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Key factors in tag recognition for RFID system

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Abstract

The research effort described here was a study of factors that affect the efficiency of a Radio Frequency Identification (RFID) system in reading a certain type of commonly used passive RFID tag ('squiggle' by Alien Technologies). The two sets of experiments conducted under this study focus on two response variables namely: readability and read rate. The factors in focus are distance between antenna and tags, the number and combinations of tags simultaneously read by the system and position of the tags left or right of the center of the antenna. Two separate experimental setups as explained in the following sections were used to keep some factor(s) constant while varying the rest to determine how much each affects the response variables that are direct indicators of performance of the RFID system in use. On one hand there needs to be further investigation in case of some factors to determine their true significance, one the other hand, the results of this research present substantial evidence to prove the important significance or lack of it for factors in question; decreasing the distance between tags and antenna for instance, directly affects how well a certain tag is recognized by the system – increases the read rates.

Summary

The following research summary describes a research effort to develop test protocols for commercially implemented RFID system. The applications of this technology kept in mind while conducting this study were mostly in the areas of supply chain management and inventory control. Despite the large scale deployment starting in 1990 in libraries and for electronic article surveillance etc. [1] and a considerable theoretical database, a very fundamental aspect of the study RFID technology is still missing, which is statistical models and data establishing an empirical benchmark for the technology; this research is the first developmental step in that direction. The goal is to evaluate different configurations of systems with respect to various factors in the implementation of RFID technology. These include: distance between tags (mutual) and antenna, the angle between them, power of the antenna and relative speed of tags and antennae to name a few. Initially, tests were designed to test the system with respect to each factor, but the great number of sub-categories of each led to this research being restricted to tag interference; in other words – distance and position of tags mutually as well as relative to the antenna. There are mainly three factors that the experiments focus on. These are: the distance between tags and the antenna, position of the tags left and right relative to the center of the antenna and space between the tags themselves. The experiments and analysis is aimed to bring out the effects of these factors on the primary response variables, *readability* and *read rate*. The number of signals sent back from the passive squiggle tags to the antenna per unit of time is practically the best indicator of the efficiency of the entire system and hence was our indicator of performance for the implemented system. The purpose of the experiments was to establish standards of RFID usage in the industrial and commercial sectors. In other words, the study aims to ascertain the efficiency and reliability of RFID technology in real world applications. The few hurdles that were crossed while conducting the study, for example, the metal content of the lab space may have actually improved the simulation of an industrial/commercial environment. Still, there is great opportunity for further research with this very topic with the help of the data collected and the results detailed in this summary. The data that has been collected provides an insight to the behavior of passive tags when in a group, which is a setting that virtually all industrial/commercial sectors possess. The results aim to discover relationships between above mentioned factors and readability and read rates of tags; it includes information about the extent to which the number and proximity of tags affect each other. Of course, there is further scope for statistical modeling of the data which has the potential to be vital in creating benchmarks for implementing the technology which may prove to be the industrial revolution of the 21st century.

Introduction

Radio frequency identification (RFID) is a technology that utilizes electromagnetic waves or radio communication, in essence, to automatically collect data and to uniquely identify objects. The foremost advantage of RFID, being the transmission of information without any physical contact or even a straight line of transmission, overcomes the shortcomings of the prevalent technology [2] by eliminating human interaction and hence, human error [3]. The widely used *bar codes* for the purpose of tracking have a major limitation of being generic; they can only identify the category an object belongs to and not the specifics. An RFID tag, in contrast, is essentially a database mounted on each unit of the inventory. Consisting of typically one *interrogator, antenna* and *tag,* an RFID system completely eliminates all possibilities of human error in inventory management and control. RFID provides a kind of individualized license plate for a pallet, case, or even individual items. Unique identification capabilities make RFID a far more effective substitute to any contemporary technology used for tasks like electronic toll collection, security badge identification, tracking materials, and immediate alerting of hazardous materials requiring special handling, to name just a few [4] outside supply chain management. Though considerable work has been done in the field and detailed research is going on around the world the problem seems to be the lack of experts in the field. "We haven't had companies pounding our doors to hire RFID experts," says Dennis Adams, chairman of the decision and information sciences department of the C.T. Bauer College of Business [5]. Though huge companies have initiated large scale research and invested generously in this technology, there is still some time before RFID is universally accepted.

Great strides in the technology have been made in the past decade and RFID has gained some major global attention. It's easy to foresee how great the demand for fully developed RFID systems will be in the recent future. The planned study intends to test aspects of the operational manageability and effectiveness of fully functional and detailed RFID systems in controlled environments which will evolve to real world situations-factories, warehouses and transportation and transit facilities [4]. It is well known that managers that are able to assess their companies for internal evaluation using the tracking capabilities of RFID will equip them for making better global decisions. However, research proposed, will not be specific to industry or even research institutions, but will define the degree of reliability of the systems currently in use for most scenarios. As the global market constantly evolves, RFID is being implemented as next generation technology for the tracking sector of business more and more [4]. To be able to fully exploit the potential of RFID technology by establishing standards, a series of experiments and tasks lie ahead.

Statistical modeling is an enormous field of study, it possesses the power to support any claim as easily as to invalidate it. Our primary performance measure is *read rate* (how efficiently can tags be read when in batches); the secondary measure is tag *readability* within a predefined capture zone of an antenna. Considering the performance measures, these statistical analysis methods that seem most relevant:

- Hypothesis Testing and Confidence Interval estimation – These tests are fundamental methods used to analyze data of comparative experiments [6]. The technique is to be used to compare performance measures of tags to establish uniformity among them.
- Sensitivity Analysis – This analysis indicates the ability of tests to detect differences, in conjunction with hypothesis testing, will be used to analyze the change in the performance measures with respect to intentional changes to the various factors.
- Correlation analysis – Correlation, defined as the measure of linear relationships between variables [7] (in our case multiple variables) is an important tool of study as it will clearly indicate how the various factor affect each other in measuring the performance of systems. Balancing the factors using inferences drawn by this analysis can drastically improve implementation of the RFID (and in fact any other) system.

This research effort is dedicated to discovering the nature of tags' interference in a real world setting. Although there are many uncharted territories in the field, the experiments conducted provide a starting point for researching more complex conditions and environments that are nearly impossible simulate in a laboratory setting. Primarily, the experiments focus on the aspect of tag interference to establish the capabilities of the prevalent technology to uniquely identify tags when in close proximity of similar tags. The final results also illustrate the relationships between the read rate of the tags when compared to variables like the distance from the antenna and the lateral position of the tags with respect to the center of the antenna. Ultimately, this research is undertaken to develop statistical models of RFID systems; it would be highly beneficial for anyone studying in the field by eliminating the need of establishing a new system for standardizing results. In addition, this will also equip undergraduates, graduates, and university affiliated company personnel with the knowledge of mechanics for creating a quality RFID data collection and analysis system. Furthermore, and most importantly, it will provide invaluable statistical information that will aid future implementation and deployment of RFID systems everywhere, on large scales.

Literature Review

The planned research was focused on the readability, reliability and ability of systems to observe signals (in essence, the presence RFID tags on objects). In spite of the research dating back to the 1940s [8], the statistical modeling of data related to RFID has been underdeveloped. There are numerous variables with respect to which attributes of RFID systems like signal strength can be measured; the team aims to study and expand the knowledge base on how factors like distance and angle between antennae and tag affect the readability of tags, and a little advanced research related to how and by how much the contents of the tagged containers and the material of the containers themselves affect the functionality of the RFID system. Marketing reports like those predicting asset management and supply chain installations will have investments in RFID infrastructure exceeding $1.1 billion in 2007 [9]. Estimates that worldwide revenues from RFID tags will jump from $300 million in 2004 to $2.8 billion in 2009 [10] are reason enough to perform this research. Also, justifying the development and upkeep of a testing environment for the hardware and software applications related to the field is hardly a challenge, keeping the same reasons in mind.

Over the past few years, the RFID industry has focused on the development of standards. The advent of lower cost silicon, the raw material of WID, and increased demand for faster, more precise means of data capture have led to a surge in interest and a call for RFID standards to enable widespread adoption and use of the technology. Today, very few standards exist for RFID technologies, primarily because of the immaturity of the RFID market. The following is a brief list of the current published RFID standards and ongoing RFID standards initiatives.

- IS0 11784/11785 (Animal Identification RFID Standard)
- IS0 ANSVNCITS T6 256 - 1999 (Item Management RFID Standard)
- ISOEC 15693-2 (13.56 MHz Vicinity Cards and Smart Labels RFID Standard)
- GTAG (On-going RFID Global Tag Initiative)
- Consumer Products Manufacturers Association (CPMA) Consumer Good ID Proposal (Ongoing) [11]

There is proof all around about the keen interest companies have shown recently in the development of curricula and facilitation of RFID training at universities. Proctor & Gamble for instance, donated $150,000 to the Indiana University, for the expansion of their RFID educational resources. The current focus of their research is primarily asset management are testing the feasibility of RFID for use in various applications; simple experiments like small RC carrying tagged items in different environment to test readability with current systems [12]. Commercial and industrial institutions have also joined the race for creating experts in the field; the primary goal being equipping professionals with RFID knowledge base and not R&D. [13]

The Georgia Institute of Technology's Parking and Transportation Department presently uses a vehicle location module for location and identification of vehicles on campus and the ongoing research is about asset management for heavy machinery. The goal is to embed programmable RFID tags inside keys, coded to certain company identification numbers and certain machines so that the interchangeability of keys are maintained but localizations makes theft near impossible [14, 15] "Engineers at Purdue University are creating a wireless device designed to be injected into tumors to tell doctors the precise dose of radiation received and locate the exact position of tumors during treatment." The device uses RFID technology, eliminating the need for repeated exposure to harmful X-rays. It contains a miniature version of dosimeters worn by workers in occupations involving radioactivity. The tiny dosimeter could provide up-to-date information about the cumulative dose a tumor is receiving over time. [16]

