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An experimental approach for developing radio frequency identification (RFID) ready packaging

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ABSTRACT

Radio Frequency Identification (RFID) and related technologies have been touted to allow exponential improvements in supply chain logistics and management. The accurate location of packages, cargo containers, and truck trailers saves fuel, pollution and over-production. However, many industrial users have indicated that these technologies have not provided the anticipated benefits. Two complementary strategies required to address RFID reliability are: improving the reliability of RFID technology and/or designing packaging related infrastructure that enables RFID. This paper focuses on designing RFID Ready facilities (RRF), and an RFID-enabling packaging infrastructure that helps avoid unnecessary transportation, thereby reducing pollution. The design guidelines developed were based on a set of experiments conducted in the RFID Supply Chain Laboratory at the University of Tennessee (UT) using Design of Experiments (DOE), to help determine the operational and facility factors that impact RFID reliability. Three different packaging strategies were tested on packages, boxes, and their various combinations. The key factors considered in the experiments were the following: Package Orientation (PO), Tag Placement (TP), Package Placement (PP), Reader Location (RL), Box Orientation (BO), Tag Placement on Box (TPB) and Tag Placement on Package (TPP).

1. Introduction

RFID system consists of a tag made up of a microchip with an antenna, and a reader with an antenna. The reader sends out electromagnetic waves. The tag antenna is tuned to receive these waves. A passive RFID tag draws power from the electromagnetic field created by the reader and uses it to power the microchip. The chip then modulates the waves that the tag sends back to the reader and the reader converts the new waves into digital data.

The critical components of the shipping and receiving functions are the packaging characteristics. These characteristics determine the overall quality, cost, and timeline parameters of efficient and effective supply chains. In essence, shipping and receiving are the linkage points of a supply chain and require a reliable process for managing packed products to forecast the supply and demand of products, monitor the movement of products in the market, help R&D to study changing product trends and determine new product cost allocations. The large-scale capability of RFID to track products has been recognized by Wal-Mart (2008) and the Department of Defense (2005), two organizations that adopted this technology at an early stage. These organizations have found that this technology tends to introduce a variety of errors when tracking products (Hardgrave et al., 2005).

RFID technology is a fully automated identification technology with great capabilities to read through obstacles, to work in hostile conditions, and to capture data in real time. However, Wolk et al. (2005) and Feng (2001) suggested that it cannot deliver very reliable outputs if used in a universal manner, and therefore the infrastructure should be designed based on the impending environment. The focus of this paper is to develop operational guidelines for designing RFID into the infrastructure via the use of Design of Experiments (DOE) to conduct physical experiments within the RFID Supply Chain Laboratory at UT.

2. Literature review

Packaging plays a very crucial role in the supply chain as it affects the shipping and receiving functions in terms of overall

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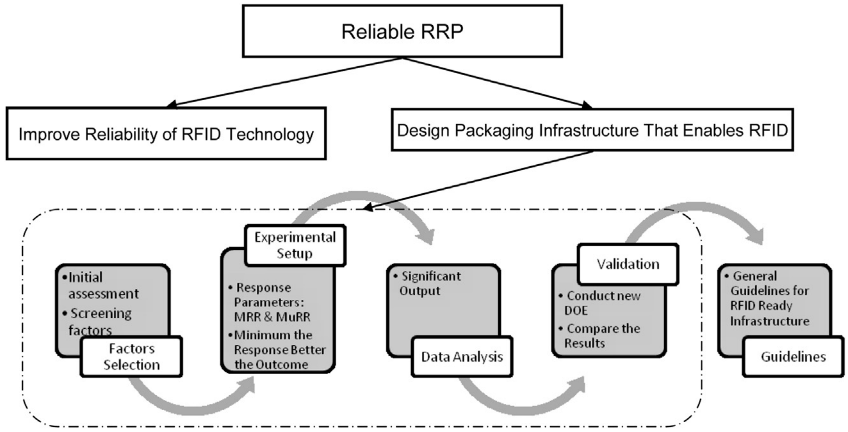


Fig. 1. Framework for developing guidelines for RFID ready packaging.

cost as well as its ability to successfully accomplish the four main objectives of a package: containment, protection, utility and communication (Ryan, 2002). RFID-driven supply chain efficiencies have the potential to reduce environmental damage by 5.4% (Moran, 2007). Another significant factor that impacts the supply chain is packaging logistics, which plays an important role in determining the time required for completing packaging operations and eventually affects the product lead time and customer delivery (Twede and Parsons, 2009; Lockamy, 1995). Gaukler (2011) analyzes the benefits of item-level RFID implementation and derives some insights into the threshold cost, at which RFID adoption would become profitable. There are privacy issues with RFID technology (Ohkubo et al., 2005; Roberts, 2006), and Ohkubo et al. proposed a protocol such that an adversary cannot track the tag. Lee and Özer (2007) presented a compilation of analytical models addressing the consequences of RFID-enhanced visibility. Saghir and Jönson (2001) and Saghir (2004) assessed the need for introducing new technology for improving the visibility and sharing information that impacts the packaging infrastructure.

Fig. 2. UT RFID laboratory and equipment.

RFID is an innovative technology that assists organizations to design, and protect product information into packaging. This information, including inventory, shipments and locations can increase confidence on the part of suppliers, manufacturers and retailers to initiate reductions in inventory and safety stocks (Intermec, 2003). Tazelaar (2007) finds that reliability of RFID technology remains a barrier to working with RFID.

