Developing and deploying optimization strategy for engine calibrations

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Public

B?l?nc? in life
is the key to
happiness.

Agenda

Problem statement

- Optimize engine performance calibrations

Approach

- Analytical calibration workflow

Tools used

- MATLAB for almost everything (Data Import, Parallel computing, statistics and Machine Learning, Optimization toolbox, MATLAB compiler)

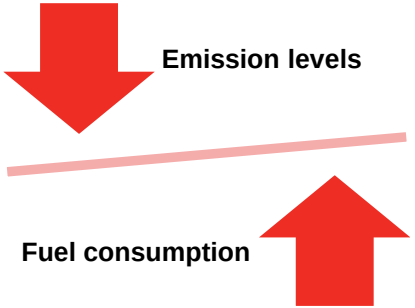
Results

- Bubble plots representation

Key takeaways

Problem statement

- Due to inherent nature of diesel engine, trying to keep fuel consumption below a certain value yielded increased smoke in some regions of operation that led to EGR fouling.
- Optimize engine performance calibrations.
  Maintain emissions - NOx and Total Hydro Carbon at or below current levels, while reducing Smoke, and minimizing fuel consumption.



Situation

- A fleet of truck shows engine light on sometimes accompanied by lack of power due to an engine derate.

Investigations

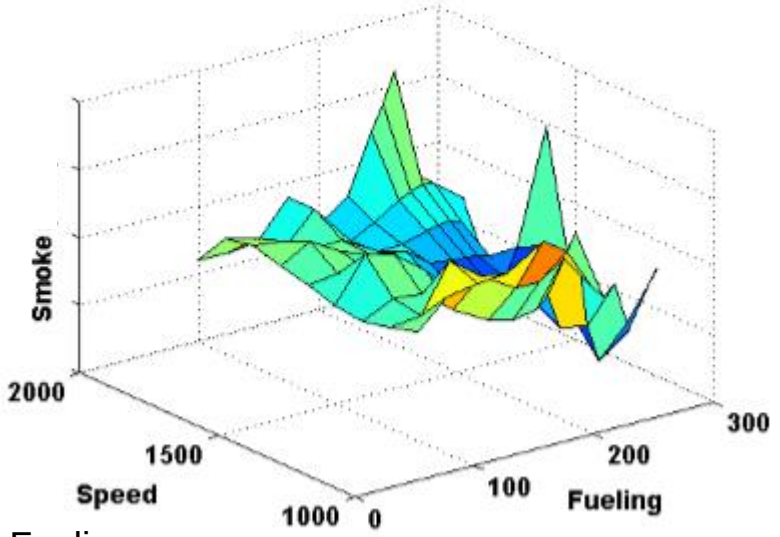
- Existing data showed Exhaust Gas Recirculation (EGR) cooler was fouled due to higher smoke levels in some regions.
- Pursue a smoke reduction effort while maintaining other emissions and fuel economy.

Problem statement

- **Optimize engine performance calibrations. Maintain emissions - NOx and Total Hydro Carbon at or below current levels, while reducing Smoke, and minimizing fuel consumption.**

Approach
Selected levers

- Scope / Deliverable:
  - Significant smoke reduction
  - Maintain acceptable:
    - NOx
    - HC
    - BSFC
- Primary levers
  - Rail Pressure,
  - Main Injection Timing,
  - Pilot Injection Quantity and Timing, adding Post Fueling
- Levers to balance NOx, THC, and BSFC impact with Smoke reduction.
  - EGR Fraction and Charge Flow Optimization