Some other fast growing applications are Point of Sale, Rental Item Tracking, Baggage Handling, Real-Time Location Systems and Supply Chain Management. Currently, Supply Chain Management, accompanied with security access control and transportation are the most widely adopted applications in WID industry and enjoy the most shares in the market [11]

RFID systems like any novel technology has many great qualities: Automatic Non-Line-of-Sight Scanning capability of RFID could yield labor savings of up to 36% in order picking and a 90% reduction in verification costs for shipping processes at facilities like a distribution center. RFID allows products to be followed in real-time across the supply chain providing accurate and detailed information on all items, allowing organizations to use this information to increase efficiency. Looking at Traceable Warranties and Product Recalls, RFID and the Electronic Product Code (EPC) can uniquely identify every individual item in the supply chain, allowing manufacturers to obtain instant access to information that allows them to issue targeted recalls of only affected products. Even in the absence of real-time tracking etc. RFID still greatly increases the accuracy of asset tracking and inventory management; applications are limitless. The greatest reason for far more research required in the field is that all these great advantages come at a price; there are still situations and inherent qualities of this technology that bar immediate, widespread implementation. Intermec predict that once item-level tracking is achieved, "physical inventories and product re-ordering will be done in a fraction of the time it now takes and retailers will be able to take inventory [counts] much more frequently", unfortunately that level hasn't been reached yet, not in a pragmatic system anyhow. A crippling drawback of RFID is in the form of privacy issues looming as one of the biggest threats to the unbridled success of RFID. Current RFID protocols are designed to offer the most optimal performance between readers and tags, neglecting to address consumer privacy concerns. Finally, the reliability of RFID tags is an issue that could determine the technology's ultimate success [17] and that is what this study effort aims to establish.

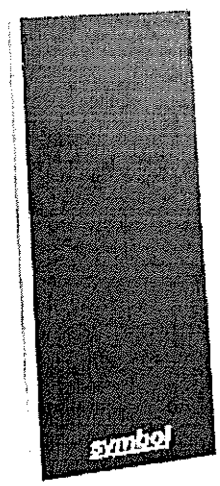
The purpose of this research is to test the operational effectiveness of RFID systems in a controlled environment and to develop statistical models of the collected data establishing a reliable literature base for the development of this technology in the future. RFID has shown promise for huge advancements in tracking and data collection from inventory, and, thus, this technology ought to be implemented on a large scale. Reliable benchmarking is an essentiality due to costs associated with setup of new RFID systems, making this research indispensable. The team intends to discover the relationship of read rates to three major factors: *distance, angle and tags' mutual proximity.*

Methodology

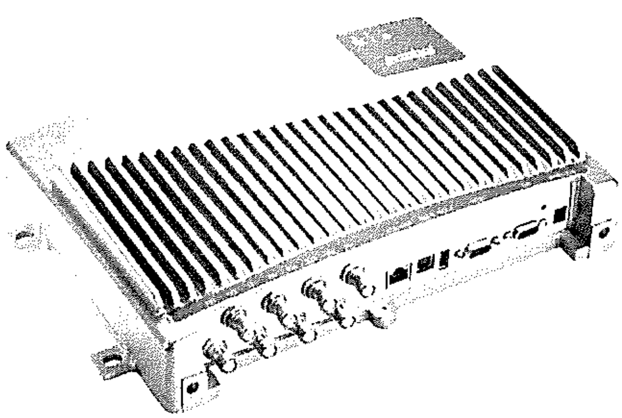
The primary objective of this research effort was to establish the extent to which multiple passive RFID tags in close proximity affect each others' behavior. This 'behavior' refers to two aspects: first, whether each tag can be individually read when used in combination with and antenna and the second was performance of each tag, which is related to the read rate. Read rate refers to the number of signals sent back from the passive tag per unit time once the antenna is activated.

The primary set of equipment for the experiments included the following:

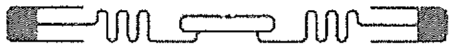
- AN400 Antenna from Symbol



- XR400 Reader from Symbol (Passive, 915 MHz, Gen2).



- 50 Alien Technology Gen2 "Squiggle" Tags



- PC with interface software

Only one antenna was used to ensure the data collection was not a result of 'brute forcing' reads and so that a conservative value of the read rate was observed. 50 performance-wise similar tags were used for consistency as well. Two separate experiments were performed with the same factor under scrutiny. The next section describes, in detail, the procedure that was followed.

Experiment 1

Figure 1 (Not to scale) illustrates the arraignment of tags for the first set of experiments. This was a panel made of cardboard that was used to hold up the tags at predetermined distances from the antenna as shown below. The board had holders for the tags and the tags were one-by-one placed in the holder and the system was turned on. The factors that were under scrutiny were the distance of all the tags (the board) from the antenna – 10/15/25 and 30 ft, gain or the power of the antenna was the second factor under consideration which ranged from 10% to 100% power; lastly the number of tags on the board simultaneously, these ranged from one tag alone to ten tags placed at constant separation relative to other tags on the board. The order in which these factors were manipulated and used in combination was determined by design of experiment methods as explained later in this section. As mentioned earlier 50 similar tags were used in performing these trials.

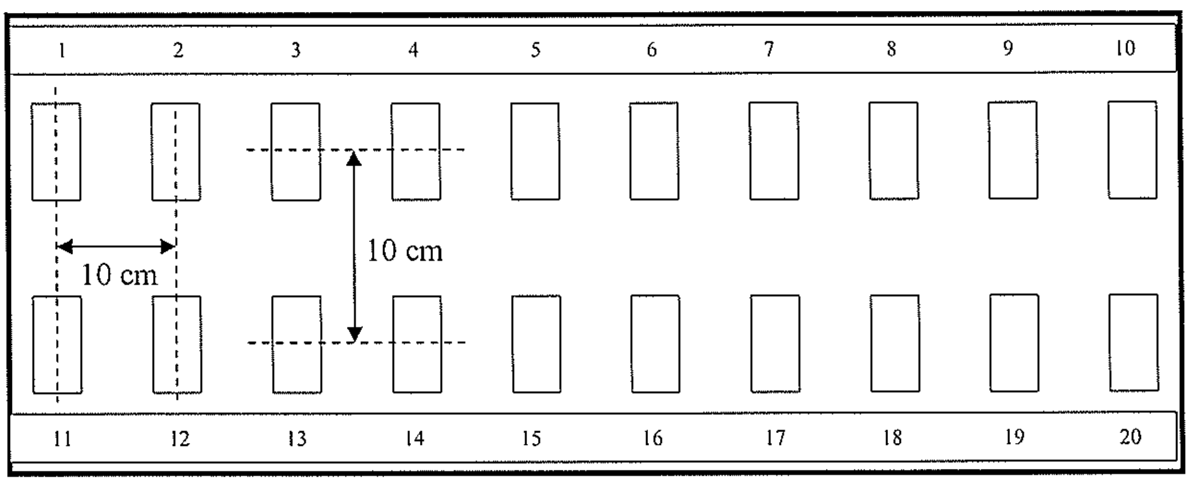


Figure 1

Front view of the board with tag holder that faced the antenna's front.

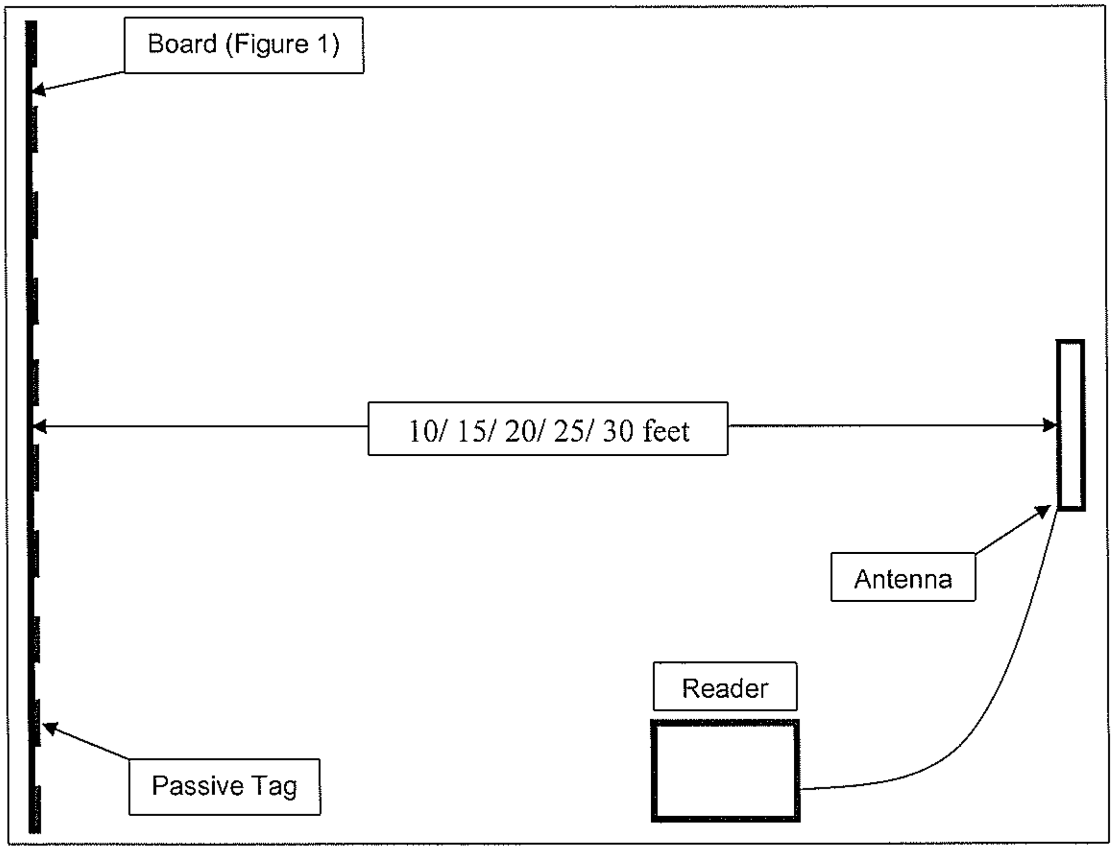


Figure 2

Top view of the experimental setup depicting the components of the tests and their spatial arraignment

The following were the steps of the first set of experiments describing how the setup shown in Figures 1 and 2 were used to collect data.

