Using RFID to Overcome Inventory Control Challenges: A Proof of Concept

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Abstract. Using a Proof of Concept approach, this paper examines RFID's impact on inventory control of a small-to-medium retailer. Results indicate that RFID technology can function effectively in a small-to-medium hardware environment. Also, the majority of the simulations recorded reasonable read rates even though the simulations were set up over a short period of time without a great deal of fine-tuning. Moreover, RFID could have a positive impact on the inventory-related processes of the organisation by either streamlining or formalizing them and facilitate the electronic storage of information captured in real-time, relating to the movement of stock and the amount of stock held, providing visibility to members of the organisation. Despite these encouraging findings in relation to using RFID for inventory control purposes within the small-to-medium retailer, it is recommended that other alternatives aimed at improving the inventory control practices of the organisation be investigated before committing to the implementation of RFID.

Keywords: RFID technology, proof of concept, simulation, business process.

1 Introduction

In recent years, (Radio-Frequency Identification) RFID technology has attracted the attention of the industrial community as well as the scientific community. RFID technology is a wireless automatic identification and data capture (AIDC) technology [1] that enables the identification of any tag item in real-time in a given supply chain with a minimum human intervention [2], [3], [4], [5]. A basic RFID system is composed of a tag containing a microprocessor, a reader and its antennas, and a computer equipped with a middleware program, in which business rules are configured to automate some decisions [6]. Despite the high potential of the technology as enabler of supply chain transformation, many questions remain. For example [3 p. 97]: How does radio interference by physical items impact usage of RFID in the business context? What other forms of interference may occur that prevent reading multiple items simultaneously? What is the rate of technical advancement in terms of RFID signal fidelity over longer distances? Will different industry settings require different technical capabilities from RFID systems? What limitations exist for the reading of tags in a mobile environment? How fast can an

item be traveling and still achieve an accurate tag reading? What is the physical proximity margin of error? How do technical limitations impact the value achieved from this technology?

This paper is a starting point to partially fill this knowledge gap by presenting the results of RFID applications in a real world environment. More precisely, the objective of this paper is to document the results of a Proof of Concept (PoC) that examines RFID's impact on inventory control. The Proof of Concept (PoC) consists of RFID simulations as well as re-engineered business processes that demonstrate whether RFID technology can operate within a small-to-medium retailer and illustrate the anticipated impact of RFID on the business' operations. The simulations focus on issues such as tag read rates and the impact of environmental factors.

Section 2 presents related works. In section 3, the methodology used in this study, including two RFID-enabled scenarios are presented. Finally, section 4 presents the discussion and conclusion.

2 Related works

The early works on the feasibility of RFID technology have mostly been conducted using a proof of concept approach in the laboratory or real-world setting [7], [8], [9]. Indeed, A Proof of Concept (PoC) is used to illustrate whether a proposed system or application is likely to operate or function as expected [10]. For example, [7] using data from "Wal-Mart RFID-enabled stores" over a period of 29 weeks concluded that RFID-enabled stores were 63% more efficient in replenishing out-of-stocks than stores without RFID, and thus, leading to a reduction of out-of-stocks by 16% over that 29 weeks period. [8], using a proof-of concept in a laboratory setting, demonstrated how process optimization can be achieved when integrating RFID technology into information systems applications. Finally, [9], using a proof-of-concept approach in a laboratory setting showed that RFID technology linked to the EPC network enables the synchronization of information flow with product flow in a given supply chain, and thus, provides a better level of information integration between supply chain members.

3 Methodology

The research study documented in this paper involves a case study examining a single small-to-medium retailer. A case study method has been employed as it is ideal for investigating contemporary events and is able to take into account a wide variety of evidence [11]. For this study data has been gathered through the collection of procedural documents, semi-structured interviews and a participant observation. This paper presents the data collected from the semi-structured interviews conducted with employees of the organization, as well as revealing the business process flows (through flowcharts) of the organization in order to determine whether RFID is a

feasible automated data capture technology for small-to-medium retailers. An observational study was also conducted over a period of two weeks in 2007. A daily diary was kept by the participant and this data was analyzed together with full-length transcripts. A single small-to-medium hardware retailer is focused on in this paper in order to analyze and present inventory control practices.

