Single Technology Matrix

Presentation to the

API Lubricants Committee

November 11-12, 2002

Background

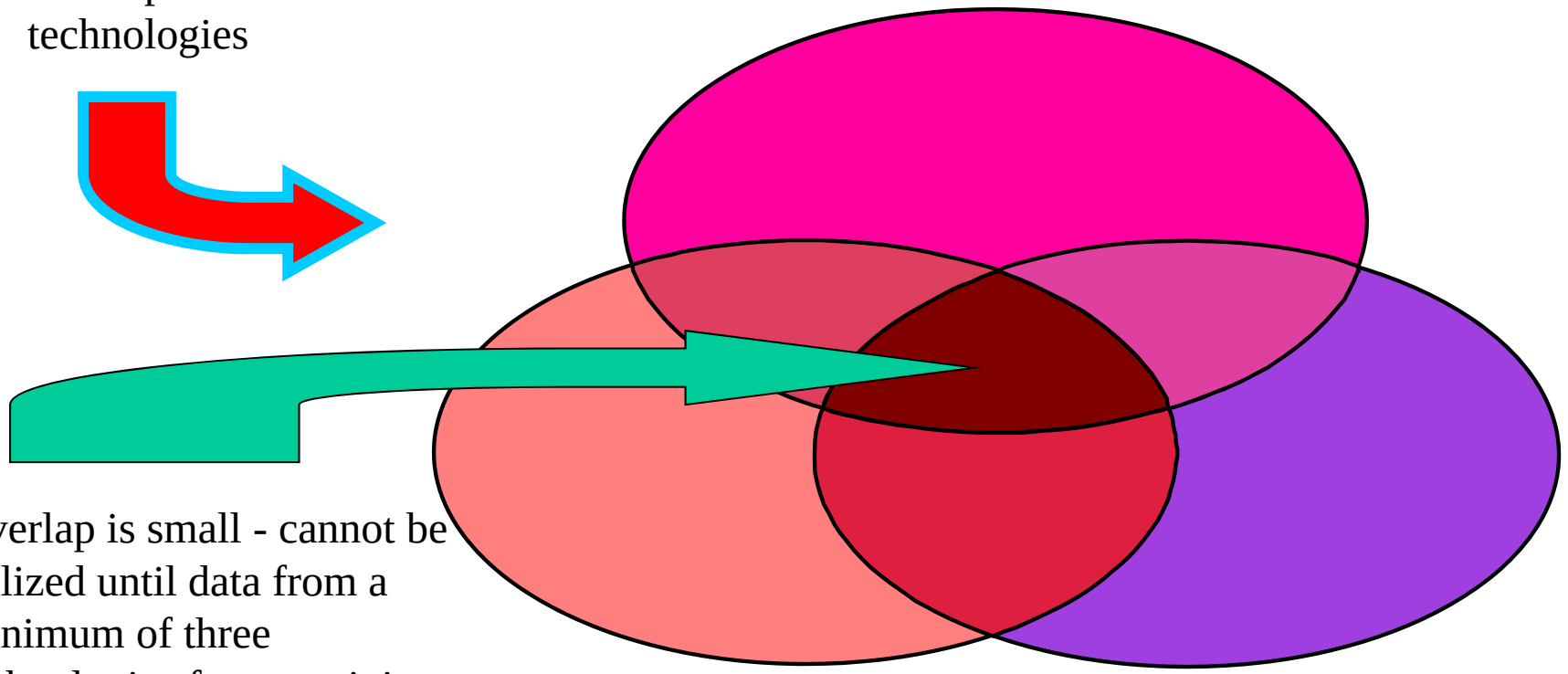
- The API LC was interested in improving efficiencies by developing technically sound enabling guidelines.
- In response, the Single Technology Matrix concept was presented to the LC.

