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Committee D02 on PETROLEUM PRODUCTS AND LUBRICANTS

Issued: Dec. 23, 2013

Reply to: Dan Worcester
Southwest Research Institute
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Email: dworcester@swri.org

These are the unapproved minutes of the 11.19.2013 Sequence VI Surveillance Panel meeting.

The meeting was called to order at 8:45 PM by Chairman Charlie Leverett.

Agenda

The Agenda is the included as Attachment 1.

1.0 Roll Call

The Attendance list Attachment 2.
There were membership changes. Terry Kowalski is the voting member for Toyota. Kaustav Sinha is the voting member for Oronite. Mark Sutherland is the voting member for TEI.
Also the Secretary managed to delete TEI while updating for this meeting and that has been corrected. I apologize for this error.

2.0 Approval of minutes

2.1 Approval of the minutes of the 08.20.2013 meeting.

Motion – Accept the minutes of the 08.20.2013 VID SP CC.
Rich Grundza, Dan Worcester, second. Unanimous.

2.2 William Buscher will be Motion and Action Recorder for this meeting.

Motions and Actions are included at Attachment 3.

3.0 Action Item Review

3.1 OHT to report VIx engine usage.
There are 25 2009 and 140 2012 engines in inventory. VIE engine life may be less than the VID so this quantity will be a concern.

3.2 The VIE oil pan levels will need to be reviewed and specification add to the draft procedure. Measure of distance from bottom surface of oil pan tab to test full mark on oil pan. – Those levels will be covered in old business.

Action Item – SwRI to report VIE oil pan levels for their individual stands. That will be included in these minutes.

3.3 Additized Fuel for VIE. See Old Business.

3.4 Find a 0W-16 reference oil, ***see progress in the New Business below***.

3.5 VIE Draft - Table 5 information which cannot be generated until sufficient testing/precision matrix has taken place (stats group).

3.6 VIE Draft - Consideration of the weighting of BLB2 and BLA for Candidate 1 & 2 calculations. It is based on the hours from Cand 1 & 2 evaluation relative to BLB2 & BLA evaluations. With aging moving from 16 plus 84 hours to 16 plus 109 hours, I believe the stats group may want to reconsider. ***At this time I'd like to make a formal request for the Stats Group to review and report their findings to me.***

Action Item – Industry statisticians group to review the weighting of BLB2 and BLA for Candidate 1 & 2 calculations. It is based on the hours from Candidate 1 & 2 evaluation relative to BLB2 & BLA evaluations. With aging moving from 16 plus 84 hours to 16 plus 109 hours, we may want to reconsider the weighting.

4.0 Old Business

4.1 Haltermann has obtained a supplier for the additized fuel which is identified as EEE + DCA and it is currently be used in the Industry, as-of this date I have not received any comments on the use of this fuel and *at this time the SP needs to have a Motion made to approve it for use in the VIE.*

Motion – Accept Haltermann EEE + DCA as the official test fuel for the Sequence VIE.
Rich Grundza / Bruce Matthews / Passed 11 – 0 – 1

4.2 Obtaining 0W 16 reference oil – Bruce has obtained a 0W 16 oil and it will be shipped to Labs that agreed to participate. *Any questions or comments?*
There was a delay in the blend. It will be called “Seq VI Experimental VIE Testing” oil. 4 labs have agreed to run the oil.

4.3 VIE Oil Pan Levels Reported:

Afton	77, 78 & 79 mm
IAR	73 & 77 mm
Lubrizol	77, 77, 77, 79& 79 mm
Ashland	no data
SwRI	75, 77, 77, 78 & 79 mm

The spec is to be obtained from the mean reported value ± 5 mm

5.0 New Business

5.1 Currently the D7589 has the current wording concerning the fuel batch used in each test:

7.2.2 *Fuel Batch Usage/Documentation*—**A complete test shall be run on a single batch of test fuel.** If a new batch of test fuel is introduced to the laboratory fuel supply system, it shall be done between finite tests. Document the fuel batch designation in the test report. In cases where the run tank contains more than one fuel batch, document the most recent fuel batch in the report.

Due to the addition of the additized VIE fuel and the likely possibility of additional fuels in GF-6 it has/will be a burden on the Labs due to the lack of available storage tanks.

At this time Austin Rhode of Afton Chemical would like to present his analysis of Haltermann EEE fuel properties on Sequence VI FEI Calculations, this was sent to the SP on 11/05/13. **See Attachment 4.**

Motion – 7.2.2 *Fuel Batch Usage/Documentation*—A lab should strive to complete test on a single batch of test fuel. If a lab is not able to complete a test on a single fuel batch, the lab may switch to the next available fuel batch. Fuel is consumed at the stand level on a first in-first out basis. Once a stand migrates to the next fuel batch, it can no longer use a prior batch. Document the fuel batch in use at the start of the test in the test report. In cases where the run tank contains more than one fuel batch, document the most prevalent fuel batch in the report.

Dave Glaenzer / No Second/ This motion was tabled pending Stat Group review and will be covered in a conference call.

6.0 Next Meeting or Conference Call

At the call of the Chairman

Meeting Adjourned

The meeting adjourned at 9:50 AM.

Sequence VI Surveillance Panel conference Call Agenda

SwRI November 19, 2013 9:00 – 11:00

<u>Call-in information is included below:</u>

Call-in Number: 866-588-1857
Conference Code: 2105226802

1.0) Roll Call

Do we have any membership changes or additions?

2.0) Approval of minutes

2.1) Approve the minutes from the <u>August 20, 2013</u> Sequence VI Surveillance Panel.

3.0) Action Item Review

3.1 OHT to report VID & VIE engine usage and expected depletion date of VID engines.

3.2 The VIE oil pan levels will need to be reviewed and specification add to the draft procedure. Measure of distance from bottom surface of oil pan tab to test full mark on oil pan. – *Labs to report to Chairman*

3.3 Additized Fuel for VIE, ***see update in Old Business below*.**

3.4 Find a 0W-16 reference oil, ***see progress in the New Business below***.

3.5 VIE Draft - Table 5 information which cannot be generated until sufficient testing/precision matrix has taken place (stats group).

3.6 VIE Draft - Consideration of the weighting of BLB2 and BLA for Candidate 1 & 2 calculations. It is based on the hours from Cand 1 & 2 evaluation relative to BLB2 & BLA evaluations. With aging moving from 16 plus 84 hours to 16 plus 109 hours, I believe the stats group may want to reconsider. ***At this time I'd like to make a formal request for the Stats Group to review and report their findings to me.***

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Due to the addition of the additized VIE fuel and the likely possibility of additional fuels in GF-6 it has/will be a burden on the Labs due to the lack of available storage tanks.

At this time Austin Rhode of Afton Chemical would like to present his analysis of Haltermann EEE fuel properties on Sequence VI FEI Calculations, this was sent to the SP on 11/05/13.

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6.) Next Meeting

Call of the chairman

7.) Meeting Adjourned

ASTM SEQUENCE VI

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Al Lopez		Intertek	[illegible]
Mike McMillan			
Gordon Farnsworth			
CHRIS TAYLOR	CHRIS.TAYLOR@VPRACINGFUELS.COM	VP SPECIALTY CHEMICALS	C.T.

* Add to distribution List

ASTM SEQUENCE VI

Name	Address	Phone/Fax/Email	Attendance
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Sequence VI Surveillance Panel
November 19, 2013
9:00AM – 11:00AM
Southwest Research Institute
San Antonio, TX

Motions and Action Items
As Recorded at the Meeting by Bill Buscher

1. Action Item – Industry statisticians group to review the weighting of BLB2 and BLA for Candidate 1 & 2 calculations. It is based on the hours from Candidate 1 & 2 evaluation relative to BLB2 & BLA evaluations. With aging moving from 16 plus 84 hours to 16 plus 109 hours, we may want to reconsider the weighting.

2. Motion – Accept Haltermann EEE + DCA as the official test fuel for the Sequence VIE.

   Rich Grundza / Bruce Matthews / Passed 11 – 0 – 1

3. Action Item – SwRI to report VIE oil pan levels for their individual stands.

4. Action Item – Industry statisticians group to review Sequence VID, Haltermann EEE fuel batch raw data and the impact of fuel batch properties on FEI results.

Sequence VI: Impact of Fuel Properties on FEI Calculations

Austin Rhodes

November 19, 2013

Executive Summary

- An analysis was performed to estimate the relationship between the fuel batch properties and the *BL Before* and *BL After* fuel consumption.

- For each of the VID reference tests, a simulated *worst case scenario* change in the fuel batch was introduced during the BL portions of the reference test.

- The impact of the simulated fuel batch change during the test was evaluated to estimate the effect on FEI1 and FEI2.

- A review of the simulated fuel batch changes suggests that the practical impact of changing a fuel batch during a VID test is negligible.

Outline

- **Ultimately we wanted to answer the following question:**
  - Do batch-to-batch differences in Sequence VID fuels affect the reported Fuel Economy Improvement values?

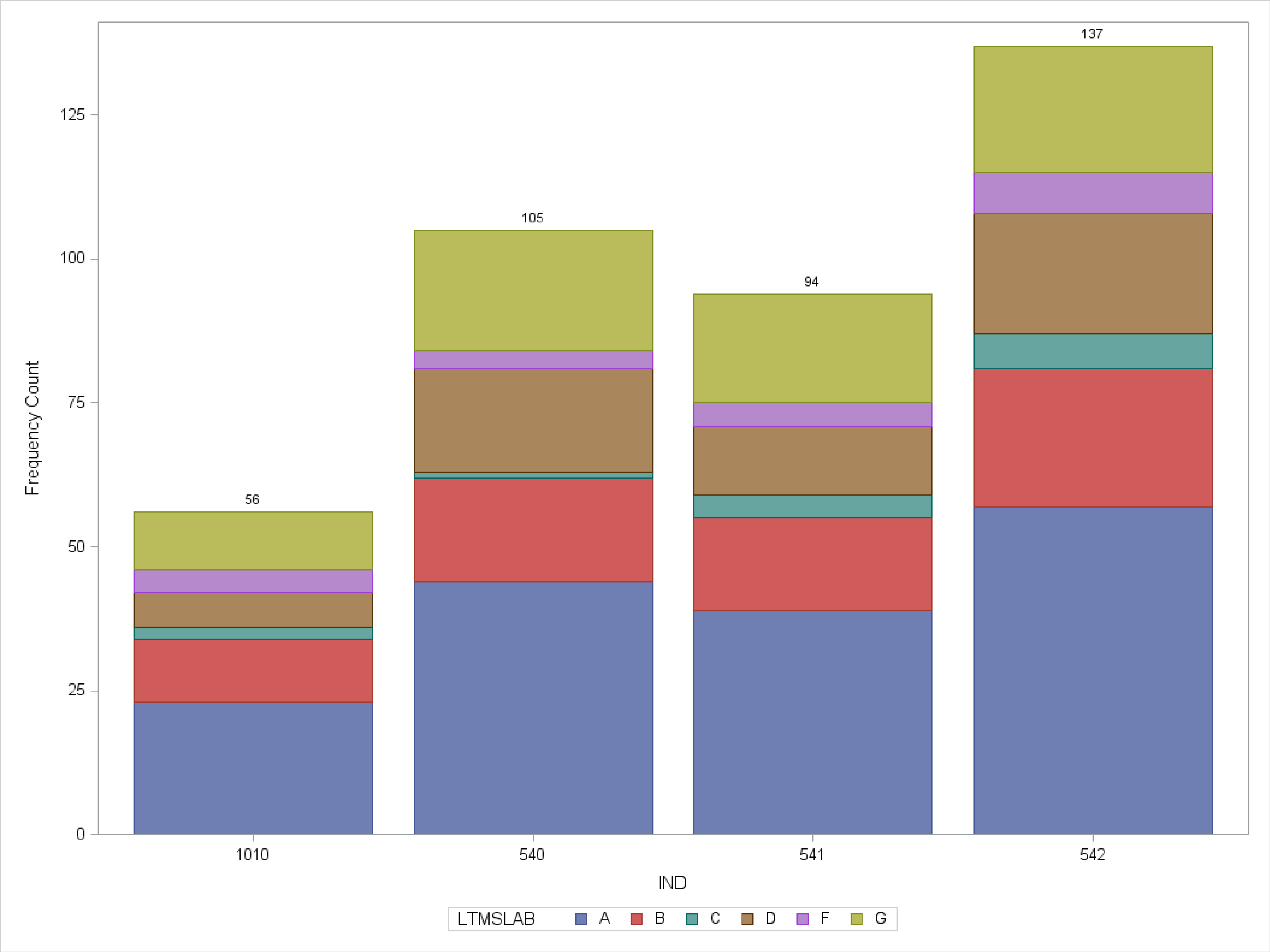
- **Analysis Approach:**
  - Use statistical analysis to relate the Haltermann Certificate of Analysis (C of A) fuel properties to the fuel consumed during the BL portions of the reference test.
  - The impact on the fuel consumption with the simulated fuel batch change is evaluated to estimate the effect on FEI1 and FEI2.
  - A review of the simulated results will help to quantify the magnitude of the FEIs with the fuel batch changes.

Scope of Analysis

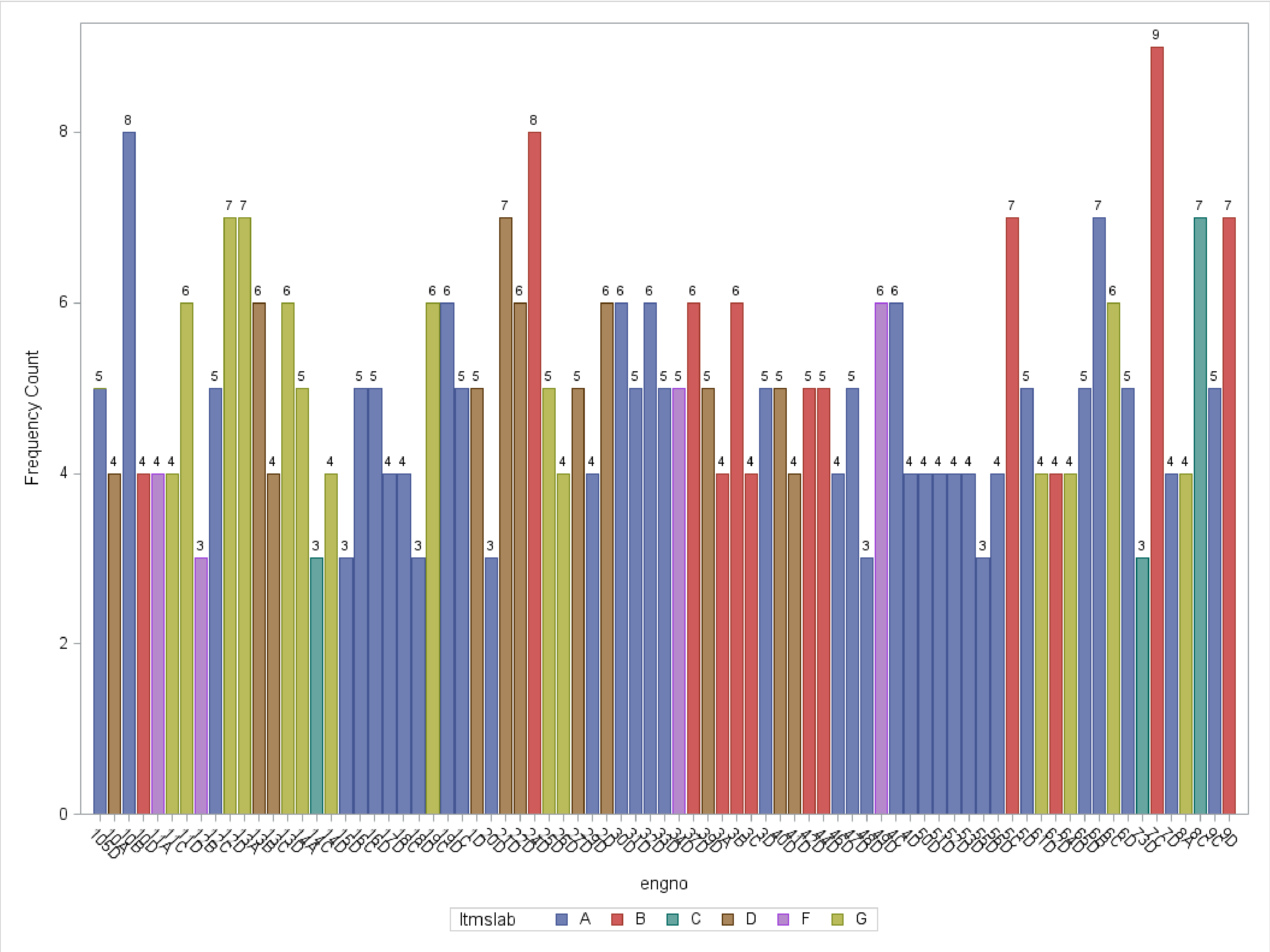
Data Set for Analysis:

- Initially included all chartable test results (n = 399) and all four reference oils (540, 541, 542, 1010)
- Dropped 4 runs due to missing fuel batch (needed batch code for Certificate of Analysis lookup)
- Dropped 3 runs due to only one run on engine (not enough information to model engine/stand bias)
- Remaining data set for analysis n = 392