Approach
Analytical calibration workflow

Calibration Planning

Design of Experiments

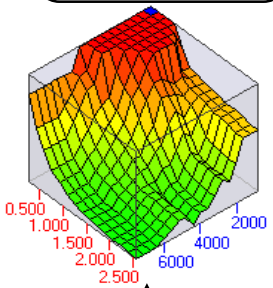
Conduct experiment and collect Data

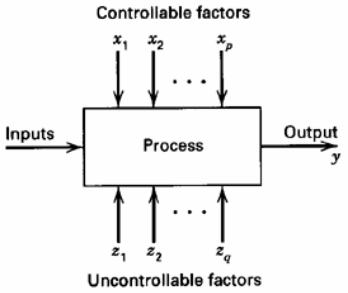
Data Import

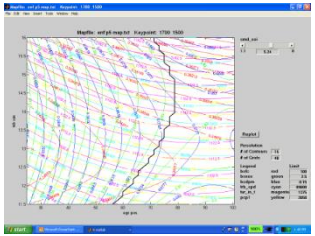
Data Analysis

Model Development & Model Validation

Generate Optimized Tables

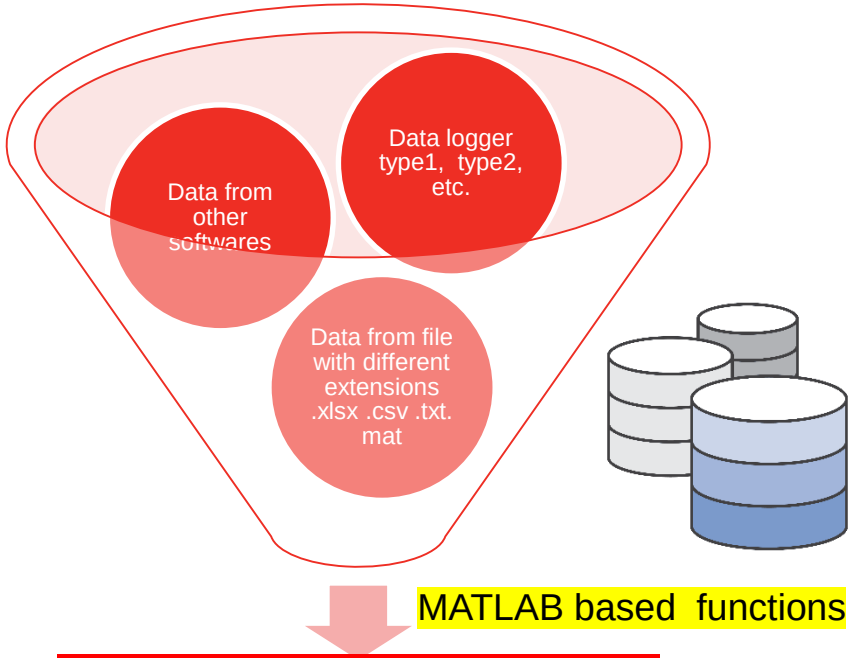






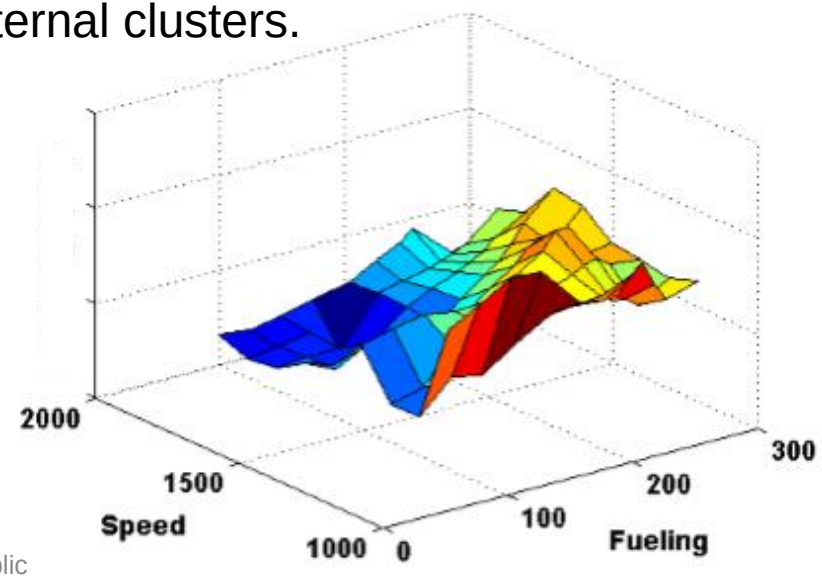
Tools used
Data Import

- Data import
  - Data from different loggers, different softwares, different file extensions, formats can be imported, merged, filtered into a fixed format using MATLAB functions.
  - It can handle out of memory data.
  - Data in this fixed format is used throughout the analytical calibration workflow.



Tools used
Analyzing Data

- How to analyze data ?
- Parallel computing allows the desktops to use their multicore processing capability by executing applications on workers that run locally.
- The analysis time was drastically reduced. It can be integrated with Cummins internal clusters.