The literature review shows evidence of some studies in which experiments were conducted to understand the impact of different factors and product selections on RFID transponder performance. In one of them, factors such as conveyor speed, packaging materials, and tags were tested by Falls (2006) to determine their impact on RFID transponder performance. In another study, factors such as tag orientations and different products were tested by Tazelaar (2007) to determine the effect on tag readability. The results of these studies showed the impact of the selected factors on the performance of RFID technology, but lacked the RFID Ready Packaging (RRP) operational guidelines for use by facilities to evaluate and integrate the technology into their packaging systems. The research presented in this paper also provides a set of guidelines that can be adopted by users to enable a reliable RRP. Through the use of these guidelines, the technological as well as infrastructural factors that impact RRP can be determined according to users' business scenarios.

3. Framework

Like any other technology, RFID has some limitations which reduce industry confidence in the technology. For example, some products may not be detected or may be mislabeled by the RFID technology, placing the customer in jeopardy of not knowing the product type, location, or quantity of a product within the supply chain. On the other hand, if a product is read multiple times, a customer may end up paying for phantom units. Fig. 1 presents a framework for integrating RFID technology into the packaging infrastructure. Specifically, the objective is to develop guidelines for RRP within a shipping/receiving function with a focus on packaging.

The research efforts conducted in this paper focus primarily on the following five phases:

Phase 1: An initial assessment was conducted to identify the infrastructural factors that could impact the reliability of the RFID application.

Phase 2: The initial sets of factors were further screened to identify factors that could impact the Missed Read Rate (MRR) and the Multiple Read Rate (MuRR) in a DOE. The MRR is defined as the number of units missed by an RFID reader during one conveyor loop cycle. The MuRR is defined as the number of units read more than one time by an RFID reader during conveyor loop cycle.

Phase 3: An experiment was conducted at the UT IIE RFID lab. This lab consists of a conveyor loop with two internal conveyor loops, each with the ability to move packages with different speed configurations. The packages, boxes and pallets were moved on these conveyors and RFID readers were utilized to identify the MRR and MuRR.

Phase 4: Data from Phase 3 were analyzed to identify the impact of settings on the MRR and MuRR.

Phase 5: Guidelines for the RFID Ready Facility were developed based on an analysis of Phase 4 and a validation of the results.

4. Experimental design

DOE was chosen as the core methodology for conducting experiments and to develop the guidelines for RRP infrastructure. The experimental testing took place at the UT RFID Laboratory in the Industrial and Systems Engineering Department at the University of Tennessee, Knoxville. Fig. 2 shows an experimental setup at the UT RFID laboratory and equipment used in this testing.

The following factors were kept constant throughout the experiments to minimize their impact on output.

- 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 was used at both reader locations (front, corner).
- Reader Power: The power of the reader was set to 9 db with reading frequency at 2.5 s. The power of the reader is the reading intensity of the RFID reader and the reading frequency depicts how frequently the reader reads the next/same tag.
- Conveyor Operation: The experiments were conducted on a 12 feet by 6 feet conveyor loop of 143.30 lbs (65 kg) weight capacity, running in a counter-clockwise direction. Two levels of speed were fixed for conveyor operation (low level at 50 m/s; high level at 100 m/s).
- Middleware Software: BOWH RFID middleware software was used to capture the RFID information in conjunction with the Alien RFID software. This middleware was used to capture and store the RFID information, which was later used for statistical analysis.

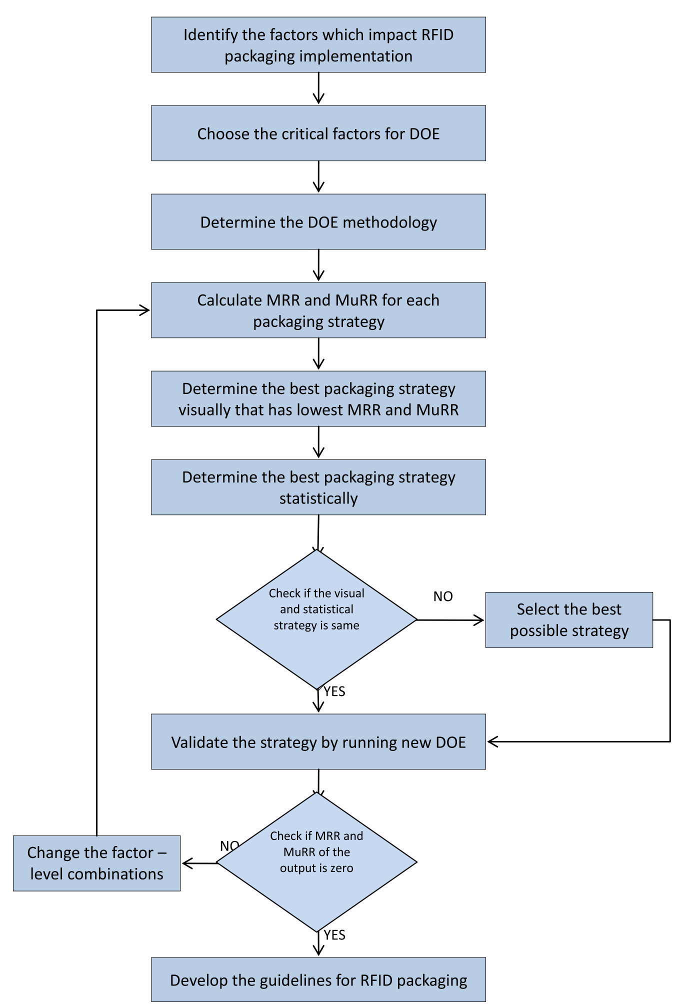


Fig. 3. Steps for developing guidelines for RFID ready packaging.

- RFID Tags: EPC Global Class 1 Gen 2 compliant Alien ALN-9640 – “Squiggle®” Inlay tags were used in all the experiments. These tags work between 860 and 960 MHz with antenna dimensions 95 mm * 8.2 mm and are provided by Alien Technology (2012).

