Cummins Surveillance Panel
October 1, 2014
Teleconference Meeting Minutes

Attendance:
Afton - Bob Campbell
ChevronOronite - Marnix Torreman, Mark Cooper, Jim Rutherford
Cummins - Dan Nyman
Infineum - Pat Fetterman, Bob Salgueiro, Elisa Santos, Jim Gutzwiller
Intertek - Mey Dewey, Jim Moritz
Lubrizol - Michael Conrad, Nick Secue, Kevin O'Malley
Southwest Research - Martin Thompson
TEI - Zack Bishop
TMC - Jeff Clark, Sean Moyer

Cummins ISM Filter Plugging Correction Factor
This topic is continued from the two previous teleconferences (9/17/14 and 9/26/14). A potential attributable cause has been found - see **Attachment 1** for Jim Moritz's explanation and photos. Kevin O'Malley, of Lubrizol, reworked his previous analysis and the updated analysis is shown in **Attachment 2**. (Note, Kevin's analysis covers all test parameters, not just FPD.) After review and discussion, it was moved (Campbell, Thompson) ***to adopt a FPD correction factor of +4 in original units (kPa) for all tests that start on or after October 1, 2014. Recent reference tests, from July 1, 2014, will also have the CF applied and then be reviewed.*** The motion passed without objection (TMC waived).

ISB Replacement Engines
Twenty blocks are to be delivered to Cummins the 3rd week of October and long block assembly will begin shortly after, assuming timely parts delivery.

ISM Oil Filter Supply
Dan Nyman has an upcoming meeting with Fleetguard to find out the timing of a filter re-supply and also what may have caused the current mild trend.

ISB Hardware
New batches of cams and tappets are expected in the near future. Zack Bishop noted that some of the remaining current cams are in spec but have some micro

pitting -- TEI has documented the affected cams (starting in kit #759) in case there are severity issues with their use. Tappet delivery is expected next week; there are only five builds' worth of tappets left.

The teleconference adjourned at 11:30 am EDT.

Jeff Clark

ATTACHMENT 1

From: Jim Moritz Intertek [jim.moritz@intertek.com]
Sent: Friday, September 26, 2014 10:59 AM
To: OMalley, Kevin; Adam Roig Intertek; Ahlborn, Jonathan; Allison Athey (Allison.Athey@Volvo.com); Rajakumar, Allison; Andrew Wong; Larch, William; Bob Campbell; Boese, Doyle; Booth, James E.; Bradley Carter Intertek; Carter, James; cathy.devlin@aftonchemical.com; cca@lubrizol.com; Conrad, Michael; Daniel A Nyman; Elisa M. Santos (elisa.santos@infineum.com); Greg Shank; NON-LZ MCCORD JIM; Jan Peters; Jeff Clark; Jim Gutzwiller; Matasic, James; Jim McGeehan (jiam@chevron.com); Jim Rutherford; JingChun Xie (xjc@luberdi.com.cn); Joe Franklin Intertek; Mark Cooper; Mark Sutherland; Martin Thompson; Mey Dewey Intertek; michael.l.alessi@exxonmobil.com; Pat Fetterman; Perry Grosch; Scinto, Phil; Riccardo Conti; Salgueiro, Bob; Scott Richards; Sean A. Moyer; Secue, Nicholas; NON-LZ KENNEDY STEVE; Terry Dyson - Cummins (terence.dyson@cummins.com); Timothy L Caudill; Torreman, Marnix; vlkersey@ashland.com; wvda@chevrontexaco.com; Zack Bishop (zbishop@tei-net.com)
Cc: Buchanan, Jessica; Wilkinson, Robert
Subject: RE: Cummins SP conf call reminder September 26, 11:00 EDT
Attachments: IMG_2049.jpg; IMG_2050.jpg

Thanks Kevin.

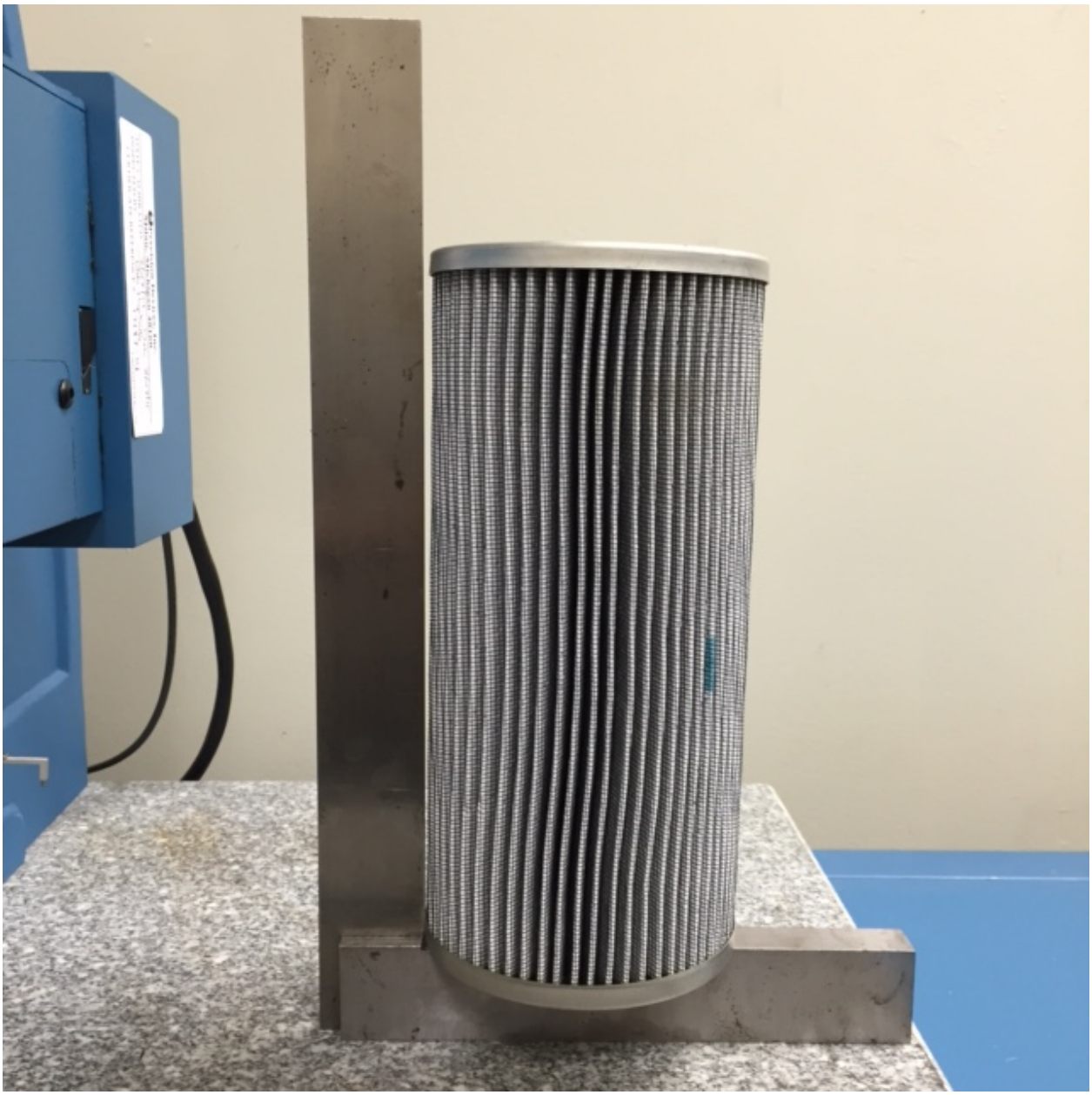
Everyone, we are pursuing a possible attributable cause we discovered since the last call. Some of the filter cartridges seem crooked or canted. I have attached some preliminary pictures. The table is level. Notice the bubble in the level in the square. The pictures are at 90 degrees to each other. We are working on better photos and more measurements right now. I think this can create a leak path internal to the filter from the high pressure side to the low pressure side resulting in a lower delta. I think the correction should be linear somehow; I don't think this is the same mechanism as plugging which is non-linear.

Jim

From: OMalley, Kevin [mailto:Kevin.OMalley@lubrizol.com]
Sent: Friday, September 26, 2014 9:41 AM
To: Jim Moritz Intertek; Adam Roig Intertek; Ahlborn, Jonathan; Allison Athey (Allison.Athey@Volvo.com); Rajakumar, Allison; Andrew Wong; Larch, William; Bob Campbell; Boese, Doyle; Booth, James E.; Bradley Carter Intertek; Carter, James; cathy.devlin@aftonchemical.com; cca@lubrizol.com; Conrad, Michael; Daniel A Nyman; Elisa M. Santos (elisa.santos@infineum.com); Greg Shank; NON-LZ MCCORD JIM; Jan Peters; Jeff Clark; Jim Gutzwiller; Matasic, James; Jim McGeehan (jiam@chevron.com); Jim Rutherford; JingChun Xie (xjc@luberdi.com.cn); Joe Franklin Intertek; Mark Cooper; Mark Sutherland; Martin Thompson; Mey Dewey Intertek; michael.l.alessi@exxonmobil.com; Pat Fetterman; Perry Grosch; Scinto, Phil; Riccardo Conti; Salgueiro, Bob; Scott Richards; Sean A. Moyer; Secue, Nicholas; NON-LZ KENNEDY STEVE; Terry Dyson - Cummins (terence.dyson@cummins.com); Timothy L Caudill; Torreman, Marnix; vlkersey@ashland.com; wvda@chevrontexaco.com; Zack Bishop (zbishop@tei-net.com)
Cc: Buchanan, Jessica; Wilkinson, Robert
Subject: RE: Cummins SP conf call reminder September 26, 11:00 EDT

All,
The attached updated presentation includes slides addressing topics/decisions discussed in the last surveillance panel call on September 17th. We can discuss this in our call later this morning.
With Kind Regards,
Kevin

Kevin O'Malley
The Lubrizol Corporation
Statistical Sciences
Statistical Consultant



ATTACHMENT 2

Cummins ISM Industry Severity

Oct 2014

Kevin O'Malley
Statistician
The Lubrizol Corporation

Summary

1. LTMS Control Charts (9/1/2004 through 9/5/2014) indicate:

	Precision	Severity
Crosshead Weight Loss Adjusted to 3.9% Soot	Borderline lower since Nov 2012	Slightly Mild since 2010
Filter Plugging Delta	OK	Bouncing in and out mild since 2010
Average Sludge Rating	OK	Slightly severe since Nov 2012 but probably okay
Injector Screw Weight Loss Adjusted to 3.9% Soot	Borderline higher since Nov 2012	OK

Could be related to crosshead batch changes or wire mesh test filter batch changes

Could be related to injector push rod batch B use

2. The surveillance panel will need to come to an agreement on whether correction factors are warranted.
    1. If warranted, agreement will be needed on how they are calculated and what data is used in the calculations.

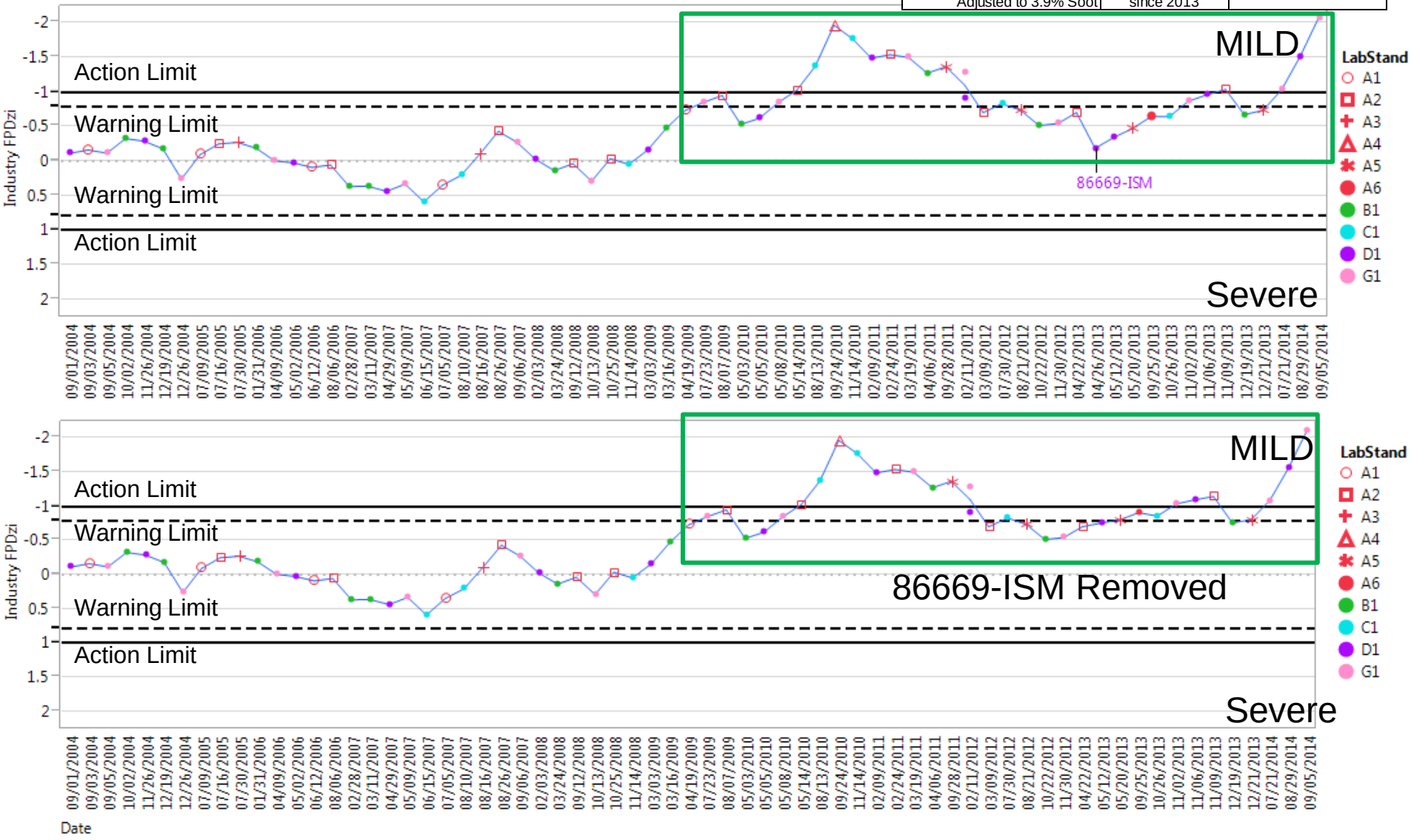
Surveillance Panel Decisions Needed:

1. Is a correction factor warranted for Crosshead Weight Loss, Filter Plugging Delta or Average Sludge Rating?
    1. If so:
        1. Correct based on crosshead batch? Wire mesh test filter batch? Injector Push Rod? other?
        2. Base correction on current vs. prior performance:
            1. Current test performance: Batches since mild trend? Just the latest batch?
            2. Prior test performance: Batches prior to mild trend? Original batch only? LTMS mean target?
        3. What data should be used in calculations? LTMS Chart=Y plus:
            1. 81547-ISM? – Not for ASR
            2. 90720-ISM?
            3. 102544-ISM? – FPD only
            4. Remove 86669-ISM? - goofy test; LTMS chart=Y
        4. Utilize data transformation?
2. Modify test precision estimates for Crosshead Weight Loss or Injector Screw Weight Loss if warranted/possible? What is past precedent?

Filter Plugging Delta

LTMS Control Charts

	Precision	Severity
Crosshead Weight Loss Adjusted to 3.9% Soot	Borderline lower since 2013	Slightly Mild since 2010
Filter Plugging Delta	OK	Bouncing in and out mild since 2010
Average Sludge Rating	OK	Slightly severe since 2012 but probably okay
Injector Screw Weight Loss Adjusted to 3.9% Soot	Borderline higher since 2013	OK

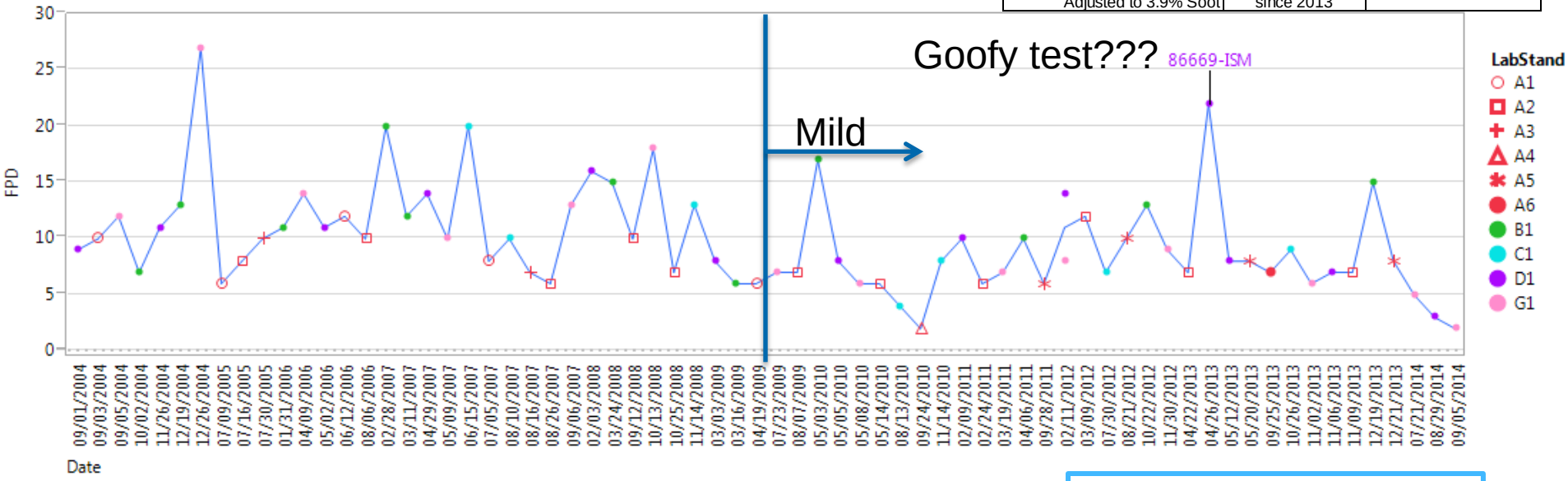


Test appears mild after April 2009.

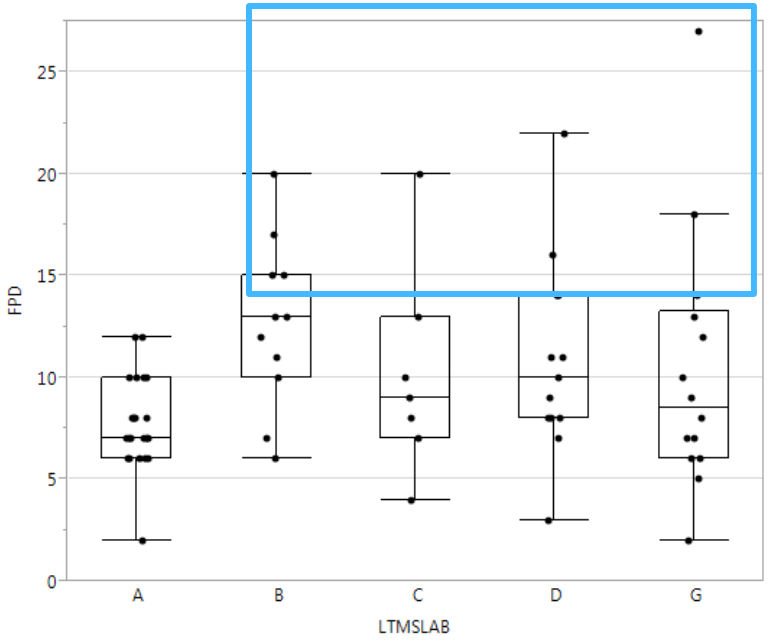
Filter Plugging Delta

LTMS Chart=Y Data

	Precision	Severity
Crosshead Weight Loss Adjusted to 3.9% Soot	Borderline lower since 2013	Slightly Mild since 2010
Filter Plugging Delta	OK	Bouncing in and out mild since 2010
Average Sludge Rating	OK	Slightly severe since 2012 but probably okay
Injector Screw Weight Loss Adjusted to 3.9% Soot	Borderline higher since 2013	OK



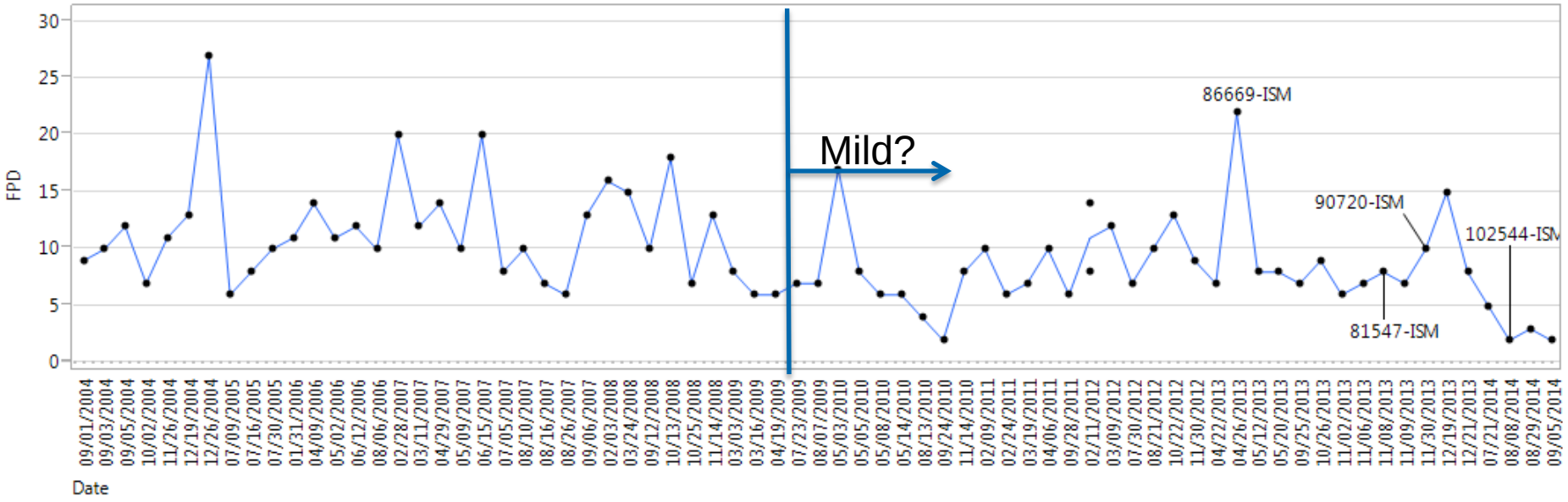
High FPD results observed in labs B,C,D, & G.



Filter Plugging Delta

LTMS Data + other possible test results

	Precision	Severity
Crosshead Weight Loss Adjusted to 3.9% Soot	Borderline lower since 2013	Slightly Mild since 2010
Filter Plugging Delta	OK	Bouncing in and out mild since 2010
Average Sludge Rating	OK	Slightly severe since 2012 but probably okay
Injector Screw Weight Loss Adjusted to 3.9% Soot	Borderline higher since 2013	OK

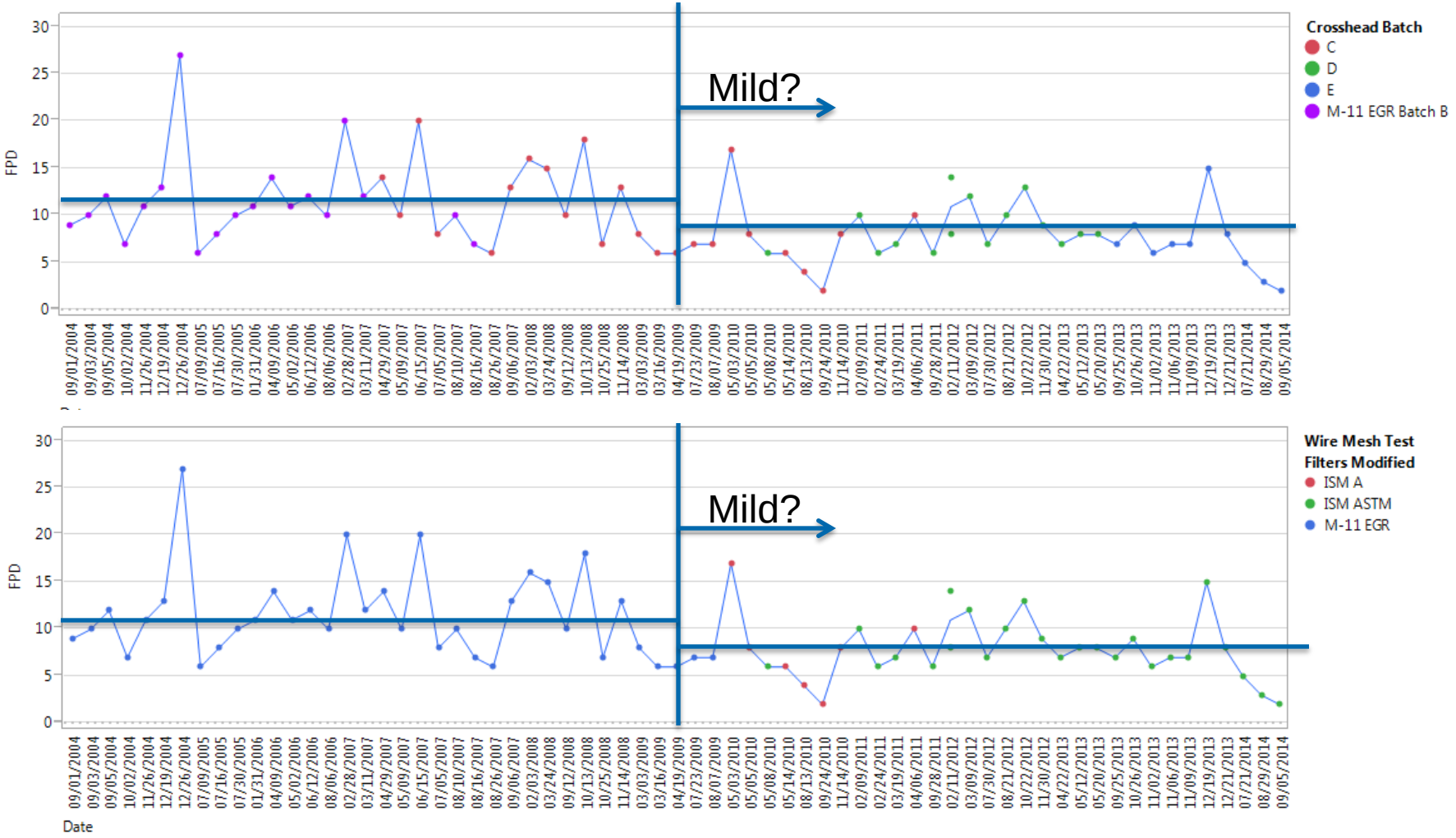


Surveillance Panel decided in 9/17/14 conference call not to include 86669-ISM, 81547-ISM, 90720-ISM, and 102544-ISM.

Filter Plugging Delta

LTMS Chart=Y Data; 86669-ISM Excluded

	Precision	Severity
Crosshead Weight Loss Adjusted to 3.9% Soot	Borderline lower since 2013	Slightly Mild since 2010
Filter Plugging Delta	OK	Bouncing in and out mild since 2010
Average Sludge Rating	OK	Slightly severe since 2012 but probably okay
Injector Screw Weight Loss Adjusted to 3.9% Soot	Borderline higher since 2013	OK

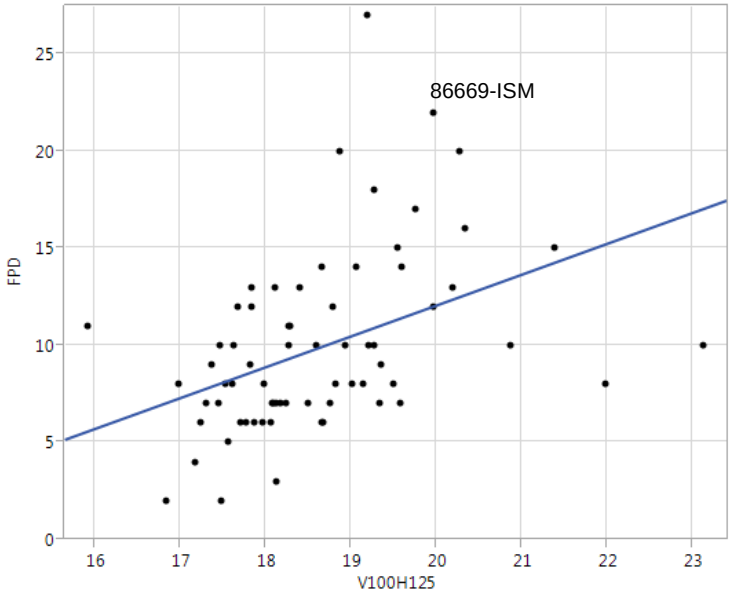


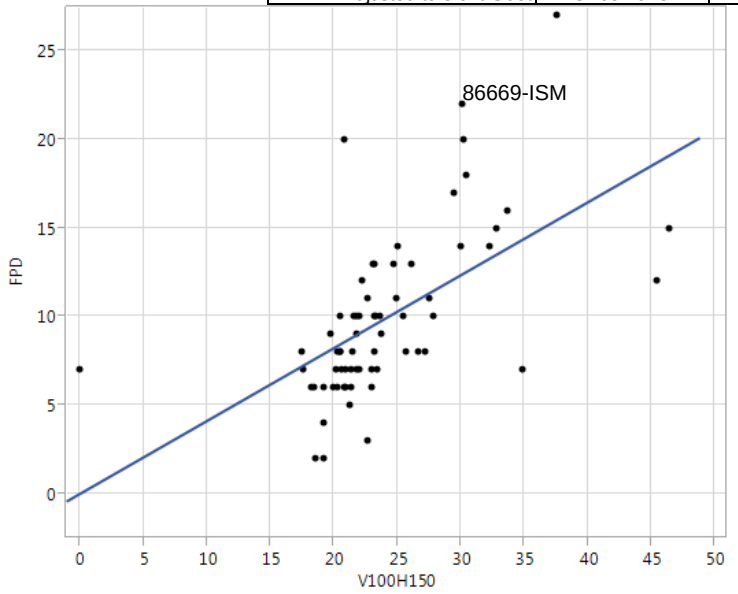
FPD appears mild when crosshead batches D & E or ISM A & ASTM filter utilized.