The STM Concept

Current Guidelines

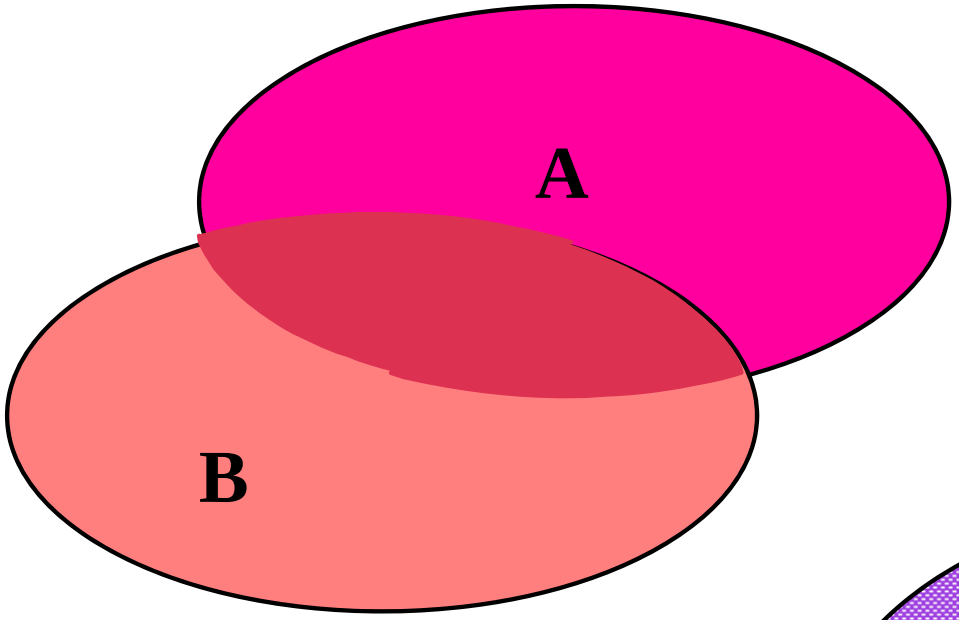
Guidelines encompass all technologies

Technology Domain: A, B, C

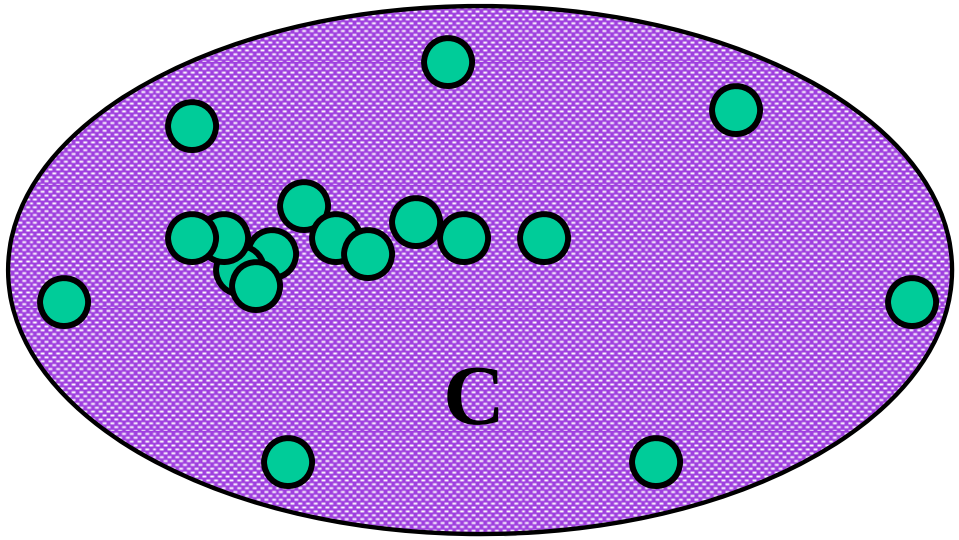


Overlap is small - cannot be utilized until data from a minimum of three technologies from a minimum of two companies are brought forward.

Concept Enhancement



Each base oil is one entity based on characterization.



Allow interchange within the sphere of performance for a single technology.

