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Using Design For Six Sigma To Develop Real-world Testing Environments For RFID Systems

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Abstract

Radio Frequency Identification (RFID) has been put into practice within industry for a number of years. To better assess its potential applications and implementation, this paper presents an approach called Design For Six Sigma (DFSS). DFSS has many applications including: creating real world warehouse testing environments, measuring and analyzing the implementation of RFID technology, and developing and optimizing the conditions for the most efficient readability. Finally, DFSS can be used to validate RFID technological principles and draw conclusions under this real circumstance.

Keywords
RFID, Six Sigma, 3P, DFSS

1. Introduction
Radio Frequency Identification (RFID) has been called the "barcode of the next generation." It is currently in use with applications ranging from libraries to toll booth e-passes. The greatest advantage in RFID systems, which are composed of an interrogator (reader) and transponders (tags), is that they do not require a line-of-sight between the reader and the tags. With a RFID system in place, entire bags of items affixed with RFID tags can be audited in seconds without ever having to open the bag.

RFID System Details
RFID systems consist of an interrogator (also referred to as a reader) and transponders, or tags. In an RFID system, the antenna of the reader emits radio signals. The signals are received by the tag's antenna, which can be powered via a battery or by the radio frequency energy from the reader's pulse. A Space Station crewmember could potentially initiate a reader in the general vicinity of a cargo transfer lab, that is full of tagged items, and record an accurate count of all items within the bag in seconds. In this paper, we will use a simulated warehouse as an environment for DFSSR techniques.

Six Sigma Methodology
With the advantages illustrated above, a series of experiments and tests will be conducted by RfSCL lab at the University of Nebraska-Lincoln. A blend of methodologies will help the RfSCL lab use information to better develop a solution that best meets the needs of customers. The methodology used in this paper is the Integrated Design for Six Sigma (DFSS) (Breyfogle, 2003). DMADO (De-may-doh) is the acronym for Design, Measure, Analyze, Develop and Optimize (Breyfogle, 2003). This new approach to research will help bridge the gap between academic organizations and industry. The experiments and analysis will be conducted following the order of scientific methodology.

2. 3P's theoretical model
In this paper we introduce a research framework Design for Six Sigma Research (DFFSSR) that is based on a common operational prototype theme that requires development teams to plan, predict, and perform. This 3p's methodology is utilized to encapsulate our DFSSR framework. For RFID technology, to better serve Industrial applications, we need to conduct a series of experiments to validate the principle of facility layout of RFID into real case scenarios. The Six Sigma methodology helps us build a scientific procedure and makes sure it is the optimum layout for real warehouse scenarios. The DFSSR process steps are organized within the 3P framework as shown in

figure 1. The results or lessons learned can be used to effectively implement the technology in this environment. Further, the compiled lessons learned can be used to determine the best practices for implementations in the future. The methodology allows for the defining of the correct prototype environment, RFID sub-system testing and integrated system testing for the prototype environment.

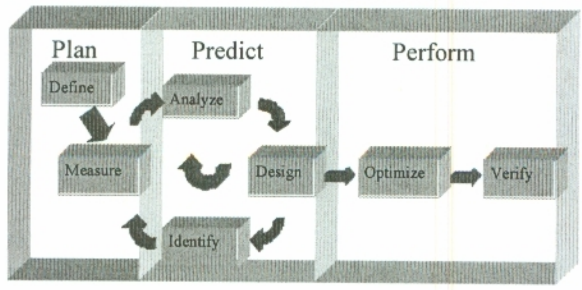

Figure 1: DFSSR 3P's methodology framework

3. Plan

In this phase, we need to identify the critical path for both information and material flow. As a beginning of plan phase, the first thing is to define the problem in real case, for example, what type of product do they use for inventory? What is frequency of transportation they have everyday? That is all related to our test design for warehouse.

3.1 Define

In the define phase it is necessary to compile the real environmental requirements into the test parameter. This makes it necessary to show the theoretical model in the design and analyze phases as an explanation and foundation for our future experiments. In this step, we describe facility layout process is based on input data, an understanding of the roles and relationships between activities, a material flow analysis, and an activity relationship analysis. The defining step is shown in the first phase – Plan the clear material flow should be identified in this step as a basis of predict and perform. The chart below shows us a clear view of thought process.

