Using RFID Inventory Reader at the Item-Level in a Library Environment: Performance Benchmark

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Abstract: Radio Frequency Identification (RFID) technology revolutionizes the library operations in areas of circulation and inventory management, and is anticipated to replace barcode. However, there is a surprisingly scarce number of conceptual and empirical researches on RFID performance testing in libraries. The literature has advocated that evaluation is an important activity in the problem-solving process and that significant difficulties in performance can occur in the absence of test in the related environment. This paper will address and apply a methodology to evaluate the RFID inventory reader in a library with the intent to provide recommendations/best practices on the utility of an inventory reader. The methodology encompassed a design of experiment approach that investigates four factors: read angle (A), read distance (B), tag location (C) and shelf material (D). The findings suggested that read angle, read distance and tag location has a significant impact on the performance on the inventory reader. Initial findings on shelf type (wood or metal) suggest that this factor has an impact on read rate of the inventory reader. The results also shows significant interaction effects between some factors. It is anticipated that the findings may help researchers and library practitioners to understand and further investigate methods to optimize the performance of the reader.

Keywords: RFID, evaluation, library, experiment, performance

1. Introduction

“Technology seems to be changing our world – seemingly on the hour – and libraries and their needs are no exception.” (Narver, 2007). Radio Frequency Identification (RFID) is a wireless technology used to track, trace or identify an individual item or group of items. Libraries are fast growing adopters of RFID; the technology promises to relieve repetitive strain injury, speed patron self-checkout, and make possible comprehensive inventory. The number of RFID implementations in libraries have been increasing based on the advantages that the technology offers in managing library materials (compared to barcode system). In particular, barcode requires strict line of sight access, while RFID tags can be read through a variety of substances irrespective of orientation. Additionally, several tags can be read at one time which further accelerate all scanning operations performed in the library. In terms of memory, barcode contain a fixed amount of data while RFID tags have greater capability with rewriteable space for additional information. In essence, RFID allows libraries to effectively automate the loan and return of library materials through real-time visibility of inventory (Boss, 2004).

With any technology, evaluation of the artifact is essential in order to optimize its performance and utility. Much of the testing in RFID has been conducted in a supply chain environment. Findings have revealed that the accuracy rates are contradictory to competing and misleading claims of 100% read rate alluded to by RFID vendors (Ramakrishnan & Deavours, 2006), within the 80%-90% range (Sullivan & Happek, 2005).On the other hand, there is a scarcity of research on factors affecting the performance of RFID system in libraries. This is supported by San Francisco Public Library (2005) who argued that aspects of RFID in libraries such as performance and operational efficiencies require further investigation. Based on the paucity of data, it has been recommended that the library community should conduct a comprehensive technology assessment of RFID as soon as possible to enable librarians to make the best possible decisions involving the implementation of this technology (Rafiq, 2004). While noting the results of RFID performance testing in the supply chain, this environment is decidedly different from that of a library. Hence, it is recommended that performance testing should be deployed in the library to determine the performance requirements, and limitations of the RFID system.

Using the definition put forward by Ramakrishnan and Deavours (2006), performance is estimated by the ratio of tag responses per requests. In the context of this paper, performance is the percentage read rate per sweep of the shelf. The primary focus of this paper is to develop and apply a methodology to evaluate the RFID inventory reader and determine the relationship between independent factors (read angle, read distance, shelf material (wood or metal), and tag location) and

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read rate. The primary focus of this paper is to develop and apply a methodology to evaluate the RFID inventory reader and determine the relationship between independent factors investigated and the performance of the inventory reader.

1.1 Purpose of the study

Hevner et al (2004) argued that the utility and quality of an artifact must be rigorously demonstrated via well-executed evaluation methods. This absence of a methodology to evaluate performance of the RFID library system has suggested that the research community has neglected testing in this environment. As a result, the purpose of this paper is to propose and execute a methodology to investigate performance of RFID library reader, that is, the inventory reader. Evaluation of key factors that may affect the performance of the RFID reader may provide a premise to suggest best practices to optimize the read rate.

1.2 Research question

This study considers the library as a suitable test setting as it provides a controlled environment with circulation of items. The research sought to investigate the following questions:

- What is the read performance at selected angles of the inventory reader?
- What is the accuracy of read rate based on the distance between tag and reader during inventory?
- What is the optimal location for tag placement on books?
- What is the effect of shelf material on the performance of the RFID inventory reader?
- What is the role of interaction of factors on the performance of the RFID inventory reader?

2. Literature review

Performance testing is a methodology that examines the behaviour of a system under a particular workload (Bousquet, 2005). Evaluation has been a topic in general IS Research and is generally regarded from two perspectives, namely, ex ante and ex post (Pries-Heje, Baskerville and Venable, 2008) and (Klecun and Cornford, 2005). With ex ante perspective, candidate systems or technologies are evaluated before they are chosen and acquired or implemented, while for ex post perspective, a chosen system or technology is evaluated after it is acquired or implemented. This paper will examine a RFID Inventory reader from an ex post perspective.

In citing Venable (2006a), Pries-Heje, Baskerville and Venable (2008) pointed out that that design science research has two primary forms: artificial and naturalistic evaluation. Artificial evaluation evaluates a solution technology in a contrived and nonrealistic way, while naturalistic evaluation explores the performance of a solution technology its real environment. It was also highlighted that naturalistic evaluation is critical as it tests the “real proof the pudding”. This concept is in harmony with this paper as it describes a set of experimental procedures to evaluate the performance of a RFID reader in its operating environment.

The literature below will discuss the design science theoretical framework and a review on the performance factors will be discussed in the methodology.

2.1 Theoretical framework

Design Science is a concept/theory whereby innovations define the ideas, practices, technical capabilities and products through which the analysis, design, implementation, management and use of information system can be effectively and efficiently accomplished (Hevner, 2004). It addresses research through the building and evaluation of artifacts designed to meet the business needs identified in the course of behavioral research (Kuechler et al, 2007), and is the core of any IS design science research methodology.

