Investigating the Factors that Affect the Cooking Time of Steak

STAT 424: Stats Experimental Design Project

Prepared for
Professor Wei-Yin Loh

by
QiWen Shu
Dept of Statistics

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Summary:

This project was meant to investigating the impacts of four factors on the cooking time of a piece of standard steak. These factors including the type of steak to cook (sirloin or ribeye), adding salt or not, poking holes or not, and type of cooking method(stove vs frying pan) that were used to cook with. Each factor contained two levels, thus a total of sixteen trials were conducted in this experiment.

With the statistical approaches that were taught in class, I find out that the type of steak as well as poking holes or not are the dominant factor that affects the cooking time of steak, whereas the other two factors we are investigating are turned out to have a minor effect on the cooking time.

Introduction:

Throughout the US history, beef has been served as the major portion of meat consumption in the past few decades. Among various kinds of beef, steak is considered as the most primary one. The oldest continuously operating steakhouse was opened 150 years ago in New York City. Along with crispy fries and mashed potatoes with amazing gravy, the steak meal can offer you a delighted and satisfactory dining experience.

I have been a loyal steak-lover since middle school, and used to have steak for breakfast everyday when I was an athlete in high school. Starting from an ametaur who used to trigger fire alarms while cooking burned steaks, I have gradually got the hang of cooking steak. Instead of viewing cooking steak as a tedious task, I take it as a certain form of art.

One of the most crucial element that determines the flavor of a cooked steak is timing. Here we mark the timing where the steak happens to display no pink as the observation time. There are several factors seem to have impact on the cooking time. We have picked out four major factors with two levels to study in this experiment, and they are : 2 types of steak(lean and ribeye), 2 types of cooking method(stove vs pan), adding salt or not, poking holes or not.

The reason why I choose these factors to investigate is because they may be the most common alternatives to be considered while one is cooking steak. My past experience has told me that pork belly usually take less time to be done than lean pork chop, so I wonder if the percentage of fat in the meat can affect the cooking time. In addition, some people prefer cooking steak with frying pan, while others prefer cooking steak with stove, and I want to compare the cooking efficiency between these two methods. Moreover, I have heard that sometimes people add salt to accelerate melting the snow on the ground and since steak is usually taken out from a freezer, so I think adding salt might help reduce the cooking time. What's more, I remembered that my grandma used to poke holes in chicken wings while cooking for me since I do not want any pink in my chicken wings. Therefore, I believe the same mechanism should be useful on cooking steak as well.

The response variable in this experiment is the time required to cook a piece of steak from its raw status to where there is no pink observed.

Experiment Setup:

In this experiment, we bought 8 pieces of sirloins steaks and 8 pieces of ribeye steak and a bottle can of salt. Each steak weight around 0.7lb. Ribeye steak cost about one third more than sirloin steak at local fresh market. I also borrowed a stainless steel frying pan from my friends and decided to use stove come within my rent. In addition, we used chopsticks in 2mm of radius to poke holes on the steak and those holes were equally distributed on the steak. The amount of salt that put on the steak were also chosen with the edibility taken under consideration.

The frying pan we used was T-fal stainless frying pan and oven we used came within my apartment. I also used a spoon that contains a volume of 0.5oz. Every time before cooking a new piece of steak, we preheated the stove to 380 F which is considered as the ideal temperature to cook steak. As for oven ,we preheated the oil until they started sparkling and boiling. The person who helped me cook and record time is Bo and Diana.

In terms of convenience, I labelled choice of type of steak as factor A, poking holes or not as factor B, cooking method as factor C, adding salt or not as factor D. The designation of different factors and their levels are presented in the following table.

Factors	Level	
Type of Steak	All Lean(+)	Fat and Lean(-)
Poking holes	Yes(+)	No(-)
Cooking Method	Stove(+)	Pan(-)
Salt input	Yes(+)	No(-)

Since the experiment requires a total of 16 trials, and the average cooking time was estimated to be 15-30 minutes. Therefore, in order to avoid any waste of steak and overuse of the cookers, we decided to divide this experiment into four blockings. Four out of sixteen runs were done in the evening of a Friday night and Saturday night, and we continuously had steak dinner for 2 weeks.

