | Small |
| Data transfer rate | Slow | Medium | Fast |
| Ability to read near metal or wet surface | Best | Better | Worse |
| Tag cost | High | Lower than LF tags | Lowest |
| Typical application | Livestock tracking, Beer Kegs, Auto Key & Lock, Library Books | Item level tracking, Airline baggage, Building access | Supply chain tracking, Warehouse management, Case, pallet, truck and trailer tracking |

However, UHF RFID tags can be distinguished into three types, i.e. active tag, semi-passive tag, and passive tag. Table 5 shows the specification comparison of three different types of UHF RFID tags. For active-type tag, the size and the weight of the tag is certainly not suitable for attaching on each carton box, thus, active-type tag is not considered in this case. However, for semi-passive tag, the size and the weight of the tag is lighter than the active tag, and also the tag has the similar read range to the active tag of more than one hundred meters; but it required a built-in battery installed inside the tag, which cause its potential shelf life to be around 2-7 years, depending on how often the tag is being used.

Even though the semi-passive tag is reusable, however, the tracking data could be lost due to the process of removing and collecting tags from each carton box before loading into the shipping container, thus, the tags should be attached on the carton boxes and shipped into the container in order to avoid the discrepancy in inventory data. Also, the cost of semi-passive tag is relatively high compared to the passive tag.



Therefore, in this case, for warehouse tracking system, passive UHF RFID is the most suitable due to outstanding advantages such as fast data transfer rate, small tag size, easy to attach, longest shelf life of more than 20 years, and especially the lowest tag cost compared to other systems.

*Table 5 - Shows the Specification Comparison of three different types of UHF RFID Tags (Active, Semi-Passive, and Passive) (Khan, et al., 2009)*

| Description | UHF RFID Tags | | |
|---|---|---|---|
| | Active | Semi-Passive | Passive |
| Example |  |  |  |
| Internal Power Source (Battery) | Required | Required | No |
| Resistance to Harsh Environment | No | No | Yes |
| Size | Largest | Medium | Smallest |
| Weight | Heaviest | Medium to light | Light |
| Potential Shelf life | 2-7 years | 2-7 years | > 20 years |
| Read Range | >100meters | >100meterss | 3-5meters |
| Reusable | Yes | Yes | No |
| Able to communicate with other active tags | Yes | No | No |
| Additional Sensors (i.e. temperature and pressure sensor, etc.) | Yes | Yes | No |
| Tag Cost | Most expensive 500-3,000 Thai Baht (depends on quantity) | More expensive 200-1,500 Thai Baht (depends on quantity) | Cheapest 1.20-5.00 Thai Baht (depends on quantity) |

*3.2.1.1 Material effects on Antenna Power Pattern*

Radio waves can be reflected and refracted by different materials especially metal and liquid. For example, during the signal transmitting, if a tag is attached to any metal-like surfaces, a large portion of radio energy will become reflected, thereby, the transmitting signals will become degraded and be interfered in the reception quality of the tag antenna (Wu, et al., 2006), (Battini, et al., 2015). In figure 15, shows the comparison of signal power pattern deflection of (a) a tag not attached to any products (good pattern), and (b) a tag on a metal product (bad pattern).

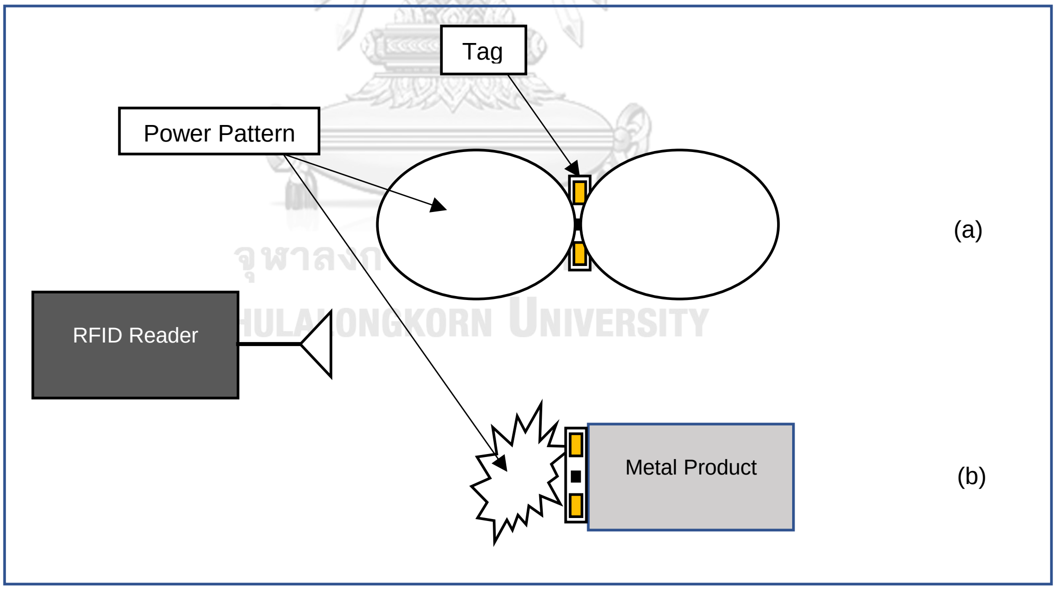


*Figure 15 - shows the comparison of signal power pattern deflection of (a) a tag not attached to any products (good pattern), and (b) a tag on a metal product (bad pattern). (Wu, et al., 2006)*

#### *3.2.1.2 Collision in Radio Wave Transmission*

One of the most outstanding advantages of RFID technology is the reading capability; hundreds of transponders or tags can be read by a reader in few seconds. However, the simultaneous transmitted radio signals can possibly cause collision interference to the reader, leading to a chance of reading failure. In figure 16, shows the illustration of signals collision of (a) tag collision, and (b) reader collision. Nevertheless, there is a technical access protocol that facilitates the handling of multi-radio transmission without any interference, namely an *anti-collision algorithm (Finkenzeller, 2010)*. The anti-collision algorithm enables a reader to effectively identify tags with minimum chance of simultaneous interfering transmission. The anti-collision protocol identifies the staying tags by remembering the sequence order in which the tags were recognized in the previous scanning process. However, Wu et al. (2006) suggest that to increase a success reading rate of RFID tags, the RFID system has to be configured so that the tags are read one at a time by a reader; however, it is time-consuming especially with a great number of tags.

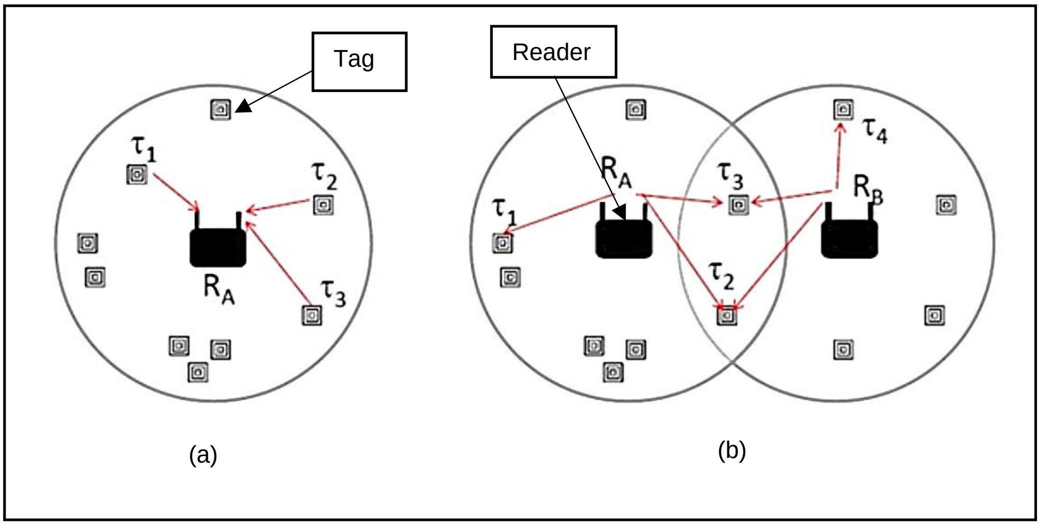


*Figure 16 - Shows the Illustration of (a) tag collision, and (b) reader collision*

### *3.2.1.3 Effect of Tag Orientation to Radio Wave Reception*

In real-world tracking application, RFID tags will have random antenna orientations since the tags are attached on variety of packages or products, hence, some tag antennas may happen to be in perpendicular orientation to a reader antenna (Wu, et al., 2006). Tag antenna orientation affects readability of the reader antenna due to degradation of radio wave power pattern (Finkenzeller, 2010). As shown in figure 17, the tag antenna (A and B) are perpendicular to the reader antenna (C, red), in this orientation, the tag antenna cannot receive the radio signal emitted from the reader. However, in figure 15, another reader antenna (D, green) which is installed with a different orientation can solve the issue (Wu, et al., 2006).

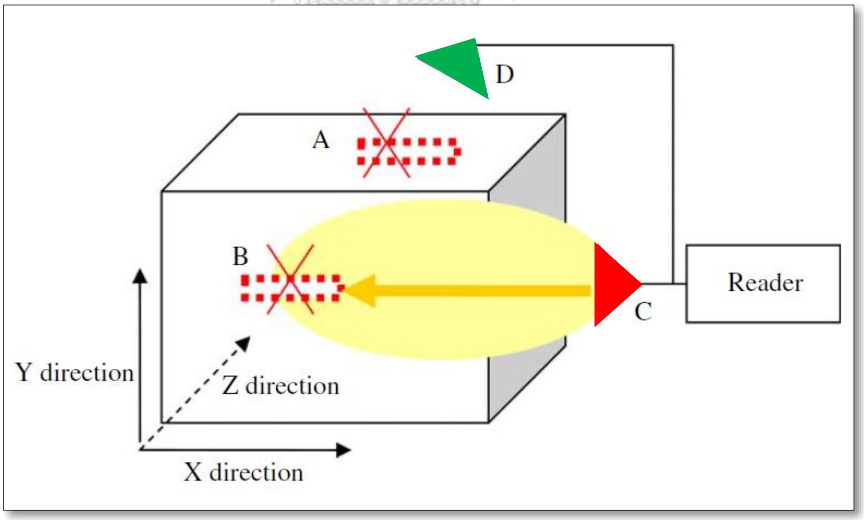


*Figure 17 – Shows the tag antenna orientation and radio wave reception issue (Wu, et al., 2006)*

### 3.2.2 Wireless Network and Communication System

One of the most common wireless networking technologies used in industrial warehouse is Wireless Fidelity technology (Wi-Fi). In warehouse tracking operation, a handheld tracking device is one of the most significant equipment which requires an effective wireless network system to successfully transfer and exchange data with the management software such as WMS and ERP system. Wu et al. (2006) also state that if one hundred per cent accuracy of any tracking system cannot be achieved, there would be a serious problem in the operation.

Wi-Fi also uses radio waves to transmit and exchange data between any Wi-Fi-supported devices, hence, when the radio signals transmit through some mediums such as water, air, and metal; the transmitted signals can be refracted and reflected which can cause a significant loss in signal strength, see figure 18. Typical automotive warehouse consists of metal racks, plastic pallets, and carton boxes with metal components inside. Therefore, to make sure that the Wi-Fi signals are covered the entire area of usage, many companies conduct site survey studies to determine the quantity and location of required access points (APs) (Plets, et al., 2016).

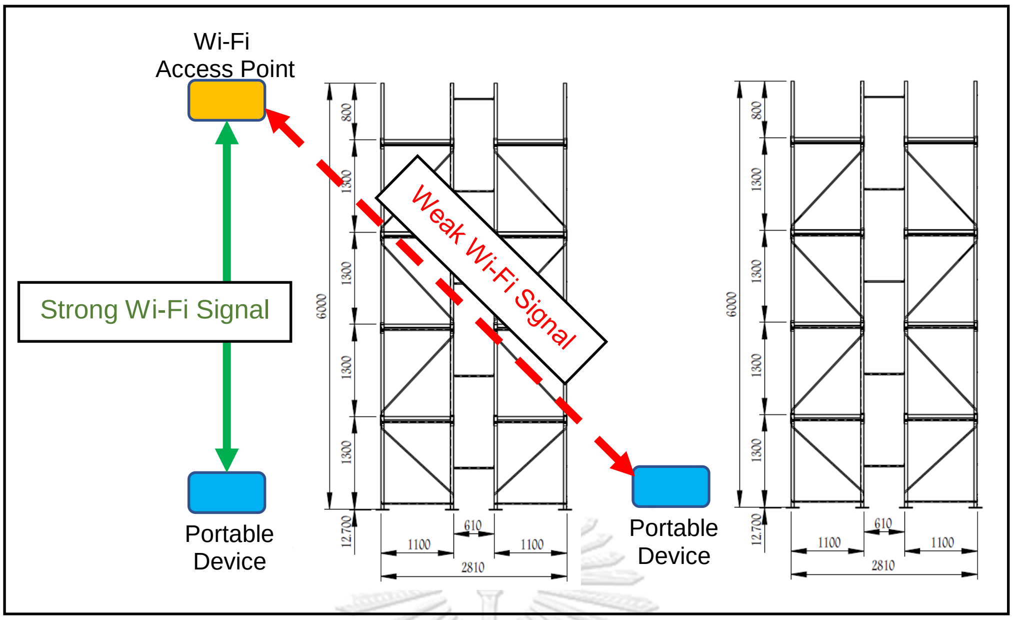


*Figure 18 – Shows how the transmitted signals can be blocked by a warehouse rack (side-view layout)*

## 3.3 Stage 3: Hardware Adoption and Selection

Before designing and implementing the technologies into the existing system, the warehouse resources, layouts, and other environment constraints are recognised. According to the case study, the discrepancy and errors in warehousing data are the main issue in the warehouse management; the errors are probably caused from a human error due to the manual operation. Hence, to overcome the issue, RFID tracking technology is introduced; the RFID can be flexibly implemented or designed based on a specific business requirement.

### 3.3.1 RFID Equipment Design and Selection

Since the discrepancy and errors in inventory data are evidently caused from human errors due to manual operation. There are more than six thousand units of finished goods moving in and out of the warehouse, thus, some finished goods might be mistakenly transferred in or out without any records. Therefore, to solve the issue, fixed RFID readers should be thoroughly installed at each gate of the warehouse, including inbound and outbound gates as shown in figure 19.

