

2020 MathWorks 中国汽车年会

国六车辆的预测性健康检查 ——数字孪生的产品化落地

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THE POWER OF CUMMINS

- The world's largest independent engine manufacturer, founded in 1919
- 23Bil USD revenue in 2018
- Global manufacturing & distribution in 190+ countries and territory, with over 60,000 employees
- China business started in 1975. 30+ manufacturing & distribution locations with over 10,000 China employees



DIGITAL TO ENABLE CUMMINS TRANSFORMATION

Cummins is not just an engine company...

Cummins is a technology company with a broad range of power solutions

Cummins digital mandate:

We will leverage Digital technologies to transform customers' experience with Cummins products & services.

- Smart device
- Connected solutions
- Big Data driven operations

什么是预测性健康检查

预测性健康检查是数字孪生产品生命周期管理中的重要技术。

什么是预测性健康检查？

- 一种预测技术
- 数据驱动
- 基于机器学习模型
- 差异化/定制化服务战略



为什么选 MATLAB?



数据处理

- **MATLAB 基础信号处理** 为我们带来更多挖掘数据价值的机会，提高工作效率，开发数据科学相关产品。



机理模型

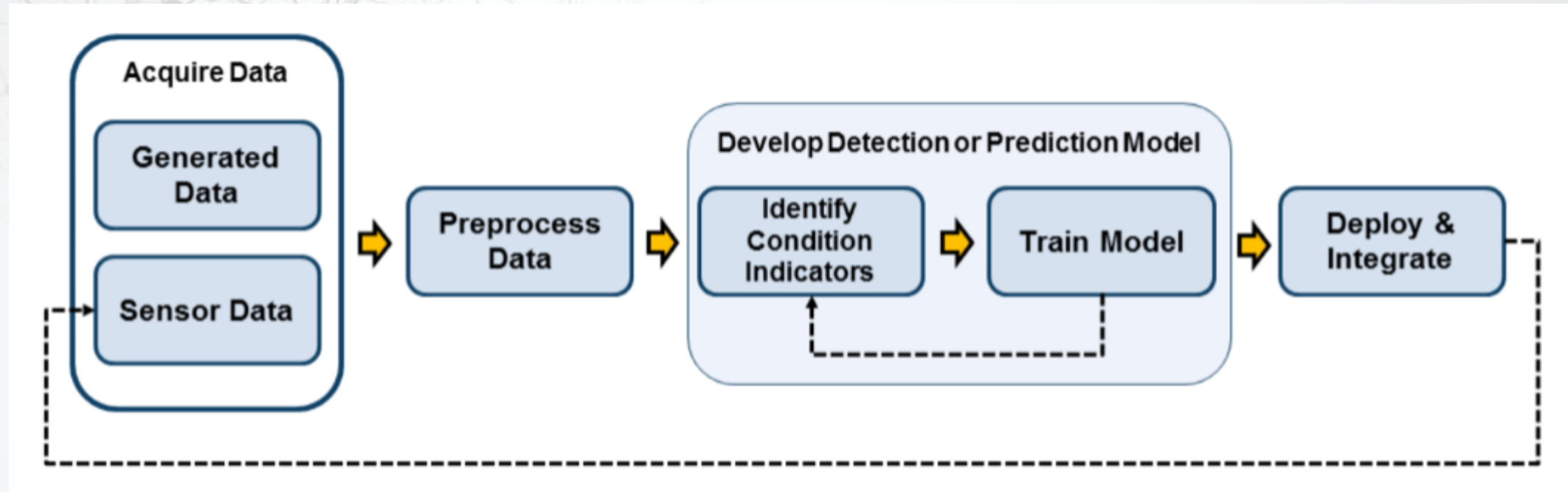
- **Simulink** 帮助将原理模型和机器学习耦合在一起，包括建立调优数据集，在线实时运行。