3.1 Case Study

3.1.1 Background

The organization examined in this study is located on the south coast of New South Wales, approximately 128 kilometers from the centre of Sydney. The company employs ten staff including casuals and is classified as a small-to-medium hardware retailer. The current proprietors have operated the business since 2003.

3.1.2 Physical Layout

The premises of the retailer measures approximately 2000 square meters, with about 550 square meters of this area making up the internal shop floor. The shop floor is composed of four sheds, each with independent access. There are two small internal offices, one designed to deal with customer purchasing and Point of Sale (POS) transactions while the other is used by managers and bookkeepers for ordering, accounting and other administrative practices. The external perimeter of the organization is surrounded by an eight foot high barbed wire fence.

3.1.3 Stock and Inventory

The retailer currently possesses between $300,000 to $400,000 worth of inventory which is kept on the premises. The inventory held by the organization is estimated to consist of 5000 products lines, which are provided by 110 active suppliers. Products and other inventory are stored or displayed before purchase inside the store or outside within the confines of the premises. Items and stock within the store are positioned based on the type of product as well as the supplier. Most items kept inside the store are also shelved on racks that measure 2.1m in height. The shop floor is divided into five separate areas that include general hardware, timber, gardening, cement and building supplies. Products stored outside are generally unaffected by environmental and weather conditions such as landscaping supplies, cement blocks, treated pine sleepers and sheets of steel reinforcing. Stock is usually delivered to the store packaged at pallet, crate, carton or item level.

3.1.4 Services

The retailer provides many services to its customers primarily through the selling of hardware and other building related supplies. The organization provides a delivery service to its customers if they purchase products that are too large to be transported or products that they wish to be delivered on a certain day. Products are delivered to customers in one of the three vehicles the organization owns. A flat top truck is used for steel deliveries, a tip truck is used for landscaping supplies and a utility vehicle is used for general deliveries. The organization also has a front-end loader that it uses to

load landscaping supplies on vehicles. The organization offers accounts for customers that purchase products frequently.

3.1.5 Information Technology (IT) Infrastructure

The retailer currently has limited Information Technology (IT) infrastructure and does not utilize a server, as the current operations of the business do not require a large volume storage device. The organization utilizes two desktop computers in their administration office that are primarily used to manage customer accounts through the software package MYOB Premier Version 10. At the end of each month, the organization uses the MYOB software to generate invoices which are sent out to account holding customers, requesting that they pay for the items they have purchased. The organization has another desktop computer which is used by employees to search a program that acts as an index of paint colors provided by different paint suppliers. All computers within the organization are able to access the Internet.

3.2 Interviews

3.2.1 Interviewees

Insights into the current inventory control practices at the small-to-medium retailer are based on semi-structured interviews carried out on four employees of the organization. The roles and duties of these employees are documented in Table 1.

Table 1. Employee roles and duties

ID	Job Title	Duties
1	Proprietor/Manager	Stock replenishment, capital purchasing, staff management, delivery scheduling, customer service
2	Proprietor/Part-Time Manager	Stock replenishment, staff management, delivery scheduling, delivery truck driver, customer service
3	Store Manager	Stock control and replenishment (for some of the stock), customer service, staff management, shop maintenance
4	Delivery Truck Driver	Stock delivery, stock control and replenishment (for some of the stock), customer service

As can be seen from Table 1, employees of the organization have minimal job specialization, which reinforces [12] observations of small businesses. The proprietor/manager and proprietor/part-time manager are responsible for the overall running of the business whereas the store manager is specifically responsible for shop maintenance and management. The delivery truck driver is primarily responsible for making outbound deliveries. The store manager and delivery truck driver are answerable to both of the proprietor/managers.

