C. Control Charts

In Section 1, the construction of the control charts that contribute to the Lubricant Test Monitoring System is outlined. For Sequence VIF, the following two statistics are used for calibration purposes at the stand/engine level for each parameter.

$$Average\ Y_i = W_i = \frac{Y_i + Y_{i-1} + Y_{i-2}}{n}$$

$$Repeatabilty\ Check = V_i = \frac{(Y_i - W_{i-1})}{R}$$

Where R = 1.00 for FEI1 and R = 0.95 for FEI2.

The calculation and calibration constants used for the construction of the control charts for the VIF, and the response necessary in the case of control chart limit alarms, are depicted below.

LUBRICANT TEST MONITORING SYSTEM CONSTANTS

Chart Level	Statistic	LAMBDA	Limit
Stand/Engine	Average Yi	N/A	±2.0
	Repeatability Check	N/A	+4.46 -2.80
Industry	Severity EWMA	0.2	±0.859

D. Acceptance Criteria

1. New Stand/Engine

a. A minimum of two operationally valid calibration test, with no acceptance limits exceeded (all parameters), is required to calibrate each stand/engine. Severity adjustments are only to be evaluated after an acceptable calibration test.

- Second operationally valid calibration test;

- If the repeatability check does not exceed the limit and the average Yi, does not exceed the limit, then calculate a stand/engine Severity Adjustment (SA) for each parameter as follows:

FEI1: $SA = (-W_i) \times (0.22)$
FEI2: $SA = (-W_i) \times (0.30)$

- If the repeatability check exceeds the limit or the average Yi exceeds the limit, then an additional calibration test is required in order to judge engine calibration. The laboratory has the option to remove the stand/engine.

- Third operationally valid calibration test;

  - If the repeatability check does not exceed the limit and the average Yi, does not exceed the limit, then calculate a stand/engine Severity Adjustment (SA) for each parameter as follows:

$$\text{FEI1: } SA = (-W_i) \times (0.22)$$
$$\text{FEI2: } SA = (-W_i) \times (0.30)$$

  - If the repeatability check exceeds the limit or the average Yi exceeds the limit, any additional testing on the stand/engine is not suitable for calibration purposes.

- Exceed EWMA Industry chart severity limit

  - TMC informs the surveillance panel that the limit has been exceeded. The surveillance panel then investigates and pursues resolution of the alarm.

3. Removal of Test Stand/Engines from the System

The laboratory must notify the TMC and the ACC Monitoring Agency when removing a stand/engine from the system. No reference oil data shall be removed from the control charts from test stand/engines that have been used for registered candidate oil testing. Reintroduction of a stand/engine into the system requires completion of new stand/engine acceptance requirements. In all instances of stand/engine removal, stand/engine renumbering can occur only if the stand/engine undergoes a significant rebuild, as agreed upon by the laboratory and the TMC.

24. ISB LTMS Requirements

The following are the specific ISB calibration test requirements.

A. Reference Oils and Parameters

The critical parameters are Average Cam Shaft Wear and Average Tappet Weight Loss. The reference oils required for test stand and test laboratory calibration are reference oils accepted by the ASTM Cummins Test Surveillance Panel. The mean and standard deviation for the current reference oils for each critical parameter are presented below.

AVERAGE CAM SHAFT WEAR
Unit of Measure: Micrometers

Reference Oil	Mean	Standard Deviation
831-3	42.5	8.7
831-4	42.5	8.7

AVERAGE TAPPET WEIGHT LOSS
Unit of Measure: Milligrams

Reference Oil	Mean	Standard Deviation
831-3	97.2	14.8
831-4	97.2	14.8

B. Acceptance Criteria

1. New Test Stand

- A minimum of two (2) operationally valid calibration tests with no level 3 e_i or Level 2 Z_i alarms after the second operationally valid test must be conducted in a new stand on any approved reference oils.
- Note that industry matrix runs may be included, as well as reference runs, at the discretion of the surveillance panel.
- Following the necessary tests, check the status of the control charts and follow the prescribed actions.