机器学习

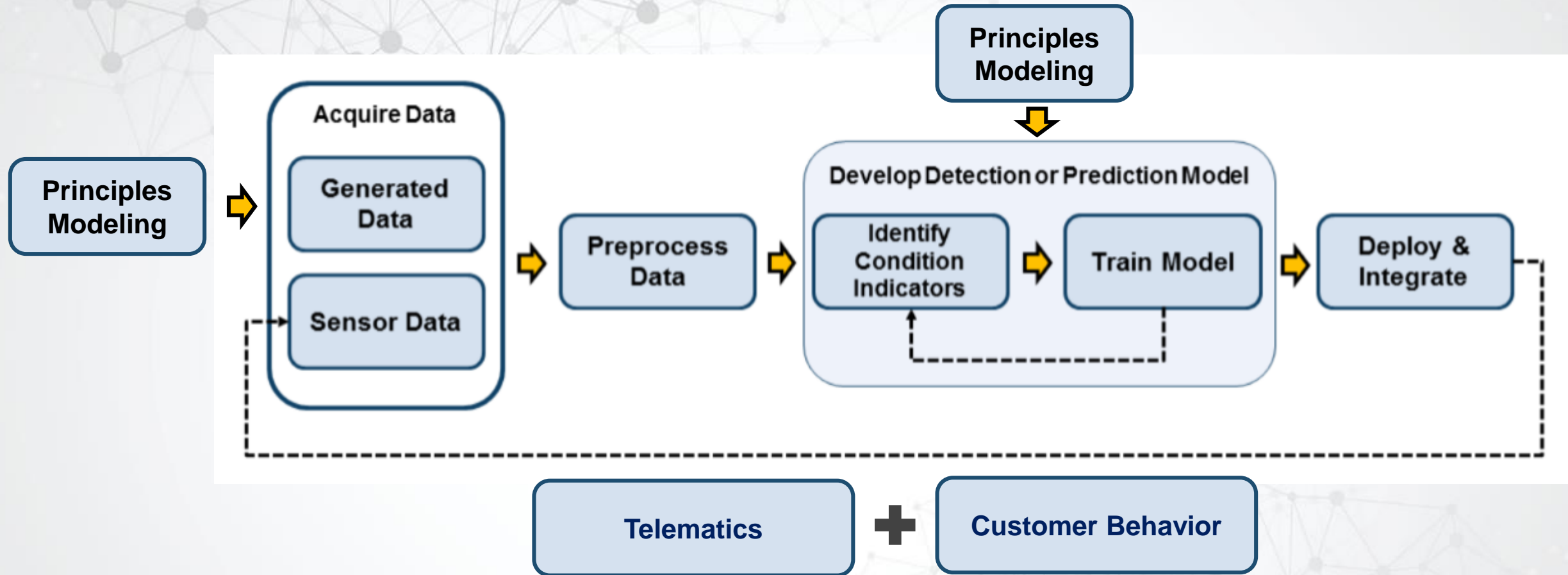
- **MATLAB Statistics and Machine Learning Toolbox** 加快了模型选择处理的速度。

概念 - 基于模型的预测



* Overcoming Four Common Obstacles to Predictive Maintenance with MATLAB and Simulink White Paper

概念 - 基于模型的预测



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基于Simulink使用DFEMA和机理建模

- 根据DFEMA和服务数据估计发动机相关故障模式。
- 以原理建模为基础，建立提案产品的模型。
- 运行原理模型与控制模型收集数据
- 利用故障数据、历史测试数据和模拟数据来调整数据科学模型。