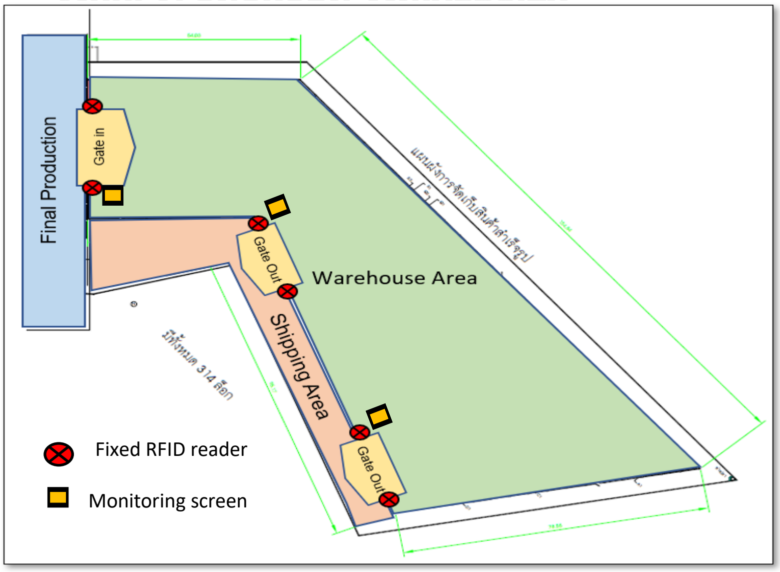


*Figure 19 - Shows the location of fixed RFID readers and monitoring screens.*

In addition, to achieve the highest data reading accuracy, the quantity, signal orientation, and location of readers are significantly to be concerned. In figure 20, five fixed RFID readers, two at both side (left and right) and one at the top of the gate, are installed to effectively transmit radio signals to the RFID tag antennas that attached on each carton box.

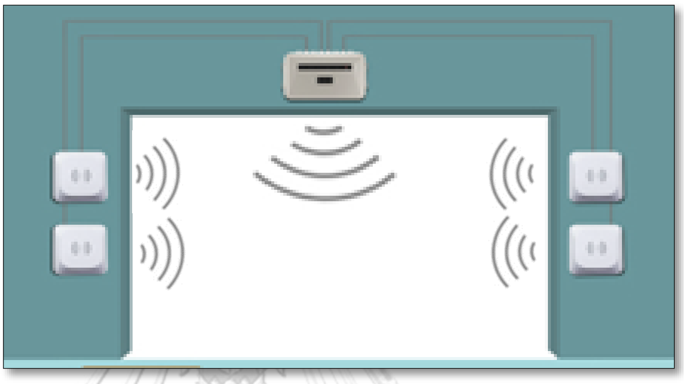

*Figure 20 - Shows the location and signal orientation of fixed RFID reader antennas at the gate.*

### *3.3.1.1 Hardware Network System Structure*

In typical warehouse, Sujing et al. (2010) suggest that the network system can be distinguished into two parts, i.e. for warehouse office area and warehouse storage area. According to the existing environment of the case study, in office area, there are mainly consisted of application server, database servers, and workstations. The users can access, e.g. WMS or ERP on the application servers by their own workstations. Another part is used for the warehousing operation in storage area, it is mainly consisted of, in this case, RFID equipment, including, handheld readers, fixed readers, forklift readers, RFID tags and other wireless devices as shown in figure 21. These devices are connected to the same intranet with wireless routers or access points.

Warehouse operators manage goods movements, including receiving, storing, and picking by using the embedded application running on these devices.

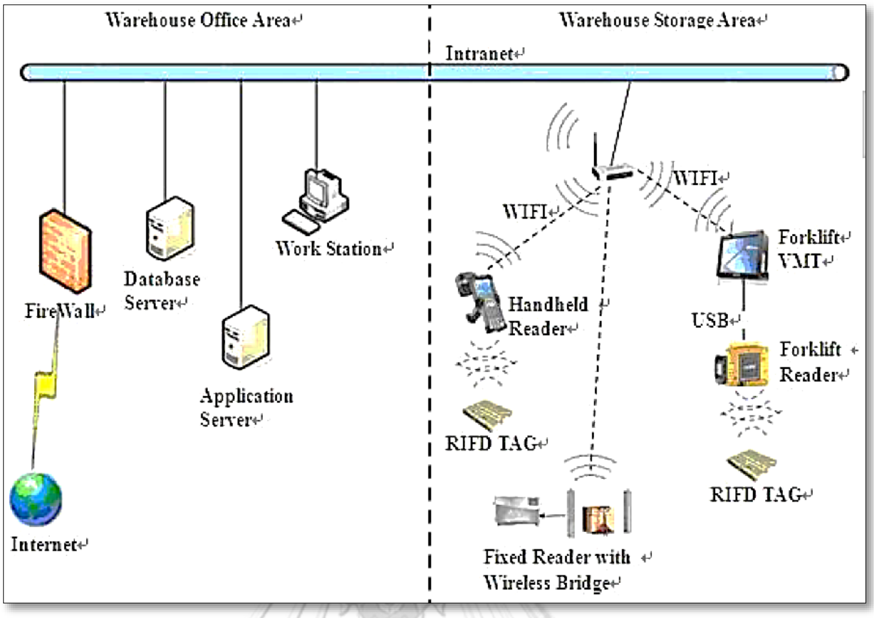


*Figure 21 - Shows the overall network architecture in a typical RFID warehouse (Sujing, et al., 2010)*

The implementing warehouse system integrates RFID technology with embedded mobile application and database into the wireless network communication. Thus, the warehousing operation such as inbound, outbound, and inventory control can be efficiently managed and controlled via the wireless network in real-time; in addition, the information and operation, and the overall cycle time can be significantly enhanced by implementing these intelligent technologies (Ma & Liu, 2011).

*3.3.1.2 Carton and Tag Orientation Designs*

The passive UHF RFID tag is selected to be used in the study due to the outstanding advantages of tag size (smallest), data transfer rate (fastest), and tag cost (cheapest), which are widely adopted in many supply chain applications, especially in warehouse management and tracking system (Yatinkumar, 2017).

However, refer to the product of Company X, the physical product is made from aluminum as the main material; unfortunately, UHF radio waves can barely pass through the metal surface, instead a large portion of radio energy will become reflected, and the signal strength will be reduced (Wu, et al., 2006).

Therefore, the orientation of the tags attached on each carton box should be carefully arranged in order to minimise errors that may occur during the reading or scanning process. The tags should be clearly detectable by the reader antennas; thus, an operator should arrange the carton boxes on the pallet in the position that the tags can easily be read by the reader antennas. The orientation of the tags and the reader antennas can be configured as shown in figure 22, moreover, two additional reader antennas are installed at the top of the gates to minimise the reading errors when the tags are wrongly arranged by the operators.

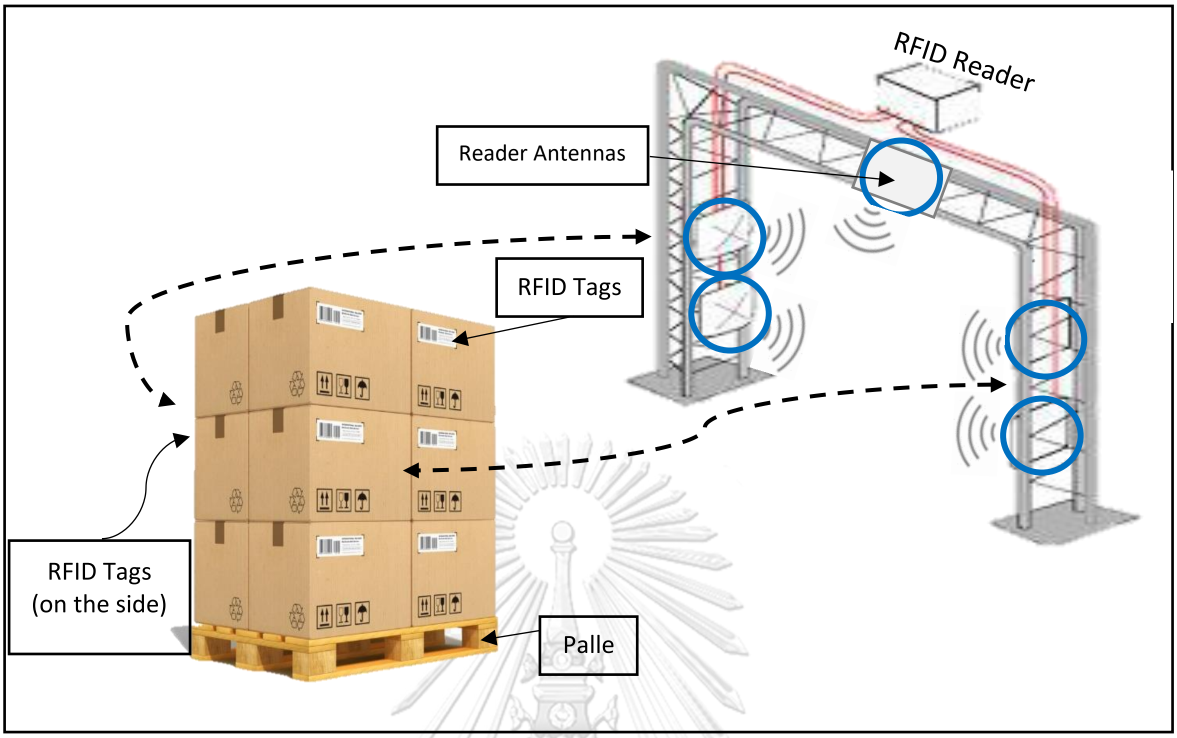


*Figure 22 - Show the Orientation of RFID Tags and Reader Antennas at the Gates.*

### 3.3.1.3 Forklift Antenna Orientation Designs

According to the position and orientation of the reader antennas at the gates, the main reader antennas are installed at both sides (left and right) to scan and verify any finished goods that passed through the gates. Thus, the location of the tag should be also arranged to the side (left and right) of the forklift while moving through the gates. However, the typical location of the reader antenna is located only at the back rest of the forklift, in this case, the signal can barely pass through the metal products, which can cause errors in the readings, leading to the discrepancy in inventory data.

RFID readers and antennas are mounted on forklift for an operator to scan and to update product information such as quantity and location to the warehouse management system. However, with the limitations of the UHF radio waves and the tag reading orientation, the radio signals can be disrupted and unable to be read by the readers. In figure 23, shows the typical position and orientation of the reader antennas mounted on the forklift; however, due to the limitations, two additional antennas should be mounted at the sides extending from the back rest of the forklift to cover a longer read range for a higher success rate of readings shown in figure 24. Moreover, a small reader antenna should be installed at the bottom of the forklift's back rest specifically for rack location readings as shown in figure 23 and figure 24.

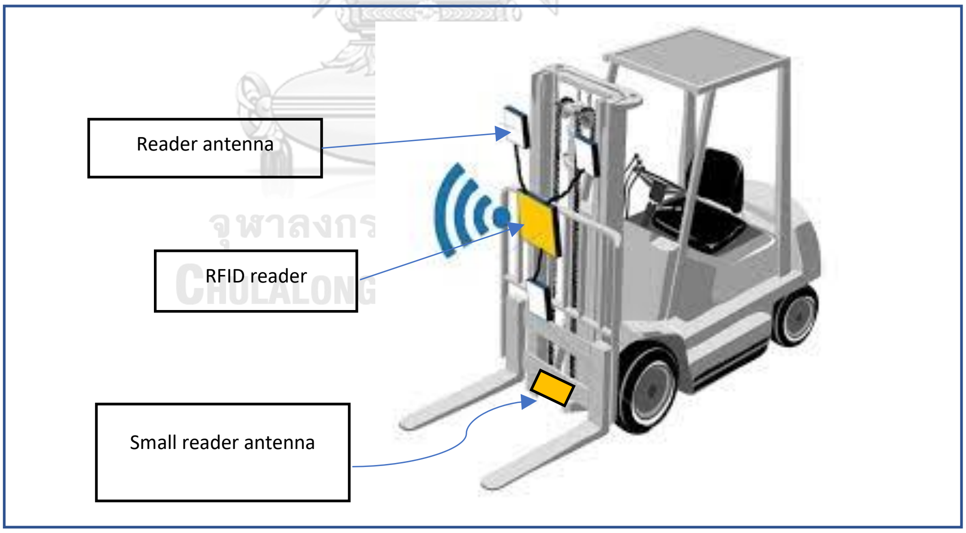


*Figure 23 - Shows the Typical Orientation of RFID Reader and Antennas.*

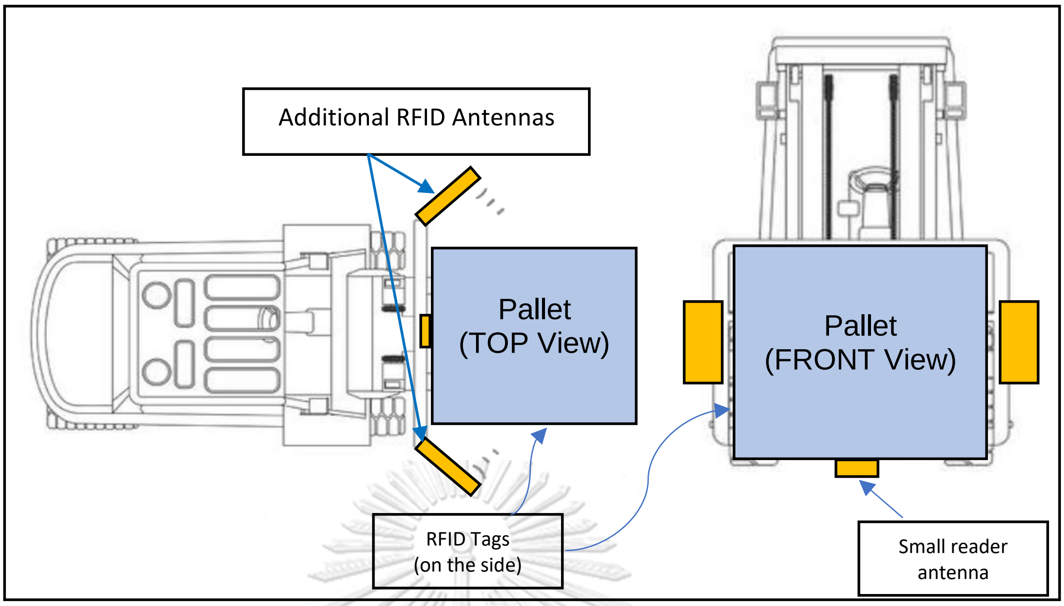


*Figure 24 - Shows the Orientation of the Additional RFID Antennas Mounted on the Forklift.*

*3.3.1.4 Pallet Rack and Location Tagging*

In putaway process, the finished goods are moved to the storage location suggested by the WMS software. First, a putaway operator drives a forklift to the receiving area to pick the finished goods. The driver then presses scan button to read the product information and moves the goods to the assigned location. After the goods are placed at the suggested location, the driver presses scan button to confirm the putaway location, so the WMS can verify and record the location address of the goods. The information of storage location is captured and transferred to the WMS via RFID system.

