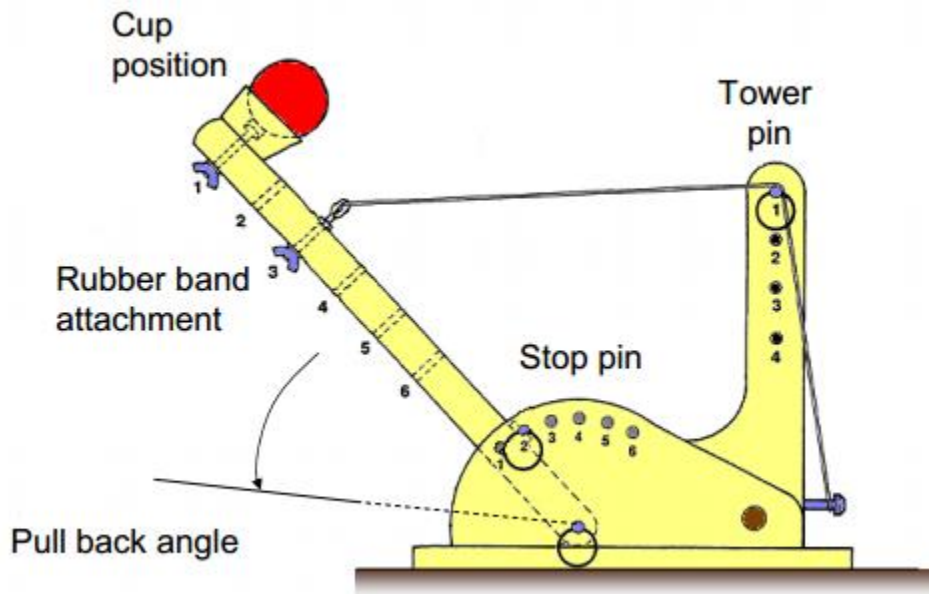*-Ashwin Anbazhagan Angammal*
-Meenakshi Nagarajan

Catapult model final report

Objective:

The objective of the experiment is to perform the catapult operation and to find out the future predicted values using a 2^3 full factorial design with 3 factors two levels each.

Design:

The catapult consists of five controllable variables with different levels.

| Controllable variable	Levels	Comment
Pull back angle	90 to 180 degrees	Continuous variable
Stop pin	1 to 6	Categorical variable
Tower pin	1 to 4	Interaction with pull back
Cup position	1 to 6	Interaction with rubber band attachment
Rubber band attachment	1 to 6	Interaction with cup position

Variables investigated:

The input factors are stop pin, tower pin and the cup position. The pullback angle and rubber band attachment are kept constant.

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The table below shows the various input factors and their corresponding levels for the experiment:

Factors	Input factor	High level (+)	Low level (-)
A	Cup Position	5	2
B	Tower Pin	4	2
C	Stop Pin	5	2

Cause and Effect Diagram
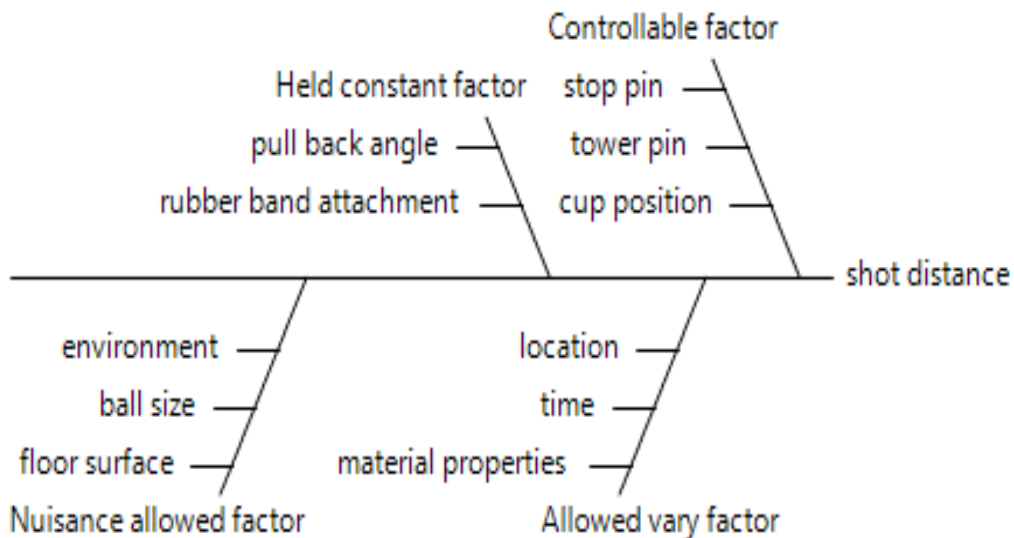
Cause and effect diagram

