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An Experimental Approach for Developing RFID Ready Receiving and Shipping

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Radio Frequency Identification (RFID) and related technologies have been touted to allow exponential improvements in supply chain logistics and management. However, many industrial users have indicated that these technologies have not provided the anticipated benefits some are skeptical of its reliability. The two complimentary strategies required to address the RFID reliability are: to improve the reliability of RFID technology and to design the supply chain infrastructure that enables RFID. The focus of this paper is to design supply chain infrastructure to enable RFID by developing guidelines for "RFID Ready Facilities" based on a set of experiments conducted at RFID supply chain laboratory. These guidelines were developed by using Design of Experiments (DOE) to determine the operational and facility factors that impact RFID infrastructure. The factors considered in the experiments are package orientation (vertical, horizontal, side), tag placement (front, side), package placement (straight, facing reader, not facing reader) and reader location (front, corner). Based on the DOE results, general guidelines were developed for RFID packaging.

Keywords

RFID Design of Experiments, Industrial Engineering, Taguchi Methods, Packaging

1. Introduction

Packaging is one of the most critical components of receiving and shipping functions that determine the overall quality, cost and time line parameters of an efficient and effective supply chain. In essence, receiving and shipping are the linkage points of a supply chain. The key in linkage points is how we receive and manage the inventory and how we ship and manage the packaging. The packaging department is the end node between the products leaving the facility and reaching at customer's end. This function is critical because a reliable packaging enables the company to: forecast the supply and demand of products, monitor the movement of products in the market, help the R & D of company to study the changing product trends in the market, modify and determine new product cost allocations and determine the type of shipping logistics. A current market study reveals that barcode is the primary technology utilized to facilitate the packaging process, which is considered as outdated technology, because barcode is not fully automated and is time consuming for large scale scanning operations [1-3].

RFID technology on the other hand is a fully automated identification technology and can be a successful replacement for barcode technology [1]. RFID has greater capabilities to read through obstacles, work in hostile conditions and a real time-all time data capturing technology when customized according to the scenarios of impending environment. However, it cannot deliver very reliable outputs if used in a universal manner. The focus of this paper is to produce operational guidelines for RFID packaging by using Taguchi method (TM).

2. RFID Design of Experiments

DOE is chosen as core methodology to conduct experiments that produce the guidelines for RFID packaging.

Table 1 Selected DOE Factors

	Factors	Sensitivity	Levels		
			1	2	3
A	Package Orientation	2	vertical	horizontal	side
B	Package Material	1	Metallic	Non-Metallic	x
C	Distance between boxes	1	Joined	Separated	x
D	Reader Location	2	Front	Corner	x
E	Vibration Level	0	1	2	3
F	Conveyor Speed	2	Low	High	x
G	Package Condition	1	Good	Bad	x
H	Package Placement	2	straight	angle facing reader	angle not facing reader
I	Conveyor Operation	0	Intermitted	Continuous	x
J	Temperature Condition	0	Cold	Room Temp	Hot
K	Tag placement	2	on vertical side	on horizontal side	x

The factors considered in this DOE were chosen after a literature review and a subsequent brainstorming session of University of Tennessee (UT) RFID team which consists of RFID lab technicians, industrial, mechanical and electrical engineers. As a result, eleven potential factors were identified for RFID packaging as shown in Table 1 [1-5]. These potential factors were assigned a sensitivity number ranging from 0 to 2, where: 0 is for uncontrollable variable, 1 for partial-controllability variable and 2 for controllable variable. After initial assessment, five factors (package orientation, reader location, conveyor speed, package placement and tag placement), that are highlighted in Table 1 above were considered for further analysis.

The following factors were kept constant throughout the experiment to minimize their impact on outputs.

