Cummins Surveillance Panel
September 17, 2014
Teleconference Meeting Minutes
3:00 P.M. EDT

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

Cummins ISM Filter Plugging Mild Alarm

The current filter plugging mild trend has triggered a comprehensive review (all parameters, not just FPD), by Kevin O'Malley of Lubrizol. Kevin's analysis is shown in **Attachment 1**. Kevin found that there may be hardware based effects for severity and/or precision of the test parameters and the panel may need to consider revising existing correction factors (or implementing new ones where they don't exist). For all parameters, Kevin prepared several potential correction factors for the panel to consider.

Kevin's presentation spurred much discussion on the timing of past hardware changes, what the best data sets to use are, and what to do going forward. Eventually, the data set was agreed to (one test will be resubmitted as invalid, the non-chartable tests will not be used, and one test will have the filter batch corrected). Much more discussion and brainstorming followed. Based on these discussions, Kevin will revise his work and the panel will review at the next meeting.

ISB Replacement Engines

Labs are running low on ISB engines. Dan Nyman of Cummins stated that 20 blocks have been ordered, but the problem is a time issue (not parts availability). Dan noted that he can get long or short blocks built quicker than a full assembly.

He asked which of those is the best option to keep the labs running. Labs indicated that they could keep running with either a long or short block. If necessary, Dan will have short or long blocks sent to the labs rather that the full engine. The blocks have not yet been received. It was stated that long blocks are preferable to short blocks. Dan will look into the cost for the labs to order themselves or to pool the order through a large distributor. Dan was asked to try to get 6-8 long blocks as a triage supply to keep the industry going; timeline expected to be about two months. It was noted that at some point the panel will have to consider moving to the 6.7L engine.

ISM Scalloped Heads

Dan asked how the labs were situated on their head supply. He noted that the panel needs to start considering introducing the heads. It was commented that the panel should work on coordinating reference tests to accomplish this.

The next call is tentatively scheduled for Friday, Sept. 26 at 11:00 am EDT. The teleconference adjourned at 5:10 pm EDT.

ATTACHMENT 1

Cummins ISM Industry Severity

Sept 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.

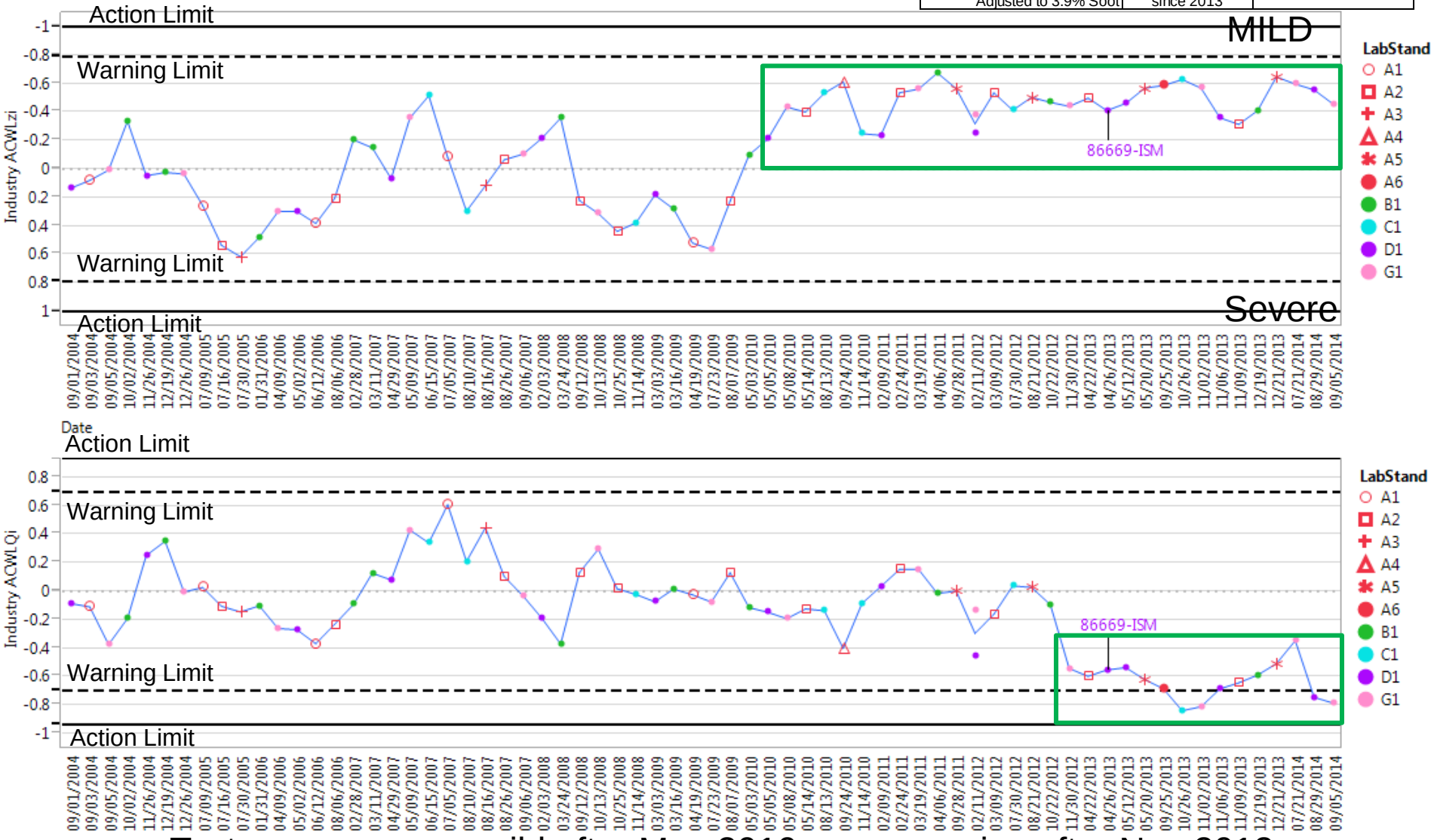
Surveillance Panel Decisions Needed:

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?

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

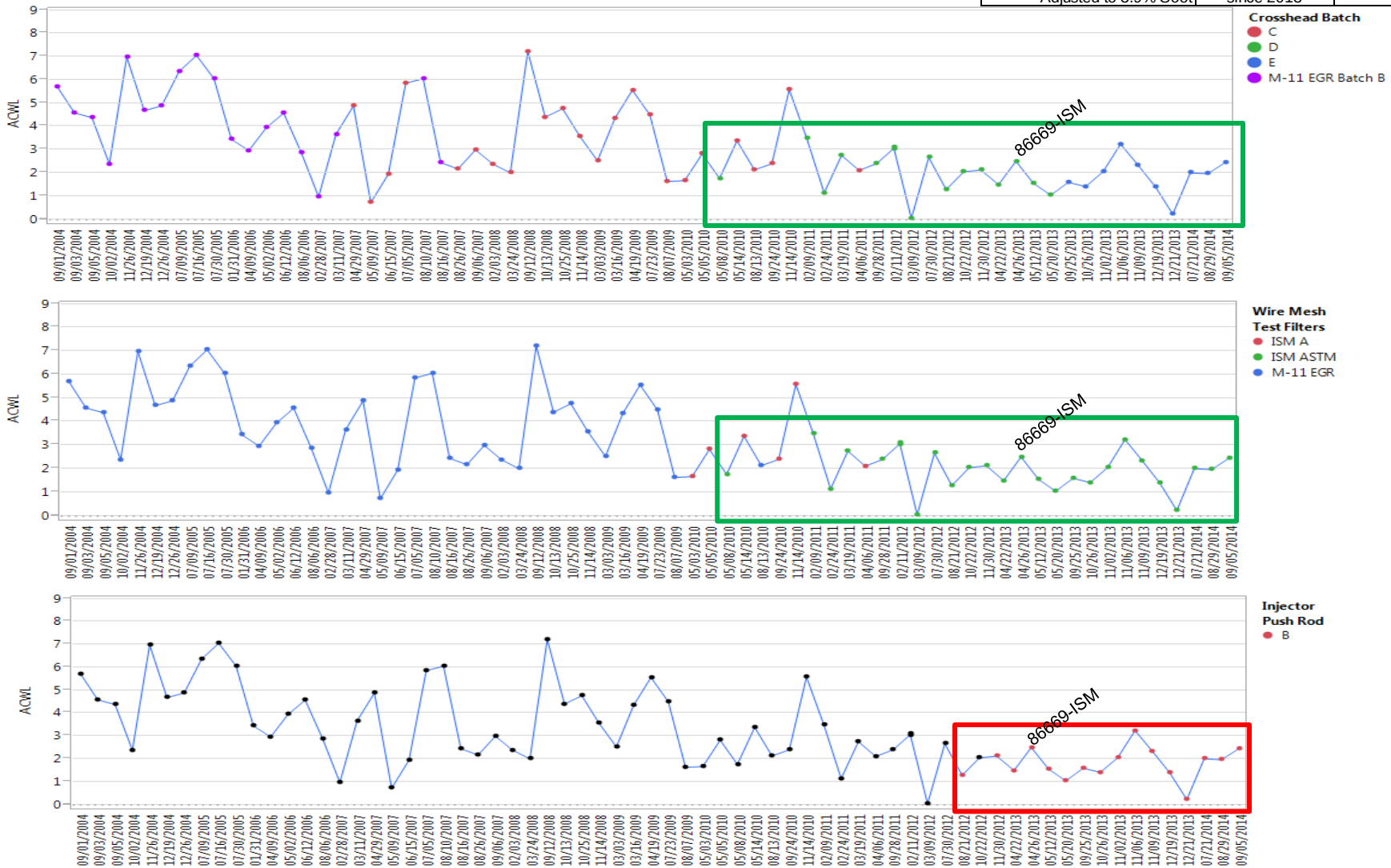


Test appears more mild after May 2010; more precise after Nov 2012.
Does this warrant a change to the current correction factor?

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:



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

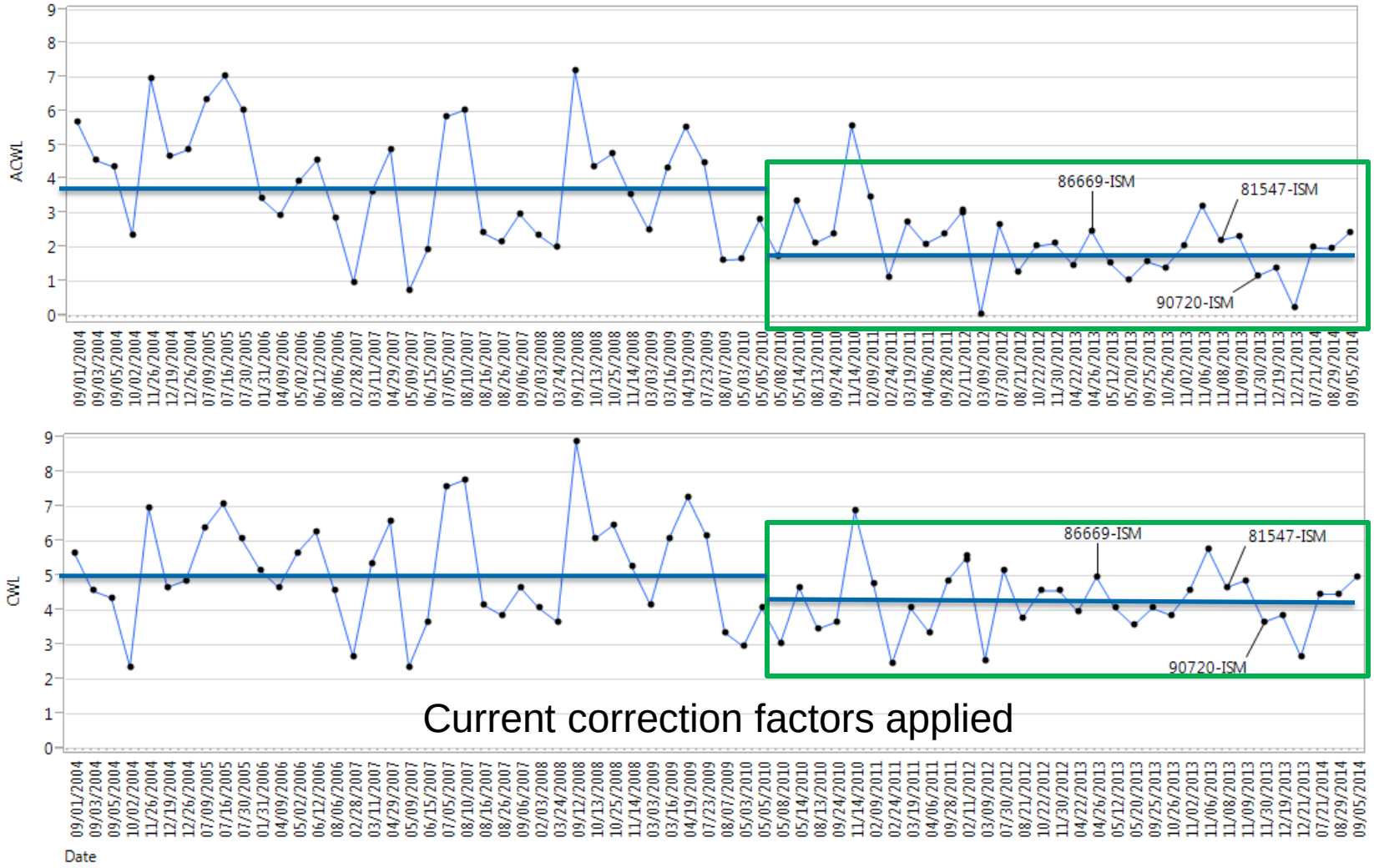
Does it make sense that any of these hardware changes affect test severity?

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



Surveillance Panel will need to decide if additional data should be included in the analysis.

Crosshead Weight Loss

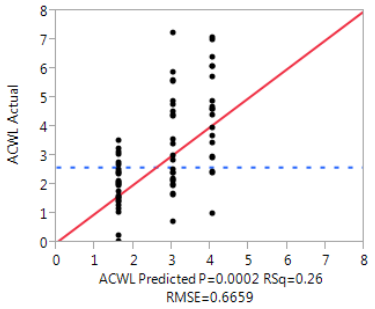
LTMS Chart=Y Data:

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

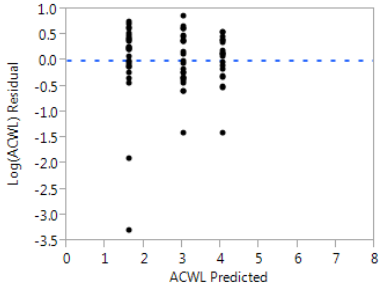
Analysis of Variance

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

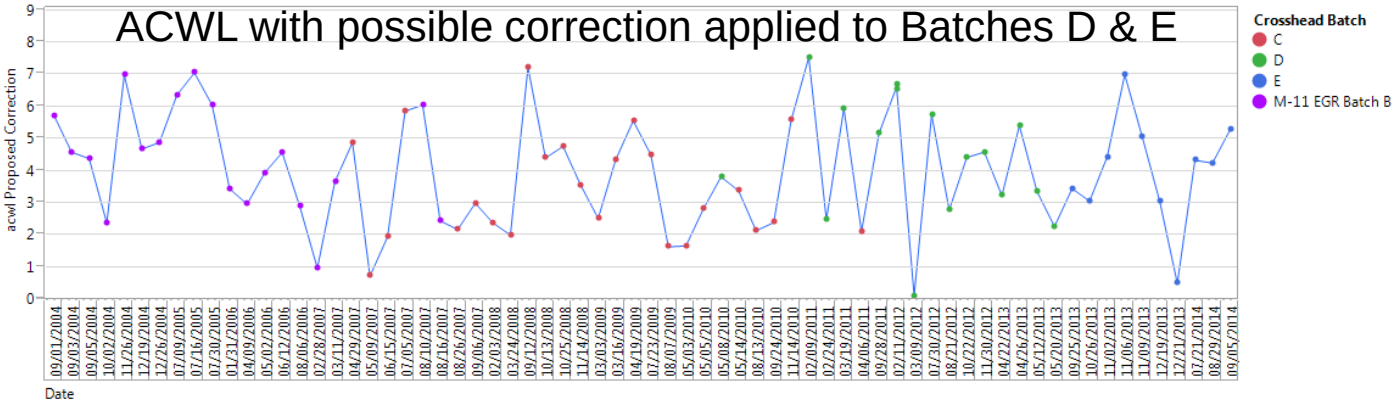


Expanded Estimates

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

	Data Used	Transformation	Crosshead Weight Loss Adjusted to 3.9% Soot
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

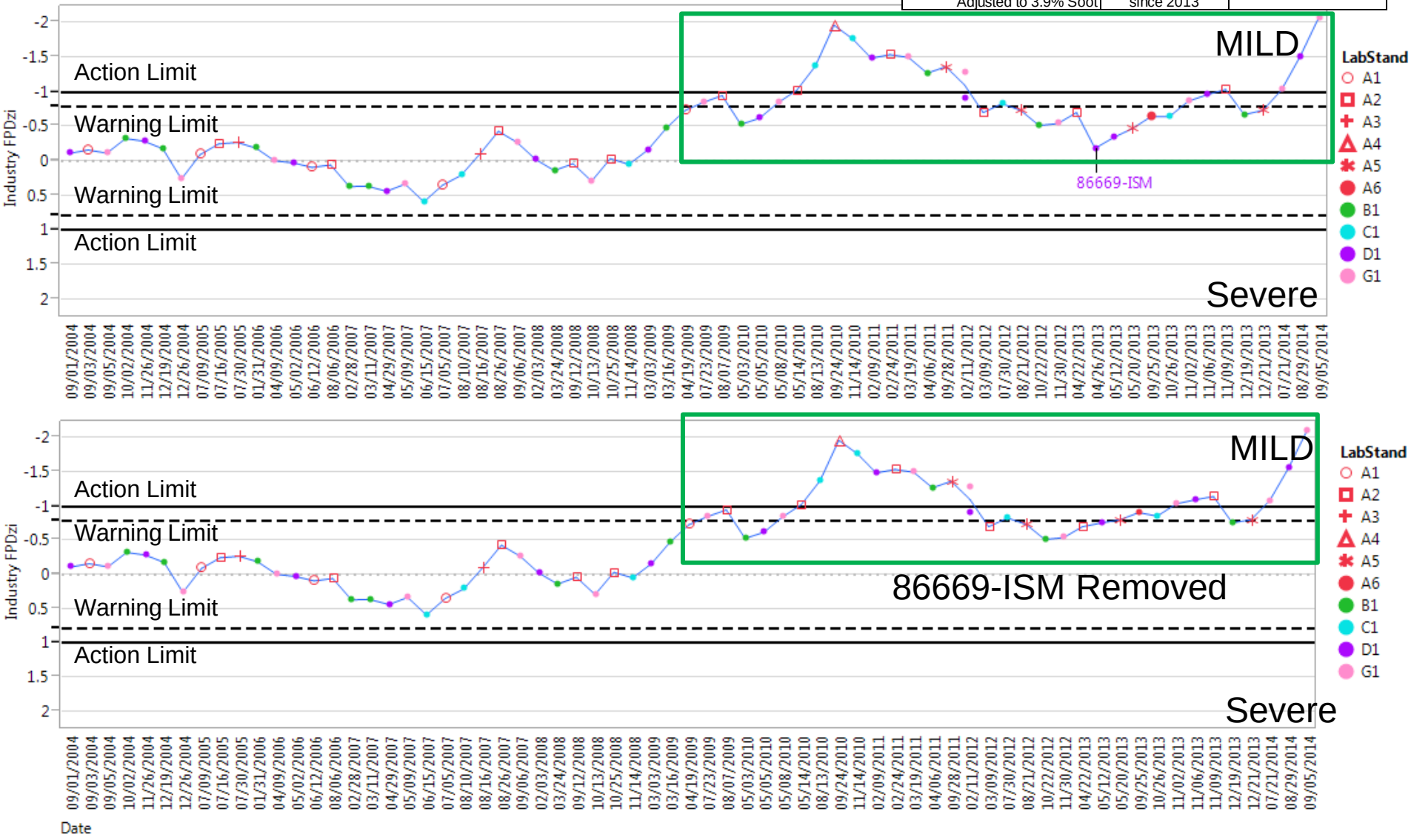
Possible Correction Factors

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

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

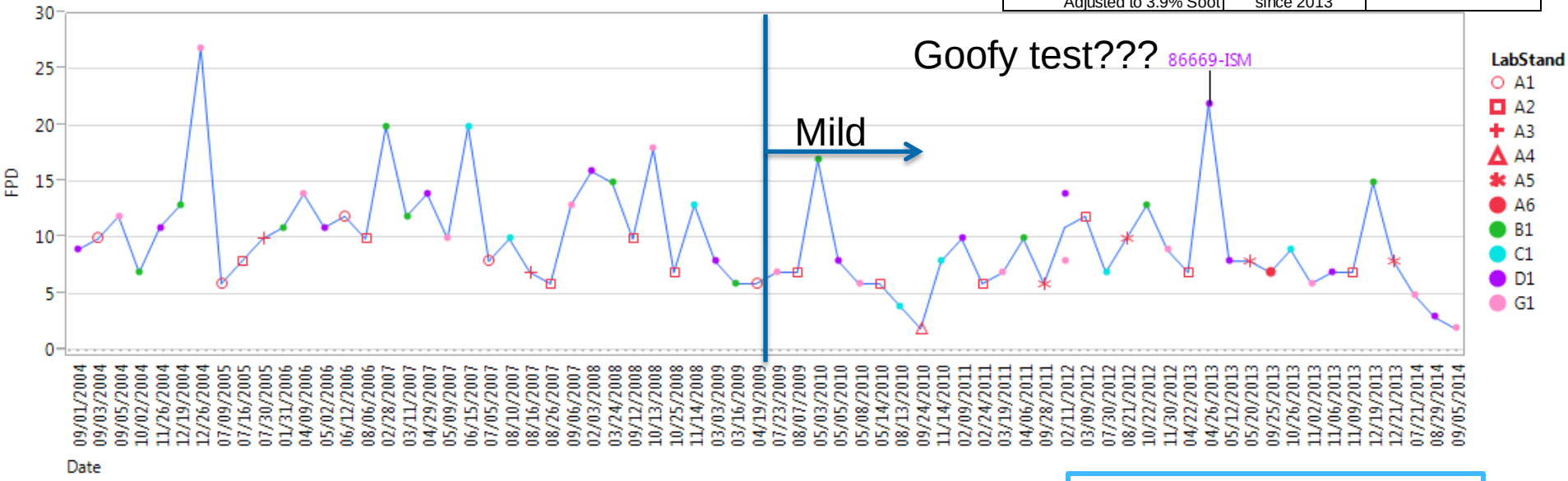


Test appears mild after April 2009.