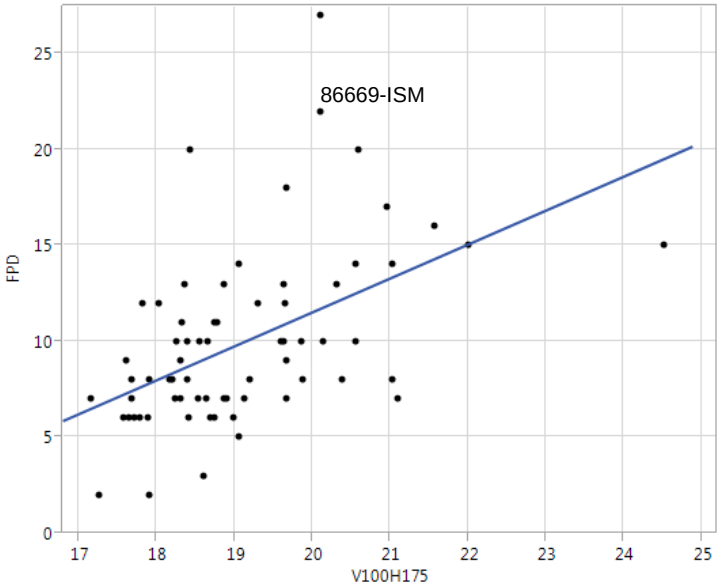
Filter Plugging Delta

LTMS Chart=Y Data

	Precision	Severity
Crosshead Weight Loss Adjusted to 3.9% Soot	Borderline lower since 2013	Slightly Mild since 2010
Filter Plugging Delta	OK	Bouncing in and out mild since 2010
Average Sludge Rating	OK	Slightly severe since 2012 but probably okay
Injector Screw Weight Loss Adjusted to 3.9% Soot	Borderline higher since 2013	OK





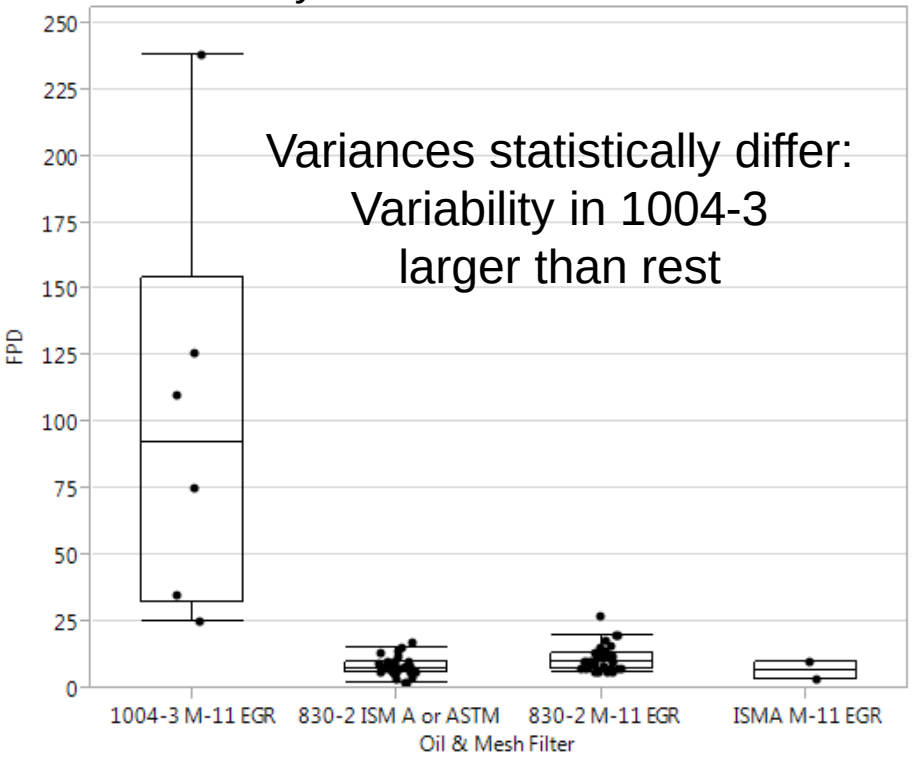


Higher viscosity at 100°C is correlated with higher filter plugging delta

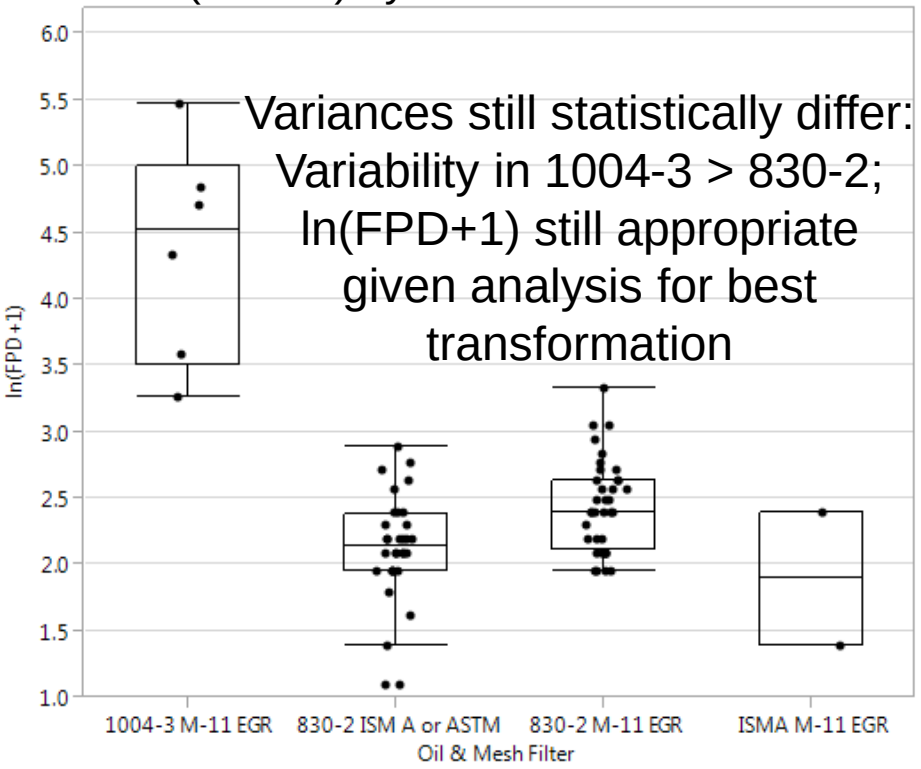
Filter Plugging Delta
Is a transformation warranted

LTMS Chart = Y; 86669-ISM removed; Matrix data included

FPD by oil & Mesh Filter Batch



Ln(FPD+1) by oil & Mesh Filter Batch



Oil & Mesh Filter	# of tests	Standard Deviation of FPD	Range of FPD	Standard Deviation of ln(FPD+1)	Range of ln(FPD+1)
1004-3 M-11 EGR	6	77.82	213	0.83	2.22
830-2 ISM A or ASTM	32	3.45	15	0.41	1.79
830-2 M-11 EGR	36	4.65	21	0.35	1.39
ISMA M-11 EGR	2	4.95	7	0.72	1.01

If a piecewise transformation is desired, then we would need to identify the cutoff(s)

Filter Plugging Delta

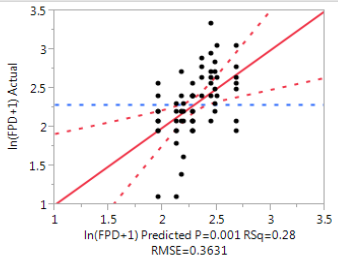
Correction Factor Calculation Example

LTMS Chart=Y Data; 86669-ISM Excluded;
If M-11 mesh filter used, then wire mesh test filter indicator = 0
If A or ASTM mesh filter used, then wire mesh test filter indicator = 1
63708-ISM wire mesh test filter indicator = 1

Response ln(FPD+1)

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.276853
RSquare Adj	0.218534
Root Mean Square Error	0.363126
Mean of Response	2.28919
Observations (or Sum Wgts)	68

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	3.129890	0.625978	4.7473
Error	62	8.175361	0.131861	Prob > F
C. Total	67	11.305250		0.0010*

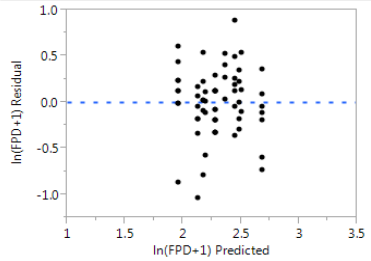
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	VIF
Intercept	2.3215874	0.047672	48.70	<.0001*	.
LTMSLAB[A]	-0.203085	0.074624	-2.72	0.0084*	1.5427304
LTMSLAB[B]	0.2019474	0.097805	2.06	0.0431*	1.804021
LTMSLAB[C]	0.0252172	0.116787	0.22	0.8298	2.0976341
LTMSLAB[D]	0.0098306	0.094158	0.10	0.9172	1.7441545
mesh filter indicator[0]	0.1574686	0.044405	3.55	0.0008*	1.013345

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LTMSLAB	4	4	1.3404303	2.5414	0.0485*
mesh filter indicator	1	1	1.6581904	12.5753	0.0008*

Residual by Predicted Plot



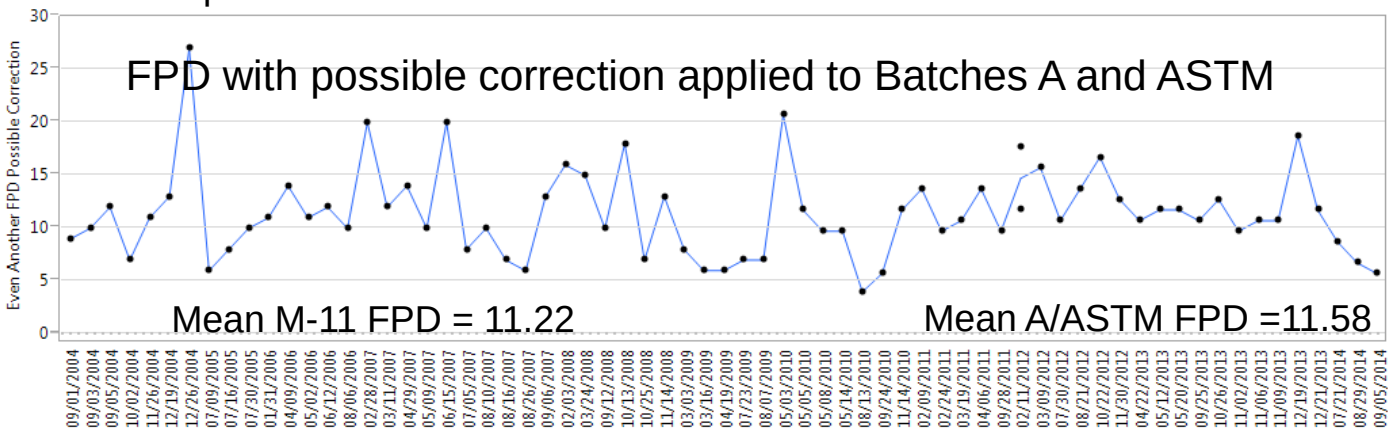
Expanded Estimates

Nominal factors expanded to all levels

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.3215874	0.047672	48.70	<.0001*
LTMSLAB[A]	-0.203085	0.074624	-2.72	0.0084*
LTMSLAB[B]	0.2019474	0.097805	2.06	0.0431*
LTMSLAB[C]	0.0252172	0.116787	0.22	0.8298
LTMSLAB[D]	0.0098306	0.094158	0.10	0.9172
LTMSLAB[G]	-0.03391	0.089016	-0.38	0.7045
mesh filter indicator[0]	0.1574686	0.044405	3.55	0.0008*
mesh filter indicator[1]	-0.157469	0.044405	-3.55	0.0008*

The model predicts ISM A/ASTM mean based on the transformed FPD data [ln(FPD+1)] = 2.16412 (7.71 in natural units)

LTMS mean = 2.5209 (11.44 in natural units)
This implies a correction factor of FPD + 3.73



Possible CFs for Filter Plugging Delta

CFs based on Wire Mesh Test Filter Batches

LTMS Chart = Y; 86669-ISM removed

If M-11 mesh filter used, then wire mesh test filter indicator = 0
If A or ASTM mesh filter used, then wire mesh test filter indicator = 1
63708-ISM wire mesh test filter indicator = 1

				Filter Plugging Delta CF
	Current			None
option 1	No Change			None
option 2	LTMS mean	vs.	Model Predicted Average of Mesh Filter ISM A/ASTM using ln(FPD +1)	ln(FPD+1) + 0.3568
option 3	exp(LTMS mean) - 1	vs.	exp(Model Predicted Average of Mesh Filter ISM A/ASTM using ln(FPD +1)) - 1	FPD + 3.73
option 4	exp(LTMS mean) - 1	vs.	exp(FPD Average of Mesh Filter ISM A/ASTM using ln(FPD +1)) - 1	FPD + 4.13

Option 3 (shown on prior slide):
(Back transformed LTMS mean) - (Back transformed model prediction for ISM A/ASTM)

Analysis done on transformed data: ln(FPD + 1);
Predicted average across labs obtained for ISM A/ASTM;
Prediction back transformed into natural units

Option 4:
(Back transformed LTMS mean) - (Back transformed data average for ISM A/ASTM)

Raw data transformed: ln(FPD + 1);
Average transFPD for ISM A/ASTM obtained;
Average was back transformed into natural units

CF options applied to test results using A/ASTM Batch

		Option 2	Option 3	Option 4
LTMS Target (natural units)	M-11 EGR Avg	A/ASTM Avg	A/ASTM Avg	A/ASTM Avg
11.44	11.22	11.8	11.7	12.1

If CF is rounded to FPD = 4, then A/ASTM Avg = 11.97
If CF is rounded to FPD = 3, then A/ASTM Avg = 10.97

Filter Plugging Delta

Test Precision

	Precision	Severity
Crosshead Weight Loss Adjusted to 3.9% Soot	Borderline lower since 2013	Slightly Mild since 2010
Filter Plugging Delta	OK	Bouncing in and out mild since 2010
Average Sludge Rating	OK	Slightly severe since 2012 but probably okay
Injector Screw Weight Loss Adjusted to 3.9% Soot	Borderline higher since 2013	OK

D7468 – 13

TABLE 6 Test Precision

Parameter[A]	Intermediate Precision (i.p.)	Reproducibility (R)
Average Sludge	0.35	0.40
Crosshead Mass Loss	3.8	4.2
Injector Adjusting Screw Mass Loss	14.9	14.9
Oil Filter Plugging Delta P (transformed units)	0.744	0.927

[A] Precision data are periodically updated and are available from the TMC.

13. Precision and Bias

13.1 *Precision*—Precision is based on operationally valid calibration test results monitored by the TMC. The research report contains industry data developed prior to the establishment of this test method.

13.1.1 *Intermediate Precision Conditions*—Conditions where test results are obtained with the same test method using the same test oil, with changing conditions such as operators, measuring equipment, test stands, test engines, and time.

ISM Reference Oil Targets

Oil	n	Effective Dates		X-Head Wear @ 3.9% Soot		OFDP[1]		Average Sludge		Injector Adj. Screw Wear @ 3.9% Soot	
		From	To[2]	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
830-2	7	9-1-04	11-30-05	4.8	1.4	2.5430	0.3936	9.04	0.20	30.0	7.0
	10	12-1-05	8-6-07	5.3	1.4	2.4342	0.3813	8.99	0.15	24.5	10.7
	21	8-7-07	***	5.1	1.5	2.5209	0.3274	9.00	0.15	29.5	5.7

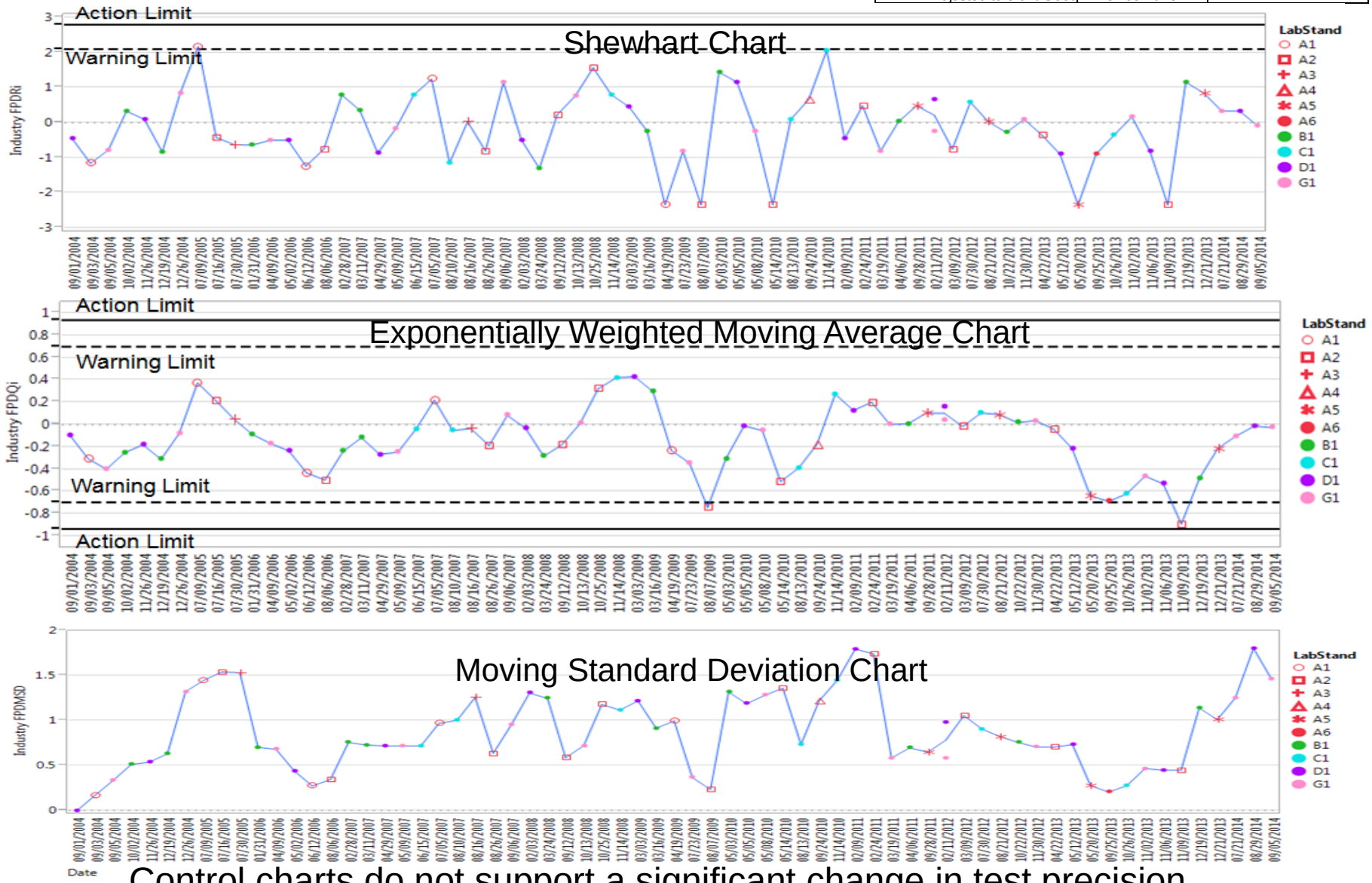
1 Transformation for OFDP is ln(OFDP+1)
2 *** = currently in effect

Filter Plugging Delta

LTMS charts for monitoring precision

86669-ISM removed

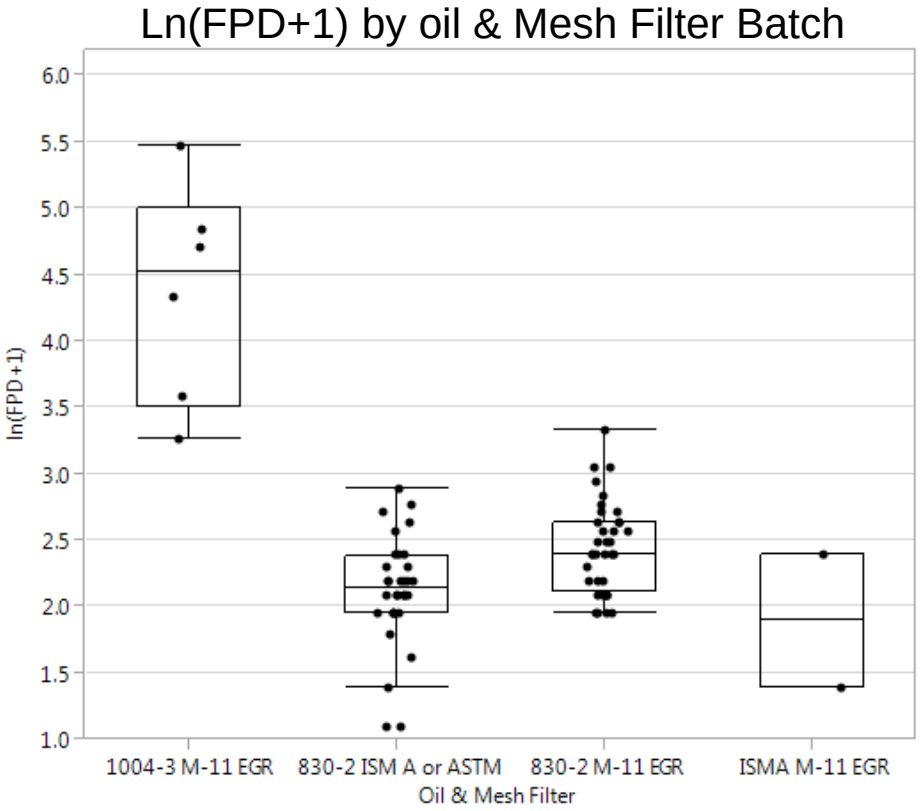
	Precision	Severity
Crosshead Weight Loss Adjusted to 3.9% Soot	Borderline lower since 2013	Slightly Mild since 2010
Filter Plugging Delta	OK	Bouncing in and out mild since 2010
Average Sludge Rating	OK	Slightly severe since 2012 but probably okay
Injector Screw Weight Loss Adjusted to 3.9% Soot	Borderline higher since 2013	OK



Control charts do not support a significant change in test precision

Filter Plugging Delta Precision

LTMS Chart = Y; 86669-ISM removed; Matrix data included



Variances statistically differ: Variability in 1004-3 > 830-2; ln(FPD+1) still appropriate given analysis for best transformation

Oil & Mesh Filter	# of tests	Standard Deviation of ln(FPD+1)	Range of ln(FPD+1)
1004-3 M-11 EGR	6	0.83	2.22
830-2 ISM A or ASTM	32	0.41	1.79
830-2 M-11 EGR	36	0.35	1.39
ISMA M-11 EGR	2	0.72	1.01

Filter Plugging Delta Precision

LTMS Chart = Y; 86669-ISM removed

Estimated s = 0.4323;
Matrix data included;
All four oil-filter batch combinations used

Response ln(FPD+1)

Whole Model

Summary of Fit

RSquare	0.679623
RSquare Adj	0.646643
Root Mean Square Error	0.432301
Mean of Response	2.442783
Observations (or Sum Wgts)	76

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Oil & Mesh Filter	3	3	24.628830	43.9289	<.0001*
LTMSLAB	4	4	0.740120	0.9901	0.4190

Expanded Estimates

Nominal factors expanded to all levels

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.7480502	0.098407	27.93	<.0001*
Oil & Mesh Filter[1004-3 M-11 EGR]	1.6377517	0.157199	10.42	<.0001*
Oil & Mesh Filter[830-2 ISM A or ASTM]	-0.596682	0.10881	-5.48	<.0001*
Oil & Mesh Filter[830-2 M-11 EGR]	-0.276997	0.106642	-2.60	0.0115*
Oil & Mesh Filter[ISMA M-11 EGR]	-0.764072	0.237241	-3.22	0.0020*
LTMSLAB[A]	-0.146191	0.084697	-1.73	0.0889
LTMSLAB[B]	0.1276252	0.109573	1.16	0.2482
LTMSLAB[C]	0.0359333	0.138962	0.26	0.7967
LTMSLAB[D]	0.0202076	0.112008	0.18	0.8574
LTMSLAB[G]	-0.037575	0.099156	-0.38	0.7059

Estimated s = 0.3631;
830-2 data only;
Mesh indicator = 1, then A/ASTM batch;
Mesh indicator = 0, then M-11 batch

Response ln(FPD+1)

Whole Model

Summary of Fit

RSquare	0.276853
RSquare Adj	0.218534
Root Mean Square Error	0.363126
Mean of Response	2.28919
Observations (or Sum Wgts)	68

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LTMSLAB	4	4	1.3404303	2.5414	0.0485*
mesh filter indicator	1	1	1.6581904	12.5753	0.0008*

Expanded Estimates

Nominal factors expanded to all levels

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.3215874	0.047672	48.70	<.0001*
LTMSLAB[A]	-0.203085	0.074624	-2.72	0.0084*
LTMSLAB[B]	0.2019474	0.097805	2.06	0.0431*
LTMSLAB[C]	0.0252172	0.116787	0.22	0.8298
LTMSLAB[D]	0.0098306	0.094158	0.10	0.9172
LTMSLAB[G]	-0.03391	0.089016	-0.38	0.7045
mesh filter indicator[0]	0.1574686	0.044405	3.55	0.0008*
mesh filter indicator[1]	-0.157469	0.044405	-3.55	0.0008*

Estimated s = 0.3696;
830-2 data only;
Only A/ASTM filter mesh batch

Response ln(FPD+1)

Whole Model

Summary of Fit

RSquare	0.306672
RSquare Adj	0.203957
Root Mean Square Error	0.369645
Mean of Response	2.117129
Observations (or Sum Wgts)	32

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LTMSLAB	4	4	1.6318113	2.9857	0.0366*

Expanded Estimates

Nominal factors expanded to all levels

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.168062	0.070152	30.91	<.0001*
LTMSLAB[A]	-0.119702	0.11124	-1.08	0.2914
LTMSLAB[B]	0.5069163	0.159427	3.18	0.0037*
LTMSLAB[C]	-0.12089	0.159427	-0.76	0.4549
LTMSLAB[D]	-0.00704	0.136327	-0.05	0.9592
LTMSLAB[G]	-0.259284	0.128969	-2.01	0.0545

Filter Plugging Delta
Possible Precision Estimates

All estimates calculated in natural log units

		Estimated s ln(FPD+1)	Estimated s ln(FPD+1) prior to A/ASTM batch ln((FPD+4)+1) for A/ASTM batch
No Change		0.3274	
Predictive model error (with lab effect)	LTMS Chart = Y; 86669-ISM removed; plus matrix data	0.4323	0.3796
Predictive model error (no lab effect)	LTMS Chart = Y; 86669-ISM removed; plus matrix data	0.4322	0.3787
Predictive model error (with lab effect)	LTMS Chart = Y; 86669-ISM removed; only M-11 and A/ASTM Batches	0.3631	0.2945
Predictive model error (no lab effect)	LTMS Chart = Y; 86669-ISM removed; only M-11 and A/ASTM Batches	0.3797	0.3112
Predictive model error (with lab effect)	LTMS Chart = Y; 86669-ISM removed; only A/ASTM batch	0.3696	0.2279
Transformed data	Chart=Y; All 32 results using A/ASTM Batch; 86669-ISM removed	0.4143	0.2663
Transformed data	Last 30 Chart=Y results using A/ASTM Batch; 86669-ISM removed	0.4023	0.2539
Transformed data	Last 25 Chart=Y results using A/ASTM Batch; 86669-ISM removed	0.3720	0.2402
Transformed data	Last 20 Chart=Y results using A/ASTM Batch; 86669-ISM removed	0.4046	0.2599
Transformed data	Last 15 Chart=Y results using A/ASTM Batch; 86669-ISM removed	0.4207	0.2651
EWMA transformed data	Last 15 Chart=Y results using A/ASTM Batch; 86669-ISM removed	0.2962	0.2012
Transformed data	Last 10 Chart=Y results using A/ASTM Batch	0.4684	0.2915
EWMA transformed data	Last 10 Chart=Y results using A/ASTM Batch	0.2988	0.2019
Transformed data	Last 5 Chart=Y results using A/ASTM Batch	0.6623	0.4178
EWMA transformed data	Last 5 Chart=Y results using A/ASTM Batch	0.3739	0.2518

Predictive model error – estimated standard deviation using model residual error

- Estimates calculated without lab effect to align with ASTM intermediate precision conditions; these are pooled estimates across hardware batches

Transformed data – estimated standard deviation using transformed raw data

- Historical transformation = ln(FPD+1)
- If shorter term estimates are used, then we should consider updating them in the future

EWMA transformed data – additional option for shorter term estimates of s; exponentially weighted moving average of the standard deviation (λ= 0.2)

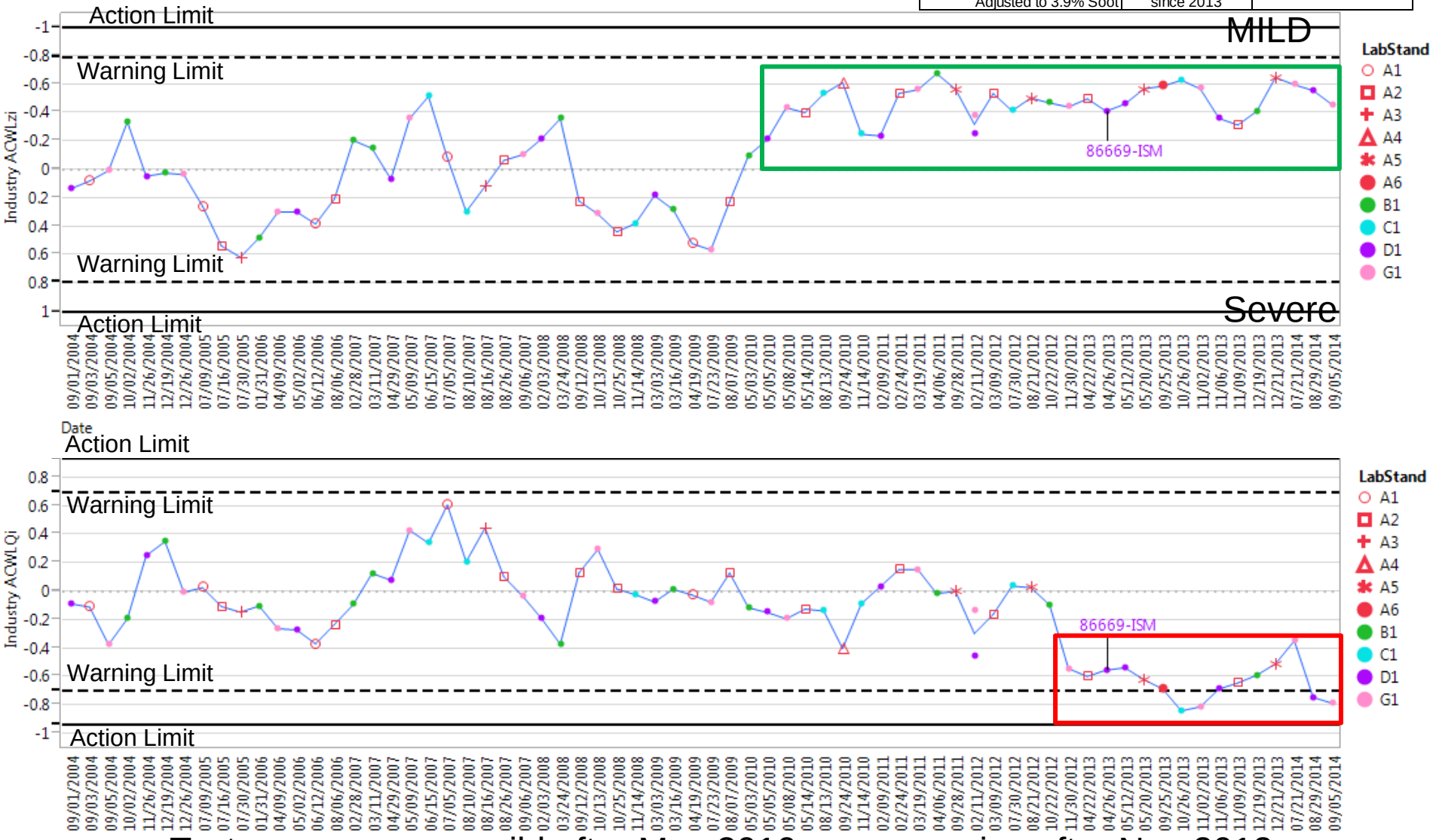
For each option the standard deviation is estimated using

