# Design of Experiments

Homework 6

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3/9/15

Problem 1

A process engineer is running a $2^3$ factorial experiment with two replications on the filling process of a soft drink using the factors Percent Carbonation {10%, 12%}, Operating Pressure {25 psi, 30 psi}, and Assembly Line Speed {200 bottles/min, 250 bottles/min}. The response variable in this design is Fill Height Deviation, the average deviation from the target fill height. Positive responses represent over-fill, and negative responses represent under-fill. The experiment's purpose is to determine if the soft drink filling machine fills the bottles with uniform heights. Therefore the hypothesis for each factor and two-way interactions are as follows:

**Hypothesis Test for Factor:** Carbonation

$H_o$: $\tau_i = 0 \quad \forall \quad i$ € Carbonation

$H_a$: $\tau_i \neq 0 \quad \forall \quad i$ € Carbonation

Level of Significance $\alpha = 0.05$

**Hypothesis Test for Factor:** Pressure

$H_o$: $\beta_j = 0 \quad \forall \quad j$ € Pressure

$H_a$: $\beta_j \neq 0 \quad \forall \quad j$ € Pressure

Level of Significance $\alpha = 0.05$

**Hypothesis Test for Factor:** Line Speed

$H_o$: $\gamma_k = 0 \quad \forall \quad k$ € Line Speed

$H_a$: $\gamma_k \neq 0 \quad \forall \quad k$ € Line Speed

Level of Significance $\alpha = 0.05$

**Hypothesis Test for Interaction:** Carbonation*Pressure

$H_o$: $(\tau\beta)_{ij} = 0 \quad \forall \quad (i,j)$ € Carbonation*Pressure

$H_a$: $(\tau\beta)_{ij} \neq 0 \quad \forall \quad (i,j)$ € Carbonation*Pressure

Level of Significance $\alpha = 0.05$

**Hypothesis Test for Interaction:** Carbonation*Line Speed

$H_o$: $(\tau\gamma)_{ik} = 0 \quad \forall \quad (i,k)$ € Carbonation*Line Speed

$H_a$: $(\tau\gamma)_{ik} \neq 0 \quad \forall \quad (i,k)$ € Carbonation*Line Speed

Level of Significance $\alpha = 0.05$

**Hypothesis Test for Interaction:** Pressure*Line Speed

$H_o$: $(\beta\gamma)_{jk} = 0 \quad \forall \quad (j,k)$ € Pressure*Line Speed

$H_a$: $(\beta\gamma)_{jk} \neq 0 \quad \forall \quad (j,k)$ € Pressure*Line Speed

Level of Significance $\alpha = 0.05$

**Hypothesis Test for Regression**

$H_o$: $\delta_m = \delta_n = 0 \;\forall\;$ m & n € Factor Coefficients s.t. m & n > 0

$H_a$: $\delta_m \neq 0$ for at least one m € Factor Coefficients s.t. m > 0

Level of Significance $\alpha = 0.05$

Figure 1 shows that the high level for each factor increases the Fill Height Deviation to the point of over-filling the bottle. The center line for the factors is a +1 [unit] deviation. Based on Figure 1 the low level for Carbonation under-fills by 0.5 [unit], the low level for Pressure is approximately on target, and the low level for Line Speed over-fills by < 0.5 [unit].

Figure 2 shows the two-way interactions between each of the three factors' levels. The green circles in each plot indicate the recommended pair of levels for the two corresponding factors to approximately meet the target fill height. The plots all agree that Carbonation should be at the low level and Line Speed should be at the high level, but there is a disagreement on the desired level for Pressure which can be found in the Carb.*Pressure Plots and Pressure*Line Speed Plots. Based on Figure 2 the best solution is yet to be seen due to the limits of 2-levels in a $2^K$ design.

