Cummins M11EGR
Precision/BOI Matrix Analysis

08/02/01

Experimental design

Lab A		Lab B	Lab D	Lab G	
S1	**S2**	**S1**	**S1**	**S1**	**S2**
B	A	B[a]	C[a]	A	C[b]
E	E	D	D	E	E
E	E	E	E	E	E
F	J	J	H	F	G
G				H	

[a] Replaced oil filter due to low oil gallery pressure

[b] CMIR 38958.Terminated at 228 hrs. due to low oil gallery pressure (only included in OFDP analysis)

		Base stock		
		1	**2**	**3**
Technology	**X**	A	B	C
	Y	D	E	F
	Z	G	H	J
		Group II	Group II	Group I

Significant Effects

- Lab
  - Crosshead Wear
  - Average Engine Sludge
  - Adjusting Screw Weight Loss
  - Rod Bearing Weight Loss
  - Average Wear Step
- Base oil
  - Crosshead Wear
- Technology
  - Rod Bearing Weight Loss
  - Average Wear Step
- Base oil/Technology
  - Oil Filter Differential Pressure
  - Average Engine Sludge

Crosshead Wear

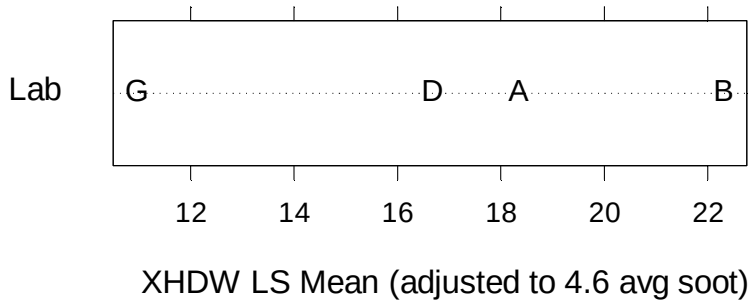
- Crosshead wear is transformed and adjusted to 4.6 average soot.

$$XHDW_{adj} = 10^{\log(XHDW) - 0.2575(avSoot - 4.6)}$$

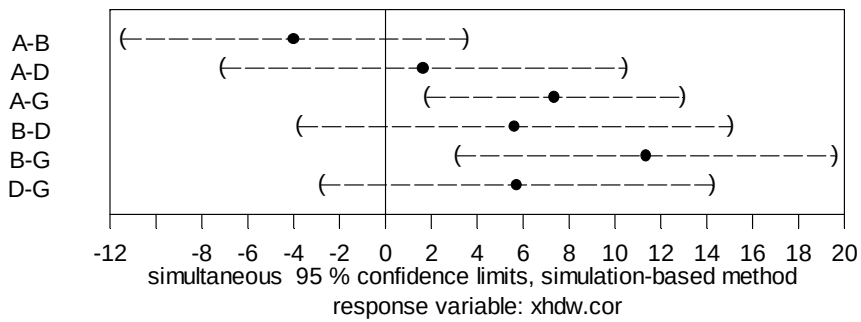
- Lab and base oil are significant
  - Lab G has lower wear than labs A and B
  - base oil 1 has lower wear that base oil 3
- RMSE = 3.7 (adj mg)
- $R^2 = 0.74$
- No highly influential observations

Crosshead Wear
(lab effect)

