Spring 2021

IE 6308 Design of Experiments

Project Report

Complete Factorial Design to study Impact of Tag and Medium on RSSI (Received Signal Strength Indicator)

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Dated: 05/10/2021

1. Introduction

Radio-frequency identification (RFID) uses electromagnetic fields to automatically identify, and track tags attached to objects. An RFID system consists of a tiny radio transponder, a radio receiver and transmitter. When triggered by an electromagnetic interrogation pulse from a nearby RFID reader device, the tag transmits digital data, usually an identifying inventory number, back to the reader. This number can be used to track inventory goods. Unlike a barcode, the tag does not need to be within the line of sight of the reader, so it may be embedded in the tracked object. RFID is one method of automatic identification and data capture (AIDC).

Main Components of RFID System

RFID tags: RFID tags are made from three pieces: a microchip (an integrated circuit which stores and processes information and modulates and demodulates radiofrequency (RF) signals), an antenna for receiving and transmitting the signal and a substrate.

RFID Reader: An Active Reader system has an active reader, which transmits interrogator signals and receives authentication replies from passive tags.

RSSI Value for RFID tags: In telecommunications, RSSI (received signal strength indicator) is a measurement (db) of the power present in a received radio signal. RSSI is invisible to user of a receiving device. It is a crucial factor in determining the performance of any RFID tag and reader system.

2. Problem statement

We are interested in evaluating performance of RFID tags by mounting it on three different surface/medium (Air, Metal and Cardboard). The primary reason being that even though RFID tags do not require line of sight to transmit and receive data, the surface/medium on which tags are mounted may significantly impact the performance of tags, as different medium/surfaces create different types of interference for antenna which may cause transmission of signals to take longer time and as a result decreasing the performance of tags. *To evaluate that the performance of tags is affected by the medium/surface* on which it is mounted, we are conducting this experiment with three different types of Tags mounted on three different medium/surface with RFID reader fixed at a 5 feet distance. We expect the surface/medium to be a significant factor which may impact the performance of RFID tags in this experiment. Three different types of tags used are Universal, Universal Mini and Universal Hard, the main difference between these three tags is the thickness of the tag, the varying thickness along with medium might also be a reason for varied performance. Universal has a thickness of 0.085”, Universal Mini has a thickness of 0.047” and Universal Hard has a thickness of 0.20”.

In this experiment, we will study the effect of different types of RFID tags manufactured by same manufacturer and medium/surface on which the tag is mounted and their respective RSSI value (Received Signal Strength Indicator).

Responsible Variable: RSSI (received signal strength indicator – db) value obtained from each of the tag.

Factor A: Factor A in this experiment is the type of tag used. Three different tags from same company have been used. Hence there are three factors. A = 3.

- 1 = Universal
- 2 = Universal mini
- 3 = Universal hard

Factor B: Factor B is the Medium on which the Tag is placed. We will record the RSSI value of different RFID tags on different Medium. For this experiment tags are being tested at a fixed 5 feet distance. There are three factor levels under consideration. B=3

- 1 = Air
- 2 = Metal
- 3 = Cardboard

Experimental Unit & Replications: For each treatment we will be conducting 4 replications and observe the RSSI value. Experimental units are 9 (treatments) * 4 (replications) = 36 samples. A total of 36 different RFID tags, (12 different universal tags, 12 different universal mini tags, and 12 different universal hard tags) will be used to obtain the RSSI value.

Purpose of the study: To determine how the medium on which the tag is placed impacts the performance of tag.

Design: As we are looking at every factor-level combination, this constitutes a *Two-factor complete factorial design*. The total number of treatments is A*B = 3*3 = 9.

2.1 Data Collection

The experiments were conducted in RAID labs at The University of Texas at Arlington. The setup includes the following:

- 36 different tags,
- Impinj speedway fixed reader.
- Imping speedway R-420, 4 port-FCC to measure RSSI values.
- PVC stand to hold the tags.

The antenna (RFID reader) is fixed at a position 4 feet from ground on a table and tapped to ensure there is no movement. 5 Feet distance from the bottom of the table holding RFID reader is marked on the floor. All the tests are conducted at a fixed 5 feet distance from reader. The Tags are fixed to the PVC stand and put on the table 4 feet from the ground to ensure the line of sight is clear for reader to interact with the RFID tags. The tags will be tested at normal room temperature and humidity (35%-45%).Tests are repeatable in nature. The tags are attached to the tape in the center and not on the frame of PVC to hold it strongly on the PVC stand. To obtain multiple readings the tags are test on different medium (i.e. Air, metal and cardboard) and are changed one after the other and to ensure there is no obstruction/interference when the reading is taken the people conducting this experiment are standing behind the reader and not behind the Tags. The RSSI values are displayed in the laptop with Impinj speedway R-420 software. The role of each of the members is listed below: *Azeem Gohar* – setting up of apparatus and providing with 36 different tags to conduct this experiment. *Abhijit Deshpande* – Randomization of 36 Tags and recording of data obtained from the experiment. *Raghavendra Punugu* – responsible for changing the medium on which the tag is tested and for changing the tags.

3. Preliminary Analysis

In this section, we perform preliminary analysis on the data obtained from performing the experiment.

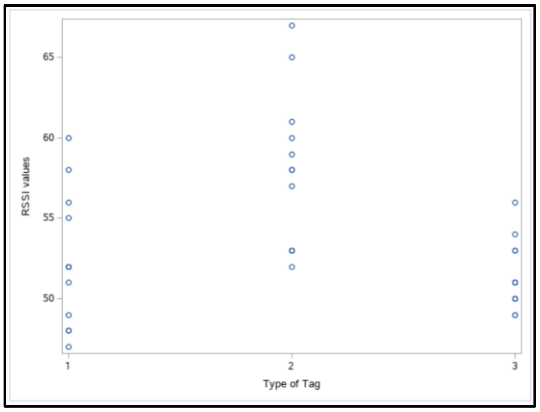

Figure 2.1: RSSI vs Type of Tag

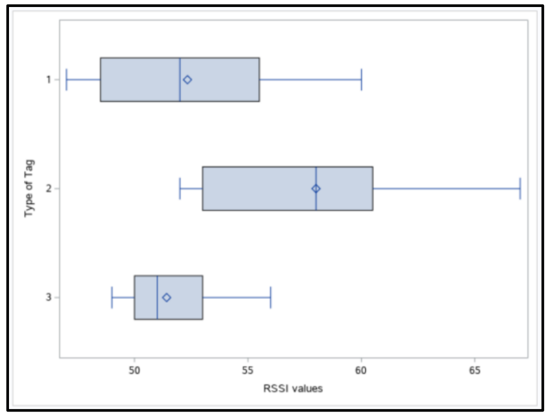

Figure 2.2: RSSI vs Type of Tag(Horizontal box plot)

Table 2.1 Descriptive statistics for RSSI value based on Tag types

Analysis Variable : RSSI RSSI values						
Type of Tag	N Obs	N	Mean	Std Dev	Minimum	Maximum
1	12	12	52.3333333	4.1633320	47.0000000	60.0000000
2	12	12	58.0000000	4.8241815	52.0000000	67.0000000
3	12	12	51.4166667	2.1514618	49.0000000	56.0000000

Factor A – Type of tag has three levels, and they are (1-Universal, 2-Universal Mini & 3- Universal hard). Figure 2.1 shows the plot for RSSI value vs type of tag. We see that the variability between treatment appears to be similar for Universal and Universal Mini tag while the variability for Universal Hard with Universal or Universal Mini is not so similar. From Figure 2.2, we observe that the means of Universal and Universal Hard appear to be similar as the box plot of Universal Hard overlaps with boxplot of Universal. Also, Universal Hard has the lower variance than the other two tags. From above figures, there are no outliers as none of the data points lie out any of the whiskers.