Large Amount of Data Exist
Let's Maximize Its Use

Registered Industry Tests

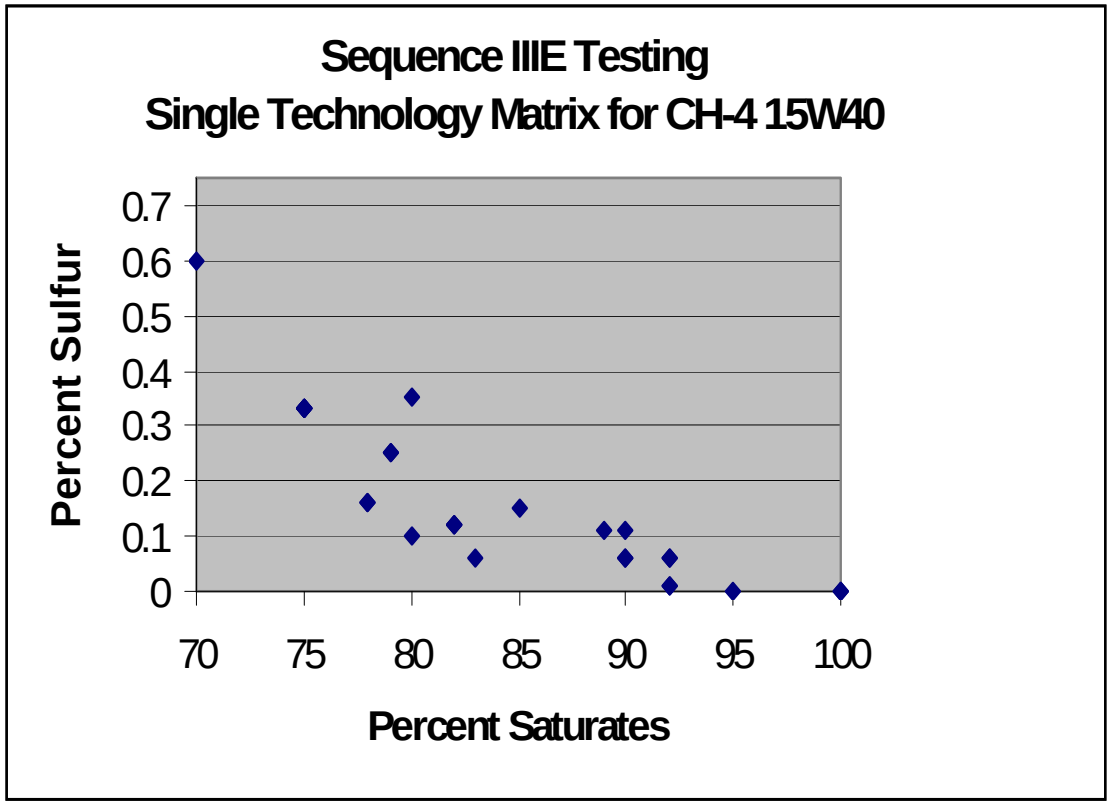
Year	IIIE	VE	VIA
1999 (thru June)	166	197	37
1998	522	445	161
1997	538	468	208
1996	631	634	427
Total Count	**1857**	**1744**	**833**
Industry $MM	37.7	50.0	12.6
Test cost increase for **IIIF, VG, VIB***	58%	22%	31%

How Can We Improve Efficiency and Increase Technical Knowledge?

Example: One API CH-4/SJ Heavy Duty Diesel Technology

- 27 Base Oils were approved in Group I and II base oils
- For required passenger car tests, 27 IIIEs and 22 VEs were run. Each resulted in a first-time pass
- When these approval tests were run, Sequence V BOI Guidelines were more restrictive than at present

Example: Single Technology CH-4 Matrix Tested Under Current API Guidelines



Volatility of Formulations

•Range 11.6% to 16.3% Noack

•27 passing tests

•cost $667,000

•5 Group II

•22 Group I

Base Oil Compositions

•100% Sats; 0% sulfur

•95% Sats; 0.03% sulfur

•90% Sats; 0.06% sulfur

•68 to 89% Sats

•0.1 to 0.6% Sulfur

•VI range typical 95 to 105

Additive Package

•In compliance with ACC Code of Practice

•One minor mod

Technically Sound Efficiency

- Running a statistically designed matrix
  - Reduces number of tests without compromising information regarding impact of base oil
  - Potentially 7 tests could give the same information as 27 tests
  - A cost savings of approximately $ 500,000

API LC Direction

- The STM concept was presented to the API LC about three years ago. The API LC found that the STM concept had merit.
- Several valid concerns about implementation of STM were raised by API and ACC members.
- API LC charged the BOI/VGRA Task Force with further developing the STM approach for BOI.

Single Technology Matrix

From Concept to Implementation

Evolution of STM

- Under guidance of the API BOI/VGRA TF a sub-group lead by Margaret Lemmon was formed.
- This group further evolved the concept and brought it closer to implementation.
- The next step was to form another sub-group of practitioners to address the practical aspects and acceptability of STM
- We now have a document and process for STM which has the unanimous approval of API BOI/VGRA TF and API legal counsel.

STM Process Summary

- New tests developed and introduced as part of new specification.
- API BOI/VGRA TF recommends use of the STM for base oil interchangeability of a new test and advises base oil variables for the tests. API Lubricant Committee approves use and the base oil variables.
- ACC accepts the test into the COP. Registration begins.
- Single Technology Matrix can be conducted on a single technology as per the defined procedure. STM document will be part of API 1509. STM data is included in candidate data packages and API is informed of the use of STM and the analysis.
- API staff call for development of industry guidelines based on information available.