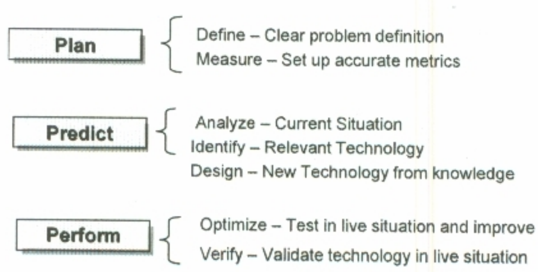

Figure 2: 3P's thought process

3.2 Measure

Multi-objective RF Warehouse architecture is the overall RFID Warehouse Implementing System. It includes 3 main parts: a RFID edge layer, a RFID physical layer, and an enterprise integration network. The RFID physical layer is the connection of the other two layers. The RFID system is designed to process streams of tags, or sensor data, coming from one or more readers. The edge layer has the capability to filter and aggregate data prior to sending it to a requesting application. For example, an action (tag read) is triggered when the object moves or a new object comes into the reader's view. The RFID edge servers filter and collect the tag data at each individual site and send it over the internet to the third layer-enterprise integration layer. The localized data is identified by moving actions and stationary actions separately. This difference divides the usage of RFID antenna into 2 types of equipments, one is a fixed reader for warehouse portal door, and another is a mobile reader for tracking inventory. The fundamental tenet of the warehouse portal distribution system is that they must be able to accommodate changes that may occur on a network. The portal devices provide real-time, positioning access capabilities to user communities, and delivering and searching personal data. It allows external customers and partners access to data secure access.

We can now divide the RFID warehouse system into three parts as we discussed before: the physical layer, the logic layer, and the system integration layer. Each layer has different components depending on what functions the RFID system needs. By understanding the flow in the warehouse we can determine the types of tags and antennas needed. In short, RFID implementation in any process has two or three layers. The physical layer produces log events for RF sensors during process executions. The logic layer records the log events related data including filter and integrate functions. The analysis of the physical layer activity has been discussed in facility layout research. Previous research with RFID facility layout does not include data flow as a factor that influences the RFID warehouse efficiency and performance.

4. Predict

In this phase, the major issue is to analyze the outcome and process of our RFID operation. As we know, the critical results of experiment or test are very important for the company who wants to implement RFID; the situation may vary from each company. Combine the real environment and site requirements, the test should be conducted in appropriate and cost-effective ways.

4.1 Analyze

Data environment analysis: One of the design components of the RFID warehouse layout is the data flow through the distribution process. This is included in the experimental design phase. The goal of such an activity is to define the input and output data in order to confirm the efficiency of data flow and its physical flow. Data standards can be smoothly exchanged within the supply chain because the data is already formatted and organized. The work flow and data flow are both generated by the production flow from the physical layer to the logical layer. Therefore, the location of the RFID equipment is influential on the accuracy of the distribution process which forms the individual data flow according to the work flow. The location of the RFID antenna, also called a sensor, will be discussed later on.

4.2 Design

According to our analysis of site environment and data types, we choose to use passive tag as our technology in warehouse which means low cost but high volume information flow.

First, the 'sensor' is used to refer to a device which is connected, via network or RF communication medium, to other sensor devices in the network. The location of the sensors in the warehouse relate to either its environment or its data traffic flow which is detected by a fixed antenna on the portal door. Similarly, the data flow will be employed by sensors specifically in the picking entrance portal and the distributing portal. Therefore, the data traffic through the two portal doors and its layout will be considered in this paper. The other communication between the nodes in the warehouse will be discussed in future work. In order to measure the accuracy and efficiency of RFID performance in the warehouse, we are using a *ratio* to evaluate the relationship of performance and efficiency of RFID readability. This is σ which equals the simple relationship between input and output data which will be related to a regression analysis to show fair performance.

$$\sigma_r = \alpha_I / \beta_O \qquad (1)$$

$$\sigma_r = ratio; \alpha_I = Input; \beta_o = Output$$

However, this ratio only gives an average performance for RFID readability. We measured the benchmark of the performance used to compare the different input data and data flow. For example, the different amounts of workflow reflect the different data flow in the warehouse, but the benchmark gives us reliable data to measure different warehouse environments and work flows.

5. Perform

The last phase of our study will be Perform, after previous experiments and design applications. The next stage is to prove the feasibility of our design by using DOE and optimize the system performance according to the current configurations.

5.1 Optimize

Based on our theoretical model, we will conduct experiments following the order of the optimum facility layout and cost-effective equipment. As a major part of statistical analysis in Six Sigma methodology, we use Design of Experiment (DOE) as a possible improvement through process. For experiment 1, two independent variables (factors) and one dependent variable were used. The two independent variables include the tag replacement and the number of antennas. The dependent variable was the readability of the tags. The observed results of the experiment had an effect on the independent variable.

$$\mathrm{Re}\,adability = f(TP, AN) \tag{2}$$

TP: Tag placement
AN: Antennae Number

For experiment 2, we needed to regulate some of the variables until the results achieved full-read efficiency. This was done to satisfy the customer's requirement of 100% readability. The model of the experiment is:

$$\mathrm{Re}\,adability = f(AP, PP) \tag{3}$$

AP: antenna's position
PP: portal's positiona. 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. Experiment 1 was a two factor, two-level experiment. A total four trials were needed (i.e., $2^2 = 4$) to address all assigned combinations of the factor levels. In this experiment, levels are quantitative. Experiment 1 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 antennas were only used in one trial within the experiment.

