Introduction

American Chemistry Council Candidate Proactive Monitoring Control Charts plot the Exponentially Weighted Moving Average (EWMA) of the various test pass/fail parameters for engine tests covered by the American Chemistry Council Code of Practice in order to detect consistent changes and trends in candidate test severity over time. The EWMA charts are actually weighted averages of the differences between "candidate test results" and estimates of the "true performance levels" or "targets" for the candidates. In the ASTM referencing system, "targets" for all reference oils can be calculated based on repeat test data available for all reference oils. Since candidate data are a collection of oils of differing performance levels from different sponsors, their "targets" must be estimated.

Only operationally valid candidate test data for the most frequently tested viscosity grades are included in calculating the EWMA. Charts for other viscosity grades are developed and reviewed internally by RSI on a regular basis to ensure consistency of trends between all viscosity grades, but these charts are not published outside of RSI.

Calculation of a Standardized Test Result

The data points used to generate the EWMA values for charting are referred to as "standardized test results" in "order i", and are identified as Y_i. Therefore Y_1 is the first standardized test result, Y_2 is the second, and so on. The calculation of the standardized test result is best explained using an example.

Example

For this example, assume that the "true performance level" (referred to as the "target") and standard deviation for "Bearing Weight Loss" in the Seq. VIII test are 24.4 mg and 5.5 mg, respectively. (How the "target" and the standard deviation are established for each test parameter will be covered later.)

Assume the Bearing Weight Loss for Seq. VIII Test Number 1 was 23.4 mg.

Test Result Number 1 **= 23.4 mg**

Target = 24.4 mg

Difference From Target = - 1.0 mg

Estimated Standard Deviation for Bearing Weight Loss = 5.5 mg.

Standardized Test Result for Test Number = Difference From Target / Standard Deviation

$Y_1 = (-1.0) / 5.5 = - 0.182$

This negative Standardized Test Result (Y_i) for Bearing Weight Loss says that the test result was 0.182 standard deviations mild, indicating "Higher Performance". If the difference had turned out to be a positive number, it would have indicated that the test result was severe, indicating "Lower Performance".

Positive and negative numbers are interpreted as reflecting higher or lower performance according to the following table:

Interpretation of Positive and Negative Results	
Type of Test Parameter	Interpretation
For test parameters, such as merit ratings, where the pass limit is stated as a minimum required	• Positive indicates mild or higher performance • Negative indicates severe or lower performance
For test parameters, such as demerits, wear, viscosity increase, and oil consumption, where the requirements are stated as maximums allowed	• Positive indicates severe or lower performance • Negative indicates mild or higher performance

Selection of data to be plotted on the Proactive Monitoring Charts

Every standardized test result is not plotted on the Candidate Proactive Monitoring Charts primarily because:

- Candidate Oils are actually a collection of oils of differing performance levels from different sponsors, and using blocks or groups of candidate test results tends to homogenize the effects of individual candidates and present a better overall picture of candidate performance.
- Plotting every candidate test could compromise the confidentiality of the candidate data.

Rather than plotting every candidate test result, test results are grouped into block sizes that are targeted to produce about two blocks of data per month (and therefore two data points on the EWMA Charts). The median test result in each block of data is actually plotted on the Candidate Proactive Monitoring Control Charts. Test block sizes are occasionally changed to reflect changes in testing volumes in order to maintain the generations of approximately two data points per month. The block sizes range from 5 tests for some of the lower-volume heavy-duty engine tests to 21 for some of the higher-volume PCMO engine tests.

Example

Assume for this example that 30 Seq. VIII Tests were run in the latest month and the Seq. VIII block size in use is 15. That would mean that two blocks of data were generated in the latest month (30 / 2 = 2). Suppose that the following 15 test results for Bearing Weight Loss were developed in one of the two blocks of data:

Result Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Test Result, mgs.	21.0	20.6	32.4	**24.4**	24.8	22.3	25.6	19.6	27.4	22.7	23.4	33.8	25.3	27.1	15.6

The median test result is used to calculate the Standardized Test Result that is then used to calculate the EWMA to be plotted on the Proactive Monitoring Chart. The median test result for this block of 15 test results is Result Number 4, which was 24.4 mgs, since there were 7 results greater than 24.4 mgs and 7 results smaller than 24.4 mgs. The test result of 24.4 mgs is therefore used to calculate the EWMA.