STM Definition of Technology

- **STM.1.2.1** A ***Single Technology*** as designed for the purpose of use in a Single Technology Matrix is a single additive package (DI) at a constant treat rate, a single Viscosity Modifier, and a single Viscosity Grade.

- **STM.1.2.2** A ***Single Technology Matrix*** is comprised of a group of data meeting the criteria outlined in STM.2. The test results in the matrix reflect data from a Single Technology as described in STM.1.2.1.

- **STM.1.2.3** A ***Multiple Technology Matrix*** is comprised of two or more Single Technology matrices meeting the criteria outlined in STM.2. A Multiple Technology Matrix developed within an API category cannot extend to future API categories unless recommended by the BOI/VGRA Task Force and approved by the API Lubricants Committee.

Number of Base Oils Required for STM

Technology in the Matrix	Minimum Number of Base Oils per Technology
First Technology	The greater of 5 or (Defined Base Oil Variables + 2)
Second Technology	The greater of 4 or (Defined Base Oil Variables + 1)
Third and Subsequent Technologies	The greater of 3 or Defined Base Oil Variables

Critical STM Requirements

- The API BOI/VGRA Task Force defines the critical base oil variables of interest for the Single Technology Matrix. The API Lubricants Committee approves the critical base oil variables
- The Matrix Data Criteria must be met as defined in STM.2.1.
- All tests in the development of the Single Technology Matrix dataset and analysis must be registered according to the American Chemistry Council (ACC) Code of Practice.
- The technology must pass within a single test result or by using the appropriate Multiple Test Evaluation Procedure (MTEP) for each Base Oil in the Single Technology Matrix for all relevant test parameters
- Test results or observations dropped for evaluation in an MTEP procedure may not be dropped from the Single Technology Matrix analysis unless declared an outlier according to STM.2.4.

Critical STM Requirements

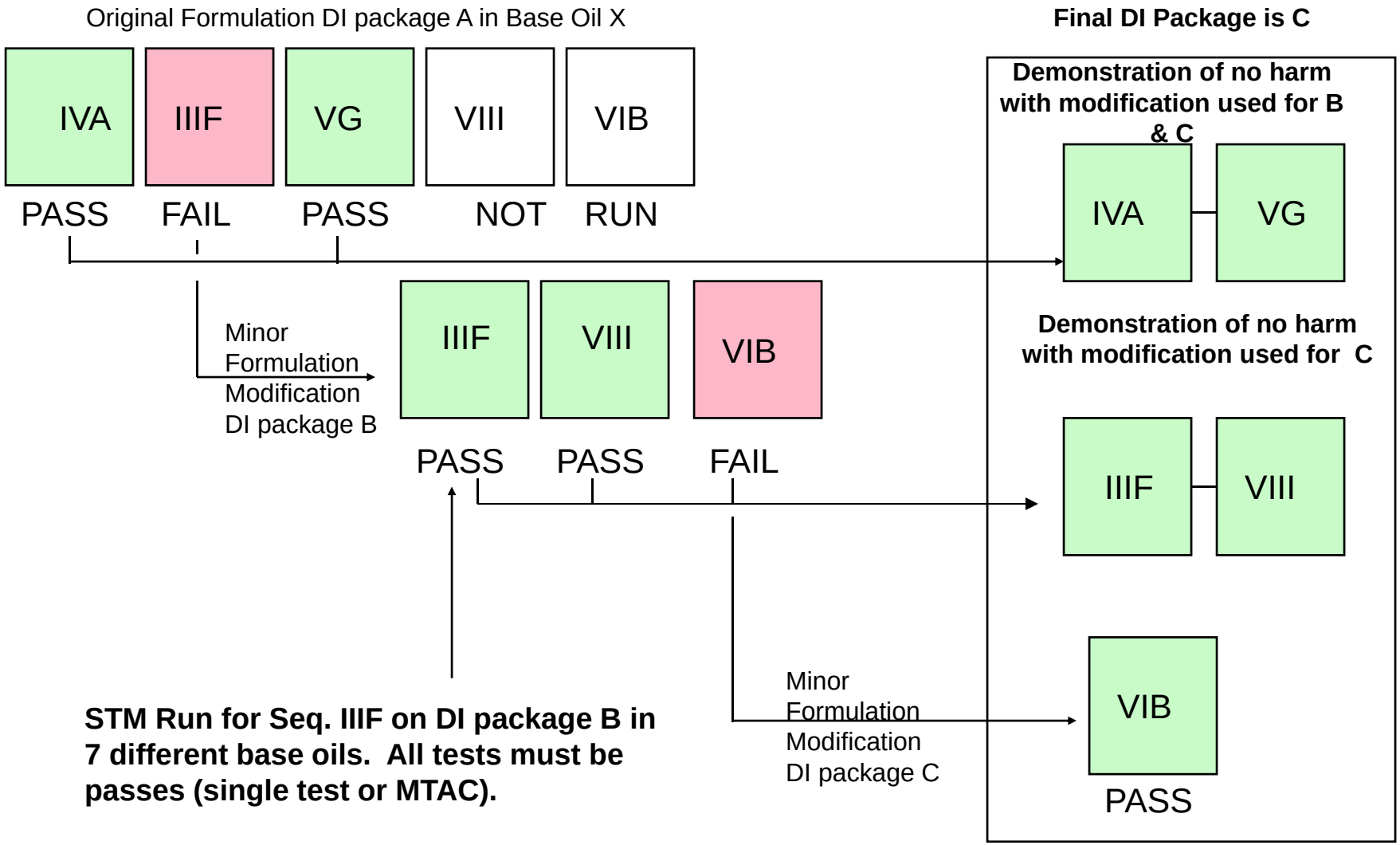
(continued)