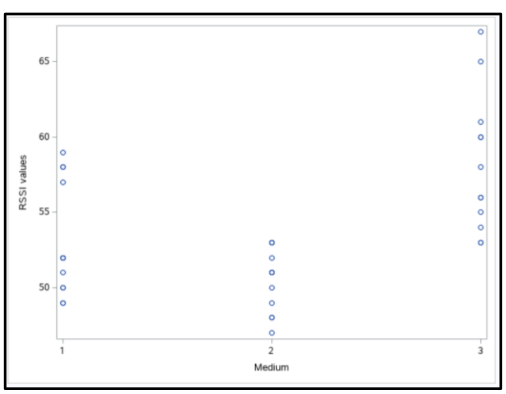

Figure 2.3: RSSI vs Type of surface

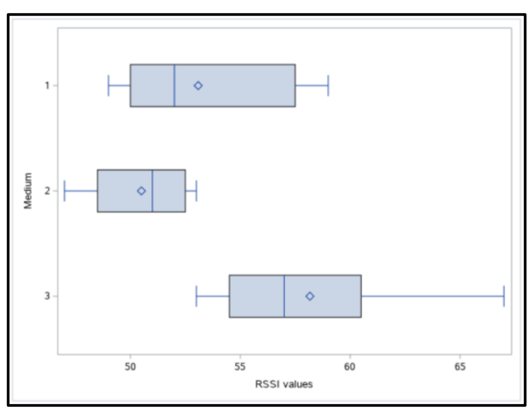

Figure 2.4: RSSI vs Type of surface (Horizontal box plot)

Table 2.2 Descriptive statistics for RSSI value based on surface

Analysis Variable : RSSI RSSI values						
Medium	N Obs	N	Mean	Std Dev	Minimum	Maximum
1	12	12	53.0833333	3.8009170	49.0000000	59.0000000
2	12	12	50.5000000	2.1105794	47.0000000	53.0000000
3	12	12	58.1666667	4.5693312	53.0000000	67.0000000

Factor B – Type of medium/surface has three levels, and they are (1-Air, 2-Metal & 3-cardboard). Figure 2.3 shows the plot for RSSI value vs type of medium/surface. It is observed that the variance for Air and cardboard appear to be somewhat similar compared to metal vs cardboard or air. From Figure 2.4, we see that the mean for Metal is lower than the other two, which is expected as the metal may cause reflection of RFID waves and cause interference in readings. There appears to be significant overlap between air and metal which could be the reason for somewhat similar means. From above figures, there are no outliers as none of the data points lie out any of the whiskers.

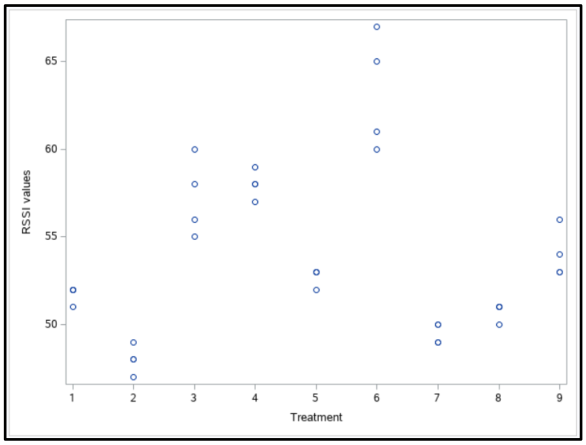

Figure 2.5: RSSI vs Type of surface

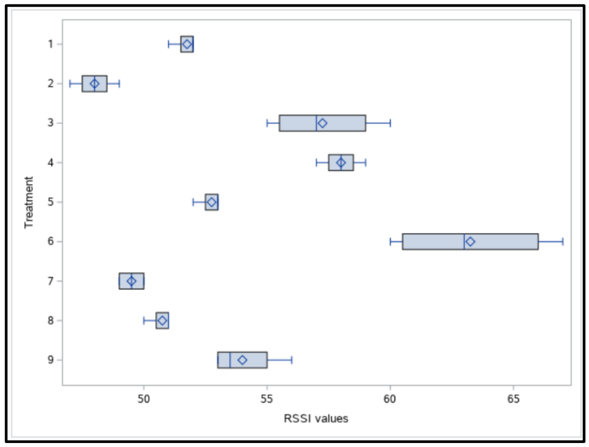

Figure 2.6: RSSI vs Type of surface(Horizontal box plot)

Table 2.3 Descriptive statistics for RSSI value based on surface

Analysis Variable : RSSI RSSI values						
Treatment	N Obs	N	Mean	Std Dev	Minimum	Maximum
1	4	4	51.7500000	0.5000000	51.0000000	52.0000000
2	4	4	48.0000000	0.8164966	47.0000000	49.0000000
3	4	4	57.2500000	2.2173558	55.0000000	60.0000000
4	4	4	58.0000000	0.8164966	57.0000000	59.0000000
5	4	4	52.7500000	0.5000000	52.0000000	53.0000000
6	4	4	63.2500000	3.3040379	60.0000000	67.0000000
7	4	4	49.5000000	0.5773503	49.0000000	50.0000000
8	4	4	50.7500000	0.5000000	50.0000000	51.0000000
9	4	4	54.0000000	1.4142136	53.0000000	56.0000000

Figure 2.5 shows the raw data plot for RSSI value vs treatment combinations. We see that universal tag on air has similar spread/variance as that of universal mini on metal, universal hard on air and universal hard on metal and from boxplot they appear to somewhat overlap which is the reason for them to have similar

mean. Universal tag on cardboard and Universal mini on cardboard appear to have larger spread which among all the other treatment combinations. Universal on metal and Universal mini on air appear to have similar spread but their means are significantly different reason being that the box plots do not overlap.

3.1 Residual Analysis

In this section, we perform residual analysis to verify model assumptions which are listed below.

- Normality
- Constant Variance
- No serial correlation
- No outliers

3.1.1 Normality

To verify that the data follow normality, we conduct the Residual analysis to verify normality of residuals. Figure 2.7 shows the Normal probability plot.

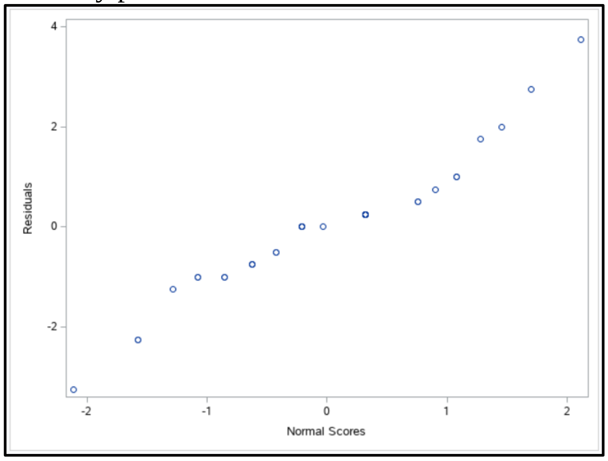

Figure 2.7: Normal Probability Plot

NPP plot exhibits reasonably straight line with slight deviation in the center along with long tails at the ends, which explains the reason for more variance than we would normally expect. On this basis we can infer that the normality appears to be violated. To confirm our hypothesis that normality is violated, we perform test for normality. The test was performed by calculating sample correlation between residuals and normal scores which was obtained using SAS, shown in Table 2.4. This correlation coefficient value is compared against cutoff value C(α,n).

Table 2.4 Pearson Correlation

Pearson Correlation Coefficients, N = 36 Prob > |r| under H0: Rho=0		
	E	enrm
E	1.00000	0.96904 <.0001
enrm Rank for Variable E	0.96904 <.0001	1.00000

The hypothesis test for normality is presented below:

Test for Normality:

Hypothesis: H_0 : Normality is OK

H_1 : Normality is violated

Decision rule: $\rho < C(\alpha,n)$, reject H_0

Conclusion:

$C(\alpha,n) = C(0.1, 36) = 0.974$

Correlation – 0.96904

Since $\rho = 0.96904 < C(0.1, 36) = 0.974$, we reject H_0, i.e., based on the Test of Linearity in the NPP, we reject H_0 in favor of H_1. Normal probability plot and Test for normality confirm the assumption that normality is violated.

3.1.2 Constant Variance

Residual analysis was performed to verify whether residuals are constant. Figure 2.8 shows constant variance plot for residuals vs estimated RSSI values.