5. Methodology

Fig. 3 represents the methodology for developing the guidelines for RRP. Initially, the critical factors were identified that impact RRP. These factors were then used to determine the DOE methodology to calculate the MRR and MuRR for each packaging strategy. The physical results and experimental results were then compared to determine the best packaging strategy. Lastly, the best results were validated, and the guidelines for RRP were developed.

5.1. Step 1 – factor selection

The factors critical to RRP are identified by following a two-step procedure. In the first step, an initial assessment is conducted in which all factors that impact RRP are identified, subsequently followed by a screening for the factors. Critical factors are those that directly impact the RFID readability of the package. The potential factors identified in the initial assessment are ranked according to criticality, thus determining the sensitivity of each factor. A sensitivity number ranging from 0 to 2 is assigned, and factors having a sensitivity number 2 are considered as critical.

5.2. Step 2 – DOE

The DOE methodology is applied to three different scenarios. In the first scenario, the experiments are performed for United States Postal Service (USPS) priority mail small flat rate boxes ($8^{5/8''} \times 5^{3/8''} \times 1^{5/8''}$). Twenty packages were tested in this scenario; the details of the procedure are discussed in the following sections. In the second scenario, the small packages are packed inside USPS medium flat rate ($11'' \times 8^{1/2''} \times 5^{1/2''}$) boxes. Ten boxes were tested in this scenario with five packages inside each box. The third scenario tests the pallet tagging using USPS large flat rate boxes ($10'' \times 12'' \times 15''$). Ten pallets were tested in this scenario with six boxes in each pallet.

5.2.1. DOE for package testing

The RFID embedded packages were run on the conveyor loop at different speeds and passed in front of a fixed RFID reader. The results of the DOE were then used for statistical analysis. Consequently, an RFID packaging strategy in which all the packages are detected successfully was chosen for implementation. The following were the real world examples related to Scenario 1:

- Tropicana Pure Premium Juice Bottles – 12 Bottles
- Egg Cartons – 200 Cartons
- Marlboro King Size Cigarette Packets – 24 Packets
- Corona Extra Beer Bottles – 12 Bottles

5.2.2. DOE for box testing

The objective of this testing was to develop a packaging strategy for medium boxes in which only the RFID tag on the box was detected and the packages inside the box were not detected. In this scenario, the 6 tagged packages used in Scenario 1 were packed in a medium box embedded with an RFID tag. This scenario mimics the packaging in which multiple units of items are packed together and shipped as a consolidated unit. Therefore, in such cases, it is more convenient to detect a consolidated package rather than reading multiple items together, as latter results in a more complex and more time consuming system. A sample size of 10 boxes was selected for box testing. The following were the real world examples related to Scenario 2:

- 12 bottles of Tropicana Pure Premium juice in 1 box
- 200 cartons of eggs in 1 box
- 24 packets of Marlboro King Size cigarettes in 1 carton
- 12 packs of Corona Extra beer

5.2.3. DOE for pallet testing

The objective of this testing was to develop a packaging strategy for large boxes in which only the RFID tag on the pallet was detected and the boxes along with the packages inside the pallet were not detected. In this scenario, the 6 tagged boxes, with each box consisting of 6 tagged packages, were packed in a large box embedded with an RFID tag. This scenario mimics the mass packaging in which a large number of packages are packed in the boxes and these boxes are further combined on pallets to ship as a consolidated unit. The outside tag reading on the pallet prevents the accumulation of unnecessary (redundant) data and enables faster tracking. A sample size of 10 pallets was selected for pallet testing. The following are the real world examples related to Scenario 3:

- 30 boxes of Tropicana Pure Premium juice on 1 pallet (each box consisted of 12 bottles)
- 50 boxes of egg cartons on 1 pallet (each box consisted of 200 egg cartons)
- 500 cartons of Marlboro King Size cigarettes on 1 pallet (each carton consisted of 24 packets)
- 25 packs of Corona Extra beer on 1 pallet (each pack consisted of 12 bottles)

The DOE procedure for pallet testing has an additional factor testing step. In this step, the factors identified as potential are tested by running screening experiments. This step is necessary because the pallet testing scenario has a large number of potential factors due to the influence of the package and box factors.

5.3. Step 3 – data analysis

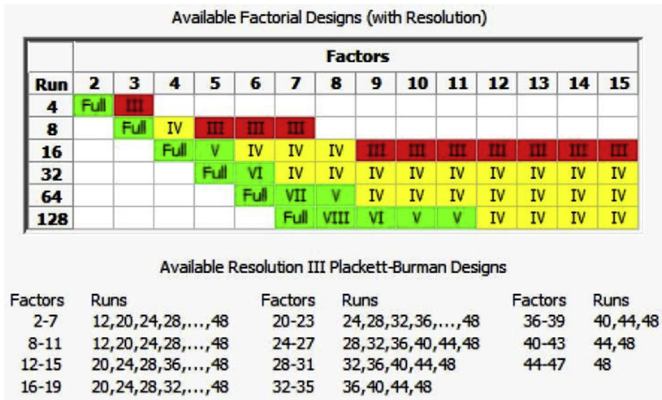
The data analysis is subdivided into two parts: visual analysis and statistical analysis. In the visual analysis, the packaging strategies with “zero” MRR and MuRR were identified by visually skimming the DOE results. In the statistical analysis, the MRR and MuRR are used to identify the reliable packaging strategies. Consequently, the strategies which are common in visual and statistical analysis were selected as the best strategies for implementation.

5.4. Step 4 – validation

In this step, the best RFID packaging strategy provided by data analysis was validated by running a new DOE. The noise factors were varied by keeping the significant factors constant. On the other hand, in some cases, all the factors were significant, i.e. there are no noise factors. In such cases, a new DOE was not required, and the selected strategy was run for several trials to validate the statistical results.

