

Accelerate the Development and Introduction of Advanced Technologies Through Model Based System Engineering

**2015 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 2015 (Maintenance)
– September 2015 (MBSE)

Barriers

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

Budget

- Total Project Funding (FY15)
- Autonomie Maintenance: \$400k
 - MBSE Enhancements: \$250k

Partners

- LMS/Siemens
- MathWorks
- Third Party Tool Companies (Gamma Technology, Mechanical Simulation ChiasTek, Esse)
- OEM users (GM, Ford, Chrysler, Cummins...)
- National Labs users (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 FY14 projects related to Autonomie
 - Projects using Autonomie to perform studies include AN044, ACE011, ACE016, ACE082, FT008, FT016, VAN008, VSS048, VSS075, VSS087, VSS125, VSS127, VSS128, VSS133, VSS134, VSS140, VSS141...
 - Projects using Autonomie results include FC017, ACE022, VAN001, VAN002, VAN005, VAN012, VAN014, VSS119...
 - Projects feeding Autonomie include AN046, AEP006, VSS005, VSS030, VSS031, VSS097...
 - Autonomie is also used by Gate Programs (TI025), DOT and DOD funded activities

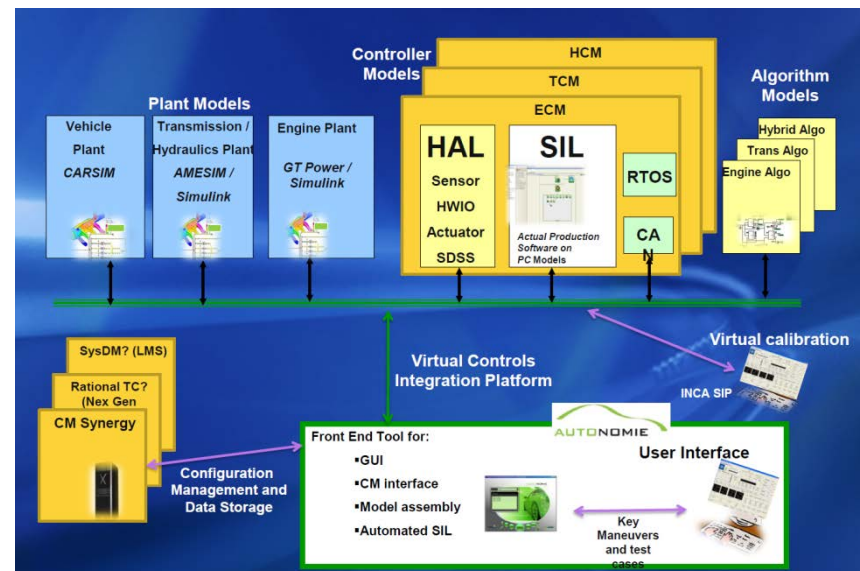
Relevance

Users Benefits

Due to its large user base (>175 companies worldwide), Autonomie contributes to accelerate the market introduction of new technologies

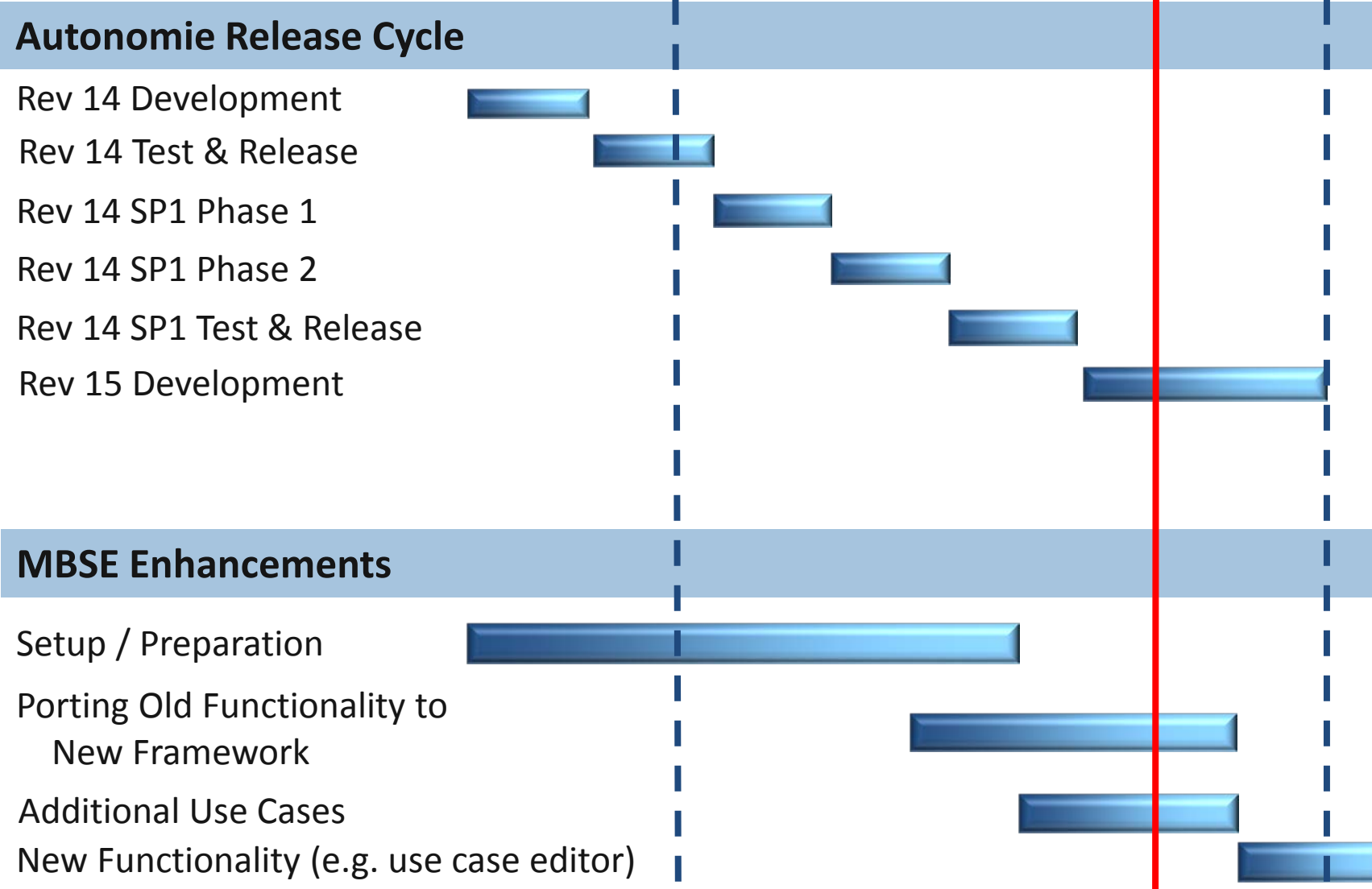
Example: Production control development at GM

