Accelerating the Evaluation and Market Introduction of Advanced Technologies Through Model Based System Engineering

2014 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review
June 16th, 2014

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Project ID # VSS139
### Project Overview

#### Timeline
- Start – October 2014
- End – September 2014 (Maintenance)
- – September 2015 (MBSE)
- 50% Complete

#### Barriers
- Bring technologies to market faster
- Accelerate technology evaluation
- Support requirements definition

#### Budget
- **Total Project Funding (DOE)**
  - Autonomie Maintenance: $300k
  - MBSE Enhancements: $200k

#### Partners
- General Motors
- LMS/Siemens (AMESim)
- MathWorks
- Expert Tool Companies (Gamma Technology, Mechanical Simulation, ChiasTek, Esse)
- National Labs (NREL, ORNL)
- Argonne (MCS & CSE divisions)
Autonomie is used by a very large number of VTO projects to define R&D targets, evaluate the benefits of advanced technologies at a vehicle system level, provide R&D guidance...

- Examples of projects related to Autonomie
  - Projects using Autonomie to perform studies include VSS048, VSS127, VSS128, VSS133, VSS139, VSS140, VSS141, VAN008, ACE011...
  - Projects using Autonomie results include VAN001, VAN002, VAN005, VAN006, VAN012, VAN014...
  - Projects feeding Autonomie include VSS001, VSS020, VSS030, VSS031, VSS097, ST001, ST100, APE006, ES189, FC017, FC018...
  - Autonomie is also used by Gate Programs (TI020, TI023, TI024)
Due to its large user base (>160 companies worldwide), Autonomie contributes to accelerate the market introduction of new technologies.

Example: Production control development at GM

“Autonomie is a fundamental game changer for math-based design, development and engineering of automotive systems and controls”, Mike Steele, Manager, Controls Modeling and Architecture at GM

*(1) Source – GM – LMS Vehicle Conference 2012*
Milestones

**Autonomie Release Cycle**
- Rev 13 SP1 Development
- Rev 13 SP1 Test & Release
- Rev 14 Phase 1
- Rev 14 Phase 2
- Rev 14 Test & Release

**MBSE Enhancements**
- Design
- GUI Enhancements
- Framework Enhancements
- Matlab Enhancements

Current Status
Approach

Use Virtual Engineering Approach to Accelerate the Vehicle Development Process

Problem:
- Heavy reliance on hardware leads to high cost and longer development time
- Integration of new technologies in a system lowers its expected benefit

Result:
Wasted Opportunities, Time, and Resources (People & $)

Solution:
OEMs are moving towards an increasing reliance on modeling to accelerate the introduction of advanced technologies

DOE is leading the way with the development of Autonomie
Approach
Gather Requirements from Autonomie User Community to Prioritize Development

User Community
- National Laboratories
- Universities,
- OEMs,
- Suppliers,
- Research Institutions,
- Other Gov Agencies...

DOE VTO R&D (i.e. autonomous vehicles)

Enhancements & New Features

Conferences, Papers

Development Prioritization
**Approach**

*Autonomie Workflow Enhancement to Enable Larger MBSE Use*

**Current Flow**

- Model Selection → Process Selection → Generic analysis

Issues: not all processes require models, some processes require multiple models, not all processes require the same analysis...

**Future Flow**

- Process Selection → Model, vehicle Selection – or no selection at all → Analysis selected according to study

Benefit: we can now integrate processes with multiple vehicles (i.e. BaSce VTO benefits), analyze large databases (i.e. USDrive Requirement study), additional DOE VTO tools (i.e. BatPac, GREET, MA3T...)**
Technical Accomplishments
Main New Features

- **Models**
  - New powertrain configurations (i.e., Honda 2 Motor, hydraulic hybrids)
  - New component models (i.e., dual clutch transmission)
  - New controllers (i.e., shifting algorithm for advanced transmissions)
  - Support for Matlab .slx files (R2012a and up)

- **Tool Integration**
  - Link to Functional Mock-up Interface (FMI) standard
  - Link with ANL battery cost model (BatPac)
  - New multi-objective optimization algorithm (POUNDERER)
  - Improved CosiMate support