5.5. Step 5 – RFID operational guidelines

This step presents the operational and procedural guidelines for RFID ready shipping and receiving based on the results of the data analysis and other experimental conclusions. The purpose of these


Available Factorial Designs (with Resolution)

Run	Factors 2	3	4	5	6	7	8	9	10	11	12	13	14	15
4	Full	III												
8		Full	IV	III	III	III								
16			Full	V	IV	IV	IV	III	III	III	III	III	III	III
32				Full	VI	IV	IV	IV	IV	IV	IV	IV	IV	IV
64					Full	VII	V	IV	IV	IV	IV	IV	IV	IV
128						Full	VIII	VI	V	V	IV	IV	IV	IV

Available Resolution III Plackett-Burman Designs

Factors	Runs	Factors	Runs	Factors	Runs
2-7	12,20,24,28,...,48	20-23	24,28,32,36,...,48	36-39	40,44,48
8-11	12,20,24,28,...,48	24-27	28,32,36,40,44,48	40-43	44,48
12-15	20,24,28,36,...,48	28-31	32,36,40,44,48	44-47	48
16-19	20,24,28,32,...,48	32-35	36,40,44,48		

Fig. 4. Main DOE available on Minitab displaying classical factorial designs.

guidelines was to encourage RFID packaging in different sectors of industry by providing the following:

- The need for RFID packaging in the company
- The hardware and software requirements to implement RFID packaging
- The standard operating procedure for RFID packaging
- The guidelines to sustain RFID packaging

6. Data analysis and results

The DOE data were analyzed using Minitab statistical software (2010) for three scenarios: Package Testing, Box Testing and Pallet Testing. Fig. 4 presents the designs available when choosing a DOE on Minitab. When selecting a DOE using such a scheme, three important features will end up in an appropriate design: the number of factors that are of interest, the number of runs you can perform, and the desired resolution of the design. Classical Factorial Designs are two level full or fractional designs. Taguchi Designs as shown in Table 1 allow more than 2 level factors.

The design resolution describes the extent to which effects in a fractional factorial design are aliased with other effects. When you run a fractional factorial design, one or more of the effects are confounded, meaning they cannot be estimated separately from one another. In general, you want to use a fractional factorial design with the highest possible resolution for the amount of fractionation required. For example, it is usually better to choose a design where main effects are confounded with 3-way interactions (Resolution IV) over a design where main effects are confounded with 2-way interactions (Resolution III). Plackett–Burman and Taguchi Designs are considered Resolution III designs.

Table 1
Taguchi designs.

Designs	Number of levels 2	3	4	5
L4 (2**3)	2–3			
L8 (2**7)	2–7			
L9 (3**4)		2–4		
L12 (2**11)	2–11			
L16 (2**15)	2–15			
L16 (4**5)			2–5	
L25 (5**6)				2–6
L27 (3**13)		2–13		
L32 (2**31)	2–31			

Designs	Number of levels 2	3
L18 (2**1 3**7)	1	1–7
L36 (2**11 3**12)	1–11	2–12
L36 (2**3 3**13)	1–3	13
L54 (2**1 3**25)	1	3–25

Designs	Number of levels 2	4
L8 (2**4 4**1)	1–4	1
L16 (2**12 4**1)	2–12	1
L16 (2**9 4**2)	1–9	2
L16 (2**6 4**3)	1–6	3
L16 (2**3 4**4)	1–3	4
L32 (2**1 4**9)	1	2–9

Design	Number of levels 2	8
L16 (2**8 8**1)	1–8	1

Design	Number of levels 3 level	8 level
L18 (3**6 6**1)	1–6	1

6.1. DOE for package testing

Test runs are conducted on the packages primarily to identify potential factors and to determine the package testing sample size. The test results indicated that the sample size of 20 units was appropriate to measure the output of the MRR and MuRR on packages. Eleven potential factors were identified with their levels of interest as shown in Table 2. The vertical columns of the table represent the factors impacting the RFID package testing, and each horizontal row represents a combination of factor levels.

Based on the controllability, 5 significant from the list of 11 potential factors were selected to conduct the DOE for package testing, as highlighted in Table 2. A mixed level (5 factors) with an orthogonal array L_{36} (2**3 3**2) is used in the methodology for package testing. This means that a resolution IV design and at least 36 runs are sufficient to estimate the effect of each factor. In this case, the interactions between the main factors can be considered, and the design is randomized. 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) (2008). Fig. 5 represents the main effect plots of the MuRR and MRR for package testing. In this figure, the main effect plots of the S/N ratio are combined with the mean plots for the ease of comparing the levels of factors. The factor–level combination with a high S/N ratio and a low mean was selected as the best RFID packaging strategy based on the MuRR dataset.

Table 2
Potential factors for package testing.

	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	Vertical side	Horizontal side	X