A	B	C	D	ABC	ABD	Block
-	-	-	-	-	-	1st
+	-	-	-	+	+	4th
-	+	-	-	+	+	4th

+	+	-	-	-	-	1st
-	-	+	-	+	-	3rd
+	-	+	-	-	+	2nd
-	+	+	-	-	+	2nd
+	+	+	-	+	-	3rd
-	-	-	+	-	+	2nd
+	-	-	+	+	-	3rd
-	+	-	+	+	-	3rd
+	+	-	+	-	+	2nd
-	-	+	+	+	+	4th
+	-	+	+	-	-	1st
-	+	+	+	-	-	1st
+	+	+	+	+	+	4th

Here we determined the blockings through the following matrix from the ABC,ABD columns :

-	-	1st night(Friday)
-	+	2nd night(Saturday)
+	-	3rd night(Friday)
+	+	4th night(Saturday)

We conducted the 1st group of experiment determined by the matrix in the first Friday night, the 2nd group of experiment in the first Saturday night, 3rd group of experiment in the following Friday night, and 4th group of experiment in the following Saturday night, each of group of trials has a total of four trials.

The experiment was conducted based on the abovementioned matrix. The oven was pre-heated to 380 F to ensure that each run was done under approximately same condition. Relatively, we also preheated the frying pan with oil to approximately 380 F in order to maintain the same initial condition for cooking steak. Four pieces of steak were cooked one after another

in the assigned condition. A timer was started to measure the period of time that takes to reach the point where there was no pink shown in the steak. The steak was cooked in a way where we flipped the steak to the other side to maintain balanced absorption of heat. Between each round of cooking, we boiled the fry pan or cleaned up the stains from previous cooking in the stove to ensure the same initial condition.

Statistical Analysis:

The data for the experiment (including the cooking time) are displayed as the following:

Run Order	Original Order	Type of Steak	Poking Holes	Type of Pan	Salt Input	Block	Time(round to ½ min)
1	1	-	-	-	-	1st	16.5
2	4	+	+	-	-	1st	21.5
3	14	+	-	+	+	1st	19.0
4	15	-	+	+	+	1st	14.0
5	6	+	-	+	-	2nd	18.5
6	7	-	+	+	-	2nd	16.5
7	9	-	-	-	+	2nd	12.0
8	12	+	+	-	+	2nd	21.5
9	5	-	-	+	-	3rd	15.5
10	8	+	+	+	-	3rd	22.5
11	10	+	-	-	+	3rd	18.5
12	11	-	+	-	+	3rd	17.0
13	2	+	-	-	-	4th	18.5
14	3	-	+	-	-	4th	16.0
15	13	-	-	+	+	4th	13.5
16	16	+	+	+	+	4th	20.5

Under such blocking design, we divided the experiment into four blocks and we had to sacrifice the examination of the interaction effect of ABC, ABD as well as CD. The reason that we chose factor C and D to be confounding factors is that I believed method of cooking and salt input will not have a strong interaction effect on altering the cooking time since presumably no matter which method of cooking we chose, the salt absorption on the steak was always

undermined after the steak was flipping to the other side. With such 2-factor interaction effect being confounded, we also need to have ABC,ABD as confounded.

	A	B	C	D	AB	AC	AD	BC	BD	***CD***	***ABC***	***ABD***	ACD	BCD	ABCD
A	+	-	-	-	-	-	-	+	+	+	+	+	+	-	-
B	-	+	-	-	-	+	+	-	-	+	+	+	-	+	-
C	-	-	+	-	+	-	+	-	+	-	+	-	+	+	-
D	-	-	-	+	+	+	-	+	-	-	-	+	+	+	-
AB	+	+	-	-	+	-	-	-	-	+	-	-	+	+	+
AC	+	-	+	-	-	+	-	-	+	-	-	+	-	+	+
AD	+	-	-	+	-	-	+	+	-	-	+	-	-	+	+
BC	-	+	+	-	-	-	+	+	-	-	-	+	+	-	+
BD	-	+	-	+	-	+	-	-	+	-	+	-	+	-	+
CD	-	-	+	+	+	-	-	-	-	+	+	+	-	-	+
ABC	+	+	+	-	+	+	-	+	-	-	+	-	-	-	-
ABD	+	+	-	+	+	-	+	-	+	-	-	+	-	-	-
ACD	+	-	+	+	-	+	+	-	-	+	-	-	+	-	-
BCD	-	+	+	+	-	-	-	+	+	+	-	-	-	+	-
ABCD	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Therefore, the confounding relations can be written in a compact form as follows :
We denote the blocking effects as
ABC = F
ABD = G
CD = FG

