

# 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



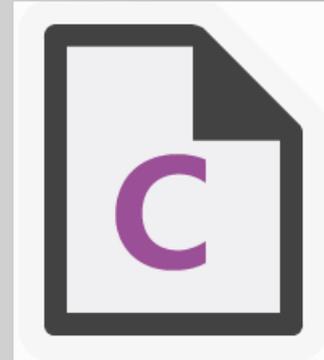
# Adopting Model Based Software

## 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



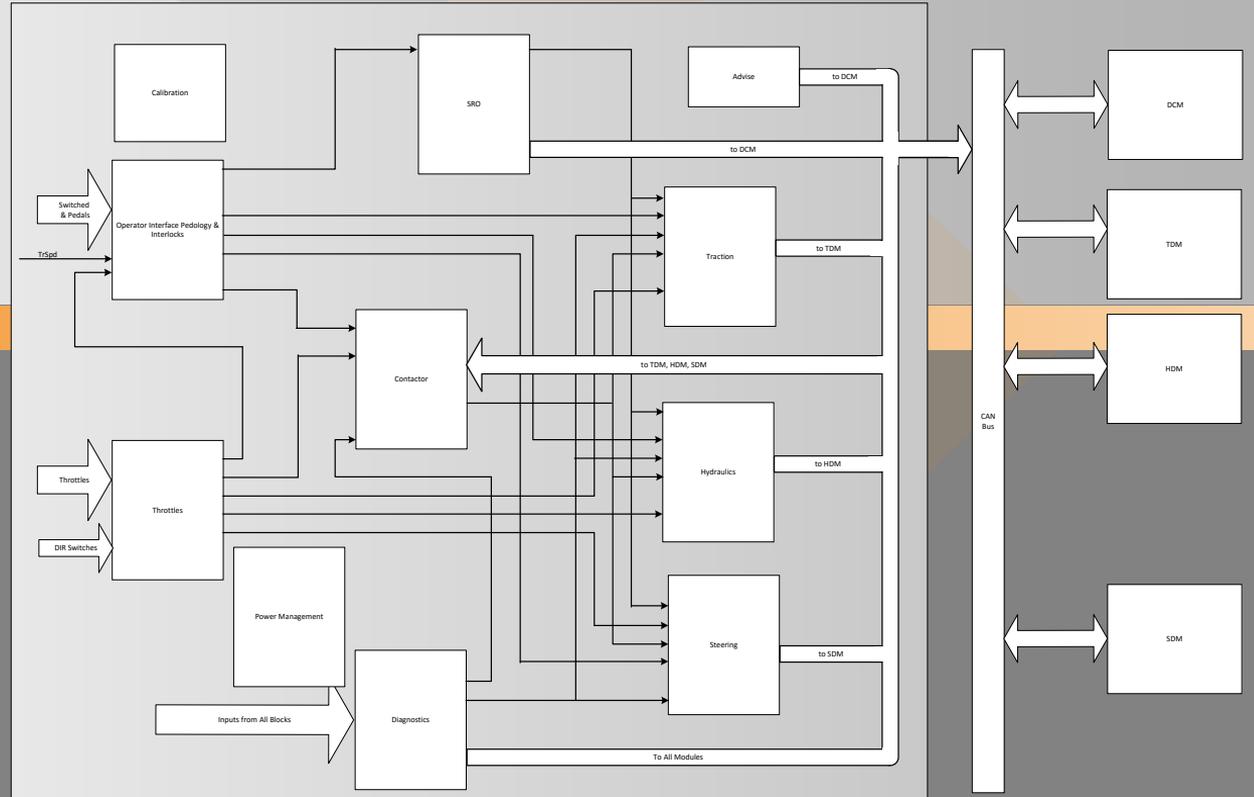
# II. Model Based Software – Architecture Decisions