For experiment 2, In order to test the readability of the 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 at two different heights (3 ft, 5 ft).
b. *The distance between each side of the portal:* 5 ft; 7 ft.

The standardized time scale was 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 2.

Table 1: Experiment Factors and Level

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

5.2 Verify

We have several ways to optimize the current layout design to improve the reading accuracy: For experiment 1, the placement of the tags on the pallet or item can be classified by in three ways: top, front, and side. The performance of each classification is different. To sum up, the best position of a tag on an item is on the side, (face to the antennae) because of the polarization and magnetic field (Polarization test report). The performance of the antennae and tags are totally different with these three classifications. The third classification, tag on the side, had the best performance. Compared with the other two classifications results, the readability of the tags, when they are on the side, can be up to 60% of full satisfaction. We also determined that a significant change occurred when the number of antennas was varied. We ran the experiment using 1 antenna with 10 items first. The readability of the tags was only 80%, compared with almost 100% when using 2 antennas. The read rate graph is showed in figure 2.

For experiment 2, the influence of the variable *Tag Placement* in the model is the same as in experiment 1. 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. *Portal dock's position* is an important factor that has an influence on reading accuracy, especially in experiment 2. The hypothesis was that the shorter the distance is, the better read efficiency would be. The requirements are the distance between each side of the portal must be 5 feet with the antenna on the same horizontal line and the distance between readers must be 7 feet with different heights.

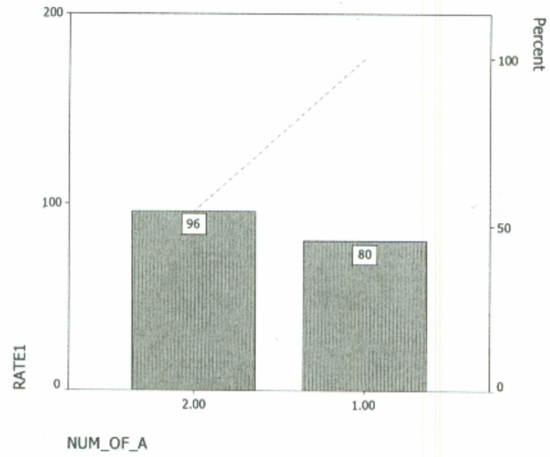

Figure 3: Read Rate graph

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.

6. Conclusion

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

- The full-read range is 3-5 feet when antennas are fixed at the same horizontal line on each side of portal.
- The full-read range is 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.

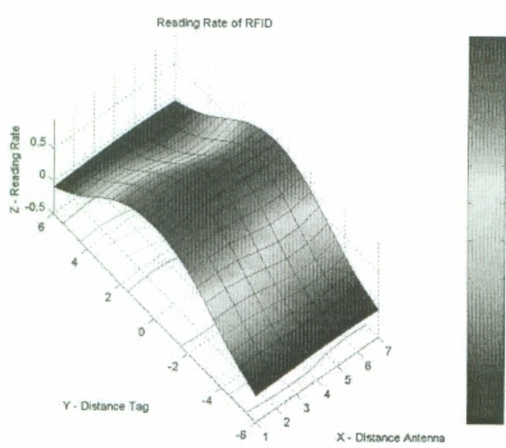

Figure 4: 3-D Graph for effective reading rate

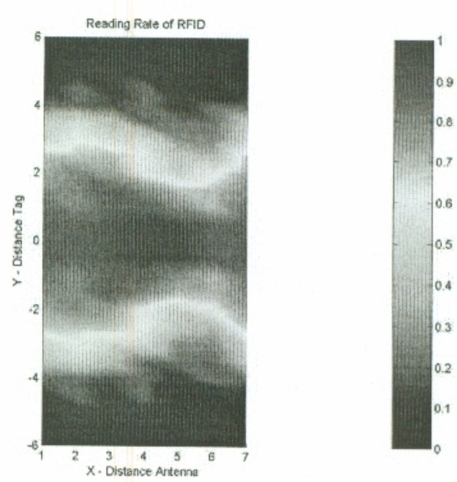

Figure 5: 2-D Graph for effective reading scale

The effective reading distance was analyzed in MATLAB (6.0, Release 13), for visualizing the results and provided documents for future research. The data points on the graph showed 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 the read rate which is based on our experiment specification of 10 tags per pallet. The reading rate can be reached at 90% or better under this specification.

Using Six Sigma methodology increases the efficiency of test procedures and validates the influence of real warehouse case layout scenarios. The total conditions for receiving more than 90% readability include several considerations as below: a. The placement of tags. b. The distance between antennas (If there is more than one antenna). c. Appropriate stop-by time when going through the portal (At least 3 sec). d. The change of the position of the antenna when other limitations are fixed.

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