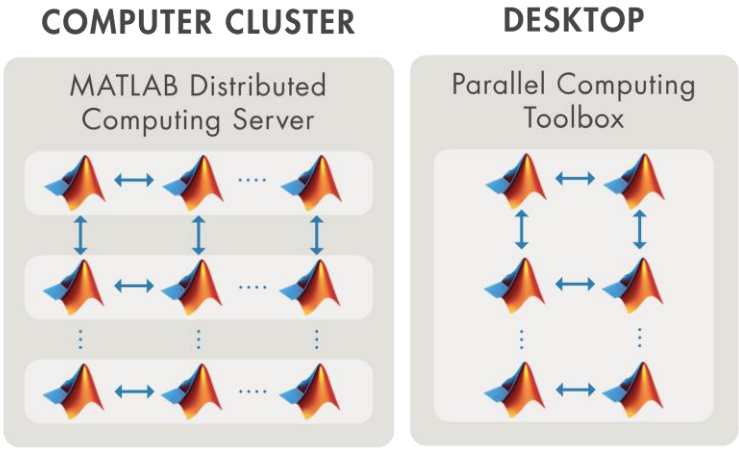
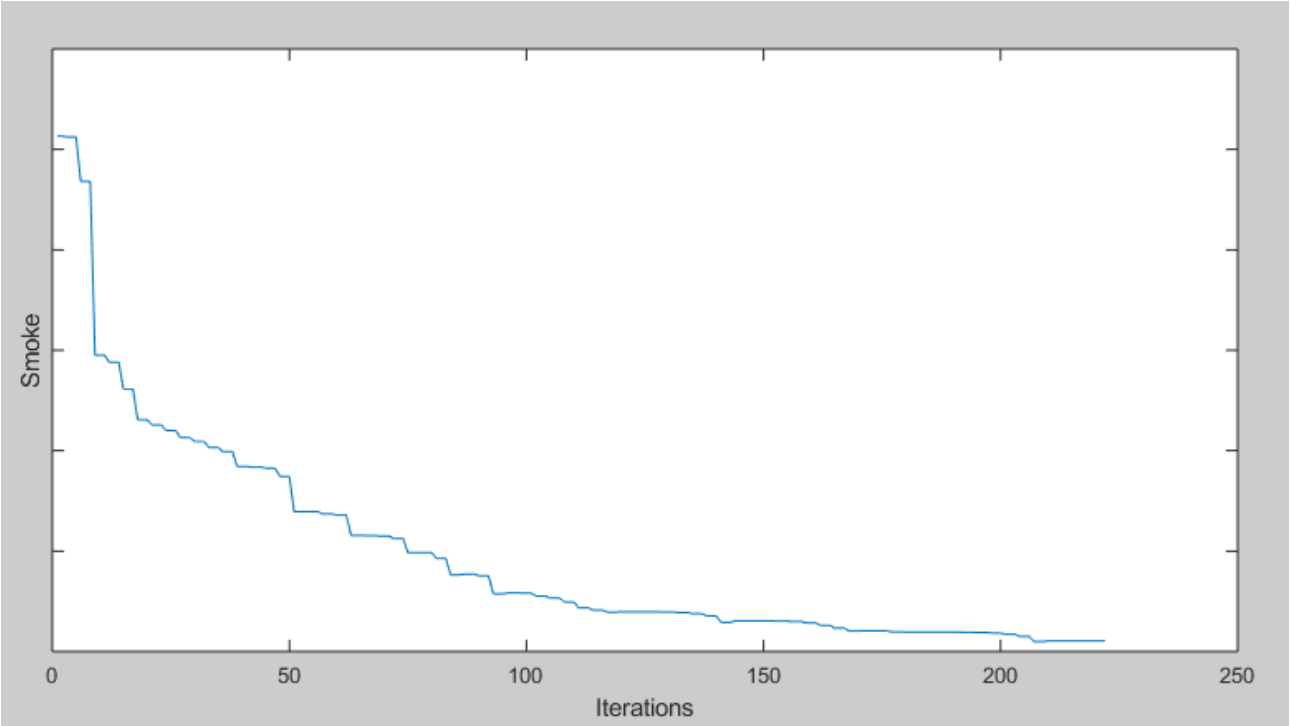


Image source : Mathworks

Tools used

Statistics and machine learning; Optimization Toolbox

- To create analytical model.
- MATLAB optimizer implemented in the calibration toolkit gives successful results.

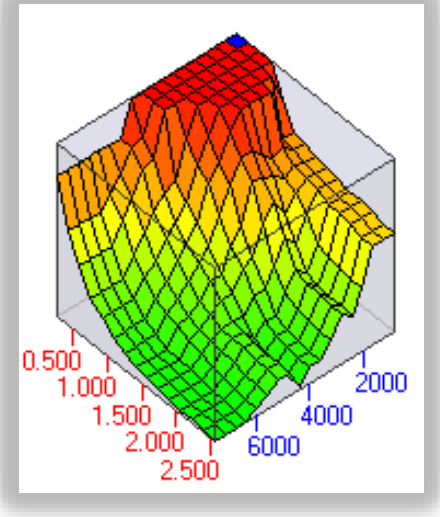


Smoke values getting reduced with the number of optimization iterations.

Tools used
Data visualization

- Data visualization
  - While developing engine performance calibrations, data visualization is done at multiple stages using MATLAB.

