Autonomie
Large Scale Deployment

2011 DOE Hydrogen Program and Vehicle Technologies
Annual Merit Review
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Argonne National Laboratory

Sponsored by David Anderson

Project ID #VSS009

U.S. Department of Energy
Energy Efficiency and Renewable Energy
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Project Overview

Timeline
- Start – July 2007
- End – September 2011
- 90% Complete

Budget
- Four Year Project
  - First 3 years (50% DOE/50% GM)
  - Fourth year (26% DOE/74% GM)
- Funding (cash)
  - FY08 $ 500k
  - FY09 $ 500k
  - FY10 $ 500k + $400k (legacy transition)
  - FY11 $ 500K (DOE) + $ 300K (GM)

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

Partners
- General Motors
- MathWorks
- Gamma Technology (GTPower)
- LMS (AMESim)
- Mechanical Simulation (CarSim)
Autonomie’s objective is to accelerate the development and introduction of advanced technologies through a Plug&Play architecture that will be adopted by the entire industry and research community.

- Reduce cost and time to production by minimizing hardware iterations through virtual environment
- Enterprise wide solution through database management maximize model and process reusability
Milestones

Large Scale Deployment
- Develop First Public Version
- Website Development
- Users Support
- Report and Track Issues
- Automated Release Generation
- Automated Release Testing
- Second Release

Control Development Process
- Develop & Test all Use Cases
- Database Interface
- Linkage with expert tools

Year 1-3

Year 4

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
PSAT users are able to acquire Autonomie at no cost

More than 65 companies are using Autonomie (as of 03/11/11)

Numerous new companies have licensed Autonomie or purchased additional licenses based on the new features

(1) Different funding source
Technical Accomplishments

Multi-Controller Simulation

- Process developed & documented to integrate several expert system models in Autonomie
- New Architecture developed to ensure that the different models run properly
- Opens new doors for control engineers holy grail: multi-controller optimization
- Next challenge: improve execution time (i.e., multiple processors...)

![Diagram showing various components and their interactions]

- Driver
- Environment
- Vehicle Controller
- Vehicle Propulsion Architecture
  - Engine (GT-Power)
  - Transmission (AMESim)
  - Veh.Dynamics (CarSim)
Technical Accomplishments
Large Scale Deployment - Overview

User Support
- Installation
- Training
- Onsite support
- Customer and license tracking
- User Community
- Issue Report
- Enhancement request
- Custom Development

Reporting & Addressing Issues
- Users can enter new issues and track their status
- Developers can assign, solve, test and close issues
- Issues are included in sprints based on their importance

Automated Release Generation
- Quickly generate new versions
- Protect the code
- Ensure file consistency
- Generate installer

Automated Testing
- Setup environment
- Test Matlab functions
- Test user interface
- Run fuel economy tests
- Store test results
- Generate Report
Technical Accomplishments
Support & Training - Overview

Support Types

- Installation
- Training
- Issue fix
- Enhancement Request
- On-site Support
- Custom Development
...

Support Options

- FAQ page\(^{(1)}\)
- Forum\(^{(2)}\)
- Documentation\(^{(1)}\)
- Email\(^{(1)}\)
- Chat Room\(^{(2)}\)
- Web meeting\(^{(1)}\)
- Phone Support\(^{(1)}\)
- Issue Reporting\(^{(1)}\)
- Paid Contracts\(^{(1)}\)

(1) Currently available
(2) Planned in Year 4
Technical Accomplishments
Entering and Tracking Issues

User

Access Issue
Status, Statistic, Roadmap...

Enter Issue

Review Issue
(bug vs. improvements...)

Assign Issue
to Release

Resolve & Test
Issue

Close Issue

Developer
Technical Accomplishments
New Website Launched

Website statistics (as of 03/10/11):
- Pages viewed (6500/month)
- Demo downloads > 135
- ACEA HD version downloads > 70

- Describe tool & capabilities
- Download documents (>70 presentations, >55 papers)
- Download versions (demo, HD)
- Manage support (training, videos, user issues...)

www.autonomie.net
Technical Accomplishments

Automatic Release Generation Process

Databases

- GUI
- Core
- Standard
- OEM1
- OEM2
- OEM3
- ...