- ln(FPD+1): historical transformation
- ln(FPD+1) & ln((FPD+4)+1): ln(FPD+1) results prior to A/ASTM; ln((FPD+4)+1) A/ASTM results (example of CF applied)

Crosshead Wt Loss

LTMS Control Charts

	Precision	Severity
Crosshead Weight Loss Adjusted to 3.9% Soot	Borderline lower since 2013	Slightly Mild since 2010
Filter Plugging Delta	OK	Bouncing in and out mild since 2010
Average Sludge Rating	OK	Slightly severe since 2012 but probably okay
Injector Screw Weight Loss Adjusted to 3.9% Soot	Borderline higher since 2013	OK

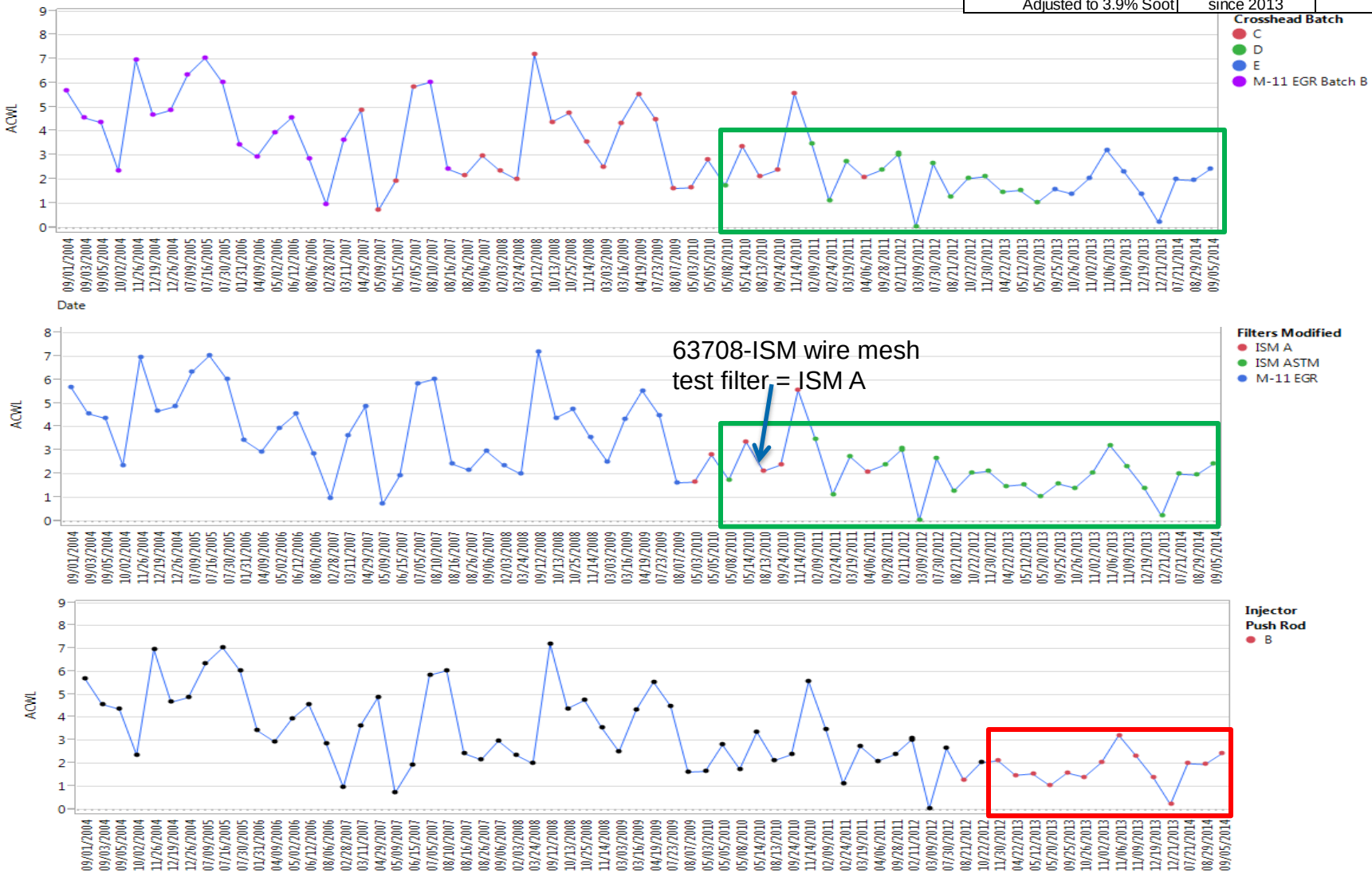


Test appears more mild after May 2010; more precise after Nov 2012.
Does this warrant a change to the current correction factor?

Crosshead Wt Loss

	Precision	Severity
Crosshead Weight Loss Adjusted to 3.9% Soot	Borderline lower since 2013	Slightly Mild since 2010
Filter Plugging Delta	OK	Bouncing in and out mild since 2010
Average Sludge Rating	OK	Slightly severe since 2012 but probably okay
Injector Screw Weight Loss Adjusted to 3.9% Soot	Borderline higher since 2013	OK

LTMS Chart=Y Data; 86669-ISM Removed



ACWL appears mild and more precise when crosshead batch D & E, ISM ASTM filter, or push rod B utilized.

Does it make sense that any of these hardware changes affect test severity?

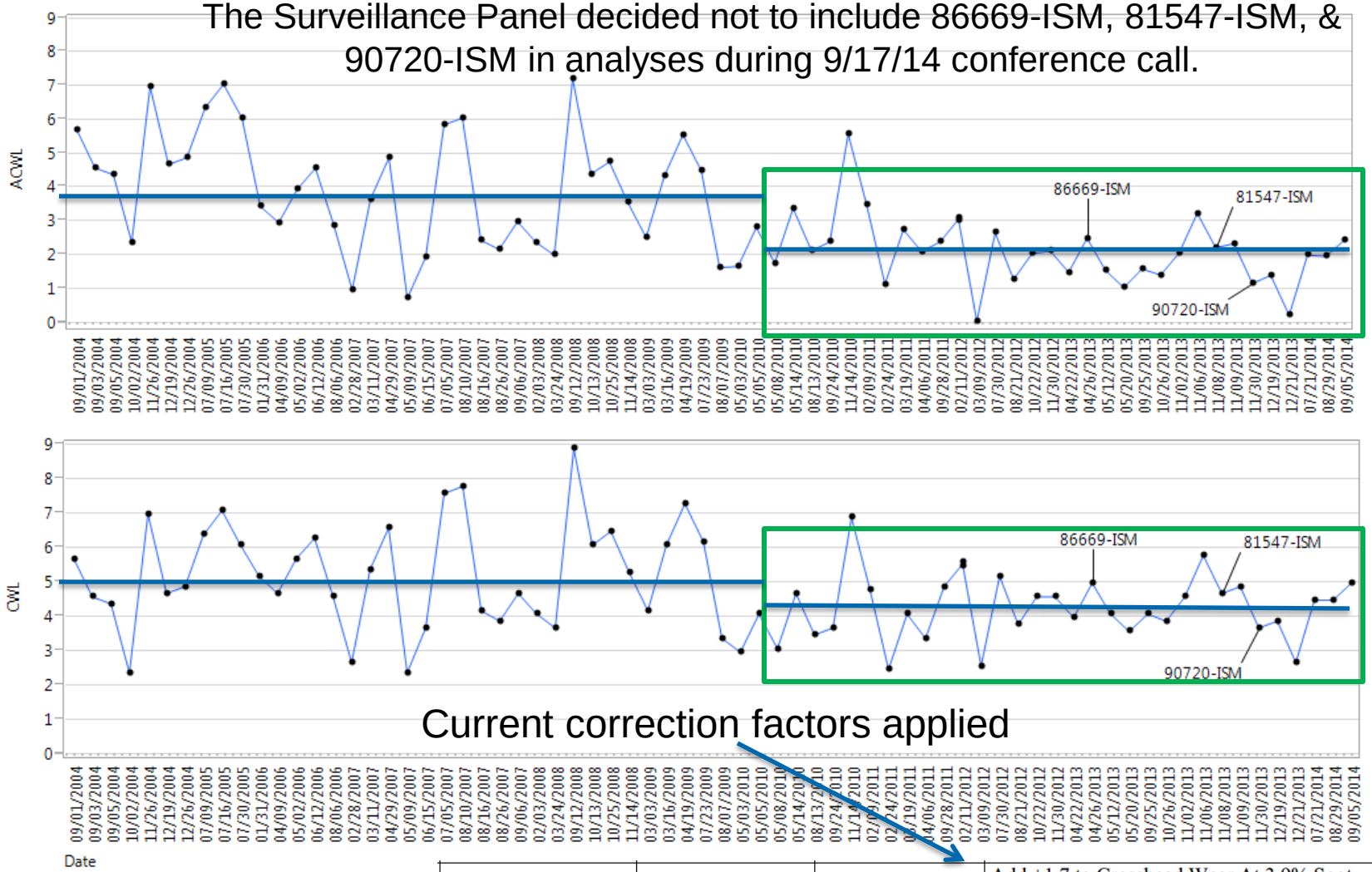
Is test precision due to hardware change or simply a function of the ACWL scale?

Crosshead Wt Loss

LTMS Chart=Y Data + Other possible test results

	Precision	Severity
Crosshead Weight Loss Adjusted to 3.9% Soot	Borderline lower since 2013	Slightly Mild since 2010
Filter Plugging Delta	OK	Bouncing in and out mild since 2010
Average Sludge Rating	OK	Slightly severe since 2012 but probably okay
Injector Screw Weight Loss Adjusted to 3.9% Soot	Borderline higher since 2013	OK

The Surveillance Panel decided not to include 86669-ISM, 81547-ISM, & 90720-ISM in analyses during 9/17/14 conference call.



Current correction factors applied

June 28, 2007	***	All Tests	Add +1.7 to Crosshead Wear At 3.9% Soot Add +19.1 to Injector Adjusting Screw Wear At 3.9% Soot
March 4, 2010	***	All Tests	Add +1.3 to Crosshead Wear At 3.9% Soot
April 30, 2011	***	All Tests	Add +2.5 to Crosshead Wear At 3.9% Soot

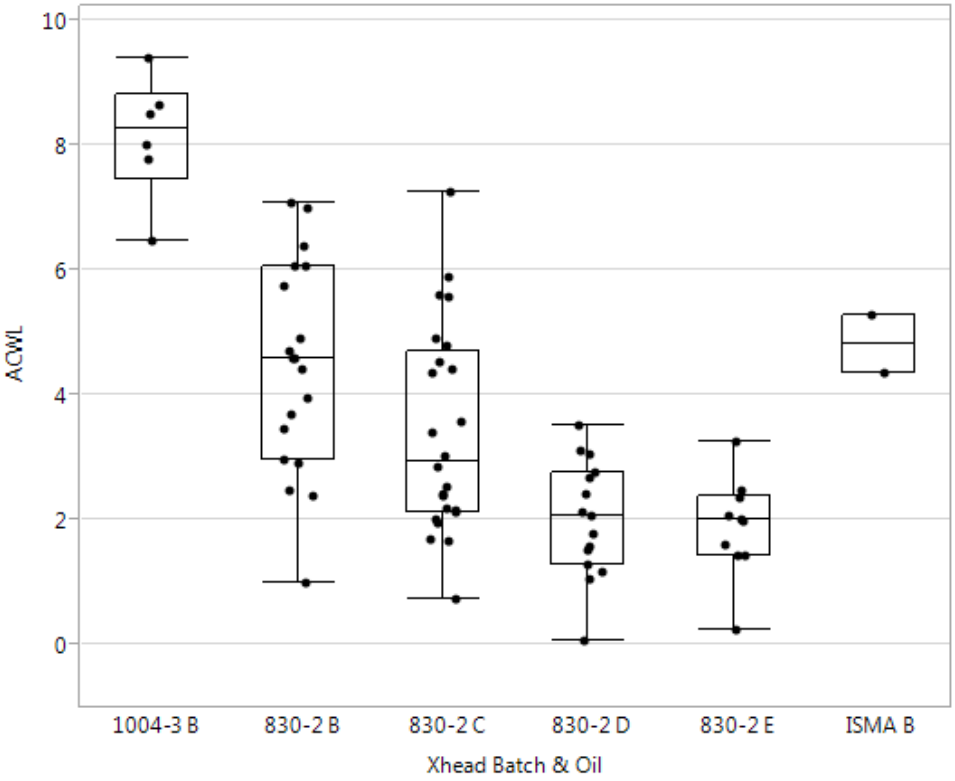
Crosshead Wt Loss

Is a transformation warranted

LTMS Chart=Y Data + Matrix Data;

86669-ISM Removed

	Precision	Severity
Crosshead Weight Loss Adjusted to 3.9% Soot	Borderline lower since 2013	Slightly Mild since 2010
Filter Plugging Delta	OK	Bouncing in and out mild since 2010
Average Sludge Rating	OK	Slightly severe since 2012 but probably okay
Injector Screw Weight Loss Adjusted to 3.9% Soot	Borderline higher since 2013	OK



Variances significantly differ;
no systematic change over ACWL range:
Differences: 830-2 B & C have larger variability than 830-2 D & E

Analysis indicates SQRT(ACWL) or no transformation as appropriate

No transformation reasonable since change in variability doesn't depend on ACWL scale

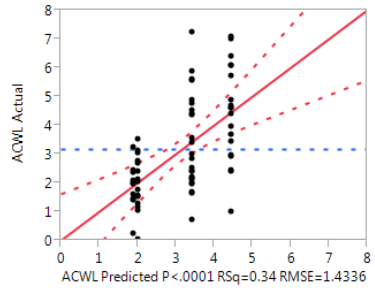
Crosshead Weight Loss

LTMS Chart=Y Data; 86669-ISM Excluded

Response ACWL

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.343357
RSquare Adj	0.312577
Root Mean Square Error	1.433614
Mean of Response	3.167379
Observations (or Sum Wgts)	68

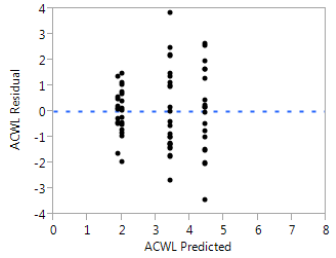
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	VIF
Intercept	2.9383011	0.183089	16.05	<.0001*	.
Crosshead Batch[C]	0.4779489	0.276296	1.73	0.0885	1.5835208
Crosshead Batch[D]	-0.926968	0.319422	-2.90	0.0051*	1.6762029
Crosshead Batch[E]	-1.053301	0.369167	-2.85	0.0058*	1.8440116

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Crosshead Batch	3	3	68.779827	11.1551	<.0001*

Residual by Predicted Plot

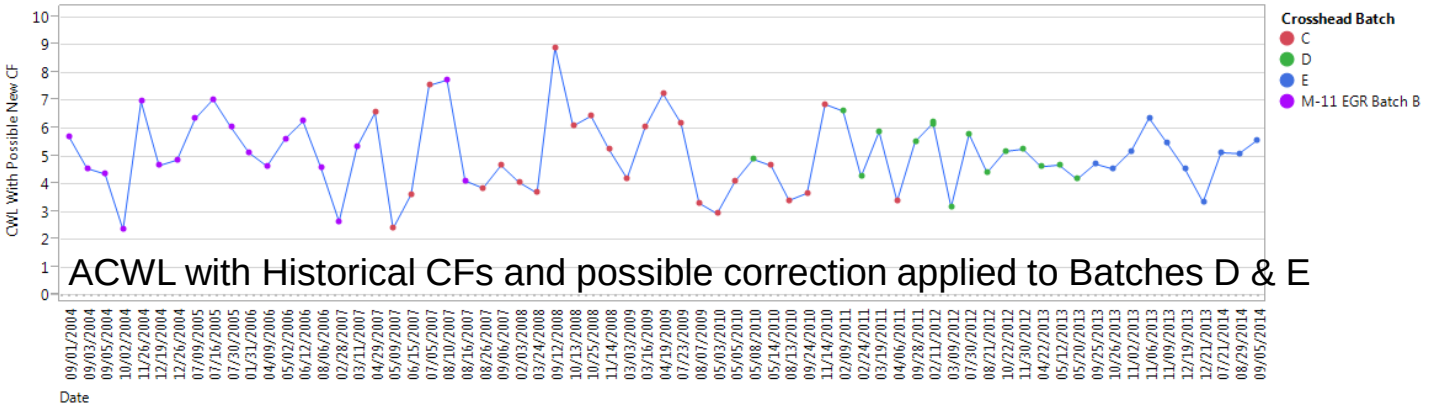


Expanded Estimates

Nominal factors expanded to all levels

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.9383011	0.183089	16.05	<.0001*
Crosshead Batch[C]	0.4779489	0.276296	1.73	0.0885
Crosshead Batch[D]	-0.926968	0.319422	-2.90	0.0051*
Crosshead Batch[E]	-1.053301	0.369167	-2.85	0.0058*
Crosshead Batch[M-11 EGR Batch B	1.50232	0.295985	5.08	<.0001*

Based on the model, we obtain a CF of ACWL + 3.15
Correction based on matching average of D & E to LTMS Target



ACWL with Historical CFs and possible correction applied to Batches D & E

June 28, 2007	***	All Tests	Add +1.7 to Crosshead Wear At 3.9% Soot Add +19.1 to Injector Adjusting Screw Wear At 3.9% Soot
March 4, 2010	***	All Tests	Add +1.3 to Crosshead Wear At 3.9% Soot
April 30, 2011	***	All Tests	Add +2.5 to Crosshead Wear At 3.9% Soot

Possible CFs for Cross Head Weight Loss Adjusted to 3.9% Soot

LTMS Chart=Y; 86669-ISM Excluded

		Crosshead Weight Loss
	Current	ACWL + 2.5
option 1	No Change	ACWL + 2.5
option 2	(LTMS mean) - (Model Predicted Average of Xhead Batches D&E)	ACWL + 3.15
option 3	(LTMS mean) - (Model Predicted Average of Xhead Batches E)	ACWL + 3.215
option 4	(LTMS mean) - (Average of Xhead Batches D&E)	ACWL + 3.14
option 5	(LTMS mean) - (Average of Xhead Batches E)	ACWL + 3.215

All calculations done in natural units

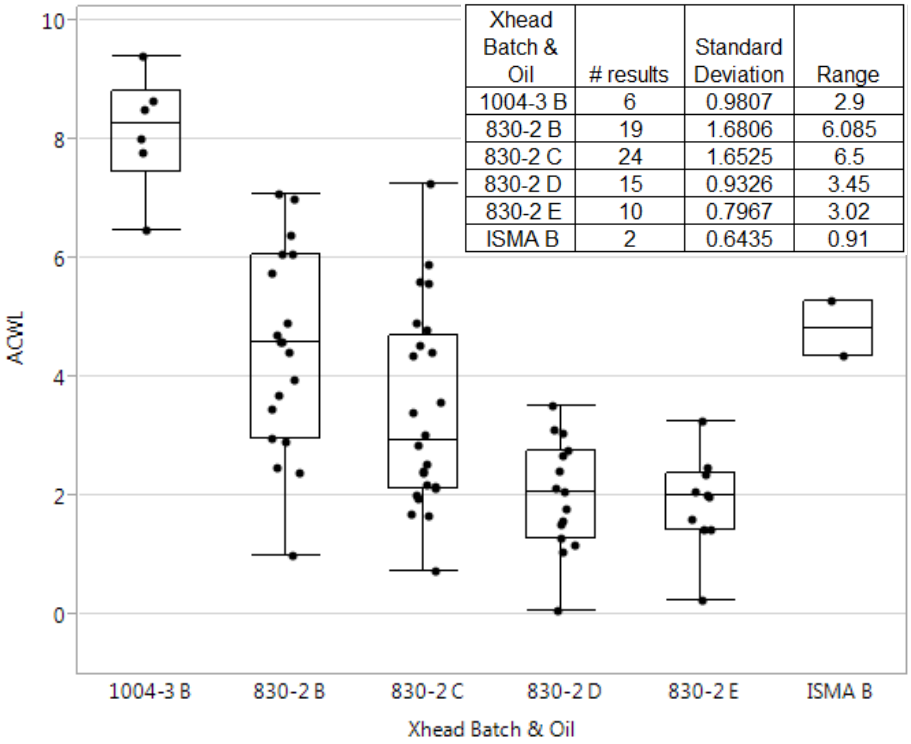
Other possible correction factors could be based on wire mesh test filter changes

Crosshead Wt Loss

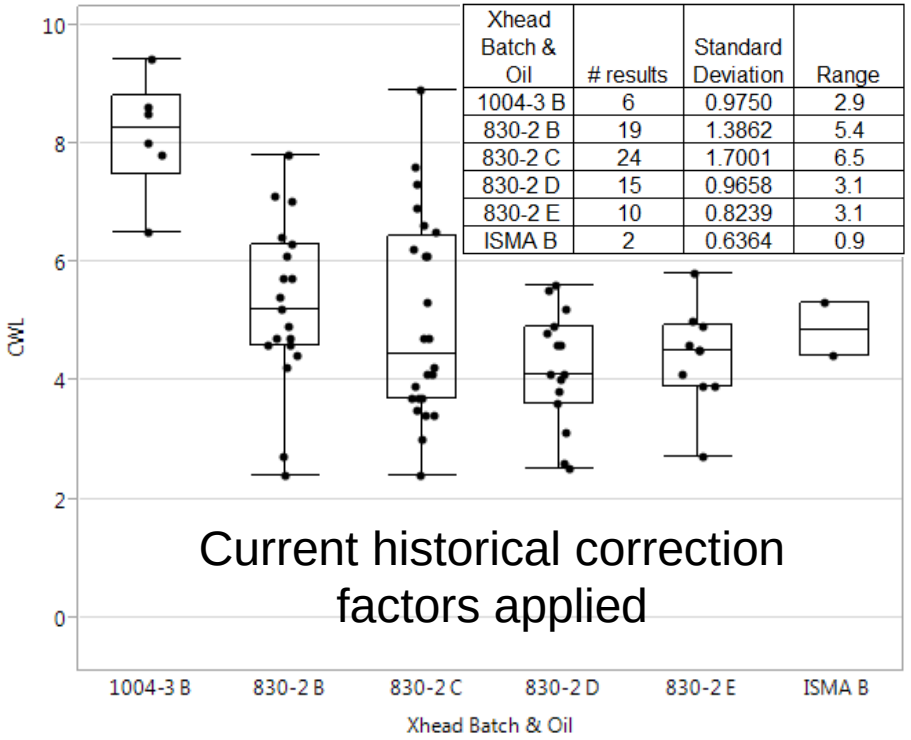
	Precision	Severity
Crosshead Weight Loss Adjusted to 3.9% Soot	Borderline lower since 2013	Slightly Mild since 2010
Filter Plugging Delta	OK	Bouncing in and out mild since 2010
Average Sludge Rating	OK	Slightly severe since 2012 but probably okay
Injector Screw Weight Loss Adjusted to 3.9% Soot	Borderline higher since 2013	OK

Precision

LTMS Chart=Y Data + Matrix Data; 86669-ISM Removed



Xhead Batch & Oil	# results	Standard Deviation	Range
1004-3 B	6	0.9807	2.9
830-2 B	19	1.6806	6.085
830-2 C	24	1.6525	6.5
830-2 D	15	0.9326	3.45
830-2 E	10	0.7967	3.02
ISMA B	2	0.6435	0.91



Xhead Batch & Oil	# results	Standard Deviation	Range
1004-3 B	6	0.9750	2.9
830-2 B	19	1.3862	5.4
830-2 C	24	1.7001	6.5
830-2 D	15	0.9658	3.1
830-2 E	10	0.8239	3.1
ISMA B	2	0.6364	0.9

Current historical correction factors applied

Batches D & E have lower variability than target

Oil	n	Effective Dates From	Effective Dates To[2]	X-Head Wear @ 3.9% Soot $\bar{X}$	X-Head Wear @ 3.9% Soot s
830-2	7	9-1-04	11-30-05	4.8	1.4
	10	12-1-05	8-6-07	5.3	1.4
	21	8-7-07	***	5.1	1.5

Adjustment to test precision needs to be done using CWL

Crosshead Wt Loss
Possible Precision Estimates

	Pooled Estimated for s using CWL	Pooled Estimated for s using CWL with new possible CF
LTMS Chart = Y; 86669-ISM removed; plus matrix data (i.e. all Xhead-oil combos included)	1.3384	1.3025
LTMS Chart = Y; 86669-ISM removed; only Xhead batches D & E	0.9129	0.7778
LTMS Chart = Y; 86669-ISM removed; only Xhead batches E	0.8239	0.7967
LTMS Chart = Y; 86669-ISM removed; only injector push rod B	0.7138	0.6977

Where CWL with new possible CF:

June 28, 2007	***	All Tests	Add +1.7 to Crosshead Wear At 3.9% Soot Add +19.1 to Injector Adjusting Screw Wear At 3.9% Soot
March 4, 2010	***	All Tests	Add +1.3 to Crosshead Wear At 3.9% Soot
April 30, 2011	***	All Tests	Add +2.5 to Crosshead Wear At 3.9% Soot

Add 3.15 to Xhead Batches D&E

Standard deviation by Xhead batch & oil

Xhead Batch & Oil	# results	Standard Deviation (CWL)	Standard Deviation (CWL with new possible CF)
1004-3 B	6	0.9750	0.9853
830-2 B	19	1.3862	1.2701
830-2 C	24	1.7001	1.7012
830-2 D	15	0.9658	0.9326
830-2 E	10	0.8239	0.7967
ISMA B	2	0.6364	0.6435

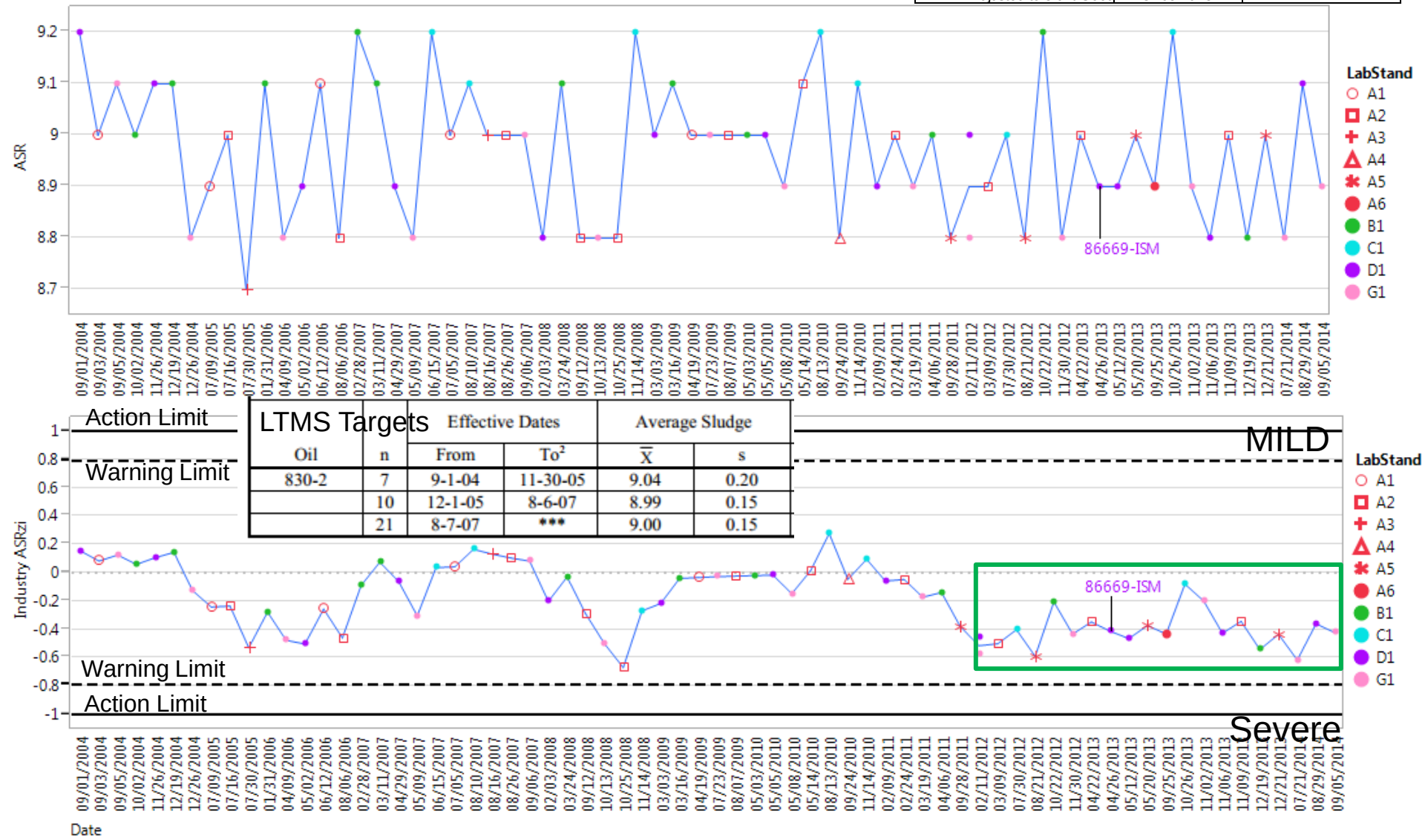
Standard deviation by Injector Push Rod & oil

Injector Push Rod & Oil	# results	Standard Deviation (CWL)	Standard Deviation (CWL with new possible CF)
1004-3 B4 B	6	0.9750	0.9853
830-2 B	15	0.7138	0.6977
830-2 B4 B	53	1.5161	1.4466
ISMA B4 B	2	0.6364	0.6435

Average Sludge Rating

	Precision	Severity
Crosshead Weight Loss Adjusted to 3.9% Soot	Borderline lower since 2013	Slightly Mild since 2010
Filter Plugging Delta	OK	Bouncing in and out mild since 2010
Average Sludge Rating	OK	Slightly severe since 2012 but probably okay
Injector Screw Weight Loss Adjusted to 3.9% Soot	Borderline higher since 2013	OK

LTMS Control Charts

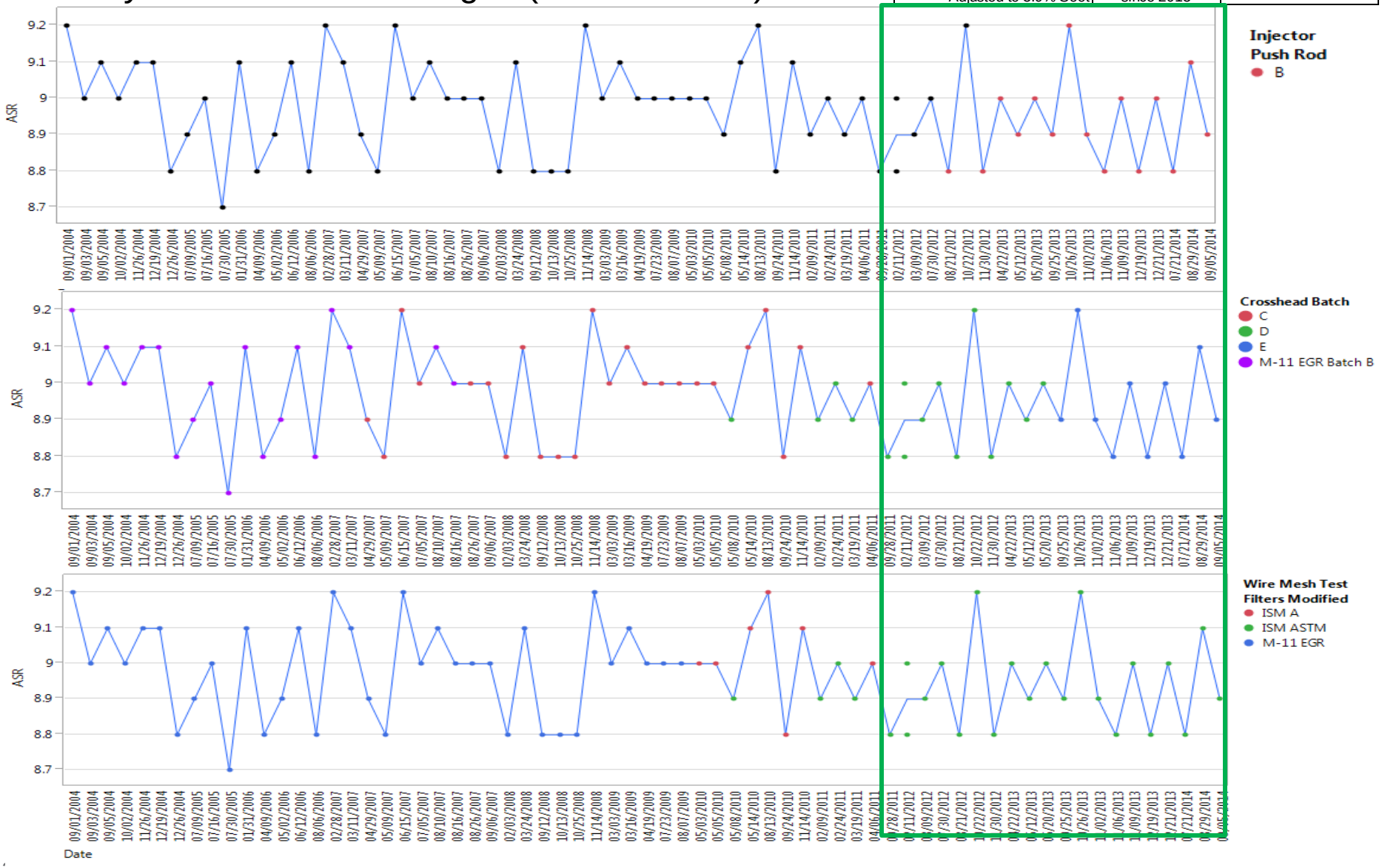


ASR appears slightly severe since Nov 2012. Does this constitute a correction factor?

