Annotated SAS Code and Output for Water Heater Data

SAS Code

Here is the SAS Code for three way ANOVA

```
Data;
input Cap$ Flo$ Exp$    Eff;
datalines;
high  high  high  41.6
high  high  high  41.3
high  high  low   39.9
high  high  low   39.7
high  low   high  51.9
high  low   high  52.4
high  low   low   43.0
high  low   low   44.9
low   high  high  39.2
low   high  high  38.4
low   high  low   37.5
low   high  low   35.0
low   low   high  50.2
low   low   high  51.3
low   low   low   41.3
low   low   low   43.5
;
proc glm;
class Cap Flo Exp ;
model Eff = Cap Flo Exp Cap*Flo Cap*Exp Flo*Exp Cap*Flo*Exp/ss3;
lsmeans Cap Flo Exp Cap*Flo Cap*Exp Flo*Exp Cap*Flo*Exp/stderr pdiff;
run;
quit;
```

Alternatives for model and lsmeans

Rather that write out all the main effects and interactions, one can simplify the model and lsmeans statements by using vertical lines between the names of the variables as follows:

```
model Eff = Cap|Flo|Exp/ss3;
lsmeans Cap|Flo|Exp/stderr pdiff ;
```

The pdiff option will create a lot of output as pairwise comparisons are done for all 3-way, 2-way, and 1-way means. An alternative approach would be to first do the analysis without the pdiff option or without the lsmeans statement altogether. Then re-run the analysis with the lsmeans statement and pdiff option just for the means that the ANOVA indicates are important. For instance, with the water heater data, the significance of the Cap and Flo*Exp interaction suggest using the following LSMEANS statement:

```
lsmeans Cap Flo*Exp /stderr pdiff;
```

Output

This is information on the class variables and number of observations.

```
The GLM Procedure

     Class Level Information
Class         Levels    Values

Cap                2    high low
Flo                2    high low
Exp                2    high low


Number of Observations Read          16
Number of Observations Used          16
```

This part of the output is equivalent to doing a one-way analysis of variance on the eight treatments. The significant F indicates that there are main effects and/or interactions that are significant.

```
Dependent Variable: Eff

                                   Sum of
Source                     DF         Squares     Mean Square    F Value    Pr > F
Model                       7     441.1843750      63.0263393      59.56    <.0001
Error                       8       8.4650000       1.0581250

Corrected Total            15     449.6493750

R-Square     Coeff Var      Root MSE      Eff Mean
0.981174      2.381484      1.028652      43.19375
```

The analysis of variance for the components shows that there are significant main effects for Cap, Flo, and Exp, and significant Flo*Exp interaction.

```
Source                     DF     Type III SS     Mean Square    F Value    Pr > F

Cap                         1      20.9306250      20.9306250      19.78    0.0021
Flo                         1     271.4256250     271.4256250     256.52    <.0001
Exp                         1     107.6406250     107.6406250     101.73    <.0001
Cap*Flo                     1       2.6406250       2.6406250       2.50    0.1528
Cap*Exp                     1       0.2756250       0.2756250       0.26    0.6236
Flo*Exp                     1      38.1306250      38.1306250      36.04    0.0003
Cap*Flo*Exp                 1       0.1406250       0.1406250       0.13    0.7249
```

Here is the output using the following LSMEANS statement:

```
lsmeans Cap Flo*Exp /stderr pdiff;
```

The main effect means for Cap shows that high capacity gives the highest mean efficiency. Looking at the table of two-way means with p-values, we see that all pairwise differences are significant. However, the low flow and high exposure produces an efficiency that is more than 8% greater than the next largest efficiency.

```
Least Squares Means

                                                        H0:LSMean1=
                            Standard    H0:LSMEAN=0      LSMean2
Cap       Eff LSMEAN           Error       Pr > |t|       Pr > |t|

high      44.3375000       0.3636834         <.0001         0.0021
low       42.0500000       0.3636834         <.0001


                                    Standard                   LSMEAN
Flo     Exp       Eff LSMEAN           Error    Pr > |t|      Number

high    high      40.1250000       0.5143260      <.0001           1
high    low       38.0250000       0.5143260      <.0001           2
low     high      51.4500000       0.5143260      <.0001           3
low     low       43.1750000       0.5143260      <.0001           4


          Least Squares Means for effect Flo*Exp
           Pr > |t| for H0: LSMean(i)=LSMean(j)

                 Dependent Variable: Eff

i/j              1             2             3             4

   1                       0.0203        <.0001        0.0030
   2         0.0203                      <.0001        0.0001
   3         <.0001        <.0001                      <.0001
   4         0.0030        0.0001        <.0001


NOTE: To ensure overall protection level, only probabilities associated with pre-planned
comparisons should be used.
```