- Lab effect is due to Lab G having lower wear than Labs A and B



Confidence intervals for lab differences

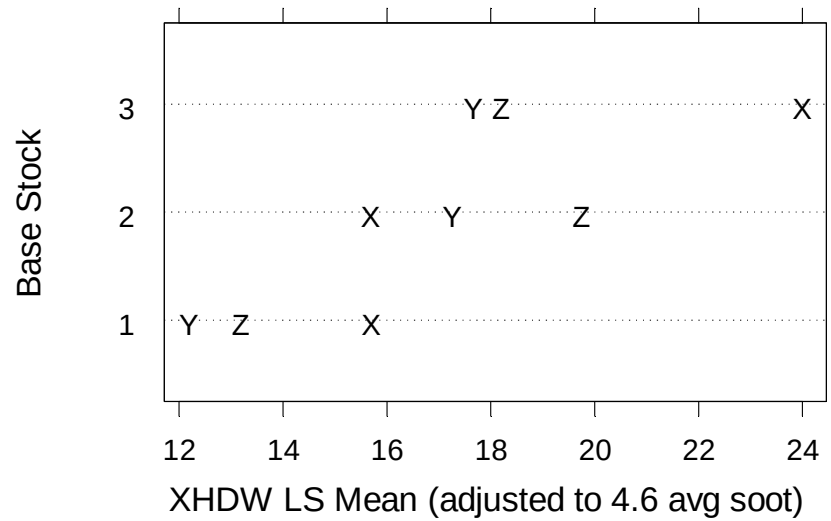


Lab LS Means

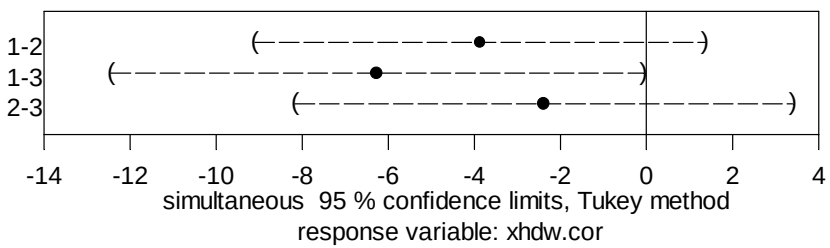
Lab	A	B	D	G
LS Mean	18.3	22.3	16.7	11.0

Crosshead Wear
(base oil effect)

- Base oil effect is due to lower wear in base oil 1 than in base oil 3



Confidence intervals for base oil differences

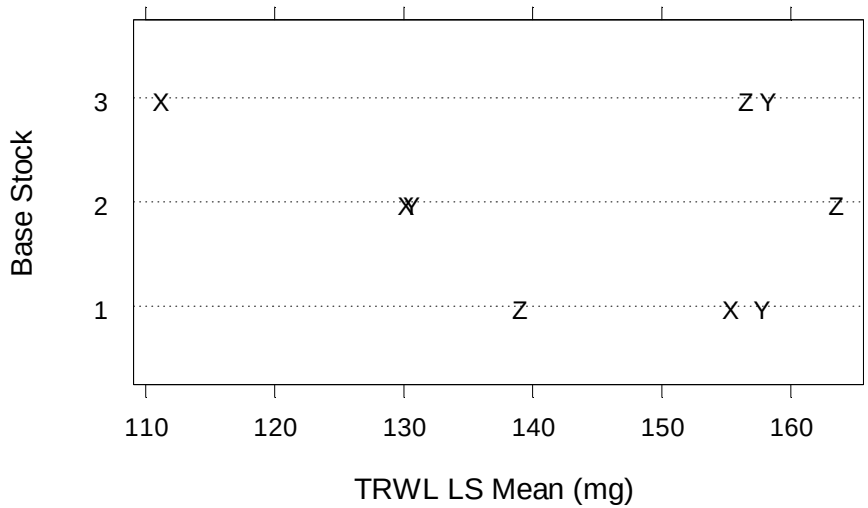


Oil LS Means

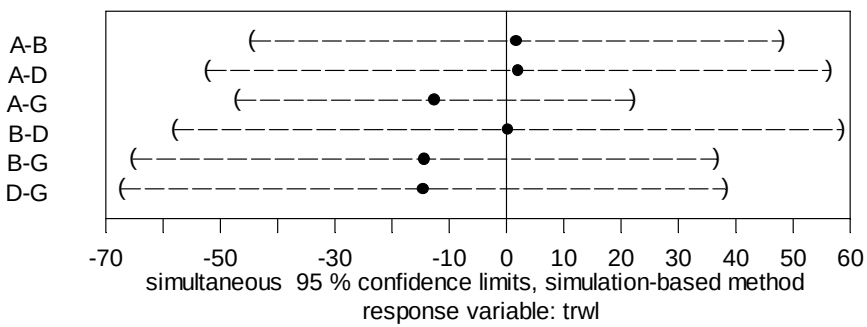
BS \ Tech	X	Y	Z
1	15.7	12.2	13.2
2	15.7	17.3	19.7
3	24.0	17.7	18.2

Top Ring Weight Loss

- No significant effects
- No transform necessary
- RMSE = 22.9
- $R^2 = 0.49$
- No highly influential observations