2. Existing Test Stand

- The test stand must have been previously accepted into the system by meeting LTMS calibration requirements.
- One operationally valid test with no level 3 e_i or level 2 Z_i alarms must be conducted on any approved reference oil.
- Following the necessary tests, check the status of the control charts and follow the prescribed actions.

3. Reference Oil Assignment

Once test stands have been accepted into the system, the TMC will assign reference oils for continuing calibration according to the following reference oil mix:

- 100% of the scheduled calibration tests should be conducted on reference oil 831 (or subsequent approved reblends).

4. Control Charts

In Section 1, the construction of the control charts that constitute the Lubricant Test Monitoring System is outlined. For the ISB, Z_0=mean Y_i of the first two operationally valid tests in the stand. The constants used for the construction of the control charts for the ISB, and the response necessary in the case of control chart limit alarms, are depicted below. Note that control charting all parameters is required.

LUBRICANT TEST MONITORING SYSTEM CONSTANTS

		EWMA Chart		Stand Prediction Error	
Chart Level	Limit Type	Lambda	Alarm	Limit Type	Limit
Stand	Level 1	0.3	0.000	Level 2	±1.734
	Level 2		±1.800	Level 3	±2.066
Industry	Level 1	0.2	±0.775	--	--
	Level 2		±0.859	--	--

The following are the steps that must be taken in the case of exceeding control chart limits. The steps are listed in order of priority, although charts should be studied simultaneously to determine the cause(s) of a problem. In the case of multiple alarms, contact the TMC for guidance. The laboratory always has the option of removing any stand from the system

Exceed Stand chart of Prediction Error (e_i)

Level 3:

– Conduct one additional reference test in the stand that triggered the alarm. Do not update the control charts until the follow up reference test is completed and the Excessive Influence (refer to Section 1.A.5) has been performed.

Level 2:

– The Level 2 limit applies in situations that have been pre-determined by the surveillance panel to have a potential impact on test results. These situations may include the introduction of new critical parts, fuel batches, reference oil reblends, or other test components. When these conditions have been met and a Level 2 alarm is triggered, immediately conduct one additional reference test in the stand that triggered the alarm. Evaluate any subsequent test(s) using Level 3 e_i limits.

Exceed Stand EWMA of Standardized Test Result (Z_i)

Level 2:

– Conduct one additional reference test in the stand that triggered the alarm. The stand that triggered the alarm is not qualified for non-reference tests until the Level 2 alarm is cleared.
– In instances where surveillance panel has deemed that industry-wide circumstances are impacting the Level 2 alarm, the TMC may be asked to review stand calibration status in accordance with the surveillance panel's findings.

Level 1:

– The Level 1 limit applies to all reference tests that are control charted, even when other alarms have been triggered. Level 1 uses Z_i to determine the stand severity adjustment (SA). Calculate the stand SA as follows and confirm the calculation with the TMC:

Average Cam Shaft Wear:	$SA = (-Z_i) \times (8.7)$
Average Tappet Weight Loss:	$SA = (-Z_i) \times (14.8)$

- Exceed Industry EWMA of Standardized Test Result (Z_i)

Level 2:

- TMC informs the surveillance panel that the limit has been exceeded. The surveillance panel then investigates and pursues resolution of the alarm.

Level 1:

- The TMC investigates whether severity adjustments are adequately addressing the trend, investigates the possible causes, and communicates as appropriate with industry.

34. L-33-1 LTMS Requirements

The following are the specific L-33-1 calibration test requirements.

A. Reference Oils and Critical Parameter

The critical parameter is Final Rust. The reference oils required for test stand and test laboratory calibration are reference oils accepted by the ASTM L-33-1 Surveillance Panel. The mean and standard deviations for the current reference oils for the critical parameter are presented below.