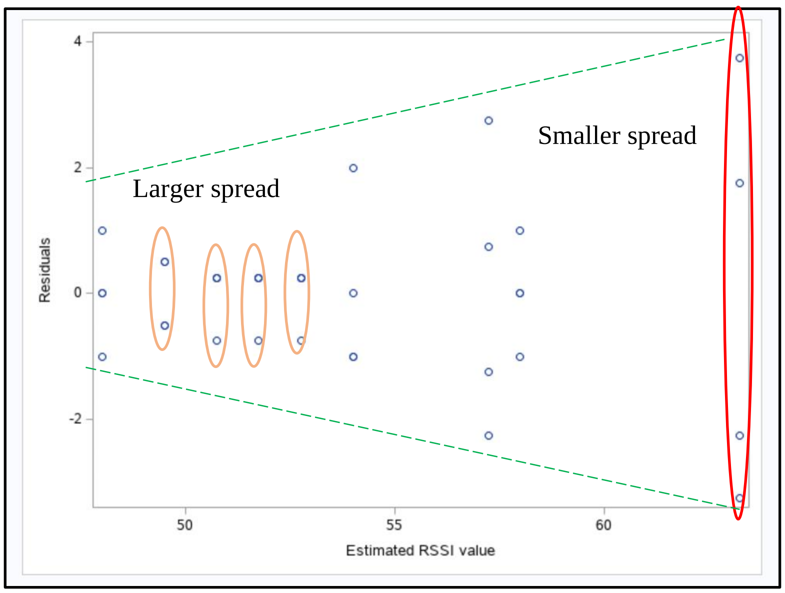

Figure 2.8: Variance Plot

From Figure 2.8 and Table 2.3 we see that treatments have nonconstant variance as the plot shows funnel shape, this violates the assumption of constant variance. Since the data is not normally distributed, we refrain from using Hartley Test for nonconstant variance. In this case we use Modified-Levene Test as it is robust against serious departures from normality. Modified-Levene test is presented below.

Modified-Levene Test:

Table 2.5 ANOVA output for Modified-Levene Test

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	23.55555556	2.94444444	6.24	0.0001
Error	27	12.75000000	0.47222222		
Corrected Total	35	36.30555556			

R-Square	Coeff Var	Root MSE	d Mean
0.648814	79.80204	0.687184	0.861111

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Trt	8	23.55555556	2.94444444	6.24	0.0001

Hypothesis: H_0 : Means of the d_{it} populations are all equal.
H_1 : Not all means are equal.
Decision rule: $P > \alpha$, we fail to reject H_0
Conclusion: Based on the output from SAS, we observe that the P-value is smaller than $\alpha = 0.1$, we reject H_0. Based on Modified-Levene Test and Figure 2.8 (variance plot), we conclude that constant variance assumption is not okay. In order to have constant error variance, we use variance stabilization technique to resolve the issue of nonconstant variance and nonnormality, which is presented in section 3.2

3.1.3 Serial Correlation

We test for serial correlation as the data was collected in specific order and we observe that the data points are randomly jagged, which implies they are uncorrelated.

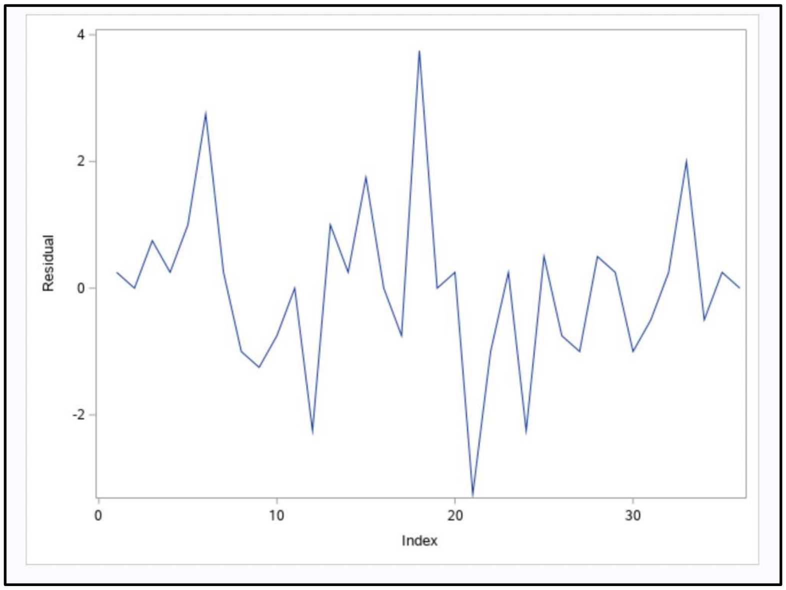

Figure 2.9: Series plot

3.1.4 Outlier Test

We perform outlier test for check for any outliers present in the data. There appear to be no noticeable outliers visible from the Figure 2.8 and Figure 2.6, none of the data points appear beyond the whiskers in Figure 2.6 and from constant variance plot in Figure 2.8, we do not notice any significant outliers which may be of interest to test. However, we still chose to test for outliers using Bonferroni outlier test. We use studentized deleted residuals to perform Bonferroni Outlier Test, absolute studentized residual value is compared against cutoff value-
$t_{n-v-1,\alpha/2m}$. If $|t_{it}| > t_{n-v-1,\alpha/2m}$, then we conclude it is an outlier. When absolute studentized residual values (In Table A.3, in appendix) are compared with cutoff value- $t_{26,0.000138} = 4.20$, all the absolute studentized values are smaller than cutoff value, therefore we conclude that there are no outliers.

3.2 Transformation

Based on the analysis above, we noticed that model assumptions which are constant variance and normality are violated while outlier and serial correlation assumptions are satisfied. To resolve the issue of nonconstant variance and nonnormality, we use variance-stabilizing transformation on the response variable (RSSI).

Table 2.6 Proportionality test for mean and variance for Transformation

Treatment	Variance/Mean	SD/Mean	SD/Mean Sq.
1	0.004830918	0.009661836	0.000186702
2	0.01388889	0.017010346	0.000354382
3	0.085880642	0.038731106	0.000676526
4	0.011494253	0.014077528	0.000242716
5	0.004739336	0.009478673	0.00017969
6	0.172595517	0.052237753	0.000825893
7	0.006734007	0.011663642	0.000235629
8	0.004926108	0.009852217	0.000194132
9	0.037037039	0.026189141	0.000484984

Among above used transformation methods from Table 2.6, we selected Standard Deviation/Mean Square as it has constant values across all treatments. For transformation we use 1/y, which is 1/RSSI values. The below figure 2.10 and figure 2.11 show normality plot and constant variance plot respectively, it is clear that though the NPP has slightly longer tails it still satisfies normality while the constant variance assumption is violated in Figure 2.11. As the nonconstant variance assumption is still not satisfied, we performed transformation with $1/y^2$ (y – RSSI) and $1/y^3$ (y- RSSI) and observe that nonconstant variance is still not satisfied. We performed transformation on response variable (RSSI) using $1/y^4$, the analysis is presented in section 3.2.1.

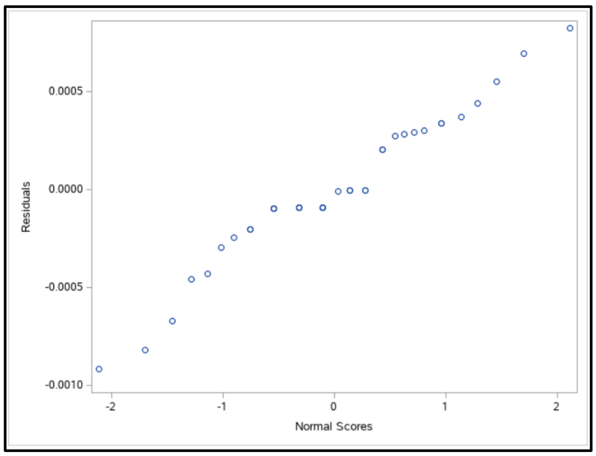

Figure 2.10: Normality Plot

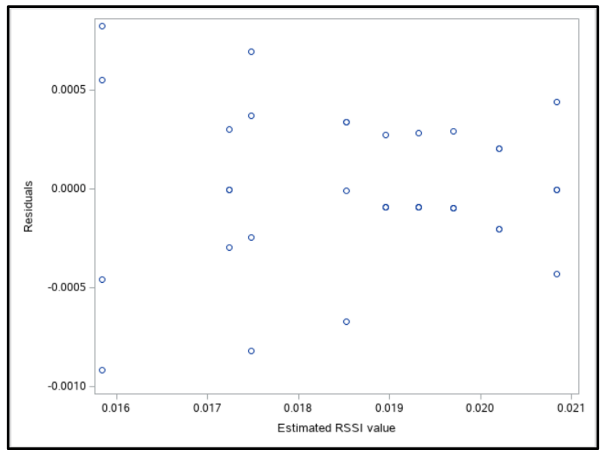

Figure 2.11: Constant Variance

Test for Normality:
H_0 : Normality is OK
H_1 : Normality is violated
Correlation – 0.98155
$C(\alpha,n) = C(0.1, 36) = 0.974$

Table 2.7 Pearson Correlation

Pearson Correlation Coefficients, N = 36 Prob > |r| under H0: Rho=0		
	e2	enrm
e2	1.00000	0.98155 <.0001
enrm Rank for Variable e2	0.98155 <.0001	1.00000

Since $\rho = 0.98155 > C(0.1, 36) = 0.974$, we fail to reject H_0, i.e., based on the Test of Linearity in the NPP, Normal probability plot and Test for normality confirm the assumption that normality is okay.