The forklift RFID reader transmits radio signals to the RFID tag to exchange the information. The RFID tag is attached to each of the slot location on the rack (see figure 25). However, the tag can be affected by the metal rack, causing the blocking, reflecting, and scattering of the transmitting radio waves; therefore, (Park & Eom, 2011) found that inserting a Styrofoam (insulator) between tag and metal surface can enhance the quality of the signals (see figure 26).



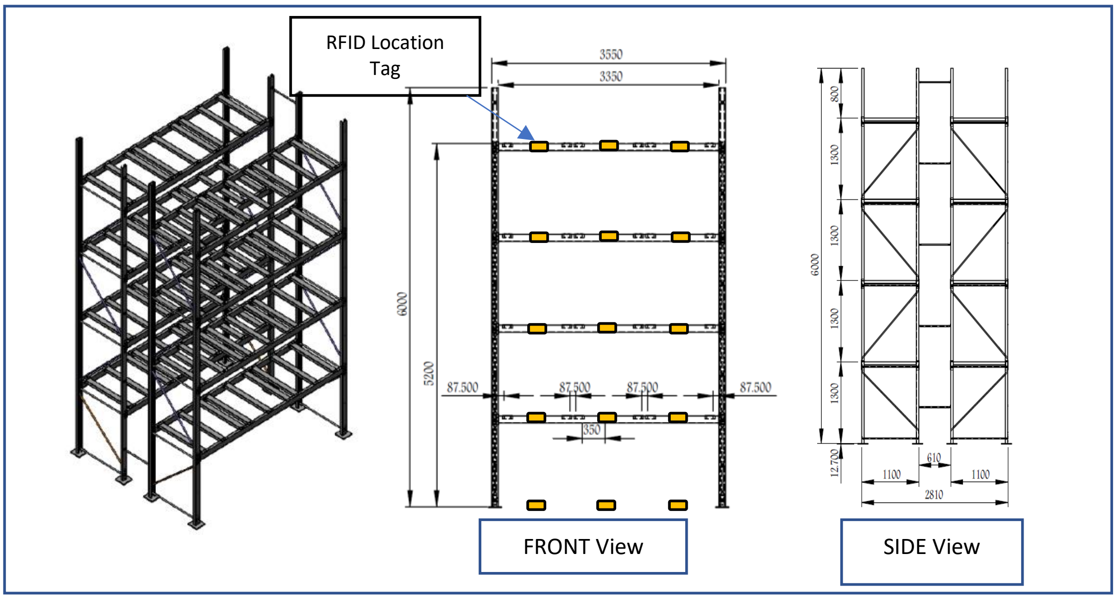


*Figure 25 - Shows the position of the location tag mounted on the pallet rack*

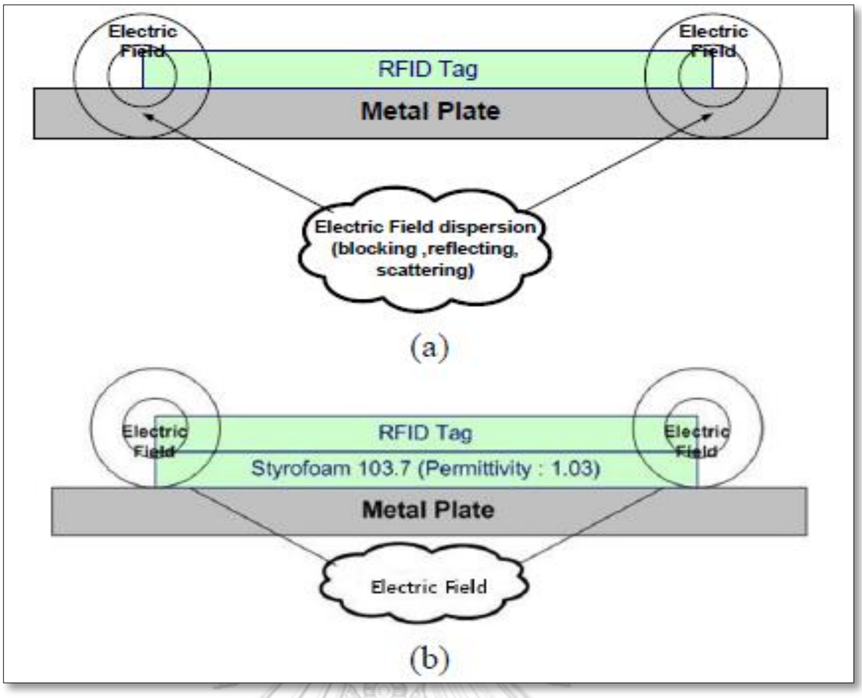


*Figure 26 - Shows the Difference Range of Electromagnetic Field between (a) RFID tag and Metal Plate (Without Styrofoam), and (b) RFID tag and Metal Plate (With Styrofoam), (Park & Eom, 2011)*

### *3.3.1.5 Software Function Design and Implementation*

The Warehouse Management System (WMS) consists of the WMS main application and the embedded application in handheld devices, both software applications are run on the same application web server. The software applications can be specifically customised according to the business requirements. Based on the case study, the WMS database should be interfaced with the existing business management software, i.e. Enterprise Resource Planning (ERP); as a result, the warehouse information can be quickly accessed by any related business functions such as production, sales, and finance department for achieving more effective management in production planning, stock availability check, and inventory audit respectively.

The embedded application should automatically suggest the putaway location after a tag reading process in the receiving stage (figure 27). Then, the operator is able to correctly move the pallet of goods to the assigned location, and after the process, the application should send the update information to the WMS database. In addition, the WMS application should provide the function of inventory check including generating inventory checklists, creating inventory check reports, and record the inventory check information into the system database (Sujing, et al., 2010). The designed software architecture is shown in figure 28.

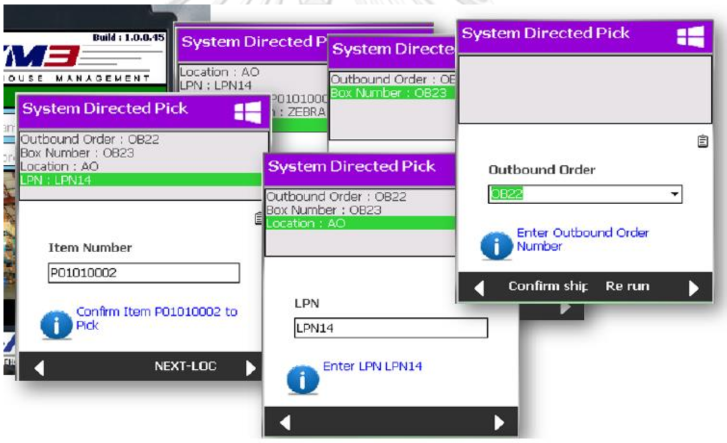




*Figure 27 - Shows the Example of Embedded Application on a Handheld device.*

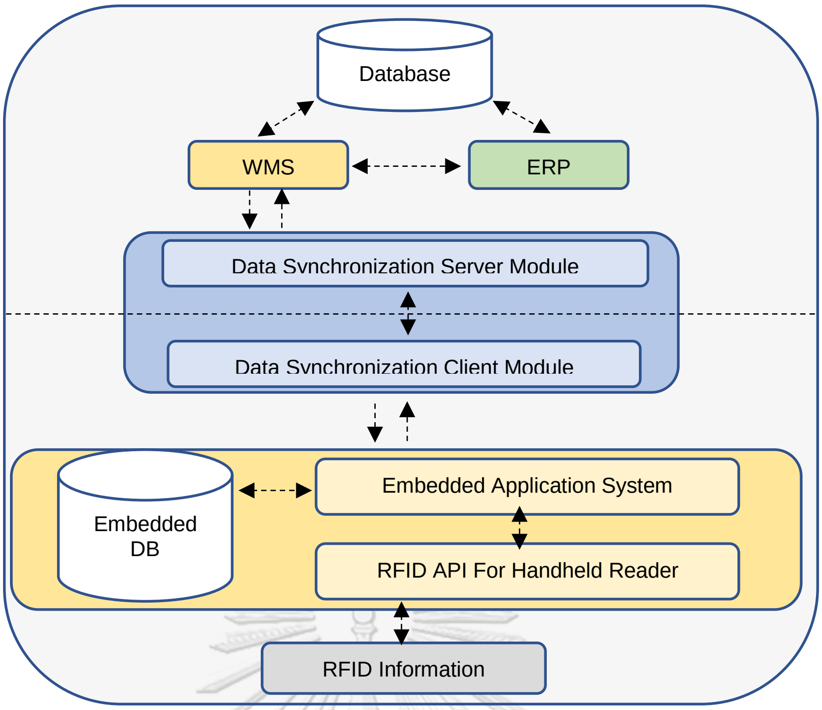


*Figure 28 - Shows the Architecture of the Designed Software System, [modified: (Sujing, et al., 2010)]*

Furthermore, to effectively manage and control the inventory, the optional technology called Virtual Warehouse is introduced. The virtual warehouse can display goods location and information in different level of rack in real-time; however, the user interface of the application can be flexibly customized based on a specific requirement. In figure 29, shows the example of the virtual warehouse in WMS application.


*Figure 29 - Shows the example of the virtual warehouse in WMS application*

*3.3.1.6 Determine the quantity and location of required access points*

According to the case study of Company X, the company's warehouse has a total area of 8,000 Sq.m. which consists of 25 rows of metal racks (5,000 pallet slots), the height of each rack is 6 m., plastic pallets and carton boxes filled with aluminum components are stored in the pallet slots as shown in figure 30 and figure 31.

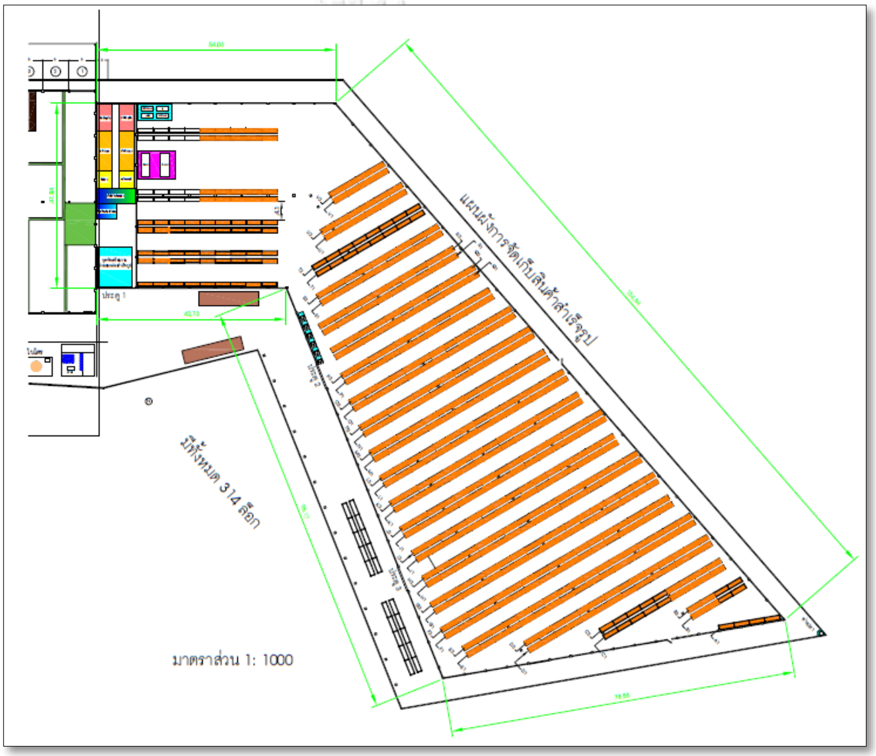


*Figure 30 - Shows the overall layout of Compay X's warehouse*

*Figure 31 - Shows the actual pallet racking design in the warehouse of Company X*

To determine the suitable quantity and location of the required access point (APs) for obtaining the most effective Wi-Fi network coverage, many companies conduct site survey studies; however, for a very large warehouse area, the site survey method can be very time-consumed and expensive (Plets, et al., 2016). Nevertheless, there is a wireless site survey simulation software called AirMagnet, the software can simulate a heatmap showing the signal strength in different color shades. The heatmap simulation of Company X's warehouse is shown in figure 19. The signal strength, in this case, is ranged in negative numbers from (-)30 to (-)95 dBm (decibel-milliwatts), the higher the number, the stronger the signal.

The signal strength can be divided into two areas ,namely active and inactive; for active area of more than (-)65 dBm in signal strength means that the chance of connectivity loss is relatively low; and for inactive area of less than (-)70 dBm in signal strength means that the chance of connectivity loss is relatively high, which also means that any connected devices located in those areas may loss the connection from the main server. Any information captured during the connection loss may affect the accuracy in inventory data; however, the captured data is still recorded in the device. Once the device is successfully reconnected back to the system, the information will be automatically updated into the system (confirmation may be required). Although, the information losses during the connection problem can be recovered, but the inventory data can be delayed, and possibly cause errors in other business functions.

