Evaluation of a Radio Frequency Identification (RFID) Library System: Preliminary Results

Paul Golding and Vanesa Tennant
University of Technology, Jamaica
School of Computing and Information Technology
cashmere@cwjamaica.com, vtennant@cwjamaica.com

Abstract

The literature has indicated that libraries in developed countries are fast growing early adopters of Radio Frequency Identification (RFID) technology. The adoption of RFID in supply chain has reported superior growth, spurred by mandate compliance from global retailers such as Wal-Mart and Target. Numerous tests have been performed in a variety of supply chain environment to determine the performance requirements, physical characteristics and limitations to achieve a near 100% read rate. However, the literature is sparse on reports of performance testing in a library setting, and results from supply chain testing should be reluctantly applied to other environments. Based on the above, this study addresses this gap in the literature with the execution of test cases to examine the operational efficiencies of the inventory reader and the self-check station. The study was conducted at a university library with a test sample of 200 books of different types. The factors examined include tag placement, reader orientation sensitivity, read distance, and metal and other possible sources of electromagnetic interference. Each test case was executed repeatedly and the accuracy rate was recorded. Additionally, a spectrum analyzer was used to monitor possible sources of interference. The preliminary findings suggested that mobile phones and wireless computers have no effect on the performance of the self-check station or inventory reader. In addition, the preliminary results also suggest that metallic shelves affect the performance of the inventory reader with reduced read rate accuracy.

1. Introduction

Radio Frequency Identification (RFID) is an automated data-capture technology that can be used to electronically identify, track and store information on groups of products or individual items. Industry and public interest in RFID technology took a major leap in 2003 when Wal-Mart mandated its largest 100 suppliers to commence using RFID tags on shipped items at the pallet level by 2005 [1,2]. The literature [3, 4] highlighted that the individual tag prices are expected to fall to 5 cents per unit threshold by 2008. This anticipated price should be a catalyst to increase the adoption and diffusion of RFID technology in a number of applications.

Libraries are fast growing adopters of RFID as the technology promises to relieve repetitive strain injury, speed patron self check, reduce pilferage and provide accurate and timely inventory management. It has been suggested that library RFID applications may be the first major deployment of item level tagging [7, 8]. The library provides the panorama to study the operational issues of RFID tagging at the item level.

While the literature has discussed a number of perceived and expected problems with RFID in the supply chain, it is sparse on performance and reliability of RFID library systems. The implementation issues highlighted in the supply chain include failed or erroneous reads [9], handling of large amounts of data generated by the tags [10, 11], lack of mature standards

[4,6,12], collision [13,14,15] and failure in the presence of metal and liquid based products [16,17,18]. Investigation of RFID in the library environment is important, as it is decidedly different from a distribution or manufacturing environment. This study will collect data from library that has recently implemented RFID and undertake testing assessment of the equipment, namely, self check stations and inventory reader.

The outline of the paper will be presented as follows: Section 2 will provide a brief overview of the RFID technology in libraries; Section 3 and 4 will discuss the purpose of the study and background of the problem respectively. Section 5 will state the research questions examined in the study; Section 6 will discuss the theoretical foundation, which forms the premise on which test cases were developed. Section 7 will discuss the literature on the performance factors and the methodologies used in the testing. Section 8 will discuss the preliminary findings on mobile interference and effect of metal shelves on performance. Section 9 will provide a conclusion and future work.

2. Overview of RFID library system

RFID is a sensor-based technology consisting of three key elements: RFID tags (transponders), RFID readers (transceivers), and a data collection, distribution, and management system (middleware) that has the ability to identify or scan information with increased speed and accuracy [19].

In library systems, the tag is designed as an RFID label which comprises of four elements, namely, the chip, the antenna on a foil, the cover paper or plastic label and the silicon liner [20]. Passive tags, typically used in library application, gain electric power through an inductive field generated by a reader. This is chosen, as they are smaller, cheaper and have a longer shelf life compared to active tags. The standard tag used on books can be described as flexible, paper thin label approximately 2”× 2” in size that can be attached inconspicuously [21]

There are variations of readers, and the types include: handheld, mobile mounted, fixed and combination reader/writer. In a typical library, readers are configured to identify tags for purposes of circulation, which include inventory management and theft control. Readers in the library are either fixed or handheld, as listed below by [22]:

a) Staff workstation at circulation: used to charge and discharge library materials

b) Self check station: used to check in and out library materials without staff assistance

c) Exit sensors: to verify that all material leaving the library has been checked out

d) Book-drop reader: used to automatically discharge library materials and reactivate security

e) Sorter and conveyor: automated system for returning material to proper area of library
f) Hand-held reader: used for inventorying and verifying that material is shelved correctly

The information stored by the tag is interpreted by the reader and sent to the server, which communicates with the Integrated Library System (ILS). In terms of frequency range, library systems operate in high frequency (HF) band at 13.56 MHz.

3. Background of the problem

Radio Frequency Identification is slated to replace barcodes in library applications [23]. The barcode system used in libraries is extremely time consuming and labor intensive. This problem results in delayed inventory management and physically demanding practices and procedures for staff activities in handling and processing materials. In contrast, RFID provides a solution to effectively collect, manage and distribute books. This is achieved by automating the loan and return of library materials through real-time visibility of inventory [6,7]. While there are over 500,000 RFID systems installed in warehouses and retail establishments worldwide, RFID systems are still relatively new in libraries [7]. This is supported by [24] which reported that approximately 120 million media and books in about 500 libraries are already attached with RFID tags. Hence, although RFID has become increasing popular in libraries, it is still in its infancy as expressed by [25].