Materials:

1. Catapult equipment with ball
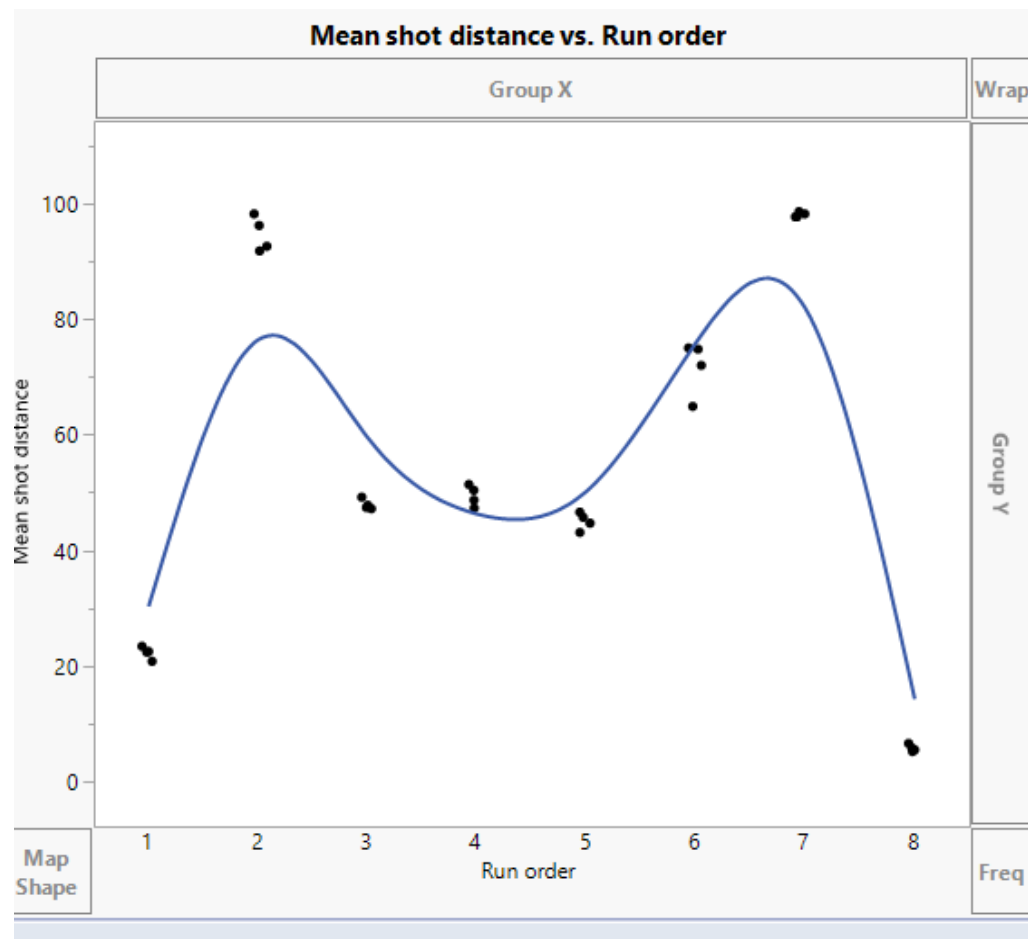2. Aluminum foil
3. Masking tape
4. Measuring tape

Procedure:

1. Place the catapult on the floor usually on the flat surface.
2. Roll the aluminum foil on the floor opposite to the catapult so that the ball length to be measured can be easily marked using the foil.
3. Using masking tape fix the foil in the corners.
4. Measuring tape should be aligned with the aluminum foil.
5. Make sure the measuring tape is placed from the start of the catapult till the other end.
6. Now based on the input factors and levels, the ball showed be launched.
7. Once the ball pitch the foil, measure the shot distance using measuring tape.

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8. Repeat the same procedure for all factors and levels while measuring the shot distance.
9. Make sure forming a data table with all the readings randomly and note the shot sequence.
10. Analyze with respect to various factors.