3.2.2 Interview Questions and the Inventory Cycle

Inventory control as defined by [13] involves "coordinating the purchasing, manufacturing and distribution functions to meet marketing needs". Coordinating these functions requires many discrete activities including ordering stock or materials and shelving or putting it in the correct position so that customer's have access to it. In this section, the inventory control process has been broken down so that the inventory practices of the small-to-medium retailer can be explored in greater detail. Fig. 1 illustrates the Inventory Cycle. It should be noted that [14 p. 21] Inventory Flow Cycle is focused on the flow of raw materials to their finished state, while this inventory control cycle has been developed based on a retailer that sells finished goods.

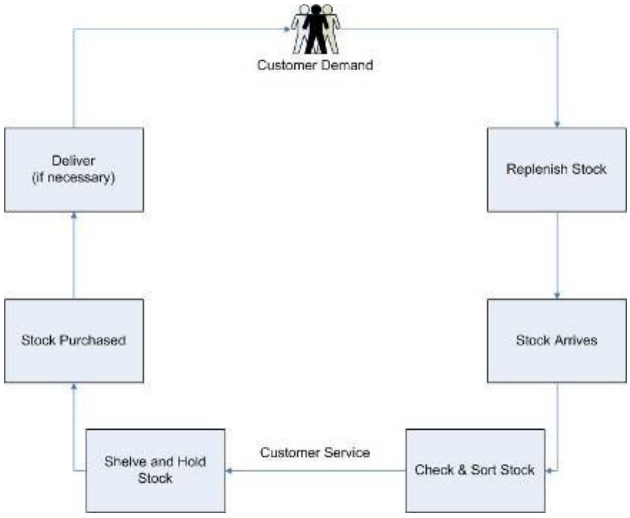


Fig. 1. The inventory cycle

As can be seen in Fig. 1, customer demand triggers the ordering or re-ordering of stock. Stock then arrives at the retailer, where it is checked and sorted before being shelved in the correct position. Stock is then purchased by a customer and delivered by the retailer if necessary.

The inventory cycle demonstrated in Fig. 1 was considered when developing questions for the semi-structured interviews. The majority of the questions asked related to the six different processes that were identified in the inventory control cycle. There were a total of twenty-eight questions included in the original semi-structured interview protocol but additional probing sub-questions were asked where the respondent was able to expand their response due to their knowledge of operations. The questions covered the background of the company case, the role of the employee in the organization, questions related to the current mode of operation to gauge the current inventory control practices and set-up, and more speculative questions regarding the transition of the organization from a manual-based system to barcode and/or RFID. For instance the proprietor was asked:

1. Can you describe the process that you use to check that orders have been delivered with the correct contents?
2. Do you keep any sort of record of how much stock you carry, either in physical or electronic form?
3. How would you describe the theft prevention measures in your workplace?
4. What triggers your organization to reorder or order stock?
5. Are there any issues affecting your adoption of automated data capture technology?
6. Do you think that RFID could be used within your business to improve inventory control?

The interview transcripts were analyzed using a qualitative approach and the findings were presented using a modular narrative style based on the steps in the inventory control cycle. The following sections summarize the findings of the semi-structured interviews.

3.3 Participant Observation

A participant observation requires the researcher to become a direct participant in the social process being studied, by becoming a member of an organization. The participant observation was carried out over a two week period with the intention of recording observations relating to the inventory control practices used within the small-to-medium retailer. This study utilizes an overt participant observation as members of the organization were already aware of the researcher's presence due to interviews being carried out at an earlier date. The overt approach was perceived to have had minimal influence on the behavior of the organization's members as they were informed that the purpose of the study was to examine inventory control practices of the retailer, not their personal behaviors. During the participant observation annotations and issues were documented through the use of a diary. Field notes were recorded during each day, and were formalized at the end of the day.

3.4 Procedural Documentation

The small-to-medium retailer's procedural documents were used to complement the semi-structured interviews and participant observation. Documentary secondary data, such as an organization's communications, notes, and other policy and procedural documents have been examined. Moreover, [15 p. 104] states that official documents, like procedural documents can be treated as unproblematic statements of how things are or were. The procedural documents have been used as evidence to support the determination of the inventory control practices of the small-to-medium retailer. The interviews conducted, participant observation and the collection of procedural documents were combined to develop the business process flows of the organization. A narrative presentation is used to bring together participant observational data and interviewee responses.