A report by [26] articulated that there exist aspects of RFID in libraries that require further investigation, namely performance and operational efficiencies. This is a gap in the literature that will be addressed by this study. To date, only two small studies [27, 28] have been conducted on RFID in libraries. Both studies provided limited detail on performance issues, and the results were inconclusive. The issues that require testing in library systems include the precision of the inventory wand in identifying missing and misplaced items, metallic and electromagnetic interference, and operational issues with self check stations and security gate.

Academic and management research on RFID performance and reliability issues in the library is necessary for further growth and adoption of the technology. These sentiments are also expressed by [29] which stated that it is paramount that the library community conducts a comprehensive technology assessment of RFID to enable librarians to make the best possible decisions involving the use of the technology..

4. Purpose of the study

As industry adoption of RFID increases coupled with the reduction in cost of tags and establishment of standardization bodies, it is essential to comprehend the technical and operational issues of item level RFID tagging.

The purpose of this research is to investigate and test the performance and reliability of RFID system in libraries. This study aims to address the gap in the literature as studies [27, 28, 30] on RFID library system have not addressed the performance and reliability of the technology. However respondents in the aforementioned studies and anecdotal evidence based on interviews with RFID users highlighted performance issues with inventory wand, self-check systems and security gates.

This study will examine RFID operational issues as it relates to performance of the inventory reader and self check station to obtain optimal accuracy rate. The results will help to determine best practices for the use of the technology. In addition, the methodologies outlined in Section 6 can be applied to performance testing for other vendor solutions.

5. Research question

The library is deemed as a suitable test setting as it provides a closed environment with circulation of items. In a library application, open loop RFID system would include the movement of tagged books between libraries such as inter-loan of materials. On the other hand, closed loop RFID applications involve the processing of books internally to an organization solely. On discussing open vs. closed systems, [31] argued that closed loop application offers greater flexibility in terms of hardware selection and the standardized protocol utilized.

This study focuses on the testing of RFID library system in an academic institution that has tagged the majority of the library materials by conducting tests on the performance and reliability of the system. The research questions are as follow:

1. What is the read performance difference at varying angles of the inventory reader with respect to the tag?
2. What is the accuracy read rate based on distance between tag and reader for inventory management?
3. Do metal shelves affect the performance of the RFID inventory reader?
4. What is the effect of mobile devices such as cell phones and computers on the performance of the system?
5. What is the average check-in/out rate with near 100% accuracy with multiple books (1, 3, 10, and 20) and multiple mixed types of books (paper back, hard cover, metal binding, etc)? What causes erroneous reads/failures?
6. What is the optimal location for tag placement on books?

6. Theoretical foundation

Performance testing is an integral aspect of RFID application, with users' anticipation of near 100% accuracy rate. Tag read rates have been a publicized challenge for the technology. This study will execute test cases and record data on the performance of RFID library system, namely self check stations and inventory reader. Despite the fact that there exist theories for hardware reliability and software reliability [32] and [33], this research hypothesize that the testing of RFID system cannot be isolated to either, as there is no distinction between the hardware and software for the RFID library system. It has been argued by [34] that the key distinction between software and hardware reliability is the difference between intellectual failure (software) and physical failure (hardware). However due to the fact that the researcher has no access to the RFID library software and the hardware cannot be disaggregated from the software, it is posited that the system reliability will be examined.

Performance testing [35] is characterized as a methodology that examines the behavior of a system under a particular workload. It also validates and verifies other quality attributes of the system such as reliability. Although performance testing is a software engineering concept, as mentioned earlier, the testing of RFID system cannot be isolated to either hardware or software.

The evaluation or testing of RFID system as outlined by [36] can be executed as benchmark test, laboratory test or field test. Benchmark tests are used is to discover the advantages and disadvantages of products by comparing and analyzing the features and performance of each product. While, laboratory tests are performed to check the degree of recognizing selected tags and readers in the laboratory. The last type, field test is performed for developed products in an actual site after laboratory tests. This study will perform field test, based on the advantages suggested by [36] which include the prospect to test the recognition rate, study the optimal recognition rate, and to discover issues that occur when the RFID is applied to processes in the actual environment. The strategy applied in performance engineering process has been modified to reflect the testing of RFID system as outlined in Figure 1.

