Sequence IV Surveillance Panel | MINUTES

REVISION DATE: 4/10/2018 7:57:00 AM

Relevant Test:	Sequence IVB
Note Taker:	Chris Mileti
Meeting Date:	03-28-2018
Comments:	Conference call to discuss the proposed LTMS system for the Sequence IVB test.

1. OPEN ACTION ITEMS (B. BUSCHER):

1.1. KA24E Fuel:

1.1.1. The IVB procedure must be updated with instructions for mixing different batches of KA24E fuel.

1.1.2. The Sequence VG/VH procedure can be referenced because it includes instructions for switching to a new fuel batch.

1.2. OHT Updates:

1.2.1. OHT is currently manufacturing clutch alignment tools.

1.2.2. Timing Chain Wedge and Engine Rotation Locking Tool:

1.2.2.1. These two action items are still open.

1.2.2.2. OHT is waiting on feedback regarding the design of these tools.

1.2.3. Thermal Barrier Coating:

1.2.3.1. The Surveillance Panel is interested in possibly applying a thermal coating to components of the IVB engine that have large surface areas (oil pan and front cover).

1.2.3.2. OHT has not yet identified a suitable product.

1.3. Oil Consumption:

1.3.1. The Surveillance Panel still needs to discuss a test validity limit for oil consumption.

1.4. Oil Samples:

1.4.1. There is an open action item for SWRI and IAR to swap oil samples and compare analytical results.

1.4.2. SWRI, Exxon and Lubrizol have provided Precision Matrix oil samples to IAR for analysis.

1.4.2.1. Afton provided samples from their recent prove-out testing.

1.4.2.2. These samples will be re-tested by IAR to eliminate laboratory bias.

1.5. Quality Index Calculations:

1.5.1. The Surveillance Panel has an open action item to reevaluate the QI calculations for oil gallery temperature.

1.6. TMC Updates:

1.6.1. Some test reports for the Prove-Out Matrix and Precision Matrix are incomplete.

1.6.2. The TMC will send an email to each laboratory that still needs to provide data for their Industry tests.

1.7. Parameter Database:

1.7.1. The Surveillance Panel has an open action item to create a database of parameters that are believed to have a significant impact on severity.

1.7.2. One example of such a parameter would be oil gallery temperature.

1.8. Oil Temperature Histogram:

1.8.1. Lubrizol has an open action item to evaluate whether a histogram is a more appropriate way to analyze the oil gallery temperature parameter.

1.8.2. IAR will follow-up with Lubrizol.

1.9. Blowby System:

1.9.1. The IVB procedure needs to be updated with instructions for cleaning the external blowby system.

1.10. 200HR Operational Data Plots:

1.10.1. The plots from SWRI and Lubrizol are available on the TMC website.

1.10.2. IAR has almost finished compiling its plots.

1.11. Engine Build Workshop:

1.11.1. Most of the labs participated in an engine build workshop earlier in the year.

1.11.2. The Surveillance Panel needs to compile all the notes from this meeting into a single document.

1.12. Unscheduled Downtime:

1.12.1. The IVB procedure needs to be updated with instructions about how to handle extended periods of unscheduled downtime.

1.12.2. These instructions need to reduce the likelihood of oxidation on camshafts and lifters.

1.13. Anomalous Operational Parameters:

1.13.1. The Surveillance Panel needs to further analyze the four anomalous operational parameters identified by Lubrizol.

1.13.2. Parameter List:

1.13.2.1. Exhaust Gas Temperature

1.13.2.2. Crankcase Pressure / Blowby Flow Rate

1.13.2.3. Intake Manifold Pressure

1.13.2.4. AFR

1.14. Appendix K:

1.14.1. Appendix K needs to be updated for the Sequence IVB test.

2. STATISTICAL ANALYSIS OF OPERATIONAL DATA (STATISTICS GROUP):

2.1. Background:

2.1.1. The Statistics Group conducted another analysis of Precision Matrix operational data (dated 03-20-2018).

2.1.2. The focus of this analysis was on exhaust gas temperature, AFR, intake manifold pressure and crankcase pressure.

2.1.3. A partial least squares analysis was used on all (28) Precision Matrix tests.

2.2. Slide #3:

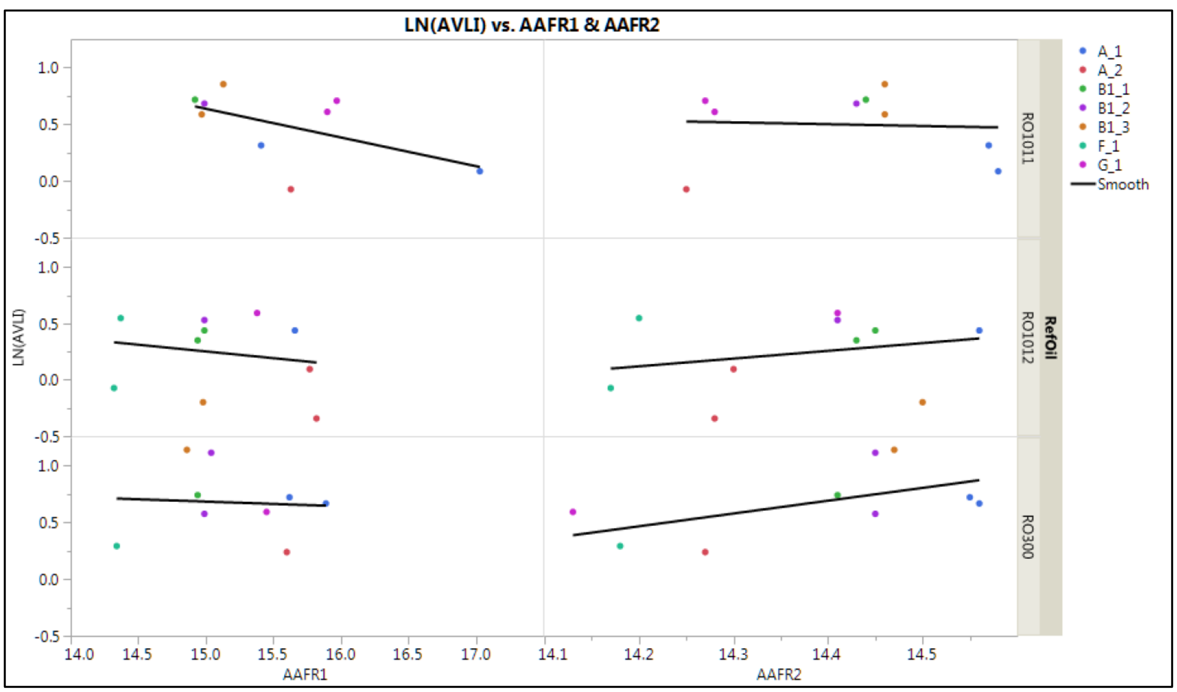
Statistical Analysis of Operational Data

- Due to multicollinearity, a Partial Least Squares (PLS) Analysis was performed on the data set
- PLS analysis results *(with 2 latent variables)* for centered and scaled data are summarized below (and sorted by their centered and scaled coefficients):

Rank	Term	Coefficient (Centered & Scaled)
1	A-2	-0.3198
2	1012	-0.2625
3	300	0.2378
4	ABLOWBY1	0.1554
5	AAFR1	-0.1487
6	B1-2	0.1337
7	G-1	0.1286
8	AMAP1	0.1065
9	AAFR2	0.0828
10	AMAP2	-0.0764
11	ACCASEP2	0.075
12	B1-1	0.0621
13	ABLOWBY2	0.0612
14	B1-3	0.0535
15	F-1	-0.0342
16	ACCASEP1	0.0332
17	1011	0.0315
18	A-1	-0.0256
19	AEXHT1	-0.0241
20	AEXHT2	0.0132
21	Intercept	0

2.2.1. The average Stage 1 blowby and AFR parameters are interesting.

2.3. Slide #5:



2.3.1. The rows in the chart correspond to different reference oils.

2.3.2. The Surveillance Panel needs to decide whether tighter controls should be implemented on the parameters of interest (particularly AFR and blowby).

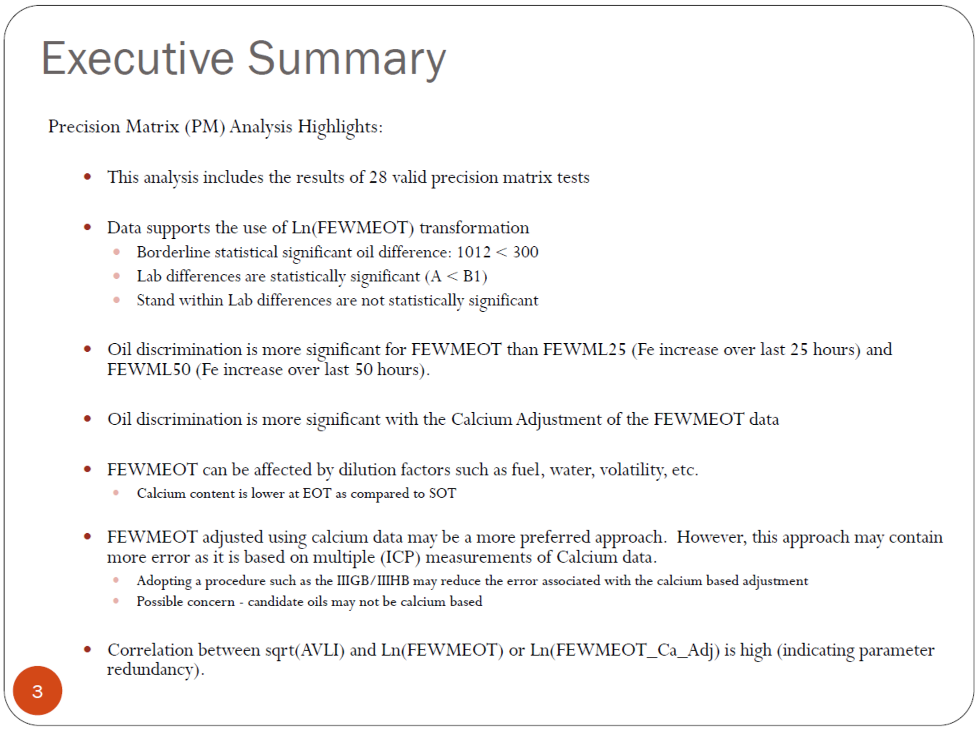
2.3.3. Buscher requested that each laboratory review this analysis and be prepared to provide feedback during the next meeting.

3. STATISTICAL ANALYSIS OF IRON PARAMETER (STATISTICS GROUP):

3.1. Background:

3.1.1. The Statistics Group conducted an analysis of the iron parameter (dated 03-26-2018).
3.1.2. Iron is measured in the oil drain samples.

3.2. Slide #3:



3.2.1. Several months ago, the Statistics Group analyzed several key parameters from the Precision Matrix data set.
3.2.1.1. AVLI (average intake lifter volume loss) demonstrated the best discrimination.
3.2.2. The Statistics Group recently revisited the iron parameter.
3.2.2.1. The N=21and N=28 data sets were both used in the analysis.
3.2.2.2. However, the Executive Summary deals exclusively with the N=28 analysis.
3.2.3. Iron demonstrates oil discrimination that is borderline statistically significant.
3.2.4. Lab differences with iron are statistically significant.
3.2.4.1. For example, Lab B1 is more severe than Lab A.

3.2.5. Rate-of-Change of Iron:

3.2.5.1. The statisticians also looked at the rate-of-change of the iron parameter during the last 50-hours of the test and the last 25-hours of the test.
3.2.5.2. The statisticians confirmed that the rate-of-change of iron provides less discrimination than the end-of-test iron.

3.2.6. Iron vs. Engine Hours:

3.2.6.1. There is not a clear correlation between iron loss and engine hours.
3.2.6.2. The 1st run on an engine generally exhibits the most iron generation.
3.2.6.3. The 2nd run on an engine generally exhibits the lowest iron generation.

3.2.6.4. The statisticians will need more data (including data from tests with higher engine hours) before they can recommend a correction factor.

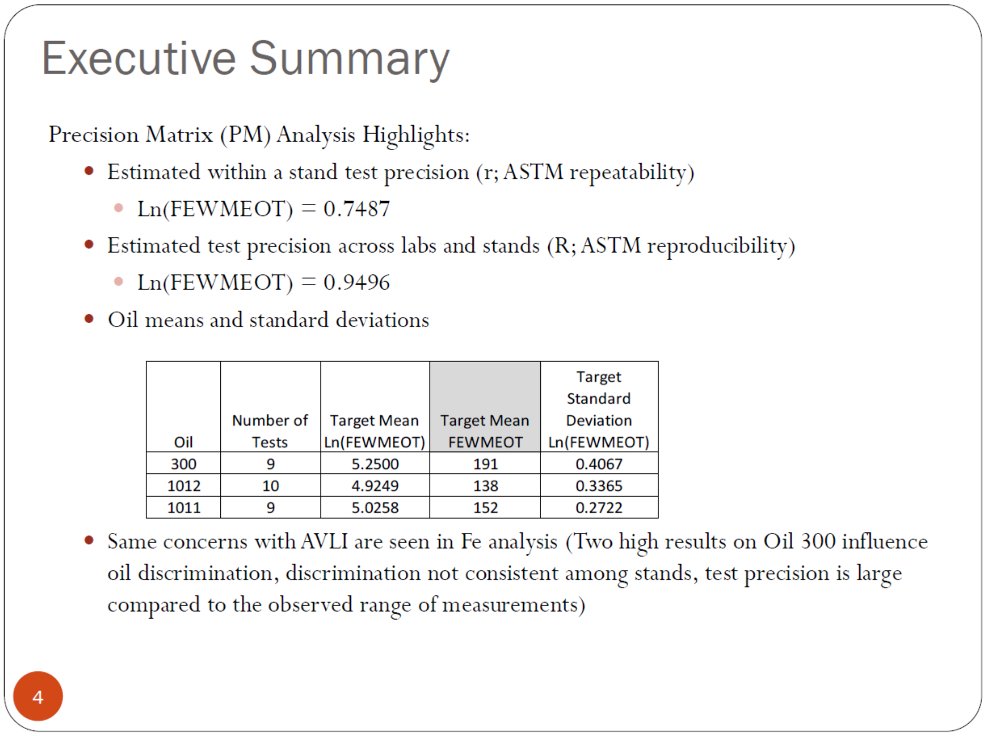
3.2.7. Calcium Adjustment:

3.2.7.1. Oil discrimination with end-of-test iron did improve when a calcium adjustment was applied.

3.2.7.2. However, there are some challenges to applying a calcium adjustment.

3.2.7.3. The IVB may need to adopt an iron analysis procedure that is like the one used for the Sequence IIIG/H.

3.3. Slide #4:



3.3.1. Concerns:

3.3.1.1. The statisticians have the same concerns with the iron parameter that they do with the AVLI parameter.

3.3.1.2. There are two severe results with REO300 that are driving oil discrimination.

3.3.1.3. Oil discrimination is not consistent among test stands.

3.3.1.4. There is a lot of overlap in the results for the three reference oils.

3.3.2. Comments from Toyota:

3.3.2.1. The increase in the rate-of-change of iron at the end of each test may be due to oil degradation.

3.3.2.2. Adding iron as a secondary parameter will provide protection against unusually performing oils.

3.3.2.3. Additional data collected during the Technology Demonstration period will aid in this analysis.

3.4. Slide #5:

Executive Summary

Precision Matrix (PM) Analysis Highlights:

- Estimated within a stand test precision (r; ASTM repeatability)
  - Ln(FEWMEOT_Ca_Adj) = 0.7162
- Estimated test precision across labs and stands (R; ASTM reproducibility)
  - Ln(FEWMEOT_Ca_Adj) = 0.9410
- Oil means and standard deviations

Ref. Oil	Number of Tests	Target Mean Ln(FEWMEOT_Ca_Adj)	Target Mean FEWMEOT	Target Standard Deviation Ln(FEWMEOT_Ca_Adj)
300	9	5.3987	221	0.3967
1012	10	5.0581	157	0.3277
1011	9	5.1648	175	0.2863

- Same concerns with AVLI are seen in Fe analysis (Two high results on Oil 300 influence oil discrimination, discrimination not consistent among stands, test precision is large compared to the observed range of measurements)

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3.4.1. The final calcium level is lower than the initial calcium level for all the Precision Matrix tests.

3.4.1.1. This supports the theory that the oil becomes diluted during the test.

3.5. Slide #7:

Reference Oil Discrimination Comparison

The table below compares the numbers of standard deviations of separation between the highest and lowest reference oil across GF-6 test types. The median of other tests is approx. 3.55 and the mean (without PHOS) is 3.99.

Test	Parameter	Oil 1	Oil 2	Range	Test s_r	SDs of Separation
IIIH	Ln(PVIS)	4.7191	3.3289	1.3902	0.4641	3
IIIH	WPD	4.63	3.66	0.97	0.47	2.1
IIIHA	Ln(MRV)	11.1107	9.7854	1.3253	0.4214	3.1
IIIHB	PHOS	94.15	78.92	15.23	1.53	10
VIE	FEI 1	2.56	1.3	1.26	0.29	4.3
VIE	FEI 2	1.82	1.41	0.41	0.12	3.4
VIF	FEI 1	2.23	1.45	0.78	0.21	3.7
VIF	FEI 2	2.25	1.41	0.84	0.19	4.4
IX (LSPI)	Sqrt(AvPIE + 0.5)	4.2644	3.3819	0.8825	0.2856	3.1*1
VH	AES	8.43	6.47	1.96	0.5	3.9
VH	Ln(10-RCS)	0.9155	-0.5294	1.4449	0.2194	6.6
VH	AEV50	9.26	8.77	0.49	0.25	2
VH	APV50	8.67	7.35	1.32	0.53	2.5
X (CW)	Ln(CHST)	-2.10574	-2.63174	0.526	0.14148	3.7*2
IVB	Sqrt(AVLI)	1.3931	1.1543	0.2388	0.168	1.4
IVB	Ln(FEWMEOT)	5.25	4.9249	0.3251	0.2701	1.2
IVB	Ln(FEWMEOT_Ca_Adj)	5.3987	5.0581	0.3406	0.2584	1.3

*1: Oil 220 not used as a reference oil. Including this oil would yield approx. 12 SDs of separation between 220 and 222.
*2: 271 vs. 1011

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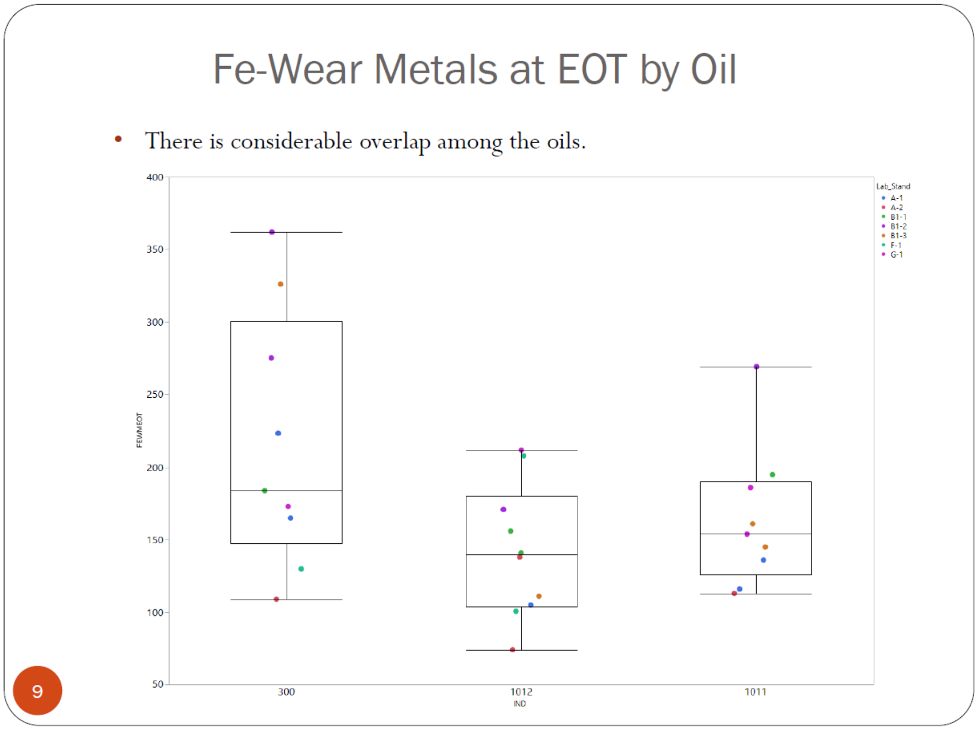
3.5.1. The Sequence IVB parameters are shown in yellow.

3.5.2. These parameters are separated by standard deviations that range between 1.2 and 1.4.

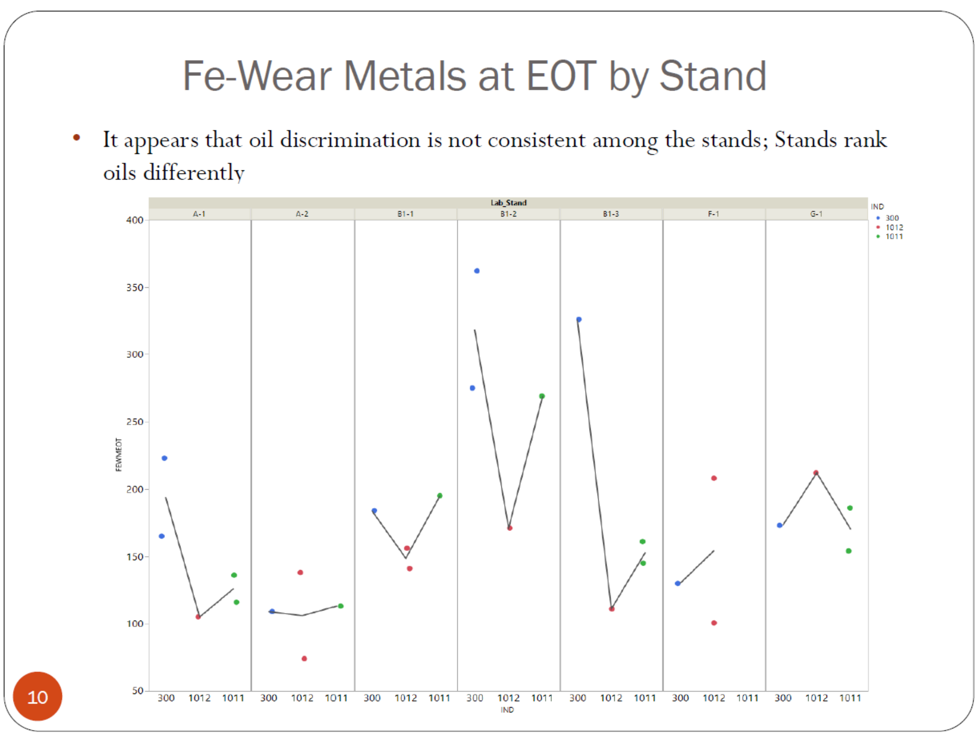
3.5.2.1. These are the lowest standard deviations of any GF-6 test.

3.6. Slide #9:



3.6.1. The best discrimination is exhibited between REO300 and REO1012.
3.6.2. There is still significant overlap between all three oils.

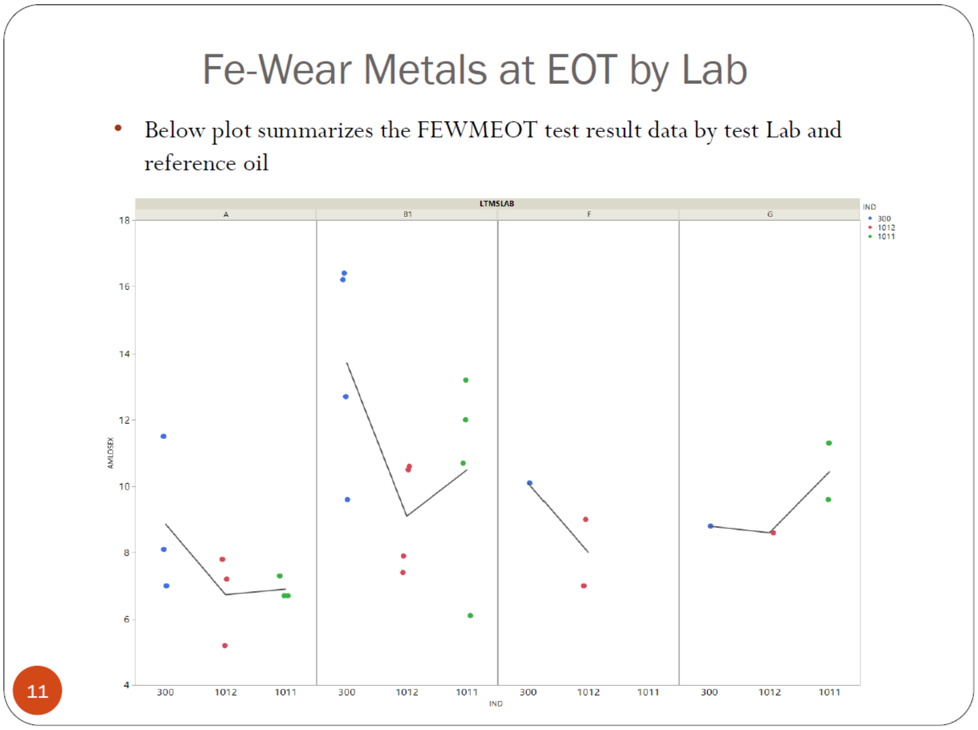
3.7. Slide #10:



3.7.1. The oil vs. wear pattern is different between test stands.
3.7.2. Some stands have a "V' pattern and some have an inverted "V" pattern.
3.7.3. The line for stand F-1 is flat.
3.7.4. The legs on some "V" patterns are longer than on others.

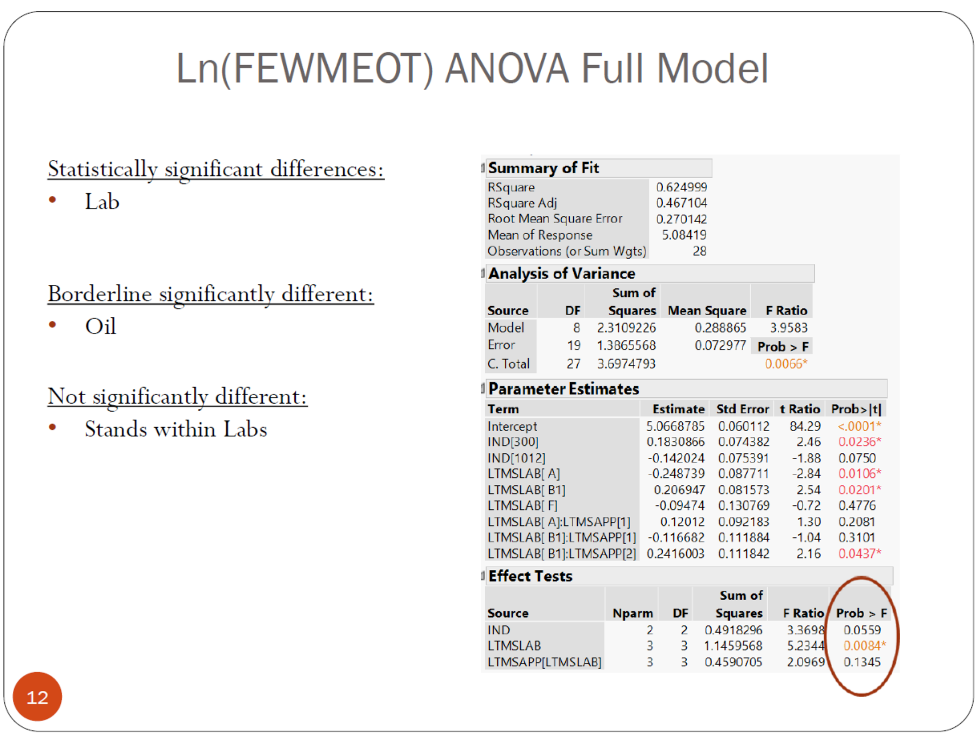
3.7.5. A-2 is the mildest stand while B1-2 is the most severe.

3.8. Slide #11:



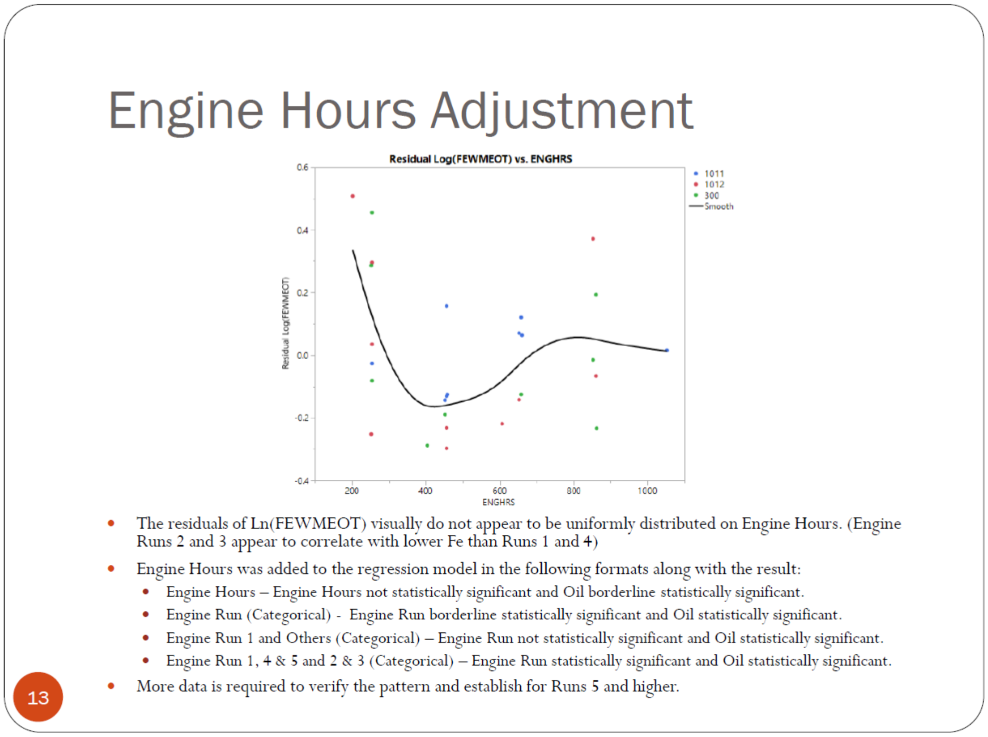
3.8.1. Lab A has a relatively flat profile.
3.8.2. Lab B1 has a "check mark" shaped profile.
3.8.3. Lab F has a decreasing profile (only two oils were run during the Precision Matrix).
3.8.4. REO300 and REO1012 yielded almost identical results at Lab G.