3.5 Simulation of RFID enabled scenarios

Eight simulations have been developed which are aimed at examining different aspects of inventory control and known RFID issues that have been documented in the literature. Fig. 2 illustrates which RFID simulations are related to stages in the inventory cycle (documented previously in Fig. 1). Each simulation is **colour-coded** (in Fig. 2 and following sections) to correspond to the relevant stage in the inventory cycle. However, within the scope of this paper, we will only present and discuss two scenarios namely the RFID-enabled-Point of Sale and the RFID-enabled- checking deliveries and invoices.

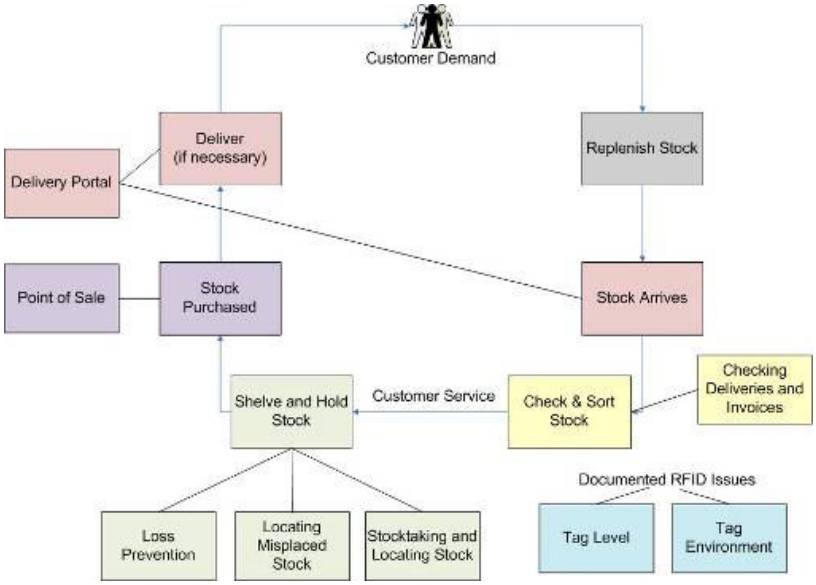


Fig. 2. The focus of the overall simulations

The results of the simulations are documented qualitatively, discussing read rates as well as any other technical issues experienced in the following section.

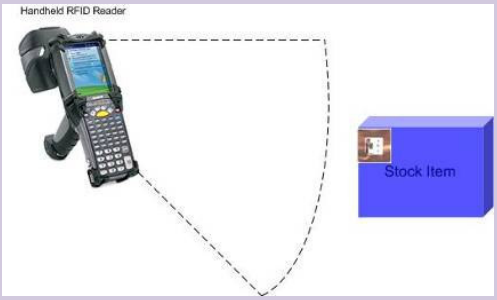
3.5.1 Scenario 1: RFID enabled-Point of Sale (POS) simulation

AIM: To simulate a Point of Sale (POS) system that utilises RFID technology to accurately identify items.

SIGNIFICANCE: This simulation should reveal how RFID can identify items compared to using a manual process. It should also reveal how visibility can be improved through recording information at POS, as purchasing history would be able to be maintained by the retailer.

APPARATUS: Symbol MC9090-G mobile computer, stock (products) and passive RFID tags.

METHOD: Ten items and products from the retailer will be RFID tagged and scanned using the mobile RFID reader prior to purchase. Multiple tagged items will be brought to the counter where they will be scanned and the tag read rates of the simulation will be recorded.



The Point of Sale (POS) simulation carried out in the retailer involved ten products and items being tagged in different arrangements. The initial test in this simulation involved the mobile RFID reader being utilised to scan or interrogate transponders located on tagged products.

Ten attempts were made with the reader to identify each tagged product individually from different orientations. This aspect of the simulation was designed to demonstrate the purchasing of a single item by a customer. Table 2 summarises the read rates experienced by the mobile reader (□= read successfully).