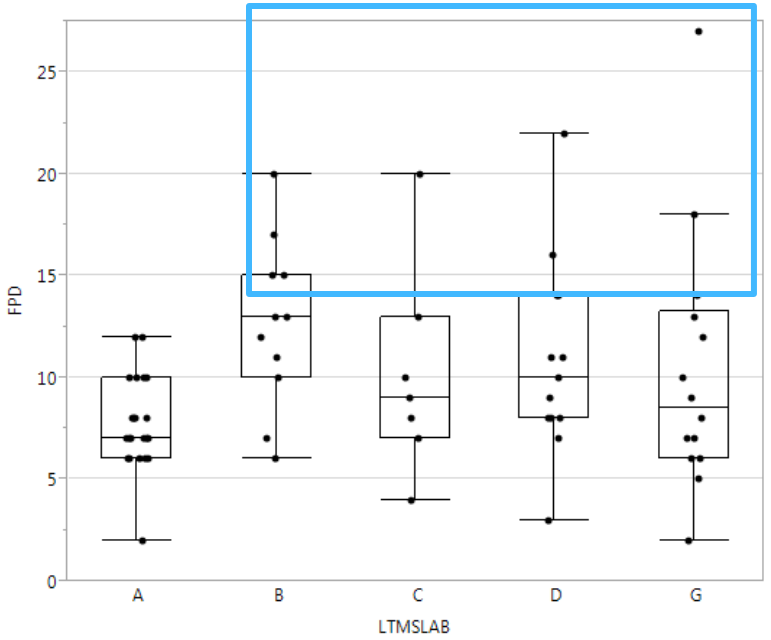
Filter Plugging Delta

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



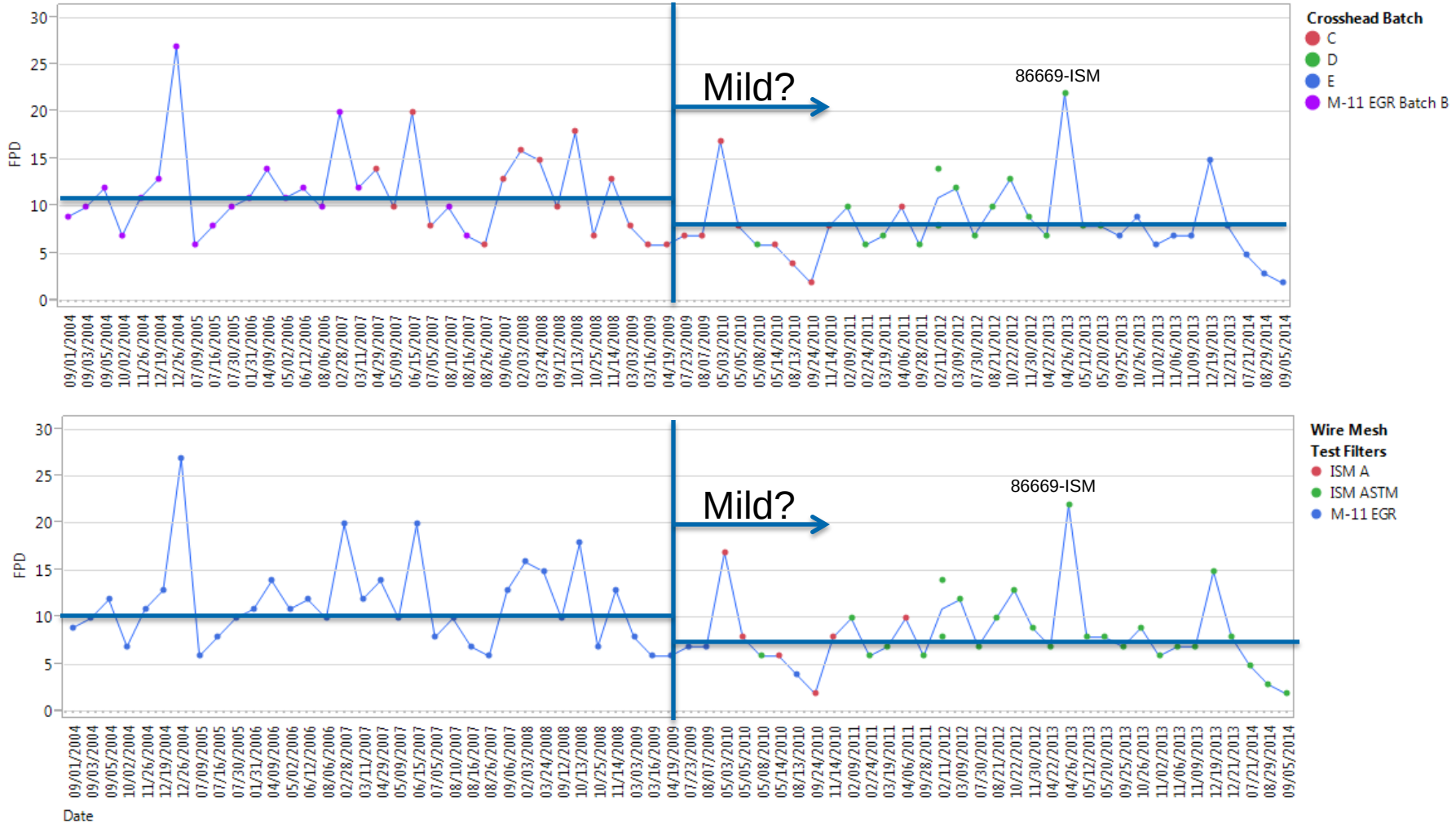
High FPD results observed in labs B,C,D, & G.



Filter Plugging Delta

LTMS 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

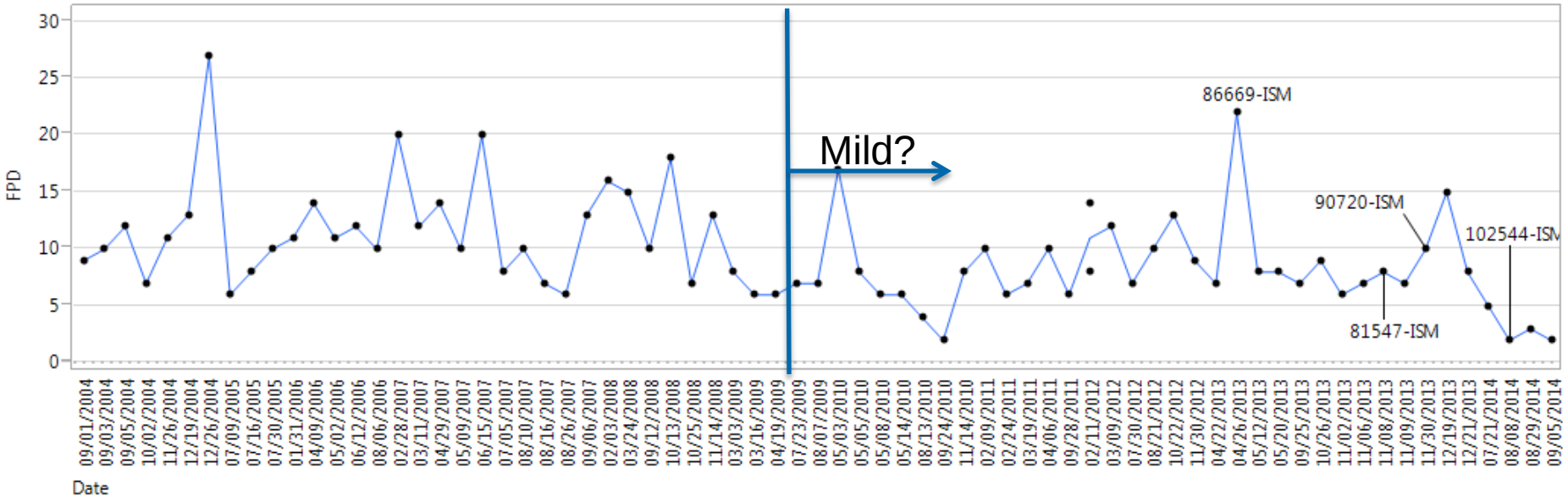


FPD appears mild when crosshead batches D & E or ISM ASTM filter utilized.
Does it make sense that either of these hardware changes affect test severity?

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

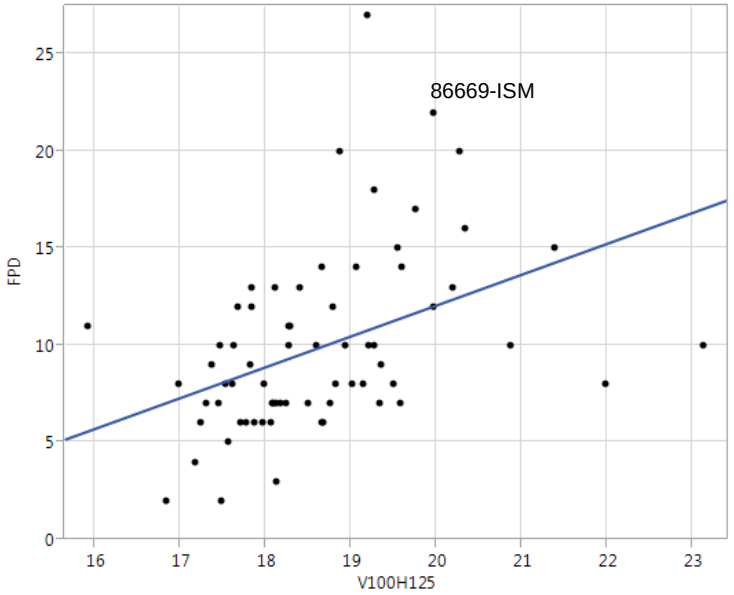


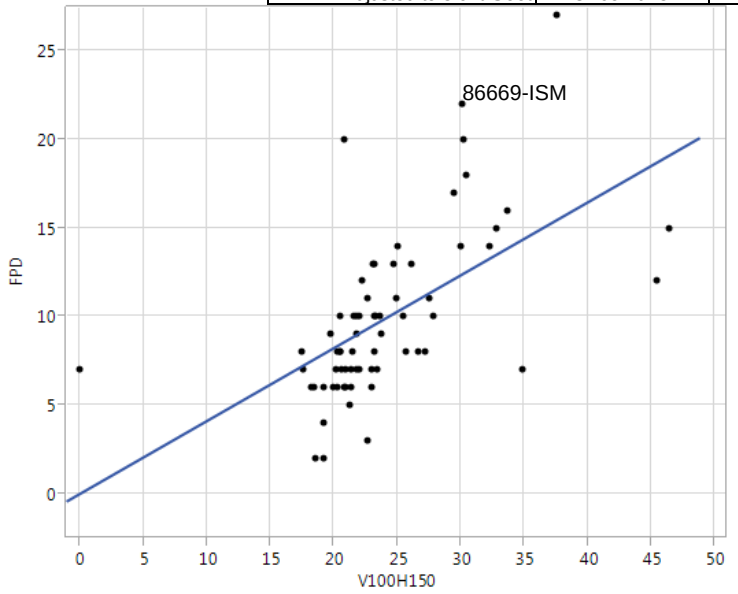
Surveillance Panel will need to decide if additional data should be included in the analysis.

