Adoption of Model-Based Software for Vehicle Systems Development

Presented by:
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Crown Equipment Company

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One of the World’s Largest Material Handling Companies

- Leader in material handling innovation and technology
- 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:
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### III. Model Based Software – Code Generation

#### Initial MBS Version:
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- Legacy MATLAB Users

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

#### Model Based Software – Code Generation

#### Modular Model Design

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

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## III. Model Based Software – Signals and Parameters

| Column 1 | Column 2 | Column 3 | Column 4 | Column 5 | Column 6 | Column 7 | Column 8 | Column 9 | Column 10 | Column 11 | Column 12 | Column 13 | Column 14 | Column 15 | Column 16 | Column 17 | Column 18 | Column 19 | Column 20 | Column 21 | Column 22 | Column 23 | Column 24 | Column 25 | Column 26 | Column 27 | Column 28 | Column 29 | Column 30 | Column 31 | Column 32 | Column 33 | Column 34 | Column 35 | Column 36 | Column 37 | Column 38 | Column 39 | Column 40 | Column 41 | Column 42 | Column 43 | Column 44 | Column 45 | Column 46 | Column 47 | Column 48 | Column 49 | Column 50 | Column 51 | Column 52 | Column 53 | Column 54 | Column 55 | Column 56 | Column 57 | Column 58 | Column 59 | Column 60 | Column 61 | Column 62 | Column 63 | Column 64 | Column 65 | Column 66 | Column 67 | Column 68 | Column 69 | Column 70 | Column 71 | Column 72 | Column 73 | Column 74 | Column 75 | Column 76 | Column 77 | Column 78 | Column 79 | Column 80 | Column 81 | Column 82 | Column 83 | Column 84 | Column 85 | Column 86 | Column 87 | Column 88 | Column 89 | Column 90 | Column 91 | Column 92 | Column 93 | Column 94 | Column 95 | Column 96 | Column 97 | Column 98 | Column 99 | Column 100 | Column 101 | Column 102 | Column 103 | Column 104 | Column 105 | Column 106 | Column 107 | Column 108 | Column 109 | Column 110 | Column 111 | Column 112 | Column 113 | Column 114 | Column 115 | Column 116 | Column 117 | Column 118 | Column 119 | Column 120 |
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Software environment
Code replacement library: None
Shared code placement: Shared location

Individual Builds:
• Simscape
• MATLAB Report Generator
• Simulink Report Generator
Virtual Truck, HiL
Shared Code Placement
Reference Config Sets
(8) System Developers
III. Model Based Software – Code Generation

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**R2011b**
- Individual Builds:
  - Simscape
  - MATLAB Report Generator
  - Simulink Report Generator
  - Virtual Truck, HiL
  - Shared Code Placement
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  - (8) System Developers

**R2012b**
- Auto Gen C-CODE

**R2014a**
- Energy
- Hydraulic
- Common

**Diagnosis**
- Traction
- Steering

**Common**
- VFB
- CAL
- Energy
- Hydraulic
- Common

**Auto Gen C-CODE**
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Individual Builds:
10-20 Minute Code Gen
Single Core - 16 GB RAM
IBM’s RTC Source Control
(8) System Developers
OnTrac™ Traction Control
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

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

Individual Builds:
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Desktop

Parallel Computing Toolbox

Simulink, Blocksets, and Other Toolboxes
V. Model Based Software – Improved Performance

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**Parallel Builds:**
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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
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**Desktop**

- Parallel Computing Toolbox
  - Simulink, Blocksets, and Other Toolboxes
- MATLAB

**R2011b**
- R2012b
- R2014a
- R2015b
VI. Model Based Software – Verify, Test & Report

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**Test & Report:**
- Simulink Test
- MATLAB Compiler
- Bi-Directional Req’s Links
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  - MATLAB Report Generator
  - Simulink Report Generator
  - Virtual Truck, HIL,
  - Shared Code Placement
  - Reference Config Sets
(8) System Developers

**R2014a**
- Verification:
  - Dependency Analysis
  - Simulink Design Verifier
  - 3-way compare and merge
(16) System Developers

**R2015b**
- Test & Report:
  - Simulink Test
  - MATLAB Compiler
  - Bi-Directional Req’s Links
(20) System Developers

**R2016b**
- Parallel Simulation and Build
(12) System Developers

**R2017?**
VI. Model Based Software – Verify, Test & Report

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R2011b
R2012b
R2014a
R2015b
R2016b
R2017?

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VI. Model Based Software – Verify, Test & Report

- Design
  - Specification
  - Control Algorithm Fine Tuning
- Simulation
  - Virtual
  - Coverage Analysis
- Truck
  - Physical
- Code
  - Verification
Global Locations

500 retail locations across 84 countries
386 dealers and 114 branches

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