$$Y = \eta + A/2*X1 + B/2*X2 + C/2*X3 + D/2*X4 + AB/2*X1*X2 + BC/2 *X2*X3 + AD/2*X1*X4 + BD/2*X2*X4 + (CD+FG)/2*X3*X4 + (ABC+F)/2*X1*X2*X3 + (ABD+G)/2*X1*X2*X4 + BCD/2*X2*X3*X4 + ABCD/2*X1*X2*X3*X4 + e$$

where η is the grand mean, block denotes the effect of block, A, B, C, D the main effects of the factors, AB, AC, AD, ··· the 2-factor interactions, and so on. e ~ IIDN(0, σ2).

The estimation of the rest variable effects after blockings is calculated as following:

A= 19.5

B= -12.5

C= 2.5

D=-0.5

AB=-7.5

AC=6.5

AD=1.5

BC=-0.5

BD = -2.5

ACD=6.5

BCD=8.5

ABCD=2.5

CD=-1.5 (with blocking effects)

ABC=8.0 (with blocking effects)

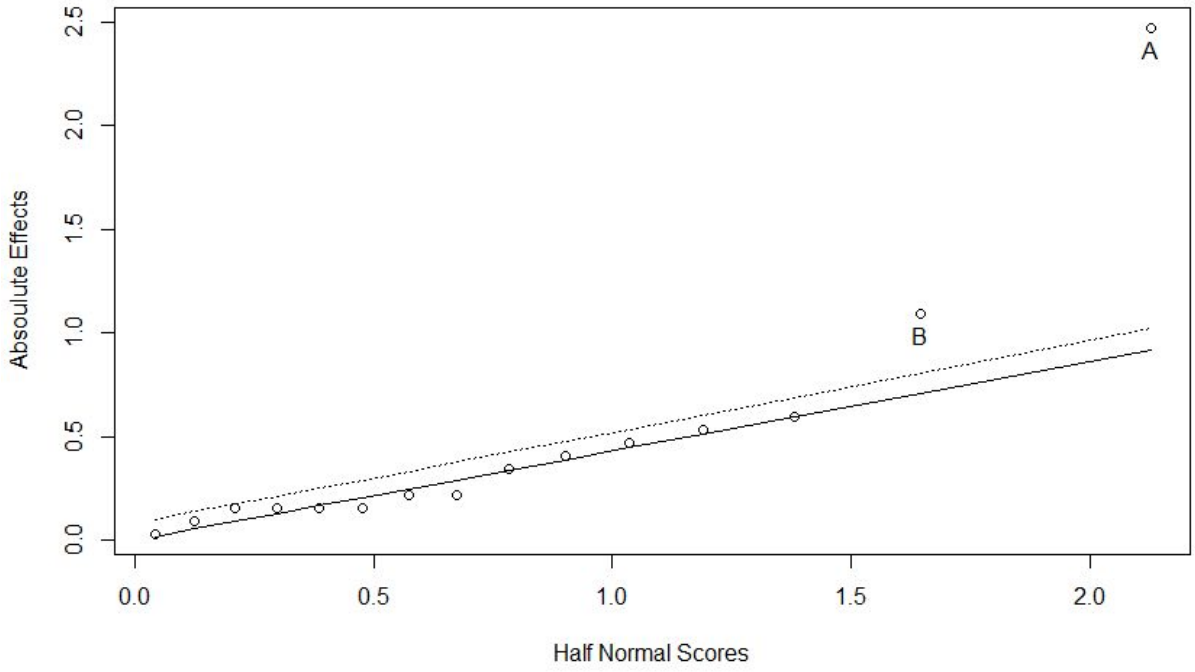
ABD=-4.5 (with blocking effects)

Therefore, the ranked effect were presented as following:

A>B>BCD>ABC>AB>AC=ACD>ABD>C=ABCD=BD>CD=AD>D=BC

Then we start to perform the different methods that we have learned in class to find out the significant effects.