	0.270	0.570	0.730	1.00	1.17	1.30	1.47	1.640	1.800	1.980	2.200	2.300	2.400	2.480	2.560
800	14.7	14.7	14.7	14.7	13.8	13.2	13.1	12.98	12.89	12.80	12.71	12.71	12.63	12.54	12.54
1200	14.7	14.7	14.7	14.7	14.7	13.2	13.1	12.98	12.89	12.80	12.71	12.71	12.63	12.54	12.54
1600	14.7	14.7	14.7	14.7	14.7	14.7	13.3	13.07	12.98	12.89	12.71	12.71	12.63	12.54	12.54
2000	14.7	14.7	14.7	14.7	14.7	14.7	13.2	12.89	12.71	12.38	11.76	11.61	11.54	11.47	11.47
2400	14.7	14.7	14.7	14.7	14.7	14.7	13.4	13.16	12.30	11.69	11.07	10.94	10.88	10.88	10.81
2800	14.7	14.7	14.7	14.7	14.7	14.7	13.8	13.25	12.80	12.06	11.33	11.20	11.13	11.07	11.07
3200	14.7	14.7	14.7	14.7	14.7	14.3	13.7	13.34	12.38	11.40	10.88	10.63	10.57	10.51	10.51
3600	14.7	14.7	14.7	14.7	14.0	13.5	13.2	12.22	11.54	10.94	10.34	10.23	10.17	10.12	10.12
4000	14.7	14.7	14.7	13.9	13.4	13.2	12.5	11.83	11.47	10.88	10.40	10.23	10.17	10.12	10.12
4400	14.7	14.7	14.7	12.9	12.5	12.2	11.8	11.20	10.94	10.45	10.12	9.96	9.85	9.80	9.75
4800	14.7	13.8	13.4	12.7	12.1	11.8	11.4	11.20	10.88	10.51	10.45	10.40	10.34	10.34	10.28
5200	13.7	13.7	13.3	12.4	11.8	11.4	11.1	10.75	10.63	10.45	10.45	10.45	10.34	10.34	10.28
5600	13.7	13.2	12.7	11.9	11.3	11.0	10.8	10.51	10.40	10.34	10.28	10.23	10.12	10.12	10.06
6000	13.7	12.7	12.2	11.5	11.1	10.7	10.5	10.45	10.28	10.12	10.01	9.96	9.90	9.85	9.85
6400	13.7	12.4	11.6	10.9	10.6	10.3	10.1	9.96	9.90	9.85	9.80	9.75	9.75	9.70	9.65
6800	13.7	12.4	11.6	10.9	10.6	10.3	10.1	9.96	9.90	9.85	9.80	9.75	9.75	9.70	9.65
7200	13.7	12.4	11.6	10.9	10.6	10.3	10.1	9.96	9.90	9.85	9.80	9.75	9.75	9.70	9.65
7600	13.7	12.4	11.6	10.9	10.6	10.3	10.1	9.96	9.90	9.85	9.80	9.75	9.75	9.70	9.65



Tools used
Deploying toolkit

- How to deploy toolkit to users who don't have MATLAB ?
- The toolkit is deployed as an standalone executable, that enables users to run compiled MATLAB applications without installing MATLAB.

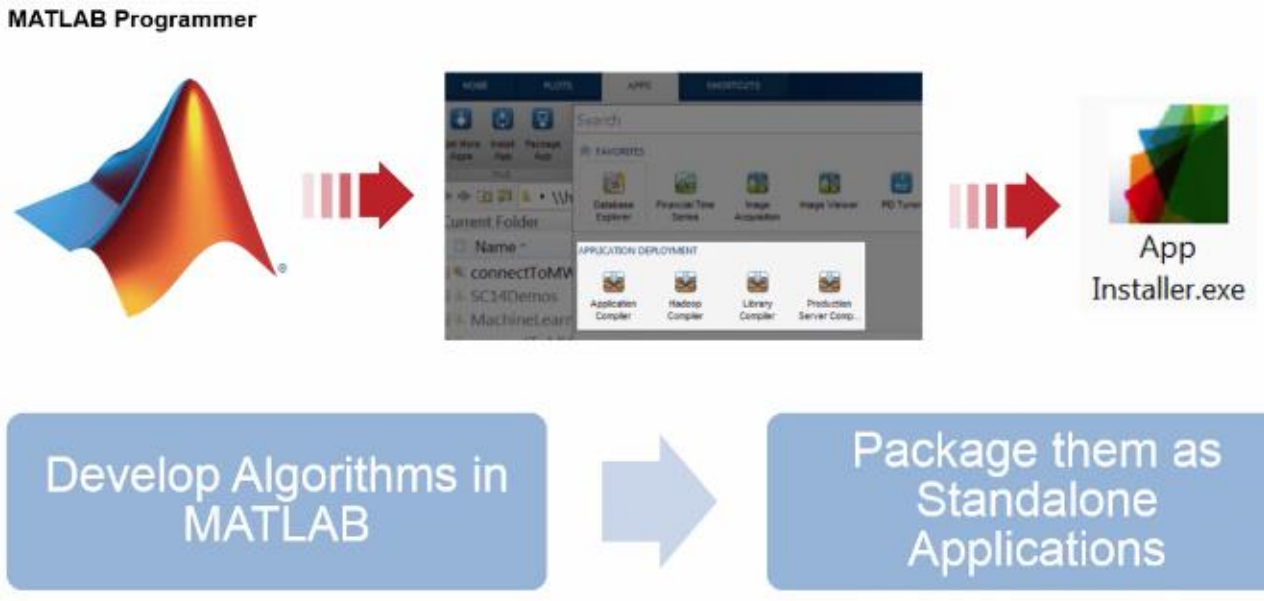
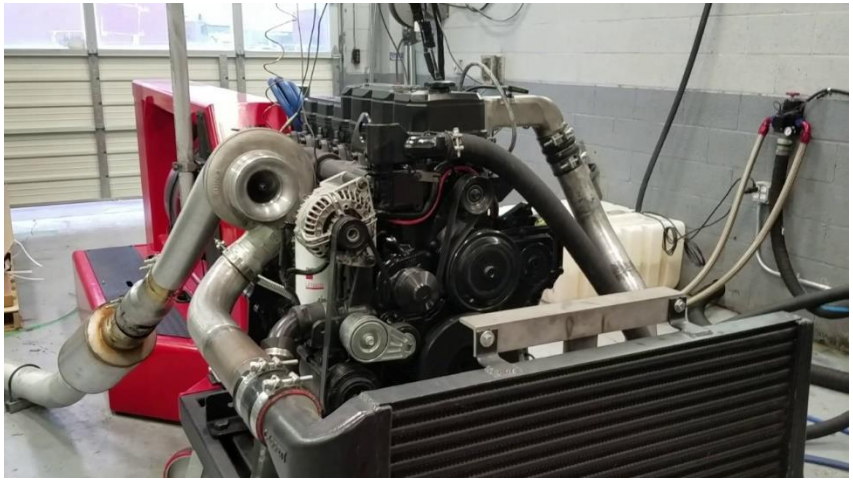