Therefore, in figure 32, shows the minimum quantity requirement of access point for the specific warehouse infrastructure of at least 14 units to cover the overall areas in active mode with more than (-)65 dBm in signal strength. Therefore, in the study, 14 access points with the specific configurations are suggested to be applied.

However, the heatmaps results are not a hundred percent accurate since the simulation software is an approximation based on the input parameters; hence, a proper test run or a short site-survey should be made due to the complex environment.

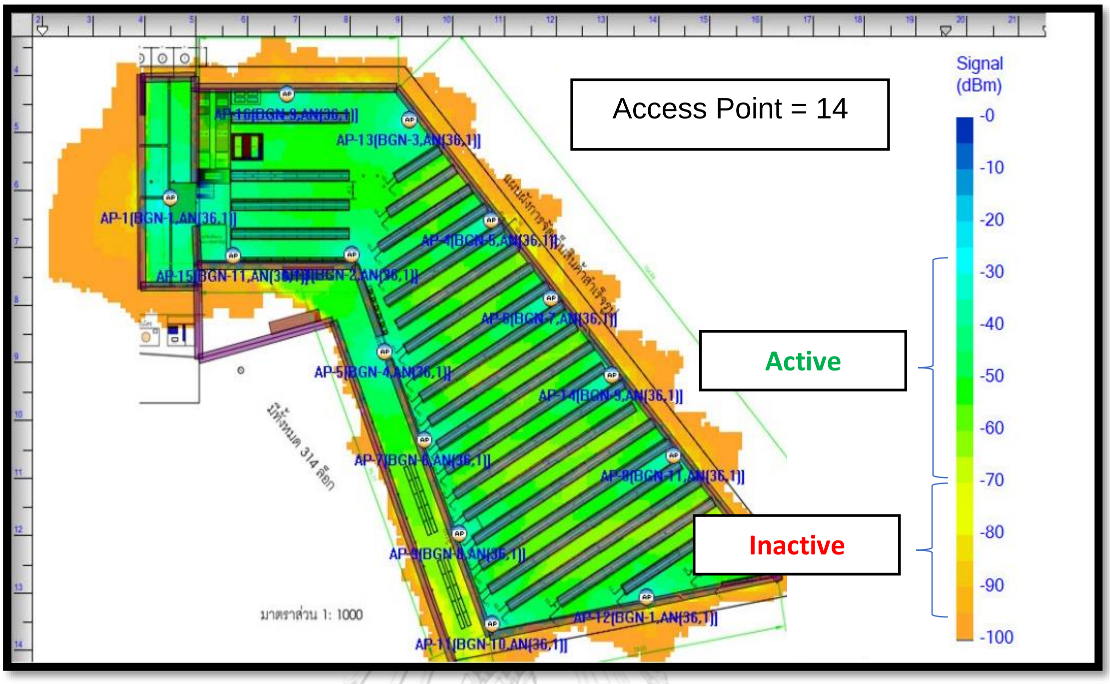


*Figure 32 - Shows heatmap of wireless signal and location of access point of Company X's warehouse [14 APs]*

## 3.4 Stage 4: Process Redesign (TO-BE)

The warehouse processes comprise of receiving, putaway, order picking, and shipping; however, in term of the warehouse flow system, those processes can be categorised into three main flows, including inbound flow (receiving and putaway), outbound flow (order picking and shipping), and inventory control flow. Information and operation flows of the proposed system are explained step-by-step for each warehousing process as follows:

### 3.4.1 Inbound/Input Flow (Receiving and Putaway)

According to figure 33, the first stage of the tracking process is the RFID tagging preparation; operator at final production process (packing) writes or enters the product information (including lot number, model code, date, and quantity) into the RFID tags which are attached on each carton box, meanwhile the entry information will be automatically updated to warehouse management system before sending to the next process.



The second stage is the warehouse receiving process; the operator moves the finished goods into the warehouse through the gate-in process which there are fixed RFID readers installed at the gate. Then the information of the goods should be displayed on the receiving monitoring screen, and the reader embedded application should automatically check and verify with the warehousing entry information that were previously inputted into the system. If discrepancy or errors are detected, the system should immediately alert in the form of light and sound for the operator to repeat or recheck the process.

The last stage is the putaway or storing process; a forklift driver presses the button on the forklift reader to scan the goods information for the suggested rack location from WMS, then the driver moves and places the pallet of goods to the suggested location. After the putaway process, the forklift reader and the application should automatically send the location confirmation to WMS for inventory updates. However, during the scanning process, if the location or quantity information that read by the forklift reader are invalid, a handheld reader can be used to further support for the unusual reading orientation of the tag antennas.

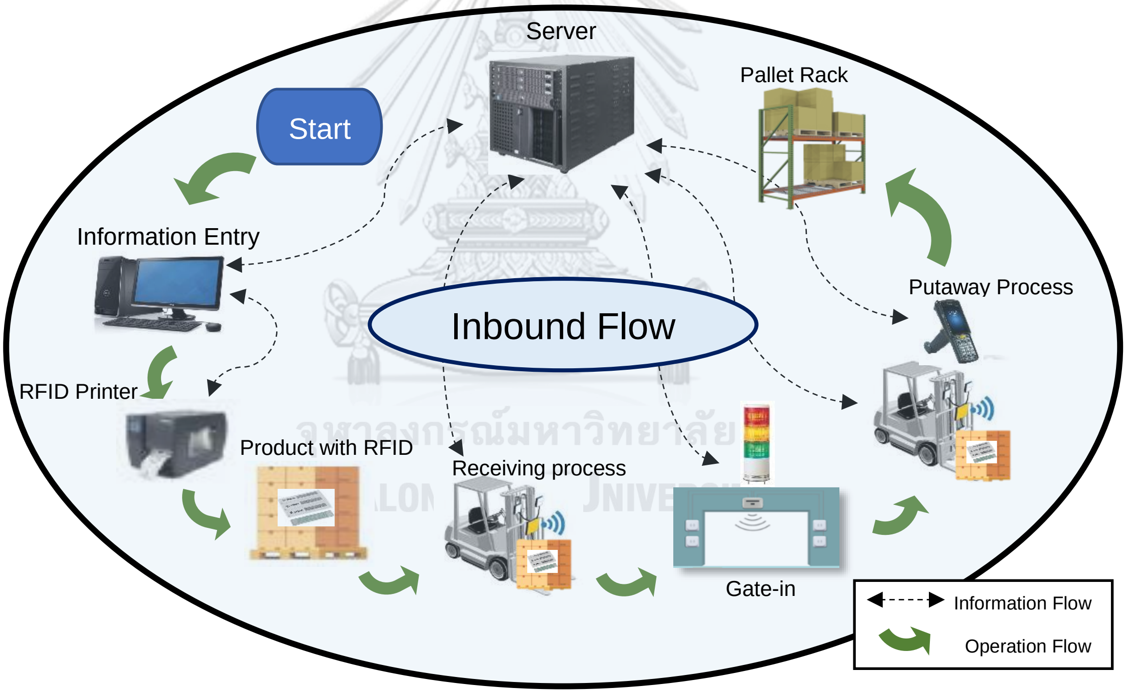


*Figure 33 - Shows the Inbound Information and Operation Flows of RFID*

### 3.4.2 Outbound/Output Flow (Order Picking and Shipping)

The outbound operations are composed of order picking and shipping process. According to the figure 34, the order picking process initiates when an order notification from sales department is sent to the warehouse via the ERP-WMS software interface. The warehouse forklift driver is required to respond to the application to get the order picking list from WMS database. Then the forklift operator should navigate to the picking location that displayed on the forklift information screen.

Once the operator reaches the picking location, the operator presses the button on the forklift reader to scan the tag information. Then the reader and the embedded application should automatically check and verify for discrepancy or errors. If any issues are found, the system should immediately alert in the form of light and sound for the operator to repeat or recheck the process.



After the picking confirmation is validated, the operator is allowed to move the picking pallet to the handover area waiting for the next process. The shipping process is the final warehousing operation where there is a significant inventory deduction process. At this stage, the final shipping quantity of goods will be permanently deducted from the warehouse inventory, which has a direct impact to the stock accuracy. As a result, the final goods will be automatically confirmed by the fixed RFID readers at the outbound gates to effectively verify with the shipping information lists for discrepancy or errors before validating for the final inventory deduction.

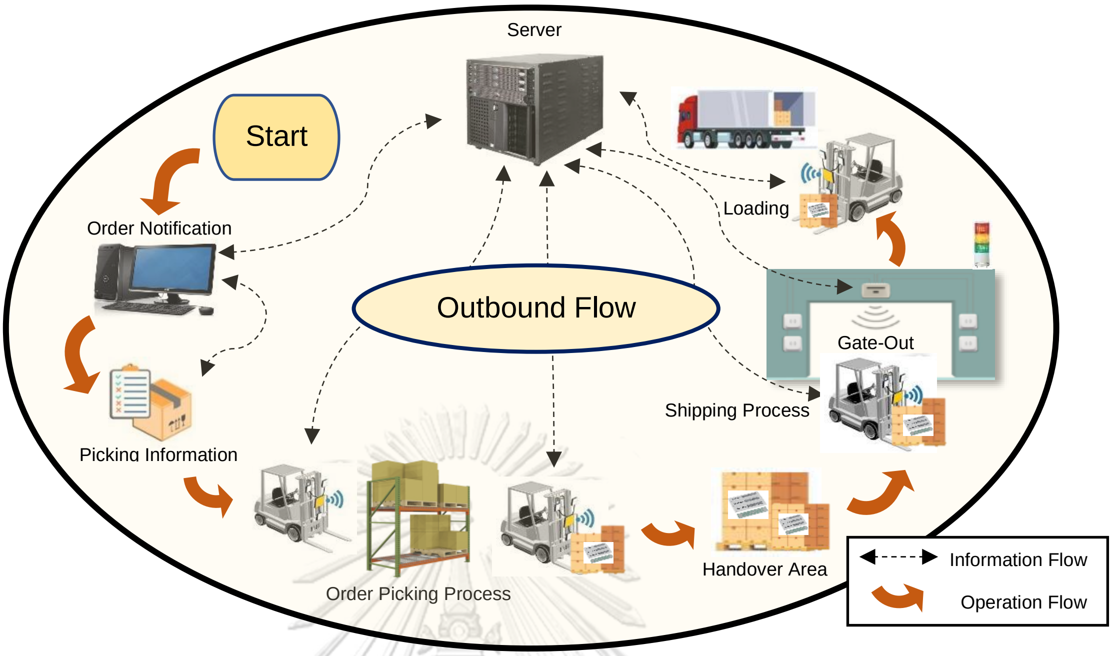


*Figure 34 - Show the Outbound Information and Operation Flows of RFID*

### 3.4.3 Inventory Control Flow

The inventory control process is mainly consisted of basic warehousing management, including product relocating, status updating, inventory counting, and inventory adjustment. An extra movement of items in warehouse can regularly happen especially for a narrow-type of warehouse. Due to the limited in warehouse space, the location of goods has to be relocated for maximising the space utilisation.

The product relocating process is started when an operator scans the tag by using a handheld device, the goods information will display on the device, then, the operator has to input the information, including new location and quantity of goods into the device. The operator then moves the goods to the assigned new location, and scan the tag location for confirmation. Meanwhile, the new location and quantity information will be sent to the WMS for data updating. For inventory check process, an operator starts the operation by generating inventory checklists, and conducting an actual inventory counting. After that the system will create inventory check reports for the operator to conduct an inventory adjustment via the workstation. Meanwhile, the inventory check results will be automatically recorded into the WMS database.

The overall proposed warehousing operation flowchart (TO-BE) is shown in figure 35. The proposed RFID system provides many outstanding benefits for each warehousing operation such as in receiving, the system provides an automatic quantity counting, product confirming, and data recording into the system; in putaway, the stock location is automatically suggested by the WMS system, and after the operation, the putaway location is automatically recorded into the system without any human interaction; in order picking, the digital picking list is generated, and displayed on the handheld device navigating to the picking location, and also, the system can automatically check and verify model number and quantity of the picked item; in shipping, final shipment information is automatically checked and verified, and communicate with WMS system to update the remaining inventory data.



With the proposed RFID system, information of each step of the operations is automatically recorded and updated into the WMS in real-time, therefore, any errors caused by human factors can be reduced, and the operation efficiency can be significantly increased.