- The first step was to randomize the order of settings in which to proceed. This was to ensure that any pattern that emerged in the data was solely due to the properties, arraignment and proximity of the tags to the antenna and not the order of factor combinations. There were two key factors that were of the value: Distance between the antenna and the tags (10-30ft) and the gain (10, 25, 33, 50, 66, 80 and 100% power approx.) level of antenna. All combinations of these two factors had to be tested. The 'Design of Experiment' feature of Minitab statistical software was utilized that determined (randomized) the order and the combination of the two; a few combinations are shown in the next table.

distance (feet)	Gain (% of total power)
10	22
15	79
20	63
25	50
30	22

Table 1
Sample of five random combinations of distance and gain used in the first experiment out of 24 in total

- Once the order was established, the tag holder was set at the appropriate distance and the antenna turned on.
- The first few readings were taken without and tags in place to ensure no 'phantom' tags were being read.
- One more factor that was tested was the proximity of individual tags from one another. As shown in Figure 1, there were two possible combinations – 10 and 20 inches apart (center to center).
- There was a specific way that the tags were arraigned to keep the data consistent. The following table shows how the tags were progressively arraigned for readings taken.

Distance	Gain	Tag Distance	#of Tags	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
10	32	10	1	1										1									
		10	2	1	1									1	1								
		10	3	1	1	1								0	0	0							
		10	4	1	1	1	1							1	0	0	1						
		10	5	1	1	0	0	1						1	1	0	1	0					
		10	10	1	1	1	0	1	1	0	1	1	1	1	0	1	1	0	1	1	0	1	0
		20	1																				
		20	2	0	1									1	1								
		20	3	1	1	0								1	1	1							
		20	4	0	1	0	1							0	1	1	1						
		20	5	0	1	0	1	1						0	1	0	0	0					
		20	10	1	1	0	0	1	0	1	0	0	0	0	0	0	0	1	1	1	0	1	1

Table 2
A sample of the data collected in conducting the first experiment.

Each of the bordered boxes with a "1" or "0" in it represents a reading. For example, the very first line shows when tag #1 was placed alone with antenna gain of 32 at a distance of 10 feet from the antenna it was read, signified by '1'. However when tags #1 through #5 were placed 10 inches apart with the rest of the settings the same, tags #3 and #4 were not read by the reader, signified by a '0'. The same applies to the set when tags were 20 inches apart. All 50 tags were utilized in sets of ten, for example tag numbers 1, 11, 21, 31 and 41 were all on the same location for the five repetitions on constant distance and gain; similarly tags 1 and 2 were placed where tags 11 and 12 were placed later in the next repetitions and so on.

- This procedure was replicated through the entirety of the experiment in the predetermined order of combinations as shown in Table 1.

Experiment 2

The first experiment showed that the position left/right of the antenna's center has a nominal effect on the readability but other factors had to be tested further. The second experiment was hence, set on a smaller scale with reduced number of tags and a modified setup. This experiment aimed to study the effects of interference when the tags are not positioned together on an equidistant plane from the antenna. To create such an arraignment, three tags were individually placed on holders that could independently move with respect to each other. To narrow the scope of the study, ten tags were randomly selected from the pool of fifty tags in the last experiment. This was done to reduce the number of combinations of the experimental setup. Using all fifty tags and all their combination would have expanded the study beyond the scope of this research effort. Once the combinations of distances in each lane and the tags to be used were determined, for the readings, the tags were placed on the designated holders in specific lanes and the system turned on. The first tag that was read was noted and the reader was allowed one minute to stay activated. At the end of the minute the number of times each tag was read (response variable: read rate) and the order in which they were read was documented and the data saved for analysis.

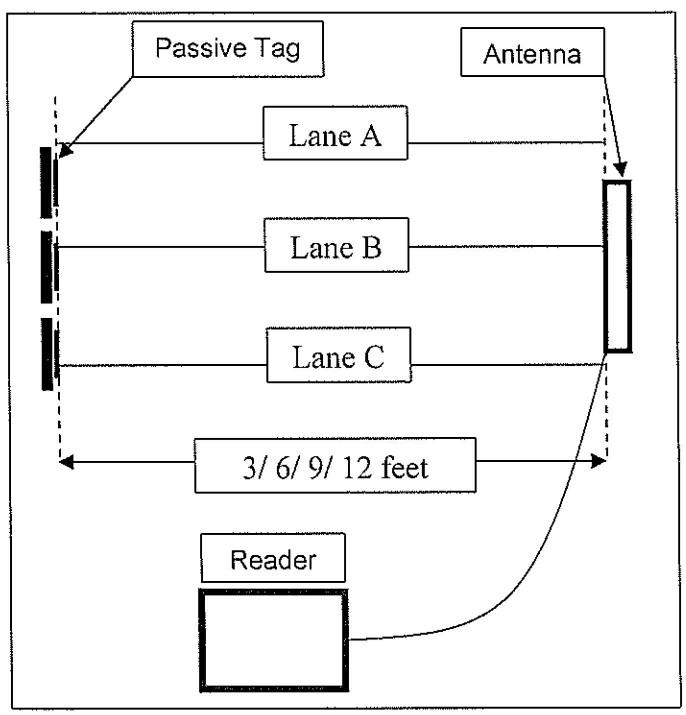


Figure 3
Setup of the second experiment; it depicts the top view of the components and their spatial arraignment.

The previous diagram was the top view of the setup for the second set of experiments. Unlike the first experiments, the three tags shown here are free to move towards and away from the antenna independent of each other providing further insight into the pattern of interference in a slightly modified setting. The independence of movement between tags took the experiment a little closer to a more life-like scenario and also added a dimension of tags not moving on an equidistant plane from the antenna.

There were four key aspect of the seconds set of trials:

- Table 3 lists the first five of the 36 scenarios that were tested. These encompassed all combinations of the three random tags selected for the test.
- These tags similar in performance were used to eliminate the possibility of recording data offset by the tags themselves.
- The actual order scenarios to be tested were randomized to maintain impartiality. Once the order of the tests was established and the tags in question were randomly selected and datasheets were prepared for collecting data.
- The trials themselves were rather simple - each tag was placed on the designated holder and moved to a predetermined distance; the reader was turned on and the number of reads per minute was recorded for each of tags in the sets of three.

The following table shows the first five of 36 combinations/scenarios that were tried. The 'Exp Description' column shows the number of tags at the specified distances. 'Format' refers to the lanes that these tags were placed in.

Scenario	Exp Description	Format
1	2@3 & 1@6	AC, B
2	2@3 & 1@6	AB, C
3	2@3 & 1@6	BC, A
4	1@3 & 2@6	A, BC
5	1@3 & 2@6	B, AC

Table 3
The first five scenarios used in the experiment with various combinations of factors.

All 36 combinations were tested in a random order. Once the tags were arraigned as the setup required, the antenna was activated and individual read rates from each of the three tags were noted. Also noted were the tags that registered first out of the three and lastly, the order in which the tags were recognized.

Results

Experiment 1

The main goal of these tests was to find any pattern in the way that tags in close proximity are read. According to the design of experiment, there were one to ten tags together on the board simultaneously. This board was moved closer and away from the antenna, in effect, moving all tags together keeping each one's distance from the antenna equal. The primary response variable for this experiment was the readability of the tags. The aim was simple; it was to determine how consistently each tag is read by the reader at various combinations of other similar tags in close proximity. As explained in the methodology section, the data that was collected was analyzed to discover any type of pattern the tags were read in.

The following table is part of the analysis for the first set of collected data. Calculation for the analysis can be seen in tables in Appendix A. Due to the extraordinary number of combinations of the factors – distance, gain, number of tags on the board and mutual planar distance between tags, it's beyond the scope of the study to exactly identify unique data points for each factors. However, after calculating the average number of times a tag at a certain position is read and finding the standard deviation of the same, it was discovered that the numbers were random in the sense that the increasing number of tags in proximity after each reading had no direct effect on the readability of a tag. Secondly, just looking at the means and standard deviations and how close in value they are, it was concluded that there was no pattern in the tags being read by the system. Lastly, when arraigned in a definite order either ascending or descending by the factors distance and gain, no regular pattern emerged either in the results' table. The same analysis was done with tags arraigned 20 inches apart as well with the same results. The following table is a sample of the analysis followed by a brief explanation of the analysis. Readings 7-58 have been omitted here but the mean and standard deviation reflect values of the complete dataset. Since there were 50 tags in use, the pattern of arraignments were repeated 10 times, hence, a certain position had a tag in it 10 times except the case of all 10 tags on which could only be done 9 times (need 55 tags to get 10 repetitions). This is why ratios were calculated 'read/ 10' or 'read/9'.

	Times read / 10 times					Times read / 9 times					Ratio of times read to total times									
	Position on the board																			
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
1	3										.30									
2	2	5									.20	.50								
3	2	6	1								.20	.60	.10							
4	3	6	0	6							.30	.60	.00	.60						
5	1	6	2	6	7						.10	.60	.20	.60	.70					
6	7	3	2	8	5	5	3	2	7	5	.70	.30	.20	.80	.50	.56	.33	.22	.78	.56
59	5	0	3	2	0						.50	.00	.30	.20	.00					
60	5	0	3	0	0	4	0	2	0	0	.50	.00	.30	.00	.00	.44	.00	.22	.00	.00
61	5	0	7	0	5						.50	.00	.70	.00	.50					
62	5	2	5	0	5	4	2	6	0	4	.50	.20	.50	.00	.50	.44	.22	.67	.00	.44
Mean	**5.15**	**3.50**	**2.78**	**3.30**	**4.54**	**4.78**	**2.91**	**2.74**	**3.48**	**3.87**	**.51**	**.35**	**.28**	**.33**	**.45**	**.48**	**.29**	**.27**	**.35**	**.39**
SD	**3.41**	**3.00**	**2.44**	**2.83**	**3.05**	**3.27**	**2.21**	**2.30**	**3.07**	**2.60**	**.34**	**.30**	**.24**	**.28**	**.31**	**.36**	**.25**	**.26**	**.34**	**.29**

Table 4

Sample of the analysis/calculations for the first experiments with means and standard deviations.

