Model Based Calibration Optimization Using Machine Learning Algorithms

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Shehan Haputhanthri and Shuzhen Liu

Electrified Powertrain Engineering (EPE)

Ford Motor Company

Outline

Part I : Introduction
Part II : Infrastructure and Process Development
Part III : Example Study

Outline

Part I : Introduction

Calibration Optimization Efficiency

Manual powertrain calibration optimization

- Requires hardware prototypes
- Substantial cost
- Engineering (design validation) time

Design Validation (DV) efficiency improvement

- Use high fidelity CAE powertrain models (Simulink) for initial calibration
- Optimized combination of design variables
- Reduce prototype vehicles and engineering time
- Explore designs which would otherwise not be possible

Calibration Optimization of Electrified Powertrains

Electrified vehicles

- Complex hardware architecture and software controls
- 1000s of design (calibration) variables

Finding the optimum design

- Millions of design combinations
- Higher computation time for high fidelity Simulink SIL models
- Substantial amount of computing resources
- Cluster/ parallel computing for simulation
- Machine learning (Genetic Algorithm) for optimization
- 100s (even 1000s) of designs to run in parallel

Parallalization, Licenses and Scalability

Parallel computing

- Running 100s/1000s of designs in parallel
- Not cost effective with standalone licenses

Parallel/distributed computing licenses for MATLAB & Simulink

- Parallel Computing Toolbox (PCT)
- MATLAB Distributed Computing Server (MDCS)

Scalable parallel/distributed computing

- Final solution test in workstations (before deployed to HPC)
- HPC utilization for computation
  - With varying number of workers
- Scalable from sequential to 100s CPUs in parallel

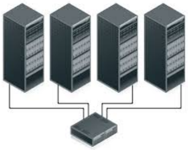
Outline

Part II : Infrastructure and Process Development

Distributed Computing Capability

Distributed Computing

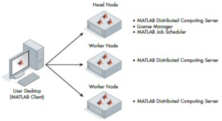
HPC
Ford Internal



Online Clusters
Pay per Use

amazon web services™ EC2

Local Cluster (Unused CPUs)
MATLAB DCS/Other SW



Cost Effective Parallel/Distributed Computing Licenses

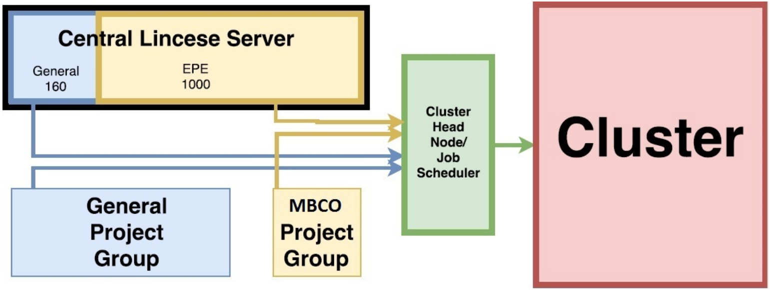
Model Based Calibration Optimization (MBCO) team

Purchased 1000 MDCS licenses

Added to existing PCT/MDCS license pool

Dedicated "Project Group"

For license management



Machine Learning Algorithms for Optimization

Need of machine learning algorithms

- All design possibilities can't be evaluated
  - With in the simulation budget and available time
- Change calibration variables
- Optimize for multi-objectives
- Subjected to multi-constraints

Alternatives evaluating (in-progress)

- No "all-in-one" solution algorithm
- MATLAB Global Optimization Toolbox
- modeFrontier
- Several other commercial optimization SW packages

Currently modeFrontier is used as the optimization tool

- Compatibility with non MathWorks SW tools
- Off the shelf optimization algorithms

Optimization SW packages and Large Scale Parallelization

"Off the shelf" optimization SW packages - Issues

- Parallel jobs are launched using internal schedulers
- Individual job submitted to cluster
- Uses standalone license
- Do not use PCT and MDCS for MATLAB & Simulink
- Not suitable for large scale parallel computing