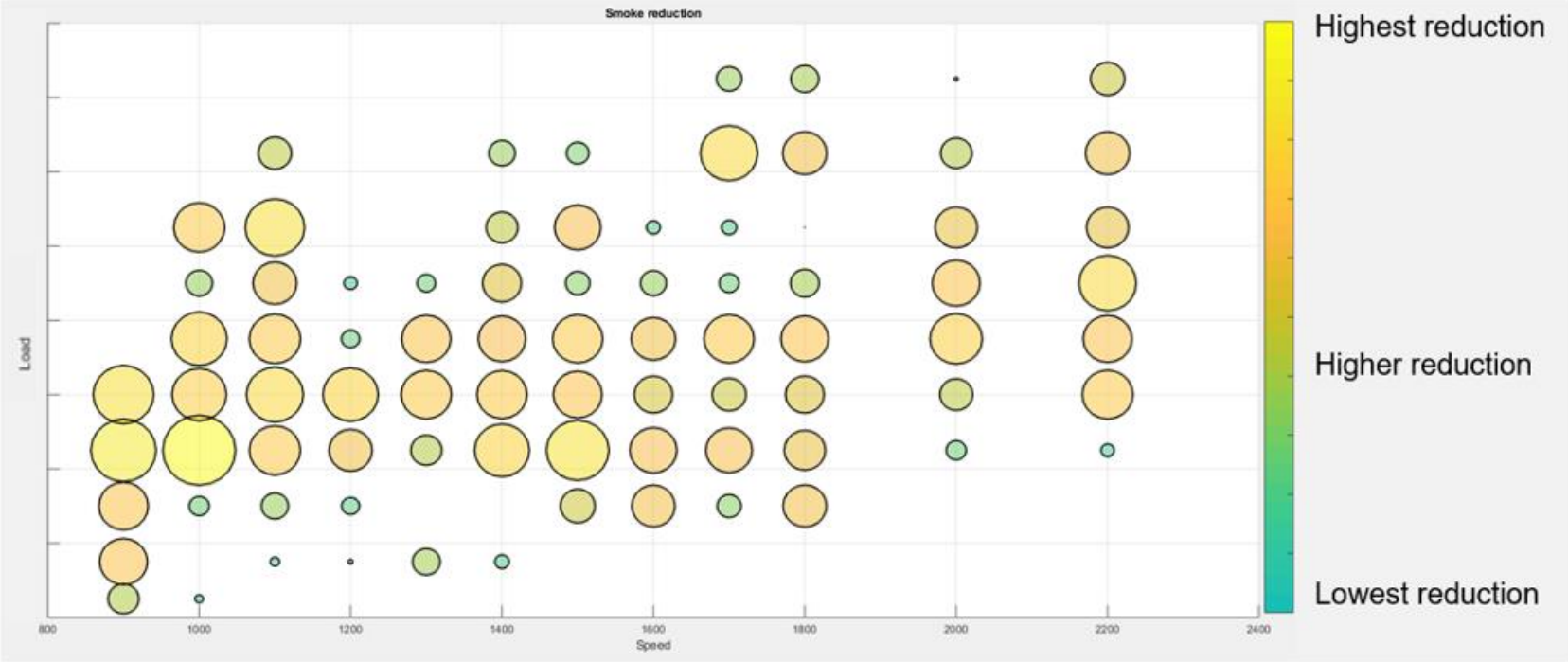
Image source : Mathworks

Results achieved

- Engine dyno testing done to verify the results.
- Bubble plots showing
  - Reduction in Smoke
  - Acceptable increase in NOx, HC, PM and fuel consumption.