LGB Method:



From the LGB method, we found the main effect of A and B as the significant effects from the half-normal plot.

Lenth Method :

Then we perform lenth method to double check the if there is any significant effects between any levels:

First, we obtain the median of the effect as ABD which has the absolute value of 4.5,

S0 = 1.5 * median(effects) = 1.5 * 4.5 = 6.75

Pseudo std error = 1.5 * median {effects which is smaller than 2.5S0 = 16.875}

= 1.5*(4.5+2.5)/2

= 5.25

Let V = I/4 = 15/4 = 3.75

and r = 1/2 * (1+(1-alpha)^(1/I)) (alpha = 0.1)

r = 1/2 * (1+0.9^(1/15))

r = 0.996

Then we compare all the effects with t,v,1-r * PSE = 22.3755

As a result, we can conclude that there are no significant effect detected from the lenth method.

Such method is considered as inferior to LGB method it is based on a restrictive set of assumptions: independent contrast estimates that all have the same variance. In our design of experiment, these assumptions are not necessarily met.

Dong's Method:

Then we perform Dong's method to double check the if there is any significant effects between any levels:

m1 = # of {effects <= 2.5 S0} = 14

S1(effects <= 2.5 S0) = 6.04

m2 = # of {effects <= 2.5 S1} = 14

S2(effects<= 2.5 S1) = 6.04

Compare all the effects with t,m2, 1-r *S2 = 16.21 , only main effect A > 16.21

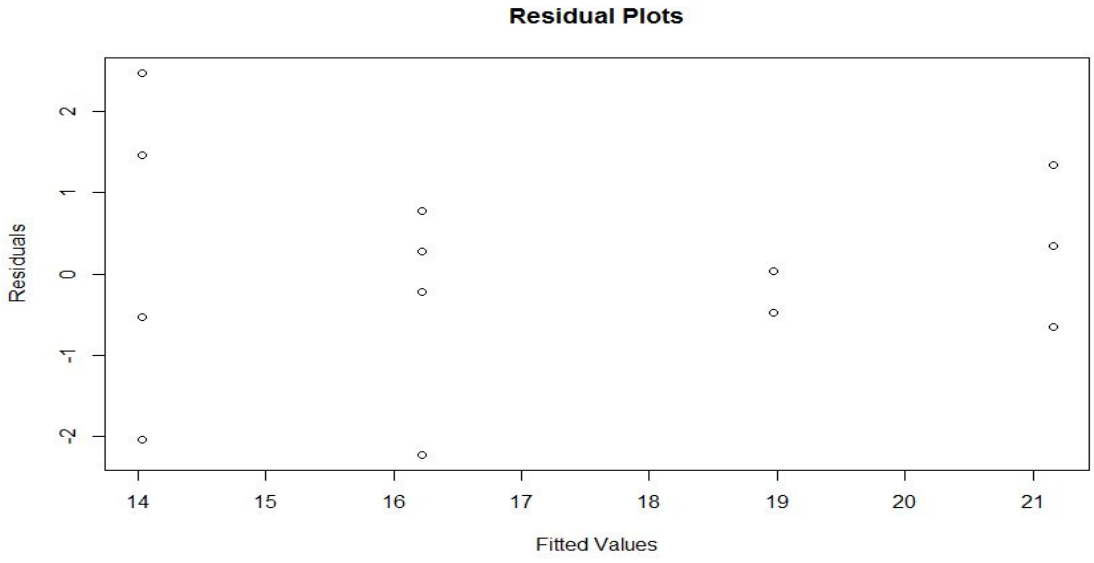
As a result, we found out that the main effect A as significant and it is consistent with the result from the LGB method and no additional significant effects are found.