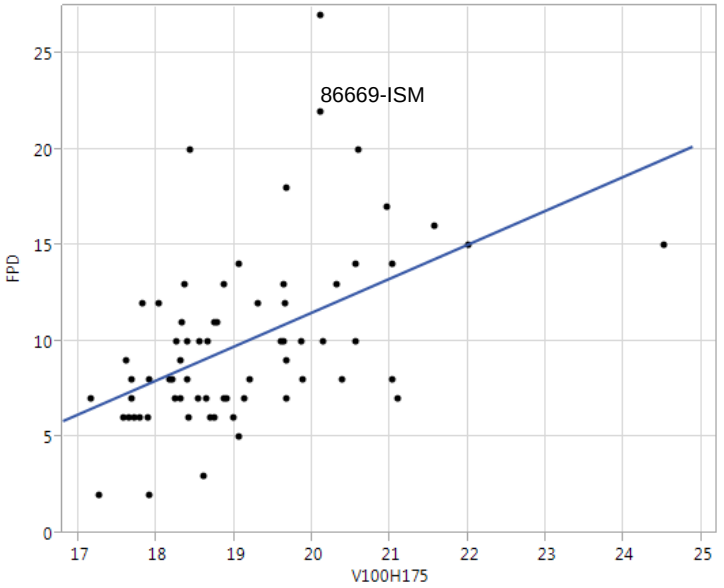
Filter Plugging Delta

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

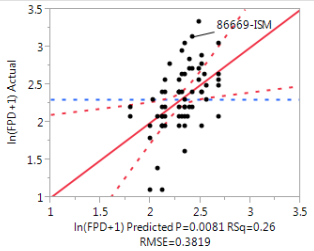
LTMS Chart=Y Data

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*

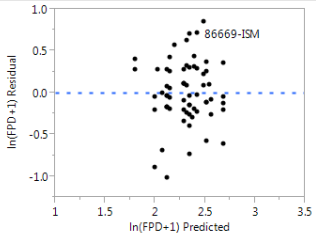
Parameter Estimates

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



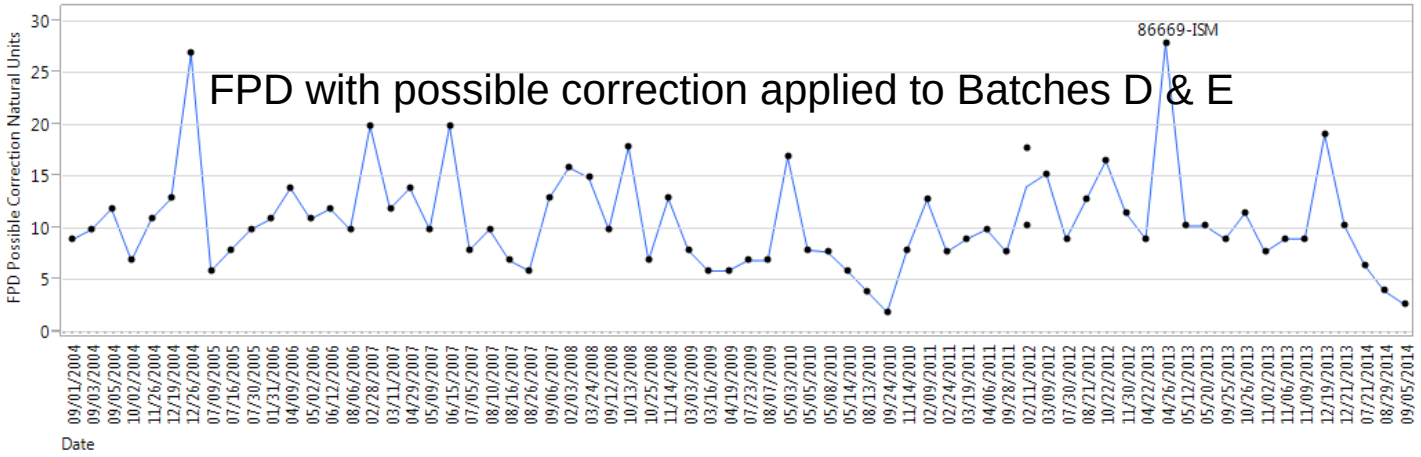
Expanded Estimates

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

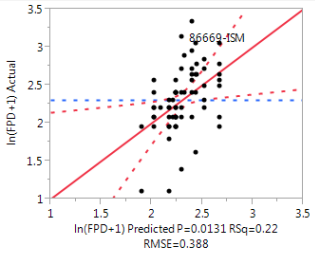
LTMS Chart=Y Data

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*

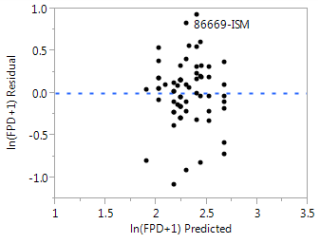
Parameter Estimates

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



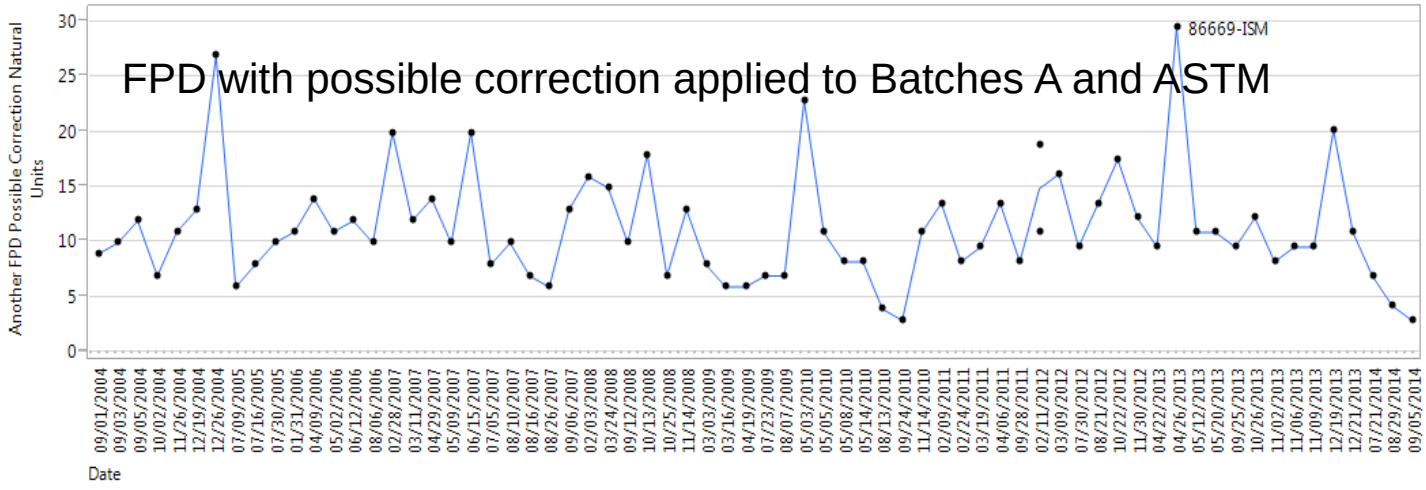
Expanded Estimates

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



Possible CFs for Filter Plugging Sludge

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

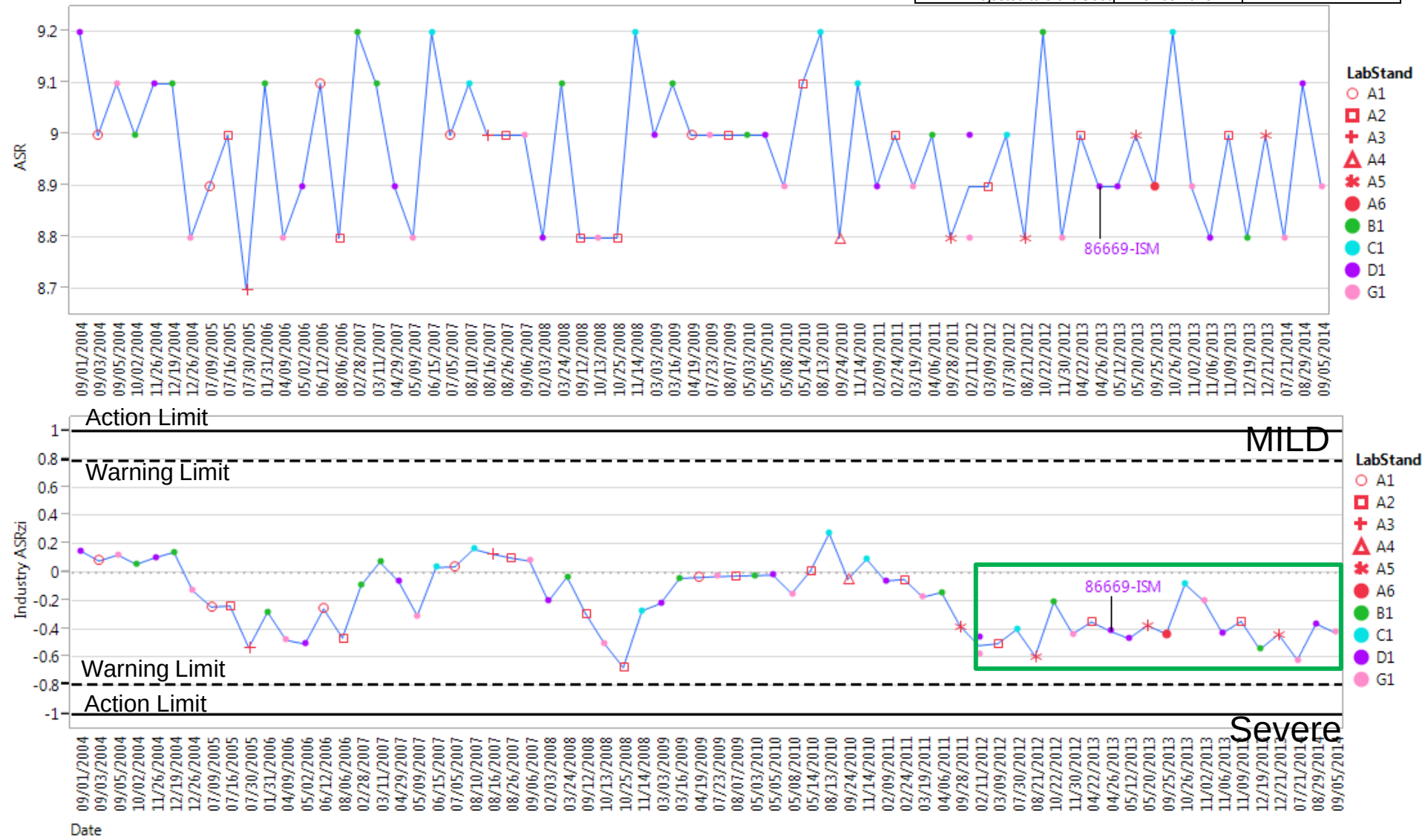
	Data Used	Filter Plugging Delta
Current		None: ln(FPD+1)
No Change		None: ln(FPD+1)
Adjust based on average of Mesh Filter ISM A & ASTM versus M-11 EGR	830-2, LTMS Chart = Y	ln(FPD+1) + 0.2827
Adjust based on average of Mesh Filter ISM A & ASTM versus M-11 EGR	830-2, LTMS Chart = Y minus 86669-ISM	ln(FPD+1) + 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.

Average Sludge Rating

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

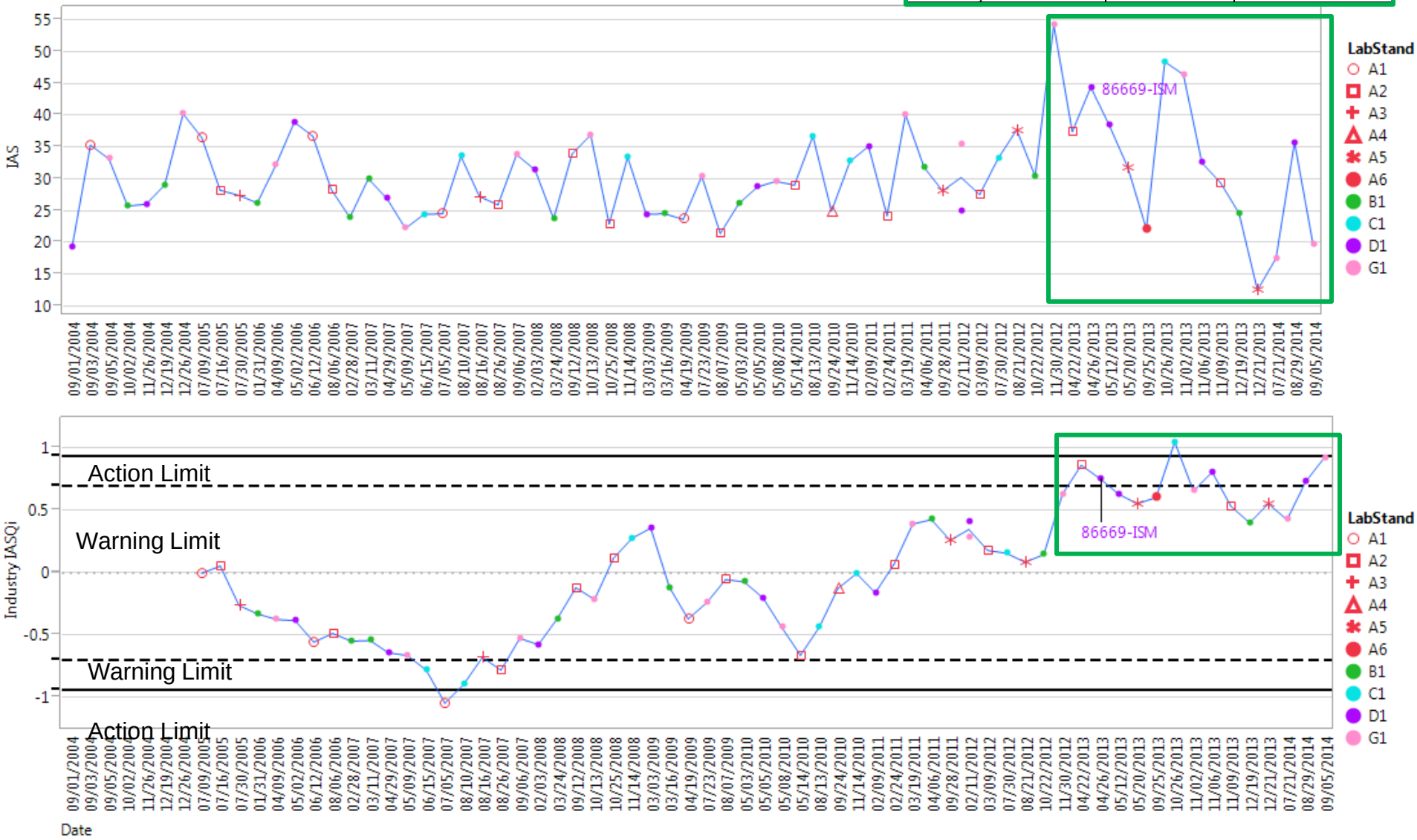


ASR appears slightly severe since Nov 2012. Does this constitute a correction factor?

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

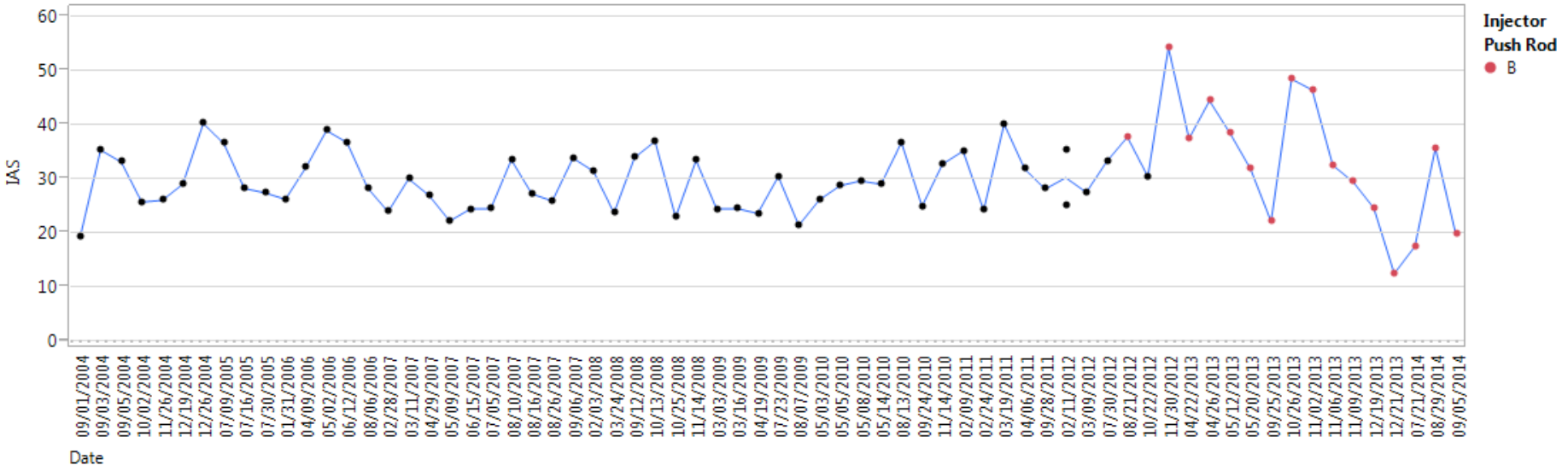


Corrected SAIAS has more variability since Nov 2012.

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

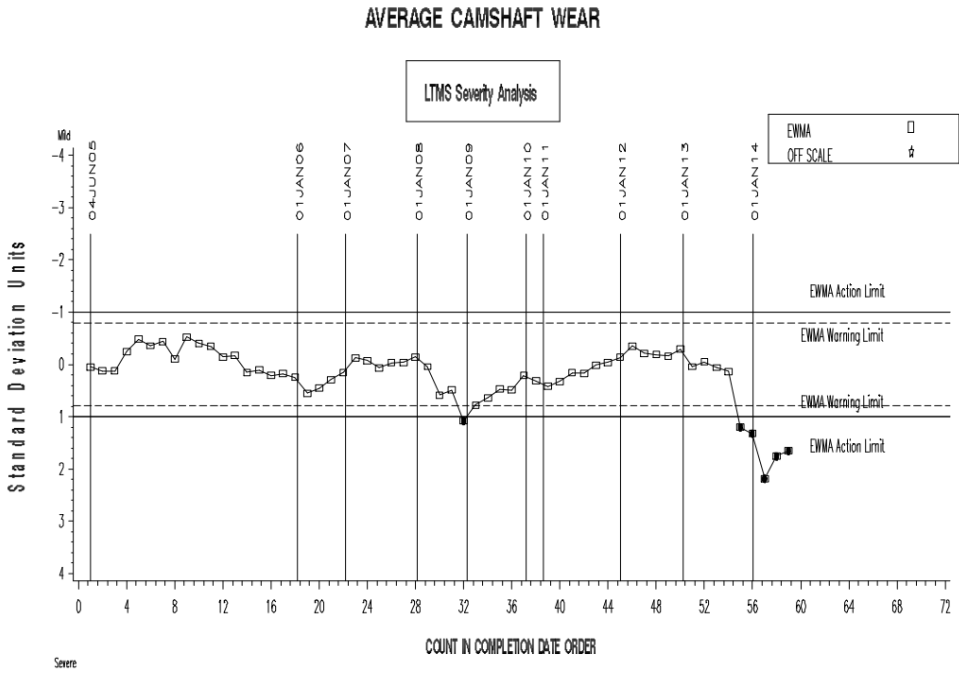


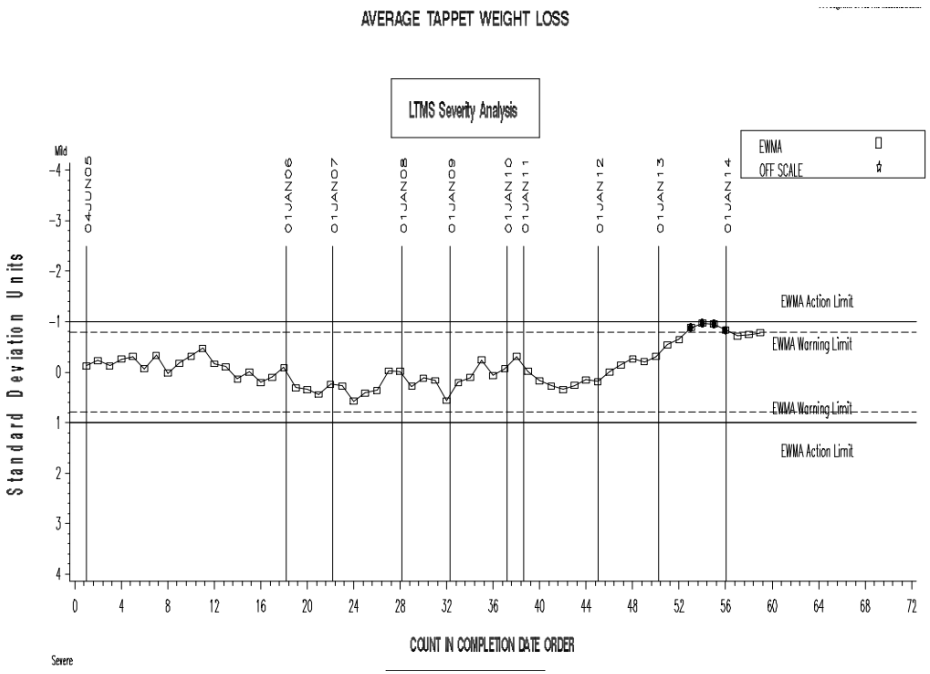
The increase in corrected SAIAS variability corresponds to the use of injector push rod B

Current 830-2 standard deviation = 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?

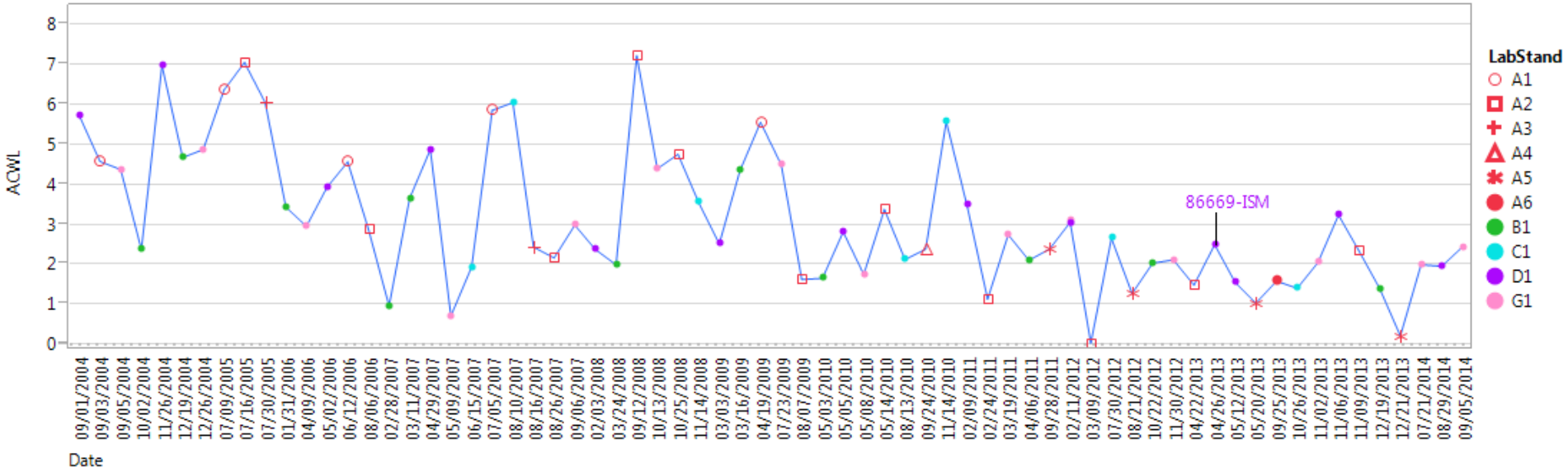




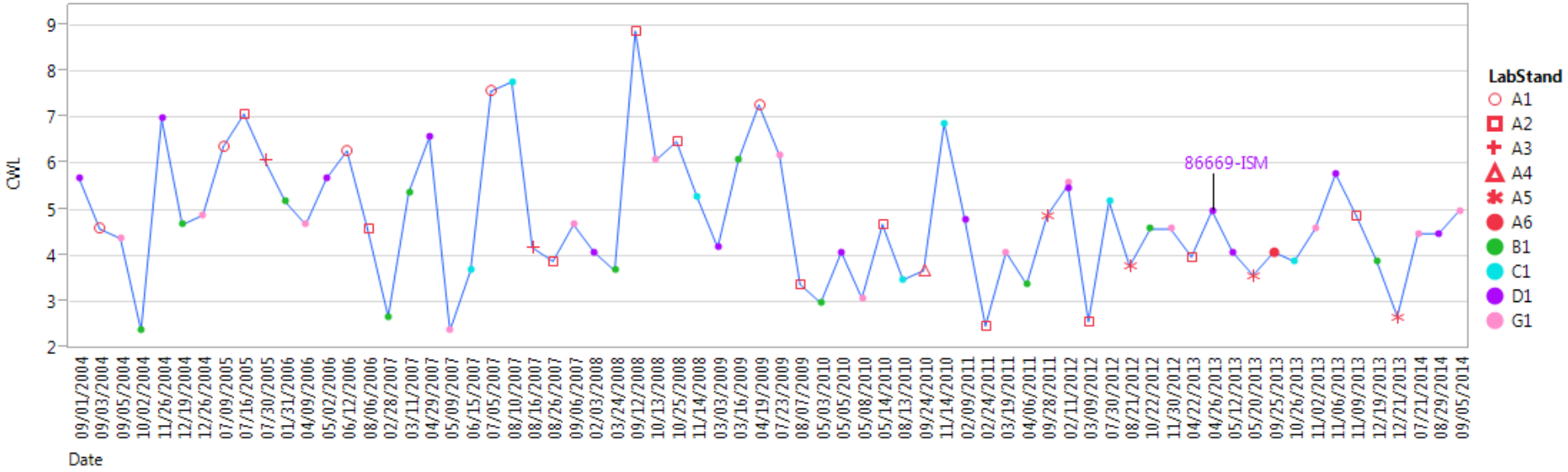
Appendix

Crosshead Weight Loss Adjusted to 3.9% Soot

Crosshead Weight Loss Adjusted to 3.9% Soot Original Units



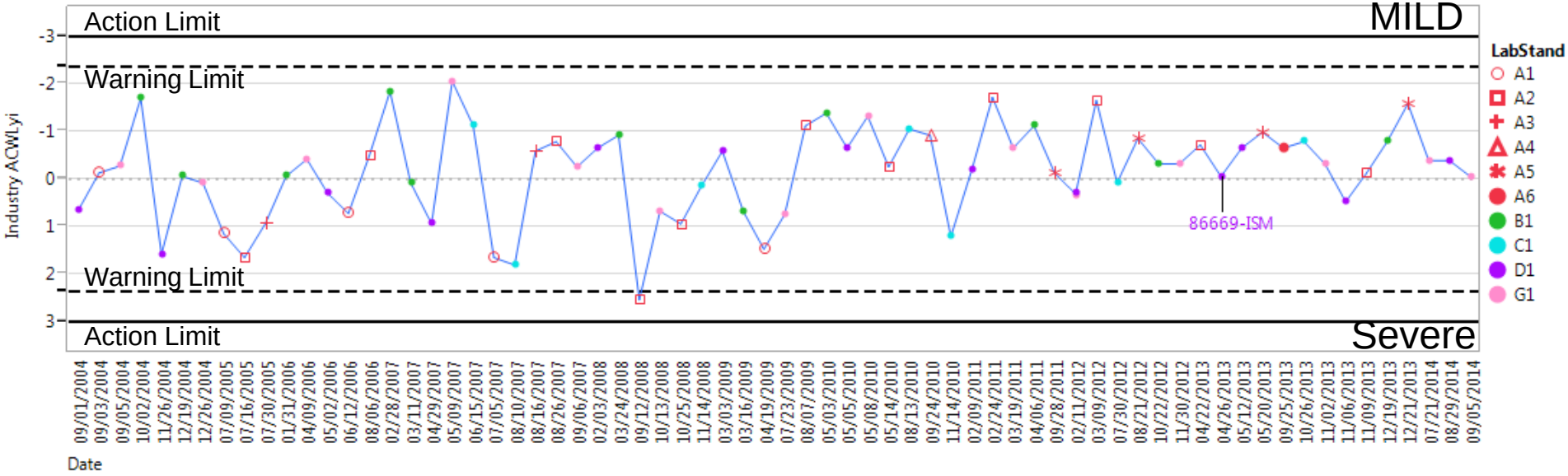
Crosshead Weight Loss Adjusted to 3.9% Soot Corrected Units



