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Design of an RFID-based Inventory Control and Management System: A Case Study

Jacky S.L. Ting [aΨ] and Albert H.C. Tsang [b]

Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hung Hom, Hong Kong, China
[a] E-mail: jacky.ting@polyu.edu.hk
[b] E-mail: mfalbert@inet.polyu.edu.hk

[Ψ] *Corresponding Author*

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Abstract: *This paper proposes an RFID-based Inventory Control and Management System (RICMS) for manufacturing enterprises. It aims to collect accurate real-time data relating to transactions of physical stock items for enhancing product life cycle management. In RICMS, the business logic for classifying transactions associated with specific product movements is encoded as a set of decision rules. These rules support the two-point mechanism embedded in the system to obtain accurate real-time data for updating inventory records. This approach improves the timeliness, visibility and integrity of goods transaction and location records. A case in the paper product industry is presented to illustrate the seven-stage framework for system implementation and the expected benefits after deployment of the proposed system. Results of this case study illustrate that RICMS can help to improve warehouse management in eliminating errors, speeding up operations and significantly reducing operation costs. Apart from reducing spoilage of products that have passed their expiry dates, the proposed system will also improve operation efficiency and increase profits through elimination of various forms of chronic wastes found in typical warehouse management operations.*

Keywords: *Radio Frequency Identification (RFID), Inventory Control, Warehousing*

1. Introduction

With the increasing demand in today's competitive environment, providing accurate real-time inventory information is key to survival. This is particularly true for situations involving inventories of perishable items like paper products, farm produce and pharmaceuticals. Given the limited shelf life of these goods, it is essential to have the ability to visualise the logistics flow of these items at pallet level in real-time. Typically, such information is captured with the use of barcode scanning or even extensive manual record keeping. However, these approaches are time-consuming, labor-intensive and error prone (Zipkin, 2000; Sellitto et al., 2007; Hamilton et al., 2009).

At present, information and communications technologies are widely adopted in warehouse management. As stated in numerous studies (Gurin, 1999; Randall, 1999; Karkkainen et al., 2010), inventory can be controlled and managed accurately in a technology-driven warehouse environment. Recently, several researchers (Zhou et al., 2007; Chen et al., 2008; Battini et al., 2009; Wang et al., 2010) extend the warehouse applications with the use of radio frequency identification (RFID) so as to enhance the intelligence and efficiency of their warehouse management operations.

So far, RFID has been adopted in the manufacturing industry for visualising product movement and combating counterfeits (Angeles, 2005; Garfinkel and Rosenberg, 2006; Kwok et al., 2010b; Tsang et al., 2010). It is one of the powerful enabling wireless technologies being used by major enterprises such as WalMart, Tesco, METRO Group and the United States (US) Department of Defense to manage their stock. Through application of RFID technology, the transactions of each product in the distribution network can be tracked. When such solution is applied in physical asset management, manufacturers will be able to gain benefits from automated forecasting for inventory diversion, simplified workflow, tighter control over the manufacturing and distribution supply chain (Paret, 2005).

This paper presents an RFID-based Inventory Control and Management System (RICMS) that can be easily deployed by manufacturing enterprises to support inventory planning activities with effective trace-and-track capability. It aims at enhancing the accuracy of inventory records by recording finished goods movement information instantly and accurately, and increasing inventory visibility. Using RICMS will help enterprises to prevent inventory discrepancies in advance. This paper is divided into four sections, with

Section 2 describing the studies related to RFID and how RFID is applied in inventory control and management aspects. Section 3 depicts the critical elements in RICMS, complemented with a description of the case study and implementation of the proposed system. Section 4 presents the conclusions of using RICMS.

2. Related Works

RFID makes use of radio frequency (RF) waves and microchip technologies to transfer data between reader and the tagged item for remote data collection and automatic objects identification. With its fast, reliable, and effective operation while not requiring physical sight or contact between reader and the tagged item, RFID ensures real time access to up-to-date information about relevant products at any point interrogated by a reader. Theoretically, the technology allows us to track every tagged item on earth (Kwok et al., 2010a).

Whilst most attention has focused on adopting RFID in visualising the supply chain, inventory control and management is considered as the next focus area of RFID. In recent years, there has been a variety of research on using RFID as a form of information system to reduce inventory errors, shrinkage, misplacements, and counterfeiting (Heese, 2007; Kok et al., 2008; Rekik et al., 2008; Rekik et al., 2009). In particular, the use of RFID in reducing inventory discrepancies is already a popular application in many manufacturing organisations. For example, Wang et al. (2010) design an RFID-based digital warehouse management system to improve the visualisation of inventory management, assignment of inventory storage and retrieval, and inventory control. Collins (2006) compares the efficiency of traditional barcode system with the RFID-based system, and his study points out that RFID outperforms barcode in terms of elimination of fragmented visibility, inefficient inventory management, and excessive stock-in taken. However, with an emphasis on adopting RFID in inventory control and management, the focus of this paper is quite different. This paper focuses on the conversion of the raw data captured by RFID, into meaningful information that can be used to support further decision making.