Theory and theorizing have played an important role in the evolution and practice of science (Venable, 2006b). In particular, the literature has shown differing views on the role and definition of theory in design science. Theory is an integral aspect of design science in IS research (Nunamaker et al, 1991; Walls, Widmeyer, & El Sawy, 1992; Rossi and Sein, 2003; Venable, 2006; and Gregor and

Jones, 2007). On the other hand, research by March and Smith (1995) and Hevner, March, Park and Ram (2004) have stated that design science provides explicit prescriptions for constructing and evaluating an artifact, while natural science is concerned with theory. In highlighting this debatable topic, Vaishnavi and Kuechler (2004) mentioned that "even within the design research communities there is a lack of consensus as to the precise objective- and therefore the desired outputs- of design research." (p. 4)

Venable (2006b), an advocate of the relevance of theory in design science has proposed the utility theory. This theory makes an assertion that a particular type or class of technology has some level of utility (or usefulness) in solving or improving a problematic situation (with specified characteristics). This proposed utility theory has three components, the problem space, solution space and nature of utility that links them. In explaining, the author notes that the problem space represents the researcher's understanding of the problem(s) being addressed by a proposed technological solution, specified and placed in context by relationships with other problems and problem aspects. The solution space provides a description of the concepts that describe the type of solution, including relevant relationships between the concepts. A utility theory then links some concept or group of technology concepts to aspects of the problem(s) that it/they address.

From a design science perspective, the arguments of Venable (2006b) has some unison with one of the guidelines of Hevner et al (2004) which states that utility, quality, and efficacy of a design artifact must be rigorously demonstrated by means of well-executed evaluation methods. The proposed framework for Design Science Research by Venable (2006b) (See Figure 1) incorporates theory building as a central activity related to problem diagnosis, technology invention and technology evaluation.

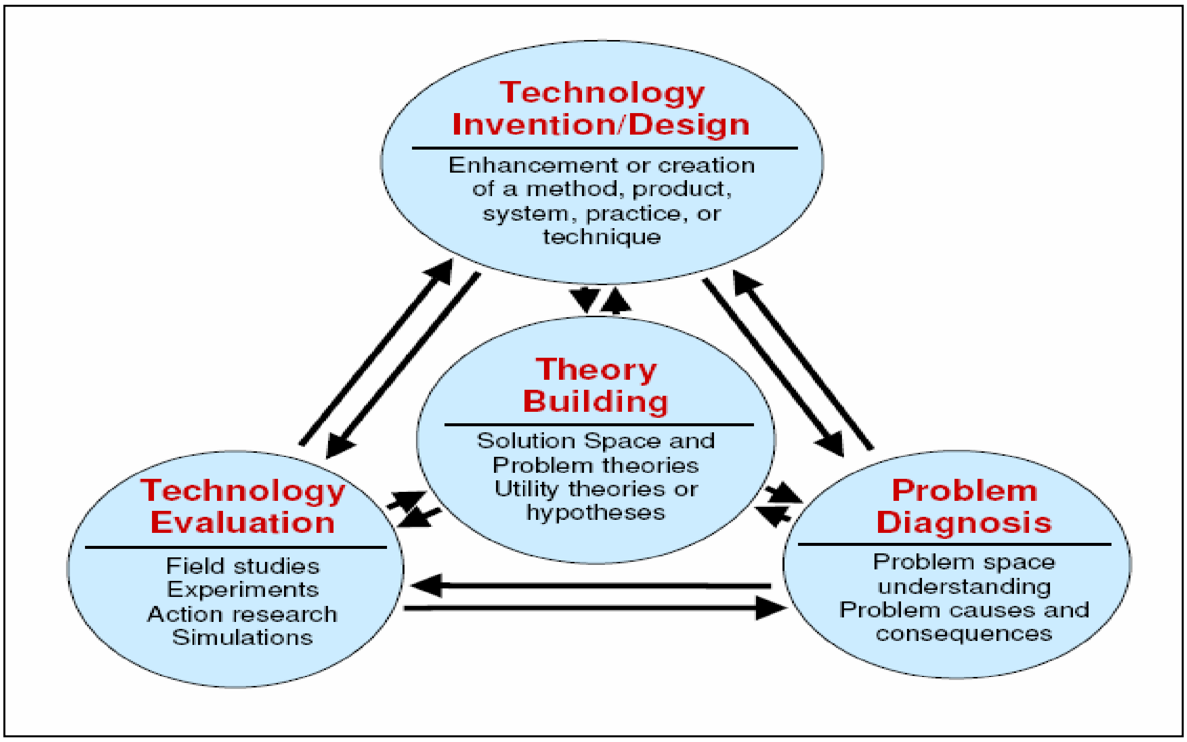

Figure 1: An activity framework for design science research (Venable, 2006)

This paper is constructed in a manner that applies each component of this framework to the study with a focus on the evaluation a RFID inventory reader.

2.2 Technology invention/design

The RFID Reader is an important component of the RFID system. It involves activating tags by sending query signals, supplying power to passive tags, encoding the data signals going to the tag and decoding the data received from the tag (US Department of Commerce, 2005). The RFID reader used in this study is a portable handheld reader used for inventory purposes, and allows the individual to scan materials on the shelf without tipping or removing them. There are three main functions of the inventory reader (Shahid, 2005): (1) Screen the entire book collection on the shelves for inventory control, (2) search for books, which are mis-shelved and (3) search for requested books.

2.3 Problem diagnosis

Significant difficulties in design science result from the fact that artifact performance is related to the environment in which it operates (March & Smith 1995). Although RFID vendors have cited that their solution indicates quality, the use of the technology in the 'real world' setting suggests that there are factors that require further testing (Ramakrishnan & Deavours, 2006). Zoch and Ferguson (2004) recommended that logical steps should be taken to identify those variables/factors that would most affect a particular client's simulated RFID model and to understand the interplay of these variables/factors. In selecting variables applicable to the library environment and the reader tested, the following factors were investigated.