- RFID Readers - The Alien 9500 RFID readers were used to read the RFID chips on packages. A single reader unit was used in experiments and the same unit used at both reader locations (front, corner).
- Reader Power – The power of the reader was set to 9db with reading frequency at 2.5 seconds. The power of the reader means the reading intensity of RFID reader and reading frequency depicts how frequent the reader reads the next/same tag.
- Conveyor Operation – The experiments were conducted on a 12 feet by 6 feet conveyor loop and 143.30 lbs (65kg) weight capacity, running in counter-clockwise direction. Two levels of speed were fixed for conveyor operation: low level at 50 ms; high level at 100 m/s.
- Middleware Software - BOWH RFID middleware software was used to capture the RFID information in conjunction with Alien RFID software. This middleware was used to capture and store RFID information, which was later used for statistical analysis.
- RFID Tags – EPC Global Class 1Gen 2 compliant Alien ALN-9640 - "Squiggle®" Inlay tags were used in all the experiments. These tags work between 860-960MHZ with antenna dimensions: 95mm * 8.2 mm. These tags are powered by the industry leading Higgs – 3 IC boasting a total of 800 bits of memory and are top ranking general purpose Squiggle inlay with exceptional performance in multiple applications, including package tagging and pallet tagging, etc [6]
- Package Boxes – The boxes used in experiments are United States Postal Service priority mail small flat rate boxes (8-5/8" x 5-3/8" x 1-5/8"). Twenty units of boxes were used in the experiments.

Table 2 shows the five selected factors used in the DOE: (1.) Package Orientation (PO). (2.) Reader Location (RL). (3.) Conveyor Speed (CS). (4.) Package Placement (PP) and (5.) Tag Placement (TP).

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Table 2 Factors Selected for DOE

	Factors	Levels		
		1	2	3
A	Package Orientation	vertical	horizontal	side
B	Reader Location	Front	Corner	x
C	Conveyor Speed	Low	High	x
D	Package Placement	straight	angle facing reader	angle not facing reader
E	Tag placement	on vertical side	on horizontal side	x

3. Taguchi Design of Experiment

Taguchi Method (TM) has been extensively used in diverse areas like biotechnology, marketing, advertising industries, corporations and universities. These methods are deliberate cost effective methods to improve the performance of a product by reducing its variability in customer's usage conditions [7-8]. TMs were used over classical methods in the methodology because:

- These methods have less hypothesis testing and are more robust with visual results.
- Orthogonal arrays are used to assure the reproduction of effects of parameters [9].
- These methods are more oriented toward engineering applications rather than advanced statistical techniques [10].

Mixed level TM (5 factors) with orthogonal array L_{36} (2**3 3**2) is used in the methodology. This means that resolution I\/ design with generator I = ABCDE and at least 36 runs will be able to estimate the effect of each factor. In this case, the interactions between the main factors could be considered and the design is randomized. The outcome is based on two response parameters: Y_1 – Missed Read Rate (MRR); Y_2 – Multiple Read Rate (MuRR). MRR is defined as the number of units missed by RFID reader during one cycle. MuRR is defined as the number of units read more than one time by RFID reader during one cycle. The DOE data was collected based on the layout described in section 3. There are 4 setups (replicated twice) that showed maximum RFID reliability and these setups are highlighted in Table 3.

Table 3 Design of Experiments and Reliable Data

	Factors					Output	
Randomized Serial Number	**Reader Location (RL)**	**Conveyor Speed (CS)**	**Tag Placement (TP)**	**Package Orientation (PO)**	**Package Placement (PP)**	**Missed Read Rate**	**Multiple Read Rate**
7	Front	Low	Horizontal	Vertical	Straight	0	1
27	Corner	Low	Vertical	Side	Facing	0	0
36	Corner	High	Vertical	Side	Facing	0	0
29	Corner	High	Horizontal	Horizontal	Straight	0	0
30	Corner	High	Horizontal	Side	Facing	0	0
1	Front	Low	Vertical	Vertical	Straight	0	3
23	Corner	Low	Horizontal	Horizontal	NotFacing	5	0
19	Corner	Low	Horizontal	Vertical	Facing	0	0
18	Front	High	Horizontal	Side	Straight	0	1
6	Front	Low	Vertical	Side	NotFacing	0	10
34	Corner	High	Vertical	Vertical	NotFacing	0	0
16	Front	High	Horizontal	Vertical	Facing	1	0
14	Front	High	Horizontal	Horizontal	NotFacing	4	0
35	Corner	High	Vertical	Horizontal	Straight	5	0
4	Front	Low	Vertical	Vertical	Straight	0	0
13	Front	High	Horizontal	Vertical	Facing	0	1
2	Front	Low	Vertical	Horizontal	Facing	9	0
3	Front	Low	Vertical	Side	NotFacing	0	11
20	Corner	Low	Horizontal	Horizontal	NotFacing	7	0