The goal, to look for more effective and efficient RFID adoption in inventory control and management, is widely acknowledged; however, merely collecting data through RFID technology is not enough. The data needs to be transformed into meaningful information that is easy to access, interpret and manipulate. For example, it is necessary to convert the raw incoming RFID data into a meaningful context for further processing and subsequent actions. This is a challenging task and how this information can be organised and presented is a critical area of concern.

In order to address the issue stated above, this paper focuses on the RFID information manipulation to support efficient inventory control and management. In this paper, an RFID-based Inventory Control and Management System (RICMS) is presented to improve warehouse operations by keeping track of and trace numerous RFID-tagged goods simultaneously. This system benefits from the RFID technology in offering a platform for users to obtain instant and accurate inventory records, which in turn streamlines their warehouse management. To make the captured RFID data meaningful to decision making in inventory control and management, the RFID-based system traces and keeps track of the finished goods status by using a two-point working principle.

Consider the case when an item is transferred from one area to another; two different readers are used to determine the item’s transaction. For example, if an item has been detected by readers at the Production Department and a while later, the same item was picked up by readers at the Warehouse, the system would then automatically record the set of actions as a “Stock-In” transaction; on the other hand, if the item moves from Warehouse to Ground Floor, is the set of actions that will be recorded as a “Stock-Out” transaction. Through such automatic tracking and tracking of the status of items, the visibility of tagged items would be greatly improved. In turn, the enterprise would not only benefit from cost and manpower savings, it will also improve data accuracy and the company’s productivity. In addition, this paper also reviews effectiveness of the proposed RFID system through a real life case study. Most existing literatures on RFID applications assume perfect reading performance of RFID devices; however, from our case study, this assumption does not hold true in practice. Several practitioners even assert that RFID applications are not easy to implement in reality. Thus, a development framework and the way to manage captured data with less than perfect accuracy are presented in this paper.

3. A Case Study

Midas Printing Company Limited (so called Midas in the rest of the paper) is a Hong Kong based paper product printing company. It has manufacturing plants at several locations in China. To study its performance, the proposed RICMS was implemented in three main areas, namely Docking Area (G/F), Production Department (3/F) and Warehouse (5/F), in one of the Midas plants. Armed with previous experiences (Kwok et al., 2010a; Kwok et al., 2010b; Ting et al., 2011a; Ting et al., 2011b), a seven-stage structured system implementation framework was adopted in the design of this research study: establishment of a cross-functional team, workflow analysis, baseline measurement, system design, onsite environmental assessments, system implementation, and performance review. Each stage of this framework will be discussed below.

3.1 Establishment of a Cross-Functional Team

Establishing an RFID team is an important strategy for assuring success of an RFID project. It is better to have senior executives from the main functional areas such as manufacturing /operations, packaging, and warehouse management. The reason is that implementation of an RFID project may involve significant changes of current operation processes. For instance, EPC mapping will be a new process that needs to be performed by the Packaging Department in such applications. Sometimes executives may need to cope with the change of operations such as the way products are received, stored, recorded and shipped. Therefore, having regular meetings with top management to keep them well informed of the project progress is a must. Other than that, RFID team members who come from different departments should be assigned different roles and authorisation to manage the RFID project.

The cross-functional team established at Midas has members who come from three different departments: IT, Logistics and Production Departments. They are further divided into management and operations teams. The former one is responsible for monitoring project progress, making decisions and providing support to the operations team. The latter one is tasked to implement the application system. Education is a critical issue that assures smooth execution of the project. Not only the RFID team needs to have good knowledge about the components and operation of the RFID system, frontline staff also need to have basic RFID knowledge, especially the benefits the new application can bring.

3.2 Workflow Analysis

Understanding the current process is an important step, it can help the project team members to understand the existing processes along with the stakeholders and critical information involved. The processes were reviewed through the use of focus groups, individual interviews, questionnaire surveys, observations and document analysis. Data obtained from baseline measurements were utilised to determine which parts of the current processes that are time consuming and labor intensive so that the team can identify and prioritise improvement projects on these processes.

