MBD Adoption Trends from a US perspective

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Agenda

- What are MBD industry leaders doing?
- Plant Modeling in support of MBD
- Virtual Engine Calibration Optimization (VECO)
What are MBD industry leaders doing?

- Adopting MBD at CNH showed a significant decrease in implementation errors, …
- … but also an increase in integration errors.

1Presentation by William Fleming from CNH Industrial
What are MBD industry leaders doing?

- Start with Requirements, not Implementation

1Presentation by William Fleming from CNH Industrial
What are MBD industry leaders doing?

- These facts allowed CNH to realize that they needed to focus more on developing requirements, architecture specifications and performing up-front testing.

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1Presentation by William Fleming from CNH Industrial
What are MBD industry leaders doing?

- MBD Maturity Framework evaluation in completed in 2013 by MathWorks Consulting

1. Presentation by William Fleming from CNH Industrial
What are MBD industry leaders doing? Key questions from our customers about MBD

- What is the current **industry maturity**?
- What are the **industry trends**?
- How do I compare against others?
- Am I getting the **full value** out of my tool investments?
- How can I **unify** and streamline various **processes**?
- How do I **improve quality** of my designs?
- How do I manage **organization-wide deployment**?
- How do I **reduce waste** in the development life cycle?
- How do I **minimize risk** during deployment?
What are MBD industry leaders doing?
Assessment is based on Model-Based Design Maturity Framework™

- Developed by MathWorks while working with leading companies worldwide
- Maturity determined by rating:
  - 6 Pillars
  - 32 Process Groups
  - 200+ Process Attributes

Key Features
- Comprehensive measurement of capabilities
- Independently measures each capability
- Applies to any level of expertise
- Applies to any domain
- Independent of process
What are MBD industry leaders doing? Model-Based Design Maturity Framework™ Results
What are MBD industry leaders doing?
Automotive Industry Current Trends

- **Plant modeling** to support controls development
- **ISO 26262** certification with Model-Based Design
- Further **automation** of V&V tasks
- AUTOSAR
What are MBD industry leaders doing? Plant Modeling in support of MBD

- “… Many of the practitioners of MBD do not get the full benefit of MBD because they fail to fully integrate their modeling of the controls with the model of the physical system.”

2Edmund Hodzen from Cummins
Plant Modeling in support of MBD

- Odyne Hybrid Bucket Truck Plant Modeling

Target Market / Applications

Aerial Device (Bucket Truck)
- For maintenance and construction of electric lines

Cranes/Digger Derricks
- For installation of electric poles and transformers

Underground Utility Vehicle
- For construction and maintenance of underground natural gas and electrical lines

1Presentation by Bill Mammen from Odyne
Plant Modeling in support of MBD

Project Goals

- Improve system simulation capabilities to help during development to quickly evaluate the performance across all applications
- Combine controls development and simulation development so that they support each other with minimal effort
- Leverage the same control code used during automatic code generation for the embedded code in production

1Presentation by Bill Mammen from Odyne
Plant Modeling in support of MBD

Architecture Management

- Essential to use the Control and Plant models to develop robust embedded control systems
  - Control algorithm development, simulation, data analysis, and implementation are all tied together
  - The coordination of interfaces/definition reduces issues
  - Can be used in all phases of development

- Allows for the collaboration across tools and resources
  - Control and Plant model development
  - Commonizes testing and data collection efforts
    - Can use data from all vehicle and component testing
    - Can use data from telematics of actual customer usage

1Presentation by Bill Mammen from Odyne
Plant Modeling in support of MBD

- Control System Architecture
Plant Modeling in support of MBD
Vehicle Plant Model Overview - HCU Model Structure

Input Processing

HCU Algorithms

Output Processing
Plant Model Objectives

- Handles multiple chassis configurations
  - International Chassis & MaxxForce Engine
  - Ford Chassis & Cummins Engine
- Handles multiple drive cycle profiles
  - CILCC, Orange County, custom (telematics field data)
- Used chassis dyno test data to correlate/characterize simulation
Plant Modeling in support of MBD
Simscape Overview