Average Sludge Rating

The slightly severe trend in ASR does not line up exactly with hardware changes (Xhead is best)

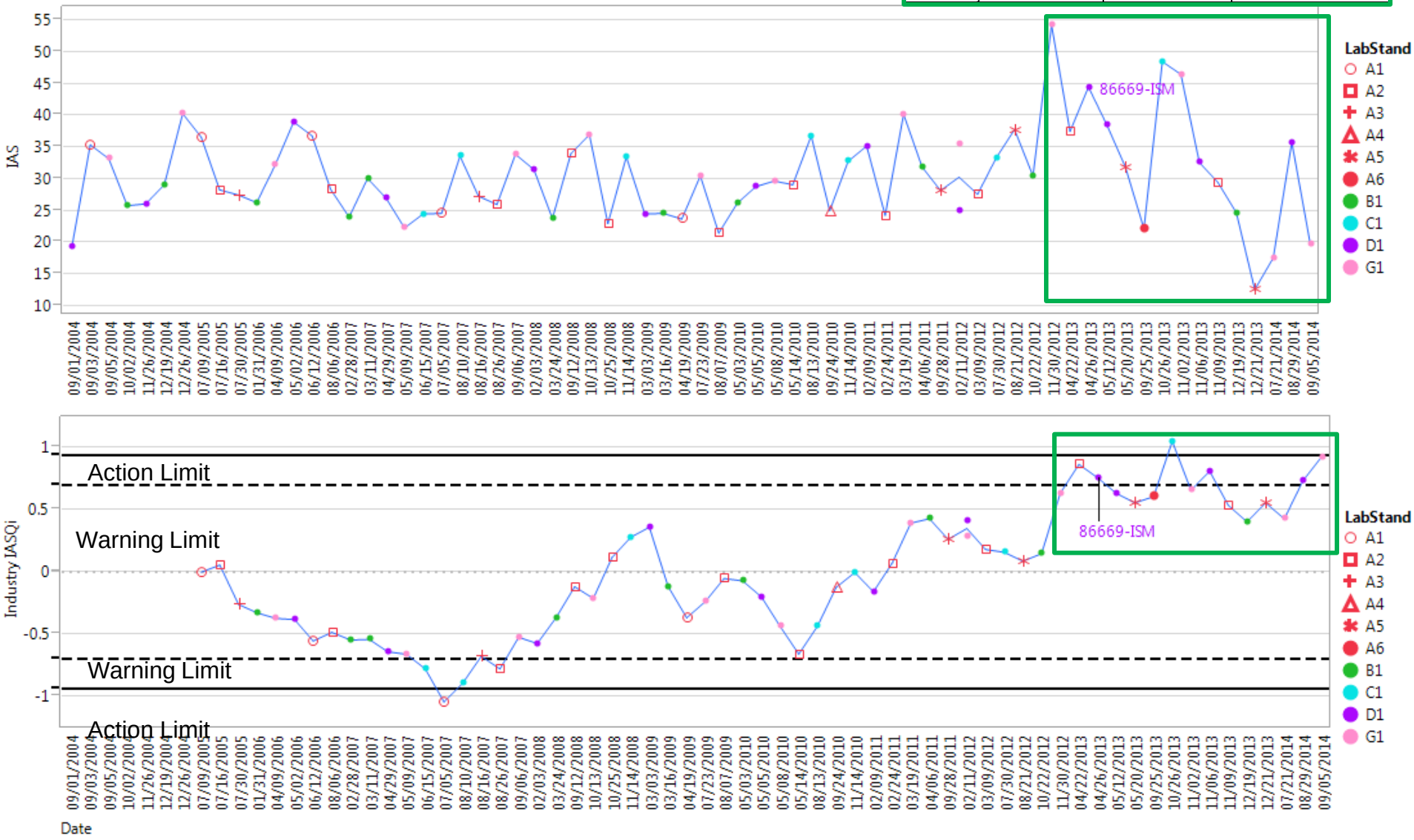
	Precision	Severity
Crosshead Weight Loss Adjusted to 3.9% Soot	Borderline lower since 2013	Slightly Mild since 2010
Filter Plugging Delta	OK	Bouncing in and out mild since 2010
Average Sludge Rating	OK	Slightly severe since 2012 but probably okay
Injector Screw Weight Loss Adjusted to 3.9% Soot	Borderline higher since 2013	OK



Injector Screw Weight Loss

LTMS Control Charts

	Precision	Severity
Crosshead Weight Loss Adjusted to 3.9% Soot	Borderline lower since 2013	Slightly Mild since 2010
Filter Plugging Delta	OK	Bouncing in and out mild since 2010
Average Sludge Rating	OK	Slightly severe since 2012 but probably okay
Injector Screw Weight Loss Adjusted to 3.9% Soot	Borderline higher since 2013	OK

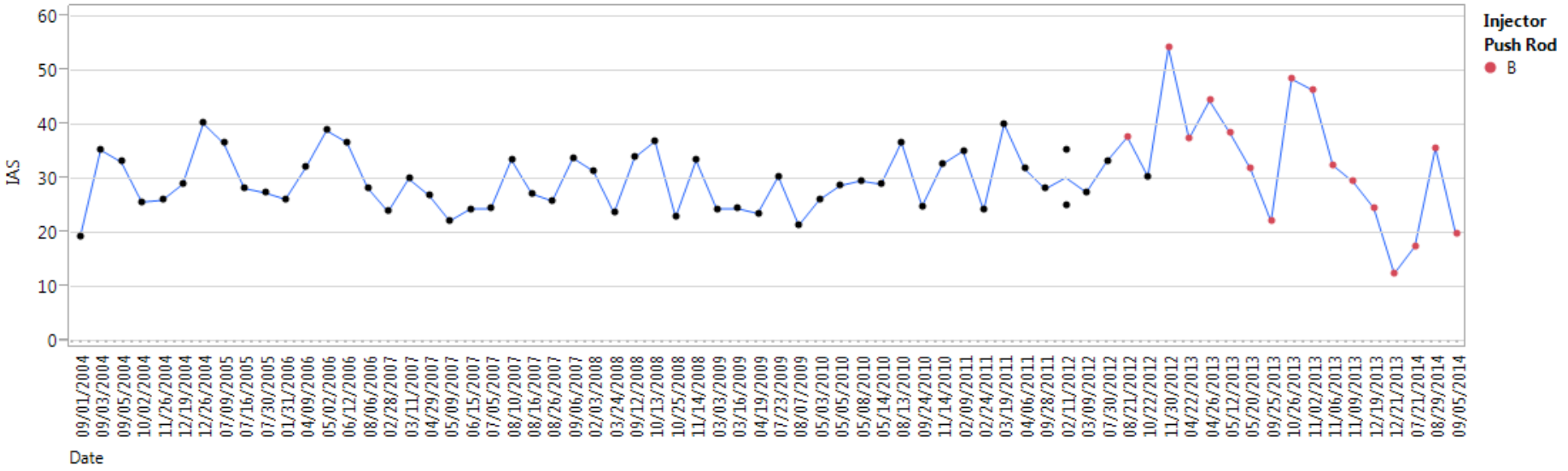


Corrected SAIAS has more variability since Nov 2012.

Injector Screw Weight Loss

LTMS Chart=Y Data

	Precision	Severity
Crosshead Weight Loss Adjusted to 3.9% Soot	Borderline lower since 2013	Slightly Mild since 2010
Filter Plugging Delta	OK	Bouncing in and out mild since 2010
Average Sludge Rating	OK	Slightly severe since 2012 but probably okay
Injector Screw Weight Loss Adjusted to 3.9% Soot	Borderline higher since 2013	OK

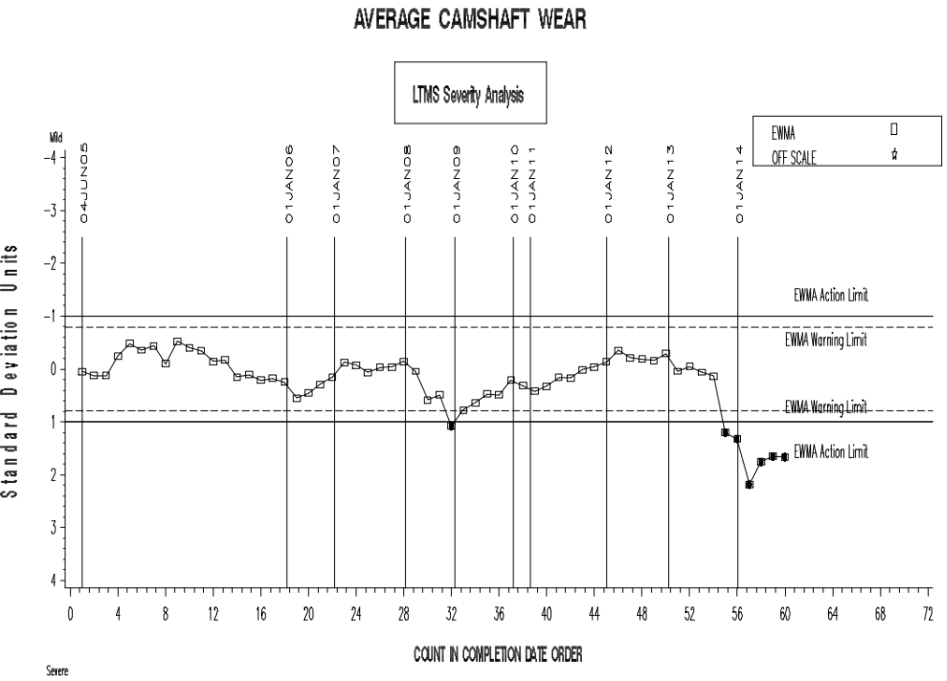


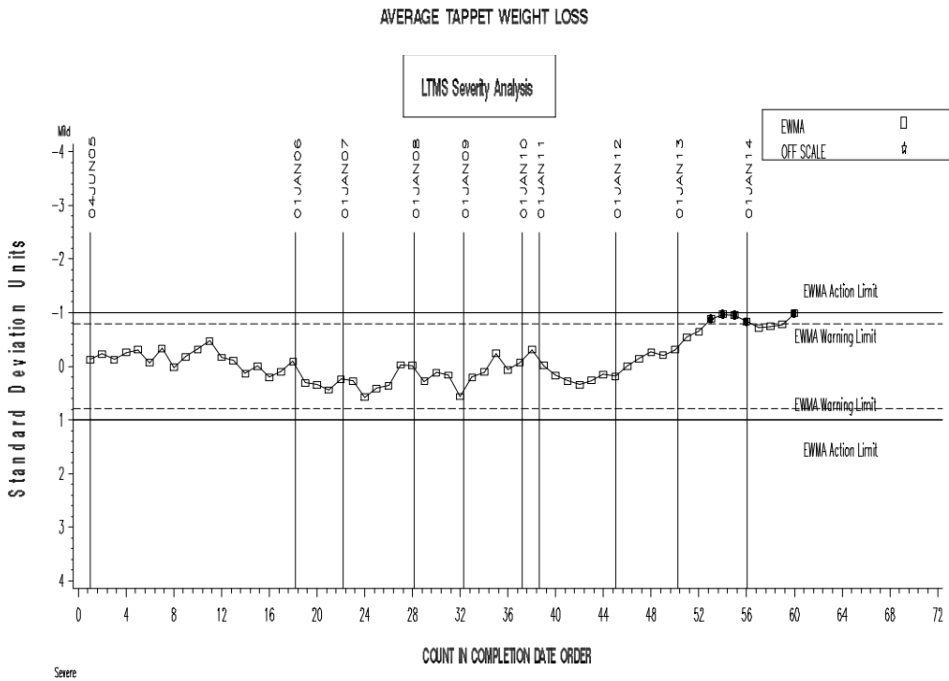
The increase in corrected SAIAS variability corresponds with use of injector push rod B

Current 830-2 standard deviation target = 5.7 (LTMS Appendix A)
Estimated standard deviation prior to the use of injector push rod B = 5.14
Estimated standard deviation when injector push rod B used = 11.87

Additional Topic:

1. Does the surveillance panel want to pursue an ISB CF analysis?





Previous Slides

Filter Plugging Delta

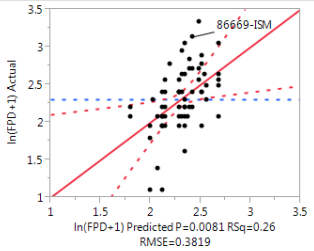
LTMS Chart=Y Data

Correction Factor Example: I arbitrarily assumed crosshead batch affects test severity and LTMS chart=Y

Response ln(FPD+1)

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.259346
RSquare Adj	0.174353
Root Mean Square Error	0.381886
Mean of Response	2.301456
Observations (or Sum Wgts)	69

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	3.115035	0.445005	3.0514
Error	61	8.896065	0.145837	Prob > F
C. Total	68	12.011100		0.0081*

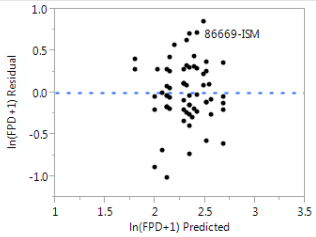
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	VIF
Intercept	2.3053107	0.052375	44.02	<.0001*	.
LTMSLAB[A]	-0.22071	0.07842	-2.81	0.0066*	1.5412712
LTMSLAB[B]	0.1799816	0.104433	1.72	0.0899	1.8598309
LTMSLAB[C]	0.005797	0.124059	0.05	0.9629	2.1412648
LTMSLAB[D]	0.0589054	0.096552	0.61	0.5441	1.7249784
Crosshead Batch[C]	0.0308035	0.074372	0.41	0.6802	1.6171099
Crosshead Batch[D]	0.057965	0.084128	0.69	0.4934	1.692232
Crosshead Batch[E]	-0.288934	0.098738	-2.93	0.0048*	1.8601723

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LTMSLAB	4	4	1.4504409	2.4864	0.0527
Crosshead Batch	3	3	1.5342908	3.5069	0.0205*

Residual by Predicted Plot



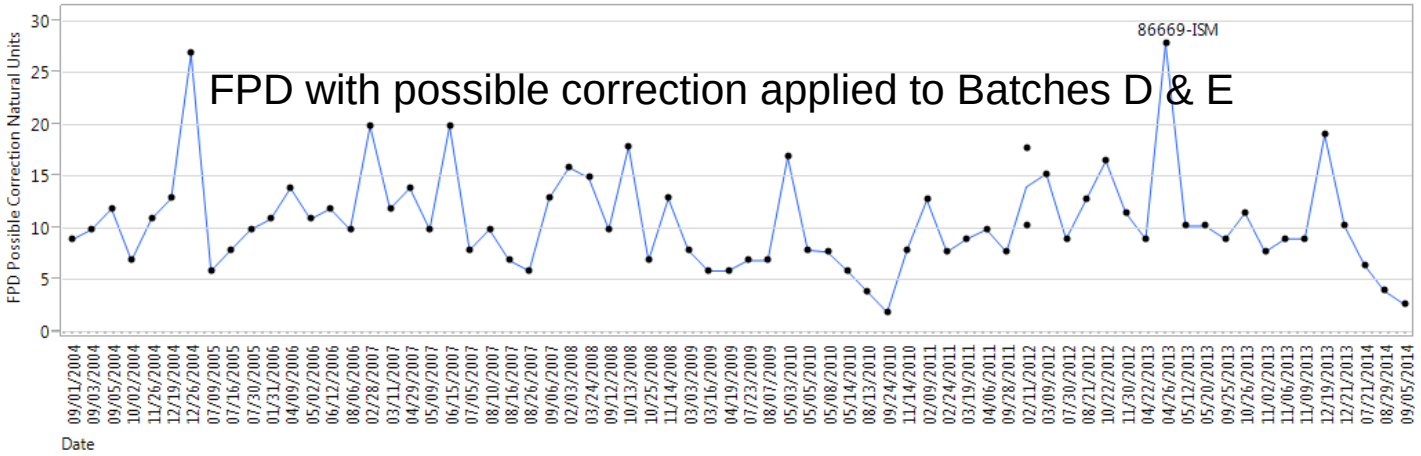
Expanded Estimates

Nominal factors expanded to all levels

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.3053107	0.052375	44.02	<.0001*
LTMSLAB[A]	-0.22071	0.07842	-2.81	0.0066*
LTMSLAB[B]	0.1799816	0.104433	1.72	0.0899
LTMSLAB[C]	0.005797	0.124059	0.05	0.9629
LTMSLAB[D]	0.0589054	0.096552	0.61	0.5441
LTMSLAB[G]	-0.023974	0.094402	-0.25	0.8004
Crosshead Batch[C]	0.0308035	0.074372	0.41	0.6802
Crosshead Batch[D]	0.057965	0.084128	0.69	0.4934
Crosshead Batch[E]	-0.288934	0.098738	-2.93	0.0048*
Crosshead Batch[M-11 EGR Batch B	0.200166	0.080386	2.49	0.0155*

Based on the model, we obtain a CF ln(FPD+1) + 0.231

Correction based on matching average of D & E to average of M-11 & C



Filter Plugging Delta

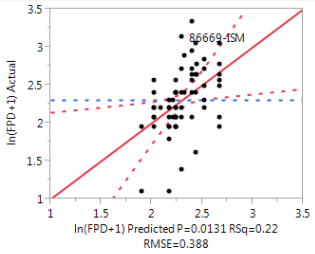
LTMS Chart=Y Data

Another Correction Factor Example: I arbitrarily assumed Wire Mesh Test Filters affect test severity and LTMS chart=Y

Response ln(FPD+1)

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.222927
RSquare Adj	0.147726
Root Mean Square Error	0.387995
Mean of Response	2.301456
Observations (or Sum Wgts)	69

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	2.677599	0.446266	2.9644
Error	62	9.333502	0.150540	Prob > F
C. Total	68	12.011100		0.0131*

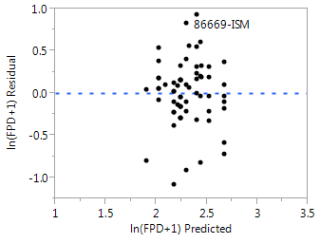
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	VIF
Intercept	2.2657263	0.064699	35.02	<.0001*	.
LTMSLAB[A]	-0.210574	0.079509	-2.65	0.0102*	1.5348675
LTMSLAB[B]	0.2150797	0.10581	2.03	0.0464*	1.8495532
LTMSLAB[C]	-0.017339	0.124704	-0.14	0.8899	2.0959625
LTMSLAB[D]	0.068126	0.097984	0.70	0.4895	1.7210164
Wire Mesh Test Filters[ISM A]	-0.154486	0.113315	-1.36	0.1777	2.4797413
Wire Mesh Test Filters[ISM ASTM]	-0.033998	0.079085	-0.43	0.6688	2.5445889

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LTMSLAB	4	4	1.5494257	2.5731	0.0463*
Wire Mesh Test Filters	2	2	1.0968540	3.6431	0.0319*

Residual by Predicted Plot



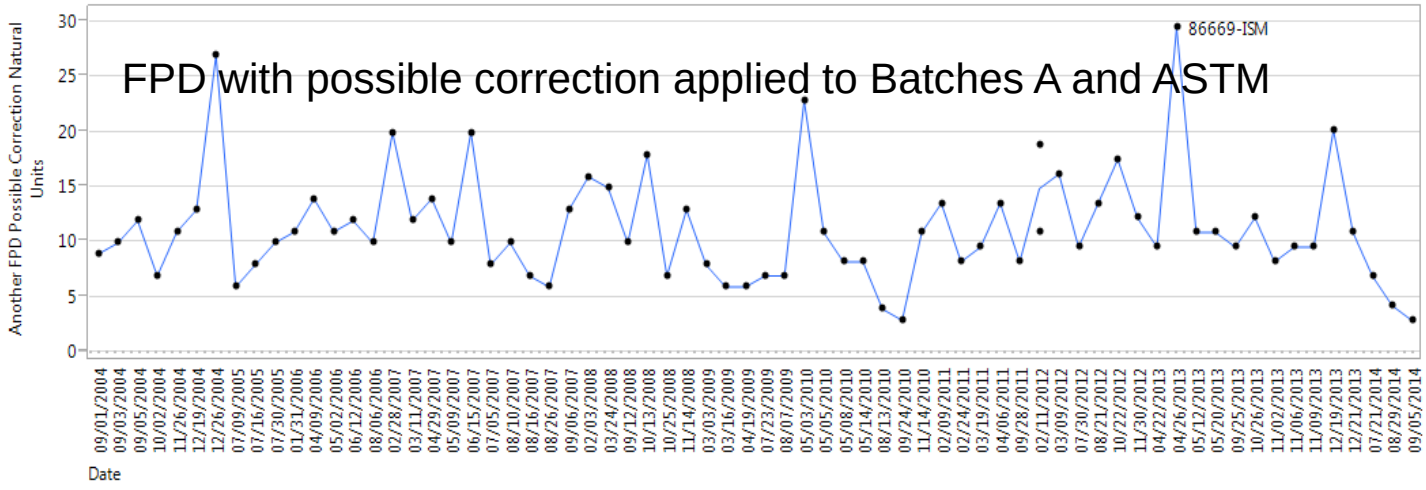
Expanded Estimates

Nominal factors expanded to all levels

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.2657263	0.064699	35.02	<.0001*
LTMSLAB[A]	-0.210574	0.079509	-2.65	0.0102*
LTMSLAB[B]	0.2150797	0.10581	2.03	0.0464*
LTMSLAB[C]	-0.017339	0.124704	-0.14	0.8899
LTMSLAB[D]	0.068126	0.097984	0.70	0.4895
LTMSLAB[G]	-0.055292	0.096878	-0.57	0.5702
Wire Mesh Test Filters[ISM A]	-0.154486	0.113315	-1.36	0.1777
Wire Mesh Test Filters[ISM ASTM]	-0.033998	0.079085	-0.43	0.6688
Wire Mesh Test Filters[M-11 EGR]	0.1884845	0.07256	2.60	0.0117*

Based on the model, we obtain a CF ln(FPD+1) + 0.2827

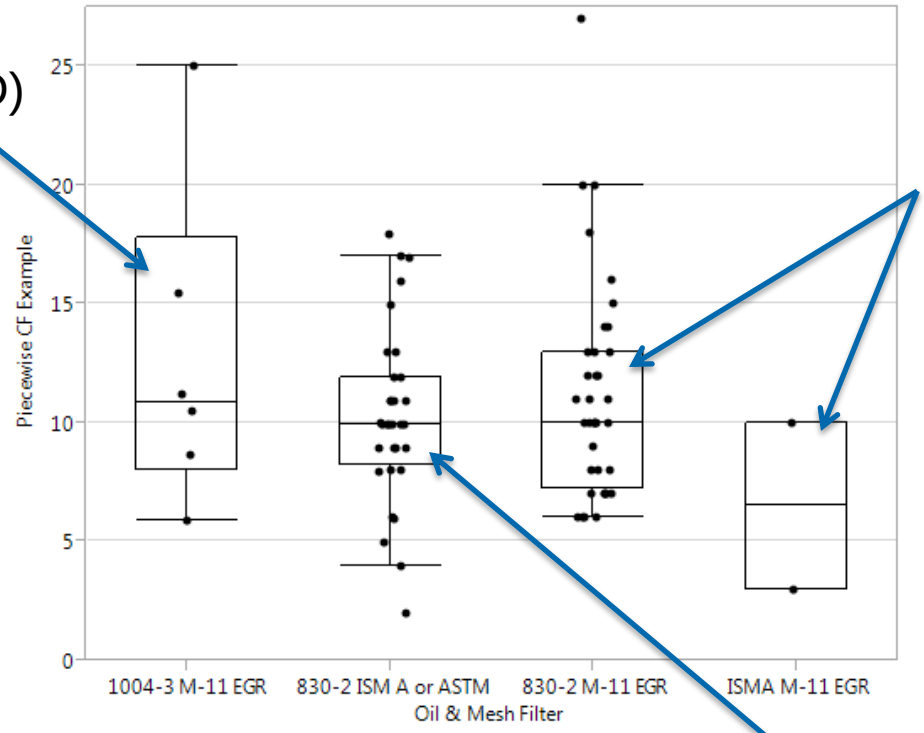
Correction based on matching average of A and ASTM to average of M-11



Filter Plugging Delta
Is a transformation warranted

LTMS Chart = Y; 86669-ISM removed; Matrix data included

Piecewise transformation example:



Transformation:

If FPD > 30, then sqrt(FPD),

If FPD ≤ 30, then FPD + 2.94 ← In graph, only 830-2 ISM A & ASTM adjusted where 2.94 is a possible CF estimate

This approach needs work if pursued; 1004-3 similar to 830-2 under this CF

Filter Plugging Delta

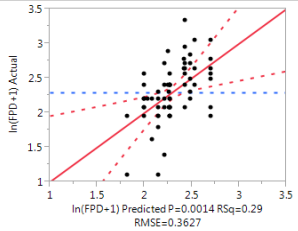
Correction Factor Calculation Example

LTMS Chart=Y Data minus 86669-ISM; 63708-ISM wire mesh test filter = ISM A

Response ln(FPD+1)

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.290274
RSquare Adj	0.220465
Root Mean Square Error	0.362677
Mean of Response	2.28919
Observations (or Sum Wgts)	68

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	3.281617	0.546936	4.1581
Error	61	8.023633	0.131535	Prob > F
C. Total	67	11.305250		0.0014*

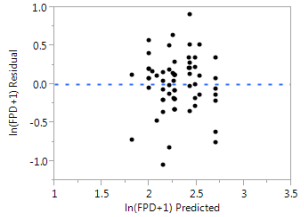
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	VIF
Intercept	2.2403721	0.057069	39.26	<.0001*	.
LTMSLAB[A]	-0.209883	0.074801	-2.81	0.0067*	1.5538572
LTMSLAB[B]	0.2159895	0.098555	2.19	0.0322*	1.8363383
LTMSLAB[C]	0.0493282	0.118783	0.42	0.6794	2.1753338
LTMSLAB[D]	0.0014187	0.094367	0.02	0.9881	1.7562527
Wire Mesh Test Filters Modified[ISM A]	-0.208316	0.100656	-2.07	0.0427*	2.3594973
Wire Mesh Test Filters Modified[ISM ASTM]	-0.033946	0.072446	-0.47	0.6410	2.3629734

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LTMSLAB	4	4	1.4494591	2.7549	0.0358*
Wire Mesh Test Filters Modified	2	2	1.8099181	6.8800	0.0020*

