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Project Report

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Factorial Design and Analysis of Wireless Download Speed

Introduction

This experiment is designed to test the household wireless internet speed. Specifically, I hope to seek for significant factors that affect the wireless internet download rate. Each factor that I choose has only two levels, or yes/no value. The instruments involved in this experiment are two laptops, carrying Windows and MacOS system and a USB internet adaptor, network instruments are one dual-band router and the internet that is supposed to have download speed of one hundred Megabits per second (Mbps).

Measurement

I used the internet speed test comes with google chrome, named Measurement Lab, to measure the wireless internet speed. The speed test is based on the time to transfer 40 MB data from remote server to local IP address and the time to upload same size of data from local to remote. In this experiment, I focused on only download speed.

Estimable Factors

A. WLAN channels (in unit of hertz)

Wireless Local Area Network (WLAN) channels are distinct ranges of radio frequencies used for internet communication. The most common ranges are 2.4 Ghz and 5.0 Ghz.

- Level 1, with wireless frequency of 2.4 Ghz, i.e. not 5.0 Ghz.
- Level2, with wireless frequency of 5.0 Ghz.

B. Wireless Internet Adaptor

Internet adaptor is the hardware placed in personal computer that used to receive and output signals. PCI-E adaptor is directly plugged into motherboard as part of the computer. USB adaptor is an external device.

- Level1, adaptor of USB connector, i.e. not PCI-E.
- Level2, adaptor of PCI-E.

C. Simultaneously Use

To make sure the consistency of this factor, I opened new YouTube video for each run, avoiding caches.

- Level1, the test carrier is single user connected to the router, i.e. there is no another user at the same time.

- Level2, another user is watching online video when the test is going on.

D. Computer Operation System (2 levels)

- Level1, use computer system of Mac OS, i.e. not on Windows 10.

- Level2, on Windows 10

E. Across the Wall

For each level of this factor, the distance from router and computer stays same, which is 5 meters, the only difference is whether a wall in between.

- Level1, adapted wireless signals did not transfer across the wall.

- Level2, signals travel across the wall before adapted.

Block Factor

The block factor is time of the day. I did one block at 9 a.m. and another at 9 p.m. of the same day. I set interaction factor BD to be confounded with block effect for a clear reason. Since PCI-E internet adaptor is fixed on motherboard, i.e. each computer has unique and inflexible PCI-E, as well as the computer system, one PCI-E cannot be applied to both Windows and Mac systems.

Block 1, i.e. BD=-1, contains [b, ad, bc, abc, d, ad, cd, acd, be, abe, bce, abce, de, ade, cde, acde]

Block 2, i.e. ABCDE=1, contains [(1), a, c, ac, bd, abd, bcd, abcd, e, ae, ce, ace, bde, abde, bcde, abcde]

Randomization Attempt

In each block, the order of treatment is randomized, using R to generate the random order.

Data Collected from Experiment

Denote the factor Wireless Frequency as factor A; Internet Adaptor as factor B; Another User connection as factor C; Operation System as factor D; Across the Wall as factor E.

Use Yate's notation to record the data. Since there is only one run for each treatment combination, (1) in Yate's implies all treatment factors are on level 1, similarly (a) implies all factors are on level 1 except A is on level 2.