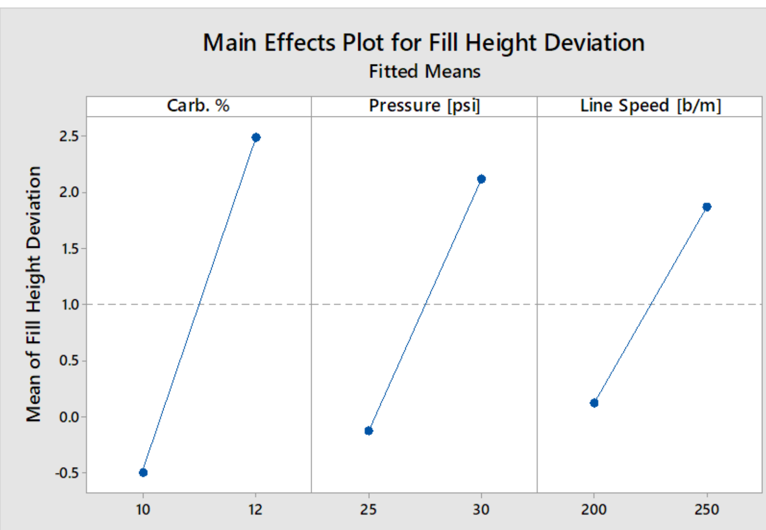


Figure 1: Main Effects Plot

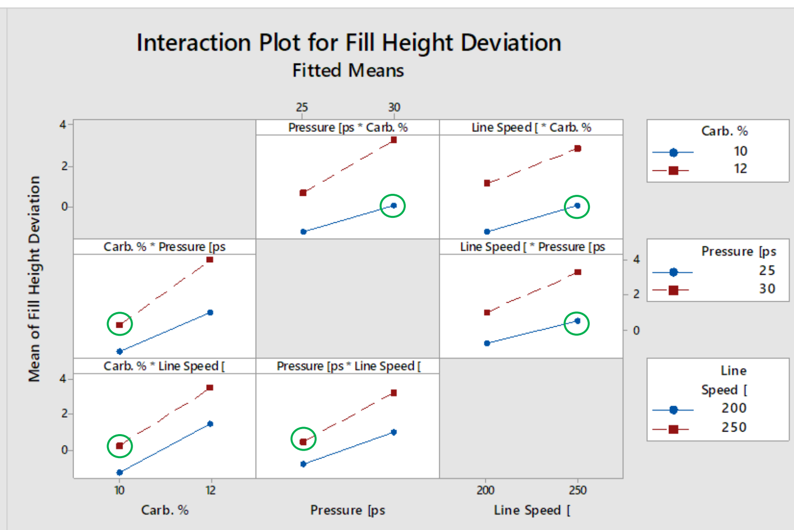


Figure 2: Interaction Plot

**Regression Analysis (Two-Way Interaction) Conclusion:**

The ANOVA table below shows that the regression equation has at least one factor which explains the Fill Height Deviation at a 0.05 level of significance due to a P-Value of > 0.000 < 0.05. Therefore we reject the null hypothesis for Regression. The factors of Carbonation, Pressure, and Line Speed show significant differences in average Fill Height Deviation across their corresponding levels at a 0.05 level of significance due to their P-Values < 0.05. Therefore we reject the null hypotheses for each of these three factors and conclude that there is a significant difference in Fill Height Deviation across the corresponding levels of each factor. All of the two-way interaction factors between Carbonation, Pressure, and Line Speed show no significant difference in average fill height deviation across their corresponding levels at a 0.05 level of significance due to their P-Values > 0.05. Therefore we fail to reject the null hypotheses for each of these factors and interactions and conclude that there isn't a significant difference in Fill Height Deviation across the corresponding levels of each factor and interaction.

The Coded Coefficients Table (*Continuous predictor standardization: Levels coded to -1 and +1*) below shows that Carbonation has the largest magnitude of impact on Fill Height Deviation due to the highest absolute value in the Coefficients column. The remaining magnitudes of impact ranking high to low are Pressure, Line Speed, Carbonation*Pressure, Pressure*Line Speed, and Carbonation*Line Speed. Notice that the magnitude of the Coefficient values and corresponding P-Values are inversely related.

The Model Summary below shows a strong linear relationship between Fill Height Deviation and the three factors and their two-way interactions due to a large $R^2$ Value of 92.31% close to a perfect 100%. Therefore 92.31% of the total variance in Fill Height Deviation can be explained by the linear relationship between Fill Height Deviation and the corresponding factors and interactions. The uncoded linear regression equation can be found at the bottom of the statistical output. Notice that the large $R^2$ value agrees with the conclusion on the Regression Hypothesis Test that at least one factor explains Fill Height Deviation.

There is one additional term in the regression model, Carbonation*Pressure, which shows a significant difference in average Fill Height Deviation across its levels at a 0.10 level of significance due to a P-Value of $0.099 < 0.10$.