Crosshead Weight Loss Adjusted to 3.9% Soot

CWLyi

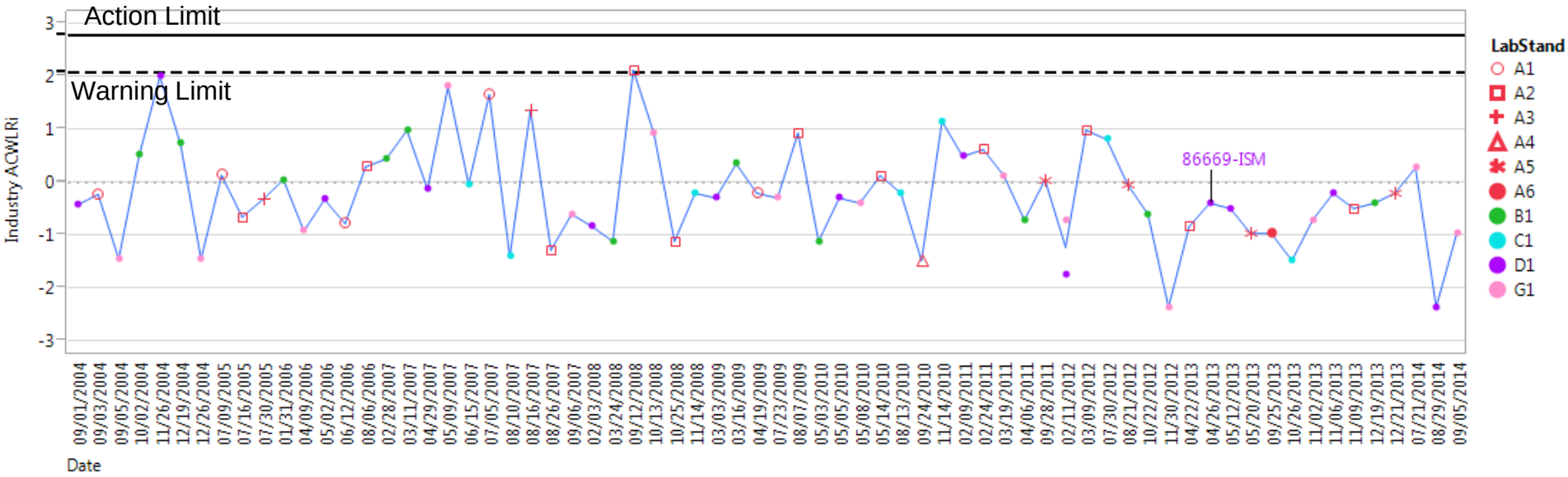
Shewhart Chart for Monitoring Severity



Crosshead Weight Loss Adjusted to 3.9% Soot

CWLRi

Shewhart Chart for Monitoring Precision

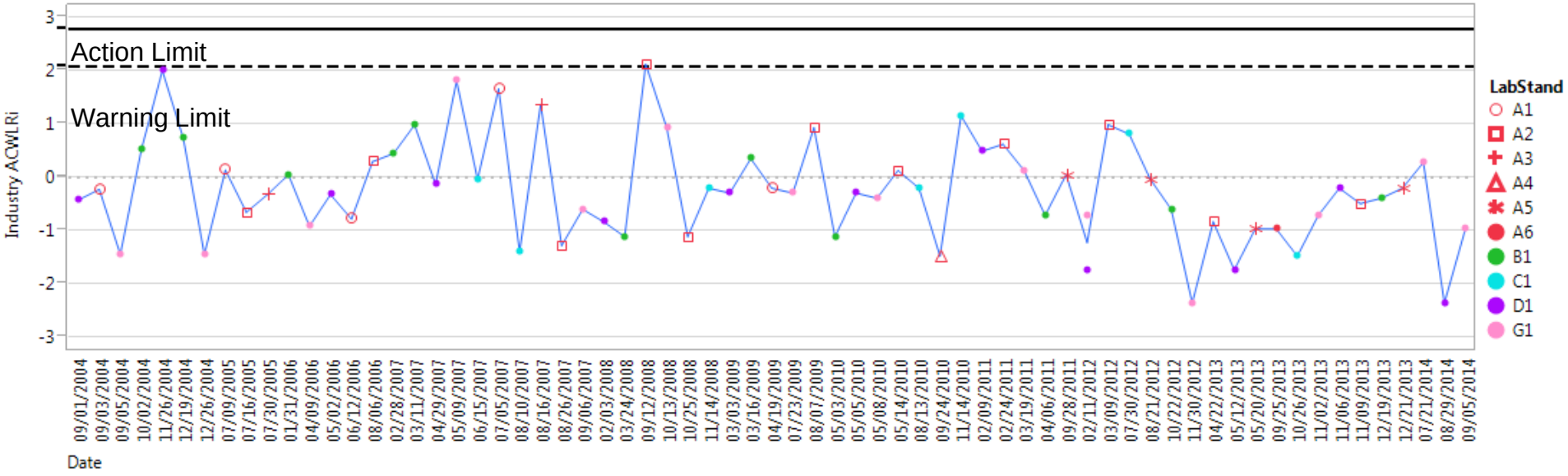


Crosshead Weight Loss Adjusted to 3.9% Soot

CWLRi

86669-ISM Excluded; CWLRi recalculated

Shewhart Chart for Monitoring Precision

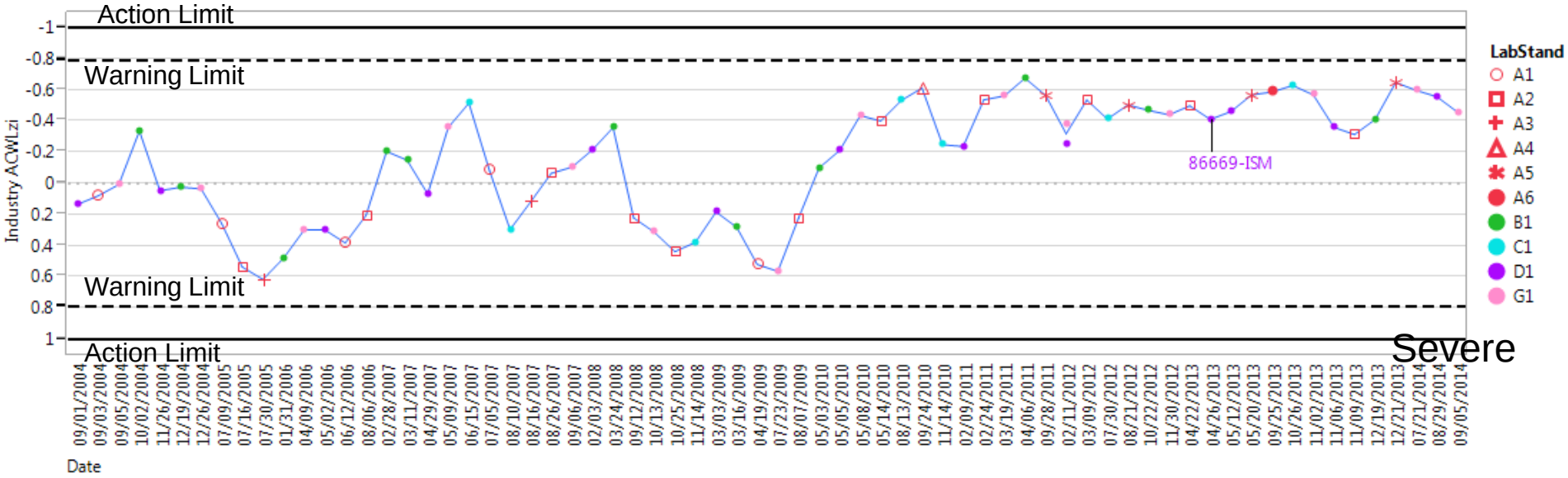


Crosshead Weight Loss Adjusted to 3.9% Soot

CWLzi

EWMA Chart for Monitoring Severity

MILD



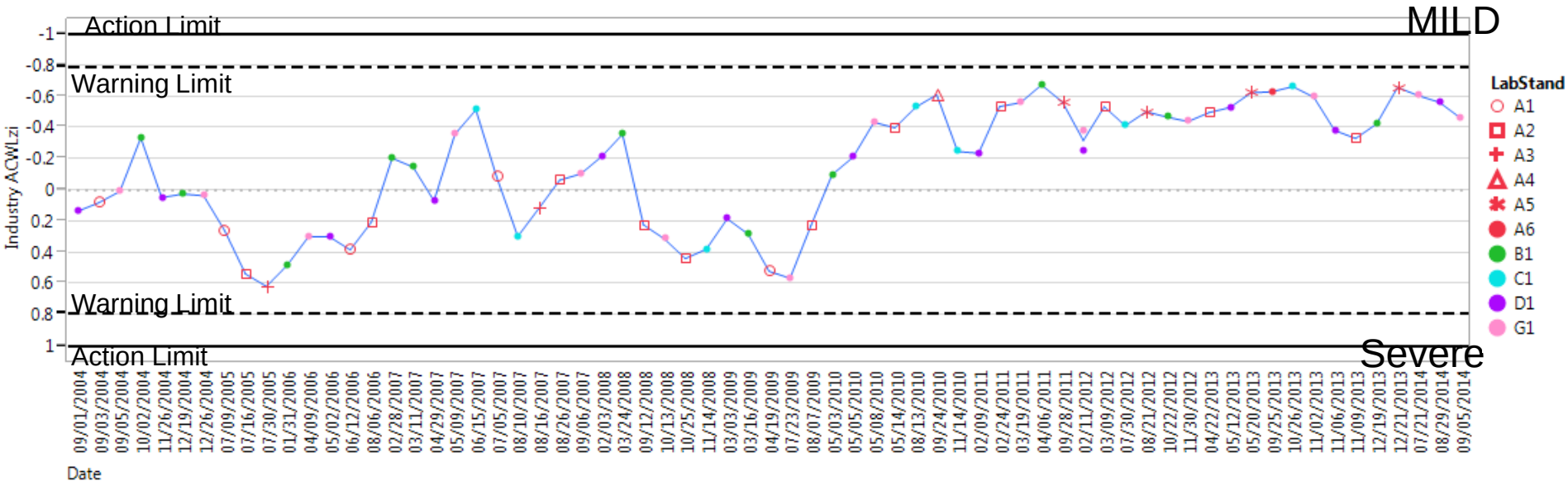
Severe

Crosshead Weight Loss Adjusted to 3.9% Soot

CWLzi

86669-ISM Excluded; CWLzi recalculated

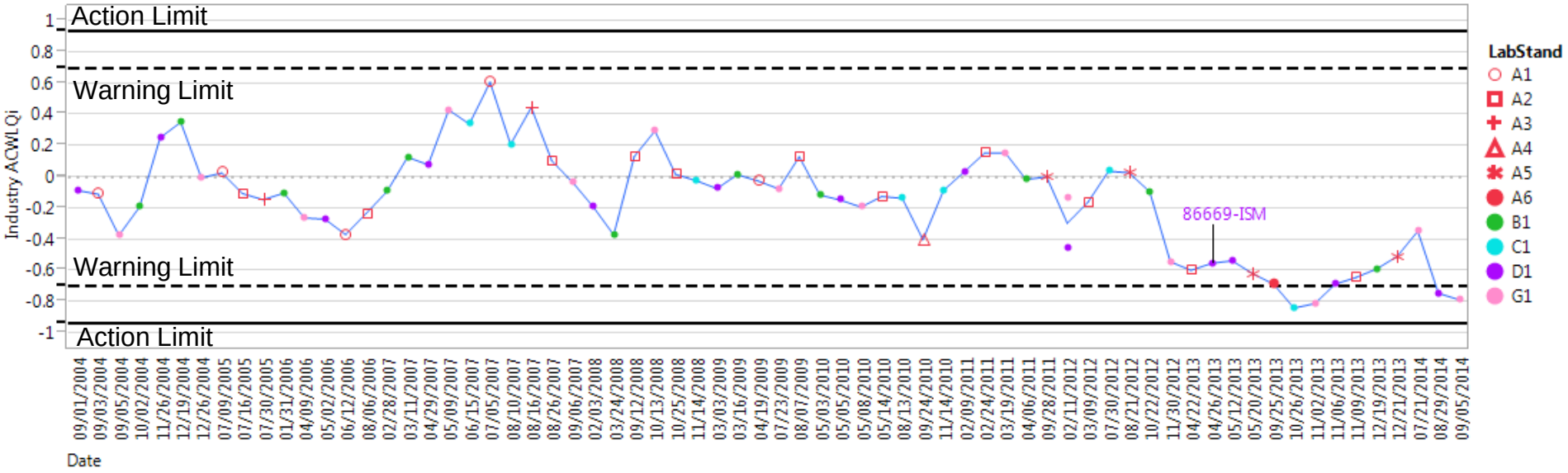
EWMA Chart for Monitoring Severity



Crosshead Weight Loss Adjusted to 3.9% Soot

CWLQi

EWMA Chart for Monitoring Precision

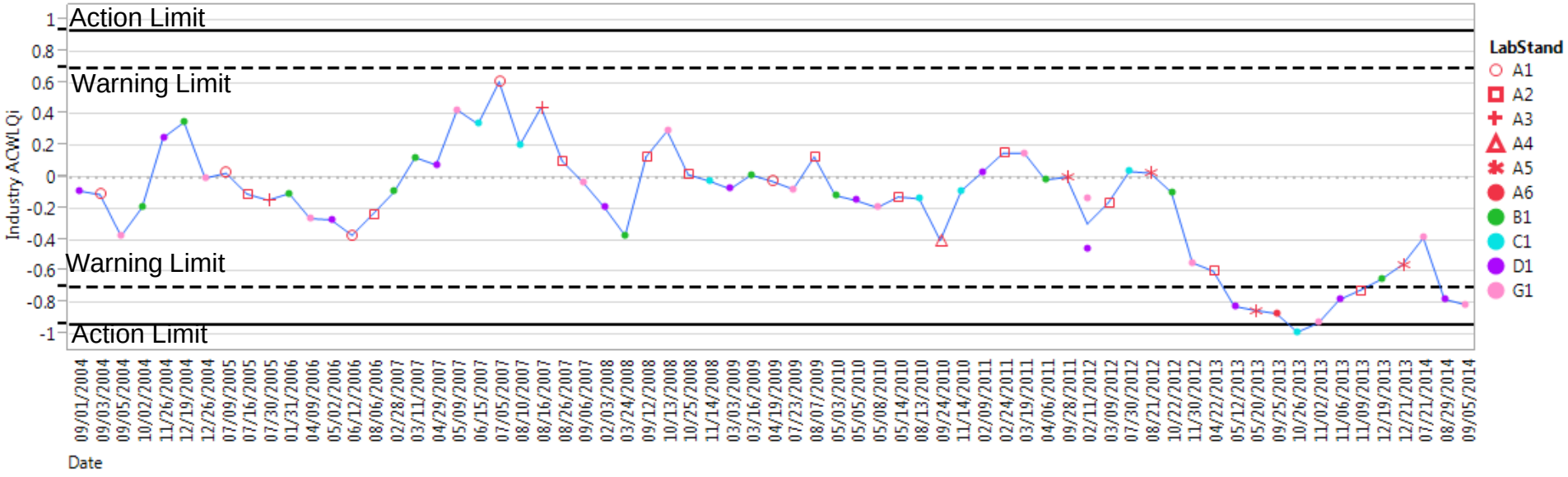


Crosshead Weight Loss Adjusted to 3.9% Soot

CWLQi

86669-ISM Excluded; CWLQi recalculated