Database selection

- License selection (i.e., USB vs License Key) *(1)*
- Compile & Obfuscate GUI *(1)*
- Check Consistency (i.e., proprietary tags) *(1)*
- Pcode mfiles *(1)*
- Generate Installer *(1)*

(1) Currently available
(2) Planned in Year 4
Technical Accomplishments

Automatic Testing Process Status

GUI Test Cases

Environment Test Cases
- Database (CMSynergy...)
- Advanced Release Testing

Matlab Test Cases
> 100 exist
Select a few
- Industry Model Testing (IMT)

To be developed
(currently manual process)

Run Cases

Distributed Computing

Previous Results

Store Results

Report Generation

To be developed
Technical Accomplishments
Process Development for Control

Source: GM
Autonomie Designed to Be Used For All Steps in the Development Process

- Build and compare large number of technology, powertrain, options
- Ensure simulation traceability, model compatibilities
- Database Management
- Easy selection & implementation of data, models, control or cycles
- Generic Processes
- Run batch mode + Distributed computing
- Analyze and compare test and simulation data
- Enables MIL, SIL, RCP, HIL, CIL
Autonomie Commercialization
Call for Proposal

- **Background**
  - Several commercial companies using Autonomie have requested more information about how enterprise deployment and support would be handled (e.g., how do we support an engineer in India?).
  - Argonne has been looking for a commercial partner

- **Benefits**
  - Extended support: worldwide, onsite, 24/7
  - Training
  - Licensing
  - Argonne retains the IP (code) and continues to focus on R&D, studies and code development

- **Major Dates**
  - Document sent: March 2011
  - Partner selected: May 2011
  - Agreement signed: August 2011
Collaborations

- Autonomie is used to support large number of DOE activities.

Examples of Autonomie Usage in FY10 AMR

<table>
<thead>
<tr>
<th>Task</th>
<th>Lead</th>
<th>Project #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Cycle Analysis with GREET</td>
<td>ANL</td>
<td>AN012</td>
</tr>
<tr>
<td>Evaluation of powertrain options and component sizing for MD and HD applications</td>
<td>ANL</td>
<td>VSS048</td>
</tr>
<tr>
<td>MD &amp; HD Electric Drive Vehicle Simulation and Analysis</td>
<td>NREL</td>
<td>VSS043</td>
</tr>
<tr>
<td>ArvinMeritor CRADA</td>
<td>ORNL</td>
<td>VSS061</td>
</tr>
<tr>
<td>Evaluation of flex fuels for PHEVs using modeling and EIL</td>
<td>ANL</td>
<td>VSS049</td>
</tr>
<tr>
<td>Advanced Engine System and Emissions Control Modeling and Analysis</td>
<td>ORNL</td>
<td>VSS041</td>
</tr>
<tr>
<td>LDV HVAC model development and validation</td>
<td>NREL/ANL</td>
<td>VSS045</td>
</tr>
<tr>
<td>System Level Analysis of Hydrogen Storage Options</td>
<td>ANL</td>
<td>ST001</td>
</tr>
</tbody>
</table>

- Additional projects include EcoCAR, University classes (teaching), program requirements, GPRA, market penetration...
Collaborations (Cont’d)

- Provide inputs on “best practices”
- Implementation of MathWorks developed models and algorithms to support studies
- Provide technical support to automate the integration of GTpower (engine modeling) into Autonomie
- Provide technical support to automate the integration of AMESim (transmission modeling) into Autonomie
- Provide technical support to automate the integration of CarSim and TruckSim (vehicle dynamics modeling) into Autonomie
Future Activities

- Continue to update Autonomie to maintain state-of-the-art
- Continue to provide guidance for DOE R&D activities
- Expand Autonomie usage throughout DOE to promote Virtual Engineering approach
- Continue to enhance the tool based on DOE needs and user’s feedback
- Define the industry standard for modeling and simulation to be adopted by the entire industry through existing SAE committee
- Continue to discuss potential use of Autonomie to support future Medium and Heavy Duty fuel consumption labeling / regulations
Summary - ANL Will Continue to Accelerate Technology Development and Introduction