Target Results and Standard Deviations for Candidates

In the ASTM Lubricant Test Monitoring System for referencing test stands, the target results and standard deviations for the various reference oils are well established by the number of repeat tests made on each reference oil. Because multiple runs are not generally available for candidate oils, the target results and standard deviations for the candidate oils in the test must be estimated. The values are estimated by calculating the median and standard deviation for median test results from several blocks (typically 30) of candidate data run early in the test life.

The various test targets are generally set by test data generated right after the adoption of the test into the American Chemistry Council Code of Practice. Because they are based on actual test results, they are not the same as the pass/fail limits for the various test parameters. Most of the targets are passing results, but some are failing results.

Exponentially Weighted Moving Average (EWMW)

The standardized test results (Y_i) are used to generate the EWMA (represented by Z_i) for monitoring severity as follows:

$$Z_i = (\text{Lambda})\ Y_i + (1 - \text{Lambda})\ Z_{i-1}$$

Lambda is a smoothing constant between 0 and 1. As lambda is increased, the latest data point is given increased weight compared to past data points in calculating the EWMA. A relatively low lambda value of 0.1 is used for the Candidate Monitoring Control

Charts. Therefore, the latest data point is less-heavily weighted, and the EWMA tends to be smoother and react more slowly to abrupt changes in Y_i. The ASTM TMC generally uses slightly larger lambda values of 0.2 that would weight the most recent data point more heavily, tend to make the charts a little less smooth, and react slightly faster to abrupt changes in Y_i.

The following equations for lambda values of 0.1 and 0.2 show how the EWMA (Z_i in the equation) is more heavily weighted by recent standardized test results (Y_i) than by older standardized test results and how increasing lambda from 0.1 to 0.2 increases the weighting on the more recent test results. Only the first tem terms are shown for the equations for calculating Z_i for candidate data, but there are several more terms with continuing reduction in the coefficient.

For Lambda = 0.1:

$$Z_i = 0.100Y_1 + 0.090Y_2 + 0.081Y_3 + 0.073Y_4 + 0.066Y_5 + 0.059Y_6 + 0.053Y_7 + 0.048\,Y_8 + 0.043Y_9 + 0.039\,Y_{10} + \ldots$$

For Lambda = 0.2:

$$Z_i = 0.200Y_1 + 0.160Y_2 + 0.128Y_3 + 0.102Y_4 + 0.082Y_5 + 0.066Y_6 + 0.052Y_7 + 0.042Y_8 + 0.034Y_9 + 0.027Y_{10} + \ldots$$

As discussed under "Standardized Test Results" above, the Y_i values can be either positive or negative.

Interpreting Candidate Proactive Monitoring Charts

Interpretation of the EWMA values plotted in the Proactive Monitoring Control Charts primarily involves looking at whether the EWMA line has exceeded either the three-sigma or four-sigma control limits in a positive or negative direction. The control limits are placed on the Candidate Proactive Monitoring Control Charts (EWMA) at three and four standard deviations from the target in both a positive and a negative direction. The three-sigma control limit is labeled with a probability of P=0.00135 (0.135%), and the four-sigma control limit is labeled with a probability of P=00003 (0.003%). The interpretation of these probabilities is:

- When a result falls outside of the three-sigma control limit, there is only a 0.135% chance that a shift in test severity has not occurred.

- When a result falls outside of the four-sigma control limit, there is only a 0.003% chance that a shift in test severity has not occurred

Therefore the statistical interpretation would be that when a result falls outside of either the three-sigma or four-sigma control limits in the "Lower Performance" direction, there

is a high probability that the test is running severe; and when the a result falls outside of either the three-sigma or four-sigma control limits in a “Higher Performance” direction, there is a high probability that the test is running mild.

Certain other considerations must be made when interpreting the Candidate Proactive Monitoring Control Charts. One very important factor is the “Learning Curve” effect for the development of engine oil additive packages. As previously discussed, the “Target Results” used to generate candidate EWMA charts are estimates of candidate true performance that are generated based on candidate oil performance when the test is first accepted into the American Chemistry Council Code of Practice. Since many of there tests are newly developed at that time, the industry has had little time to identify what chemistry is needed to pass the test; and lower or poorer candidate oil performance would be expected. As the required chemistry is identified in subsequent testing (“Learning Curve” effect), the average performance of candidate oils would be expected to move towards higher performance. Comparing later results to the initial targets can therefore lead to an erroneous conclusion that the test is running mild when the test severity is actually on target.