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Section 1

MANE 6313

Subsection 1

Week 11, Module B

Student Learning Outcome

- Select an appropriate experimental design with one or more factors,
- Select an appropriate model with one or more factors,
- Evaluate statistical analyses of experimental designs,
- Assess the model adequacy of any experimental design, and
- Interpret model results.

Module Learning Outcome

Analyze a one-eighth fraction using R.

Problem 8_37 (Textbook 9th Edition)

8.37 An article in *Soldering & Surface Mount Technology* ("Characterization of a Solder Paste Printing Process and Its Optimization," 1999, Vol. 11, No. 3, pp. 23–26) describes the use of a 2^{8-3} fractional factorial experiment to study the effect of eight factors on two responses; percentage volume matching (PVM) – the ratio of the actual printed solder paste volume to the designed volume; and nonconformities per unit (NPU)—the number of solder paste printing defects determined by visual inspection (20′ magnification) after printing according to an industry workmanship standard. The factor levels are shown below and the test matrix and response data are shown in Table P8.9.

Figure 1: Problem 8.37 Statement

Parameters	Levels	
	Low (−)	High (+)
A. Squeegee pressure, *MPa*	0.1	0.3
B. Printing speed, *mm/s*	24	32
C. Squeegee angle, *deg*	45	65
D. Temperature, *°C*	20	28
E. Viscosity, *kCps*	1,100-1,150	1,250-1,300
F. Cleaning interval, *stroke*	8	15
G. Separation speed, *mm/s*	0.4	0.8
H. Relative humidity, %	30	70

2^{8-3}

(a) Verify that the generators are $I = ABCF$, $I = ABDG$, and $I = BCDEH$ for this design.

(b) What are the aliases for the main effects and two-factor interactions? You can ignore all interactions of order three and higher.

(c) Analyze both PVM and NPU responses.

(d) Analyze the residual for both responses. Are there any problems with model adequacy?

(e) The ideal value of PVM is unity and the NPU response should be as small as possible. Recommend suitable operating conditions for the process based on the experimental results.

■ TABLE P8.9
The Solder Paste Experiment

Run Order	Parameters								PVM	NPU (%)
	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*		
4	−	−	−	−	−	−	−	+	1.00	5
13	+	−	−	−	−	+	+	+	1.04	13
6	−	+	−	−	−	+	+	−	1.02	16
3	+	+	−	−	−	−	−	−	0.99	12
19	−	−	+	−	−	+	−	−	1.02	15
25	+	−	+	−	−	−	+	−	1.01	9
21	−	+	+	−	−	−	+	+	1.01	12
14	+	+	+	−	−	+	−	+	1.03	17
10	−	−	−	+	−	−	+	−	1.04	21
22	+	−	−	+	−	+	−	−	1.14	20
1	−	+	−	+	−	+	−	+	1.20	25
2	+	+	−	+	−	−	+	+	1.13	21
30	−	−	+	+	−	+	+	+	1.14	25
8	+	−	+	+	−	−	−	+	1.07	13
9	−	+	+	+	−	−	−	−	1.06	20
20	+	+	+	+	−	+	+	−	1.13	26
17	−	−	−	−	+	−	−	−	1.02	10
18	+	−	−	−	+	+	+	−	1.10	13
5	−	+	−	−	+	+	+	+	1.09	17
26	+	+	−	−	+	−	−	+	0.96	13
31	−	−	+	−	+	+	−	+	1.02	14
11	+	−	+	−	+	−	+	+	1.07	11
29	−	+	+	−	+	−	+	−	0.98	10
23	+	+	+	−	+	+	−	−	0.95	14
32	−	−	−	+	+	−	+	+	1.10	28
7	+	−	−	+	+	+	−	+	1.12	24
15	−	+	−	+	+	+	−	−	1.19	22
27	+	+	−	+	+	−	+	−	1.13	15
12	−	−	+	+	+	+	+	−	1.20	21
28	+	−	+	+	+	−	−	−	1.07	19
24	−	+	+	+	+	−	−	+	1.12	21
16	+	+	+	+	+	+	+	+	1.21	27

One-eighth Design

$2^{8-3} = 2^5 = 32$

```r
# Create Design using Advanced Features
library(FrF2)
p8_37.df <- FrF2(nruns=32,factor.names=list(SquegPress=c(0.1,0.2),PrintSpeed=c(24,32),SquegAngle=c(45,65),Temp=c(20,28),Viscosity=c("lo","high"),Cleaning=c(8,15),Separation=c(0.4,0.8),Humidity=c(30,70)),gen=c("ABC","ABD","BCDE"),randomize=FALSE)
summary(p8_37.df)
```