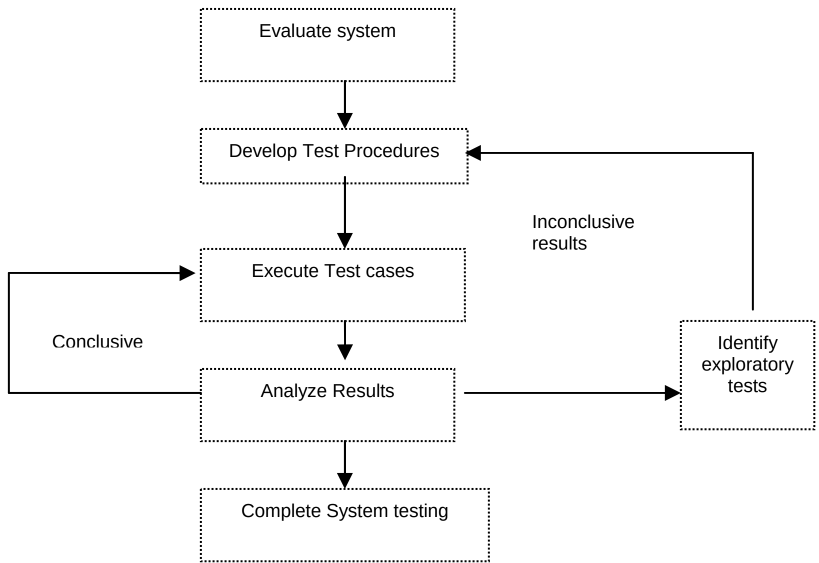

Figure 1. RFID System Testing

As highlighted by [37], test cases/processes should follow logical steps to identify those variables that would most affect a particular client's simulated RFID model. Furthermore, it is important to understand the interplay of these variables, and to ensure that tag placement is optimized for greater performance. This study will apply performance testing to measure variables including tag placement, reader orientation sensitivity, read distance, and metal and other possible sources of electromagnetic interference. The methodology applied to test the above variables will be outlined in the next section.

7. Methodology

The test environment chosen was an academic library with a fully implemented RFID system and approximately 120,000 tagged books. The inventory reader and the self check station was used in this study. The test sample consisted of 200 books including paper back, hard cover, and metal binding of varying sizes. For each test, the reads were performed and recorded 40 times. An analysis will also be performed on the type of books that experience reading problem. Based on each test, a hypothesis was examined that correspond to research questions listed earlier. This section will discuss the literature on the variables tested followed by the test cases that were executed.

Whilst the literature has outlined different testing procedures to measure performance variables in the supply chain, this is not the case in the library environment. Hence this section will briefly discuss testing in the supply chain with focus on library system. Each discussion of the performance variables will be followed by an outline of the test procedure used in this study.

7.1. Tag location

As many RFID pilot tests have indicated over the past year, tag-reader inaccuracies are a major challenge the new technology has faced, with one of the biggest challenges being tag placement for item tagging. RFID technology does not require direct line of sight (as with barcode) between the reader and tags, hence there are a host of potential tag placement options. Determining the correct tag placement in the supply chain is time consuming and impractical due to the wide variety of goods (packaging) and environments. Tag placement options in library applications are not as wide compared to the supply chain.

Testing on proper tag location has reported different results in the supply chain. For example, at the pallet level, a consultant in [38] suggested that one-way pallet (that is, forks can enter the pallet from only one direction) could be tagged with one RFID device. However with four way pallets, the pallet had to be tagged on each side to ensure readability. On the other hand, RFID manufacturers in [38] argued that the tagging the shrink-wrap could impact performance in terms of metal and water interference. Some RFID manufacturers recommend tagging the last carton, whilst others argued tagging the conveyance. Hence there is no consistency on tag placement for pallet shipped items.

There are no empirical findings of similar testing in the library environment. However, the literature has shown dissimilar views on the effect of tag attachment position on RFID library system performance. It has been argued by [39], that the inside of the back cover is the recommended location because it is fastest for right handled tag installers to reach. A library vendor [40] suggested that it is generally recommended that tags be placed at the bottom of the inside book as close to the spine as possible. The vendor also noted that strict consistency should be avoided and actual height of the tag placement should be staggered in approximately four different positions. [41] concurred with the inside of the back cover as a suitable location, with specification that the tag be placed 7 cm above the bottom. The author also suggested that the tag be attached to the spine. On the other hand, [39] highlighted that a vendor proposed that three locations should be selected to reduce the possibility that the tags of two or more books will align exactly on top of one another and cancel signals.

7.1.1. Test procedure:

Objective: The objective of this test is to evaluate the effect on tag location on the performance of the system. As a result, the location sets will be used in all tests that will be discussed below.

Test:

a) The tags were placed at two locations, namely inside the front cover, and the inside of the back cover (approximately 6 inches above the bottom) as shown in Figure 2. Tests were also performed on a three sets of tagged books, front only, back only, and mixture of front and back.

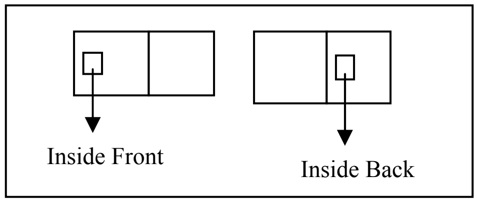

Figure 2. Tag Location

b) The tag placement described above was used in all subsequent tests to ultimately determine the effect of location.

7.2. Reader orientation sensitivity

The literature on the supply chain focuses primarily on tag orientation sensitivity. With tag orientation, it is argued that the radiation pattern of a RFID tag antenna determines the ability to read the tag in any orientation [42]. This focus is due to the type of tag antenna used in UHF systems (used in supply chain). It has been suggested that with UHF tags and microwave passive tags, conventional dipole-like antennas are employed which has orientation sensitivity issues. The issue of tag orientation sensitivity is not prevalent in high frequency systems as the tag typically uses coil antenna as related by [6]. Hence tag orientation was not examined in this study. Hereafter, reader orientation will be discussed.

It was articulated by [43], that the size of the transmitting and receiving antenna is largely a function of the frequency of transmission. Since the function of the RFID antenna is to transmit and receive electromagnetic (EM) radio waves, the antenna design should be optimized for the particular frequency, polarity, and directionality desired. It was noted by [27] that the typical RFID-based library system has internal antenna within the readers. This section of the experiment focuses on the directionality desired for the inventory reader to effectively scan books.