- **Software**
  - Improved import process based on OEMs feedback
  - In-GUI display and edit of HTML reports
  - New Autonomie help using Microsoft-style format
Technical Accomplishments

Functional Mock-up Interface (FMI) Standard Integration

- Allow medium and high fidelity component models developed within VTO to be shared amongst researchers while protecting IP
- “Functional Mock-up Interface (FMI) is a tool independent standard to support both model exchange and co-simulation of dynamic models using a combination of xml-files and compiled C-code” (https://www.fmi-standard.org/)
- Integrate FMI into Autonomie via Modelon toolbox for Matlab

FMU

User creates a Simulink model with the FMU ME/CS S-Function to interface with the FMU file.

Autonomie

User imports model in Autonomie.
Autonomie reads information from .fmu for parameter and signal properties.
Model is ready is use.
Technical Accomplishments

Link with BatPac Provides Detailed Battery Costs

BatPac used to estimate the cost of advanced battery technologies to guide DOE VTO R&D

**Autonomie**

- Usable/Total energy
- # of cells
- SOC window
- Charge/Discharge Power
- Battery Chemistry
- Vehicle type (EV, HEV, PHEV)
- Cooling (air/liq)

**BatPaC**

- Cost
- Uncertainty (max/min)
- Power @ SOC
- Pulse duration
- Mass
- Volume
Technical Accomplishments
Multi-Objective Optimization

- New algorithms used to support VTO studies relying on multi-objectives (i.e. increase performance while decreasing fuel consumption and minimizing cost)
- Two optimization algorithms, “Pounder” and “Random Search” were developed for Autonomie by the Argonne Mathematical and Computing Sciences (MCS) division
- The generic optimization process also allows users to substitute their own optimization algorithm.
Technical Accomplishments
Accelerate Simulation Time of High Fidelity Models Through Co-Simulation

- Simulation time is critical when using multiple high fidelity models (i.e. production control development).
- To leverage MBSE benefits and accelerate the introduction of new technologies, co-simulation algorithms are critical.
- Argonne worked with several OEMs to provide a generic solution that could be used throughout the industry.

Added support for integrating Sabre models with CosiMate
Technical Accomplishments
Large Scale Simulations

- The objective is to be able to launch and analyze >100,000 individual vehicle simulations automatically through the GUI

Tasks Performed
- Decoupled framework kernel from application
- Entire user interface “use case” driven
  - No mandatory vehicle selection
  - Flexibility on type of data analysis (i.e. analyzing many simulations is different than analyzing a single simulation)
- Separated “developer” use cases from “user” use cases
  - Varying levels of complexity depending on selections, not “one size fits all”
- Better tools for editing processes
Collaboration and Coordination with Other Institutions

- **Model Providers**
  - National Labs (i.e., NREL, ORNL...)
  - Argonne (i.e., Battery group...)
  - Expert Tool Companies (i.e., LMS, Gamma Technology, Mechanical Simulation...)

- **Process Definition & Direction**
  - OEMs (i.e., General Motors, Ford...)
  - MathWorks
  - Expert Tool Companies (i.e., LMS, ChiasTek, Esse...)
  - Argonne (i.e., Math. group, HPC...)

Logos of: Argonne National Laboratory, NREL, Oak Ridge National Laboratory, GM, AMESim, Gamma Technologies, Carsim, and LMS.
Proposed Future Work

- Continue to enhance Autonomie to support DOE VTO R&D activities by gathering requirements from all users (i.e., Nat Labs, Univ, OEMs, Gov agencies...), including:
  - Expand Autonomie EcoSystem with linkages to additional expert tools (i.e., link with traffic flow tool to evaluate benefits of autonomous vehicles...)
  - Focus on large scale simulation leveraging High Performance Computing (i.e., >100,000 individual vehicle packages) and co-simulation
- Continue to provide guidance for DOE R&D activities.
- Expand Autonomie usage throughout DOE to promote Virtual Engineering approach.
Summary - ANL Will Continue to Accelerate Technology Development and Market Introduction

- Support DOE VTO R&D activities
- Support usage of Autonomie for OEMs...
- Support virtual engineering processes throughout OEMs and DOE