Autonomie
Plug&Play Software Architecture

2009 DOE Hydrogen Program and Vehicle Technologies
Annual Merit Review
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Aymeric Rousseau, Shane Halbach, Phil Sharer,
Sylvain Pagerit, Charles Folkerts, Ram Vijayagopal
Argonne National Laboratory
Sponsored by Lee Slezak

Project ID #VSS020
Project Overview

Timeline
- Start – July 2007
- End – September 2010
- 60% Complete

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

Budget
- Three year Project
  - 50% DOE
  - 50% GM
- DOE
  - FY08 $ 500k
  - FY09 $ 500k
  - FY10 $ 500k

Partners
- General Motors
- MathWorks
- Mechanical Simulation
Main Objectives

- Provide a software environment and standard framework to unify the entire engineering organization, enterprise-wide, for efficient operation.
- Facilitate simulation of subsystems, systems, collections or combinations of systems and subsystems (e.g. powertains), or entire vehicles.
- Integrate models, rapidly and easily, with varying levels of detail/abstraction from simple steady-state to highly detailed physics models through a plug-and-play architecture.
- Use one tool throughout the entire development process from modeling (e.g. MIL, SIL), to hardware evaluation (e.g. HIL), to control development (e.g. RCP), and finally through to production.
- Include configuration and database management for controlling, storing, and archiving of models, calibration, simulation, analysis, test data and any results or report from these activities.
Milestones

Year 1
Define Data Organization
Define Model Organization
Validate Model Organization
Implement Controls
Validate Vehicle Model
Demonstrate SIL
Demonstrate HIL
Linkage with expert tools
Implement Drive Quality
Implement Emission Models
Discuss Industry Standard

Year 2

Year 3

Current Status
Approach

Component Organization
Command from Controller
Info to Controller (Sensors)

Vehicle
Transmission
Engine

Hardware Modeling & Analysis
Requirements

Graphical User Interface

Data Organization

Post-processing Tools

DOE/ANL

GM

Control Algorithm Design & Analysis
Requirements

Control
Key Benefits

- Flexibility & Reusability
- Customizable architectures
- Common Nomenclature
- Code Neutral

Plug&Play

- Sorts technologies quickly to reduce hardware build iterations
- Reduces/eliminates duplicate modeling and analysis work
- Delivers designs that balance Fuel Economy, Emissions and Drivability (FEED) requirements

Reduces Cost & Time to Production

Enterprise Wide Solution

- Database Management
- Provides common methods and tools for comparing/evaluating technologies
Key New Features

Implement any language
Automated process to import legacy code (data, model, control, process)...

Calibration
Validation
Tuning
Drive Quality...

Plug & Play

Legacy Code

Legacy Processes

Specialty Software

CarSim
GTPower
Amesim
AVL Drive...

Database Management

Version Control
Database Search
Math-based, Plug-and-Play Software for Automotive System

Maximum User Access
Maximum Flexibility
Reusability
Enterprise Solution
Selectability
Complexity
Code Neutrality

Database

Interface

Models, Data

Graphical User Interface

Models, Data

Setup Simulation
Generic Processes
Results Visualization
Linkage with Other Tools

User Access Control
Enterprise Wide Solution
Version Control
Database Search

Database
Model & Data Requirements

- **Maximum Reusability**
  - Automated integration of existing models / controls / data
  - All models for a specific area of expertise in a single location
  - Systems duplicated using Matlab API

- **Maximum Flexibility**
  - Any system can be built automatically
  - User can add their own configurations
  - Single components or entire vehicles can be simulated

- **Selectable Complexity**
  - Common nomenclature (i.e., naming, I/O...)
  - Common model organization (i.e, CAPS)
  - Model compatibility checked

- **Code Neutrality**
  - Matlab / Simulink main environment
  - Use S-functions
  - Co-simulation (i.e., CoSimate)
Model & Data Requirements

Common Model Organization

All Systems have 3I/3O

Subsystem buses aggregated so that other systems can access information

Each subsystem has its own bus

Cmd ➔ Info / Sensors
Effort /J ➔ Effort /J
Flow ➔ Flow

Actuator

Controller

Plant

Sensor
Model & Data Requirements

Maximum Flexibility

- Users can create any new configurations by adding a new file (which can be automatically created from existing Simulink Model)

- Users can design their model to represent a hardware setup

Example: Systems that share a controller should be located under the same subsystem

Each subsystem can have its own control (CAPS)
Graphical User Interface Requirements

Setup Simulation
- Predefined or user defined architectures
- Select existing / Add legacy model and data
- Check compatibilities
- Select simulation type (i.e., fuel efficiency, performance...)

Generic Processes
- Calibration, Validation, Tuning
- Parametric study, including Monte Carlo analysis
- Optimization algorithms
- Predefined or user defined processes & report

Results Visualization
- Predefined or user defined calculations (i.e., fuel economy...)
- Predefined or user defined plots
- Energy balance
- Specific plots available for different models (experts defined)

Linkage with Other Tools
- Co-simulation (i.e., CoSimate)
- Specialty Tools (i.e, GT-Power, CarSim, AMESIM, AVL Drive...)
- Database Management (i.e., SourceSafe...)
- Well-to-Wheel (i.e., GREET)
Graphical User Interface Requirements
Integrate Any Processes

- Each process is defined by a file listing the pre-processing, simulation and post-processing files.
- Legacy/New processes can be automatically added in GUI
- Users have options to combine processes

Processes:
- Fuel Economy
- Performance Validation
- Tuning
- Calibration
- Drive Quality
- Sizing...
- SOC correction
- Parametric Study
- Optimization
- MonteCarlo...
Graphical User Interface Requirements