3.9. Slide #12:



3.9.1. The laboratories are statistically different.
3.9.2. The stands within a single lab do not appear to be statistically different.
3.9.3. ***IMPORTANT NOTE:*** None of this iron data has been adjusted for calcium.

3.10. Slide #13:



3.10.1. The 1st run on an engine generates the highest end-of-test iron.
3.10.2. The 2nd run on an engine generates the lowest end-of-test iron.
3.10.3. The 3rd and 4th runs on an engine generate more wear than the 2nd run.
3.10.4. The statisticians were hoping to see a linear relationship between the residual and engine hours.

3.10.5. Intertek's Comments about Engine Longevity:

3.10.5.1. Most of the labs are running a given engine and cylinder head combination for up to six runs.
3.10.5.2. IAR has performed cylinder head swaps.
3.10.5.2.1. They found that this will extend engine longevity to approximately 8-9 runs.
3.10.5.2.2. At (9) runs, the engines must be decommissioned for excessive oil consumption.

3.10.6. Comments from Statisticians:

3.10.6.1. They need more data before they can recommend an engine hour adjustment.
3.10.6.1.1. This would include data generated on an engine after a cylinder head change.
3.10.6.1.2. Ideally, it would also include 8th or 9th run data.
3.10.6.2. There is a consensus within the Statistics Group that an engine hour adjustment is needed for the iron parameter.
3.10.6.3. They may need to revisit the AVLI parameter (to determine if there is an engine hour effect) once additional data is available.

3.10.7. Comments from Toyota:

3.10.7.1. Toyota is not surprised to see that the 1st run on an engine delivers the highest end-of-test wear.
3.10.7.1.1. The first run occurs right after the break-in.

3.10.7.1.2. IAR noted that the break-in does not generate much iron.

3.10.7.2. The proposed iron pass/fail limit is intended to screen out high wear oils only.

3.10.7.2.1. All the reference oils would pass if the limit were set at 400ppm.

3.10.8. Carry-Over Effect:

3.10.8.1. Both Lubrizol and Exxon are concerned about a "carry-over" effect.

3.10.8.2. Exxon noted that there is no "carry-over" effect with procedures like the Sequence III because the engine is rebuilt after each test.

3.10.8.3. Lubrizol noted that wear in areas of the engine other than the rings and bore can lead to a "carry-over" effect.

3.10.8.3.1. For example, deformed valve stems may be causing excessive lifter button wear.

3.10.8.3.2. Toyota responded that AVLI correlates well to weight loss.

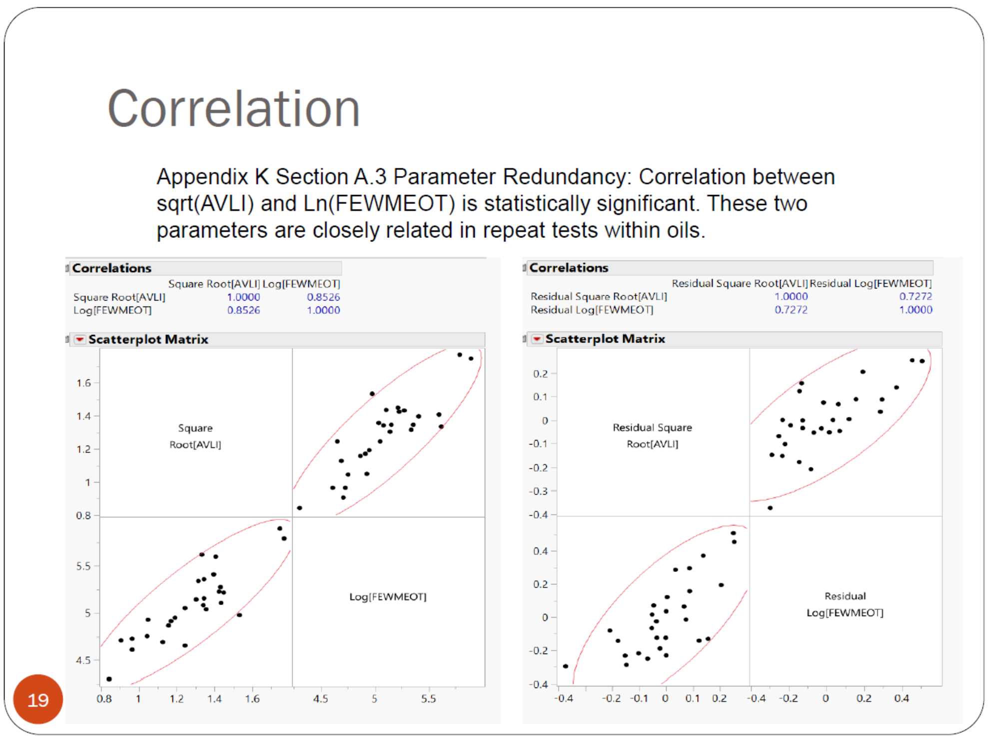
3.10.8.3.2.1. This indicates that most of the weight loss is coming from the wear surface of the lifter in most cases.

3.10.8.4. IAR noted that timing chains may have a "carry-over" effect as well.

3.10.8.5. There was a consensus within the group that an end-of-test checklist is needed to confirm that the engine was not damaged.

3.10.8.5.1. IAR uses a similar checklist whenever they run a high wear oil.

3.11. Slide #19:



3.11.1. There is a very strong correlation between AVLI and iron.

3.11.1.1. This a concern if both are considered primary parameters.

3.11.2. Comments from TMC:

3.11.2.1. They are not sure how to handle iron in LTMS if it is a secondary parameter.

3.11.2.2. This parameter may require Y_i charts without severity adjustments.

3.11.2.3. Ultimately, this is a decision that should be made by the Surveillance Panel.

3.12. Slide #21:

Fe-Wear Metals - Correction Approach

- Method Summary:
  - Calcium concentration is believed to remain constant from SOT to EOT
    - Reference ASTM 7320 - Sequence IIIGB for more information
    - Changes in Ca levels can be due to volatility or dilution (i.e. fuel, water, etc.)
  - Ratio of (Ca_SOT/Ca_EOT) is used to correct the FEWMEOT data to equivalent SOT levels
  - Example of correction calculations are provided below

TESTKEY	LTMSLAB	Stand	RefOil	ENGHRS	FEWMEOT	Ca_SOT	Ca_EOT	Ca_SOT/Ca_EOT	FEWMEOT_Ca_Adj	AVLI
127173-IVB	B1	S1	RO1012	254	156	2400	2168	1.1070	172.7	1.55
129759-IVB	B1	S2	RO300	254	275	2029	1781	1.1392	313.3	1.78
125879-IVB	B1	S3	RO1011	254	161	2111	1861	1.1343	182.6	1.8
125882-IVB	A	S2	RO1012	252	74	2449	2163	1.1322	83.8	0.71
129752-IVB	A	S1	RO300	252	223	2076	1773	1.1709	261.1	1.95
129762-IVB	B1	S1	RO1011	456	195	2107	1805	1.1673	227.6	2.05
129766-IVB	B1	S2	RO1012	456	171	2439	2058	1.1851	202.7	1.7
129767-IVB	B1	S3	RO1012	456	111	2419	2035	1.1887	131.9	0.82
130948-IVB	A	S2	RO300	452	109	2069	1783	1.1604	126.5	1.27
129760-IVB	B1	S1	RO300	658	184	2056	1700	1.2094	222.5	2.1
129763-IVB	B1	S2	RO1011	658	269	2137	1811	1.1800	317.4	1.98
109201-IVB	A	S1	RO1011	452	116	2115	1878	1.1262	130.6	1.09
130944-IVB	G	S1	RO1012	254	212	2521	2264	1.1135	236.1	1.81
125183-IVB	F	S1	RO1012	202	208	2396	2192	1.0931	227.4	1.73
129768-IVB	B1	S1	RO1012	860	141	2401	2052	1.1701	165	1.42
130938-IVB	B1	S2	RO300	860	362	2009	1726	1.1640	421.4	3.05
129755-IVB	A	S1	RO1012	652	105	2496	2148	1.1620	122	1.55
125184-IVB	G	S1	RO1011	458	154	2129	1840	1.1571	178.2	1.84
125880-IVB	A	S2	RO1011	652	113	2159	1866	1.1570	130.7	0.93
130939-IVB	B1	S3	RO300	254	326	1993	1798	1.1085	361.4	3.13
120739-IVB	F	S1	RO300	404	130	1988	1711.7	1.1614	151	1.34
131277-IVB	A	S1	RO300	852	165	2100	1798	1.1680	192.7	2.06
129756-IVB	A	S2	RO1012	852	138	2478	2145	1.1552	159.4	1.1
130943-IVB	G	S1	RO1011	660	186	2186	1842	1.1868	220.7	2.03
129764-IVB	B1	S3	RO1011	456	145	2094	1816	1.1531	167.2	2.35
130940-IVB	G	S1	RO300	862	173	2102	1767	1.1896	205.8	1.81
130945-IVB	F	S1	RO1012	606	101	2442.3	2158.1	1.1317	114.3	0.93
125881-IVB	A	S1	RO1011	1052	136	2121	1894	1.1199	152.3	1.37

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3.12.1. The calcium adjustment used in this analysis was taken from the Sequence IIIGB.
3.12.2. Calcium reduction is assumed to be the result of volatility and dilution.
3.12.3. Comments from Intertek:

3.12.3.1. The Sequence IVB generates a lot of water and fuel dilution.

3.12.3.2. If a calcium adjustment is used, the Surveillance Panel may want to adopt the ICP measurement restrictions listed in the Sequence IIIGB procedure.

3.12.3.2.1. The IIIGB procedure specifies that start-of-test and end-of-test ICP samples be measured at the same time and on the same machine.

3.13. Slide #25:

Ln(FEWMEOT_Ca_Adj) - ANOVA Full Model

Statistically significant differences:
- Lab, Oil

Not significantly different:
- Stands within Labs

Summary of Fit

RSquare	0.657934
RSquare Adj	0.513907
Root Mean Square Error	0.258386
Mean of Response	5.226639
Observations (or Sum Wgts)	28

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	2.4398569	0.304982	4.5681
Error	19	1.2685020	0.066763	Prob > F
C. Total	27	3.7083589		0.0031*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.2072249	0.057496	90.57	<.0001*
RefOil[RO1011]	-0.042438	0.073795	-0.58	0.5720
RefOil[RO1012]	-0.149076	0.07211	-2.07	0.0526
LTMSLAB[A]	-0.249068	0.083894	-2.97	0.0079*
LTMSLAB[B1]	0.2137059	0.078023	2.74	0.0130*
LTMSLAB[F]	-0.11074	0.125078	-0.89	0.3870
LTMSLAB[A]:Stand[S1]	0.1176384	0.088171	1.33	0.1979
LTMSLAB[B1]:Stand[S1]	-0.111157	0.107015	-1.04	0.3120
LTMSLAB[B1]:Stand[S2]	0.246849	0.106975	2.31	0.0324*

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
RefOil	2	2	0.5391278	4.0376	0.0346*
LTMSLAB	3	3	1.1972860	5.9778	0.0048*
Stand[LTMSLAB]	3	3	0.4703869	2.3485	0.1049

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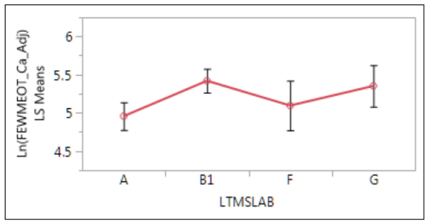
3.13.1. The calcium adjustment does improve the significance of the oil discrimination.
3.13.2. It improves the oil discrimination from a borderline level to a statistically significant level.

3.14. Slide #28:

Ln(FEWMEOT_Ca_Adj) Lab Differences

- Model is Ln(FEWMEOT_Ca_Adj) ~ Oil, Lab, Stand(Lab)
- Plot below of Ln(FEWMEOT_Ca_Adj) LSMeans by Lab, with 95% confidence intervals
- Lab A is statistically significantly different than Lab B1.



LSMeans by Lab

Lab	Ln(FEWMEOT_Ca_Adj) LSMean	FEWMEOT_Ca_Adj LSMean
A	4.9581	142
B1	5.4209	226
F	5.0965	163
G	5.3533	211

LSMeans Differences Between Labs

Lab1	Lab2	Ln(FEWMEOT_Ca_Adj) LSMean Difference	p-Value
B1	A	0.4628	0.0035
G	A	0.3952	0.0886
B1	F	0.3244	0.2672
G	F	0.2568	0.6063
F	A	0.1383	0.8625
B1	G	0.0676	0.9689

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3.14.1. The p-values are more significant with the calcium adjustment.

3.15. Slide #30:

Ln(FEWMEOT_Ca_Adj) Precision

Repeatability Model: Ln(FEWMEOT_Ca_Adj) ~ Oil, Lab, Stand(Lab)
Reproducibility Model: Ln(FEWMEOT_Ca_Adj) ~ Oil

Model RMSE	Repeatability	Reproducibility
• s_r = 0.2584	• s_r = 0.2584 • r = 0.7162	• s_R = 0.3395 • R = 0.9410

Based upon the Ln(FEWMEOT_Ca_Adj) pooled standard deviation (s_r) and ASTM's repeatability (r), there is no significant difference between an FEWMEOT_Ca_Adj *result*[1] of 200 and 409.

Note 1: An FEWMEOT_Ca_Adj result of 200 was arbitrarily selected for comparison

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3.15.1. There is an improvement in overall repeatability with the calcium adjustment.
3.15.1.1. This is a small improvement and not necessarily a "slam dunk".

3.15.2. The final decision about using a calcium adjustment will be up to the Surveillance Panel.

3.15.3. Comments from Intertek:

3.15.3.1. They are in favor of the calcium adjustment.

3.15.3.2. A transform is needed.

3.15.3.3. They are concerned about the potential redundancy between AVLI and end-of-test iron.

3.15.3.4. This issue can be resolved by making iron a secondary parameter.

3.15.4. Comments from General Motors:

3.15.4.1. *What should be done about oils that do not use calcium?*

3.15.4.1.1. They have concerns about using calcium to assess volatility and dilution.

3.15.4.1.2. Calcium is a detergent, so it is surface active.

3.15.4.1.3. Some calcium will be lost due to this surface activation.

3.15.4.1.4. IAR noted that the Industry may need to look at magnesium or sulfur when testing formulations that do not use calcium.

3.15.4.2. *Would it be more appropriate to use fuel dilution or water content to assess volatility/dilution?*

3.15.4.3. The three Precision Matrix oils probably use similar chemistry.

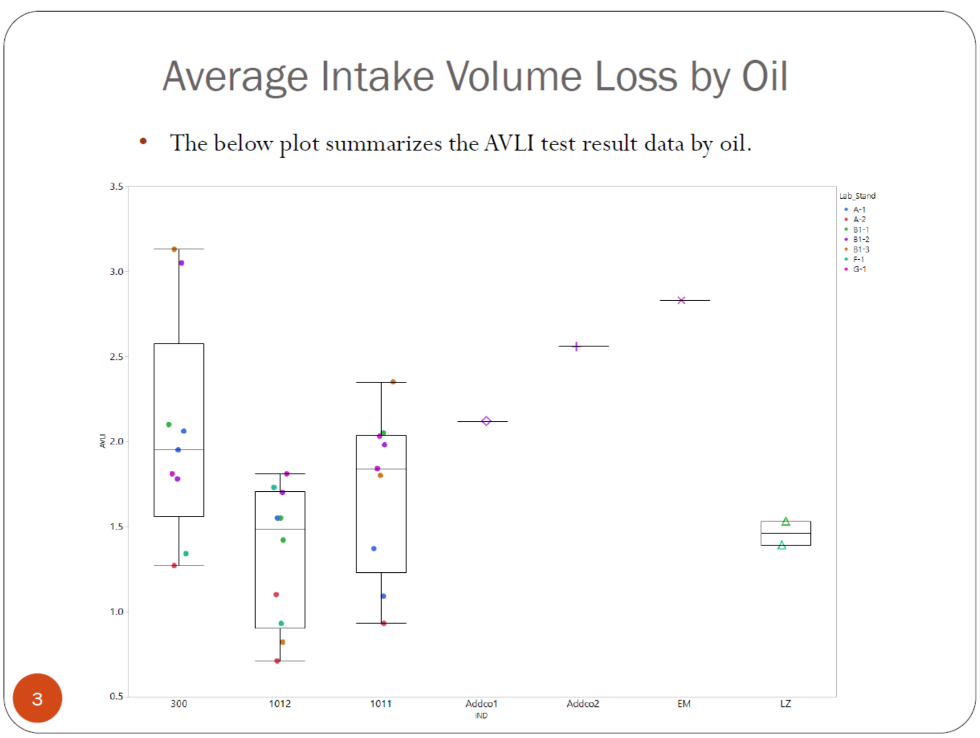
3.15.4.3.1. The Surveillance Panel will need to look at outlier oils to determine if they display a different relationship between iron and AVLI.

4. STATISTICAL ANALYSIS OF HIGH WEAR OILS (STATISTICS GROUP):

4.1. Background:

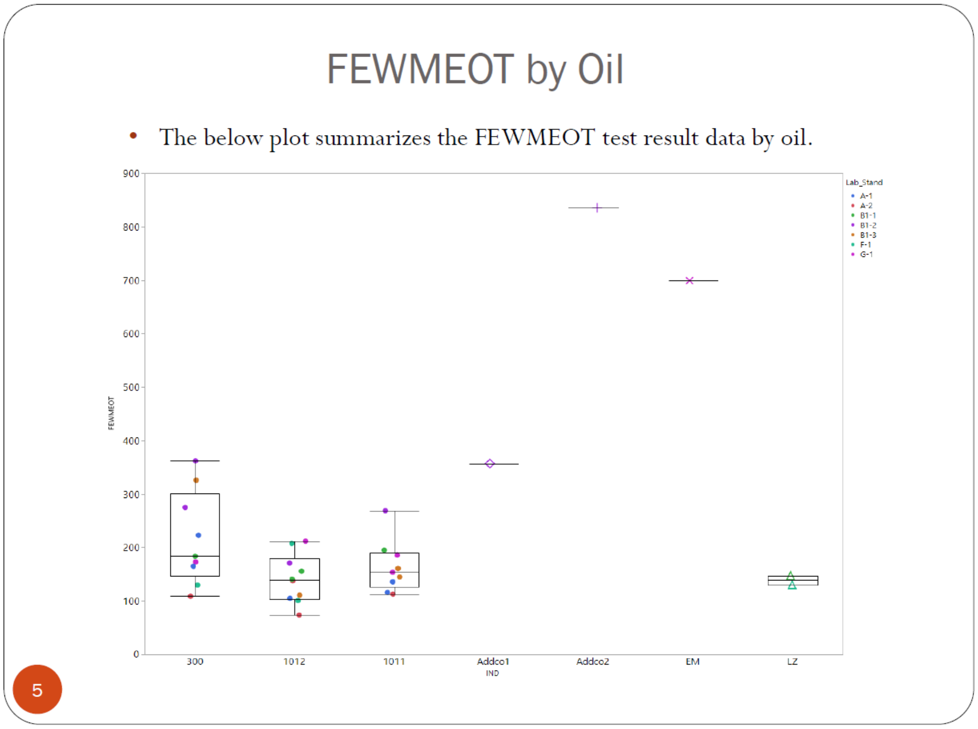
4.1.1. The Statistics Group conducted an analysis of results from oils that were intended to generate high wear on the Sequence IVB test (dated 03-27-2018).

4.2. Slide #3:



4.2.1. This slide shows the Precision Matrix oils and the high wear oils on the same plot.

4.3. Slide #5:



4.3.1. IAR cannot explain the two consecutive mild results with the Lubrizol high wear oil.

4.3.2. Comments from Toyota:

4.3.2.1. The Lubrizol oil had a late TAN-TBN cross-over.

4.3.2.2. This suggests that the oil offers good degradation control.

4.3.3. General Motors asked if Lubrizol had any Sequence IIIG data for this oil.

4.3.4. Comments from Lubrizol:

4.3.4.1. This oil was not run on the Sequence III.

4.3.4.2. However, Lubrizol's statistical models predict that this oil would fail the Sequence IIIG for both WPD and PVIS.

4.3.4.3. The oil uses a typical AO package for a GF-4 formulation.

4.3.5. Comments from Intertek:

4.3.5.1. They have reports and/or presentations from the Surveillance Panel members that have run high wear oils.

4.3.5.2. This data will be compiled and shared with the Industry.

4.3.6. Statement from Unnamed Additive Company (Conveyed by Buscher):

4.3.6.1. This company is identified as "Addco2".

4.3.6.2. The data in the plot is for an oil with no ash and minimal anti-wear additives.

4.3.6.2.1. *Average Intake Lifter Volume Loss = 2.56mm^3*

4.3.6.2.2. *E.O.T. Iron = 836ppm*

4.3.6.3. They rescinded the results from their second oil (which was an SN+ formulation).

4.3.7. Comments from Lubrizol:

4.3.7.1. The 200HR iron from the "Addco2" test is extremely high, especially considering that it had an average intake lifter volume loss around 2.5mm^3.

4.3.7.2. *Was there excessive wear or damage to the engine?*

4.3.8. Intertek Response to Lubrizol's Question:

4.3.8.1. IAR confirmed that the engine did exhibit excessive wear after the test.

4.3.8.2. This was the 9th run on the engine.

4.3.8.3. The engine was "healthy" during the 8th run.

4.3.8.4. The crankshaft was worn to a point at which it would no longer meet factory tolerances.

4.3.8.5. PDI bore traces indicate a wear scar of approximately 40-microns on the thrust-side.

4.3.8.5.1. The block would need to be honed if it were to be used again.

4.3.8.6. There is excessive piston ring wear.

4.3.8.7. There is some timing chain wear.

4.3.8.8. Oil consumption was around 1000g.

4.3.8.9. IAR believes that this oil would have even rendered a 1st run engine unserviceable.

4.3.9. Comments from Exxon:

4.3.9.1. The results from "Addco2" are like what they experienced with their high wear oil.

4.3.9.2. Their oil rendered a 6th run block unserviceable.

4.3.9.3. These two situations exemplify why they are concerned with iron as a pass/fail parameter.

4.3.10. Comments from Lubrizol:

4.3.10.1. Lubrizol shares Exxon's concerns about iron as a pass/fail parameter.

4.3.10.2. Lubrizol is also confused by the lack of consistency in engine wear with the "poor" oils.

4.3.10.2.1. Lubrizol completely disassembled the Precision Matrix engine that was used to test its "poor" proof-of-performance oil.

4.3.10.2.2. Wear was minimal.

4.3.10.3. IAR confirmed that the engine used for the repeat test with Lubrizol's "poor" proof-of-performance oil is still in service.

4.3.10.3.1. So, wear with this engine was also minimal.

5. IVB LTMS SUGGESTIONS SUMMARY (STATISTICS GROUP):

5.1. Background:

5.1.1. The Word document outlines the proposed LTMS system for the Sequence IVB test (dated 03-08-2018).

5.1.2. The Excel spreadsheet has tabs that display the output of the proposed LTMS system.

5.2. Overview of Proposed LTMS System (Word Document):

5.2.1. This would be a stand-based system with charts for AVLI (average intake lifter volume loss) and 200HR (end-of-test) iron.

5.2.1.1. The statisticians have proposals for unadjusted iron and iron that is adjusted for calcium.

5.2.1.2. The Excel file with the calcium adjustment was completed today.

5.2.2. Test stands will be charted separately with their own severity adjustments.

5.2.3. Z_i Limit:

5.2.3.1. A default recommended limit is used.

5.2.3.2. This default limit is used in all GF-6 test types except the Sequence IX.

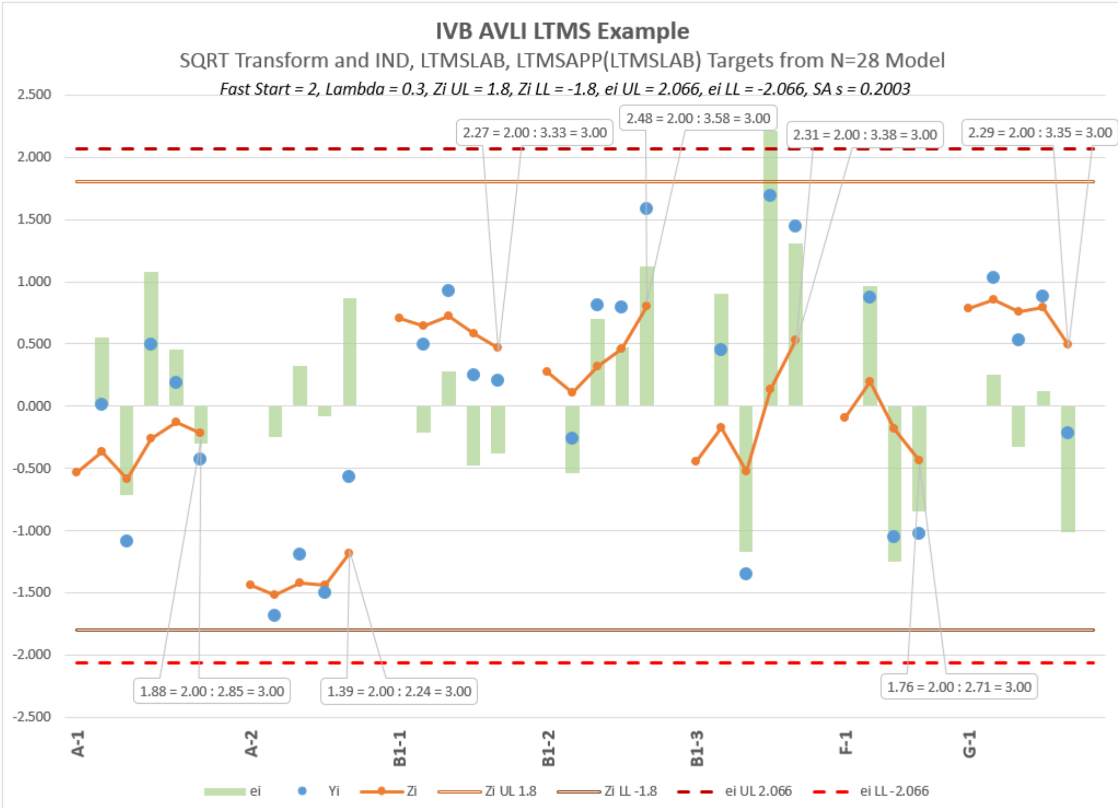
5.2.4. Z_o Limit:

5.2.4.1. A "fast start" Z_o limit is proposed.

5.2.4.2. Two tests are the default setting.

5.2.4.3. It will be up to the discretion of the Surveillance Panel to increase this to three tests.

5.3. LTMS Chart AVLI (Spreadsheet):



5.3.1. Stands A-1 and A-2 (which are in the same lab) are statistically very similar (even though they display some small visual differences).

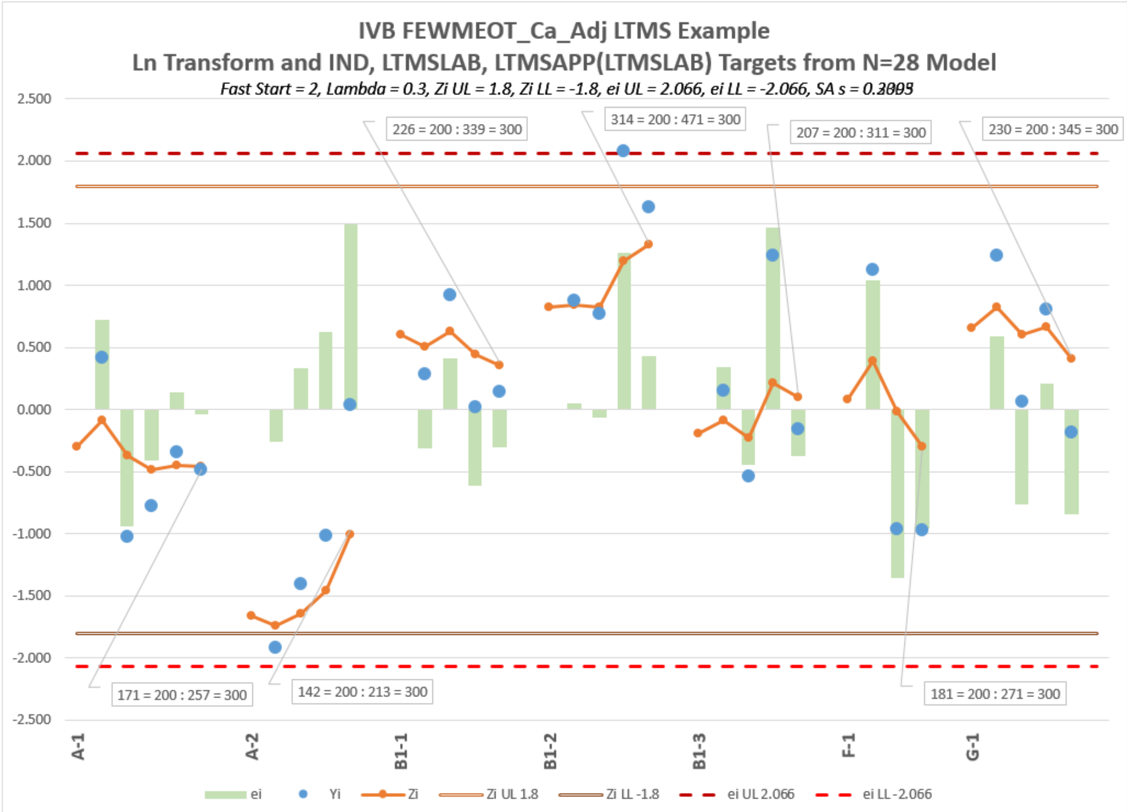
5.3.1.1. This supports the stand-based system.