### Regression Analysis: Fill Height Deviation versus Carb. %, Pressure [psi], Line Speed [b/m] (Two-Way Interaction)

```
Method
Continuous predictor standardization
Levels coded to -1 and +1

Predictor          Low  High
Carb. %             10    12
Pressure [psi]      25    30
Line Speed [b/m]   200   250


Analysis of Variance
Source                               DF   Adj SS   Adj MS  F-Value  P-Value
Regression                            6  72.0000  12.0000    18.00    0.000
  Carb. %                             1  36.0000  36.0000    54.00    0.000
  Pressure [psi]                      1  20.2500  20.2500    30.38    0.000
  Line Speed [b/m]                    1  12.2500  12.2500    18.38    0.002
  Carb. %*Pressure [psi]              1   2.2500   2.2500     3.38    0.099
  Carb. %*Line Speed [b/m]            1   0.2500   0.2500     0.38    0.555
  Pressure [psi]*Line Speed [b/m]     1   1.0000   1.0000     1.50    0.252
Error                                 9   6.0000   0.6667
  Lack-of-Fit                         1   1.0000   1.0000     1.60    0.242
  Pure Error                          8   5.0000   0.6250
Total                                15  78.0000
```

```
Model Summary
       S    R-sq  R-sq(adj)  R-sq(pred)
0.816497  92.31%     87.18%      75.69%


Coded Coefficients
Term                                 Coef  SE Coef  T-Value  P-Value   VIF
Constant                            1.000    0.204     4.90    0.001
Carb. %                             1.500    0.204     7.35    0.000  1.00
Pressure [psi]                      1.125    0.204     5.51    0.000  1.00
Line Speed [b/m]                    0.875    0.204     4.29    0.002  1.00
Carb. %*Pressure [psi]              0.375    0.204     1.84    0.099  1.00
Carb. %*Line Speed [b/m]            0.125    0.204     0.61    0.555  1.00
Pressure [psi]*Line Speed [b/m]     0.250    0.204     1.22    0.252  1.00

Regression Equation in Uncoded Units
Fill Height Deviation = 46.8 - 3.75 Carb. % - 2.10 Pressure [psi] - 0.130 Line Speed [b/m]
                        + 0.1500 Carb. %*Pressure [psi] + 0.00500 Carb. %*Line Speed [b/m]
                        + 0.00400 Pressure [psi]*Line Speed [b/m]
```

**Regression Analysis (Refit) Conclusion:**

The significant factors at a 0.10 level of significance are refitted into a regression model whereas the insignificant factors at a 0.10 level of significance are ignored.

The ANOVA table below shows very similar results to the previous ANOVA table for each of the corresponding sources. The Regression Equation, and factors of Carbonation, Pressure, Line Speed, and Carbonation*Pressure show significant differences in average Fill Height Deviation across their corresponding levels at a 0.10 level of significance due to their P-Values < 0.10. Therefore we reject the null hypotheses for each of these source terms and conclude that there is a significant difference in Fill Height Deviation across the corresponding levels of each term.

The Coded Coefficients table below shows very similar results to the previous Coded Coefficients table for each of the corresponding Factors. All of the corresponding Coefficient values are exactly the same as in the previous table and therefore have the same rank in magnitude of impact on Fill Height Deviation.

The Model Summary below shows different results from the previous Model Summary for each Coefficient of Determination which can be found in Table 1 below the statistical output. The $R^2$ value decreases, the $R^2_{ADJ}$ value increases, and the $R^2_{PRED}$ value increases by 1.60%, 0.15%, and 4.64% respectively. The $R^2$ value decreases when the Regression model is refitted because the total number of factors in the model has decreased. The $R^2_{ADJ}$ value and $R^2_{PRED}$ value increase because the Regression Model has been refitted with only significant terms; therefore the Coefficient of Determination isn't penalized the same as in the previous model for including insignificant factors at a 0.10 level of significance.

## Regression Analysis (Refit with Significant Factors at α = 0.10)

```
Method
Continuous predictor standardization
Levels coded to -1 and +1

Predictor          Low  High
Carb. %             10    12
Pressure [psi]      25    30
Line Speed [b/m]   200   250


Analysis of Variance
Source                    DF   Adj SS    Adj MS  F-Value  P-Value
Regression                 4   70.750   17.6875    26.84    0.000
  Carb. %                  1   36.000   36.0000    54.62    0.000
  Pressure [psi]           1   20.250   20.2500    30.72    0.000
  Line Speed [b/m]         1   12.250   12.2500    18.59    0.001
  Carb. %*Pressure [psi]   1    2.250    2.2500     3.41    0.092
Error                     11    7.250    0.6591
  Lack-of-Fit              3    2.250    0.7500     1.20    0.370
  Pure Error               8    5.000    0.6250
Total                     15   78.000

Model Summary
       S    R-sq  R-sq(adj)  R-sq(pred)
0.811844  90.71%     87.33%      80.33%

Coded Coefficients
Term                     Coef  SE Coef  T-Value  P-Value   VIF
Constant                1.000    0.203     4.93    0.000
Carb. %                 1.500    0.203     7.39    0.000  1.00
Pressure [psi]          1.125    0.203     5.54    0.000  1.00
Line Speed [b/m]        0.875    0.203     4.31    0.001  1.00
Carb. %*Pressure [psi]  0.375    0.203     1.85    0.092  1.00

Regression Equation in Uncoded Units
Fill Height Deviation = 9.6 - 2.62 Carb. % - 1.200 Pressure [psi] + 0.03500 Line Speed [b/m]
                        + 0.1500 Carb. %*Pressure [psi]
```

| Model | R^2 | R^2 (Adj) | R^2 (Pred) |
|---|---|---|---|
| *2-Way Interaction* | 92.31% | 87.18% | 75.69% |
| *Refit Factors* | 90.71% | 87.33% | 80.33% |