Modified-Levene Test:
H_0 : Means of the d_{it} populations are all equal.
H_1 : Not all means are equal.

Table 2.8 ANOVA output for Modified-Levene Test

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	1.4507669E-6	1.8134586E-7	3.74	0.0046
Error	27	1.3108756E-6	4.8550947E-8		
Corrected Total	35	2.7616424E-6			

Decision rule: If $P > \alpha$, we fail to reject H_0

Conclusion: Based on the output from SAS, we observe that the P-value is smaller than $\alpha = 0.1$, we reject H_0. In this case, the test is consistent with our plot for constant variance, and we conclude that the assumption of constant variance is not okay.

3.2.1 Normality (Transformed Data)

We conducted normality test on transformed data for which the figure is shown below. From the below figure 2.12, we observe that though the tails appear to be long at both the ends and with slight deviations at the center , the normality plot is reasonably straight, we test using Pearson correlation coefficient.

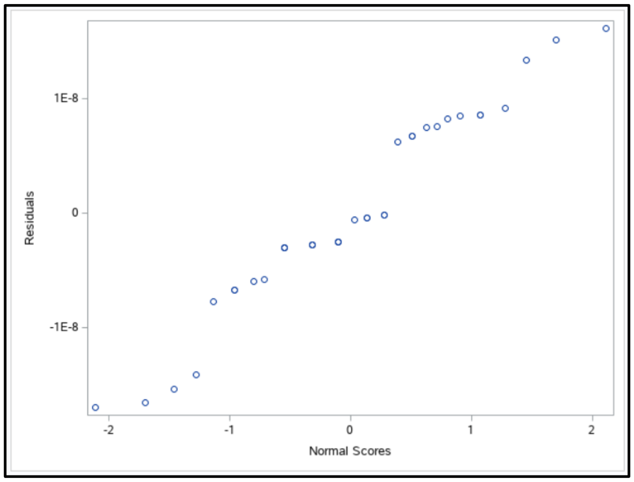

Figure 2.12: Normal Probability

Test for Normality:

H_0 : Normality is OK

H_1 : Normality is violated

Table 2.9 Pearson Correlation

Pearson Correlation Coefficients, N = 36 Prob > |r| under H0: Rho=0		
	e2	enrm
e2	1.00000	0.97921 <.0001
enrm Rank for Variable e2	0.97921 <.0001	1.00000

$C(\alpha,n) = C(0.1, 36) = 0.974$, Correlation – 0.97921. Since $\rho = 0.97921 > C(0.1, 36) = 0.974$, we fail to reject H_0, i.e., based on the Test of Linearity in the NPP, Normal probability plot and Test for normality confirm the assumption that normality is okay.

3.2.2 Constant Variance (Transformed Data)

Residual analysis was performed on transformed response variable (RSSI) to verify whether residuals are constant. Figure 2.13 shows constant variance plot for residuals vs estimated RSSI values.

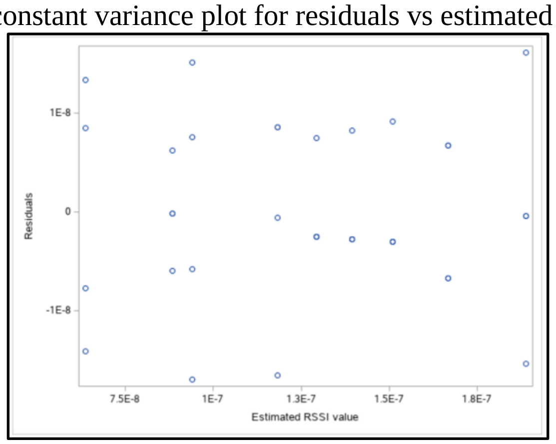

Figure 2.13: Constant Variance

From Figure 2.13 we see that treatments have constant variance as the plot does not show any trend and are spread out relatively similar and this satisfies the assumption of constant variance. To further our test, we conduct Modified-Levene test, which is presented below.

Modified-Levene Test:
H_0 : Means of the d_{it} populations are all equal.
H_1 : Not all means are equal.

Table 2.10 ANOVA for Modified-Levene Test

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	4.11185E-16	5.139813E-17	1.57	0.1799
Error	27	8.828297E-16	3.26974E-17		
Corrected Total	35	1.294015E-15			

Decision rule: If P > α, we fail to reject H_0

Conclusion: Based on the output from SAS, we observe that the P-value is larger than $\alpha = 0.01$, we *fail to reject* H_0. In this case, the test is consistent with our plot for constant variance, and we conclude that the assumption of constant variance is not okay.

3.2.3 Serial Correlation (Transformed Data)

After transformation we tested for serial correlation and we observed that the data points are randomly jagged, which implies they are uncorrelated.

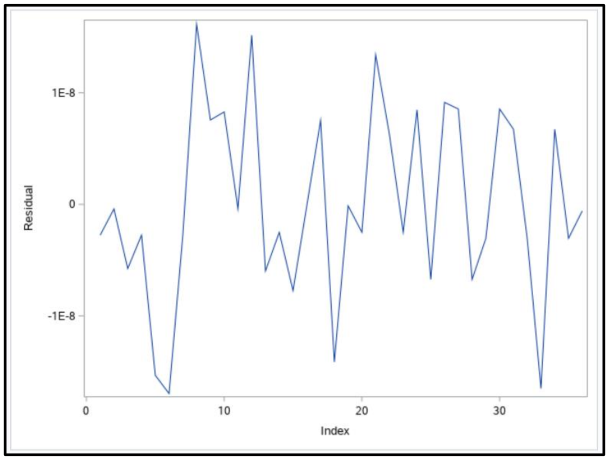

Figure 2.14: Serial Correlation

3.2.4 Outlier (Transformed Data)

After transformation was performed on the response variable (RSSI) we test for outliers again and we observe no noticeable outliers from the Figure 2.12 and Figure 2.13, we use Bonferroni outlier test. We use studentized deleted residuals to perform Bonferroni Outlier Test, absolute studentized residual value is compared against cutoff value-
$t_{n-v-1,\alpha/2m}$. If $|t_{it}| > t_{n-v-1,\alpha/2m}$, then we conclude it is an outlier. When absolute studentized residual values (In table A.4 in appendix) are compared with cutoff value- $t_{26,0.000138} = 4.20$, all the absolute studentized values are smaller than cutoff value, therefore we conclude that there are no outliers, which is pretty consistent with our observation from the plots.

4. Analysis of Variance

In this section we will study the interaction effect if any and perform ANOVA to check if two or more groups mean vary significantly.

4.1 Interaction Effect

In our experiment, we have two factors, and we are interested to know if there exists any interaction between them, if there exist any interaction between them then must be studied in conjunction with each other rather than separately. To check for interaction effect following plots are shown in Figure 2.15 and Figure 2.16. We say that an interaction exists between two factors if a change in level of one factor affects level change in second factor.