- The width of the 95% Confidence Interval (based upon the Student T distribution) for the predicted mean performance based on the Single Technology Matrix model cannot be greater than the width of the 95% Confidence Interval (based upon the Normal Frequency Distribution and the current standard deviation of the test used in the calculation of severity adjustments) for an actual test result at the predicted performance level.
- Single Technology Matrix results must be included in ACC candidate data packages
- Notification for use of Single Technology Matrix data for API license will be present on an Oil Marketer's API license form and must be checked if used. An example is provided in STM.5
- API staff are directed to survey additive companies on a regular basis for Single Technology Matrix data

Objectives of the STM Guideline

- Provides clear, uniform guidelines to anyone who wishes to use the STM approach for BOI
- Outlines the minimum number of base oils which must be used and a step by step procedure to determine confidence intervals and outliers
  - Examples are included
- Lists all the requirements for STM
- Specific criteria for a particular test are (will be) listed

Engine Test Program with STM
Example



Current BOI Process Enhanced by STM

- New test is developed and introduced as part of a new specification.
  - Initial Guidelines are carried forward from previous version of the test via API approval or new Guidelines are developed from Precision/Guideline Matrix data.
- As the test is used for current and future categories, additive and oil companies develop in-house databases on candidate oils. The STM data is captured in the CDP and API staff is informed when STM is used in a candidate development. STM is a more systematic approach to understand base oil impact for a technology supplied by a single supplier
- There is NO official trigger point for calling for data to enhance current guidelines. The API BOI/VGRA TF takes on the responsibility of reviewing the current tests and determining if sufficient time has passed to generate new data on a specific test. API staff can now determine when a sufficient amount of data has been generated on a new test.

Current BOI Process Enhanced by STM

- API BOI/VGRA TF puts out an official call for data to API company members along with a template to capture the data. Since the API BOI/VGRA TF decides on relevant variables for the STM for a particular test, data should be readily available for the template.
- Data is sent to API staff who codes the data and summarizes all inputs for review by the API BOI/VGRA TF.
- API BOI/VGRA TF votes to recommend a new Guideline to the API LC or decides there is not sufficient data at present time. API staff continues to monitor when new candidate programs use STM.

Industry Guidelines - Incentives

- STM is narrowly focused on a single technology. Industry guidelines can be used for multiple technology applications across several product areas (i.e. PCMO & HDMO) HDMOs continue to be universal. STM does not permit read across from PCMO to HDMO or vice versa.

- Tests usually transcend more than one performance category. Industry guidelines are evergreen compared to STM. An industry-wide guideline is necessary to support carrying guidelines to a new sequence test or new category. STMs can support such a guideline but cannot carry a guideline to a new test and maybe not to a new category.

- Data pooling has the potential to expand the range of coverage.

- STM would focus on a particular product development. An industry guideline with broader applications is useful when expanding the scope of the technology's initial application (e.g.: to cover Asia Pacific after North America).

- Industry guidelines are based on additional insight of industry experts. Establishing industry guidelines will continue to be more appealing to all stakeholders.

- STM can form the basis to examine data sets in support of industry guidelines. STM information disclosure process will heighten awareness of data generation and will trigger prompt review of data for development of industry guidelines.