2.3.1 Read angle

The directionality/angle of the reader is paramount for handheld readers due to the location of the antenna. Lahiri (2005) noted that proper positioning of the external antenna is essential for achieving optimal read rates. However, for readers with inbuilt antenna, positioning the reader's antenna is equivalent to positioning the reader itself. In libraries, the inventory reader is handheld with inbuilt antenna, thus by extension how the reader is handled can affect performance of the system. This argument is directly related to a characteristics of handheld readers put forward by Weigand, Crook and Dobkin (2005), which noted that it should be frontside-directed, meaning that most of the energy ought to go in the direction the user intuitively expects based on the construction of the unit, usually in a forward direction away from the handheld display. However, as expressed by the authors, there exists an issue with handheld readers with small antennas due to the poor front-back ratio. To this end, it may be proposed that the angle at which the reader is held plays a role in the number of tags read. There is no known literature on the angle directionality of the reader in terms of how it should be handled. A recent study by Paxar (2007) noted that the scanning mechanism would have an impact on the performance of the RFID system. As a result, rotating the antenna or the reader by a certain degree may adversely affect the read rate. This is important for libraries and recommendations based on testing should suggest best practices for scanning library materials.

2.3.2 Read distance

Researchers conducting tests in the supply chain have argued that read range claims by RFID vendors are unverified and fail to mention the deterioration of tag performance with distance (Ramakrishnan and Deavours, 2006). Although manufacturers generally indicate the maximum read range of the RFID reader, the actual range varies significantly (Cheng et al. 2006). High frequency RFID systems operate on the principle of inductive coupling also referred to as near-field systems (Finkenzeller, 2003) and is normally around 0-36 inches. High Frequency RFID tags used in libraries have a very short read range. Although there is some overlap on the reported read range for libraries, there exist differences (See Table 1).

2.3.3 Tag location

In the library, there is lack of testing on the impact of tag placement on the read rate. A review of the sparse literature on tag placement in the library is seemingly based on anecdotal evidence. The typical tag placement for books is inside the back cover near the spine (Fabbi, Watson and Marks, 2005). This however is not based on optimization of read rate. For instance, Boss (2004) recommended tag placement at the inside of the back cover because it is fastest for right-handed tag installers to reach.

Table 1: Summary of read ranges distance in libraries

Source	Read Distance
Haley et al (2007)	6 to 12 inches
Chachra (2003)	8 to 18 inches
NISO Working Group (2007)	8 to 12 inches
Boss (2004)	12 to 14 inches.

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A library vendor, TagSys also suggested the back cover while noting that it should be placed close to the spine as possible (TagSys, 2006). Prakash (2006) concurred with the view that the inside of the back cover is a suitable location, with specification that the tag is placed 7 cm above the bottom. The author also suggested that locating tags on the spine might also be beneficial. Some RFID vendors have recommended that strict consistency in tag placement should be avoided. According to 3M's website, many libraries should stagger the placement of RFID tags, making it less likely that tags on thin items will directly overlap on the checkout pad or on the shelf during shelf reading or inventory operations. TagSys (2006) suggested that the actual height of the tag placement should be staggered in approximately four different positions. Boss (2004) related that another 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. This lack of empirical evidence highlights the necessity to examine the effect of tag location on performance in RFID library systems.

2.3.5 Shelf material

Wood or metal shelving can be used in libraries. Metal shelving is most commonly used for book stacks (Siems and Demmers, 1998). A drawback to High Frequency (the defacto frequency in RFID library system) and Ultra High Frequency systems is the inability to accurately read tags on objects with or surrounded by metal content. Metals reflect electromagnetic (EM) waves and scatter them in all directions, which reduces the power needed by tags to respond (Asif and Mandviwalla, 2005). Library collections stored on metal shelves and metal bins used for high-density storage can interfere with RFID. In most cases, this problem is restricted to items that are next to metal end panels and upright (the first and last book on the shelf) (Haley, Jacobson, and Robkin, 2007). In support, Kern and Nauer (2003), and Prakash (2006) argued that metal shelves in libraries might cause interference, which may perhaps be avoided by properly locating the tag. Khong and White (2005) recommended that locating tags on the inside back cover near the spine is more suited as the inventory reader can be held right up against the book. While, one vendor recommended near the spine approximately three inches above the bottom (Boss, 2004). In order to argue the above-mentioned point there is a need for testing to support claims. This area should be explored in libraries, as wood can be used as an alternative shelf material. This requires a comparative analysis of read rate accuracy on both shelves (wood and metal).

3. Technology evaluation (methodology)

3.1 Environment

While vendor-based testing performed in an anechoic chamber is good for initial estimation of performance, testing in the operating environment is still paramount (Cook, 2005). Consequently, testing for this research was performed in an actual library in the United States. In the test environment, electromagnetic interference can occur due to co-channelling, spurious emissions, inter-modulations and noise. A spectrum analyzer was used to scan the radio frequency environment to detect external sources of interference to the RFID transmission and reception. As a result, the frequency range of the analyzer was 100 KHz to 3.0 GHz for interference detection. The process involved a signal analysis to identify levels of activity in the broadcast bands (97 – 107MHz), 800MHz cellular bands and 2.4GHz bands. Additionally, the analyzer was used to check the operating frequency of 13.56 MHz (High Frequency).

3.2 Selection of subjects (books) with common characteristics

The subject for this study was books and these items were the only type of library material used. With recommendations from the librarian, books were randomly selected to reflect an appropriate variation of books (including paper back, hard cover and metal binding and varying thickness level) in the library and on a shelf. A sample of 200 books were selected based on recommendations from Cook

(2005) who argues that it is imperative to test a significant number of tags to provide sufficient information to determine performance.