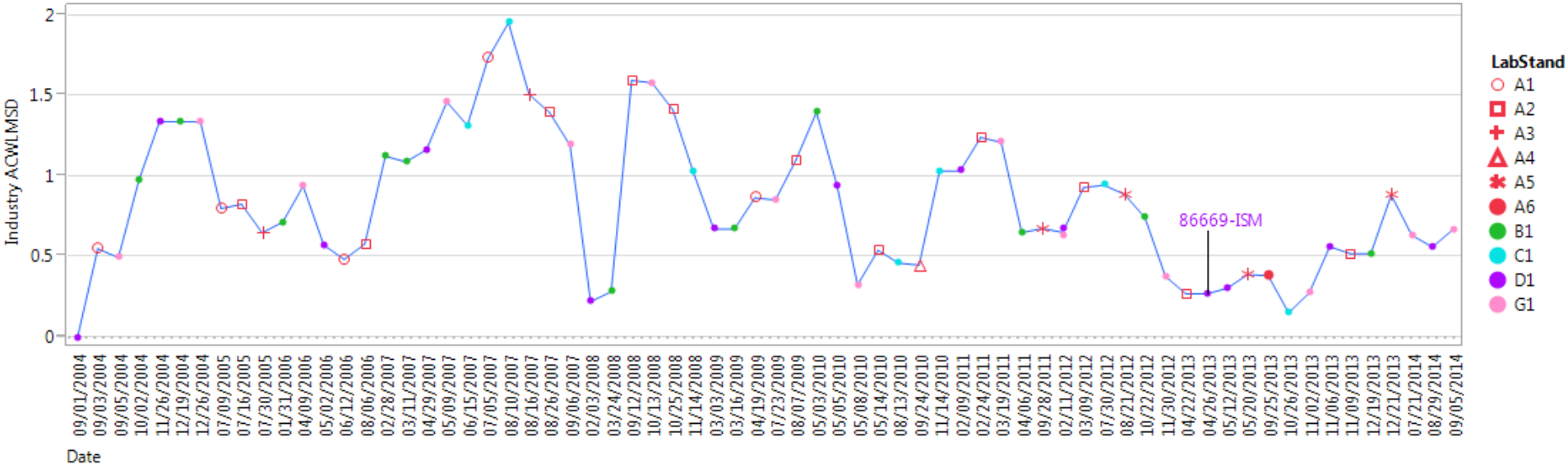
EWMA Chart for Monitoring Precision



Crosshead Weight Loss Adjusted to 3.9% Soot

CWLMSD

MSD Chart for Monitoring Precision

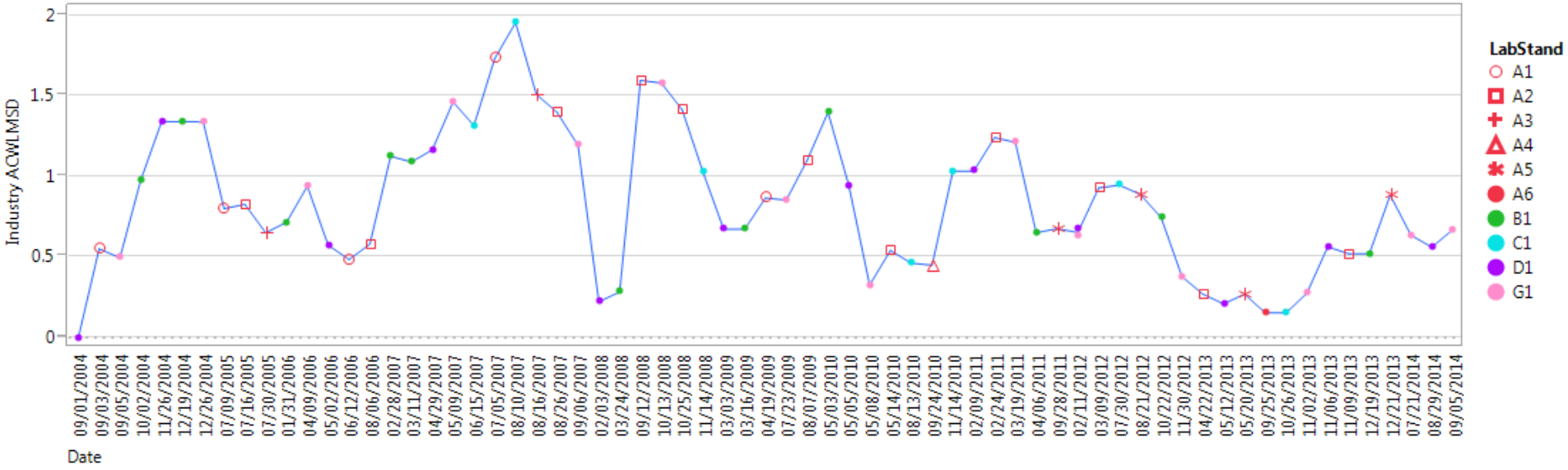


Crosshead Weight Loss Adjusted to 3.9% Soot

CWLMSD

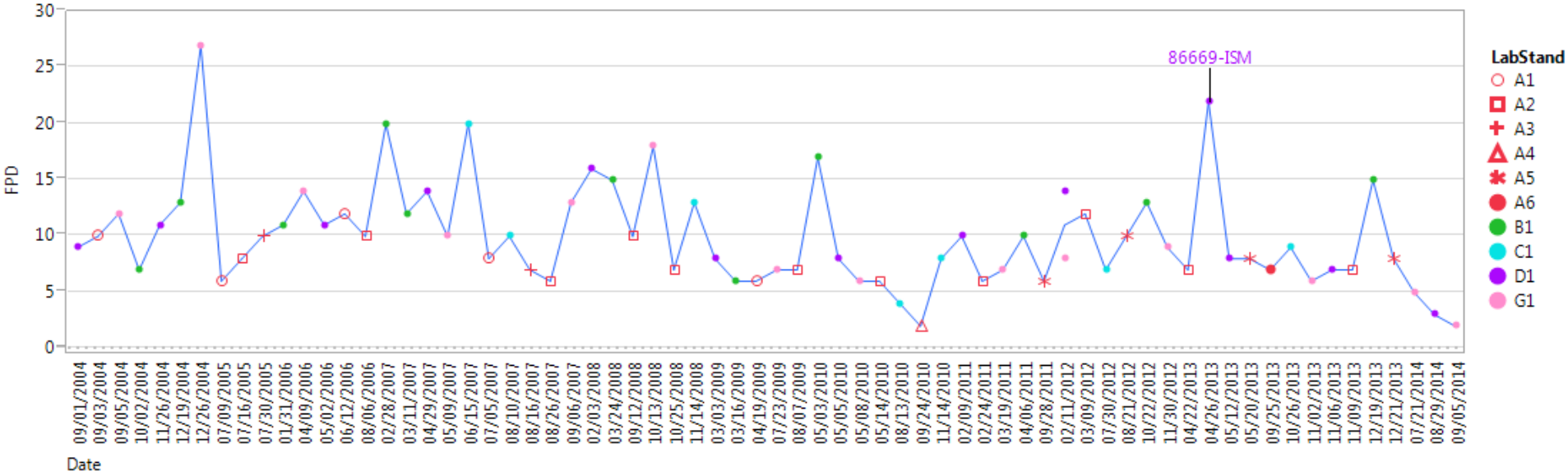
86669-ISM Excluded; CWLMSD recalculated

MSD Chart for Monitoring Precision

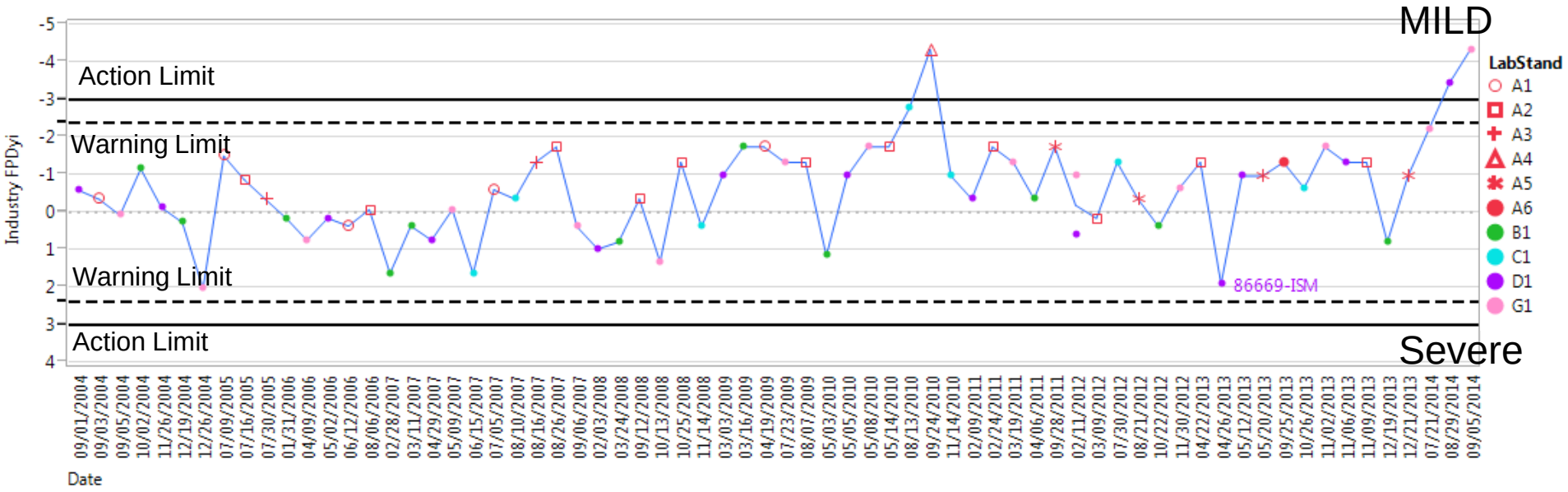


Filter Plugging Delta

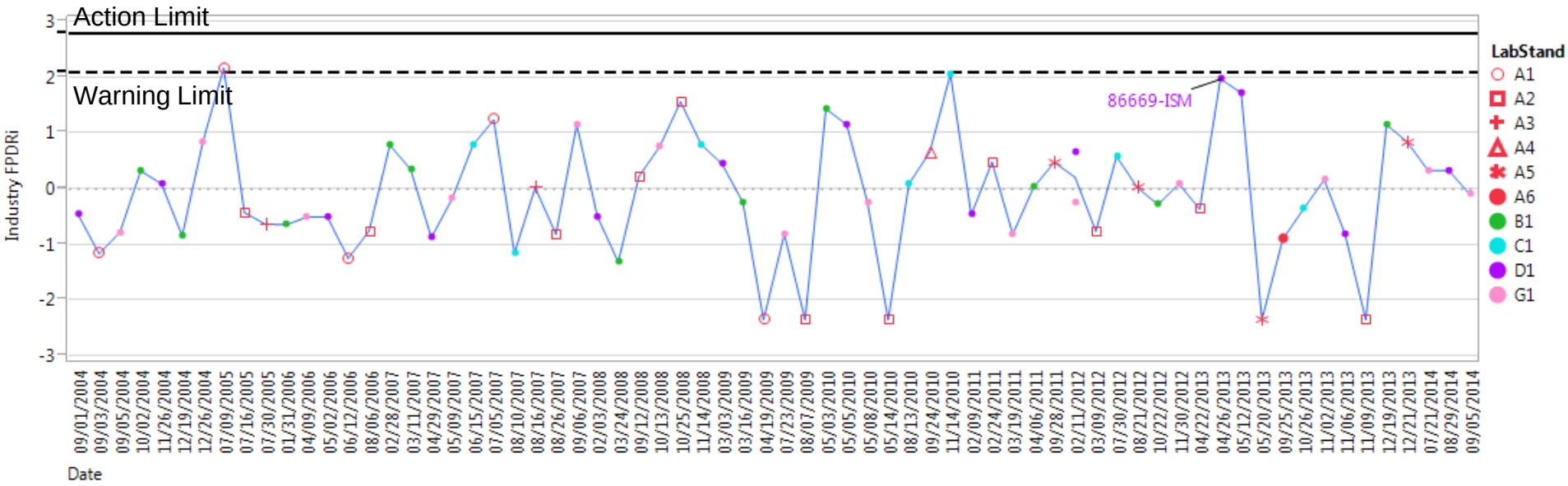
Filter Plugging Delta
Original Unit



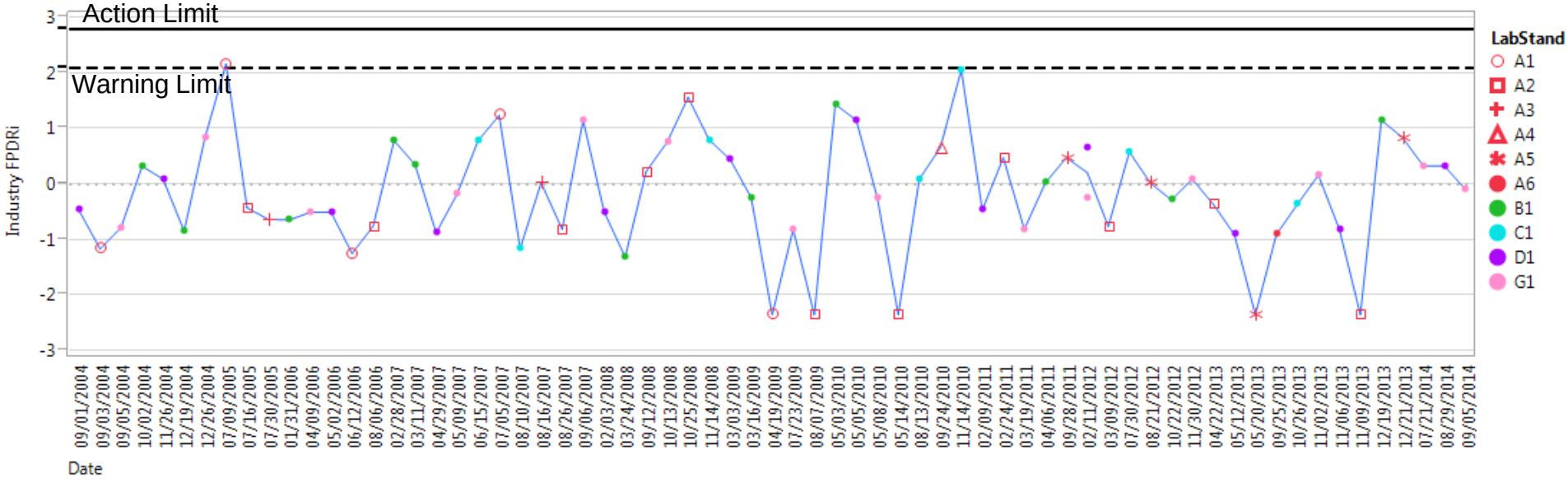
Filter Plugging Delta
FPDyi
Shewhart Chart for Monitoring Severity



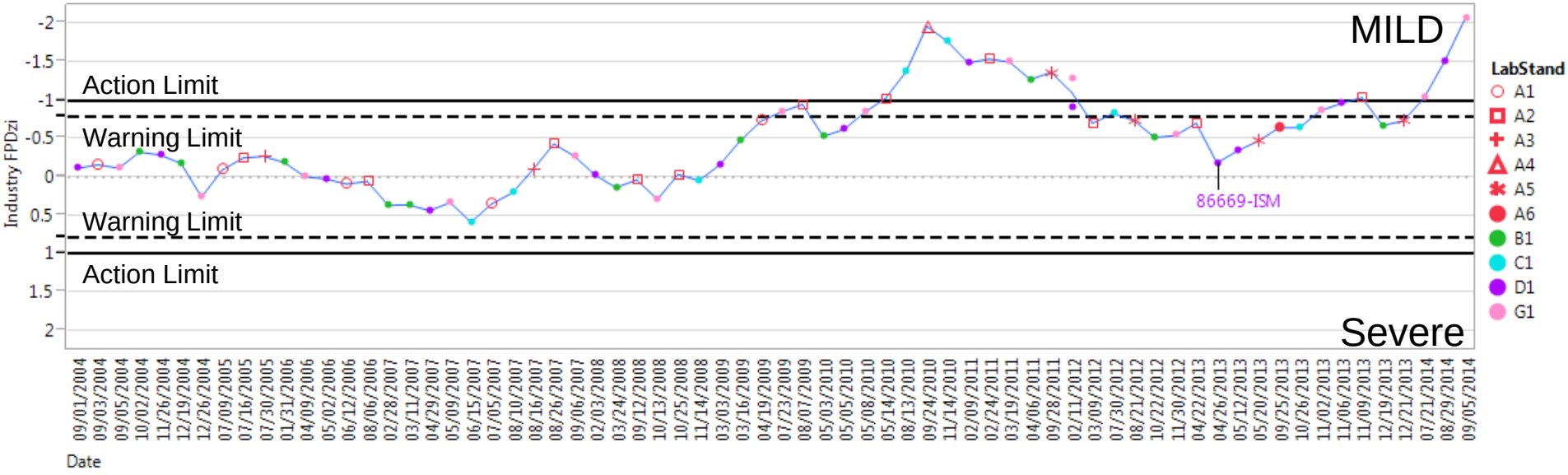
Filter Plugging Delta
FPD Ri
Shewhart Chart for Monitoring Precision



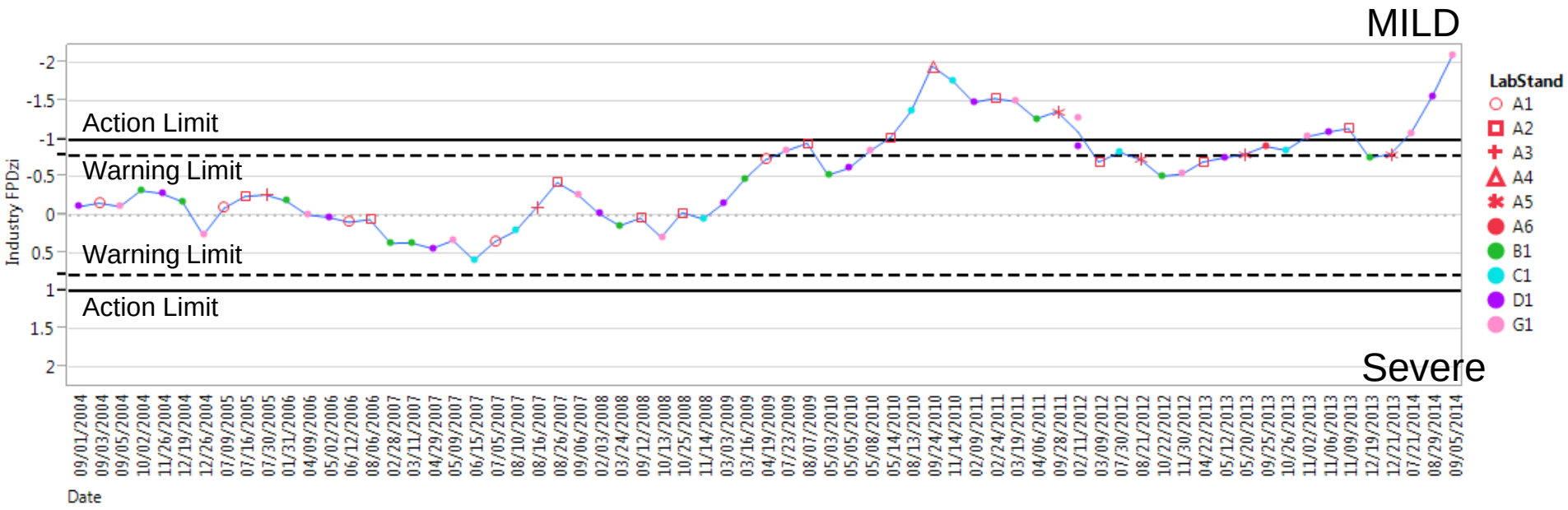
Filter Plugging Delta
FPD Ri (86669-ISM; FPDRi recalculated)
Shewhart Chart for Monitoring Precision



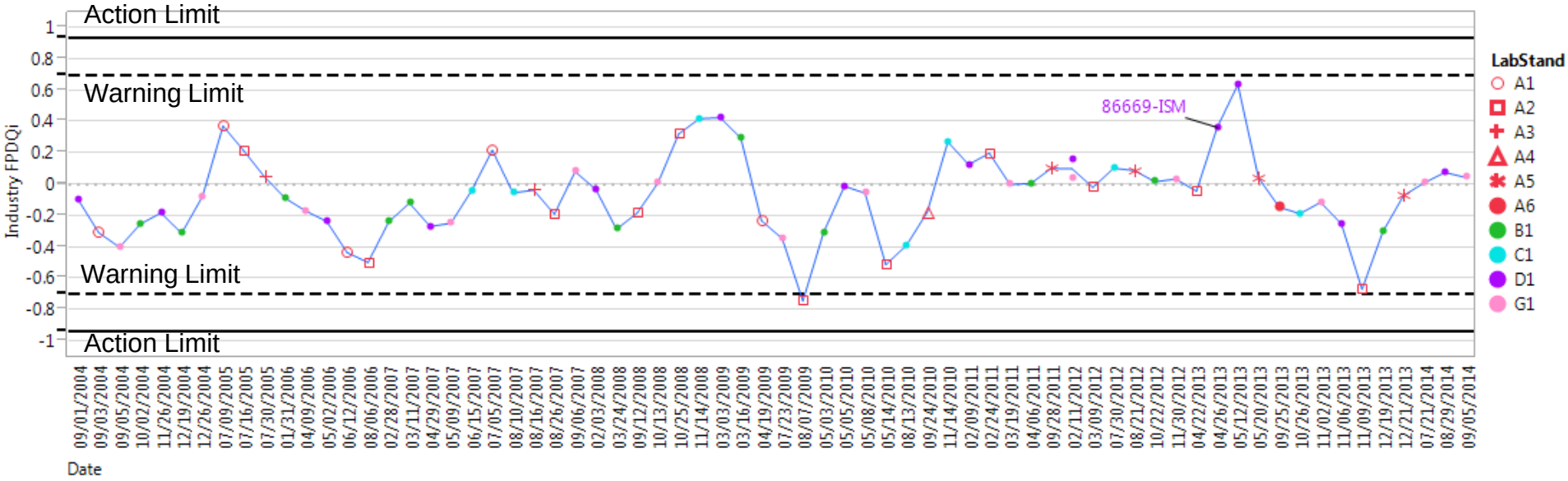
Filter Plugging Delta
FPDzi
EWMA Chart for Monitoring Severity