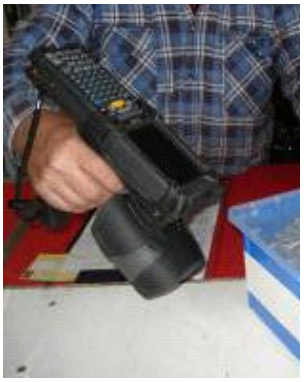


Exhibit 1. The ten tagged products (left); scanning an RFID tagged carton of nails (right)

Table 2. POS single item simulation results

Item	Mobile Reader		
	Read on	Read on	Read on all

	some (40%) attempts	majority (80%) of attempts	(100%) attempts
Flat sheet of Metal 300mmx 900mmx0.5mm	□		
3/8 inch Mudguard Washer	□		
Electrical Tape		□	
Sleeve bolt Anchors 12mmx99mm (in cardboard box)		□	
76mm Zinc Eyebolt (in plastic/cardboard packaging)		□	
Wooden Hammer Handle		□	
1 Litre Methylated Spirits Litre (in plastic bottle)		□	
Concrete Paver			□
5kg Galvanised Flathead Nails 65mmx2.8mm (in plastic container)			□
4kg White Cement (in plastic bag)			□

The results revealed that the mobile reader was able to read data from all tagged items. For tagged products composed of metal, namely the flat sheet of metal and the mudguard washer, the mobile RFID reader was only able to read data from them on 40% of attempts. Larger flat items such as the cement, container of nails and the concrete paver were read on 100% of attempts, at any orientation as the tag was attached in a flat configuration. The majority of tagged items that were identified in 80% of attempts had RFID tags wrapped around these objects so that the tag was overlapping itself.

The second part of this simulation involved attempting to read data from multiple tagged items simultaneously. Ten attempts were made with the mobile RFID reader to identify tagged products, with only four out of the ten products being successfully interrogated. The tagged items that were unable to be identified were orientated perpendicular to the reader in the majority of cases.

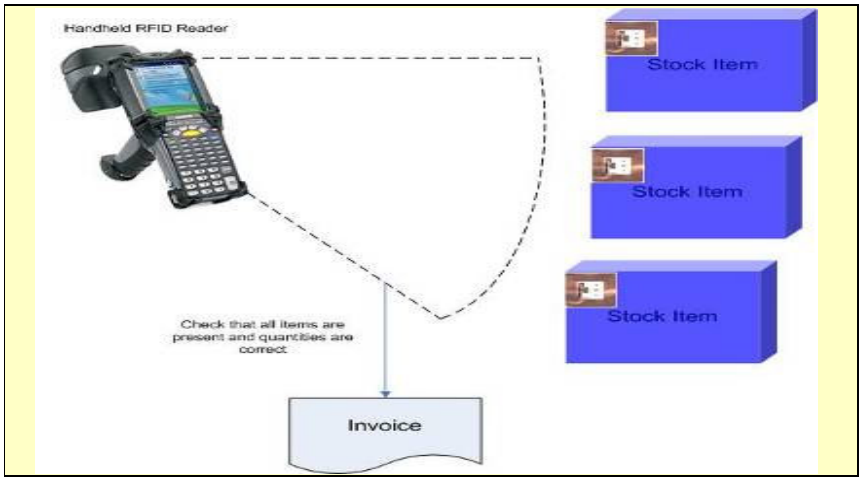
3.5.2 Scenario 2: RFID enabled- checking deliveries and invoices simulation

AIM: To use an RFID reader to accurately identify multiple products in a delivery which have been labelled with RFID tags.

SIGNIFICANCE: This simulation will demonstrate how RFID can improve the invoice checking process (for deliveries). The use of RFID should result in greater accuracy and improvements made in relation to time taken to carry out these processes.

APPARATUS: Symbol MC9090-G mobile computer, Symbol XR440 fixed RFID reader, Symbol AN400 High Performance Area Antenna, stock (products), a pallet and passive RFID tags.

METHOD: A mock delivery or order will be simulated by packing a variety of RFID tagged items onto a pallet as if they had just been delivered. The mock delivery will be scanned from each side of the pallet three times using an RFID reader with results being recorded and tag orientation examined to determine the effect it has on the accuracy of the reader.