Table 1: Model Summary Comparison

### Center Points and Curvature in the $2^3$ Bottle Filling Factorial Design:

Table 2 below shows the values for each of the design factors that represents the center point for this $2^3$ design. Curvature may be present in Fill Height Deviation because of adding interaction terms to the main effects model. Curvature is due to the interaction terms inducing the twist of the geometric plane. If a quadratic effects model were to be better representation for Fill Height Deviation, then curvature would be present in Carbonation, Pressure, and Line Speed. The center point in Table 2 would be used in this experiment to evaluate curvature.

| | Carb. % | Pressure [psi] | Line Speed [b/m] |
|---|---|---|---|
| *Center Point:* | 11 | 27.5 | 225 |

Table 2: Bottle Filling Center Point

Problem 2

Continuing off of the $2^3$ bottle filling factorial experiment, four center points with Fill Height Deviation values of 4, 5, 4, and 6 are incorporated into the design for the analysis of curvature. The Hypothesis Tests associated with this design are the same as before plus the third level interaction, and a test for means which is due to the addition of a factor Point {Center, Factorial}. The factor Point represents which Fill Height Deviation values are from factorial points and are from center points. The additional Hypothesis Tests are as follows:

**Hypothesis Test for Curvature:** Point

$H_o$: $\mu_f = \mu_c$ $\forall$ f & c € Point

$H_a$: $\mu_f \neq \mu_c$ for at least 1-f & 1-c € Point

Level of Significance: $\alpha = 0.05$

**Hypothesis Test for Interaction:** Carbonation*Pressure*Line Speed

$H_o$: $(\tau\beta\gamma)_{ijk} = 0$ $\forall$ (i,j,k) € Carbonation*Pressure*Line Speed

$H_a$: $(\tau\beta\gamma)_{ijk} \neq 0$ $\forall$ (i,j,k) € Carbonation*Pressure*Line Speed

Level of Significance $\alpha = 0.05$

**Regression Analysis (Three-Way Interaction w/ Center Points) Conclusion:**

The ANOVA table below shows that the regression equation doesn't have a factor which explains the Fill Height Deviation at a 0.05 level of significance due to a P-Value of 0.090 > 0.05. Therefore we fail to reject the null hypothesis for Regression. Carbonation shows a significant difference in average Fill Height Deviation across it's levels at a 0.05 level of significance due to a P-Value of 0.014 < 0.05. Therefore we reject the null hypothesis for Carbonation and conclude that there is a significant difference in Fill Height Deviation across the levels of Carbonation. Pressure, Line Speed and all of the interaction factors between Carbonation, Pressure, and Line Speed show no significant difference in average fill height deviation across their corresponding levels at a 0.05 level of significance due to their P-Values > 0.05. Therefore we fail to reject the null hypotheses for each of these factors and interactions and conclude that there isn't a significant difference in Fill Height Deviation across the corresponding levels of each factor and interaction.

The Coded Coefficients Table below shows similar results in to the *Regression Analysis (Two-Way Interaction)* in Coefficient values. Carbonation has the largest magnitude of impact on Fill Height Deviation due to the highest absolute value in the Coefficients column. The remaining magnitudes of impact ranking high to low are Pressure, Line Speed, Carbonation*Pressure, Pressure*Line Speed, Carbonation*Pressure*Line Speed, and Carbonation*Line Speed. The coefficient of the Constant term increases from 1.000 to 1.750 in comparison to *Regression Analysis (Two-Way Interaction).* Notice that the magnitude of the Coefficient values and corresponding P-Values are inversely related.

The Model Summary below shows a weaker linear relationship between Fill Height Deviation and the three factors and their interactions in comparison to *Regression Analysis (Two-Way Interaction).* This is due to a $R^2$ Value decreasing from 92.31% to 58.05%. Therefore 58.05% of the total variance in Fill Height Deviation can be explained by the linear relationship between Fill Height Deviation and the corresponding factors and interactions. The uncoded linear regression equation can be found at the bottom of the statistical output. Notice that the smaller $R^2$ value agrees with the conclusion on the Regression Hypothesis Test that no factors explain the Fill Height Deviation.

The P-Value of Lack-of-Fit under Error is significant at a 0.05 level of significance in the ANOVA table below. This shows that there is a significant factor which isn't included in the regression model. All factors and levels of interactions have been included which indicates that there is a quadratic term to better explain the regression model. Therefore curvature appears to be present.

