# Homework 5

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## 5.1

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| A | 1 | 0.322 | 0.322 | 0.037 | |
| B | 2 | 80.554 | 40.2771 | 4.59 | |
| Interaction | 2 | 45.348 | 22.674 | 2.58 | |
| Error | 12 | 105.327 | 8.7773 | | |
| Total | 17 | 231.551 | | | |

## 5.4

```
depth_of_cut <- c(0.15,0.15,0.15,0.18,0.18,0.18,0.2,0.2,0.2,0.25,0.25,
                  0.25,0.15,0.15,0.15,0.18,0.18,0.18,0.2,0.2,0.2,0.25,
                  0.25,0.25,0.15,0.15,0.15,0.18,0.18,0.18,0.2,0.2,0.2,
                  0.25,0.25,0.25)
depth_of_cut <- factor(depth_of_cut)

feed_rate <- c(0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,
               0.2,0.2,0.25,0.25,0.25,0.25,0.25,0.25,0.25,0.25,
               0.25,0.25,0.25,0.25,0.3,0.3,0.3,0.3,0.3,0.3,
               0.3,0.3,0.3,0.3,0.3,0.3)
feed_rate <- factor(feed_rate)

surface_finish <- c(74,64,60,79,68,73,82,88,92,99,
                    104,96,92,86,88,98,104,88,99,108,
                    95,104,110,99,99,98,102,104,99,95,
                    108,110,99,114,107,111)

df1 <- data.frame(depth_of_cut, feed_rate, surface_finish)
```

### a

According to the ANOVA the main effects of depth cut and feed rate are significant $p-values < 0.001$ there is a significant interaction between the factors as well $p-value = 0.01797$.

```
model1 <- lm(surface_finish ~ depth_of_cut + feed_rate + depth_of_cut*feed_rate,df1)
anova(model1)
```

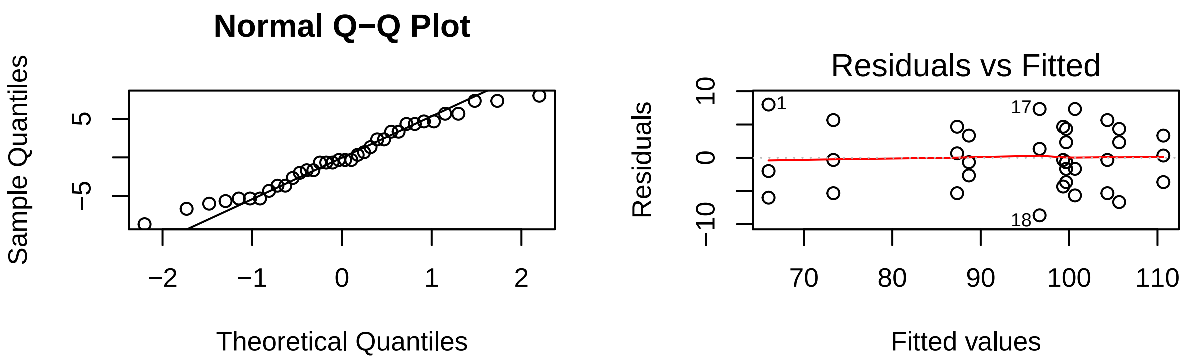
```
## Analysis of Variance Table
##
## Response: surface_finish
##                         Df  Sum Sq Mean Sq F value    Pr(>F)
```

```
## depth_of_cut             3 2125.11  708.37 24.6628 1.652e-07 ***
## feed_rate                2 3160.50 1580.25 55.0184 1.086e-09 ***
## depth_of_cut:feed_rate  6  557.06   92.84  3.2324   0.01797 *
## Residuals               24  689.33   28.72
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

### b

The errors seem to follow normal distribution since they qq-plot shows they are approximately linear. There is no indication of non-constant variance in the residual plot.

```r
par(mfrow = c(2,2))
qqnorm(model1$residuals)
qqline(model1$residuals)
plot(model1, 1)
```




### c

| Feed Rate | Estimate |
|---|---|
| 0.20 | 81.58333 |
| 0.25 | 97.58333 |
| 0.30 | 103.8333 |

### d

Feed rate: $p-value = 1.086 \times 10^{-9}$
Depth of cut: $p-value = 1.653 \times 10^{-7}$
Feed rate*depth of cut: $p-value = 0.01797$

## 5.5

$$CI(\mu_1 - \mu_2) = (\bar{y_{1..}} - \bar{y_{2..}}) \pm t_{\frac{\alpha}{2},ab(n-1)}\sqrt{\frac{2MS_E}{n}} \quad (1)$$
$$= -16 \pm 2.064 * \sqrt{\frac{2*28.72}{3}} \quad (2)$$
$$CI = [-25.03, -6.97] \quad (3)$$

## 5.10

```r
Glass_Type <- c(1,1,1,2,2,2,3,3,3,1,1,1,2,2,
                2,3,3,3,1,1,1,2,2,2,3,3,3)
Glass_Type <- factor(Glass_Type)
Temperature <- c(100,100,100,100,100,100,100,
                 100,100,125,125,125,125,125,
                 125,125,125,125,150,150,150,
                 150,150,150,150,150,150)
Light_Output <- c(580,568,570,550,530,
                  579,546,575,599,1090,
                  1087,1085,1070,1035,1000,
                  1045,1053,1066,1392,1380,
                  1386,1328,1312,1299,867,904,889)
df2 <- data.frame(Glass_Type,Temperature, Light_Output)
```

### a

The ANOVA table shows that there is significant interaction between glass type and both temperature and temperature squared. The effects of glass type and temperature also significantly affect the response.