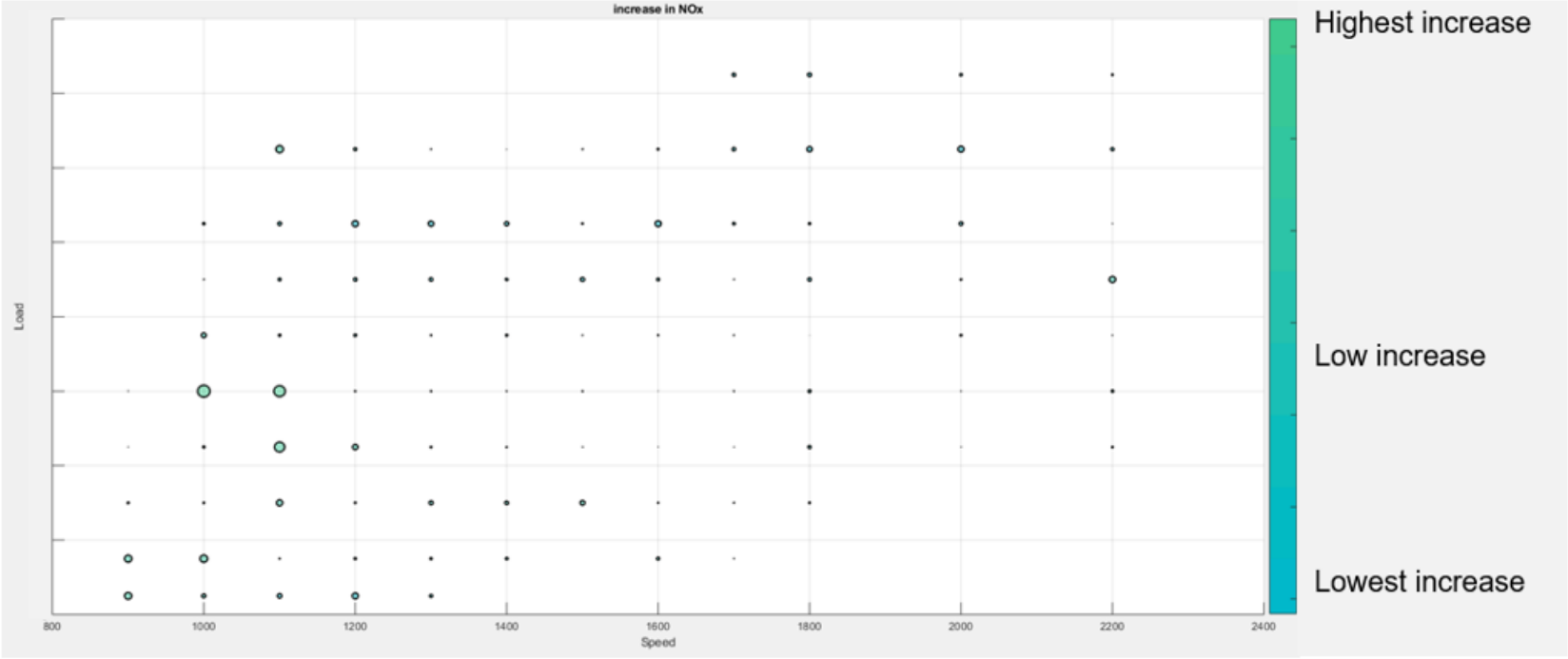


Results
Smoke reduction



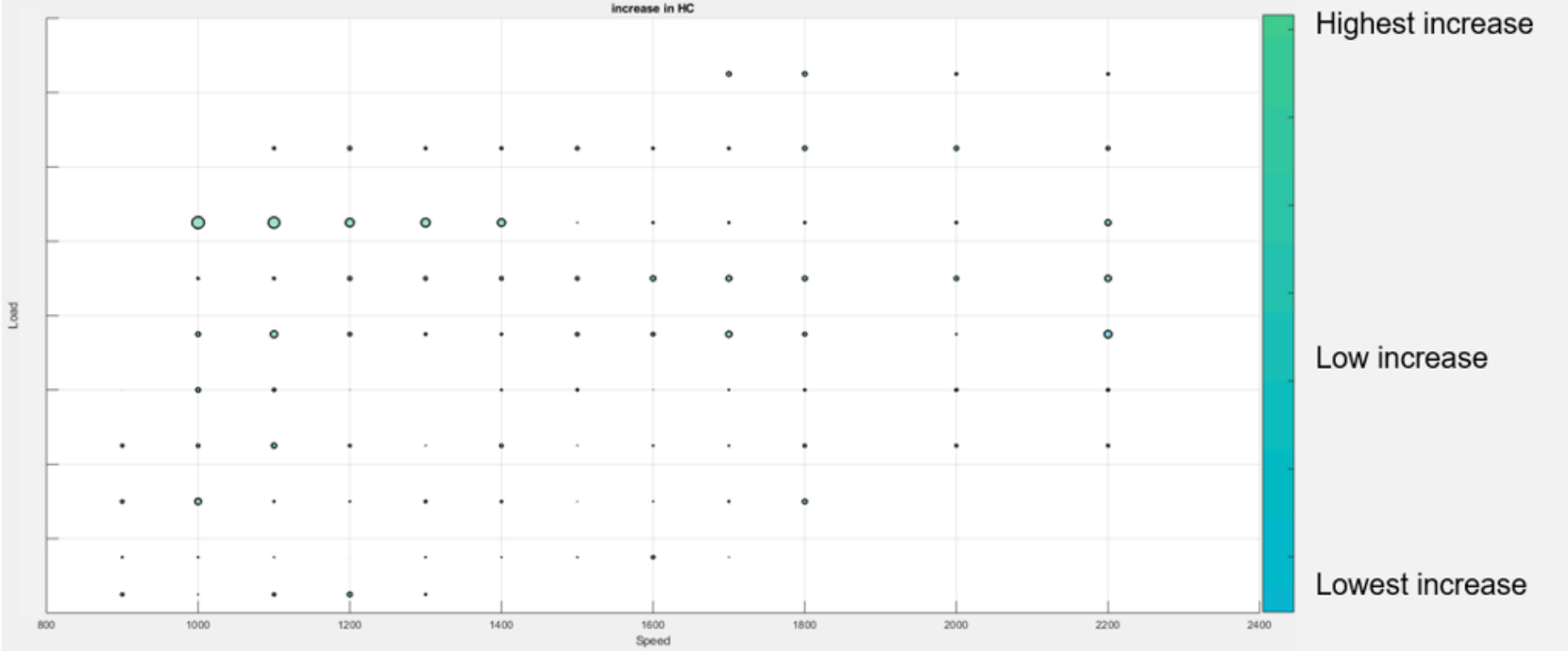
Smoke was significantly reduced

Results
Acceptable increase in NOx