5.3.2. Stand B1-3 did have one result that failed due to an e_i alarm.

5.3.2.1. However, the subsequent Precision Matrix result would have allowed the stand to reference.

5.3.2.2. This is the only example of a failing result with the proposed LTMS system.

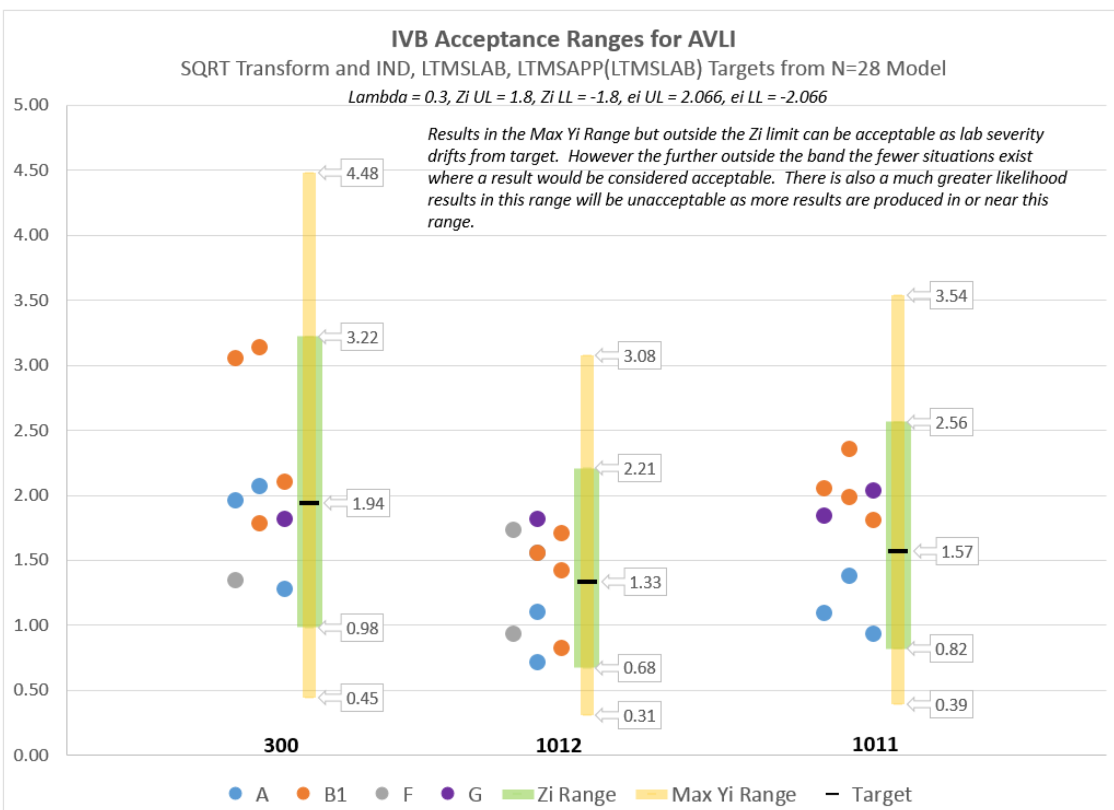
5.4. LTMS Chart FE_Ca_Adj (Spreadsheet):



5.4.1. The pattern is like that of the AVLI parameter.

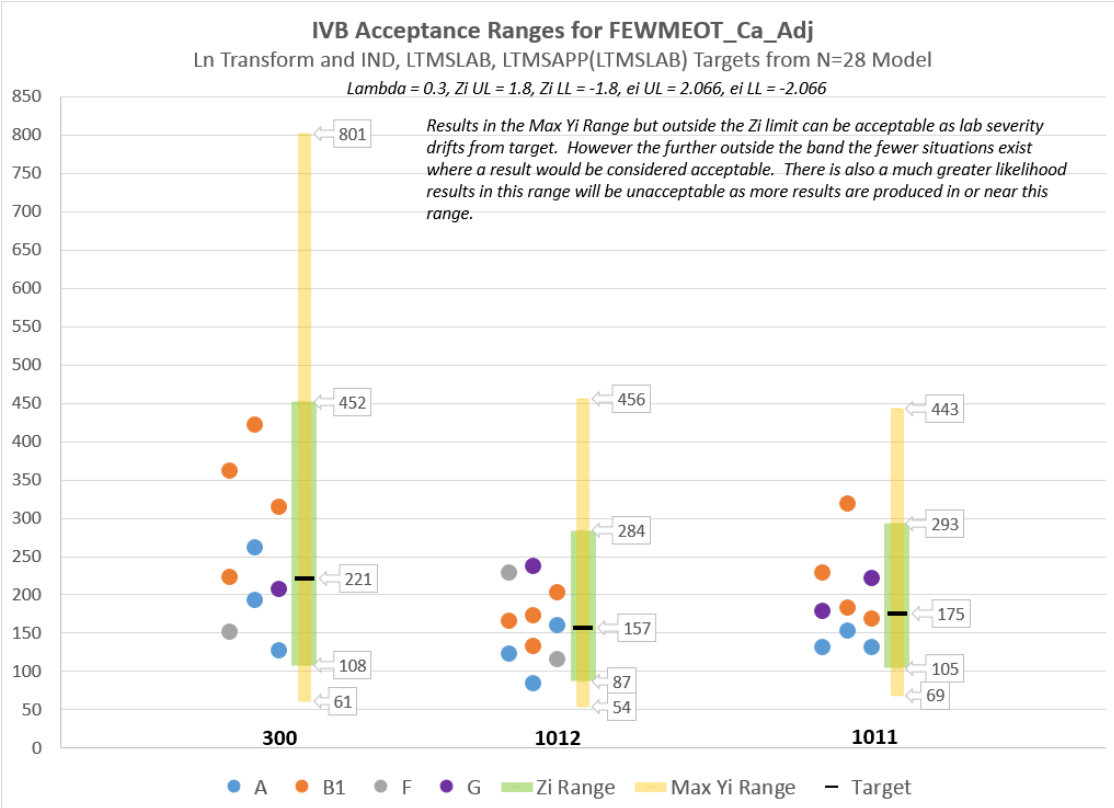
5.4.2. Stand B1-3 does not trip an e_i alarm with the iron parameter.

5.5. Range Chart AVLI (Spreadsheet):



5.5.1. A lab that repeatedly operated in the yellow bands would trigger an alarm.

5.6. Range Chart FEWMEOT_Ca_Adj (Spreadsheet):



5.6.1. In certain situations, an 801ppm result with REO300 or a 456ppm result with REO1012 would be acceptable.

5.6.1.1. However, a lab cannot operate close to these limits for long.

5.6.2. Comments from Lubrizol:

5.6.2.1. Stand B1-2 is operating with a Z_i of 1.3.

5.6.2.2. So, a high iron result on B1-2 would be acceptable.

5.6.2.3. However, the next test would need to have a lower iron for that stand to maintain calibration.

5.7. General Discussion:

5.7.1. Comments from Exxon:

5.7.1.1. They would like the Surveillance Panel to formally discontinue any further discussion or analysis with the N=21 dataset.

5.7.1.2. There was unanimous approval within the Surveillance Panel to discontinue the N=21 dataset.

5.7.2. How Should the Three Existing Reference Oils be Used?

5.7.2.1. The statisticians stated that this is an engineering decision and not a statistical decision.

5.7.2.2. Afton believes that REO1011 should be checked [during reference tests] more often than the other two oils because of its 0W-16 viscosity.

5.7.2.3. IAR reminded the Surveillance Panel that it can decide on a reference oil frequency now and change it later.

5.7.2.4. There was a broad consensus within the Surveillance Panel to initially test all three reference oils at an equal frequency.

5.7.3. Transformations:

5.7.3.1. There was a general agreement within the Panel that a square-root would be used for AVLI and a natural log would be used for the calcium-adjusted iron.

5.7.4. Iron:

5.7.4.1. Afton and the TMC are concerned about implementing iron as a pass/fail parameter before there is a clear understanding about how engine life will impact it.

5.7.4.1.1. They suggested making iron a "report only" parameter until more data is available.

5.7.4.2. *Comments from Intertek:*

5.7.4.2.1. The IVB Data Dictionary will need to be updated to reflect the proposed LTMS system.

5.7.4.2.2. The Sequence IIIGB procedure uses magnesium or sodium to adjust the iron for formulations that lack calcium.

5.7.4.2.3. The IVB will need to adopt the following IIIGB oil sample methodology:

5.7.4.2.3.1. S.O.T. and E.O.T. ICP samples will need to be run consecutively and in duplicate.

5.7.4.2.3.2. The average of the duplicate runs will be reported.

5.7.4.3. Lubrizol, Infineum and Exxon would all like to see more clarity with the iron parameter before the Surveillance Panel votes on the LTMS system.

5.7.4.4. General Motors and Ford agree that this test needs an iron parameter because AVLI is not sufficient.

5.7.4.4.1. They want to make iron a pass/fail parameter now to eliminate the timing uncertainty with making it a pass/fail parameter in the future.

5.7.4.4.2. They do not want any more delays with GF-6.

5.7.5. Communication:

5.7.5.1. The TMC will issue an information letter that summarizes all the procedural and process changes that accompany the new LTMS system.

5.7.6. Proposed Pass/Fail Limits:

5.7.6.1. Toyota is considering a 400ppm pass/fail limit for iron.

5.7.6.1.1. This limit may be increased to 450ppm if a calcium adjustment is used.

5.7.6.2. Exxon noted that all three reference oils have Y_i's that would allow them to get into the 450ppm range for iron.

5.7.6.2.1. Two of these three oils are considered good performers.

5.7.6.2.2. One of these oils is considered a borderline performer.

5.7.6.3. *Consensus within Surveillance Panel:*

5.7.6.3.1. Chart iron using the unadjusted targets for now.

5.7.6.3.2. Implement the calcium adjustment after more data becomes available.

5.7.6.3.3. Limit the application of iron severity adjustments to candidate oils.

5.7.6.3.4. Do not implement calibration requirements for iron.

5.7.6.4. *Lobe Failures:*

5.7.6.4.1. Lobe failures should be captured in LTMS.

5.7.6.4.2. They will be reported as valid but not charted.

5.7.7. Vote:

5.7.7.1. The Surveillance Panel ran out of time during this conference call to hold a vote on the proposed LTMS system.

5.7.7.2. Buscher will issue an electronic ballot.

5.7.7.3. Intertek made the motion and Toyota seconded the motion.

Action Items	Person responsible	Completion Date

Follow-up Notes/Updates	Initials	Date Added

Attendees	Organization	Contact Information

Sequence IV Surveillance Panel

Conference Call
March 28, 2018
9:00 a.m. - 12:00 p.m.

AGENDA

1. Chairman comments
2. Previous action item review
3. Sequence IVB Precision Matrix 2 AFR, exhaust gas temperature, crankcase pressure and intake manifold pressure operational data analysis
4. Sequence IVB Precision Matrix 2 statistical analysis review:
   Analysis and conclusions on iron content
5. Sequence IVB Precision Matrix 2 + high wear candidate
   oils statistical analysis review:
   Analysis and conclusions on AVLI and FEWMEOT
6. Sequence IVB LTMS review
7. Possible vote to accept a Sequence IVB LTMS
8. Motion and action item review
9. Next meeting
10. Adjourn

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SEQUENCE IV SURVEILLANCE PANEL

March 28, 2018

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March 28, 2018

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SEQUENCE IV SURVEILLANCE PANEL

March 28, 2018

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TOYOTA

Sequence IVB LTMS

Sequence IV Surveillance Panel
eBallot

March 30, 2018

Sequence IVB Definitions

TOYOTA

- AVLI = Intake lifter average volume loss, mm^3
- FEWMEOT = Iron content at end of test, ppm

Sequence IVB LTMS eBallot

TOYOTA

- Stand based LTMS
  - All stands will be charted separately
  - Severity adjustments will be calculated on a stand basis
- Use ASTM reference oils 300, 1012 and 1011
- Use an equal reference oil assignment frequency
- Adopt the transform Sqrt(AVLI) for LTMS and severity adjustment calculations
- Adopt the transform Ln(FEWMEOT) for severity adjustment calculations

Sequence IVB LTMS eBallot

TOYOTA

- Set reference oil targets from the complete, N = 28, precision matrix 2 data set
  - IND, LTMSLAB, LTMSLAP (LTMSAPP) w/ Sqrt from N = 28 Model
    - AVLI Targets

Oil	Number of Tests	Target Mean AVLI	Target Mean Sqrt(AVLI)	Target Standard Deviation Sqrt(AVLI)
300	9	1.94	1.3931	0.2230
1012	10	1.33	1.1543	0.1847
1011	9	1.57	1.2538	0.1932

    - Severity adjustment standard deviation (SA s) is RMSE from Oil only model Sqrt(AVLI) = 0.2003

Sequence IVB LTMS eBallot

TOYOTA

- Set reference oil targets from the complete, N = 28, precision matrix 2 data set
  - IND, LTMSLAB, LTMSLAP (LTMSAPP) w/ Ln from N = 28 Model
    - FEWMEOT Targets

Oil	Number of Tests	Target Mean FEWMEOT	Target Mean Ln(FEWMEOT)	Target Standard Deviation Ln(FEWMEOT)
300	9	191	5.2500	0.4067
1012	10	138	4.9249	0.3365
1011	9	152	5.0258	0.2722

    - Severity adjustment standard deviation (SA s) is RMSE from Oil only model Ln(FEWMEOT) = 0.3426

Sequence IVB LTMS eBallot

TOYOTA

- AVLI will be a primary, critical LTMS parameter, with calibration acceptance criteria and severity adjustments
  - Will be charted
- FEWMEOT will be a secondary, non-critical LTMS parameter, with severity adjustments, but without calibration acceptance criteria
  - Will be charted
- Tests with lobe failures would be un-chartable

Sequence IVB LTMS eBallot

TOYOTA

- Utilize limits on Z_i (EWMA of severity), e_i (prediction error), and the excessive influence calculation to determine acceptance and calculate severity adjustments
  - Z_i Lambda = 0.3
  - Z_0 = Average of first two tests in a stand
    - Note this is how many references a new stand will require to enter the system
  - Z_i Limit = +1.800/-1.800; a stand that exceeds these limits requires additional references until it is within the limits
    - Do not update severity adjustments until after an acceptable reference is conducted

Sequence IVB LTMS eBallot

TOYOTA

- e_i Limit 1 = +/-1.351; this limit applies to previously calibrated stands that have not been calibrated for two reference periods and are attempting to calibrate again
  - The stand can calibrate with one test if the Level 1 limits are not exceeded
  - References after the first attempt will be judged against the level 3 ei limits
- e_i Limit 2 = +/-1.734; this limit applies in situations pre-determined by the SP to have potential impact to severity
  - Some situations that warrant consideration include hardware changes or engine build changes in a currently calibrated stand

Sequence IVB LTMS eBallot

TOYOTA

  - The stand can calibrate with one test if the Level 2 limits are not exceeded
  - References after the first attempt will be judged against the level 3 ei limits
- e_i Limit 3 = +/-2.066; this limit applies to all other situations when determining an acceptable reference.
  - If the limit is exceeded do not update control charts until after an additional reference is conducted and apply excessive influence calculations
- The excessive influence calculation minimizes the impact of a failing reference test if the following reference test does not agree with the initial failing results and returns to historical severity performance (LTMS 1.A.5)

Sequence IVB LTMS eBallot

TOYOTA

- A minimum of two references will be required for each new stand
- The reference calibration period will expire after 15 full length non-reference tests or 6 months, whichever comes first

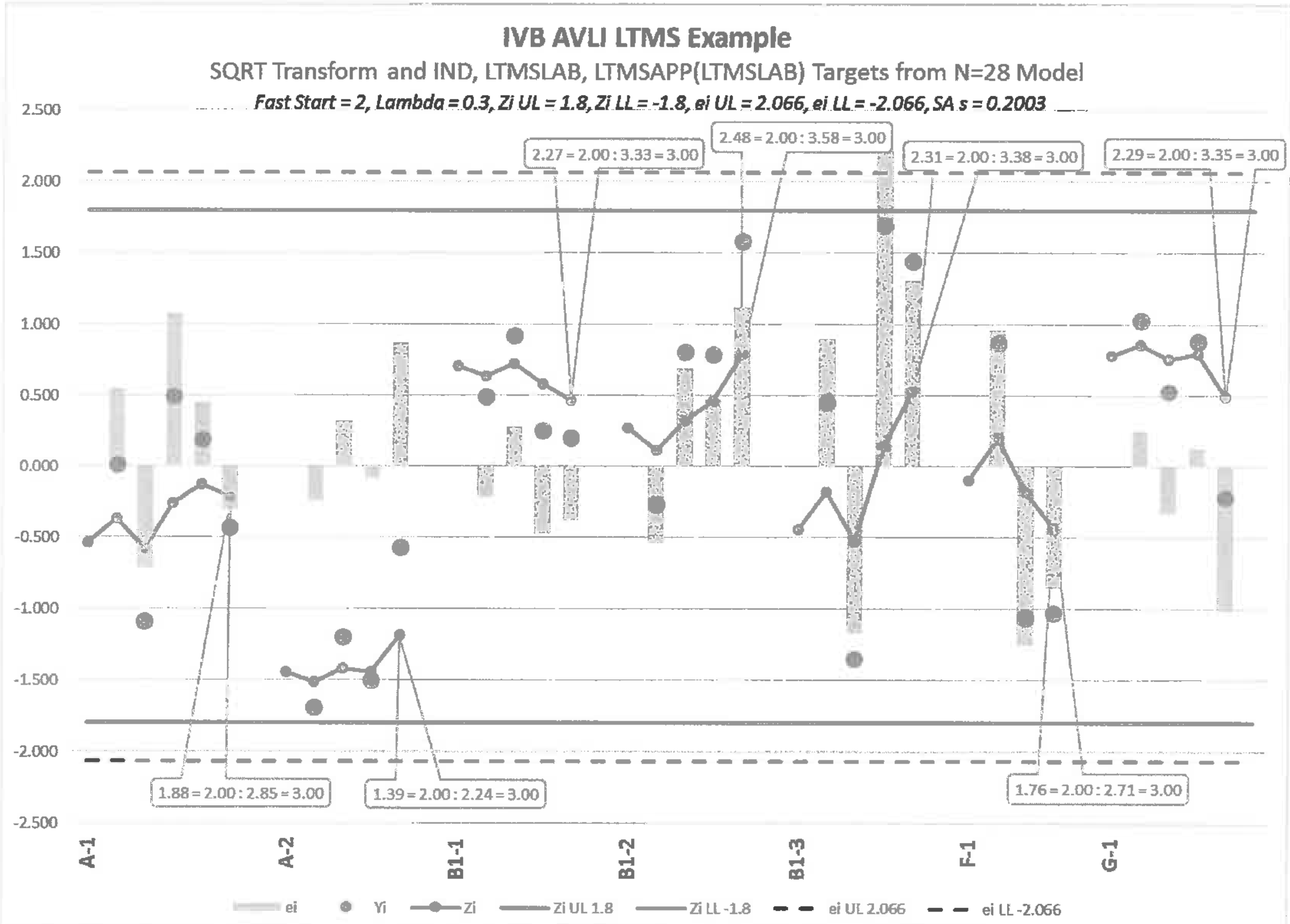
Sequence IVB LTMS eBallot

TOYOTA

- The TMC will plot industry Zi charts to identify potential shifts in industry wide performance
  - Lambda = 0.2
  - Z_0 = 0.000
  - Z_i Limit 1 = +/-0.775
    - When industry level one limits are exceeded the TMC investigates whether severity adjustments are adequately addressing the trend, investigates the possible causes, and communicates as appropriate with industry
  - Z_i Limit 2 = +/-0.859
    - When industry level two limits are exceeded the TMC informs the surveillance panel that the limit has been exceeded. The surveillance panel then investigates and pursues resolution of the alarm

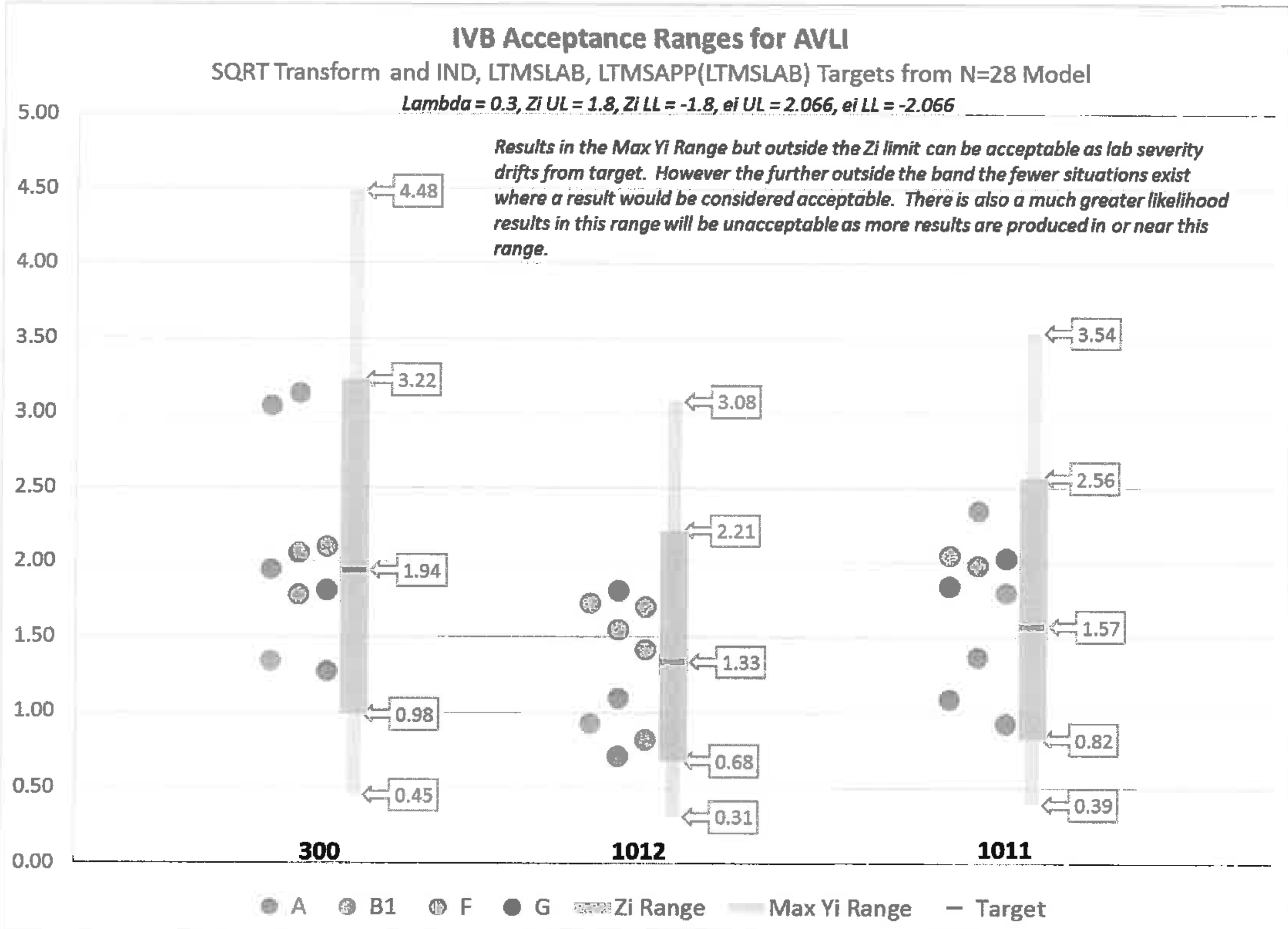
Sequence IVB LTMS eBallot

TOYOTA



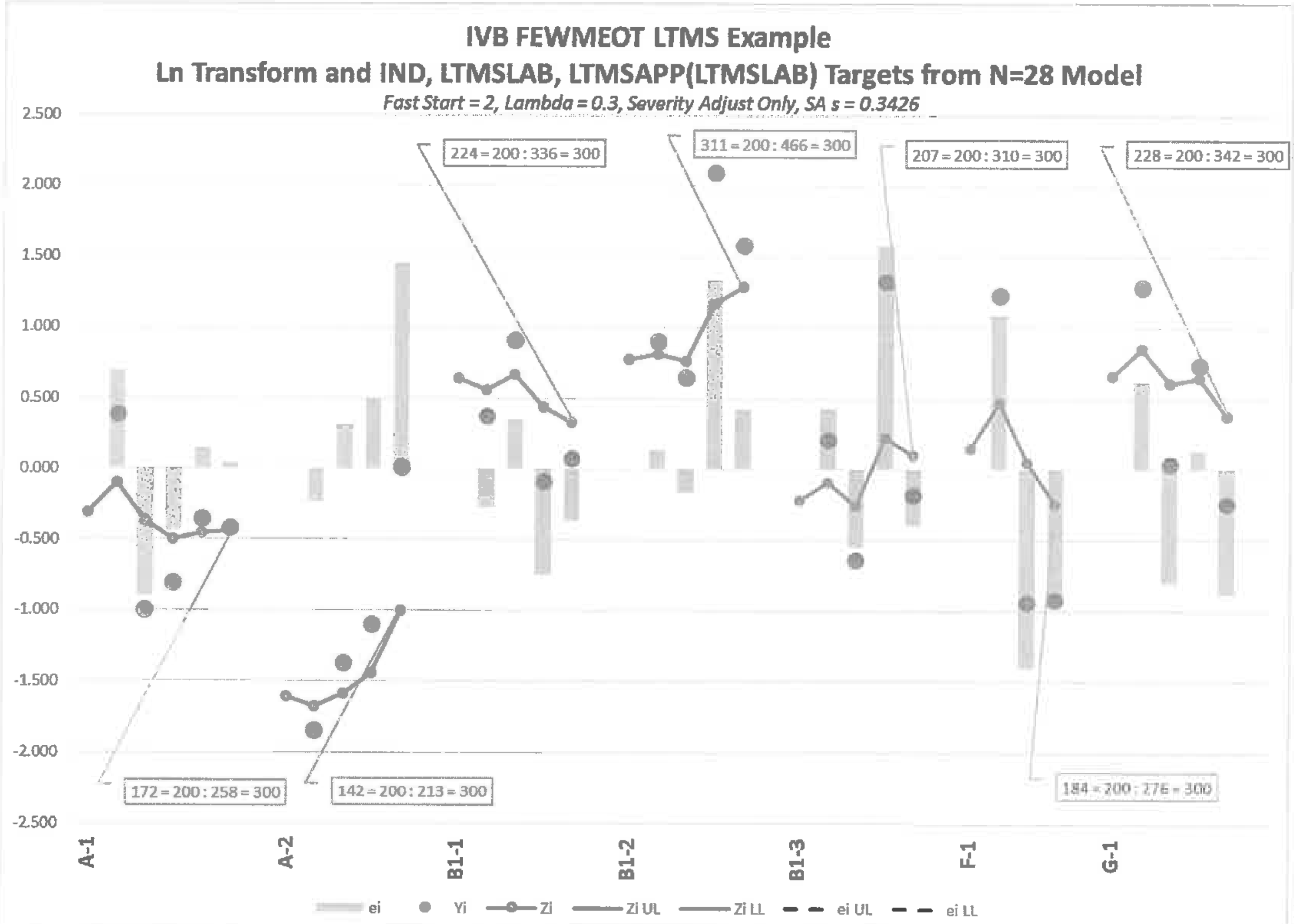
Sequence IVB LTMS eBallot

TOYOTA



Sequence IVB LTMS eBallot

TOYOTA



Sequence IVB LTMS eBallot

TOYOTA

- Motion:
  - Sequence IV surveillance panel accepts the Sequence IVB LTMS, as documented in the previous slides of this presentation (IVB LTMS eBallot 20180329.pptx). Effective 4/18/18 (two weeks after the close of this eBallot) to be applied to all Precision Matrix 2 and later reference tests. The ASTM TMC will grant calibration status where applicable, based on the agreed on LTMS, with calibration intervals effective based on reference test EOT dates.
- Motion by:
  - Bill Buscher
- Seconded by:
  - Teri Kowalski
- This eBallot will close on Wednesday, 4/4/18

IVB LTMS Suggestion Summary – **Items in BOLD need particular attention from the SP**

1. Adopt the transform sqrt(AVLI) for LTMS and severity adjustment calculations.
2. **References will be conducted on RO's 300 (40%), 1012 (40%) and 1011 (20%).**
3. **Select Reference Oil targets from presented n=21, n=28, or other model.**
    a. IND, LTMSLAB, LTMSLAP(LTMSAPP) w SQRT from N=21 Model
        i. AVLI Targets

IND	Mean sqrt(AVLI)	Std dev sqrt(AVLI)
300	1.4306	0.2269
1011	1.2373	0.2136
1012	1.1104	0.1815

        ii. Severity adjustment standard deviation (SA s) is RMSE from Oil only model sqrt(AVLI) = 0.2082
    b. IND, LTMSLAB, LTMSLAP(LTMSAPP) w SQRT from N=28 Model
        i. AVLI Targets

IND	Mean sqrt(AVLI)	Std dev sqrt(AVLI)
300	1.3931	0.2230
1011	1.2538	0.1932
1012	1.1543	0.1847

        ii. Severity adjustment standard deviation (SA s) is RMSE from Oil only model sqrt(AVLI) = 0.2003
4. **All stands will be charted separately.**
    a. **Severity adjustments will be calculated on a stand basis**
5. Utilize limits on Z_i (EWMA of severity), e_i (prediction error), and the excessive influence calculation to determine acceptance and calculate severity adjustments.
    a. Z_i Lambda = 0.3
    b. Z_0 = Average of **first two tests** in a stand. Note this is how many references a new stand will require to enter the system.
    c. Z_i Limit = **+1.800/-1.800**; a stand that exceeds these limits requires additional references until it is within the limits. Do not update severity adjustments until after an acceptable reference is conducted.
    d. e_i Limit 1 = +/-1.351; this limit applies to previously calibrated stands that have not been calibrated for two reference periods and are attempting to calibrate again. The stand can calibrate with one test if the Level 1 limits are not exceeded. References after the first attempt will be judged against the level 3 ei limits.
    e. e_i Limit 2 = +/-1.734; this limit applies in situations pre-determined by the SP to have potential impact to severity. Some situations that warrant consideration include hardware changes or engine build changes in a currently calibrated stand. The stand can calibrate with one test if the Level 2 limits are not exceeded. References after the first attempt will be judged against the level 3 ei limits.
    f. e_i Limit 3 = +/-2.066; this limit applies to all other situations when determining an acceptable reference. If the limit is exceeded do not update control charts until after an additional reference is conducted and apply excessive influence calculations.

g. The excessive influence calculation minimizes the impact of a failing reference test if the following reference test does not agree with the initial failing results and returns to historical severity performance (LTMS 1.A.5).

6. A minimum of two references will be required for each new stand.
7. The reference calibration period will expire after **fifteen full length non-reference tests or 6 months**, whichever comes first.
8. The TMC will plot industry Zi charts to identify potential shifts in industry wide performance.
   a. Lambda = 0.2
   b. Z_0 = 0.000
   c. Z_i Limit 1 = +/-0.775
      i. When industry level one limits are exceeded the TMC investigates whether severity adjustments are adequately addressing the trend, investigates the possible causes, and communicates as appropriate with industry.
   d. Z_i Limit 2 = +/-0.859
      i. When industry level two limits are exceeded the TMC informs the surveillance panel that the limit has been exceeded. The surveillance panel then investigates and pursues resolution of the alarm.