3.3 Experiment design

In this study, performance of the inventory reader was estimated by the ratio of tag responses per requests, that is, the read rate per sweep of the shelf. There was one dependent variable, read rate and four independent variables: (1) read angle, (2) read distance, (3) tag location, and (4) shelf material. In this research, a two level, three factors experimental design (that is 2^3), was deduced which resulted in eight (8) experiments for variations of read angle, read distance, and tag location (See Table 2). This design was used as the three aforementioned factors were randomized. The de-facto shelf material used was metal, as this type is commonly used in libraries.

Table 2: Factors and levels for factorial design

Factor	Units	Low Level (-)	High Level (+)
A. Read Angle	Degree	0	30
B. Read Distance	Inches	4	6
C. Tag Location		Inside of the Back Cover	Inside of the Front Cover

Forty (40) replicates were used resulting in three hundred and twenty runs (320) runs (40*8). This number of replicates was justified on the premise that it provided the ability to compute effective estimates of pure error based on statistical principles. At each combination level of the factors (low and high), the read rate were recorded. Using the same experimental design and factors outlined in Table 2, shelf material was investigated by applying the identical methodology to run the factors on the wood shelf resulting in a separate 320 runs.

3.3.1 Experiment: read angle

The sensitivity of the reader was measured in terms of the angle of the reader's antenna facing the books. The two angles selected were 0°(X), and 30° (Y) (See Figure 2), as the reader should be held at in the direction that allow electromagnetic waves from the reader to reach the tags on the books. A protractor was used to measure the angles.

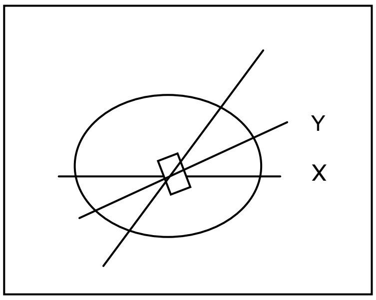

Figure 2: Reader angle measurement

Model hypothesis: The independent variable was the read angle (A) and the dependent variable was the read rate, that is, the readability of the tags. The observed results of experiment have an effect on the independent variable, hence $\text{Re}\,adability = f(A)$. As a result the hypothesis (in the null), is

H_{01}-The performance of the inventory reader is independent of the read angle

3.3.2 Experiment: read distance

A ruler was attached to the reader, and measured the distance in inches between the reader and the spine of the book on the shelf. The read range of the inventory reader specified in the vendor's operation manual was 8 to 12 inches. A pre-test was conducted to investigate the read range; hence, a tagged book was held in free space and read at distances between the specified ranges. This test was performed ten times at each distance (8 and 12 inches). The results revealed that the book was not readable at 8 or 12 inches. As a result, the read distance was adjusted to 4 and 6 inches.

Model hypothesis: The independent variable was read distance (B) and the dependent variable was the read rate, that is, the readability of the tags. The observed results of experiment have an effect on the independent variable, hence *Readability = f (B)*. As a result the hypothesis (in the null), is

H_{02}-The performance of the inventory reader is independent of read distance

3.3.3 Tag location

Tags were placed at two locations, namely, inside the front cover and inside of the back cover (See Figure 3).

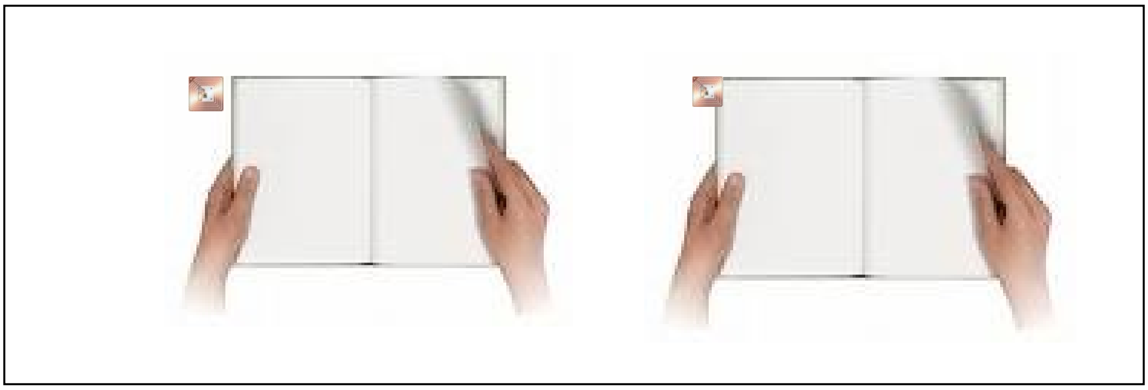

Figure 3: Tag Location for experiment

Model hypothesis: The independent variable was tag location (C) and the dependent variable was the read rate, that is, the readability of the tags. The observed results of experiment have an effect on the independent variable, hence *Readability = f (C)*. As a result, the hypothesis, in the null, is:

H_{03}-The performance of the inventory reader is independent of the tag location

3.3.4 Shelf material

Unlike the other factors, shelf material was not randomized during runs as it is a Hard-To-Change factor. Two procedures were used to investigate the effect of shelf material, however no hypothesis was formulated. The procedures are as follows:

- A spectrum analyzer was used to measure the observed power level during radio frequency transmission on wooden and metal shelves: A test bed was setup where the spectrum analyzer was placed at a distance of 24 inches from the RFID reader. The analyzer was set to center frequency of 13.56 MHz (operating frequency of RFID library system) and a span of 10MHz and the value of the maximum signal strength were recorded in dBm. With the use of a spectrum analyzer, the power level observed during radio frequency transmission on both shelf types was recorded. The test conditions included: (1) RFID transmission in free space (no books) (2) Penetration of books placed on table (3) Penetration of metallic shelf without books (4) Penetration of metallic shelf with books, (5) Penetration of wooden shelves without books, and (6) Penetration of wooden shelves with books
- A means comparison test was done to observe the read rate on wood and metal shelves.