17	Front	High	Horizontal	Horizontal	NotFacing	6	0
28	Corner	High	Horizontal	Vertical	NotFacing	0	0
12	Front	High	Vertical	Side	NotFacing	0	18
31	Corner	High	Vertical	Vertical	NotFacing	0	0
21	Corner	Low	Horizontal	Side	Straight	0	0
15	Front	High	Horizontal	Side	Straight	0	1
8	Front	Low	Horizontal	Horizontal	Facing	6	0
10	Front	High	Vertical	Vertical	Straight	0	0
22	Corner	Low	Horizontal	Vertical	Facing	0	0
25	Corner	Low	Vertical	Vertical	NotFacing	0	0
33	Corner	High	Vertical	Side	Facing	0	0
9	Front	Low	Horizontal	Side	NotFacing	0	0
26	Corner	Low	Vertical	Horizontal	Straight	4	0
24	Corner	Low	Horizontal	Side	Straight	0	0
11	Front	High	Vertical	Horizontal	Facing	10	0
32	Corner	High	Vertical	Horizontal	Straight	5	0
5	Front	Low	Vertical	Horizontal	Facing	10	0

4. Analysis of Experimental Data

The DOE data was analyzed using the MINITAB software. Taguchi proposes a summary statistic with an attempt to combine the information about the mean and variance, called the Signal-to-Noise ratio (S/N ratio). These S/N ratios are purportedly defined so that a maximum value of the ratio minimizes the variability transmitted from noise variables [11]. The outcome is based on various types of S/N ratios, to measure the variability around target performance. Therefore higher S/N ratios indicate better target performance. Subsequently, the means plot signifies how close the mean is to the target value. Therefore, lower means plot indicates better target performance [12-14]. The main effects plots of MRR and MuRR are represented in Figure 1 and Figure 2.