Confidence intervals for lab differences

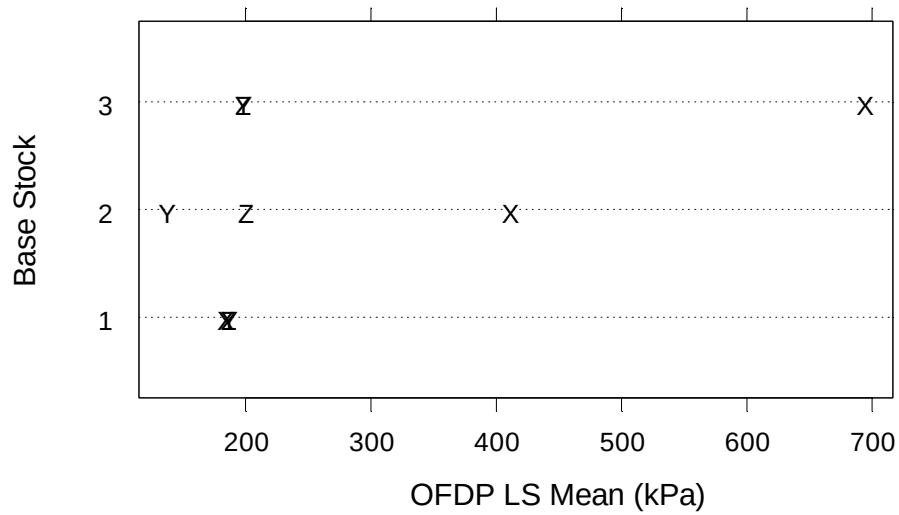


Oil LS Means

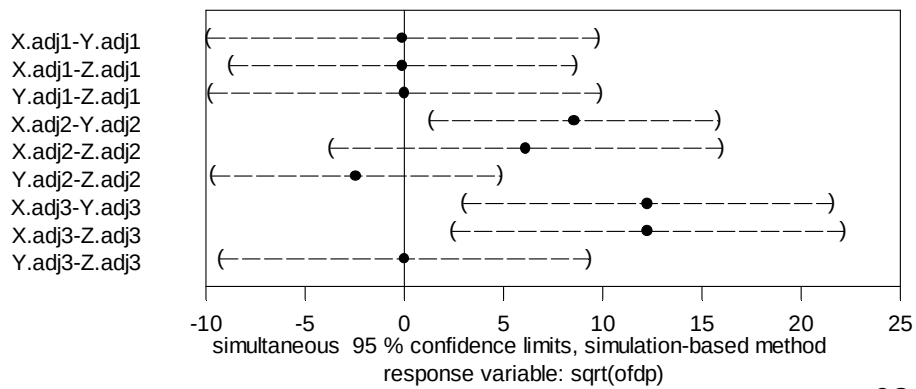
BS \ Tech	X	Y	Z
1	156.3	157.9	140.1
2	131.5	131.7	162.8
3	111.3	161.5	158.2

Oil Filter Differential Pressure
(including extreme values)

- Significant base oil/technology interaction
- Square root transformation
- RMSE = 2.7 (sqrt kPa)
- $R^2 = 0.81$



Confidence intervals for technology differences



Oil LS Means

BS \ Tech	X	Y	Z
1	184.1	186.9	186.7
2	411.2	137.3	200.2
3	694.2	198.3	198.1

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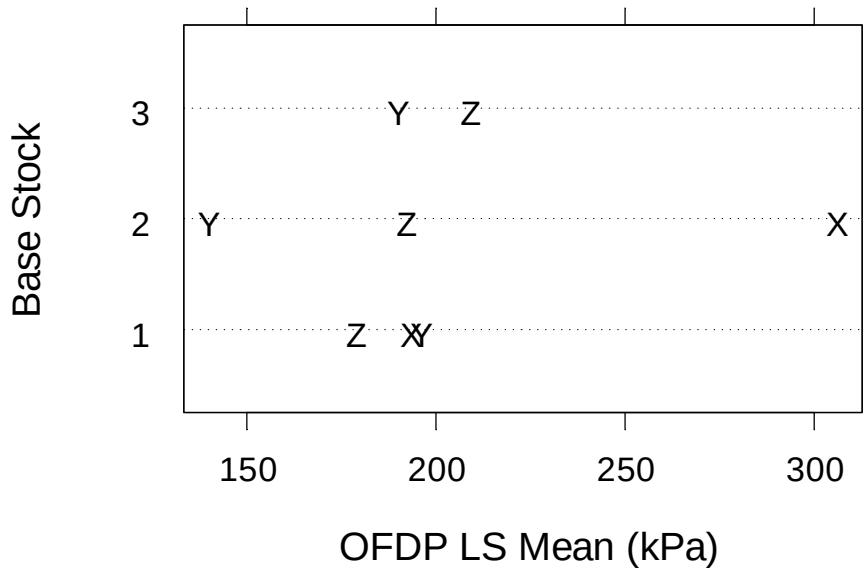
Oil Filter Differential Pressure
(excluding extreme values)

- This excludes
  - CMIR 38972 (oil B, lab B)
  - CMIR 38965 (oil C, lab D)
  - CMIR 38958 (oil C, lab G)
- Collectively these observations are highly influential
- Nothing significant
- No transformation necessary
- RMSE = 67
- $R^2 = 0.46$