Table 4 depicts the results from the analysis of the first set of data: 50 tags, 10 inch placement distance. The first ten columns are the number of times the tags were read in the position as specified by that column. The second ten columns contain the ratios of times read to times put in front of the activated antenna. Columns 6 through 10 are tags on the bottom row of the tags holding board. The alternating highlights distinguish the sets of certain distance and gain combinations. As mentioned earlier, the tags are similar in their performance. This meant that the only aspect to keep in mind was the position on the board. As shown in Table 2, all 50 tags were utilized and the positions of various tags were noted. The averages of the ratios for different tags at the same position can be considered as that of one single tag repeated, hence, imparting the ability to add the reads across multiple trials. Therefore, the 'read/not read' ratios are out of 10 or 9. The Last two lines are calculated numbers from the data above. The first row is the average number of times the tags at that position were read and the bottom line is the standard deviation of the same.

Experiment 2

There were three factors that were taken in consideration while performing these tests:

1. Tags' distance from the antenna
2. Linear distance between tags on the plane of the antenna
3. Position of the tag relative to the center of antenna across the plane or the 'lane' as in Figure 3.

Scenario	Exp Description	Format	Tag Numbers	First tag Read	Reads	Any Patterns?	if Yes, Sequence??
1	2@3 & 1@6	AC, B	34,15,48	15 @ 3	109,109,109	Yes (15,34,48)	A-C-B
2	2@3 & 1@6	AB, C	44,29,11	11 @ 6	110,110,110	Yes (11,29,44)	A-B-C
3	2@3 & 1@6	BC, A	32,34,44	32 @ 3	110,110,81	Yes (32-34-44)	B-A-C
4	1@3 & 2@6	A, BC	34,15,32	15 @ 6	107,107,107	Yes (15-32-34)	B-A-C
5	1@3 & 2@6	B, AC	10,28,29	10 @ 3	109,109,109	Yes (10-28-29)	B-C-A

Table 5

Small section of the larger dataset originating from the second set of trials.

The data shown in the table above describes how the test results were organized.

- 'Scenario' is just a serial number the tests were not actually in this order
- 'Exp Description' shows the number of tags at the specified distances.
- 'Format' gives the lanes in which the respective tags were positioned.
- 'Tag Number' is the serial number of the tags in each scenario.
- 'First Tag Read' specifies the first tag recognized by the system.
- 'Reads' the number of readings every 60 seconds.
- 'Any Pattern?' is the order in which the three tags were read.
- The last column is the sequence of tags as they were read, for the analysis the lanes have been numbered as follows - Lane A/1, B/2 and C/3 respectively.
- For example, the first row of table 5 can be interpreted like this:
  2 tags at 3' in lanes A and C. 1 tag at 6' in lane B. the tags used in lanes A, B and C are tag numbers 34, 48 and 15 respectively. All tags were read 109 times in 60 sec and tag #15 was the first one recognized. The pattern that the tags read in was A-C-B which means the tags in the lanes A, C and B were read in that order.

The results show (Appendix B) that except one tag (tag #32 at 12 ft) in one scenario all the tags were at least recognized by the system. Given this situation, the read rate became the primary response variable. All factors, hence, were judged solely by their effect on the read rates. The following analysis is aimed at recognizing the cause and effect relationship between read rates and the three factors mentioned before.

Tag Number	Distance vs. Count		Lane vs. Count	
	Pearson Correlation	P-Value	Pearson Correlation	P-Value
6	-0.751	0.005	0.071	0.826
10	-0.368	0.265	0.087	0.798
11	-0.481	0.159	0.092	0.801
15	-0.688	0.009	0.76	0.003
28	-0.502	0.115	-0.386	0.241
29	-0.842	0.001	0.246	0.442
32	-0.65	0.058	0.19	0.624
34	-0.606	0.048	-0.279	0.407
44	-0.826	0.006	0.469	0.203
48	-0.914	0	0.159	0.66

Table 6

Correlation analysis with constant tag number.

Table 6 shows the results of correlation measurements. In this, the tags numbers have been kept constant and the correlation between distances versus count (read rate) as well as the lane of the tags in focus. It is clear that read rates are inversely related to distance, i.e. read rates decrease as the distance between tags and antenna increases and vice versa.

Distance	Tag # vs. Count		Lane vs. Count	
	Pearson Correlation	P-Value	Pearson Correlation	P-Value
3	0.284	0.151	-0.251	0.207
6	0.37	0.058	-0.259	0.192
9	0.124	0.537	0.214	0.285
12	0.421	0.029	-0.324	0.099

Table 7
Correlation analysis with constant distances.

Table 7 lists the Pearson Correlation between the individual tags and count (read rate) and also the lane of the tags. The distance between the tags and the antenna has been kept as the constant factor. There is a need for more data for this analysis since the evaluations' reliability is questionable given the high p-values reducing the test's credibility.

Lane	Distance vs. Count		Tag # vs. Count	
	Pearson Correlation	P-Value	Pearson Correlation	P-Value
1 - A	-0.761	0	0.155	0.367
2 - B	-0.724	0	-0.286	0.091
3 - C	-0.358	0.032	0.247	0.146

Table 8
Correlation analysis with constant lanes.

The final table, Table 8, is the correlation analysis of the effects that distance and individual tags have on the read rate or count when looked at lane by lane. Seeing the low p-values it can be confidently said that within each lane, the read rate is quite sensitive to distance.

It is simpler to interpret the results by inspecting charts. Hence, to bring out the results more clearly, the data from the three previous tables has been plotted and is shown below.

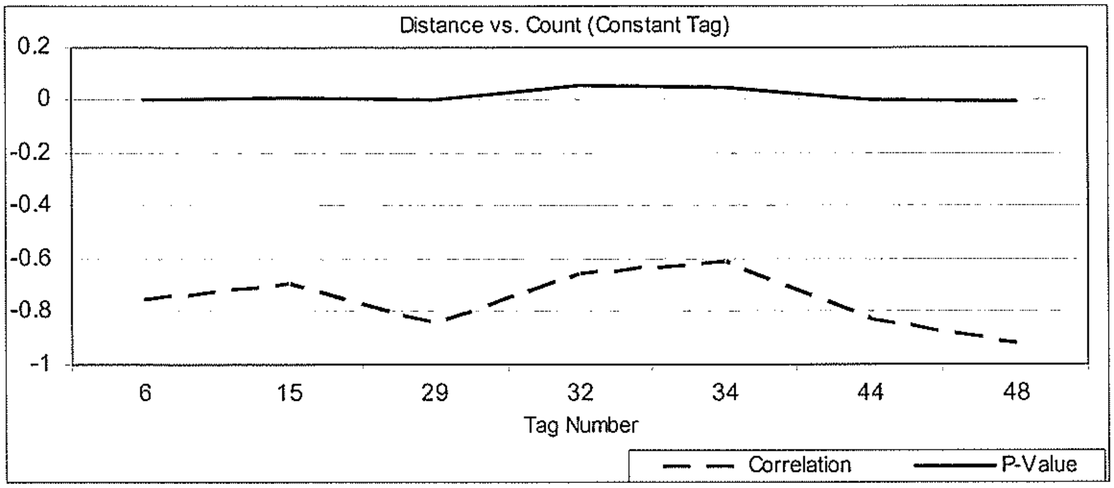


Figure 4

Correlation and p-values across tags – distance vs. count

Across the individual tags it seems that distance, once again, is a constant and rather strong predictor of read rates given the low p-values and high correlation.

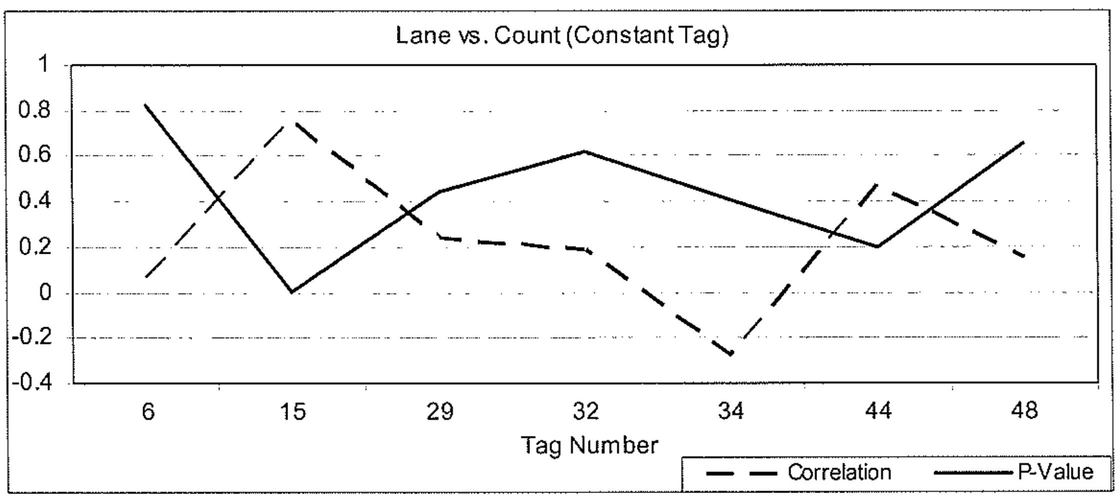


Figure 5

Correlation and p-values across tags – lane vs. count

Figures 4 and 5 illustrate the correlation and p-value when distance from the antenna and the lane of the tag are analyzed for their effect on the 'count' or the read rate keeping the tags constant. In the figures, tags 10, 11 and 28 have been excluded as outliers given the high p-values. It seems that it can be confidently said the there is rather uniform negative correlation between distance and the read rate. Figure 5, however, shows the absence of a uniform correlation between the lane of the tag and the read rate.