The checking deliveries and invoices simulation involved RFID tagging 24 cardboard cartons containing stock such as sponges, tape measures and crow bars from a general hardware supplier. The tagged cartons were placed on a pallet made of steel, measuring 80 centimeters in width by 1 meter in length with a metal barrier surrounding it that measured 90 centimeters in height.

Exhibit 2. Delivery pallet with tagged cartons

In this simulation the mobile RFID reader was used to read data from tagged items, whilst standing one meter from the pallet. Fig. 3 illustrates how many tags were successfully read by the mobile reader from each side of the pallet.
The results of this part of the simulation revealed that the mobile reader was reasonably accurate at reading data from tagged cartons in the mock delivery. Majority of the tags that were not able to be identified were located the furthest

distance from where scanning was conducted or the tags were orientated perpendicular to the reader. For example, when the mobile reader was used to scan the pallet from the northern side seven tagged items were not able to be scanned; four of these tagged items were located on the southern side (far side) of the pallet. Of the other three tagged cartons that were unable to be read two of them were on the western side of the pallet, with tags orientated perpendicular to the reader and one was located in the centre of the pallet, with its tag located on the southern side (far side) of the carton.

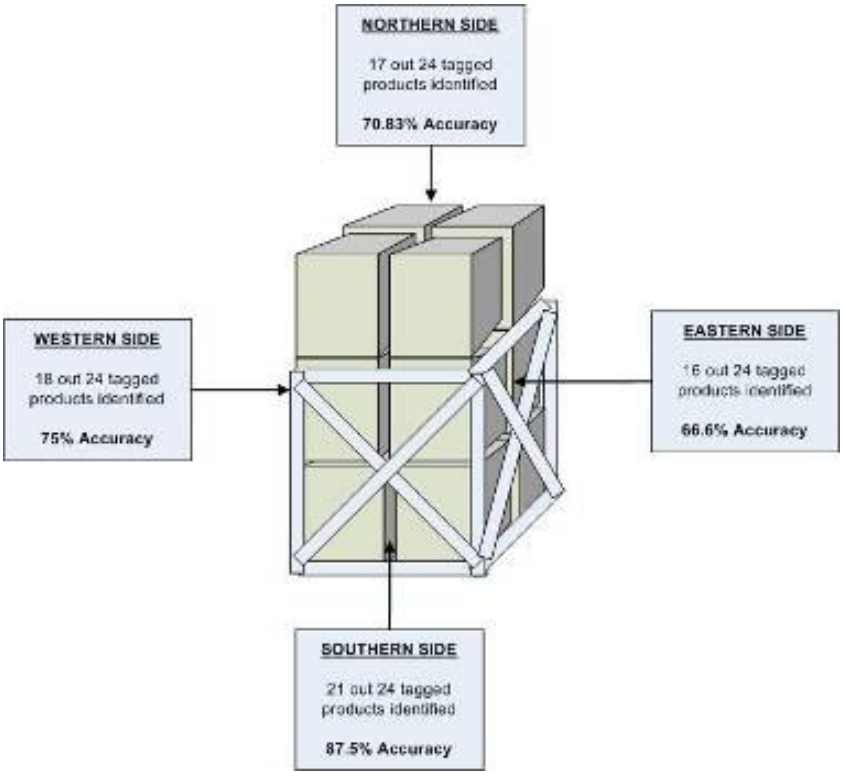


Fig. 3. Tags successfully read by the mobile reader

The latter part of this simulation involved employing a fixed RFID reader and a single antenna to scan the pallet of RFID tagged cartons to determine which reader was most accurate (Fig. 4). The antenna was fixed 1 meter above the ground and positioned 1 meter away from the pallet which resulted in less accurate read rates than those experienced with the mobile reader. Based on the scans conducted from the four sides of the pallet it was recorded that on average 58.32 % of tags were successfully interrogated by the fixed reader. As was the case in the initial part of this simulation it was observed that the majority of tagged cartons that were not identified by the reader

were located the furthest distance from where scanning was conducted or tags were orientated perpendicular to the reader.

Overall, this simulation illustrated that RFID could be used to improve the checking of deliveries and orders, but tag orientation and proximity were established as two factors that affected the successful identification of RFID tagged cartons in a delivery or order.