Residual by Predicted Plot



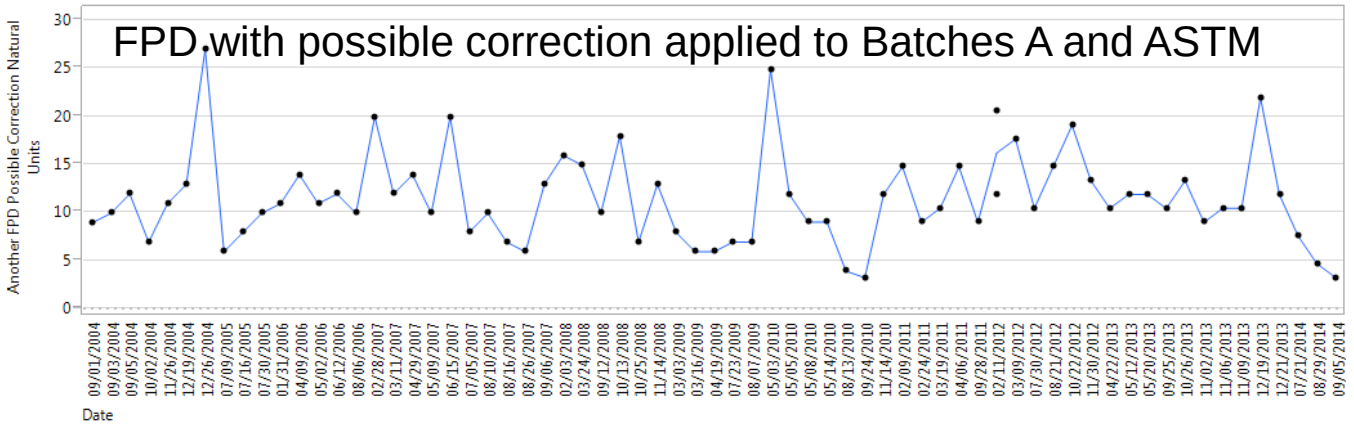
Expanded Estimates

Nominal factors expanded to all levels

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.2403721	0.057069	39.26	<.0001*
LTMSLAB[A]	-0.209883	0.074801	-2.81	0.0067*
LTMSLAB[B]	0.2159895	0.098555	2.19	0.0322*
LTMSLAB[C]	0.0493282	0.118783	0.42	0.6794
LTMSLAB[D]	0.0014187	0.094367	0.02	0.9881
LTMSLAB[G]	-0.056853	0.091436	-0.62	0.5364
Wire Mesh Test Filters Modified[ISM A]	-0.208316	0.100656	-2.07	0.0427*
Wire Mesh Test Filters Modified[ISM ASTM]	-0.033946	0.072446	-0.47	0.6410
Wire Mesh Test Filters Modified[M-11 EGR]	0.2422624	0.066344	3.65	0.0005*

Based on the model, we obtain a CF ln(FPD+1) + 0.3634

Correction based on matching average of A and ASTM to average of M-11



Possible CFs for Filter Plugging Delta

CFs based on Wire Mesh Test Filter Batches

LTMS Chart = Y; 86669-ISM removed

63708-ISM wire mesh test filter = ISM A

	Filter Plugging Delta
Current	ln(FPD+1)
No Change	ln(FPD+1)
Adjust based on average of Mesh Filter ISM A & ASTM versus M-11 EGR	ln(FPD+1) + 0.3634
Adjust based on average of Mesh Filter ISM A & ASTM versus M-11 EGR	FPD + 3.4
Adjust based on average of Mesh Filter ISM A & ASTM versus LTMS mean	ln(FPD+1) + 0.4017
Adjust based on average of Mesh Filter ISM A & ASTM versus LTMS mean	FPD + 3.16

63708-ISM wire mesh test filter = ISM ASTM

	Filter Plugging Delta
Current	ln(FPD+1)
No Change	ln(FPD+1)
Adjust based on average of Mesh Filter ISM A & ASTM versus M-11 EGR	ln(FPD+1) + 0.3341
Adjust based on average of Mesh Filter ISM A & ASTM versus M-11 EGR	FPD + 3.13
Adjust based on average of Mesh Filter ISM A & ASTM versus LTMS mean	ln(FPD+1) + 0.3757
Adjust based on average of Mesh Filter ISM A & ASTM versus LTMS mean	FPD + 2.91

If M-11 mesh filter used, then wire mesh test filter indicator = 0

If A or ASTM mesh filter used, then wire mesh test filter indicator = 1

63708-ISM wire mesh test filter indicator = 1

	Filter Plugging Delta
Current	ln(FPD+1)
No Change	ln(FPD+1)
Adjust based on average of Mesh Filter ISM A & ASTM versus M-11 EGR	ln(FPD+1) + 0.3149
Adjust based on average of Mesh Filter ISM A & ASTM versus M-11 EGR	FPD + 3.16
Adjust based on average of Mesh Filter ISM A & ASTM versus LTMS mean	ln(FPD+1) + 0.3568
Adjust based on average of Mesh Filter ISM A & ASTM versus LTMS mean	FPD + 2.94

Possible CFs for Filter Plugging Delta

63708-ISM wire mesh test filter = M11 EGR

CFs based on Crosshead Batches

	Data Used	Filter Plugging Delta
Current		None: ln(FPD+1)
No Change		None: ln(FPD+1)
Adjust based on average of Xhead D & E versus M-11 & C	830-2, LTMS Chart = Y	ln(FPD+1) + 0.231
Adjust based on average of Xhead D & E versus M-11 & C	830-2, LTMS Chart = Y minus 86669-ISM	ln(FPD+1) + 0.2538
Adjust based on average of Xhead D & E versus M-11 & C	830-2, LTMS Chart = Y, plus 81547-ISM, 90720-ISM, & 102544-ISM	ln(FPD+1) + 0.2498
Adjust based on average of Xhead D & E versus M-11 & C	830-2, LTMS Chart = Y minus 86669-ISM plus 81547-ISM, 90720-ISM, & 102544-ISM	ln(FPD+1) + 0.2732
Adjust based on average of Xhead D & E versus M-11	830-2, LTMS Chart = Y	ln(FPD+1) + 0.3157
Adjust based on average of Xhead D & E versus M-11	830-2, LTMS Chart = Y minus 86669-ISM	ln(FPD+1) + 0.3383
Adjust based on average of Xhead D & E versus M-11	830-2, LTMS Chart = Y, plus 81547-ISM, 90720-ISM, & 102544-ISM	ln(FPD+1) + 0.3333
Adjust based on average of Xhead D & E versus M-11	830-2, LTMS Chart = Y minus 86669-ISM plus 81547-ISM, 90720-ISM, & 102544-ISM	ln(FPD+1) + 0.3565
Adjust based on average of Xhead D & E versus LTMS mean	830-2, LTMS Chart = Y	ln(FPD+1) + 0.3311
Adjust based on average of Xhead D & E versus LTMS mean	830-2, LTMS Chart = Y minus 86669-ISM	ln(FPD+1) + 0.3564
Adjust based on average of Xhead D & E versus LTMS mean	830-2, LTMS Chart = Y, plus 81547-ISM, 90720-ISM, & 102544-ISM	ln(FPD+1) + 0.3521
Adjust based on average of Xhead D & E versus LTMS mean	830-2, LTMS Chart = Y minus 86669-ISM plus 81547-ISM, 90720-ISM, & 102544-ISM	ln(FPD+1) + 0.378

CFs based on Wire Mesh Test Filter Batches

	Data Used	Filter Plugging Delta
Current		None: ln(FPD+1)
No Change		None: ln(FPD+1)
Adjust based on average of Mesh Filter ISM A & ASTM versus M-11 EGR	830-2, LTMS Chart = Y	ln(FPD+1) + 0.2827
Adjust based on average of Mesh Filter ISM A & ASTM versus M-11 EGR	830-2, LTMS Chart = Y minus 86669-ISM	ln(FPD+1) + 0.2976
Adjust based on average of Mesh Filter ISM A & ASTM versus M-11 EGR	830-2, LTMS Chart = Y, plus 81547-ISM, 90720-ISM, & 102544-ISM	ln(FPD+1) + 0.3087
Adjust based on average of Mesh Filter ISM A & ASTM versus M-11 EGR	830-2, LTMS Chart = Y minus 86669-ISM plus 81547-ISM, 90720-ISM, & 102544-ISM	ln(FPD+1) + 0.3229
Adjust based on average of Mesh Filter ISM A & ASTM versus LTMS mean	830-2, LTMS Chart = Y	ln(FPD+1) + 0.3494
Adjust based on average of Mesh Filter ISM A & ASTM versus LTMS mean	830-2, LTMS Chart = Y minus 86669-ISM	ln(FPD+1) + 0.3672
Adjust based on average of Mesh Filter ISM A & ASTM versus LTMS mean	830-2, LTMS Chart = Y, plus 81547-ISM, 90720-ISM, & 102544-ISM	ln(FPD+1) + 0.3766
Adjust based on average of Mesh Filter ISM A & ASTM versus LTMS mean	830-2, LTMS Chart = Y minus 86669-ISM plus 81547-ISM, 90720-ISM, & 102544-ISM	ln(FPD+1) + 0.3937

Other possible correction factors could be based on latest batches of hardware.

Crosshead Weight Loss

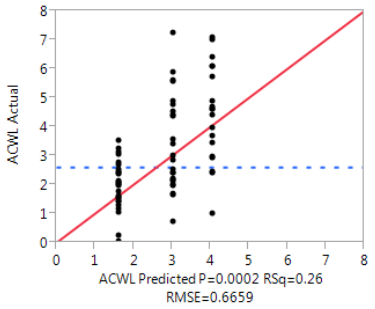
LTMS Chart=Y Data: 86669-ISM Included

Correction Factor Example: I arbitrarily assumed crosshead batch affects test severity and test precision is a function of the AWCL scale

Response Log(ACWL)

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.257372
RSquare Adj	0.223097
Root Mean Square Error	0.665913
Mean of Response	0.954757
Observations (or Sum Wgts)	69

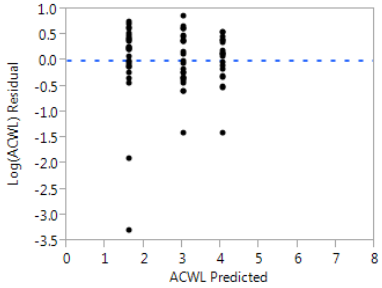
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	9.989377	3.32979	7.5090
Error	65	28.823638	0.44344	Prob > F
C. Total	68	38.813015		0.0002*

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Crosshead Batch	3	3	9.9893770	7.5090	0.0002*

Residual by Predicted Plot

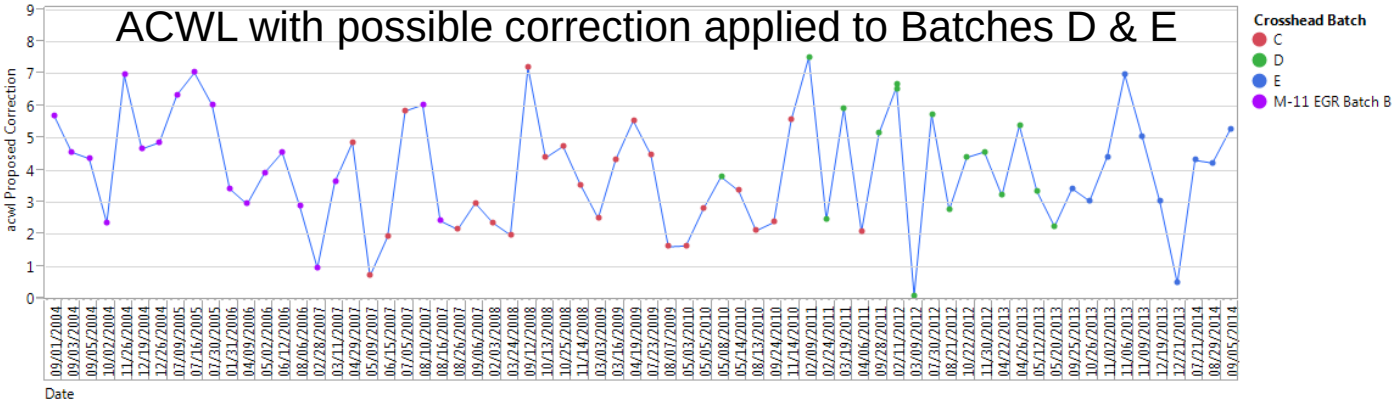


Expanded Estimates

Nominal factors expanded to all levels

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.8704977	0.084363	10.32	<.0001*
Crosshead Batch[C]	0.2356841	0.127889	1.84	0.0699
Crosshead Batch[D]	-0.377197	0.144826	-2.60	0.0114*
Crosshead Batch[E]	-0.389323	0.171141	-2.27	0.0262*
Crosshead Batch[M-11 EGR Batch B	0.5308364	0.137064	3.87	0.0003*

Based on the model, we obtain a CF of ln(acwl) + 0.7665
Correction based on matching average of D & E to average of M-11 & C



Possible CFs for Cross Head Weight Loss Adjusted to 3.9% Soot

86669-ISM Included

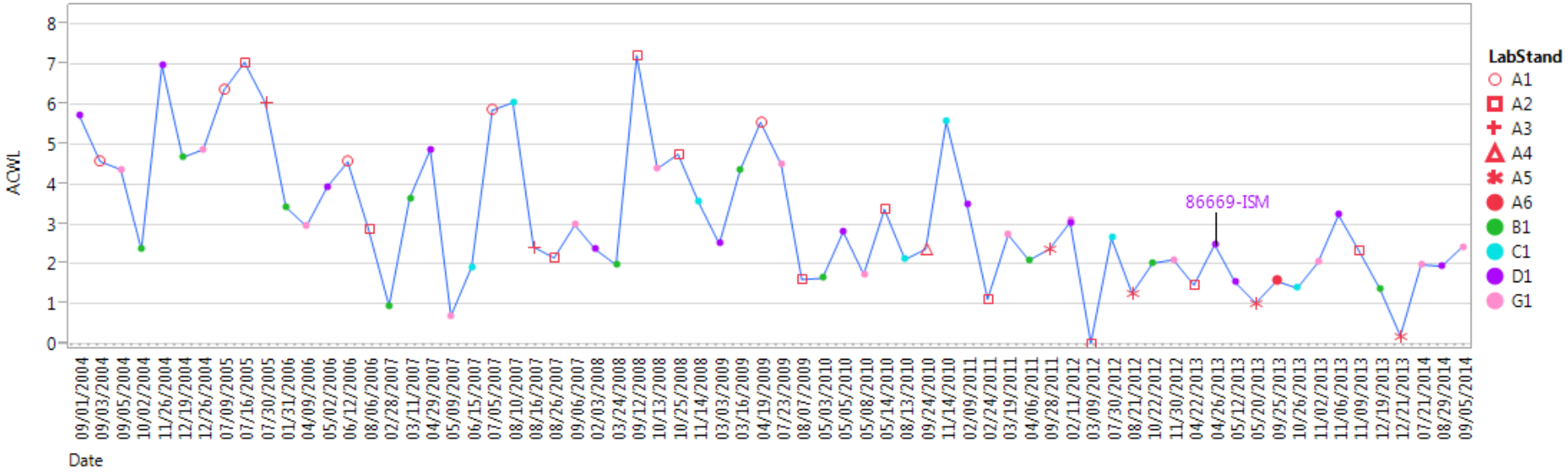
		Data Used	Transformation	Crosshead Weight Loss Adjusted to 3.9% Soot
Possible Correction Factors	Current			acwl + 2.5
	No Change			Stay with current (acwl + 2.5)
	Adjust based on average of Xhead D & E versus M-11 & C	830-2, LTMS Chart = Y	Ln	ln(acwl) + 0.7665
	Adjust based on average of Xhead D & E versus M-11 & C	830-2, LTMS Chart = Y	None	acwl + 1.964
	Adjust based on average of Xhead D & E versus M-11 & C	830-2, LTMS Chart = Y, plus 81547-ISM & 90720-ISM	Ln	ln(acwl) + 0.7661
	Adjust based on average of Xhead D & E versus M-11 & C	830-2, LTMS Chart = Y, plus 81547-ISM & 90720-ISM	None	acwl + 1.979
	Adjust based on average of Xhead D & E versus M-11	830-2, LTMS Chart = Y	Ln	ln(acwl) + 0.9141
	Adjust based on average of Xhead D & E versus M-11	830-2, LTMS Chart = Y	None	acwl + 2.477
	Adjust based on average of Xhead D & E versus M-11	830-2, LTMS Chart = Y, plus 81547-ISM & 90720-ISM	Ln	ln(acwl) + 0.9137
	Adjust based on average of Xhead D & E versus M-11	830-2, LTMS Chart = Y, plus 81547-ISM & 90720-ISM	None	acwl + 2.4911
	Adjust based on average of Xhead D & E versus LTMS mean	830-2, LTMS Chart = Y	Ln	ln(acwl) + 1.142
	Adjust based on average of Xhead D & E versus LTMS mean	830-2, LTMS Chart = Y	None	acwl + 3.136
	Adjust based on average of Xhead D & E versus LTMS mean	830-2, LTMS Chart = Y, plus 81547-ISM & 90720-ISM	Ln	ln(acwl) + 1.1416
	Adjust based on average of Xhead D & E versus LTMS mean	830-2, LTMS Chart = Y, plus 81547-ISM & 90720-ISM	None	acwl + 3.1505

Other possible correction factors could be based on wire mesh test filter changes or only using crosshead batch E.

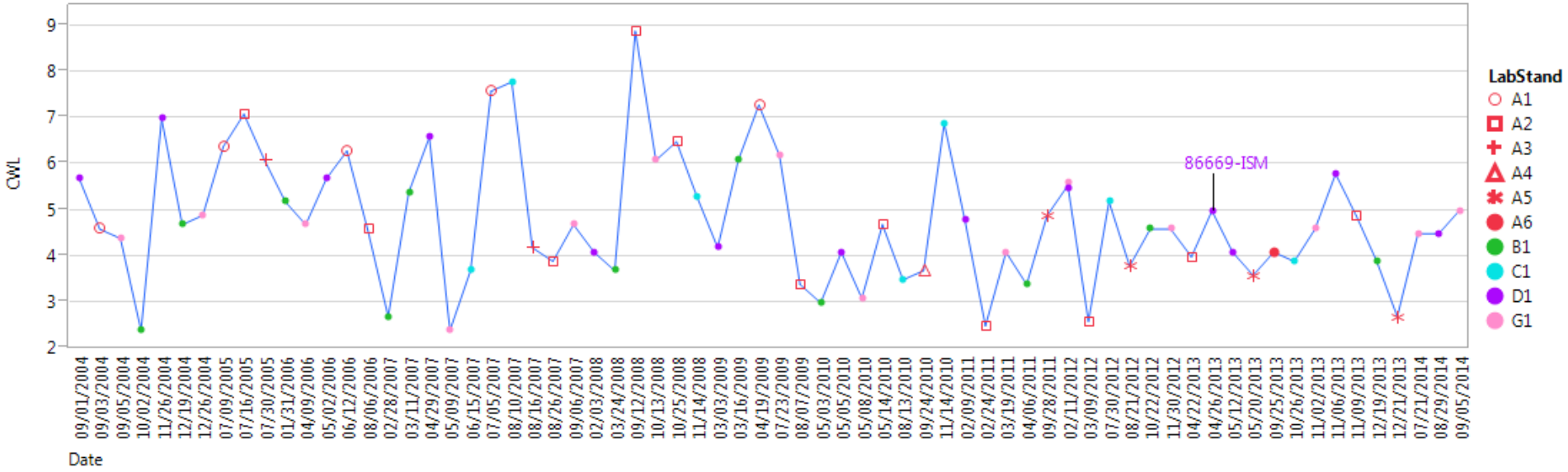
Appendix

Crosshead Weight Loss Adjusted to 3.9% Soot

Crosshead Weight Loss Adjusted to 3.9% Soot Original Units



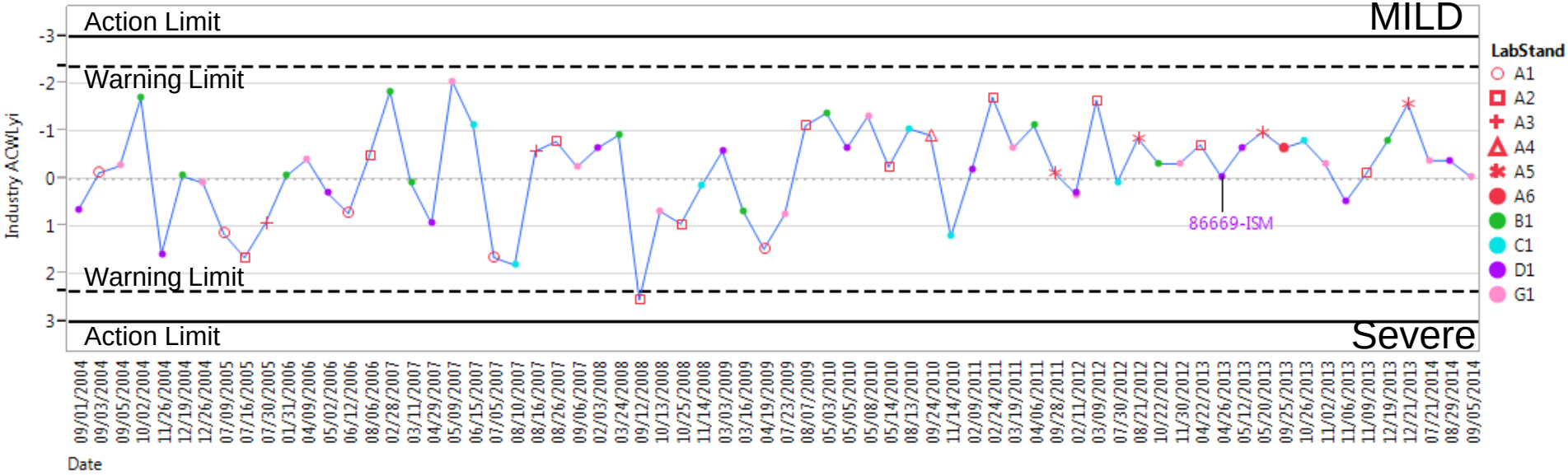
Crosshead Weight Loss Adjusted to 3.9% Soot Corrected Units