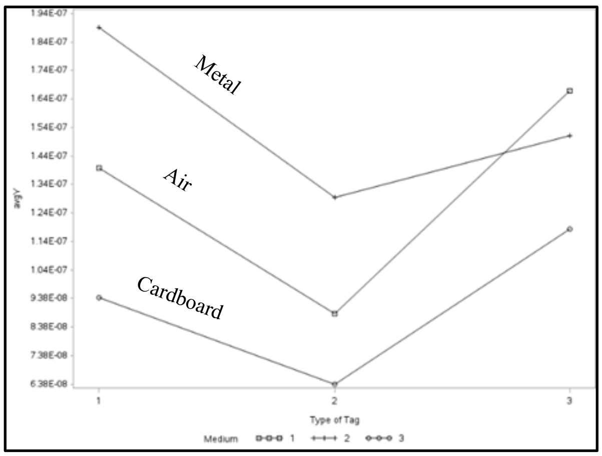

Figure 2.15: Interaction Plot

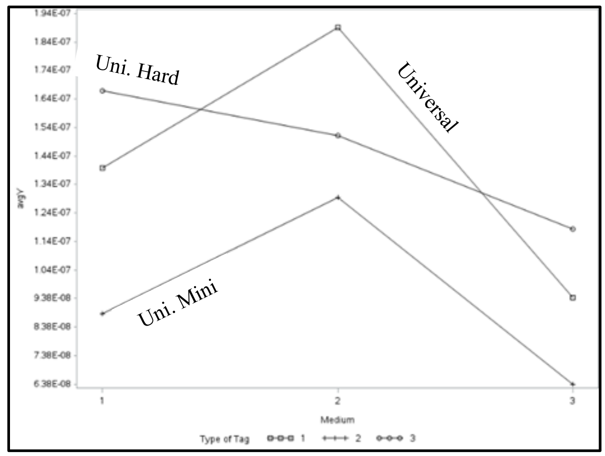

Figure 2.16: Interaction Plot

These are interaction plots between RSSI value and Type of Tag and RSSI value and Medium,

Table 2.11 Different Tags and Medium used

Type of Tag	Tag	Medium	Medium
1	Universal	1	Air
2	Universal mini	2	Metal
3	Universal hard	3	Cardboard

Interaction effect between Tag & Medium: Figure 2.16 shows interaction plot for the Types of Tag and Medium. The plot suggests that both Universal and Universal mini tag shows parallel lines for mean RSSI value in all three-medium giving better performance in Metal then in air and least in Cardboard. From Figure 2.16 we see that Universal hard shows a declined line, we see that it performs better in Air than other tags. Mean RSSI value among three types of Tags changes with type of Medium, so we can conclude that there is an interaction between Type of Tag and Medium.

Main Tag Effect: In Figure 2.15, x-axis contains Type of Tag factor levels (denoted by 1, 2 and 3), and the y-axis contains RSSI value. We can observe that Universal and Universal mini tags have obtained higher RSSI values having Metal as Medium except for Universal hard which performs slightly better with Air than Metal. The lines have slope ≠ 0 which means that with change in type of Tag we observe change in the mean RSSI value. Thus, we conclude that Main Tag effect exists.

Main Medium effect: In Figure 2.16, x-axis contains the Medium factor levels (denoted by 1, 2 and 3), and the y-axis contains RSSI value. We observe three distinct lines for type of Medium meaning that main Medium effect exist. Universal and Universal mini perform in similar way giving better performance in

Metal than in air and least performance in Cardboard. But Universal hard which gives better results in Air than other two, there is not big performs difference in Metal than Cardboard. Thus, we conclude that main Medium effect exists.

4.2 Analysis of Variance

Dependent Variable: RSSI_value

Table 2.12 ANOVA

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	5.106976E-14	6.38372E-15	67.13	<.0001
Error	27	2.567569E-15	9.509515E-17		
Corrected Total	35	5.363733E-14			

R-Square	Coeff Var	Root MSE	RSSI_value Mean
0.952131	7.700541	9.75167E-9	1.26636E-7

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Tag	2	1.948761E-14	9.743804E-15	102.46	<.0001
Medium	2	2.522875E-14	1.261437E-14	132.65	<.0001
Tag*Medium	4	6.353404E-15	1.588351E-15	16.70	<.0001

In the two-factor ANOVA, it compares the mean differences of RSSI value due to influence of Type of Tag and Type of Medium and whether if there is an interaction between these two factors. The first test is an overall test to assess whether there is a difference among the 9 treatment means. (Treatment is defined by Type of Tag and Medium). The *F* statistic is 67.13 and is highly statistically significant with p=0.0001. When the overall test is significant, it appears to be reasonable to proceed for *F* tests for factor effects.

F-Tests for two-way ANOVA Test for Interaction Effect

H_0: $(\alpha\beta)_{ij} = 0$ for all (i,j)
H_1: $(\alpha\beta)_{ij} \neq 0$ for at least one (i,j)

The decision rule for testing the null hypothesis H_0 that interaction effect is zero, against the alternative hypothesis H_1 that interaction effect is nonzero, is *reject H_0* if $p < \alpha$,

Considering a confidence level of 90% (α=0.10), the p-value which is <.0001 is less than α=0.10, hence we reject H_0. Therefore, we conclude, there exist interaction between type of tag and medium.

Since the two factors interact, we don't test main Tag effect and main Medium effect separately. The interaction between Type of Tag and type of Medium is statistically significant, we can use the full interaction model for future work.

Full interaction model form : $\boldsymbol{Y}_{ijt} = \mu_{\bullet\bullet} + \alpha_i + \beta_j + (\alpha\beta)_{ij}$

4.3 Main Effects and Interaction Effects:

Overall mean $\hat{\mu} = \bar{Y}\ldots = 1.2667E\text{-}07$

Main Tag effect: The main Tag effects are defined in corresponding fashion, and denoted by $\hat{\alpha_i}$ is estimated by subtracting overall mean $\hat{\mu}$ from factor level mean for each type of Tag.

$\hat{\mu}_{1.} = \bar{Y}_{1..} = 1.4075E\text{-}0$ $\hat{\alpha}_1 = 1.4075E\text{-}07 - 1.2667E\text{-}07 = 1.4083E\text{-}08$

$\hat{\mu}_{2.} = \bar{Y}_{2..} = 9.3917E\text{-}08$ $\hat{\alpha}_2 = 9.3917E\text{-}08 - 1.2667E\text{-}07 = -3.275E\text{-}08$

$\hat{\mu}_{3.} = \bar{Y}_{3..} = 1.4533E\text{-}07$ $\hat{\alpha}_3 = 1.4533E\text{-}07 - 1.2667E\text{-}07 = 1.8667E\text{-}08$

The above calculations show that Universal and Universal hard have the effect of a relative increase in RSSI value, whereas Universal mini decrease the RSSI value. These also sum to zero so there is no net effect.

Main Medium effect: The main Medium effects are defined in corresponding fashion, and denoted by $\hat{\beta}_i$ is estimated by subtracting overall mean $\hat{\mu}$ from factor level mean for each Medium

$\hat{\mu}_{.1} = \bar{Y}_{.1.} = 1.3158E\text{-}07$ $\hat{\beta}_1 = 1.3158E\text{-}07 - 1.2667E\text{-}07 = 4.9167E\text{-}09$

$\hat{\mu}_{.2} = \bar{Y}_{.2.} = 1.5633E\text{-}07$ $\hat{\beta}_2 = 1.5633E\text{-}07 - 1.2667E\text{-}07 = 2.9667E\text{-}08$

$\hat{\mu}_{.3} = \bar{Y}_{.3.} = 9.2083E\text{-}08$ $\hat{\beta}_3 = 9.2083E\text{-}08 - 1.2667E\text{-}07 = -3.458E\text{-}08$

This means that RSSI value for tags increases with Metal, followed by Air, while Cardboard decreases the RSSI value.

Interaction Effects:

This is the difference of the treatment mean and the overall mean and main effects. It is denoted by $(\alpha\beta)_{ij}$.