The internet speed test interface is shown below, measuring the downloading speed of the current IP address.
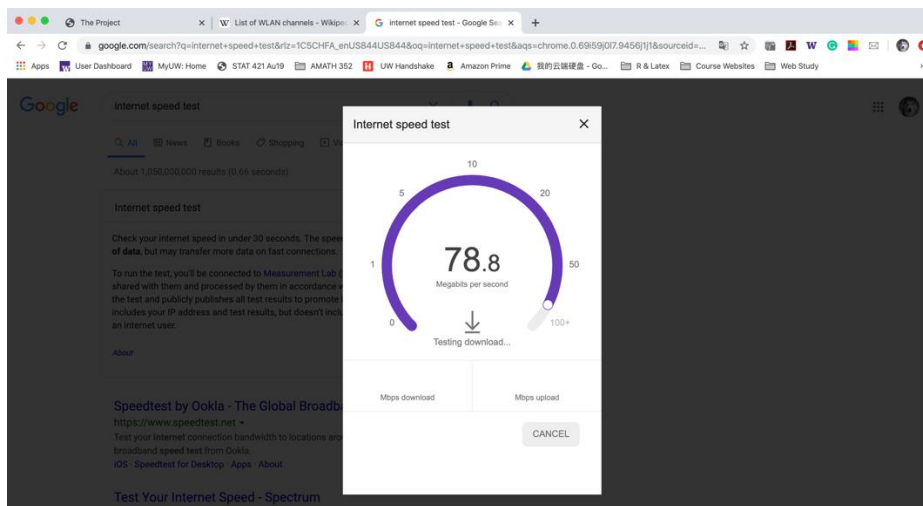
Data in unit: Mbps

Block 1

b	ab	bc	abc	d	ad	cd	acd
85.0	93.1	76.7	79.9	70.1	86.2	69.5	74.5
be	abe	bce	abce	de	ade	cde	acde
62.4	59.0	54.8	59.9	58.9	63.7	69.8	67.2

Block 2

(1)	a	c	ac	bd	abd	bcd	abcd
74.6	94.4	83.3	85.0	77.5	85.1	76.1	79.6

e	ae	ce	ace	bde	abde	bcde	abcde
59.9	71.9	60.4	66.9	62.5	71.4	57.0	55.6

Explore the Data

```
y <- c(74.6, 94.4, 85, 93.1, 83.3, 85, 76.7, 79.9, 70.1, 86.2, 77.5, 85.1, 69.5, 74.5, 76.1, 79.6,
    59.9, 71.9, 62.4, 59, 60.4, 66.9, 54.8, 59.9, 58.9, 63.7, 62.5, 71.4, 69.8, 67.2, 57, 55.6)
qqnorm(y)
```
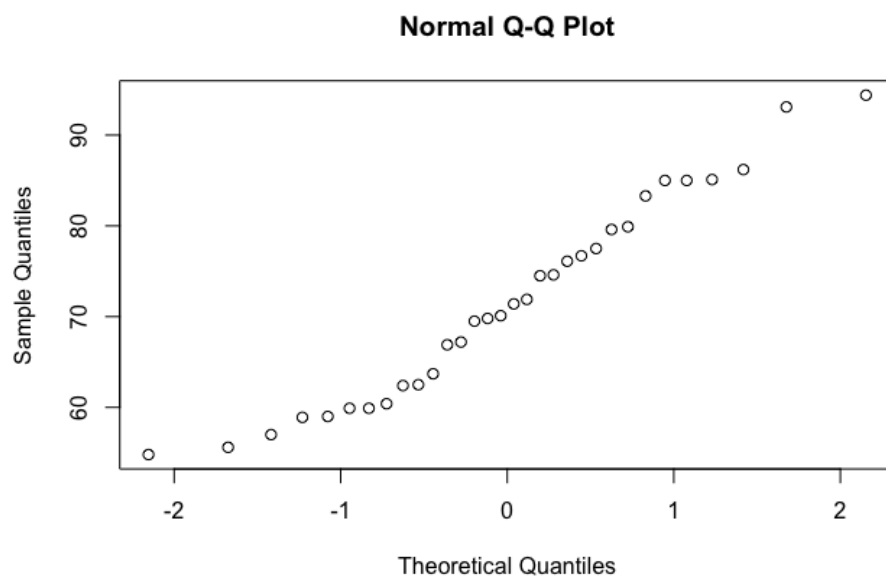

Normal Q-Q Plot

The qqplot of collected data is approximately a straight line, implying that the normality assumption is not violated.