Final Requirements and Solution

Combining modeFrontier and MATLAB

- MATLAB - Capable of parallelization to any scale
- modeFrontier - License issue
- Simulations to run in HPC

Must use distributed computing licenses

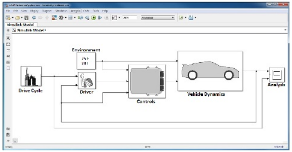
- PCT and MDCS
- Jobs submitted to HPC from a remote MATLAB Client

New in-house tool and a process developed

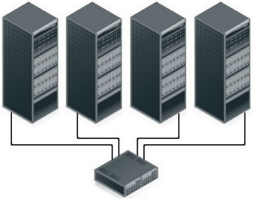
- MATLAB GUI - ModefrontierSCVSP
- Copyrighted
- Combines modeFrontier and MATLAB & Simulink
- Meets above requirements

Challenge - 4 Unconnected Dots

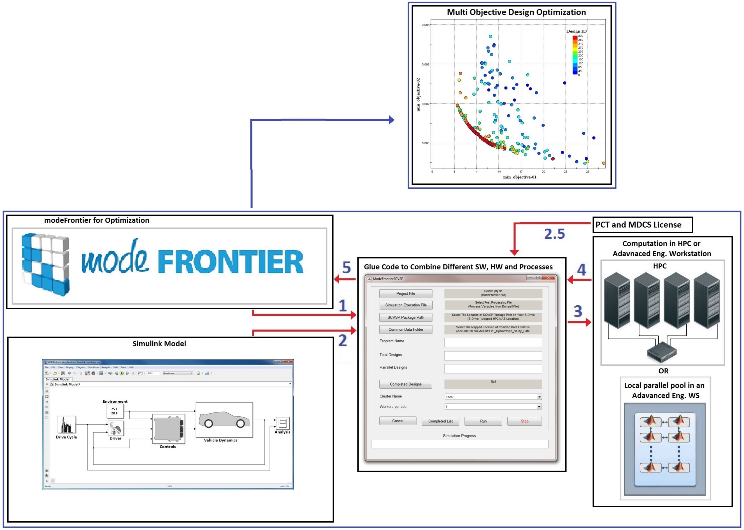
modeFRONTIER



License Usage
PCT and MDCS



Connecting Dots via a MATLAB GUI - ModefrontierSCVSP



1. Genetic algorithm
2. Model + cal file
2.5 License mgt.
3. Job submission
4. Results collection
5. Results reporting

ModefrontierSCVSP - Standardized Modular Solution

MATLAB GUI - Glue Code

- Combines HW, SW and Licenses seamlessly
- Across both Windows and Linux platforms
- Uses PCT/MDCS
- Manages the large scale Simulink simulations

Modular (runs simulations in)

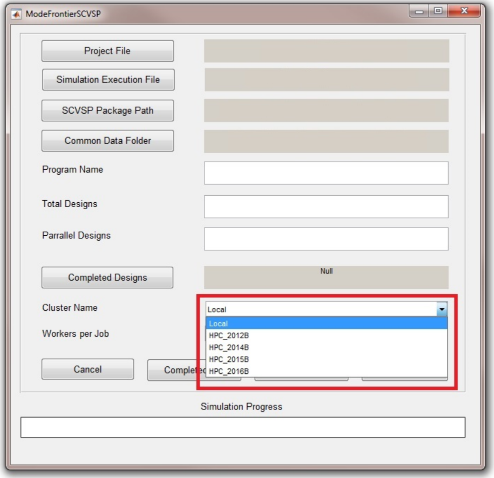
- In workstation with PCT (limited by physical cores)
- HPC with MDCS (limited by MDCS licenses)