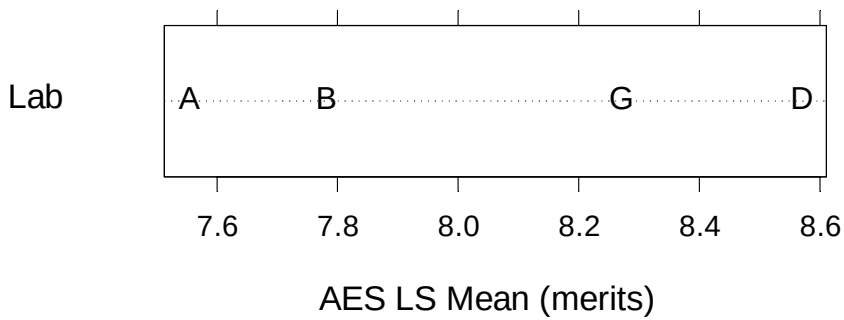
Oil LS Means

BS \ Tech	X	Y	Z
1	193.4	196.1	178.9
2	306.0	139.9	192.3
3	NA	189.9	209.2

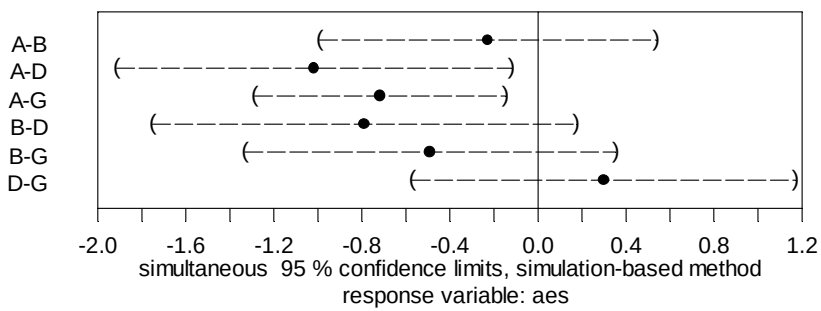
Average Engine Sludge

- Significant lab differences and technology/base stock interaction
  - Lab effect is due to Lab A having lower sludge than Labs D and G
  - Interaction is due to low sludge rating for technologies Y and Z in base oil 1

- No transformation necessary
- RMSE = 0.38
- R^2 = 0.82
- No highly influential observations



Confidence intervals for lab differences

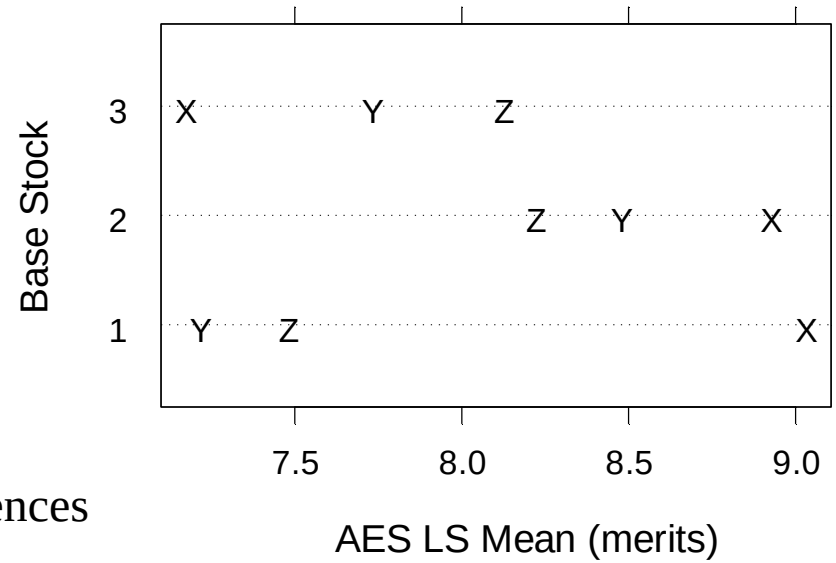


Lab LS Means

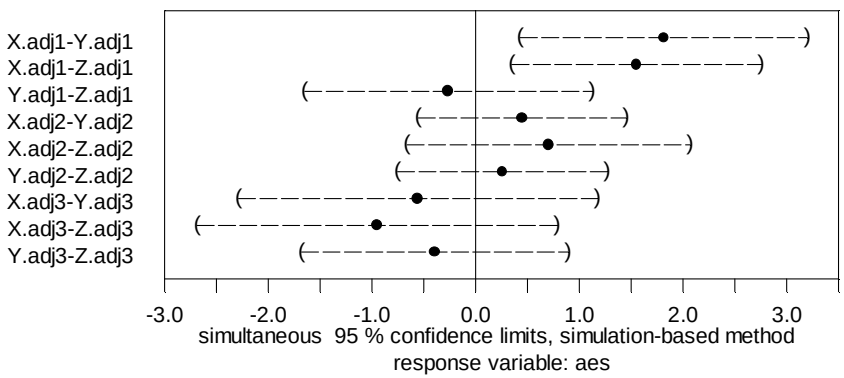
Lab	A	B	D	G
LS Mean	7.6	7.8	8.6	8.3

Average Engine Sludge
(technology/base oil interaction)

