UNIVERSITI MALAYSIA PAHANG

BSD3433 EXPERIMENTAL DESIGN ANALYSIS

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GROUP NAME: IK GREEN

TITLE:

STRENGTH OF THE PAPER PRODUCED

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1.0 CASE STUDY

Figure 1.1 IK Green's Logo

The increasing competition in the world paper and board market inspires paper makers to continually develop and improve their products. One way to meet this competition is to increase paper strength properties. Strong papers are important not only in the current paper industry, but they are also of interest for new fields of application such as fiber-based packaging. The main ingredient in the process of making paper is trees. To utilize the use of the trees, the paper produced must be of high quality, especially in terms of paper strength.

IK Green is a company that produces paper. To further strengthen their brand in the paper market, they want to produce premium paper with high quality that is stronger. Hence, the company has assigned a group of data analysts from their company to study the factors in the process of making paper that can increase the strength of the paper.

After the observation and discussion between the team members, three factors that can be considered to be important are the percentage of hardwood concentration in raw pulp, the vat pressure, and the cooking time of the pulp. The main purpose of pulp cooking is to remove lignin and other impurities from plant fiber raw materials. The pulp is cooked in the vat with different pressure to produce different levels of paper strength. An experiment is designed by the team using three percentages of hardwood concentration in raw pulp, three levels of the vat pressure, and two duration of the cooking time. The team decides to run two replicates of a factorial design in these three factors. The response variable observed is the mean tensile strength (kN/m) of the paper produced. The data from the experiment that has been collected are shown in the table 1.1.

2.0 DATASET

Table 1.1: Mean Tensile Strength of Paper (kN/m)

Hardwood Concentration (%)	Cooking Time (Hours)					
	3.0			4.0		
	Pressure (psi)			Pressure (psi)		
	400	500	600	400	500	600
2	1.87, 2.47	2.66, 1.94	2.27, 2.66	2.18, 1.98	2.61, 2.29	2.37, 2.69
4	2.29, 2.37	2.28, 2.06	2.60, 2.46	2.42, 2.05	2.26, 2.15	3.13, 2.68
8	2.27, 2.90	3.02, 2.72	3.42, 2.91	3.01, 3.12	2.62, 3.06	2.99, 3.40

Information Extracted:-

Response variable: mean tensile strength

Control variables: hardwood concentration, cooking time, and vat pressure

Factor A: hardwood concentration Level of Factor A: a = 3

Factor B: cooking time Level of Factor B: b = 2

Factor C: vat pressure Level of Factor C: c = 3

Treatment:

k = a x b x c

= 18

List of Treatments:

2,3,400	2,3,500	2,3,600	2,4,400	2,4,500	2,4,600
4,3,400	4,3,500	4,3,600	4,4,400	4,4,500	4,4,600
8,3,400	8,3,500	8,3,600	8,4,400	8,4,500	8,4,600

Replication, r = 2

3.0 ANALYSIS

3.1 Insert Data

```
Hardwood <- c(rep("2",12),rep("4",12),rep("8",12))
Time <- c(rep("3.0",6),rep("4.0",6))
Pressure <- c(rep("400",2),rep("500",2),rep("600",2))
Strength <- c(1.87,2.47,2.66,1.94,2.27,2.66,2.18,1.98,2.61,2.29,2.37,2.69,2.29,2.37,2.28,2.06,2.60,2.46,2.42,2.05
,2.26,2.15,3.13,2.68,2.27,2.90,3.02,2.72,3.42,2.91,3.01,3.12,2.62,3.06,2.99,3.40)
data <- data.frame(Hardwood, Time, Pressure, Strength)
data
```

Hardwood <chr>	Time <chr>	Pressure <chr>	Strength <dbl>
2	3.0	400	1.87
2	3.0	400	2.47
2	3.0	500	2.66
2	3.0	500	1.94
2	3.0	600	2.27
2	3.0	600	2.66
2	4.0	400	2.18
2	4.0	400	1.98
2	4.0	500	2.61
2	4.0	500	2.29