3.3.5 Interaction of factors

In order to examine the interaction of all aforementioned factors, the hypothesis below was tested

H_{04}- The performance of the inventory reader is independent of the interaction of factors (read angle, read distance and tag location)

3.4 Model formulation and data analysis

After the development of the experimental design, the design software, Design Expert 7.1.3, was used to analyze the data collected. An appropriate mathematical model was developed in order to predict read rate. The following techniques were used in the Design of Experiment (DOE) analysis: (1)

Analyze the results by using ANOVA for identifying the significant main and interaction factors using p-value significance information, (2) Perform analysis to identify the contribution effect of each independent factor on the dependent factor (read rate), (3) Test the model assumption using residuals graphs, and (4) Plot model graphs where there is an interaction between factors.

4. Findings and discussion

A half-normal plot of effects was used to select significant factors for the two-level factorial design. The results revealed a statistically significant relationship with main effects: Read Angle (A), Read Distance (B), Tag Location (C) and interaction effects between AB, AC, BC, and ABC.

4.1 Read angle

What is the read performance difference at selected angles of the inventory reader with respect to the tag?

H_{01}-The performance of the inventory reader is independent of read angle

As shown in Table 3, the mean read at angle 0° was approximately 91 books (46%), and reduced to 45° (22%) books at read angle of 30°. The mean percentage read rate is considered low. However this is based on the fact that interplay of factors at different levels (high and low—See table 2 was used in the experiment design. This is reflected in the dispersal of reads in Figure 4 which shows some reads charting at high and low reads. In essence the findings reported that at a read angle of 0° (holding the reader antenna directly towards the book on the shelf), the read rate is greater.

Table 3: Means descriptive for read angle

	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	Upper Bound
0 deg	91.3250	56.226	4.44506	82.5460	100.1040
30 deg	44.9750	28.851	2.28094	40.4702	49.4798

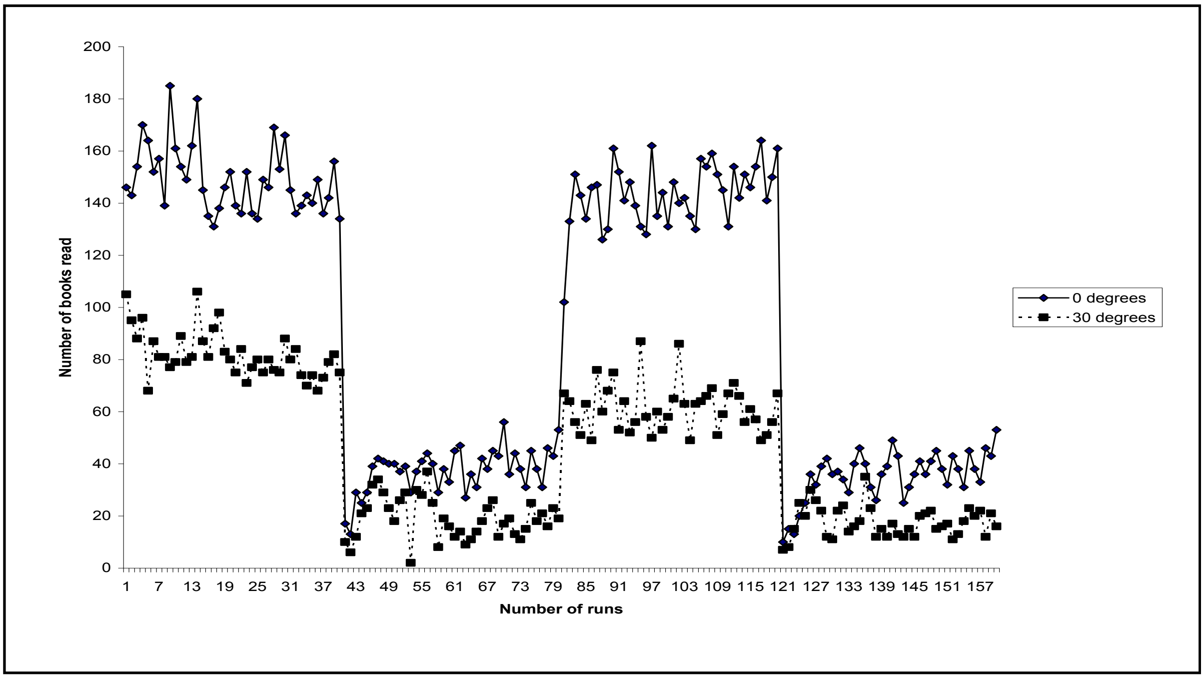

Figure 4: Read rate at measured angles

The findings reported a negative correlation of -0.462 which suggested that as the angle of the inventory reader changed from zero (0) to thirty (30) degrees the read rate decreases. With reference to the ANOVA summary, a p-value less than 0.05 indicated that the factor, read angle, was significant. In addition, the effect list demonstrated that Read Angle (A) provided a contribution of 21.30% to the model. The null hypothesis, H_{01}, is rejected and indicates that the performance of the inventory reader is dependent on the read angle. The findings are analogous with sentiments echoed by Lahiri (2005), who argued that with handheld readers the correct positioning of the antenna is equivalent to correct positioning of the reader itself. Findings were also similar to Paxar (2007), which noted that the scanning method impacts performance. Based on interviews with librarians, it was reported that caution is not necessarily always taken with the scanning mechanism (angle of the reader) during inventory of books of shelves. It could also be argued that moving the reader upward and downward during inventory may affect the performance, as there is no direct orientation of the reader towards the tag. The results showed that the tag detection improvement is greatest when the reader was held at an angle of 0° with the reader antenna affixed towards the shelf.