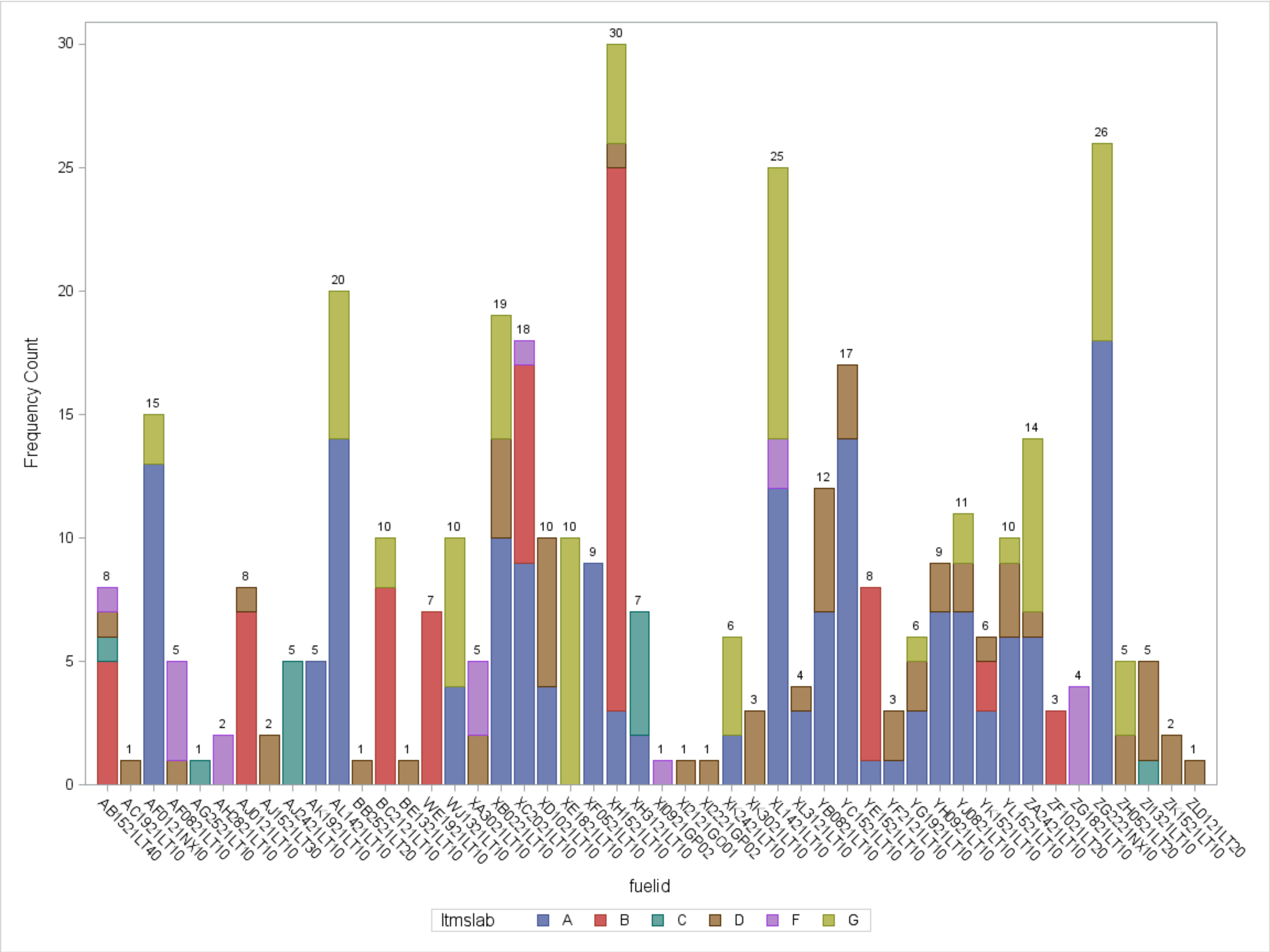
Scope of Analysis: Reference Test Oil - Histogram



Scope of Analysis: Ref. Runs per Engine/Stand

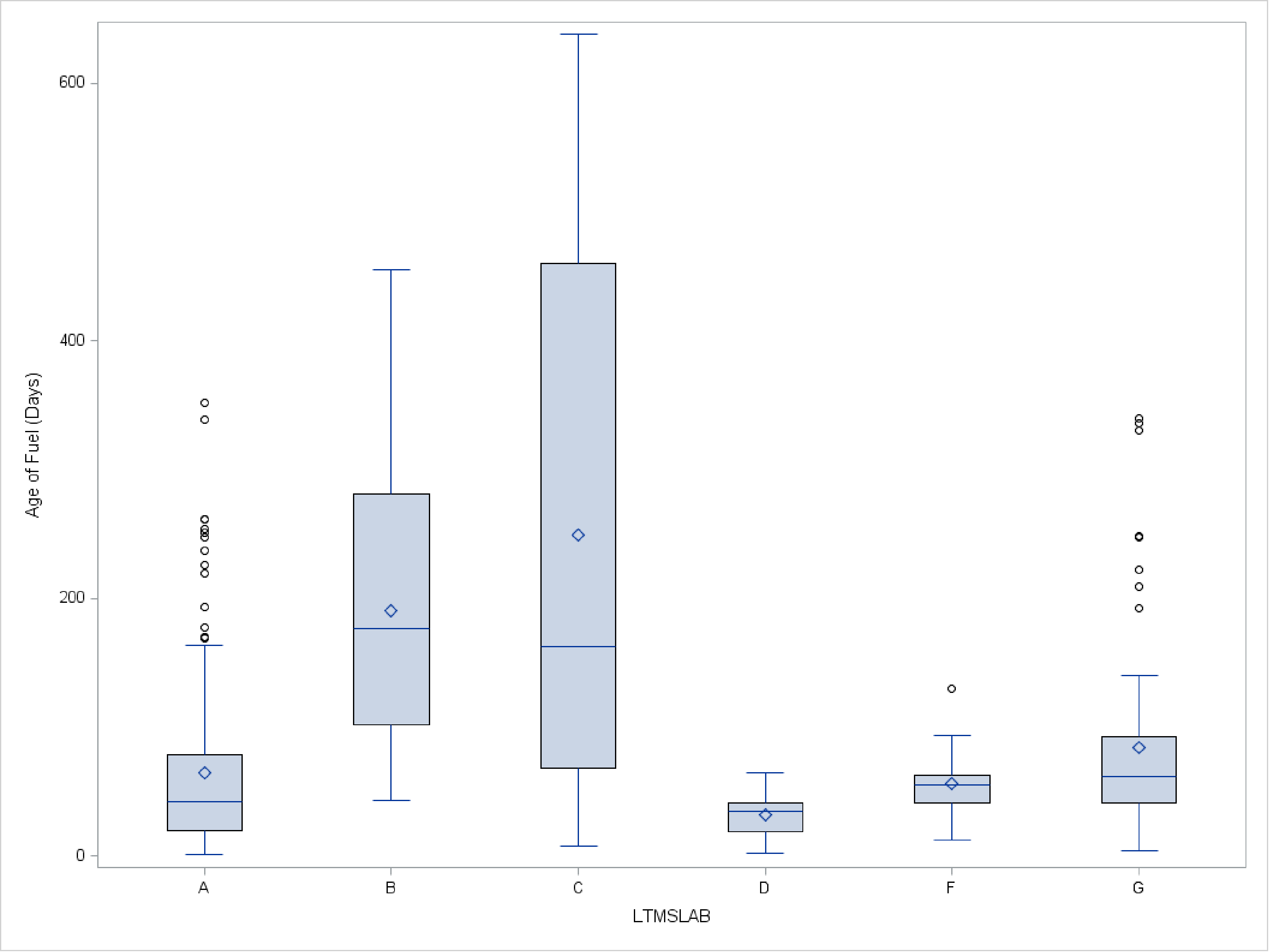


Scope of Analysis: Ref. Test Fuel Batches



Scope of analysis: Reference Test Fuel Age

(time lag between reference test date and last C of A)



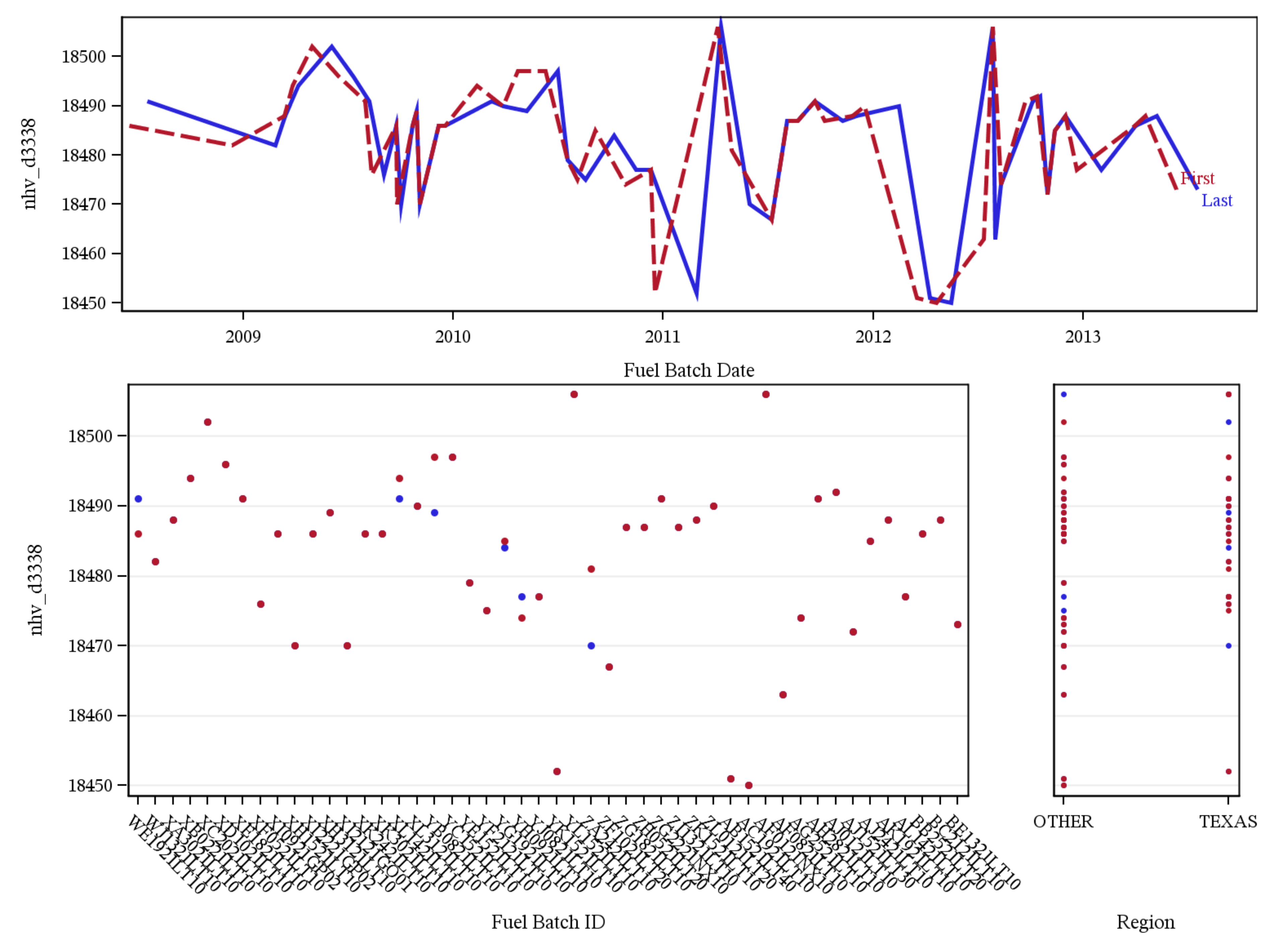
Scope of Analysis

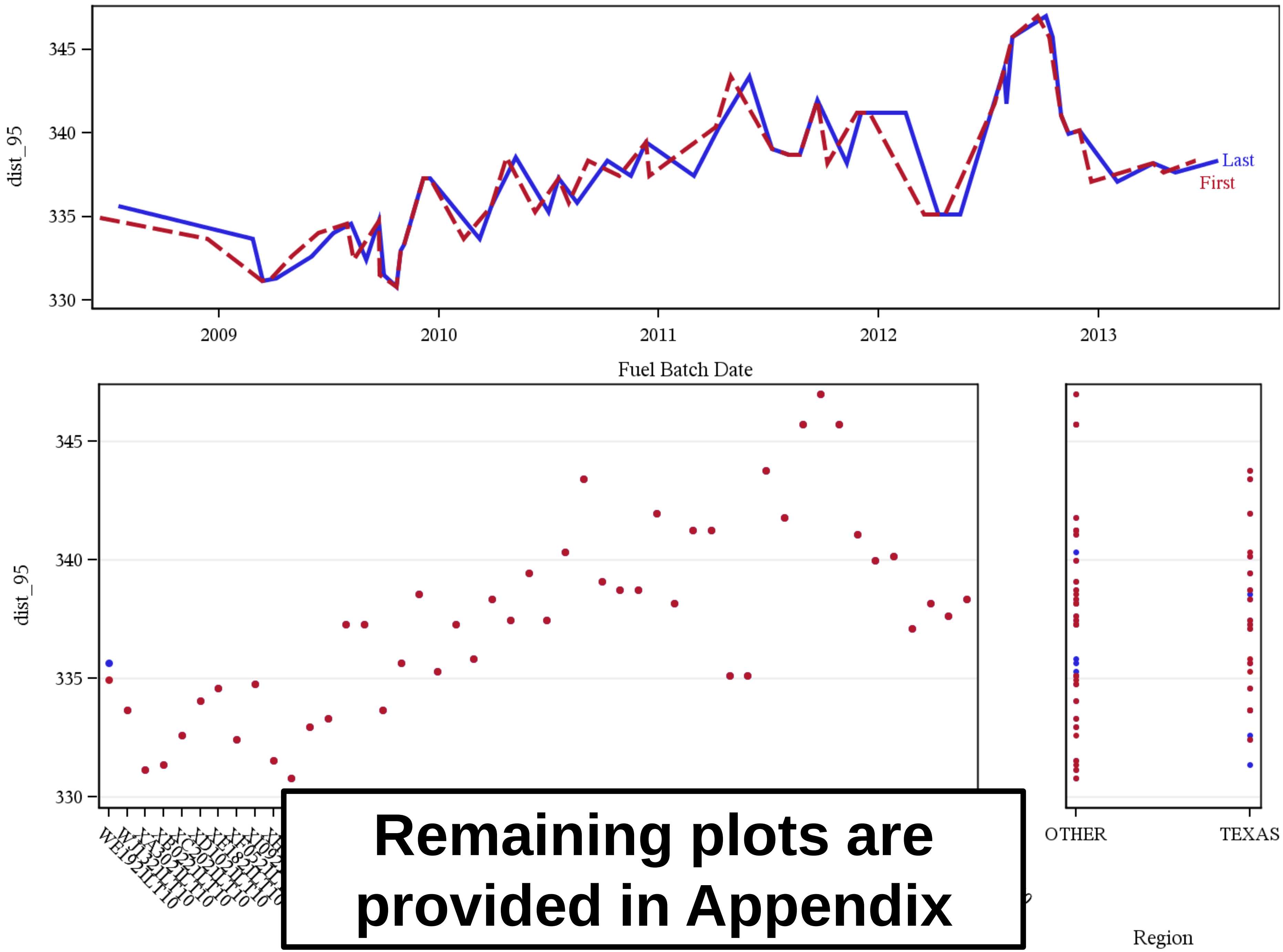
Due diligence to ensure integrity of data:

- **Cleaned minor typos in reported fuel batch codes**
  - For example: “O” to 0, prefix 2 to “Z”, etc.

- **Extensively analyzed C of A results to detect changes in reported units**
  - For example: Some RVP values reported in PSI, others in KPA → had to convert data to same scale

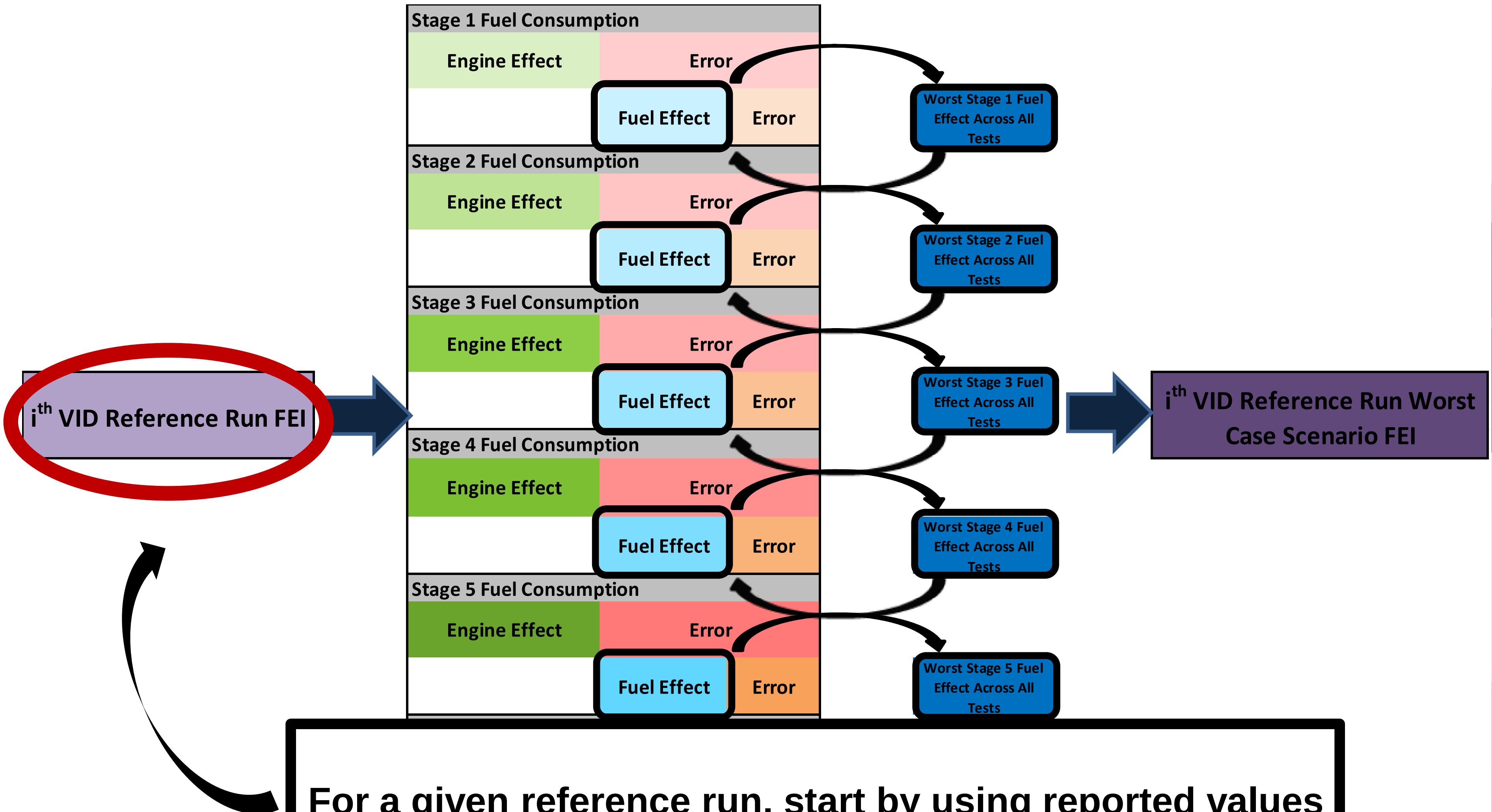
- **Univariate time series plots to detect changes in C of A results across time and from batch-to-batch**
  - For example: Some fuel batches had multiple Certificates of Analysis → made sure trends/measurements were consistent
  - Looked for possible regional differences in fuel properties


nhv_d3338
18500
18490
18480
18470
18460
18450
2009
2010
2011
2012
2013
Fuel Batch Date
First
Last
Fuel Batch ID
OTHER
TEXAS
Region


dist_95
345
340
335
330
2009
2010
2011
2012
2013
Last
First
Fuel Batch Date
dist_95
345
340
335
330
OTHER
TEXAS
Region
Remaining plots are provided in Appendix