Data table:

Run order	Shot sequence	Factor			Distance			
		A	B	C	Run 1	Run 2	Run 3	Run 4
1	2	-	-	-	91.8	92.6	98.	96.2
2	7	-	-	+	97.7	98.2	97.7	98.2
3	5	-	+	-	46.6	45.7	43.1	44.7
4	4	-	+	+	47.3	48.7	50.4	51.4
5	3	+	-	-	47.8	47.4	47.2	49.2
6	6	+	-	+	74.8	72	75	64.9
7	1	+	+	-	20.8	23.4	22.4	22.5
8	8	+	+	+	6.6	5.5	5.5	5.8

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Mean shot distance vs. Run order

The graph between mean shot distance vs run order shows that there is some drift in run 2, 6, 7, 8.

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Data table in jmp:

	Cup position	Tower pin	Stop pin	Run order	Mean shot distance
1	+	+	-	1	20.8
2	+	+	-	1	23.4
3	-	-	-	2	91.8
4	+	-	-	3	47.8
5	-	+	+	4	47.3
6	-	+	-	5	46.6
7	-	-	-	2	92.6
8	-	+	+	4	48.7
9	+	-	+	6	74.8
10	-	-	-	2	98.2
11	+	-	+	6	72
12	+	-	-	3	47.4
13	-	-	+	7	97.7
14	+	+	-	1	22.4
15	-	-	+	7	98.2
16	-	+	-	5	45.7
17	+	-	+	6	75
18	-	+	-	5	43.1
19	+	+	+	8	6.6
20	+	-	-	3	47.2
21	-	+	+	4	50.4
22	-	-	+	7	97.7
23	+	+	+	8	5.2
24	+	-	+	6	64.9
25	-	-	-	2	96.2
26	-	-	+	7	98.6
27	+	+	-	1	22.5
28	-	+	+	4	51.4
29	-	+	-	5	44.7
30	+	-	-	3	49.2
31	+	+	+	8	5.5
32	+	+	+	8	5.8

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Response Mean shot distance

Summary of Fit

RSquare	0.996005
RSquare Adj	0.99484
Root Mean Square Error	2.221017
Mean of Response	54.35625
Observations (or Sum Wgts)	32

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	29515.489	4216.50	854.7678
Error	24	118.390	4.93	Prob > F
C. Total	31	29633.879		<.0001*

The overall F – statistic of the model is large with a very small P – value; there is strong evidence that at least one of the factors is different and influence the response.

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	54.35625	0.392624	138.44	<.0001*
Cup position[+]	-17.45	0.392624	-44.44	<.0001*
Tower pin[+]	-23.725	0.392624	-60.43	<.0001*
Stop pin[+]	1.88125	0.392624	4.79	<.0001*
Cup position[+]*Tower pin[+]	0.84375	0.392624	2.15	0.0419*
Cup position[+]*Stop pin[+]	-0.0625	0.392624	-0.16	0.8749
Tower pin[+]*Stop pin[+]	-4.9	0.392624	-12.48	<.0001*
Cup position[+]*Tower pin[+]*Stop pin[+]	-5.16875	0.392624	-13.16	<.0001*

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Cup position	1	1	9744.080	1975.318	<.0001*
Tower pin	1	1	18012.020	3651.394	<.0001*
Stop pin	1	1	113.251	22.9583	<.0001*
Cup position*Tower pin	1	1	22.781	4.6182	0.0419*
Cup position*Stop pin	1	1	0.125	0.0253	0.8749
Tower pin*Stop pin	1	1	768.320	155.7537	<.0001*
Cup position*Tower pin*Stop pin	1	1	854.911	173.3075	<.0001*

From the effect tests, except for the two interaction of factor (cup position * stop pin) all other factors and two interactions are significant as the p-value is smaller than $\alpha = 0.05$

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Effect Details

Cup position

LSMeans Differences Student's t

α= 0.050 t= 2.0639

Level		Least Sq Mean
-	A	71.806250
+	B	36.906250

Levels not connected by same letter are significantly different.

Tower pin

LSMeans Differences Student's t

α= 0.050 t= 2.0639

Level		Least Sq Mean
-	A	78.081250
+	B	30.631250

Levels not connected by same letter are significantly different.

Stop pin

LSMeans Differences Student's t

α= 0.050 t= 2.0639

Level		Least Sq Mean
+	A	56.237500
-	B	52.475000

Levels not connected by same letter are significantly different.

Cup position*Tower pin

LSMeans Differences Student's t

α= 0.050 t= 2.0639

Level			Least Sq Mean
-,-	A		96.375000
+,-	B		59.787500
-,+		C	47.237500
+,+		D	14.025000

Levels not connected by same letter are significantly different.