NOx was on par with the baseline with a slight acceptable increase.

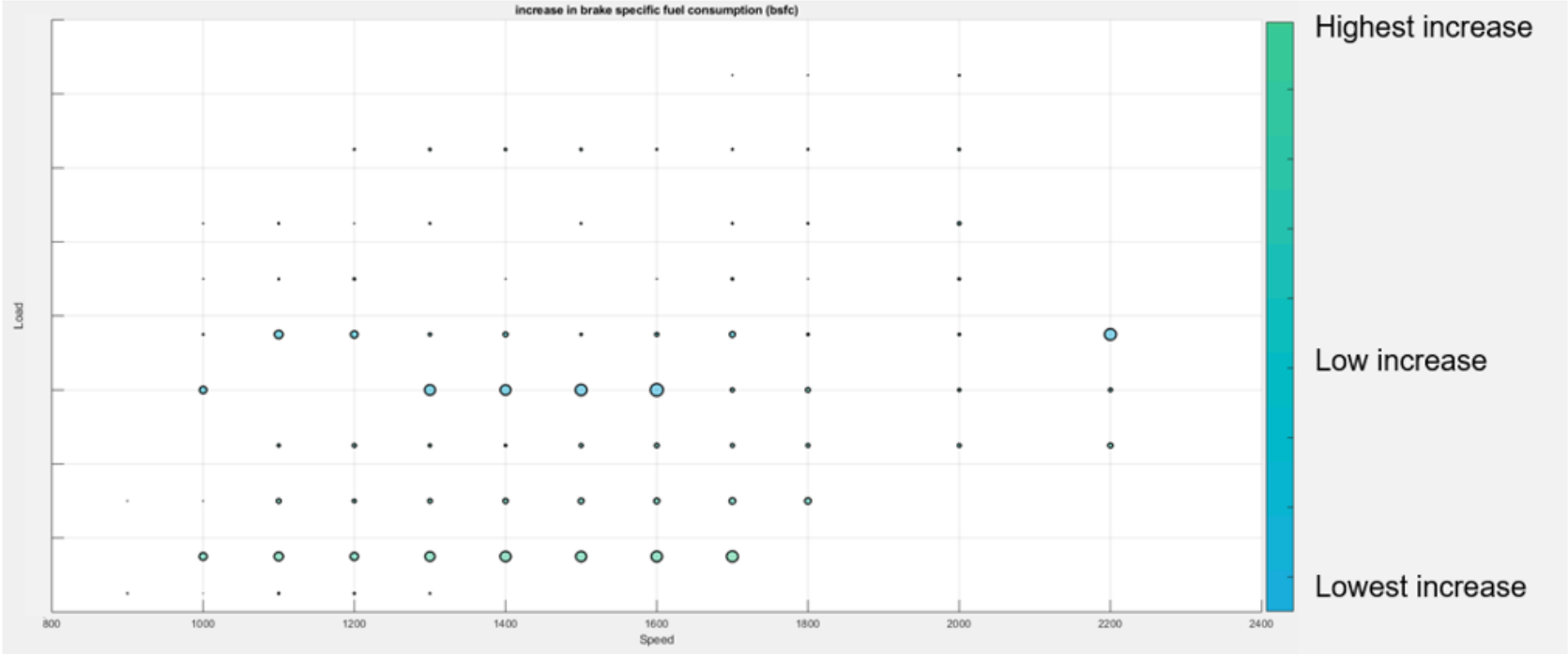
Results
Acceptable increase in Hydrocarbon



HC was on par with the baseline. There was a slight acceptable increase.

