

# Statistical Aspects Relating to SPI Test Data to Evaluate Fuel and Lubricant Effects

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# Order of Presentation

- Stochastic Pre-Ignition (SPI) Tests
- Sequence IX test details
- Sequence IX Low Speed Pre-Ignition (LSPI) event definition
- Outlier (Event) identification procedure
- Transient versus steady state
- Baseline tests
- Test and designed experiment considerations

# Stochastic Pre-Ignition (SPI) Tests



- Low Speed Pre-Ignition (LSPI) is a subset of SPI
- Literature and standardized test describe numerous SPI methods
- These tests differ by:
  - Engine
  - Test conditions including duration and severity
  - Fuel
  - Steady state or transient
- Sequence IX (ASTM D8291) is a rigorous, controlled and closely monitored test method used here to illustrate statistical concepts
  - Fixed fuel, lubricant is varied

# Sequence IX (D8291)

- Ford 2.0 L Ecoboost engine
- Steady state
- 4 valid segments of 175k cycles
- Haltermann EEE fuel
- Test is monitored via Lubricant Test Monitoring System (LTMS) to periodically verify engine health and adjust for severity differences including engine-to-engine variability and engine age drift.
- Specialized PCM for test:
  - Fixed ignition timing
  - Rapid fuel enrichment eliminates LSPI clusters
- Additional details can be found in Mounce<sup>1</sup>

<sup>1</sup> Mounce, F., “Development of a Standardized Test to Evaluate the Effect of Gasoline Engine Oil on the Occurrence of Low Speed Pre-Ignition – The Sequence IX Test,” SAE Technical Paper 2018-01-1808, 2018, doi:10.4271/2018-01-1808.

# Sequence IX LSPI Event Definition

- For the Sequence IX, an LSPI event is identified as an outlier with respect to both Peak Pressure (PP) and 2% Mass Fraction Fuel Burned (MFB).
  - Some tests count PP Only and MFB Only as well.
- Multiple events LSPI chain events are extremely rare in the Sequence IX.
- For those tests for which chain events occur, for statistical analysis, the chain event should be counted as 1 event as most statistical procedures assume counts are independent.
  - Other statistical analyses can be performed to test the tendency towards chain events.

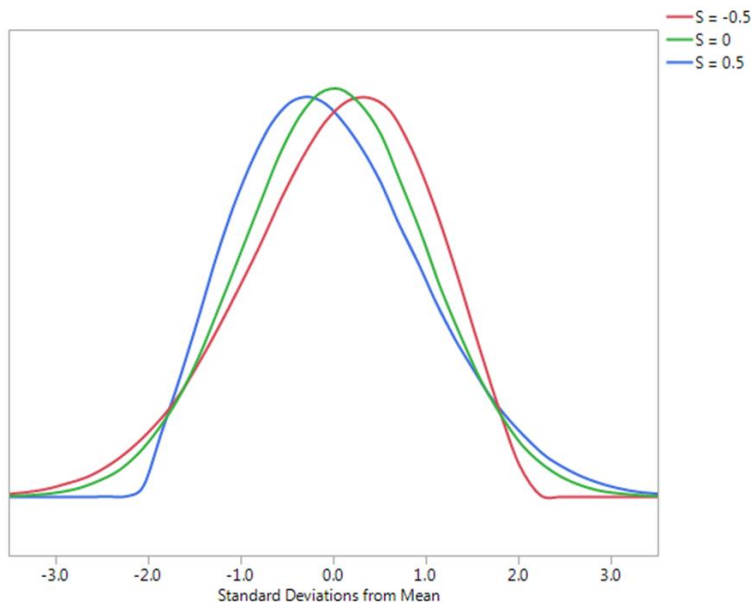
# Outlier Identification Procedure

- The outlier (event) identification procedure for PP and MFB of each independent test segment for each cylinder follows:
  - Data is screened for obvious errors (e.g., due to failures related to pressure transducers)
  - The first 170k valid cycles are used
  - Obvious events ( $PP > 9 \text{ MPa}$  and  $MFB02 < 0^\circ$ ) are removed and included in event count
  - The mean and standard deviation of PP and MFB for each cylinder are calculated.
  - For a sample size of 170k, Grubbs Test for Outliers identifies an outlier as being 5 or more standard deviations from the mean assuming a Normal distribution.