$(\widehat{\alpha\beta})_{11} = \bar{Y}_{11.} - (\hat{\mu} + \hat{\alpha}_1 + \hat{\beta}_1)$ 1.3975E-07 – (1.2667E-07 + 1.4083E-08 + 4.9167E-09) = -5.91667E-09

$(\widehat{\alpha\beta})_{12} = \bar{Y}_{12.} - (\hat{\mu} + \hat{\alpha}_1 + \hat{\beta}_2)$ 1.885E-07 – (1.2667E-07 + 1.4083E-08 + 2.9667E-08) = 1.80833E-08

$(\widehat{\alpha\beta})_{13} = \bar{Y}_{13.} - (\hat{\mu} + \hat{\alpha}_1 + \hat{\beta}_3)$ 0.000000094 – (1.2667E-07 + 1.4083E-08 - 3.458E-08) = -1.21667E-08

$(\widehat{\alpha\beta})_{21} = \bar{Y}_{21.} - (\hat{\mu} + \hat{\alpha}_2 + \hat{\beta}_1)$ 8.85E-08 – (1.2667E-07 - 3.275E-08 + 4.9167E-09) = -1.03333E-08

$(\widehat{\alpha\beta})_{22} = \bar{Y}_{22.} - (\hat{\mu} + \hat{\alpha}_2 + \hat{\beta}_2)$ 1.295E-07 – (1.2667E-07 - 3.275E-08 + 2.9667E-08) = 5.91667E-09

$(\widehat{\alpha\beta})_{23} = \bar{Y}_{23.} - (\hat{\mu} + \hat{\alpha}_2 + \hat{\beta}_3)$ 6.375E-08 – (1.2667E-07 - 3.275E-08 - 3.458E-08) = 4.41667-09

$(\widehat{\alpha\beta})_{31} = \bar{Y}_{31.} – (\hat{\mu} + \hat{\alpha_3} + \hat{\beta}_1)$ 1.665E-07 – (1.2667E-07 + 1.8667E-08 + 4.9167E-09) = 1.625E-08

$(\widehat{\alpha\beta})_{32} = \bar{Y}_{32.} – (\hat{\mu} + \hat{\alpha_3} + \hat{\beta}_2)$ 0.000000151 – (1.2667E-07 + 1.8667E-08 + 2.9667E-08) =0.000000024

$(\widehat{\alpha\beta})_{33} = \bar{Y}_{33.} – (\hat{\mu} + \hat{\alpha_3} + \hat{\beta}_3)$ 1.185E-07 – (1.2667E-07 + 1.8667E-08 - 3.458E-08) = 7.75E-09

5. Analysis of Effect

5.1 Pairwise Comparison with Tukey method and Line Plots

In this section, we do pairwise comparison of interaction effects using Tukey method. We are using interaction effects; we cannot use main Tag effects and main Medium effects separately since there is statistically significant interaction. So, we ignore main effects. We conduct the test at a significance level of $\alpha = 0.01$.

Table 2.13 Estimated treatment mean

Tag	Medium	RSSI_value LSMEAN	LSMEAN Number
1	1	1.3953032E-7	1
1	2	1.8878954E-7	2
1	3	9.4123029E-8	3
2	1	8.8498054E-8	4
2	2	1.2924341E-7	5
2	3	6.3757457E-8	6
3	1	1.6673326E-7	7
3	2	1.5086145E-7	8
3	3	1.1818941E-7	9

Table 2.14 P-value for various Factor-level combinations

Least Squares Means for effect Tag*Medium Pr > |t| for H0: LSMean(i)=LSMean(j) Dependent Variable: RSSI_value									
i/j	1	2	3	4	5	6	7	8	9
1		<.0001	<.0001	<.0001	0.8496	<.0001	0.0128	0.7734	0.0896
2	<.0001		<.0001	<.0001	<.0001	<.0001	0.0719	0.0002	<.0001
3	<.0001	<.0001		0.9953	0.0007	0.0041	<.0001	<.0001	0.0377
4	<.0001	<.0001	0.9953		<.0001	0.0300	<.0001	<.0001	0.0052
5	0.8496	<.0001	0.0007	<.0001		<.0001	0.0003	0.0824	0.7950
6	<.0001	<.0001	0.0041	0.0300	<.0001		<.0001	<.0001	<.0001
7	0.0128	0.0719	<.0001	<.0001	0.0003	<.0001		0.3754	<.0001
8	0.7734	0.0002	<.0001	<.0001	0.0824	<.0001	0.3754		0.0017
9	0.0896	<.0001	0.0377	0.0052	0.7950	<.0001	<.0001	0.0017	

Table 2.15 Confidence Interval for the level of significance $\alpha = 0.01$

Least Squares Means for Effect Tag*Medium					Significance
i	j	Difference Between Means	Simultaneous 99% Confidence Limits for LSMean(i)-LSMean(j)		
1	2	-4.925922E-8	-7.715732E-8	-2.136113E-8	***
1	3	4.5407291E-8	1.7509196E-8	7.3305386E-8	***
1	4	5.1032266E-8	2.3134171E-8	7.8930361E-8	***
1	5	1.0286913E-8	-1.761118E-8	3.8185008E-8	
1	6	7.5772863E-8	4.7874769E-8	0.000000104	***
1	7	-2.720294E-8	-5.510104E-8	6.95152E-10	
1	8	-1.133113E-8	-3.922923E-8	1.6566964E-8	
1	9	2.134091E-8	-6.557185E-9	4.9239004E-8	
2	3	9.4666516E-8	6.6768421E-8	0.000000123	***
2	4	0.000000100	7.2393396E-8	0.000000128	***
2	5	5.9546137E-8	3.1648043E-8	8.7444232E-8	***
2	6	0.000000125	9.7133993E-8	0.000000153	***
2	7	2.2056282E-8	-5.841813E-9	4.9954377E-8	
2	8	3.7928093E-8	1.0029999E-8	6.5826188E-8	***
2	9	7.0600134E-8	4.2702039E-8	9.8498229E-8	***
3	4	5.6249748E-9	-2.227312E-8	3.352307E-8	
3	5	-3.512038E-8	-6.301847E-8	-7.222284E-9	***
3	6	3.0365572E-8	2.4674774E-9	5.8263667E-8	***
3	7	-7.261023E-8	-0.000000101	-4.471214E-8	***
3	8	-5.673842E-8	-8.463652E-8	-2.884033E-8	***
3	9	-2.406638E-8	-5.196448E-8	3.8317132E-9	
4	5	-4.074535E-8	-6.864345E-8	-1.284726E-8	***
4	6	2.4740597E-8	-3.157497E-9	5.2638692E-8	
4	7	-7.823521E-8	-0.000000106	-5.033711E-8	***
4	8	-6.23634E-8	-9.026149E-8	-3.44653E-8	***
4	9	-2.969136E-8	-5.758945E-8	-1.793262E-9	***
5	6	6.5485951E-8	3.7587856E-8	9.3384045E-8	***
5	7	-3.748986E-8	-6.538795E-8	-9.591761E-9	***
5	8	-2.161804E-8	-4.951614E-8	6.2800509E-9	
5	9	1.1053997E-8	-1.68441E-8	3.8952092E-8	
6	7	-0.000000103	-0.000000131	-7.507771E-8	***
6	8	-8.710399E-8	-0.000000115	-5.92059E-8	***
6	9	-5.443195E-8	-8.233005E-8	-2.653386E-8	***
7	8	1.5871812E-8	-1.202628E-8	4.3769906E-8	
7	9	4.8543852E-8	2.0645758E-8	7.6441947E-8	***
8	9	3.2672041E-8	4.773946E-9	6.0570136E-8	***

Comparisons significant at the $\alpha = 0.01$ level are indicated by ***

Line Plot: From line plot we can say that Trt 6 (Universal mini and Cardboard) gives less RSSI value while Trt 2 (Universal and Metal) gives maximum RSSI value in this case.

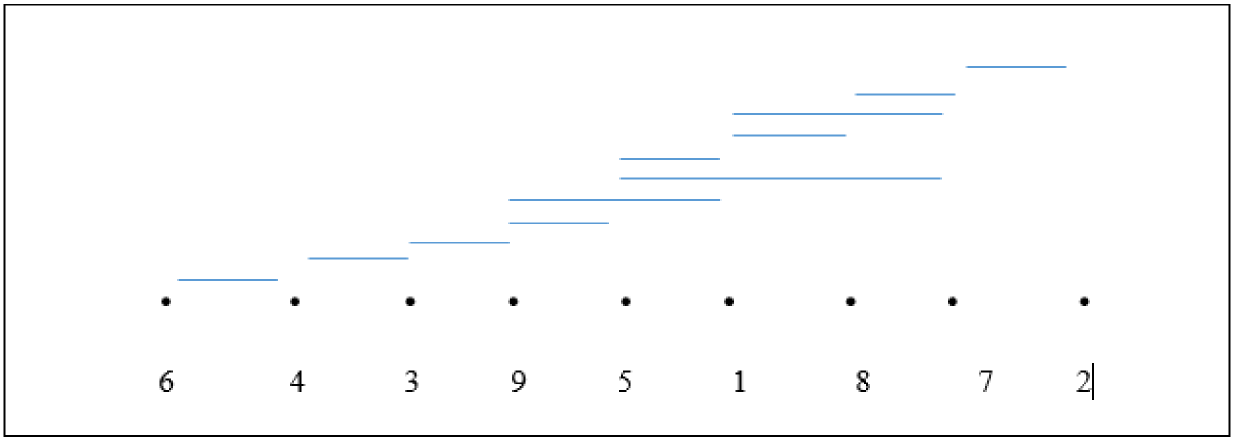

Figure 2.17: Line plot

5.2 Multiple Comparisons using Bonferroni Method.

In this section we conduct multiple comparisons for a pre-selected set of three contrasts which are meaningful in our study using Bonferroni method. Since in previous section we conclude that there is statistically significant relationship between the response and factors, we want to analyze for factor level effects. For a family confidence coefficient of 1-α, the Bonferroni simultaneous confidence limits for *m* contrasts are given by:

Hypothesis Test :

H_0: $L_i = 0$ *for* $i = 1, 2, 3$

H_1: $L_i \neq 0$ *for* $i = 1, 2, 3$

The decision rule for testing the null hypothesis H_0 that contrast is zero, against the alternative hypothesis H_1 that contrast is nonzero, is

reject H_0 if 0 does not lie within the CI,

$\hat{L} \pm W_B\, S_e(\hat{L})$ and $W_B = t_{n-v,\ \alpha/2m}$ where m is number of contrasts used. We want to take 3 contrasts so m=3.

$W_B = t27, 0.0016 = 3.2754$ (Bonferroni Value)

$S_e(\hat{L}) = \sqrt{mse(\Sigma Ci^2)/ri},\ \ \alpha = 0.01$

Contrast 1: We want to check how well does Universal Hard on Air performs over Universal Hard on metal.

$L_1 = \mu_{31} - \mu_{32} = 1.6673326E\text{-}7 - 1.5086145E\text{-}7 = 1.587175\ E\text{-}8$

C = 1, -1

$S_e(\hat{L}) = \sqrt{9.509515\text{E} - 17 \times (2/4)}$ = 6.8954748E-9

$L_1 \in$ (-6.71368816E-9, 3.84718816E-8)

CI contains 0 in the Interval as a result we FTR H_0, we are at least 99% confident that the mean RSSI value of Universal hard on air is about (-6.71368816E-9, 3.84718816E-8) better/lower than universal hard on Metal.

Table 2.15: SAS output for contrast

Table 2.15Parameter	Estimate	Standard Error	t Value	Pr > |t|
Universal hard Tag with Air vs. Universal hard Tag with Metal	-4.925922E-8	6.8954748E-9	-7.14	<.0001

Contrast 2: We want to check the performance of Universal hard over universal and universal mini on metal.

$L_2 = \mu_{32} - \frac{\mu 22 - \mu 12}{2}$ = 1.5086145E-7- 1.34386865E-7= 1.6474585 E-8

C = 1, -1/2, -1/2

$S_e(\hat{L}) = \sqrt{9.509515\text{E} - 17 \times (1.5/4)}$ = 5.971656491 E-9

$L_2 \in$ (-3.084978667E -9, 3.603414867E -8)

CI contains 0 in the Interval as a result we FTR H_0, we are at least 99% confident that the mean RSSI value of Universal hard is about (-3.084978667E -9, 3.603414867E -8) better/lower than universal and universal mini on metal.

Contrast 3: We want to check the performance of tags on metal over air, this is of significant interest as our point of interest is the medium.

$L_3 = (\frac{\mu 12 + \mu 22 + \mu 32}{3}) - (\frac{\mu 11 + \mu 21 + \mu 31}{3})$ = 1.5633E-07 - 1.3158E-07 = 2.475 E-8

C = 1/3, 1/3, 1/3, -1/3, -1/3, -1/3

$S_e(\hat{L}) = \sqrt{9.509515\text{E} - 17 \times (0.166/4)}$ = 3.9811042E-9

$L_3 \in$ (1.17102913E -8, 3.77897087E -8)

CI does not contain 0 in the interval as a result we reject H_0. We are at least 99% confident that the mean RSSI value of tags on Metal is about (1.17102913E -8, 3.77897087E -8) better than tags on air.

Table 2.16: SAS output for contrast

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Metal vs. Air	-2.471092E-8	3.9811042E-9	-6.21	<.0001

6. Final Discussion

The objective of this study was to study how the medium on which the tag was placed impacted the performance (RSSI) of tags. We performed experiment with three types of Tags (Universal, Universal min and Universal hard) on three different medium (Air, Metal and Cardboard) with 4 replications.

In initial analysis, model assumptions for Normality and Constant Variance were checked and it was observed that both were violated. Serial correlation was checked with time series plot which showed random jaggedness of residuals which suggest that there was no serial correlation. Bonferroni outlier test was performed to check for outliers in data. Results from Bonferroni outlier test concluded that no outliers were present in data. As the model assumptions were violated, different transformations were performed, and we selected transformation based on std and mean RSSI ratios. Negative power of one to RSSI transformation was done and we checked model assumptions but still it was violating the assumptions. Power was decreased consequently and checked again assumptions through graph as well by tests statistics. Negative power of 4 to RSSI satisfied all assumptions by observing plots as well tests.

In analysis of variance, main Tag effects, main Medium effects and interactions effects between Tag and Medium were analyzed through plot and found presence of interaction effects and main effects. Statistical significance of interaction effects was checked by performing F test. Due to presence of interaction effects, for any future work on this study it is advisable to use full interaction model.

In final section, pairwise comparison of Types of Tags and Medium were analyzed and found that there were 11 treatment combinations were statically not significant. This was observed with line plot. Next, Multiple comparisons of treatments were done by Bonferroni method.

Based on this study, we conclude that metal performed better over other medium (air and cardboard) tested here, while cardboard as the medium performed lowest among the three medium. This also confirms our premise that the medium on which the tags are placed do impact the performance of RFID even though the RFID reader is fixed at a distance as close as 5 feet.

7. Appendix

Table A.1 Randomization of Factor-level combinations

Obs	Factor A	Factor B	Trt	Random #
1	Universal hard	Metal	6	-1.8863
2	Universal	Metal	4	-1.16087
3	Universal min	Air	2	0.369978
4	Universal min	Cardboard	8	1.801163
5	Universal	Cardboard	7	-2.48895
6	Universal min	Air	2	0.892751
7	Universal hard	Cardboard	9	3.668538
8	Universal min	Metal	5	-1.62924
9	Universal hard	Air	3	2.496517
10	Universal hard	Metal	6	4.775175
11	Universal hard	Cardboard	9	-0.09009
12	Universal	Air	1	0.306864
13	Universal hard	Air	3	-1.41404
14	Universal	Cardboard	7	3.107498
15	Universal min	Cardboard	8	0.121431
16	Universal min	Air	2	-0.78241
17	Universal	Air	1	2.124893
18	Universal	Metal	4	0.070399
19	Universal min	Air	2	-0.15047
20	Universal min	Metal	5	0.182326
21	Universal min	Cardboard	8	2.644624
22	Universal min	Metal	5	-0.46384
23	Universal min	Cardboard	8	-0.96726
24	Universal min	Metal	5	1.950757
25	Universal	Metal	4	-2.32255
26	Universal hard	Cardboard	9	-0.98619
27	Universal	Cardboard	7	0.040791
28	Universal hard	Cardboard	9	-1.38288
29	Universal hard	Air	3	1.258404
30	Universal	Air	1	1.203739
31	Universal hard	Metal	6	-2.62435
32	Universal	Metal	4	-2.18277
33	Universal	Air	1	1.868584
34	Universal	Cardboard	7	-0.08411
35	Universal hard	Metal	6	0.592665
36	Universal hard	Air	3	1.131166