At Midas, after reviewing the current warehouse management process, several critical problems were identified in its stock-in and stock-out workflow, such as inaccurate inventory records, inefficient (manual) location of stock items, ineffective product identification, labor intensive (manual) product counts, and delayed update of inventory records.

3.3 Baseline Measurements

In general, effective and efficient working processes usually require less labor and processing time which, in turn, will reduce cost and increase revenues. Before implementation of the RFID project, performance of the affected process and error rate, as reflected in relevant key performance indicators such as the processing time, labor cost and error rate of standard tasks in the process, were measured to serve as baseline of the process. Similar measurements would also be made after implementation of the RFID solution. With these two sets of measurements, the benefits of the RFID solution, especially its return on investment (ROI), can be determined.

3.3.1 Previous Workflow – Stock-In

The processing times of the tasks in the previous stock-in process are listed in Table 1. The two departments involved in the process are the Production Department on 3/F and the Warehouse on 5/F of the plant.

Table 1. Processing Time of the Previous Stock-In Process

	Job Task	**Processing Time (min)**	**Location**	**Operator**
1.	Pack the finished goods with packing label	7	3/F Production Department	Packaging Worker
2.	Carry out stock-in registration	3		
3.	Inspect the quality of goods in accordance with Acceptable Quality Label (AQL)	3		QC Team
4.	Write the finished product inspection report	3		
5.	Approve the report	2		QC Supervisor
6.	Pass the goods to 3/F warehouse workers and verify the stock-in record	3		3/F Warehouse Worker
7.	Move the goods to 5/F warehouse by elevator	5		
8.	Count and check the arrived stock-in goods with marking it down into the inventory transfer table temporarily	10	5/F Warehouse	5/F Warehouse Worker
9.	Locate and store goods into specific zone	5		
10.	Receive the copy of approved finished product inspection report and use it to verify the temporary records marked in inventory transfer table	3		
11.	Input the verified records in accordance with the report copy into excel form for backups	3		Data Entry Clerk
12.	File the report copy and save the excel for	2		
	Total	**49**		

Tasks 8, 10, 11 and 12 were identified to have significant potentials for improvement. They are finished goods verification tasks, such as checking and counting, data recording, and filing, which are time consuming, labor intensive and error prone. These tasks can be automated with application of RFID technology, reducing the total processing time of the entire stock-in process by an estimate of at least 30%.

3.3.2 Previous Workflow – Stock-Out

Table 2 lists the processing times of the tasks in the previous stock-out process. The two departments involved are Sales and Logistics Departments, covering three areas, namely the General Office on 2/F, the Production Department on 3/F and the Docking Area on G/F of the plant.

Five tasks in the process were identified to have significant potentials for improvement. They are tasks 7, 8, 9, 10 and 12, relating to the time-consuming and labour-intensive operations of inventory checking, stock taking and goods verification before shipping out. Through application of RFID technology, these tasks will be automated, reducing the total processing time of the entire stock-out process by an estimate of nearly 30%.

In the two workflows described above, the manual recording and checking operations performed by the Production Department (3/F) and the Warehouse (5/F) are time consuming. There are also tasks that involve transfers of documents from one hand to another, lengthening lead times and causing high error rates. All these problems can be eliminated by an RFID enabled automated system.

Table 2. Processing Time of the Previous Stock-Out Process

	Job Task	Processing Time (min)	Location	Operator
1.	Receive customer request, check inventory and book truck	7	2/F Sales Department	Customer Service
2.	Print out the truck booking table with ship out lit and put it into tray for warehouse	5		
3.	Take the table and list in specific time from 2/F warehouse tray	2	5/F Warehouse	Warehouse Worker
4.	Prepare the shipped goods	10		
5.	Stock-out registration	3		
6.	Move the prepared goods to G/F by elevator	5		
7.	Check and count the prepared goods and mark down the verified records	5	G/F Docking Area	G/F Logistic Worker
8.	Take the verified record to salesperson	1		
9.	Prepare and print out the delivery note for truck loading	3	2/F Sales Department	Customer Service
10.	Give the delivery note the truck driver	1		G/F Logistic Worker
11.	Ship out	1	1/F Logistic Department	Truck Driver
12.	Input the ship out records into excel form	5		Data Entry Clerk
	Total	**48**		

3.4 System Design

The RFID-based System for Midas enables bi-directional communication flows between the readers and the back end. The physical items of this system include the RFID tags, readers, antennas, and the physical environments of the three areas covered by movements of goods in the plant (the Docking Area on G/F, the Packaging Department on 3/F, and the Warehouse on 5/F). The software of the system comprises four main programs: "RFID Operating System" for front-end operators; "RFID Reporting System" for both front-end operators and top management, "RFID Monitoring System" for IT staff, and "ERP" for Sales Department. The architecture is depicted in Figure 1 and the specifications and quantity of each major hardware component of the system are listed in Table 3.