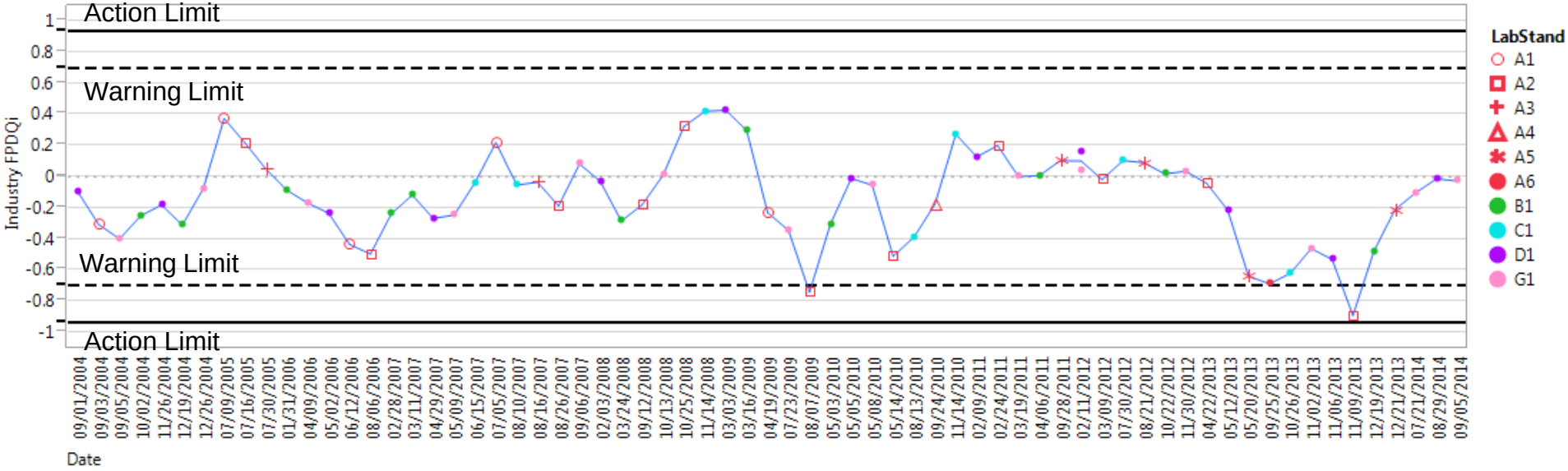
Filter Plugging Delta
FPDzi (86669-ISM; FPDzi recalculated)
EWMA Chart for Monitoring Severity



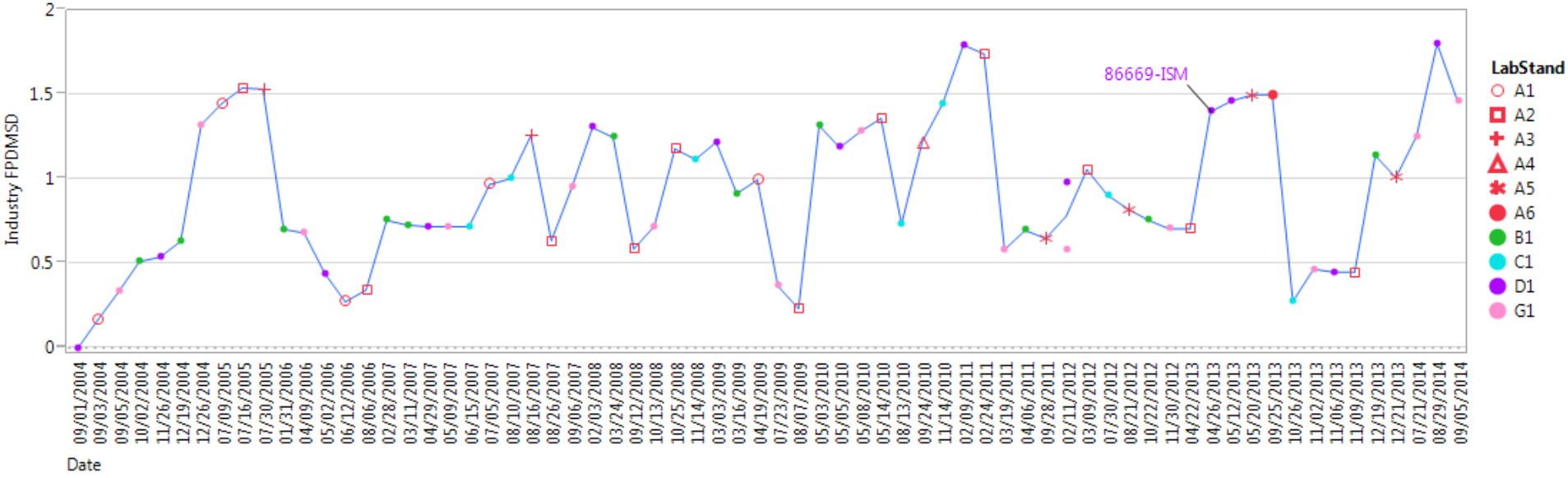
Filter Plugging Delta
FPDQi
EWMA Chart for Monitoring Precision



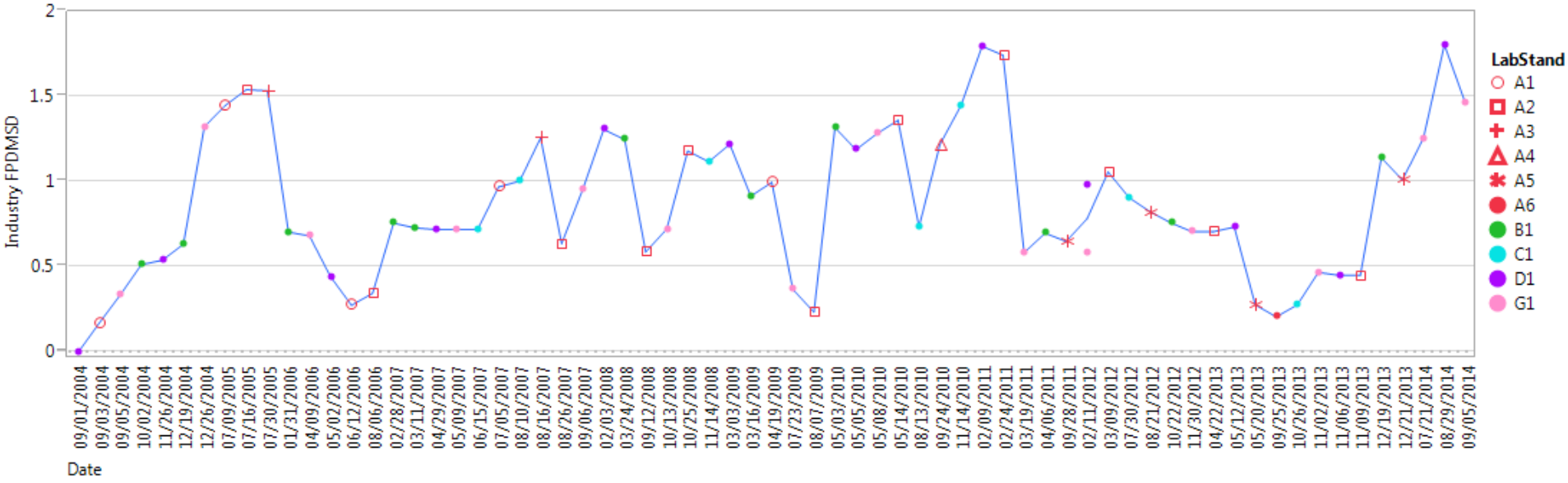
Filter Plugging Delta
FPDQi (86669-ISM; FPDQi recalculated)
EWMA Chart for Monitoring Precision



Filter Plugging Delta
FPDMSD
MSD Chart for Monitoring Precision

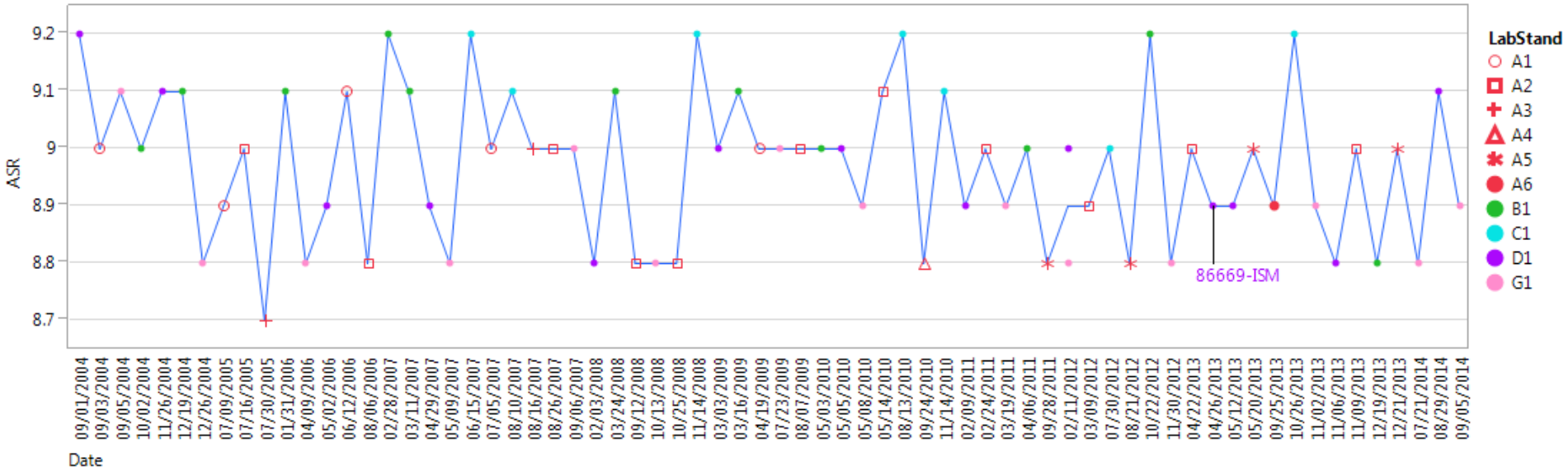


Filter Plugging Delta
FPDMSD (86669-ISM; FPDMSD recalculated)
MSD Chart for Monitoring Precision

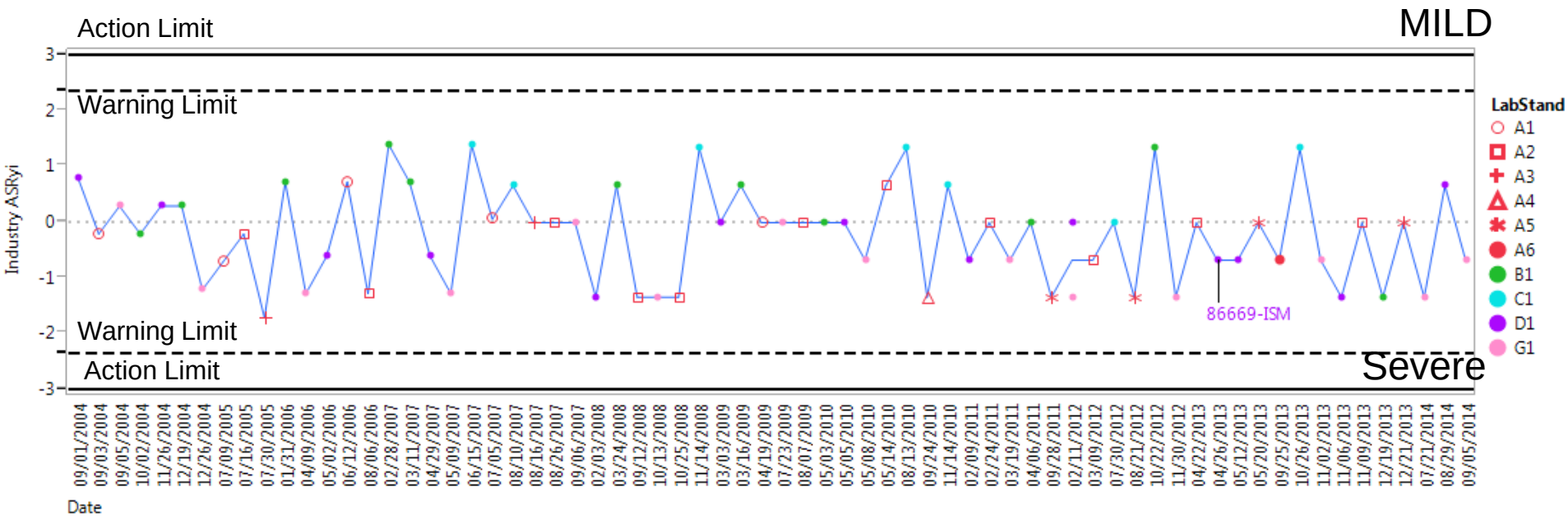


Average Sludge Rating

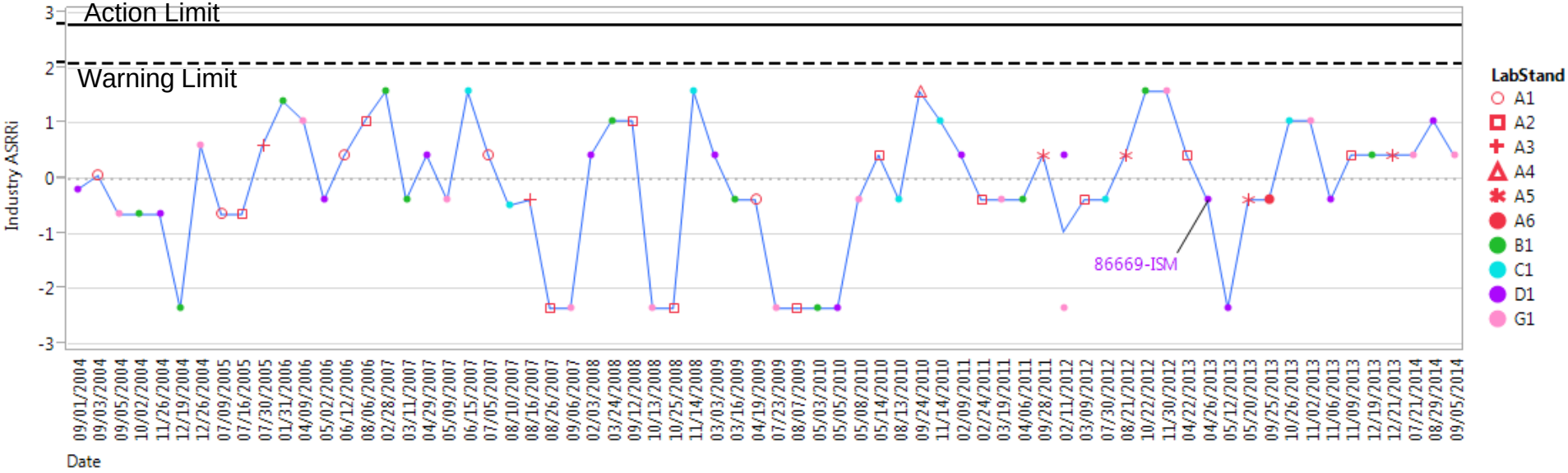
Average Sludge Rating
Original Units



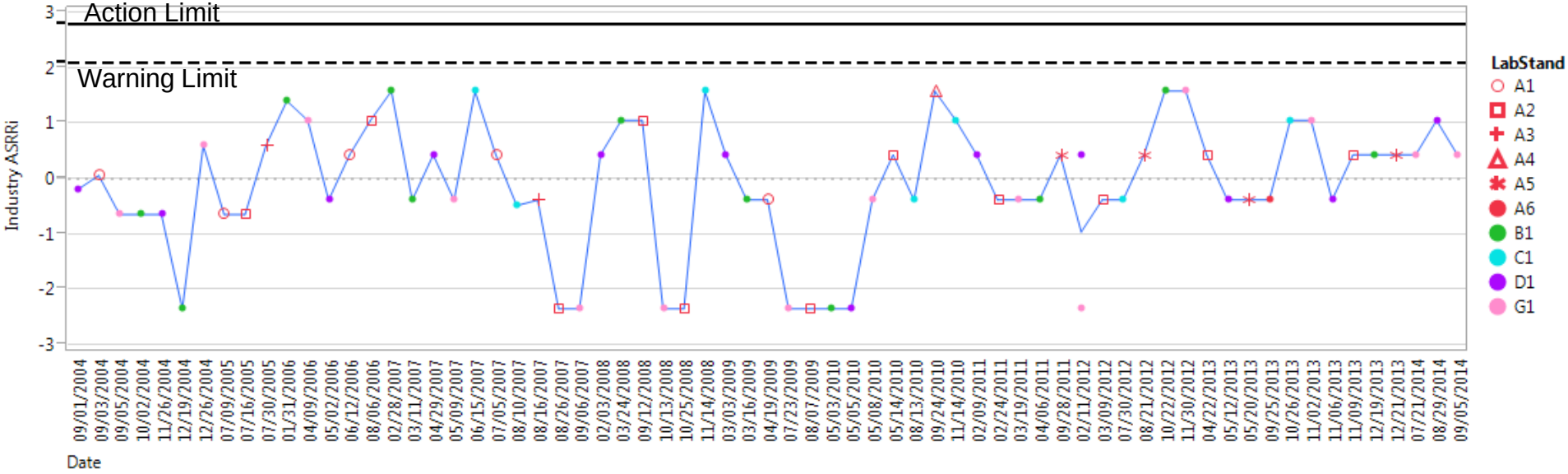
Average Sludge Rating
ASRyi
Shewhart Chart for Monitoring Severity



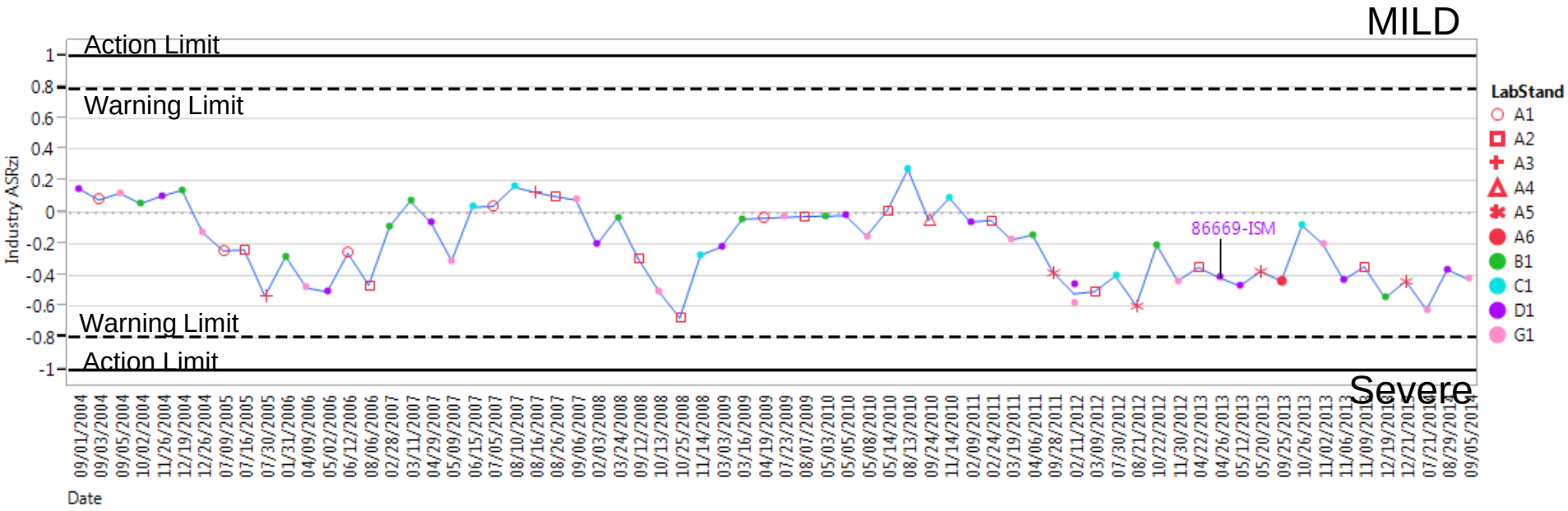
Average Sludge Rating
ASR Ri
Shewhart Chart for Monitoring Precision