Table A.2 Data Collected

Observation	Factor A	Factor B	Treatment	RSSI (db)
1	Universal	Air	1	52
2	Universal	Metal	2	48
3	Universal	CardBoard	3	58
4	Universal	Air	1	52
5	Universal	Metal	2	49
6	Universal	CardBoard	3	60
7	Universal	Air	1	52
8	Universal	Metal	2	47
9	Universal	CardBoard	3	56
10	Universal	Air	1	51
11	Universal	Metal	2	48
12	Universal	CardBoard	3	55
13	Universal Mini	Air	4	59
14	Universal Mini	Metal	5	53
15	Universal Mini	CardBoard	6	65
16	Universal Mini	Air	4	58
17	Universal Mini	Metal	5	52
18	Universal Mini	CardBoard	6	67
19	Universal Mini	Air	4	58
20	Universal Mini	Metal	5	53
21	Universal Mini	CardBoard	6	60
22	Universal Mini	Air	4	57
23	Universal Mini	Metal	5	53
24	Universal Mini	CardBoard	6	61
25	Universal Hard	Air	7	50
26	Universal Hard	Metal	8	50
27	Universal Hard	CardBoard	9	53
28	Universal Hard	Air	7	50
29	Universal Hard	Metal	8	51
30	Universal Hard	CardBoard	9	53
31	Universal Hard	Air	7	50
32	Universal Hard	Metal	8	51
33	Universal Hard	CardBoard	9	56
34	Universal Hard	Air	7	49
35	Universal Hard	Metal	8	51
36	Universal Hard	CardBoard	9	54

Table A.3 Studentized residuals on the original data (without Transformation)

Obs	Obsn	Tag	Medium	Trt	RSSI	yhat	e	tres
1	1	1	1	1	52	51.8333	0.1667	0.03945
2	4	1	1	1	52	51.8333	0.1667	0.03945
3	7	1	1	1	52	51.8333	0.1667	0.03945
4	10	1	1	1	51	51.8333	-0.8333	-0.19735
5	2	1	2	2	48	54.3750	-6.3750	-1.52747
6	5	1	2	2	49	54.3750	-5.3750	-1.27450
7	8	1	2	2	47	54.3750	-7.3750	-1.78928
8	11	1	2	2	48	54.3750	-6.3750	-1.52747
9	3	1	3	3	58	56.9167	1.0833	0.25667
10	6	1	3	3	60	56.9167	3.0833	0.73591
11	9	1	3	3	56	56.9167	-0.9167	-0.21711
12	12	1	3	3	55	56.9167	-1.9167	-0.45510
13	13	2	1	4	59	51.3750	7.6250	1.85635
14	16	2	1	4	58	51.3750	6.6250	1.59202
15	19	2	1	4	58	51.3750	6.6250	1.59202
16	22	2	1	4	57	51.3750	5.6250	1.33702
17	14	2	2	5	53	53.9167	-0.9167	-0.20759
18	17	2	2	5	52	53.9167	-1.9167	-0.43504
19	20	2	2	5	53	53.9167	-0.9167	-0.20759
20	23	2	2	5	53	53.9167	-0.9167	-0.20759
21	15	2	3	6	65	56.4583	8.5417	2.10866
22	18	2	3	6	67	56.4583	10.5417	2.70246
23	21	2	3	6	60	56.4583	3.5417	0.82798
24	24	2	3	6	61	56.4583	4.5417	1.06917
25	25	3	1	7	50	50.9167	-0.9167	-0.21711
26	28	3	1	7	50	50.9167	-0.9167	-0.21711
27	31	3	1	7	49	50.9167	-1.9167	-0.45510
28	34	3	1	7	49	50.9167	-1.9167	-0.45510
29	26	3	2	8	50	53.4583	-3.4583	-0.80810
30	29	3	2	8	51	53.4583	-2.4583	-0.57155
31	32	3	2	8	51	53.4583	-2.4583	-0.57155
32	35	3	2	8	51	53.4583	-2.4583	-0.57155
33	27	3	3	9	53	56.0000	-3.0000	-0.71569
34	30	3	3	9	53	56.0000	-3.0000	-0.71569
35	33	3	3	9	56	56.0000	0.0000	0.00000
36	36	3	3	9	54	56.0000	-2.0000	-0.47502

Table A.4 Studentized residuals on the original data (After Transformation)

Obs	Obsn	Tag	Medium	Trt	RSSI	Trans_Y	yhat2	e2	yhat	e	tres
1	1	1	1	1	52	.000000137	.000000140	-2.76165E-9	51.8333	0.1667	0.03945
2	2	1	2	2	48	.000000188	.000000189	-4.0943E-10	54.3750	-6.3750	-1.52747
3	3	1	3	3	58	.000000088	.000000094	-5.75645E-9	56.9167	1.0833	0.25667
4	4	1	1	1	52	.000000137	.000000140	-2.76165E-9	51.8333	0.1667	0.03945
5	5	1	2	2	49	.000000173	.000000189	-1.5323E-8	54.3750	-5.3750	-1.27450
6	6	1	3	3	60	.000000077	.000000094	-1.69625E-8	56.9167	3.0833	0.73591
7	7	1	1	1	52	.000000137	.000000140	-2.76165E-9	51.8333	0.1667	0.03945
8	8	1	2	2	47	.000000205	.000000189	1.614188E-8	54.3750	-7.3750	-1.78928
9	9	1	3	3	56	.000000102	.000000094	7.559864E-9	56.9167	-0.9167	-0.21711
10	10	1	1	1	51	.000000148	.000000140	8.284948E-9	51.8333	-0.8333	-0.19735
11	11	1	2	2	48	.000000188	.000000189	-4.0943E-10	54.3750	-6.3750	-1.52747
12	12	1	3	3	55	.000000109	.000000094	1.515912E-8	56.9167	-1.9167	-0.45510
13	13	2	1	4	59	.000000083	.000000088	-5.97183E-9	51.3750	7.6250	1.85635
14	14	2	2	5	53	.000000127	.000000129	-2.50842E-9	53.9167	-0.9167	-0.20759
15	15	2	3	6	65	.000000056	.000000064	-7.73701E-9	56.4583	8.5417	2.10866
16	16	2	1	4	58	.000000088	.000000088	-1.3148E-10	51.3750	6.6250	1.59202
17	17	2	2	5	52	.000000137	.000000129	7.525263E-9	53.9167	-1.9167	-0.43504
18	18	2	3	6	67	.000000050	.000000064	-1.41324E-8	56.4583	10.5417	2.70246
19	19	2	1	4	58	.000000088	.000000088	-1.3148E-10	51.3750	6.6250	1.59202
20	20	2	2	5	53	.000000127	.000000129	-2.50842E-9	53.9167	-0.9167	-0.20759
21	21	2	3	6	60	.000000077	.000000064	1.340304E-8	56.4583	3.5417	0.82798
22	22	2	1	4	57	.000000095	.000000088	6.23479E-9	51.3750	5.6250	1.33702
23	23	2	2	5	53	.000000127	.000000129	-2.50842E-9	53.9167	-0.9167	-0.20759
24	24	2	3	6	61	.000000072	.000000064	8.466398E-9	56.4583	4.5417	1.06917
25	25	3	1	7	50	.000000160	.000000167	-6.73326E-9	50.9167	-0.9167	-0.21711
26	26	3	2	8	50	.000000160	.000000151	9.138549E-9	53.4583	-3.4583	-0.80810
27	27	3	3	9	53	.000000127	.000000118	8.545576E-9	56.0000	-3.0000	-0.71569
28	28	3	1	7	50	.000000160	.000000167	-6.73326E-9	50.9167	-0.9167	-0.21711
29	29	3	2	8	51	.000000148	.000000151	-3.04618E-9	53.4583	-2.4583	-0.57155
30	30	3	3	9	53	.000000127	.000000118	8.545576E-9	56.0000	-3.0000	-0.71569
31	31	3	1	7	49	.000000173	.000000167	6.733263E-9	50.9167	-1.9167	-0.45510
32	32	3	2	8	51	.000000148	.000000151	-3.04618E-9	53.4583	-2.4583	-0.57155
33	33	3	3	9	56	.000000102	.000000118	-1.65065E-8	56.0000	0.0000	0.00000
34	34	3	1	7	49	.000000173	.000000167	6.733263E-9	50.9167	-1.9167	-0.45510
35	35	3	2	8	51	.000000148	.000000151	-3.04618E-9	53.4583	-2.4583	-0.57155
36	36	3	3	9	54	.000000118	.000000118	-5.8463E-10	56.0000	-2.0000	-0.47502

8. References

[1] Automatic Identification and Data Collection (AIDC) Archived May 5, 2016, at the Wayback Machine

[2] Construction of RFID Tags - RFID chip and antenna". RFID4U. n.d. Retrieved 2020-03-01.

[3] Design and Analysis of Experiments Textbook.