FINAL RUST
Unit of Measure: Merits
Gear Versions V99.1 & V01.1

Reference Oil	Mean	Standard Deviation
123	8.560	0.230
123-2	8.740	0.260
151-3	9.640	0.250
155	9.580	0.250
155-1	9.580	0.250

FINAL RUST
Unit of Measure: Merits
Gear Version AAM K2XX

Reference Oil	Mean	Standard Deviation
123-2	8.12	0.38
155-1	9.25	0.22

B. Acceptance Criteria

1. New Test Stand

   - A minimum of two (2) operationally valid calibration tests, with no stand Shewhart severity alarms, must be conducted on any approved reference oils assigned by the TMC.

   - All operationally valid calibration test results must be charted to determine if the test stand is currently “in control” as defined by the control charts from the Lubricant Test Monitoring System.

2. Existing Test Stand

L-33-1 Reference Oil Targets						
			Effective Dates		Rust	
Oil	Gear Version	n	From[1]	To	$\overline{X}$	s
121	V94.1	12[2]	6-5-96	4-19-00	9.370[2]	0.280[2]
	V95.1	12[2]	6-5-96	4-19-00	9.370[2]	0.280[2]
121-1	V94.1	--	1-19-98	4-29-99	9.370[3]	0.280[3]
	V94.1	45[2]	4-30-99	11-17-00	9.390[2]	0.218[2]
	V95.1	--	1-19-98	4-29-99	9.370[3]	0.280[3]
	V95.1	45[2]	4-30-99	11-17-00	9.390[2]	0.218[2]
	V99.1	8	4-20-00	11-17-00	9.830	0.260[4]
121-2	V94.1	--	12-14-99	11-17-00	9.390[5]	0.218[5]
	V95.1	--	12-14-99	11-17-00	9.390[5]	0.218[5]
	V99.1	--	4-20-00	11-17-00	9.830[6]	0.260[4]
123	V94.1	54[2]	5-5-95	4-19-00	9.000[2]	0.330[2]
	V95.1	54[2]	5-5-95	4-19-00	9.000[2]	0.330[2]
	V99.1	12	6-11-02	8-24-04	8.430	0.390
	V01.1	--	11-25-02	8-24-04	8.430[10]	0.390[10]
	V99.1 & V01.1	30	8-25-04	***	8.560	0.230
123-1	V94.1	13[7]	4-20-00	11-17-00	8.240[7]	0.330[8]
	V95.1	--	12-14-99	4-19-00	9.000[9]	0.330[9]
	V95.1	13[7]	4-20-00	11-17-00	8.240[7]	0.330[8]
	V99.1	13[7]	4-20-00	11-17-00	8.240[7]	0.330[8]
123-2	V99.1	--	11-25-02	8-24-04	8.430[10]	0.390[10]
	V99.1 & V01.1	--	8-25-04	6-1-06	8.560[9]	0.230[9]
	V99.1 & V01.1	15	6-2-06	***	8.740	0.260
	AAM K2XX	10	6-24-16	11-07-17	8.05	0.43
	AAM K2XX	22	11-08-17	***	8.12	0.38
151-3	V99.1	13	6-11-02	8-24-04	9.690	0.350
	V01.1	--	11-25-02	8-24-04	9.690[11]	0.350[11]
	V99.1 & V01.1	30	8-25-04	***	9.640	0.250
155	V99.1 & V01.1	--	6-2-06	---	9.580	0.250[12]
155-1	V99.1 & V01.1	--	4-4-12	---	9.580	0.250[12]
	AAM K2XX	9	6-24-16	11-07-17	9.26	0.12
	AAM K2XX	23	11-08-17	***	9.25	0.22