- Low sludge rating for technologies Y and Z in base oil 1



Confidence intervals for technology differences



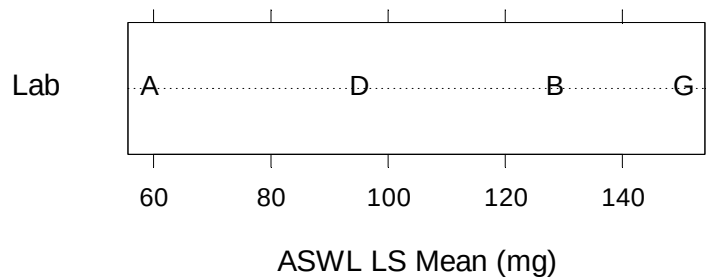
Oil LS Means

BS \ Tech	X	Y	Z
1	9.0	7.2	7.5
2	8.9	8.5	8.2
3	7.2	7.7	8.1

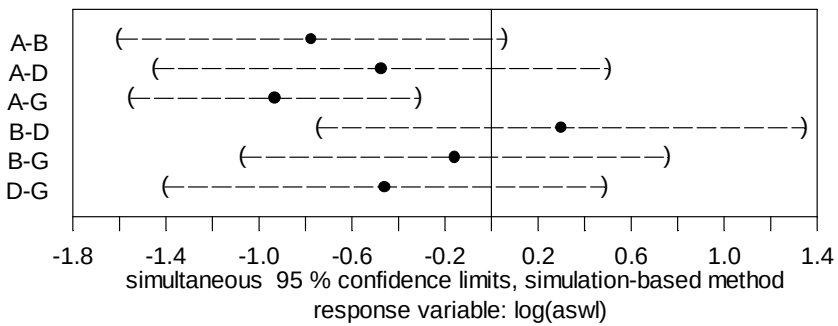
Adjusting Screw Weight Loss

- Lab is significant, with Lab A having lower wear than labs B and G
- Base oil is close to significant

- Ln transformation
- RMSE = 0.41 (ln mg)
- $R^2 = 0.74$



Confidence intervals for lab differences

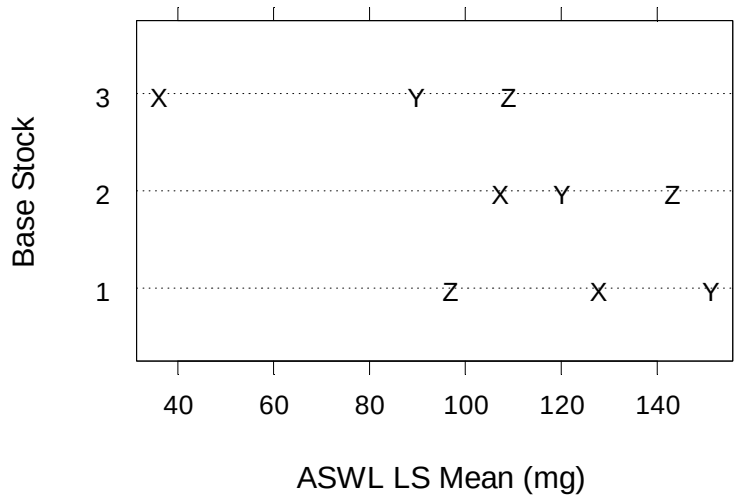


Lab LS Means

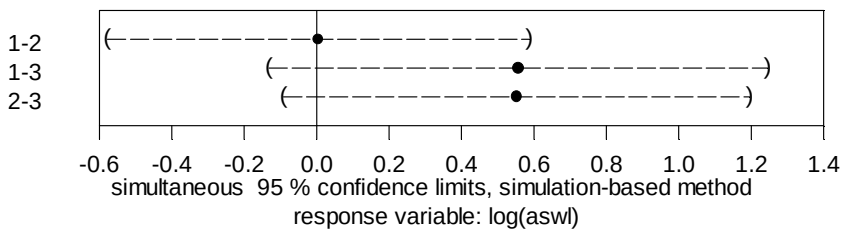
Lab	A	B	D	G
LS Mean	59.3	128.5	95.1	150.4

Adjusting Screw Weight Loss (base oil)

- While not statistically significant, base oil 3 appears to have slightly lower wear than base oils 2 and 3



