Using Design of Experiments to Test RFID portals

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Abstract

Radio Frequency Identification (RFID) has the potential to revolutionize warehouse management systems. Dramatic benefits can be achieved through the ability of RFID to more effectively track parts and inventory throughout the supply chain. This includes manufacturing, storage, and distribution operations. In this research effort, a design of experiments methodology was utilized to evaluate RFID tag reader performance in a portal antennae configuration designed for operational receiving docks. The results indicate that both shorter distances and scanning angles have significant effects on inventory scanning accuracy with passive tags. Recommendations are provided on how to improve the performance of antennas and increase the effective read rate under specific conditions.

Keywords:

RFID, scanning accuracy, portal, DOE, experiment, variable

1. Overview

Two experiments were conducted utilizing passive RFID tags. Experiment 1 focused on determining scanning effectiveness of reading RFID tags under different practical usage conditions. This experiment attempt to simulate a real-world receiving dock operation with an RFID antennae portal design commonly recommended by RFID vendors. The test items were fixed on a pallet and moved through a dock door with an RFID test portal. This research measured the relationships between a variety of common warehouse environment operational variables and their affect on the scanning accuracy. The basic experimental conditions of Experiment 2 were similar to that of Experiment 1. However, Experiment 2 specifically focused on evaluating the ability of the antenna portal to read the RFID tags with respect to the distance.

1.1 Objective

The overall objective of this research was to introduce an experimental design approach for testing RFID technologies in warehouse operations. The objective of experiment 1 was to evaluate the best RFID methods for attaining optimal scanning accuracy to meet customer needs. Further by establishing a methodology for testing different configurations we realize the additional benefit of instructing end users on how to effectively test for the best RFID system design. This includes testing antennae positions in terms of RFID signal propagation; tag placement, read range validation, and antenna selection. The most important outcome of this experiment is to identify which factors influence the readability of the antennae. For experiment 2, the objective is to determine readability, distance, and accuracy on dock-door portal applications and study the performance under 100 readability requirements. This included determining the optimum placement of tags, antennas, and portal.

2. Test Description

The ability to read tags is the foundation of any RFID-enabled system. In this research, we examine a number of aspects of tag performance, including the yield (what fraction of the tags that you receive will actually work), and the variance (the difference in the performance among tags of the same model). Among the many variables that can affect positive RFID outcomes, we focused on these: 1) Label types: Label placement and orientation, at pallet-, case-, or item- levels. 2) Antenna distance and correlation of distance to the number of correct reads. 3) We run the experiment as following steps: (Appendix: Flow chart).

2.1 Experiment hardware and software

A variety of hardware and software was utilized in this research. A list of these items is presented in Table 1.

Table 1. RFID hardware and software table

Hardware	**Software**
• Alien Squiggle • Circular Antenna • Symbol X2040 • Symbol AR400 Reader • Matrics antenna	• Symbol tagvis v1.2.0 • Verdasee navigator

2.2 Experiment limitations

The first experimental limitation involves the testing environment. The experiments were performed utilizing the RFID reader and tags under controlled laboratory conditions. These conditions do not necessarily include all of the influences present in a real-world environment. For example, a real-world warehouse may contain radio frequency interference that was not present in the laboratory. However, the experimental results still provide a close indication of the level of performance that can be expected.

The second experimental limitation involves the RFID tags themselves. An unfortunate characteristic of the currently available RFID tags is inconsistent manufacturing quality. This means that the tags may also perform inconsistently. There are considerable variations in performance from one tag to the next, even among tags of the same manufacturer and model. Some models of tags show more variation than others. Therefore, the design of experiment was adopted as primary methodology to develop the model of experiments.

3. Design of Experiment (DOE)

3.1 Model hypothesis

For experiment 1, two independent variables (factors) and one dependent variable were involved. The two independent variables include the tag replacement and the numbers of antennae. The dependent variable was readability of the tags. The observed results of experiment have an effect on our independent variable.

$$\mathrm{Re}\,adability = f(TP, AN) \quad \textbf{(1)}$$

TP: Tag placement

AN: Antennae Number

For experiment 2, the experiment was evaluated for customer's requirements by 100% readability, which means we needed to regulate some of those variables till the results achieve full-read efficiency.
The model of the experiment is:

$$\mathrm{Re}\,adability = f(AP, PP) \quad \textbf{(2)}$$

AP: antenna's position

PP: portal's position

3.2 Factors and levels

When executing a full factorial experiment, a response is obtained for all possible combinations of the experiment. Because of the large number of possible combinations in full factorial experiments, two level factorial experiments are frequently utilized. In this research, in experiment 1 a two factor, two level experiment was conducted. As described in Table 2, a total four trials are needed (i.e., $2^2 = 4$) to address all assigned combinations of the factor levels.