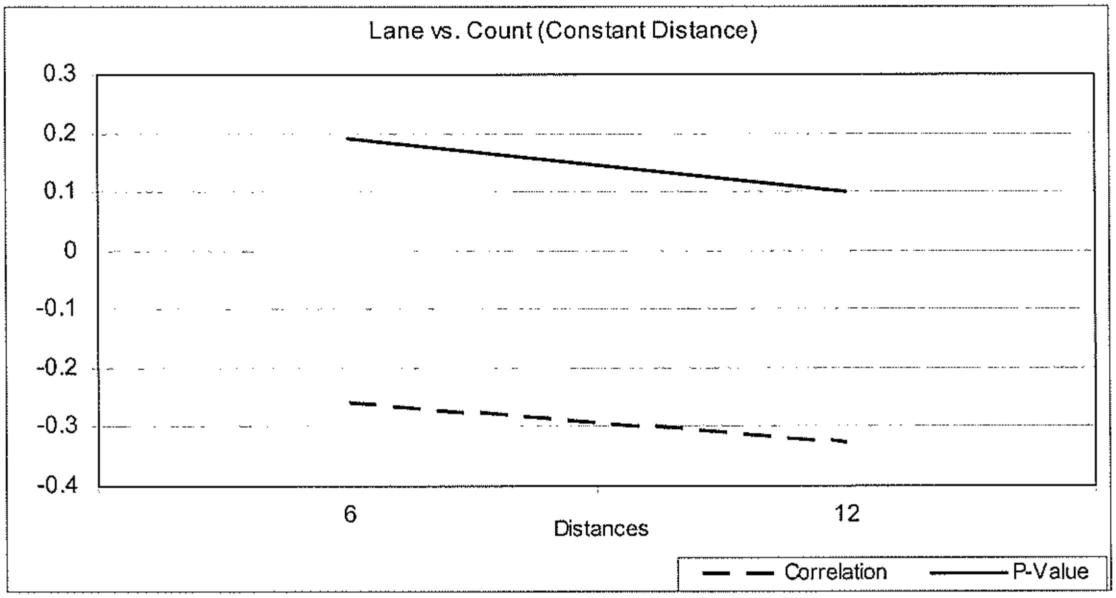


Figure 6

Correlation and p-values across distances – lane vs. count.

Two of the distances - 3 and 9 ft had to be omitted from this chart given the high p-value that takes away from the accuracy of the numbers. However, it can be concluded that as the distance increases, the correlation between read rate and lane of the tag decreases.

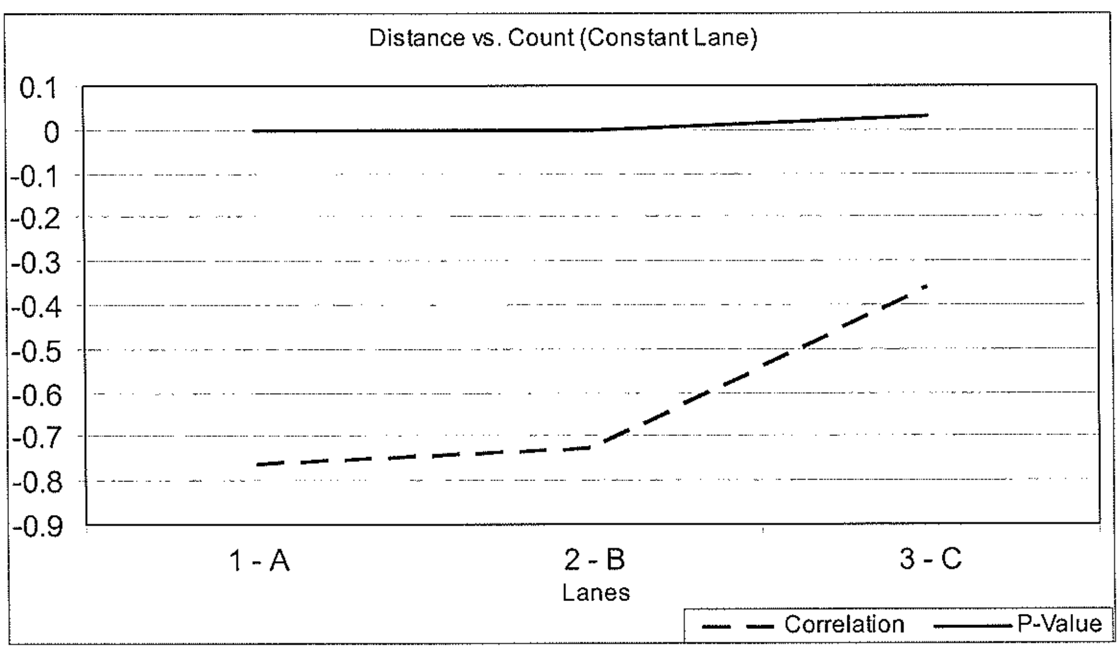


Figure 7

Correlation and p-values across lanes – distance vs. count.

Conclusion

The experimentation began with two response variables in consideration: *readability* and *read rate*. The first set of experiments were aimed to discover the relationship of readability of tags when their positions relative to the antenna are changed, closer or farther, as well as position, left/right relative to the middle of the antenna. The analysis was based on two sets of this data: one in which the tags were 10 inches apart and the other with 20 inches between them. As explained in the previous section, there were no patterns that emerged that dictated which tags were read by the system. The tables are arraigned in ascending order of distance and then gain; still, going down the columns, it appears that there was no trend in the number of times the tags were read at a certain position or that increasing distance and gain. Hence, it can be concluded that the relative position of tags to the center of the antenna has no definite effect on whether tags register in the system or not. One, caveat is that without further experiments and detailed study, it would be difficult to assess the importance of the gain of the antenna. It cannot be denied, just by common knowledge of the subject that the gain (power) of the antenna has to be one of the most vital factors affecting readability and read rates. Hence further study is essential to establish the exact relationship.

The second part of the study mainly focused on the second response variable: *read rate.* With the knowledge that the distance is a key factor determining the efficiency of the system and that position of a tag left or right of the antenna is not a major factor, the experiment was setup to explore the effects of tags not being equidistant from the antenna. The spread of tags on the plane facing the antenna was reduced and only three lanes were used for the trials. Tags were mounted to allow movement independent of each other. The gain of the antenna was kept constant. The same set of tags was used from the previous experiment which had been pre-tested for uniformity in individual performances. As predicted, distance of a tag from the antenna was found to be a factor in the read rates of tags. The correlation was found to be negative; read rates decrease as distance increases in other words. The result from the first experiment that showed minimal effect of tags' position left/right of the center of the antenna, were reinforced by these tests; lanes showed nominal effect on the read rates. In addition, Figure 6 shows that the effect of the lanes decreases further with the tag-antenna distance increasing.

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Appendix A

Table A

This table depicts the sums of '1' and '0's across the 10 or 9 repetitions. Hence, the numbers in the first columns 1-10 are the number of times the tags were recognized in those positions on the board. The second ten columns are the actual ratios out of 10 or 9. The mean and the standard deviations are calculated from the number of reads at a certain position across the repetitions.

	Times read / 10 times					Times read / 9 times					Ratio in decimal form									
	Positions																			
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
1	3										.30									
2	2	5									.20	.50								
3	2	6	1								.20	.60	.10							
4	3	6	0	6							.30	.60	.00	.60						
5	1	6	2	6	7						.10	.60	.20	.60	.70					
6	7	3	2	8	5	5	3	2	7	5	.70	.30	.20	.80	.50	.56	.33	.22	.78	.56
7	10										1.00									
8	9	9									.90	.90								
9	8	6	5								.80	.60	.50							
10	6	5	5	8							.60	.50	.50	.80						
11	9	6	4	8	7						.90	.60	.40	.80	.70					
12	8	5	5	6	6	8	4	6	8	5	.80	.50	.50	.60	.60	.89	.44	.67	.89	.56
13	9	1	4	5	7						.90	.10	.40	.50	.70					
14	8	2	3	5	5	6	1	3	6	7	.80	.20	.30	.50	.50	.67	.11	.33	.67	.78
15	7	1	0	2	4						.70	.10	.00	.20	.40					
16	4	2	1	0	3	2	1	0	2	3	.40	.20	.10	.00	.30	.22	.11	.00	.22	.33
17	2	3	1	0	2						.20	.30	.10	.00	.20					
18	2	2	1	3	2	1	2	2	1	1	.20	.20	.10	.30	.20	.11	.22	.22	.11	.11
19	3	1	1	0	6						.30	.10	.10	.00	.60					
20	3	3	0	1	1	1	1	2	1	3	.30	.30	.00	.10	.10	.11	.11	.22	.11	.33
21	1										.10									
22	0	0									.00	.00								
23	2	0	0								.20	.00	.00							
24	0	0	0	3							.00	.00	.00	.30						
25	0	0	0	0	0						.00	.00	.00	.00	.00					
26	0	1	0	4	0	1	2	0	2	0	.00	.10	.00	.40	.00	.11	.22	.00	.22	.00
27	9										.90									
28	9	0									.90	.00								
29	9	0	4								.90	.00	.40							
30	9	1	3	4							.90	.10	.30	.40						
31	9	3	6	4	0						.90	.30	.60	.40	.00					
32	7	2	2	9	0	7	1	3	8	0	.70	.20	.20	.90	.00	.78	.11	.33	.89	.00