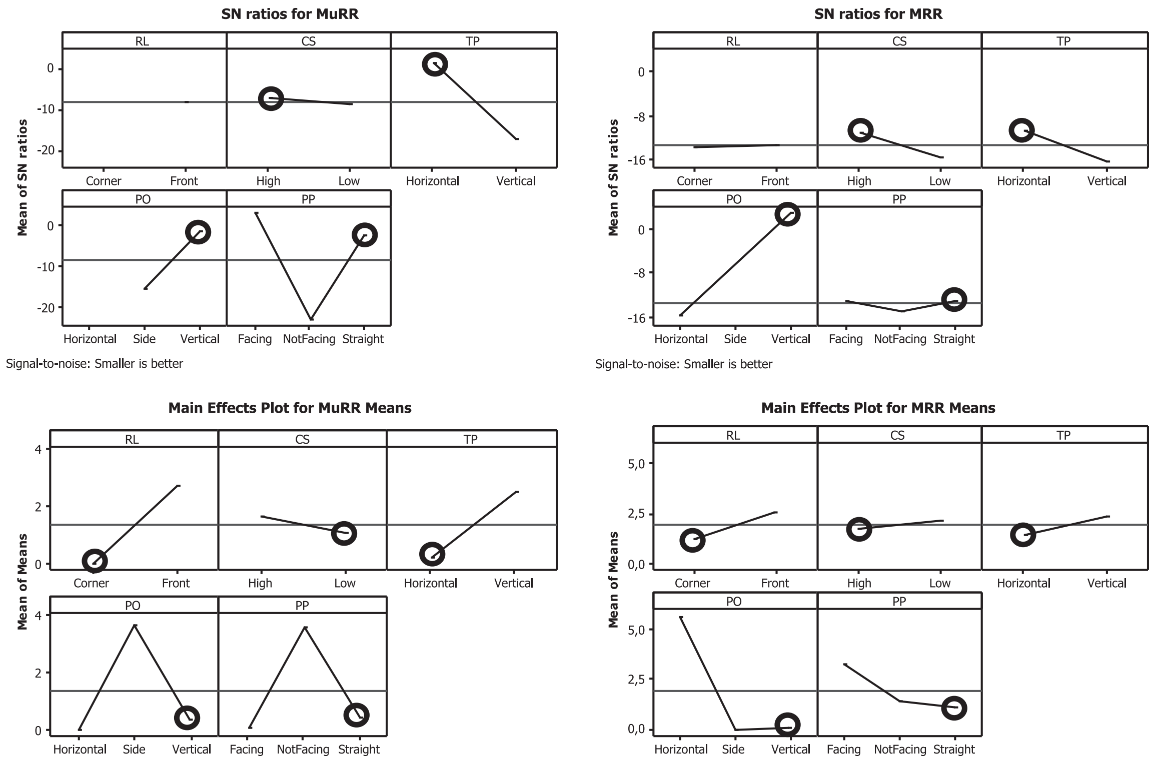


Fig. 5. Main effects plot and signal to noise ratio for MuRR and MRR for package testing.

Table 3 shows the best factor–level combinations for package testing based on the Taguchi analysis (Tsui, 1996; Dura and Isac, 2009). The configuration shown in this table illustrates the settings of the experimental factors for package testing and how these factors should be handled to get the maximum RFID reliability.

6.2. DOE for box testing

In this scenario, 13 potential factors were identified with their levels of interest that have direct or indirect influences on RFID box packaging, as shown in Table 4. In addition to the box factors, the package factors were also considered in this scenario (because the packages inside the box were also embedded with RFID tags, the potential for direct or indirect impact on the RFID box packaging).

The test runs indicated little difference in the read rate with the change in the reader location from front to corner, or vice-a-versa. Therefore, to simplify the experiments, the reader location was fixed at the front. The reader power was fixed at 6 db and kept constant throughout the box testing. Similarly, the conveyor speed was fixed at 100 m/s and kept constant. Four significant of 13 potential factors were selected to conduct DOE on boxes, as highlighted in Table 4. As the number of factors in a two level factorial design increases, the number of runs for a single replicate of the 2^k design becomes very large. For example, a single replicate of an eight factor, two level experiment would require 256 runs. Therefore, fractional factorial designs are used in this case to draw out valuable conclusions from fewer runs. This design obtains information about main effects and lower order interactions with fewer experiment runs. The 2^{4-1}_{IV} factorial design is used in the methodology for box testing, signifying a resolution IV design and at least 8 runs to estimate the effect of each factor. Since the design is randomized and replicated 2 times, a minimum of 16 runs will estimate the effect of each factor in this case. In the resolution IV designs, no main effects are aliased with any other main effects or two factor interactions. However, some main effects are aliased with three factor interactions, and the two factor interactions are aliased with each other. As shown in Fig. 6, only two setups were required for maximum RFID reliability.

The following conclusions are illustrated in Fig. 6 for fractional factorial design box testing:

Table 3
Best factor level combination for package testing.

Factors	Levels
Reader location	Corner of lab room
Conveyor speed	High (100 m/s)
Tag placement	Horizontal side of package
Package orientation	Placed vertically on the conveyor
Package placement	Placed straight facing the reader

Table 4
Potential factors for box testing.

	Factors	Sensitivity	Levels		
			1	2	3
A	Package orientation	2	Vertical	Horizontal	x
B	Condition of box	1	Good	Bad	x
C	Box orientation	2	Straight	Angle	x
D	Distance b/w boxes	1	Joined	Separated	x
E	Package material	1	Metallic	Non-metallic	x
F	Vibration level	0	1	2	3
G	Conveyor operation	0	Intermitted	Continuous	x
H	Temp condition	0	Cold	Room Temp	Hot
I	Tag placement on box	2	Front	Side	x
J	Condition of package	1	Good	Bad	x
K	Distance b/w packages	1	Joined	Separated	x
L	Tag placement on package	2	Vertical side	Horizontal side	x
M	Box material	1	Metallic	Non-metallic	x