Sequence IIIF Example

Technology 1

Base Oil	D2007 Sats	Sulfur	Noack Volatility D5800	100 C BO Vis	BO Vis Index	Vis Inc	WPD	APV	ACLW	Stuck Rings
1	61.2	0.3641	16.0	4.31	96	311.1	3.95	9.5	8.7	0
1	61.2	0.3641	16.0	4.31	96	212	3.97	9.5	5.7	0
2	66.7	0.2171	16.6	4.86	104	111.4	5.20	9.2	7.7	0
3	68.3	0.3055	18.2	4.46	100	270.4	4.17	9.1	7.9	0
4	70.7	0.3132	15.8	4.39	102	108.3	3.76	8.9	6.8	0
4	70.7	0.3132	15.8	4.39	102	268	4.44	9.1	8.2	0
5	73.9	0.3423	13.9	5.10	103	162.1	4.32	9.2	5.6	0
6	75.4	0.2049	16.9	5.61	105	311.2	4.92	9.1	10.8	0
6	75.4	0.2049	16.9	5.61	105	190	4.44	9.4	7.0	0
7	84.1	0.0740	14.7	5.47	102	67	4.2	9.4	5.1	0
New	72	0.25	16.2	5.00	102					

STM Step-By-Step

Do we have Base Oil Interchange for Technology 1 in a new Base Oil that is within the ranges for Base Oil Saturates, Sulfur, Viscosity, Viscosity Index and Blend Volatility in the Sequence IIIF with STM?

- Technology 1 is the same DI at a constant treat level
- Same VM is used in all blends
- All tests are run in same viscosity grade

Step 1

- Do we have sufficient Base Oils in the Matrix?
- Yes
  - There are 7 Base Oils in the Matrix. The Minimum Number of Tests is the Number of Base Oil Variables (5) plus (2).
- The base oil variables considered for the Sequence IIIF example are:
  - Base Saturate Level (ASTM D2007)
  - Base Oil Sulfur Level (API Approved ASTM Test)
  - NOACK Volatility (ASTM D 5800)
  - Base Oil Viscosity at 100 °C (ASTM D 445)
  - Base Oil Viscosity Index (ASTM D 2270)

Step 2

- Do we have an approximate Evenly Distributed Spread of Base Oil Saturates in the Matrix?
- Yes.
  - The Saturates Delta between Minimum and Maximum Function Equals Delta divided by two in the STM Procedure. 84.1 - 61.2 = 22.9; 22.9/2 = 11.45
  - This represents the Maximum Allowable Difference in Saturates between two consecutive Base Oils sorted by Saturate Level
  - The Maximum Difference in Base Oil Saturates from the Matrix is 8.7; 84.1 -75.4 = 8.7

Step 2 (continued)

- For the Sequence IIIF, in addition to a Spread Requirement for the Base Oil Saturates in the matrix, there is a Spread Requirement for Base Oil Viscosity Index. The maximum difference in Base Oil Viscosity Index, between two base oils sorted and listed by Base Oil Viscosity Index, can be no greater than the difference between the base oil with the highest Base Oil Viscosity Index and the base oil with the lowest Base Oil Viscosity Index, divided by 2.
- Do we have evenly distributed spread of base oil viscosity index in the matrix?
- YES
  - Maximum allowable difference is (105-96)/2 = 4.5
  - Maximum difference from the matrix is 4

Step 3

- Do we pass the Sequence IIIF with the Technology in every Base Oil in the Matrix?

- Yes
  - Some with one test and some by MTAC.

Step 4

- Do we predict a pass for the technology in the new base oil based on the analysis of the matrix?
- **Yes**
  - **The new oil falls within the range, all the other base oils passed.**

						Predicted				
Base Oil	D2007 Sats	Sulfur	Noack Voltlty D5800	100C BO Vis	BO Vis Index	**Vis Inc**	**WPD**	**APV**	**ACL W**	**Stuck Rings**
New	72	0.25	16.2	5.00	102	**201**	**4.3**	**9.2**	**7.4**	**0**

Range of Base Oil Variable from the STM Data Set				
Saturates	Sulfur	Noack	100C Vis	Vis Ind
61.2 to 84.1	0.074 to 0.364	14.7 to 18.2	4.31 to 5.61	96 to 105