In a report by [44] on “RFID handheld reader benchmark”, it was stressed that orientation sensitivity contributes significantly to the ergonomics of a mobile reader. It was also highlighted that if a reader is highly orientation sensitive, it is likely that the user will be forced to twist his or her wrist by ninety degrees to capture tag data, depending on the orientation and the type of tag being read. Therefore, the report argued that the orientation sensitivity of a reader is directly linked to the polarization of the reader antenna.

As noted by [45], although some antennas try to capture all tags within a regular hemisphere, most are designed to have gain in a particular direction. It was also argued that directionality enables the reader to focus its energy in a region of interest, whereas the narrowness of the beam determines the angular accuracy. It was highlighted by [46] that HF readers are highly orientation sensitive, imposing requirements on package orientation, which also impacts read reliability. UHF readers, on the other hand, can be easily configured for optimal readability and orientation indifference.

It was also highlighted by [50], that the polarity is very important because it affects the quality of communication between the interrogator and tag. Linear polarized antennas transmit in a straight line, and their orientation to the RFID tags is critical. Whilst, circular polarized antennas radiate in a 90-degree pattern and are less sensitive to the tag's orientation on the package. It has been recommended that the interrogator's antenna and the tag's antenna should have the same polarization to increase read range [47]. A study by [44] concurred with the above sentiment and argued that many RFID tags are linearly polarized hence the reader should be oriented in the same direction for optimal communication. This in forces the user to turn the unit ninety degrees to be effective

Hence we posit in the null relating to research question 1:

H_{01}-Orientation sensitivity does not affect the performance of the inventory reader

7.2.1. Test procedure:

Objective: The directionality of the reader, that is, the angle of reader's antenna may affect performance of the system. The objective of this test is to determine the orientation sensitivity of the inventory reader.

The Test

a) While noting the tag and reader polarization, the directionality of the reader was tested at four angles, 0^{o} (X), 30^{o}, 60^{o}(Z) ,90^{o}(Y) (See Figure 3)

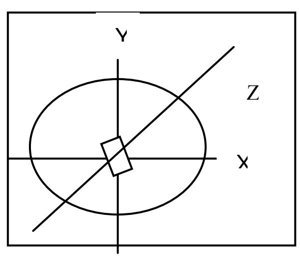

Figure 3. Reader Angle Measurement

b) The three tag placement sets were measured and recorded at each reader position. At each angle, the reading distance between the tag and the reader will be kept constant at the best read range

7.3. Reading distance

Read range refers to the maximum distance at which RFID reader can detect signal from the tag. The literature articulates that read range is sensitive to tag orientation, tag location, and the propagation environment. The Friis formula is used to measure read range [48]

$$r = \frac{\lambda \cos \theta y}{4\pi} \sqrt{\frac{P_t G_t G_r (1 - s^2)}{P_{th}}} \qquad 0 \le s^2 \le 1$$

where, G_r is the gain of the tag antenna, λ is the wavelength of the EM RF waves, P^{th} is the minimum threshold power required to power an RFID tag, θy is the angle made by the tag with the reader plane, and s^2 is the power reflection coefficient, which is the ratio of reflected power to incident power by the tag.

It has been argued by [42] (which conducted testing in the supply chain) that the read range claims by RFID vendors are unverified and fail to mention the deterioration of tag performance with distance. It was also articulated by [49] that although its manufacturer generally labels the maximum data rate supported by an RFID tag on the tag, it varies significantly from the actual read rate. It was further noted by [49] that their experiment and others show that data rate is affected by the distance and orientation between the tags and the readers. In a test by [9], the same sentiments were echoed with the range of the tags falling between 2 and 18 inches, as opposed to the specified range by vendors, which was 8 to 80 inches.

It has been suggested by [42] that there are two fundamental properties of RFID performance: the number of tags that respond at any read, and the speed in which it responds. The former metric is estimated by the ratio of tag responses per time, and the latter is estimated by the number of responses per time. For library applications, [23] argued that the full tag value of RFID in libraries can be read at a range of 8 to 18 inches. [39] also argued that anecdotal evidence suggests that detection rate is almost 100% whenever a reader is within 12 to 14 inches of tags, but there appears to be no statistical data to support the claims.

Hence we posit in the null relating to research question 2:

H_{02}-Reading distance does not affect the performance of RFID inventory system

7.3.1. Test procedure:

Objective: To determine the maximum distance at which the tag is readable by the Inventory reader

The test

a) The reading angle with optimal performance in the reader orientation sensitivity test was used to experiment with the different read distances.

b) Each set of tag placement was initially read at distances (d) from 8 to 12 inches as specified by the vendor. Distances outside of the specified range were also experimented with. A ruler was attached to the reader to ensure that the distance was kept constant at each measurement. See Figure 4 for test set up.

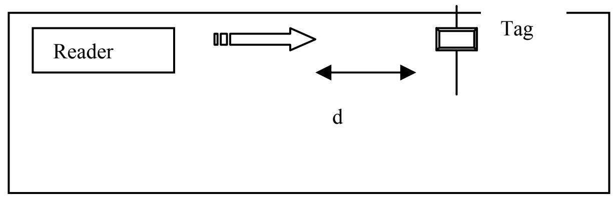

Figure 4. Test set up to measure read rate at varying distances

7.4. Metal interference

In the supply chain, much testing is performed on metal interference as it has been argued UHF systems experience difficulties in accurately read tags on objects with or surrounded by water or metal [42, 50]. Metals reflect electromagnetic (EM) waves and scatter them in all directions, which reduce the power needed by tags to respond [9]. However regarding HF systems and library applications, reports on effect on metal shelves on system performance are sparse.