User friendly GUI

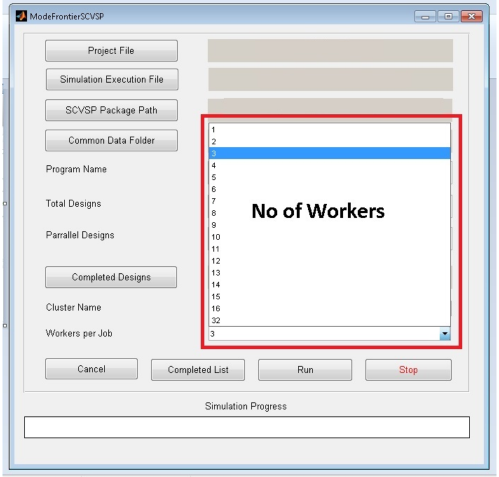
- No coding/programming required
- Easy to train, learn and apply

ModefrontierSCVSP - Standardized Modular Solution

Select to run in local workstation or HPC



Select the number of cores to run



Possibilities With the New Tool

Scalabale parallel/distributed computing

- Sequential computing(1 CPU) to parallel in HPC (1000 CPUs)
- Click of a button
- 12000 Simulink simulations (4000-6000 hours)
- Completed in less than 15 hours (approx.)
- Using 512 simulations in parallel

modeFrontier combined with MATLAB & Simulink

- Machine learning algorithms
- Design of Experiments (DoE)
- Scheduling (Genetic Algorithms)
- Multi-objectives (+ multi-constraints) optimization
- Selected 12000 out of 1000000+ design combinations

Deployed and used by the MBCO team

Outline

Part III : Example Study

Optimizing Vehicle Attributes with Battery Power Table

Battery power table

Optimum power - different conditions

f(Driver Pwr, Bat. SOC)

Linked attributes

Fuel Economy/Emissions

Performance/Regeneration/NVH etc.

modeFrontier - machine learning

Optimize battery power table*

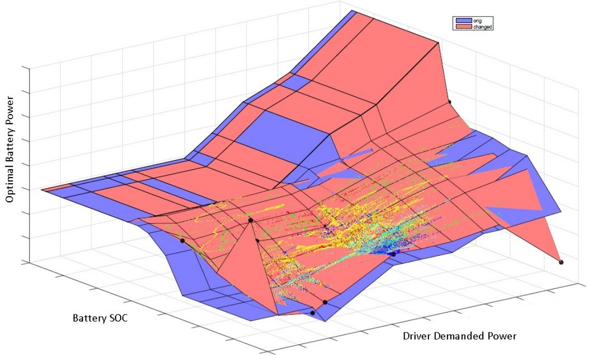
Using *Genetic Algorithms (MOGA-II)*

Evolutionary (generation) algorithm

Simulation in HPC

512 in parallel

Population size



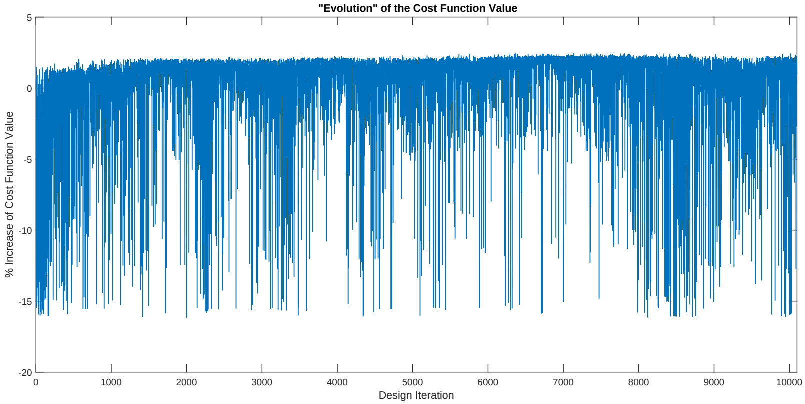
*Indirect method used - Non Uniform Rational Basis Spline (NURBS) based

*Developed by Ford Model Based Systems Engineering (MBSE) team (@ RIC)

Optimizing Vehicle Attributes with Battery Power Table*

Cost function - maximize vehicle attribute(s) mentioned above

Single objective optimization**



*Exact details not shared due to confidentiality
*Not validated with prototypes yet
**Unfeasible/error designs excluded

Acknowledgments

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Thank You!!!