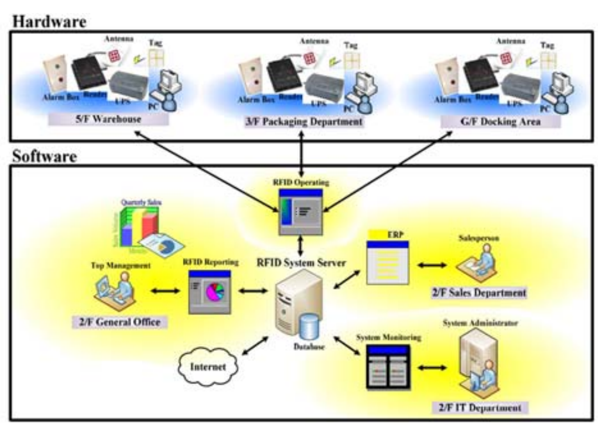

Figure 1. Hardware and Software Architecture of RCIMS

Table 3. Hardware Specifications of RCIMS

System Hardware		**Unit**
Lenovo	Server with Microsoft ® Windows ® Server 2003 R2 Standard Edition English (5 CALs), F1	1
Lenovo	PCs with Microsoft ® Windows ® 2000	3
Alien Technology	ALR-9780, Multi-Port General Purpose RFID Stationary Reader	3
Alien Technology	Circular Antenna	6
American Power Conversion (APC)	Uninterruptible Power Supply, 500VA/300W, Input 230V/Output 230V *(used to support the reader and antenna with Power Consumption 25 Watts (120 VAC at 500 mW))*	3
RSI ID Technologies	IN-10, UHF Gen 2 96 bit, Read/Write Tag 80mm x 80mm	-
Self-developed	Stack Light *(red light with beep sound indicates invalid products are passing through the gateway; green light indicates normal status, i.e. the products passing through the gateway are valid)*	3

3.5 Environmental Assessments

Onsite analysis is an essential part of RFID implementation to ensure the system performance. Two sets of tests (Kwok et al., 2007), namely Tag Placement Analysis and Interrogation Zone Analysis, were conducted to identify the optimal placement of RFID tags on pallets, and to assess the profile of readability performance at the sites of system deployment, respectively.

3.5.1 Tag Placement Analysis (TPA)

The TPA is a dynamic test performed to determine the optimal placement of the RFID tag when the pallet with finished goods passes through an RFID reader equipped gateway at operating speeds. In this test, multiple tags were placed on the pallet in various locations and orientations. In Figure 2, four tags at different orientations are placed on one side of the pallet for performing the TPA. Data on tag readability was captured when the tagged pallet was moved by a forklift truck through the gateway.

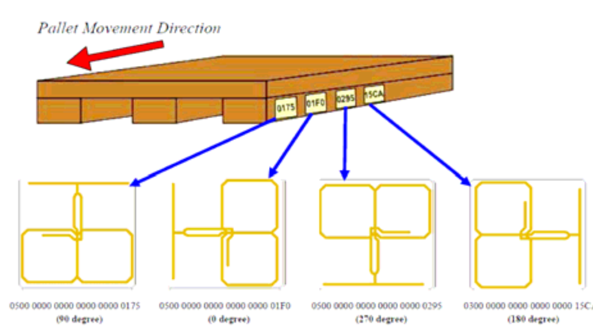

Figure 2. Locations and Orientations of Four Testing Tags on the Pallet

Figure 3 shows the results of four tag placements and their respective readability against time. According to the results of this example, the four options for tag placement being tested would provide comparable readability performance.

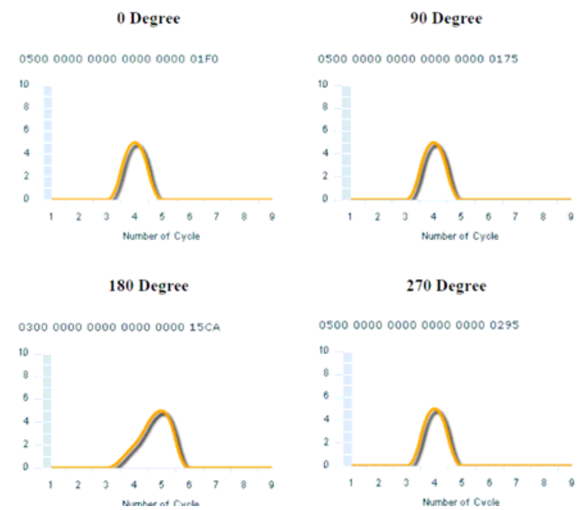

Figure 3. TPA Results of the Four Tags (as shown in Figure 4)

3.5.2 Interrogation Zone Analysis (IZA)

IZA was performed to assess the tag readability profile of an RFID reader equipped gateway (interrogation zone). In the IZA conducted at Midas, each interrogation zone was covered by a 20 by 9 grid (see Figure 4).