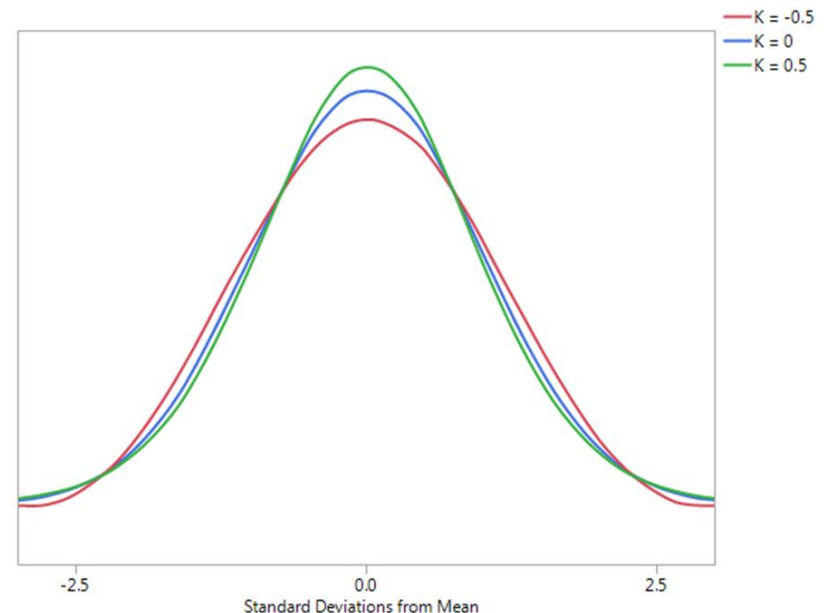
# Outlier Identification Procedure (Continued)

- Skew and Kurtosis is calculated to determine degree of deviation from Normal distribution and a procedure<sup>2</sup> is used to adjust trigger point (5 standard deviations)
- Not accounting for departures from normality can lead to false positives or negatives

## Three Values of Skew



## Three Values of Excess Kurtosis



# Outlier Identification Procedure (Continued)



- Outliers are removed.
- The process is repeated until no additional outliers are identified.

<sup>2</sup> Boese, D., Ritchie, A., and Young, A., “Controlling Low-Speed Pre-Ignition in Modern Automotive Equipment: Defining Approaches to and Methods for Analyzing Data in New Studies of Lubricant and Fuel Related-Effects (Part 2),” SAE Technical Paper 2016-01-0716, 2016, doi:10.4271/2016-01-0716

# Transient Versus Steady State

- Transient tests simulate actual driving conditions while steady state is artificial.
  - Sequence IX test conditions are rarely experienced in normal driving conditions.
- Transient tests by their nature will have less repeatable conditions than a steady state test leading to the expectation of poorer test precision.
  - Bigger data sets will be needed for transient tests for the same level of statistical discrimination.
- Steady state statistics are less complicated than those required for transient tests to similarly account for known sources of variation.
  - New statistical methods are required to rigorously identify SPI events for transient tests.

# Frequent Baseline Tests are Essential



- SPI severity changes as the engine is broken in and ages.
  - The Sequence IX tends to trend mild as the engine ages.
  - SPI engines are subject to damage which impacts test severity and may pass without detection in operational diagnostics.
    - Example: low event RO 220 detects shifts to higher severity.
- In Sequence IX:
  - Two acceptable tests with reference oils are required to be run after break in and prior to any candidates (calculate initial Severity Adjustment).
  - Thereafter, references are run after every five candidates to detect severity shift and estimate severity drift (update Severity Adjustment).
- Baseline oils should be of medium severity:
  - If the baseline oil has too few events, it will be difficult to detect if the severity has shifted mild.
  - If the baseline oil has too many events, the likelihood of engine failure increases.

- Baseline or reference oil should be of medium severity (~ 5 events per segment).
- Segments / test severity should target ~ 4 or 5 for medium severity oil.
- Segment length should not be too long so that if it is interrupted, minimal retesting is required.
- The expected engine life should be considered when determining the number of tests in a designed experiment.
  - Sequence IX median engine life is 470 hours which corresponds to roughly 19 tests, 4 of which being references.
- If more than one engine is used in a designed experiment (or meta analysis) the same baseline oil should be used and it is preferred if one or more test oils are run in at least 2 engines to estimate engine severity differences.

# Next Steps

- Explore operational space around Sequence IX test conditions.
- Develop statistically rigorous method of identifying SPI events in transient tests.

# Contact Information



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