33	6	5	4	5	4						.60	.50	.40	.50	.40					
34	7	7	4	4	5	9	6	4	7	4	.70	.70	.40	.40	.50	1.00	.67	.44	.78	.44
35	5	8	5	7	8						.50	.80	.50	.70	.80					
36	6	9	5	8	7	7	5	4	8	7	.60	.90	.50	.80	.70	.78	.56	.44	.89	.78
37	6	7	5	7	8						.60	.70	.50	.70	.80					
38	5	9	5	5	6	7	6	4	7	5	.50	.90	.50	.50	.60	.78	.67	.44	.78	.56
39	0	1	4	6	8						.00	.10	.40	.60	.80					
40	3	5	3	4	7	2	3	4	6	5	.30	.50	.30	.40	.70	.22	.33	.44	.67	.56
41	0	2	0	0	6						.00	.20	.00	.00	.60					
42	0	3	1	0	5	0	3	0	0	3	.00	.30	.10	.00	.50	.00	.33	.00	.00	.33
43	5	6	3	1	7						.50	.60	.30	.10	.70					
44	3	6	4	0	5	3	4	3	2	5	.30	.60	.40	.00	.50	.33	.44	.33	.22	.56
45	9	8	7	6	10						.90	.80	.70	.60	1.00					
46	8	7	7	7	10	9	5	7	6	8	.80	.70	.70	.70	1.00	1.00	.56	.78	.67	.89
47	8	7	8	1	8						.80	.70	.80	.10	.80					
48	9	9	7	3	8	9	8	6	2	7	.90	.90	.70	.30	.80	1.00	.89	.67	.22	.78
49	2	0	0	0	0						.20	.00	.00	.00	.00					
50	1	0	0	0	2	1	0	0	0	2	.10	.00	.00	.00	.20	.11	.00	.00	.00	.22
51	9	5	0	2	5						.90	.50	.00	.20	.50					
52	10	4	0	1	4	8	4	0	1	2	1.00	.40	.00	.10	.40	.89	.44	.00	.11	.22
53	10	2	0	4	2						1.00	.20	.00	.40	.20					
54	9	0	0	3	3	9	1	0	2	5	.90	.00	.00	.30	.30	1.00	.11	.00	.22	.56
55	9	8	6	3	8						.90	.80	.60	.30	.80					
56	8	4	4	4	8	7	5	5	4	8	.80	.40	.40	.40	.80	.78	.56	.56	.44	.89
57	0	0	0	0	0						.00	.00	.00	.00	.00					
58	0	0	0	0	0	0	0	0	0	0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
59	5	0	3	2	0						.50	.00	.30	.20	.00					
60	5	0	3	0	0	4	0	2	0	0	.50	.00	.30	.00	.00	.44	.00	.22	.00	.00
61	5	0	7	0	5						.50	.00	.70	.00	.50					
62	5	2	5	0	5	4	2	6	0	4	.50	.20	.50	.00	.50	.44	.22	.67	.00	.44
Mean	**5.15**	**3.50**	**2.78**	**3.30**	**4.54**	**4.78**	**2.91**	**2.74**	**3.48**	**3.87**	**.51**	**.35**	**.28**	**.33**	**.45**	**.48**	**.29**	**.27**	**.35**	**.39**
SD	**3.41**	**3.00**	**2.44**	**2.83**	**3.05**	**3.27**	**2.21**	**2.30**	**3.07**	**2.60**	**.34**	**.30**	**.24**	**.28**	**.31**	**.36**	**.25**	**.26**	**.34**	**.29**

Table B

Table B shows the results of the experiments in terms of times read and reads out of 10 or 9 times. This is similar to Table A with the difference that this is the set in which tags were 20 inches apart instead of 10.

	Times read / 10 times					Times read / 9 times					Ratio of times read to total times									
	Positions																			
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
1	2	0									.20	.00								
2	3	0	0								.30	.00	.00							
3	3	0	0	3							.30	.00	.00	.30						
4	3	1	0	3	2						.30	.10	.00	.30	.20					
5	3	3	0	5	1	3	2	0	4	2	.30	.30	.00	.50	.10	.33	.22	.00	.44	.22
6	5	9									.50	.90								
7	7	9	7								.70	.90	.70							
8	4	9	5	7							.40	.90	.50	.70						
9	5	9	4	5	6						.50	.90	.40	.50	.60					
10	6	8	3	2	8	6	7	4	4	5	.60	.80	.30	.20	.80	.67	.78	.44	.44	.56
11	10	9	1								1.00	.90	.10							
12	10	9	3	9							1.00	.90	.30	.90						
13	10	9	2	5	7						1.00	.90	.20	.50	.70					
14	9	9	2	6	7	7	7	2	6	7	.90	.90	.20	.60	.70	.78	.78	.22	.67	.78
15	9	8	4								.90	.80	.40							
16	9	9	2	4							.90	.90	.20	.40						
17	9	7	2	5	4						.90	.70	.20	.50	.40					
18	8	5	1	4	5	7	6	2	6	4	.80	.50	.10	.40	.50	.78	.67	.22	.67	.44
19	9	4	3								.90	.40	.30							
20	9	6	2	4							.90	.60	.20	.40						
21	9	7	3	3	3						.90	.70	.30	.30	.30					
22	2	2	1	3	3	0	2	1	3	4	.20	.20	.10	.30	.30	.00	.22	.11	.33	.44
23	10	8	5								1.00	.80	.50							
24	8	7	2	6							.80	.70	.20	.60						
25	10	8	1	4	1						1.00	.80	.10	.40	.10					
26	9	5	1	4	3	9	4	1	4	2	.90	.50	.10	.40	.30	1.00	.44	.11	.44	.22
27	0	0									.00	.00								
28	0	0	0								.00	.00	.00							
29	0	0	0	0							.00	.00	.00	.00						
30	0	0	0	0	0						.00	.00	.00	.00	.00					
31	0	0	0	0	0	0	0	0	0	0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
32	4	7									.40	.70								
33	5	7	2								.50	.70	.20							
34	3	6	3	0							.30	.60	.30	.00						
35	5	7	3	0	3						.50	.70	.30	.00	.30					
36	3	7	3	2	2	4	6	3	0	3	.30	.70	.30	.20	.20	.44	.67	.33	.00	.33
37	6	9	4								.60	.90	.40							

38	7	8	5	3							.70	.80	.50	.30						
39	6	9	3	4	7						.60	.90	.30	.40	.70					
40	5	8	4	3	8	6	7	3	2	5	.50	.80	.40	.30	.80	.67	.78	.33	.22	.56
41	7	6	5								.70	.60	.50							
42	6	5	5	5							.60	.50	.50	.50						
43	6	5	4	6	8						.60	.50	.40	.60	.80					
44	6	4	5	7	8	6	4	2	5	7	.60	.40	.50	.70	.80	.67	.44	.22	.56	.78
45	8	7	6								.80	.70	.60							
46	10	6	4	9							1.00	.60	.40	.90						
47	10	7	4	7	9						1.00	.70	.40	.70	.90					
48	9	4	2	6	8	9	5	3	6	9	.90	.40	.20	.60	.80	1.00	.56	.33	.67	1.00
49	10	2	4								1.00	.20	.40							
50	10	2	6	1							1.00	.20	.60	.10						
51	9	2	4	1	8						.90	.20	.40	.10	.80					
52	8	3	3	2	7	7	3	4	0	9	.80	.30	.30	.20	.70	.78	.33	.44	.00	1.00
53	7	0	1								.70	.00	.10							
54	6	0	1	5							.60	.00	.10	.50						
55	7	0	1	5	1						.70	.00	.10	.50	.10					
56	7	0	2	4	2	6	0	0	3	3	.70	.00	.20	.40	.20	.67	.00	.00	.33	.33
57	8	2	4								.80	.20	.40							
58	5	1	4	4							.50	.10	.40	.40						
59	7	0	4	5	2						.70	.00	.40	.50	.20					
60	5	0	2	6	2	7	0	3	5	1	.50	.00	.20	.60	.20	.78	.00	.33	.56	.11
61	10										1.00									
62	9	8	3								.90	.80	.30							
63	9	10	3	10							.90	1.00	.30	1.00						
64	10	9	5	10	10						1.00	.90	.50	1.00	1.00					
65	10	10	3	10	10	7	4	7	6	7	1.00	1.00	.30	1.00	1.00	.78	.44	.78	.67	.78
66	7	5	8								.70	.50	.80							
67	8	7	8	6							.80	.70	.80	.60						
68	8	6	8	6	10						.80	.60	.80	.60	1.00					
69	9	5	7	9	7	8	6	7	7	8	.90	.50	.70	.90	.70	.89	.67	.78	.78	.89
70	0	0	0								.00	.00	.00							
71	0	0	0	1							.00	.00	.00	.10						
72	0	0	0	1	2						.00	.00	.00	.10	.20					
73	0	0	0	2	5	0	0	0	4	2	.00	.00	.00	.20	.50	.00	.00	.00	.44	.22
74	3	3	0								.30	.30	.00							
75	2	4	0	0							.20	.40	.00	.00						
76	5	3	0	0	2						.50	.30	.00	.00	.20					
77	1	4	1	1	7	3	3	0	1	3	.10	.40	.10	.10	.70	.33	.33	.00	.11	.33
78	0	7	1								.00	.70	.10							
79	1	8	0	1							.10	.80	.00	.10						
80	1	8	0	1	1						.10	.80	.00	.10	.10					
81	1	9	0	2	0	0	8	0	3	1	.10	.90	.00	.20	.00	.00	.89	.00	.33	.11
82	10	10	3								1.00	1.00	.30							
83	10	10	3	7							1.00	1.00	.30	.70						