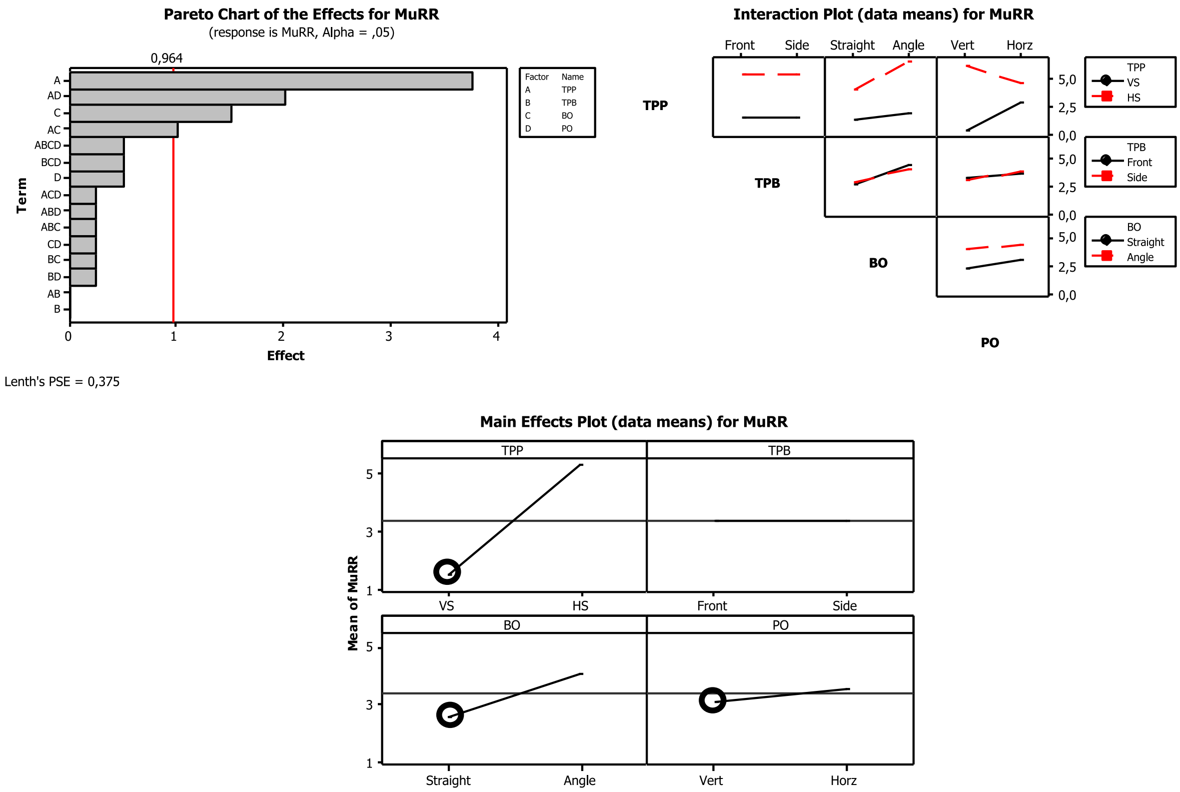


Fig. 6. Pareto, interactions plot & main effects for fractional factorial design for box testing.

- The factors *Tag Placement on Package*, *Tag Placement on Package/Package Orientation*, and *Box Orientation and Tag Placement on Package/Box Orientation* are most critical, impacting the reliability of box packaging.
- The factors *Tag Placement on Package/Tag Placement on Box* and *Tag Placement on Box* do not impact box packaging.
- *Tag Placement on Box/Box Orientation* has the most significant interaction. The MuRR changes drastically when the *Box Orientation* is changed from *straight* to *angle*, depending upon the level of *Tag Placement on Box*.
- *Tag Placement on Package/Tag Placement on Box* has the least significant interaction. The MuRR does not change with the change in the levels of either factor.

6.3. DOE for pallet testing

In this scenario, 23 potential factors were reduced to 6 using Plackett–Burman DOE screening experiments. Table 5 shows the experimental design for the pallet factors. Since, all the factors have 2 levels of interest, the 2_{IV}^{6-1} fractional factorial design is selected as the most suitable design to test the significance of these factors with a resolution IV design and at least 16 runs to estimate the effect of each factor in this case. The statistical significance of the run orders was estimated using the average MuRR for all runs. The MRR was observed to be zero for all run orders, indicating an overall reliability for the MRR.

For the MuRR, only run order showed maximum RFID reliability; therefore, it was selected as the most reliable RFID pallet packaging strategy in fractional factorial design.

The following conclusions are given by Fig. 7 for fractional factorial design for pallet testing:

- The factors *Reader Location/Pallet Orientation* and *Pallet Orientation* are most critical, impacting the reliability of pallet packaging.
- The factors *Tag Placement on Pallet*, *Tag Placement on Package–Tag Placement on Box*, and *Tag Placement on Package/Reader Location/Pallet Orientation* do not impact pallet packaging.
- *Reader Location/Pallet Orientation* has the most significant interaction. The MuRR changes drastically when the Pallet Orientation is changed from *straight* to *angle*, depending upon the level of the *Reader Location*.
- *Pallet Orientation/Tag Placement on Pallet* has the least important interaction. The MuRR does not change with a change in the levels of either factor.

Table 5
Pallet factors selected for pallet DOE using fractional factorial design.

	Factors	Levels	
		1	2
A	Tag placement on pallet	Front	Side
B	Tag placement on box	Front	Side
C	Pallet orientation	Straight	Angle
D	Package orientation	Vertical	Horizontal
E	Tag placement on package	Vertical side	Horizontal side
F	Reader location	Front	Corner

7. Conclusions

Companies willing to install this technology should first identify and understand the impact of potential factors related to RFID technology and the physical infrastructure required for its implementation. Further, a guided pilot study followed by test experiments can determine:

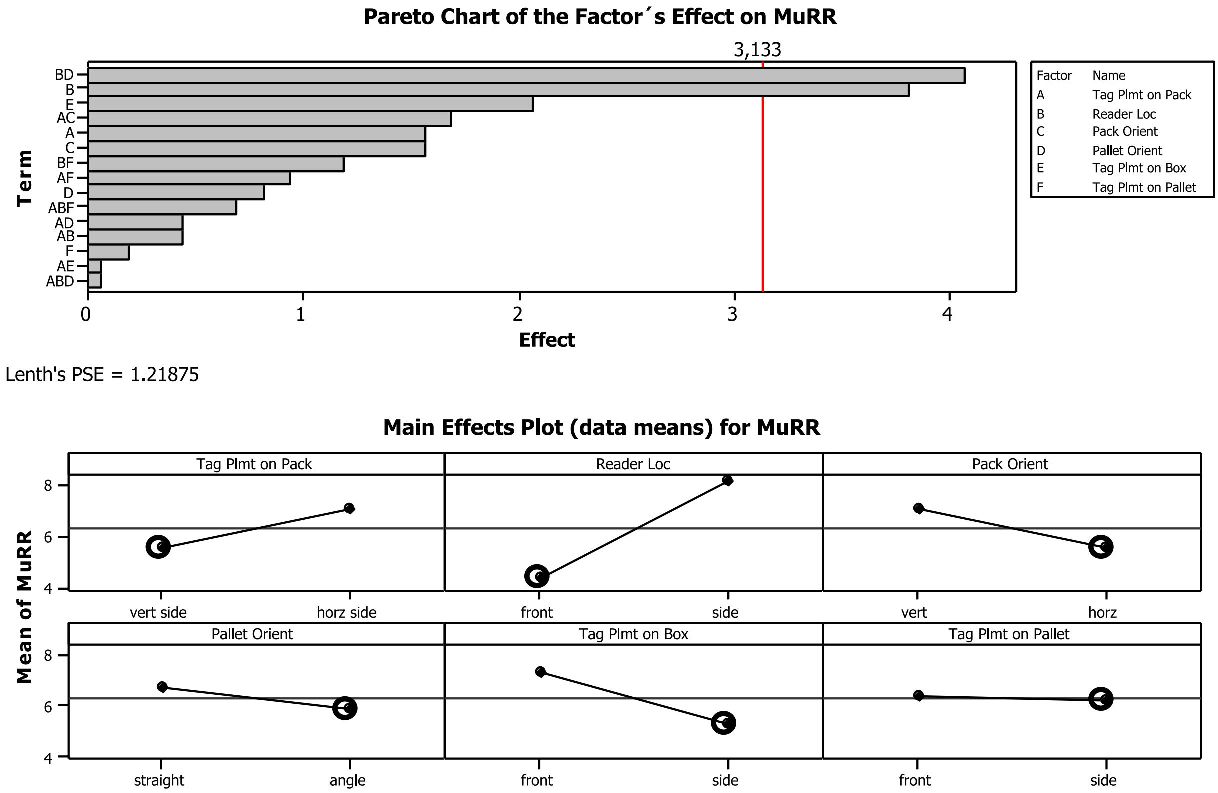


Fig. 7. Pareto and main effects plot for fractional factorial design for pallet testing.

Table 6
Functional guidelines for RFID package tagging.

	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. 2. The RFID reader sustained constant tracking with the following configuration:- • Reader Power – 9 db • Tracking Frequency – 2.5 s.	1. There is variety 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 indicate 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 (50 m/s) and high (100 m/s). High speed of conveyor at 100 m/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.
3.	Package orientation	1. The package, when placed vertically on the conveyor loop, provides better tracking results. The vertical position orients the packages horizontal side to the RFID reader and therefore, provides a good platform where RFID tags are visible.	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. 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 experimental results occurred when the tags were placed on the horizontal side of the package. This is because the horizontal position of package is 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.

Table 7
Functional guidelines for RFID box tagging.

	Setup factor	Experimental result	Guidelines
1.	Package orientation	1. The physical and statistical results indicate that vertical orientation of the package delivers maximum RFID reliability. This is because the RFID tags are blocked when the packages are placed facing vertical to each other.	1. The most stable method to block the tags when placed inside the box is to embed the RFID tag on the vertical surface of the package and to place the package vertically inside the box. This orientation of the package blocks the visibility of RFID tags and only the outer tag on the box is detected.
2.	Box orientation	1. The physical results indicate that both angle and straight orientations of the box deliver maximum RFID reliability depending upon the level of Tag Placement on Box. 2. The statistical results indicate that straight orientation of the box delivers maximum RFID reliability. 3. Box Orientation—Tag Placement on Box is the most significant interaction.	1. The level of Box Orientation depends on the Tag Placement on Box. 2. The best orientation of the box is angle when the tag is placed on the side of the box. This configuration enables RFID tag to be more visible to RFID reader. 3. The best orientation of the box is straight when the tag is placed on the front of the box. This configuration enables the position of RFID tag directly facing RFID reader therefore provides better stability.
3.	Tag placement on box	1. The physical and statistical results indicate that the Tag Placement on Box can be either on the front or side of the box. 2. The tag placed on the front of the box with straight orientation delivers the same RFID reliability when the tag is placed on the side of the box with angled orientation of the box. This is because in either configuration, the RFID tag is facing the RFID reader.	1. The tag can be placed either on the front or side of the box if the geometry of the box is cubic. 2. The Tag Placement on Box is significant with Box Orientation.
4.	Tag placement on package	1. The physical and statistical results indicate that the tag placement on vertical side of package delivers maximum RFID reliability. This is because the vertical side of the package is not visible to the RFID reader and therefore the tags embedded on the vertical side are not detected by the reader.	1. Tag Placement on the package should be such that the RFID tags are not visible to the RFID reader. 2. The vertical position of the package is the best to embed RFID tags if the number of packages inside the box is more than two.

- How much potential does the RFID technology hold for the scenario?
- Will RFID technology be a success or a failure for the scenario?
- If implementation is successful, what will the economic and other benefits of the RFID technology be?