```r
model2 <- lm(Light_Output ~ Glass_Type *(Temperature + I(Temperature^2)) , df2)
anova(model2)
```

```
## Analysis of Variance Table
##
## Response: Light_Output
##                              Df  Sum Sq Mean Sq  F value    Pr(>F)
## Glass_Type                    2  150865   75432  206.371 3.886e-13 ***
## Temperature                   1 1779756 1779756 4869.126 < 2.2e-16 ***
## I(Temperature^2)              1  190579  190579  521.394 9.665e-15 ***
## Glass_Type:Temperature        2  226178  113089  309.393 1.152e-14 ***
## Glass_Type:I(Temperature^2)   2   64374   32187   88.058 5.069e-10 ***
## Residuals                    18    6579     366
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

### b

```r
glass_type1 <- lm(Light_Output ~ (Temperature + I(Temperature^2)),
                  subset = Glass_Type == 1,data = df2 )
glass_type2 <- lm(Light_Output ~ (Temperature + I(Temperature^2)),
                  subset = Glass_Type == 2,data = df2 )
glass_type3 <- lm(Light_Output ~ (Temperature + I(Temperature^2)),
                  subset = Glass_Type == 3,data = df2 )
```

**Glass Type I**
$LightOutput = -3646.00 + 59.47 * Temperature - 0.1728 * Temperature^2$
**Glass Type II**
$LightOutput = -3415.00 + 56.00 * Temperature - 0.1623 * Temperature^2$

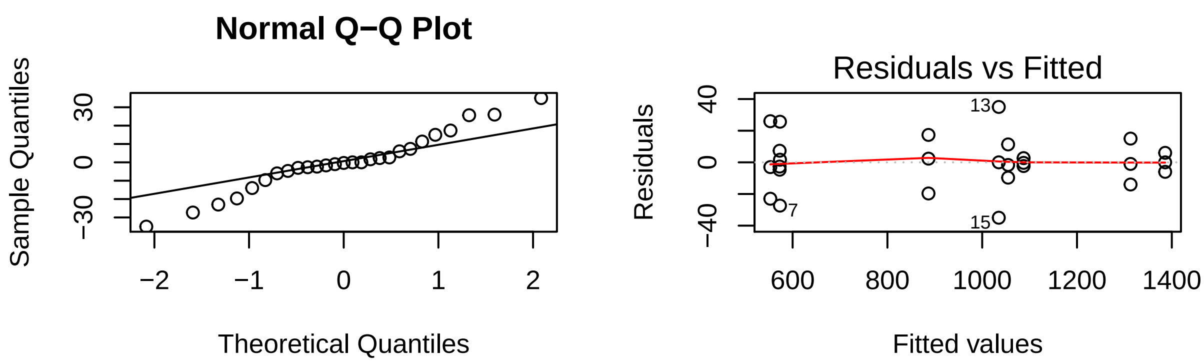
**Glass Type III**

$LightOutput = -7845.33 + 136.13 * Temperature - 0.5195 * Temperature^2$

### c

The residuals are not following a normal distribution according to the Normal Q-Q plot. There are no signs of non-constant variance in residual plot.

```r
par(mfrow=c(2,2))
qqnorm(model2$residuals)
qqline(model2$residuals)
plot(model2,1)
```




## 5.17

| Source | DF | SS | MS | Expected MS | F |
|---|---|---|---|---|---|
| A | $a-1$ | $SS_A$ | $MS_A$ | $\sigma^2 + \frac{bc\sum\tau_i^2}{(a-1)}$ | $\frac{MS_A}{MS_E}$ |
| B | $b-1$ | $SS_B$ | $MS_B$ | $\sigma^2 + \frac{ac\sum\beta_i^2}{(b-1)}$ | $\frac{MS_B}{MS_E}$ |
| C | $c-1$ | $SS_C$ | $MS_C$ | $\sigma^2 + \frac{ab\sum\gamma_i^2}{(c-1)}$ | $\frac{MS_C}{MS_E}$ |
| AB | $(a-1)(b-1)$ | $SS_{AB}$ | $MS_{AB}$ | $\sigma^2 + \frac{c\sum\sum(\tau\beta)_{ij}^2}{(a-1)(b-1)}$ | $\frac{MS_{AB}}{MS_E}$ |
| BC | $(b-1)(c-1)$ | $SS_{BC}$ | $MS_{BC}$ | $\sigma^2 + \frac{a\sum\sum(\gamma\beta)_{jk}^2}{(b-1)(c-1)}$ | $\frac{MS_{BC}}{MS_E}$ |
| Error | $(ab-b)(c-1)$ | $SS_E$ | $MS_E$ | $\sigma^2$ | |
| Total | $abc-1$ | $SS_{Total}$ | | | |

## 5.43

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| A | 350.00 | 2 | 175 | 21.0084 |
| B | 300.00 | 2 | 150 | 18.0072 |
| AB | 200.00 | 4 | 50 | 6.0024 |
| Error | 150.00 | 18 | 8.33 | |
| Total | 1000.00 | 26 | | |

## 5.44

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| A | 350.00 | 2 | 175 | 31.11 |
| B | 300.00 | 2 | 150 | 26.67 |
| AB | 200.00 | 4 | 50 | 8.89 |
| Block | 60.00 | 2 | 30 | 5.33 |
| Error | 90.00 | 16 | 5.625 | |
| Total | 1200.00 | 26 | | |