DFEMA

Potential Failure Mode

Interface Agreement

Engine/ATS Design

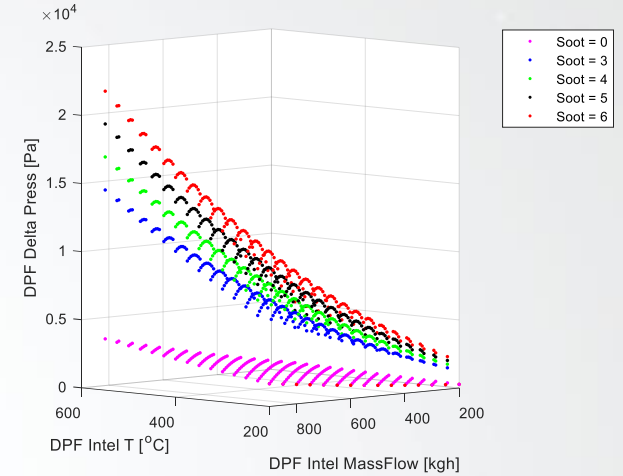
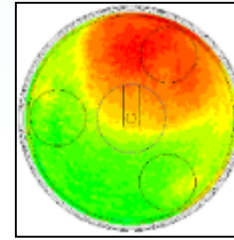
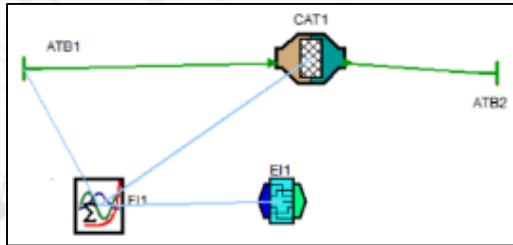
Principles Modeling



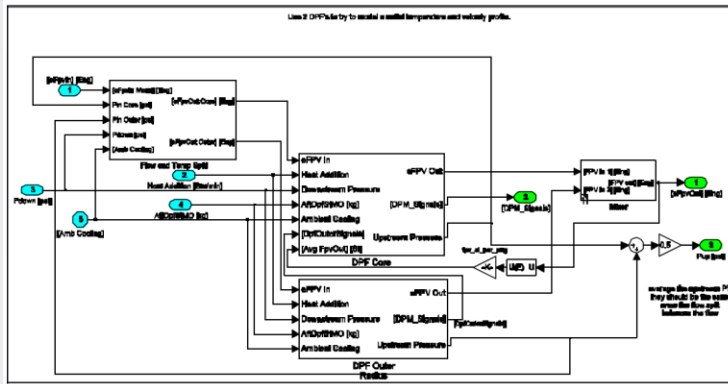
Simulation Data for Failure Mode

MATLAB&Simulink为基础 使用DFEMA和原理建模

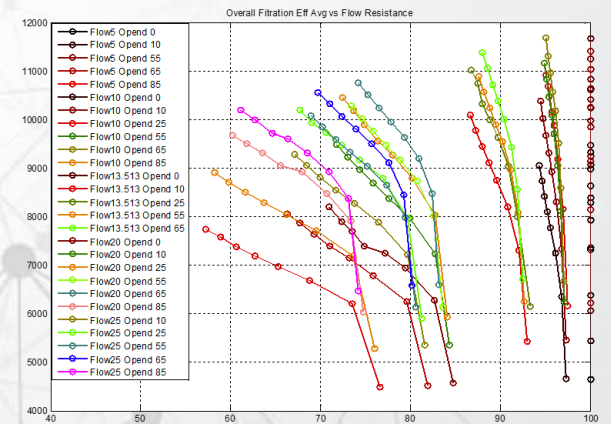
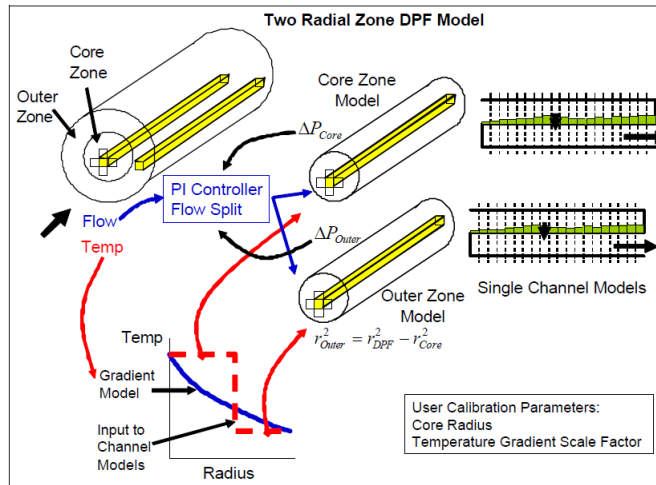
0D & 1D & 3D Coupling Simulation