Sequence IVB High Wear Oil

Statistics Group

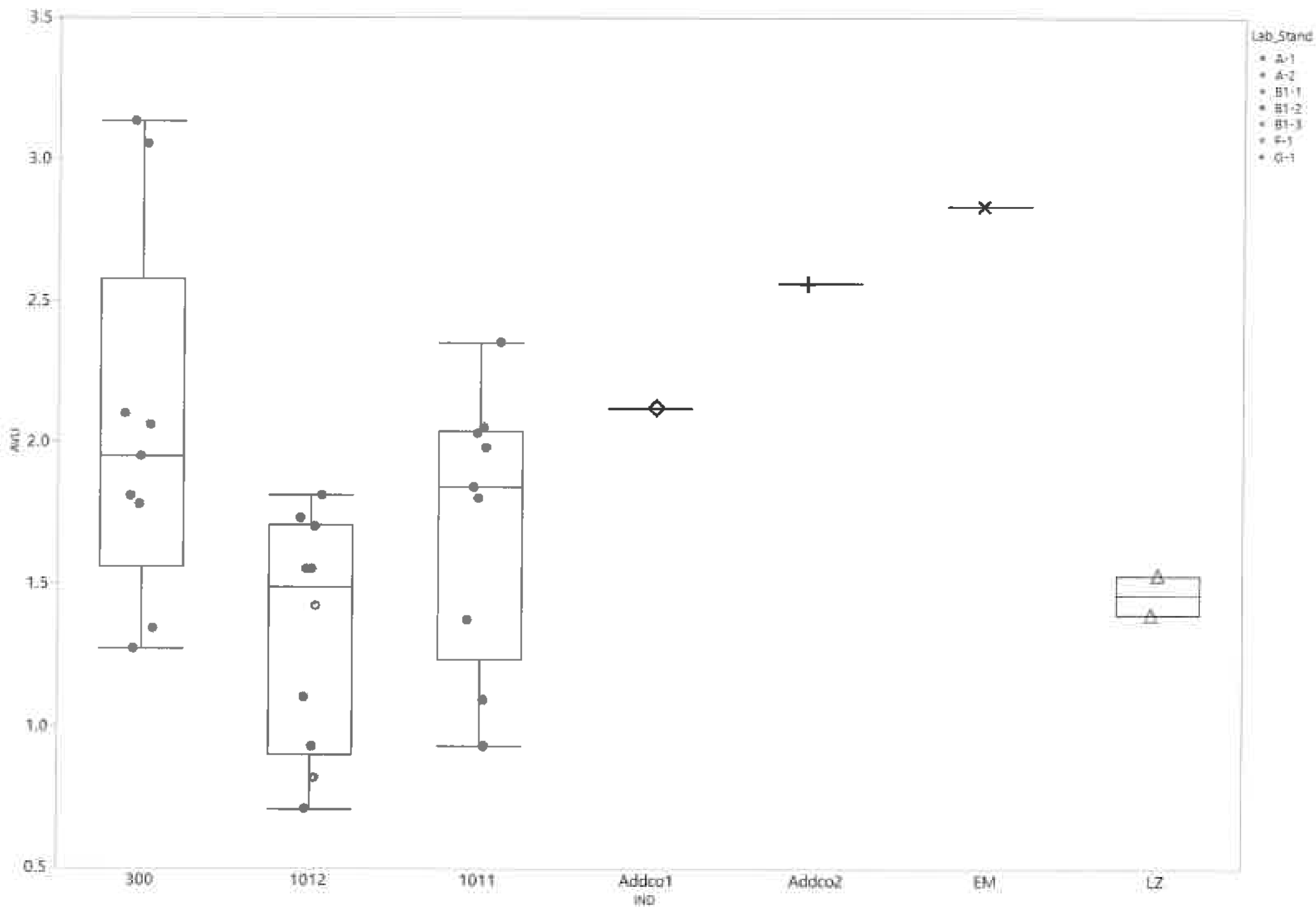
March 27, 2018

Statistics Group

- Arthur Andrews, ExxonMobil
- Doyle Boese, Infineum
- Jo Martinez, Chevron Oronite
- Kevin O'Malley, Lubrizol
- Martin Chadwick, Intertek
- Richard Grundza, TMC
- Lisa Dingwell, Afton
- Todd Dvorak, Afton
- Travis Kostan, SwRI

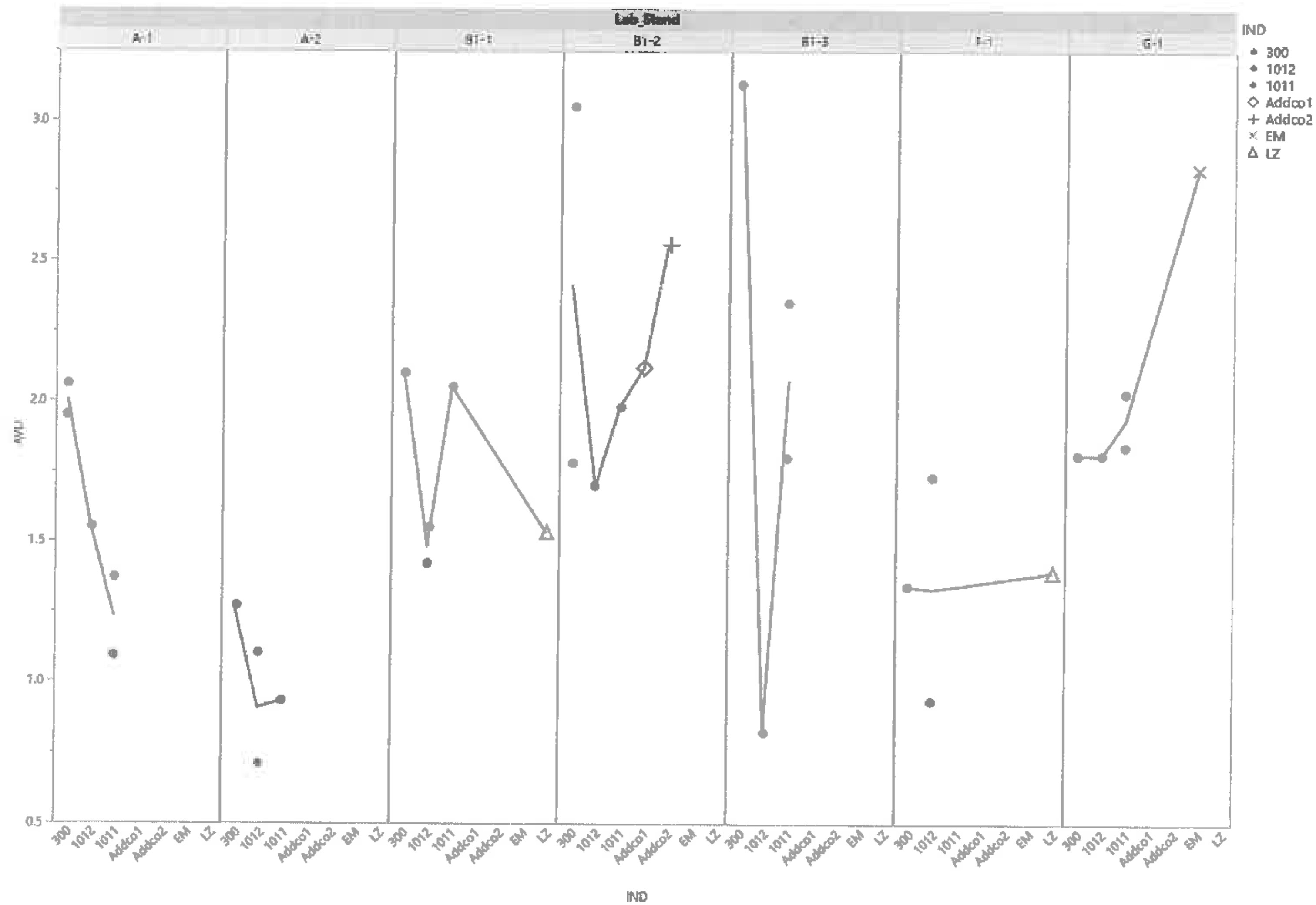
Average Intake Volume Loss by Oil

- The below plot summarizes the AVLI test result data by oil.



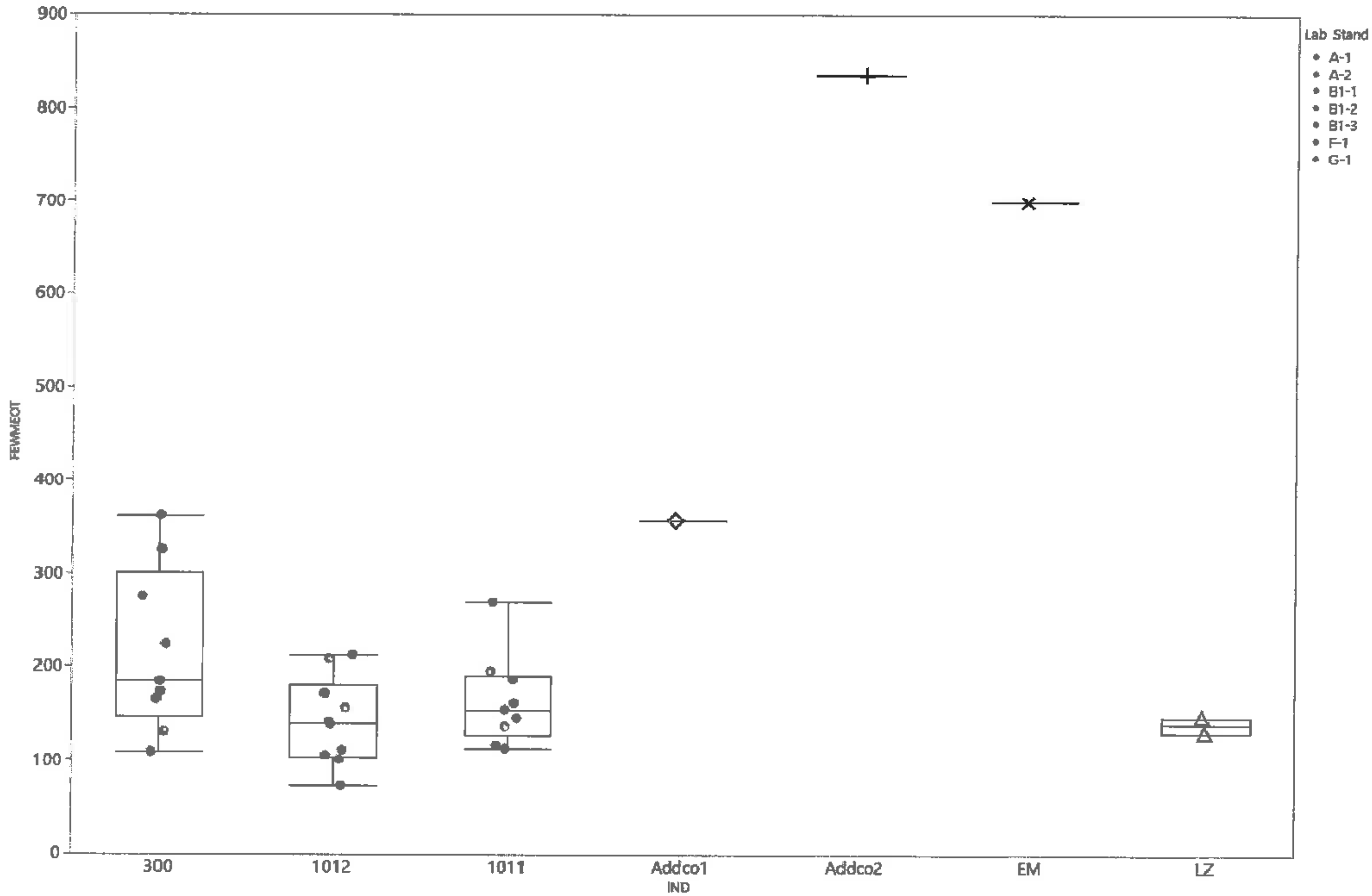
Average Intake Volume Loss by Stand

- The below plot summarizes the AVLI test result data by oil within the stand.



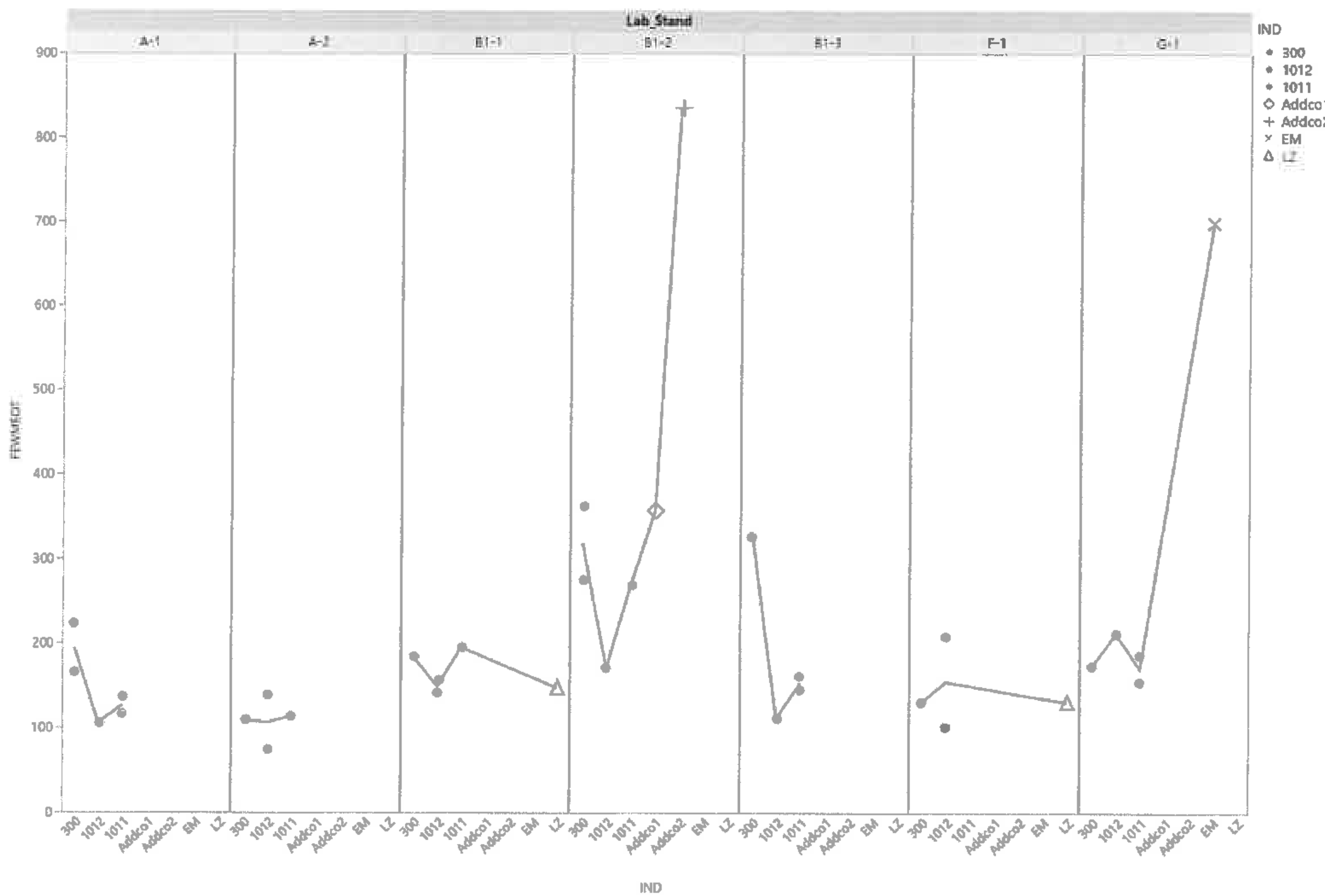
FEWMEOT by Oil

- The below plot summarizes the FEWMEOT test result data by oil.



FEWMEOT by Stand

- The below plot summarizes the FEWMEOT test result data by oil within the stand.



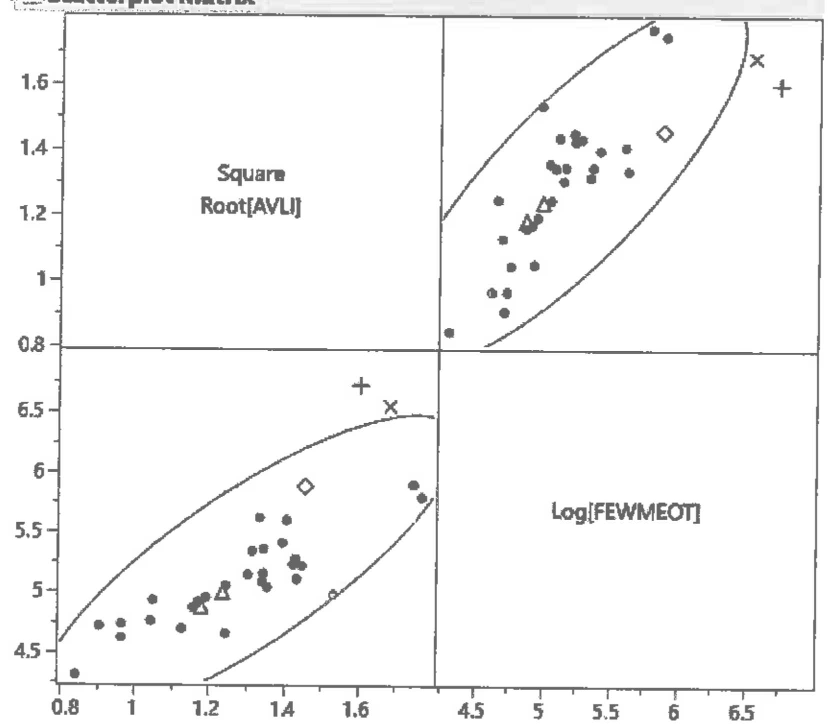
Correlation

- There is significant correlation between AVLI and FEWMEOT.

Correlations

	Square Root[AVLI]	Log[FEWMEOT]
Square Root[AVLI]	1.0000	0.8136
Log[FEWMEOT]	0.8136	1.0000

Scatterplot Matrix



Legend for shape

- ● 300
- ● 1012
- ● 1011
- ◇ Addco1
- + Addco2
- × EM
- Δ LZ

Statistical Analysis of Sequence IVB Operational Data

(Includes EGT, AFR, IntManPres, Crankcase Pressure Operational Data, Exclusivel

By: Industry Stats Team

03-20-18

tatistical Analysis of Operational Data

Analysis was performed to investigate the relationship of Sqrt(AVLI) parameter with respect to the below list of variables:

- Reference Oil (indicator coding of variable)
- Stand[Lab] (indicator coding of variable)
- AFR (stage 1 & 2)
- Blowby Flow Rate (stage 1 & 2)
- Crankcase Pressure (stage 1 & 2)
- Exhaust Temps (stage 1 & 2)
- Manifold Pressure (stage 1 & 2)

Analyzed data included all 28 PM test results

tatistical Analysis of Operational Data

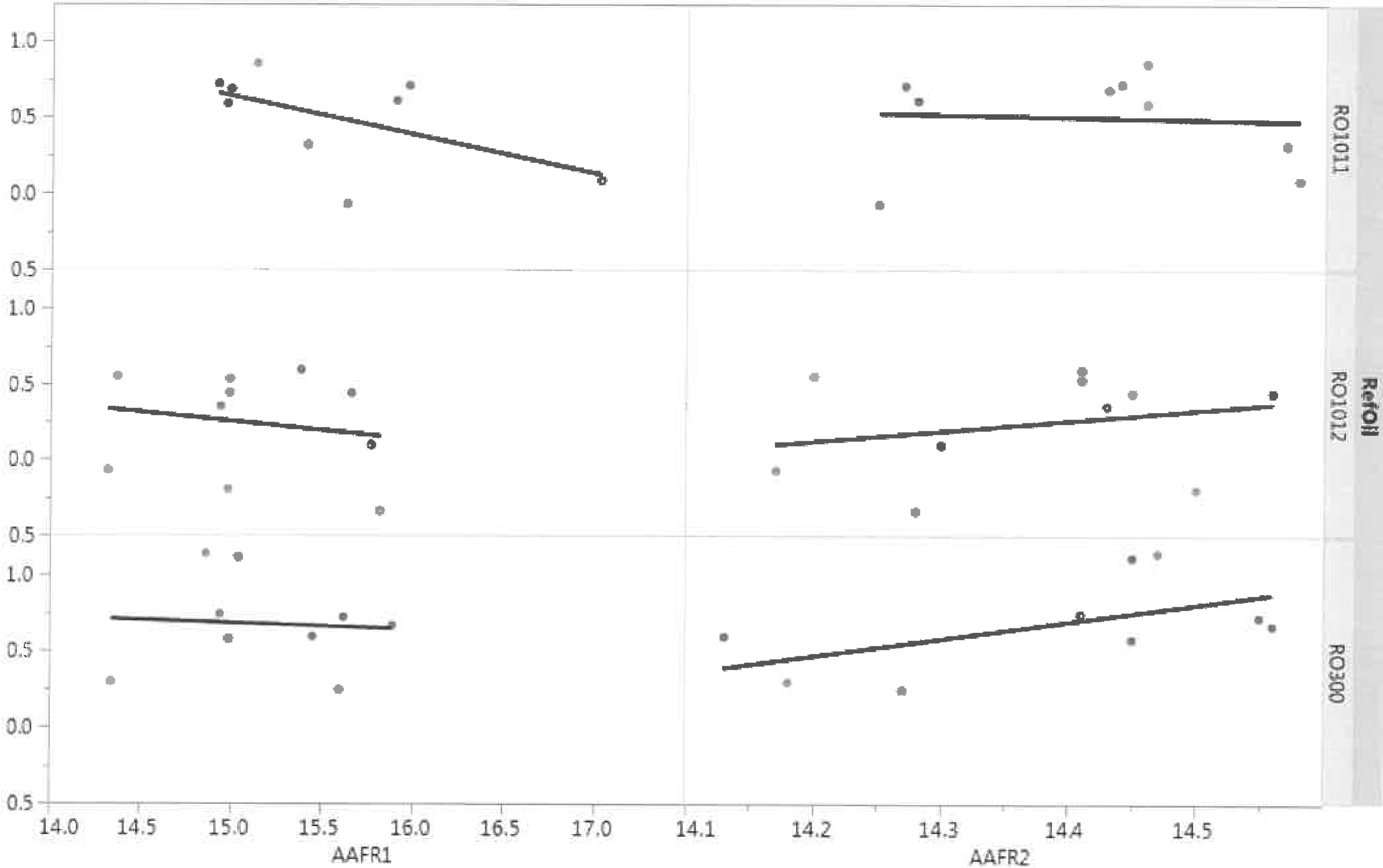
-)ue to multicollinearity, a Partial Least Squares (PLS) Analysis was ›erformed on the data set
- 'LS analysis results *(with 2 latent variables)* for centered and scaled ıre summarized below (and sorted by their centered and scaled :oefficients):

Rank	Term	Coefficient (Centered & Scaled)
1	A-2	-0.3198
2	1012	-0.2625
3	300	0.2378
4	ABLOWBY1	0.1554
5	AAFR1	-0.1487
6	B1-2	0.1337
7	G-1	0.1286
8	AMAP1	0.1065
9	AAFR2	0.0828
10	AMAP2	-0.0764
11	ACCASEP2	0.075
12	B1-1	0.0621
13	ABLOWBY2	0.0612
14	B1-3	0.0535
15	F-1	-0.0342
16	ACCASEP1	0.0332
17	1011	0.0315
18	A-1	-0.0256
19	AEXHT1	-0.0241
20	AEXHT2	0.0132
21	Intercept	0