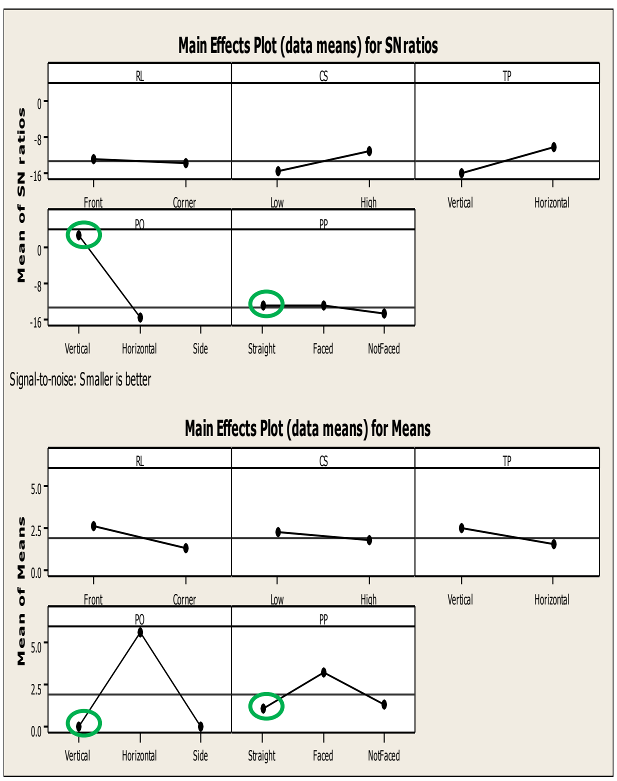

Figure 1 Multiple Read Rate (MuR) Main Effects Plot

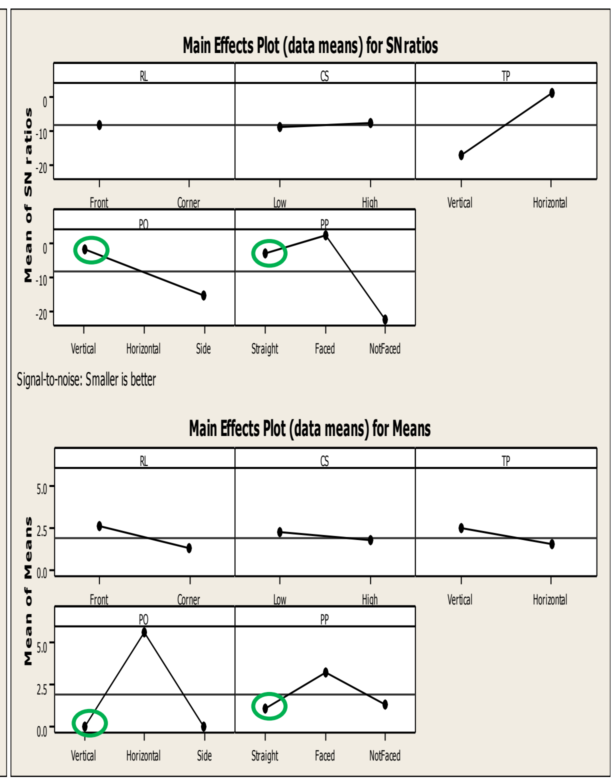

Figure 2 Missed Read Rate (MR) Main Effects Plot

The following observations are made from these two analyses:

- The main significant effects for MuRR are: Package Orientation (PO) and Package Placement (PP)
- The main significant effects for MRR are: Package Orientation (PO) and Package Placement (PP)
- The reader location (RL) does not have significant effect on RFID packaging; this indicates that readers may be placed on either of the two positions: front or corner. Therefore it is considered as noise factor as well as conveyor speed (CS) and tag placement (TP).
- Reader location (RL) and conveyor speed (CS) do not have significant effect on RFID packaging, therefore they are considered as noise factors, including tag placement (TP).

Table 4 Significant Output

	Noise Factors			Significant Factors	
	Reader Location (RL)	Conveyor Speed (CS)	Tag Placement (TP)	Package Orientation (PO)	Package Placement (PP)
MRR (Y_1) S/N Ratio	5	3	2	1	4
	Corner	High	Horizontal	Vertical	Straight
MRR(Y_1) Mean	3	5	4	1	2
MuRR (Y_2) S/N Ratio	5	4	2	3	1
	Corner	High	Horizontal	Vertical	Straight
MuRR (Y_2) Mean	3	5	4	1	2

The summary of the analysis is presented in Table 4. Each factor was allocated a rank ranging from 1 to 5, where, 1 is most significant factor and 5 is least significant factor. The responses with minimum Y_1 (MRR) and Y_2 (MR) yield the best results. Therefore, two factors: PO (vertical) and PP (straight) have the most significant effect in determining RFID packaging. However, in order to choose the optimum configuration of RFID packaging, it is necessary to consider significant levels of noise factors. The significant levels of noise factors are RL (corner), CS (high) and TP (horizontal).