Table2. 2^k Factorial Design

Factors: 2	**Replicates:** 10
Base runs: 4	**Total runs:** 40
Base blocks: 1	**Total blocks:**1
Number of levels: 2, 2	

The specific situations to which a DOE is being applied will affect how factors and levels are chosen. Factor levels also can take different forms. In this experiment, levels are quantitative. For experiment 1, an experiment should allow for a systematic observation of a particular behavior under controlled circumstances.

Therefore, two principles were conducted in the experiment as below:

a. Tag placement:

Top, Side

b. Number of Antennae:

One antenna and two antennas (on each side of portal)

*Two antenna were only used in one trial within the experiment

For experiment 2, In order to test the readability of tags and metrics performance, the same trials were performed as experiment 1, with the following variables:

a. Position of antennas: We installed two antennas at the same height on each side and the different height (3 ft, 5 ft).

b. The distance between each side of portal: 5 ft; 7 ft.

The standardized time scale is 30 seconds in consideration of limited real world data acquisition times. All of the specifications were conducted in ten times with three different replacements of tags and ten items in each trial. The experiment factors and levels are summarized in Table 3.

Factors and Designations		**Levels** (1)	(2)
Experiment 1	A1:Tag Placement (TA)	Top	Side
	B1:AntennaNumber (AN)	1	2
Experiment 2	A2:Antenna's Position (AP)	Horizontal	Non-Horizontal
	B2: Portal's Distance (PD)	5 feet	7 feet

Table 3. Experiment Factors and Level

4. Experiment Results and Analysis

From the hypothesized formula, the influence on the readability of tags of each variable could identified, including the amount of items, the placement of the tag on the item, and the number of antennae installed on the portal. Each of experiment was conducted for 10 trials, and the data points were collected and organized for model analysis.

Table 4. Results for Experiment 1

Tag Placement	**Top**		**Side**	
Antennae	1	2	1	2
Trials	10	10	10	10
Average	5	7.8	7.4	9.6
Standard Deviation	0.34	0.26	0.8	0.2

Table 5. Results for Experiment 2

Antenna Position	**Horizontal**		**Non-Horizontal**	
Distance	5	7	5	7
Trials	10	10	10	10
Average	9.6	8	9.8	9.9
Standard Deviation	0.78	0.5	0.2	0.32

For Experiment 1, the average readability varied given tag placement. The tags were located on the top and the side of items. The average value for the second factor level, placement--on side is larger than the first factor level, placement--one top. For Experiment 2, the average value for Horizontal was no dispersion when the distance of antenna is comparatively short. However, the readability of the antennas improved when the distance between antennas increased to 7 feet. The population is normally distributed with low standard deviation scores indicating low variability.

4.1 ***Variables analysis***

4.1.1*Tag placement*

For experiment 1, the placement of the tag on the pallet or items can be classified by three classifications, top, front, and side. The performance of each classification is different. To sum up, the best position of a tag on the item is on the side of item, (face to the antennae) because of the polarization and magnetic field. (Polarization test report).

The performance of antennae and tags are totally different in these three occasions. The premium performance is the third one —tags on side. Compared with other two results, the readability of tags on the side can get 60% satisfaction on full read level. In fact, this occasion is still not very satisfied but is the reality.

For experiment 2, the influence of the variable *Tag Placement* in the model is the same as experiment 1.

4.1.2 *Antenna V.S 2 Antennas*

For experiment 1, the significant results on performance were obtained when changing the number of antennas. We ran the experiment on 1 antenna with 10 items first. The readability of the tags was only 80%, compared with almost 100% for 2 antennas (AVE: 96%).

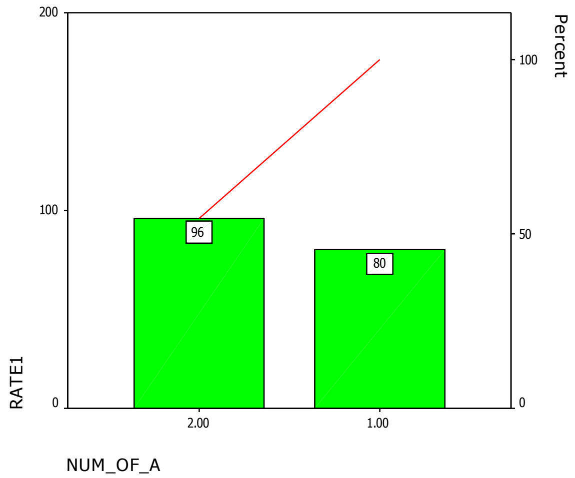

Figure1. Read Rate graph

4.1.3*Antenna's position (Only in experiment 2)*

The antenna position had different effects on the two experiments. The experiment hypothesized that the antenna, when placed in different horizontal planes would have a positive influence on readability. The non-horizontal antenna showed better results when distance between antennas increased. For example, the experiment conducted from 5 feet to 7 feet demonstrated better results at 7 feet than at 5 feet.