1 Effective for all tests completed on or after this date.

2 Based on V94.1 & V95.1 data.

3 Based on oil 121 data.

4 Based on lab pooled s of V94.1 & V95.1 data (all blends of oil 121).

5 Based on oil 121-1 data.

6 Based on V99.1 data on oil 121-1.

7 Based on V99.1 and V95.1 data.

8 Based on lab pooled s of V94.1 & V95.1 data (all blends of oil 123).

9 Based on oil 123 data.

10 Based on V99.1 data on oil 123.

11 Based on V99.1 data on oil 151-3.

12 Based on V99.1 & V01.1 data on oil 151-3.

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	±0.000 (Continuous)
IIIGA	Laboratory	All	±0.550
IIIGB	Laboratory	All	±0.550
IIIH	Stand	All	±0.000 (Continuous)
IIIHA	Stand	All	±0.000 (Continuous)
IIIHB	Stand	All	±0.000 (Continuous)
IVA	Laboratory	All	±0.600
VG	Laboratory	All	±0.653
VH	Laboratory	All	±0.000 (Continuous)
IX	Stand	All	±0.000 (Continuous)
X	Stand	All	±0.000 (Continuous
VIE	Stand	All	±2.0
			±2.8
VIF	Stand	All	±2.0
			±2.8
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
COAT	Stand	All	±0.000 (Continuous)
ISB	Stand	All	±0.000 (Continuous)
ISM	None	None	None
T-8/T-8E	Laboratory	All	±0.653
T-11	Laboratory	All	±0.653
T-12	Laboratory	All	±0.653
T-13	Laboratory	All	±0.000 (Continuous)
RFWT	Laboratory	All	±0.600

HISTORY OF SEVERITY ADJUSTMENT (SA)
STANDARD DEVIATIONS (Continued)

Test	Parameter	s	Effective Dates	
			From	To
ISB	Camshaft Wear	8.7	20171129	***
	Tappet Wt. Loss	14.8	20171129	***
ISM	X-Head Wear	None	--	--
	OFDP	None	--	--
	Average Sludge	None	--	--
	Adj. Screw Wear	None	--	--
T-8	Vis. Inc. @ 3.8%	1.19	19940401	19960930
		0.93	19961001	19990131
		0.90	19990201	20070524
		0.00	20070525	20110916
		0.56	20110917	***
T-8E	Rel. Vis. @ 4.8% 50% DIN Shear	0.26	19970127	20070524
		0.00	20070525	20110916
		0.08	20110917	***
	Rel. Vis. @ 4.8% 100% DIN Shear	0.27	20020306	20070524
		0.00	20070525	20110916
		0.09	20110917	***
T-11	Soot@4.0 cSt Vis	0.23	20050528	20130702
	Soot@12.0 cSt Vis	0.21	20030308	20130702
	Soot@15.0 cSt Vis	0.26	20050528	20130702
	MRV Viscosity	1097	20030308	20130702
	Soot@4.0 cSt Vis	0.20	20130703	***
	Soot@12.0 cSt Vis	0.50	20130703	***
	Soot@15.0 cSt Vis	0.61	20130703	***
	MRV Viscosity	584	20130703	***

History of Industry Correction Factors
Appendix B

Test Area	Effective		Condition	Description
	From	To		
1M-PC	None		All Tests	None
1K	None		All Tests	None
1N	May 1, 2004	September 27, 2005	All Tests	Add -1.135 to ln(TLHC+1)
	September 28, 2005	March 31,2015	All Tests	Add -0.451 to ln(TLHC+1)
	April 1,2015	***	All Tests on 1Y3998 Liners	Add 0.419954 to ln(TGF+1)
1P	None		All Tests	None
1R	None		All Tests	None
C13	None		All Tests	None
COAT	None		All Tests	None
ISB	April 21, 2011	October 18, 2017	All tests using batch B tappets with batch E, F, and G cams	Multiply ATWL by 0.637; Add -9.5 to ACSW
	December 11, 2011	November 12, 2012	All tests using batch C tappets with batch H cams	Multiply ATWL by 0.637; Add -9.5 to ACSW
	November 13, 2012	October 18, 2017	All tests using batch C tappets with batch H and J cams	Multiply ATWL by 0.711; Add -5.6 to ACSW
	None	October 18, 2017	All test using batch D tappets and batch K cams	Multiply ATWL by 1; Add -11.3 to ACSW
	October 19, 2017	***	All tests using batch K cams with batch D tappets and batch E crossheads	Multiply ATWL by 0.7851; Add -18.5 to ACSW