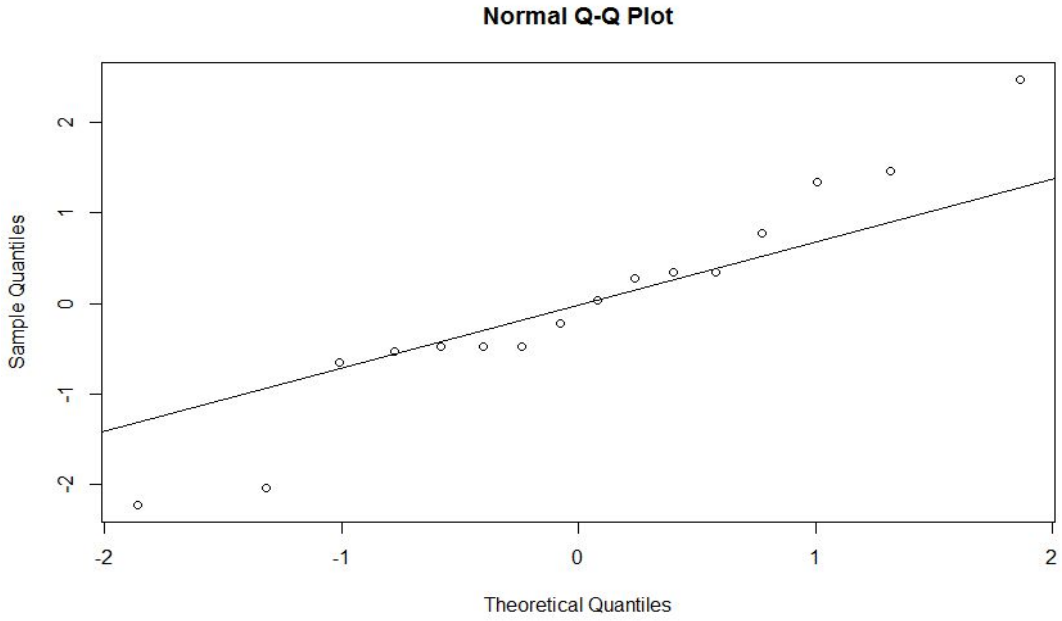
To start the analysis, we can see that the first two ranked effects were defined as significant effects, in addition, one of them seemed to exert positive effect on expanding the cooking time, while the other seemed to have the opposite effect. Such result is within my expectation since factor A (type of steak) determines the fat percentages in a piece of steak and cooking time on lean meat and fat is presumably different, thus rendering factor A as a significant one. As for factor B, I am not surprised that poking holes can help reduce the cooking time since it increases the cooking area on a piece of steak, thus fastening the heat absorption. In addition, factor C and D are probably significant factors on cooking time of steak according to the original data, which makes sense to me.

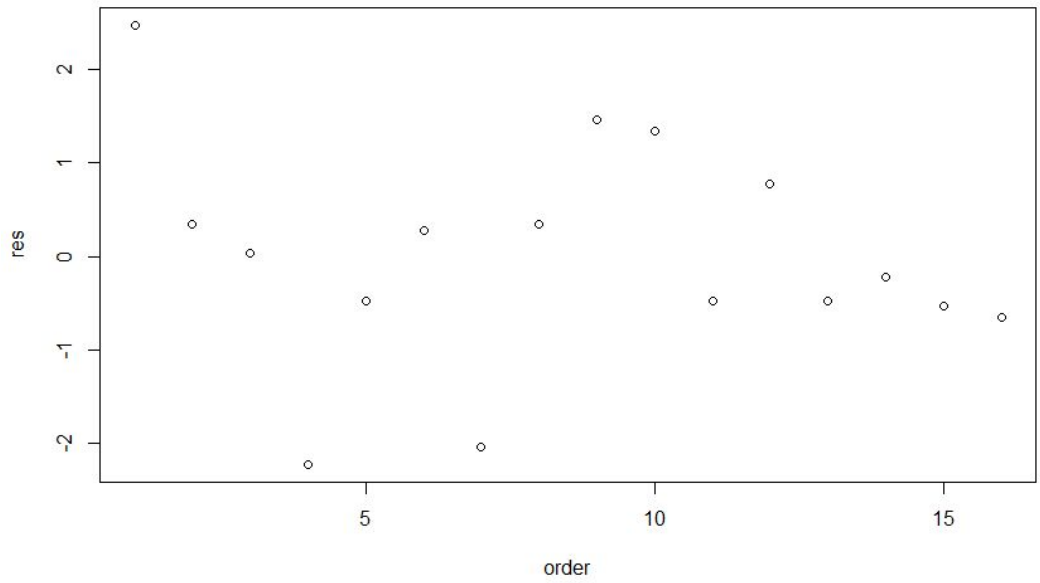
Then we take a look at the interaction effect, no major salience of the interaction effect between these four factors are detected. Such consequence can be contributed to the counteraction between the main effects, especially between A and B. Furthermore, their significance can also be contributed to the blocking effects. The blocking effect can be caused by the difference between oxidation level of the steaks since we bought all 16 pieces of steak one at a time. In addition, difference between the room temperatures varied by days may also contribute to blocking effects.