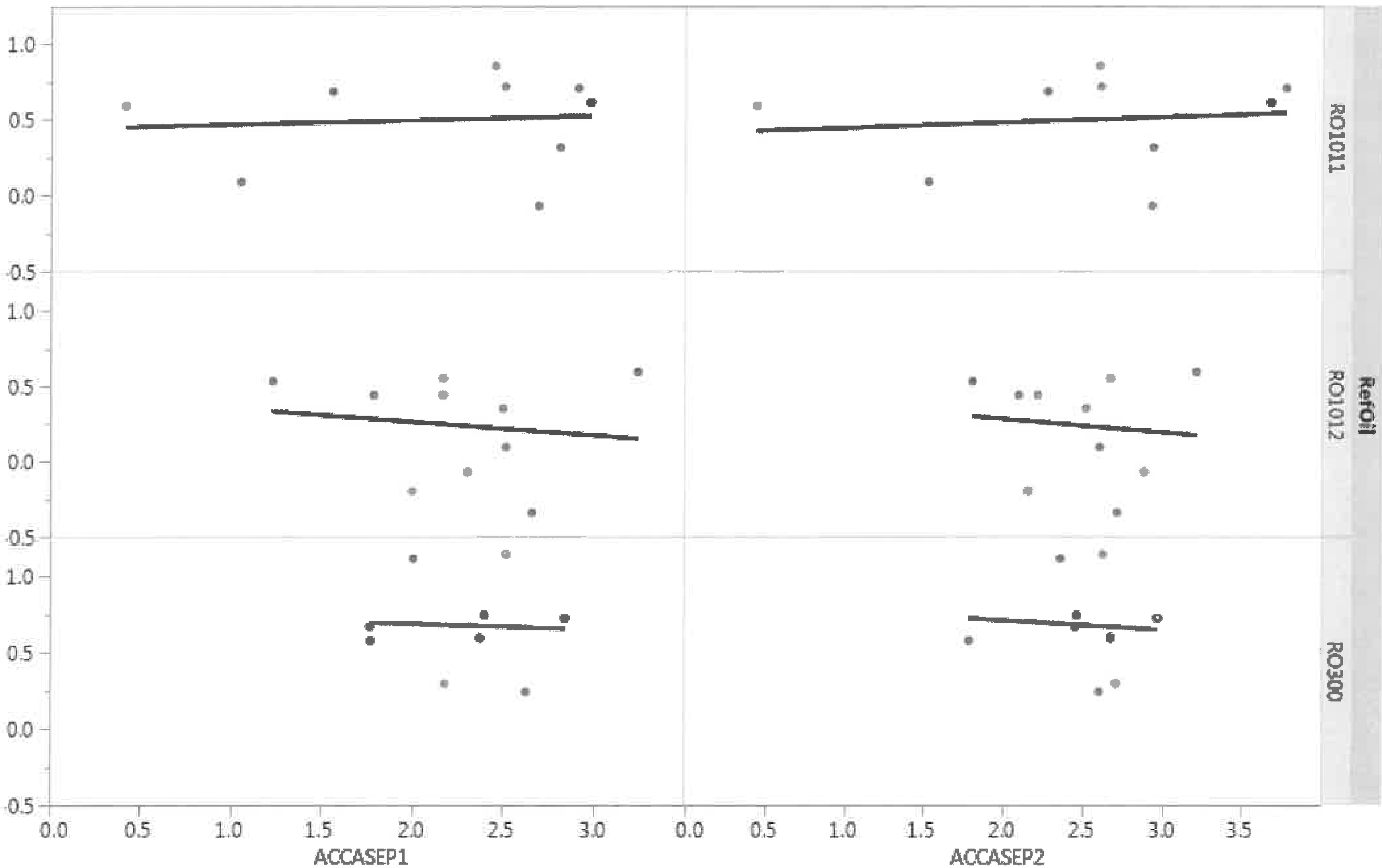
-Appendix-

Plots of PLS Variables

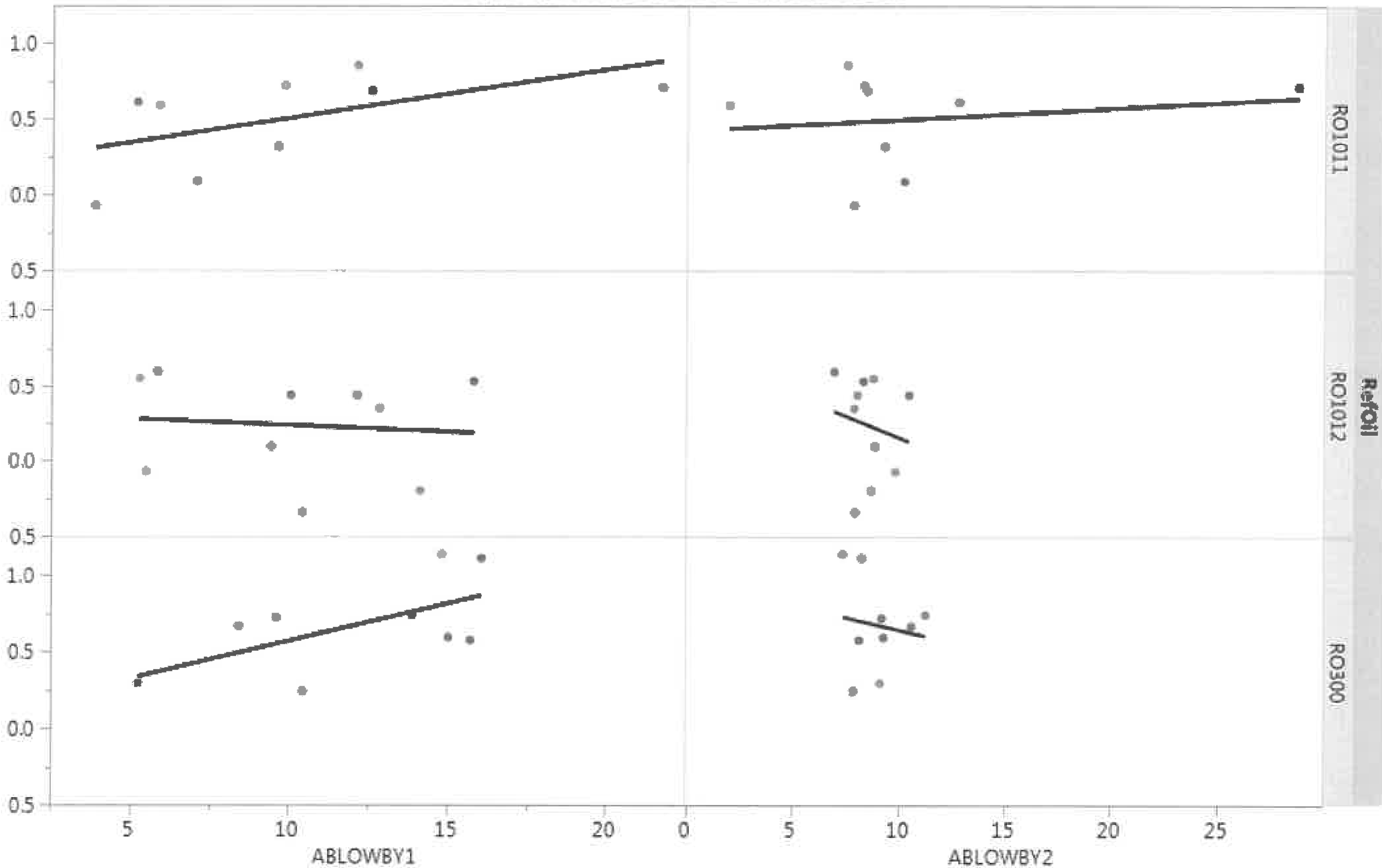
LN(AVLI) vs. AAFR1 & AAFR2



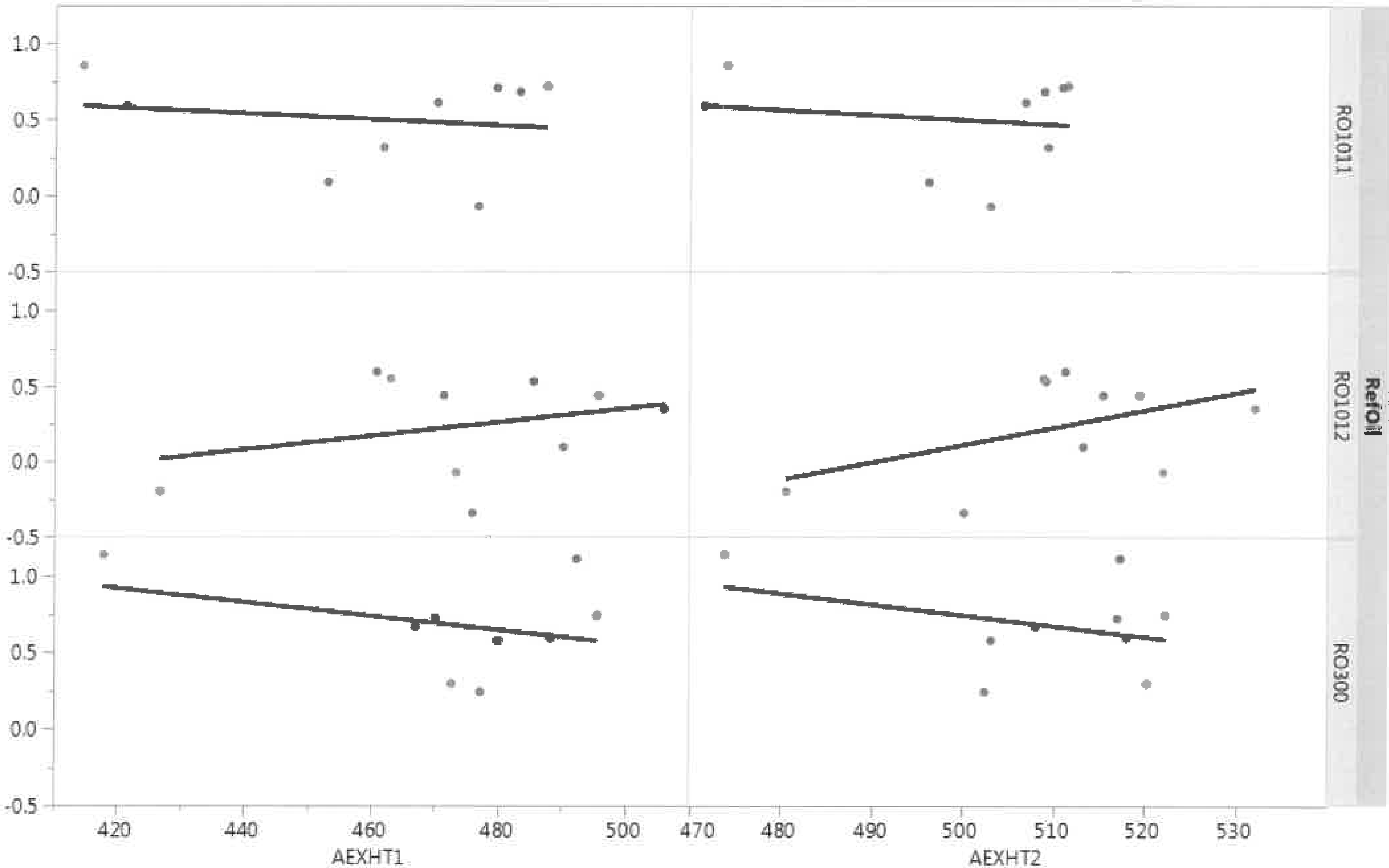
LN(AVLI) vs. ACCASEP1 & ACCASEP2

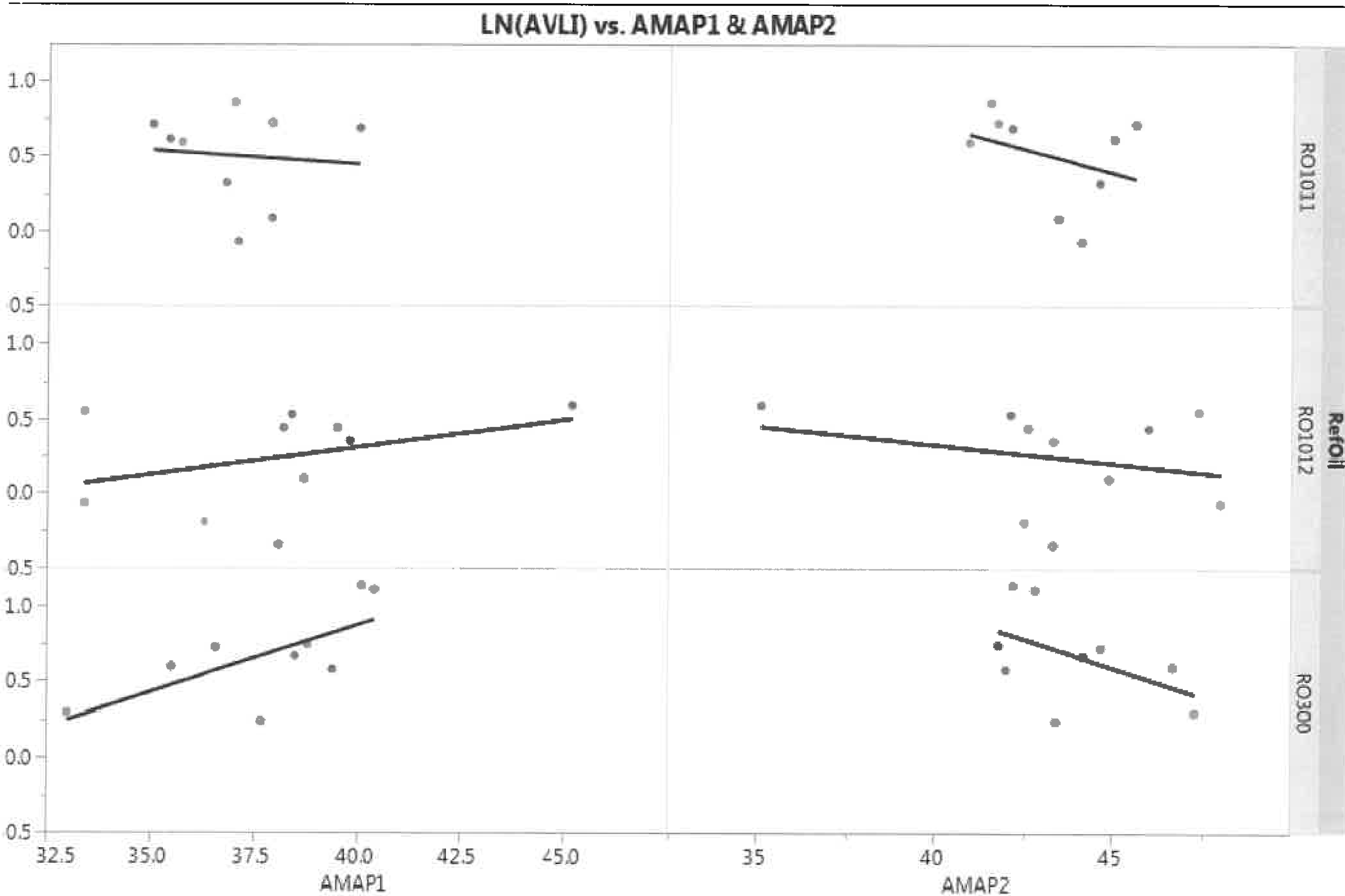


LN(AVLI) vs. ABLOWBY1 & ABLOWBY2



LN(AVLI) vs. AEXHT1 & AEXHT2




LN(AVLI) vs. AMAP1 & AMAP2
RefOil
RO1011
RO1012
RO300
AMAP1
AMAP2
1.0
0.5
0.0
0.5
32.5
35.0
37.5
40.0
42.5
45.0
35
40
45

Sequence IVB Precision Matrix
Iron Analysis

Statistics Group

March 26, 2018

Statistics Group

- Arthur Andrews, ExxonMobil
- Doyle Boese, Infineum
- Jo Martinez, Chevron Oronite
- Kevin O'Malley, Lubrizol
- Martin Chadwick, Intertek
- Richard Grundza, TMC
- Lisa Dingwell, Afton
- Todd Dvorak, Afton
- Travis Kostan, SwRI

Executive Summary

Precision Matrix (PM) Analysis Highlights:

- This analysis includes the results of 28 valid precision matrix tests

- Data supports the use of Ln(FEWMEOT) transformation
  - Borderline statistical significant oil difference: 1012 < 300
  - Lab differences are statistically significant (A < B1)
  - Stand within Lab differences are not statistically significant

- Oil discrimination is more significant for FEWMEOT than FEWML25 (Fe increase over last 25 hours) and FEWML50 (Fe increase over last 50 hours).

- Oil discrimination is more significant with the Calcium Adjustment of the FEWMEOT data

- FEWMEOT can be affected by dilution factors such as fuel, water, volatility, etc.
  - Calcium content is lower at EOT as compared to SOT

- FEWMEOT adjusted using calcium data may be a more preferred approach. However, this approach may contain more error as it is based on multiple (ICP) measurements of Calcium data.
  - Adopting a procedure such as the IIIGB/IIIHB may reduce the error associated with the calcium based adjustment
  - Possible concern - candidate oils may not be calcium based

- Correlation between sqrt(AVLI) and Ln(FEWMEOT) or Ln(FEWMEOT_Ca_Adj) is high (indicating parameter redundancy).

Executive Summary

Precision Matrix (PM) Analysis Highlights:

- Estimated within a stand test precision (r; ASTM repeatability)
  - Ln(FEWMEOT) = 0.7487
- Estimated test precision across labs and stands (R; ASTM reproducibility)
  - Ln(FEWMEOT) = 0.9496
- Oil means and standard deviations

Oil	Number of Tests	Target Mean Ln(FEWMEOT)	Target Mean FEWMEOT	Target Standard Deviation Ln(FEWMEOT)
300	9	5.2500	191	0.4067
1012	10	4.9249	138	0.3365
1011	9	5.0258	152	0.2722

- Same concerns with AVLI are seen in Fe analysis (Two high results on Oil 300 influence oil discrimination, discrimination not consistent among stands, test precision is large compared to the observed range of measurements)

Executive Summary

Precision Matrix (PM) Analysis Highlights:

- Estimated within a stand test precision (r; ASTM repeatability)
  - Ln(FEWMEOT_Ca_Adj) = 0.7162
- Estimated test precision across labs and stands (R; ASTM reproducibility)
  - Ln(FEWMEOT_Ca_Adj) = 0.9410
- Oil means and standard deviations

Ref. Oil	Number of Tests	Target Mean Ln(FEWMEOT_Ca_Adj)	Target Mean FEWMEOT	Target Standard Deviation Ln(FEWMEOT_Ca_Adj)
300	9	5.3987	221	0.3967
1012	10	5.0581	157	0.3277
1011	9	5.1648	175	0.2863

- Same concerns with AVLI are seen in Fe analysis (Two high results on Oil 300 influence oil discrimination, discrimination not consistent among stands, test precision is large compared to the observed range of measurements)

Data Utilized

- Precision Matrix Data:
  - 4 Labs {A, B1, F and G}
  - 3 Reference Oils {300, 1012, and 1011}
  - 7 Stands {A-1, A-2, B1-1, B1-2, B1-3, F-1 and G-1}
  - Total number of tests = 28

- Precision Matrix Data Table from Rich Grundza's 20180115 IVB Matrix update.

Run order	B1-1	B1-2	B1-3	A-1	A-2	F-1	G-1	E-1
1	1012 12[illegible]73-IVB	300 129759-IVB	1011 125879-IVB	300 129752-IVB	1012 125882-IVB	1012 125183-IVB	1012 130944-IVB	300
2	1011 129762-IVB	1012 129766-IVB	1012 129767-IVB	1011 109201-IVB 1011* 125881-IVB	300 130948-IVB	300 120739-IVB	1011 125184-IVB	1011
3	300 129760-IVB	1011 129763-IVB	300 129761-IVB 300 130939-IVB	1012 129755-IVB	1011 125880-IVB	1012 130945-IVB	1011 130943-IVB	300
4	1012 129768-IVB	300 130938-IVB	1011 129764-IVB	300 1[illegible]1277-IVB	1012 129756-IVB		300# 130940-IVB	
Reported			Invalid					

* Laboratory is running additional test because of Lean AFR and lower fuel flow on original matrix test

\# Additional test donated by lab

Reference Oil Discrimination Comparison

The table below compares the numbers of standard deviations of separation between the highest and lowest reference oil across GF-6 test types. The median of other tests is approx. 3.55 and the mean (without PHOS) is 3.99.

Test	Parameter	Oil 1	Oil 2	Range	Test s_r	SDs of Separation
IIIH	Ln(PVIS)	4.7191	3.3289	1.3902	0.4641	3
IIIH	WPD	4.63	3.66	0.97	0.47	2.1
IIIHA	Ln(MRV)	11.1107	9.7854	1.3253	0.4214	3.1
IIIHB	PHOS	94.15	78.92	15.23	1.53	10
VIE	FEI 1	2.56	1.3	1.26	0.29	4.3
VIE	FEI 2	1.82	1.41	0.41	0.12	3.4
VIF	FEI 1	2.23	1.45	0.78	0.21	3.7
VIF	FEI 2	2.25	1.41	0.84	0.19	4.4
IX (LSPI)	Sqrt(AvPIE + 0.5)	4.2644	3.3819	0.8825	0.2856	3.1*1
VH	AES	8.43	6.47	1.96	0.5	3.9
VH	Ln(10-RCS)	0.9155	-0.5294	1.4449	0.2194	6.6
VH	AEV50	9.26	8.77	0.49	0.25	2
VH	APV50	8.67	7.35	1.32	0.53	2.5
X (CW)	Ln(CHST)	-2.10574	-2.63174	0.526	0.14148	3.7*2
IVB	Sqrt(AVLI)	1.3931	1.1543	0.2388	0.168	1.4
IVB	Ln(FEWMEOT)	5.25	4.9249	0.3251	0.2701	1.2
IVB	Ln(FEWMEOT_Ca_Adj)	5.3987	5.0581	0.3406	0.2584	1.3

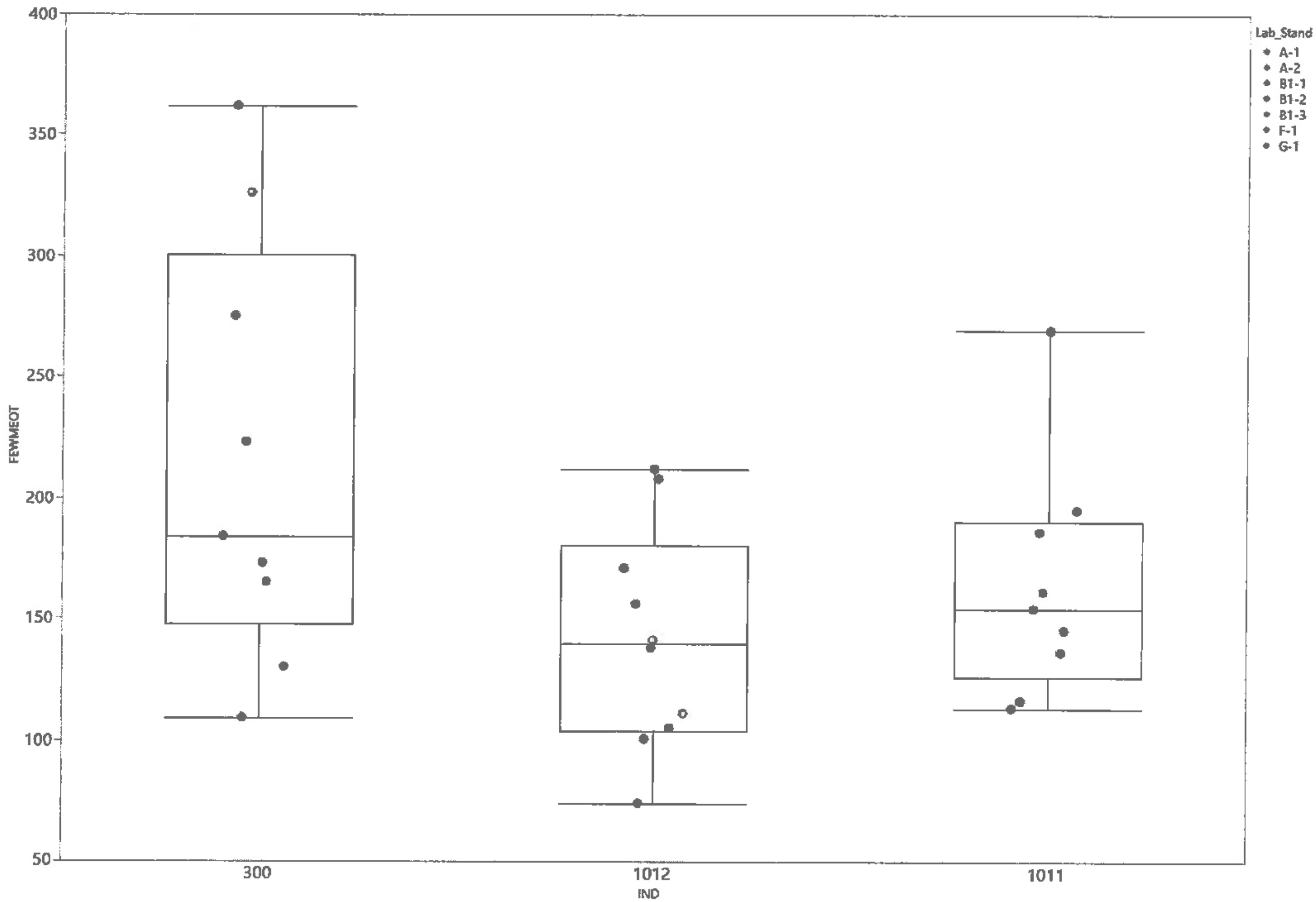
*1: Oil 220 not used as a reference oil. Including this oil would yield approx. 12 SDs of separation between 220 and 222.
*2: 271 vs. 1011

FEWMEOT (n=28)

Fe-Wear Metals at end of test

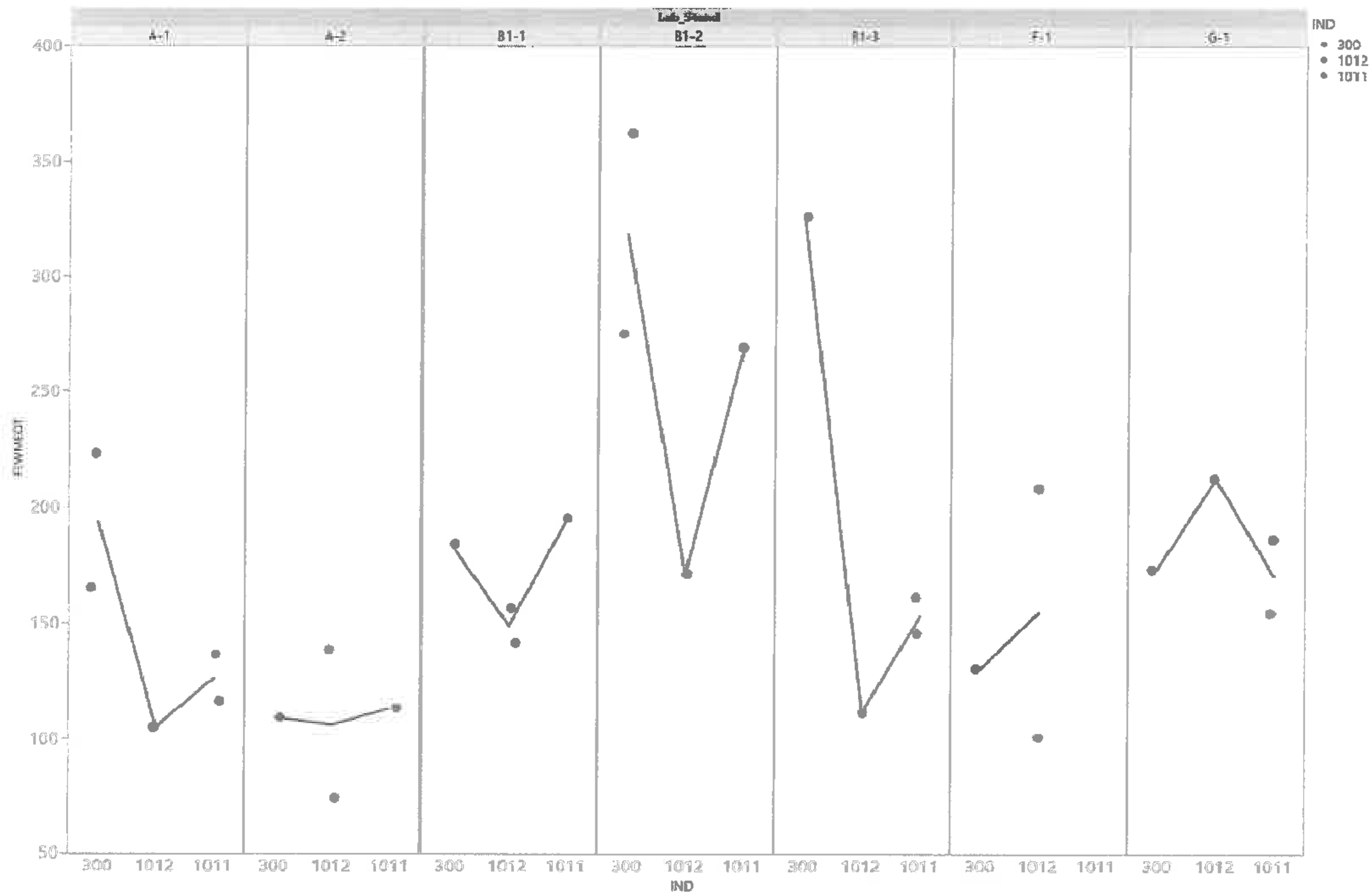
Fe-Wear Metals at EOT by Oil

- There is considerable overlap among the oils.



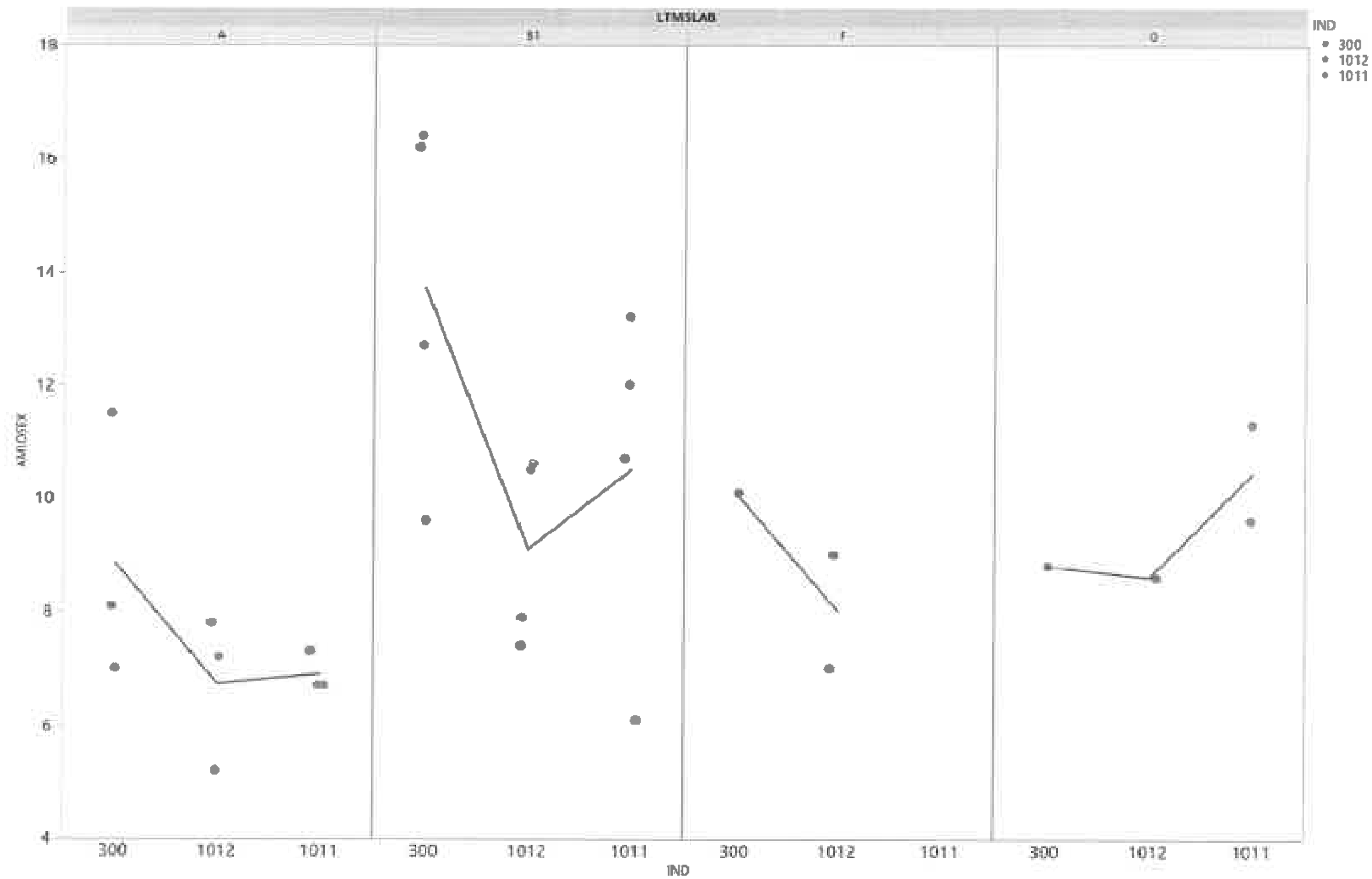
Fe-Wear Metals at EOT by Stand

- It appears that oil discrimination is not consistent among the stands; Stands rank oils differently



Fe-Wear Metals at EOT by Lab

- Below plot summarizes the FEWMEOT test result data by test Lab and reference oil



Ln(FEWMEOT) ANOVA Full Model

Statistically significant differences:

- Lab

Borderline significantly different:

- Oil

Not significantly different:

- Stands within Labs

Summary of Fit

RSquare	0.624999
RSquare Adj	0.467104
Root Mean Square Error	0.270142
Mean of Response	5.08419
Observations (or Sum Wgts)	28

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	2.3109226	0.288865	3.9583
Error	19	1.3865568	0.072977	Prob > F
C. Total	27	3.6974793		0.0066*

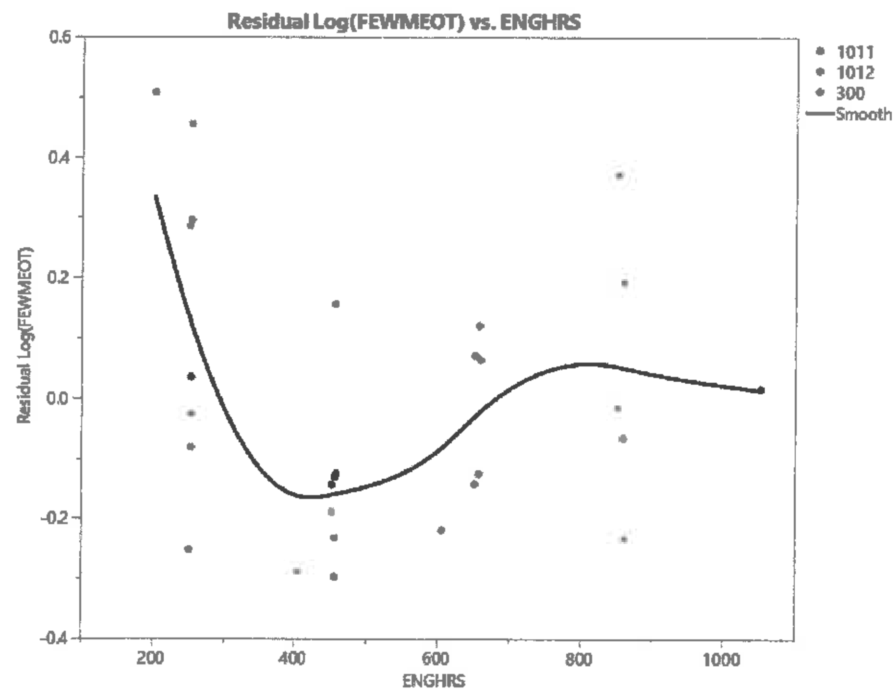
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.0668785	0.060112	84.29	<.0001*
IND[300]	0.1830866	0.074382	2.46	0.0236*
IND[1012]	-0.142024	0.075391	-1.88	0.0750
LTMSLAB[A]	-0.248739	0.087711	-2.84	0.0106*
LTMSLAB[B1]	0.206947	0.081573	2.54	0.0201*
LTMSLAB[F]	-0.09474	0.130769	-0.72	0.4776
LTMSLAB[A]:LTMSAPP[1]	0.12012	0.092183	1.30	0.2081
LTMSLAB[B1]:LTMSAPP[1]	-0.116682	0.111884	-1.04	0.3101
LTMSLAB[B1]:LTMSAPP[2]	0.2416003	0.111842	2.16	0.0437*

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
IND	2	2	0.4918296	3.3698	0.0559
LTMSLAB	3	3	1.1459568	5.2344	0.0084*
LTMSAPP[LTMSLAB]	3	3	0.4590705	2.0969	0.1345

Engine Hours Adjustment

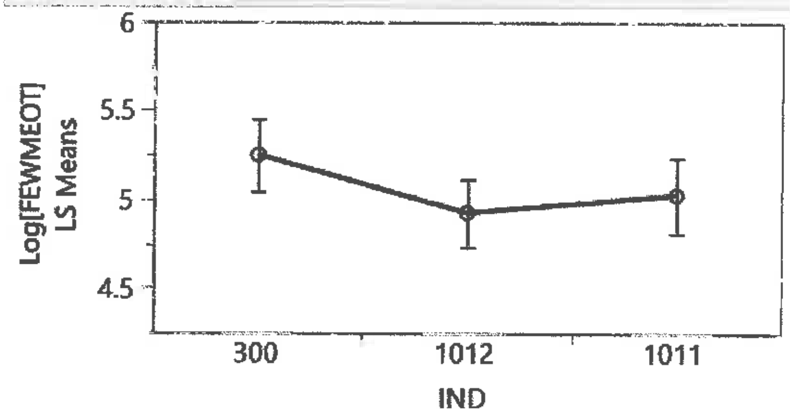


- The residuals of Ln(FEWMEOT) visually do not appear to be uniformly distributed on Engine Hours. (Engine Runs 2 and 3 appear to correlate with lower Fe than Runs 1 and 4)
- Engine Hours was added to the regression model in the following formats along with the result:
  - Engine Hours – Engine Hours not statistically significant and Oil borderline statistically significant.
  - Engine Run (Categorical) - Engine Run borderline statistically significant and Oil statistically significant.
  - Engine Run 1 and Others (Categorical) – Engine Run not statistically significant and Oil statistically significant.
  - Engine Run 1, 4 & 5 and 2 & 3 (Categorical) – Engine Run statistically significant and Oil statistically significant.
- More data is required to verify the pattern and establish for Runs 5 and higher.

