Adoption of Model-Based Software for Vehicle Systems Development

Presented by:

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Crown Equipment Company

Material prepared for MathWorks Automotive Conference, May 9, 2017
One of the World’s Largest Material Handling Companies

- 5 regional headquarters
- 2.5 Billion USD FY2014
- 12,000 employees

- 17 manufacturing plants in 11 locations worldwide
- Over 500 retail locations across 84 countries
- Leader in material handling innovation and technology

- Global line of trucks designed to local work practices
- Innovative fleet management solutions
- Family owned and managed industry leader since 1945
Adopting Model Based Software

Agenda

I. Initial Goals
II. Architecture Decisions
III. Code Generation Experience
IV. Virtual Truck Simulations
V. Performance Improvements
VI. Verify, Test and Report
I. Model Based Software – Initial Goals

- Code Generation from Reusable Models for All Products
- Support Expansion of Features for New Technology
II. Model Based Software – Architecture Decisions

Initial MBS Version:
- MATLAB
- Simulink
- Stateflow

Data Dictionary Concept
Shared Network Files
(8) Legacy MATLAB Users
II. Model Based Software – Architecture Decisions

Initial MBS Version:
- MATLAB
- Simulink
- Stateflow
Data Dictionary Concept
Shared Network Files
(8) Legacy MATLAB Users

R2011b
### III. Model Based Software – Code Generation

#### Initial Code Gen:
- MATLAB Coder
- Simulink Coder
- Embedded Coder
(4) System Developers

#### Initial MBS Version:
- MATLAB
- Simulink
- Stateflow
Data Dictionary Concept
Shared Network Files
(8) Legacy MATLAB Users

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Virtual Subsystem</th>
<th>Atomic Subsystem</th>
<th>Model Reference</th>
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<tbody>
<tr>
<td>Ease of Use</td>
<td>+</td>
<td>+</td>
<td>-</td>
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<tr>
<td>Readability</td>
<td>+</td>
<td>+</td>
<td>+</td>
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<td>Traceability</td>
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<td>Reusability</td>
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<tr>
<td>Concurrent Development</td>
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<tr>
<td>Unit Testing</td>
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<tr>
<td>Performance</td>
<td></td>
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<td>+, -</td>
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#### Modular Model Design

- Simulink Coder
- Embedded Coder
(4) System Developers

- MATLAB Coder
- Simulink Coder
- Embedded Coder
(8) Legacy MATLAB Users

- (8) Legacy MATLAB Users
- Simulink
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- (8) Legacy MATLAB Users
III. Model Based Software – Code Generation

Initial Code Gen:
> 2 Hrs to Generate Code
Single Core - 8 GB RAM
SVN Source Control
(4) System Developers

Initial MBS Version:
- MATLAB
- Simulink
- Stateflow
Data Dictionary Concept
Shared Network Files
(8) Legacy MATLAB Users

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R2012b
### III. Model Based Software – Signals and Parameters

<table>
<thead>
<tr>
<th>Signal</th>
<th>Type</th>
<th>Interconnection</th>
<th>Signal-to-Signal</th>
<th>Signal-to-Parameter</th>
<th>Parameter-to-Signal</th>
<th>Parameter-to-Parameter</th>
<th>Constraint</th>
<th>Additional</th>
<th>Notes</th>
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Initial Code Gen:
- MATLAB Coder
- Simulink Coder
- Embedded Coder
- (4) System Developers

Individual Builds:
- Simscape
- MATLAB Report Generator
- Simulink Report Generator
- Virtual Truck, HiL
- Shared Code Placement
- Reference Config Sets
- (8) System Developers

Software environment
-CODE Replacement library: None
-Shared code placement: Shared location
III. Model Based Software – Code Generation

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- > 2 Hrs to Generate Code
- Single Core - 8 GB RAM
- SVN Source Control
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Initial MBS Version:
- MATLAB
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Individual Builds:
- 10-20 Minute Code Gen
- Single Core - 16 GB RAM
- IBM’s RTC Source Control
- (8) System Developers