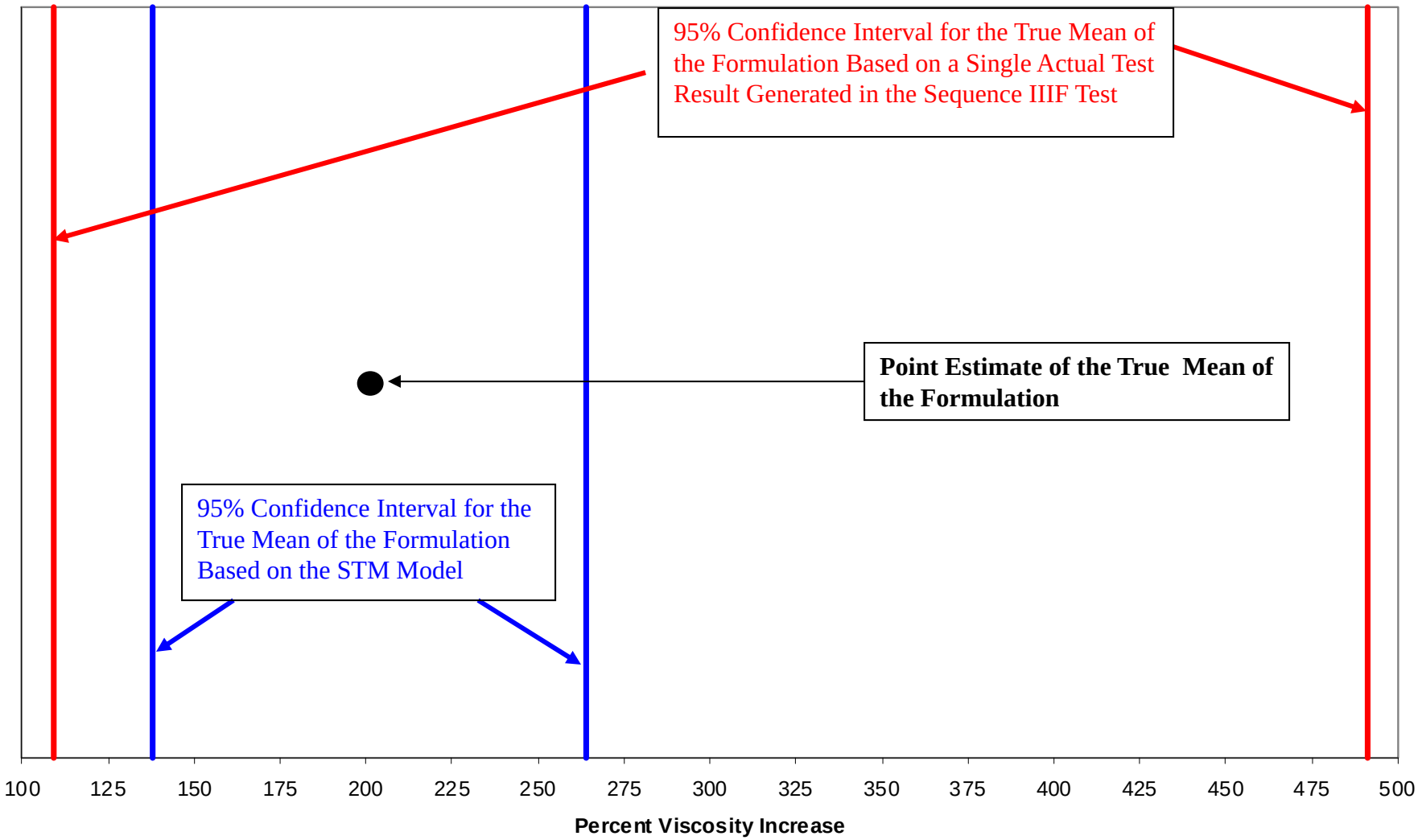
Range Results from the STM Data Set				
Vis Inc	WPD	APV	ACLW	Stuck Rings
67-311.2	3.76-5.2	8.9-9.5	5.1-10.8	0

Step 5

- No outliers were found in the data set

Step 6

95% Confidence Intervals for the Predicted Mean Viscosity Increase Based on a Single Test Result on the Exact Formulation versus the Estimate Based on the STM Model



Step 7

Summary of Confidence Interval Widths

Parameter	Actual Test Result Confidence Interval Width	Predicted Test Result Confidence Interval Width	Predicted Test Result CI Width Smaller?
Vis Inc	382	126	YES
WPD	2.58	0.63	YES
APV	0.86	0.29	YES
ACLW	NA	2.44	NA

How can the width of the confidence interval for a predicted test result be smaller than the width for and actual test result?
Although there is more error in the model there is also more data to overcome that error. In this example we are looking at 1 piece of information on the exact formulation versus 10 pieces of information on similar formulations.

Do We Have BOI?