ANOVA Table

Five-way, four-way and three-way interaction effects are out of consideration.

```
library(AlgDesign)
rm(list=ls(all=T))
design1 <- gen.factorial(c(2,2,2,2,2), varNames = c("A","B","C","D","E"))
attach(design1)
y <- c(74.6, 94.4, 85, 93.1, 83.3, 85, 76.7, 79.9, 70.1, 86.2, 77.5, 85.1, 69.5, 74.5, 76.1, 79.6,
    59.9, 71.9, 62.4, 59, 60.4, 66.9, 54.8, 59.9, 58.9, 63.7, 62.5, 71.4, 69.8, 67.2, 57, 55.6)
Block <- B*D
```

```
lm1 <- lm(y~A+B+C+D+E+A:B+A:C+A:D+A:E+B:C+B:D+B:E+C:D+C:E+D:E + Block)
```

```
> summary.aov(lm1)
            Df Sum Sq Mean Sq F value   Pr(>F)
A            1  281.4   281.4  16.693 0.000862 ***
B            1   13.4    13.4   0.794 0.386026
C            1  110.6   110.6   6.562 0.020904 *
D            1   56.4    56.4   3.348 0.085980 .
E            1 2615.5  2615.5 155.135  1.2e-09 ***
Block        1   29.1    29.1   1.724 0.207662
A:B          1   31.4    31.4   1.863 0.191206
A:C          1   87.5    87.5   5.187 0.036836 *
A:D          1    3.9     3.9   0.228 0.639191
A:E          1   38.5    38.5   2.284 0.150242
B:C          1   88.8    88.8   5.266 0.035612 *
B:E          1   82.9    82.9   4.916 0.041436 *
C:D          1    1.7     1.7   0.099 0.757363
C:E          1   17.0    17.0   1.006 0.330723
D:E          1  129.2   129.2   7.664 0.013707 *
Residuals   16  269.7    16.9
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Under the significance level of 0.05, within the 15 effects we care about, factors A, C, E, AC, BC, BE, DE have significant effect. We can say WLAN channel, simultaneously use, wall and their interactions have significant effect on wireless Internet speed.

Model with Eliminated Factors

From above model, significant effects are A, C, E, AC, BC, BE, DE. By hierarchical principle, factors B, C should also be included in new model.