R2011b
R2012b
R2014a

Auto Gen C-CODE

Steering
Traction
Diagnoistic
Energy
Common
Hydraulic
VFB
CAL
Vehicle Apps

- **20** System Apps
- **200** Simulink Models
- **2000** Model Parameters
- **1** Auto Gen C-Code
  - 325K Lines of Code

Model Based Vehicle System Apps

- Steering
- Traction
- Diagnostic
- Energy
- Common
- Hydraulic
- Auto Gen C-CODE

APP Verification

System App Design
IV. Model Based Software – Virtual Truck
IV. Model Based Software – Virtual Truck

Lift Speed Correlation (test vs model)

Pressure Correlation (test vs model)
V. Model Based Software – Improved Performance

Initial MBS Version:
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Initial Code Gen:
- MATLAB Coder
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- Embedded Coder
- (4) System Developers

Parallel Builds:
- Parallel Computing Toolbox
- Polyspace Static Analysis
- V&V Toolbox
- Parallel Simulation and Build
- (12) System Developers

Individual Builds:
- Simscape
- MATLAB Report Generator
- Simulink Report Generator
- Virtual Truck, HiL
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- Reference Config Sets
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Desktop
Parallel Computing Toolbox
Simulink, Blocksets, and Other Toolboxes
MATLAB®
V. Model Based Software – Improved Performance

Initial MBS Version:
- MATLAB
- Simulink
- Stateflow
- Data Dictionary Concept
- Shared Network Files
- (8) Legacy MATLAB Users

Parallel Builds:
- 5-10 Minute Code Gen
- Quad Core - 32 GB RAM
- GIT Distributed Source Control
- (12) System Developers

Individual Builds:
- 10-20 Minute Code Gen
- Single Core - 16 GB RAM
- IBM’s RTC Source Control
- (8) System Developers

Initial Code Gen:
- > 2 Hrs to Generate Code
- Single Core - 8 GB RAM
- SVN Source Control
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VI. Model Based Software – Verify, Test & Report

Initial MBS Version:
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Parallel Builds:
- Parallel Computing Toolbox
- Polyspace Static Analysis
- V&V Toolbox
Parallel Simulation and Build
(12) System Developers

Test & Report:
- Simulink Test
- MATLAB Compiler
- Bi-Directional Req's Links
(20) System Developers

Individual Builds:
- Simscape
- MATLAB Report Generator
- Simulink Report Generator
Virtual Truck, HIL,
Shared Code Placement
Reference Config Sets
(8) System Developers

Verification:
- Dependency Analysis
- Simulink Design Verifier
- 3-way compare and merge
(16) System Developers

R2011b
R2012b
R2014a
R2015b
R2016b
R2017?
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Data Dictionary Concept
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Initial Code Gen:
> 2 Hrs to Generate Code
Single Core - 8 GB RAM
SVN Source Control
(4) System Developers

Parallel Builds:
5-10 Minute Code Gen
Quad Core - 32 GB RAM
GIT Distributed Source Control
(12) System Developers

Test & Report:
Simulink Test,
MATLAB Compiler,
Bi-Directional Req's Links
(20) System Developers

Individual Builds:
10-20 Minute Code Gen
Single Core - 16 GB RAM
IBM’s RTC Source Control
(8) System Developers

Verification:
5-10 Minute Code Gen
Quad Core with 32 GB RAM
GIT Distributed Source Control
(16) System Developers

VI. Model Based Software – Verify, Test & Report
VI. Model Based Software – Verify, Test & Report

- Design
- Simulation
- Truck
- Code

- Specification
- Control Algorithm Fine Tuning
- Virtual
- Physical
- Verification
- Coverage Analysis
Global Locations

- **USA**
  - New Bremen, Ohio
  - New Castle, Indiana
  - Greencastle, Indiana
  - Kinston, North Carolina
  - Celina, Ohio
  - Minster, Ohio
  - New Bremen, Ohio
  - New Knoxville, Ohio

- **EUROPE**
  - Munich, Germany
  - Roding, Germany

- **MEXICO**
  - Querétaro

- **CHINA**
  - Suzhou

- **AUSTRALIA**
  - Sydney

- **SINGAPORE**
  - Singapore