**Regression Analysis: Fill Height Devi versus Carb. %, Pressure [psi], Line Speed [b/m] (Three-Way Interaction w/ Center Points)**

```
Method
Continuous predictor standardization
Levels coded to -1 and +1
```

| Predictor | Low | High |
|---|---|---|
| Carb. %_CP | 10 | 12 |
| Pressure [psi]_CP | 25 | 30 |
| Line Speed [b/m]_CP | 200 | 250 |

Analysis of Variance

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Regression | 7 | 73.000 | 10.4286 | 2.37 | 0.090 |
| Carb. %_CP | 1 | 36.000 | 36.0000 | 8.19 | 0.014 |
| Pressure [psi]_CP | 1 | 20.250 | 20.2500 | 4.61 | 0.053 |
| Line Speed [b/m]_CP | 1 | 12.250 | 12.2500 | 2.79 | 0.121 |
| Carb. %_CP*Pressure [psi]_CP | 1 | 2.250 | 2.2500 | 0.51 | 0.488 |
| Carb. %_CP*Line Speed [b/m]_CP | 1 | 0.250 | 0.2500 | 0.06 | 0.816 |
| Pressure [psi]_CP*Line Speed [b/m]_CP | 1 | 1.000 | 1.0000 | 0.23 | 0.642 |
| Carb. %_CP*Pressure [psi]_CP*Line Speed [b/m]_CP | 1 | 1.000 | 1.0000 | 0.23 | 0.642 |
| Error | 12 | 52.750 | 4.3958 | | |
| Lack-of-Fit | 1 | 45.000 | 45.0000 | 63.87 | 0.000 |
| Pure Error | 11 | 7.750 | 0.7045 | | |
| Total | 19 | 125.750 | | | |

Model Summary

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 2.09662 | 58.05% | 33.58% | 23.47% |

Coded Coefficients

| Term | Coef | SE Coef | T-Value | P-Value | VIF |
|---|---|---|---|---|---|
| Constant | 1.750 | 0.469 | 3.73 | 0.003 | |
| Carb. %_CP | 1.500 | 0.524 | 2.86 | 0.014 | 1.00 |
| Pressure [psi]_CP | 1.125 | 0.524 | 2.15 | 0.053 | 1.00 |
| Line Speed [b/m]_CP | 0.875 | 0.524 | 1.67 | 0.121 | 1.00 |
| Carb. %_CP*Pressure [psi]_CP | 0.375 | 0.524 | 0.72 | 0.488 | 1.00 |
| Carb. %_CP*Line Speed [b/m]_CP | 0.125 | 0.524 | 0.24 | 0.816 | 1.00 |
| Pressure [psi]_CP*Line Speed [b/m]_CP | 0.250 | 0.524 | 0.48 | 0.642 | 1.00 |
| Carb. %_CP*Pressure [psi]_CP*Line Speed [b/m]_CP | 0.250 | 0.524 | 0.48 | 0.642 | 1.00 |

```
Regression Equation in Uncoded Units
Fill Height Deviation_CP = -225 + 21.0 Carb. %_CP + 7.8 Pressure [psi]_CP
                           + 1.08 Line Speed [b/m]_CP - 0.75 Carb. %_CP*Pressure [psi]_CP
                           - 0.105 Carb. %_CP*Line Speed [b/m]_CP
                           - 0.0400 Pressure [psi]_CP*Line Speed [b/m]_CP
                           + 0.00400 Carb. %_CP*Pressure [psi]_CP*Line Speed [b/m]_CP
```

**One-Way ANOVA Conclusion:**

The ANOVA table below shows that Point has a significant difference in average Fill Height Deviation between its levels of Center and Factorial at a 0.05 level of significance due to a P-Value of 0.005 < 0.05. Therefore we reject the null hypotheses for curvature and conclude that there is a significant difference in Fill Height Deviation across the levels of Point. This confirms that there is curvature in the Regression model with the addition of center points. Notice that this conclusion agrees with the Lack-of-Fit result in the *Regression Analysis (Three-Way Interaction w/ Center Points)* above.

### One-way ANOVA: Fill Height Deviation versus Point

```
Factor Information
Factor  Levels  Values
Point        2  Center, Factorial

Analysis of Variance
Source  DF  Adj SS  Adj MS  F-Value  P-Value
Point    1   45.00  45.000    10.03    0.005
Error   18   80.75   4.486
Total   19  125.75
```

Figure 3 below visually shows the quadratic effect of curvature with the addition of center points.