“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



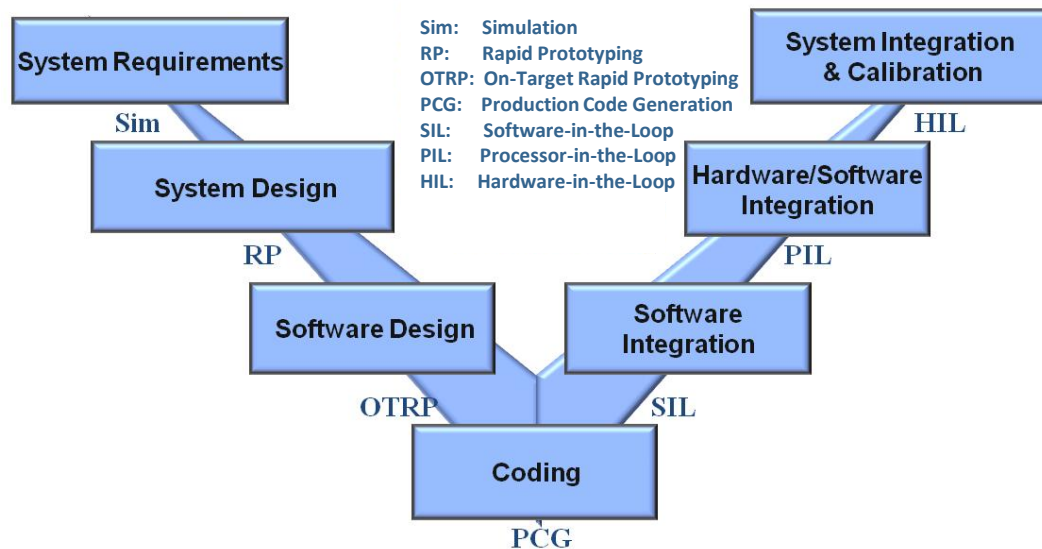
Current Status



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

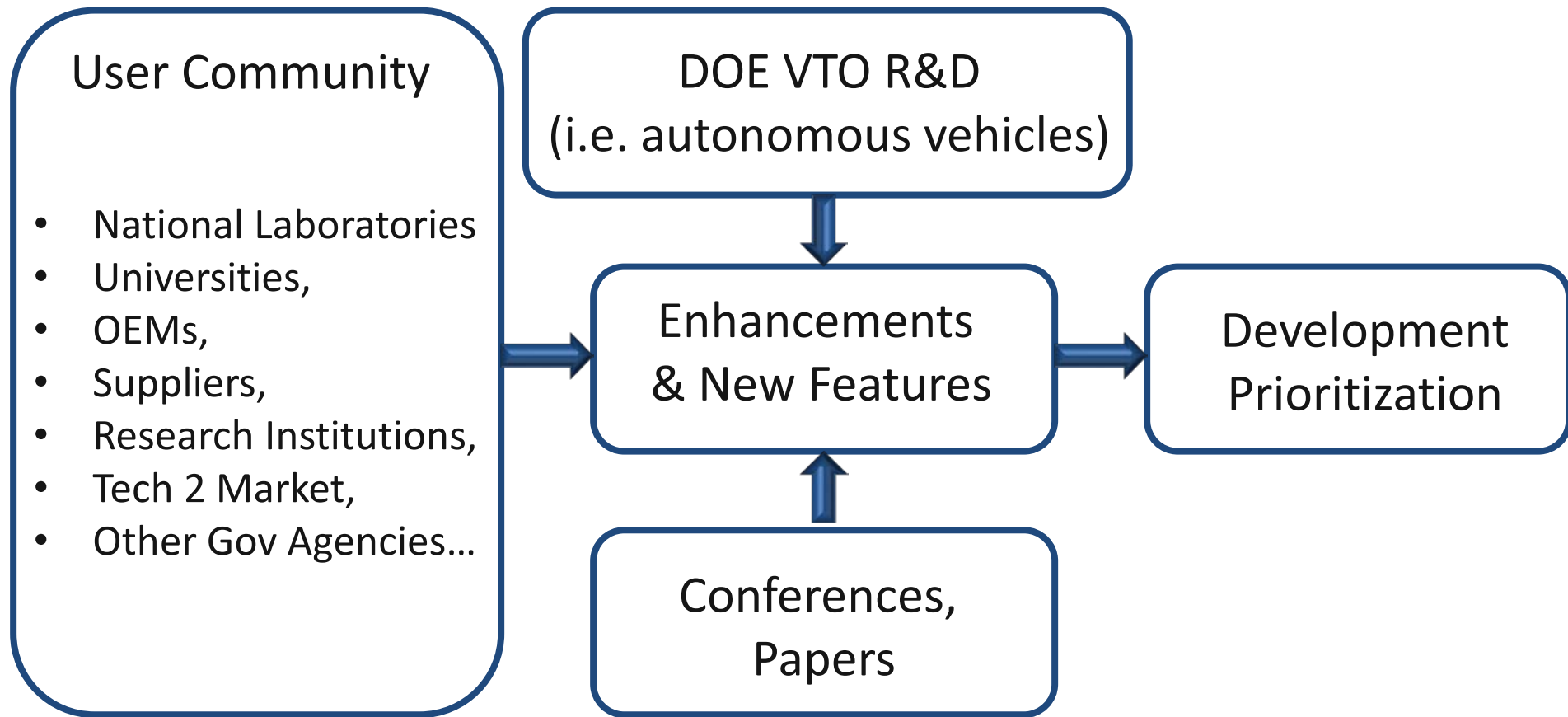
Result:

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

DOE is leading the way with the development of Autonomie

Approach

Gather Requirements from Autonomie User Community to Prioritize Development



Approach

Enhance Autonomie Workflow to Expand MBSE Usage

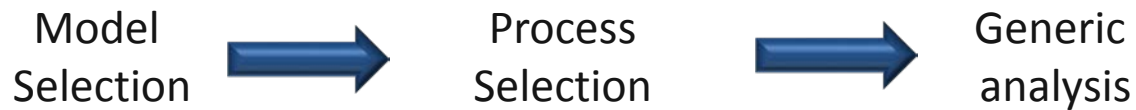
- Going forward, we're looking at how to best position Autonomie for future usage
- Two areas of focus have been identified:
 1. Large scale simulation
 2. Increase Autonomie EcoSystem by integrating additional tools
- These areas of focus are a logical extension of the on-going work
 - Integrate processes with multiple vehicles (i.e. BaSce VTO benefits),
 - Analyze large databases (i.e. USDrive requirement study),
 - Connect additional DOE VTO tools (i.e. BatPac, GREET, MA3T...)



Approach

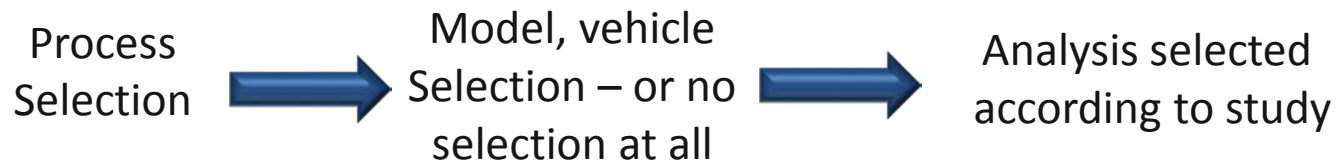
Enhance Autonomie Workflow to Expand MBSE Usage

Current Flow



Issue: this workflow is hardcoded! Not all processes require models, some processes require multiple models, not all processes require the same analysis...