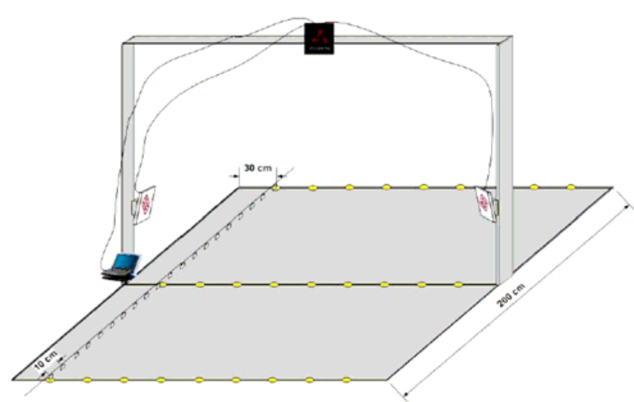

Figure 4. Setup of the Interrogation Zone to perform IZA

Tag readability, defined as the ratio of response counts to request counts, at each of the 180 intersection points on the grid was measured. Results of these readability measurements in the zone can be plotted in a color-coded surface graph for analysis. This graph is known as the interrogation zone map.

Figure 5 shows that the region bounded within the black line is the area that is adequately covered by the RF signals emitted by the antenna. The 30 cm-wide corridor in the middle defines the region at the dock door through which the tagged pallet should move to guarantee success in reading the tag. The small cell on the right side of the map indicates an area where interference exists. The problem can be eliminated through identification and removal of the root cause which might be related to metal objects in the vicinity. In this particular case, the interference region is outside the principal (and preferred) pathway at the gateway. Thus, it would not affect performance of the deployed system.

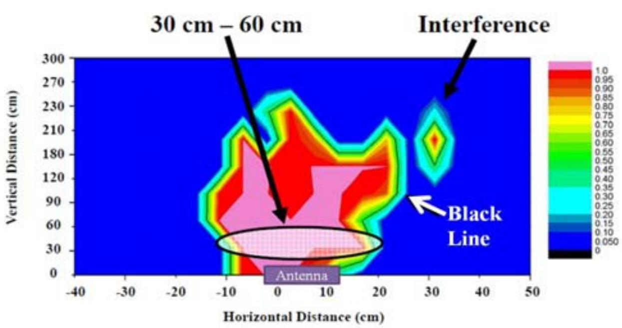

Figure 5. Tag Readability Profile of an Interrogation Zone

3.6 System Implementation

To serve the inventory management needs of the company, several transactions need to be tracked and the related records transmitted to the database in real time. These transactions are listed in Table 4.

Table 4. Finished Goods Transactions Tracked by RFID

From		To	Transaction
5/F	→	G/F	Stock-Out
3/F	→	G/F	Stock-Out
3/F	→	5/F	Stock-In
G/F	→	3/F	Return
G/F	→	5/F	Return

With such requirements, an RFID system with three read points was deployed in Midas. To maintain visibility of tagged items (finished goods) in the plant without manual intervention, an RFID reader equipped gateway was installed at each of the three main access points in the Docking Area on G/F, the Production Department on 3/F, and the Warehouse on 5/F, respectively. Figure 6 shows the hardware items and their locations deployed to support the RFID system at Midas.