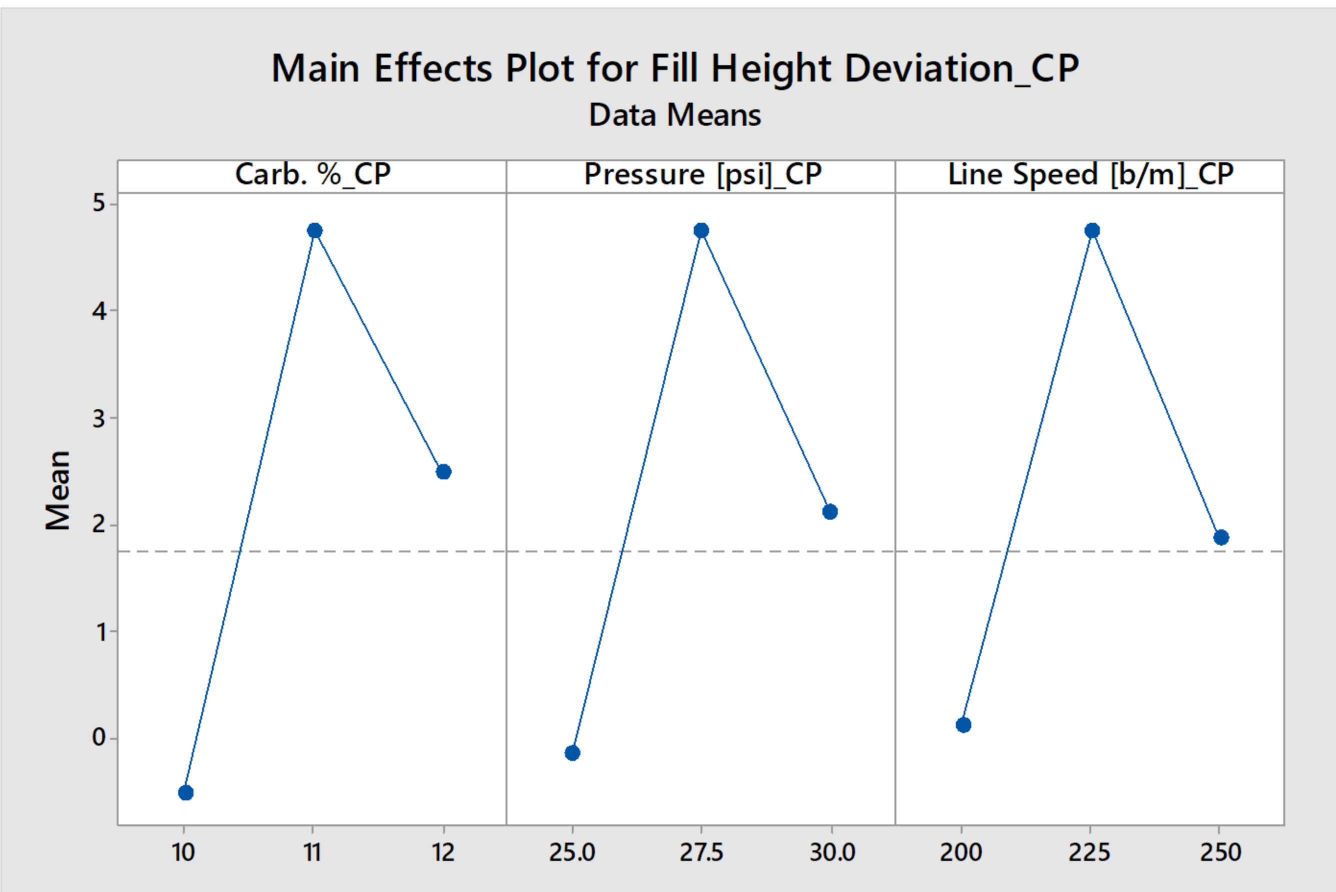


Figure 3: Main Effects Plot with Center Points

Problem 3

***The experiment from Homework 5 has since been changed and approved by the professor*

The experiment I will run is a simulation model of the Boston Duck Boat Tours. The factors and levels for a $2^3$ Factorial Design is as follows:

| Factors | | | | Response |
|---|---|---|---|---|
| *Level* | *Number of Boats* | *Mean Process Time* | *Process Distribution* | *Time in System* |
| Low | 10 | 80 [min] | Normal | [min] |
| High | 20 | 90 [min] | LogNormal | [min] |

Table 3: $2^3$ Duck Boat Tour Factorial Design

The following design has two center points for Number of Boats, Mean Process Time, and Process Distribution at (15, 85, Normal) and (15, 85, LogNormal) respectively. The Geometric View of this design can be seen below in Figure 4.