ABCDE

R Console | data.frame 2 x 8 | data.frame 32 x 8

Description: df [32 × 8]

	SquegPress <fctr>	PrintSpeed <fctr>	SquegAngle <fctr>	Temp <fctr>	Viscosity <fctr>	Cleaning <fctr>	Separation <fctr>	Humidity <fctr>
1	0.1	24	45	20	lo	8	0.4	70
2	0.2	24	45	20	lo	15	0.8	70
3	0.1	32	45	20	lo	15	0.8	30
4	0.2	32	45	20	lo	8	0.4	30
5	0.1	24	65	20	lo	15	0.4	30
6	0.2	24	65	20	lo	8	0.8	30
7	0.1	32	65	20	lo	8	0.8	70
8	0.2	32	65	20	lo	15	0.4	70
9	0.1	24	45	28	lo	8	0.8	30
10	0.2	24	45	28	lo	15	0.4	30

1–10 of 32 rows Previous 1 2 3 4 Next

Figure 4: Problem 8.37 R Design

Design Details

```r
# Create Design using Advanced Features
library(FrF2)
p8_37.df <- FrF2(nruns=32,factor.names=list(SquegPress=c(0.1,0.2),PrintSpeed=c(24,32),SquegAngle=c(45,65),Temp=c(20,28),Viscosity=c("lo","high"),Cleaning=c(8,15),Separation=c(0.4,0.8),Humidity=c(30,70)),gen=c("ABC","ABD","BCDE"),randomize=FALSE)
summary(p8_37.df)
```

R Console | data.frame 2 x 8 | data.frame 32 x 8

```
    28), Viscosity = c("lo", "high"), Cleaning = c(8, 15),
  Separation = c(0.4, 0.8), Humidity = c(30, 70)), gen = c("ABC",
  "ABD", "BCDE"), randomize = FALSE)

Experimental design of type  FrF2.generators
32  runs

Factor settings (scale ends):

Design generating information:
$legend
[1] A=SquegPress B=PrintSpeed C=SquegAngle D=Temp      E=Viscosity  F=Cleaning   G=Separation
H=Humidity

$generators
[1] F=ABC  G=ABD  H=BCDE


Alias structure:
$fi2
[1] AB=CF=DG AC=BF    AD=BG    AF=BC    AG=BD    CD=FG    CG=DF

The design itself:
```

$A, B, DE \rightarrow \bar{F}\ \bar{G}\ \bar{H}$

$I = ABCF \rightarrow F = ABC$

$I = ABDG \rightarrow G = ABD$

$I = BCDEH \rightarrow H = BCDE$

1) Are any Main Effects aliased with 2-factor interaction? No
Not resolution III

2 factor aliased with other 2 factor Interactions
Resolution

Adding Response Variable

```r
pvm <- c(1.0,1.04,1.02,0.99,1.02,1.01,1.01,1.03,1.04,1.14,1.2,1.13,1.14,1.07,1.06,1.13,1.02,1.1,1.09,0.96,1.02,1.07,0.98,0.95,1.1,1.12,1.19,1.13,1.2,1.07,1.12,1.21)
p8_37.df <- add.response(p8_37.df,pvm)
summary(p8_37.df)
```

R Console | data.frame 2 x 8 | data.frame 32 x 9

Description: df [32 × 9]

	SquegPress <fctr>	PrintSpeed <fctr>	SquegAngle <fctr>	Temp <fctr>	Viscosity <fctr>	Cleaning <fctr>	Separation <fctr>	Humidity <fctr>	pvm <dbl>
1	0.1	24	45	20	lo	8	0.4	70	1.00
2	0.2	24	45	20	lo	15	0.8	70	1.04
3	0.1	32	45	20	lo	15	0.8	30	1.02
4	0.2	32	45	20	lo	8	0.4	30	0.99
5	0.1	24	65	20	lo	15	0.4	30	1.02
6	0.2	24	65	20	lo	8	0.8	30	1.01
7	0.1	32	65	20	lo	8	0.8	70	1.01
8	0.2	32	65	20	lo	15	0.4	70	1.03
9	0.1	24	45	28	lo	8	0.8	30	1.04
10	0.2	24	45	28	lo	15	0.4	30	1.14