- Support DOE R&D activities
- Support usage of Autonomie for OEMs...
- Support virtual engineering processes throughout OEMs and DOE
Technical Back-Up Slides
# AUTONOMIE/PSAT Comparison

## Architecture

<table>
<thead>
<tr>
<th>Capability</th>
<th>PSAT</th>
<th>PSAT-PRO</th>
<th>Autonomie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plug &amp; Play Architecture</td>
<td>![Checkmark]</td>
<td>![Checkmark]</td>
<td>![Checkmark]</td>
</tr>
<tr>
<td>Hierarchical Architecture Standards (Vehicle, syst...)</td>
<td>![Checkmark]</td>
<td>![Checkmark]</td>
<td>![Checkmark]</td>
</tr>
<tr>
<td>Model Reusability through System Experts (Concept to Production)</td>
<td>![Checkmark]</td>
<td>![Checkmark]</td>
<td>![Checkmark]</td>
</tr>
<tr>
<td>Establish Standard Interfaces (Industry-wide)</td>
<td>![Checkmark]</td>
<td>![Checkmark]</td>
<td>![Checkmark]</td>
</tr>
</tbody>
</table>

## Features

<table>
<thead>
<tr>
<th>Capability</th>
<th>PSAT</th>
<th>PSAT-PRO</th>
<th>Autonomie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model/data Customization</td>
<td>![Checkmark]</td>
<td>![Checkmark]</td>
<td>![Checkmark]</td>
</tr>
<tr>
<td>Powertrain Configuration Customization</td>
<td>![Checkmark]</td>
<td>![Checkmark]</td>
<td>![Checkmark]</td>
</tr>
<tr>
<td>Select Appropriate Level of Modeling</td>
<td>![Checkmark]</td>
<td>![Checkmark]</td>
<td>![Checkmark]</td>
</tr>
<tr>
<td>GUI Customization (process, post-processing...)</td>
<td>![Checkmark]</td>
<td>![Checkmark]</td>
<td>![Checkmark]</td>
</tr>
<tr>
<td>Database Management</td>
<td>![Checkmark]</td>
<td>![Checkmark]</td>
<td>![Checkmark]</td>
</tr>
</tbody>
</table>
## AUTONOMIE/PSAT Comparison

### Usage*

<table>
<thead>
<tr>
<th>Capability</th>
<th>PSAT</th>
<th>PSAT-PRO</th>
<th>Autonomie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluate Fuel Consumption Benefits</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>(technology, size, powertrain configuration...)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluate and Balance FEED in Simulation</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>(Fuel Economy, Emissions &amp; Drivability)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Component Requirements</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Simulate Single Component</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Develop System/Subsystem Requirements</td>
<td></td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Develop Vehicle Level Control</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Develop System/Subsystem/Component Control</td>
<td></td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Component-in-the-Loop</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Software-in-the-Loop, Hardware-in-the-Loop...</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
</tbody>
</table>

*Final usage depends on the level of details of the models available*
Model-in-the-Loop (MIL) Examples Supporting Current DOE R&D Activities

Evaluation of Fuel Consumption Benefits of Advanced Powertrains (VSS_010)

- 2 Mode HEV
- Control Development
- Vehicle Analysis

Evaluation of Fuel Consumption Benefits of Advanced Controls

- Global Optimization
- Rule Based
- Heuristic Optimization
- Instantaneous Optimization

Evaluation of Fuel Consumption Benefits of Advanced Technologies (VSS011)

- HCCI Fuel Savings vs PI According to Hybridization Degree

Definition of Component Requirements for Program Goals

- Requirements of End of Life Energy Storage Systems for PHEVs
Software-in-the-Loop (SIL) Example to Develop Low Level Engine Control

Real Time Operating System (RTOS) ensures call of functions at specific intervals (such as CAN)

Sends and receives CAN signals

Production Code

New algorithm(s) to be tested

Hardware input/output
Component-in-the-Loop (CIL) Example to Evaluate Non-Modeled Phenomena for DOE

Example #1: Impact of battery cold start on PHEVs Fuel Consumption

Example #2: Impact of emission and engine cold start on PHEVs Fuel Consumption

Example #3: Engine and Battery are Coupled

ANL is DOE’s lead laboratory for Automotive Component-in-the-Loop