84	9	10	2	7	4						.90	1.00	.20	.70	.40					
85	8	10	5	8	5	1	8	3	9	9	.80	1.00	.50	.80	.50	.11	.89	.33	1.00	1.00
86	9	2	0								.90	.20	.00							
87	10	3	0	0							1.00	.30	.00	.00						
88	10	1	1	0	0						1.00	.10	.10	.00	.00					
89	9	3	3	0	0	9	2	1	0	1	.90	.30	.30	.00	.00	1.00	.22	.11	.00	.11
90	8	2	3								.80	.20	.30							
91	9	2	4	0							.90	.20	.40	.00						
92	10	2	3	0	0						1.00	.20	.30	.00	.00					
93	9	2	4	0	1	9	3	2	0	2	.90	.20	.40	.00	.10	1.00	.33	.22	.00	.22
94	9										.90									
95	9	0	8								.90	.00	.80							
96	9	0	8	0							.90	.00	.80	.00						
97	7	0	7	0	5						.70	.00	.70	.00	.50					
98	8	0	8	0	4	2	0	4	0	2	.80	.00	.80	.00	.40	.22	.00	.44	.00	.22
Mean	**6.36**	**4.66**	**2.84**	**3.61**	**4.30**	**5.04**	**3.78**	**2.26**	**3.39**	**4.17**	**0.64**	**0.47**	**0.28**	**0.36**	**0.43**	**0.56**	**0.42**	**0.25**	**0.38**	**0.46**
SD	**3.34**	**3.54**	**2.33**	**3.01**	**3.20**	**3.24**	**2.75**	**2.05**	**2.66**	**2.90**	**0.33**	**0.35**	**0.23**	**0.30**	**0.32**	**0.36**	**0.31**	**0.23**	**0.30**	**0.32**

Table C

Table C depicts the results of a different analysis. The first ten columns are the standard deviation of tags read or not read across the same setting for distance and gain. The values are all over the board, no steady pattern emerges, again, showing inconsistencies.

	Times read / 10 times					Times read / 9 times					Ratio of times read to total times									
	Positions																			
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
1	.483										.048									
2	.422	.527									.042	.053								
3	.422	.516	.316								.042	.052	.032							
4	.483	.516	.000	.516							.048	.052	.000	.052						
5	.316	.516	.422	.516	.483						.032	.052	.042	.052	.048					
6	.483	.483	.422	.422	.527	.527	.500	.441	.441	.527	.048	.048	.042	.042	.053	.059	.056	.049	.049	.059
7	.000										.000									
8	.316	.316									.032	.032								
9	.422	.516	.527								.042	.052	.053							
10	.516	.527	.527	.422							.052	.053	.053	.042						
11	.316	.516	.516	.422	.483						.032	.052	.052	.042	.048					
12	.422	.527	.527	.516	.516	.333	.527	.500	.000	.527	.042	.053	.053	.052	.052	.037	.059	.056	.000	.059
13	.316	.316	.516	.527	.483						.032	.032	.052	.053	.048					
14	.422	.422	.483	.527	.527	.500	.333	.500	.500	.441	.042	.042	.048	.053	.053	.056	.037	.056	.056	.049
15	.483	.316	.000	.422	.516						.048	.032	.000	.042	.052					
16	.516	.422	.316	.000	.483	.441	.333	.000	.441	.500	.052	.042	.032	.000	.048	.049	.037	.000	.049	.056
17	.422	.483	.316	.000	.422						.042	.048	.032	.000	.042					
18	.422	.422	.316	.483	.422	.333	.441	.441	.333	.333	.042	.042	.032	.048	.042	.037	.049	.049	.037	.037
19	.483	.316	.316	.000	.516						.048	.032	.032	.000	.052					
20	.483	.483	.000	.316	.316	.333	.333	.441	.333	.500	.048	.048	.000	.032	.032	.037	.037	.049	.037	.056
21	.316										.032									
22	.000	.000									.000	.000								
23	.422	.000	.000								.042	.000	.000							
24	.000	.000	.000	.483							.000	.000	.000	.048						
25	.000	.000	.000	.000	.000						.000	.000	.000	.000	.000					
26	.000	.316	.000	.516	.000	.333	.441	.000	.441	.000	.000	.032	.000	.052	.000	.037	.049	.000	.049	.000
27	.316										.032									
28	.316	.000									.032	.000								
29	.316	.000	.516								.032	.000	.052							
30	.316	.316	.483	.527							.032	.032	.048	.053						
31	.316	.483	.516	.516	.000						.032	.048	.052	.052	.000					
32	.483	.422	.422	.316	.000	.441	.333	.500	.333	.000	.048	.042	.042	.032	.000	.049	.037	.056	.037	.000
33	.516	.527	.516	.527	.516						.052	.053	.052	.053	.052					
34	.483	.483	.516	.516	.527	.000	.500	.535	.441	.527	.048	.048	.052	.052	.053	.000	.056	.059	.049	.059

35	.527	.422	.527	.483	.333						.053	.042	.053	.048	.033					
36	.516	.316	.527	.422	.483	.441	.527	.527	.333	.441	.052	.032	.053	.042	.048	.049	.059	.059	.037	.049
37	.516	.483	.527	.483	.422						.052	.048	.053	.048	.042					
38	.527	.316	.527	.527	.516	.441	.500	.527	.441	.527	.053	.032	.053	.053	.052	.049	.056	.059	.049	.059
39	.000	.316	.516	.516	.422						.000	.032	.052	.052	.042					
40	.483	.527	.483	.516	.483	.441	.500	.527	.500	.527	.048	.053	.048	.052	.048	.049	.056	.059	.056	.059
41	.000	.422	.000	.000	.516						.000	.042	.000	.000	.052					
42	.000	.483	.316	.000	.527	.000	.500	.000	.000	.500	.000	.048	.032	.000	.053	.000	.056	.000	.000	.056
43	.527	.516	.483	.316	.483						.053	.052	.048	.032	.048					
44	.483	.516	.516	.000	.527	.500	.527	.500	.441	.527	.048	.052	.052	.000	.053	.056	.059	.056	.049	.059
45	.316	.422	.483	.516	.000						.032	.042	.048	.052	.000					
46	.422	.483	.483	.483	.000	.000	.527	.441	.500	.333	.042	.048	.048	.048	.000	.000	.059	.049	.056	.037
47	.422	.483	.422	.316	.422						.042	.048	.042	.032	.042					
48	.316	.316	.483	.483	.422	.000	.333	.500	.441	.441	.032	.032	.048	.048	.042	.000	.037	.056	.049	.049
49	.422	.000	.000	.000	.000						.042	.000	.000	.000	.000					
50	.316	.000	.000	.000	.422	.333	.000	.000	.000	.441	.032	.000	.000	.000	.042	.037	.000	.000	.000	.049
51	.316	.527	.000	.422	.527						.032	.053	.000	.042	.053					
52	.000	.516	.000	.316	.516	.333	.527	.000	.333	.441	.000	.052	.000	.032	.052	.037	.059	.000	.037	.049
53	.000	.422	.000	.516	.422						.000	.042	.000	.052	.042					
54	.316	.000	.000	.483	.483	.000	.333	.000	.441	.527	.032	.000	.000	.048	.048	.000	.037	.000	.049	.059
55	.316	.422	.516	.483	.422						.032	.042	.052	.048	.042					
56	.422	.516	.516	.516	.333	.441	.518	.527	.527	.333	.042	.052	.052	.052	.033	.049	.058	.059	.059	.037
57	.000	.000	.000	.000	.000						.000	.000	.000	.000	.000					
58	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
59	.527	.000	.483	.422	.000						.053	.000	.048	.042	.000					
60	.527	.000	.483	.000	.000	.527	.000	.441	.000	.000	.053	.000	.048	.000	.000	.059	.000	.049	.000	.000
61	.527	.000	.483	.000	.527						.053	.000	.048	.000	.053					
62	.527	.422	.527	.000	.527	.527	.441	.500	.000	.527	.053	.042	.053	.000	.053	.059	.049	.056	.000	.059
Mean	.342	.337	.330	.334	.358	.314	.390	.341	.314	.388	.034	.034	.033	.033	.036	.031	.039	.034	.031	.039
SD	.185	.204	.224	.219	.210	.202	.172	.233	.199	.193	.018	.020	.022	.022	.021	.022	.019	.026	.022	.021

Table D

Table D illustrates results from analysis similar to one in Table C. The only difference is that for these trials, the tags were placed 20 inches apart instead of 10.

	Times read / 10 times					Times read / 9 times					Ratio in decimal form									
	Positions																			
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
1	.422	.000									.042	.000								
2	.483	.000	.000								.048	.000	.000							
3	.483	.000	.000	.483							.048	.000	.000	.048						
4	.483	.316	.000	.483	.422						.048	.032	.000	.048	.042					
5	.483	.483	.000	.527	.316	.500	.441	.000	.527	.441	.048	.048	.000	.053	.032	.056	.049	.000	.059	.049
6	.527	.316									.053	.032								
7	.483	.316	.483								.048	.032	.048							
8	.516	.316	.527	.483							.052	.032	.053	.048						
9	.527	.316	.516	.527	.516						.053	.032	.052	.053	.052					
10	.516	.422	.483	.422	.422	.500	.441	.527	.527	.527	.052	.042	.048	.042	.042	.056	.049	.059	.059	.059
11	.000	.316	.316								.000	.032	.032							
12	.000	.316	.483	.316							.000	.032	.048	.032						
13	.000	.316	.422	.527	.483						.000	.032	.042	.053	.048					
14	.316	.316	.422	.516	.483	.441	.441	.441	.500	.441	.032	.032	.042	.052	.048	.049	.049	.049	.056	.049
15	.316	.422	.516								.032	.042	.052							
16	.316	.316	.422	.516							.032	.032	.042	.052						
17	.316	.483	.422	.527	.516						.032	.048	.042	.053	.052					
18	.422	.527	.316	.516	.527	.441	.500	.441	.500	.527	.042	.053	.032	.052	.053	.049	.056	.049	.056	.059
19	.316	.516	.483								.032	.052	.048							
20	.316	.516	.422	.516							.032	.052	.042	.052						
21	.316	.483	.483	.483	.483						.032	.048	.048	.048	.048					
22	.422	.422	.316	.483	.483	.000	.441	.333	.500	.527	.042	.042	.032	.048	.048	.000	.049	.037	.056	.059
23	.000	.422	.527								.000	.042	.053							
24	.422	.483	.422	.516							.042	.048	.042	.052						
25	.000	.422	.316	.516	.333						.000	.042	.032	.052	.033					
26	.316	.527	.316	.516	.483	.000	.527	.333	.527	.441	.032	.053	.032	.052	.048	.000	.059	.037	.059	.049
27	.000	.000									.000	.000								
28	.000	.000	.000								.000	.000	.000							
29	.000	.000	.000	.000							.000	.000	.000	.000						
30	.000	.000	.000	.000	.000						.000	.000	.000	.000	.000					
31	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
32	.516	.483									.052	.048								
33	.527	.483	.422								.053	.048	.042							
34	.483	.516	.483	.000							.048	.052	.048	.000						
35	.527	.483	.483	.000	.483						.053	.048	.048	.000	.048					
36	.483	.483	.483	.422	.422	.527	.500	.500	.000	.500	.048	.048	.048	.042	.042	.059	.056	.056	.000	.056
37	.516	.316	.516								.052	.032	.052							