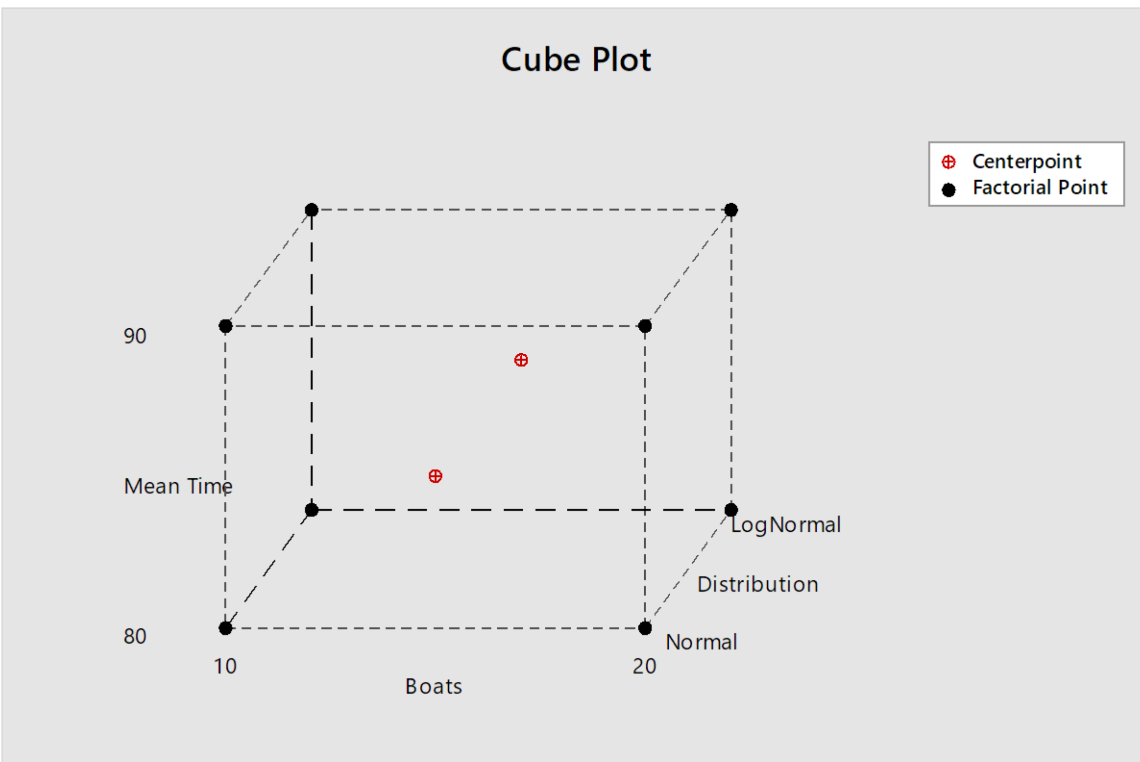


Figure 4: Cube Plot

The factors and levels for a $2^4$ Boston Duck Boat Tour Factorial Design is as follows:

| Factors | | | | | Response |
|---|---|---|---|---|---|
| *Level* | *Number of Boats* | *Mean Process Time* | *Process Distribution* | *Mean Down Time* | *Time in System* |
| Low | 10 | 80 [min] | Normal | 30 [min] | [min] |
| High | 20 | 90 [min] | LogNormal | 60 [min] | [min] |

Table 4: $2^4$ Duck Boat Tour Factorial Design

Table 5 below represents the $2^4$ Design from Table 4 with a Blocking Factor (Operator) of 4 Blocks which represents the 4 operators of the Duck Boats. Table 5 shows which run orders use a center point or a factorial point. Finally, Table 5 shows the actual units and coded units for each run.