- Simscape™ is being used for modeling each of these components
  - Simscape™ is a multidomain physical system modeling environment from MathWorks
  - Simscape™ employs a Physical Network approach, where physical connections are made in order to match the structure of the system you are developing
    - Non-causal method with domain-specific physical connections that allow the energy exchange between physical components to occur.
    - Allows the plant models to evolve over time without having to modify the overall structure
  - Simscape™ also includes the ability to create custom blocks using the object-oriented Simscape modeling language
  - In this project, we are utilizing mechanical, electrical, driveline and Power Systems domains
Plant Modeling in support of MBD
Example results: Vehicle Speed [mph]
Plant Modeling in support of MBD
Example Results: ESS SOC [%]
Plant Modeling in support of MBD

Summary

- Using Simscape™ for Vehicle Plant Model Simulation assists in the development of the vehicle system and controls
- Validation of the Plant Model can be done by easily importing Dynamometer and/or Vehicle data into Simulink and comparing against the Simulation results
- Simscape™ components can be parameterized with manufacturer's specifications
- Simulations can be run in parallel on multicore processors, GPUs, and computer clusters, using Parallel Computing Toolbox™
- Models can be parameterized for different vehicle variants, to support different Engine/Transmission combinations, for example
Virtual Engine Calibration Optimization (VECO)

- Cylinder Pressure
  - Torque (15 Operating Levels)
- Speed (15 Operating Levels)
- Fuel → Air/Fuel Ratio
- Throttle Position
- Ignition Timing
- Pressure

Turbo Wastegate Area
What Was Engine Calibration?

Sketch

Model and Design

Iterate: 4 year delay

"Calibrate" By Adjusting A Few Screws

Build

Engine’s Performance

Test

Cannot Be Judged

Until It Is Calibrated

Model and Calibrate, Build, Experiment, Optimize

What Is Advanced Engine Calibration Now?

Model, Experiment, Fit, Optimize

Calibrate 1350 Numbers via DoE, RSM, Numerical Optimization

Calibrate By Adjusting 1350 Numbers

Virtual Engine Calibration Optimization (VECO)

28 day wait on 1 Core

2 hr wait on 225 Cores

3 day wait on 64 Cores

Engine’s Performance is Calibrated
Virtual Engine Calibration Optimization (VECO)
Base Engine Calibration Problem Addressed by VECO

1. Ignition Timing
2. Throttle Position
3. Turbo Wastegate Area
4. Fuel → Air/Fuel Ratio
5. Intake Cam Phasing
6. Exhaust Cam Phasing → NOx

Cylinder Pressure → Torque (15 Operating Levels)
Speed (15 Operating Levels)
Virtual Engine Calibration Optimization (VECO) 
Calibrations Produced By VECO Process

Engine Controller

15 Engine Speeds
X
15 Engine Torques
X
6 Variables
1350 Calibration Values

Ignition Timing

Air/Fuel Ratio

Throttle Position

Intake Cam Phaser

Turbo Wastegate Area

Exhaust Cam Phaser
Virtual Engine Calibration Optimization (VECO) Example VECO At One Operating Point

Brake-Specific Fuel Consumption (BSFC)

Ignition Timing

1.5L SI DOHC I4 GDI Dual VCP Turbo Application Example
Virtual Engine Calibration Optimization (VECO) Parallel Computing Used for 225x Speed-Up

Automated Base Engine Calibration Maps In 2hrs!
Virtual Engine Calibration Optimization (VECO) Summary

- Engine Calibration Is a Major Bottleneck in Engine Design Process
- VECO Process For SI Engine Removes Base Calibration Bottleneck
- VECO Is Practical For Everyday Use Due To Parallel Computing
MBD Adoption Related Quotes

- “The most important need is the leadership vision”
- “An integrated MBD environment impacts many engineering functions and therefore it is an organizational challenge”
- “Not every organization is willing to take on the risk and in fact may not even support the initiative”
- “Change is difficult”
- “Without top level leadership support of the MBD initiative, it is extremely difficult to make substantial changes to a large organization”

Quotes of Edmund Hodzen from Cummins
Thank you for your attention!

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