4.2 Read distance

What is the accuracy read rate based on distance between tag and reader during inventory?

H_{02}-The performance of the inventory reader is independent of read distance

The average number of books read by the inventory reader at 4 and 6 inches was approximately 109 (55%) and 27 (14%) respectively (See Table 4). Figure 5 represents the dispersal of reads at 4 and 6 inches.

Table 4: Means descriptives for read distance

	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
				Lower Bound	Upper Bound
4 inches	108.9438	39.72615	3.14063	102.7410	115.1465
6 inches	27.3563	12.13879	.95966	25.4609	29.2516

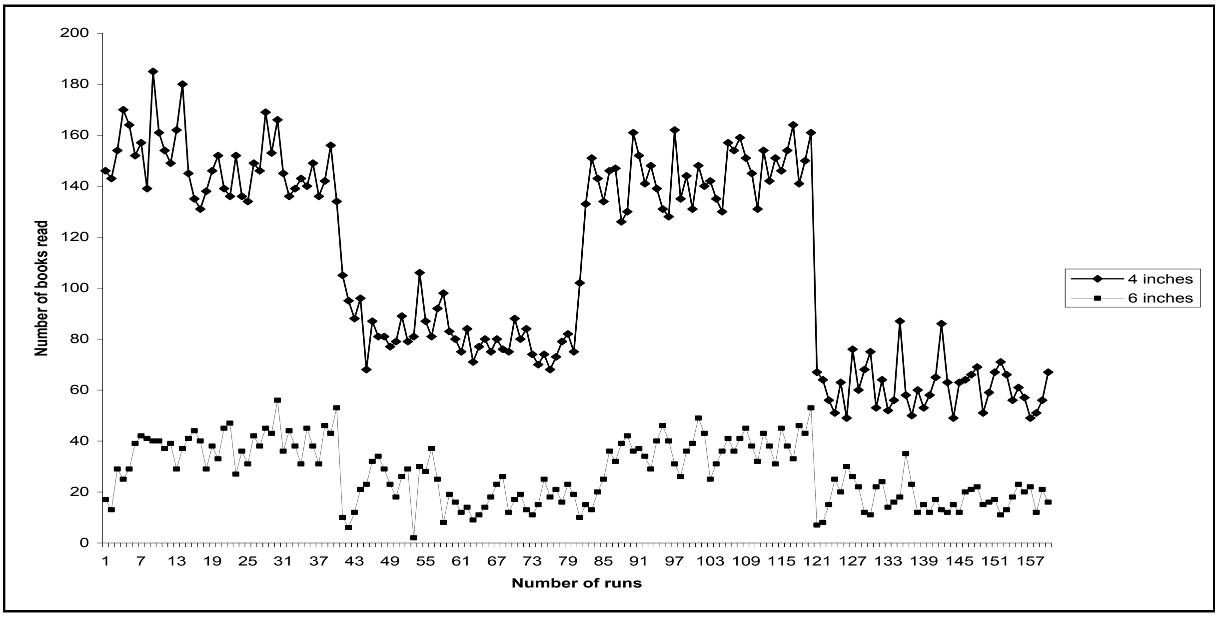

Figure 5: Read rate at measured distances

Read distance had the greatest percentage contribution to the model with 66%. The strong negative correlation of -0.812 reflects that as read distance increases the read rate decreases. The ANOVA summary reported a p value less than 0.05 and confirmed that the model term, read distance, is significant. On this premise, the null hypothesis, H_{02} is rejected and the results indicated performance of the reader is dependent of the read distance. Based on the findings, it is recommended that libraries ought to examine the effect of read distance on the performance of the reader in order to optimize read rate. This should be done despite vendors' claim of 100% read rate within a read range. Possibly, other readers in the library, such as security gate and shelf check may not operate at the distance specified by vendors, and hence require testing. For example, initial testing for the shelf check station, although outside the scope of this paper, showed that although the vendor stipulated 10 books at a time, a maximum of 5 books were read.

4.3 Tag location

What is the optimal location for tag placement on books?

H_{03}-The performance of the inventory reader is independent of the tag location

A numerical optimization method was used to generate the optimal conditions. The technique incorporates the use of a desirability function, df, that ranges from 0 to 1. The optimization parameters as seen in Table 5 are developed on the basis of constraints indicated by a specific goal which may be set to maximize, minimize, target, range or 'equal to' categories. The factors: read angle, read distance and tag location are set to the range, that is, between the lower and upper limits. The importance field (read rate) is set to five (5) with the intent to optimize the performance of the reader. Table 6 outlines four (4) possible optimal results produced with levels of desirability ranging from 0.712 to 0.804. It shows that the optimal location for tags is inside the back cover with a desirability of 0.804.

Table 5 :Constraints: Independent and dependent factors

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Read Angle	is in range	0	30	1	1	3
Read Distance	is in range	4	6	1	1	3
Tag Location	is in range	Back	Front	1	1	3
Read rate	is in range	2	185	1	1	5

Table 6: Solutions for combinations of categoric factor levels

Number	Read Angle	Read Distance	Tag Location	Read Rate	Desirability
1	0.00	4.00	Back	149 (75%)	0.804
2	0.00	4.00	Front	143 (72%)	0.773
3	1.47	4.00	Front	139 (70%)	0.751
4	0.00	4.21	Front	132 (66%)	0.712

The ANOVA summary reported that tag location is significant in the model with a p value less than 0.05. Consequently, the null hypothesis, H_{03} is rejected and suggests that the performance of the inventory reader is dependent on the tag location. However, it should be noted that this factor, tag location, has a relatively small percentage contribution to the model of 0.54%. Although a small contributor to the model, the recommendation of the inside of the back cover as the optimal tag location is similar to Boss (2004), Fabbi, Watson and Marks (2005), TagSys (2006) and Prakash (2006).