Cup position*Stop pin

LSMeans Differences Student's t

α= 0.050 t= 2.0639

Level			Least Sq Mean
-,+	A		73.750000
-,-	B		69.862500
+,+		C	38.725000
+,-		D	35.087500

Levels not connected by same letter are significantly different.

Tower pin*Stop pin

LSMeans Differences Student's t

α= 0.050 t= 2.0639

Level			Least Sq Mean
-,+	A		84.862500
-,-	B		71.300000
+,-		C	33.650000
+,+		D	27.612500

Levels not connected by same letter are significantly different.

Cup position*Tower pin*Stop pin

LSMeans Differences Student's t

α= 0.050 t= 2.0639

Level						Least Sq Mean
-,-,+	A					98.050000
-,-,-	B					94.700000
+,-,+		C				71.675000
-,+,+			D			49.450000
+,-,-			D	E		47.900000
-,+,-				E		45.025000
+,+,-					F	22.275000
+,+,+					G	5.775000

Levels not connected by same letter are significantly different.

From the connecting letters report of single factor it could be seen that the means of two levels are different at $\alpha = 0.05$

From the connecting letters report of two factor interaction it could be seen that the means of two levels are different at $\alpha = 0.05$

From the connecting letters report of three factor interaction it could be seen that the means of -,+,+ &+,-,- and +,-,-&-,+,- are same. All the other levels that are not connected by the same letter are significant at $\alpha = 0.05$

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Normal Plot
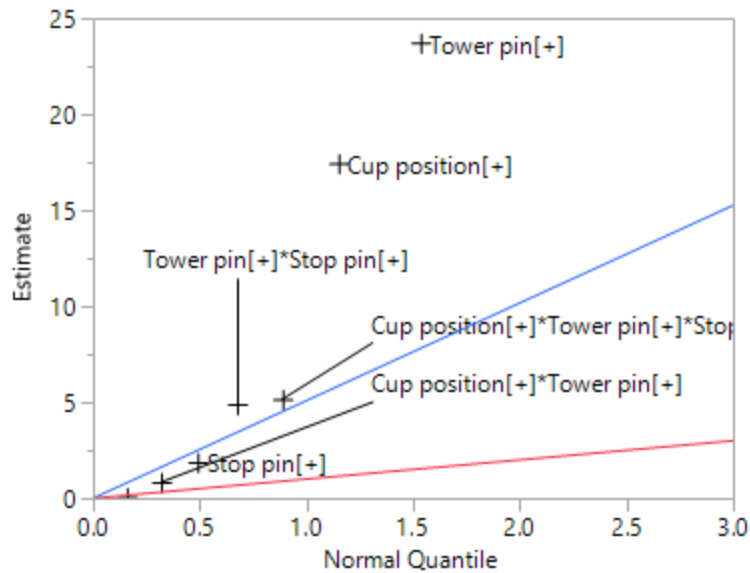
Half Normal Plot

Blue line has slope equal to Lenth's PSE.
Red line has slope 1.

From the half normal plot, we can see that all factors are significant except the interaction between cup position and stop pin and interaction between cup position and tower pin are not significant.

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-Meenakshi Nagarajan

Response Mean shot distance

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	22.90625	11.4531	2.3218
Pure Error	24	118.39000	4.9329	Prob > F
Total Error	26	141.29625		0.1197
				Max RSq
				0.9960

Summary of Fit

RSquare	0.995232
RSquare Adj	0.994315
Root Mean Square Error	2.331195
Mean of Response	54.35625
Observations (or Sum Wgts)	32

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	29492.583	5898.52	1085.389
Error	26	141.296	5.43	Prob > F
C. Total	31	29633.879		<.0001*

Parameter Estimates

| Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	54.35625	0.412101	131.90	<.0001*
Cup position[+]	-17.45	0.412101	-42.34	<.0001*
Tower pin[+]	-23.725	0.412101	-57.57	<.0001*
Stop pin[+]	1.88125	0.412101	4.57	0.0001*
Cup position[+]*Tower pin[+]*Stop pin[+]	-5.16875	0.412101	-12.54	<.0001*
Tower pin[+]*Stop pin[+]	-4.9	0.412101	-11.89	<.0001*

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Cup position	1	1	9744.080	1793.013	<.0001*
Tower pin	1	1	18012.020	3314.402	<.0001*
Stop pin	1	1	113.251	20.8394	0.0001*
Cup position*Tower pin*Stop pin	1	1	854.911	157.3127	<.0001*
Tower pin*Stop pin	1	1	768.320	141.3790	<.0001*

In the reduced model it can be seen that all the five factors that are chosen are significant at $\alpha = 0.05$