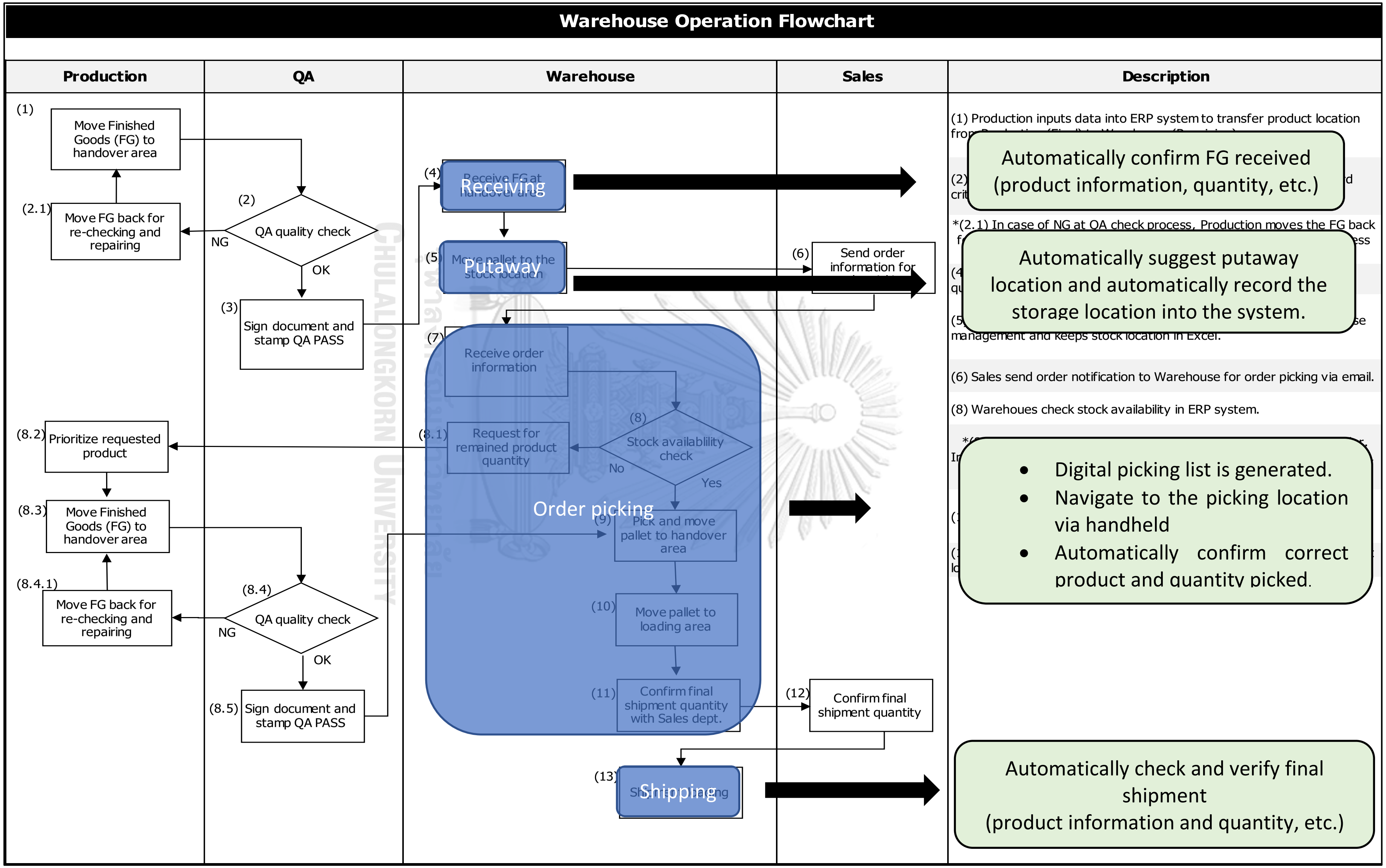


*Figure 35 - Shows the Proposed Warehouse Operation Flowchart with Warehousing Process Label (TO-BE)*

## 3.5 Stage 5: Cost Reduction and Investment Analysis

### 3.5.1 Data Collection and Data Analysis

In order to effectively analyze and determine the quantitative benefits of RFID to the business, cost reports and other required data is collected from the recent years to the present time (2018-2019); Potential costs and impacts due to an inaccurate in inventory can be identified in table 6.

The required data are collected from available documents, such as warehouse structural drawings are significant piece of information for designing the warehousing flows. Also, productivity logs, wage rates, and shift premium reports are used to analyse and determine the cost of labour for warehousing cost reduction analysis. Therefore, these required data are the important factors for achieving the most advantage from the integration of the technologies.

*Table 6 - Shows the Potential Costs and Impacts due to an Inaccurate in Inventory Data*

| Inventory Data (Error in…) | Impact | Cost Impact | Cost report |
|---|---|---|---|
| Quantity | • Overproduction<br>• Underproduction | • Overtime cost increases (difficult working environment)<br>• Revenue decreases due to sales opportunity losses | • OT record<br>• Number of products ordered Vs Number of products shipped |
| Location | • Product missing/difficult to search | • Overtime cost increases due to picking time increases | • OT record |
| Model number | • Shipping mistake | • Extra shipping cost or possible air freight charges | • Claim report<br>• Extra shipping cost |

### 3.5.2 Lead Time Reduction

In the current warehousing operations, in each process of receiving, putaway, order picking, and shipping, employees are the main driver handling and processing not only numerical information, but also physical operations, e.g. counting goods, writing paperwork, and moving goods in and out of the warehouse. Thus, those detailed tasks are time-consumed and probably cause mistakes in inventory data due to human errors. According to Company X, each warehousing process consists of quantity counting and paperwork subprocess, which consume lead time more than 30 seconds for a pallet to process through each stage.

RFID technology can effectively enhance the processes by reducing the process lead time and also increasing the accuracy of the inventory data. The quantity counting and the paperwork process can be eliminated by implementing the RFID system into the existing manual operation. Moreover, with the advanced real-time capability of WMS and RFID technology allows the company to further reduce lead time in the process such as checking stock availability, generating picking lists, searching for goods, and confirming the final shipment quantity. The overall lead time can be further reduced due to the support of the digital information in each of sub-process. For instance, QA check in receiving process, the QA operator can quickly verify and sign confirmation via handheld device (no need of paper writing). Order confirmation between sales and other related business functions can be easily verified via WMS and ERP systems instead of the traditional sending and receiving via e-mails.

According to the current production capacity of 3,000 units per day, which equals to 167 pallets (18 units for each pallet); assume that all pallets are passed through the warehouse operations. Therefore, the lead time reduction at each process can be estimated as follows: receiving (49%), Putaway (47%), Order picking (47%), and shipping (39%), see table 7.

*Table 7 - Shows the Lead Time Reduction in Each Subprocess with the Proposed RFID System*

| Receiving | Manual Lead Time (s) | RFID Lead Time (s) | Lead Time reduced (%) |
|---|---|---|---|
| Counting | 20 | 0 | 49% |
| Paperwork | 16 | 0 | |
| QA check | 63 | 63 | |
| Confirmation | 25 | 0 | |
| **Putaway** | | | |
| Counting | 20 | 0 | 47% |
| Paperwork | 16 | 0 | |
| Move to Storage | 57 | 57 | |
| Location update on paper, whiteboard | 15 | 0 | |
| **Order Picking** | | | |
| Counting | 20 | 0 | 47% |
| Paperwork | 101 | 0 | |
| Receive order confirmation | 17 | 17 | |
| Generate picking list | 5 | 5 | |
| Stock availability check | 18 | 18 | |
| Pick and Move | 84 | 84 | |
| Confirmation with sales | 12 | 12 | |
| **Shipping** | | | |
| Counting | 20 | 0 | 39% |
| Paperwork | 51 | 0 | |
| Final shipment confirmation | 18 | 18 | |
| Packing and Loading | 92 | 92 | |

### 3.5.3 Operational Cost Reduction

With the implementation of RFID, the processing time at each stage of the warehousing operations can significantly decreased due to the contactless, paperless, and real-time processing capability of the technology. RFID system provides faster and more accurate in information management comparing to the current manual operation. Thus, the manual operations such as quantity counting and updating stock location by writing on paper or whiteboard can be permanently terminated. Therefore, the labor costs can be reduced due to the decrement in the working hours. For instance, when the lead time is reduced in a process, human resource or manpower can be relocated to another process for more productivity outputs.

Since the process lead time can be reduced by almost 50% for each process, thus, it can be assumed that the additional time can be used for processing pending work-in-process jobs in normal working time instead of during overtime period. According to the company's normal wage rate (operator level, see table 8) of 400 Thai Baht per day, 8 hours working, and overtime (OT) cost of 1.5times, equals to 75 Thai Baht per OT hour. Therefore, assume that there are the pending work-in-process jobs every day, two hours per day, annually, the overtime cost can be reduced approximately 0.90 million Thai Baht (See Equation 1).

*Table 8 - Shows the Working Details of the Company X*

| Working Details | |
|---|---|
| Labor cost | 400 baht/day, OT = 1.5 times |
| Working hour | 8 hr/ day |
| Working day | 6 working day |
| Working day per month | 25 working day/month |
| Working day per year | 300 working day/ year |
| Number of staff | 20 |
| Remark | Excluding manager |
| | Manager doesn't get paid for OT |

Assume: Overtime (OT) hours = 2 hours

OT Cost per hour = 75 Thai Baht

Working day per year = 300 days

Number of staffs = 20 staffs

*Equation 1 - Shows the Overtime Cost Reduction of the Proposed RFID System*

$Overtime\ cost\ reduction$

$= (Total\ OT\ hour) \times (OT\ Cost) \times (Working\ day) \times (No.of\ Staff)$

= (2 hours) x (75 Baht) x (300 hours) x (20 staffs)

$= 900{,}000\ Thai\ Baht.$



In addition, the standard manpower at each process can be revised for reducing the operational costs. According to the subprocess of the operations, the document-related jobs such as quantity confirmation, generating picking lists, and location updating can be replaced by the RFID implementation. Since the proposed RFID lead time in receiving, putaway, and order picking are reduced by approximately 50%, thus, the manpower can be reduced by one man in each process except in shipping process as lead time reduction is less than 40%. Therefore, the total of three people working in the operations can be reduced, see table 9, thus, the total labor cost can be reduced by 0.36 million Thai Baht per year (See Equation 2), which equals to 15% of total labor cost reduction (See Equation 3); therefore, the total operational costs can be reduced by approximately 1.26 million Thai Baht per year (See Equation 4).

*Table 9 - Shows the Number of Labour Reduction for each warehousing process*

| Process | Manual Lead Time (s) | Manpower | RFID Lead Time (s) | Lead Time reduced (%) | Labor Reduction |
|---|---|---|---|---|---|
| Receiving | 124 | 2 | 63 | 49% | -1 |
| Putaway | 108 | 4 | 57 | 47% | -1 |
| Order Picking | 257 | 6 | 136 | 47% | -1 |
| Shipping | 181 | 8 | 110 | 39% | 0 |

*Equation 2 - Shows the Total Labour Cost Reduction of the Proposed RFID system*

$$Total\ Labour\ Cost\ Reduction$$
$$= (Labour\ cost\ per\ day) \times (No.of\ working\ day) \times (No.of\ staff\ reduced)$$
$$= (400\ Thai\ Baht) \times (300\ days) \times (3\ staffs)$$
$$= 360{,}000\ Thai\ Baht$$

*Equation 3 - Shows the Percentage Reduction of Labour Cost per year*

$$Percentage\ Reduction\ of\ Labour\ Cost\ per\ year$$
$$= \frac{(Total\ Labour\ Cost\ Reduction\ )}{(Current\ Labour\ Cost)} \times 100$$
$$= \frac{(360{,}000)}{(No.of\ Current\ Labour) \times (Labour\ cost) \times (No.of\ working\ day)} \times 100$$
$$= \frac{360{,}000}{(20\ staffs) \times (400\ Thai\ Baht) \times (300\ days)} \times 100$$
$$= \frac{360{,}000}{2{,}400{,}000} \times 100$$
$$= 15\%$$

*Equation 4 - Shows the Total Operational Cost Reduction of the Proposed RFID System*

$$Total\ Operational\ Cost\ Reduction$$

$$= Overtime\ Cost\ Reduction + Total\ Labour\ Cost\ Reduction$$

$$= 900{,}000 + 360{,}000$$

$$= 1{,}260{,}000\ Thai\ Baht$$

### 3.5.4 Consumable Resource Reduction

RFID technology can provide real-time product information by displaying on monitoring screen and handheld reader, including checking and confirmation capabilities that can be easily managed via the handheld devices. Thus, large amount of consumable resources such as paper, ink, markers, staplers, and other office stationeries can be reduced, see figure 36. Therefore, with the adoption of RFID technology, the company could reduce the consumable costs of approximately 0.11 million Thai Baht per year. (Table 10)

*Table 10 - Shows the Consumable Resource Reduction Cost of the Proposed RFID System*

| Consumable Resource Costs | | | | | |
|---|---|---|---|---|---|
| | Pallet | Paper per pallet | Paper used per day | Cost per year | Cost per piece (Baht) |
| Paperless | 167 | 2 | 334 | ฿ 20,040.00 | 0.2 |
| | | | | | |
| Ink | 167 | 2 | 334 | ฿ 80,160.00 | 0.8 |
| | | | | | |
| | Row | Cost/pc | month | Cost per year | |
| Whiteboard Marker | 50 | 20 | 12 | ฿ 12,000.00 | |
| | | | | | |
| | Person | | | | |
| Pen | 20 | 5 | 12 | ฿ 1,200.00 | |
| | | | | | |
| | | | | | |
| | | | | ฿ 113,400.00 | |



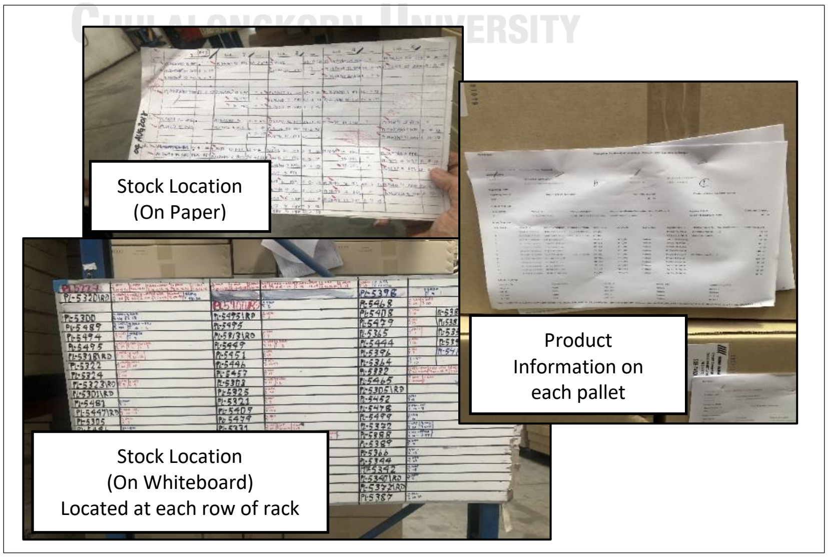


*Figure 36 - Shows the consumable paperwork and whiteboard used in current manual operation*

### 3.5.5 Investment Analysis

All costs related to the tracking system implementation are estimated based on Company X's warehouse infrastructures and the specific product characteristics. Since the company has encountered with errors and losses in inventory data due to human errors of the manual warehouse operation; therefore, the RFID tracking technologies are selected as the effective solution for increasing the accuracy in the data collection. Remark that the estimated costs are obtained from the quotation requests from three RFID suppliers in Thailand.