| RunOrder | CenterPt | Blocks | Boats | Mean Time [Min] | Distribution | Down Time [Min] | Boats Coded | Mean Time Coded | Distribution Coded | Down Time Coded |
|---|---|---|---|---|---|---|---|---|---|---|
| *1* | *Yes* | *Joe* | 15 | 85 | LogNormal | 45 | 0 | 0 | 1 | 0 |
| *2* | *No* | *Joe* | 10 | 80 | LogNormal | 30 | -1 | -1 | 1 | -1 |
| *3* | *Yes* | *Joe* | 15 | 85 | Normal | 45 | 0 | 0 | -1 | 0 |
| *4* | *No* | *Joe* | 20 | 90 | Normal | 30 | 1 | 1 | -1 | -1 |
| *5* | *No* | *Joe* | 10 | 90 | Normal | 60 | -1 | 1 | -1 | 1 |
| *6* | *Yes* | *Joe* | 15 | 85 | Normal | 45 | 0 | 0 | -1 | 0 |
| *7* | *No* | *Joe* | 20 | 80 | LogNormal | 60 | 1 | -1 | 1 | 1 |
| *8* | *Yes* | *Joe* | 15 | 85 | LogNormal | 45 | 0 | 0 | 1 | 0 |
| *9* | *Yes* | *Joe* | 15 | 85 | LogNormal | 45 | 0 | 0 | 1 | 0 |
| *10* | *Yes* | *Joe* | 15 | 85 | Normal | 45 | 0 | 0 | -1 | 0 |
| *11* | *Yes* | *Joe* | 15 | 85 | Normal | 45 | 0 | 0 | -1 | 0 |
| *12* | *Yes* | *Joe* | 15 | 85 | LogNormal | 45 | 0 | 0 | 1 | 0 |
| *13* | *Yes* | *Kate* | 15 | 85 | Normal | 45 | 0 | 0 | -1 | 0 |
| *14* | *Yes* | *Kate* | 15 | 85 | Normal | 45 | 0 | 0 | -1 | 0 |
| *15* | *Yes* | *Kate* | 15 | 85 | LogNormal | 45 | 0 | 0 | 1 | 0 |
| *16* | *Yes* | *Kate* | 15 | 85 | LogNormal | 45 | 0 | 0 | 1 | 0 |
| *17* | *Yes* | *Kate* | 15 | 85 | Normal | 45 | 0 | 0 | -1 | 0 |
| *18* | *No* | *Kate* | 10 | 90 | LogNormal | 30 | -1 | 1 | 1 | -1 |
| *19* | *Yes* | *Kate* | 15 | 85 | LogNormal | 45 | 0 | 0 | 1 | 0 |
| *20* | *No* | *Kate* | 20 | 90 | LogNormal | 60 | 1 | 1 | 1 | 1 |
| *21* | *Yes* | *Kate* | 15 | 85 | LogNormal | 45 | 0 | 0 | 1 | 0 |
| *22* | *No* | *Kate* | 10 | 80 | Normal | 60 | -1 | -1 | -1 | 1 |
| *23* | *No* | *Kate* | 20 | 80 | Normal | 30 | 1 | -1 | -1 | -1 |
| *24* | *Yes* | *Kate* | 15 | 85 | Normal | 45 | 0 | 0 | -1 | 0 |
| *25* | *Yes* | *Sara* | 15 | 85 | LogNormal | 45 | 0 | 0 | 1 | 0 |
| *26* | *Yes* | *Sara* | 15 | 85 | LogNormal | 45 | 0 | 0 | 1 | 0 |
| *27* | *Yes* | *Sara* | 15 | 85 | Normal | 45 | 0 | 0 | -1 | 0 |
| *28* | *No* | *Sara* | 10 | 90 | Normal | 30 | -1 | 1 | -1 | -1 |
| *29* | *No* | *Sara* | 20 | 90 | Normal | 60 | 1 | 1 | -1 | 1 |
| *30* | *No* | *Sara* | 20 | 80 | LogNormal | 30 | 1 | -1 | 1 | -1 |
| *31* | *Yes* | *Sara* | 15 | 85 | LogNormal | 45 | 0 | 0 | 1 | 0 |
| *32* | *No* | *Sara* | 10 | 80 | LogNormal | 60 | -1 | -1 | 1 | 1 |
| *33* | *Yes* | *Sara* | 15 | 85 | LogNormal | 45 | 0 | 0 | 1 | 0 |
| *34* | *Yes* | *Sara* | 15 | 85 | Normal | 45 | 0 | 0 | -1 | 0 |
| *35* | *Yes* | *Sara* | 15 | 85 | Normal | 45 | 0 | 0 | -1 | 0 |
| *36* | *Yes* | *Sara* | 15 | 85 | Normal | 45 | 0 | 0 | -1 | 0 |
| *37* | *No* | *Moby* | 20 | 80 | Normal | 60 | 1 | -1 | -1 | 1 |
| *38* | *Yes* | *Moby* | 15 | 85 | Normal | 45 | 0 | 0 | -1 | 0 |
| *39* | *Yes* | *Moby* | 15 | 85 | LogNormal | 45 | 0 | 0 | 1 | 0 |
| *40* | *No* | *Moby* | 20 | 90 | LogNormal | 30 | 1 | 1 | 1 | -1 |
| *41* | *Yes* | *Moby* | 15 | 85 | Normal | 45 | 0 | 0 | -1 | 0 |
| *42* | *No* | *Moby* | 10 | 80 | Normal | 30 | -1 | -1 | -1 | -1 |
| *43* | *No* | *Moby* | 10 | 90 | LogNormal | 60 | -1 | 1 | 1 | 1 |
| *44* | *Yes* | *Moby* | 15 | 85 | LogNormal | 45 | 0 | 0 | 1 | 0 |
| *45* | *Yes* | *Moby* | 15 | 85 | LogNormal | 45 | 0 | 0 | 1 | 0 |
| *46* | *Yes* | *Moby* | 15 | 85 | Normal | 45 | 0 | 0 | -1 | 0 |
| *47* | *Yes* | *Moby* | 15 | 85 | Normal | 45 | 0 | 0 | -1 | 0 |
| *48* | *Yes* | *Moby* | 15 | 85 | LogNormal | 45 | 0 | 0 | 1 | 0 |

Table 5: $2^4$ Duck Boat Tour Factorial Experiment

The potential blocking factor with 4 levels could be the 4 boat operators {Joe, Moby, Sara, Kate} which is shown in Table 5.

**Potential Problems:**

The problems foreseen with running this simulation model is being able to use the 4 operators as blocks because there are more operators in the actual Boston Duck Boat Tours due to there being as many as 20 boats. Another issue is using a blocking factor in general because a simulation model itself is homogenous by design, and accurately calculates estimates for the intended response variable, which makes a blocking factor irrelevant for a simulation design. Another issue when simulating the Boston Duck Boat Tours is that when the experiment is over, the results are exported in an organized format which doesn't show the randomization effect that occurred in the model when running the factorial combinations. The way to handle the organized exported data would be to then randomize it with the =RANDBETWEEN() Excel function to mimic the randomization that occurred when the experiment was run, despite losing the true random run order.