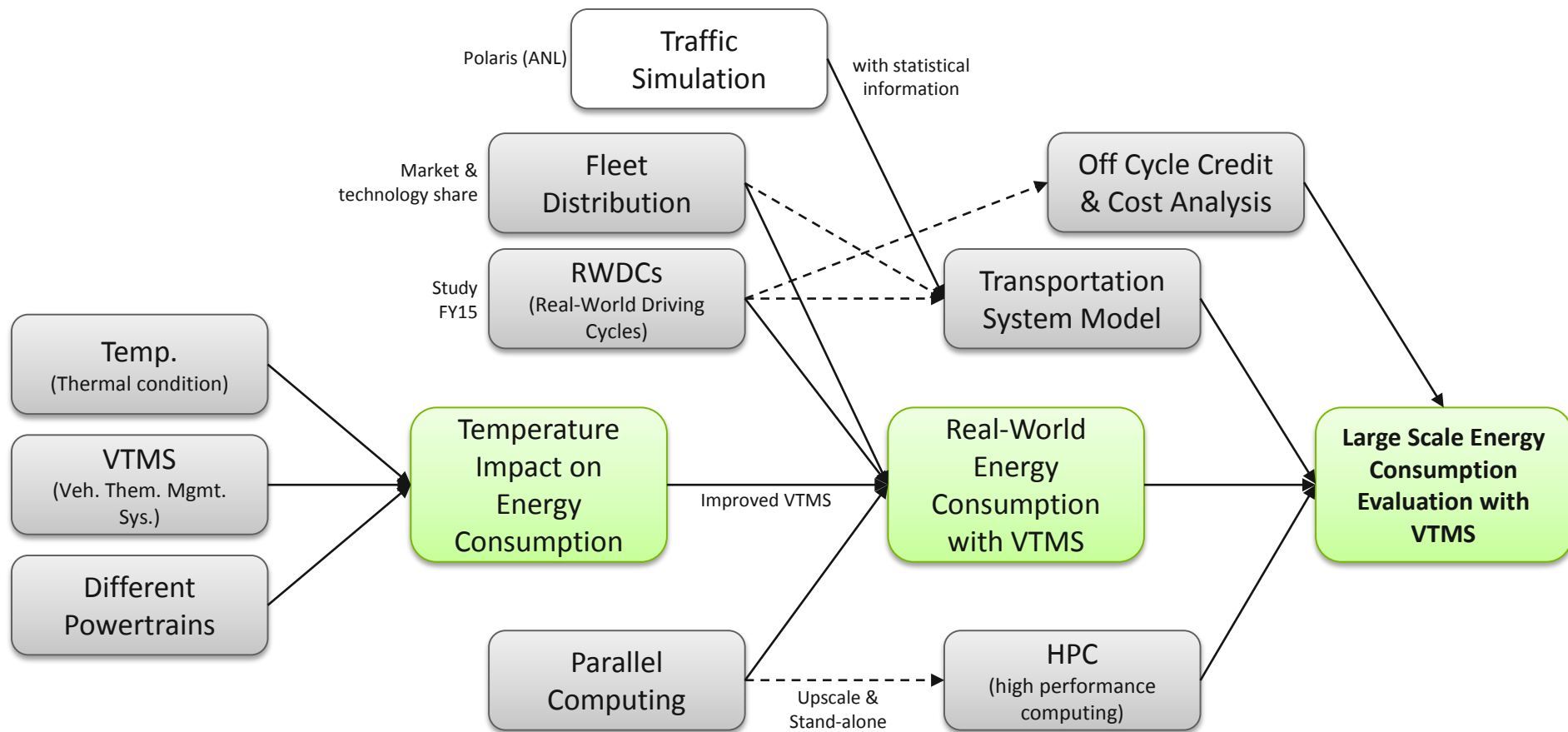
Future Flow



This extra flexibility will allow us to support the use cases necessary for the future of the software

Approach

Example of Future Autonomie Use Case



Technical Accomplishments

Main New Features

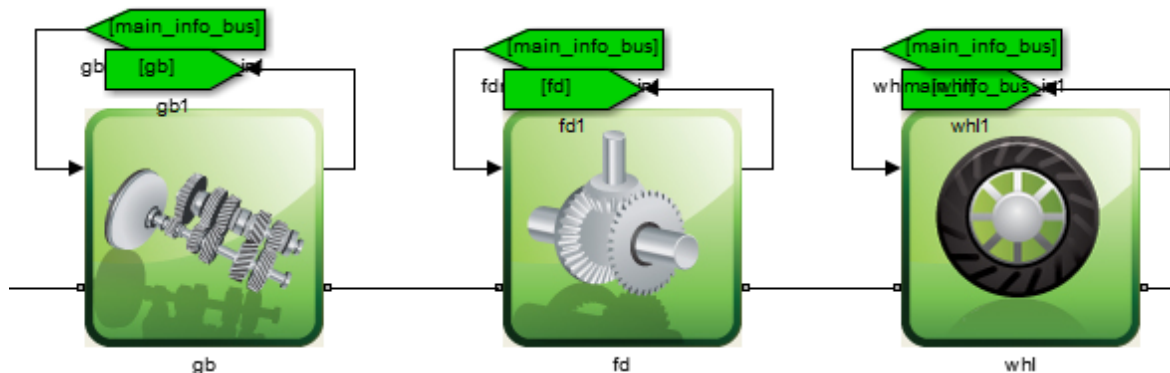
- Models
 - Physical Models
 - Thermal Models
- Large Scale Simulation Upgrades
 - Model Parallelization with MPI
 - Parametric Study on Files
 - Simulation Speed Upgrades
- Software
 - Graphical Configuration Editor
 - UI Usability Enhancements



Technical Accomplishments

Physical Models

- Physical modeling allows developers to graphically create components which are physics based, rather than equation based.
 - Users build the model without worrying about underlying equations
 - Solver optimizes equations for faster execution time
- Models produced using the Matlab Simscape™ or SimDriveline™ toolboxes can now be used directly in Autonomie
 - No need to wrap models anymore, can now directly connect physical signals to each other
- Examples provided