4.1.4*Portal dock's position (Only in experiment 2)*

The hypothesis was that the shorter the distance is; the better read efficiency would be. When the experiment simulates real world circumstances and designed in two hypothesized cases. The requirement is: the distance between each side of the portal as 5 feet with the antenna on same horizontal line and 7 feet with different height each. Therefore, the objective of the experiment was to verify the hypothesis about whether the performance of readability will be better with "non-horizontal line" orientation. If the hypothesis would be proved to be true, that meant the improvement on the antenna reading efficiency by varying the height of the two antennas when other factors are fixed.

Finally, the results of the experiment supported the above hypothesis. We identified the normal distance between each side as 7 feet, but the optimum and effective distance is approximately 5 feet. The factors of distance between each side and the non-horizontal antenna both have an influence on the effectiveness of readability.

1. **Conclusions**

The reaction time of antenna on tags was almost the same in these two cases. It can be determined, then, that readability can achieve a full-read expectation when performed under the specification given below:

- The full-read range is between 3-5 feet when antennas are fixed at the same horizontal line on each side of portal.
- The full-read range is between 6-8 feet when the antennas are fixed with different heights on each side of portal.
- The full-read requirement needs to have the tags on the sides of items or facing toward the antennas.

Frequency, distances and angles, type of tag, location and replacement, influences of moisture, and metals, and pallet patterns all played part in readability.

The effective reading distance was analyzed in MATLAB (6.0, Release 13), for visualizing the results and providing documents for future research. The data points on the graph showed as random variation, but the visualization graph gives a clue that the most effective scale for the antenna is between 2-3 feet around the middle line. The color bar on the right side indicates read rate based on our experiment specification of 10 tags per pallet. The reading rate can be reached at 90% or better under this specification.

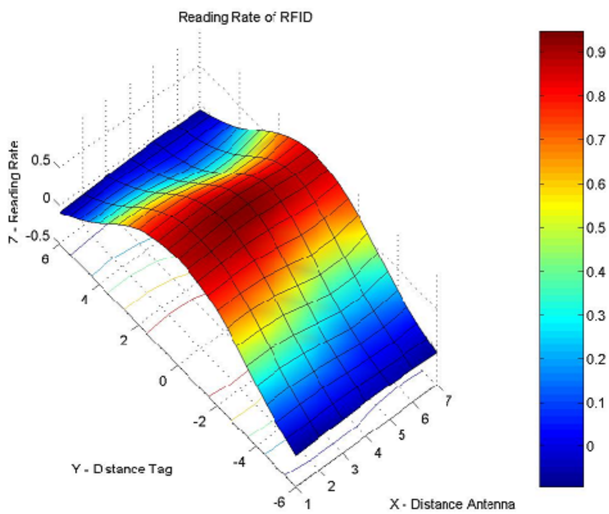

Figure 2. 2-D Graph for effective reading rate

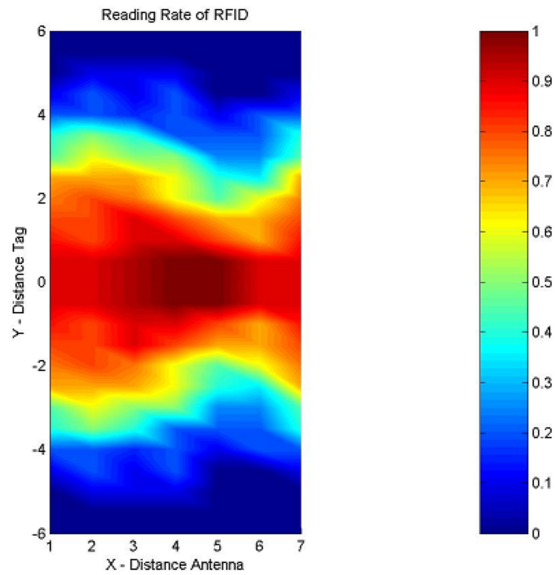

Figure 3. 3-D Graph for effective reading scale

To sum up, the total conditions for receiving more than 90% readability includes several considerations as below:

- The placement of tags.
- The distance between antennas (If there is more than one antenna).
- Appropriate stop-by time when going through the portal (At least 3 sec).
- Change the position of antenna when other limitations are fixed.

6. Recommendations and Summary

A customer established 100% readability standard is difficult to fulfill. Increased system requirements can help satisfy the customer's specific needs. These include practices such as installing more than one antenna on the portal dock, increasing the amount of tags, decreasing the distance between each side of portal, etc.

With the customer requirement of 100% scanning accuracy of tags, multi-band tags and readers that help users get accurate read rates and other technology will slowly move toward the goal of 100% reliability. For now, the issue is trying to identify the system requirements necessary to achieve a 100% read efficiency with the currently available technology. Although RFID technology is continuously improving, some suppliers may find that a customer's mandate is still unrealistic.

Table 6. Application solutions

Application solutions		
	Small-scale warehouse	Large-scale warehouse
tags	Alien	Passive/active
Dock door distance	6 feet	9-10 feet
Item/pallet's quantity	<=6	<=10
Antenna's quantity	one	two

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