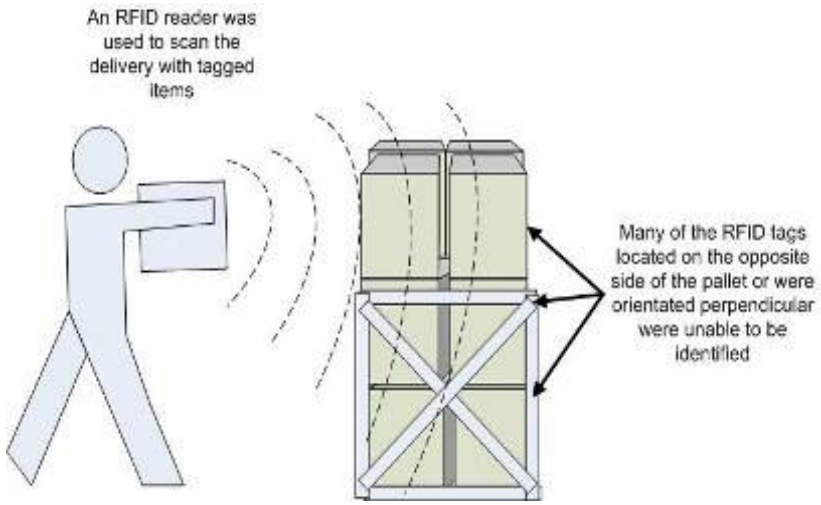


Fig. 4. The Findings of the Checking Deliveries and Invoice Simulation

4 Discussion and conclusion

The simulations produced promising results in relation to the successful functioning and operation of RFID technology in a small-to-medium hardware retailer. Some of the simulations yielded high read rates, while others produced only mediocre read rates. It should be noted that simulations were carried out over a brief period of time, using basic RFID equipment. Read rates could be improved if more antennas were employed (and attached to fixed RFID readers) and more attention was paid to orientation. It is perceived that RFID could improve the inventory control process of the small-to-medium retailer, but read rates would have to be improved for the technology to compete with the claimed 99.9% accuracy of barcodes in order to justify its implementation [16 p. 4]. The accuracy of RFID equipment is likely to be improved in the future as the technology is continually being refined.

The adaptability and robustness of RFID tags was demonstrated in the simulations as items with RFID tags attached to them were able to be identified successfully, even after being exposed to the elements for an extended period of time.

Even though the simulations did illustrate that RFID could be used successfully within the organisation a number of technical issues were raised when carrying out the simulations. It is perceived that if these technical issues are resolved the business case for implementing RFID within the retailer would be strengthened. The technical issues encountered are described in the list below:

- Items composed of metal that were RFID tagged could not be read as easily as items that were made of other materials. In the environment simulation it was noted that RFID tags attached to items composed of metal were only able to be identified in one of the six attempts made to read data from them.
- Tags that were wrapped around items so they overlapped could not be identified by RFID readers in the majority of cases. It was found when tags were applied in a flat configuration to items of stock they were able to be identified without difficulty.
- RFID tags that were orientated perpendicular to readers and not within a particular proximity (1m radius for the mobile reader and about 3m radius for antennas attached to the fixed reader) were not able to be identified. It should be noted however that the signal range of the readers can be varied.
- The inaccuracy and poor to average read rates experienced in the loss prevention simulation illustrated that RFID should not be implemented for a loss prevention application until read rates are improved. In this simulation the main difficulties were encountered when trying to identify concealed objects.
- Although RFID tags were able to be successfully read after being applied to pallets and other items that were exposed to environmental and weather conditions, there was difficulty experienced applying RFID labels to some of these objects, especially dampened wooden pallets which required tags being nailed to them.

The next logical step of this study is to conduct a pilot study to assess the business value of these scenarios. Furthermore, it'll be important to identify a set of key performance indicators to measure improvements from RFID. Also, it'll be interesting to use the latest generation of RFID tags in our RFID-enabled scenarios. Indeed, in some recent studies the tag reading accuracy has reached 100% [17].

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