1-10 of 36 rows Previous 1 2 3 4 Next

Hardwood <chr>	Time <chr>	Pressure <chr>	Strength <dbl>
2	4.0	600	2.37
2	4.0	600	2.69
4	3.0	400	2.29
4	3.0	400	2.37
4	3.0	500	2.28
4	3.0	500	2.06
4	3.0	600	2.60
4	3.0	600	2.46
4	4.0	400	2.42
4	4.0	400	2.05

11-20 of 36 rows Previous 1 2 3 4 Next

Hardwood <chr>	Time <chr>	Pressure <chr>	Strength <dbl>
4	4.0	500	2.26
4	4.0	500	2.15
4	4.0	600	3.13
4	4.0	600	2.68
8	3.0	400	2.27
8	3.0	400	2.90
8	3.0	500	3.02
8	3.0	500	2.72
8	3.0	600	3.42
8	3.0	600	2.91

21-30 of 36 rows Previous 1 2 3 4 Next

Hardwood <chr>	Time <chr>	Pressure <chr>	Strength <dbl>
8	4.0	400	3.01
8	4.0	400	3.12
8	4.0	500	2.62
8	4.0	500	3.06
8	4.0	600	2.99
8	4.0	600	3.40

31-36 of 36 rows Previous 1 2 3 4 Next

3.2 Statistical Analysis

```
A=as.factor(data$Hardwood)
B=as.factor(data$Time)
C=as.factor(data$Pressure)

results = lm(Strength ~ A + B + C + A:B + A:C + B:C + A:B:C, data = data)
anova(results)
```

```
Analysis of Variance Table

Response: Strength
          Df  Sum Sq Mean Sq F value    Pr(>F)
A          2 2.80101 1.40050 17.8661 5.313e-05 ***
B          1 0.09404 0.09404  1.1997  0.287818
C          2 1.04051 0.52025  6.6368  0.006932 **
A:B        2 0.02104 0.01052  0.1342  0.875286
A:C        4 0.19678 0.04919  0.6276  0.648997
B:C        2 0.01661 0.00830  0.1059  0.900055
A:B:C      4 0.28621 0.07155  0.9128  0.477671
Residuals 18 1.41100 0.07839
---
Signif. codes:
0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Interaction ABC:

$\boldsymbol{H_0}$: $\alpha\beta\gamma_{ijk} = 0$

$\boldsymbol{H_1}$: $\alpha\beta\gamma_{ijk} \neq 0$ for at least one j,k

p-value = 0.4777

Since (**p-value = 0.4777**) > ($\boldsymbol{\alpha}$ **= 0.05**), do not reject $\boldsymbol{H_0}$.

At $\boldsymbol{\alpha}$ **= 0.05**, $\alpha\beta\gamma_{ijk} = 0$. There is no interaction effect of percentage of hardwood concentration, cooking time and vat pressure to the tensile strength of paper.

Since there is no interaction effect, we have to test the effect of factor A, B, and C.

Factor A:

$\boldsymbol{H_0}$: $\alpha_i = 0$

$\boldsymbol{H_1}$: $\alpha_i \neq 0$ for at least one i

p-value = 0.0000

Since (**p-value = 0.0000**) < ($\boldsymbol{\alpha}$ **= 0.05**), reject $\boldsymbol{H_0}$.

At $\boldsymbol{\alpha}$ **= 0.05**, $\alpha_i \neq 0$ for at least one i. There is an interaction effect of percentage of hardwood concentration to the tensile strength of paper.

<u>Factor B:</u>

$\boldsymbol{H_0}$: $\beta_j = 0$

$\boldsymbol{H_1}$: $\beta_j \neq 0$ for at least one j

p-value = 0.2878

Since (**p-value = 0.2878**) > ($\boldsymbol{\alpha}$ **= 0.05**), do not reject $\boldsymbol{H_0}$.

At $\boldsymbol{\alpha}$ **= 0.05**, $\beta_j = 0$. There is no interaction effect of cooking time to the tensile strength of paper.

<u>Factor C:</u>

$\boldsymbol{H_0}$: $\gamma_k = 0$

$\boldsymbol{H_1}$: $\gamma_k \neq 0$ for at least one k

p-value = 0.0069

Since (**p-value = 0.0069**) < ($\boldsymbol{\alpha}$ **= 0.05**), reject $\boldsymbol{H_0}$.

At $\boldsymbol{\alpha}$ **= 0.05**, $\gamma_k \neq 0$ for at least one k. There is an interaction effect of vat pressure to the tensile strength of paper.

<u>Interaction AB:</u>

$\boldsymbol{H_0}$: $\alpha\beta_{ij} = 0$

$\boldsymbol{H_1}$: $\alpha\beta_{ij} \neq 0$ for at least one i,j

p-value = 0.8753

Since (**p-value = 0.8753**) > ($\boldsymbol{\alpha}$ **= 0.05**), do not reject $\boldsymbol{H_0}$.

At $\boldsymbol{\alpha}$ **= 0.05**, $\alpha\beta_{ij} = 0$. There is no interaction effect of percentage of hardwood concentration and cooking time to the tensile strength of paper.

<u>Interaction AC:</u>

$\boldsymbol{H_0}$: $\alpha\gamma_{ik} = 0$

$\boldsymbol{H_1}$: $\alpha\gamma_{ik} \neq 0$ for at least one i,k

p-value = 0.6490

Since (**p-value = 0.6490**) > ($\boldsymbol{\alpha}$ **= 0.05**), do not reject $\boldsymbol{H_0}$.

At $\boldsymbol{\alpha}$ **= 0.05**, $\alpha\gamma_{ik} = 0$. There is no interaction effect of percentage of hardwood concentration and vat pressure to the tensile strength of paper.

Interaction BC:

$\boldsymbol{H_0}$: $\beta\gamma_{jk} = 0$

$\boldsymbol{H_1}$: $\beta\gamma_{jk} \neq 0$ for at least one j,k

p-value = 0.9001

Since (**p-value = 0.9001**) > ($\boldsymbol{\alpha}$ **= 0.05**), do not reject $\boldsymbol{H_0}$.

At $\boldsymbol{\alpha}$ **= 0.05**, $\beta\gamma_{jk} = 0$. There is no interaction effect of cooking time and vat pressure to the tensile strength of paper.

Hence, from all the hypothesis above, we can see that only the percentage of hardwood concentration and vat pressure are significantly affect the tensile strength (kN/m) of the paper produced.

3.3 Assumption Checking

The fitting of regression model, estimation of parameters testing of hypothesis properties of the estimator, is based on the following major assumptions:

- The error are normally distributed.
- The error term has a constant variance.
- The errors are uncorrelated.

Predicted value