Hence, based on Taguchi analysis, the best result is given by following factor level combination, shown in Table 5: -

Table 5 Best Factor Level Combination

Factors	Levels
Reader Location	Corner of lab room
Conveyor Speed	High (100m/s)
Tag Placement	Horizontal Side of package
Package Orientation	Placed vertically on the conveyor
Package Placement	Placed straight facing the reader

5. Validation and Conclusion

This research presented a TM based DOE approach to develop the guidelines for an “RFID Ready” receiving and shipping infrastructure. The development of these guidelines requires a validation of the results. Therefore, a new DOE was designed to validate the results. The new DOE, shown in Table 5 is planned by keeping the significant factor levels constant and varying the noise factor levels.

Table 5 Validation of Results with New Design of Experiments

	Varied Factors			Constant Factors	
S.No	**RL**	**CS**	**TP**	**PO**	**PP**
1	Front	Low	Horizontal	Vertical	Straight
2	Corner	Low	Vertical	Vertical	Straight
3	Front	High	Vertical	Vertical	Straight
4	Corner	High	Horizontal	Vertical	Straight

The half-fractional factorial design with resolution III was selected to perform validation experiments. The results of new DOE indicate no failures in package tracking. This means that all the packages were tracked accurately in new setup configurations.

The following general guidelines for RFID ready infrastructure are presented in Table 6 below: -

Table 6 General Guidelines for RFID Packaging

	Setup Factor	**Experimental Result**	**Guidelines**
1.	RFID Reader	1. The RFID reader when placed at corner position provides better tracking results than other positions. This is mainly due to ample visibility of the products to the reader at corner position. Therefore, the products remain in the reader range for a longer period of time. 2. The most suitable operating configuration for RFID reader is 9db @ 2.5 secs.	1. There is an extensive range of RFID readers available for industrial use. Therefore, the reader selection should be based on the type of environment, reader frequency and the sample size of the products. 2. The initial trials tell us what configuration best matches with reader's operating conditions. It has been observed that RFID readers at medium power and high frequency deliver most desirable results for the products that are close in read range. But if the distance between the products and reader is too far, then RFID readers at high power and low frequency deliver better results.
2.	Conveyor Operation	1. The two levels of conveyor speed were considered in DOE: low (50m/s) and high (100m/s). High speed of conveyor at 100m/s delivered good tracking results in the experiments.	1. The speed of conveyor should be set high when the RFID reader is at corner location because products are in the range of the reader for a longer time period. Consequently, the speed of conveyor should be low when the RFID reader is at front position because it will facilitate the products to be in read range for long time period.
3.	Package Orientation	1. The package when placed vertically on the conveyor loop provides better tracking results. The vertical position of the package brings horizontal side of the package	1. The orientation of package should be selected according to the location of RFID reader and should be kept constant unless there is any change in reader location.

		upfront RFID reader and therefore, provides a good platform where RFID tags are visible.	2. The vertical position should be selected if the geometry of the package is cubic. Package orientation can change for different geometric shapes.
4.	Package placement	1. The corner location of RFID reader receives maximum exposure when the package is placed straight resting on the vertical side.	1. Package placement was found to have significant effect on RFID packaging. The range of the reader is an important factor that determines the location of the package on conveyor loop.
5.	Tag Placement	1. The best results were observed in the experiments when the tags were placed on the horizontal side of the package. This is because the horizontal position of package is upfront RFID reader and the tags are placed in the center of the horizontal position so that there is no interference between RFID tags when the products reach the corner of conveyor loop.	1. The tag placement is based on the package material, number of products to be tagged, RFID reader configuration and conveyor speed.

The DOE conducted on RFID packages investigates a lot of issues related to RFID packaging and which consequently resulted into general guidelines for RFID packaging, represented in Table 6. This work was confined to RFID packages only. The scope of further research is to investigate the RFID packaging issues related to boxes and pallets. The structure of further research is as follows: (1) Packages are tagged with RFID chips and packed in RFID tagged boxes. The objective is to read the RFID tag on the box. (2) The RFID tagged boxes are packed into RFID tagged pallets. The objective is to read the RFID tag on pallet. (3) Finally, to develop the general RFID packaging guidelines for an “RFID Ready Facility” using the data and conclusions of package, box and pallet.

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