In a document by [51], it was stated that the performance of HF is affected by the environment in which it operates, as the presence of metallic objects can interfere with communication between tag and readers. High Frequency absorbs metal and is more susceptible to attenuation. In library application, it was noted by [41] and [52] that metal shelves can cause possible interference, and may be avoided by properly locating the tag. However there has been no statistical data supporting the above. [53] suggested that the location of tags on the inside back cover near the spine is more suited as the inventory reader can be held right up against the book, which minimizes possible interference from metal shelves. It was not stated whether the conclusion was based on experimental results.

Hence we posit in the null relating to research question 3

H_{03}-Metal does not affect the performance of RFID inventory system

7.4.1. Test procedure:

Objective: To determine the effect of metal shelves on performance of inventory reader.

The test

This test was carried out in two stages, with and without the spectrum analyzer. The two approaches are discussed below:

a) All test variables (reader orientation sensitivity and read distance) with the different placement sets were performed on wood and metal shelves, and results compared.

b) A test bed was setup where the spectrum analyzer is placed at a distance of 24 inches from the RFID reader. The analyzer was set to center frequency of 13.56 MHz and a span of 10MHz, and the value of the maximum signal strength was recorded in dBm (unit for expression of power level in decibels with reference to a power of 1 milliwatt). The steps are as follows:

1. The first test recorded the RFID reader's output in free space.

2. The second test recorded the RFID reader's output with books placed between the reader and the antenna.

Metal Shelves

3. The third test recorded the RFID reader's output on a metal shelf. The reader was placed in front of a metal shelf without books and the antenna was placed behind the shelf. The distance between the reader and the antenna was kept constant and the maximum reading was recorded.

4. The fourth test recorded the RFID reader's output when books were placed on metal shelf. The reader was placed in front of a metal shelf with books and the antenna was placed behind the shelf.

Wood Shelves

5. The fifth test recorded the RFID reader's output on wooden shelf. The reader was placed in front of a wooden shelf without books and the antenna was placed behind the shelf.

6. The sixth test recorded the RFID reader's output when books were placed on wooden shelf. The reader was placed in front of a wooden shelf with books and the antenna was placed behind the shelf.

7.5. Interference from mobile devices

There exist other sources of electromagnetic interference between the tag and reader communication. According to [9] and [58] a proliferation of wireless devices such as cordless and mobile phone, and wireless computer or network can cause interference.

It is important to note that even though these devices may operate at a higher frequency than the library RFID system they may cause harmonic interference. Harmonic interference is the unintentional radiation of signal components whose frequency is a multiple of the intended signal. Depending on the type of equipment, the harmonic components may sufficiently lessen or attenuate which causes interference to the RFID signal operating at or adjacent to the frequency of the harmonics. They may also cause interference due to intermodulation. This is caused by the mixing of transmitted signals in close proximity to generate additional signal of other frequencies, which may interfere with RFID signal. There have been no reports of mobile phones and wireless computers causing interferences in libraries, hence this is an area that will be examined.

Hence we posit in the null relating to research question 4:

H_{04}-Ubiquitious devices items do not affect the performance of RFID inventory System

7.5.1. Test procedure:

Objective: To determine the effect of mobile phone and wireless computer on system performance.

The test

a) For this experiment, the spectrum analyzer was used to monitor interferences from cell phone. Four (4) mobile phones and wireless computers were placed at varying distances from the shelves as inventory is performed at different tag placement sets.

b) The read distance, and the reader orientation were held constant.

7.6. Accuracy rate-self check station

The literature has suggested problems reading certain types of books. It has been argued by [55] that it may not be possible to accurately check out a stack of items that are particularly thin such as journals and children's books. As suggested by [40], the anti-collision features of the tags and the self-check system are stipulated at 20 items to be processed. However, [20] argued that the thickness of the items determine the number of items that can be checked out within the read range. It was noted by [30] that even though the number of items may be vendor dependent, other factors that should be considered include the strength of the RFID signal, the strength of the RFID reading technology, and the size of the items (which determines the distance each tag is from the reading pad).

Hence we posit in the null relating to research question 5:

H_{05}- Type of book and stack amount does not affect the performance of self-check station.

7.6.1. Test procedure:

Objective: The objective of the test is to the checkout rate with a near 100% accuracy rate for varying number and mixed type of books.

The test

a) This procedure tested twenty (20) books in multiples of 5. The stacks were compiled using different types of books (paper back, hard cover and metal binding) at varying sizes.

b) For the combination of the three types of book, permutation (a mathematical principle) was used. Permutation (P) provides the number of ways to arrange elements in a definite order. However due to time constraints and the large number of combination that are derived, only 4 combinations was used to represent each stack of books.

On executing and evaluating all the tests, the study will determine research question 6, which was posited in the null:

H_{06}- Tag placement does not the affect the performance of RFID library system

8. Preliminary results

The analysis of data collected was not completed in time for the publication. However, provided below are some preliminary results for metal and mobile (cell phone and wireless communication) interference.