Confidence intervals for base oil differences

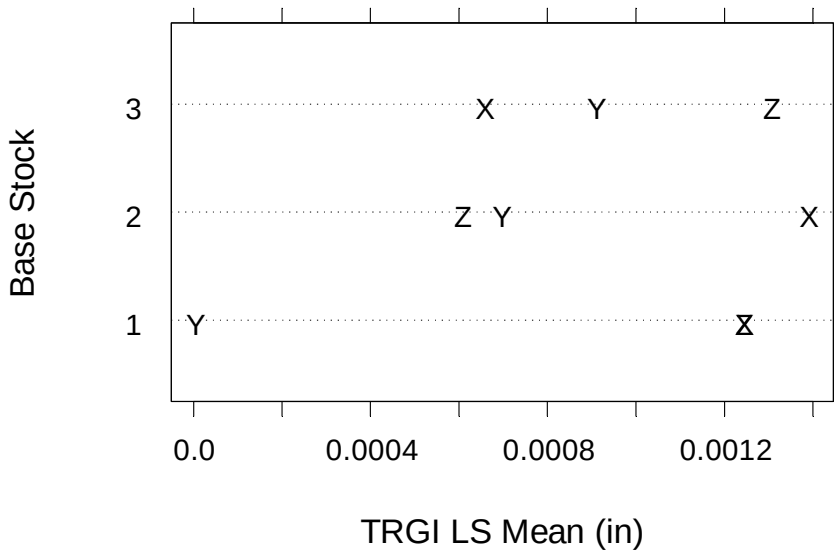


Oil LS Means

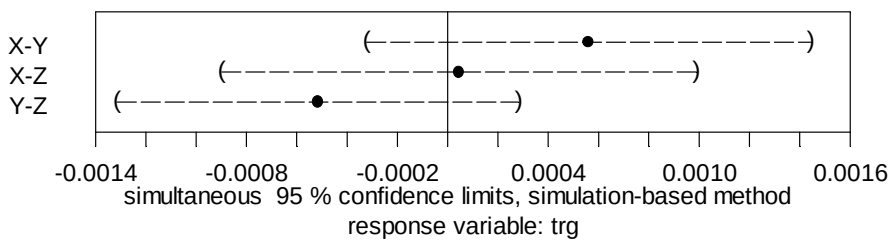
BS \ Tech	X	Y	Z
1	127.7	151.2	96.8
2	107.2	120.1	143.2
3	36.0	89.7	109.0

Top Ring Gap Increase

- Nothing is significant
- Does not correlate with TRWL
- No transformation necessary
- RMSE = 0.00056
- $R^2 = 0.43$



Confidence intervals for technology differences



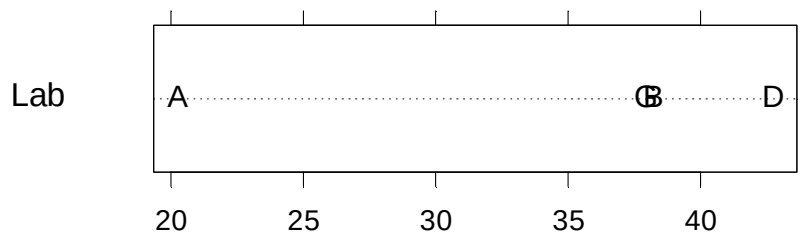
Oil LS Means

BS \ Tech	X	Y	Z
1	0.0013	0.0000	0.0013
2	0.0014	0.0007	0.0007
3	0.0006	0.0009	0.0013

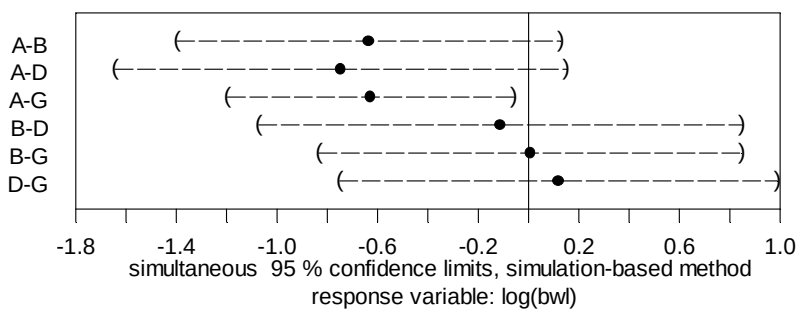
Rod Bearing Weight Loss

- Lab and technology are significant
  - Lab A is has lower weight loss than labs B, D, and G
  - Technology X has higher weight loss than Technologies Y and Z