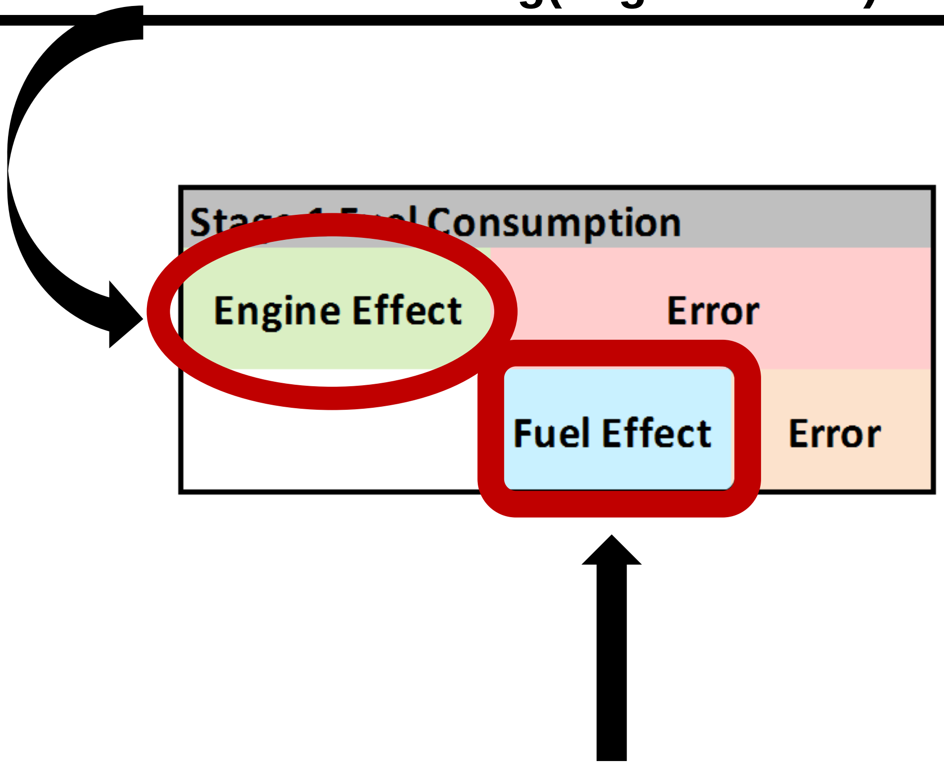
2. FEI modeling based on fuel properties

The approach can be confusing at first glance – will start by using some diagrams for illustration….



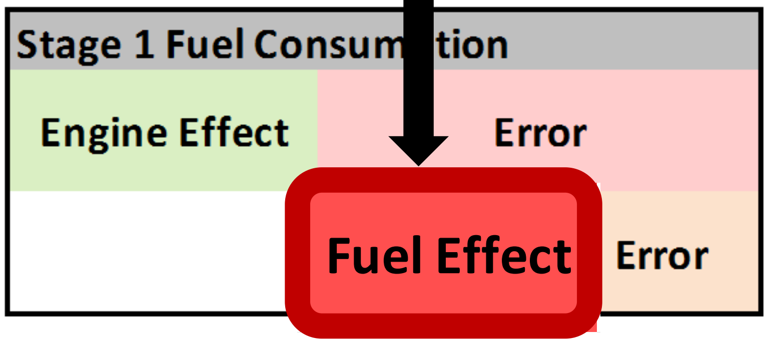
For a given reference run, start by using reported values found in Test Report

For each stage: using all reference runs, model fuel consumption as a function of log(engine hours) and engine bias.



What variability in fuel consumption is not explained by the engine? Use Certificate of Analysis variables to develop models for this.

Find the absolute maximum and minimum fuel consumption impact predicted by the fuel model, across all 392 test runs. Swap the individual run-specific fuel effect with the worst-case scenario fuel effect.



(A more mathematical explanation)

Recall, for general Stage j, $\mathrm{BSFC}_j = \dfrac{(average\ fuel\ flow, \frac{kg}{h})(9549.3)}{(average\ speed, \frac{r}{min})(average\ torque, Nm)}$

Stage j Fuel Consumption		
Engine Effect	Fuel Effect	Error

Our approach builds the model: $\mathrm{BSFC}_{jk} = \hat{y}_{Engine(Stand),j,k} + \hat{y}_{CofA,j,k} + r_{j,k}$

where

- j = 1, 2, 3, 4, 5, 6 denotes the Test Stage
- k = 1, 2, …, 392 denotes the individual test run
- $\hat{y}_{Engine(Stand),j,k}$ is the predicted engine/stand effect for the jth stage and kth reference run
- $\hat{y}_{CofA,j,k}$ is the predicted fuel effect for the jth stage and kth reference run
- r_{jk} is the unexplained error in BSFC_{jk}

and $\hat{y}_{CofA,j,k}$ **is modeled using C of A variables:**

$$\hat{y}_{CofA,j,k} = \beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p$$

(A more mathematical explanation)

For the all 392 reference runs, we then select the minimum predicted fuel effect and maximum predicted fuel effect →

Fuel Batch	Reference Run	Predicted Fuel Effect
AAA	1	$\hat{y}_{CofA,j,1}$
AAA	2	$\hat{y}_{CofA,j,2} = \hat{y}_{max,j}$
BBB	3	$\hat{y}_{CofA,j,3}$
BBB	4	$\hat{y}_{CofA,j,4}$
BBB	5	$\hat{y}_{CofA,j,5} = \hat{y}_{min,j}$
BBB	6	$\hat{y}_{CofA,j,6}$
⋮	⋮	⋮
RRR	392	$\hat{y}_{CofA,j,392}$

Thus, for each **stage j** and **reference run k**, we use the worst-case fuel effect to calculate final weighted fuel consumption:

$$BSFC_{jk} = \hat{y}_{Engine(Stand),j,k} + \hat{y}_{max,j} + r_{j,k}$$ or $$BSFC_{jk} = \hat{y}_{Engine(Stand),j,k} + \hat{y}_{min,j} + r_{j,k}$$

For example: The max worst-case weighted BLA fuel consumption for k^{th} reference run =

$$0.50 \cdot 21.99 \cdot 0.300 \cdot (\hat{y}_{Engine(Stand),1,k} + \hat{y}_{max,1} + r_{1,k}) +$$
$$0.50 \cdot 21.99 \cdot 0.032 \cdot (\hat{y}_{Engine(Stand),2,k} + \hat{y}_{max,2} + r_{2,k}) +$$
$$0.50 \cdot 16.49 \cdot 0.310 \cdot (\hat{y}_{Engine(Stand),3,k} + \hat{y}_{max,3} + r_{3,k}) +$$
$$0.50 \cdot 1.46 \cdot 0.174 \cdot (\hat{y}_{Engine(Stand),4,k} + \hat{y}_{max,4} + r_{4,k}) +$$
$$0.50 \cdot 1.46 \cdot 0.011 \cdot (\hat{y}_{Engine(Stand),5,k} + \hat{y}_{max,5} + r_{5,k}) +$$
$$0.50 \cdot 2.91 \cdot 0.172 \cdot (\hat{y}_{Engine(Stand),6,k} + \hat{y}_{max,6} + r_{6,k})$$

(A more mathematical explanation)

For the all 392 reference runs, we then select the minimum predicted fuel effect and maximum predicted fuel effect →

Fuel Batch	Reference Run	Predicted Fuel Effect
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BBB	4	$\hat{y}_{CofA,j,4}$
BBB	5	$\hat{y}_{CofA,j,5} = \hat{y}_{min,j}$
BBB	6	$\hat{y}_{CofA,j,6}$
	⋮	
RRR	392	$\hat{y}_{CofA,j,392}$

Thus, for each **stage j** and **reference run k**, we use the worst-case fuel effect to calculate final weighted fuel consumption:

Stage Length (h)

Weight Factor

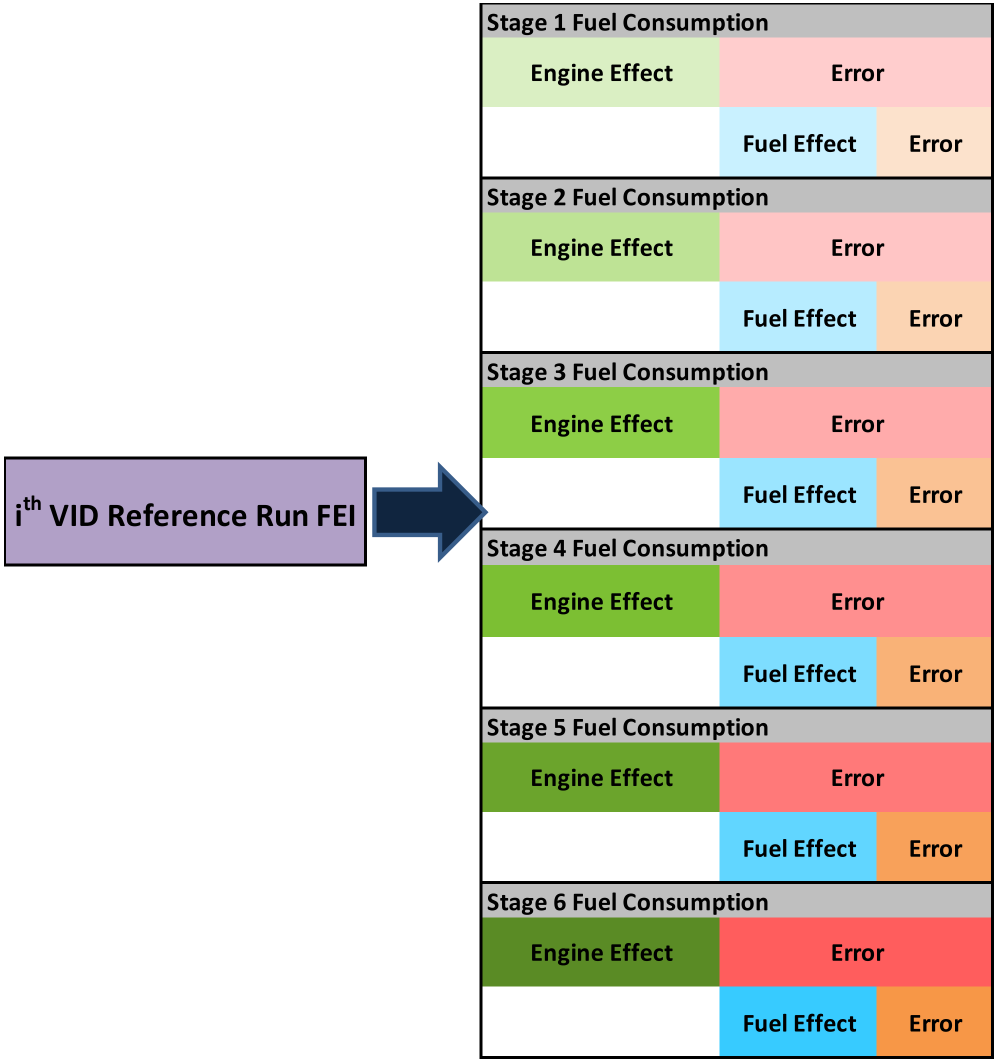
Nominal Power (kW)

For example: The max worst-case weighted BLA fuel consumption for k[th] reference run =

$$0.50\cdot 21.99\cdot 0.300\cdot(\hat{y}_{Engine(Stand),1,k} + \hat{y}_{max,1} + r_{1,k}) +$$
$$0.50\cdot 21.99\cdot 0.032\cdot(\hat{y}_{Engine(Stand),2,k} + \hat{y}_{max,2} + r_{2,k}) +$$
$$0.50\cdot 16.49\cdot 0.310\cdot(\hat{y}_{Engine(Stand),3,k} + \hat{y}_{max,3} + r_{3,k}) +$$
$$0.50\cdot 1\text{[illegible]}6\cdot 0.174\cdot(\hat{y}_{Engine(Stand),4,k} + \hat{y}_{max,4} + r_{4,k}) +$$
$$0.50\cdot 1.46\cdot 0.011\cdot(\hat{y}_{Engine(Stand),5,k} + \hat{y}_{max,5} + r_{5,k}) +$$
$$\ldots(\hat{y}_{Engine(Stand),6,k} + \hat{y}_{max,6} + r_{6,k})$$

Passion for Solutions™

Once we substitute worst-case fuel impact for each stage, calculate overall weighted fuel consumption and new FEI value



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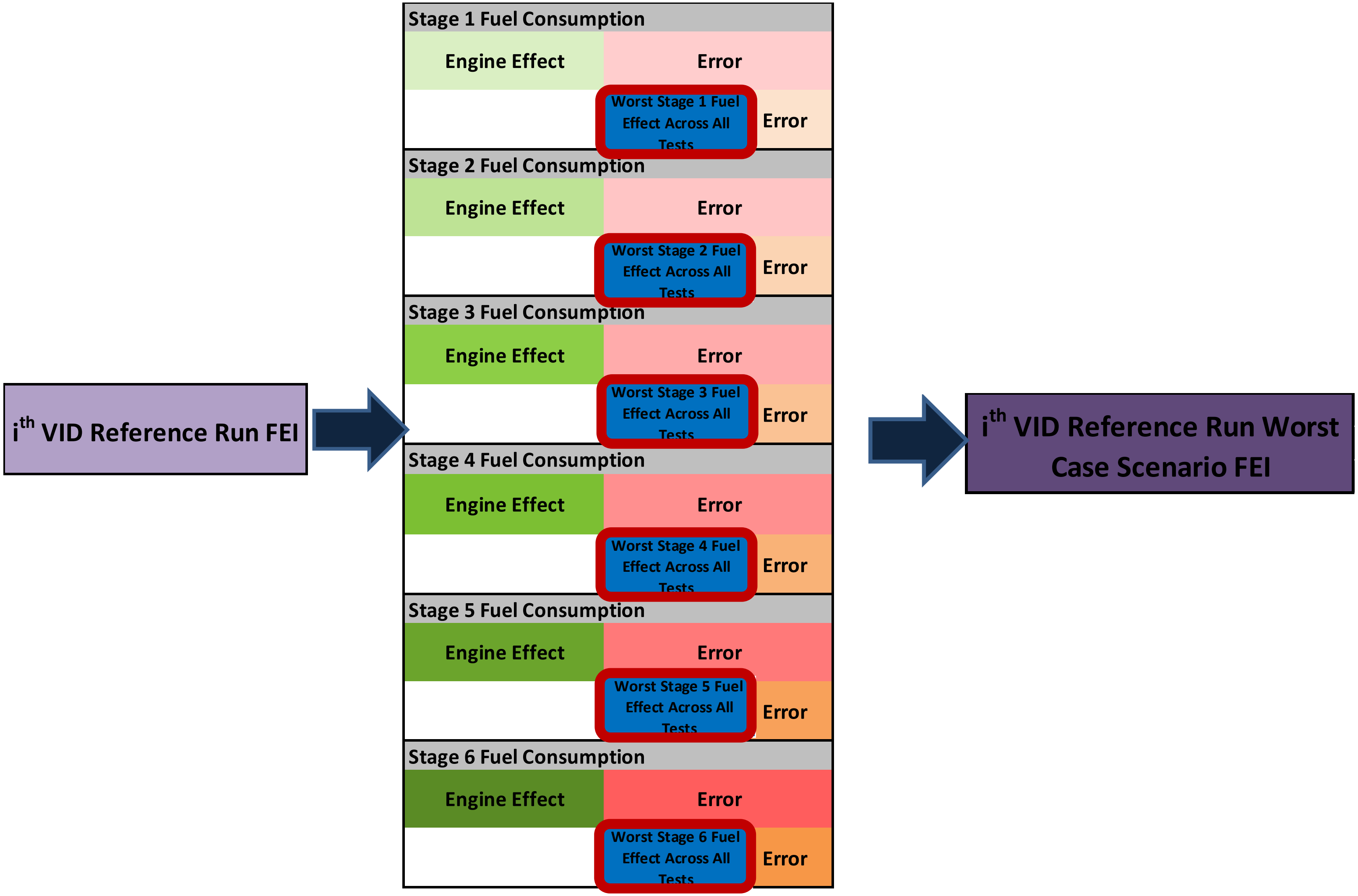
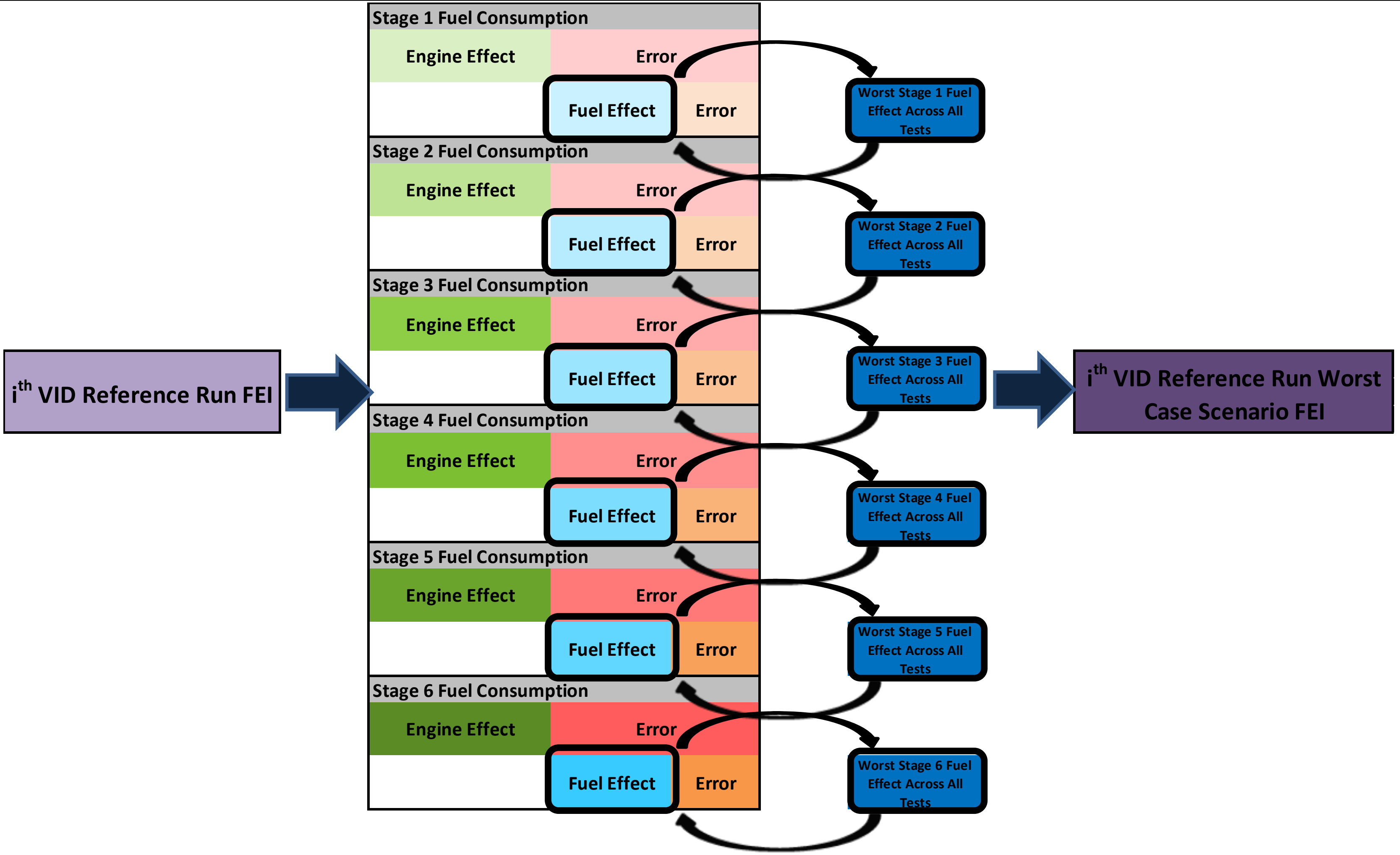