Technical Accomplishments

Thermal Models Released

Test data from ANL APRF



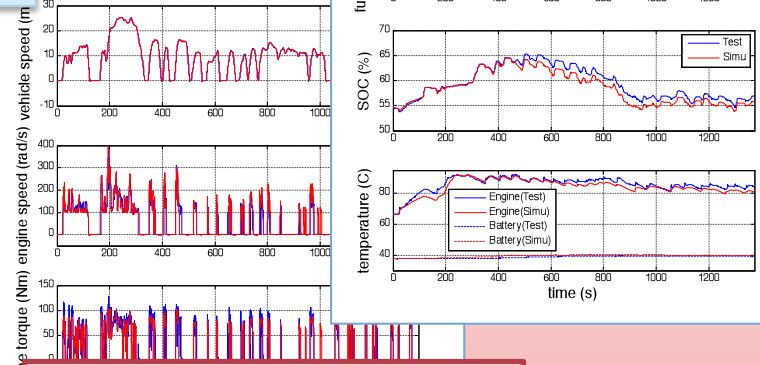
Test data

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21

35



Model Validation

Simulation data

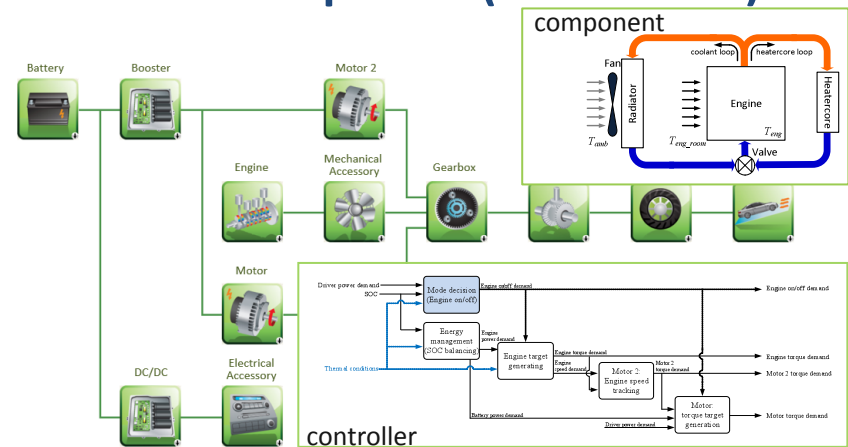
Control and Performance Analysis

engine operation target

Heat capacity estimation

mode behaviors

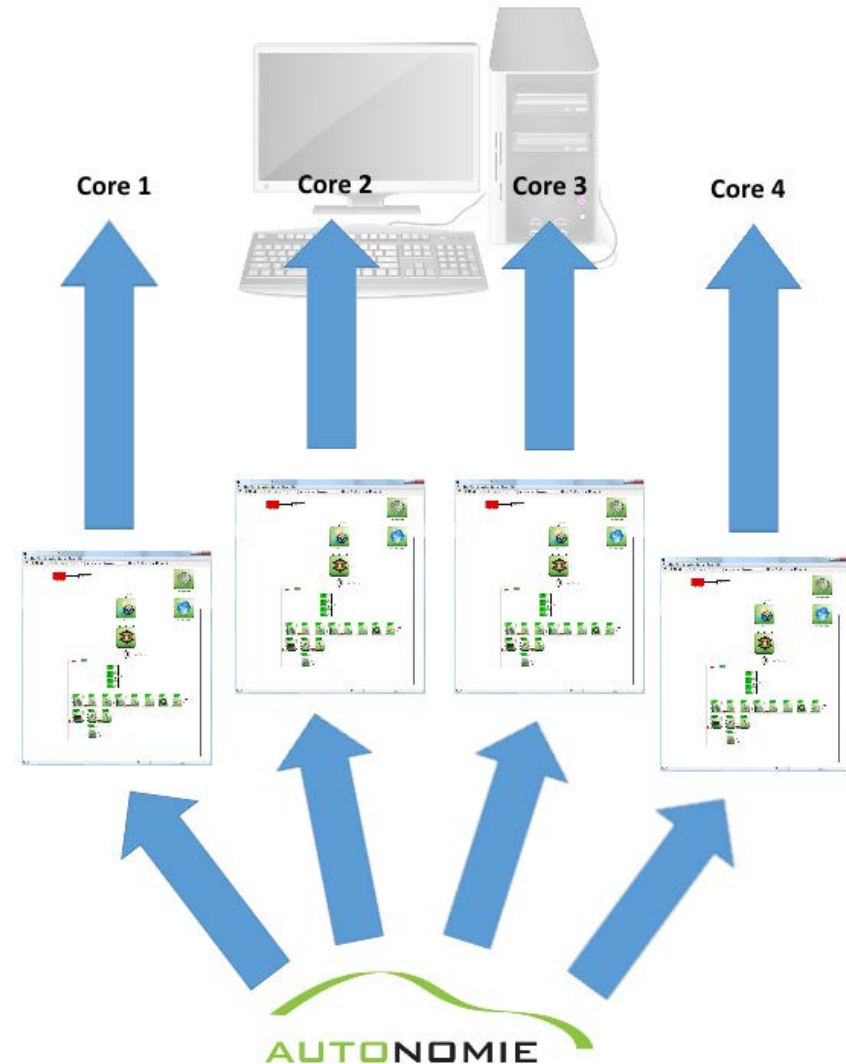
Model Development (Autonomie)