4.4 Shelf material

What is the effect of shelf material on the performance of the RFID inventory reader?

As mentioned earlier, two procedures were used to investigate the effect of shelf material on the performance of the inventory reader. This section will outline the findings of each approach.

Spectrum Analyzer Results

Table 7 shows the power levels (measured in dbm) observed during radio frequency transmission on the metal and wood shelves.

Table 7: Power levels of metal and wood

Reading in MHz	Free space / dBm	Books only / dBm	Metal shelf no books / dBm	Metal shelf with books / dBm	Wooden shelf no books / dBm	Wooden shelf with books / dBm
13.560	-57.28	-51.09	-61.98	-56.42	-65.24	-68.51

With respect to the shelf material, it was observed that the signals transmitted from the reader were significantly absorbed by wood shelves based on power levels recorded by the analyzer with a reading of -68.51 dbm. The metal shelves absorbed less at -56.42 dbm. To eliminate the effect of the books as a factor, the readings were also recorded without books. The results for wood and metal shelves were -65.24 dbm and -61.98 dbm, respectively. The difference in power level with and without books was 3.27 dbm and 5.56 dbm on wood and metal shelf respectively, which is not considered high. The stronger the power level the less the material (wood or metal) is absorbed. It can be argued that the metal shelves with books reflected the radio signals at a higher rate, and may cause the reduction in performance.

Means Comparison Test

The descriptive statistics for shelf material reported a mean readings of 68 (34%) and 77 (39%) books for the metal and wood shelves respectively with factors combined at high and low levels. This suggests that a higher average of books were read on the wood shelf by the inventory reader. The independent sample t-test, and the Levene's test (with p value greater than 0.05) indicate that equal variances for both the groups can be assumed. The low significance value for the t-test (p-value less than 0.05) indicates that there is a significant difference between the two groups means. As noted earlier, runs/test on both the metal and wood shelf was not randomised. This is justified by the notion that shelf material is a hard to change factor. Although the difference in performance on the both shelf materials was not vast, the result suggested a higher read rate on the wood shelf, and hence warrants further investigation.

In an ideal scenario, shelves are made of metal and books separators are made of heavy gauge steel that keeps the books in an upright / standing position. During testing, it was observed that books located beside the separators and at the end of the shelf (adjacent to the metal) were often times not read by the inventory reader. Hence, it may be required that these books be physically removed to capture the read. As an alternative, Hayes (1991), Canadian Conservation Institute (1995), and Robertson (2003) argue, that wood is an undesirable material for the storage of books, paper, and other archival materials because lumber (both treated and untreated) provides an acidic influence to book materials stored. Although the initial results implied that the performance of the reader was greater on the wood shelf, the practicality of the solution must be considered, as the longevity of library materials is also an important goal of libraries. The effect of shelf material on the performance of the reader is an area that requires further testing, and solutions may involve reengineering the design of tags and inventory reader used in RFID library systems.

4.5 Interaction of factors

What is the role of interaction of factors on the performance of the RFID inventory reader?

H_{04}- The performance of the inventory reader is independent of the interaction of factors

The findings suggest that interaction factors: read angle and read distance (AB), read angle and tag location (AC), read distance and tag location (BC) and read angle, read distance and tag location (ABC) are significant model terms. As a result, the null hypothesis, H_{04}, can be rejected and it is suggested that the read rate is dependent on the interaction of factors in the environment However, only the two interactions that made the greatest contribution to the model will be discussed, that is, AB and BC

4.5.1 Read angle and read distance (AB)

The descriptive statistics in Table 8 indicates that at a read angle of 0 degrees and 4 inches, the average number of books read was approximately 146 (73%). When the distance increased to 6 inches, the number of books read reduced to 36 books (18%). At an angle of 30 degrees, the number of books read at 4 and 6 inches were 71(36%) and 18 respectively. This interaction had the strongest contribution to the model. The contribution of 66% and 21.30% for read distance and read angle respectively may have contributed to this.

Table 8: Means descriptive of interaction between read angle and distance

Angle	Distance	Mean	Std. Deviation
0 deg	4 inches	146.2750	12.85850
	6 inches	36.3750	9.05311
30 deg	4 inches	71.6125	13.72745
	6 inches	18.3375	7.06201

At the combination of the lower limit of read angle and distance (0 degrees and 4 inches respectively), the optimal reading was 146 books (73%). (See Figure 6)