Simulink Platform



Failure Simulation for Parallel Zone Model



特征工程 - MATLAB信号分析

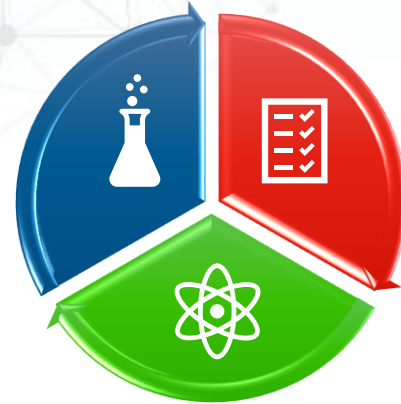
Porous Media Princely Formula – Ergun

$$\frac{\Delta P}{L} = \frac{150(1-\varepsilon)^2}{d^2 \varepsilon^3} \mu u + \frac{7(1-\varepsilon)}{4d \varepsilon^3} \rho u^2$$

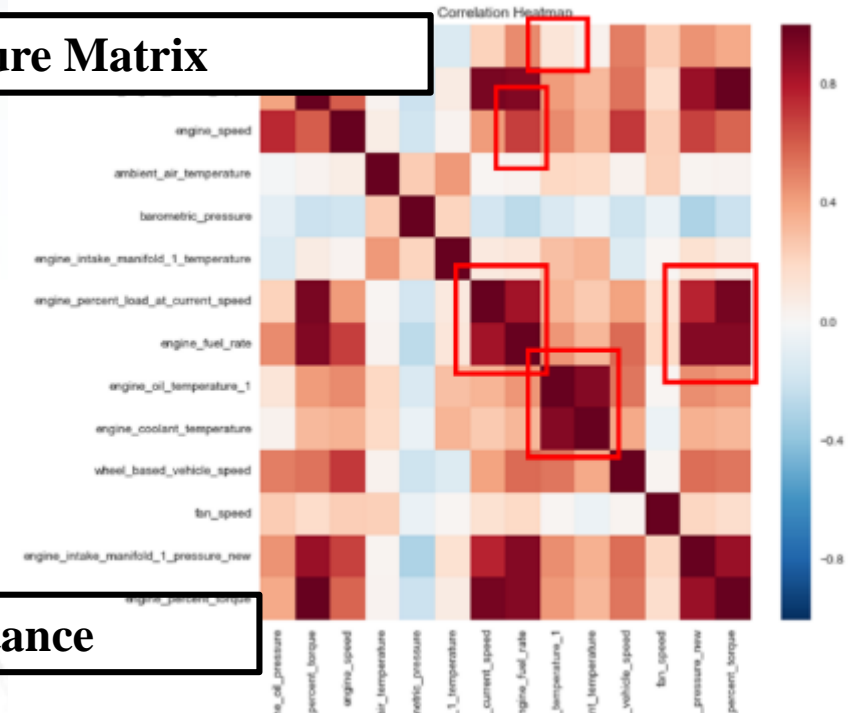
$$u = \frac{Q}{\rho A} = \frac{4Q}{\rho \pi d_c^2}$$

$$\frac{\mu}{\mu_0} = \left(\frac{T}{288.15}\right)^{1.5} \frac{288.15 + B}{T + B} \quad \text{Air } B=110.4 \text{ K}$$

$$\Delta P = L \left(\frac{600(1-\varepsilon)^2}{\rho \pi d^2 d_c^2} \mu Q + \frac{28(1-\varepsilon)}{\rho d \varepsilon^3 \pi^2 d_c^4} Q^2 \right)$$