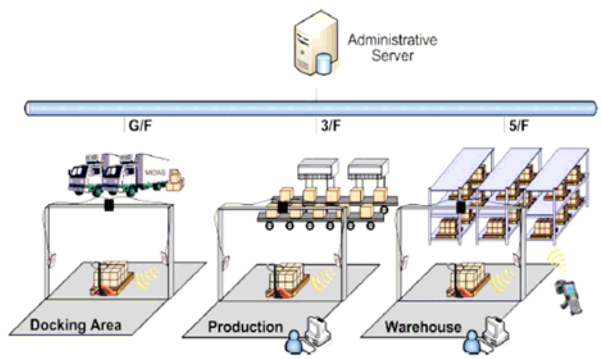

Figure 6. Deployment of RFID Readers in Midas

Each access point was equipped with two antennas hooked to a stationary RFID reader. These antennas were mounted on both sides of the gateway as shown in Figure 7. A pair of antennas instead of a single one was used so as to ensure that effective coverage of the interrogation zone would include the center of the passageway through which tags are most likely to pass. Data gathered by the RFID system would be analysed to extract information on transactions performed. The solution used data picked up at two access points to determine the nature of a transaction. For example, tagged items detected to have moved from 5/F to G/F would be interpreted as a stock-out transaction, as inferred from the logic tabulated in Table 4. These decision rules were encoded in the middleware of the RFID system to enable automatic determination of transactions in the system.

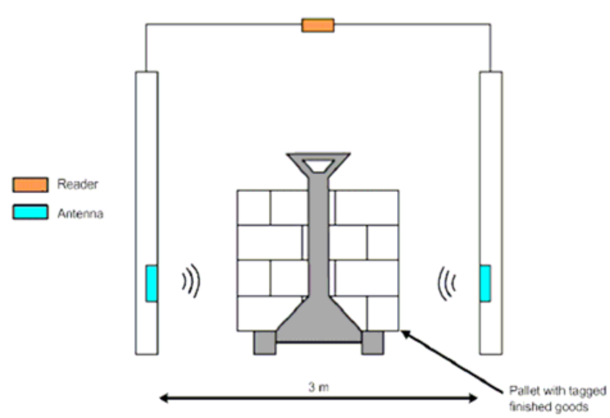

Figure 7. Deployment of Antennas and RFID Reader at Each Gateway

In the deployment of the RFID solution at Midas, passive tags were used and they were placed on the side of pallet (which had been determined by TPA to be the location which would provide optimal readability performance) throughout the entire stock-in or stock-out process until the tracked items were shipped out. Once a tagged pallet passes through an access point, a record is kept in a temporary storage. After the same pallet passes through the second access point, the nature of the transaction would then be determined and the information transmitted to the ERP system.

3.7 Two-Point Mechanism

The RFID reading process and the mechanisms for stock-in, stock-out, and goods return operations are briefly described below.

1) *Stock-In Operation* – Movements from the Production Department (3/F) to the Warehouse (5/F). After a pallet of finished goods has been built in the Production Department, the RFID stock-in process would start. First, the operator would perform the tag registration operation which assigned and programmed a new tag with unique EPC for the finished goods and fix the programmed tag onto the pallet. The pallet with the registered tag would then pass through the gateway at the exit point on 3/F as shown in the upper diagram of Figure 8. The signal received by the antennae is stored in temporary memory. After the tagged pallet has arrived at the Warehouse by elevator, it would pass through another pair of antennae as shown in the lower diagram of Figure 8. This signal together with the earlier record of the same item kept in the temporary memory would indicate that a "Stock-Out" transaction had been performed as determined by the decision rules listed in Table 4.

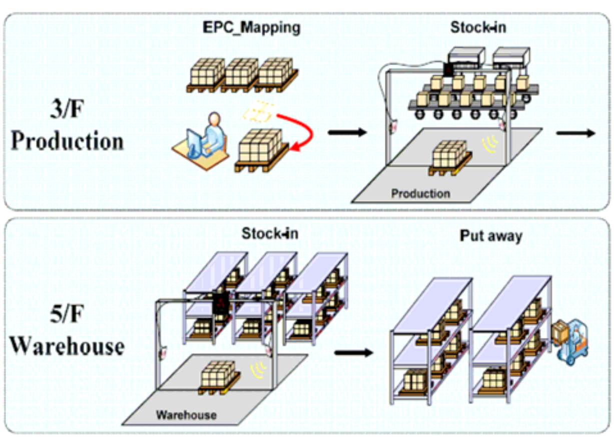

Figure 8. RFID-enabled Workflow of the Stock-In Process

2) *Stock-Out Operation* – Movements from Warehouse (5/F) to Docking Area (G/F). On receipt of a purchase order from customer, the salesperson would release a "Sales Order" and prepare a "Truck Booking Table" which lists out all the finished goods covered by the order. Every morning, the salesperson would issue the "Truck Booking Tables" listing all the finished goods to be shipped out on that day, to be processed by the Warehouse.