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Normal Quantile Plot
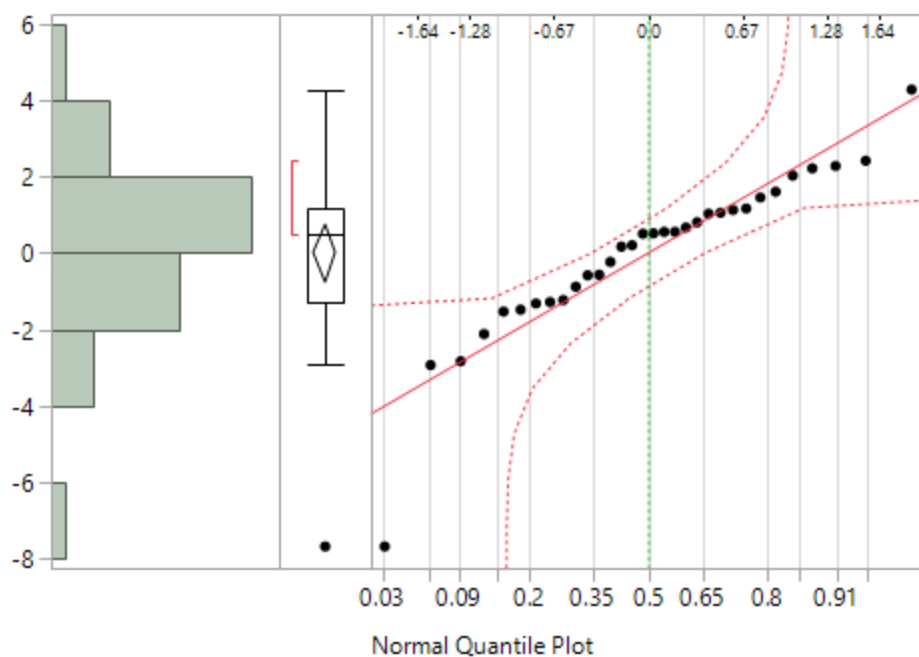
From the normal quantile plot of residuals it could be seen that except two points all the other points lie close to the line and it's within the error bounds. Therefore there is no significant deviation of the normality assumption.

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-Meenakshi Nagarajan
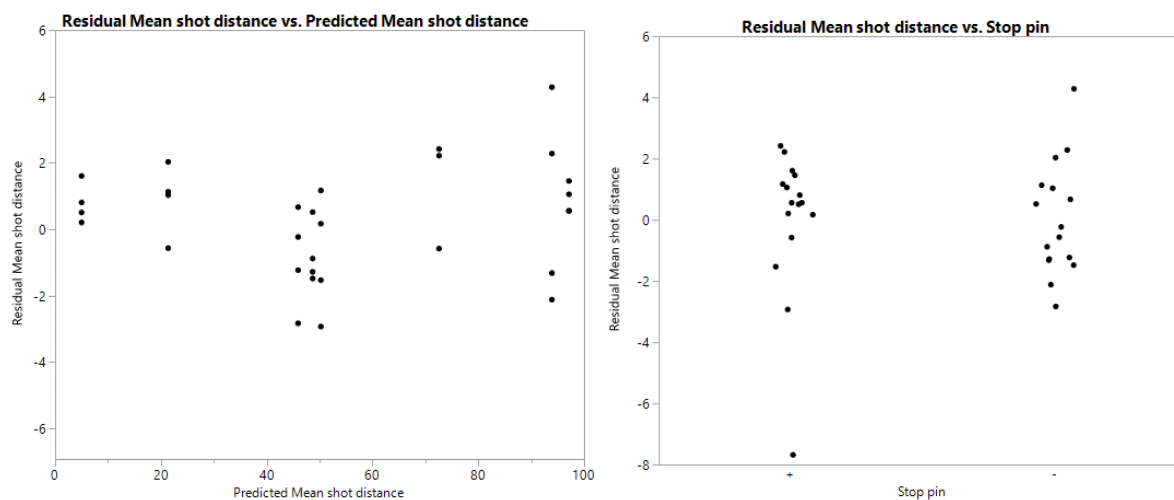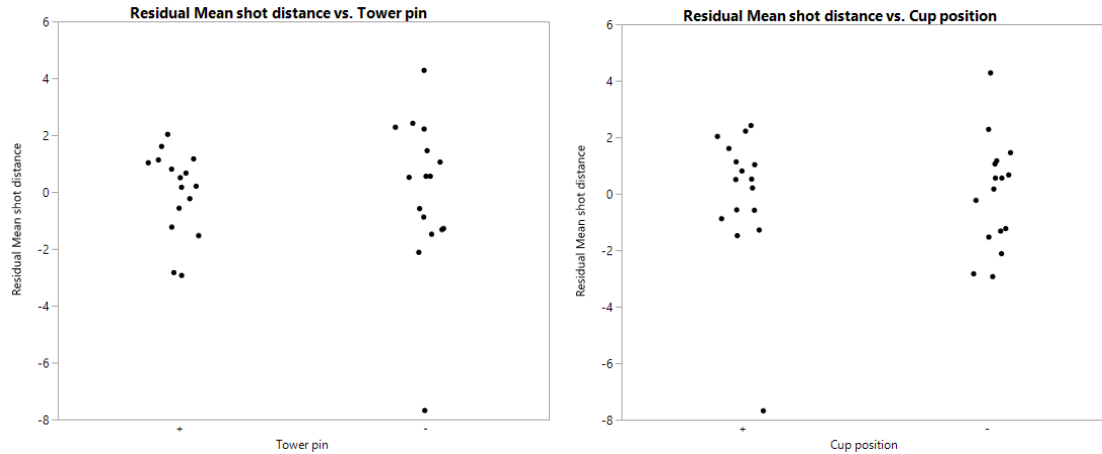
The plot of residual vs predicted shows that there is a similar range of variation across the predicted values and so the plot of residuals vs the factors.