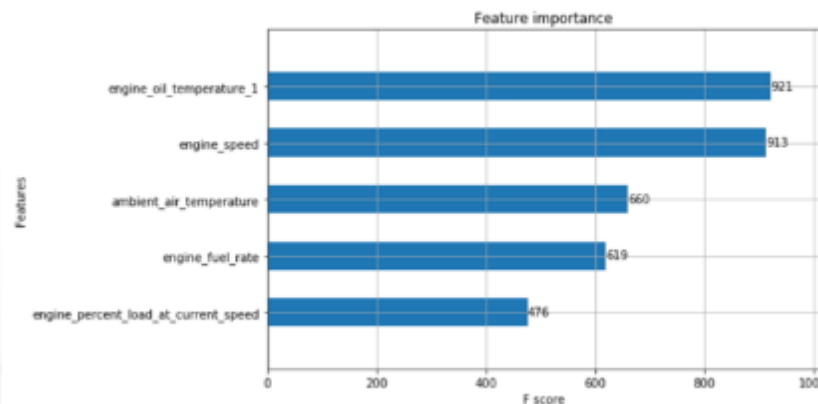


Feature Matrix



Feature Importance

MSE: 78.8213398817

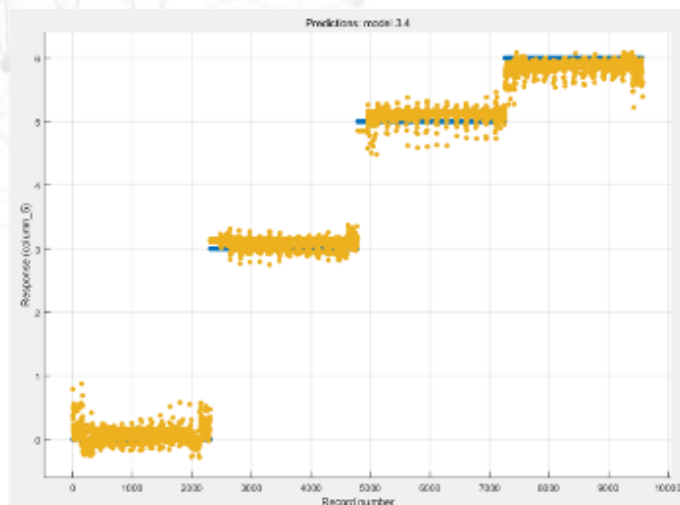


模型开发 - MATLAB机器学习

模型选择

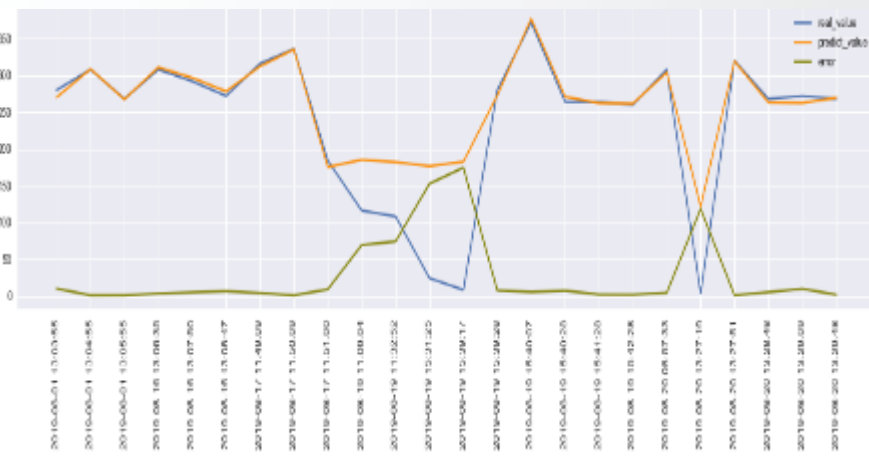
1.1 ☆ Linear Regression	RMSE: 1.0481
Last change: Linear	4/4 features
1.2 ☆ Linear Regression	RMSE: 0.70358
Last change: Interactions Linear	4/4 features
1.3 ☆ Linear Regression	RMSE: 1.0519
Last change: Robust Linear	4/4 features
1.4 ☆ Stepwise Linear Regression	RMSE: 0.70374
Last change: Stepwise Linear	4/4 features
2.1 ☆ Tree	RMSE: 0.44211
Last change: Fine Tree	4/4 features
2.2 ☆ Tree	RMSE: 0.49469
Last change: Medium Tree	4/4 features
2.3 ☆ Tree	RMSE: 0.63141
Last change: Coarse Tree	4/4 features
3.1 ☆ SVM	RMSE: 1.0776
Last change: Linear SVM	4/4 features
3.2 ☆ SVM	RMSE: 0.52299
Last change: Quadratic SVM	4/4 features
3.3 ☆ SVM	RMSE: 0.21815
Last change: Cubic SVM	4/4 features
3.4 ☆ SVM	RMSE: 0.14358
Last change: Fine Gaussian SVM	4/4 features
3.5 ☆ SVM	RMSE: 0.14431
Last change: Medium Gaussian SVM	4/4 features
3.6 ☆ SVM	RMSE: 0.49512
Last change: Coarse Gaussian SVM	4/4 features