Ln(FEWMEOT) Oil Differences

- Model is Ln(FEWMEOT) ~ Oil, Lab, Stand(Lab)
- Oils significantly differ
  - Oil 300 is borderline significantly different than oil 1012
  - Oil 1011 is not statistically significantly different than oils 300 and 1012
- Plot shows Ln(FEWMEOT) LSMeans by Oil, with 95% confidence intervals

LS Means Plot



LSMeans by Oil

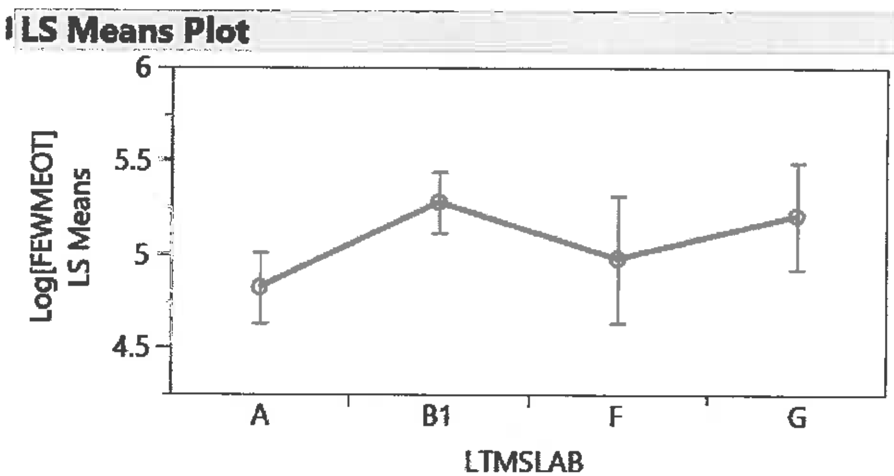
Oil	Ln(FEWMEOT) LSMean	FEWMEOT LSMean
300	5.2500	191
1012	4.9249	138
1011	5.0258	152

LSMeans Differences Between Oils

Oil1	Oil2	Ln(FEWMEOT) LSMean Difference	p-Value
300	1012	0.3251	0.0508
300	1011	0.2241	0.2292
1011	1012	0.1010	0.7325

Ln(FEWMEOT) Lab Differences

- Model is Ln(FEWMEOT) ~ Oil, Lab, Stand(Lab)
- Plot below of Ln(FEWMEOT) LSMeans by Lab, with 95% confidence intervals
- Lab A is statistically significantly different than Lab B1.



LSMeans by Lab

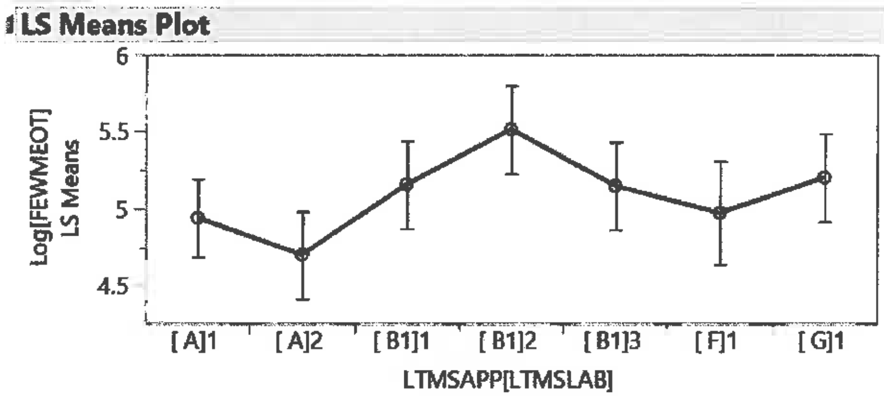
Lab	Ln(FEWMEOT) LSMean	FEWMEOT LSMean
A	4.8181	124
B1	5.2738	195
F	4.9721	144
G	5.2034	182

LSMeans Differences Between Labs

Lab1	Lab2	Ln(FEWMEOT) LSMean Difference	p-Value
B1	A	0.4557	0.01
G	A	0.3853	0.12
B1	F	0.3017	0.36
G	F	0.2313	0.71
F	A	0.1540	0.84
B1	G	0.0704	0.97

Ln(FEWMEOT) Stand within Lab Differences

- Model is Ln(FEWMEOT) ~ Oil, Lab, Stand(Lab)
- Plot below of Ln(FEWMEOT) LSMeans by Stand, with 95% confidence intervals
- Stands within labs are not statistically significantly different from each other



LSMeans by Stand

Stand	Ln(FEWMEOT) LSMean	FEWMEOT LSMean
[A]1	4.9383	140
[A]2	4.6980	110
[B1]1	5.1571	174
[B1]2	5.5154	248
[B1]3	5.1489	172
[F]1	4.9721	144
[G]1	5.2034	182

LSMeans Differences Between Stands within a Lab

Stand1	Stand2	Ln(FEWMEOT) LSMean Difference	p-Value
[B1]2	[B1]3	0.3665	0.51
[B1]2	[B1]1	0.3583	0.53
[A]1	[A]2	0.2402	0.84
[B1]1	[B1]3	0.0082	1

Ln(FEWMEOT) Precision

Repeatability Model: Ln(FEWMEOT) ~ Oil, Lab, Stand(Lab)
Reproducibility Model: Ln(FEWMEOT) ~ Oil

Model RMSE

- $s_r = 0.2701$

Repeatability

- $s_r = 0.2701$
- $r = 0.7487$

Reproducibility

- $s_R = 0.3426$
- $R = 0.9496$

Based upon the FEWMEOT pooled standard deviation (s_r) and ASTM's repeatability (r), there is no significant difference between an FEWMEOT *result*[1] of 200 and 423.

Note 1: An FEWMEOT result of 200 was arbitrarily selected for comparison

Reference Oil Targets

Model: Ln(FEWMEOT) ~ Oil, Lab, Stand(Lab)

Iron at EOT (FEWMEOT)

Unit of Measure: Ln(FEWMEOT)

Ref. Oil	Target Mean Ln(FEWMEOT)	Target Mean FEWMEOT	St. Dev
300	5.2500	191	0.4067
1012	4.9249	138	0.3365
1011	5.0258	152	0.2722

Target Means are the Oil LSMeans from the Model and Standard Deviations are calculated straight from Ln(FEWMEOT).

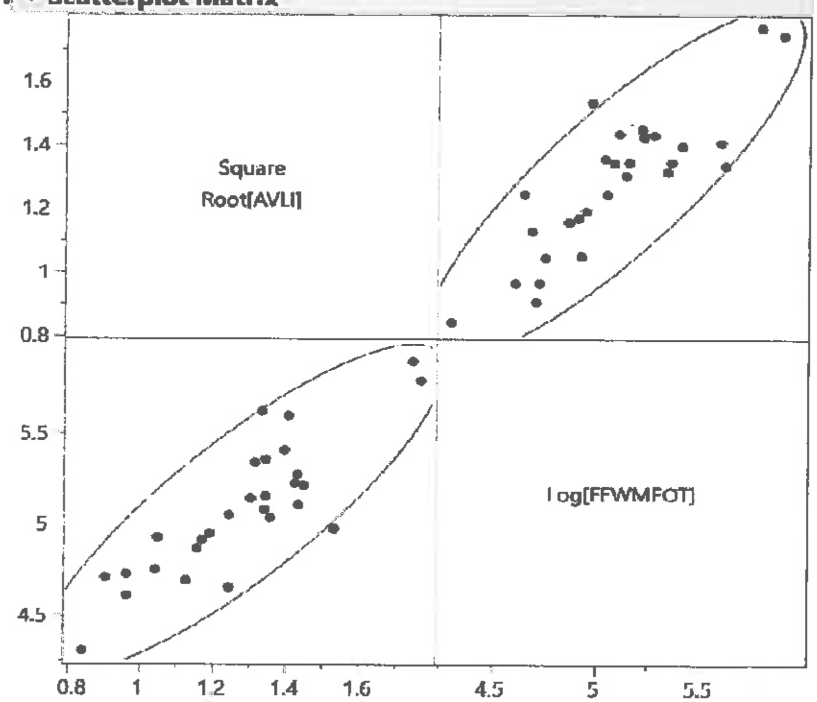
Correlation

Appendix K Section A.3 Parameter Redundancy: Correlation between sqrt(AVLI) and Ln(FEWMEOT) is statistically significant. These two parameters are closely related in repeat tests within oils.

Correlations

	Square Root[AVLI]	Log[FEWMEOT]
Square Root[AVLI]	1.0000	0.8526
Log[FEWMEOT]	0.8526	1.0000

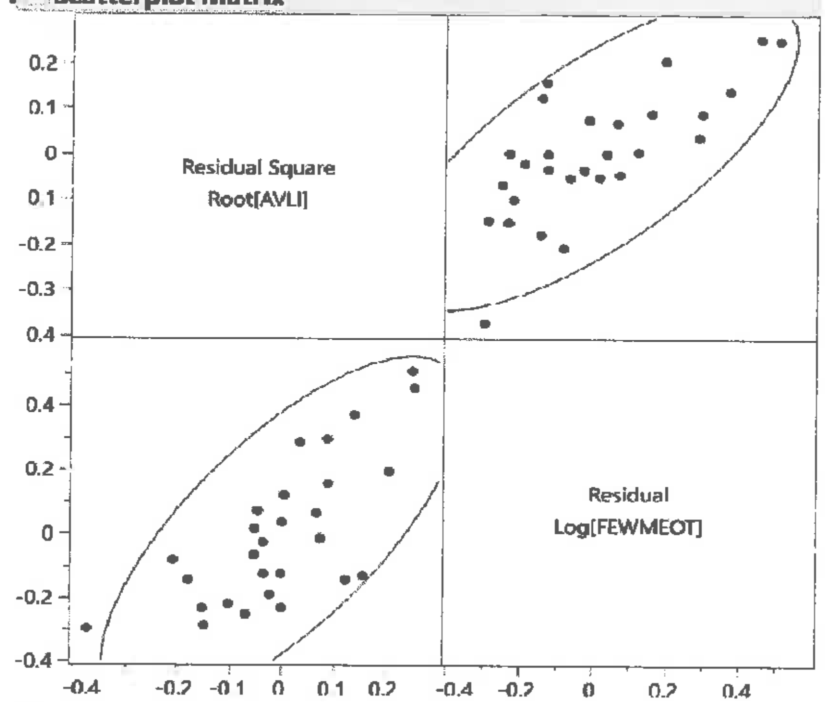
Scatterplot Matrix



Correlations

	Residual Square Root[AVLI]	Residual Log[FEWMEOT]
Residual Square Root[AVLI]	1.0000	0.7272
Residual Log[FEWMEOT]	0.7272	1.0000

Scatterplot Matrix



Calcium Adj FEWMEOT (n=28)

Fe-Wear Metals at end of test

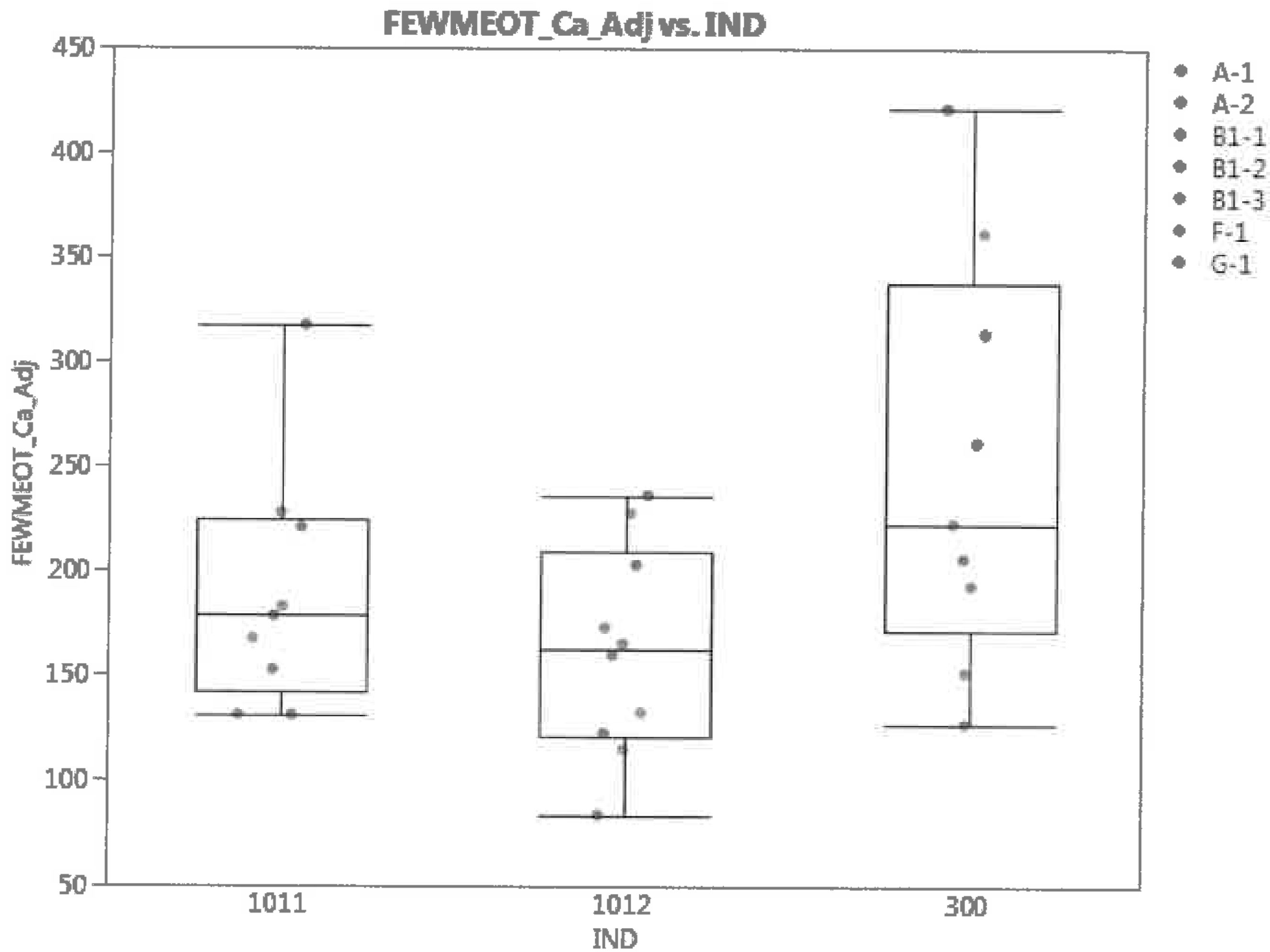
Fe-Wear Metals - Correction Approach

- Method Summary:
  - Calcium concentration is believed to remain constant from SOT to EOT
    - Reference ASTM 7320 - Sequence IIIGB for more information
    - Changes in Ca levels can be due to volatility or dilution (i.e. fuel, water, etc.)
  - Ratio of (Ca_SOT/Ca_EOT) is used to correct the FEWMEOT data to equivalent SOT levels
  - Example of correction calculations are provided below

TESTKEY	LTMSLAB	Stand	RefOil	ENGHRS	FEWMEOT	Ca_SOT	Ca_EOT	Ca_SOT/Ca_EOT	FEWMEOT_Ca_Adj	AVLI
127173-IVB	B1	S1	RO1012	254	156	2400	2168	1.1070	172.7	1.55
129759-IVB	B1	S2	RO300	254	275	2029	1781	1.1392	313.3	1.78
125879-IVB	B1	S3	RO1011	254	161	2111	1861	1.1343	182.6	1.8
125882-IVB	A	S2	RO1012	252	74	2449	2163	1.1322	83.8	0.71
129752-IVB	A	S1	RO300	252	223	2076	1773	1.1709	261.1	1.95
129762-IVB	B1	S1	RO1011	456	195	2107	1805	1.1673	227.6	2.05
129766-IVB	B1	S2	RO1012	456	171	2439	2058	1.1851	202.7	1.7
129767-IVB	B1	S3	RO1012	456	111	2419	2035	1.1887	131.9	0.82
130948-IVB	A	S2	RO300	452	109	2069	1783	1.1604	126.5	1.27
129760-IVB	B1	S1	RO300	658	184	2056	1700	1.2094	222.5	2.1
129763-IVB	B1	S2	RO1011	658	269	2137	1811	1.1800	317.4	1.98
109201-IVB	A	S1	RO1011	452	116	2115	1878	1.1262	130.6	1.09
130944-IVB	G	S1	RO1012	254	212	2521	2264	1.1135	236.1	1.81
125183-IVB	F	S1	RO1012	202	208	2396	2192	1.0931	227.4	1.73
129768-IVB	B1	S1	RO1012	860	141	2401	2052	1.1701	165	1.42
130938-IVB	B1	S2	RO300	860	362	2009	1726	1.1640	421.4	3.05
129755-IVB	A	S1	RO1012	652	105	2496	2148	1.1620	122	1.55
125184-IVB	G	S1	RO1011	458	154	2129	1840	1.1571	178.2	1.84
125880-IVB	A	S2	RO1011	652	113	2159	1866	1.1570	130.7	0.93
130939-IVB	B1	S3	RO300	254	326	1993	1798	1.1085	361.4	3.13
120739-IVB	F	S1	RO300	404	130	1988	1711.7	1.1614	151	1.34
131277-IVB	A	S1	RO300	852	165	2100	1798	1.1680	192.7	2.06
129756-IVB	A	S2	RO1012	852	138	2478	2145	1.1552	159.4	1.1
130943-IVB	G	S1	RO1011	660	186	2186	1842	1.1868	220.7	2.03
129764-IVB	B1	S3	RO1011	456	145	2094	1816	1.1531	167.2	2.35
130940-IVB	G	S1	RO300	862	173	2102	1767	1.1896	205.8	1.81
130945-IVB	F	S1	RO1012	606	101	2442.3	2158.1	1.1317	114.3	0.93
125881-IVB	A	S1	RO1011	1052	136	2121	1894	1.1199	152.3	1.37

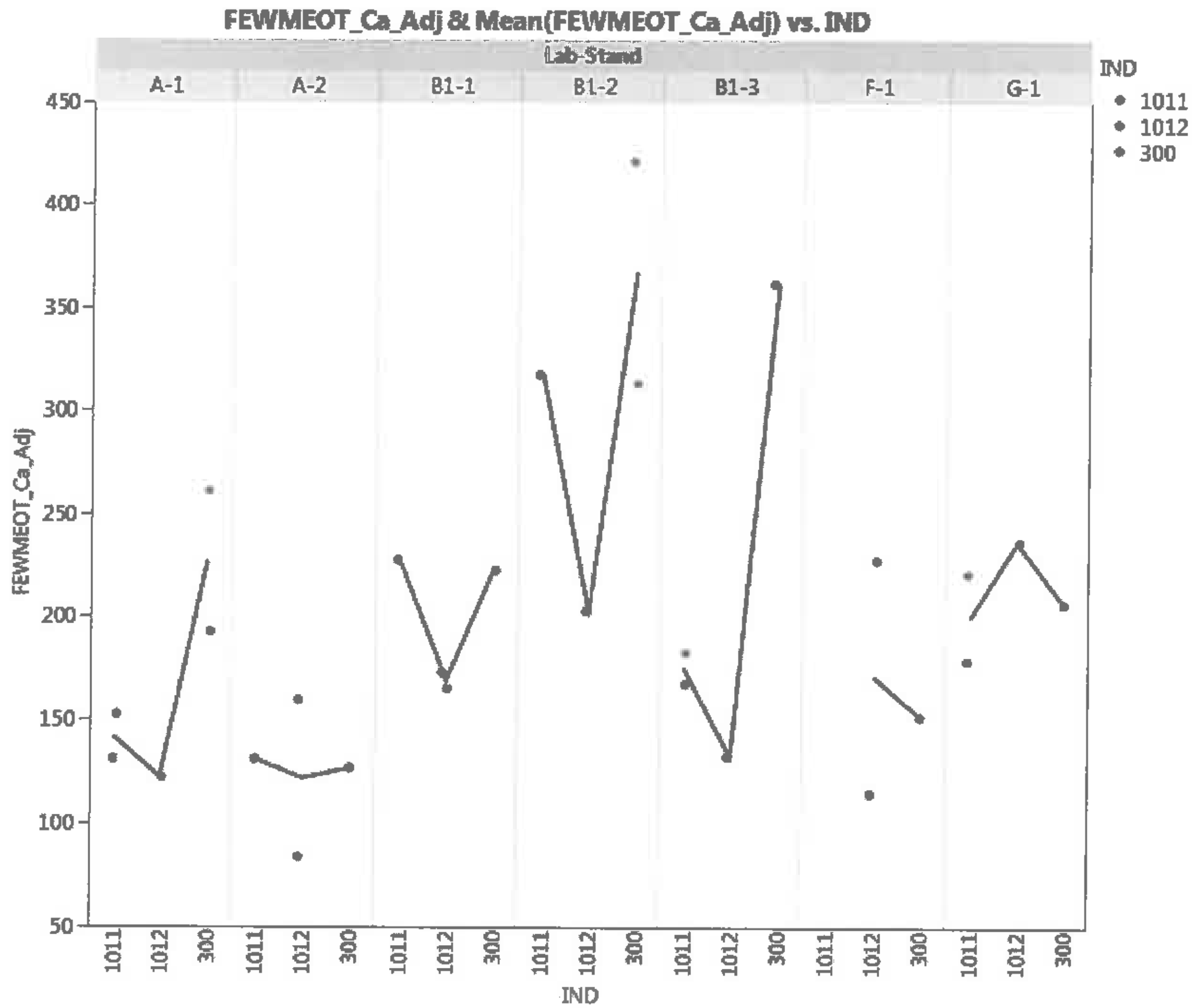
Calcium_Adj_Fe-Wear Metals at EOT by Oil

- There is considerable overlap among the oils.



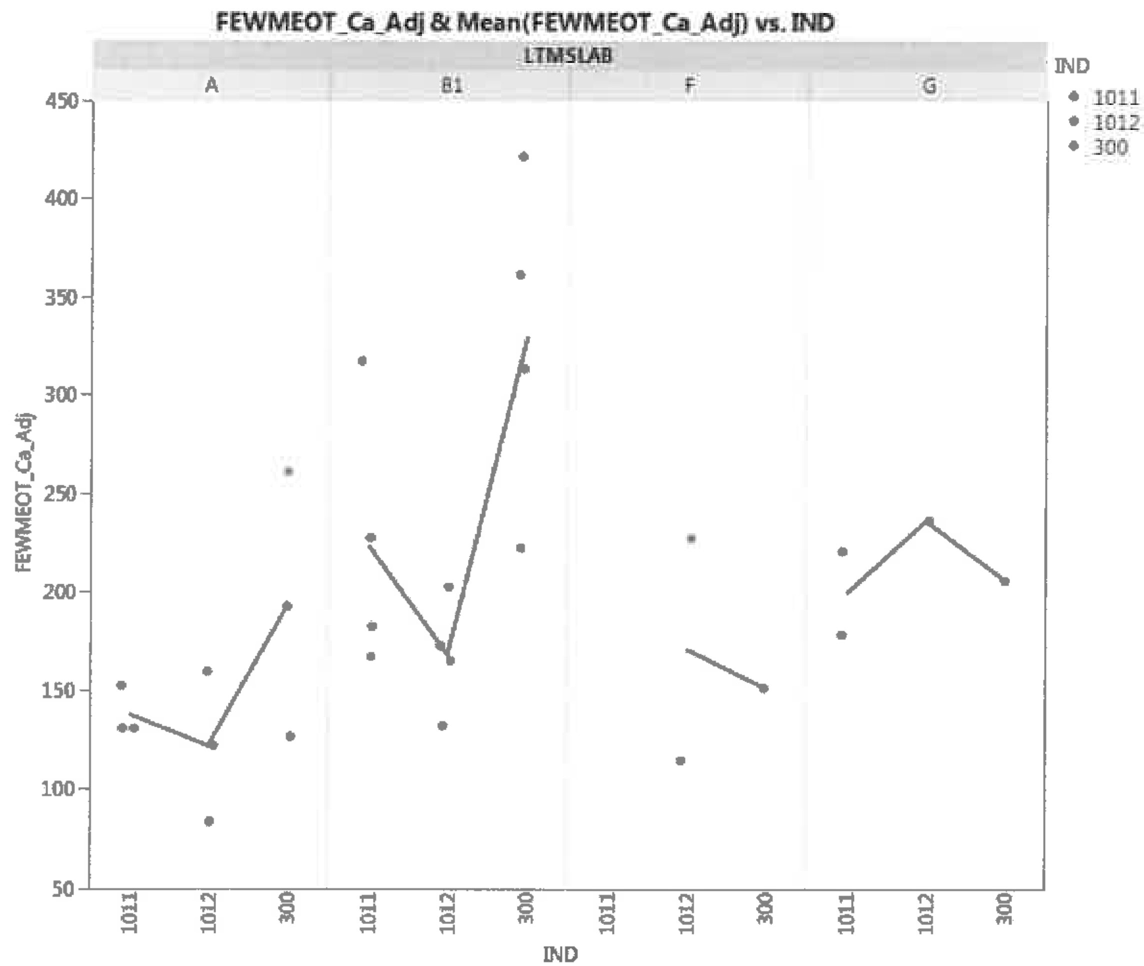
Calcium_Adj_Fe-Wear Metals at EOT by Stand

- It appears that oil discrimination is not consistent among the stands; Stands rank oils differently



Calcium_Adj_Fe-Wear Metals at EOT by Lab

- Below plot summarizes the FEWMEOT_Ca_Adj test result data by test Lab and reference oil



Ln(FEWMEOT_Ca_Adj) - ANOVA Full Model

Statistically significant differences:

- Lab, Oil

Not significantly different:

- Stands within Labs

Summary of Fit

RSquare	0.657934
RSquare Adj	0.513907
Root Mean Square Error	0.258386
Mean of Response	5.226639
Observations (or Sum Wgts)	28

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	2.4398569	0.304982	4.5681
Error	19	1.2685020	0.066763	Prob > F
C. Total	27	3.7083589		0.0031*

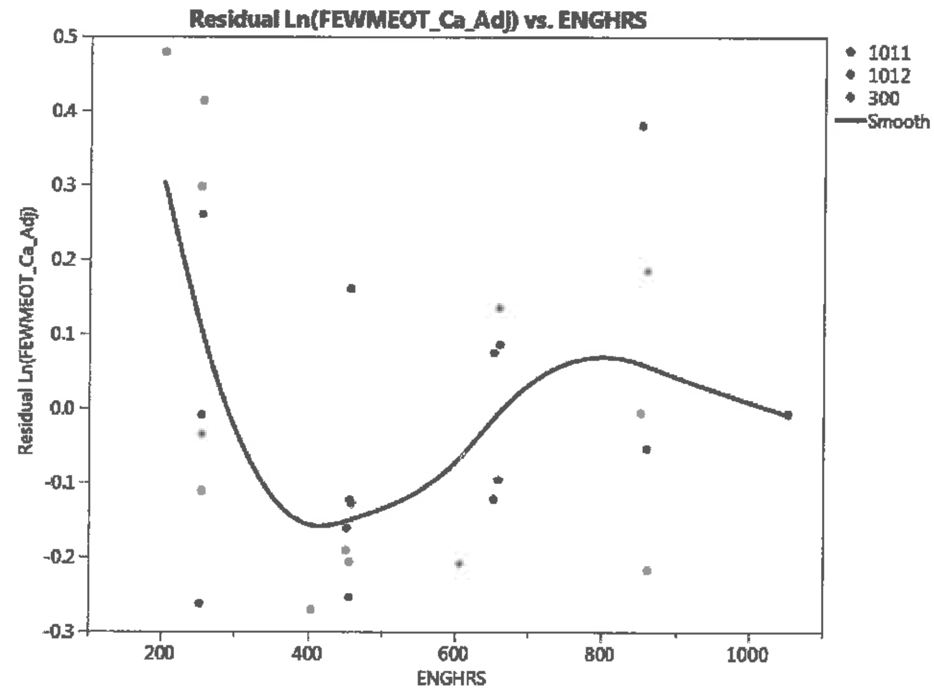
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.2072249	0.057496	90.57	<.0001*
RefOil[RO1011]	-0.042438	0.073795	-0.58	0.5720
RefOil[RO1012]	-0.149076	0.07211	-2.07	0.0526
LTMSLAB[A]	-0.249068	0.083894	-2.97	0.0079*
LTMSLAB[B1]	0.2137059	0.078023	2.74	0.0130*
LTMSLAB[F]	-0.11074	0.125078	-0.89	0.3870
LTMSLAB[A]:Stand[S1]	0.1176384	0.088171	1.33	0.1979
LTMSLAB[B1]:Stand[S1]	-0.111157	0.107015	-1.04	0.3120
LTMSLAB[B1]:Stand[S2]	0.246849	0.106975	2.31	0.0324*

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
RefOil	2	2	0.5391278	4.0376	0.0346*
LTMSLAB	3	3	1.1972860	5.9778	0.0048*
Stand[LTMSLAB]	3	3	0.4703869	2.3485	0.1049

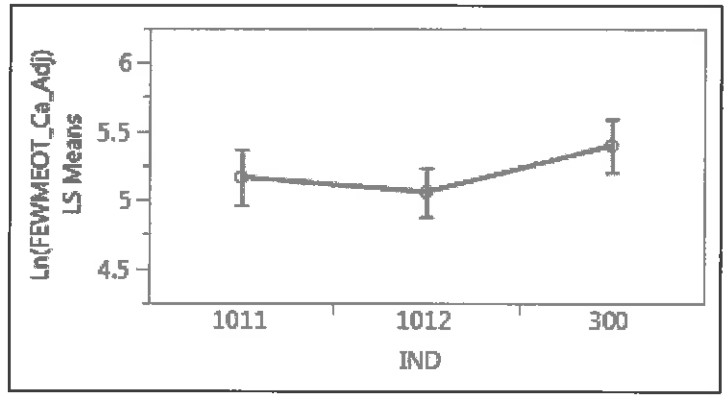
Engine Hours Adjustment



- The residuals of Ln(FEWMEOT_Ca_Adj) visually do not appear to be uniformly distributed on Engine Hours. (Engine Runs 2 and 3 appear to correlate with lower Fe than Runs 1 and 4)
- Engine Hours was added to the regression model in the following formats along with the result:
  - Engine Hours – Engine Hours not statistically significant and Oil statistically significant.
  - Engine Run (Categorical) - Engine Run not statistically significant and Oil statistically significant.
- More data is required to verify the pattern and establish for Runs 5 and higher.