```
lm2 <- lm(y~A+B+C+D+E+A:C+B:C+B:E+D:E + Block)
summary.aov(lm2)
```

```
            Df Sum Sq Mean Sq F value   Pr(>F)
A            1  281.4   281.4  16.321 0.000591 ***
B            1   13.4    13.4   0.777 0.388187
C            1  110.6   110.6   6.416 0.019349 *
D            1   56.4    56.4   3.273 0.084757 .
E            1 2615.5  2615.5 151.670 4.51e-11 ***
Block        1   29.1    29.1   1.686 0.208236
A:C          1   87.5    87.5   5.071 0.035155 *
B:C          1   88.8    88.8   5.148 0.033932 *
B:E          1   82.9    82.9   4.806 0.039761 *
D:E          1  129.2   129.2   7.492 0.012345 *
Residuals   21  362.1    17.2
```

The new model indicates factors A, C, E, AC, BC, BE, DE have significant effects on y value.

Check Significance Via Daniel Method
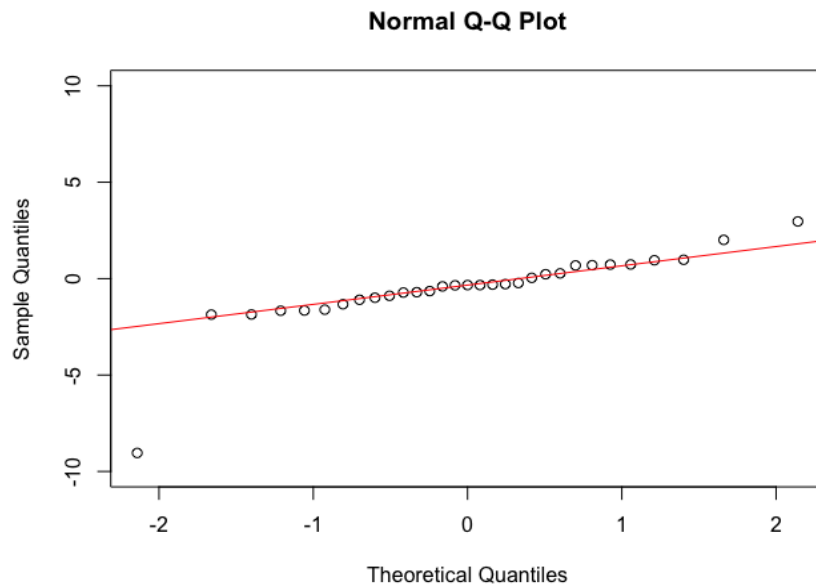
Base on the qqplot of the effects, we can see the factor with smallest effect (highest negative effecct) and factors with highest two effects are out of linear pattern. They are factors A, E and DE.
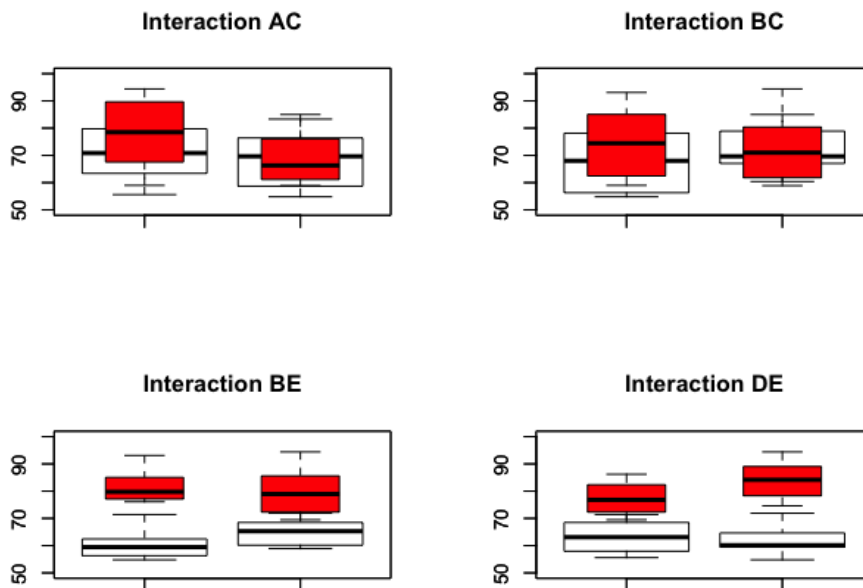
Check Significance Via Interaction Plot

```
par(mfrow=c(2,2))

boxplot(y[A==1 & C==1 ],y[A==-1 & C==1],ylim=c(50,100) , main="Interaction AC")
boxplot(y[A==1 & C==-1 ],y[A==-1 & C==-1], add=2,col=2, boxwex = 0.5)

boxplot(y[B==1 & C==1 ],y[B==-1 & C==1],ylim=c(50,100) , main="Interaction BC")
boxplot(y[B==1 & C==-1 ],y[B==-1 & C==-1], add=2,col=2, boxwex = 0.5)

boxplot(y[B==1 & E==1 ],y[B==-1 & E==1],ylim=c(50,100) , main="Interaction BE")
boxplot(y[B==1 & E==-1 ],y[B==-1 & E==-1], add=2,col=2, boxwex = 0.5)

boxplot(y[D==1 & E==1 ],y[D==-1 & E==1],ylim=c(50,100) , main="Interaction DE")
boxplot(y[D==1 & E==-1 ],y[D==-1 & E==-1], add=2,col=2, boxwex = 0.5)
```

Base on the interaction plots, the "X" pattern appears on all these interactions, i.e. these interactions have significant effects.

Conclusion

We can conclude that the experiment data show significant evidence against the non-effect hypothesis, implying that household wireless internet speed could be significantly affected by three main factors: WLAN channel, a wall in between adaptor and router, simultaneous use. Four interaction factors also have significant effect on internet speed.