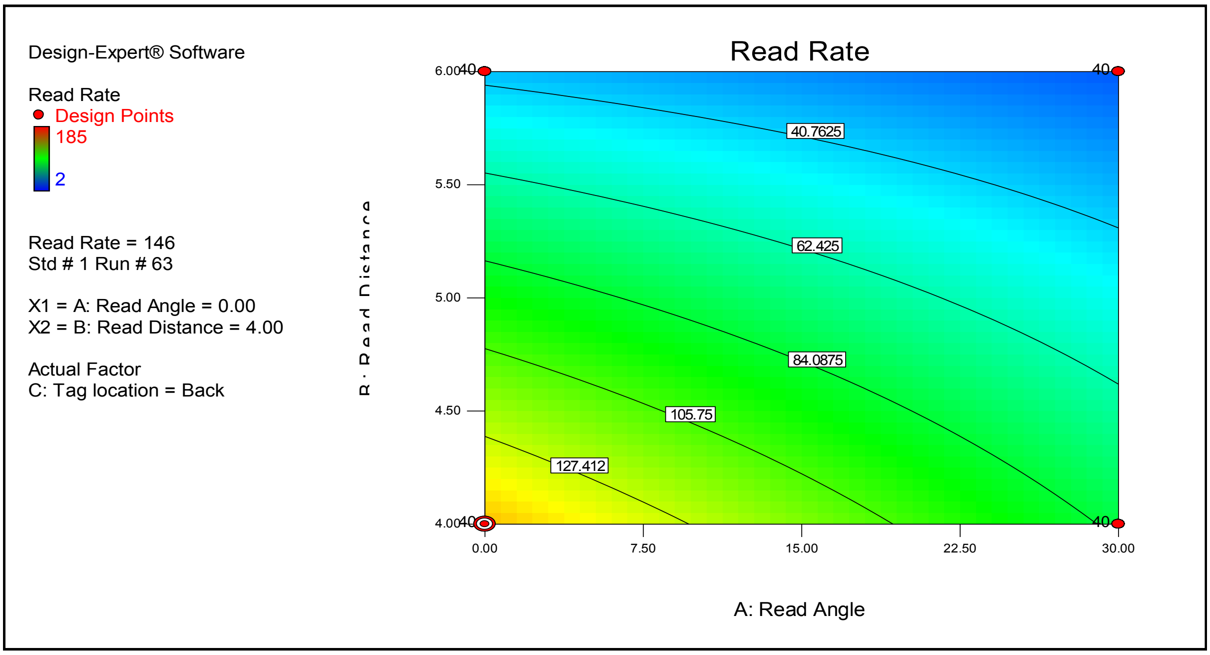

Figure 6: Contour plot of read angle and read distance interaction

A strong correlation between interaction factors, AB, and the read rate of 93.4% and accounted for 87.3% of the variance was also found.

4.5.2 Read distance and tag location (BC)

The trend in the interaction graph in Figure 7 shows that as the read distance changed from 4 to 6 inches, and the tag location changed from the inside back cover to the front cover, read rate decreases. Figure 7 also denotes that the optimal read rate of 93% (185 books) was obtained at a read distance of 4 inches and with the tag located at the inside of the back cover.

5. Conclusion

Librarians have a significant advantage in maintaining their collection while using a portable inventory scanner. Successful identification of library materials is the primary objective of RFID technology during inventory. It is recommended that on scanning library materials, the RFID reader should be held at an angle of zero (0) degrees, with the antenna directly facing the books. In testing, an angle of 30 degrees was explored (a slight movement of the reader from zero degree), and the read rate was reduced significantly. The recommended read distance specified by the vendor may not optimize performance. As a result, libraries should perform testing to determine a read range that achieves the highest or acceptable read rate. This study indicated that a distance of 4 inches or less is recommended, despite the vendor's recommendation of 8 to 12 inches. The results showed how the type of shelf/furniture may play a role in the performance of the reader, and require further investigations. It is anticipated that findings from this study may help researchers and library practitioners understand the effectiveness of the RFID reader in inventory management, and identify methods to optimize the performance of the reader. Additionally, this paper should provide statistical data for the library community and serve as a basis for future work on evaluating a host of RFID equipment used in the library.

6. Limitations

A limitation of this study is that only one reader was tested and hence the results are not generalizable and should not be extrapolated to other readers from the specific vendor or any other vendor products. Further tests are required with a variety of vendor products to deepen the body of literature. Another limitation of the study is the methodology used to determine the effect of shelf material on the performance of the reader. A limitation of this methodology was a single interchange of the wood and metal shelf, hence not accounting for interferences in the environment.

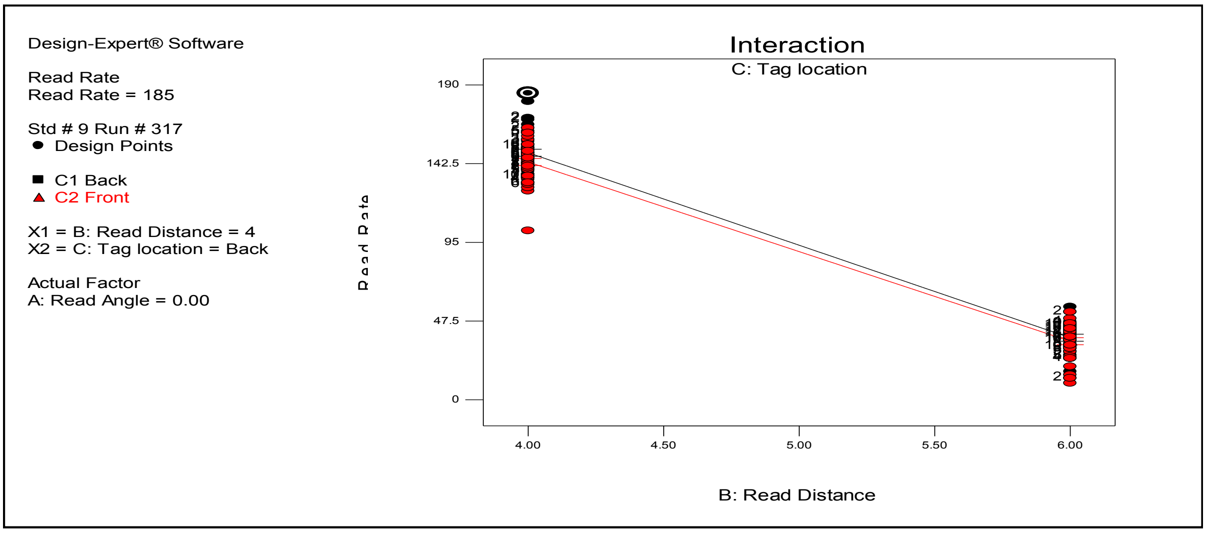

Figure 7: Interaction graph of factors read distance and tag location

7. Suggestion for future studies

The performance factors examined in this study, read angle, read distance, tag location and shelf material require further investigation and it is recommended that future work should include a benchmark test in order to have a comparative evaluation. Additionally, other readers in the RFID library system such as the self check station and the security gate may be evaluated in order to further optimise the performance of the system. For shelf material, future testing would include a complete split-plot design with more than one interchange between the wood and metal shelf while examining the other easy-to-change factors. Another approach although more time consuming may randomise the shelf material during runs.

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