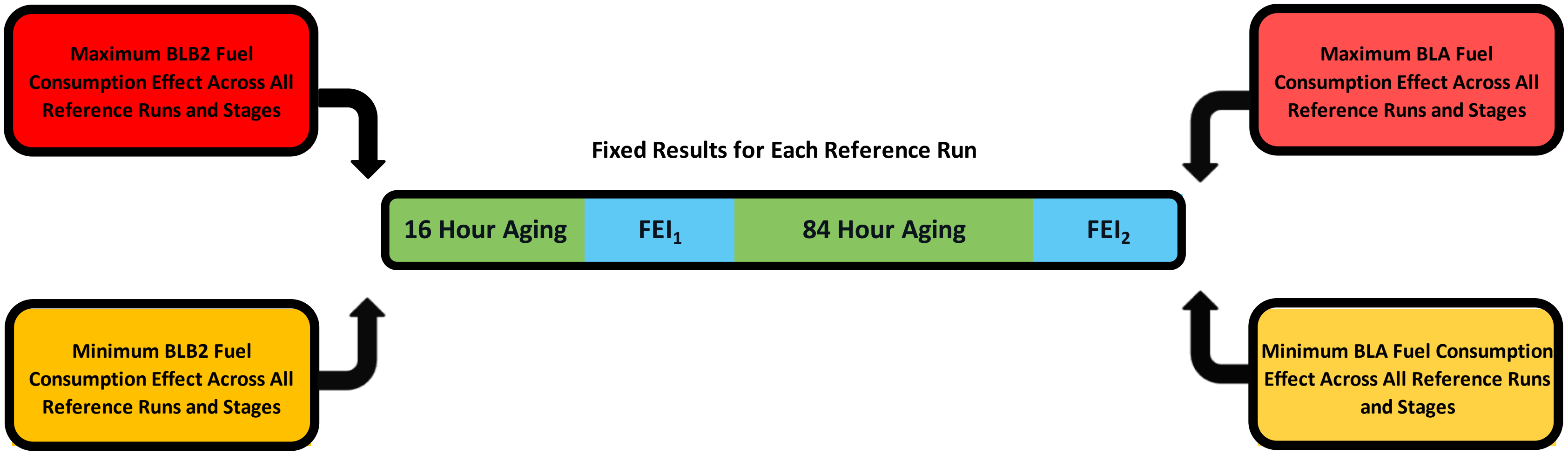
Modeling approach

Note: No oil effect modeled since BLB2 and BLA use common baseline oil.



4 Worst Case Scenario Bookends:

Swapping each individual fuel impact with minimum or maximum fuel impact across all reference runs



4 Worst Case Scenario Bookends:

Swapping each individual fuel impact with minimum or maximum fuel impact across all reference runs

Maximum BLB2 Fuel Consumption Effect Across All Reference Runs and Stages

Maximum BLA Fuel Consumption Effect Across All Reference Runs and Stages

$$FEI_1 = 1 - \frac{Weighted\ RO\ FC_{16}}{0.80BLB2_{Wgt.} + 0.20BLA_{Wgt.}}$$

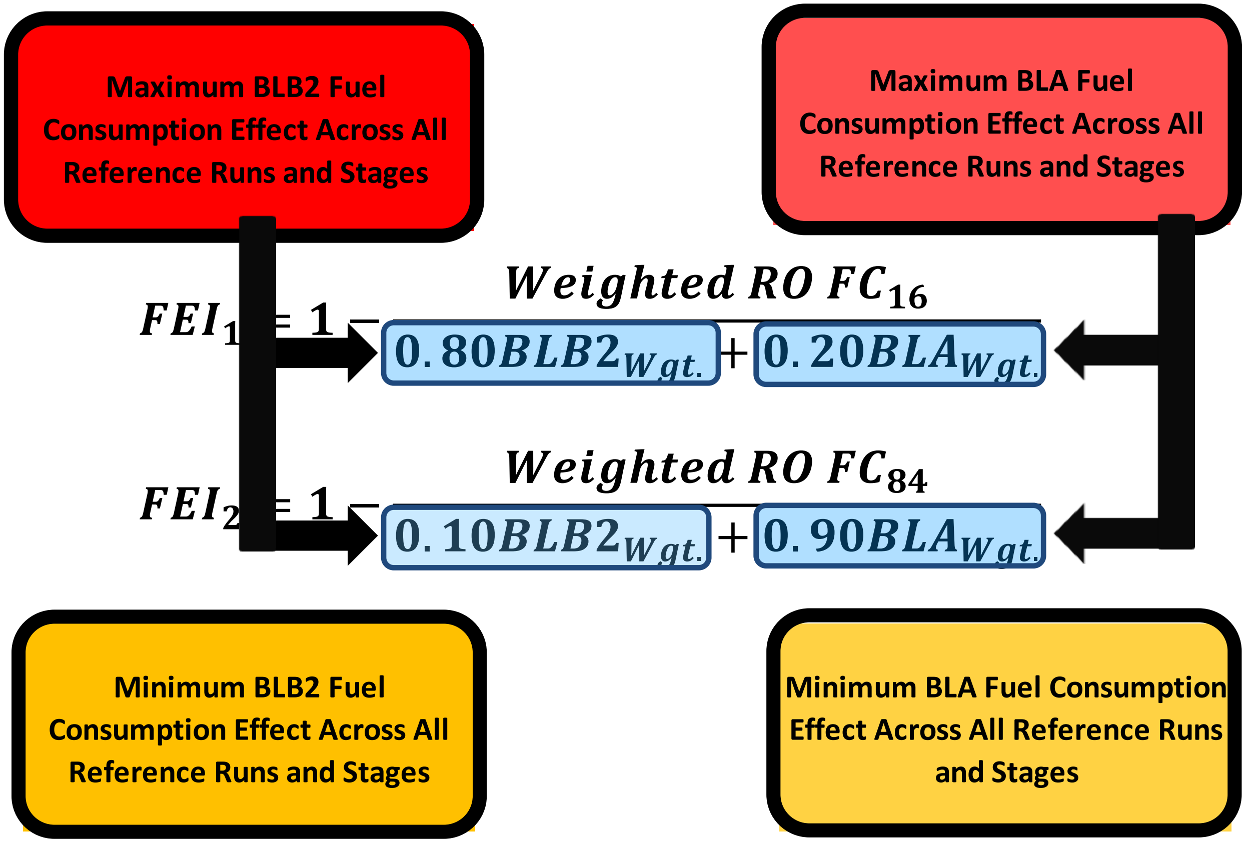
$$FEI_2 = 1 - \frac{Weighted\ RO\ FC_{84}}{0.10BLB2_{Wgt.} + 0.90BLA_{Wgt.}}$$

Minimum BLB2 Fuel Consumption Effect Across All Reference Runs and Stages

Minimum BLA Fuel Consumption Effect Across All Reference Runs and Stages

4 Worst Case Scenario Bookends:

Swapping each individual fuel impact with minimum or maximum fuel impact across all reference runs



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Minimum BLB2 Fuel Consumption Effect Across All Reference Runs and Stages

Minimum BLA Fuel Consumption Effect Across All Reference Runs and Stages

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Maximum BLB2 Fuel Consumption Effect Across All Reference Runs and Stages

Maximum BLA Fuel Consumption Effect Across All Reference Runs and Stages

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Minimum BLB2 Fuel Consumption Effect Across All Reference Runs and Stages

Minimum BLA Fuel Consumption Effect Across All Reference Runs and Stages

4 Worst Case Scenario Bookends:

Swapping each individual fuel impact with minimum or maximum fuel impact across all reference runs

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Maximum BLA Fuel Consumption Effect Across All Reference Runs and Stages

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Minimum BLB2 Fuel Consumption Effect Across All Reference Runs and Stages

Minimum BLA Fuel Consumption Effect Across All Reference Runs and Stages

Modeling Approach

- **For each stage model, used stepwise regression to determine potential C of A variables to model fuel.**
- **Verified these results using Partial Least Squares Modeling**
- **Next slide highlights top 5 C of A variables associated with fuel consumption, broken into Stage.**
  - Slide illustrates bivariate linear relationships
  - Model fit results indicates more success modeling idle portions of the VID fuel consumption

Fuel Consumption - Regression Model Summary

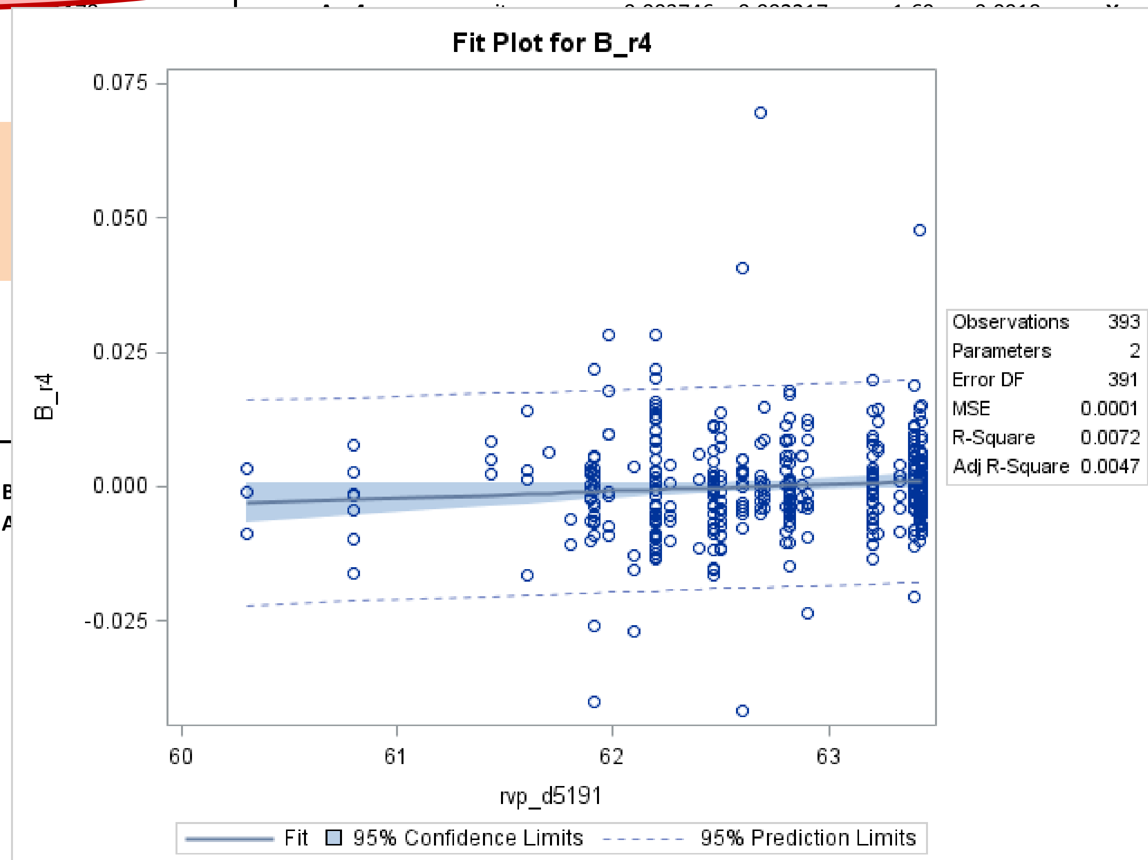
Y-variable	X-variable	Estimate	StdErr	tValue	P-value	Sig. at 10%?
B_r1	particulat	-0.00044	0.000303	-1.46	0.1451	
B_r1	rvp_d5191	0.000116	9.88E-05	1.17	0.2427	
B_r1	saturates	-5.8E-05	7.87E-05	-0.74	0.4582	
B_r1	cfactor	-0.01114	0.017158	-0.65	0.5166	
B_r1	nhv_d3338	-3.2E-06	5.08E-06	-0.63	0.5266	
B_r2	rvp_d5191	0.000188	0.000114	1.64	0.1012	
B_r2	dist_80	-2.6E-05	2.01E-05	-1.28	0.2015	
B_r2	washedgum	-0.00043	0.00035	-1.22	0.2236	
B_r2	hyca_ratio	0.005143	0.004251	1.21	0.2270	
B_r2	particulat	-0.00038	0.000352	-1.09	0.2776	
B_r3	particulat	-0.00048	0.000382	-1.25	0.2103	
B_r3	dist_10	3.8E-05	4.19E-05	0.91	0.3659	
B_r3	dist_5	3.59E-05	4.05E-05	0.89	0.3761	
B_r3	dist_30	3.36E-05	3.8E-05	0.88	0.3782	
B_r3	dist_ibp	4.32E-05	4.95E-05	0.87	0.3835	
B_r4	rvp_d5191	0.001275	0.000757	1.68	0.0930	X
B_r4	density	0.884834	0.564414	1.57	0.1178	
B_r4	sensitivty	-0.00223	0.001544	-1.44	0.1495	
B_r4	gravity	-0.00298	0.002377	-1.25	0.2108	
B_r4	dist_40	0.000293	0.000244	1.20	0.2309	
B_r5	dist_ibp	-0.00059	0.000303	-1.95	0.0522	X
B_r5	dist_70	-0.00038	0.000217	-1.74	0.0828	X
B_r5	rvp_d5191	0.001313	0.000761	1.72	0.0854	X
B_r5	density	0.935419	0.567447	1.65	0.1001	
B_r5	dist_60	-0.00044	0.000287	-1.53	0.1275	
B_r6	rvp_d5191	0.000534	0.000373	1.43	0.1533	
B_r6	hwt_e191	0.212559	0.198855	1.07	0.2858	
B_r6	hyca_ratio	0.014756	0.013867	1.06	0.2879	
B_r6	sensitivty	-0.0008	0.000761	-1.05	0.2936	
B_r6	dist_40	0.000106	0.00012	0.88	0.3814	

Y-variable	X-variable	Estimate	StdErr	tValue	P-value	Sig. at 10%?
A_r1	nhv_d3338	-6.54E-06	4.93E-06	-1.33	0.1852	
A_r1	saturates	-0.000101	7.64E-05	-1.32	0.1863	
A_r1	dist_70	-3.55E-05	2.73E-05	-1.30	0.1939	
A_r1	cwt_d3343	0.1583875	0.122549	1.29	0.1970	
A_r1	dist_80	-2.17E-05	1.69E-05	-1.29	0.1988	
A_r2	washedgum	-0.000458	0.000341	-1.34	0.1806	
A_r2	phosphorou	-0.003266	0.002469	-1.32	0.1866	
A_r2	particulat	-0.000372	0.000343	-1.08	0.2786	
A_r2	saturates	-9.6E-05	8.88E-05	-1.08	0.2802	
A_r2	cwt_d3343	0.150825	0.142532	1.06	0.2906	
A_r3	saturates	-0.000138	8.71E-05	-1.59	0.1137	
A_r3	particulat	-0.000515	0.000337	-1.53	0.1269	
A_r3	dist_5	5.339E-05	3.57E-05	1.50	0.1357	
A_r3	aromatics	0.0001267	8.71E-05	1.46	0.1463	
A_r3	sensitivty	0.0003077	0.000223	1.38	0.1688	
A_r4	density	0.9273595	0.526795	1.76	0.0791	X
A_r4	gravity	-0.003746	0.002217	-1.69	0.0918	X
A_r4	rvp_d5191	0.0010467	0.000708	1.48	0.1400	
A_r4	dist_ibp	-0.0003	0.000282	-1.06	0.2890	
A_r4	hyca_ratio	0.0273352	0.026311	1.04	0.2995	
A_r5	density	1.6032773	0.552313	2.90	0.0039	X
A_r5	gravity	-0.005609	0.002331	-2.41	0.0166	X
A_r5	dist_ibp	-0.000681	0.000296	-2.30	0.0221	X
A_r5	rvp_d5191	0.0014073	0.000746	1.89	0.0599	X
A_r5	dist_5	-0.000436	0.000243	-1.79	0.0740	X
A_r6	density	0.3859392	0.250431	1.54	0.1241	
A_r6	gravity	-0.001479	0.001054	-1.40	0.1614	
A_r6	rvp_d5191	0.0004231	0.000336	1.26	0.2093	
A_r6	olefins	0.0009091	0.000833	1.09	0.2755	
A_r6	phosphorou	-0.00751	0.007451	-1.01	0.3142	

Key: **B_r1 = BLB2/3 Stage 1, …, B_r6 = BLB2/3 Stage 6**
A_r1 = BLA Stage 1, …, A_r6 = BLA Stage 6