Crosshead Weight Loss Adjusted to 3.9% Soot

CWLyi

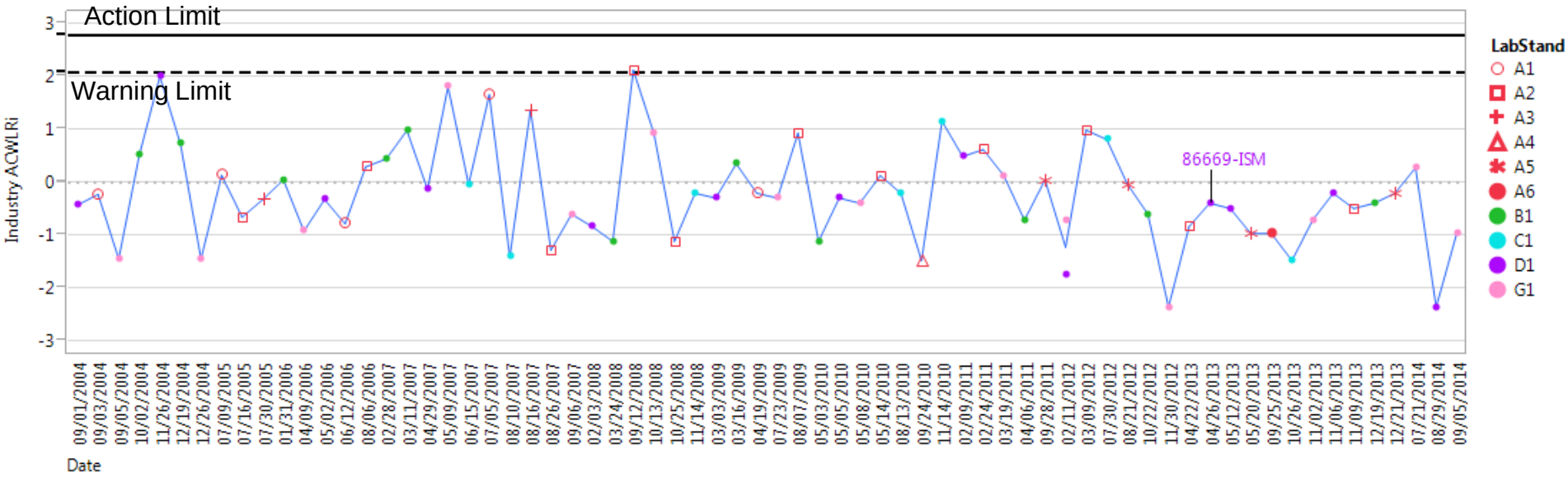
Shewhart Chart for Monitoring Severity



Crosshead Weight Loss Adjusted to 3.9% Soot

CWLRi

Shewhart Chart for Monitoring Precision

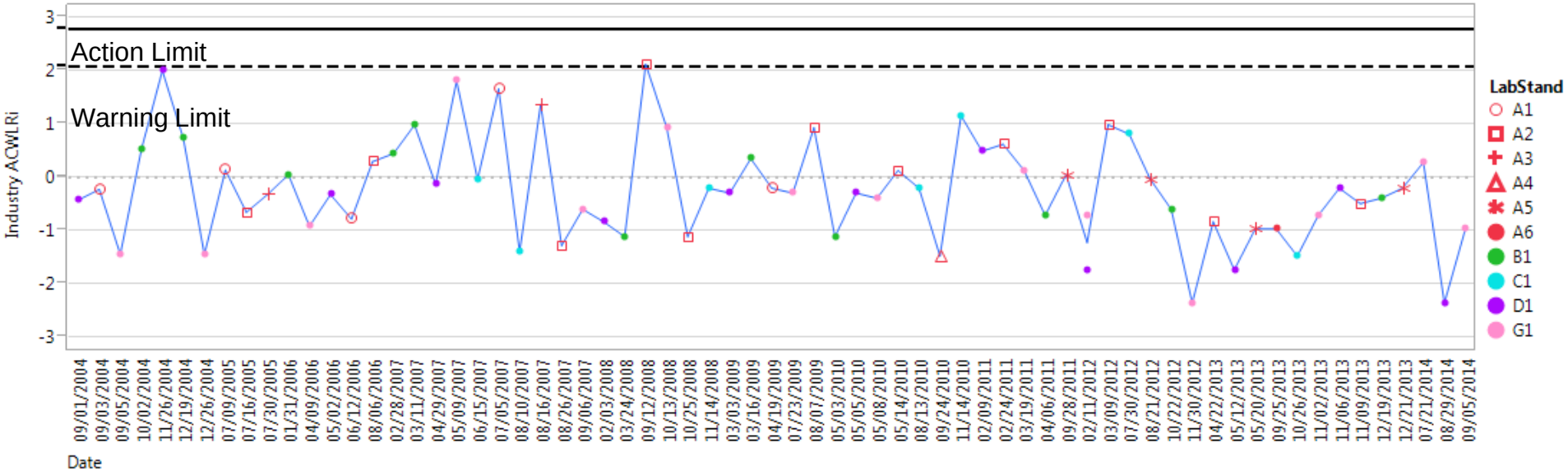


Crosshead Weight Loss Adjusted to 3.9% Soot

CWLRi

86669-ISM Excluded; CWLRi recalculated

Shewhart Chart for Monitoring Precision

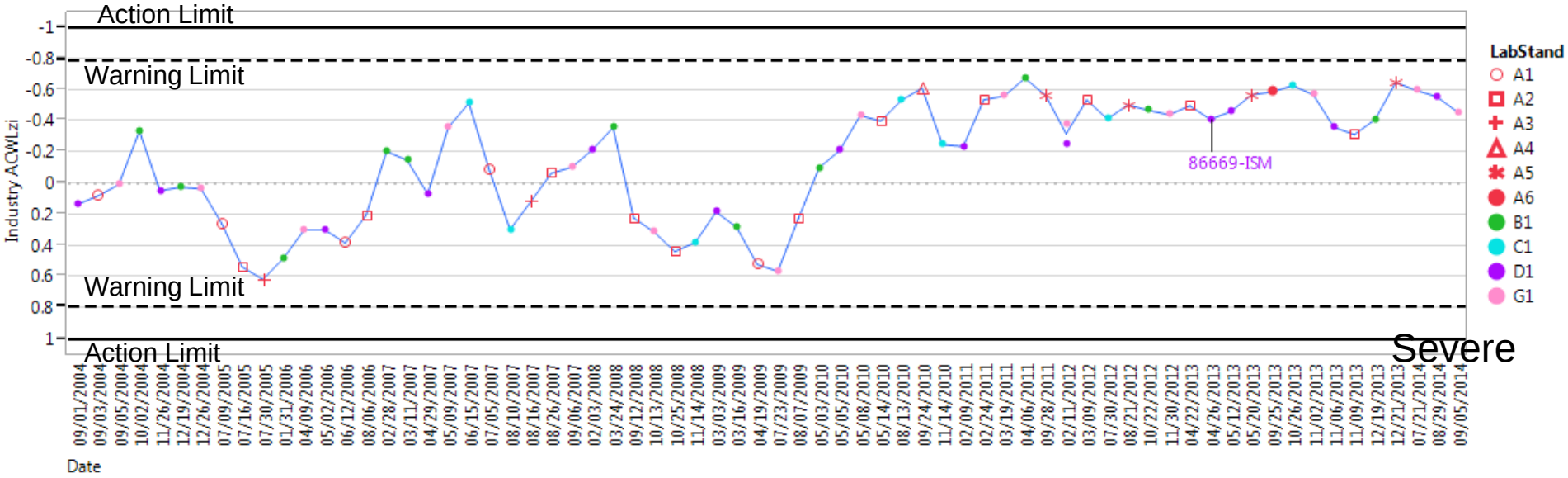


Crosshead Weight Loss Adjusted to 3.9% Soot

CWLzi

EWMA Chart for Monitoring Severity

MILD



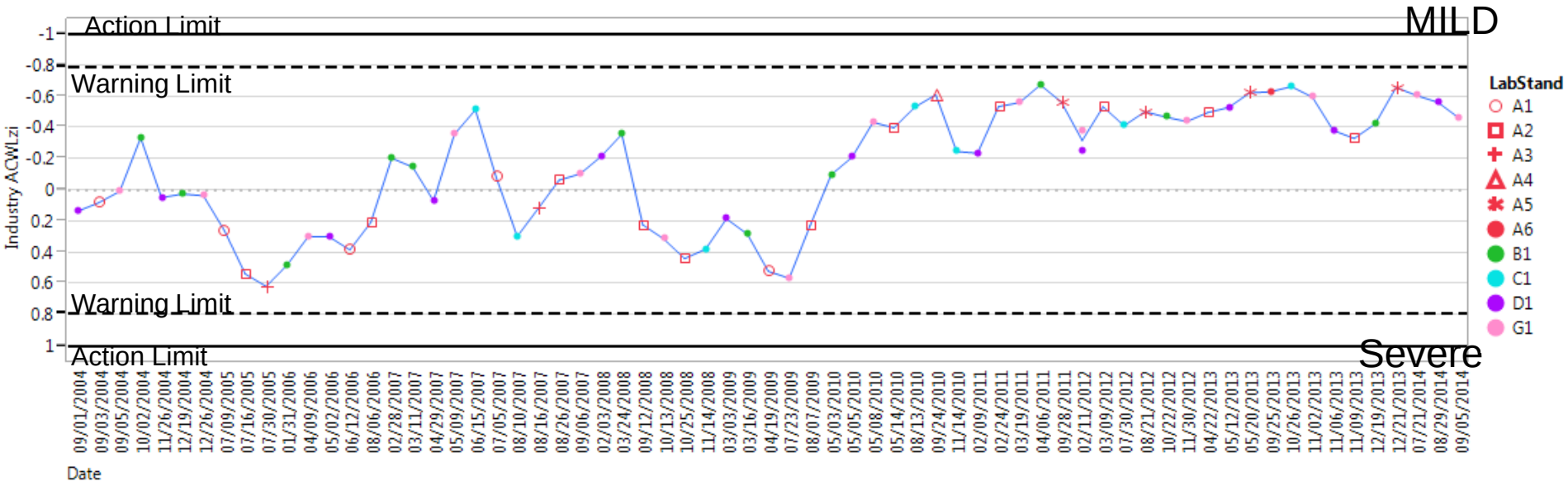
Severe

Crosshead Weight Loss Adjusted to 3.9% Soot

CWLzi

86669-ISM Excluded; CWLzi recalculated

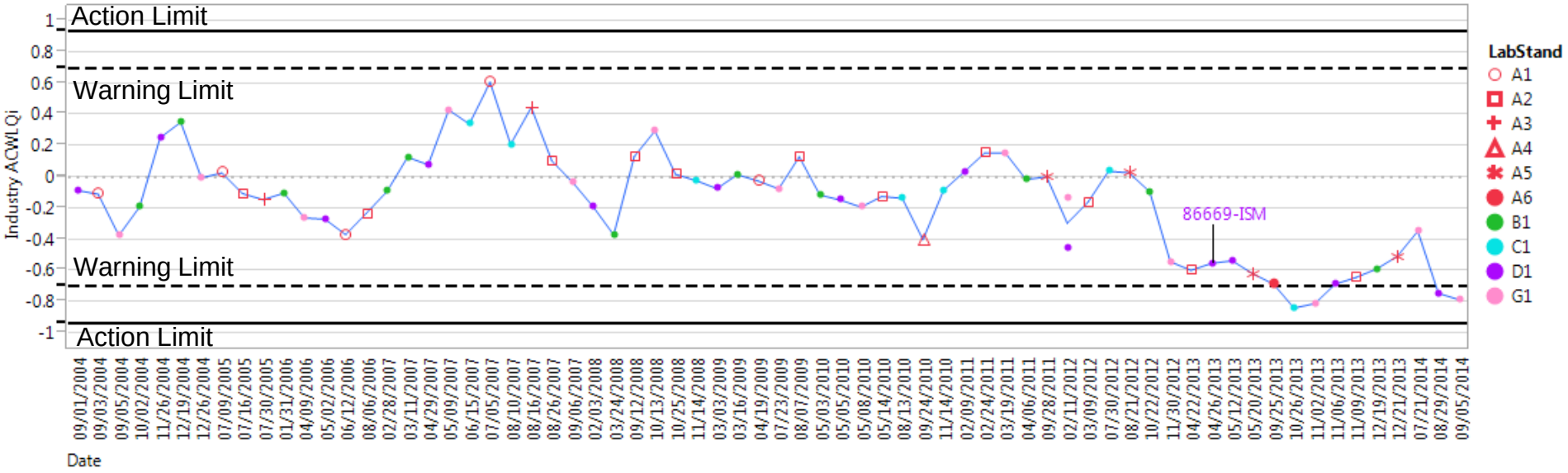
EWMA Chart for Monitoring Severity



Crosshead Weight Loss Adjusted to 3.9% Soot

CWLQi

EWMA Chart for Monitoring Precision

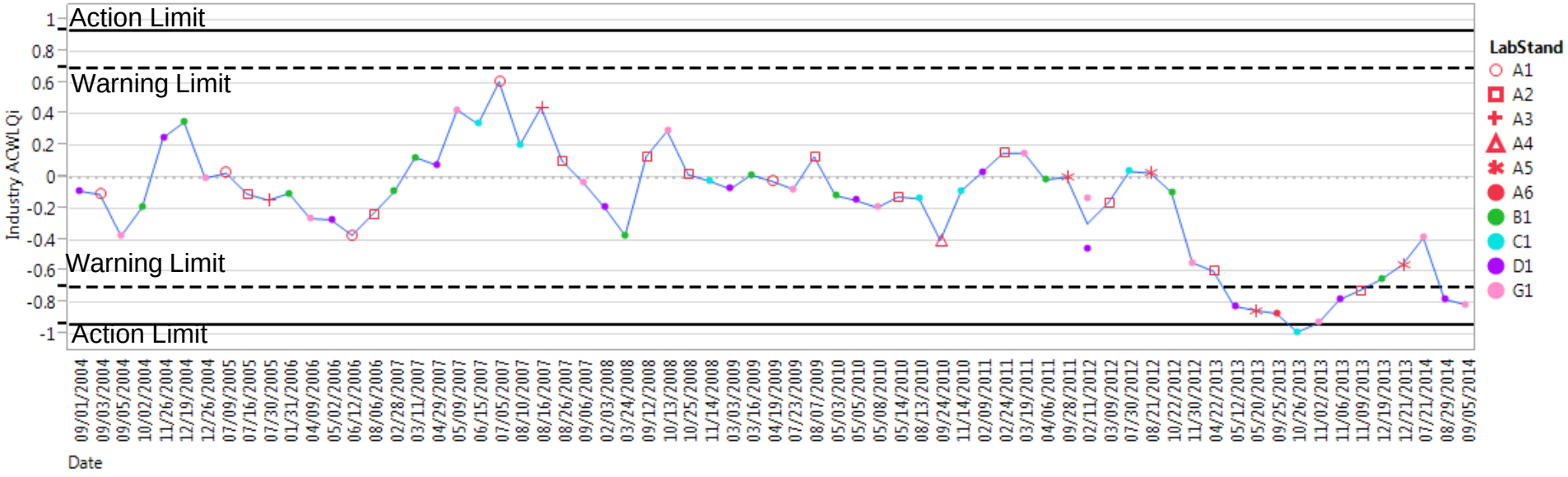


Crosshead Weight Loss Adjusted to 3.9% Soot

CWLQi

86669-ISM Excluded; CWLQi recalculated

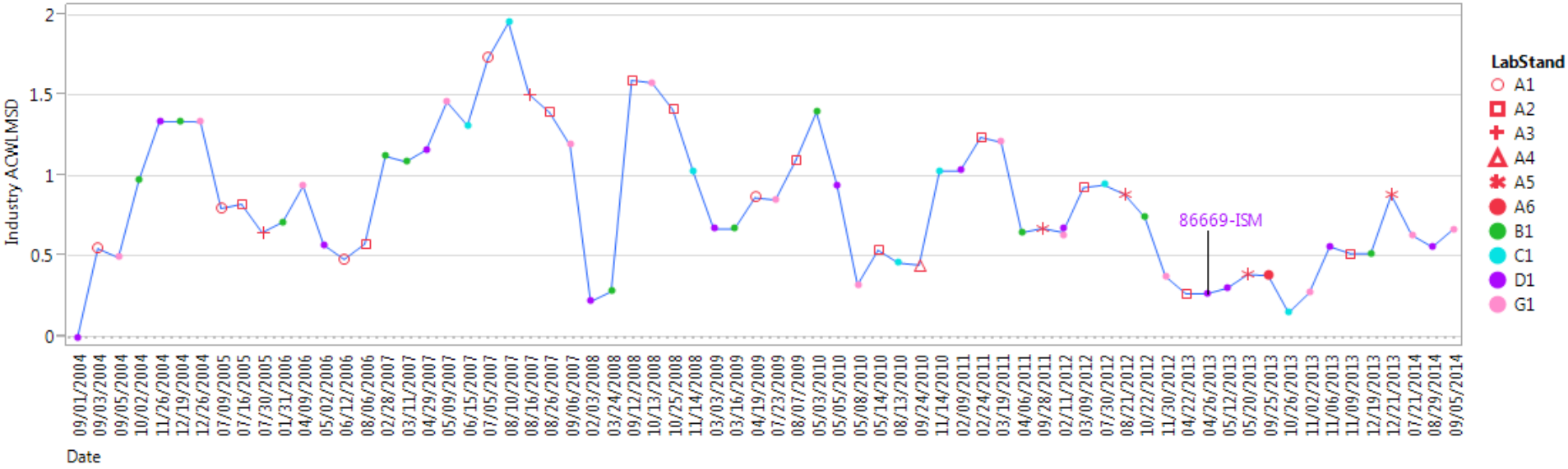
EWMA Chart for Monitoring Precision



Crosshead Weight Loss Adjusted to 3.9% Soot

CWLMSD

MSD Chart for Monitoring Precision

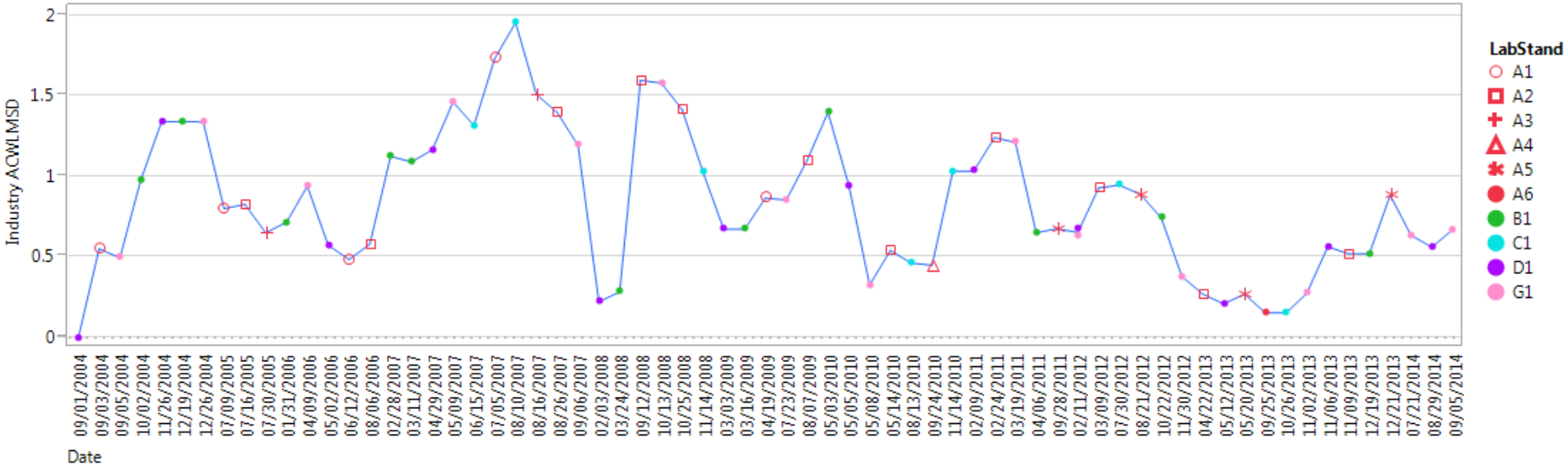


Crosshead Weight Loss Adjusted to 3.9% Soot

CWLMSD

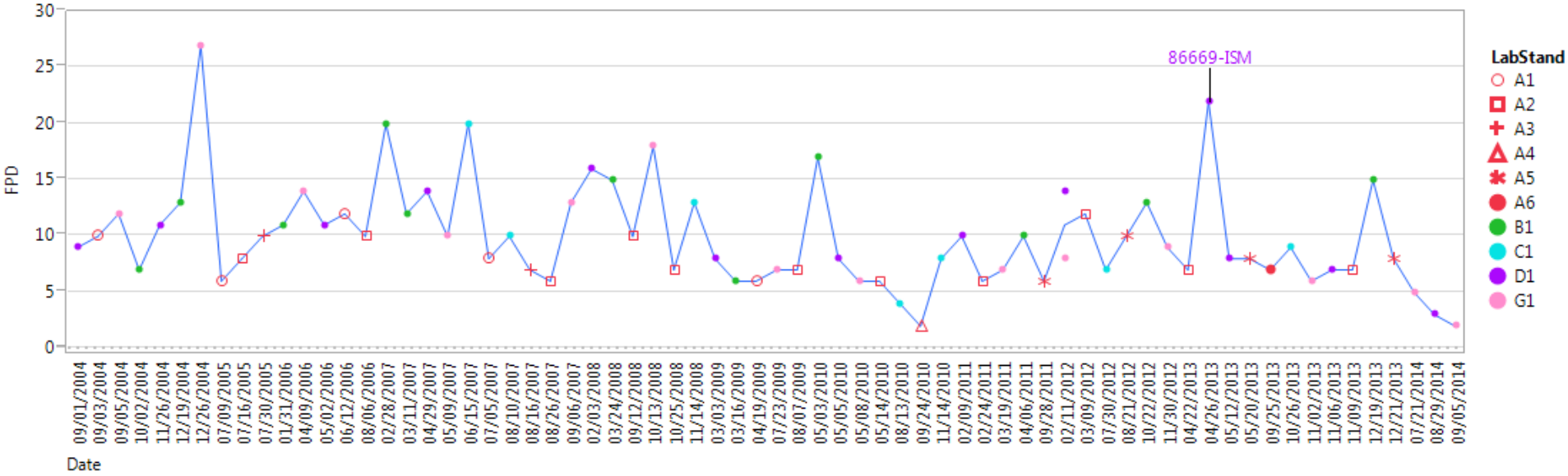
86669-ISM Excluded; CWLMSD recalculated

MSD Chart for Monitoring Precision

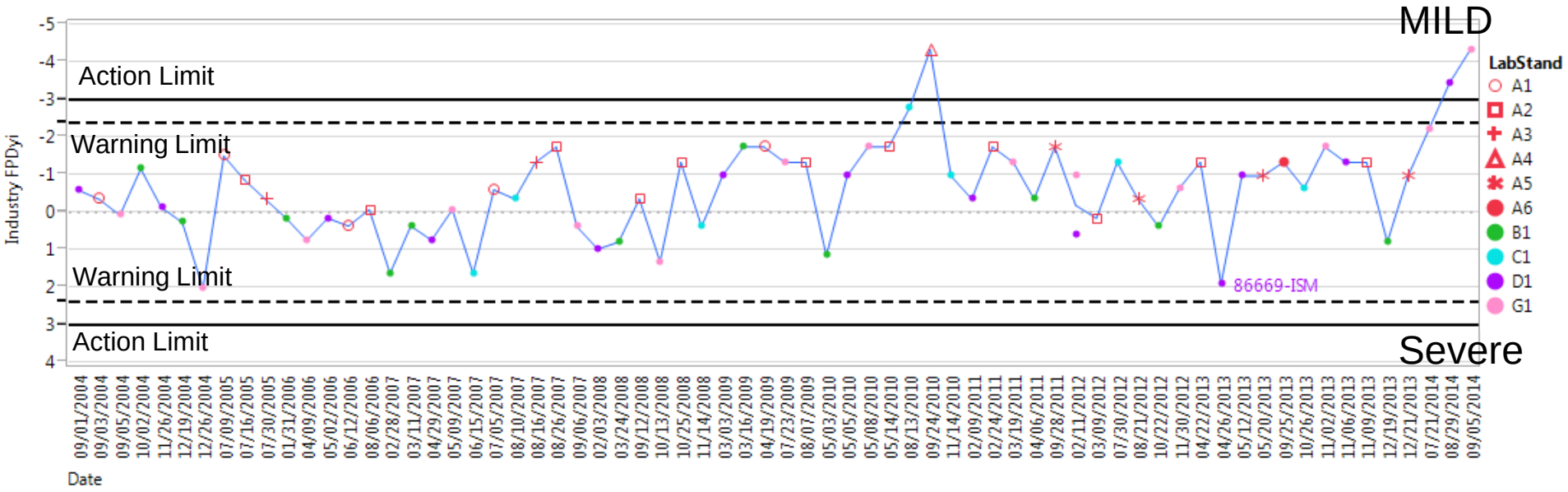


Filter Plugging Delta

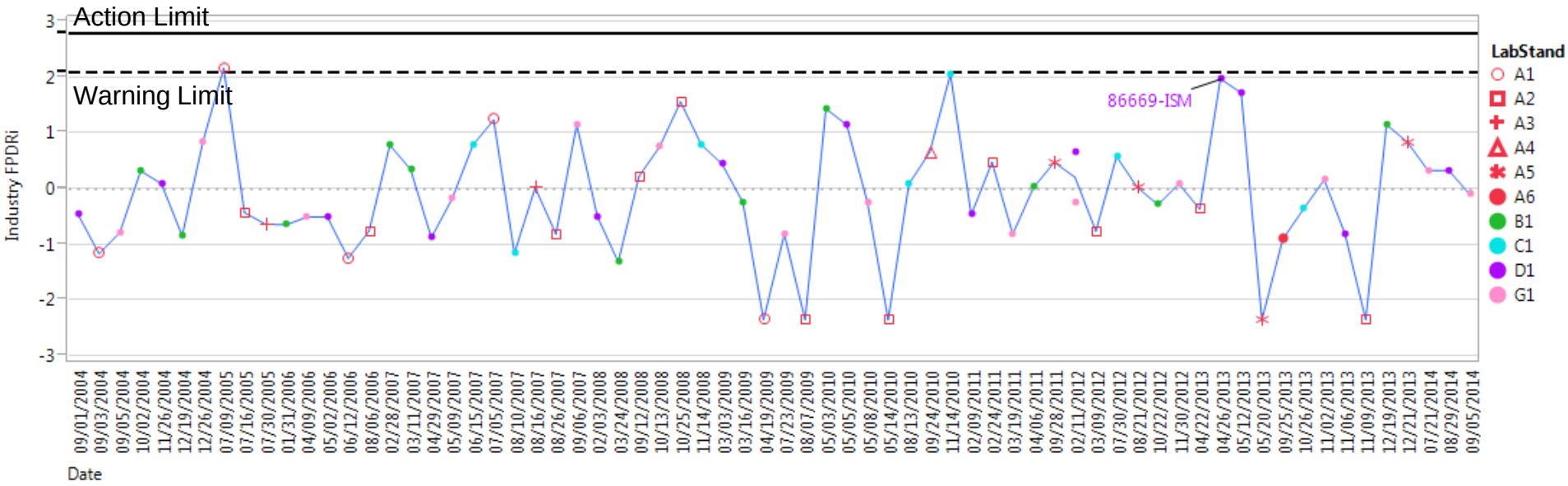
Filter Plugging Delta
Original Unit



Filter Plugging Delta
FPDyi
Shewhart Chart for Monitoring Severity



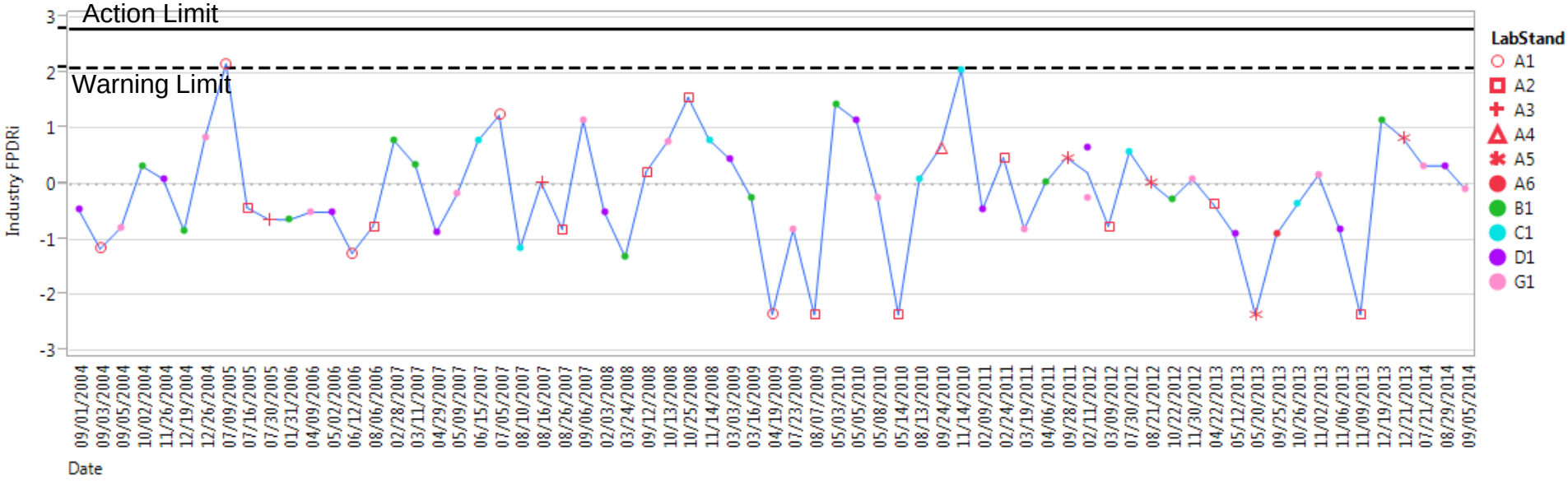
Filter Plugging Delta
FPD Ri
Shewhart Chart for Monitoring Precision



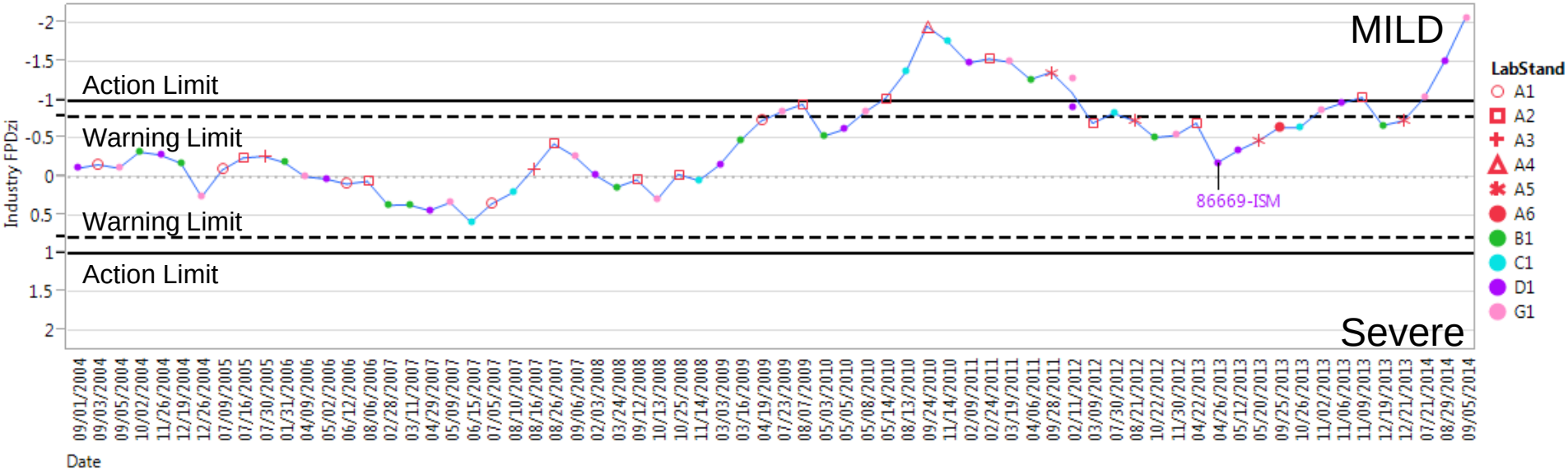
Filter Plugging Delta

FPD Ri (86669-ISM Excluded; FPDRi recalculated)

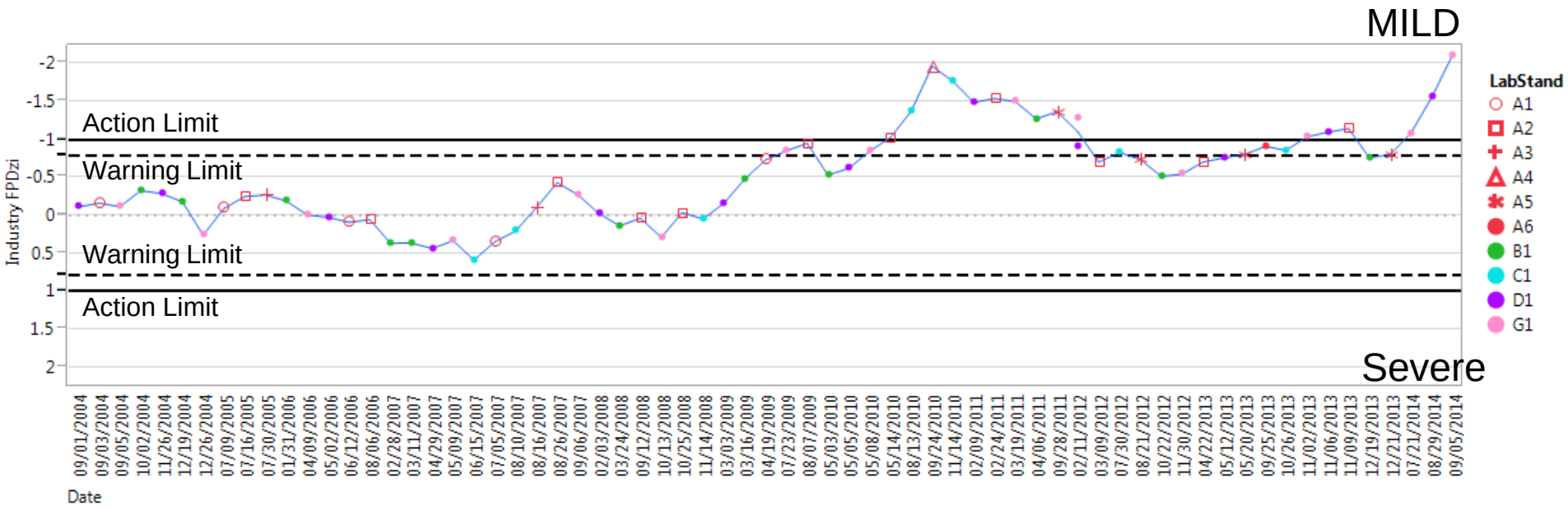
Shewhart Chart for Monitoring Precision



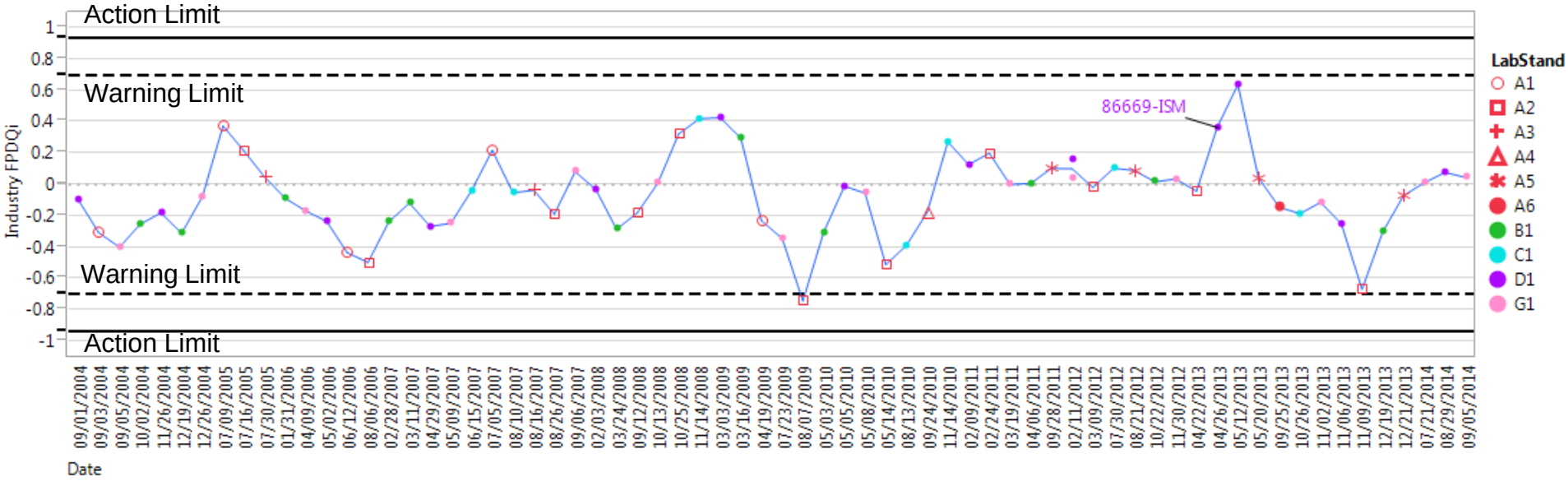
Filter Plugging Delta
FPDzi
EWMA Chart for Monitoring Severity



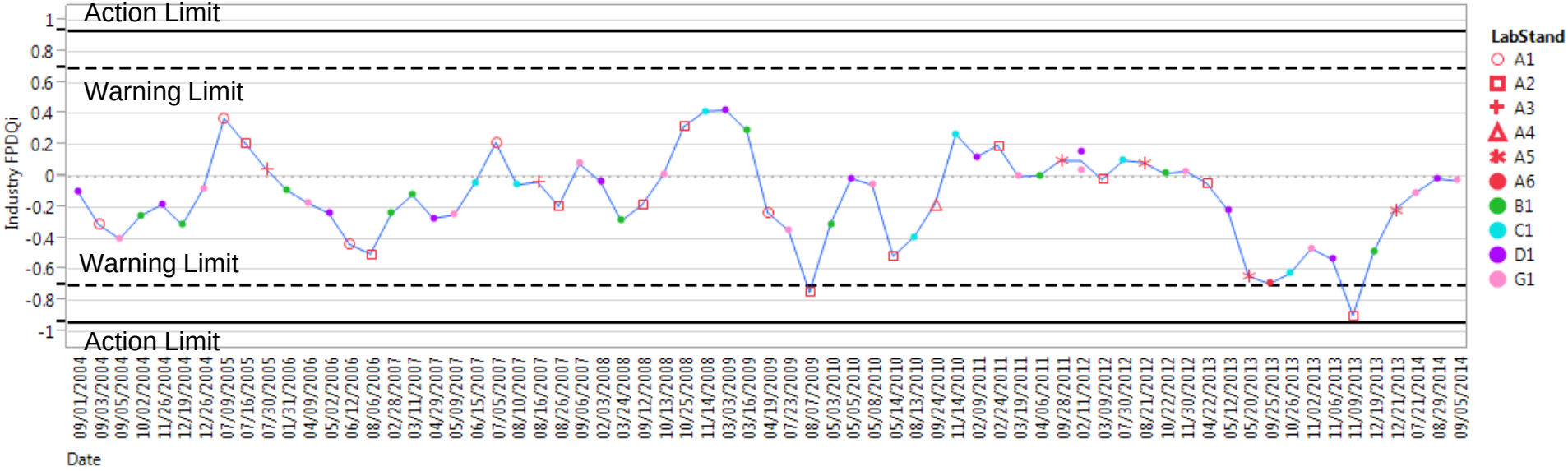
Filter Plugging Delta
FPDzi (86669-ISM Excluded; FPDzi recalculated)
EWMA Chart for Monitoring Severity