#### *3.5.5.1 Hardware & Software Cost*

RFID tracking system is consisted of RFID readers, RFID tags, RFID printer, software licenses, and wireless networking. According to Company X's warehouse infrastructures, and the specific product characteristics, the equipment layout designs can be determined as following, 1) five fixed reader antennas are installed at each gate (one inbound and two outbounds), 2) four set of forklift readers are mounted onto the existing forklifts, 3) five handheld reader are placed at each process, and 4) two printers are located in the offices, one at the end of the production process, and another at the shipping process. The total cost of RFID equipment and installation is approximately 0.85 million Thai Baht. (See Table 11)

The WMS software licenses are one of the most expensive items in RFID system. The software is customised which can be developed and modified based on the business requirements. The software is installed in each reader and interfaced with the current ERP system; thus, the total cost of WMS software and software interface is approximately 0.78 million Thai Baht. (See Table 11)

Wireless networking is one of the most important systems in warehouse that acted as the centre of communication transferring information among RFID mobile devices, database servers, WMS, and ERP system. If the wireless network is disrupted or signal loss, the RFID devices will loss communication with the WMS server, and lead to possible errors or data loss. Thus, for the specific infrastructure of the company's warehouse with high storage metal racks, 14 access points (APs) are installed to generate a strong network coverage for the entire warehouse. The total cost of wireless network equipment and installation is approximately 0.31 million Thai Baht. Finally, the overall implementation cost of the proposed RFID tracking system is estimated to be 1.94 million Thai Baht (See Table 11).



*Table 11 - Shows the Overall Implementation Cost of the Proposed RFID System*

| RFID Investment Cost | | | | | |
|---|---|---|---|---|---|
| | Description | Unit price | Quantity | Cost | Total |
| Hardware | Fixed RFID Reader Antenna | ฿ 14,900.00 | 15 | ฿ 223,500.00 | |
| | Forklift RFID Reader | ฿ 25,000.00 | 4 | ฿ 100,000.00 | |
| | Handheld RFID Reader | ฿ 38,000.00 | 5 | ฿ 190,000.00 | |
| | RFID Printer | ฿ 169,000.00 | 2 | ฿ 338,000.00 | |
| | | | | | ฿ 851,500.00 |
| Software | Software | ฿ 630,000.00 | 1 | ฿ 630,000.00 | |
| | Interface | ฿ 150,000.00 | 1 | ฿ 150,000.00 | |
| | | | | | ฿ 780,000.00 |
| Network | AP | ฿ 22,000.00 | 14 | ฿ 308,000.00 | ฿ 308,000.00 |
| | | Grand Total | | | ฿ 1,939,500.00 |

#### *3.5.5.2 Service and Maintenance*

After the complete of RFID implementation, the service and maintenance are the important costs that cannot be neglected, moreover, the costs are normally recurrent annually. Thus, after the warranty period expired, the annual service and maintenance costs are needed to be considered in the financial calculation. Refer to the acquired quotations, the warranty period is only three months after the first initiative, and the service and maintenance costs are estimated to be 0.05 million Thai Baht per year. (See Table 13)

### 3.5.6 Product cost

The RFID tag cost is the main factor to determine whether to invest in the technology or not. Even though, the RFID tag provides lots of tracking advantages for warehousing management, the tag can significantly cause the increment in the unit cost. The RFID tags are attached to each carton box of the product. The UHF RFID tag cost is 1.20 Thai Baht; thus, according to the company's production capacity of 3,000 units per day, then 3,000 RFID tags are required per day, which equal to approximately 900,000 tags per year; the tag cost per year would be approximately 1.08 million Thai Baht (1.20 Baht per tag).

### 3.5.7 Return on Investment (ROI)

Most of companies encounter difficulties in calculating potential benefits of RFID implementation in ROI numbers. When considering ROI numbers, in fact, the ROI is only positive for the customer, not interesting for other involved parts of supply chain, and also the ROI requires lots of time to become positive; however, many researchers recommend that the company must analyse what is critical for its particular business, and what will generate greater benefits (Osyk, et al., 2012) (Lim, et al., 2013) (Dovere, et al., 2017).

According to the company's warehouse performance, in recent years, the company has found a large amount of loss cost in air freight shipping due to the shipping mistakes and backorders. The company has spent more than 0.2 million Thai Baht in average for the loss cost every year. However, operation errors can occur at any stages in process if the management system is not well organised, especially for manual operations, therefore, investing in information technology is essential.



The investment cost of RFID system is relatively high, especially for RFID tag. However, the tag price has been dramatically decreased due to the intensive market competition. In the study, the overall implementation costs including hardware, software, wireless networking, service and maintenance, training, and installation are acquired from three suppliers; the quotations are collected and compared; and finally, the most suitable specification with the lowest price is selected.

Based on the company's infrastructure and requirement of RFID capability, the specific RFID system is designed, and the implementation costs can be estimated as in table 12; the RFID investment costs, including hardware, software, and wireless networking are the fixed costs (one-time expenses), however, service and maintenance, and RFID tag cost are the variable costs that can be changed depending on business productivity, in this case, the annual costs can be predicted (negative numbers) as shown in table 13. Nevertheless, the real-time tracking and high-speed information processing capabilities of RFID system enable the possibility of process lead time reduction; thus, overtime cost, manpower, and consumable cost can be significantly reduced; the reduced costs can be considered as the annual return on investment (positive numbers) shown in table 13.

*Table 12 - Shows Estimated Investment Cost of RFID Implementation for the specific system designs*

| Investment Cost (Fixed) | Million Thai Baht (M.THB) |
|---|---|
| RFID Hardware | ฿ 0.85 |
| RFID Software | ฿ 0.78 |
| Wireless networking | ฿ 0.31 |
| Total Cost | ฿ 1.94 |



*Table 13 - Shows Estimated Return of RFID Implementation for the specific system designs*

| Return (Annual) | Million Thai Baht (M.THB) |
|---|---|
| Overtime reduction | ฿ 0.90 |
| Manpower reduction | ฿ 0.36 |
| Consumable reduction | ฿ 0.11 |
| Service and maintenance | -฿ 0.05 |
| RFID Tag cost | -฿ 1.08 |
| Total Return (per year) | ฿ 0.24 |

The total investment cost is 1.94 M.THB with service and maintenance, and RFID tag cost of approximately 1.13 M.THB per year. However, the return on investment can be estimated as 1.37 M.THB per year; therefore, the total return can be calculated, which equals to 0.24 M.THB per year; then the payback period should be more than 8 years.

However, the cost of UHF RFID tag has been significantly decreased over the last decade due to higher manufacturing yields, and massive deployments of RFID tags in many industries; according to the historical data of tag cost from 2001 to 2019, the cost has rapidly decreased from 34.5 THB to 1.2 THB (Bolotnyy & Robins, 2007); the tag cost has been reduced every year at an exponential rate. (See Figure 37)

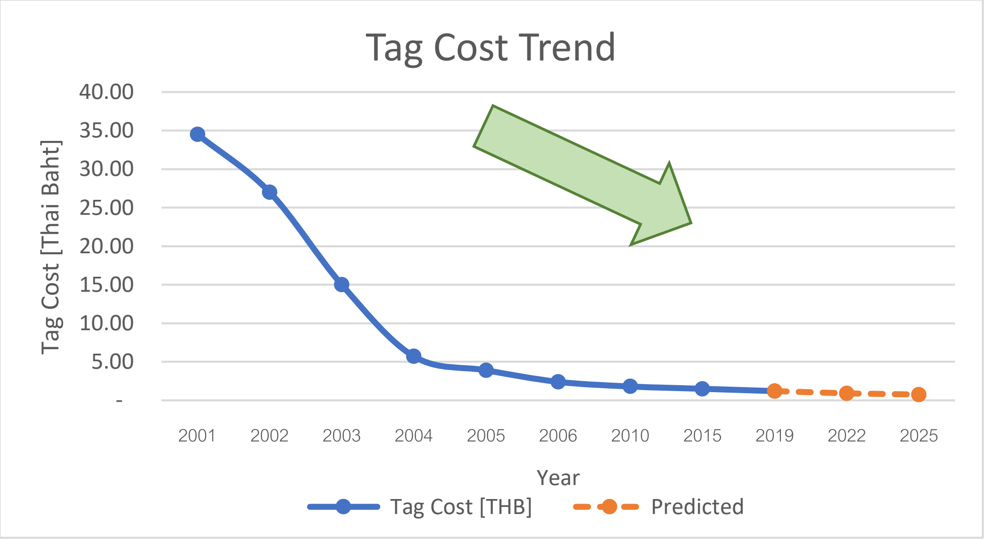


*Figure 37 - Shows the Trend Costs of Passive UHF RFID Tag.*

However, RFID tag cost can be further decreased in a slower rate but still a significant number. A tag cost VS payback period sensitivity analysis is conducted to determine how the tag cost is affected to the payback period. The sensitivity analysis can be divided into three scenarios, i.e., assume that tag cost is reduced by 5%, 10%, and 15% each year.

According to figure 38, shows that when the tag cost is reduced by 5% each year, the payback period is reduced from 8 years to 7 years. The payback period can be further decreased to 6 years and 5 years when the tag cost is reduced by 10% and 15% each year respectively. Even though the RFID implementation can be considered as a long-term investment, intangible benefits such as process improvement, competitive advantage, customer satisfaction, and company image can be achieved.

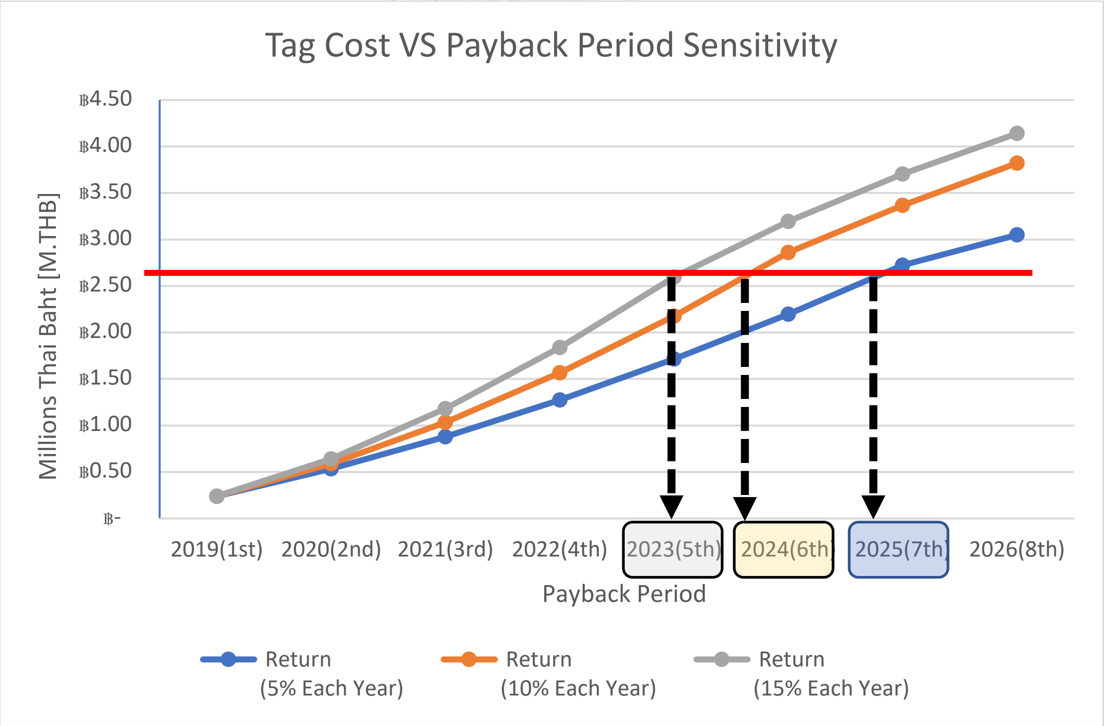


*Figure 38 - Shows the Tag Cost VS Payback Period Sensitivity*

# 4 Potential Factors affecting the RFID Implementation

## 4.1 Top Management Commitment

Implementing the RFID tracking system requires a continuity of information exchanging among internal business functions, including production, sales, and finance in order to effectively manage and control the products moving in and out of the warehouse. Thus, to achieve RFID implementation, top management should strongly support and involve in each step of the implementation, in addition, Attaran (2007) identified the involvement of top management as a success factor for RFID implementation.

Moreover, Laosirihongthong et al. (2013) mentioned that top management should involve in the important decision makings on which appropriate practices should be incorporated in the implementing RFID system. In addition, as RFID implementation will affect the existing operations, it is crucial that the top management could assign the right people in its operations to manage the change, as employees in operations are normally not motivated and resist to change, instead they only manage to work on their day-to-day operations (Ngai, et al., 2010).



## 4.2 Operation Change Management

The implementation of RFID is not only about system integration, but also the human management. People usually tend to resist new changes, since they believe that the new system can affect their daily practices and the way of doing their job; resistance to change is inevitable (Ngai, et al., 2010). Hossain

& Prybutok (2008) stated that the resistance from employees to use the proposed RFID system can delay the system implementation. Therefore, according to the case study, a set of questionnaires is handed out to the related business functions such as production, sale, finance, and especially warehouse to determine the employee's willingness to change to the new system. The questionnaires are designed to measure the cognitive and emotional buy-in to the change. The total of 61 out of 66 of all employees in the related functions have answered the questionnaires, and the results are 75% (strongly agree, 15% (agree), 9% (neither agree nor disagree), 1% (disagree), and 0% (strongly disagree) see figure 39. More than 90% of all employees in the related function are agreed to the change of the new system.

In addition, any potential problems must be recognized at the early stage of implementation in order to avoid any conflicts or difficulties. New standard procedure or work instruction (WI) must be thoroughly established by concerning on practical working environment. Also, a person in charge (PIC) must be clearly specified for each process, so that any problems that may arise from the changes can be effectively resolved in time.