- Ln transformation
- RMSE = 0.38 (ln mg)
- $R^2 = 0.73$



Confidence intervals for lab differences

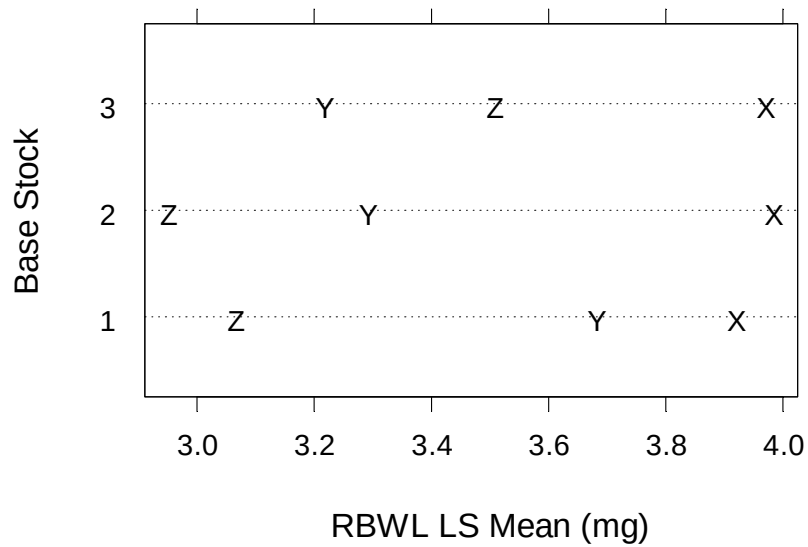


Lab LS Means

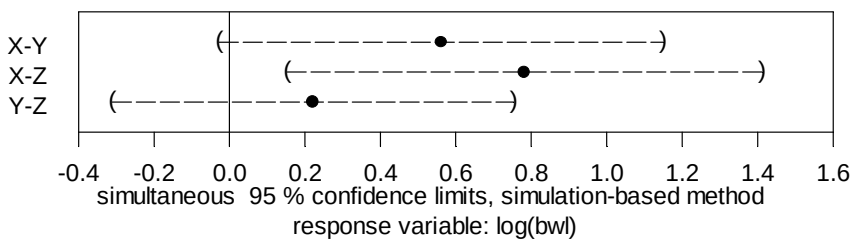
Lab	A	B	D	G
LS Mean	20.2	38.2	42.7	37.9

Rod Bearing Weight Loss
(technology effect)

- Technology effect is due to technology X having higher weight loss than technologies Y and Z



Confidence intervals for technology differences

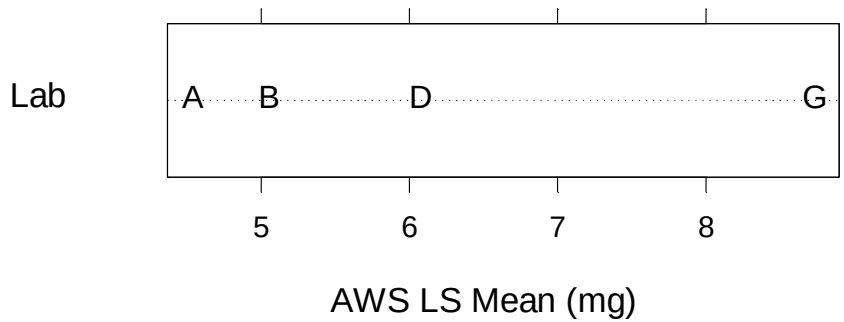


Oil LS Means

BS \ Tech	X	Y	Z
1	50.4	39.7	21.5
2	53.7	26.9	19.1
3	53.0	25.0	33.4

Average Wear Step

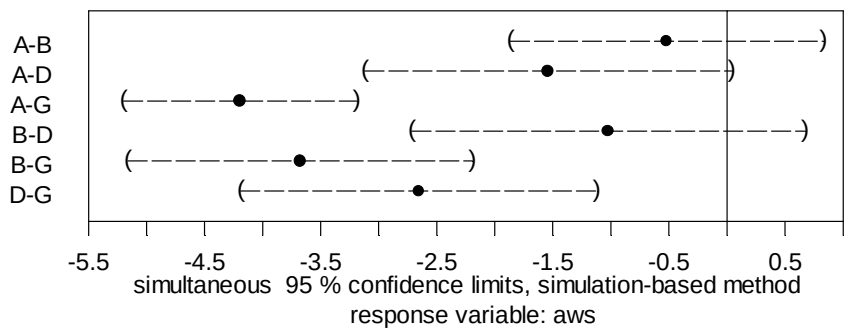
- Lab is highly significant
  - Labs G has much higher than Labs A, B, and D
- No transformation
- RMSE = 0.67
- $R^2 = 0.94$



Lab LS Means

Lab	A	B	D	G
LS Mean	4.5	5.1	6.1	8.7

Confidence intervals for lab differences



Oil LS Means

BS \ Tech	X	Y	Z
1	5.3	6.2	6.4
2	5.9	5.9	7.0
3	5.5	6.4	6.2

Parameter Correlations

Residuals							
XHDW	0.19	0.27	-0.03	-0.01	-0.27	0.08	-0.15
	TRWL	0.13	-0.35	0.20	0.03	-0.01	-0.07
		OFDP	0.12	-0.21	-0.69	-0.11	0.08
			AES	-0.22	-0.45	0.12	-0.13
				ASWL	0.35	0.55	-0.21
					TRGI	0.17	-0.10
						RBWL	-0.62
							AWS

Raw data							
XHDW	-0.05	0.60	-0.18	0.00	0.09	0.26	-0.43
	TRWL	-0.22	-0.10	0.22	0.04	-0.09	0.31
		OFDP	-0.08	-0.26	0.08	0.45	-0.26
			AES	0.31	0.01	0.23	0.33
				ASWL	0.26	0.53	0.49
					TRGI	0.35	-0.03
						RBWL	0.05
							AWS