8.1. Metal interference

With respect to the type of shelf, it was observed that the signals transmitted from the reader were significantly absorbed by wood based on power levels recorded by the analyzer with a reading of -68.51 dbm (See table 1) On the other hand, the metal shelves absorbed less at -56.42 dbm. It should be noted that the stronger the power level the less the material (wood or metal) absorbs.

The above readings were recorded with tagged book on shelves. To eliminate the effect of the books as a factor, the readings were recorded without books. The results for wood and metal shelves were -65.24 dbm and -61.98 dbm respectively. The readings show that the difference in the power level between both shelving type with and without books was not significant.

Table 1. Power levels of metal and wood

Free space	Books only /dBm	Metal shelf no books / dBm	Metal shelf with books /dBm	Wooden shelf no books /dBm	Wooden shelf with books /dBm
-57.28	-51.09	-61.98	-56.42	-65.24	-68.51

Hence, it can be argued that metal shelves with books reflect the radio signals at a higher rate than wood. This is a possible cause of erroneous reads. Based on the readings of the spectrum analyzer, there was no other source of interference in the operating environment. Therefore it can be concluded that the reflective nature of the metal can cause misreads. The overall statistical data is to be analyzed to determine the actual performance difference in the system with metal and wood shelves.

8.2. Mobile interference

The spectrum analyzer was used to conduct a frequency scan of the RFID reader to confirm frequency of operation at 13.56 MHz. Activities were examined and seen in broadcast bands (97 – 107MHz), 800MHz cellular bands and 2.4GHz bands (See Figure 6 and 7).

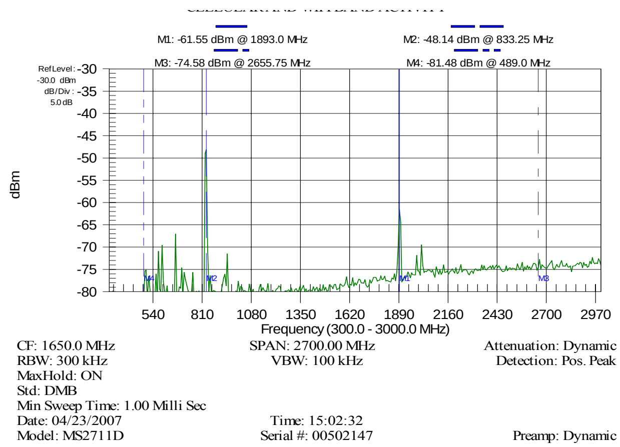

Figure 6. Cellular and Wi-Fi band activity

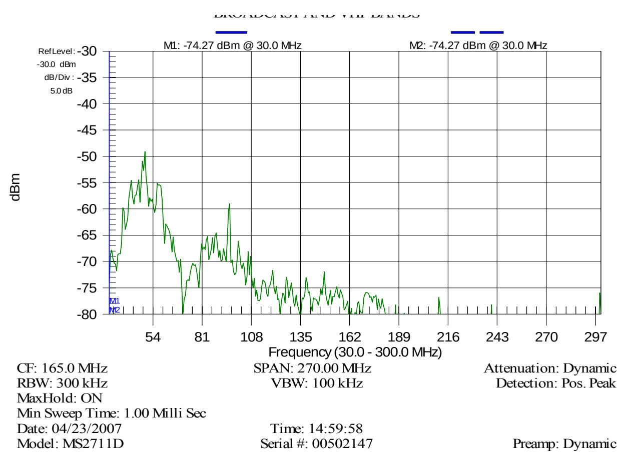

Figure 7. Broadcast and Very High Frequency (VHF) band

However the tests showed that with the inclusion of cell phone and laptop computers during reads, there was no observable effect on the RFID transmission and reception. It should be noted that the similar results were observed with the self-check station.

9. Conclusion

The preliminary findings of the study examine the effect of metal shelves and mobile equipment of system performance. With regards to metal interference, the study sought to examine its effect on performance and to note the similarities/differences compared to the supply chain. However, the data has not yet been analyzed to determine the extent of the effect. The analysis will compare readings obtained from both wooden and metal shelves. During testing, it was observed that books closest to the metal separator or to the metal upright were consistently misread. These books had to be physically removed from the shelf to obtain a reading. As a result, a possible recommendation is the use of wooden shelves to enhance performance.

While persons have argued that a proliferation of mobile devices may cause possible interference, our test, using only 4 devices did not cause any interference. While the number of phones used in the testing cannot be classified as a proliferation of mobile devices, it should be noted that cell pones are prohibited in most libraries, and therefore should not generally cause interference in this environment. However, it is recommended that future research should include a larger number of devices to determine the effect on performance.

For future study, the researchers will use the methodologies outlined in this paper to perform benchmark tests on a group of different RFID library vendor solution. The results will compare and analyze the features and performance of each system.

10. References

[1] R. Bansal, "Coming Soon to a Wal-Mart Near You", *IEEE Antennas and Propagation Magazine*, 2003, pp. 105-106

[2] M. Roberti, "Wal-Mart Spells Out RFID Vision," *RFID Journal,* June 16, 2003. Available on the Internet at 09.182.51.148/article/articleview/211?Redirect=/article/articleview/463.

[3] J. Han, H. Gonzalez, X. Li and D. Klabjan, "Warehousing and Mining Massive RFID Data Sets", (Keynote Speech), 2006 Int. Conf. on Advance Data Mining and Its Applications (ADMA'06), Xi'An, China, Aug. 2006.