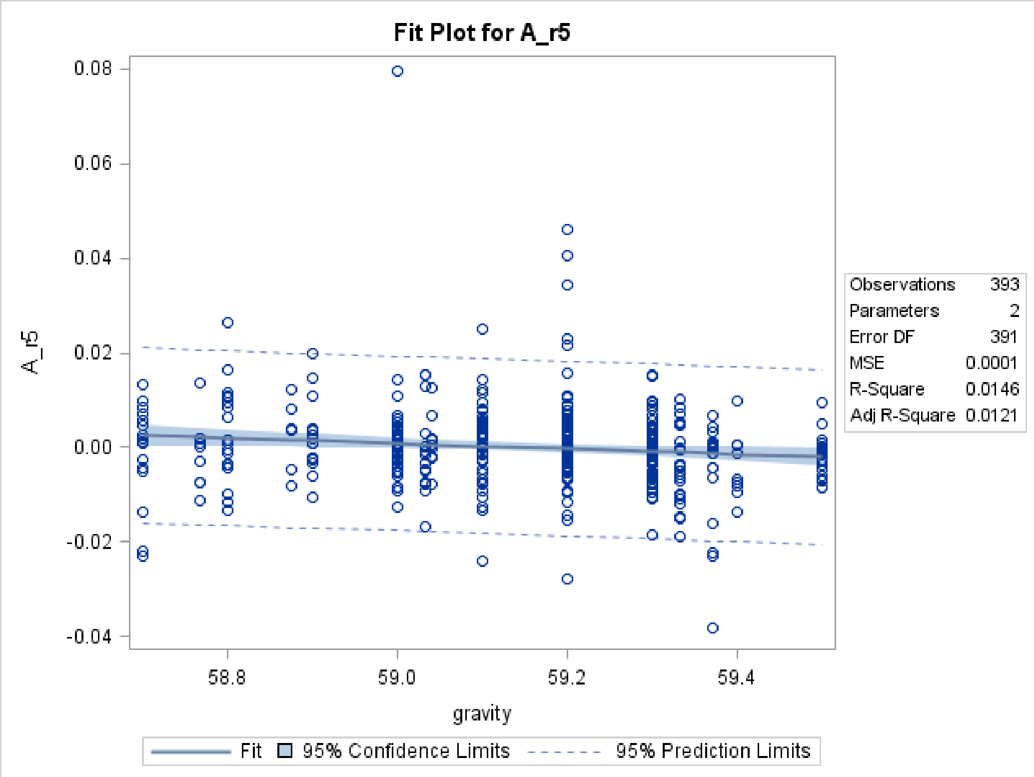
Y-variable	X-variable	Estimate	StdErr	tValue	P-value	Sig. at 10%?
B_r1	particulat	-0.00044	0.000303	-1.46	0.1451	
B_r1	rvp_d5191	0.000116	9.88E-05	1.17	0.2427	
B_r1	saturates	-5.8E-05	7.87E-05	-0.74	0.4582	
B_r1	cfactor	-0.01114	0.017158	-0.65	0.5166	
B_r1	nhv_d3338	-3.2E-06	5.08E-06	-0.63	0.5266	
B_r2	rvp_d5191	0.000188	0.000114	1.64	0.1012	
B_r2	dist_80	-2.6E-05	2.01E-05	-1.28	0.2015	
B_r2	washedgum	-0.00043	0.00035	-1.22	0.2236	
B_r2	hyca_ratio	0.005143	0.004251	1.21	0.2270	
B_r2	particulat	-0.00038	0.000352	-1.09	0.2776	
B_r3	particulat	-0.00048	0.000382	-1.25	0.2103	
B_r3	dist_10	3.8E-05	4.19E-05	0.91	0.3659	
B_r3	dist_5	3.59E-05	4.05E-05	0.89	0.3761	
B_r3	dist_30	3.36E-05	3.8E-05	0.88	0.3782	
B_r3	dist_ibp	4.32E-05	4.95E-05	0.87	0.3835	
B_r4	rvp_d5191	0.001275	0.000757	1.68	0.0930	X
B_r4	density	0.884834	0.564414	1.57	[illegible]	
B_r4	sensitivty	-0.00223	0.001544	-1.44		
B_r4	gravity	-0.00298	0.002377	-1.25		
B_r4	dist_40	0.000293	0.000244	1.20		
B_r5	dist_ibp	-0.00059	0.000303	-1.95		
B_r5	dist_70	-0.00038	0.000217	-1.74		
B_r5	rvp_d5191	0.001313	0.000761	1.72		
B_r5	density	0.935419	0.567447	1.65		
B_r5	dist_60	-0.00044	0.000287	-1.53		
B_r6	rvp_d5191	0.000534	0.000373	1.43		
B_r6	hwt_e191	0.212559	0.198855	1.07		
B_r6	hyca_ratio	0.014756	0.013867	1.06		
B_r6	sensitivty	-0.0008	0.000761	-1.05		
B_r6	dist_40	0.000106	0.00012	0.88		

Y-variable	X-variable	Estimate	StdErr	tValue	P-value	Sig. at 10%?
A_r1	nhv_d3338	-6.54E-06	4.93E-06	-1.33	0.1852	
A_r1	saturates	-0.000101	7.64E-05	-1.32	0.1863	
A_r1	dist_70	-3.55E-05	2.73E-05	-1.30	0.1939	
A_r1	cwt_d3343	0.1583875	0.122549	1.29	0.1970	
A_r1	dist_80	-2.17E-05	1.69E-05	-1.29	0.1988	
A_r2	washedgum	-0.000458	0.000341	-1.34	0.1806	
A_r2	phosphorou	-0.003266	0.002469	-1.32	0.1866	
A_r2	particulat	-0.000372	0.000343	-1.08	0.2786	
A_r2	saturates	-9.6E-05	8.88E-05	-1.08	0.2802	
A_r2	cwt_d3343	0.150825	0.142532	1.06	0.2906	
A_r3	saturates	-0.000138	8.71E-05	-1.59	0.1137	
A_r3	particulat	-0.000515	0.000337	-1.53	0.1269	
A_r3	dist_5	5.339E-05	3.57E-05	1.50	0.1357	
A_r3	aromatics	0.0001267	8.71E-05	1.46	0.1463	
A_r3	sensitivty	0.0003077	0.000223	1.38	0.1688	
A_r4	density	0.9273595	0.526795	1.76	0.0791	X
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	X



key:

Typical small scale trend analysis is picking up: slight relationship between BLB2 Stage 4 Fuel Consumption and rvp_d5191



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A_r1	cwt_d3343	0.1583875	0.122549	1.29	0.1970	
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A_r2	washedgum	-0.000458	0.000341	-1.34	0.1806	
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A_r2	cwt_d3343	0.150825	0.142532	1.06	0.2906	
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A_r3	particulat	-0.000515	0.000337	-1.53	0.1269	
A_r3	dist_5	5.339E-05	3.57E-05	1.50	0.1357	
A_r3	aromatics	0.0001267	8.71E-05	1.46	0.1463	
A_r3	sensitivty	0.0003077	0.000223	1.38	0.1688	
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A_r4	gravity	-0.003746	0.002217	-1.69	0.0918	X
A_r4	rvp_d5191	0.0010467	0.000708	1.48	0.1400	
A_r4	dist_ibp	-0.0003	0.000282	-1.06	0.2890	
A_r4	hyca_ratio	0.0273352	0.026311	1.04	0.2995	
A_r5	density	1.6032773	0.552313	2.90	0.0039	X
A_r5	gravity	-0.005609	0.002331	-2.41	0.0166	X
A_r5	dist_ibp	-0.000681	0.000296	-2.30	0.0221	X
A_r5	rvp_d5191	0.0014073	0.000746	1.89	0.0599	X
A_r5	dist_5	-0.000436	0.000243	-1.79	0.0740	X
A_r6	density	0.3859392	0.250431	1.54	0.1241	
A_r6	gravity	-0.001479	0.001054	-1.40	0.1614	
A_r6	rvp_d5191	0.0004231	0.000336	1.26	0.2093	
A_r6	olefins	0.0009091	0.000833	1.09	0.2755	
A_r6	phosphorou	-0.00751	0.007451	-1.01	0.3142	

B_r5	density	0.935419	0.567447	1.65	0.1001
B_r5	dist_60	-0.00044	0.000287	-1.53	0.1275
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B_r6	hwt_e191	0.212559	0.198855	1.07	0.2858
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B_r6	sensitivty	-0.0008	0.000761	-1.05	0.2936
B_r6	dist_40	0.000106	0.00012	0.88	0.3814

Key: **B_r1 = BLB2/3 Stage 1, …, B_r6 = BLB2/3 Stage 6**
A_r1 = BLA Stage 1, …, A_r6 = BLA Stage 6

Typical small scale trend analysis is picking up: slight relationship between BLA Stage 5 Fuel Consumption and gravity

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Fuel Property Correlation Matrix

Some caution needed in interpreting final significant variables – high degree of collinearity in C of A data.

Used Variance Inflation Factors (VIFs) to gauge collinearity during final model selection.