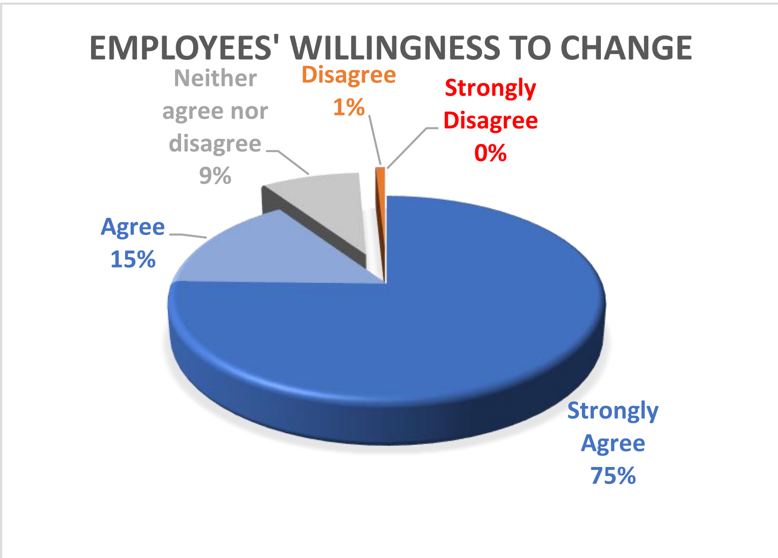


*Figure 39 - Shows the Employees's Willingness to Change to the New RFID System (Company X)*

## 4.3 Project Management and Team Formulation

Adopting an effective project management is significant for achieving the RFID implementation since it enables efficient management of resources such as time, manpower, and costs (Laosirihongthong, et al., 2013). Ngai et al. (2010) suggest that experienced, competent, and challenging project leaders and team members are required to manage and execute the RFID system implementation; the researchers also recommend the parties that should be included in the team, i.e. project manager, analyst, RFID expert, system designer, operation department, and IT department.

Project manager should manage the schedule, scope, and cost of the project; communicate among the parties and make decision. Analyst, RFID expert, and system designer should together develop the most suitable RFID solution. Operation department should provide information about operations and business processes; participate in the RFID process redesign, and finally pass on knowledge to the operators to drive the changes. Therefore, to achieve the RFID implementation, project management team members should have the same objectives and willingness to form a teamwork, otherwise the implementation would be struggling and time-consumed; as Tseng et al. (2004) state that the formation of a multi-functional team is a key problem in most project management.

## 4.4 Training and technical support for users

Due to new technology of RFID is being implemented, the business processes also have to be redesigned, thus, the RFID users must be prepared by attending the training sessions, including both classroom training and on-the-job training. The RFID project team should be able to provide the true understanding of the need of the technology, benefits, and the workflow of the system to the users; this will allow users to able to easily adapt themselves for the changes in the business operations. (Ngai, et al., 2010). Moreover, during the operation, the RFID system may encounter unexpected technical problems, thus, the project team should be able to immediately provide technical and operational supports to resolve the problems for the users, otherwise, the operational efficiency can be negatively impacted.

# 5 Security and Risk Management

In the RFID system, the important information is captured and stored in handheld device before sending to the main server, however, if the device is lost or stolen, it is not only the economic loss, but also the loss of valuable corporate data to the business competitors. Therefore, the information must be encrypted with high-level security password, and able to format or erase the information itself in case of loss.

Moreover, Lerner (2019) mentioned that certain Windows handheld operating systems began reaching the end of life; Microsoft will stop supporting or updating for all the Windows Embedded operating systems in January 2020, unfortunately, after the end of life, these operating systems may possibly encounter a security risk; security updates will be discontinued, causing a vulnerability in data leakage. Therefore, if a company is considering of RFID implementation, a new handheld operating system, such as Android operation system is recommended; Android offer more advanced features, such as application programming interfaces (APIs), and security capabilities (Lerner, 2019).

# 6 Findings and Recommendations

To successfully implement the RFID technology into the existing business environment, a sufficient knowledge and understandings of the technology's principle, capability, and limitation are required. Since the RFID system rely on the radio frequency technology, the system can be easily interfered when passing through any kind of metal or liquid surface. Therefore, before implementing the RFID technology into the business, the existing environment must be thoroughly analyzed in order to effectively customise the equipment design for each material type of goods in its specific working environment.

Wu et al. (2006) suggested that the RFID system can achieve more reliability in information accuracy by developing system configurations for the specific application purposes. Greater performance of RFID can be achieved in a number of ways such as installing antennas with different orientations per reader, deploying multiple reader antennas to increase tag readability, and adapting anti-collision algorithm technique for better simultaneously tag readings. The distance between tags and readers is very significant to the ability of signal reception, thus, the closer the distance, the stronger the signal strength will be.

RFID tracking system can be adopted in many other applications; however, companies should carefully justify the investment of RFID tags and system based on the potential returns on the investment. The companies should start with a specific application for a prioritized business mission to ensure that the investment returns are valuable and profitable.

# 7 Conclusion

Inventory information is transferred across different business functions, including production, sales and finance, thereby, the information is extremely important, and needed to be effectively managed and controlled in order to achieve the maximum profitability. In the study, the current warehouse operations are managed and processed by manual, causing significant errors in inventory data, thus, RFID technology is introduced to minimise those errors that caused from human factors.

In order to successfully implement the RFID technology, there are several areas to be concerned, including, organisational analysis, warehouse characteristics, technological analysis, investment analysis, and potential factors affecting the implementation. Investigating into the current operations is significant for process analysing; the process lead time of each operations is measured in order to clearly identify the current problems; therefore, the implementor can determine what technology configuration is needed to solve the specific problems.



RFID system transmits radio waves to communicate and transfer information between a reader antenna and a tag receiver. However, for passive UHF RFID, the power pattern of radio waves can be intensely interfered by metal and liquid surface, thus, the location and orientation of RFID equipment should be thoroughly designed in order to avoid the degradation of the transmitting radio signals. Wireless network also transmits radio signals to wirelessly transfer information from RFID handheld device to the WMS database server, however, the transmitting radio signals might be affected by the metal racks, thus, to determine the location and quantity of the wireless access point, a proper site survey or heatmap simulation should be applied.

According to the investment analysis, the total implementation cost is 1.94 million Thai baht with the annual return of 0.24 million Thai baht, therefore the investment payback period should be approximately 8 years, however, based on the historical data, the tag cost has been reduced every year, thus, according to the sensitivity analysis, the payback period can be reduced to 5 years if the price of the tag is reduced by 15% each year. Even though the payback period takes some time to become positive, however it is acceptable as a valuable long-term investment.

Finally, to successfully implement new technologies into the existing operation, not only a true understanding of the technology's principle is required, but also the potential difficulties in human management must be recognised. As people usually resist new changes, top management should be involved and kindly explain the benefits of the implementing technology so that people would strongly believe in the future positive outcomes of the implementation; any conflicts during the system integration should be easily resolved, and thus, the implementation should be effectively achieved.

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# Appendix

*Shows the Production Capacity of Company X*

| Total production per year | Total production per day (unit) | Avg. Quantity per pallet | Pallet input per day |
|---|---|---|---|
| 900000 | 3000 | 18 | 167 |

*Shows the Labour cost and Working hours*

| Working Details | |
|---|---|
| Labor cost | 400 baht/day, OT = 1.5 times |
| Working hour | 8 hr/ day |
| Working day | 6 working day |
| Working day per month | 25 working day/month |
| Working day per year | 300 working day/ year |
| Number of staff | 20 |
| Remark | Excluding manager |
| | Manager doesn't get paid for OT |

*Shows the Lead Time Reduction of Each Process when Implementing RFID*

| Receiving | Manual Lead Time (s) | RFID Lead Time (s) | Lead Time reduced (%) |
|---|---|---|---|
| Counting | 20 | 0 | |
| Paperwork | 16 | 0 | 49% |
| QA check | 63 | 63 | |
| Confirmation | 25 | 0 | |
| **Putaway** | | | |
| Counting | 20 | 0 | |
| Paperwork | 16 | 0 | 47% |
| Move to Storage | 57 | 57 | |
| Location update on paper, whiteboard | 15 | 0 | |
| **Order Picking** | | | |
| Counting | 20 | 0 | |
| Paperwork | 101 | 0 | |
| Receive order confirmation | 17 | 17 | |
| Generate picking list | 5 | 5 | 47% |
| Stock availability check | 18 | 18 | |
| Pick and Move | 84 | 84 | |
| Confirmation with sales | 12 | 12 | |
| **Shipping** | | | |
| Counting | 20 | 0 | |
| Paperwork | 51 | 0 | 39% |
| Final shipment confirmation | 18 | 18 | |
| Packing and Loading | 92 | 92 | |

## Shows the Process Lead Time Summary

| Process Lead Time Summary | | | | | |
|---|---|---|---|---|---|
| Process | Manual Lead Time (s) | Manpower | RFID Lead Time (s) | Lead Time reduced (%) | Labor Reduction |
| Receiving | 124 | 2 | 63 | 49% | -1 |
| Putaway | 108 | 4 | 57 | 47% | -1 |
| Order Picking | 257 | 6 | 136 | 47% | -1 |
| Shipping | 181 | 8 | 110 | 39% | 0 |

## Shows the Total Labour Cost per year

| Total Labor Cost | | | | |
|---|---|---|---|---|
| | Cost per day (Baht) | Number of staff | Working day per year (day) | Total cost |
| Cost per year | 400 | 20 | 300 | ฿ 2,400,000.00 |

## Shows the Labour Cost Reduction per year

| Labour Cost Reduction (per year) | | | | | |
|---|---|---|---|---|---|
| | Cost per day (Baht) | Number of staff | Working day per year (day) | Cost reduction | |
| Receiving | 400 | 1 | 300 | 120000 | |
| Putaway | 400 | 1 | 300 | 120000 | |
| Order Picking | 400 | 1 | 300 | 120000 | |
| | | | | | Reduced by (%) |
| | | | | ฿ 360,000.00 | 15% |

## Shows the Consumable Resource Cost Reduction per year

| Consumable Resource Costs | | | | | |
|---|---|---|---|---|---|
| | Pallet | Paper per pallet | Paper used per day | Cost per year | Cost per piece (Baht) |
| Paperless | 167 | 2 | 334 | ฿ 20,040.00 | 0.2 |
| Ink | 167 | 2 | 334 | ฿ 80,160.00 | 0.8 |
| | Row | Cost/pc | month | Cost per year | |
| Whiteboard Marker | 50 | 20 | 12 | ฿ 12,000.00 | |
| | Person | | | | |
| Pen | 20 | 5 | 12 | ฿ 1,200.00 | |
| | | | | ฿ 113,400.00 | |

*Shows the Total Investment Costs*

| RFID Investment Cost | | | | | |
|---|---|---|---|---|---|
| | Description | Unit price | Quantity | Cost | Total |
| Hardware | Fixed RFID Reader Antenna | ฿ 14,900.00 | 15 | ฿ 223,500.00 | |
| | Forklift RFID Reader | ฿ 25,000.00 | 4 | ฿ 100,000.00 | |
| | Handheld RFID Reader | ฿ 38,000.00 | 5 | ฿ 190,000.00 | |
| | RFID Printer | ฿169,000.00 | 2 | ฿ 338,000.00 | |
| | | | | | ฿ 851,500.00 |
| Software | Software | ฿630,000.00 | 1 | ฿ 630,000.00 | |
| | Interface | ฿150,000.00 | 1 | ฿ 150,000.00 | |
| | | | | | ฿ 780,000.00 |
| Network | AP | ฿ 22,000.00 | 14 | ฿ 308,000.00 | ฿ 308,000.00 |
| | | Grand Total | | | ฿ 1,939,500.00 |

*Shows the Historical Data of Passive UHF RFID Tag Cost*

| Year | Tag Cost $US | Tag Cost [THB] | % Decreased |
|---|---|---|---|
| 2001 | $ 1.15 | 34.50 | |
| 2002 | $ 0.90 | 27.00 | 22% |
| 2003 | $ 0.50 | 15.00 | 44% |
| 2004 | $ 0.19 | 5.70 | 62% |
| 2005 | $ 0.13 | 3.90 | 32% |
| 2006 | $ 0.08 | 2.40 | 38% |
| 2010 | $ 0.06 | 1.80 | 25% |
| 2015 | $ 0.05 | 1.50 | 17% |
| 2019 | $ 0.04 | 1.20 | 20% |




*Shows the Tag Cost Trend*

*Shows the Annual Cost of RFID tag (5% reduction each year)*

| Historical Data of Passive UHF RFID Tag Cost (5%) | | | | | |
|---|---|---|---|---|---|
| **Year** | **Tag Cost $US** | **Tag Cost [THB]** | **% Decreased** | **Annaul Cost** | **Cost Reduced** |
| 2001 | $ 1.150 | 34.50 | | 31,050,000.00 | #VALUE! |
| 2002 | $ 0.900 | 27.00 | 22% | 24,300,000.00 | 6,750,000.00 |
| 2003 | $ 0.500 | 15.00 | 44% | 13,500,000.00 | 10,800,000.00 |
| 2004 | $ 0.190 | 5.70 | 62% | 5,130,000.00 | 8,370,000.00 |
| 2005 | $ 0.130 | 3.90 | 32% | 3,510,000.00 | 1,620,000.00 |
| 2006 | $ 0.080 | 2.40 | 38% | 2,160,000.00 | 1,350,000.00 |
| 2010 | $ 0.060 | 1.80 | 25% | 1,620,000.00 | 540,000.00 |
| 2015 | $ 0.050 | 1.50 | 17% | 1,350,000.00 | 270,000.00 |
| 2019 | $ 0.040 | 1.20 | 20% | 1,080,000.00 | 270,000.00 |
| 2020 | $ 0.038 | 1.14 | 5% | 1,026,000.00 | 54,000.00 |
| 2021 | $ 0.036 | 1.08 | 5% | 974,700.00 | 51,300.00 |
| 2022 | $ 0.034 | 1.03 | 5% | 925,965.00 | 48,735.00 |
| 2023 | $ 0.033 | 0.98 | 5% | 879,666.75 | 46,298.25 |
| 2024 | $ 0.031 | 0.93 | 5% | 835,683.41 | 43,983.34 |
| 2025 | $ 0.029 | 0.88 | 5% | 793,899.24 | 41,784.17 |
| 2026 | $ 0.028 | 0.84 | 5% | 754,204.28 | 39,694.96 |
| 2027 | $ 0.027 | 0.80 | 5% | 716,494.07 | 37,710.21 |
| 2028 | $ 0.025 | 0.76 | 5% | 680,669.36 | 35,824.70 |
| 2029 | $ 0.024 | 0.72 | 5% | 646,635.89 | 34,033.47 |