模型校验



MATLAB的工具包 在模型选择方面加速了过程。

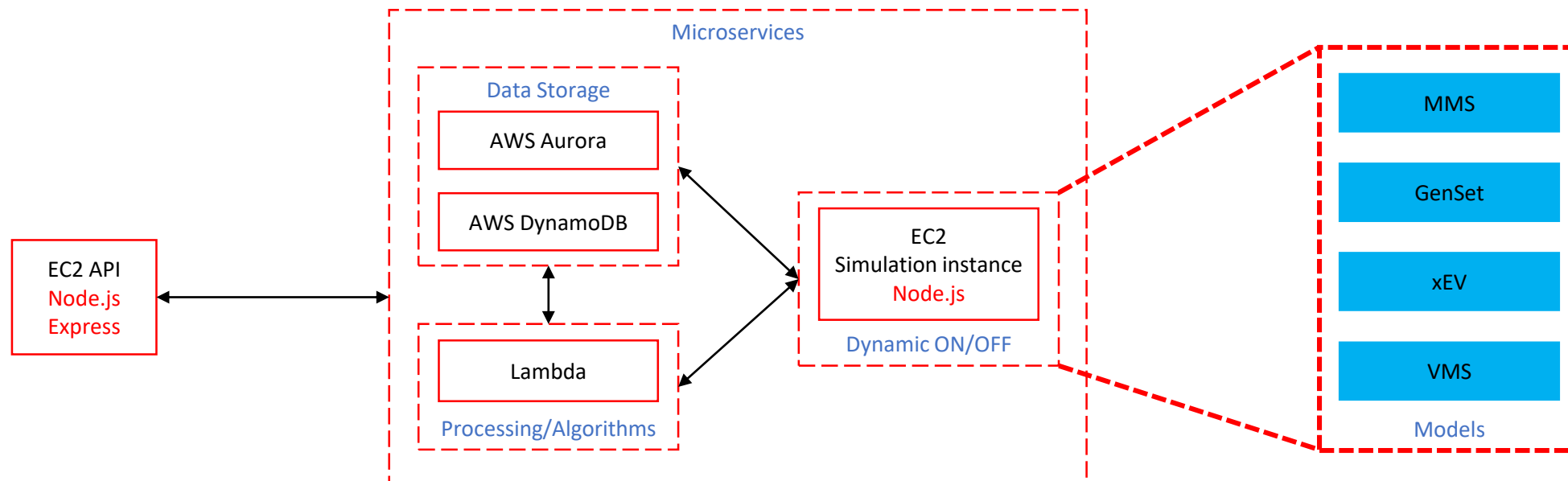
模型验证



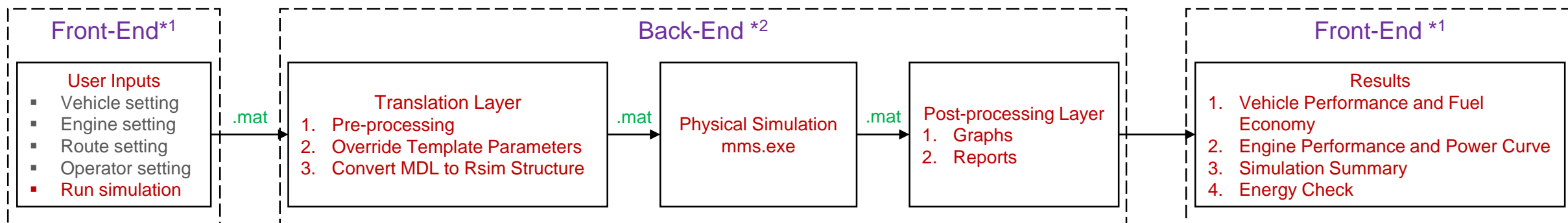
基于失效数据，建立云端数学模型。

云端仿真

微服务



云端仿真模型



模型运算结果展示

Machine Mission Simulation

Run Email Me

Settings

Vehicle Engine Route Operator

Select Vehicle: 830C Select Parastic: parastc_HC3_Seltest Select Gen LA: 3300R_1800rpm_5tpc

Vehicle

Empty Mass [kg] 164200 Payload [kg] 221648

Gross Weight [kg]: 385848.0


Height [m]: 6.88

Width [m]: 7.32

Frontal Area [m²]: 45.32544

Aero Drag Coefficient 0

Motor Parameter Value



Machine Mission Simulation

Run Email Me

Settings

Vehicle Engine Route Operator

Select Engine: Q960_F86791

Engine

Compression ratio: 14.5:1 Bore: 6.26 in (159 mm)

Fuel system: Cummins HCRS Stroke: 7.48 in (190 mm)

Emission certification: U.S. EPA Tier 2 Displacement: 3661 in³ (60 L)

Aspiration: Turbocharged and Aftercooled Number of cylinders: 16.0

Engine Torque Curve



Machine Mission Simulation

Run Email Me

Settings


Vehicle Engine Route Operator

Select Route: HC3_Seg_RouteData_PPT Select Traffic: single_vehicle

Loading/Dropping

Parameter	Value
Loading Time [s]	240
Dropping Time [s]	150

Route



Machine Mission Simulation

Run Email Me

Settings

Vehicle Engine Route Operator

Select Operator: Mtd

Operator

Max Acceleration [m/s²] 5