Ln(FEWMEOT_Ca_Adj) Oil Differences

- Model is Ln(FEWMEOT_Ca_Adj) ~ Oil, Lab, Stand(Lab)
- Oils significantly differ
  - Oil 300 is significantly different than oil 1012
  - Oil 1011 is not statistically significantly different than oils 300 and 1012
- Plot shows Ln(FEWMEOT_Ca_Adj) LSMeans by Oil, with 95% Confidence Interval



LSMeans by Oil

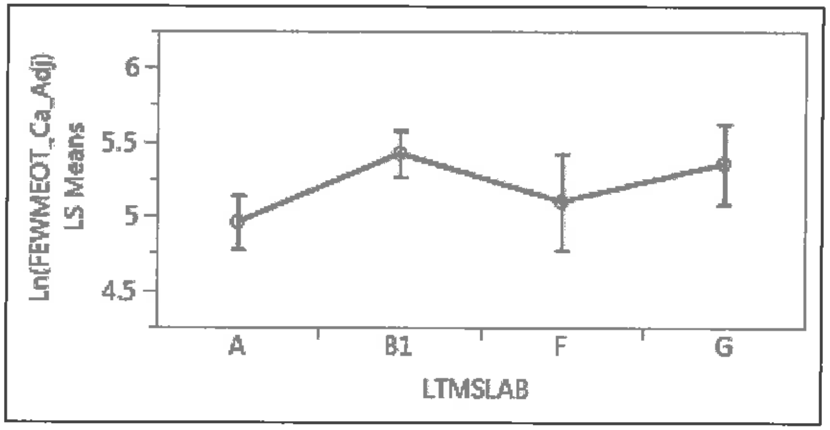
Oil	Ln(FEWMEOT_Ca_Adj) LSMean	FEWMEOT_Ca_Adj LSMean
1011	5.1648	175
1012	5.0581	157
300	5.3987	221

LSMeans Differences Between Oils

Oil1	Oil2	Ln(FEWMEOT_Ca_Adj) LSMean Difference	p-Value
300	1012	0.3406	0.0310
300	1011	0.2339	0.1775
1011	1012	0.1066	0.6852

Ln(FEWMEOT_Ca_Adj) Lab Differences

- Model is Ln(FEWMEOT_Ca_Adj) ~ Oil, Lab, Stand(Lab)
- Plot below of Ln(FEWMEOT_Ca_Adj) LSMeans by Lab, with 95% confidence intervals
- Lab A is statistically significantly different than Lab B1.



LSMeans by Lab

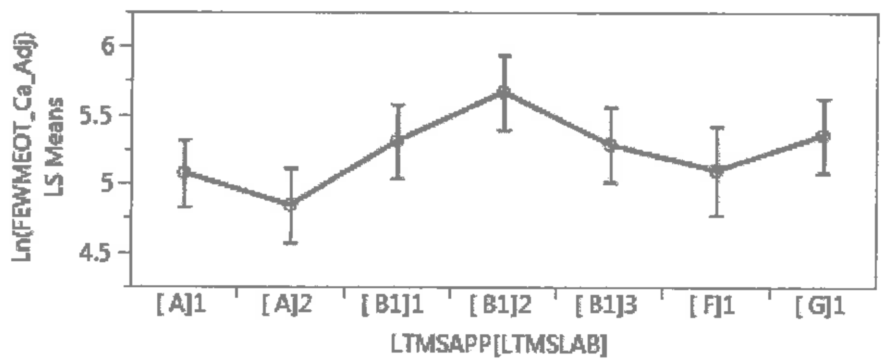
Lab	Ln(FEWMEOT_Ca_Adj) LSMean	FEWMEOT_Ca_Adj LSMean
A	4.9581	142
B1	5.4209	226
F	5.0965	163
G	5.3533	211

LSMeans Differences Between Labs

Lab1	Lab2	Ln(FEWMEOT_Ca_Adj) LSMean Difference	p-Value
B1	A	0.4628	0.0035
G	A	0.3952	0.0886
B1	F	0.3244	0.2672
G	F	0.2568	0.6063
F	A	0.1383	0.8625
B1	G	0.0676	0.9689

Ln(FEWMEOT_Ca_Adj) Stand within Lab Differences

- Model is Ln(FEWMEOT_Ca_Adj) ~ Oil, Lab, Stand(Lab)
- Plot below of Ln(FEWMEOT_Ca_Adj) LSMeans by Stand, with 95% confidence intervals
- Stands within labs are not statistically significantly different from each other



LSMeans by Stand

Level	Ln(FEWMEOT_Ca_Adj) LSMean	FEWMEOT_Ca_Adj LSMean
[A]1	5.0758	160
[A]2	4.8405	127
[B1]1	5.3098	202
[B1]2	5.6678	289
[B1]3	5.2852	197
[F]1	5.0965	163
[G]1	5.3533	211

LSMeans Differences Between Stands within a Lab

Lab_Stand1	Lab_Stand2	Ln(FEWMEOT_Ca_Adj) LSMean Difference	p-Value
[B1]2	[B1]3	0.3825	0.4108
[B1]2	[B1]1	0.3580	0.4847
[A]1	[A]2	0.2353	0.8278
[B1]1	[B1]3	0.0245	1.0000

Ln(FEWMEOT_Ca_Adj) Precision

Repeatability Model: Ln(FEWMEOT_Ca_Adj) ~ Oil, Lab, Stand(Lab)
Reproducibility Model: Ln(FEWMEOT_Ca_Adj) ~ Oil

Model RMSE

- $s_r = 0.2584$

Repeatability

- $s_r = 0.2584$
- r = 0.7162

Reproducibility

- $s_R = 0.3395$
- R = 0.9410

Based upon the Ln(FEWMEOT_Ca_Adj) pooled standard deviation (s_r) and ASTM's repeatability (r), there is no significant difference between an FEWMEOT_Ca_Adj *result*[1] of 200 and 409.

Note 1: An FEWMEOT_Ca_Adj result of 200 was arbitrarily selected for comparison

Reference Oil Targets

Model: Ln(FEWMEOT_Ca_Adj) ~ Oil, Lab, Stand(Lab)

Iron at EOT (FEWMEOT_Ca_Adj)

Unit of Measure: Ln(FEWMEOT_Ca_Adj)

Ref. Oil	Target Mean Ln(FEWMEOT_Ca_Adj)	Target Mean FEWMEOT_Ca_Adj	St. Dev
300	5.3987	221	0.3967
1012	5.0581	157	0.3277
1011	5.1648	175	0.2863

Target Means are the Oil LSMeans from the Model and Standard Deviations are calculated straight from Ln(FEWMEOT_Ca_Adj).

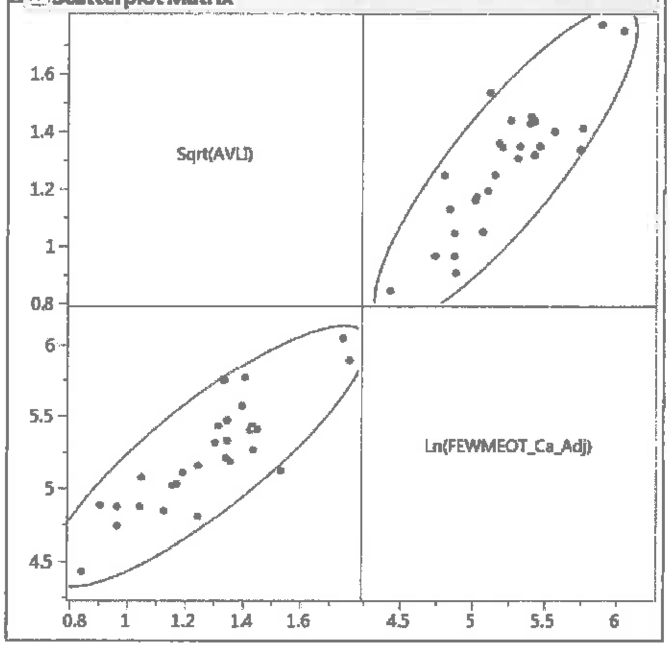
Correlation

Appendix K Section A.3 Parameter Redundancy: Correlation between Sqrt(AVLI) and Ln(FEWMEOT_Ca_Adj) is statistically significant. These two parameters are closely related in repeat tests within oils.

Correlations

	Sqrt(AVLI)	Ln(FEWMEOT_Ca_Adj)
Sqrt(AVLI)	1.0000	0.8557
Ln(FEWMEOT_Ca_Adj)	0.8557	1.0000

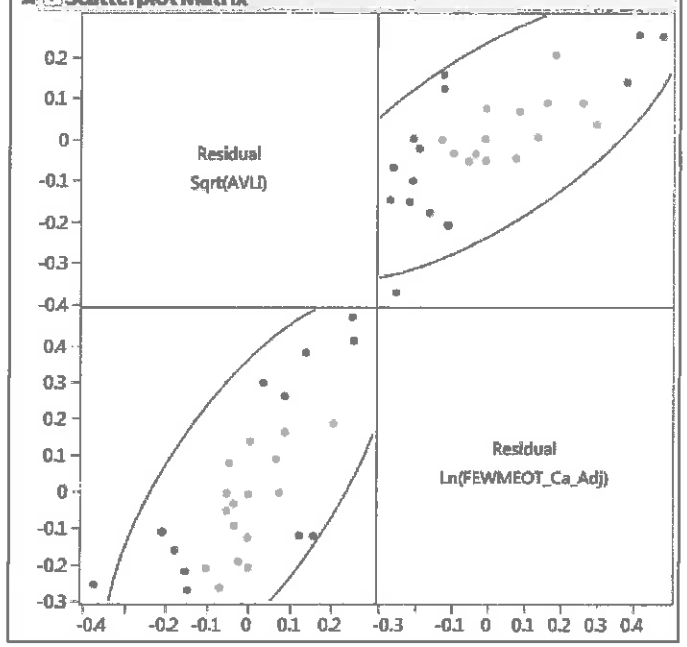
Scatterplot Matrix



Correlations

	Residual Sqrt(AVLI)	Residual Ln(FEWMEOT_Ca_Adj)
Residual Sqrt(AVLI)	1.0000	0.7278
Residual Ln(FEWMEOT_Ca_Adj)	0.7278	1.0000

Scatterplot Matrix



Appendix A: FEWMEOT (n=21)

Fe-Wear Metals at end of test

Executive Summary

Precision Matrix (PM) Analysis Highlights:

- This analysis includes the results of 21 valid precision matrix tests from independent laboratories

- Data supports the use of Ln(FEWMEOT) transformation
  - Significant oil difference: 1012 < 300
  - Lab differences are statistically significant (A < B1)
  - Stand within Lab differences are not statistically significant

- Oil discrimination is better for FEWMEOT than FEWML25 (Fe increase over last 25 hours) and FEWML50 (Fe increase over last 50 hours).

- Correlation between sqrt(AVLI) and Ln(FEWMEOT) is high (parameter redundancy).

Executive Summary

Precision Matrix (PM) Analysis Highlights:

- Estimated within a stand test precision (r; ASTM repeatability)
  - Ln(FEWMEOT) = 0.6381
- Estimated test precision across labs and stands (R; ASTM reproducibility)
  - Ln(FEWMEOT) = 0.9499
- Oil means and standard deviations

Oil	Number of Tests	Target Mean Ln(FEWMEOT)	Target Mean FEWMEOT	Target Standard Deviation Ln(FEWMEOT)
300	7	5.3095	202	0.4204
1012	7	4.8146	123	0.2859
1011	7	5.0172	151	0.3064

- Same concerns with AVLI are seen in Fe analysis (discrimination not consistent among stands, test precision is large compared to the observed range of measurements)

- Calcium content data from all labs is not available at this time for adjusting iron content

Data Utilized

- Precision Matrix Data:
  - 2 Labs {A, B1}, independent labs only
  - 3 Reference Oils {300, 1012, and 1011}
  - 5 Stands {A-1, A-2, B1-1, B1-2, B1-3}
  - Total number of tests = 21

- Precision Matrix Data Table from Rich Grundza's 20180115 IVB Matrix update.

Run order	B1-1	B1-2	B1-3	A-1	A-2	F-1	G-1	[illegible]-1
1	1012 127173-IVB	300 129759-IVB	1011 125879-IVB	300 129752-IVB	1012 125882-IVB	[illegible]	10[illegible]	[illegible]
2	1011 129762-IVB	1012 129766-IVB	1012 129767-IVB	1011 109201-IVB 1011* 125881-IVB	300 130948-IVB	120[illegible]	[illegible]	[illegible]011
3	300 129760-IVB	1011 129763-IVB	300 129761-IVB 300 130939-IVB	1012 129755-IVB	1011 125880-IVB	1[illegible] 1[illegible]	[illegible]	300
4	1012 129768-IVB	300 [illegible]-IVB	1011 129764-IVB	300 131277-IVB	1012 129756-IVB		300# 130940-IVB	
Reported			Invalid					

* Laboratory is running additional test because of Lean AFR and lower fuel flow on original matrix test

Additional test donated by lab

Reference Oil Discrimination Comparison

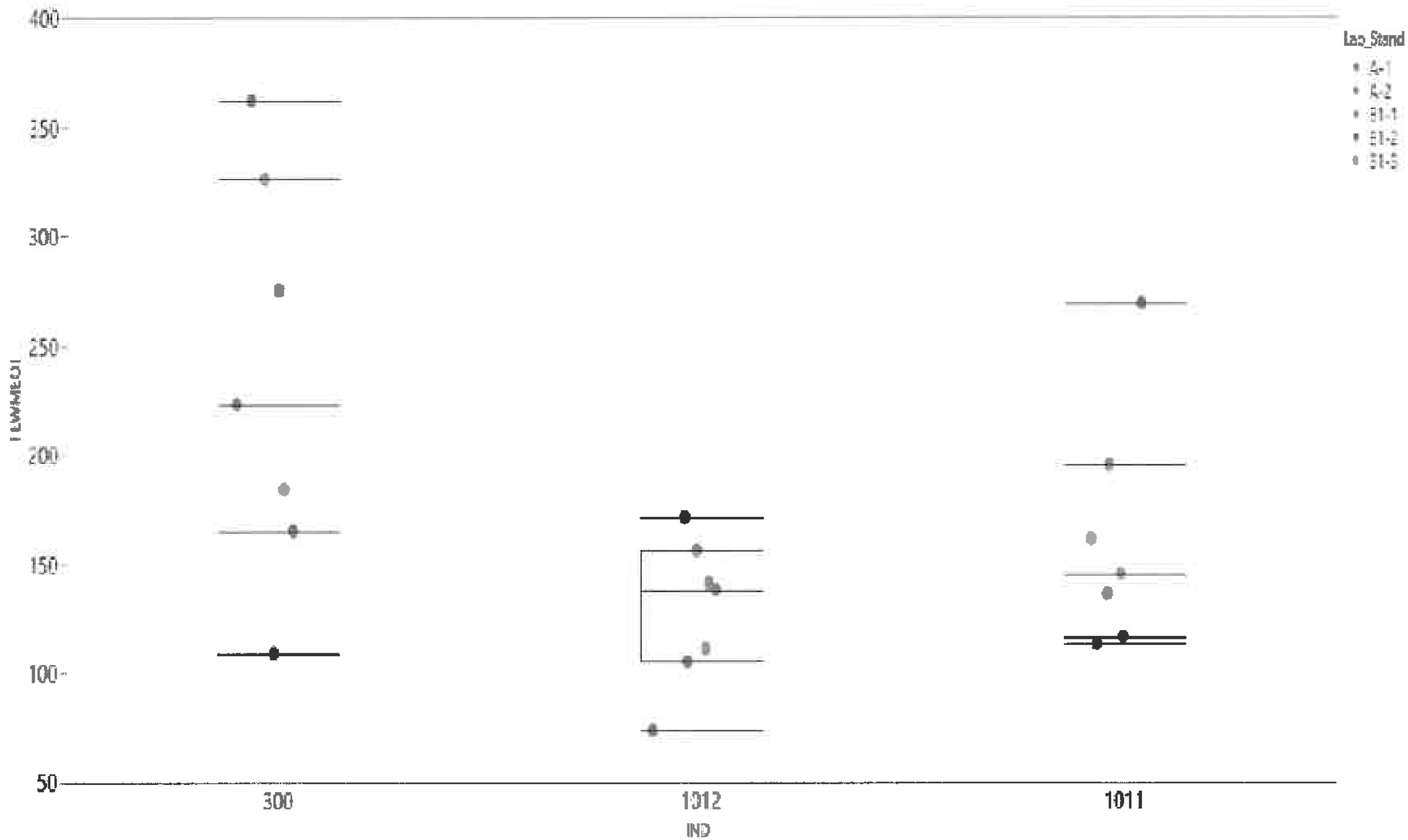
The table below compares the numbers of standard deviations of separation between the highest and lowest reference oil across GF-6 test types. The median of other tests is approx. 3.55 and the mean (without PHOS) is 3.99.

Test	Parameter	Oil 1	Oil 2	Range	Test s_r	SDs of Separation
IIIH	Ln(PVIS)	4.7191	3.3289	1.3902	0.4641	3.0
IIIH	WPD	4.63	3.66	0.97	0.47	2.1
IIIHA	Ln(MRV)	11.1107	9.7854	1.3253	0.4214	3.1
IIIHB	PHOS	94.15	78.92	15.23	1.53	10.0
VIE	FEI 1	2.56	1.3	1.26	0.29	4.3
VIE	FEI 2	1.82	1.41	0.41	0.12	3.4
VIF	FEI 1	2.23	1.45	0.78	0.21	3.7
VIF	FEI 2	2.25	1.41	0.84	0.19	4.4
IX (LSPI)	Sqrt(AvPIE + 0.5)	4.2644	3.3819	0.8825	0.2856	3.1*1
VH	AES	8.43	6.47	1.96	0.5	3.9
VH	Ln(10-RCS)	0.9155	-0.5294	1.4449	0.2194	6.6
VH	AEV50	9.26	8.77	0.49	0.25	2.0
VH	APV50	8.67	7.35	1.32	0.53	2.5
X (CW)	Ln(CHST)	-2.10574	-2.63174	0.526	0.14148	3.7*2
IVB	Sqrt(AVLI)	1.4306	1.1104	0.3202	0.1657	1.9
IVB	Ln(FEWMEOT)	5.3095	4.8146	0.4949	0.2302	2.1

*1: Oil 220 not used as a reference oil. Including this oil would yield approx. 12 SDs of separation between 220 and 222.
*2: 271 vs. 1011

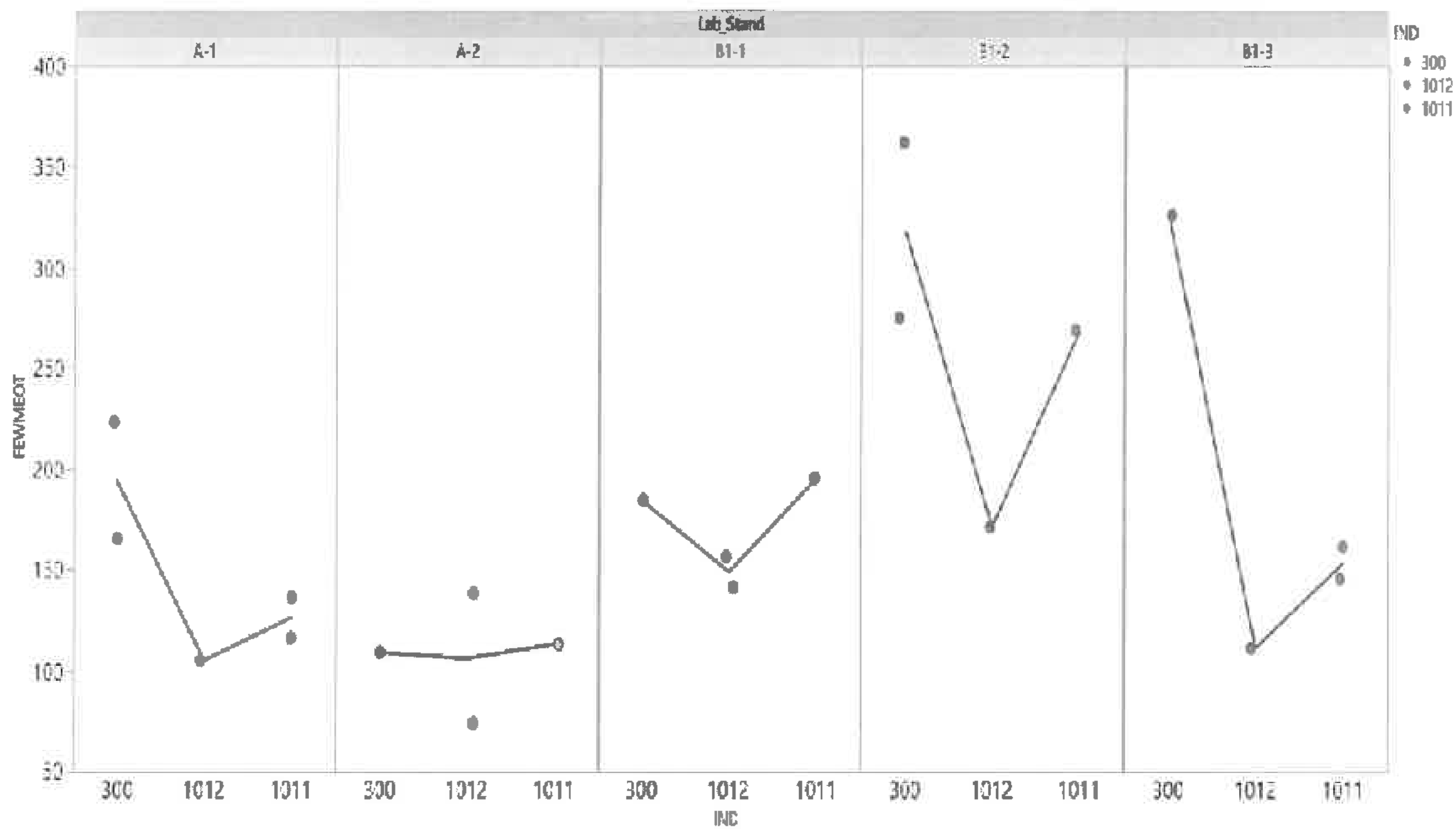
Fe-Wear Metals at EOT by Oil

- There is considerable overlap among the oils.



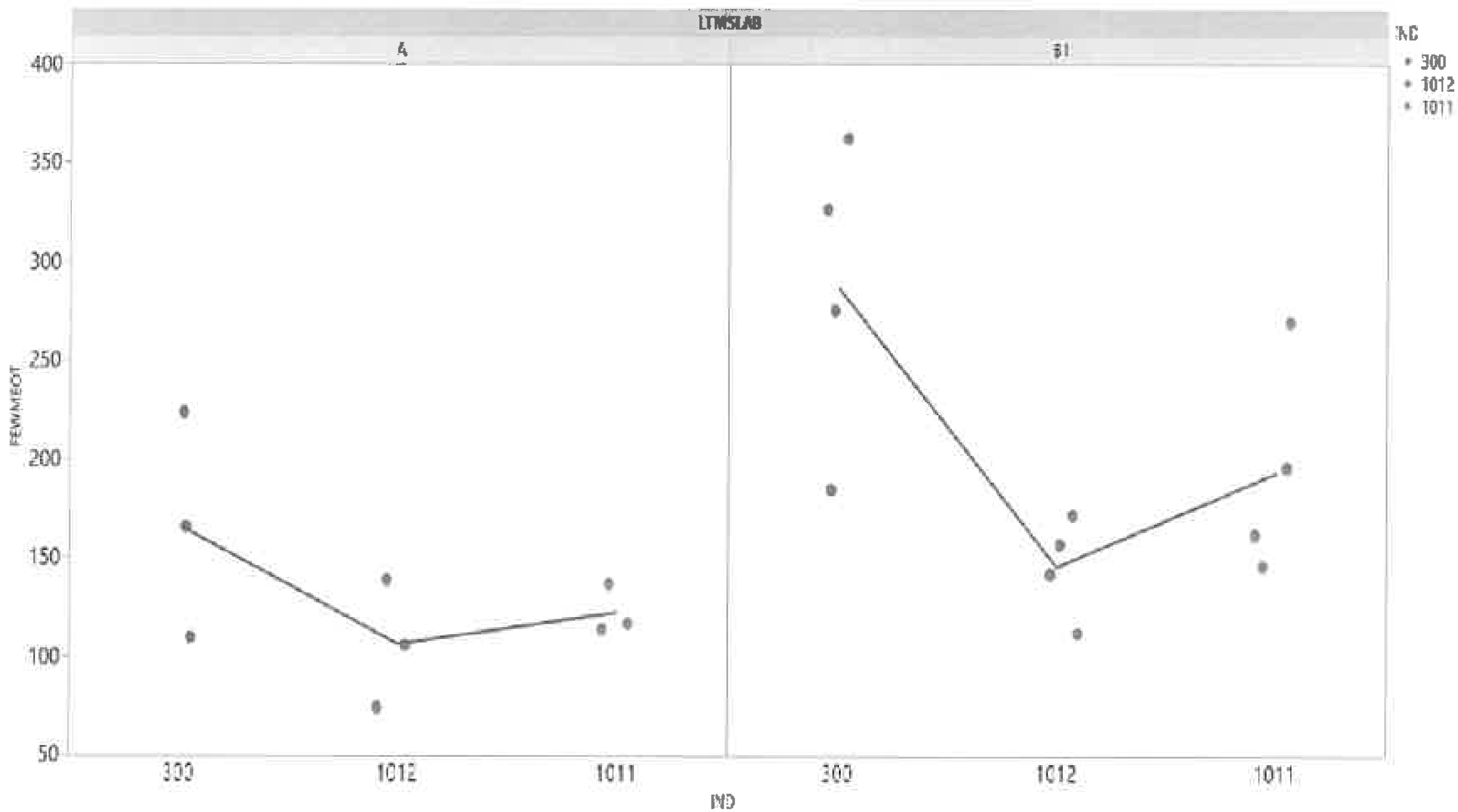
Fe-Wear Metals at EOT by Lab

- It appears that oil discrimination is not consistent among the stands; Stands rank oils differently



Fe-Wear Metals at EOT by Stand

- Below plot summarizes the FEWMEOT test result data by test Lab and reference oil



Ln(FEWMEOT) ANOVA Full Model

Statistically significant differences:

- Oil
- Lab

Not significantly different:

- Stands within Labs

Summary of Fit

RSquare	0.772531
RSquare Adj	0.675045
Root Mean Square Error	0.230183
Mean of Response	5.084252
Observations (or Sum Wgts)	21

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	2.5192333	0.419872	7.9245
Error	14	0.7417780	0.052984	Prob > F
C. Total	20	3.2610112		0.0007*

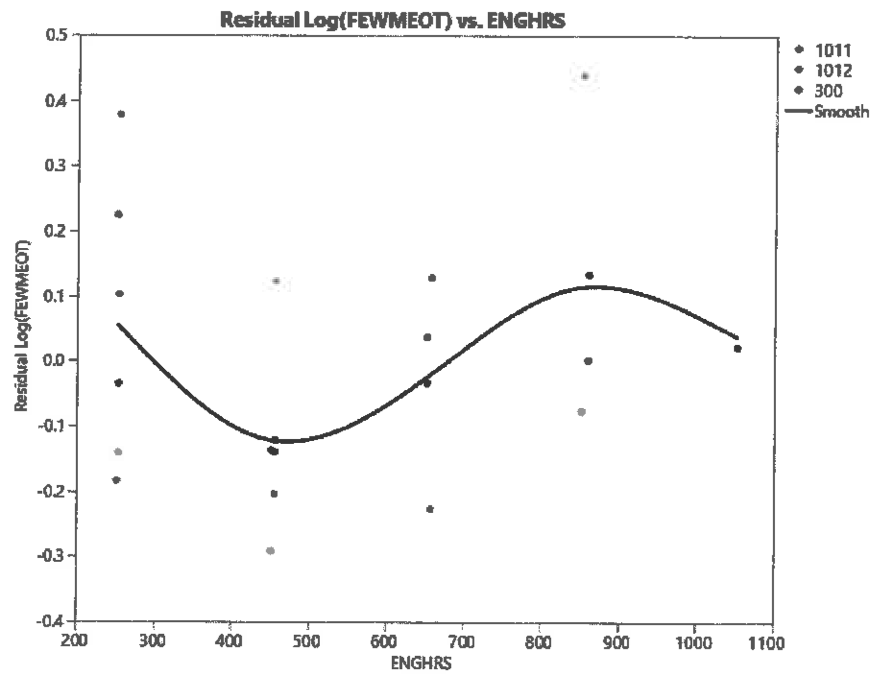
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.0471138	0.05094	99.08	<.0001*
IND[300]	0.2623813	0.072759	3.61	0.0029*
IND[1012]	-0.232514	0.074003	-3.14	0.0072*
LTMSLAB[A]	-0.226712	0.05094	-4.45	0.0005*
LTMSLAB[A]:LTMSAPP[1]	0.0997597	0.078981	1.26	0.2272
LTMSLAB[B1]:LTMSAPP[1]	-0.094059	0.095776	-0.98	0.3427
LTMSLAB[B1]:LTMSAPP[2]	0.2217766	0.095716	2.32	0.0362*

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
IND	2	2	0.8113142	7.6562	0.0057*
LTMSLAB	1	1	1.0494905	19.8076	0.0005*
LTMSAPP[LTMSLAB]	3	3	0.3660636	2.3030	0.1216

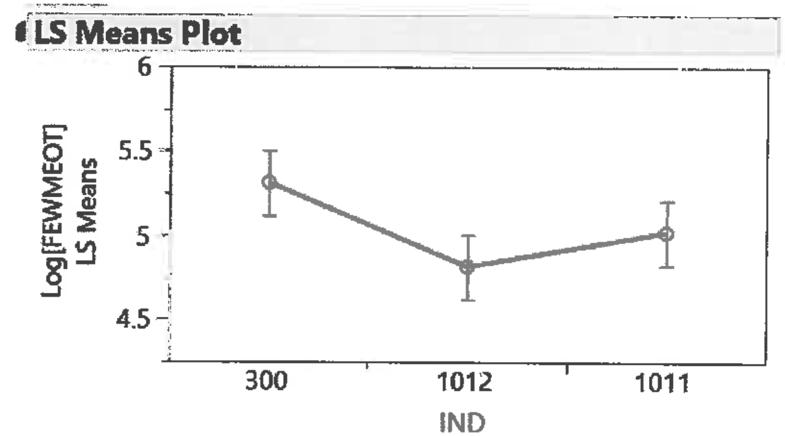
Engine Hours Adjustment



- The residuals of Ln(FEWMEOT) visually do not appear to be uniformly distributed on Engine Hours. (Engine Runs 2 and 3 appear to correlate with lower Fe than Runs 1 and 4)
- Engine Hours was added to the regression model in the following formats along with the result:
  - Engine Hours – Engine Hours not statistically significant and Oil statistically significant.
  - Engine Run (Categorical) - Engine Run not statistically significant and Oil statistically significant.
  - Engine Run 1 and Others (Categorical) – Engine Run not statistically significant and Oil statistically significant.
  - Engine Run 1, 4 & 5 and 2 & 3 (Categorical) – Engine Run borderline statistically significant and Oil statistically significant.
- For this dataset, Engine Hours/Run explains minimal additional variation. These terms should be re-evaluated after collecting additional data.