38	.483	.422	.527	.483							.048	.042	.053	.048						
39	.516	.316	.483	.516	.483						.052	.032	.048	.052	.048					
40	.527	.422	.516	.483	.422	.500	.441	.500	.441	.527	.053	.042	.052	.048	.042	.056	.049	.056	.049	.059
41	.483	.516	.527								.048	.052	.053							
42	.516	.527	.527	.527							.052	.053	.053	.053						
43	.500	.527	.516	.516	.422						.050	.053	.052	.052	.042					
44	.516	.516	.527	.483	.422	.500	.527	.441	.527	.441	.052	.052	.053	.048	.042	.056	.059	.049	.059	.049
45	.422	.483	.516								.042	.048	.052							
46	.000	.516	.516	.316							.000	.052	.052	.032						
47	.000	.483	.516	.483	.316						.000	.048	.052	.048	.032					
48	.316	.516	.422	.516	.422	.000	.527	.500	.500	.000	.032	.052	.042	.052	.042	.000	.059	.056	.056	.000
49	.000	.422	.516								.000	.042	.052							
50	.000	.422	.516	.316							.000	.042	.052	.032						
51	.316	.422	.516	.316	.422						.032	.042	.052	.032	.042					
52	.422	.483	.483	.422	.483	.441	.500	.527	.000	.000	.042	.048	.048	.042	.048	.049	.056	.059	.000	.000
53	.483	.000	.316								.048	.000	.032							
54	.516	.000	.316	.527							.052	.000	.032	.053						
55	.483	.000	.316	.527	.316						.048	.000	.032	.053	.032					
56	.483	.000	.422	.516	.422	.500	.000	.000	.500	.500	.048	.000	.042	.052	.042	.056	.000	.000	.056	.056
57	.422	.422	.516								.042	.042	.052							
58	.527	.316	.516	.516							.053	.032	.052	.052						
59	.483	.000	.516	.527	.441						.048	.000	.052	.053	.044					
60	.527	.000	.422	.516	.422	.441	.000	.500	.527	.333	.053	.000	.042	.052	.042	.049	.000	.056	.059	.037
61	.000										.000									
62	.316	.422	.483								.032	.042	.048							
63	.316	.000	.483	.000							.032	.000	.048	.000						
64	.000	.316	.527	.000	.000						.000	.032	.053	.000	.000					
65	.000	.000	.483	.000	.000	.441	.535	.441	.500	.441	.000	.000	.048	.000	.000	.049	.059	.049	.056	.049
66	.483	.527	.422								.048	.053	.042							
67	.422	.483	.422	.516							.042	.048	.042	.052						
68	.422	.516	.422	.516	.000						.042	.052	.042	.052	.000					
69	.316	.527	.483	.316	.483	.333	.500	.441	.441	.333	.032	.053	.048	.032	.048	.037	.056	.049	.049	.037
70	.000	.000	.000								.000	.000	.000							
71	.000	.000	.000	.316							.000	.000	.000	.032						
72	.000	.000	.000	.316	.422						.000	.000	.000	.032	.042					
73	.000	.000	.000	.422	.527	.000	.000	.000	.527	.441	.000	.000	.000	.042	.053	.000	.000	.000	.059	.049
74	.483	.483	.000								.048	.048	.000							
75	.422	.516	.000	.000							.042	.052	.000	.000						
76	.527	.483	.000	.000	.422						.053	.048	.000	.000	.042					
77	.316	.516	.316	.316	.483	.500	.500	.000	.333	.500	.032	.052	.032	.032	.048	.056	.056	.000	.037	.056
78	.000	.483	.316								.000	.048	.032							
79	.316	.422	.000	.316							.032	.042	.000	.032						
80	.316	.422	.000	.316	.316						.032	.042	.000	.032	.032					
81	.316	.316	.000	.422	.000	.000	.333	.000	.500	.333	.032	.032	.000	.042	.000	.000	.037	.000	.056	.037
82	.000	.000	.483								.000	.000	.048							
83	.000	.000	.483	.483							.000	.000	.048	.048						

84	.316	.000	.422	.483	.516						.032	.000	.042	.048	.052					
85	.422	.000	.527	.422	.527	.333	.333	.518	.000	.000	.042	.000	.053	.042	.053	.037	.037	.058	.000	.000
86	.316	.422	.000								.032	.042	.000							
87	.000	.483	.000	.000							.000	.048	.000	.000						
88	.000	.316	.316	.000	.000						.000	.032	.032	.000	.000					
89	.316	.483	.483	.000	.000	.000	.441	.333	.000	.333	.032	.048	.048	.000	.000	.000	.049	.037	.000	.037
90	.422	.422	.483								.042	.042	.048							
91	.316	.422	.516	.000							.032	.042	.052	.000						
92	.000	.422	.483	.000	.000						.000	.042	.048	.000	.000					
93	.316	.422	.516	.000	.316	.000	.500	.441	.000	.441	.032	.042	.052	.000	.032	.000	.056	.049	.000	.049
94	.316										.032									
95	.316	.000	.422								.032	.000	.042							
96	.316	.000	.422	.000							.032	.000	.042	.000						
97	.483	.000	.483	.000	.527						.048	.000	.048	.000	.053					
98	.422	.000	.422	.000	.516	.441	.000	.527	.000	.441	.042	.000	.042	.000	.052	.049	.000	.059	.000	.049
Mean	**.306**	**.308**	**.356**	**.333**	**.357**	**.297**	**.366**	**.337**	**.343**	**.368**	**.031**	**.629**	**.036**	**.033**	**.036**	**.033**	**.041**	**.037**	**.038**	**.041**
SD	**.203**	**.209**	**.199**	**.217**	**.188**	**.227**	**.204**	**.213**	**.235**	**.184**	**.020**	**.021**	**.020**	**.022**	**.019**	**.025**	**.023**	**.024**	**.026**	**.020**

Appendix B

Table E
Complete results from the second experiment.

Tag Number	Distance	Count	Lane (letter)	Lane
6	6	110	A	1
6	6	108	A	1
6	6	111	B	2
6	6	108	C	3
6	6	107	C	3
6	9	74	A	1
6	9	87	B	2
6	9	48	C	3
6	9	88	C	3
6	12	51	A	1
6	12	57	B	2
6	12	96	C	3
10	3	108	B	2
10	3	109	B	2
10	3	15	C	3
10	3	103	C	3
10	6	110	A	1
10	6	108	B	2
10	9	21	A	1
10	9	47	C	3
10	12	22	A	1
10	12	81	C	3
10	12	84	C	3
11	3	110	A	1
11	6	108	B	2
11	6	110	C	3
11	9	17	A	1
11	9	89	B	2
11	9	75	B	2
11	9	51	C	3
11	9	71	C	3
11	12	45	C	3
11	12	107	C	3
15	3	108	B	2
15	3	108	B	2
15	3	109	C	3
15	3	107	C	3

15	3	110	C	3
15	6	107	B	2
15	6	108	B	2
15	9	93	B	2
15	9	107	B	2
15	9	105	C	3
15	12	50	A	1
15	12	56	A	1
15	12	103	C	3
28	3	108	A	1
28	3	109	A	1
28	3	109	B	2
28	3	108	C	3
28	6	109	A	1
28	6	107	B	2
28	6	108	B	2
28	9	91	C	3
28	9	58	C	3
28	12	91	A	1
28	12	106	C	3
29	3	110	B	2
29	3	109	B	2
29	6	87	A	1
29	6	109	A	1
29	6	109	C	3
29	9	39	A	1
29	9	69	A	1
29	9	66	B	2
29	12	16	A	1
29	12	27	B	2
29	12	9	B	2
29	12	81	C	3
32	3	109	A	1
32	3	110	B	2
32	6	103	A	1
32	6	107	C	3
32	6	109	C	3
32	9	41	A	1
32	9	70	B	2
32	12	106	B	2
32	12	0	B	2
34	3	109	A	1
34	3	106	A	1
34	3	107	A	1
34	3	110	C	3
34	9	85	A	1
34	9	108	A	1
34	9	109	B	2

34	9	110	B	2
34	9	65	C	3
34	12	86	A	1
34	12	72	B	2
44	3	110	A	1
44	3	108	A	1
44	3	107	C	3
44	6	81	A	1
44	6	103	B	2
44	9	47	A	1
44	12	30	A	1
44	12	34	A	1
44	12	87	B	2
48	3	110	B	2
48	3	109	C	3
48	6	107	A	1
48	6	109	B	2
48	6	110	C	3
48	6	110	C	3
48	6	108	C	3
48	12	24	B	2
48	12	3	B	2
48	12	47	C	3