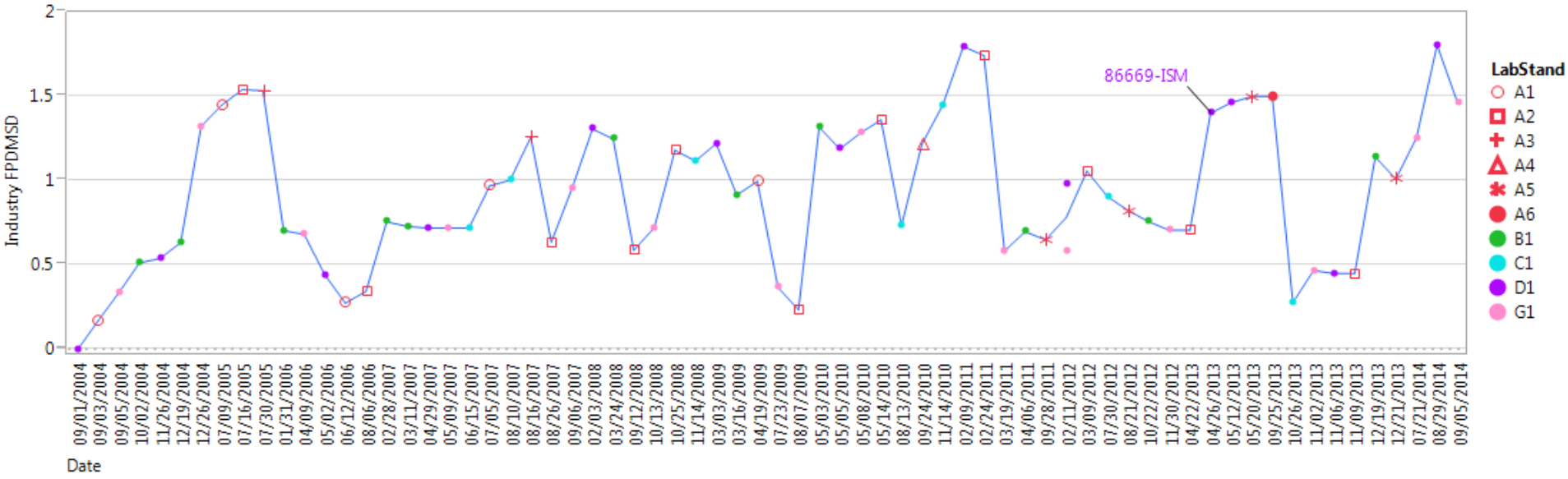
Filter Plugging Delta
FPDQi
EWMA Chart for Monitoring Precision



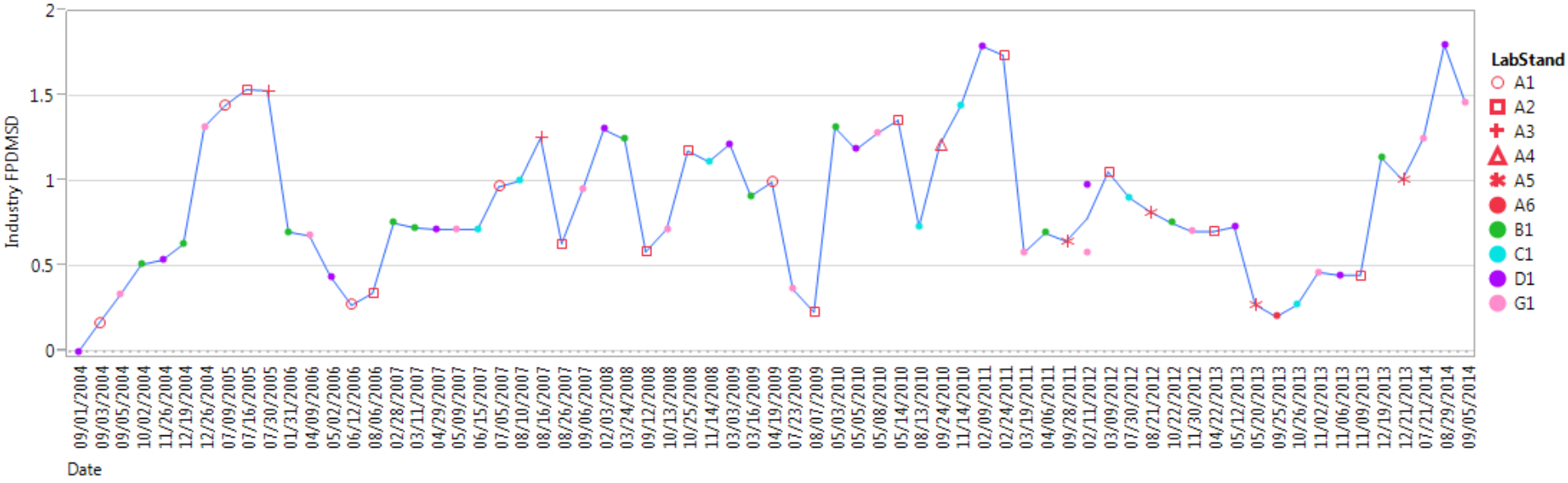
Filter Plugging Delta
FPDQi (86669-ISM Excluded; FPDQi recalculated)
EWMA Chart for Monitoring Precision



Filter Plugging Delta
FPDMSD
MSD Chart for Monitoring Precision

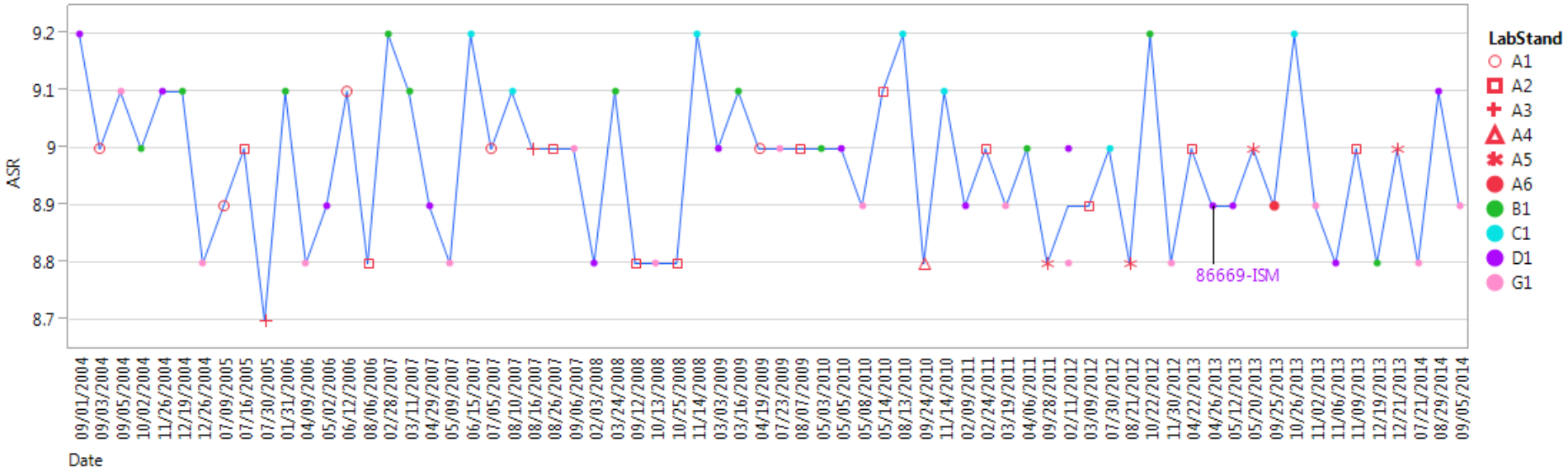


Filter Plugging Delta
FPDMSD (86669-ISM Excluded; FPDMSD recalculated)
MSD Chart for Monitoring Precision

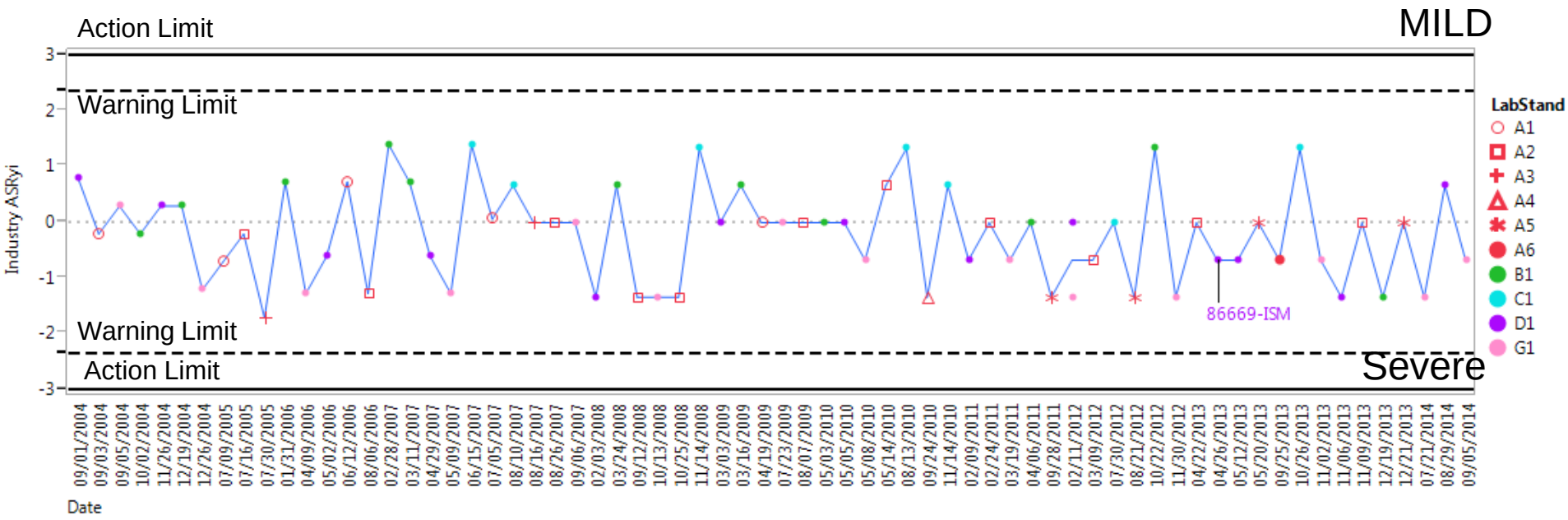


Average Sludge Rating

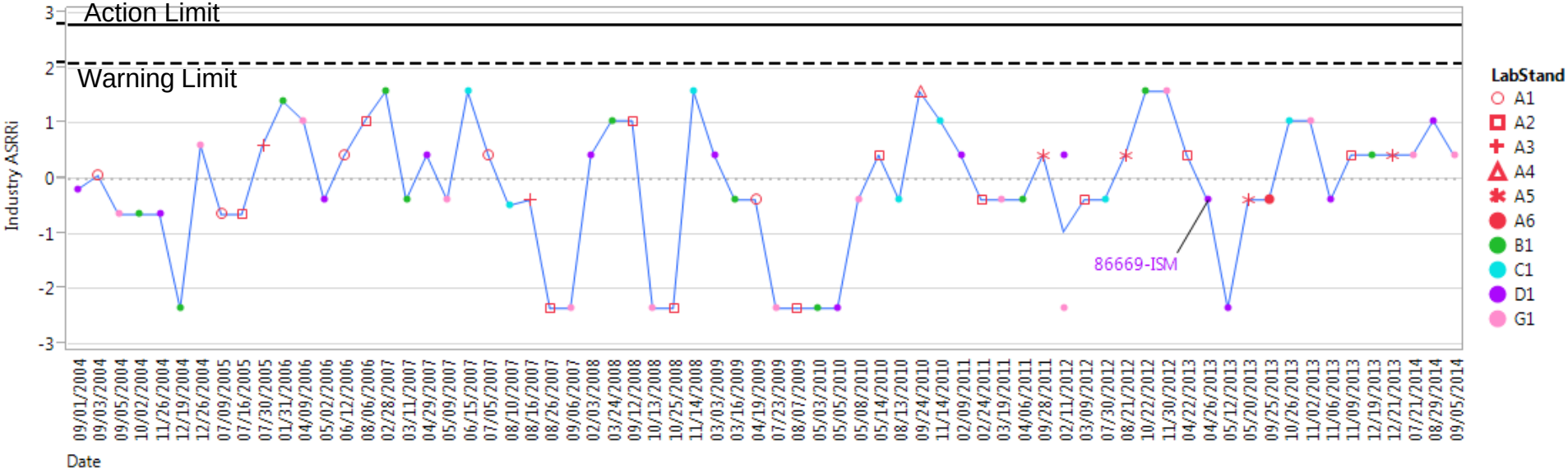
Average Sludge Rating
Original Units



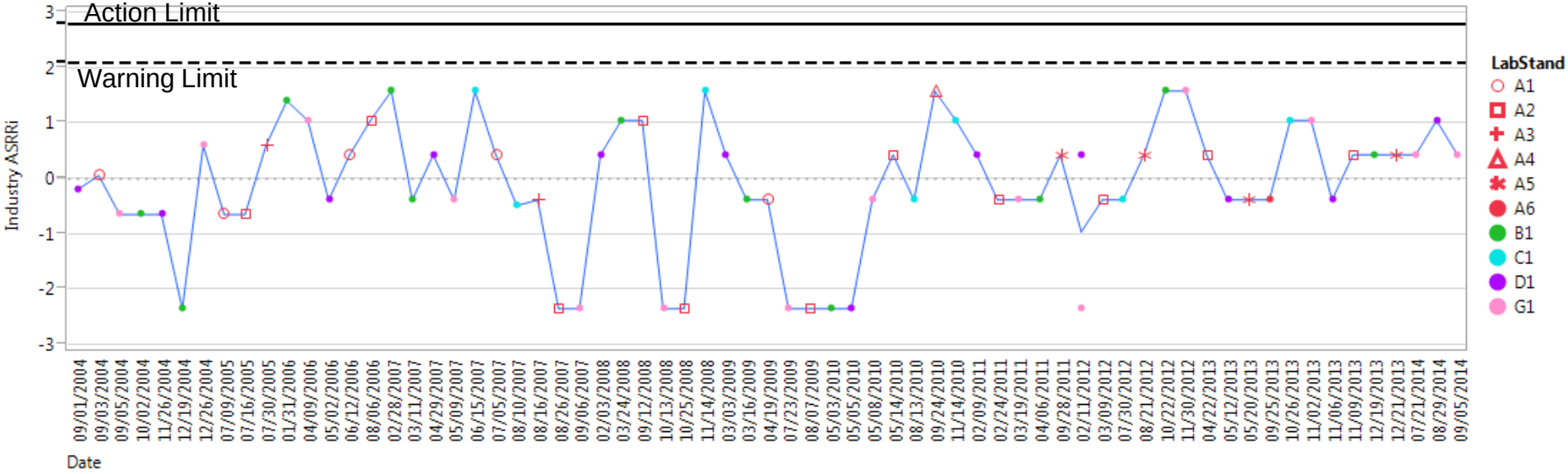
Average Sludge Rating
ASRyi
Shewhart Chart for Monitoring Severity



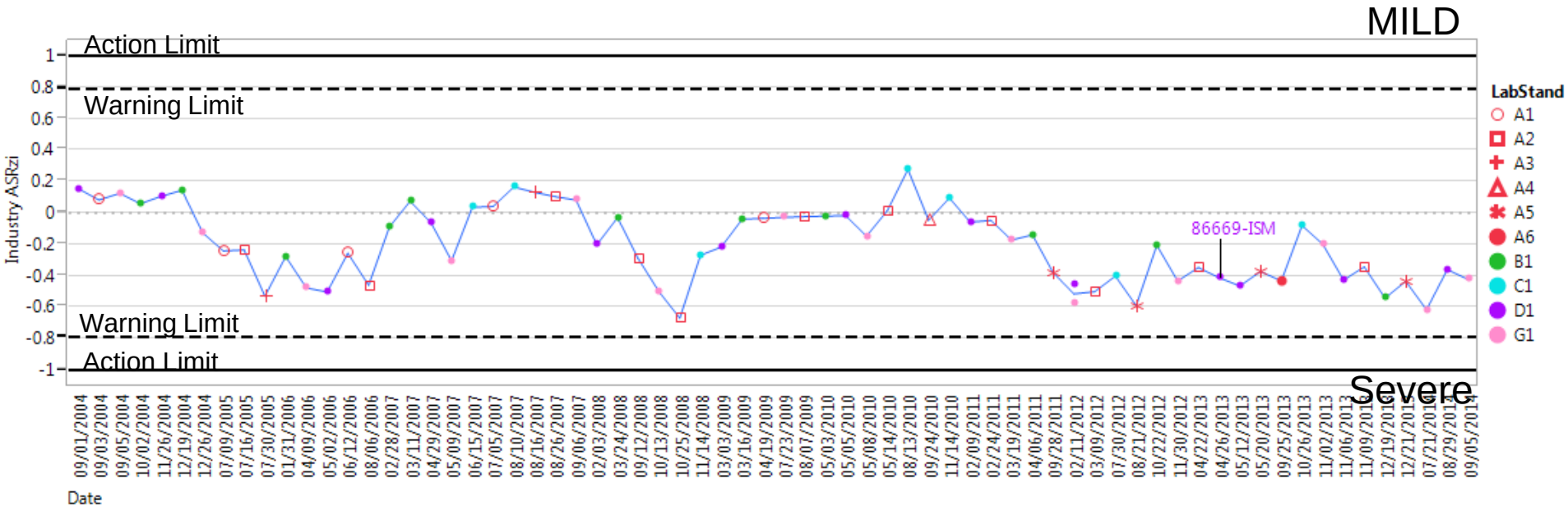
Average Sludge Rating
ASR Ri
Shewhart Chart for Monitoring Precision



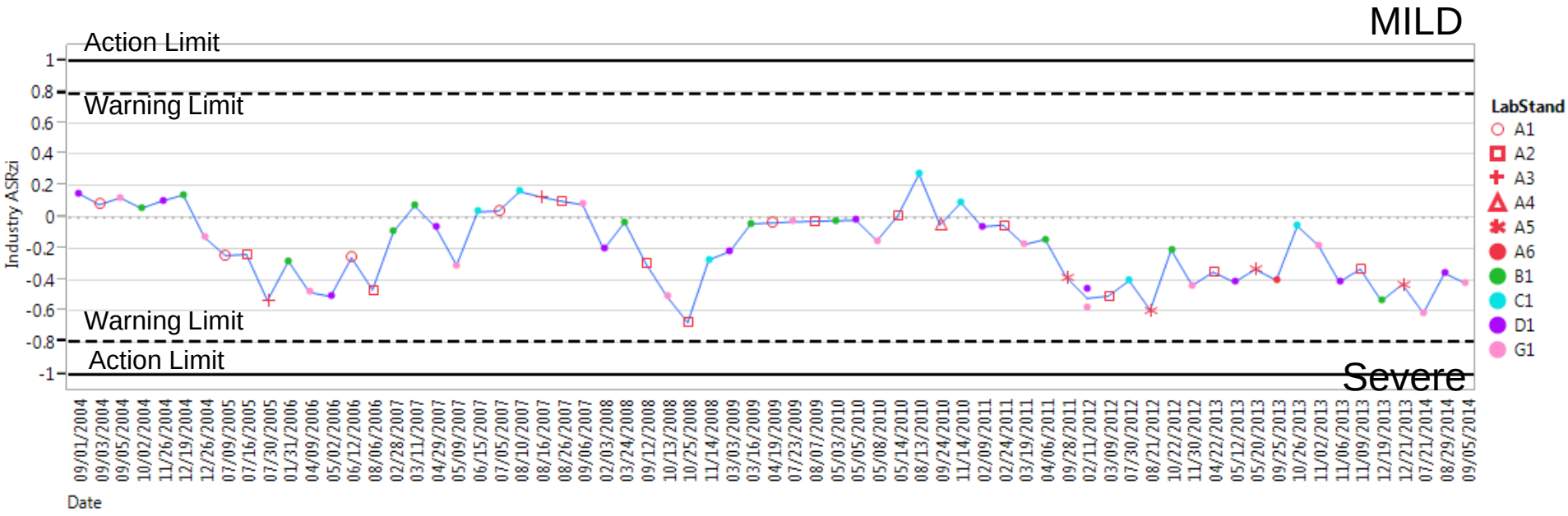
Average Sludge Rating
ASR Ri (86669-ISM Excluded; ASRRi recalculated)
Shewhart Chart for Monitoring Precision



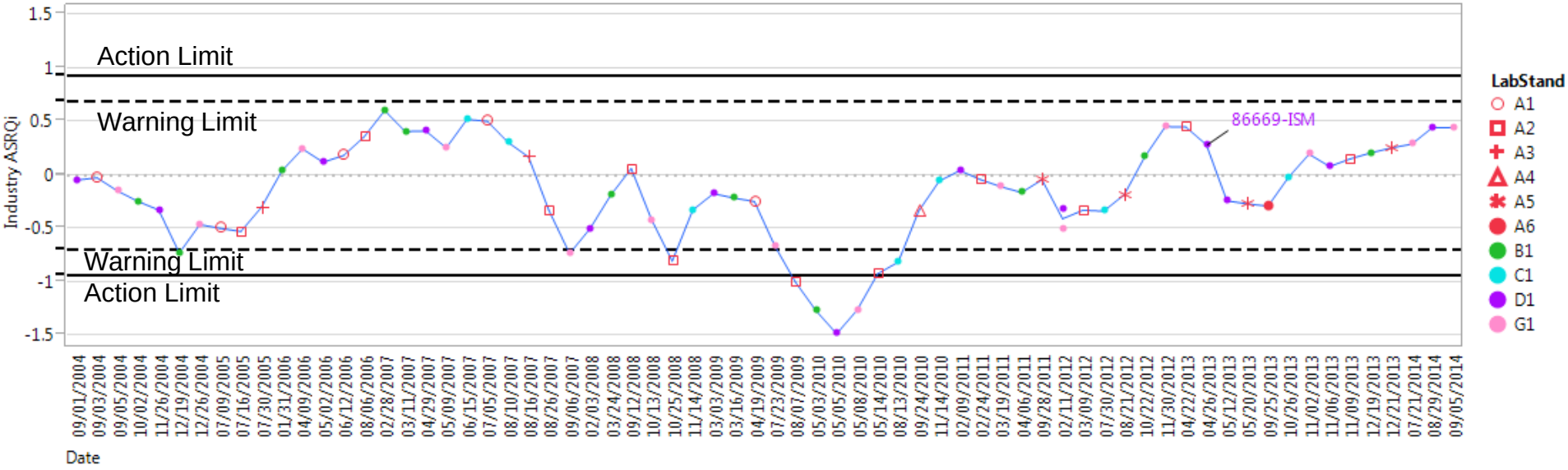
Average Sludge Rating
ASRzi
EWMA Chart for Monitoring Severity



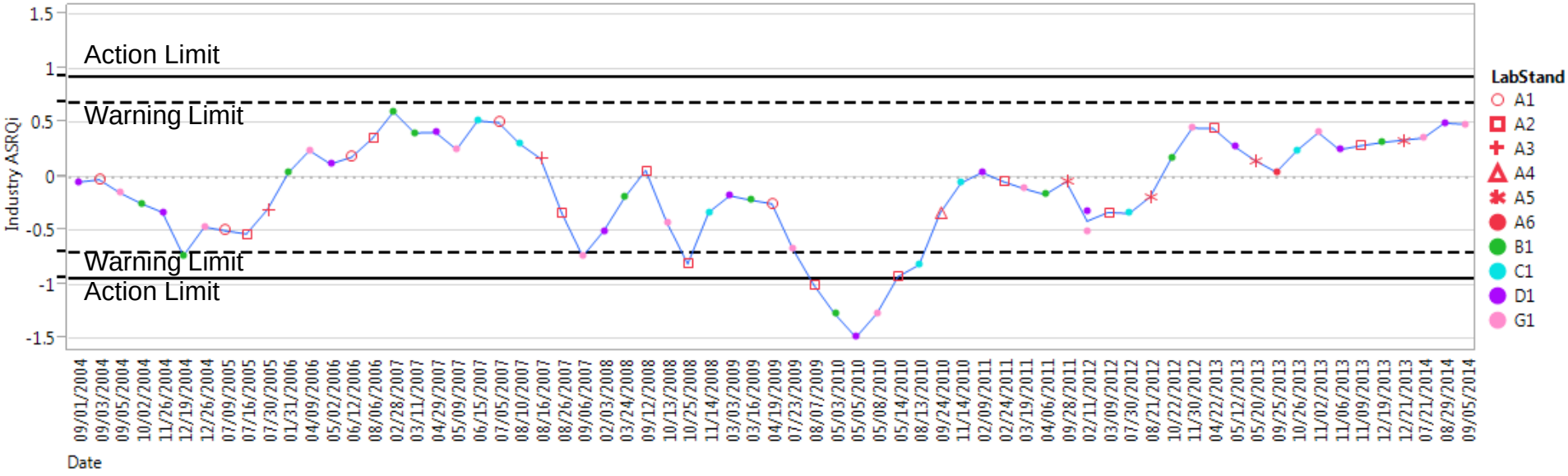
Average Sludge Rating
ASRzi (86669-ISM Excluded; ASRzi recalculated)
EWMA Chart for Monitoring Severity



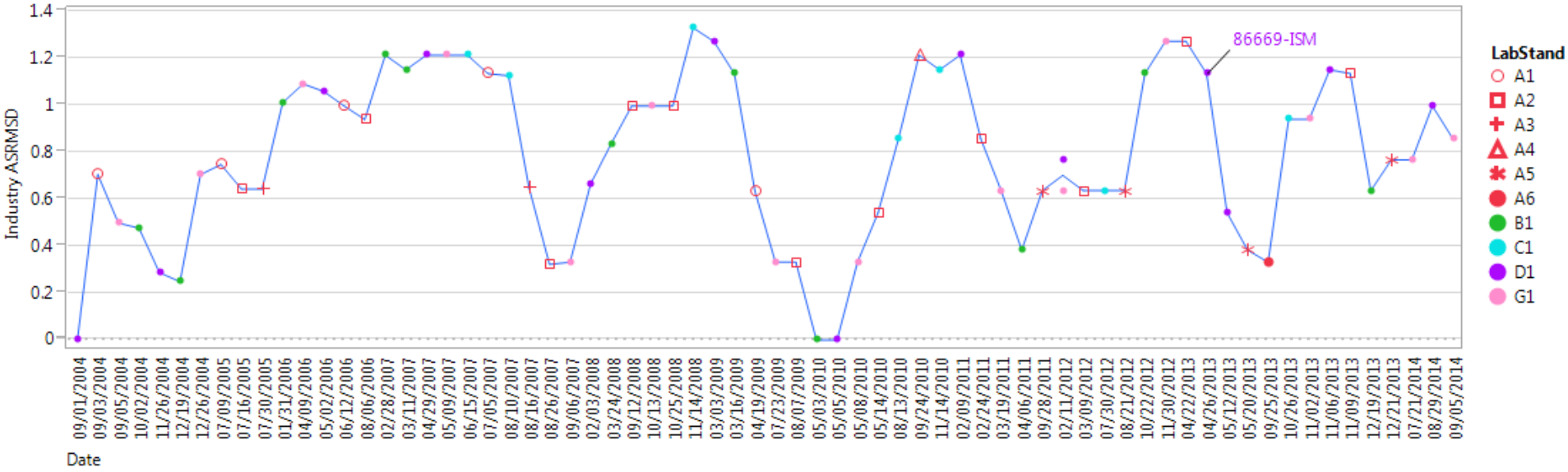
Average Sludge Rating
ASRQi
EWMA Chart for Monitoring Precision



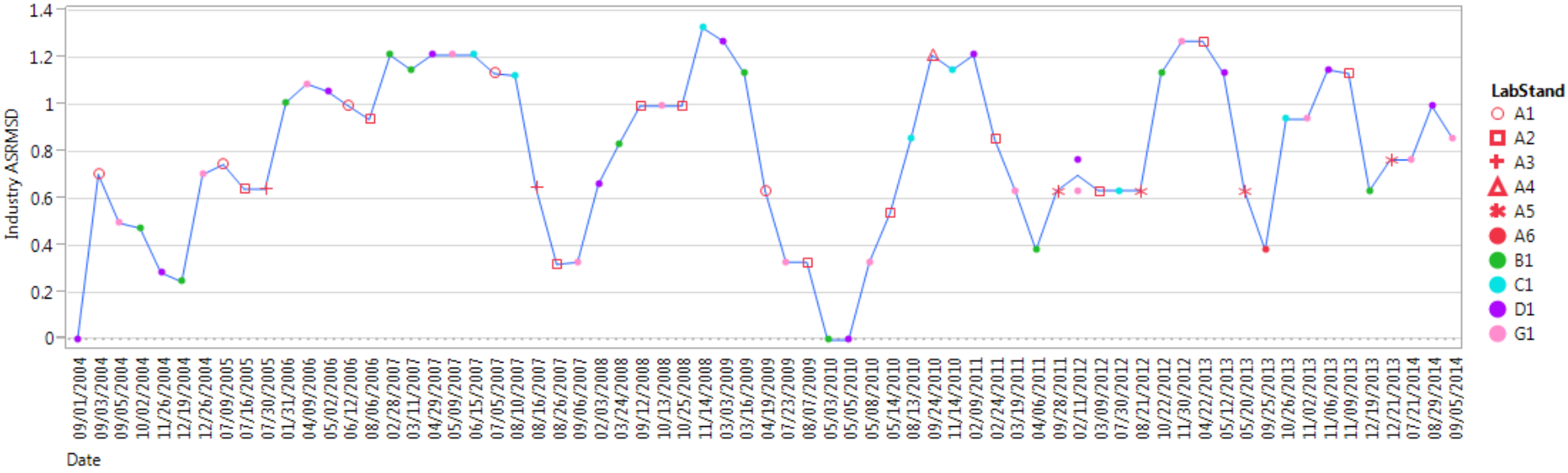
Average Sludge Rating
ASRQi (86669-ISM Excluded; ASRQi recalculated)
EWMA Chart for Monitoring Precision