*Shows the Annual Cost of RFID tag (10% reduction each year)*

| Historical Data of Passive UHF RFID Tag Cost (10%) | | | | | |
|---|---|---|---|---|---|
| **Year** | **Tag Cost $US** | **Tag Cost [THB]** | **% Decreased** | **Annaul Cost** | **Cost Reduced** |
| 2001 | $ 1.150 | 34.50 | | 31,050,000.00 | #VALUE! |
| 2002 | $ 0.900 | 27.00 | 22% | 24,300,000.00 | 6,750,000.00 |
| 2003 | $ 0.500 | 15.00 | 44% | 13,500,000.00 | 10,800,000.00 |
| 2004 | $ 0.190 | 5.70 | 62% | 5,130,000.00 | 8,370,000.00 |
| 2005 | $ 0.130 | 3.90 | 32% | 3,510,000.00 | 1,620,000.00 |
| 2006 | $ 0.080 | 2.40 | 38% | 2,160,000.00 | 1,350,000.00 |
| 2010 | $ 0.060 | 1.80 | 25% | 1,620,000.00 | 540,000.00 |
| 2015 | $ 0.050 | 1.50 | 17% | 1,350,000.00 | 270,000.00 |
| 2019 | $ 0.040 | 1.20 | 20% | 1,080,000.00 | 270,000.00 |
| 2020 | $ 0.036 | 1.08 | 10% | 972,000.00 | 108,000.00 |
| 2021 | $ 0.032 | 0.97 | 10% | 874,800.00 | 97,200.00 |
| 2022 | $ 0.029 | 0.87 | 10% | 787,320.00 | 87,480.00 |
| 2023 | $ 0.026 | 0.79 | 10% | 708,588.00 | 78,732.00 |
| 2024 | $ 0.024 | 0.71 | 10% | 637,729.20 | 70,858.80 |
| 2025 | $ 0.021 | 0.64 | 10% | 573,956.28 | 63,772.92 |
| 2026 | $ 0.019 | 0.57 | 10% | 516,560.65 | 57,395.63 |
| 2027 | $ 0.017 | 0.52 | 10% | 464,904.59 | 51,656.07 |
| 2028 | $ 0.015 | 0.46 | 10% | 418,414.13 | 46,490.46 |
| 2029 | $ 0.014 | 0.42 | 10% | 376,572.72 | 41,841.41 |

Shows the Annual Cost of RFID tag (15% reduction each year)

| Historical Data of Passive UHF RFID Tag Cost (15%) | | | | | |
|---|---|---|---|---|---|
| **Year** | **Tag Cost $US** | **Tag Cost [THB]** | **% Decreased** | **Annaul Cost** | **Cost Reduced** |
| 2001 | $ 1.150 | 34.50 | | 31,050,000.00 | #VALUE! |
| 2002 | $ 0.900 | 27.00 | 22% | 24,300,000.00 | 6,750,000.00 |
| 2003 | $ 0.500 | 15.00 | 44% | 13,500,000.00 | 10,800,000.00 |
| 2004 | $ 0.190 | 5.70 | 62% | 5,130,000.00 | 8,370,000.00 |
| 2005 | $ 0.130 | 3.90 | 32% | 3,510,000.00 | 1,620,000.00 |
| 2006 | $ 0.080 | 2.40 | 38% | 2,160,000.00 | 1,350,000.00 |
| 2010 | $ 0.060 | 1.80 | 25% | 1,620,000.00 | 540,000.00 |
| 2015 | $ 0.050 | 1.50 | 17% | 1,350,000.00 | 270,000.00 |
| 2019 | $ 0.040 | 1.20 | 20% | 1,080,000.00 | 270,000.00 |
| 2020 | $ 0.034 | 1.02 | 15% | 918,000.00 | 162,000.00 |
| 2021 | $ 0.029 | 0.87 | 15% | 780,300.00 | 137,700.00 |
| 2022 | $ 0.025 | 0.74 | 15% | 663,255.00 | 117,045.00 |
| 2023 | $ 0.021 | 0.63 | 15% | 563,766.75 | 99,488.25 |
| 2024 | $ 0.018 | 0.53 | 15% | 479,201.74 | 84,565.01 |
| 2025 | $ 0.015 | 0.45 | 15% | 407,321.48 | 71,880.26 |
| 2026 | $ 0.013 | 0.38 | 15% | 346,223.26 | 61,098.22 |
| 2027 | $ 0.011 | 0.33 | 15% | 294,289.77 | 51,933.49 |
| 2028 | $ 0.009 | 0.28 | 15% | 250,146.30 | 44,143.47 |
| 2029 | $ 0.008 | 0.24 | 15% | 212,624.36 | 37,521.95 |

Shows the Total Return and Payback Period (5% reduction each year)

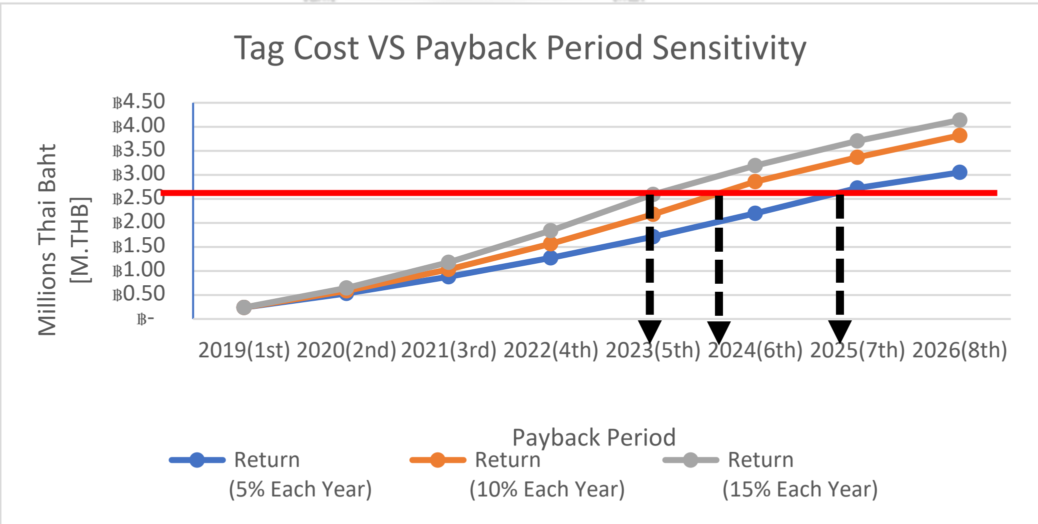
| Payback Period | Return | Tag Cost Reduction (5% Each Year) | Return (5% Each Year) |
|---|---|---|---|
| 2019(1st) | 240000 | | ฿ 240,000.00 |
| 2020(2nd) | 294000 | 54000 | ฿ 534,000.00 |
| 2021(3rd) | 345300 | 51300 | ฿ 879,300.00 |
| 2022(4th) | 394035 | 48735 | ฿ 1,273,335.00 |
| 2023(5th) | 440333 | 46298 | ฿ 1,713,668.25 |
| 2024(6th) | 484317 | 43983 | ฿ 2,197,984.84 |
| 2025(7th) | 526101 | 41784 | ฿ 2,724,085.60 |
| 2026(8th) | 565796 | 39695 | ฿ 3,049,881.32 |
| 2027(9th) | 603506 | 37710 | ฿ 3,359,387.25 |
| 2028(10th) | 639331 | 35825 | ฿ 3,653,417.89 |

*Shows the Total Return and Payback Period (10% reduction each year)*

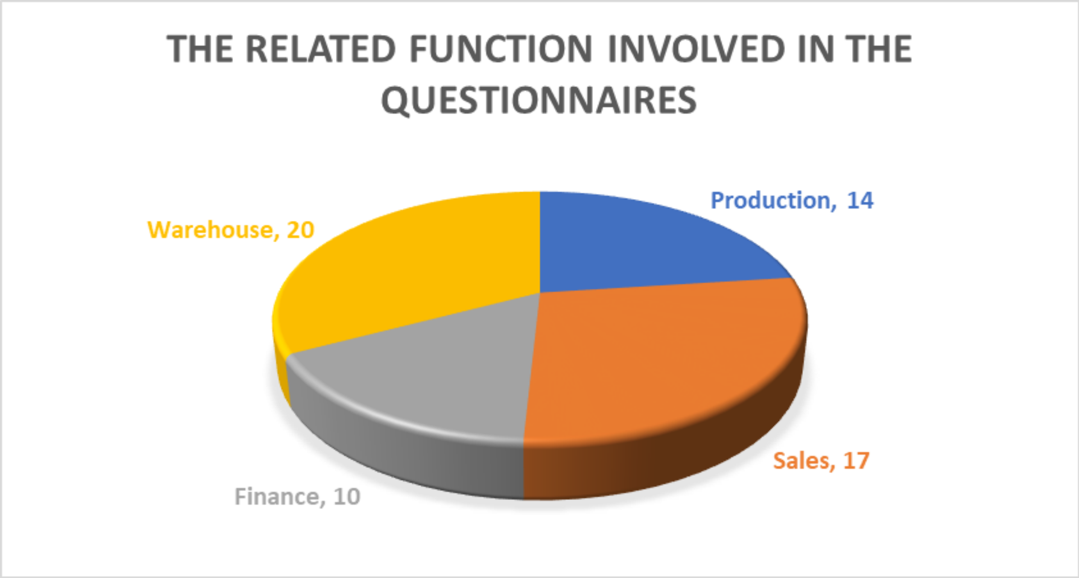
| Payback Period | Return | Tag Cost Reduction (10% Each Year) | Return (10% Each Year) |
|---|---|---|---|
| 2019(1st) | 240000 | | ฿ 240,000.00 |
| 2020(2nd) | 348000 | 108000 | ฿ 588,000.00 |
| 2021(3rd) | 445200 | 97200 | ฿1,033,200.00 |
| 2022(4th) | 532680 | 87480 | ฿1,565,880.00 |
| 2023(5th) | 611412 | 78732 | ฿2,177,292.00 |
| 2024(6th) | 682271 | 70859 | ฿2,859,562.80 |
| 2025(7th) | 746044 | 63773 | ฿3,365,606.52 |
| 2026(8th) | 803439 | 57396 | ฿3,821,045.87 |
| 2027(9th) | 855095 | 51656 | ฿4,230,941.28 |
| 2028(10th) | 901586 | 46490 | ฿4,599,847.15 |

*Shows the Total Return and Payback Period (15% reduction each year)*

| Payback Period | Return | Tag Cost Reduction (15% Each Year) | Return (15% Each Year) |
|---|---|---|---|
| 2019(1st) | 240000 | | ฿ 240,000.00 |
| 2020(2nd) | 402000 | 162000 | ฿ 642,000.00 |
| 2021(3rd) | 539700 | 137700 | ฿ 1,181,700.00 |
| 2022(4th) | 656745 | 117045 | ฿ 1,838,445.00 |
| 2023(5th) | 756233 | 99488 | ฿ 2,594,678.25 |
| 2024(6th) | 840798 | 84565 | ฿ 3,195,476.51 |
| 2025(7th) | 912679 | 71880 | ฿ 3,706,155.04 |
| 2026(8th) | 973777 | 61098 | ฿ 4,140,231.78 |
| 2027(9th) | 1025710 | 51933 | ฿ 4,509,197.01 |
| 2028(10th) | 1069854 | 44143 | ฿ 4,822,817.46 |




*Shows the Tag Cost VS Payback Period Sensitivity*




*Shows the Related Functions Involved in the Questionnaires*


*Shows the Employees' Willingness to Change*

*Shows the Summary of the Questionnaires Results*

| | 5<br>Strongly Agree | 4<br>Agree | 3<br>Neither agree nor disagree | 2<br>Disagree | 1<br>Strongly Disagree |
|---|---|---|---|---|---|
| Improve accuracy in the information and communication | 59 | 2 | 0 | 0 | 0 |
| Enhance overall work efficiency | 55 | 5 | 1 | 0 | 0 |
| Reduce working hours | 31 | 15 | 13 | 2 | 0 |
| Improve the main process | 39 | 15 | 7 | 0 | 0 |
| | | | | | |
| Average | 46 | 9 | 5 | 0.5 | 0 |
| | | | | | |
| Willingness to change | 75% | 15% | 9% | 1% | 0% |

## Shows the Questionnaires (Employees' Willingness to Change)

| Employee Satisfation (Final Production) --> 14ppl/15ppl | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| RFID Implementation --> Employee's willingness to change | Strongly Agree | Agree | Neither agree nor disagree | Disagree | Strongly Disagree |
| RFID Technology can………… | | | | | |
| | | | | | |
| Improve accuracy in the information and communication | 14 | | | | |
| Enhance overall work efficiency | 12 | 2 | | | |
| Improve production planning and forecasting | | 12 | 2 | | |

| Employee Satisfation (Sales) --> 17/19ppl | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| RFID Implementation --> Employee's willingness to change | Strongly Agree | Agree | Neither agree nor disagree | Disagree | Strongly Disagree |
| RFID Technology can………… | | | | | |
| | | | | | |
| Improve accuracy in the information and communication | 15 | 2 | | | |
| Enhance overall work efficiency | 16 | 1 | | | |
| Reduce working hours | 12 | 5 | | | |
| Improve sales forecasting | 12 | 3 | 2 | | |

| Employee Satisfation (Finance) --> 10/12ppl | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| RFID Implementation --> Employee's willingness to change | Strongly Agree | Agree | Neither agree nor disagree | Disagree | Strongly Disagree |
| RFID Technology can………… | | | | | |
| | | | | | |
| Improve accuracy in the information and communication | 10 | | | | |
| Enhance overall work efficiency | 9 | | 1 | | |
| Reduce working hours | 2 | 5 | 3 | | |
| Improve inventory auditting | 9 | | 1 | | |

| Employee Satisfation (Warehouse) --> 20/20ppl | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| RFID Implementation --> Employee's willingness to change | Strongly Agree | Agree | Neither agree nor disagree | Disagree | Strongly Disagree |
| RFID Technology can………… | | | | | |
| | | | | | |
| Improve accuracy in the information and communication | 20 | | | | |
| Enhance overall work efficiency | 18 | 2 | | | |
| Reduce working hours | 17 | 1 | 2 | | |
| Improve distribution planning and fleet management | 18 | | 2 | | |

# VITA

| | |
|---|---|
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