```
predicted<-predict(results)
predicted
```

```
    1     2     3     4     5     6     7     8     9    10    11    12    13    14    15    16    17    18    19 
   20 
2.170 2.170 2.300 2.300 2.465 2.465 2.080 2.080 2.450 2.450 2.530 2.530 2.330 2.330 2.170 2.170 2.530 2.530 2.235 
2.235 
   21    22    23    24    25    26    27    28    29    30    31    32    33    34    35    36 
2.205 2.205 2.905 2.905 2.585 2.585 2.870 2.870 3.165 3.165 3.065 3.065 2.840 2.840 3.195 3.195 
```

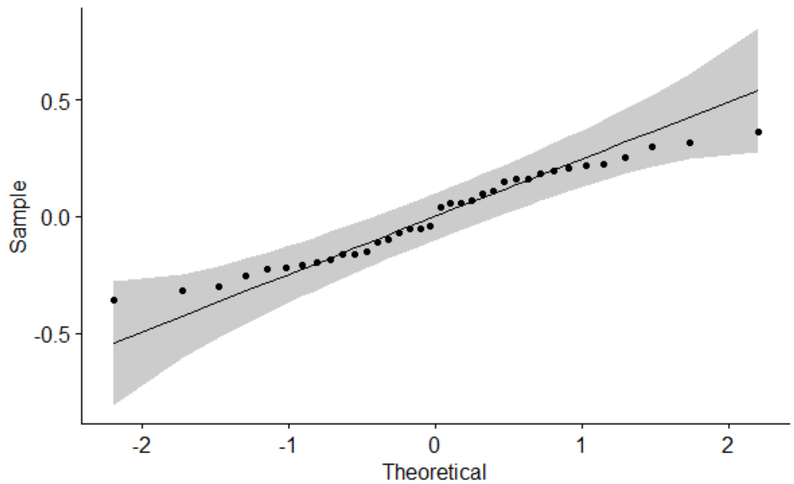
Residuals value