Average Sludge Rating
ASRMSD
MSD Chart for Monitoring Precision

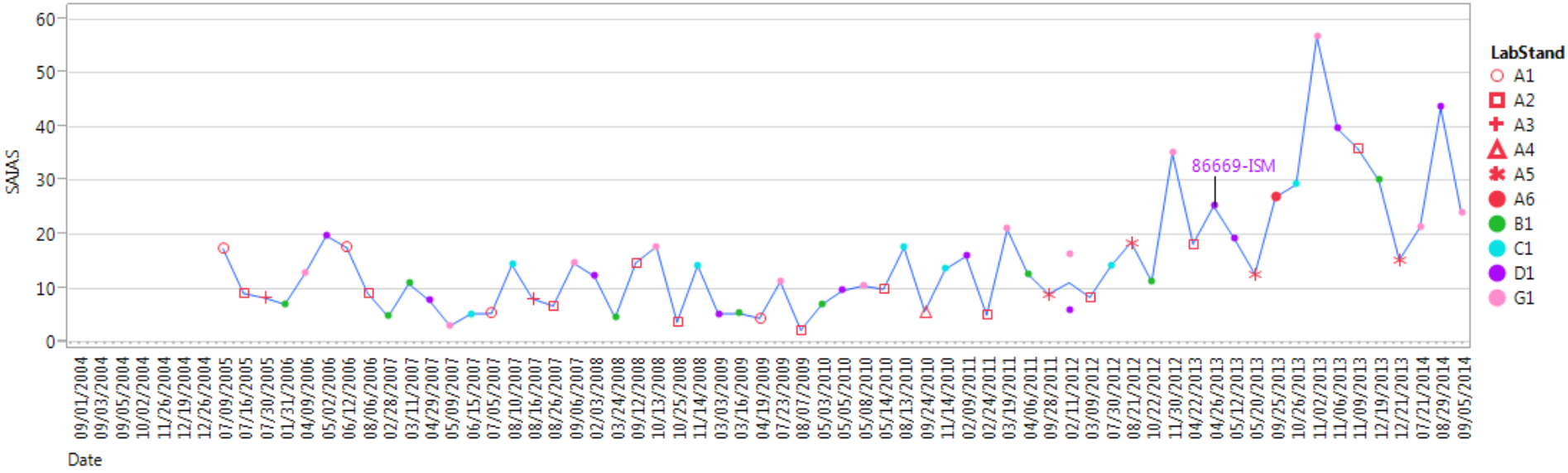


Average Sludge Rating
ASRMSD (86669-ISM Excluded; ASRMSD recalculated)
MSD Chart for Monitoring Precision

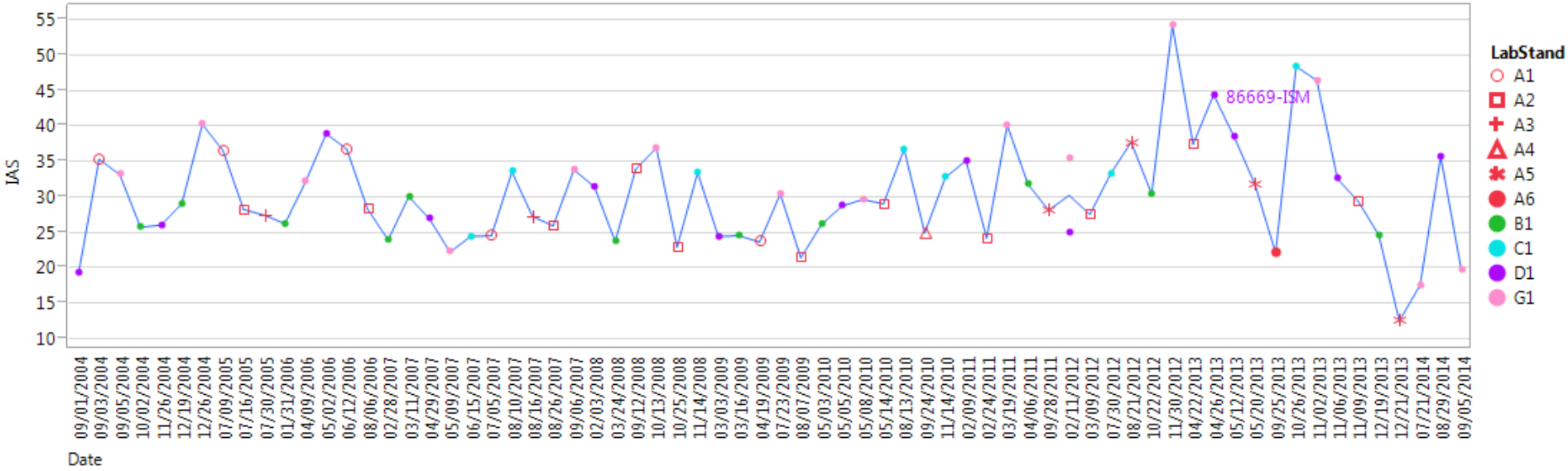


Injector Screw Weight Loss Adjusted to 3.9% Soot

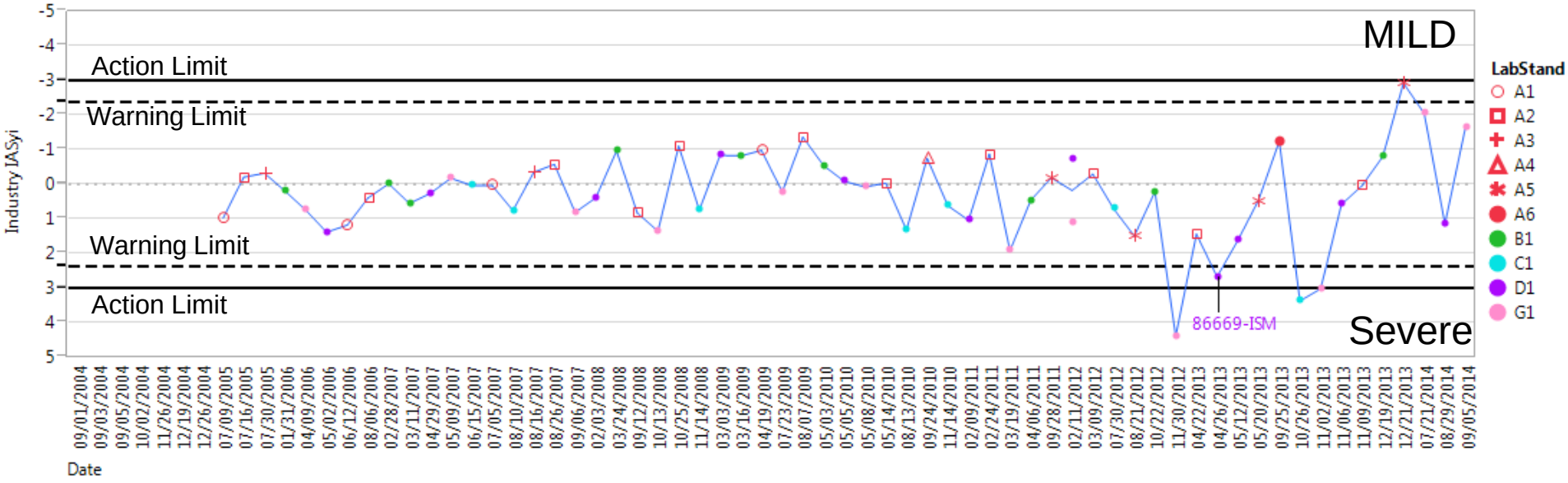
Injector Screw Weight Loss Adjusted to 3.9% Soot Original Units



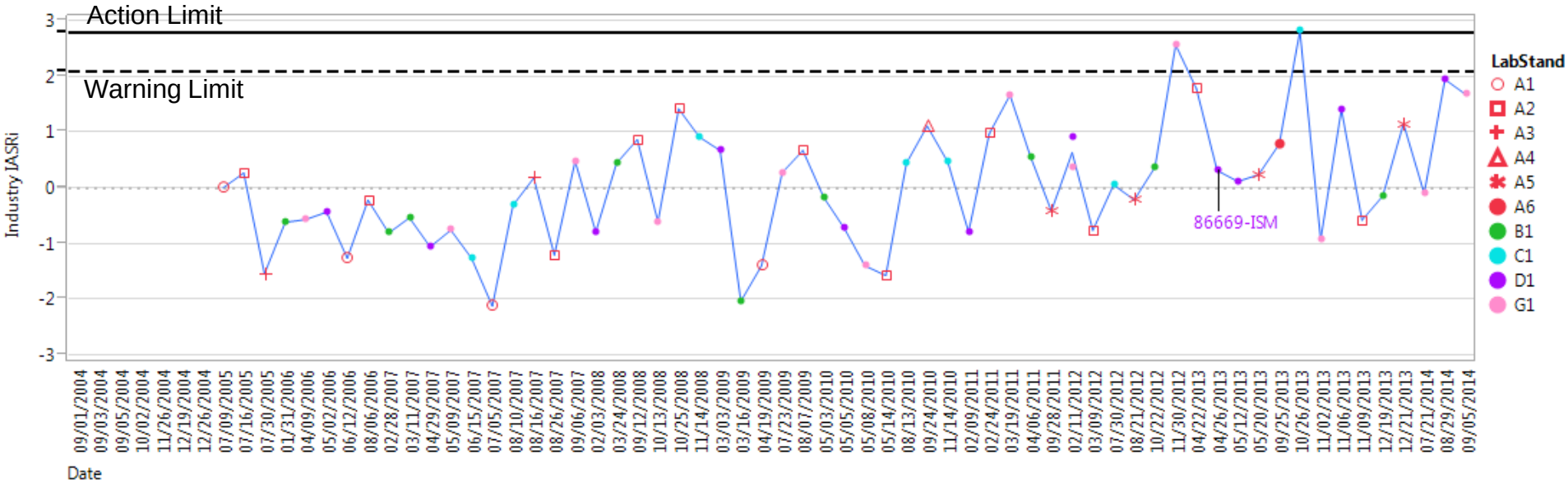
Injector Screw Weight Loss Adjusted to 3.9% Soot Corrected Units



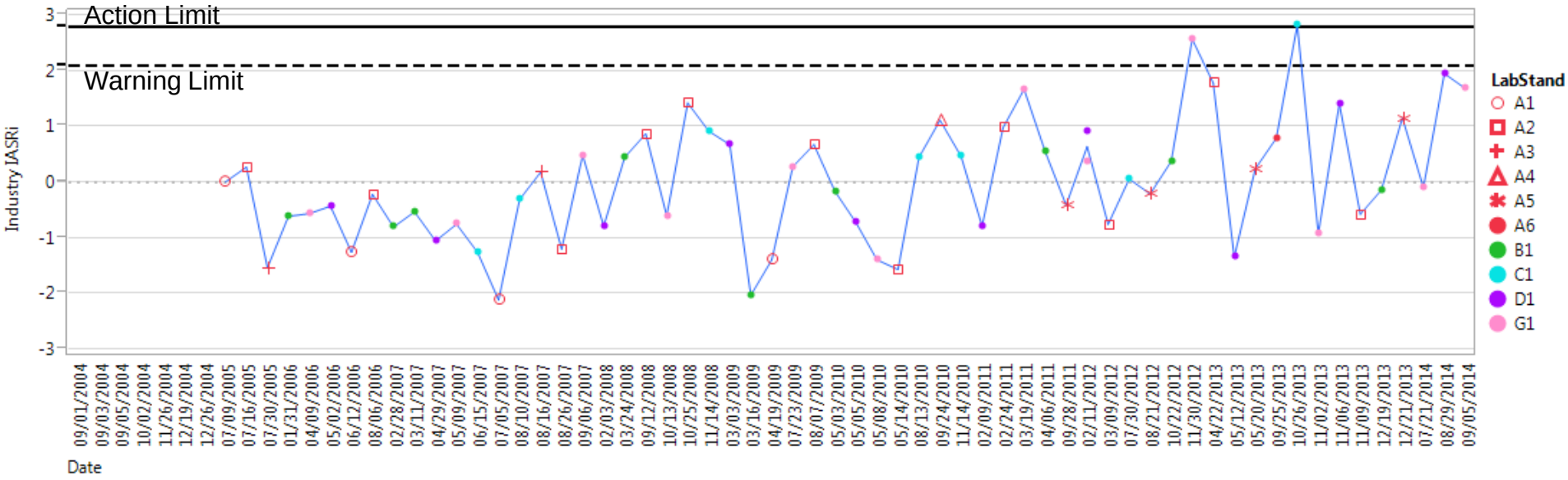
Injector Screw Weight Loss Adjusted to 3.9% Soot IASyi
Shewhart Chart for Monitoring Severity



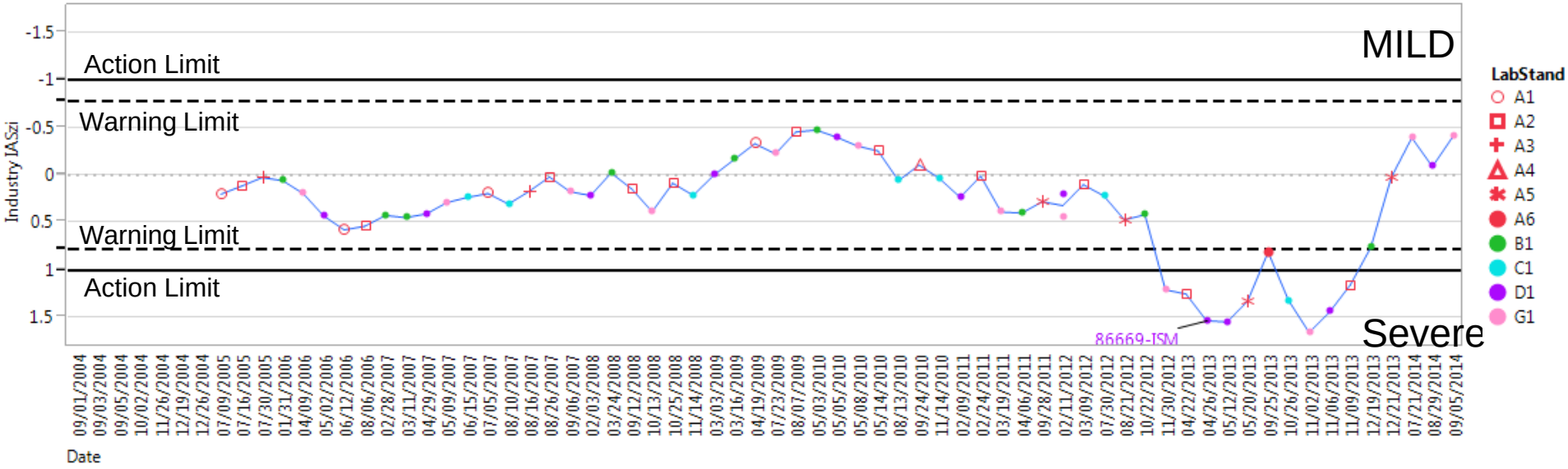
Injector Screw Weight Loss Adjusted to 3.9% Soot
IAS Ri
Shewhart Chart for Monitoring Precision



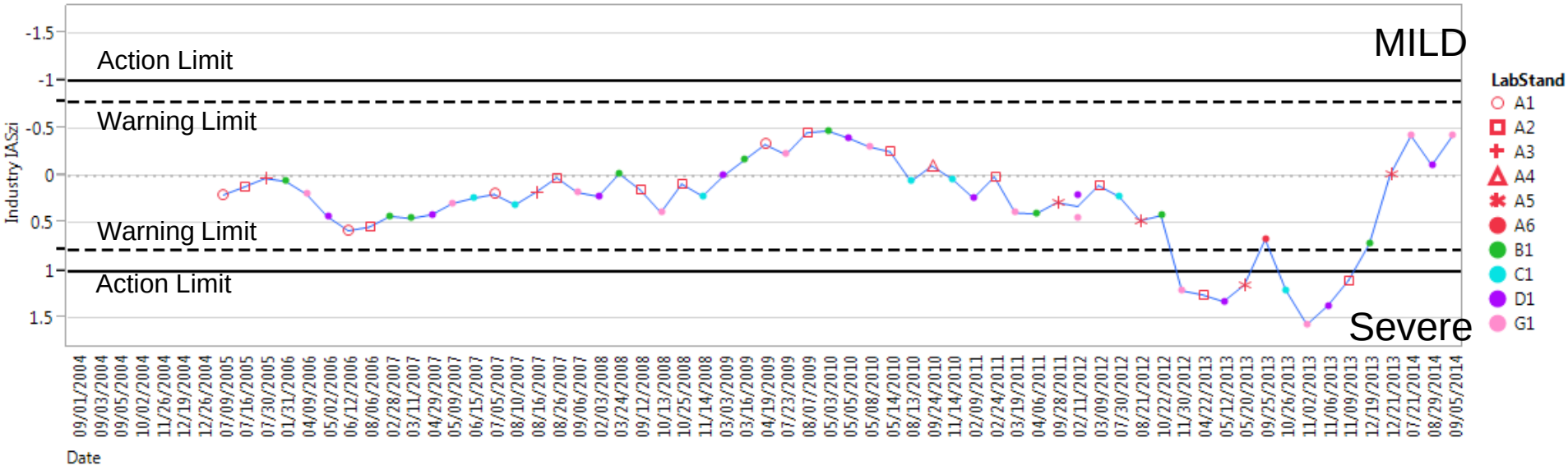
Injector Screw Weight Loss Adjusted to 3.9% Soot
IAS Ri (86669-ISM Excluded; IASRi recalculated)
Shewhart Chart for Monitoring Precision



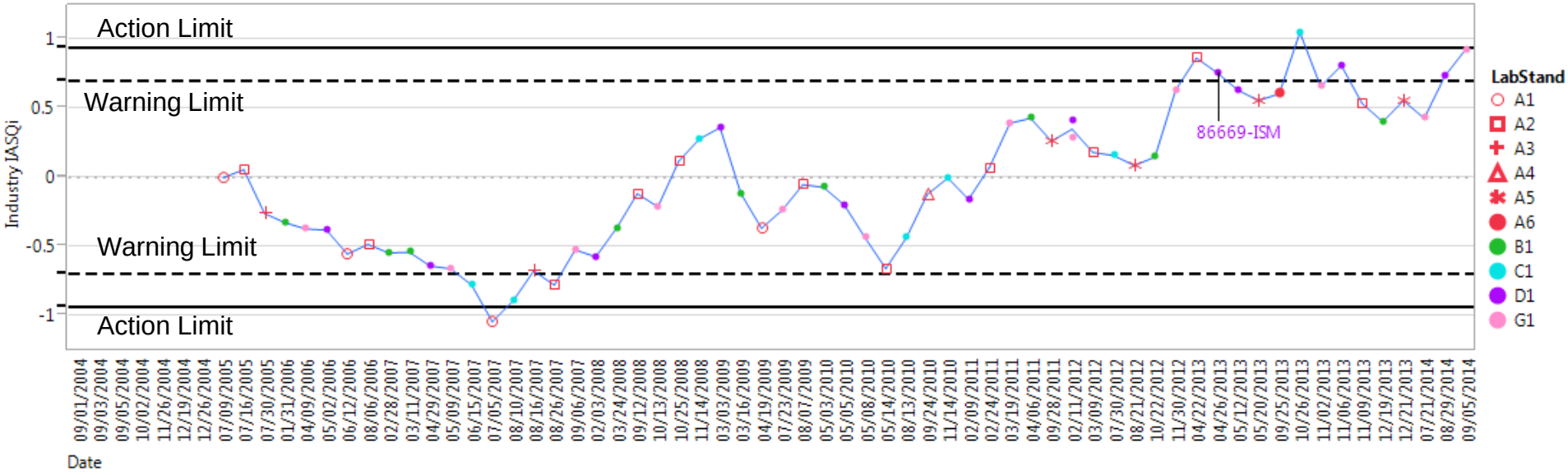
Injector Screw Weight Loss Adjusted to 3.9% Soot IASzi
EWMA Chart for Monitoring Severity



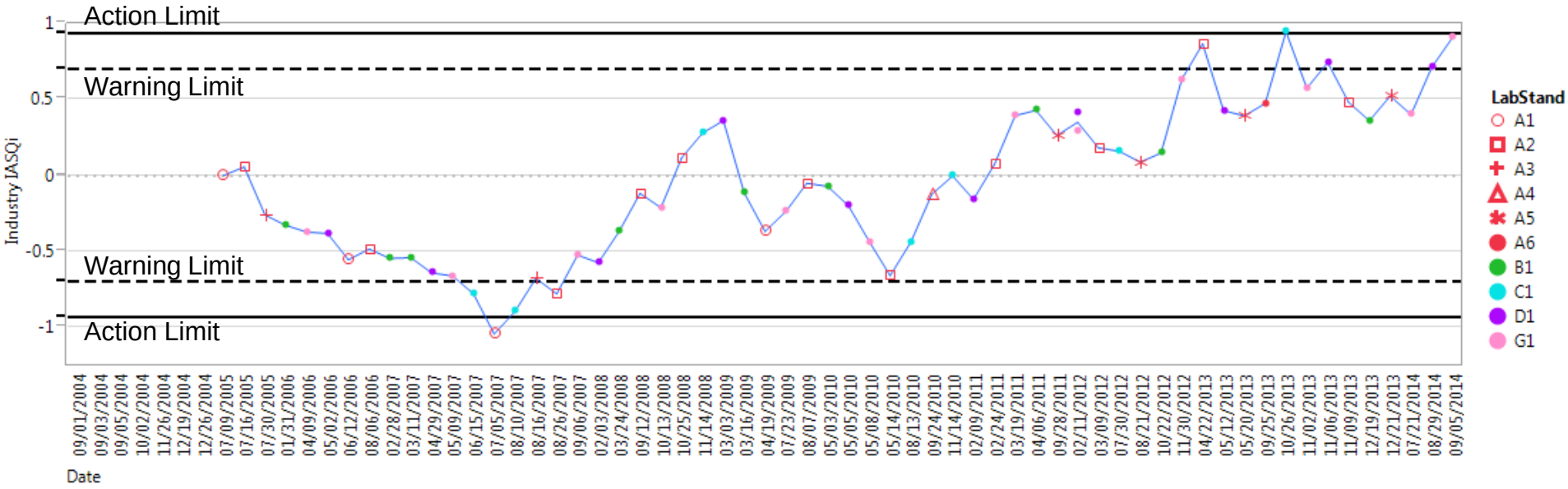
Injector Screw Weight Loss Adjusted to 3.9% Soot
IASzi (86669-ISM Excluded; IASzi recalculated)
EWMA Chart for Monitoring Severity



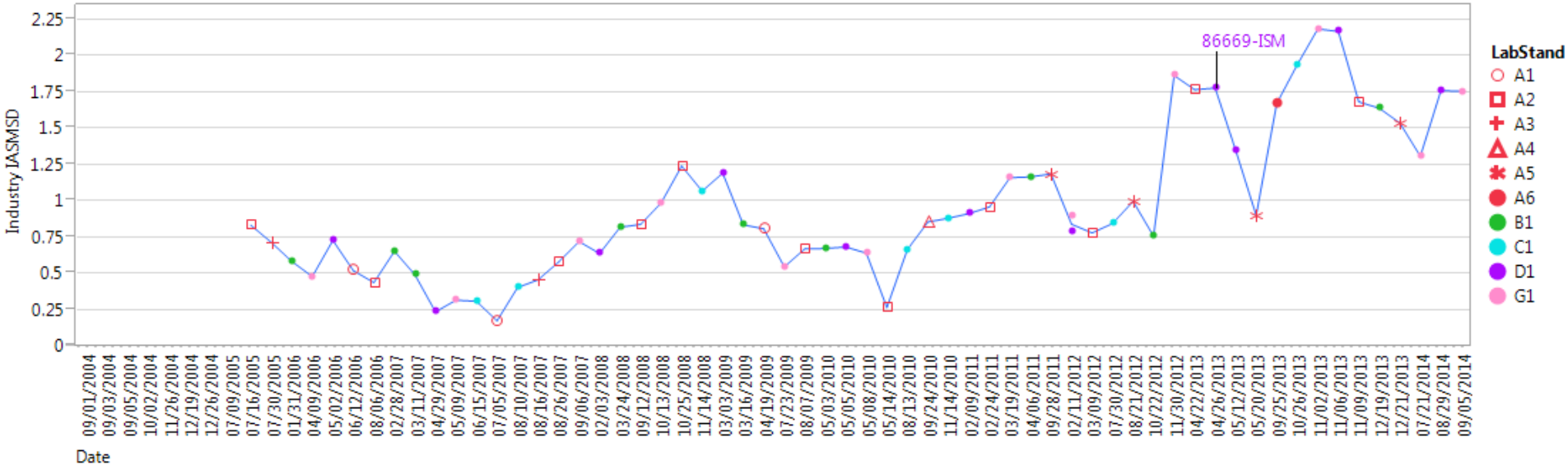
Injector Screw Weight Loss Adjusted to 3.9% Soot IASQi
EWMA Chart for Monitoring Precision



Injector Screw Weight Loss Adjusted to 3.9% Soot
IASQi (86669-ISM Excluded; IASQi recalculated)
EWMA Chart for Monitoring Precision



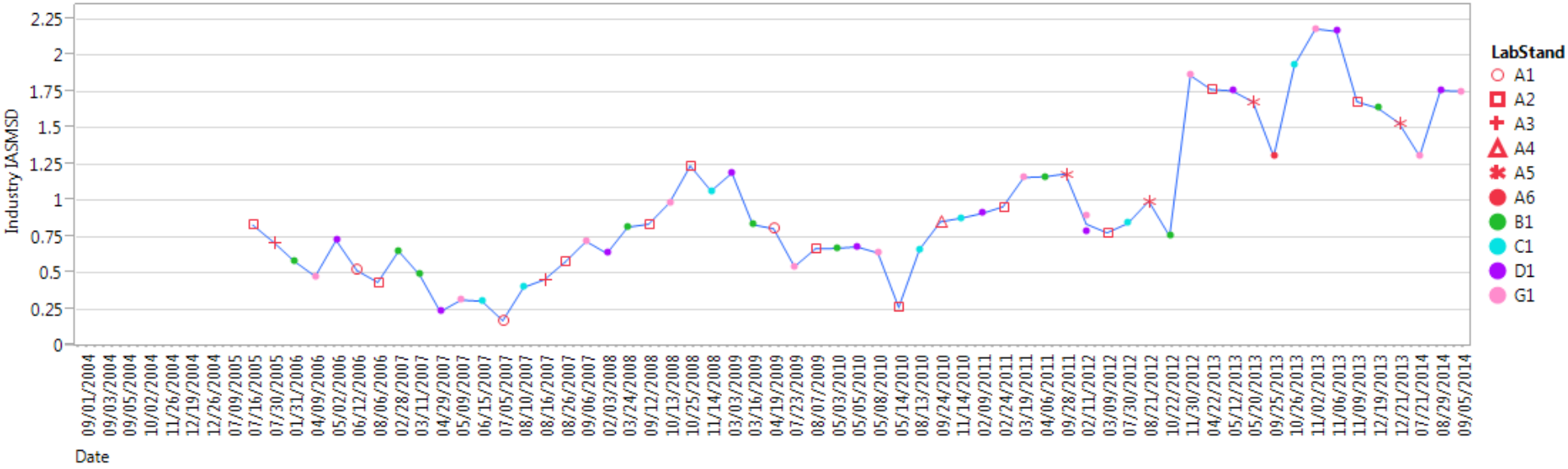
Injector Screw Weight Loss Adjusted to 3.9% Soot IASMSD
MSD Chart for Monitoring Precision



Injector Screw Weight Loss Adjusted to 3.9% Soot

IASMSD (86669-ISM Excluded; IASMSD recalculated)

MSD Chart for Monitoring Precision



LTMS Appendix B

HISTORY OF INDUSTRY CORRECTION FACTORS

ISM	June 28, 2007	***	All Tests	Add +1.7 to Crosshead Wear At 3.9% Soot Add +19.1 to Injector Adjusting Screw Wear At 3.9% Soot
	March 4, 2010	***	All Tests	Add +1.3 to Crosshead Wear At 3.9% Soot
	April 30, 2011	***	All Tests	Add +2.5 to Crosshead Wear At 3.9% Soot
	November 19, 2013	***	All Tests	Add -0.200 to ln(SAIAS)

LTMS Appendix A

ISM Reference Oil Targets											
		Effective Dates		X-Head Wear @ 3.9% Soot		OFDP[1]		Average Sludge		Injector Adj. Screw Wear @ 3.9% Soot	
Oil	n	From	To[2]	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
830-2	7	9-1-04	11-30-05	4.8	1.4	2.5430	0.3936	9.04	0.20	30.0	7.0
	10	12-1-05	8-6-07	5.3	1.4	2.4342	0.3813	8.99	0.15	24.5	10.7
	21	8-7-07	***	5.1	1.5	2.5209	0.3274	9.00	0.15	29.5	5.7

1 Transformation for OFDP is ln(OFDP+1)
2 *** = currently in effect

APPENDIX E

APPLYING SEVERITY ADJUSTMENTS

In order to adjust non-reference oil test results for laboratory or stand severity, an exponentially weighted, moving average technique (EWMA) is applied to standardized calibration test results. See Section 1.A.3 of this document for an explanation.

When the EWMA laboratory or stand (for stand based test areas) chart action limit for severity is exceeded, a severity adjustment is calculated and applied to all subsequent non-reference oil tests. The following table lists the laboratory (or stand) EWMA severity alarm limit for all tests in the current LTMS. Alarm limits are calculated by the formula listed in Section 1.A.3.

Test Type	Alarm Level	Parameter(s)	Alarm Limit
IIIF	Laboratory	All	±0.653
IIIG	Laboratory	All	±0.550
IIIGA	Laboratory	All	±0.550
IIIGB	Laboratory	All	±0.550
IVA	Laboratory	All	±0.600
VG	Laboratory	All	±0.653
VIB	Stand	All	±0.000 (Continuous)
VID	Stand	All	±0.000 (Continuous)
VIII	Laboratory	TBWL	±0.600
1M-PC	Laboratory	All	±0.653
1K	Laboratory	WTD,TGF,TLHC	±0
1N	Laboratory	WTD,TGF,TLHC	±0.653
1P	Laboratory	All	±0.653
1R	Laboratory	All	±0.653
C13	None	None	None
ISB	None	None	None
ISM	None	None	None
T-8/T-8E	Laboratory	All	±0.653
T-10A	Laboratory	All	±0.600
T-11	Laboratory	All	±0.653
T-12	Laboratory	All	±0.653
RFWT	Laboratory	All	±0.600
EOAT	Stand	All	±0.000 (Continuous)
L-33-1	Laboratory	All	±0.823
L-37	Stand	All	±0.653
L-42	None	None	None
L-60-1	Stand	All	±0.653
HTCT	None	None	None
OSCT	None	None	None

Cummins ISM Critical Parts Batch Changes

Part	Batch	Date	Starting Kit Number	Comments
Crossheads	C	Nov-06	201	Prior batch was M-11 EGR Batch B
"	D	Apr-10	425	
"	E	May-13	673	
Injector Adjusting Screws	B	Jun-05	75	
"	C	Jul-07	235	
"	D	May-13	673	
Injector Push Rods	A	?	?	No record of exact Date or first Kit use
"	B	Apr-12	571	
Intake/Exhaust Valves	B	Nov-05	111	
"	C	Aug-08	301	
"	D	Mar-12	562	
Wire Mesh Test Filters	M11 EGR-3	Dec-03	1	First batch of filters with wire mesh
"	ISM A	Aug-09	375	Second batch of filters with wire mesh
"	ISM ASTM	Apr-10	425	901 filter media with wire mesh