Max Deceleration (loaded) [m/s²] -1.35

Max Deceleration (unloaded) [m/s²] -1.35

Max Acceleration [m/s²] 5

Max Deceleration (loaded) [m/s²] -1.35

Max Deceleration (unloaded) [m/s²] -1.35

Machine Mission Simulation

Run Email Me Download

Settings

Vehicle Engine Route Operator

Graphs Summary

Vehicle Performance and Fuel Economy



Machine Mission Simulation

Run Email Me Download

Settings

Vehicle Engine Route Operator

Graphs Summary

Simulation Result

Parameter	Unit	Value
Route Length	km	6.334
Average Vehicle Speed	kph	43.126
Max Vehicle Speed	kph	65.180
Number of Stops	-	5
Total Idle Time	s	10.1
Total Running Time	s	520.7
Average Engine Speed	rpm	1467.40
Average Engine Power	hp	1233.663
Average Motor Power	hp	5133.287
Average Generator Power	hp	6062.07
Fuel consumption	[Gal]	13.624
Engine BTE	[%]	39.895
Gen Efficiency	[%]	100
Net Efficiency_Tot	[%]	79.57

CHALLENGES AND REFLECTION

1

Data Availability

- Data engineering capability
- Enterprise data lake

2

Value Creation

- Value engineering capability
- Business ownership
- Change management

3

Talent Pipeline

- Prepare for competition
- Inclusive and diversity

Demanding that everything we do leads to a cleaner,
healthier, safer environment.

我们致力于构建一个更清洁、更健康、更安全的环境

Thank You!
谢谢!

Email: Seth.S.Sun@hotmail.com

Q+A