```
residuals<-resid(results)
residuals
```

```
     1      2      3      4      5      6      7      8      9     10     11     12     13     14     15     16 
   17 
-0.300  0.300  0.360 -0.360 -0.195  0.195  0.100 -0.100  0.160 -0.160 -0.160  0.160 -0.040  0.040  0.110 -0.110 
0.070 
    18     19     20     21     22     23     24     25     26     27     28     29     30     31     32     33 
   34 
-0.070  0.185 -0.185  0.055 -0.055  0.225 -0.225 -0.315  0.315  0.150 -0.150  0.255 -0.255 -0.055  0.055 -0.220 
0.220 
    35     36 
-0.205  0.205 
```

Normality plot

```
library(ggpubr)
ggqqplot(residuals)
```



From the plot, it can be seen that the residuals is approximately normal as the data is scattered near the straight line.

Normality test using Shapiro Wilk-Test

```
shapiro.test(residuals)
```

```

    Shapiro-Wilk normality test

data:  residuals
W = 0.95967, p-value = 0.21
```

$\boldsymbol{H_0}$: The residuals is normally distributed.

$\boldsymbol{H_1}$: The residuals is not normally distributed.

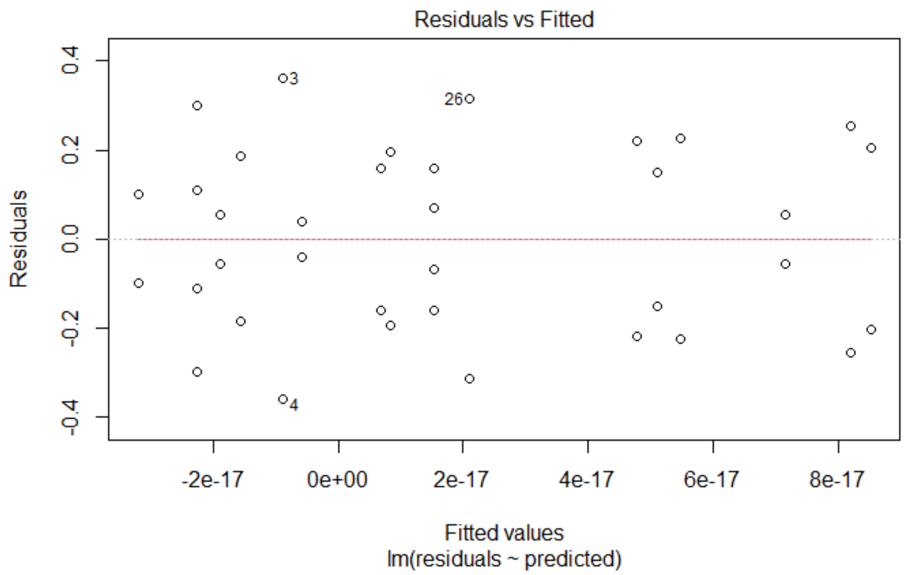
p-value = 0.21

Since (**p-value = 0.21**) > ($\boldsymbol{\alpha}$ **= 0.05**), do not reject $\boldsymbol{H_0}$.

At $\boldsymbol{\alpha}$ **= 0.05**, the residuals is normally distributed.

Test for the constant variance

```
plot(lm(residuals~predicted))
```



From the above residual plot, the points are scattered above and below reference line at horizontal 0. It is constant variance and model is adequate.

Check correlation of residuals using Durbin Watson Test