Oil LS Means							
XHDW	-0.44	0.62	-0.10	-0.70	-0.01	0.10	-0.12
	TRWL	-0.75	0.16	0.77	-0.08	-0.44	0.54
		OFDP	-0.24	-0.83	0.04	0.61	-0.41
			AES	0.45	0.57	0.19	-0.25
				ASWL	-0.08	-0.34	0.41
					TRGI	0.11	-0.24
						RBWL	-0.83
							AWS

Oil LS means and standard deviations

Oil	adjXHDW	TRWL	sqrt(OFDP)	AES	ln(ASWL)	TRGI	ln(RBWL)	AWS
A	15.7	156.3	13.5673	9.0	4.8499	0.0012	3.9209	5.3
B	15.7	131.5	20.2788	8.9	4.6749	0.0014	3.9836	5.9
C	24.0	111.3	26.3477	7.2	3.5832	0.0007	3.9706	5.5
D	12.2	157.9	13.6704	7.2	5.0184	0.0000	3.6820	6.2
E	17.3	131.7	11.7164	8.5	4.7883	0.0007	3.2919	5.9
F	17.7	161.5	14.0805	7.7	4.4964	0.0009	3.2178	6.4
G	13.2	140.1	13.6620	7.5	4.5729	0.0012	3.0668	6.4
H	19.7	162.8	14.1506	8.2	4.9642	0.0006	2.9523	7.0
J	18.2	158.2	14.0751	8.1	4.6913	0.0013	3.5089	6.2
std dev	3.7	22.9	2.7	0.38	0.4100	0.00056	0.3804	0.67

Data set

	CMIR	oil	base	tech	lab	xhdw	trwl	ofdp	aes	aswl	trgi	rbwl	aws
1	38932	E	2	Y	A	23.609126	172.0	127	7.4	108.4	0.0010000000	16.2	4.2
2	38967	B	2	X	A	18.860696	125.0	308	8.8	43.7	0.0010000000	30.1	3.9
3	38969	G	1	Z	A	12.024254	124.5	175	7.3	68.2	0.0010000000	18.6	4.7
4	38935	E	2	Y	A	17.497106	128.9	97	8.1	85.0	0.0001666667	22.3	4.1
5	38970	F	3	Y	A	20.770668	134.2	186	7.0	42.7	0.0010000000	17.6	4.3
6	38933	E	2	Y	A	11.403427	115.5	66	8.0	51.2	0.0011666667	7.6	5.3
7	38966	J	3	Z	A	20.313626	170.5	265	7.7	71.8	0.0010000000	23.8	4.5
8	38934	E	2	Y	A	16.018042	139.1	143	7.6	82.1	0.0000000000	17.1	4.5
9	38968	A	1	X	A	20.292868	144.5	288	8.9	56.6	0.0001666667	25.0	4.4
10	38936	E	2	Y	B	23.283084	147.2	246	8.7	116.6	0.0005000000	36.2	3.8
11	38971	D	1	Y	B	19.409366	144.7	191	6.9	196.6	0.0003333333	42.0	5.7
12	40920	J	3	Z	B	22.573732	139.7	179	7.8	120.7	0.0015000000	32.4	5.3
13	38972	B	2	X	B	19.005164	131.8	601	8.3	191.9	0.0016666667	66.2	5.3
14	38931	E	2	Y	D	15.914587	112.8	118	9.1	98.9	0.0011666667	37.2	6.4
15	38963	D	1	Y	D	9.810164	162.9	224	7.8	136.1	0.0000000000	54.8	5.7
16	38965	C	3	X	D	23.597374	107.1	606	7.7	33.5	0.0008333333	67.7	5.5
17	38964	H	2	Z	D	22.282757	164.0	184	8.6	155.8	0.0008333333	20.9	7.0
18	38927	E	2	Y	G	11.739236	104.1	178	9.0	160.5	0.0000000000	26.2	8.2
19	38962	F	3	Y	G	9.698728	196.9	171	8.2	160.9	0.0005000000	24.3	9.6
20	38930	E	2	Y	G	11.478874	148.2	190	8.4	96.6	0.0003333333	21.9	9.1
21	38960	H	2	Z	G	10.702293	167.7	175	8.6	180.4	0.0006666667	25.4	9.6
22	38959	A	1	X	G	6.245662	176.2	76	8.9	246.2	0.0020000000	69.8	7.3
23	38928	E	2	Y	G	14.913275	143.7	111	8.9	139.0	0.0003333333	28.1	9.0
24	38929	E	2	Y	G	12.098821	129.5	55	8.8	404.0	0.0013333333	62.6	8.0
25	38958	C	3	X	G	NA	NA	706	NA	NA	NA	NA	NA
26	38961	G	1	Z	G	9.496053	163.8	160	7.4	117.4	0.0011666667	17.0	9.1