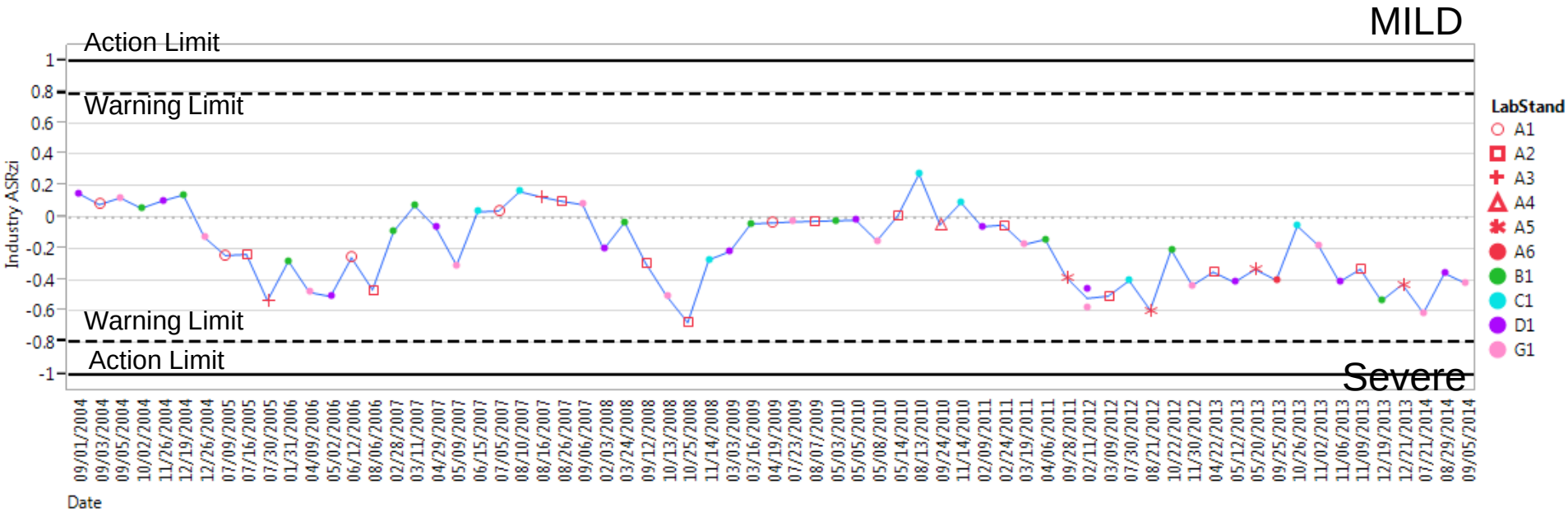
Average Sludge Rating
ASR Ri (86669-ISM; ASRRi recalculated)
Shewhart Chart for Monitoring Precision



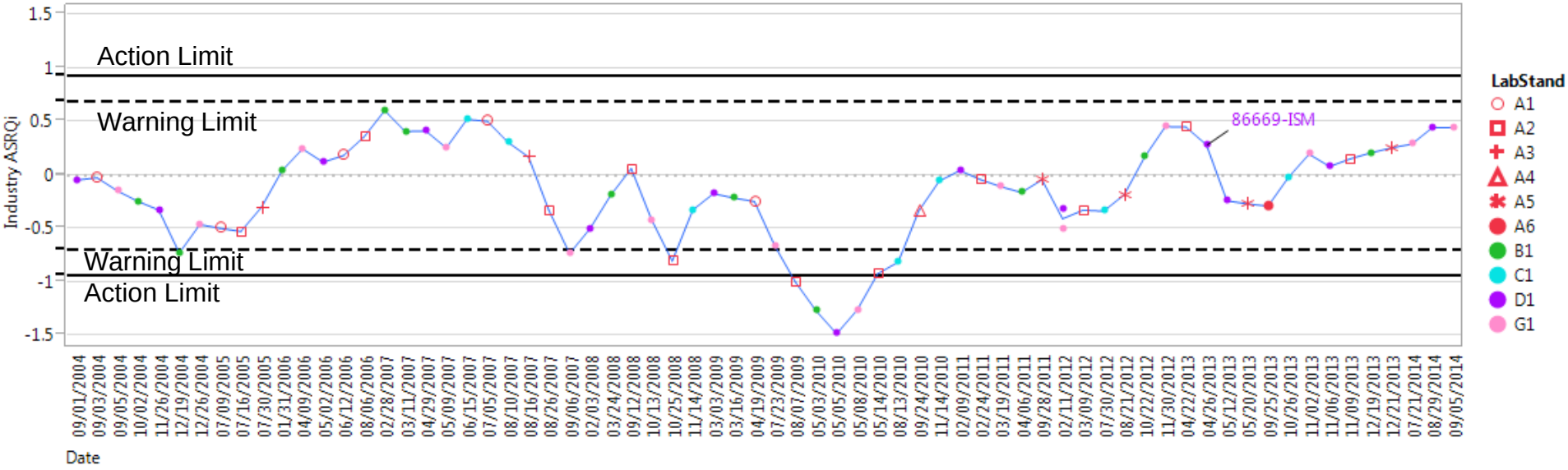
Average Sludge Rating
ASRzi
EWMA Chart for Monitoring Severity



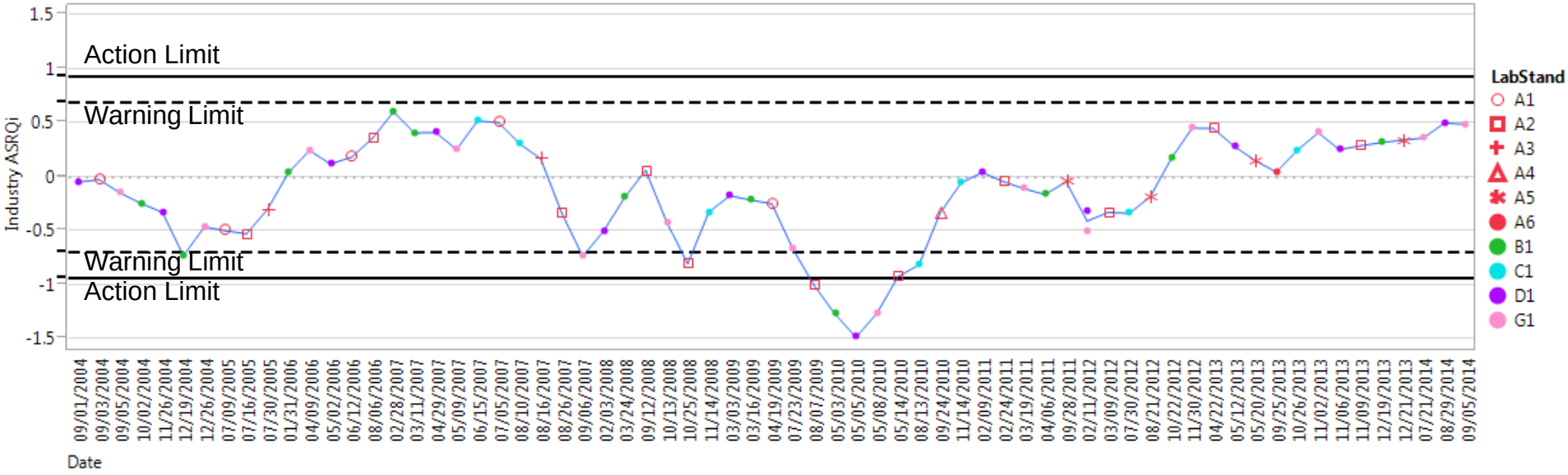
Average Sludge Rating
ASRzi (86669-ISM; ASRzi recalculated)
EWMA Chart for Monitoring Severity



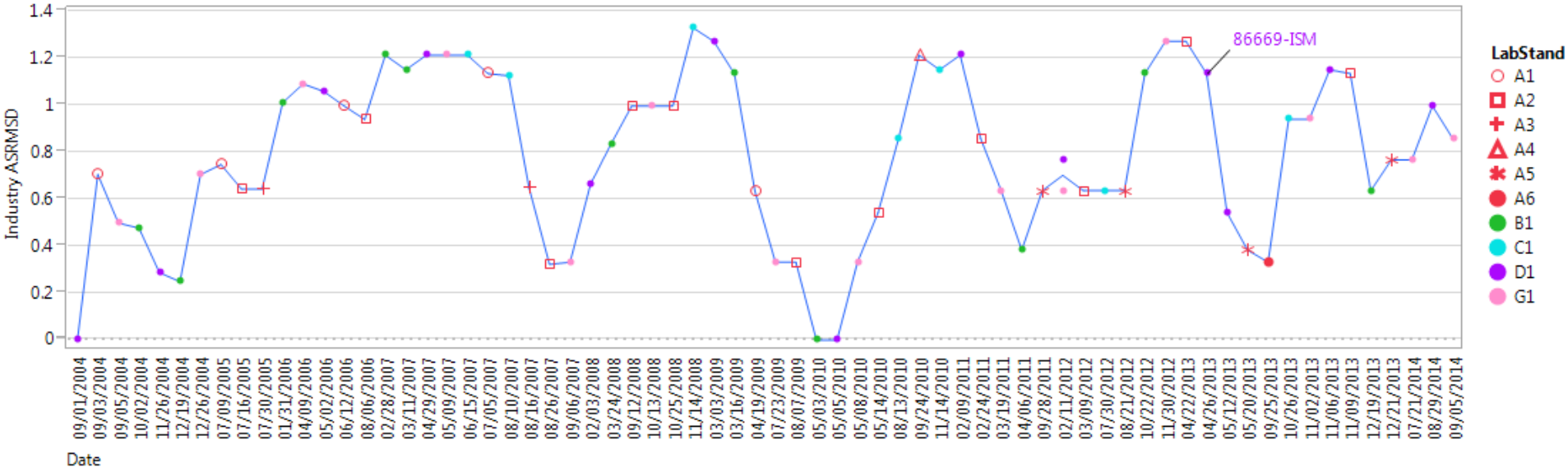
Average Sludge Rating
ASRQi
EWMA Chart for Monitoring Precision



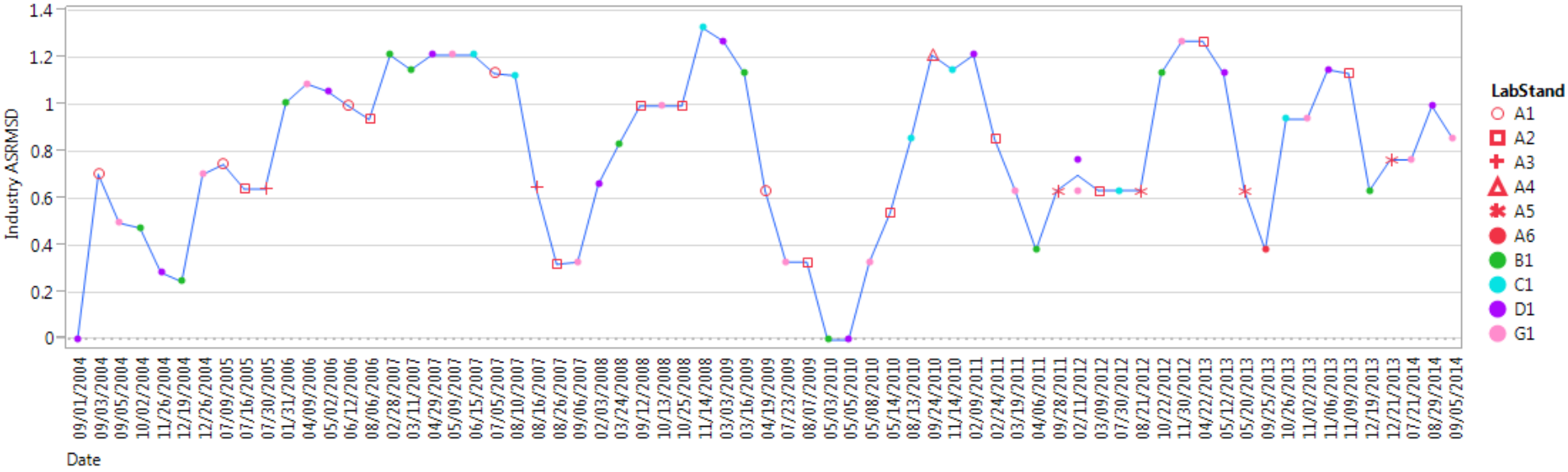
Average Sludge Rating
ASRQi (86669-ISM; ASRQi recalculated)
EWMA Chart for Monitoring Precision



Average Sludge Rating
ASRMSD
MSD Chart for Monitoring Precision

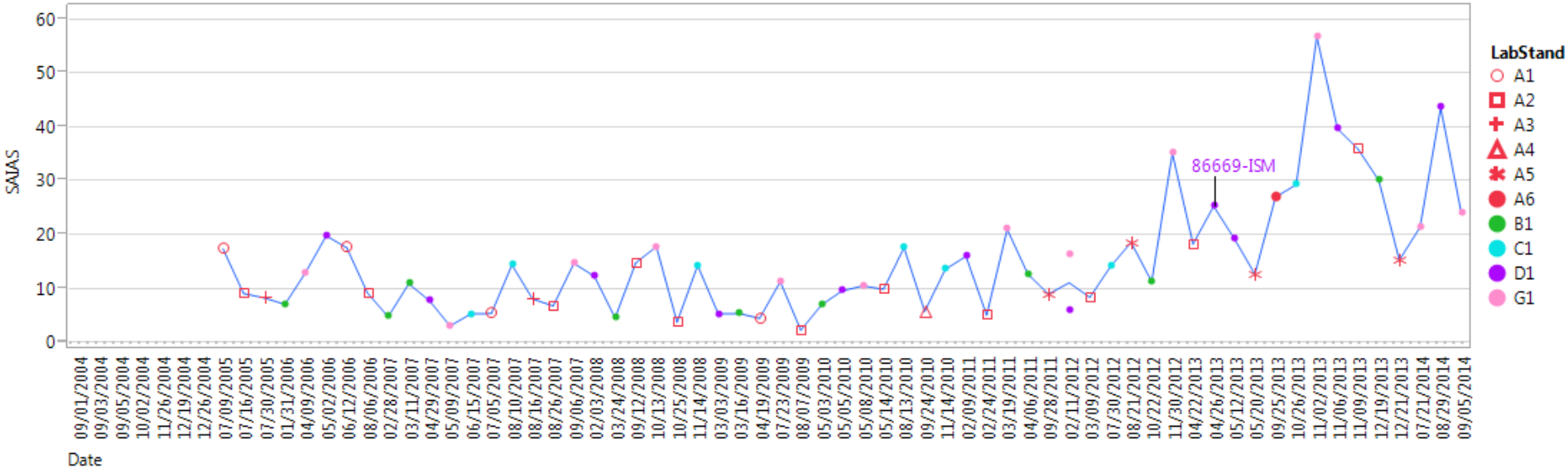


Average Sludge Rating
ASRMSD (86669-ISM; ASRMSD recalculated)
MSD Chart for Monitoring Precision

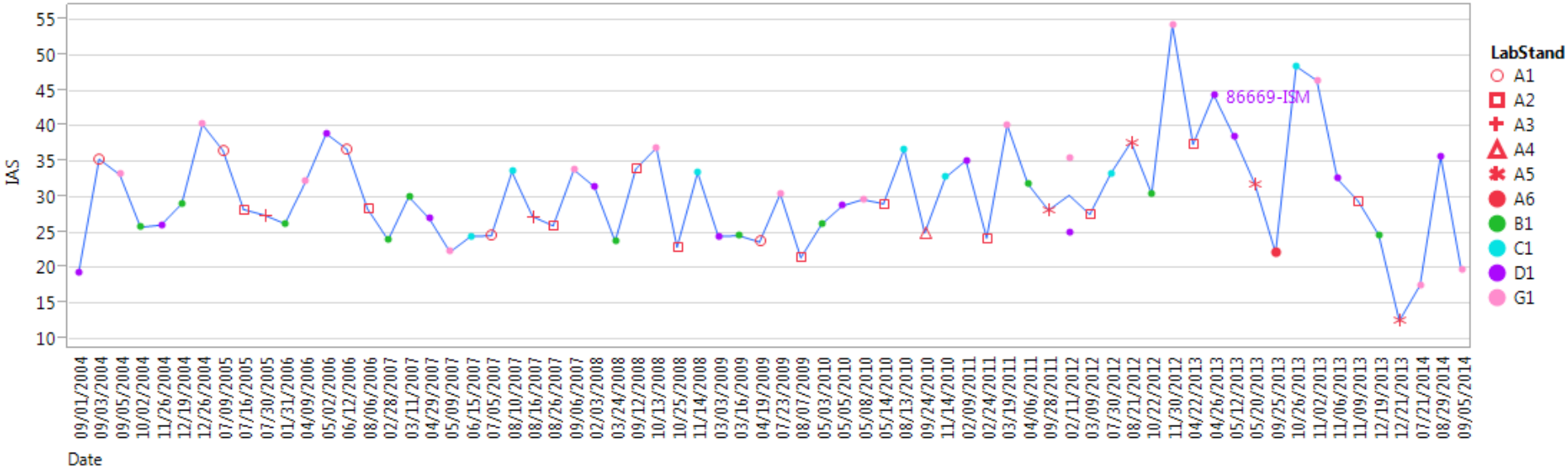


Injector Screw Weight Loss Adjusted to 3.9% Soot

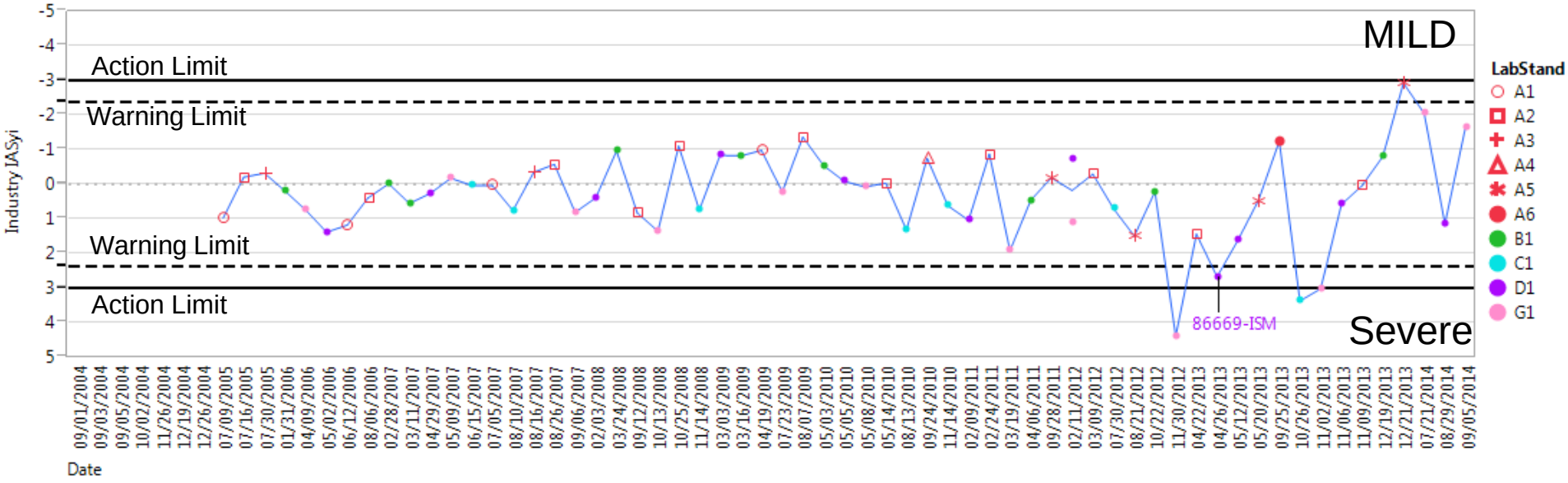
Injector Screw Weight Loss Adjusted to 3.9% Soot Original Units