Base Oil	D2007 Sats	Sulfur	Noack Voltlty D5800	100C BO Vis	BO Vis Index	Vis Inc	WPD	APV	ACLW	Stuck Rings
1	61.2	0.3641	16.0	4.31	96	311.1	3.95	9.5	8.7	0
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6	75.4	0.2049	16.9	5.61	105	311.2	4.92	9.1	10.8	0
6	75.4	0.2049	16.9	5.61	105	190	4.44	9.4	7.0	0
7	84.1	0.0740	14.7	5.47	102	67	4.2	9.4	5.1	0
New	72	0.25	16.2	5.00	102	201	4.3	9.2	7.4	0

Yes, All Criteria Were Met

Expanded IIIF Example
API Base Oil Groups I, II & III

Base Oil	D2007 Sats	Sulfur	Noack Voltlty	100C Vis	BO VI	Vis Inc	WPD	APV	ACLW	Stuck Rings
1	61.2	0.3641	16.0	4.31	96	311.1	3.95	9.5	8.7	0
1	61.2	0.3641	16.0	4.31	96	212	3.97	9.5	5.7	0
2	66.7	0.2171	16.6	4.86	104	111.4	5.20	9.2	7.7	0
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6	75.4	0.2049	16.9	5.61	105	311.2	4.92	9.1	10.8	0
6	75.4	0.2049	16.9	5.61	105	190	4.44	9.4	7.0	0
7	84.1	0.0740	14.7	5.47	102	67	4.2	9.4	5.1	0
8	95	0.003	11.9	4.97	125	24	4.11	9.3	7.6	0
9	96	0.002	12.1	5.09	110	31	5.05	9.2	5.9	0
10	100	0.0	11.2	5.41	136	10	4.36	9.5	6.2	0
New	98	0.001	12.0	5.20	120					

Step 1

- Do we have sufficient Base Oils in the Matrix?
- Yes
  - There are 10 Base Oils in the Matrix. The Minimum Number of Tests is the Number of Base Oil Variables (5) plus (2).
- The base oil variables considered for the Sequence IIIF example are:
  - Base Saturate Level (ASTM D2007)
  - Base Oil Sulfur Level (API Approved ASTM Test)
  - NOACK Volatility (ASTM D 5800)
  - Base Oil Viscosity at 100 °C (ASTM D 445)
  - Base Oil Viscosity Index (ASTM D 2270)

Step 2

- Do we have an approximate Evenly Distributed Spread of Base Oil Saturates in the Matrix?
- Yes.
  - The Saturates Delta between Minimum and Maximum Function Equals Delta divided by two in the STM Procedure. 100.0 - 61.2 = 38.8; 38.8/2 = 19.4
  - This represents the Maximum Allowable Difference in Saturates between two consecutive Base Oils sorted by Saturate Level
  - The Maximum Difference in Base Oil Saturates from the Matrix is 8.7; 95.0 –84.1 = 10.9

Step 2 (continued)

- For the Sequence IIIF, in addition to a Spread Requirement for the Base Oil Saturates in the matrix, there is a Spread Requirement for Base Oil Viscosity Index. The maximum difference in Base Oil Viscosity Index, between two base oils sorted and listed by Base Oil Viscosity Index, can be no greater than the difference between the base oil with the highest Base Oil Viscosity Index and the base oil with the lowest Base Oil Viscosity Index, divided by 2.
- Do we have evenly distributed spread of base oil viscosity index in the matrix?
- YES
  - Maximum allowable difference is (136-96)/2 = 20
  - Maximum difference from the matrix is 15 (125-110)

- Remaining Steps would Proceed as in Previous Example. The extended example covers API Group I, II & III base oils.

Summary

- STM process compliments the current process.
- STM process and document provides uniform guidelines for designing and analyzing the matrix.
- STM BOI guidelines are based on robust technologies (only passing results).
- STM information will be provided to API staff and will trigger development of industry guidelines.
- All tests to be registered. Complete data disclosure of STM tests.

API BOI/VGRA TF Unanimously Recommends API LC to Approve

- Acceptance of STM document as part of API 1509 Appendix E Base Oil Interchangeability Guidelines.
- Use of STM for Sequence IIIF
- STM Base Oil Variables for Seq IIIF:
  - Base Oil Saturate Level (ASTM D 2007)
  - Base Oil Sulfur Level (API approved tests)
  - NOACK Volatility (ASTM D 5800)
  - Base Oil Viscosity at 100 °C (ASTM D 445)
  - Base Oil Viscosity Index (ASTM D 2270)
- For the IIIF, in addition to the original requirement for spread in Base Oil Saturates, the maximum difference in Base Oil Viscosity Index, between two base oils sorted and listed by Base Oil Viscosity Index, can be no greater than the difference between the base oil with the highest Viscosity Index and the base oil with the lowest Viscosity Index, divided by 2.