Regression expression:

Shot distance = 54.35625-17.45*cup position–23.725*tower pin+1.88125*stop pin–5.16875*cup position*tower pin*stop pin-4.9*tower pin*stop pin

For factor settings, +,-,+

    =54.35625 -17.45+23.725-1.88125+5.16875+4.9

    =68.81875

This value is approximately equal to the mean shot distance that were recorded.

Anova analysis for standard deviation of short distance:

	cup position	tower pin	stop pin	Run 1	Run 2	Run 3	Run 4	Std. Dev
1	-	-	-	91.8	92.6	98	96.2	2.941088234
2	-	-	+	97.7	98.2	97.7	98.2	0.2886751346
3	-	+	-	46.6	45.7	43.1	44.7	1.4997221965
4	-	+	+	47.3	48.7	50.4	51.4	1.8156725109
5	+	-	-	47.8	47.4	47.2	49.2	0.9018499506
6	+	-	+	74.8	72	75	64.9	4.7197280995
7	+	+	-	20.8	23.4	22.4	22.5	1.0812801056
8	+	+	+	6.6	5.5	5.5	5.8	0.5196152423

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Response Std. Dev

Summary of Fit

RSquare	1
RSquare Adj	.
Root Mean Square Error	.
Mean of Response	1.720954
Observations (or Sum Wgts)	8

Effect Screening

The parameter estimates have equal variances.
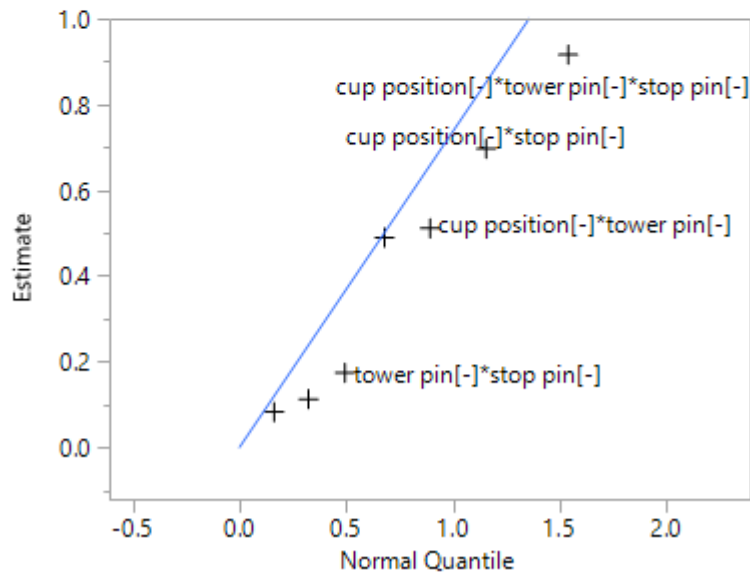The parameter estimates are not correlated.

Lenth PSE

0.7378221

Orthog t Test used Pseudo Standard Error

Normal Plot

Half Normal Plot

Blue line has slope equal to Lenth's PSE.