Ln(FEWMEOT) Oil Differences

- Model is Ln(FEWMEOT) ~ Oil, Lab, Stand(Lab)
- Oils significantly differ
  - Oil 300 is significantly different than oil 1012
  - Oil 1011 is not statistically significantly different than oils 300 and 1012
- Plot shows Ln(FEWMEOT) LSMeans by Oil, with 95% confidence intervals



LSMeans by Oil

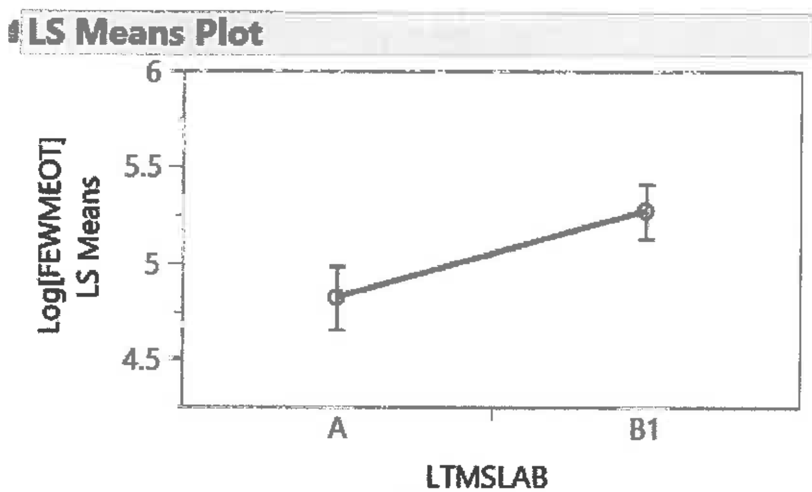
Oil	Ln(FEWMEOT) LSMean	FEWMEOT LSMean
300	5.3095	202
1012	4.8146	123
1011	5.0172	151

LSMeans Differences Between Oils

Oil1	Oil2	Ln(FEWMEOT) LSMean Difference	p-Value
300	1012	0.4949	0.00
300	1011	0.2922	0.08
1011	1012	0.2026	0.28

Ln(FEWMEOT) Lab Differences

- Model is Ln(FEWMEOT) ~ Oil, Lab, Stand(Lab)
- Plot below of Ln(FEWMEOT) LSMeans by Lab, with 95% confidence intervals
- Lab A is statistically significantly different than Lab B1.



LSMeans by Lab

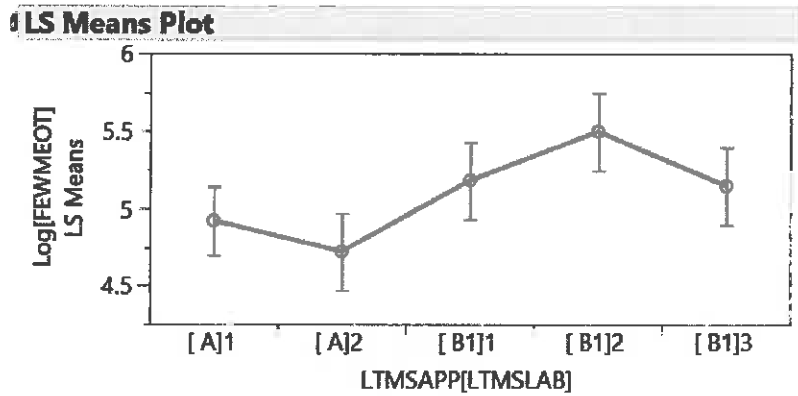
Lab	Ln(FEWMEOT) LSMean	FEWMEOT LSMean
A	4.8204	124
B1	5.2738	195

LSMeans Differences Between Labs

Lab1	Lab2	Ln(FEWMEOT) LSMean Difference	p-Value
B1	A	0.4534	0.00

Ln(FEWMEOT) Stand within Lab Differences

- Model is Ln(FEWMEOT) ~ Oil, Lab, Stand(Lab)
- Plot below of Ln(FEWMEOT) LSMeans by Stand, with 95% confidence intervals
- Stands within labs are not statistically significantly different from each other



LSMeans by Stand

Stand	Ln(FEWMEOT) LSMean	FEWMEOT LSMean
[A]1	4.9202	137
[A]2	4.7206	112
[B1]1	5.1798	178
[B1]2	5.4956	244
[B1]3	5.1461	172

LSMeans Differences Between Labs

Stand1	Stand2	Ln(FEWMEOT) LSMean Difference	p-Value
[B1]2	[B1]3	0.3495	0.27
[B1]2	[B1]1	0.3158	0.36
[A]1	[A]2	0.1995	0.72
[B1]1	[B1]3	0.0337	1

Ln(FEWMEOT) Precision

Repeatability Model: Ln(FEWMEOT) ~ Oil, Lab, Stand(Lab)
Reproducibility Model: Ln(FEWMEOT) ~ Oil

Model RMSE

- $s_r = 0.2302$

Repeatability

- $s_r = 0.2302$
- r = 0.6381

Reproducibility

- $s_R = 0.3427$
- R = 0.9499

Based upon the FEWMEOT pooled standard deviation (s_r) and ASTM's repeatability (r), there is no significant difference between an FEWMEOT *result*[1] of 200 and 379.

Note 1: An FEWMEOT result of 200 was arbitrarily selected for comparison

Reference Oil Targets

Model: Ln(FEWMEOT) ~ Oil, Lab, Stand(Lab)

Iron at EOT (FEWMEOT)

Unit of Measure: Ln(FEWMEOT)

Ref. Oil	Target Mean Ln(FEWMEOT)	Target Mean FEWMEOT	St. Dev
300	5.3095	202	0.4204
1012	4.8146	123	0.2859
1011	5.0172	151	0.3064

Target Means are the Oil LSMeans from the Model and Standard Deviations are calculated straight from Ln(FEWMEOT).

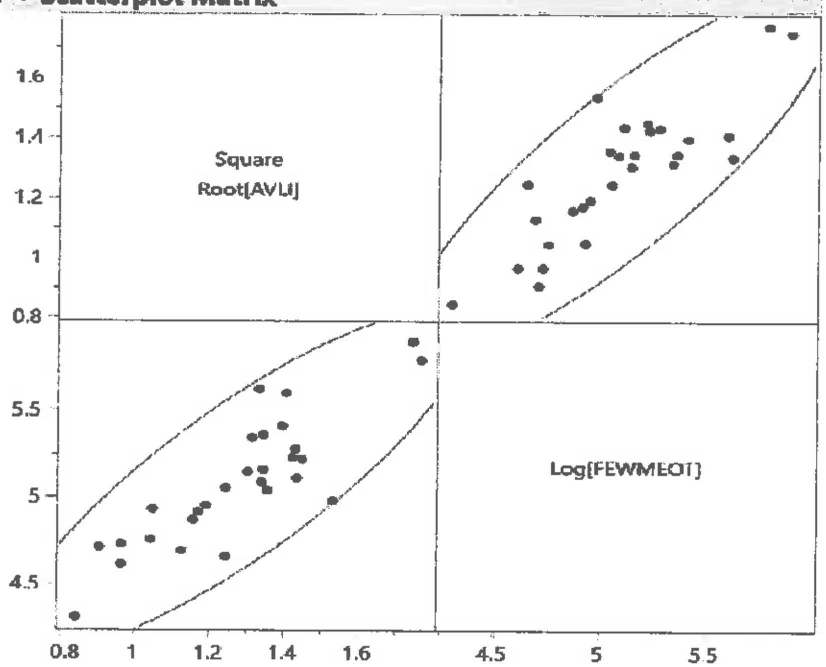
Correlation

Appendix K Section A.3 Parameter Redundancy: Correlation between sqrt(AVLI) and Ln(FEWMEOT) is statistically significant. These two parameters are closely related in repeat tests within oils.

Correlations

	Square Root[AVLI]	Log[FEWMEOT]
Square Root[AVLI]	1.0000	0.8502
Log[FEWMEOT]	0.8502	1.0000

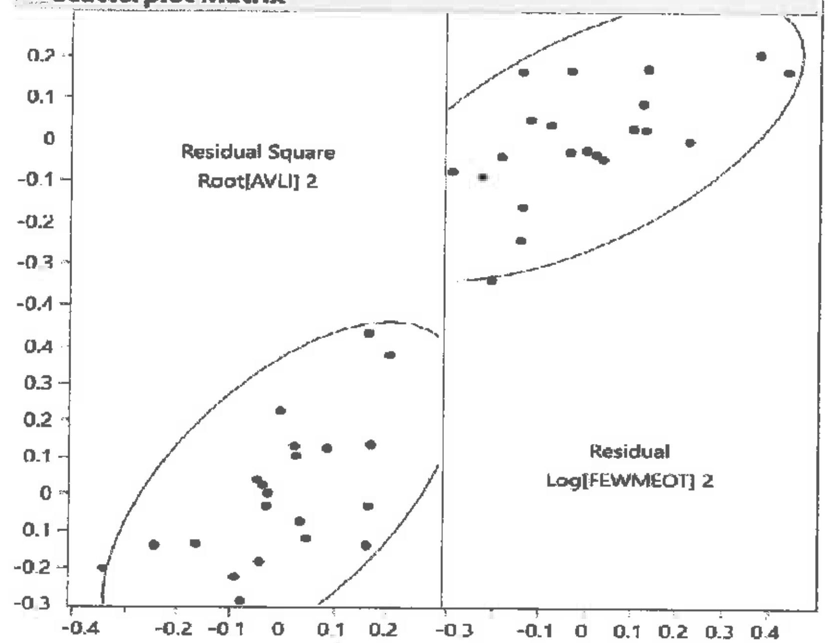
Scatterplot Matrix



Correlations

	Residual Square Root[AVLI] 2	Residual Log[FEWMEOT] 2
Residual Square Root[AVLI] 2	1.0000	0.6108
Residual Log[FEWMEOT] 2	0.6108	1.0000

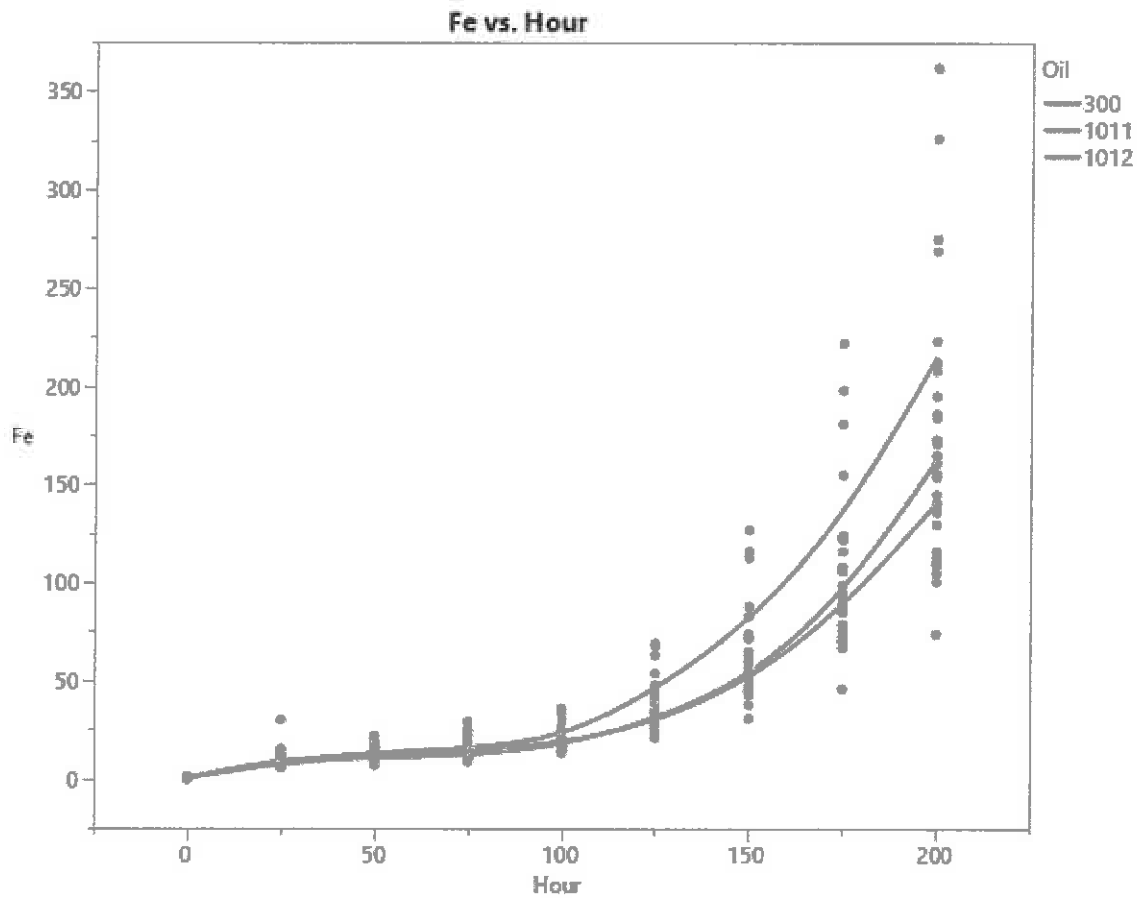
Scatterplot Matrix



Appendix B: FEWML50 (n=28)

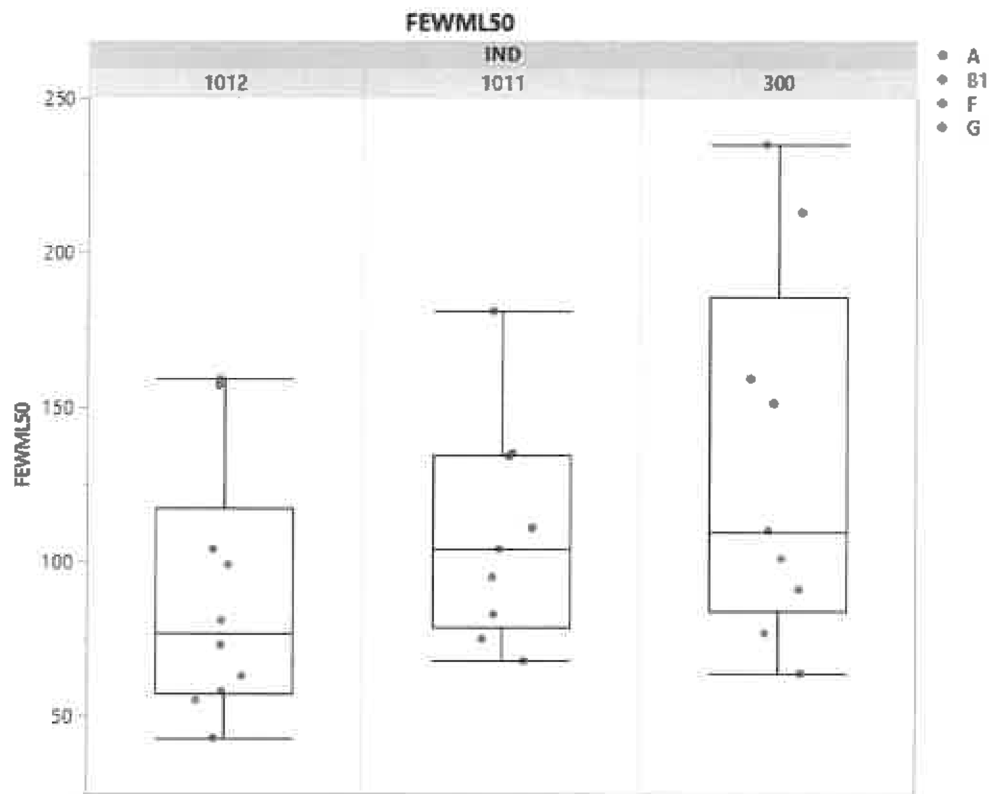
Change in Fe-Wear Metals over last 50 hours

Fe Content Profile



- The slope during the last 50 hours is highest for RO 300 and lowest for RO 1012.

FEWML50



- There is considerable FEWML50 overlap for the oils.

FEWML50 Regression Analysis

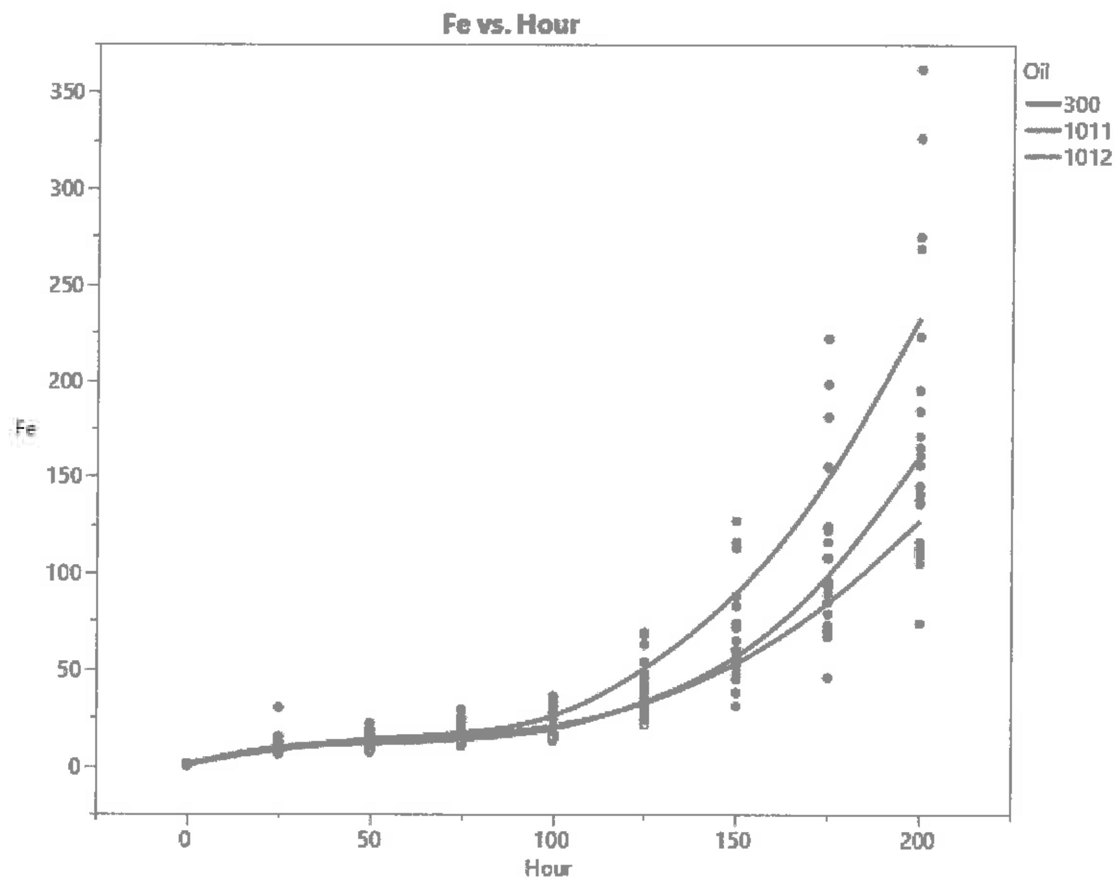
- Ln(FEWML50) is regressed on:
  - Lab
  - Stand[Lab]
  - Oil
- Oil discrimination of FEWML50 (p-Value = 0.1507) is worse than FEWMEOT (p-Value = 0.0559).

Effect	DF	p-Value
Lab	3	0.0165
Stand[Lab]	3	0.3006
Oil	2	0.1507

Appendix C: FEWML50 (n=21)

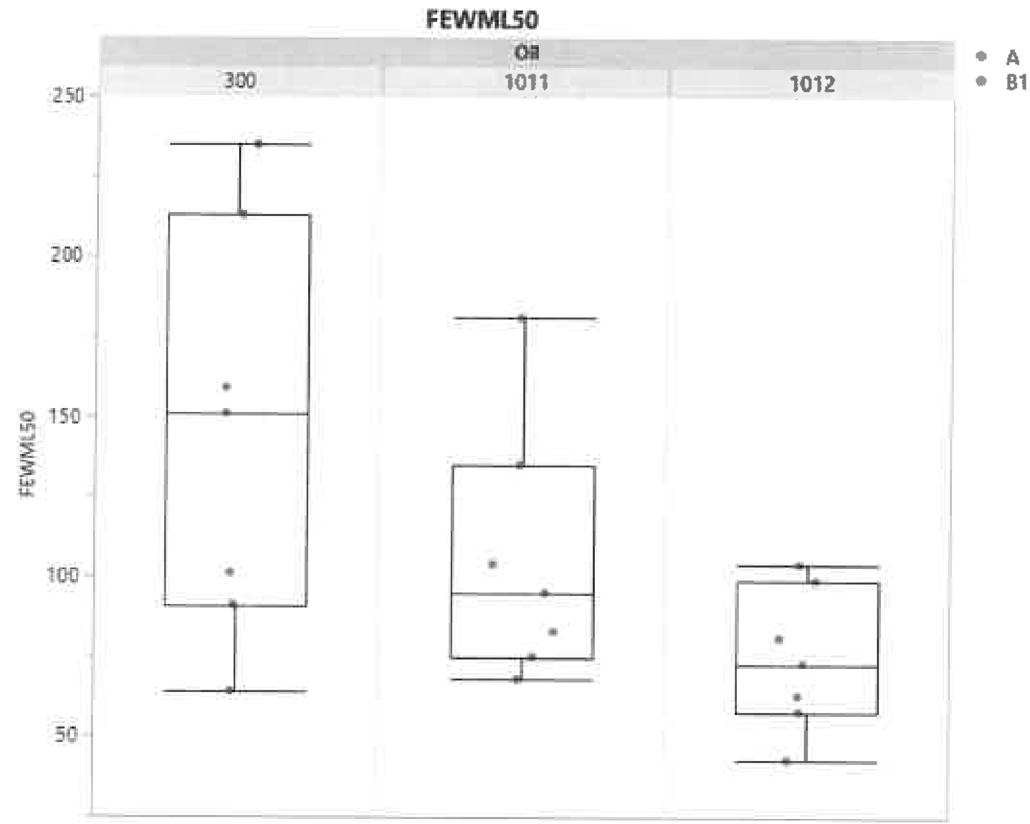
Change in Fe-Wear Metals over last 50 hours

Fe Content Profile



- As with $n = 28$, the slopes appear to differ by Oil.

FEWML50 by Oil



- The Oils overlap.

FEWML50 Regression Analysis

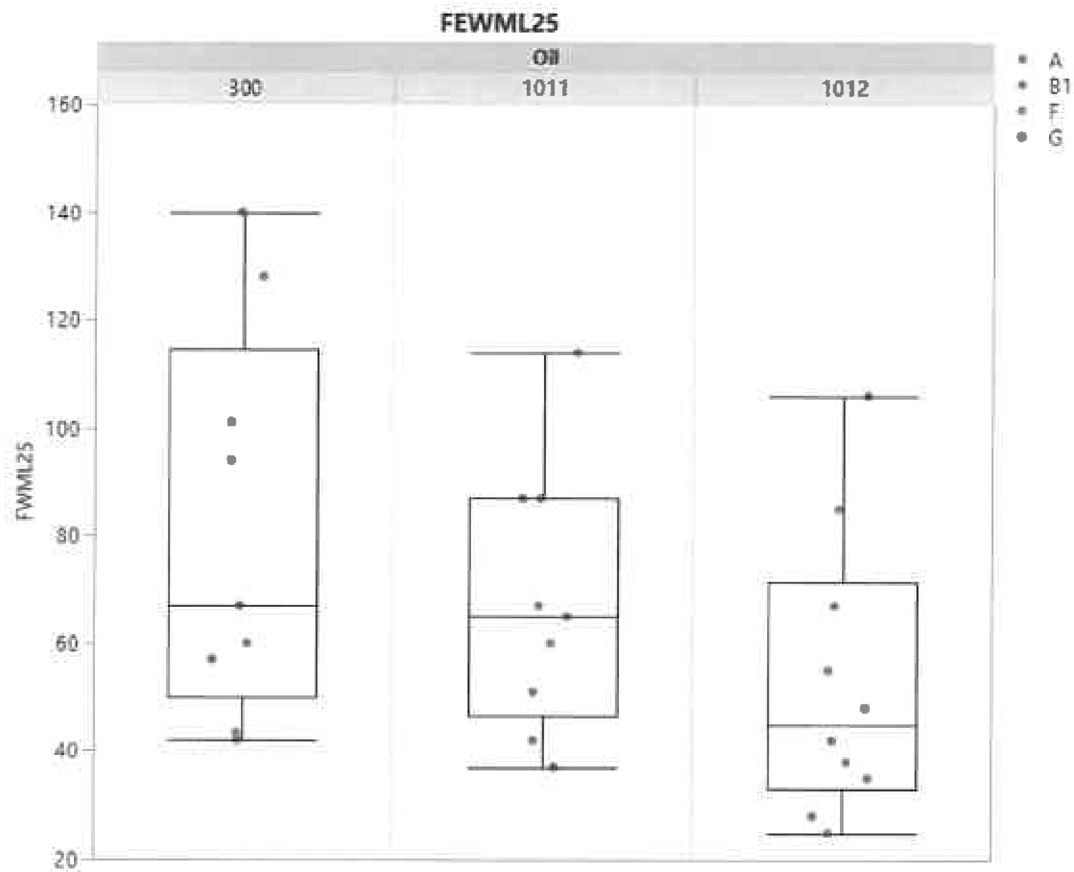
- Ln(FEWML50) is regressed on:
  - Lab
  - Stand[Lab]
  - Oil
- Oil discrimination of FEWML50 (p-Value = 0.0101) is slightly worse than FEWMEOT (p-Value = 0.0057).

Effect	DF	p-Value
Lab	1	0.001
Stand[Lab]	3	0.2493
Oil	2	0.0101

Appendix D: FEWML25 (n=28)

Change in Fe-Wear Metals over last 25 hours

FEWML25 by Oil



- The Oils overlap.

FEWML25 Regression Analysis

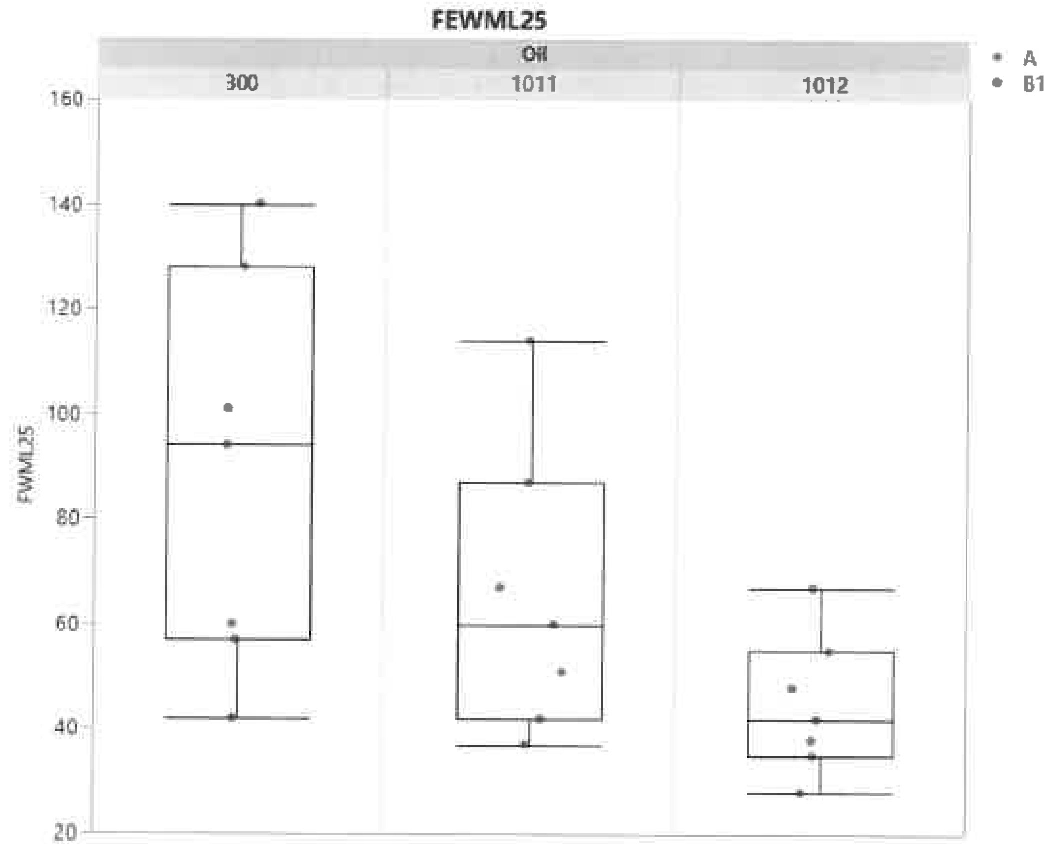
- Ln(FEWML25) is regressed on:
  - Lab
  - Stand[Lab]
  - Oil
- Oil discrimination of FEWML25 (p-Value = 0.1430) is worse than FEWMEOT (p-Value = 0.0559).

Effect	DF	p-Value
Lab	3	0.0189
Stand[Lab]	3	0.4659
Oil	2	0.1430

Appendix E: FEWML25 (n=21)

Change in Fe-Wear Metals over last 25 hours

FEWML25 by Oil



- The Oils overlap.

FEWML25 Regression Analysis

- Ln(FEWML25) is regressed on:
  - Lab
  - Stand[Lab]
  - Oil
- Oil discrimination of FEWML25 (p-Value = 0.0098) is slightly worse than FEWMEOT (p-Value = 0.0057).

Effect	DF	p-Value
Lab	1	0.0015
Stand[Lab]	3	0.4006
Oil	2	0.0098