```
library(car)
durbinWatsonTest(results)
```

```
 lag Autocorrelation D-W Statistic p-value
   1       -0.359107      2.624646   0.152
 Alternative hypothesis: rho != 0
```

$\boldsymbol{H_0}$: There is no correlation among the residuals.

$\boldsymbol{H}_1$: The residuals are autocorrelated.

p-value = 0.152

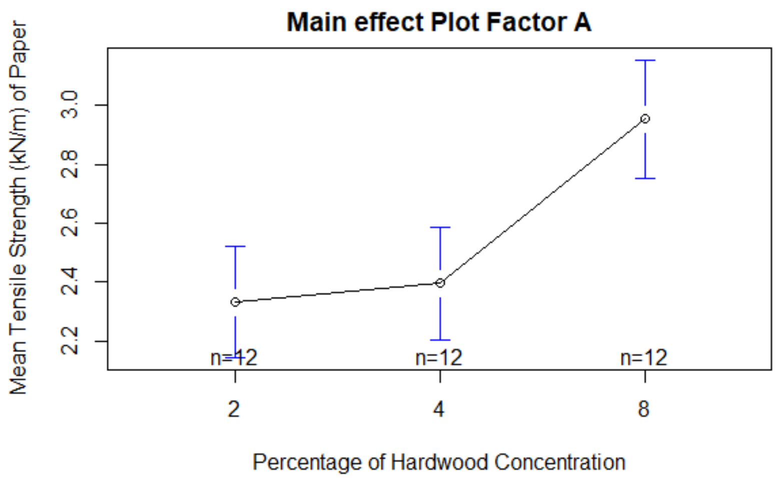
Since (**p-value = 0.152**) > ($\boldsymbol{\alpha}$ **= 0.05**), do not reject $\boldsymbol{H_0}$.

At $\boldsymbol{\alpha}$ **= 0.05**, there is no correlation among the residuals.

Hence, the assumptions are correct.

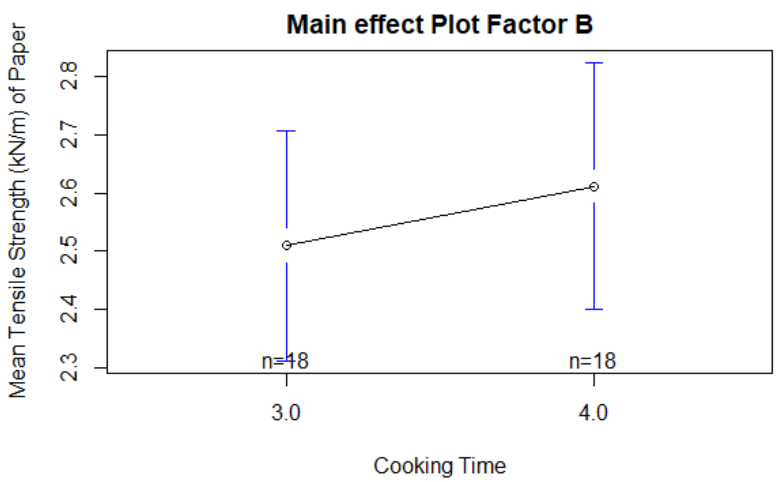
3.4 Main Effect Plot

```
library(gplots)
plotmeans(Strength~A,xlab="Percentage of Hardwood Concentration",ylab="Mean Tensile Strength (kN/m) of Paper", ma
in="Main effect Plot Factor A",barcol="blue")
```



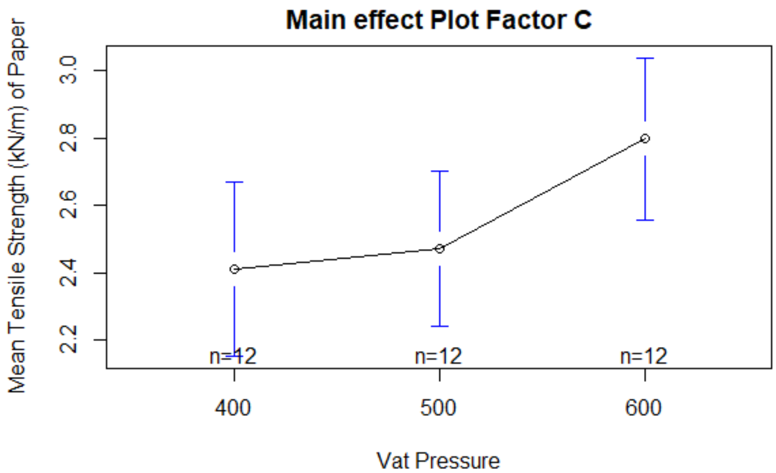
The plot of main effect factor A shows a positive main effect which is increasing the variables moves the charges target upwards. This only means that the higher the percentage of hardwood concentration, the higher tensile strength of paper.