[4]C.Seidler, "RFID Opportunities for mobile telecommunication services", *ITU-T Lighthouse Technical Paper*. May 2005.

[5] D. Molnar and D.Wagner. "Privacy and Security in Library RFID: Issues, Practices, and Architectures", *ACM Computer and Communications Security (CCS)* 2004

[6] J. Curtin, R. Kauffman., F. Riggins, "Making the 'MOST' Out of RFID Technology: A Research Agenda for the Study of the Adoption, Usage and Impact of RFID," *Information Technology and Management*, 2006

[7] S. Shahid, "Use of RFID Technology in Libraries: a New Approach to Circulation, Tracking, Inventorying, and Security of Library Materials", *Library Philosophy and Practice Vol. 8, No.* 1 (Fall 2005)

[8] R. Kranenburg, and M. Ward, "RFID: Frequency, standards, adoption and innovation", *JISC Technology and Standards Watch*, May 2006

[9] Z. Asif, and M. Mandviwalla "Integrating the Supply Chain with RFID: A Technical and Business Analysis", *Communications of the AIS*, Vol. 15, No. 24, pp. 393-426 , 2005

[10] S. A. Weis, S. E. Sarma, "Security and Privacy Aspects of Low-Cost Radio Frequency Identification Systems". Security in Pervasive Computing: *First International Conference,* Boppard, Germany: Springer-Verlag, 2004

[11] R.Westervelt., "RFID secrets: SAP customers tweak systems for RFID." *Retrieved at http://searchmobilecomputing*techtarget com/originalContent/0,289142com/originalContent/0,289142

,sid40gci112185.html, 2005

[12] E. Mousavidin "RFID Technology: An update", *ISRC Technology Briefing Series,* 2004

[13] G. Avoine and P. Oechslin. "RFID traceability: A multilayer problem" In A. Patrick and M. Yung, editors, Financial Cryptography – FC '05, Volume 3570 of Lecture Notes in Computer Science, pages 125–140.Springer-Verlag, 2005

[14] MetroGroup. "RFID: Uncovering the Value Applying RFID within the Retain and Consumer Package Goods Value Chain", Metro Group: Future Initiative Store, 2006

[15] T. Hassan, and S. Chatterjee, "A Taxonomy for RFID", *Proceedings of the 39th Hawaii International Conference on Systems Science*, Kauai, HI, January 2006, IEEE Computer Society Press, Los Alamitos, CA, 2006

[16] RFID Benchmark Study. "Making waves: RFID adoption in returnable packaging" LogicaCMG, May 2004

[17] S. Garfinkel and H. Holtzman, "Understanding RFID Technology*",* 1st ed., pp. 15-22 *Addison Wesley Professional,* 2005

[18] T. Pering and R. Want, "Spontaneous Marriages of Mobile Devices and Interactive Spaces." *Communications of the ACM*, 48, 9, 2005, 53-59

[19] Organisation for Economic Co-operation and Development (OECD). : Radio-Frequency Identification (RFID): Drivers, Challenges and Public Policy Considerations, 2006

[20] E. Erwin and C. Kern, "Radio-Frequency-Identification for Security and Media Circulation in Libraries", *Library and Archival Security. 18:2 2003. 23-38*

[21] A Narayanan, S. Singh, M Somasekharan, "Implementing RFID in Library: Methodologies, Advantages and Disadvantages", Scientific Information Resource Division, 2005

[22] R. W Boss, "RFID technology for libraries" [Monograph]. *Library Technology Reports*. November-December 2003

[23]V. Chachra, "Experiences in implementing RFID solutions in a multi-vendor environment". *IFLA Conference, Berlin,* August, 2003

[24] Wireless World, "Libraries embrace wireless, United Press International." October 2005, Retrieved at http://www.physorg.com/news7466.html

[25] C. Haley, and J. Lewis. Implementation of Radio Frequency Identification (RFID) Technology in a Voyager Library. *Chicago State University (CSU)*, 2004

[26] San Francisco Public Library Technology and Privacy Advisory Committee. "Radio Frequency Identification and the San Francisco Public Library", *LTPAC Summary Report*, 2005

[27] J. Singh, N. Brar and C. Fong, "The State of RFID in Libraries", *Information Technology and Libraries,* March 2006

[28] California Library RFID Survey. Infopeople and the Information Technology Section, California Library Association, 2004

[29]M. Rafiq, "Radio Frequency Identification (RFID): Its Usage and Libraries". *White Paper: National Textile University, Pakistan,* 2004

[30] E. Engel, "RFID Implementations in California Libraries: Costs and Benefits", Report :U.S. Institute of Museum and Library Services, under the provisions of the Library Services and Technology Act, 2006

[31] J. Havens, "Patrick J. Sweeney II: The Three Keys to RFID Implementation", AIM Global Network. August 2006. Retrieved at http://www.aimglobal.org/members/news/templates/podcast.asp?articleid=1534&zoneid=42

[32] J. Palma, J. Tian, P. Lu "Collecting Data for Software Reliability Analysis and Modeling, IBM Programming Systems Toronto", Laboratory, 1993

[33] W. Farr "Software Reliability Modeling Survey", in: Lyu, M. R. (ed.):Handbook of Software Reliability Engineering, New York, San Francisico, et al., 1996, pp. 71 – 117

