

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

**2014 DOE Hydrogen Program and Vehicle Technologies
Annual Merit Review**

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Sponsored by David Anderson

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U.S. Department of Energy

Energy Efficiency and Renewable Energy

Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

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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)



Relevance

VTO Benefits

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)

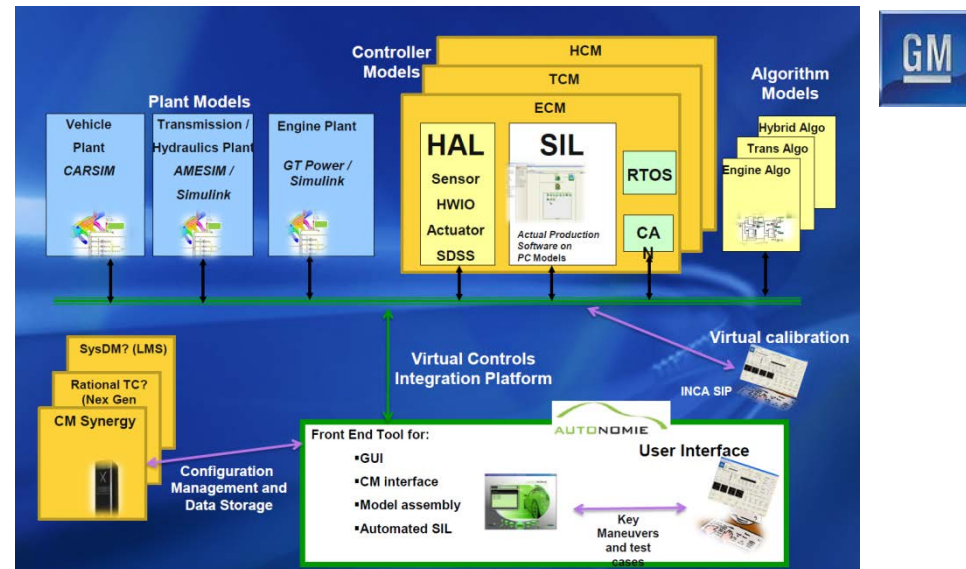
Relevance

Users Benefits

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

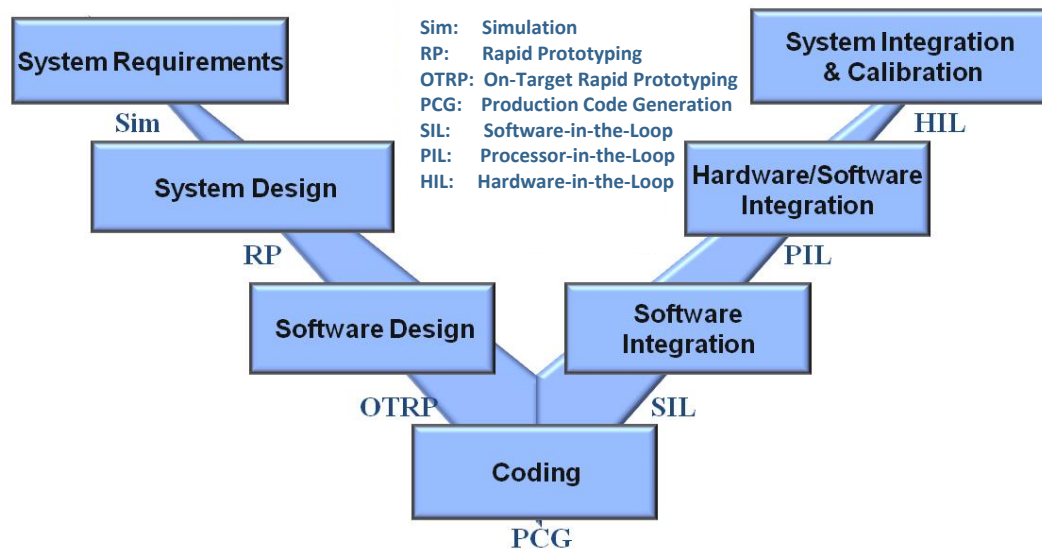
Current Status



Approach

Use Virtual Engineering Approach to Accelerate the Vehicle Development Process

Virtual Engineering Process



Solution:

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

Problem:

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

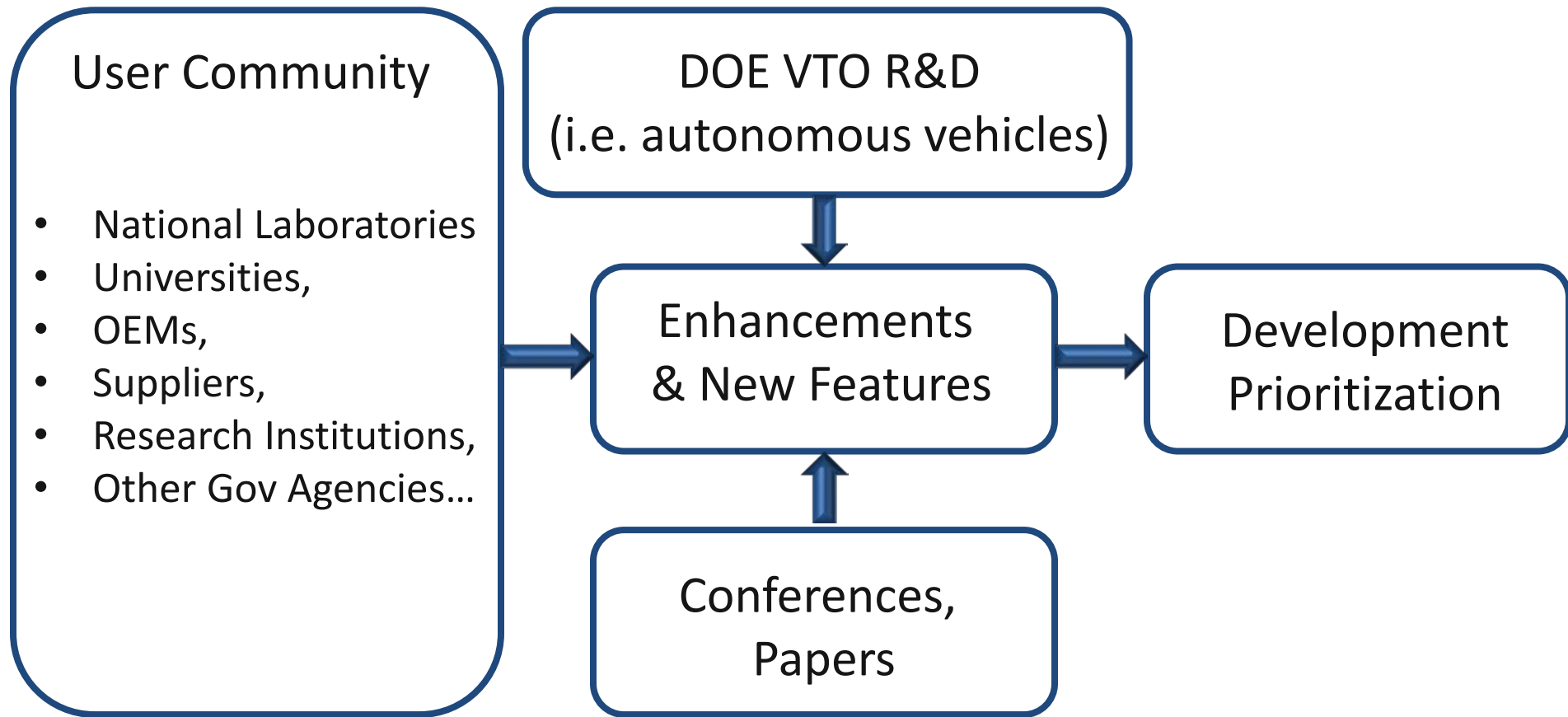
Result:

Wasted Opportunities, Time, and Resources (People & \$)

DOE is leading the way with the development of Autonomie

Approach

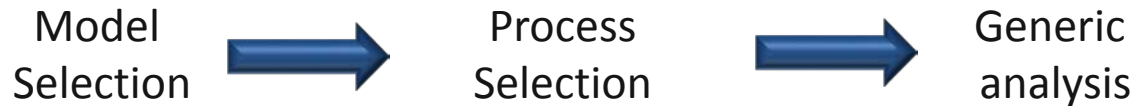
Gather Requirements from Autonomous User Community to Prioritize Development



Approach

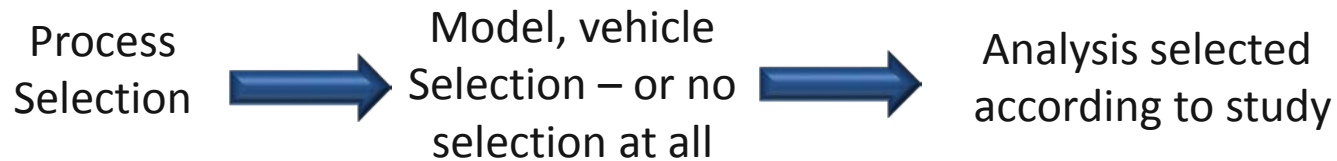
Autonomie Workflow Enhancement to Enable Larger MBSE Use

Current Flow



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

Future Flow



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

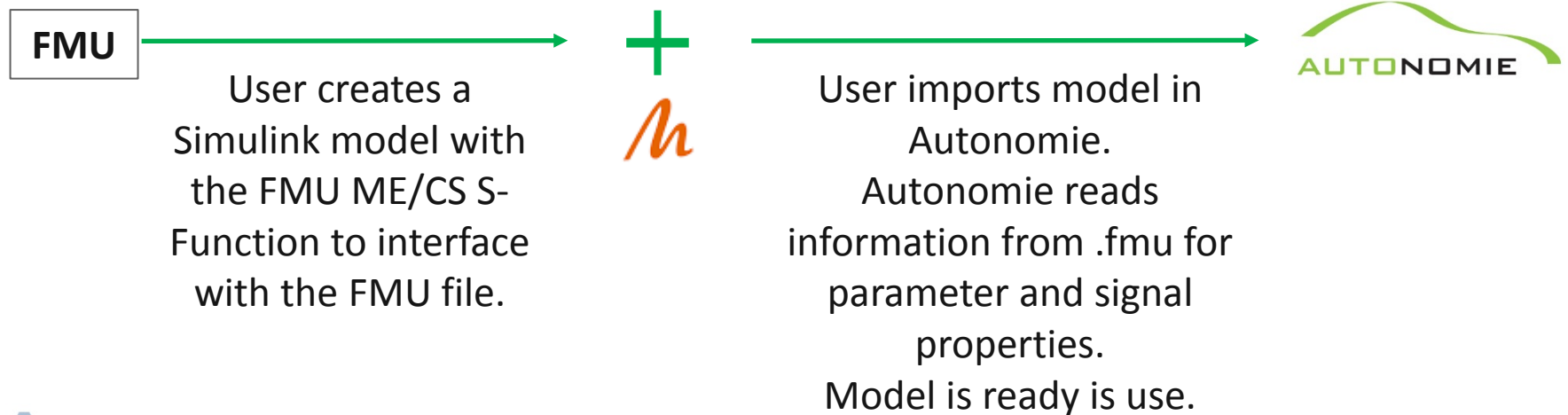
- Models
 - New powertrain configurations (i.e., Honda 2 Motor, hydraulic hybrids)
 - New component models (i.e., dual clutch transmission)
 - New controllers (i.e., shifting algorithm for advanced transmissions)
 - Support for Matlab .slx files (R2012a and up)
- Tool Integration
 - Link to Functional Mock-up Interface (FMI) standard
 - Link with ANL battery cost model (BatPac)
 - New multi-objective optimization algorithm (POUNDER)
 - 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