Technical Accomplishments

Model Parallelization with MPI

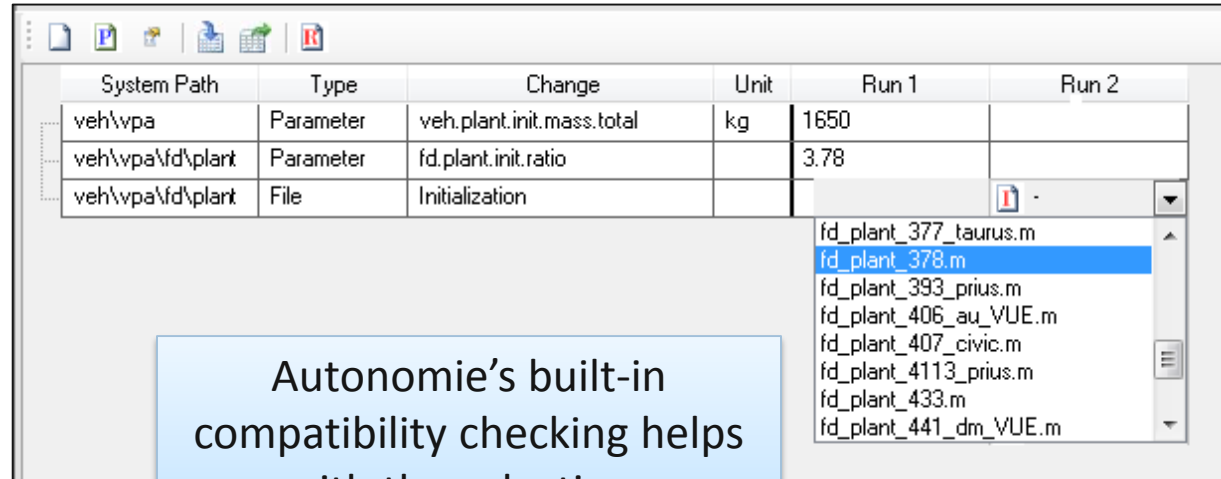
- A new message passing interface (MPI) algorithm was written for Autonomie
 - Allows simulations to be distributed across multiple cores of a computer
 - Allows model parallelization without the use of additional hardware or software (i.e. clusters, distributed computing toolboxes, etc.)
- Autonomie procedures retrofitted to call the MPI algorithm automatically



Technical Accomplishments

Large Scale Study on Files

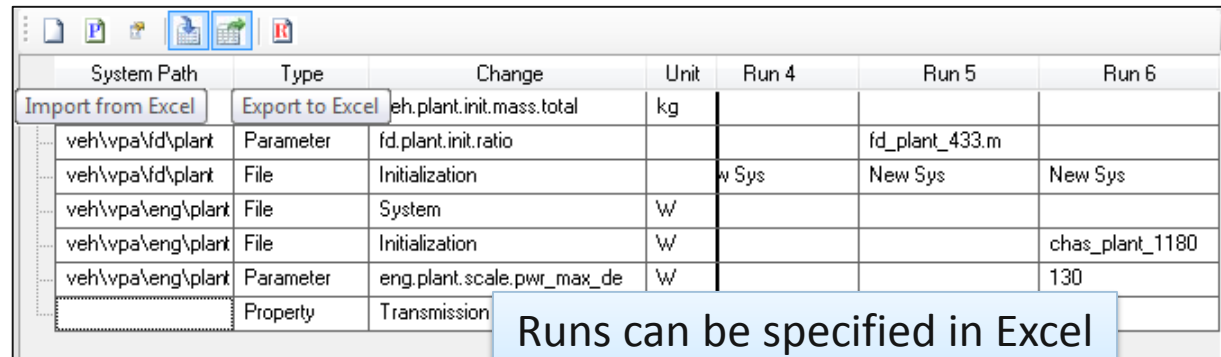
- Previously, Autonomie allowed “parameter sweeps”
 - Users asked for more freedom to define runs
 - Users asked for more intuitive interface
- Now users can run more combinations by specifying files to vary, rather than just parameters
- i.e. Run 1 with this transmission system, including plant and control, and Run 2 with a different transmission system, including plant and control



System Path	Type	Change	Unit	Run 1	Run 2
veh\vpw	Parameter	veh.plant.init.mass.total	kg	1650	
veh\vpw\fd\plant	Parameter	fd.plant.init.ratio		3.78	
veh\vpw\fd\plant	File	Initialization			

fd_plant_377_taurus.m
 fd_plant_378.m
 fd_plant_393_prius.m
 fd_plant_406_ae_VUE.m
 fd_plant_407_civic.m
 fd_plant_4113_prius.m
 fd_plant_433.m
 fd_plant_441_dm_VUE.m