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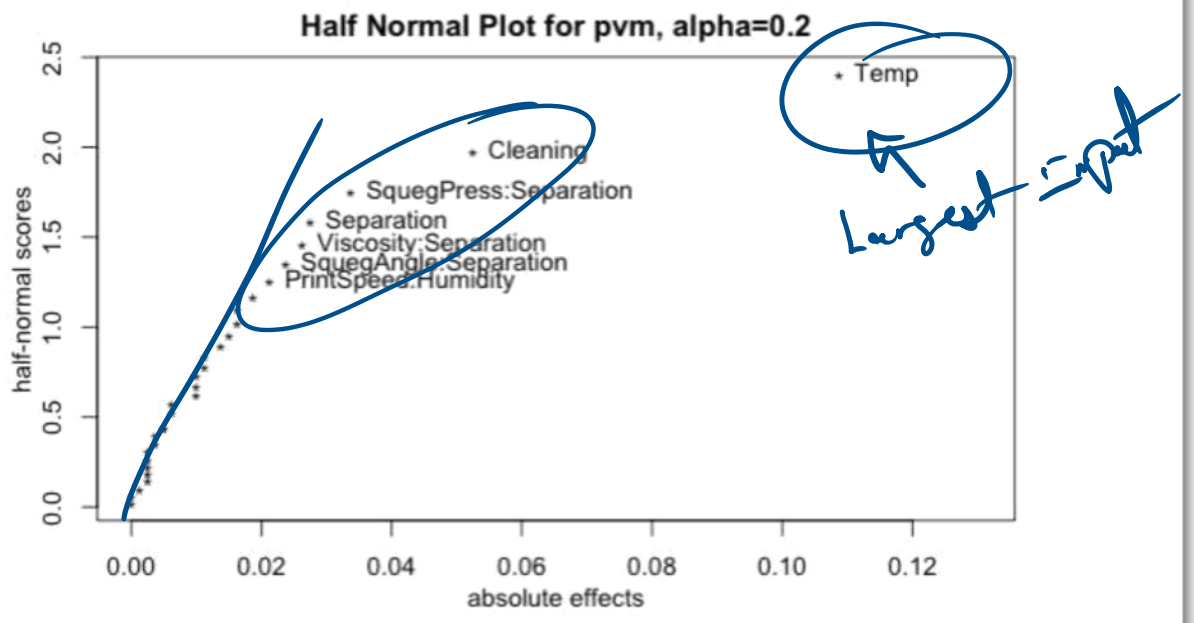
Figure 6: Adding Response Variable in R

Half-Normal Plot

```
31 ```{r}
32  # Half-Normal Plot
33  DanielPlot(p8_37.df,half=TRUE,response='pvm',alpha=0.2)
34 ```
```

trial & error



Largest input

Initial Model

```
44 ```{r}
45 # First Model
46 p8_37.model1 <- aov(pvm~Temp+Cleaning+SquegPress+Separation+SquegAngle+Viscosity+PrintSpeed+Humidity+SquegPress:Separation+
   Viscosity:Separation+SquegAngle:Separation+PrintSpeed:Humidity,data=p8_37.df)
47 summary(p8_37.model1)
48 aliases(p8_37.model1)
49 ```
```

```
                          Df  Sum Sq Mean Sq F value   Pr(>F)
Temp                       1 0.09461 0.09461 176.455 4.57e-11 ***
Cleaning                   1 0.02205 0.02205  41.124 3.78e-06 ***
SquegPress                 1 0.00011 0.00011   0.210 0.652107
Separation                 1 0.00605 0.00605  11.283 0.003296 **
SquegAngle                 1 0.00101 0.00101   1.888 0.185383
Viscosity                  1 0.00281 0.00281   5.245 0.033615 *
PrintSpeed                 1 0.00005 0.00005   0.093 0.763404
Humidity                   1 0.00211 0.00211   3.940 0.061784 .
SquegPress:Separation      1 0.00911 0.00911  16.995 0.000579 ***
Separation:Viscosity       1 0.00551 0.00551  10.281 0.004647 **
Separation:SquegAngle      1 0.00451 0.00451   8.416 0.009158 **
PrintSpeed:Humidity        1 0.00361 0.00361   6.737 0.017749 *
Residuals                 19 0.01019 0.00054
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
[1] no aliasing in the model
```

All significant using $\alpha = .05$ except for SquegPress, SquegAngle, PrintSpeed

Figure 8: Initial Model for Problem 8.37