Name	aromatics	cfactor	cwt_e191	density	dist_5	dist_10	dist_20	dist_40	dist_50	dist_60	dist_70	dist_80	dist_95	dist_ep	dist_ibp	fuecnumber	gravity
aromatics	1.00	-0.24	-0.41	0.45	0.00	0.10	0.12	0.03	-0.13	-0.20	-0.14	-0.06	-0.04	0.02	-0.05	0.34	-0.34
cfactor	-0.24	1.00	0.76	0.31	0.07	0.19	0.27	0.58	0.57	0.40	0.22	0.09	0.51	0.26	0.27	0.28	-0.40
cwt_d3343	0.97	-0.22	-0.37	0.55	-0.08	0.03	0.08	0.00	-0.20	-0.28	-0.23	-0.16	-0.06	0.01	-0.05	0.46	-0.47
cwt_e191	-0.41	0.76	1.00	0.03	0.18	0.27	0.27	0.31	0.24	0.15	-0.04	-0.18	0.38	0.30	0.50	0.24	-0.19
density	0.45	0.31	0.03	1.00	-0.12	0.07	0.20	0.40	0.20	0.05	0.00	0.02	0.32	0.22	-0.11	0.64	-0.93
dist_5	0.00	0.07	0.18	-0.12	1.00	0.93	0.76	0.21	0.02	-0.02	-0.10	-0.14	0.18	0.22	0.57	-0.14	0.07
dist_10	0.10	0.19	0.27	0.07	0.93	1.00	0.92	0.44	0.16	0.04	-0.09	-0.17	0.31	0.32	0.59	0.01	-0.12
dist_20	0.12	0.27	0.27	0.20	0.76	0.92	1.00	0.65	0.28	0.08	-0.07	-0.16	0.33	0.26	0.45	0.09	-0.21
dist_30	0.17	0.35	0.22	0.34	0.60	0.79	0.93	0.84	0.42	0.17	0.02	-0.07	0.40	0.25	0.32	0.12	-0.33
dist_40	0.03	0.58	0.31	0.40	0.21	0.44	0.65	1.00	0.80	0.54	0.37	0.25	0.52	0.27	0.18	0.25	-0.41
dist_50	-0.13	0.57	0.24	0.20	0.02	0.16	0.28	0.80	1.00	0.91	0.78	0.64	0.53	0.21	0.16	0.16	-0.28
dist_60	-0.20	0.40	0.15	0.05	-0.02	0.04	0.08	0.54	0.91	1.00	0.95	0.85	0.39	0.02	0.12	0.09	-0.14
dist_70	-0.14	0.22	-0.04	0.00	-0.10	-0.09	-0.07	0.37	0.78	0.95	1.00	0.96	0.19	-0.19	-0.03	0.03	-0.05
dist_80	-0.06	0.09	-0.18	0.02	-0.14	-0.17	-0.16	0.25	0.64	0.85	0.96	1.00	0.10	-0.26	-0.19	-0.01	-0.02
dist_90	0.04	0.41	0.09	0.32	0.05	0.10	0.12	0.53	0.75	0.78	0.76	0.78	0.58	0.19	-0.03	0.16	-0.34
dist_95	-0.04	0.51	0.38	0.32	0.18	0.31	0.33	0.52	0.53	0.39	0.19	0.10	1.00	0.73	0.24	0.24	-0.40
dist_ep	0.02	0.26	0.30	0.22	0.22	0.32	0.26	0.27	0.21	0.02	-0.19	-0.26	0.73	1.00	0.39	0.19	-0.26
dist_ibp	-0.05	0.27	0.50	-0.11	0.57	0.59	0.45	0.18	0.16	0.12	-0.03	-0.19	0.24	0.39	1.00	0.14	-0.05
fuecnumber	0.34	0.28	0.24	0.64	-0.14	0.01	0.09	0.25	0.16	0.09	0.03	-0.01	0.24	0.19	0.14	1.00	-0.70
gravity	-0.34	-0.40	-0.19	-0.93	0.07	-0.12	-0.21	-0.41	-0.28	-0.14	-0.05	-0.02	-0.40	-0.26	-0.05	-0.70	1.00
hwt_e191	-0.31	0.13	0.06	-0.15	0.20	0.18	0.18	0.15	0.08	0.02	-0.04	-0.06	0.13	0.01	0.00	-0.76	0.17
hyca_ratio	-0.18	-0.11	-0.24	-0.18	0.12	0.08	0.08	0.03	0.00	-0.03	-0.03	0.00	0.00	-0.09	-0.15	-0.82	0.24
loss	0.11	-0.07	-0.08	0.12	-0.69	-0.53	-0.40	0.05	0.15	0.20	0.20	0.12	-0.10	-0.09	-0.06	0.34	-0.14
mon	-0.09	-0.10	-0.12	-0.24	0.02	0.02	0.09	0.00	-0.16	-0.17	-0.09	-0.05	-0.59	-0.50	-0.24	-0.27	0.38
nhv_d240	-0.03	-0.62	0.00	-0.26	0.15	0.10	-0.02	-0.45	-0.57	-0.45	-0.41	-0.40	-0.27	0.00	0.23	0.03	0.22
nhv_d3338	-0.96	0.22	0.37	-0.54	0.12	0.01	-0.04	0.04	0.24	0.32	0.27	0.21	0.10	0.00	0.07	-0.44	0.44
olefins	-0.16	0.10	0.21	0.17	-0.07	0.04	0.06	0.06	0.01	-0.03	-0.14	-0.22	0.37	0.42	0.08	0.44	-0.21
particulat	-0.15	0.40	0.24	0.32	-0.14	-0.13	-0.11	0.10	0.25	0.32	0.33	0.36	0.13	-0.04	-0.18	0.18	-0.30
phosphorou	0.01	-0.09	-0.10	0.14	0.12	0.07	0.03	-0.10	-0.07	0.04	0.08	0.11	-0.26	-0.20	0.07	-0.27	-0.15
recovery	-0.12	-0.03	0.08	-0.16	0.71	0.57	0.39	-0.08	-0.19	-0.26	-0.28	-0.22	0.10	0.23	0.18	-0.33	0.19
residue	-0.02	0.30	0.08	0.09	0.05	-0.02	0.05	0.04	0.05	0.08	0.11	0.15	0.03	-0.30	-0.27	-0.05	-0.11
ron	0.14	-0.08	-0.02	-0.06	0.23	0.27	0.33	0.11	-0.06	-0.12	-0.06	-0.06	-0.45	-0.43	0.00	0.00	0.11
rvp_d5191	-0.12	-0.26	-0.10	-0.03	0.04	0.08	0.14	-0.16	-0.34	-0.32	-0.30	-0.30	-0.21	-0.08	-0.20	-0.18	0.11
saturates	-0.95	0.20	0.35	-0.51	0.02	-0.11	-0.15	-0.06	0.12	0.20	0.18	0.12	-0.08	-0.16	0.02	-0.48	0.42
sensitivty	0.25	0.04	0.13	0.19	0.27	0.30	0.32	0.16	0.11	0.05	0.04	-0.01	0.06	-0.05	0.23	0.27	-0.27
sulfur	0.16	-0.09	0.21	0.12	0.13	0.22	0.19	-0.11	-0.36	-0.50	-0.60	-0.63	0.25	0.60	0.32	0.27	-0.14
washedgum	0.23	-0.16	-0.16	0.03	-0.01	0.01	0.03	-0.06	-0.12	-0.15	-0.08	0.00	-0.30	-0.02	-0.20	-0.16	0.03
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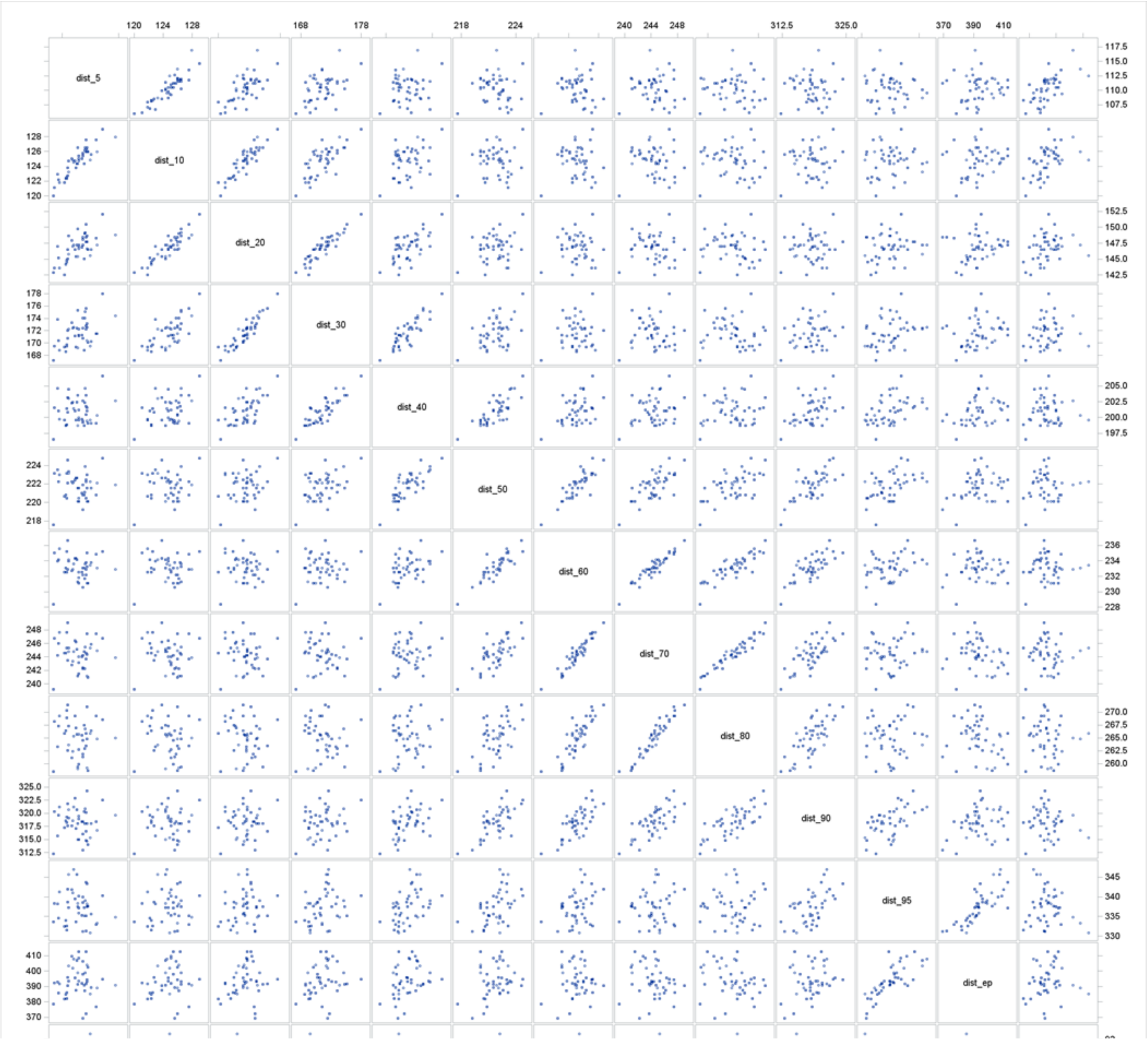
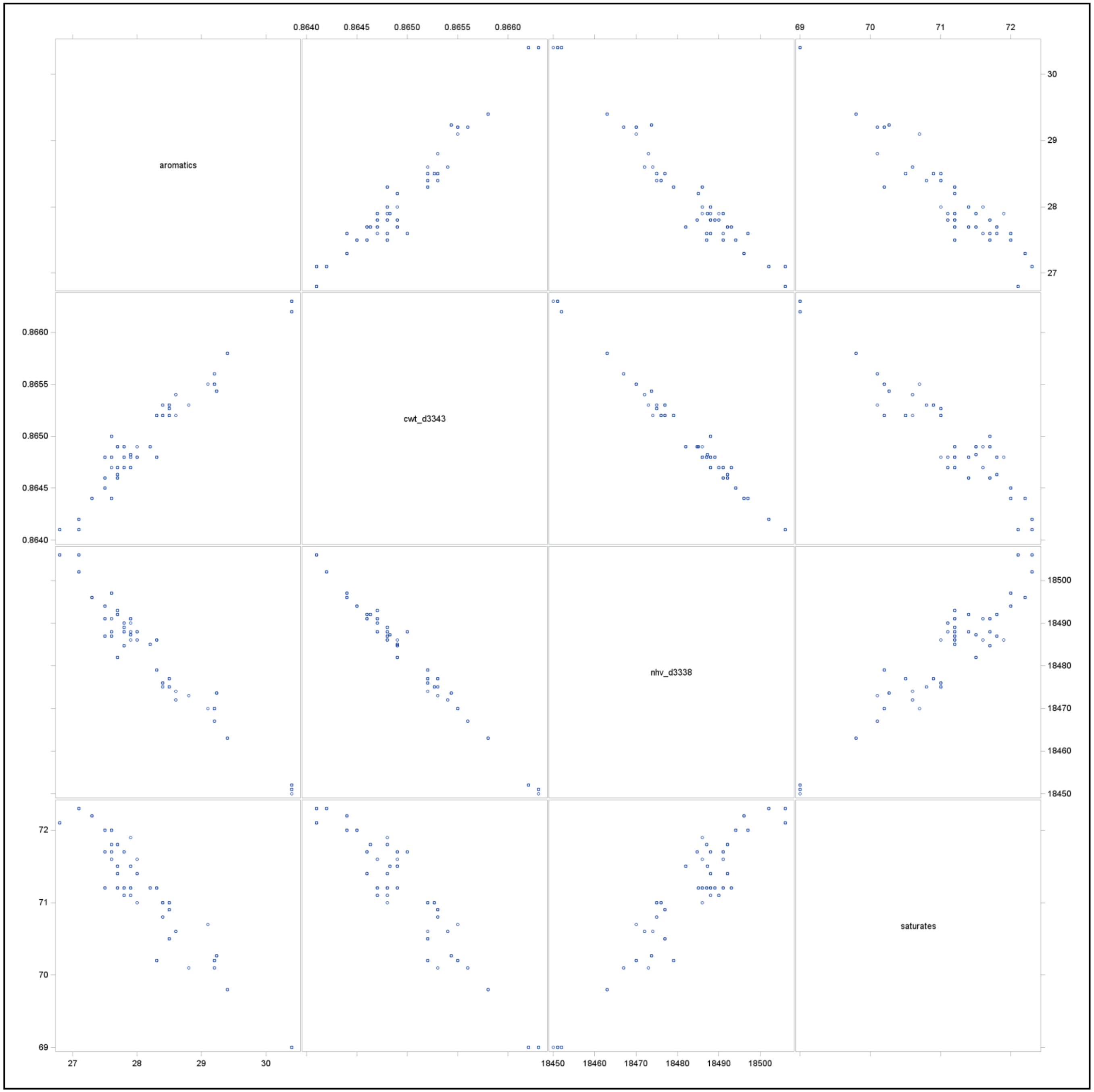
Name	hwt_e191	hyca_ratio	loss	mon	nhv_d240	nhv_d3338	olefins	particulat	phosphorou	recovery	residue	ron	rvp_d5191	saturates	sensitivty	sulfur	washedgum
aromatics	-0.31	-0.18	0.11	-0.09	-0.03	-0.96	-0.16	-0.15	0.01	-0.12	-0.02	0.14	-0.12	-0.95	0.25	0.16	0.23
cfactor	0.13	-0.11	-0.07	-0.10	-0.62	0.22	0.10	0.40	-0.09	-0.03	0.30	-0.08	-0.26	0.20	0.04	-0.09	-0.16
cwt_d3343	-0.35	-0.23	0.19	-0.13	0.03	-0.99	-0.06	-0.11	0.02	-0.20	-0.03	0.12	-0.09	-0.95	0.27	0.25	0.15
cwt_e191	0.06	-0.24	-0.08	-0.12	0.00	0.37	0.21	0.24	-0.10	0.08	0.08	-0.02	-0.10	0.35	0.13	0.21	-0.16
density	-0.15	-0.18	0.12	-0.24	-0.26	-0.54	0.17	0.32	0.14	-0.16	0.09	-0.06	-0.03	-0.51	0.19	0.12	0.03
dist_5	0.20	0.12	-0.69	0.02	0.15	0.12	-0.07	-0.14	0.12	0.71	0.05	0.23	0.04	0.02	0.27	0.13	-0.01
dist_10	0.18	0.08	-0.53	0.02	0.10	0.01	0.04	-0.13	0.07	0.57	-0.02	0.27	0.08	-0.11	0.30	0.22	0.01
dist_20	0.18	0.08	-0.40	0.09	-0.02	-0.04	0.06	-0.11	0.03	0.39	0.05	0.33	0.14	-0.15	0.32	0.19	0.03
dist_30	0.24	0.14	-0.25	0.10	-0.18	-0.09	-0.06	-0.07	-0.03	0.24	0.05	0.29	0.13	-0.17	0.26	0.07	0.04
dist_40	0.15	0.03	0.05	0.00	-0.45	0.04	0.06	0.10	-0.10	-0.08	0.04	0.11	-0.16	-0.06	0.16	-0.11	-0.06
dist_50	0.08	0.00	0.15	-0.16	-0.57	0.24	0.01	0.25	-0.07	-0.19	0.05	-0.06	-0.34	0.12	0.11	-0.36	-0.12
dist_60	0.02	-0.03	0.20	-0.17	-0.45	0.32	-0.03	0.32	0.04	-0.26	0.08	-0.12	-0.32	0.20	0.05	-0.50	-0.15
dist_70	-0.04	-0.03	0.20	-0.09	-0.41	0.27	-0.14	0.33	0.08	-0.28	0.11	-0.06	-0.30	0.18	0.04	-0.60	-0.08
dist_80	-0.06	0.00	0.12	-0.05	-0.40	0.21	-0.22	0.36	0.11	-0.22	0.15	-0.06	-0.30	0.12	-0.01	-0.63	0.00
dist_90	0.04	0.01	-0.07	-0.27	-0.52	0.10	-0.12	0.38	-0.01	-0.02	0.22	-0.19	-0.33	-0.01	0.07	-0.39	-0.08
dist_95	0.13	0.00	-0.10	-0.59	-0.27	0.10	0.37	0.13	-0.26	0.10	0.03	-0.45	-0.21	-0.08	0.06	0.25	-0.30
dist_ep	0.01	-0.09	-0.09	-0.50	0.00	0.00	0.42	-0.04	-0.20	0.23	-0.30	-0.43	-0.08	-0.16	-0.05	0.60	-0.02
dist_ibp	0.00	-0.15	-0.06	-0.24	0.23	0.07	0.08	-0.18	0.07	0.18	-0.27	0.00	-0.20	0.02	0.23	0.32	-0.20
fuecnumber	-0.76	-0.82	0.34	-0.27	0.03	-0.44	0.44	0.18	-0.27	-0.33	-0.05	0.00	-0.18	-0.48	0.27	0.27	-0.16
gravity	0.17	0.24	-0.14	0.38	0.22	0.44	-0.21	-0.30	-0.15	0.19	-0.11	0.11	0.11	0.42	-0.27	-0.14	0.03
hwt_e191	1.00	0.95	-0.26	0.08	-0.23	0.35	-0.26	0.05	0.06	0.20	0.19	-0.05	0.14	0.39	-0.13	-0.18	0.00
hyca_ratio	0.95	1.00	-0.22	0.12	-0.22	0.24	-0.31	-0.02	0.09	0.17	0.16	-0.05	0.17	0.28	-0.17	-0.24	0.05
loss	-0.26	-0.22	1.00	-0.14	0.05	-0.20	0.26	-0.04	-0.17	-0.92	-0.35	-0.27	-0.12	-0.20	-0.21	-0.03	-0.03
mon	0.08	0.12	-0.14	1.00	-0.07	0.12	-0.38	0.04	0.14	0.11	0.09	0.61	0.27	0.23	-0.27	-0.34	0.31
nhv_d240	-0.23	-0.22	0.05	-0.07	1.00	-0.03	0.20	-0.36	0.03	0.10	-0.40	0.14	0.23	-0.03	0.20	0.48	-0.03
nhv_d3338	0.35	0.24	-0.20	0.12	-0.03	1.00	0.07	0.14	-0.03	0.21	0.04	-0.11	0.08	0.94	-0.25	-0.25	-0.17
olefins	-0.26	-0.31	0.26	-0.38	0.20	0.07	1.00	-0.03	-0.30	-0.16	-0.28	-0.33	-0.07	-0.15	-0.04	0.47	-0.29
particulat	0.05	-0.02	-0.04	0.04	-0.36	0.14	-0.03	1.00	0.12	-0.10	0.33	0.00	-0.07	0.15	-0.01	-0.24	0.01
phosphorou	0.06	0.09	-0.17	0.14	0.03	-0.03	-0.30	0.12	1.00	0.10	0.19	0.03	0.09	0.09	-0.11	-0.23	-0.01
recovery	0.20	0.17	-0.92	0.11	0.10	0.21	-0.16	-0.10	0.10	1.00	-0.03	0.27	0.11	0.18	0.19	0.21	0.05
residue	0.19	0.16	-0.35	0.09	-0.40	0.04	-0.28	0.33	0.19	-0.03	1.00	0.00	0.05	0.11	0.00	-0.40	-0.04
ron	-0.05	-0.05	-0.27	0.61	0.14	-0.11	-0.33	0.00	0.03	0.27	0.00	1.00	0.24	-0.02	0.59	0.00	0.18
rvp_d5191	0.14	0.17	-0.12	0.27	0.23	0.08	-0.07	-0.07	0.09	0.11	0.05	0.24	1.00	0.14	0.03	0.15	0.22
saturates	0.39	0.28	-0.20	0.23	-0.03	0.94	-0.15	0.15	0.09	0.18	0.11	-0.02	0.14	1.00	-0.24	-0.31	-0.14
sensitivty	-0.13	-0.17	-0.21	-0.27	0.20	-0.25	-0.04	-0.01	-0.11	0.19	0.00	0.59	0.03	-0.24	1.00	0.31	-0.12
sulfur	-0.18	-0.24	-0.03	-0.34	0.48	-0.25	0.47	-0.24	-0.23	0.21	-0.40	0.00	0.15	-0.31	0.31	1.00	0.03
washedgum	0.00	0.05	-0.03	0.31	-0.03	-0.17	-0.29	0.01	-0.01	0.05	-0.04	0.18	0.22	-0.14	-0.12	0.03	1.00


dist_5
dist_10
dist_20
dist_30
dist_40
dist_50
dist_60
dist_70
dist_80
dist_90
dist_95
dist_ep


aromatics
cwt_d3343
nhv_d3338
saturates
0.8640
0.8645
0.8650
0.8655
0.8660
69
70
71
72
30
29
28
27
18500
18490
18480
18470
18460
18450
27
28
29
30
18450
18460
18470
18480
18490
18500

Y-variable	X-variable	Estimate	StdErr	tValue	P-value	Sig. at 10%?
B_r1	particulat	-0.00044	0.000303	-1.46	0.1451	
B_r1	rvp_d5191	0.000116	9.88E-05	1.17	0.2427	
B_r1	saturates	-5.8E-05	7.87E-05	-0.74	0.4582	
B_r1	cfactor	-0.01114	0.017158	-0.65	0.5166	
B_r1	nhv_d3338	-3.2E-06	5.08E-06	-0.63	0.5266	

BLB2 Stage 2:
aromatics; rvp_d5191; washedgum

Y-variable	X-variable	Estimate	StdErr	tValue	P-value	Sig. at 10%?
B_r3	dist_10	3.8E-05	4.19E-05	0.91	0.3659	
B_r3	dist_5	3.59E-05	4.05E-05	0.89	0.3761	

BLB2 Stage 4:
density; sensitivity; rvp_d5191

BLB2 Stage 5:
dist_80; gravity; dist_ibp; hwt_e191

Y-variable	X-variable	Estimate	StdErr	tValue	P-value	Sig. at 10%?
B_r6	hyca_ratio	0.014756	0.013867	1.06	0.2879	
B_r6	sensitivty	-0.0008	0.000761	-1.05	0.2936	
B_r6	dist_40	0.000106	0.00012	0.88	0.3814	

Y-variable	X-variable	Estimate	StdErr	tValue	P-value	Sig. at 10%?
A_r1	nhv_d3338	-6.54E-06	4.93E-06	-1.33	0.1852	
A_r1	saturates	-0.000101	7.64E-05	-1.32	0.1863	
A_r1	dist_70	-3.55E-05	2.73E-05	-1.30	0.1939	
A_r1	cwt_d3343	0.1583875	0.122549	1.29	0.1970	
A_r1	dist_80	-2.17E-05	1.69E-05	-1.29	0.1988	
A_r2	washedgum	-0.000458	0.000341	-1.34	0.1806	
A_r2	phosphorou	-0.003266	0.002469	-1.32	0.1866	
A_r2	particulat	-0.000372	0.000343	-1.08	0.2786	
A_r2	saturates	-9.6E-05	8.88E-05	-1.08	0.2802	
A_r2	cwt_d3343	0.150825	0.142532	1.06	0.2906	
A_r3	saturates	-0.000138	8.71E-05	-1.59	0.1137	
A_r3	particulat	-0.000515	0.000337	-1.53	0.1269	
A_r3	dist_5	5.339E-05	3.57E-05	1.50	0.1357	

BLA Stage 4:
density; rvp_d5191

BLA Stage 5:
density; sensitivity; rvp_d5191; phosphorous; washedgum

Y-variable	X-variable	Estimate	StdErr	tValue	P-value	Sig. at 10%?
A_r6	olefins	0.0009091	0.000833	1.09	0.2755	
A_r6	phosphorou	-0.00751	0.007451	-1.01	0.3142	

Key: **B_r1 = BLB2/3 Stage** … **B_r6 = BLB2/3 Stage 6**
A_r1 = BLA Stage 1, … **6 = BLA Stage 6**

Final Models

Final Models

BLB2 – Stage 2

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.00001500	0.00000500	2.39	0.0682
Error	387	0.00080918	0.00000209		
Corrected Total	390	0.00082418			

Root MSE	0.00145	R-Square	0.0182
Dependent Mean	-0.00001624	Adj R-Sq	0.0106
Coeff Var	-8903.87614		

Parameter Estimates							
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	-0.01993	0.00840	-2.37	0.0182	0
aromatics		1	0.00013731	0.00009576	1.43	0.1524	1.09331
rvp_d5191	rvp_d5191	1	0.00026015	0.00012008	2.17	0.0309	1.08842
washedgum		1	-0.00070967	0.00037413	-1.90	0.0586	1.13337

BLB2 – Stage 4

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.00075832	0.00025277	2.77	0.0415
Error	387	0.03532	0.00009127		
Corrected Total	390	0.03608			

Root MSE	0.00955	R-Square	0.0210
Dependent Mean	-0.00001297	Adj R-Sq	0.0134
Coeff Var	-73657		

Parameter Estimates							
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	-0.88210	0.42980	-2.05	0.0408	0
density	density	1	1.10411	0.57642	1.92	0.0562	1.03692
sensitivty	sensitivty	1	-0.00266	0.00157	-1.69	0.0925	1.03703
rvp_d5191	rvp_d5191	1	0.00136	0.00076132	1.79	0.0750	1.00226

BLB2 – Stage 5

BLA – Stage 4

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.00043493	0.00021746	2.72	0.0671
Error	388	0.03101	0.00007992		
Corrected Total	390	0.03144			

Root MSE	0.00894	R-Square	0.0138
Dependent Mean	0.00000184	Adj R-Sq	0.0087
Coeff Var	486308		

Parameter Estimates							
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	-0.78016	0.39709	-1.96	0.0502	0
density	density	1	0.95965	0.52992	1.81	0.0709	1.00087
rvp_d5191	rvp_d5191	1	0.00108	0.00071190	1.52	0.1285	1.00087

BLA – Stage 5

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.00213	0.00042613	4.99	0.0002
Error	385	0.03285	0.00008532		
Corrected Total	390	0.03498			

Root MSE	0.00924	R-Square	0.0609
Dependent Mean	-0.00001671	Adj R-Sq	0.0487
Coeff Var	-55280		

Parameter Estimates							
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	-1.65963	0.42417	-3.91	0.0001	0
density	density	1	2.10360	0.56754	3.71	0.0002	1.07536
phosphorou		1	-0.03234	0.01669	-1.94	0.0534	1.05707
rvp_d5191	rvp_d5191	1	0.00210	0.00076111	2.76	0.0060	1.07160
sensitivty	sensitivty	1	-0.00351	0.00156	-2.26	0.0246	1.08442
washedgum		1	-0.00584	0.00233	-2.51	0.0126	1.07891