Autonomie's built-in compatibility checking helps with the selections

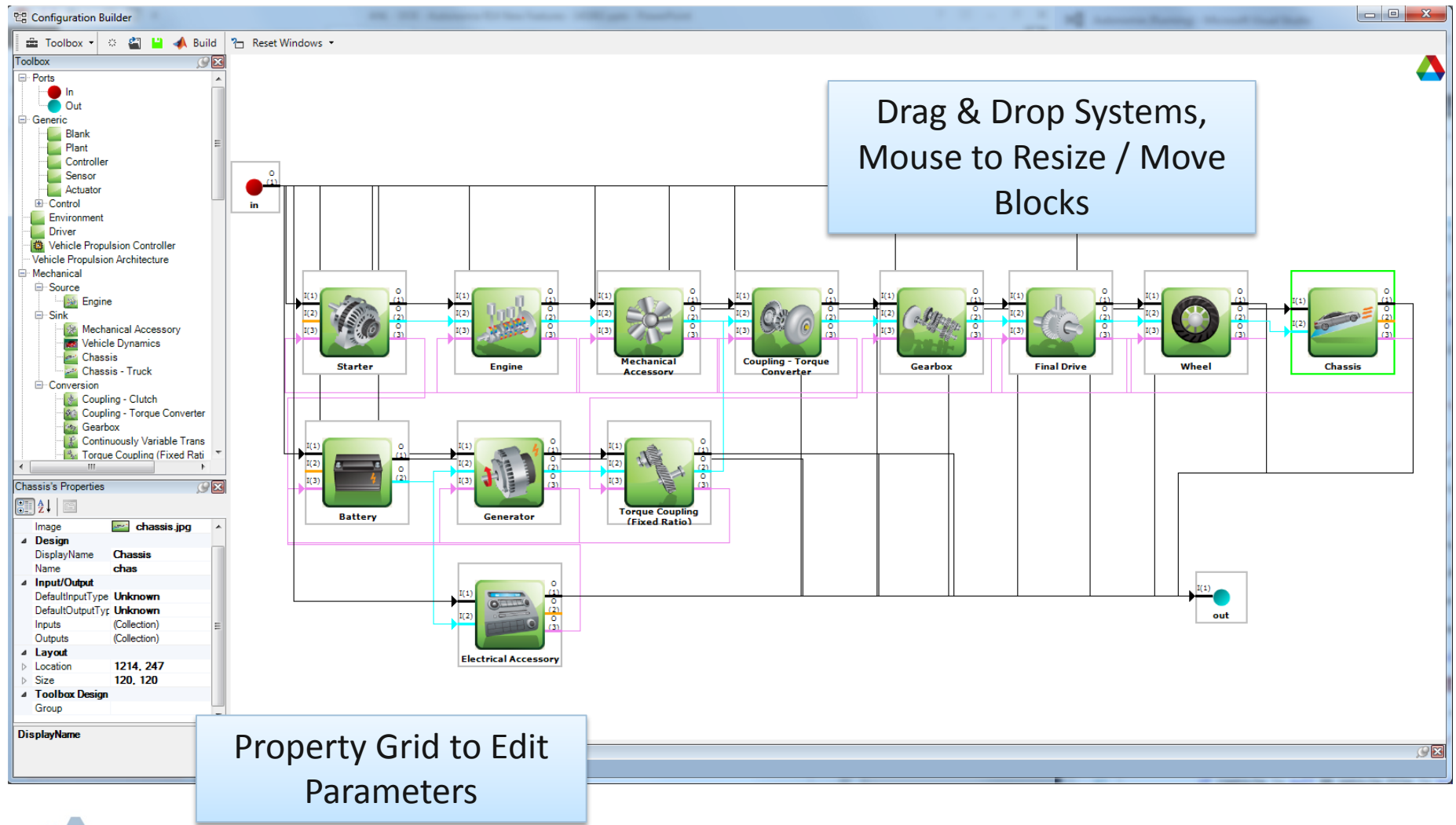


System Path	Type	Change	Unit	Run 4	Run 5	Run 6
veh\vpw	Parameter	veh.plant.init.mass.total	kg			
veh\vpw\fd\plant	Parameter	fd.plant.init.ratio			fd_plant_433.m	
veh\vpw\fd\plant	File	Initialization		W Sys	New Sys	New Sys
veh\vpw\eng\plant	File	System	W			
veh\vpw\eng\plant	File	Initialization	W			chas_plant_1180
veh\vpw\eng\plant	Parameter	eng.plant.scale.pwr_max_de	W			130
	Property	Transmission				

Runs can be specified in Excel and imported into Autonomie

Technical Accomplishments

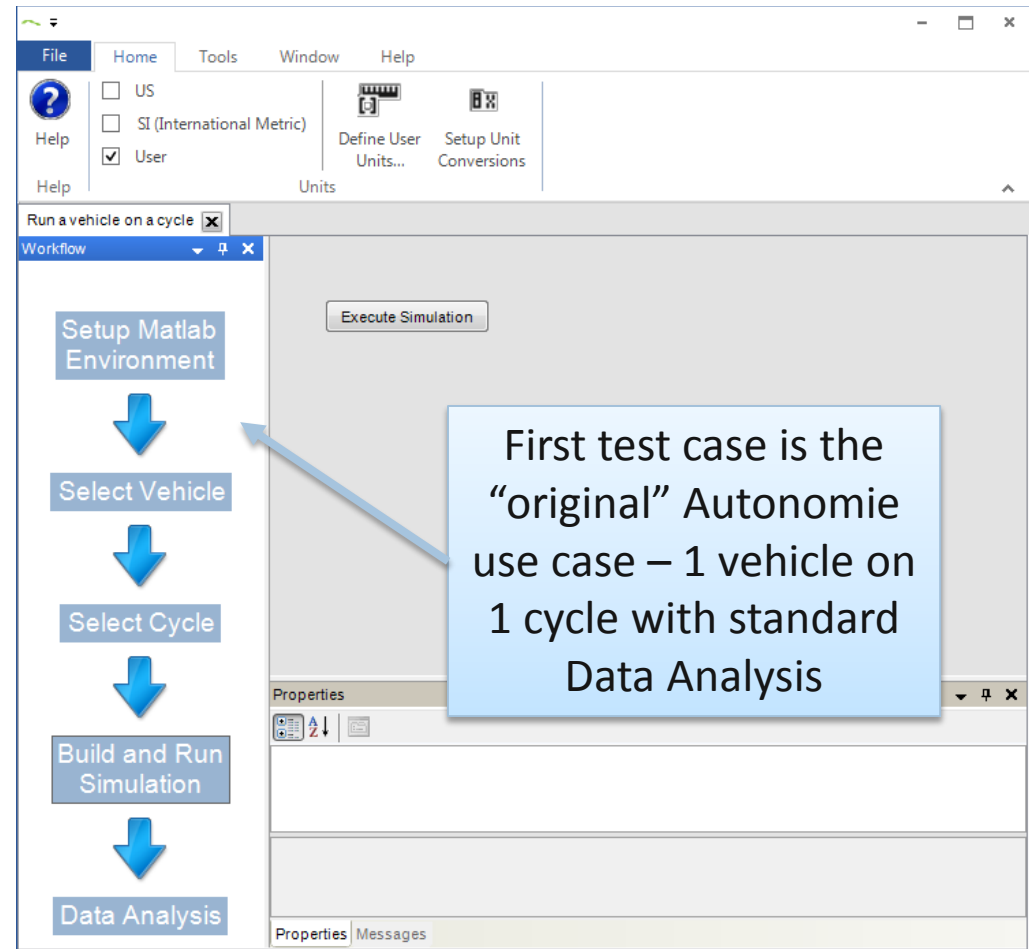
New Graphical Configuration Builder



Technical Accomplishments

MBSE Enhancements

- Initial steps taken to prepare us for the future of Autonomie
 - Decoupled framework kernel from application
 - Example file formats developed
 - Decoupled execution framework (i.e. Matlab) from kernel
- “Use case” driven user interface prototyped