Then we dropped the insignificant factors and plot the residual plots and normal quantile plot of residuals for the remaining significant factors under the fitted model:

Y =17.59375+ 2.46875A + 1.09375 B


Residual Plots
Residuals
Fitted Values
14
15
16
17
18
19
20
21
-2
-1
0
1
2


Normal Q-Q Plot
Sample Quantiles
Theoretical Quantiles
-2
-1
0
1
2



Diagnostic plots for the cooking time data

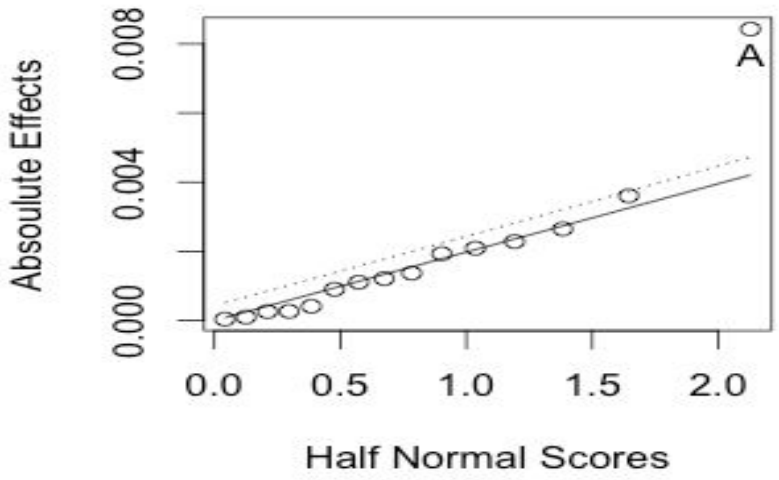
The diagnostic plots given display that there is clearly a lack of fit among the residuals. The normality assumption does not seem to hold well according to the normal quantile plot. As for the independence assumption, it seems to be hold well overall except someone may argue that we can observe an uprising trend to the middle following with a downward trend.

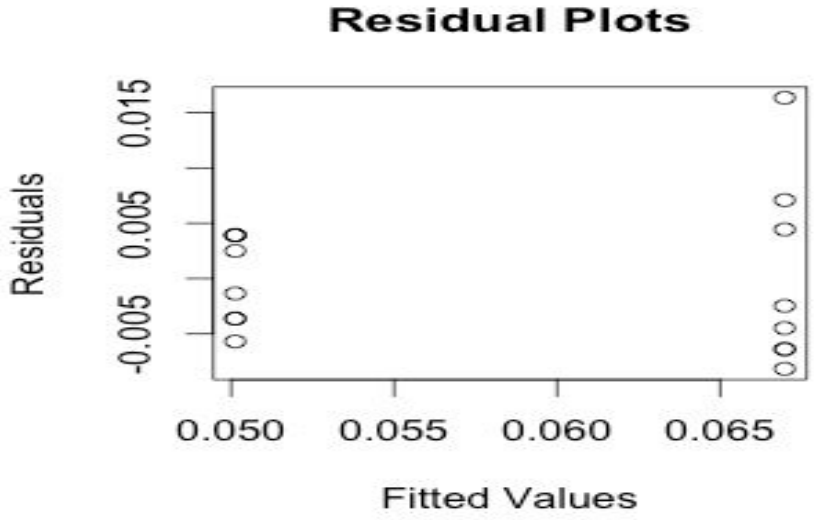
The response variables(cooking time) are measured quite objectively, though there might contain certain rounding error on timing or calculation. However, even though there seems to be no salient outliers detected and we have already detected some significant effects from the above analysis, we still decide to perform a data transformation due to the clear lack of fit among the residual plots.