From the half normal plot it can be observed that the tower pin & stop pin, cup position & tower pin, cup position & stop pin and cup position & tower pin & stop pin lies far away from the line. Hence these factors are significant factors.

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Response Std. Dev

Summary of Fit

RSquare	0.553464
RSquare Adj	-2.12575
Root Mean Square Error	2.597877
Mean of Response	1.720954
Observations (or Sum Wgts)	8

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	8.365074	1.39418	0.2066
Error	1	6.748966	6.74897	Prob > F
C. Total	7	15.114040		0.9299

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.7209539	0.918488	1.87	0.3121
cup position[-]	-0.084664	0.918488	-0.09	0.9415
tower pin[-]	0.4918814	0.918488	0.54	0.6870
cup position[-]*tower pin[-]	-0.513289	0.918488	-0.56	0.6756
stop pin[-]	-0.114969	0.918488	-0.13	0.9207
cup position[-]*stop pin[-]	0.6990845	0.918488	0.76	0.5858
tower pin[-]*stop pin[-]	-0.176397	0.918488	-0.19	0.8792

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
cup position	1	1	0.0573445	0.0085	0.9415
tower pin	1	1	1.9355787	0.2868	0.6870
cup position*tower pin	1	1	2.1077269	0.3123	0.6756
stop pin	1	1	0.1057426	0.0157	0.9207
cup position*stop pin	1	1	3.9097532	0.5793	0.5858
tower pin*stop pin	1	1	0.2489285	0.0369	0.8792

From the effect test we can see that the p value of all factors are greater than $\alpha = 0.05$. Hence the factors are not significant. Therefore, we can eliminate two factor interactions and see if that makes any difference.

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Response Std. Dev

Summary of Fit

RSquare	0.138855
RSquare Adj	-0.507
Root Mean Square Error	1.803841
Mean of Response	1.720954
Observations (or Sum Wgts)	8

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	2.098666	0.69956	0.2150
Error	4	13.015375	3.25384	Prob > F
C. Total	7	15.114040		0.8814

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.7209539	0.637754	2.70	0.0542
cup position[-]	-0.084664	0.637754	-0.13	0.9008
tower pin[-]	0.4918814	0.637754	0.77	0.4836
stop pin[-]	-0.114969	0.637754	-0.18	0.8657

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
cup position	1	1	0.0573445	0.0176	0.9008
tower pin	1	1	1.9355787	0.5949	0.4836
stop pin	1	1	0.1057426	0.0325	0.8657

From the effect test we can see that the p value of all factors are greater than $\alpha = 0.05$. Hence the factors are not significant.

Effect Details

cup position

LSMeans Differences Student's t

α= 0.050 t= 2.77645

Level		Least Sq Mean
+	A	1.8056183
-	A	1.6362895

Levels not connected by same letter are significantly different.