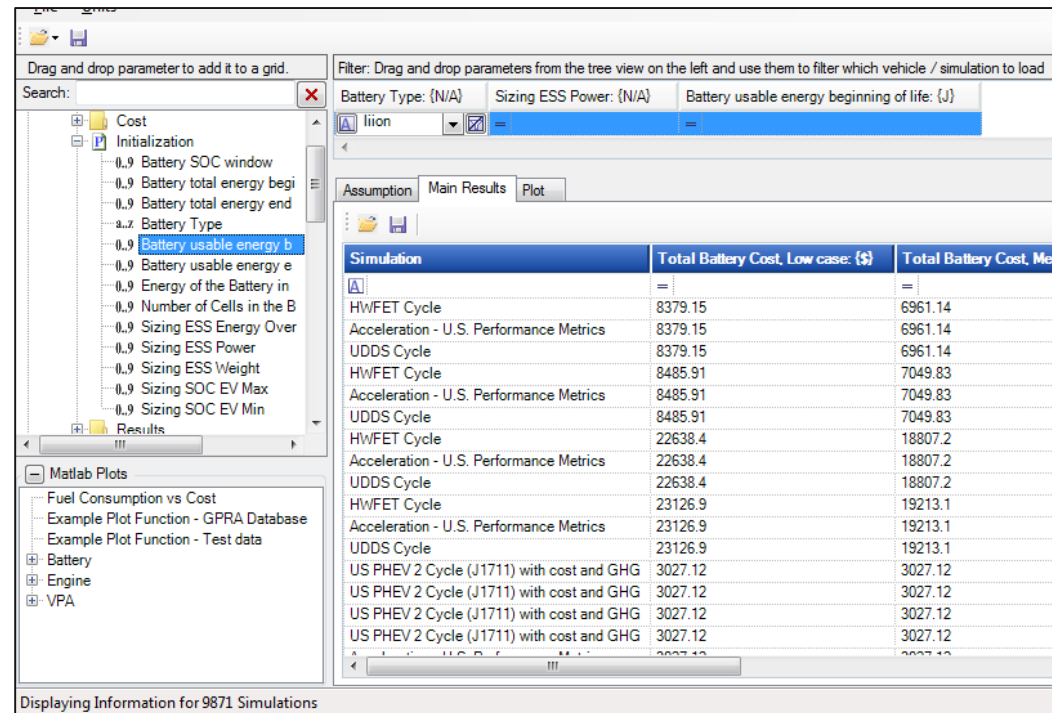
Technical Accomplishments

Large Scale Simulations

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

Tasks Performed

- Developed process for performing data analysis on large scale simulation
 - Import results into database
 - User interface for interacting with database
 - Automated checks using the database user interface to “sanity check” simulations
- This will become the default large scale data analysis



Responses to Previous Review Comments

- “The reviewer criticized that this is already being done in industry ”
 - There are two parts of Autonomie, the **framework** and the **application**. The reviewer is correct that part of the application (i.e. plant models) is used less heavily by industry, as they have their own models
 - However, the validated vehicle level controllers and framework (i.e. enterprise level collaboration tools, such as model and system sharing) are unique
 - As proof, several companies use Autonomie as the basis for their MBSE efforts
- “The reviewer noted that one alternative approach for the future is to investigate Autonomie as a stand-alone tool and wean the tool off its dependency on Matlab/Simulink.”
 - We have been taking steps under the MBSE project to realize this goal for users who do not require a full simulation environment (i.e. users who only perform data analysis on existing simulations)
 - However, we do not intend to write our own simulation environment. Users who wish to run simulations will always need a simulation environment, whether that environment is Matlab/Simulink or something else



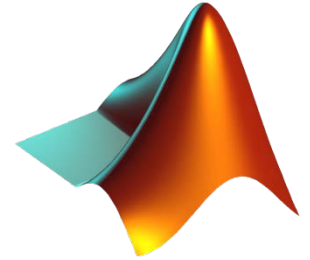
Collaboration and Coordination with Other Institutions



Gamma
Technologies

CarSim[®]
Mechanical Simulation

- Model Providers
 - National Labs (i.e., NREL)
 - Argonne (i.e., Battery group...)
 - Expert Tool Companies (i.e., Siemens, Gamma Technology, Mechanical Simulation...)
- Process Definition & Direction
 - OEMs (i.e., General Motors, Ford...)
 - MathWorks
 - Expert Tool Companies (i.e., Siemens, ChiasTek, Esse...)
 - Argonne (i.e., Math. group, HPC...)



SIEMENS



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...)
 - Continue to leverage state-of-the-art standards to facilitate industry acceptance
 - 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 MBSE 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 MBSE processes throughout OEMs and DOE