On receipt of the "Truck Booking Tables", the warehouse worker would search the inventory record to locate the relevant items to be shipped out. Since the shipped out items may need to be retrieved from multiple pallets stored in the Warehouse, the data stored in the tags of the pallets involved in the combining/splitting process should be updated to reflect the new contents of these pallets. Afterwards, the pallet attached with the updated tag would pass through the antennae at the Warehouse's dock door (5/F). The signal picked up by the reader of the gateway would be stored in temporary memory. After the pallet has arrived at the Docking Area (G/F) by the elevator, it would be scanned by the reader installed at the Docking doors (see Figure 9 for illustration). The signal received on G/F together with the earlier record of the same item stored in temporary memory would indicate that a "Stock-Out" transaction had been performed as determined by the decision rules listed in Table 4.

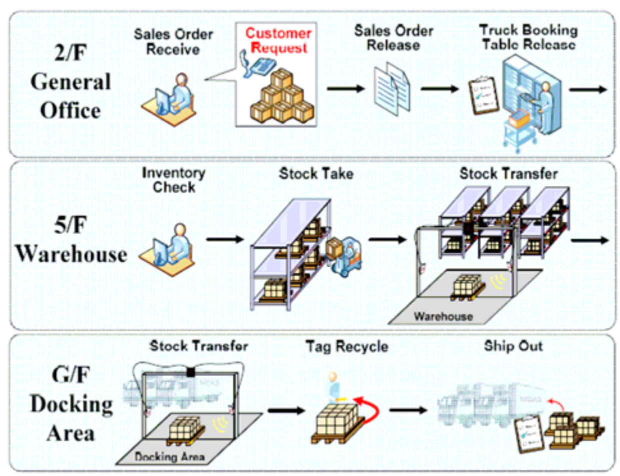

Figure 9. RFID-enabled Workflow of the Stock-Out Process

3) *Goods Return Operation* – Movements from the Docking Area (G/F) to the Warehouse (5/F). To economise deployment of the RFID solution, the tags attached to pallets would be recycled. It might also be possible that the pallets of goods returned from customers are not attached with RFID tags. In any case, a new or recycled tag must be registered before it is assigned and attached to a returned pallet and then allowed to pass through the gateway on G/F to either the Production Department (3/F) for rework or the Warehouse (5/F) for storage. The transactions involved in these movements would be inferred from the signals collected from the two-point mechanism using the decision rules listed in Table 4.

4. Results and Discussion

The benefits of implementing RICMS in Midas are discussed below.

l) Processing times of the stock-in and stock-out processes are significantly reduced after deployment of the RFID-based system. The time consuming operations such as counting, verification and data recording previously needed are automated now. As a result, about 15 minutes (approximately 30%) of processing time is saved in each of these two processes. This improvement represents a cost saving of approximately HK$2 per pallet processed, or HK$205,500 (US$1.00 ≈ HK$7.80; i.e. around US$26,400) per year in Midas' case (see Tables 5 and 6, respectively).

Table 5. Savings for Stock-In and Stock-Out Processes After Deployment of RICMS

	Stock-In Process	**Stock-Out Process**
Existing approach	49 minutes (see Table 1)	48 minutes (see Table 2)
Using RFID	34 minutes	33 minutes
Time Saving	**15 minutes**	**15 minutes**
Time Saving in %	**30.61%**	**31.25%**
Cost Saving (Saving time x HK$ 0.1389*)	**HK$ 2.08**	**HK$ 2.08**

* Assume that an operator works 10 hours per days and 24 days per month with HK$2,000 monthly salary, so the cost of work per minute = $\frac{HK\$2{,}000}{60x10x24}$ = HK$ 0.1389

Table 6. Annual Cost Savings after Deployment of RICMS in Midas

Tangible Benefits	**% Change**	**Saving (HK$)**
Increase of Inventory Visualisation		
- Disposal Reduction	60%	600,000
- Shipping Errors Reduction	30%	30,000
Subtotal		630,000
Increase of Productivity		
- Workforce of Reduction	20%	48,000
- Reduction in Stock-In and Stock-Out Transaction Time *(* Details of this reduction are shown in Table 5)*	30%	205,500
Subtotal		253,500
Total		**HK$ 883,500**

2) In the past, about 28 million pallets of stock items were spoiled per annum, amounting to an annual cost of about HK$1 million (around US$128,000). The significant level of spoilage was due to poor visibility of the inventory, making it difficult to implement the First-In-First-Out (FIFO) finished goods management principle. With the help of RFID technology, goods that will expire soon could be identified easily so that they can be shipped out first. It is estimated that RICMS will reduce spoilage by about 60%, producing a cost saving of nearly HK$600,000 (around US$77,000) each year.