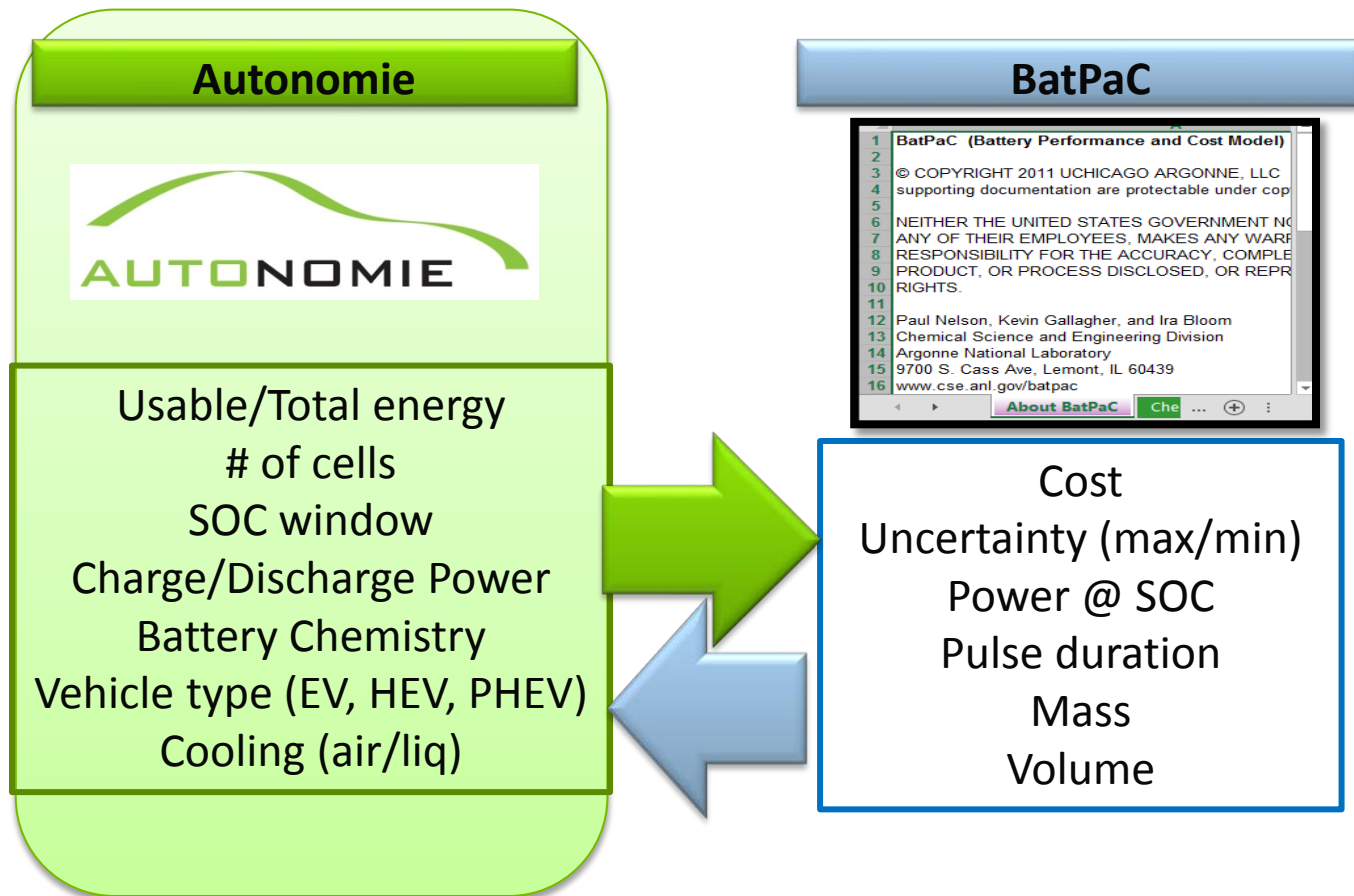
- Allow medium and high fidelity component models developed within VTO to be shared amongst researchers while protecting IP
- “Functional Mock-up Interface (FMI) is a tool independent standard to support both model exchange and co-simulation of dynamic models using a combination of xml-files and compiled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



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



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.