Results

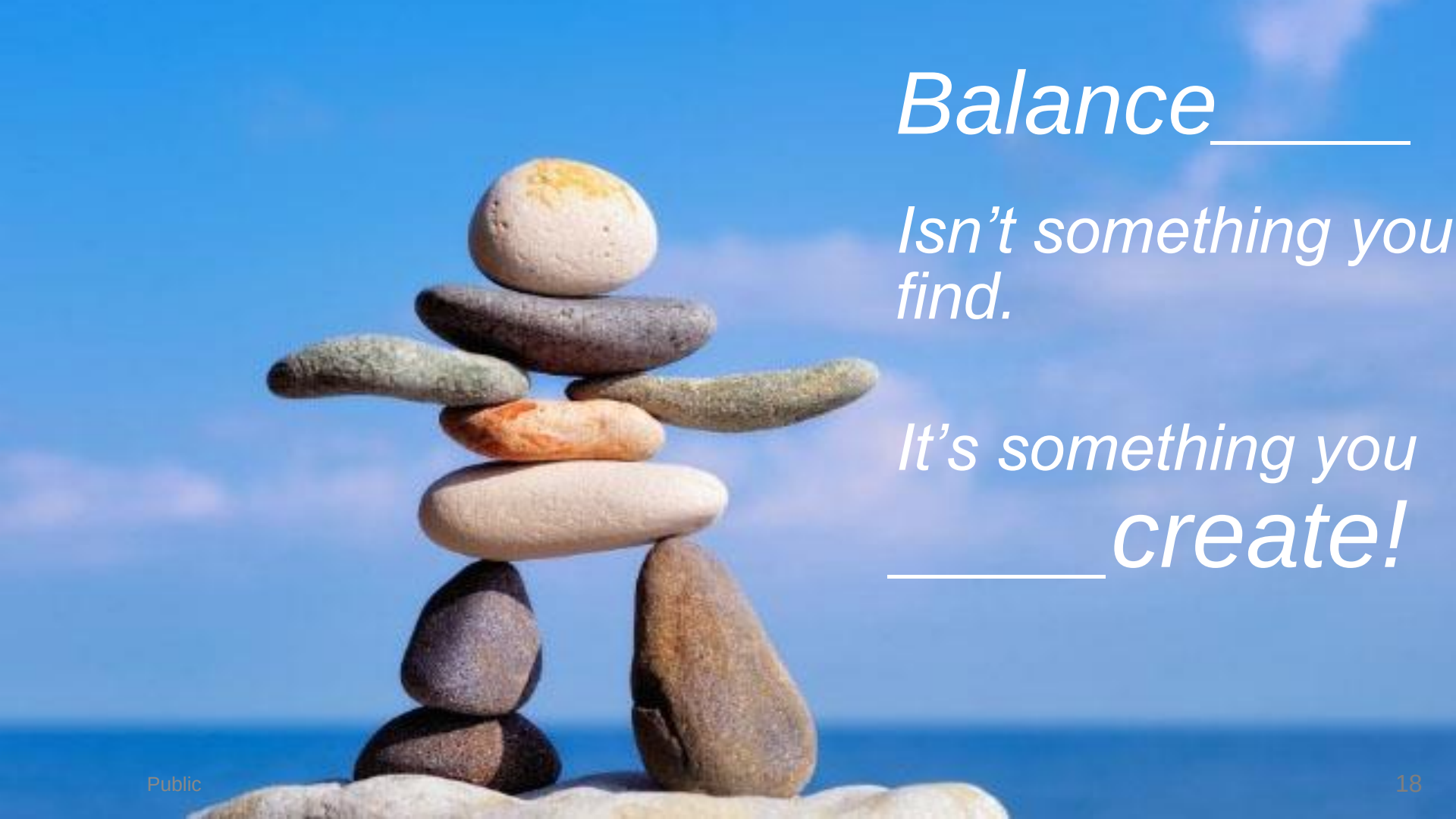
Acceptable increase in Fuel Consumption (bsfc)



Fuel consumption was on par with the baseline.

Key takeaways

- Proposed Calibration provides significant Smoke Reduction while maintaining other emissions at current levels and having minimal impact on fuel consumption.
- Analytical calibration toolkit has been developed using **MATLAB, Statistics and Machine Learning toolbox, Optimization Toolbox, Parallel Computing Toolbox**.
  - MATLAB and its products integrate computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation.
- The toolkit is deployed as an executable using **MATLAB compiler**.
  - When deployed as an standalone executable, the toolkit relies on the MATLAB Runtime, which enables users to run compiled MATLAB applications without installing MATLAB.
  - MATLAB Compiler enables to run multiple instances of code without acquiring additional licenses.
- MATLAB documentation and support from MathWorks engineers is excellent.
- This method has been very successful in optimizing engine performance calibrations.


Balance
Isn’t something you find.
It’s something you create!

Q+A

Cummins