In order to achieve these objectives, this paper proposes a methodology for RFID implementation in the area of packaging. The methodology used in this research illustrates the procedure to select potential factors and to classify these factors based on their sensitivity. Further, the DOE methodology explains how to plan the experiments by keeping non-significant factors constant and varying the potentially significant factors. The experimental approach followed for RFID packaging can be used for other scenarios as well, for example, manufacturing, warehousing, transportation, distribution, recycling etc. Statistical analysis is used to validate the physical results and to check the stability of the RFID settings provided by the experimental output. If a company is considering implementing RFID technology in packaging, this paper will help the company determine the best method of RFID implementation by providing the “Guidelines for RFID Ready Packaging”.

Table 6 represents the functional guidelines for RFID package tagging. The first column of the table represents the setup factors. The second column of the table represents the experimental results corresponding to the respective setup factor. The last column of the table represents the RFID operational guidelines for each factor.

Table 7 represents the functional guidelines for RFID box tagging. These guidelines indicate the best package and box configurations with the objective of blocking the RFID tags on the package and enabling the visibility of the RFID tag on the box.

Table 8 represents the functional guidelines for RFID pallet tagging. These guidelines indicate the best configurations of package, box and pallet with an objective of blocking the RFID tags on both the package and box so that the RFID tag on the pallet is visible.

7.1. Future work

The next step in this research would focus on combining physical experiments with computer aided simulations. The simulation models of complex physical scenarios can be created to understand how RFID technology behaves in such scenarios. If a study finds a lag between the physical experiments and computer simulations, this research can be enhanced to understand the bottleneck in the simulation model. One of the benefits of using computer simulations with physical experiments is that the potential factors impacting RFID infrastructure can be iterated and replicated millions of times in a manner not otherwise possible with physical iterations.

Another area for future research on this topic would focus on testing different types of materials in categories of packages, boxes, and pallets. In the present research, DOE was conducted using the same type of material of packages, boxes, and pallets. At the next level, heterogeneous materials could be used to fill the packages and materials of those packages. These physical scenarios could be combined with computer simulations to validate the reliability of the RFID infrastructure.

Lastly, based on the results of physical and simulation models, mathematical algorithms could be created along with IT

Table 8
Functional guidelines for RFID pallet tagging.

	Setup factor	Experimental result	Guidelines
1.	Tag placement on pallet	1. The physical and statistical results indicate that tag placement on the side of pallet delivers maximum RFID reliability. 2. The level of Tag Placement on Pallet depends on the level of Pallet Orientation. 3. The tag should be placed on the side and the orientation of the pallet should be at an angle facing RFID reader.	1. Tag Placement on the pallet should be such that the RFID tag face RFID reader. 2. It has been observed in the experiments that even if the RFID tag is placed on the side of the pallet, it will deliver maximum RFID reliability if the pallet is placed at an angle facing the reader.
2.	Tag placement on box	1. The physical and statistical results indicate that the tag placement on the side of the box delivers maximum RFID reliability. 2. The tag should be placed on the side of the box and the box should be placed vertically inside the pallet. This configuration blocks all the tags on the box.	1. Each box placed inside the pallet consists of multiple packages. Therefore, Tag Placement on Box is the most crucial factor to determine the stability of RFID readability. 2. The tag should be placed on the box in such a manner so that the tags on the packages remain hidden and the tag on the pallet is visible. 3. The best configuration is to align the RFID tag on the box with the tags on the packages and keep the same orientation of both the packages and box. These configurations will impact the tag visibility on the pallet without any interference with other tags.
3.	Pallet orientation	1. The physical and statistical results indicate that Pallet Orientation depends on the Reader Location. 2. The statistical results indicate that the angled orientation of the pallet delivers better RFID reliability provided the tags are placed on the side of the pallet with reader location upfront pallet.	1. It is very important to align Pallet Orientation with Reader Location and Tag Placement on Pallet. For example, if the tag is placed on the front of pallet with straight orientation of pallet but the reader location is on the side then there is a higher probability of not detecting the tag on pallet. Therefore, Tag Placement on Pallet, Pallet Orientation and Reader Location should be carefully aligned achieve maximum tag visibility on the pallet. 2. The pallet orientation should be such that the RFID tag on the pallet receives ample visibility in front of RFID reader.
4.	Package orientation	1. The physical and statistical results indicate that the horizontal package orientation delivers maximum RFID reliability. 2. Package Orientation depends on Tag Placement on Package.	1. The package orientation should be such that the RFID tags on the package are not visible to RFID reader. 2. The best strategy is to keep the package orientation vertical if the tags are placed on the horizontal side of package or vice-a-versa.
5.	Tag placement on package	1. The physical and statistical results indicate that the tag should be placed on the vertical side of the package.	1. The tags should be placed on the vertical side of the package and the packages should be placed horizontally inside the pallet. 2. Tag placement on package should be aligned with package orientation and box orientation.
6.	Reader location	1. The physical and statistical results indicate that the front reader location delivers maximum RFID reliability. This is because when the tags are placed on the side of the pallet and the orientation of the pallet is at an angle then the front position of reader provides ample visibility to the RFID tag on the pallet.	1. The reader location is one of the most significant factors to determine RFID reliability. This is because it is more complex to caliber RFID tag configurations of multiple tags rather than adjusting reader location. 2. The RFID tags on the packages and boxes should not be detected by the RFID reader other than the tag on the pallet. 3. The best configuration is to place the tag on the side of pallet and box and reader location to the front.

applications to automate the RFID infrastructure. These algorithms would be modified according to the needs of the scenario where RFID technology is to be implemented, thereby resulting in a standard operating procedure and sustainable RFID implementation.

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