Results Visualization

■ Numerous standard plots provided

   HTML Report

   Energy balance

   Replay Simulation

■ Users can define their own plots
  ■ Each model has an associated list of plots
  ■ Each process has an associated list of post-processing files (calculations, plots)
■ GUI can launch legacy tools
Database Requirements

User Access Control
- Prevent unauthorized users from accessing restricted or proprietary data
- Allow authorized users to download all necessary files
- Ensure model is documented before integration into database

Enterprise Wide Solution
- Allow users to collaborate (i.e. share models)
- Main database accessible anywhere
- Consistent process for interacting with files

Version Control
- Maintain traceability of all changes
- Keep linked files together through entire vehicle process (i.e. design, simulation and test)

Database Search
- Use keywords to search data, models, controls related to specific projects
- Quickly find the correct model with the correct fidelity of modeling and all related files
Key Capabilities

Production
Hardware-in-the-Loop
Software-in-the-Loop
Model-in-the-Loop
Control Model
Control Code
Production Code
Database

FEED
Fuel Economy, Emissions & Drivability

Calibration
Verification, Validation & Confirmation

Detailed Plant Model
Simple Plant Model
RCP
Product
Future Activities

- Complete first version of Autonomie (Sept 2009)
  - Demonstrate MIL, SIL, HIL, RCP...
  - Complete integration of processes
  - Complete linkages with specialty tools
- Continue discussion with OEMs, suppliers...
- Initiate definition of standard for automotive industry (SAE)
- Implement feedback from OEMs, suppliers... into second version of Autonomie
- Complete standard
A software environment and standard framework

**Summary**

- Establishes tool and framework for enterprise-wide collaboration
- Reduces costs and time to production, which will benefit both companies and government partnerships (e.g., FreedomCAR and 21CTP)
- Provides complete user customization by an open architecture
- Simulates from single components, subsystems to entire vehicles
- Manages models, data, processes, results and control code from research to production by configuration and database management
Additional Slides
Unifies the Entire Engineering Organization for Efficient Operation Virtual Environment
A Software Environment and Standard Framework

Model
- Flexibility and Reusability
- Integrate Legacy Code
- Common Nomenclature
- Code Neutral

GUI
- Customizable configurations
- Customizable processes
- Results Visualization
- Linkage with other tools

Database
- User Access Control
- Enterprise wide solution
- Version Control
- Database Search
Key New Features

- Physically-Based Plug-and-Play Model Integration Environment.
- Hierarchical layered organization of models for ease of understanding.
- Provide capabilities for simulation of subsystems, systems, collections or combinations of systems and subsystems (e.g. powertains), or entire vehicles.
- Mix-and-Match models of different levels of fidelity or abstraction for execution efficiency with higher fidelity models where analysis and high detail understanding is critical.
- Linkage with Commercial-off-the-Shelf (COTS) software applications for Detailed Physically-Based Models.
- Support Math-Based engineering activities through all stages of development from feasibility studies to production release (feasibility, control algorithm design, calibration, verification, validation, confirmation, and release).
- Support MIL, SIL, HIL, RCP.
- Entire software can be customized by users, including system architecture, processes, post-processing (calculation and plots)...
- Configuration and Database Management.
Key Capabilities

- Fuel efficiency and performance predictions and analysis
- Determine real world fuel economy potential by evaluating and balancing Fuel Economy, Emissions and Drivability (FEED)
- Virtual analysis and testing for calibration, verification, validation, and confirmation of hardware models and algorithms
- Determination of system hardware and software requirements for sensors, actuators, controllers, components, subsystems and algorithms
- Failure modes and effects analysis (FMEA)
- Drivetrain configuration analysis
- Development of high level vehicle control strategies
- Component parameter variation/robustness, and Monte Carlo studies
- Component technology evaluation
- Component sizing
- Transmission and gear ratio optimization
Key Benefits

- Establishes tool and framework for enterprise-wide collaboration and cooperation for improved productivity and efficiency.

- Reduces costs and time to production
  - Provides math-based environment for more thorough multidisciplinary integration and testing in the virtual environment before hardware builds
  - Sorts technologies quickly to reduce hardware build iterations
  - Promotes parallel and integrated virtual development of control systems and hardware
  - Reduces/eliminates duplicate modeling and analysis work and activities

- Enables Fast-to-Market with new technologies and real fuel economy
  - Delivers better-integrated, initial designs that balance Fuel Economy, Emissions and Drivability (FEED) requirements.
  - Provides common methods and tools for comparing/evaluating technologies.
  - Facilitates efficient, seamless link from research to production to maximize reuse of work products and eliminate waste.
Model & Data Requirements
Common File Organization

Model

Simulink

Includes list of systems, connection between systems, buses, location in Simulink...

XML

Includes documentation, parameters, user defined plots, bus information, compatibility, language, calibration files, CAD files...

Data File

MFile

Includes documentation, parameters, models linked to, link to raw test data, calibration files...

XML

Configuration

Includes documentation, parameters, user defined plots, bus information, compatibility, language, calibration files, CAD files...
Model & Data Requirements
Automated Integration of Legacy Models

Legacy Model

XML Compatible Documents

Matlab Function to Change Names of Simulink Models

Function to Manage Model Compatibilities

Matlab Function to Read Names

Basis of Final Model Documentation
Graphical User Interface Requirements
System and Powertrain Selection
Graphical User Interface Requirements
Select Any Architecture

■ Any configuration can be selected from the Graphical User Interface at any time
■ Configurations are searchable through key words
Database Requirements

Database Search

- The GUI works for several databases
- Users can search according to different types of files

Select Database

Select Type of File
Database Requirements
User Access Control

- Users can download selected files
- Files belonging to same project are linked together
Database Requirements

Ensure Model is Documented

- Before implementing model in database, user is guided through documentation process