Data Transformation:

Since the response variable we are measuring in this experiment is the cooking time of a steak. In other words, it can also be interpreted as the cooking rate of the steak. Therefore, we can view the total amount of cooking volumes(one piece of steak) as identical and use it to divided by the measured cooking time to obtain the cooking rates.

In order to achieve so, we perform the data transformation that takes the reciprocal of the cooking time as the new response variables and perform the LGB method as well as the residual analysis again. (Note we choose to skip the reperformance of Lenth and Dong's method because it detects less significant significant effects than the LGB methods in the previous trials)





The LGB method does not identify any more significant effects other than what we have found previously. In addition, the residual plot does not seem to look any better after the data transformation and thus we choose to stick with our original analysis results.

Conclusion:

This experiment examines various factors that may have an impact on the cooking time of a piece of steak. It shows that type of steak itself and poking holes or not play a major role on affecting the cooking time, while other factors related to the cooking environment such as cooking platform and salt input do not exert significant effect. Therefore, if we were to control the cooking time of a piece of steak, it's worth considering what kind of steak to buy and poking holes.

Discussion:

The experiment is a very fundamental one that investigates some basic elements can alter the cooking time of a piece of steak. There are many aspects that we can improve to provide a more accurate analysis.

Besides the blocking effects that we already have accounted, there may still exist subtle difference within the same day. For example, the surrounding temperature difference between different steak-cooking period can have an impact. As well, even though we tried to wash the pan or clean the stove every time we finish cooking a piece of steak, there are still chances that the dirt on the cooking tools can affect the cooking time. In addition, the conductivity of the cooking tools might change after it was used several times in one day.

On the data collection side, stricter control should be adopted next time for better accuracy.For example, we chose to round the cooking time to half minutes for more convenient calculation. Such operations can undermine certain level of precisement on the estimation, which lead to an incorrect conclusion. In addition, the type of pan/stove we choose may not be able to represent its average cooking rate, therefore, next time we should conduct the cooking experiment with replications through a couple of different tools on the market and then take their averages to obtain more representative results.

Appendix:

```
> summary(lm)

Call:
lm.default(formula = Y ~ A * B * C * D, data = df)

Residuals:
ALL 16 residuals are 0: no residual degrees of freedom!

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 17.59375         NA      NA       NA
A            2.46875         NA      NA       NA
B            1.09375         NA      NA       NA
C           -0.09375         NA      NA       NA
D           -0.59375         NA      NA       NA
A:B          0.34375         NA      NA       NA
A:C          0.15625         NA      NA       NA
B:C         -0.21875         NA      NA       NA
A:D          0.40625         NA      NA       NA
B:D          0.15625         NA      NA       NA
C:D         -0.15625         NA      NA       NA
A:B:C        0.15625         NA      NA       NA
A:B:D       -0.46875         NA      NA       NA
A:C:D       -0.03125         NA      NA       NA
B:C:D       -0.53125         NA      NA       NA
A:B:C:D      0.21875         NA      NA       NA

Residual standard error: NaN on 0 degrees of freedom
Multiple R-squared:      1,      Adjusted R-squared:    NaN
F-statistic:   NaN on 15 and 0 DF,  p-value: NA
```

```
> LGB( coef(lm)[-1], rpt = T )
Effect Report

Label     Half Effect    Sig(.05)
A          2.46875        yes
B          1.09375        yes
C         -0.09375        no
D         -0.59375        no
A:B        0.34375        no
A:C        0.15625        no
B:C       -0.21875        no
A:D        0.40625        no
B:D        0.15625        no
C:D       -0.15625        no
A:B:C      0.15625        no
A:B:D     -0.46875        no
A:C:D     -0.03125        no
B:C:D     -0.53125        no
A:B:C:D    0.21875        no

Lawson, Grimshaw & Burt Rn Statistic =  1.636169
95th percentile of Rn =  1.201
```