tower pin

LSMeans Differences Student's t

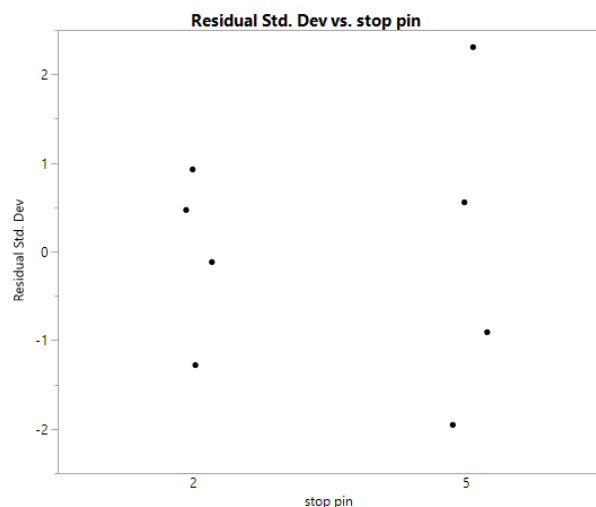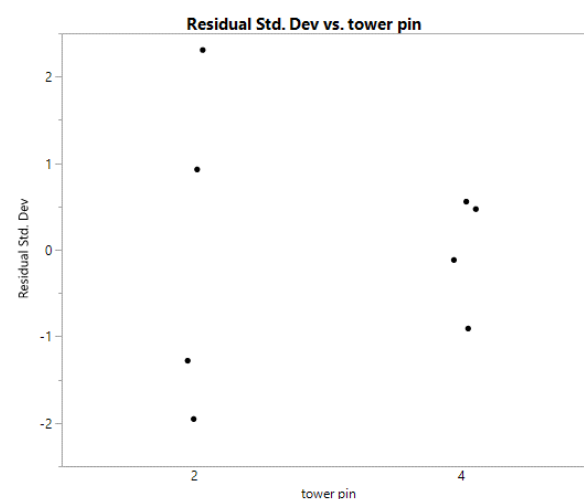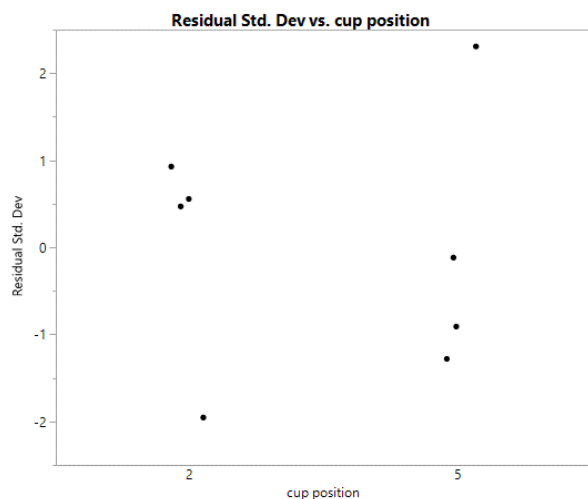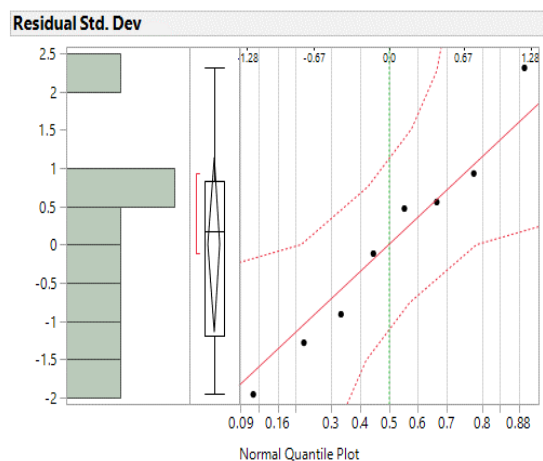α= 0.050 t= 2.77645

Level		Least Sq Mean
-	A	2.2128354
+	A	1.2290725

Levels not connected by same letter are significantly different.

Connecting letters report of factors shows that all levels are connected by same letter and they are not significantly different at $\alpha = 0.05$

stop pin

LSMeans Differences Student's t

α= 0.050 t= 2.77645

Level		Least Sq Mean
+	A	1.8359227
-	A	1.6059851

Levels not connected by same letter are significantly different.

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-Meenakshi Nagarajan

Residual Std. Dev vs. Predicted Std. Dev

Residual Std. Dev

Normal Quantile Plot

Residual Std. Dev vs. cup position

Residual Std. Dev vs. tower pin

Residual Std. Dev vs. stop pin

From the normal quantile plot it shows that all points lie close to the line and it's within the error bound. Hence there is no significant deviation of normality assumption.

From the graph of residual vs predicted shows that there is no unusual pattern of variance.

From the graph residual vs factors there is a similar range of variance for cup position. For tower pin the range of variance is smaller for higher level (4) and for stop pin the range of variance is smaller for lower level (2). There is no strong evidence against equal variance assumption.

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-Meenakshi Nagarajan

Regression expression for extra setting

Factors	Levels					
	1	**2**	**3**	**4**	**5**	**6**
Cup position		1	1/3	-1/3	-1	
Stop pin		1	1/3	-1/3	-1	
Tower pin		1	0	-1		

Shot distance

SHOT DISTANCE=54.3565 -17.45*Cup position -23.725*Tower Pin +1.88125*Stop Pin + 5.1685*Cup position*Tower Pin*Stop pin-4.9*Tower Pin*Stop Pin

SHOT DISTANCE=54.3565 -17.45*1/3 -23.725*0 +1.88125*(-1/3) + 5.1685*1/3*0 - 4.9*0*(-1/3)

Shot distance=47.913335

Conclusion:

From the ANOVA analysis, it is seen that all the factors that were selected affects the response whereas during the analysis of standard deviation, it could be seen that the same factors were not significant. If there is a change in alpha value, there is a chance of input factor 'stop pin' becoming a significant factor. The model was then validated with extra setting and was found that the mean shot distance from extra setting and the actual mean shot distance differs by abput 20cm.

We felt that the impression on aluminium foil to read the distance of the ball was quite difficult. We had to repeat the runs if we missed to notice the location where the ball was first tapped.