3) The previous warehouse management operations were labor intensive and caused frequent errors, such as delivery of incorrect goods or duplicated delivery of ordered items. These errors happened 5 to 10 times per month with each costing about HK$1,000. The increased accuracy of RICMS is expected to reduce the error rate by around 30%, with a cost saving of about HK$30,000 (around US$3,900) per year.

4) Since RICMS has automated numerous manual recording operations and increased accuracy of the inventory records, tracing and tracking such records are no longer performed by operators. As a result, two clerks for inventory recording in the Warehouse (5/F), an officer for backup in the Logistics Department and a worker in the Docking Area (G/F) can be redeployed. Given that the labor costs in China are in the range of HK$500 to HK$2,000 per month, the resultant cost saving due to reduced manpower requirements is about HK$48,000 (around US$6,200) per year.

5) The above-mentioned tangible cost savings after Midas has implemented RICMS are summarised in Table 6.

6) The investment for deployment of the solution comprised costs for the system hardware and software, expenses for system installation and commissioning, as well as the one-time incidental costs (labor and overheads) incurred in preparing and relocating the inventories in the plant. The company was able to recover this investment in about 31 months. The breakeven point will come earlier when labor costs in China increase.

5. Conclusions

Maintaining accurate inventory information is essential to developing production plans and managing warehouse operations more cost effectively. This can be achieved by maintaining a high degree of inventory visibility, but it remains a challenge to companies that use conventional data recording methods to maintain stock information. They usually spend considerable amounts of time and cost on keeping track of stock items. This problem can be resolved after implementation of an inventory management system that incorporates automatic identification technology, such as RFID.

This paper presents an RFID-based Inventory Control and Management System (RICMS) designed for manufacturing enterprises. The two-point mechanism enhances the system's capability of identifying transactions (such as Stock-In, Stock-Out, and Return in the case) and locations of tagged stock items, when compared with one-point mechanism. With one-point mechanism, users can only track the location of an item but it is not possible to tell whether the item has completed a stock-in or stock-out transaction. When the proposed two-point mechanism is in place, readings picked up at two points will indicate that a transaction associated with a tagged item has been completed.

It is recognised that RFID readers may not be 100% reliable in detecting tagged items that move at operating speeds in typical industrial settings. Thus, two sets of tests (i.e. IZA and TPA) are introduced in the environmental assessments stage of the implementation process to determine the effects of the work environment on item detection (readability) performance, and to inform system configuration designs. Results of IZA are presented to visualise blind spots in an interrogation zone; thus, they are used to assess the effects of the system deployment environment on RFID applications. TPA is performed to identify the optimal placement of RFID tags that applies to the workflow of specific deployment situation. Thus, the two sets of tests will help to facilitate successful deployment of RFID solutions in support of business automation.

RICMS is capable of being implementing in manufacturing organisations of any size, such as Midas (i.e. a small-and-medium enterprise). By applying the RFID-enabled system in the company, the warehouse operations such as receiving, storing, picking, and shipping will be made more efficiently and effectively. It will bring tangible benefits to the company in such areas as improved labor productivity, enhanced inventory visibility, lower inventory level, reduced spoilage of stock items and significant cost reduction in warehouse operations. Although costs (covering hardware, software, training, and maintenance expenses) are the most remarkable challenge in adopting the RFID technology (Kok et al., 2008; Battini et al., 2009; Ting et al., 2011a), environmental assessment is one of the suggested solutions that will bring benefits to the company without unnecessary delays. It can help users to optimise the RFID configuration (i.e. determining the number of tags and readers that should be displayed), so as to achieve the most cost-effective solution. In this way, the enterprise will benefit from increased profits, faster turnover, as well as enhanced core competency, competitive advantage, and company image.

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Authors' Biographical Notes:

Jacky S.L. Ting *is a PhD candidate at the Department of Industrial and Systems Engineering of The Hong Kong Polytechnic University. He received his BSc degree in Enterprise Engineering and E-Business at the same university. His research interests include RFID, knowledge engineering, computer modeling of medical knowledge, medical informatics and decision support systems.*

Albert H.C. Tsang *is Senior Teaching Fellow of the Department of Industrial and Systems Engineering at The Hong Kong Polytechnic University. He has provided consultancy and advisory services to enterprises and industry support organisations in manufacturing, logistics, public utilities, healthcare and government sectors on matters related to quality, reliability, maintenance, engineering asset management, performance management and assessment of performance excellence – these are also areas of his research interest. He is the author of 'WeibullSoft', a computer-aided self-learning package on Weibull analysis. Apart from publishing papers in various international refereed journals, he is also the author / co-author of three books on various aspects of engineering asset management, and two books on industrial applications of RFID.*

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