Best fuel model overall is for BLA Stage 5 Fuel consumption, only 6% R^2 value:

Dependent Variable: BSFC_BLBA_S5

ENGINE/STAND Model

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	82	0.09924494	0.00121030	10.89	<.0001
Error	315	0.03502284	0.00011118		
Corrected Total	397	0.13426778			

R-Square	Coeff Var	Root MSE	BSFC_BLBA_S5 Mean
0.739157	1.[illegible]74404	0.010544	0.897848

Source	DF	Type I SS	Mean Square	F Value	Pr > F
log_hrs	1	0.00237416	0.00237416	21.35	<.0001
ENGNO(LTMSLAB)	81	0.09687078	0.00119594	10.76	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
log_hrs	1	0.00529034	0.00529034	47.58	<.0001
ENGNO(LTMSLAB)	81	0.09687078	0.00119594	10.76	<.0001

R^2 Engine: 73.9157%

Unexplained Variation: 26.0843%

OF Unexplained Variation: 6.09% Explained by fuel

6.09% x 26.0843% = 1.6% Total Variation in BLA Stage 5 Fuel consumption explained by C of A

Dependent Variable: A_r5

FUEL Model

Number of Observations Read	392
Number of Observations Used	391
Number of Observations with Missing Values	1

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
[illegible]	[illegible]	[illegible]	[illegible]042613	4.99	0.0002
[illegible]	[illegible]	[illegible]	[illegible]008532		
Corrected Total	390	0.03498			

Root MSE	0.00[illegible]24	R-Square	0.0609
Dependent Mean	-0.00001[illegible]71	Adj R-Sq	0.0487
Coeff Var	-55280		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	-1.65963	0.42417	-3.91	0.0001	0
density	density	1	2.10360	0.56754	3.71	0.0002	1.07536
phosphorou		1	-0.03234	0.01669	-1.94	0.0534	1.05707
rvp_d5191	rvp_d5191	1	0.00210	0.00076111	2.76	0.0060	1.07160
sensitivty	sensitivty	1	-0.00351	0.00156	-2.26	0.0246	1.08442
washedgum		1	-0.00584	0.00233	-2.51	0.0126	1.07891

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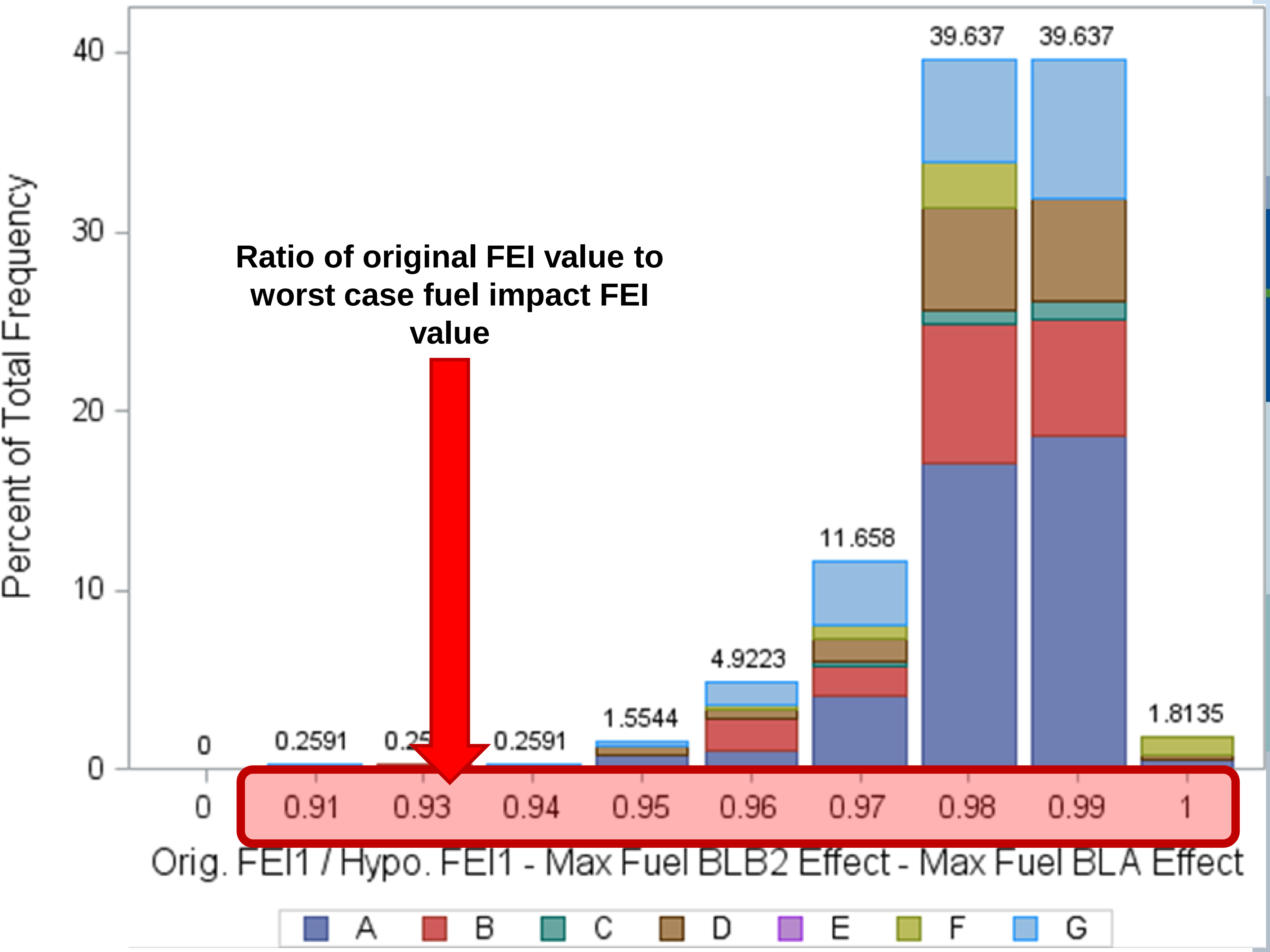
Modeling approach

Following slides summarize the worst-case scenario results. Keep in mind:

- **This really is the worst case-scenario. For example: we might apply the predicted fuel impact from a 2009 fuel batch to a 2013 test run, even though fuel batches are sequential and exhibit a fair amount of batch-to-batch consistency.**

Brief coaching on how to interpret results…



Ratio of original FEI value to worst case fuel impact FEI value
Percent of Total Frequency
40
30
20
10
0
39.637
39.637
11.658
4.9223
1.5544
1.8135
0
0.2591
0.25
0.2591
0
0.91
0.93
0.94
0.95
0.96
0.97
0.98
0.99
1
Orig. FEI1 / Hypo. FEI1 - Max Fuel BLB2 Effect - Max Fuel BLA Effect
A
B
C
D
E
F
G

For example….

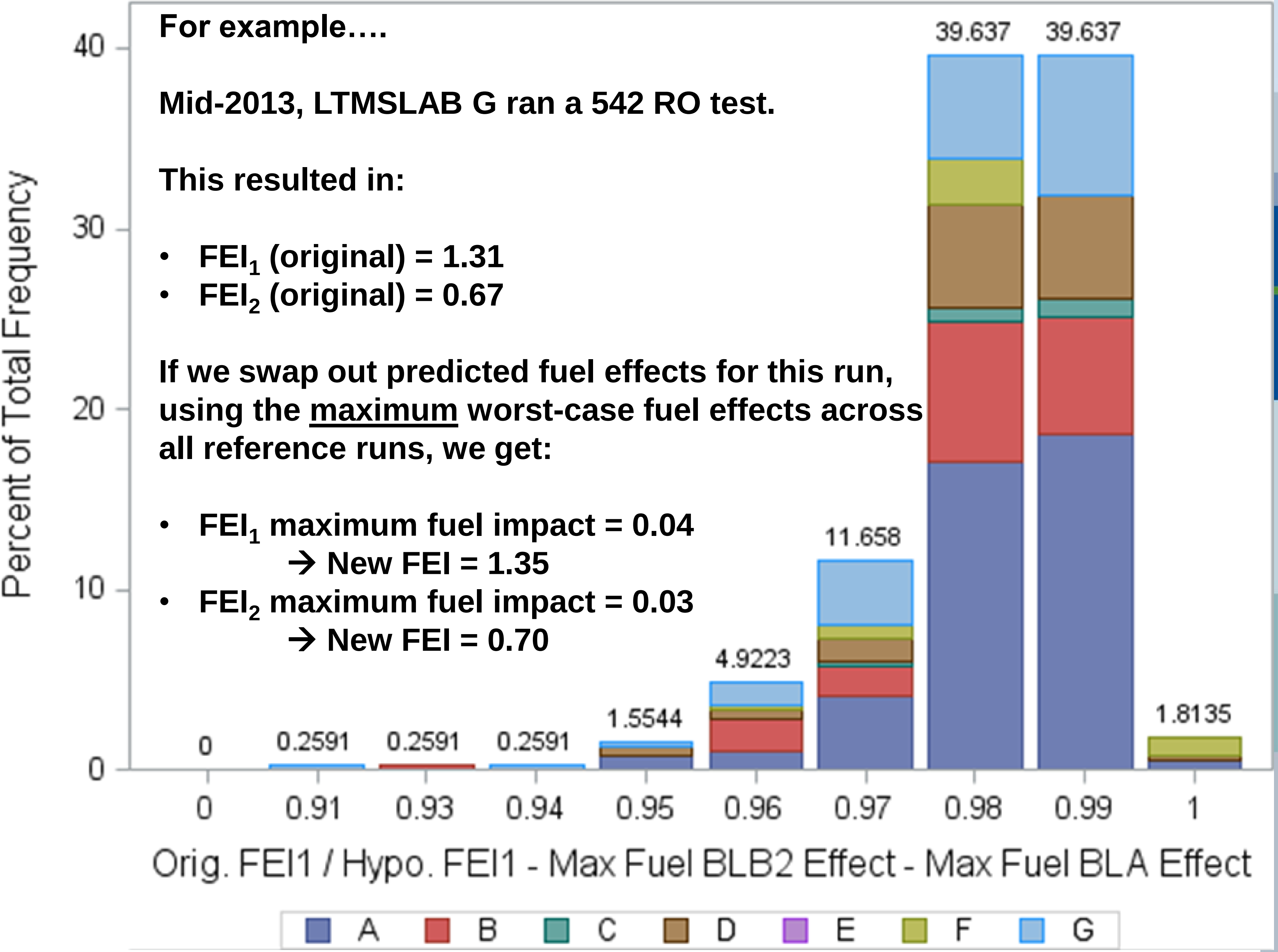
Mid-2013, LTMSLAB G ran a 542 RO test.

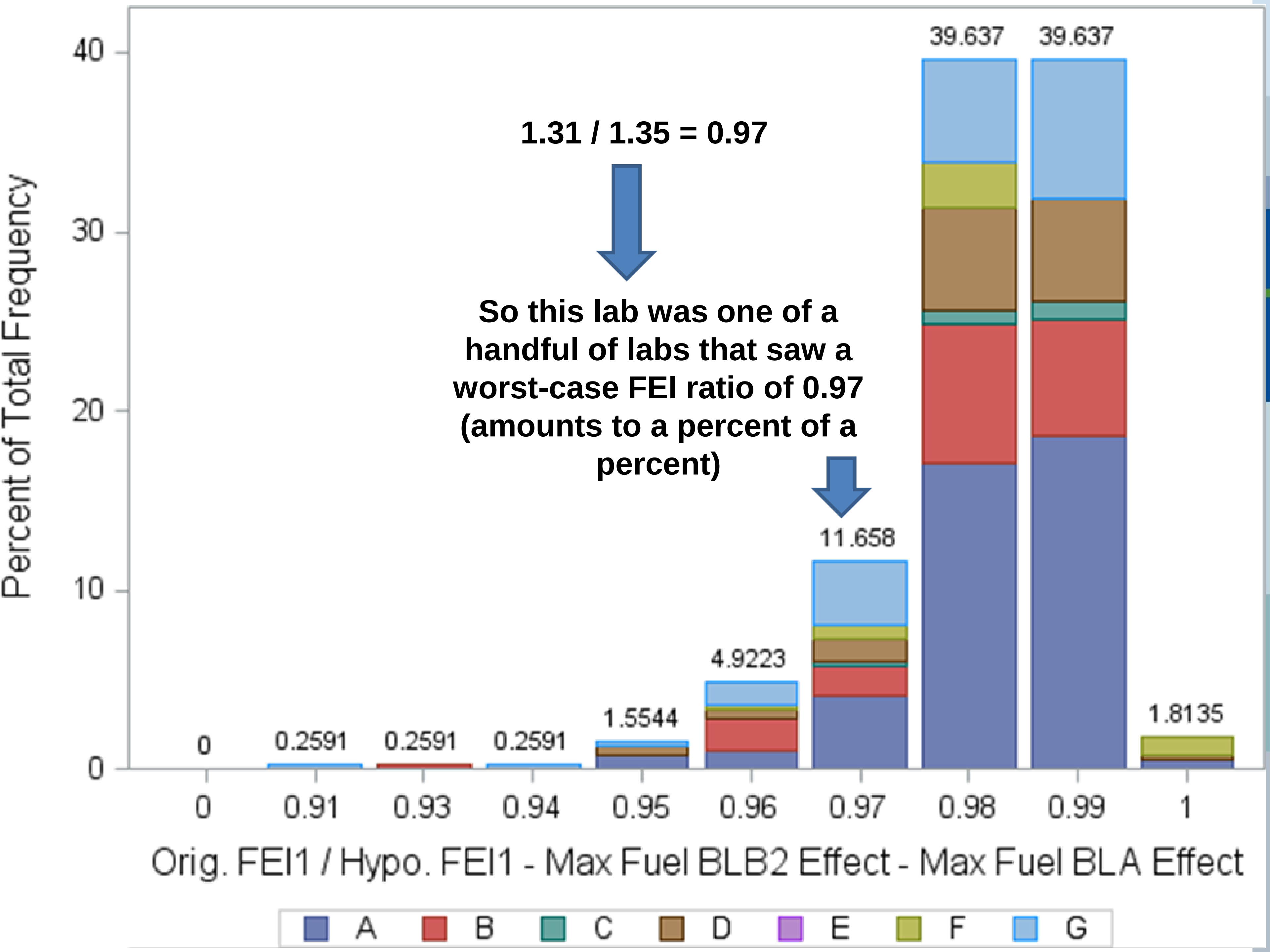
This resulted in:

- **FEI_1 (original) = 1.31**
- **FEI_2 (original) = 0.67**

If we swap out predicted fuel effects for this run, using the <u>maximum</u> worst-case fuel effects across all reference runs, we get:

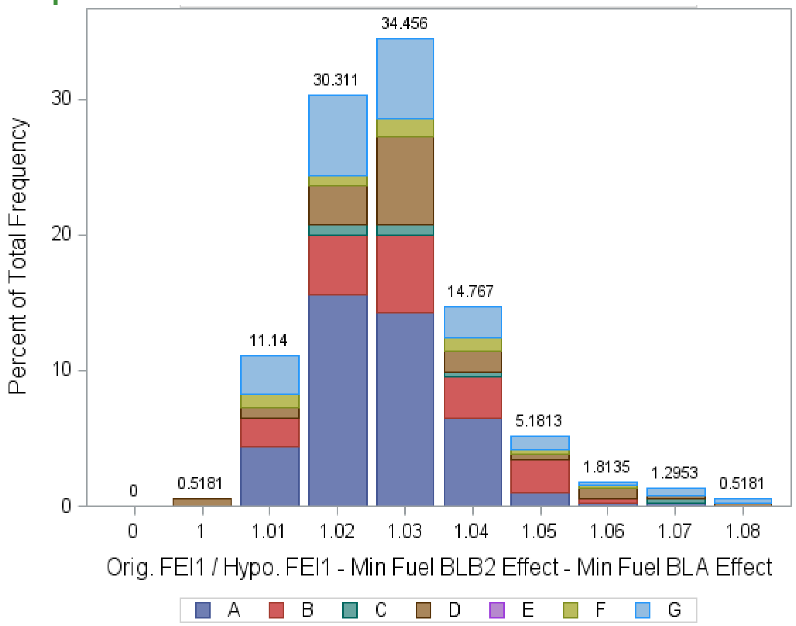
- **FEI_1 maximum fuel impact = 0.04**
  → New FEI = 1.35
- **FEI_2 maximum fuel impact = 0.03**
  → New FEI = 0.70





1.31 / 1.35 = 0.97
So this lab was one of a handful of labs that saw a worst-case FEI ratio of 0.97 (amounts to a percent of a percent)
Percent of Total Frequency
40
30
20
10
0
39.637
39.637
11.658
4.9223
1.5544
1.8135
0
0.2591
0.2591
0.2591
0
0.91
0.93
0.94
0.95
0.96
0.97
0.98
0.99
1
Orig. FEI1 / Hypo. FEI1 - Max Fuel BLB2 Effect - Max Fuel BLA Effect
A
B
C
D
E
F
G

A few more comments on how to interpret results:



Recall the formulae for FEI calculations:

$$FEI_1 = 1 - \frac{Weighted\ RO\ FC_{16}}{0.80BLB2_{Wgt.} + 0.20BLA_{Wgt.}}$$

$$FEI_2 = 1 - \frac{Weighted\ RO\ FC_{84}}{0.10BLB2_{Wgt.} + 0.90BLA_{Wgt.}}$$

→ Bigger is "better," i.e. closer to 100% FEI

To calculate worst-case FEI_1 ratios, for example:

$$\frac{1 - \frac{Weighted\ RO\ FC_{16}}{0.80BLB2_{Wgt.} + 0.20BLA_{Wgt.}}}{1 - \frac{Weighted\ RO\ FC_{16}}{0.80\mathbf{WorstBLB2}_{Wgt.} + 0.20\mathbf{WorstBLA}_{Wgt.}}}$$

So:

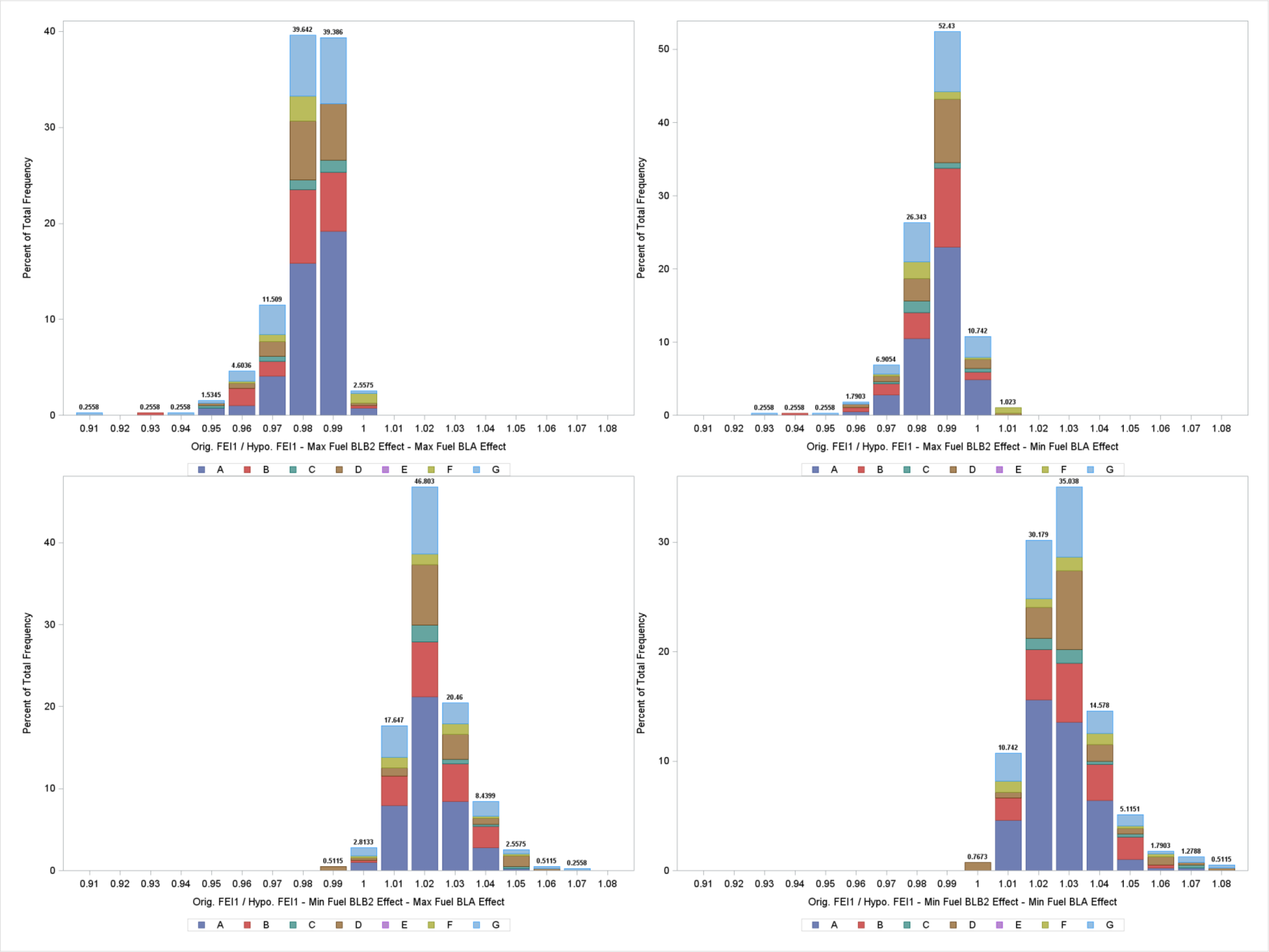
1. If we take **maximum** worst-case fuel impact on BLB2 and BLA

→ FEI increases and FEI ratio < 1. In other words, fuel boosts FEI

2. If we take **minimum** worst-case fuel impact on BLB2 and BLA

→ FEI decreases and FEI ratio > 1. In other words, fuel decreases FEI

FEI$_1$ ratios: Using worst predicted effect of fuel across all reference tests



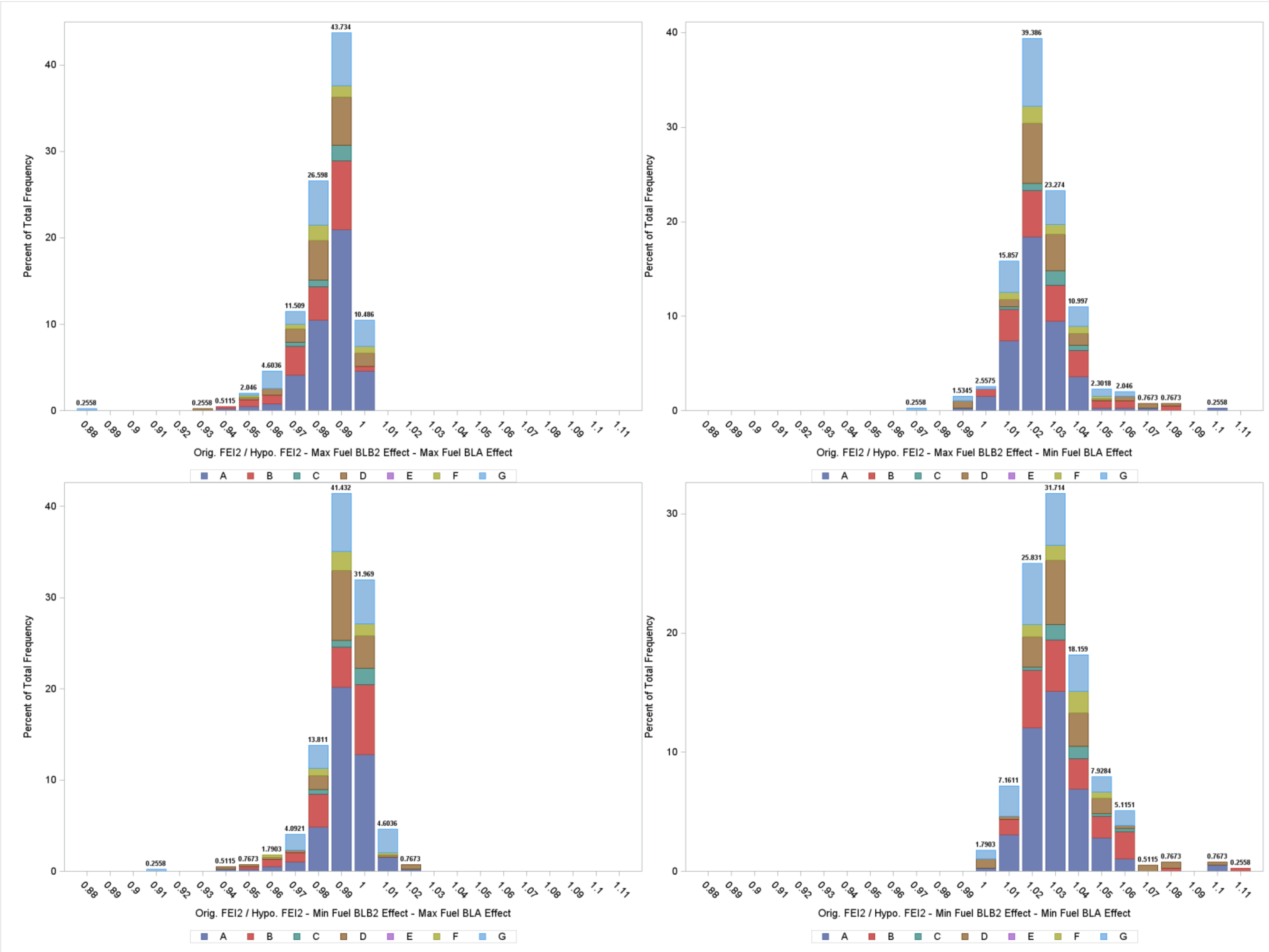
Given targeted values from ASTM test development: How do we practically interpret the previous graph?

Table of Ratio categories, target values, and worst-case impact.

FEI_1

Ratio	540 Target 1.32	541 Target 0.87	542 Target 1.49	1010 Target 1.34
1.05	-0.063	-0.041	-0.071	-0.064
1.04	-0.051	-0.033	-0.057	-0.052
1.03	-0.038	-0.025	-0.043	-0.039
1.02	-0.026	-0.017	-0.029	-0.026
1.01	-0.013	-0.009	-0.015	-0.013
1	0.000	0.000	0.000	0.000
0.99	0.013	0.009	0.015	0.014
0.98	0.027	0.018	0.030	0.027
0.97	0.041	0.027	0.046	0.041
0.96	0.055	0.036	0.062	0.056
0.95	0.069	0.046	0.078	0.071

FEI_2 ratios: Using worst predicted effect of fuel across all reference tests



Given targeted values from ASTM test development: How do we practically interpret the previous graph?

Table of Ratio categories, target values, and worst-case impact.

FEI_2

Ratio	540 Target 1.04	541 Target 0.71	542 Target 0.80	1010 Target 1.10
1.05	-0.050	-0.034	-0.038	-0.052
1.04	-0.040	-0.027	-0.031	-0.042
1.03	-0.030	-0.021	-0.023	-0.032
1.02	-0.020	-0.014	-0.016	-0.022
1.01	-0.010	-0.007	-0.008	-0.011
1	0.000	0.000	0.000	0.000
0.99	0.011	0.007	0.008	0.011
0.98	0.021	0.014	0.016	0.022
0.97	0.032	0.022	0.025	0.034
0.96	0.043	0.030	0.033	0.046
0.95	0.055	0.037	0.042	0.058

Summary

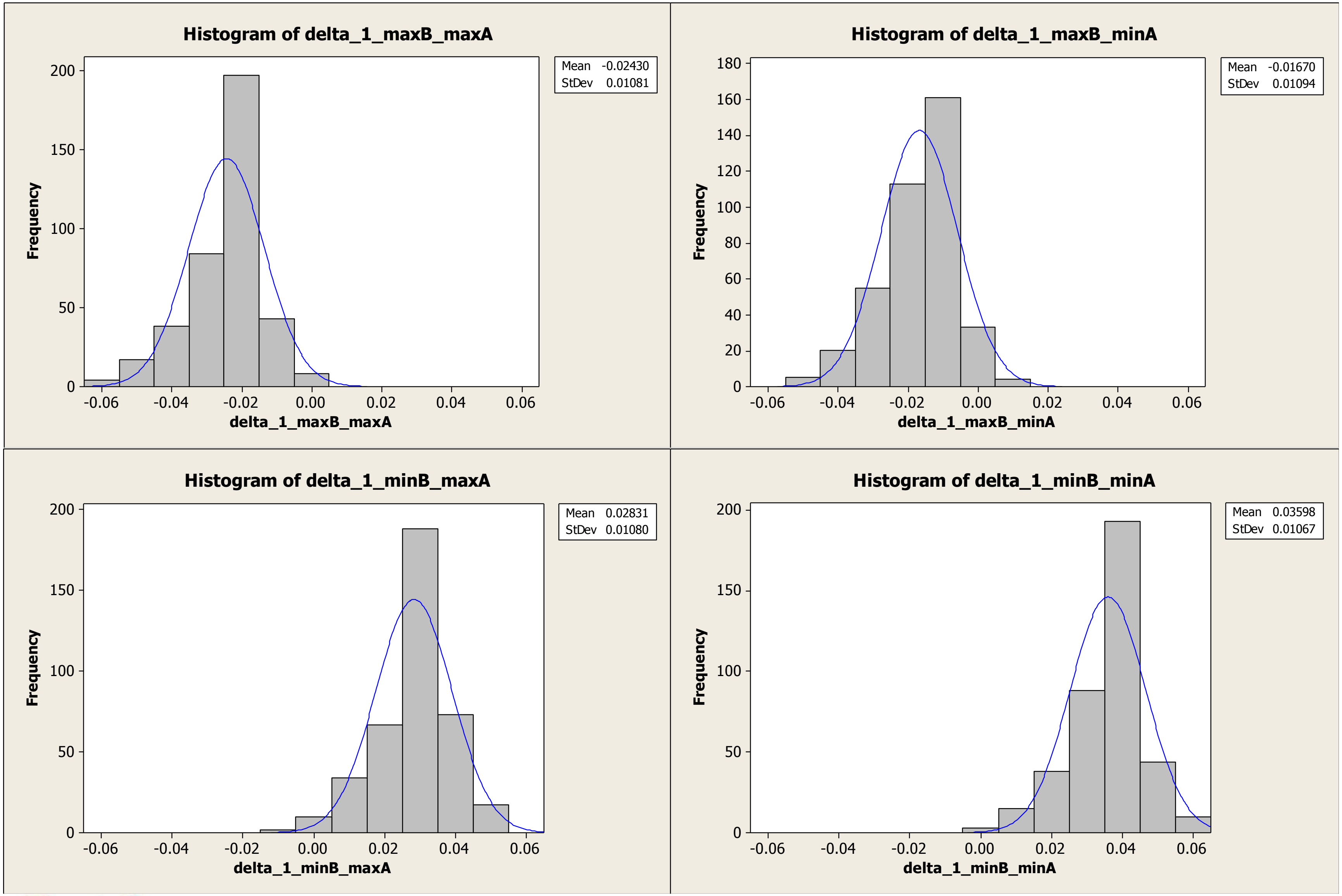
- **When we consider the worst-case impact of changing fuel batches during VID testing, the practical impact on FEI is negligible.**

- **Most of the variability in test results come from engine hours and engine bias:**
  - Typical R^2 value of fuel consumption based on engine is 75-80%.
  - Even if fuel batch changes during test, engine conditions are constant.
  - Think of FEI variability (for reference, not candidate oils!) as three partitions:
    - Engine – Fuel – Unexplained → Fuel is just a fraction of this.

Questions or comments?

Appendix A: Additional Summary Slides

Summary: Delta values of FEI calculations



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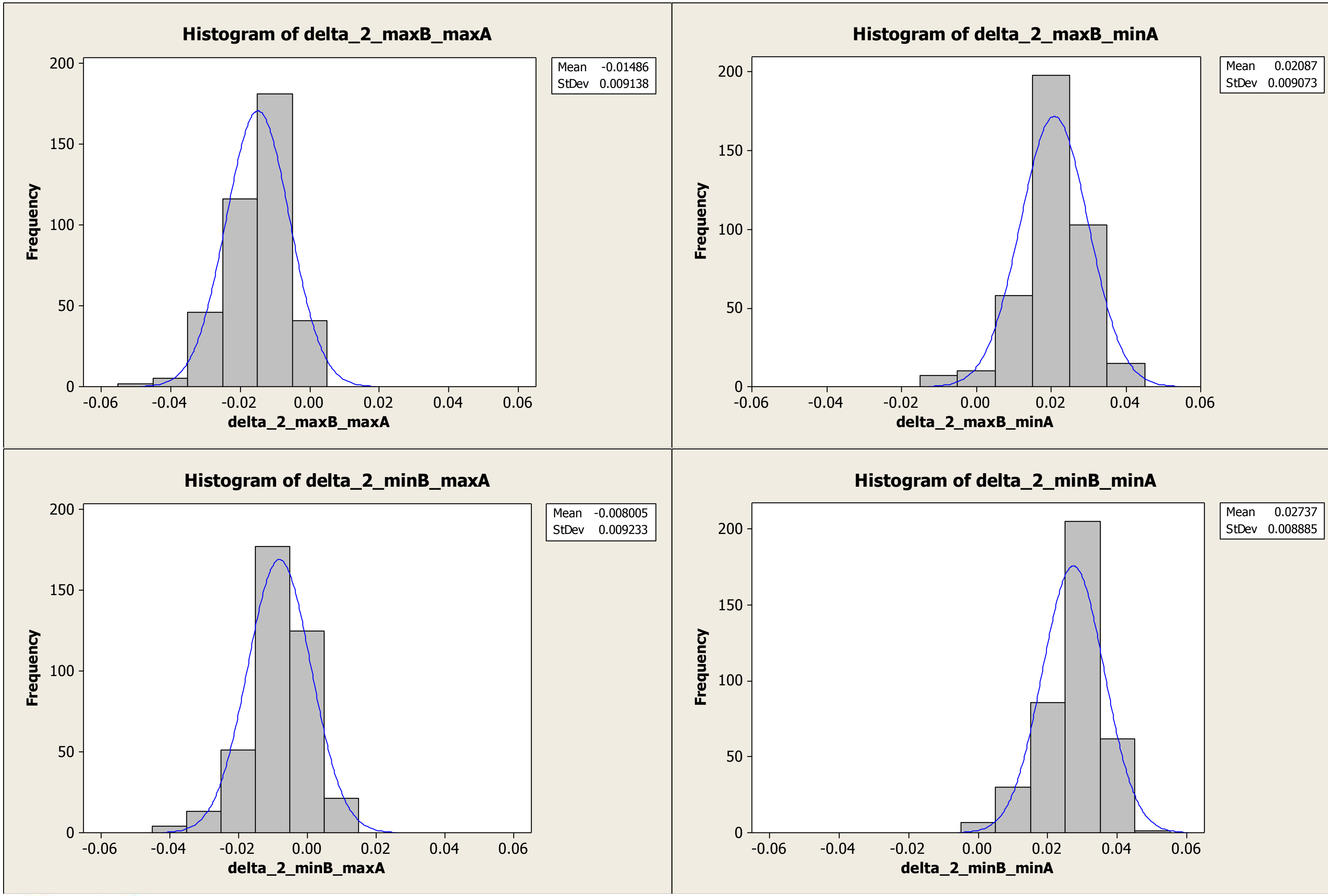
Summary: Delta values of FEI calculations



Summary

95% Confidence Intervals of delta values relative to original FEI

Variable*	Mean	StDev	SE Mean	95% CI
% FEI_1: BLB2 Max, BLA Max	-0.0188	0.0110	0.0006	(-0.019942, -0.017748)
% FEI_1: BLB2 Max, BLA Min	-0.0129	0.0100	0.0005	(-0.013928, -0.011946)
% FEI_1: BLB2 Min, BLA Max	0.0216	0.0104	0.0005	(0.020539, 0.022603)
% FEI_1: BLB2 Min, BLA Min	0.0275	0.0118	0.0006	(0.026368, 0.028705)
% FEI_2: BLB2 Max, BLA Max	-0.0170	0.0137	0.0007	(-0.018343, -0.015610)
% FEI_2: BLB2 Max, BLA Min	0.0232	0.0137	0.0007	(0.021816, 0.024548)
% FEI_2: BLB2 Min, BLA Max	-0.0092	0.0123	0.0006	(-0.010428, -0.007982)
% FEI_2: BLB2 Min, BLA Min	0.0304	0.0144	0.0007	(0.028940, 0.031800)

*** % delta relative to original FEI: (FEI original - FEI worst-case)/(FEI original)**

Appendix B: Additional Univariate C of A Plots*

***See attached .pdf document.**