Define Input Variables:

1 – Select Parameters:

Variable Name:

Split SingleMode HEV 2wd Midsize

Driver

Environment

Vehicle Propulsion Controller

Vehicle Propulsion Architecture

Variable Name: (Drag and Drop Here)

Variable Name	Lower Bound	Upper Bound	Value
eng.plant.scale.pwr_max_des	80000	200000	110269.902141002
mot2.plant.scale.pwr_max_des	20000	60000	40000.5640812811
mot.plant.scale.pwr_max_des			
ess.plant.scale.pwr_max_des			
ess.plant.scale.cap_max_des			
fd.plant.init.ratio			

Define Constraints and Goals:

Variable Name:

Split SingleMode HEV 2wd Midsize

Driver

Environment

Vehicle Propulsion Controller

Vehicle Propulsion Architecture

1 – Select Non-Linear Constraints:

Variable Name: (Drag and Drop Here)

Variable Name	Lower Bo	Upper Bo
vpa.results.percent_time_trace_misse	0	0.1

2 – Select Objective:

Variable Name: (Drag and Drop Here)

Variable Name

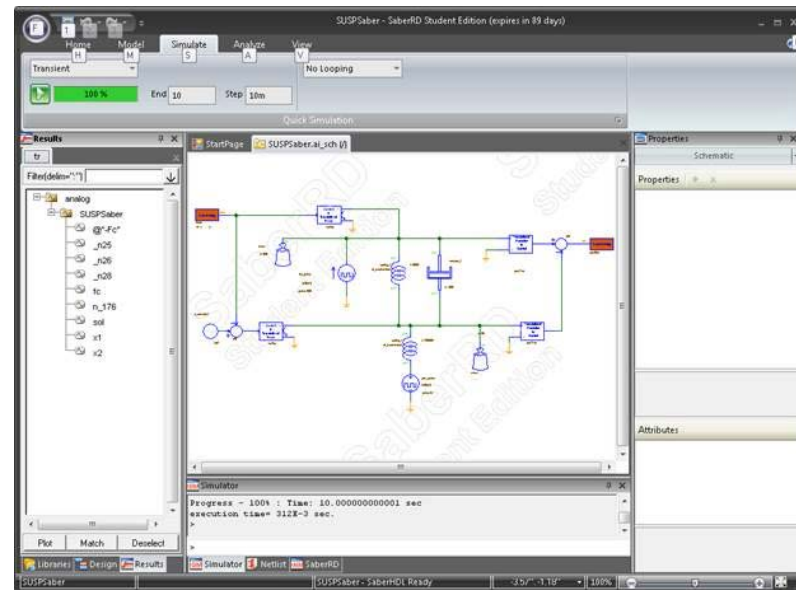
vpa.results.fuel_consumption.eng.this_fuel.total

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

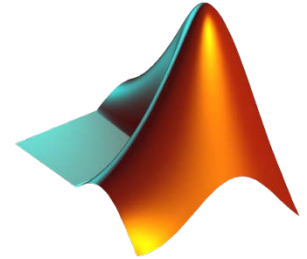
- Decoupled framework kernel from application
- Entire user interface “use case” driven
 - No mandatory vehicle selection
 - Flexibility on type of data analysis (i.e. analyzing many simulations is different than analyzing a single simulation)
- Separated “developer” use cases from “user” use cases
 - 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...)



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