```
plotmeans(Strength~B,xlab="Cooking Time",ylab="Mean Tensile Strength (kN/m) of Paper", main="Main effect Plot Fac
tor B",barcol="blue")
```



The plot of main effect factor B shows a positive main effect which is increasing the variable moves the charges target upwards. This only means that the higher cooking time, the higher tensile strength of paper.

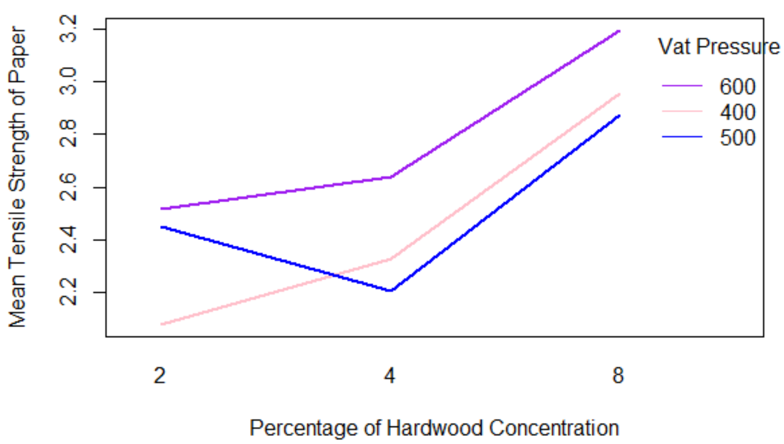
```
plotmeans(Strength~C,xlab="Vat Pressure",ylab="Mean Tensile Strength (kN/m) of Paper", main="Main effect Plot Fac
tor C",barcol="blue")
```



The plot of main effect factor C shows a positive main effect which is increasing the variable moves the charges target upwards. This only means that the higher the vat pressure, the higher tensile strength of paper.

3.5 Interaction Plot

```
interaction.plot(x.factor = data$Hardwood, #x-axis variable
trace.factor = data$Pressure, #variable for lines
response = data$Strength, #y-axis variable
fun = median, #metric to plot
ylab = "Mean Tensile Strength of Paper",
xlab = "Percentage of Hardwood Concentration",
col = c("pink", "blue", "purple"),
lty = 1, #line type
lwd = 2, #line width
trace.label = "Vat Pressure")
```



The significant interaction is indicated by the lack of parallelism of the lines. Changing from low to intermediate percentage of hardwood concentration, tensile strength of paper with 500 vat pressure may actually decrease, whereas it increase for vat pressure 400 and 600. From intermediate to high percentage of hardwood concentration, the tensile strength of paper increase for all vat pressure. To produce premium paper with high quality that is stronger, the company should consider vat pressure 400 and 600 and high percentage of hardwood concentration.

4.0 CONCLUSION

Based on the statistical analysis that has been conducted from the experiment, the data analysts team conclude that, two out of three factors have significant effect on the tensile strength of the paper which are percentage of hardwood concentration and vat pressure. However, if we see from the main effect plot, the factor cooking time also has a positive effect on the tensile strength of the paper. It can be concluded that every factor given will be a significant factor on the tensile strength of the paper.

To fulfill the wish of IK Green company which is to produce a premium paper, the data analysts team has recommended to use high percentage of hardwood concentration (8%), high vat pressure (600 psi) and longer cooking time (4 hours) in the process of making paper to produce strong paper.

Figure 4.1 Fiber-based Packaging

With the high quality of paper that will be produced after this, the data analysts team has proposed to IK Green to release a new product which is fiber-based packaging instead of just releasing a premium paper. This is because, with the analysis that has been conducted, the data analysts teams are confident enough that the paper that will be produced will be strong enough to transform to a packaging and will increase the company's profit.

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