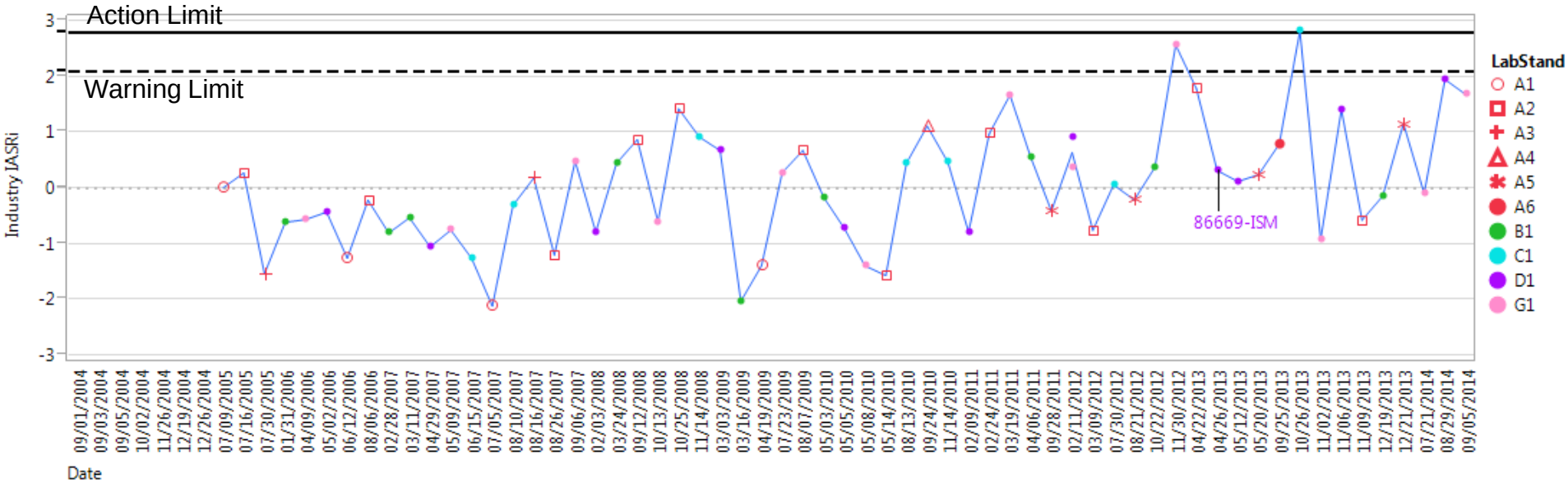
Injector Screw Weight Loss Adjusted to 3.9% Soot Corrected Units



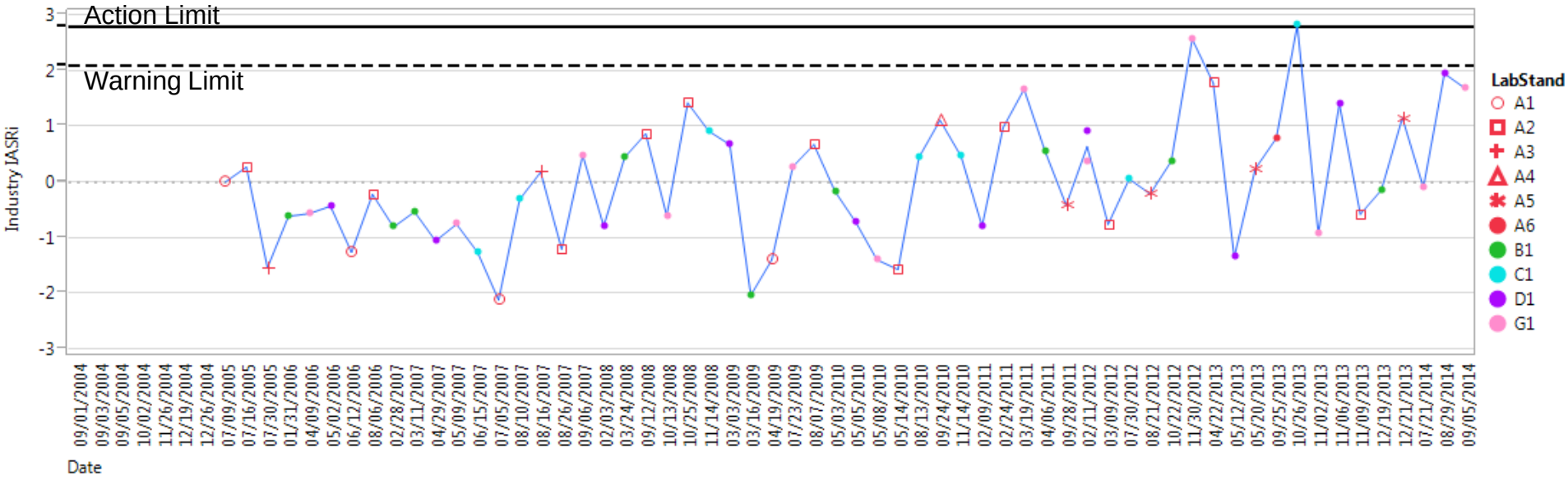
Injector Screw Weight Loss Adjusted to 3.9% Soot IASyi
Shewhart Chart for Monitoring Severity



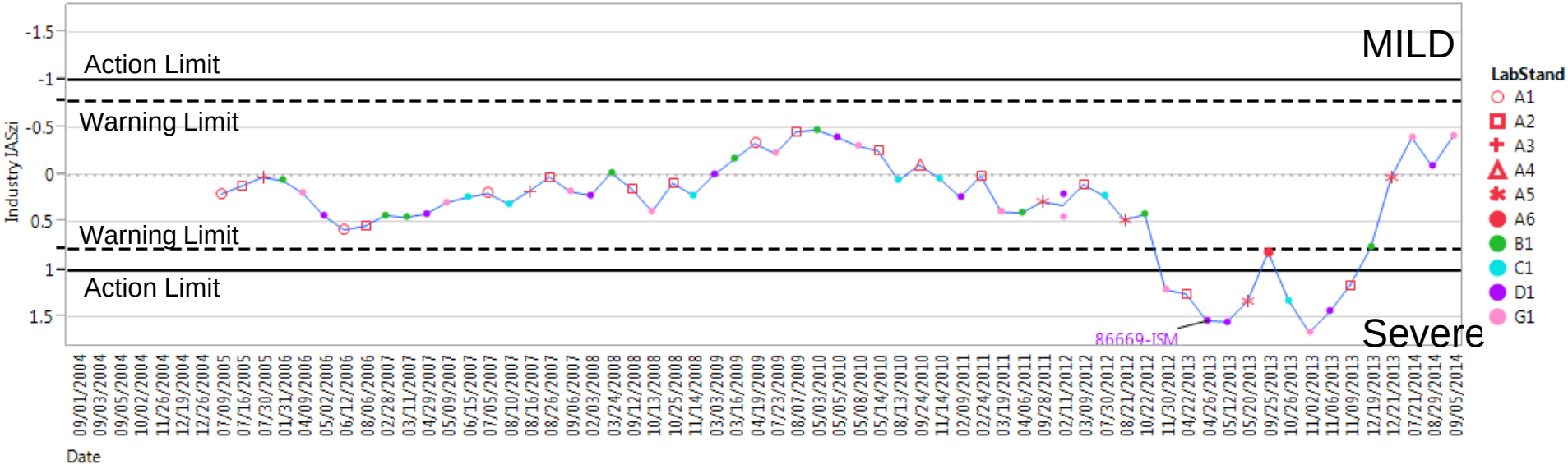
Injector Screw Weight Loss Adjusted to 3.9% Soot
IAS Ri
Shewhart Chart for Monitoring Precision



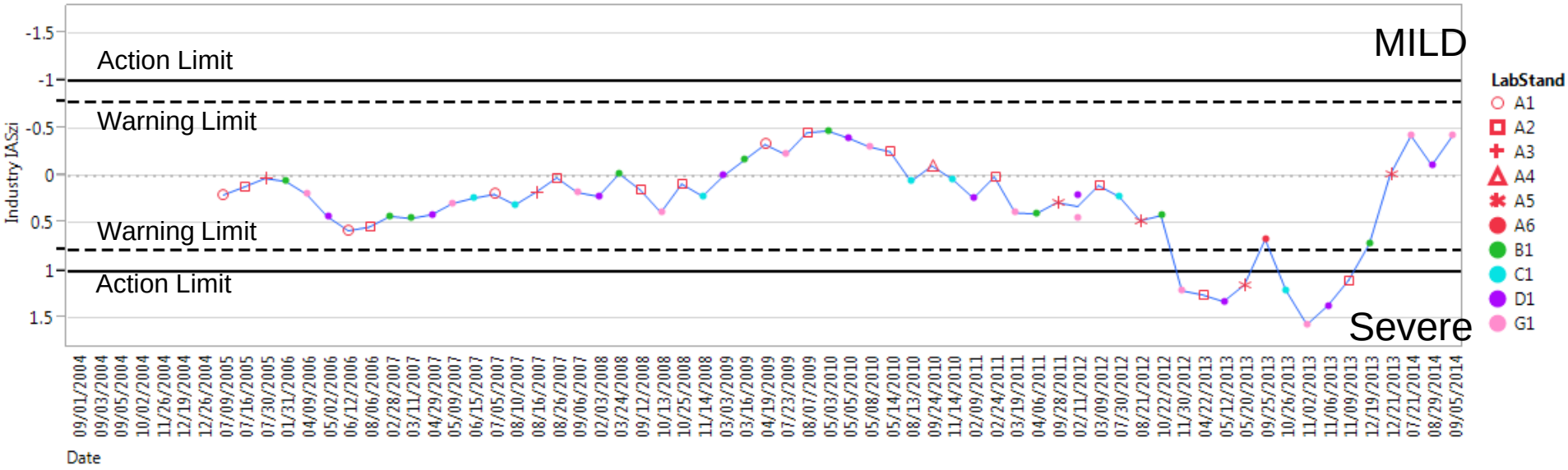
Injector Screw Weight Loss Adjusted to 3.9% Soot
IAS Ri (86669-ISM; IASRi recalculated)
Shewhart Chart for Monitoring Precision



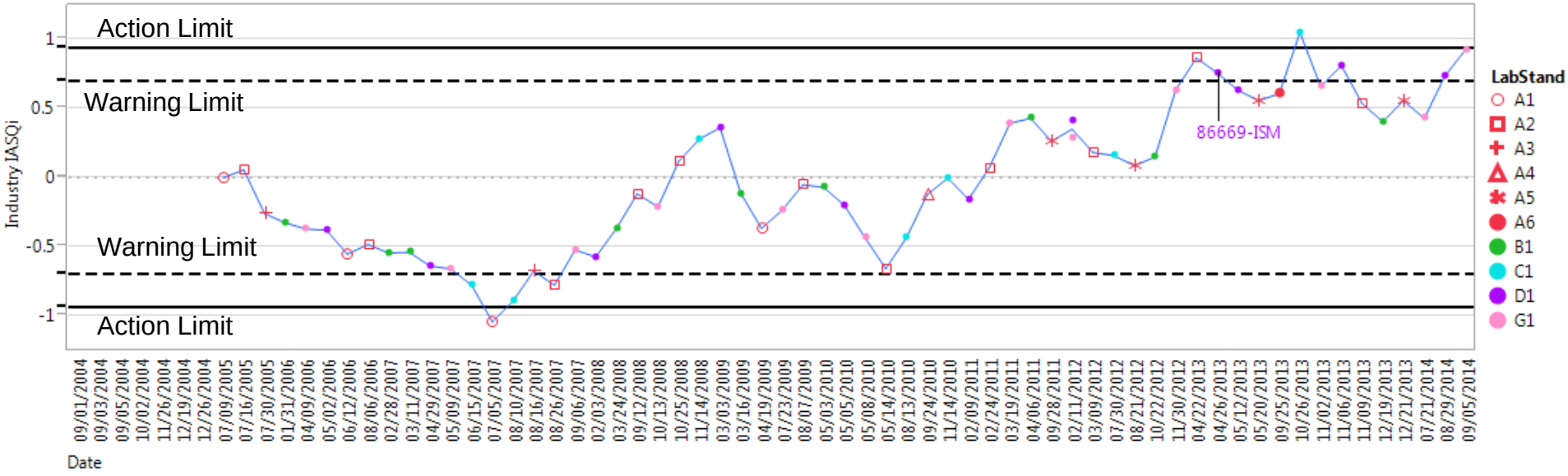
Injector Screw Weight Loss Adjusted to 3.9% Soot IASzi
EWMA Chart for Monitoring Severity



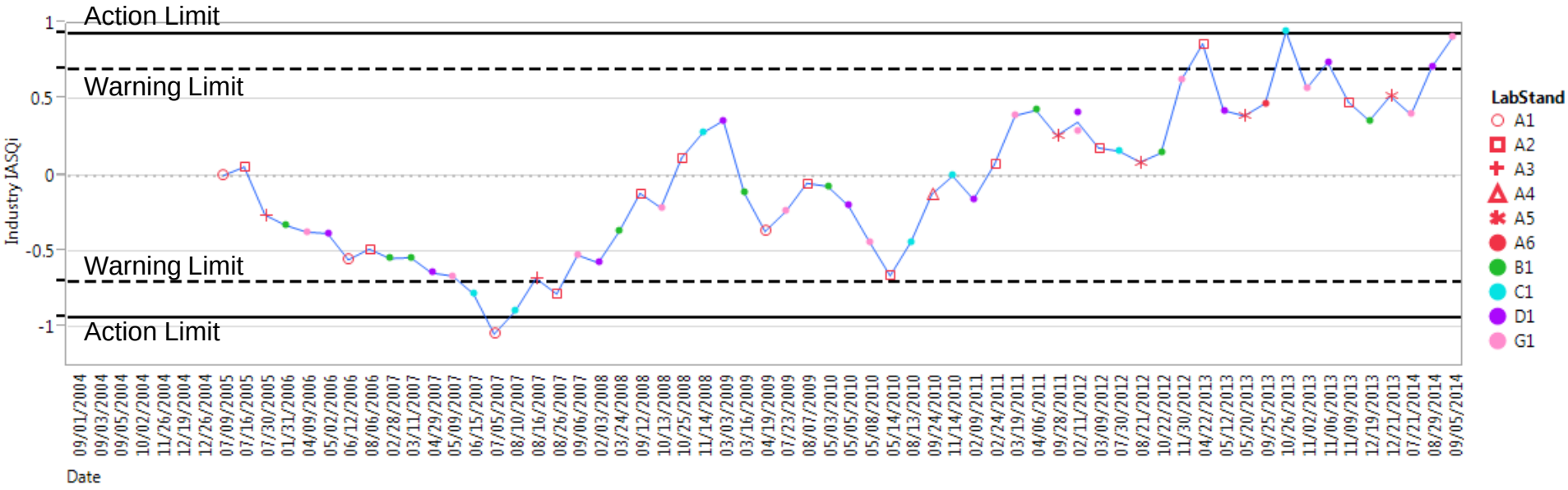
Injector Screw Weight Loss Adjusted to 3.9% Soot
IASzi (86669-ISM; IASzi recalculated)
EWMA Chart for Monitoring Severity



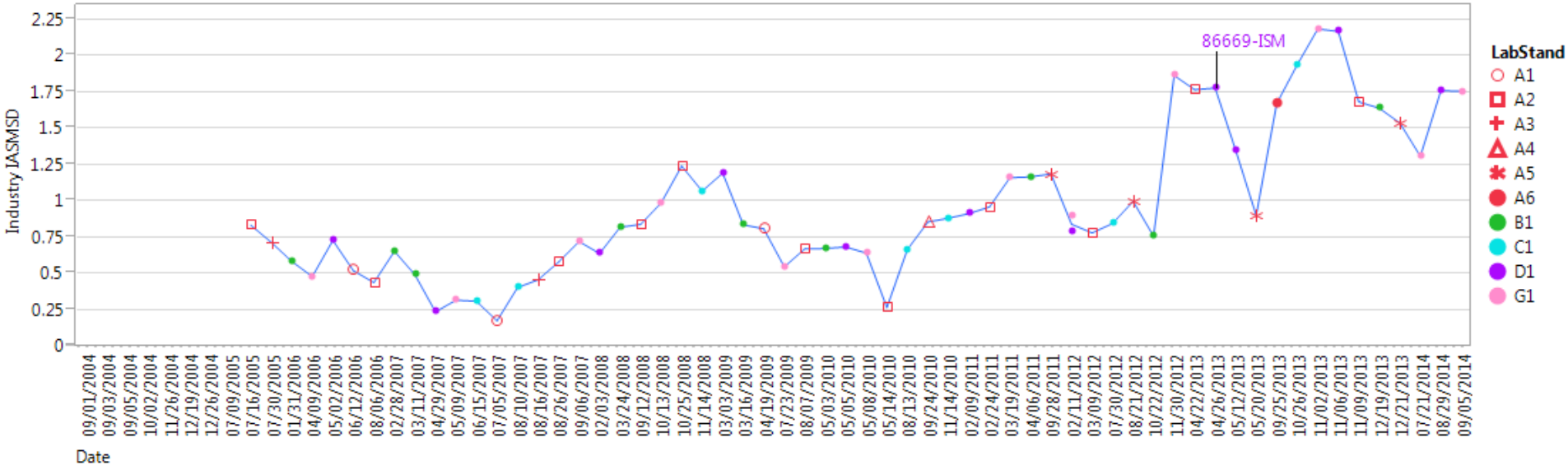
Injector Screw Weight Loss Adjusted to 3.9% Soot IASQi
EWMA Chart for Monitoring Precision



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



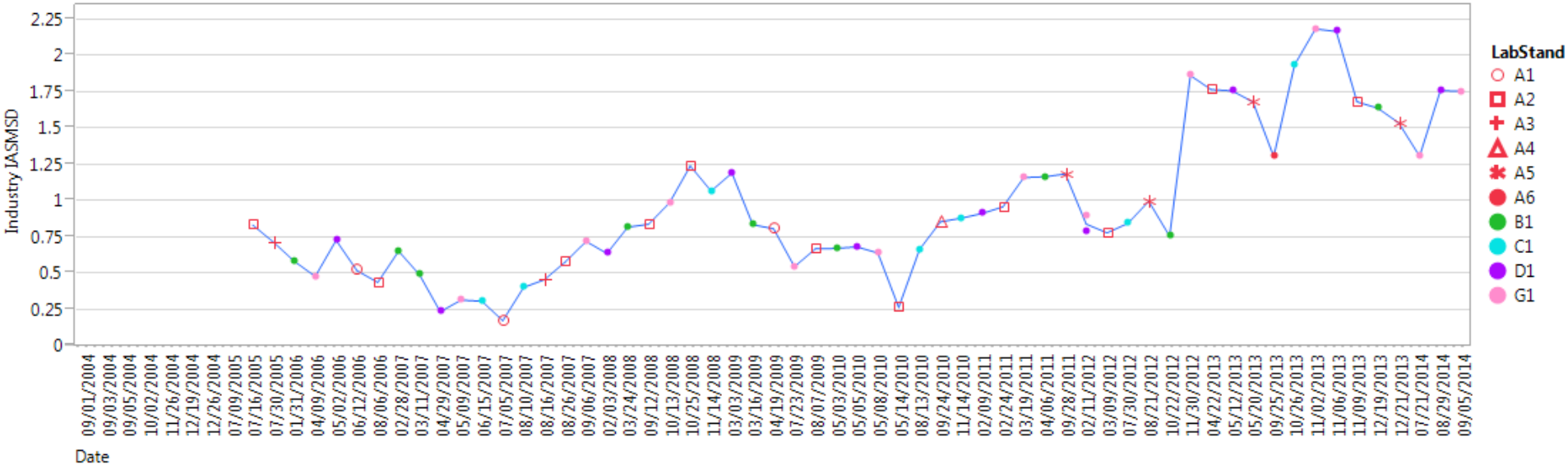
Injector Screw Weight Loss Adjusted to 3.9% Soot IASMSD
MSD Chart for Monitoring Precision



Injector Screw Weight Loss Adjusted to 3.9% Soot

IASMSD (86669-ISM; 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