[34] D. Dwyer, "Software Reliability Estimation /Projections, Cumulative and Instantaneous", *River College Online Academic Journal, Volume 2, Number 1, Spring 2006*

[35] L Bousquet, "Evaluating Behavior Correctness of Synchronous Systems through Time to Service Distribution Analysis: Tools Required." International Conference on Software Engineering Advances (ICSEA'06), 2006

[36] S. Youm, S. Cho "A Study on the Test Process and Items of Systems Related to RFID", 2006, Unpublished

[37] W. Zoch and D. Ferguson, "RFID Performance Testing, Beyond Compliance. The Importance of Pre-Deployment, Customer-Specific Performance & Integration Testing to RFID" , White Paper: Sensormatic, August 2004

[38] B. Albright, "RFID Tag Placement" *Aftermarket Business*, November 2004 Retrieved at http://www.aftermarketbusiness.com/aftermarketbusiness/article/articleDetail.jsp?id=130944

[39] R. Boss, "RFID Technology for libraries", Public Library Association Tech Notes , May 2004 Retrieved from www.ala.org/ala/pla/plapubs/technotes/rfidttechnology.htm

[40] TagSys., Sirsidynix RFID: Radio Frequency Identification, Library White Paper: SirsiDynix/TAGSYS, 2006

[41] B.G. Praskash,"No Missing Book", Business Line Publication, November 2006. Retrieved at http://www.blonnet.com/ew/2006/11/06/stories/2006110600080200.htm

[42] K. Ramakrishnan, D.Deavours, "Performance Benchmarks for Passive UHF RFID Tags" *Proceedings of the 13th GI/ITG Conference on Measurement, Modeling, and Evaluation of Computer and Communication Systems*, 2006

[43] B. A Craft .Secure Integration of Radio Frequency Identification of Radio Frequency Identification (RFID) Technology into a Supply Chain, *Thesis,* September 2005

[44] ODIN Technologies Laboratories, “The RFID Handheld Reader Benchmark: An independent evaluation of EPC Compliant Handheld RFID Reader”, 2005, White Paper: UniSys, ODIN Technologies

[45] Computer Science and Telecommunications Board (2004). Radio Frequency Identification Technologies: A Workshop Summary. Retrieved at http: //www.nap.edu/openbook .php?isbn=0309095433&page=8

[46] Extended Retail Solutions (2007). UHF Gen 2: the perfect storm. Retrieved at http://www.extendedretail.com/pastissue/article.asp?art=26549&issue=161

[47] OTA Training (2006). RFID+ Exam Cram. Retrieved at http://www.examcram2.com/articles/article.asp?p=485644&seqNum=5&rl=1

[48] K. V. S Rao, P.V Nikitin, S.F Lam “Antenna design for UHF RFID tags: A review and a practical application,” *IEEE Trans. Antennas Propag.*, vol. 53, no. 12, pp. 3870–3876, Dec. 2005

[49] S.C Cheung, W. K Chan, Penny M.K Lee, Lionel M Ni, and Peter Ng., "A combinatorial methodology for RFID benchmarking", in Proceedings of the 3rd RFID Academic Convocation (in conjunction with the China International RFID Technology Development Conference and Exposition), Shanghai, China (2006).

[50] H. Mallinson, Steve Hodges, Alan Thorne, “A System to Test the Performance of RFID-Tagged Objects”, *International Symposium on Applications and the Internet Workshops* (SAINTW'07), 2007

[51] Philips Semiconductors, TAGSYS and Texas Instruments Inc “Item-Level Visibility in the Pharmaceutical Supply Chain: A Comparison of HF and UHF RFID Technologies”, *TagSys, 2004*

[52] C. Kern, M. Nauer, “Implementing RFID in Libraries for Process Automation- Experiences from over twenty current installations”, 2003, Retrieved from http://liber.library.uu.nl/publish/articles/ /000079/article_content.htm

[53] G. Khong, S. White. “Moving Right Along: Using RFID for Collection Management at the Parliamentary Library”, Report, 2004

[54] M. Bhuptani and S. Moradpour “RFID Field Guide Deploying Radio Frequency Identification. New York, New York: Prentice Hall, 2005

[55] K. Coyle, "Management of RFID in Libraries." The Journal of Academic Librarianship, 31, (September 2005): 486- 489

Authors

Paul Golding

Received a B.S. degree in Accounting from the University of the West Indies Mona, Jamaica, 1986 and a MBA degree in Management from Barnard Baruch College, Zicklin School of Business City University of New York, 1993 and a DBA from Nova Southeastern University 2003. In 2000 he joined the faculty of the University of Technology, Jamaica where he is the head of the School of Computing and Information Technology, since 2004 he has been an adjunct lecturer at University of the West Indies, Mona School of Business. His research interest includes Electronic and Mobile Commerce, Innovation and Diffusion of Technology in Developing Countries, Knowledge Management, Radio Frequency Identification (RFID implementation issues, and Developing Teaching Cases on Information Technology and Strategy highlighting issues from developing countries perspective. He is a member of IEEE, ACM and AIS

Vanesa Tennant

Received a B.S. degree in Computing and Information Technology from the University of Technology (UTech), Jamaica, 2005 and is currently pursuing a MPhil degree in Information Systems at the UTech, Jamaica. In 2006 she joined the staff of UTech as an Assistant Lecturer. Her research interest includes Radio Frequency Identification (RFID) applications, mobile and ubiquitous computing.