R2011b

## Initial MBS Version:

- MATLAB
- Simulink
- Stateflow

Data Dictionary Concept  
Shared Network Files  
(8) Legacy MATLAB Users



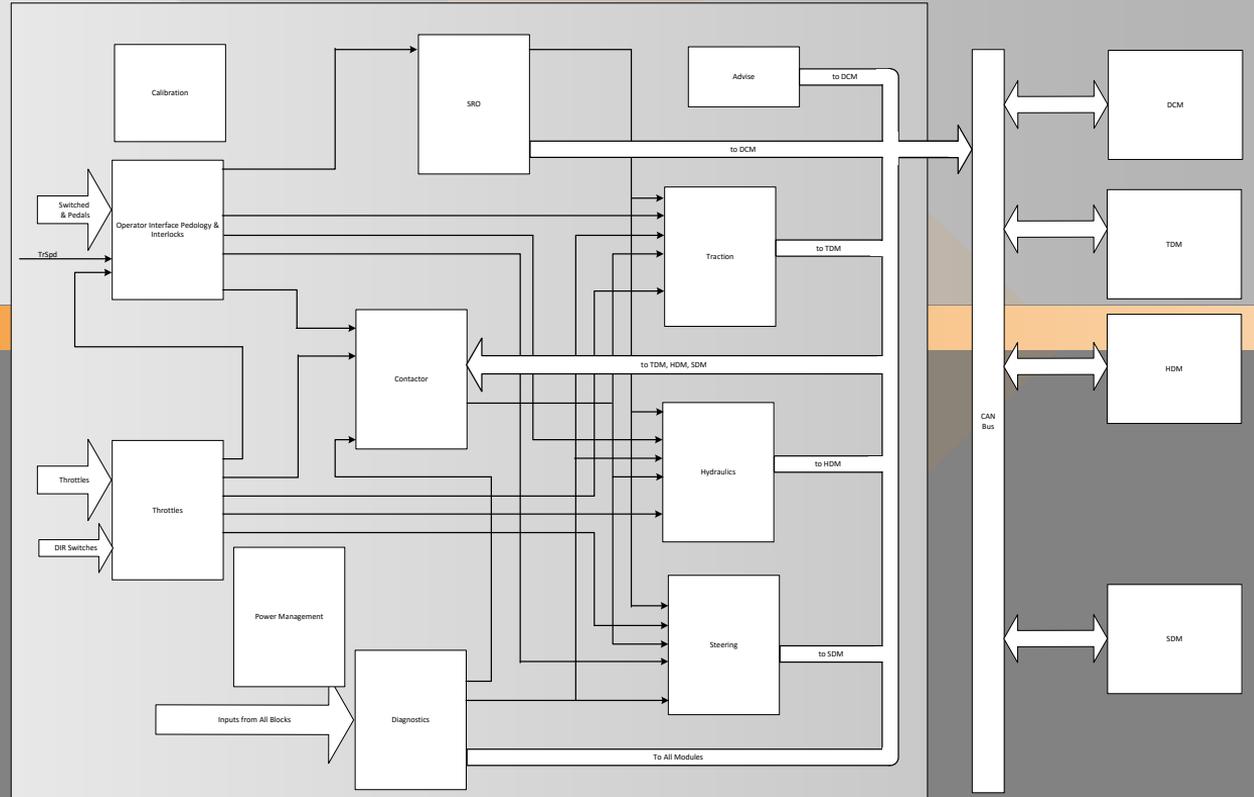
# II. Model Based Software – Architecture Decisions

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# III. Model Based Software – Code Generation

## Modular Model Design

### Initial Code Gen:

- MATLAB Coder
  - Simulink Coder
  - Embedded Coder
- (4) System Developers

R2011b

R2012b

### Initial MBS Version:

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Benefits	Virtual Subsystem	Atomic Subsystem	Model Reference
Ease of Use	+	+	-
Readability	+	+	+
Traceability		+	+
Reusability			+
Concurrent Development			+
Unit Testing			+
Performance			+, -

# III. Model Based Software – Code Generation

## Initial Code Gen:

- MATLAB Coder
  - Simulink Coder
  - Embedded Coder
- (4) System Developers

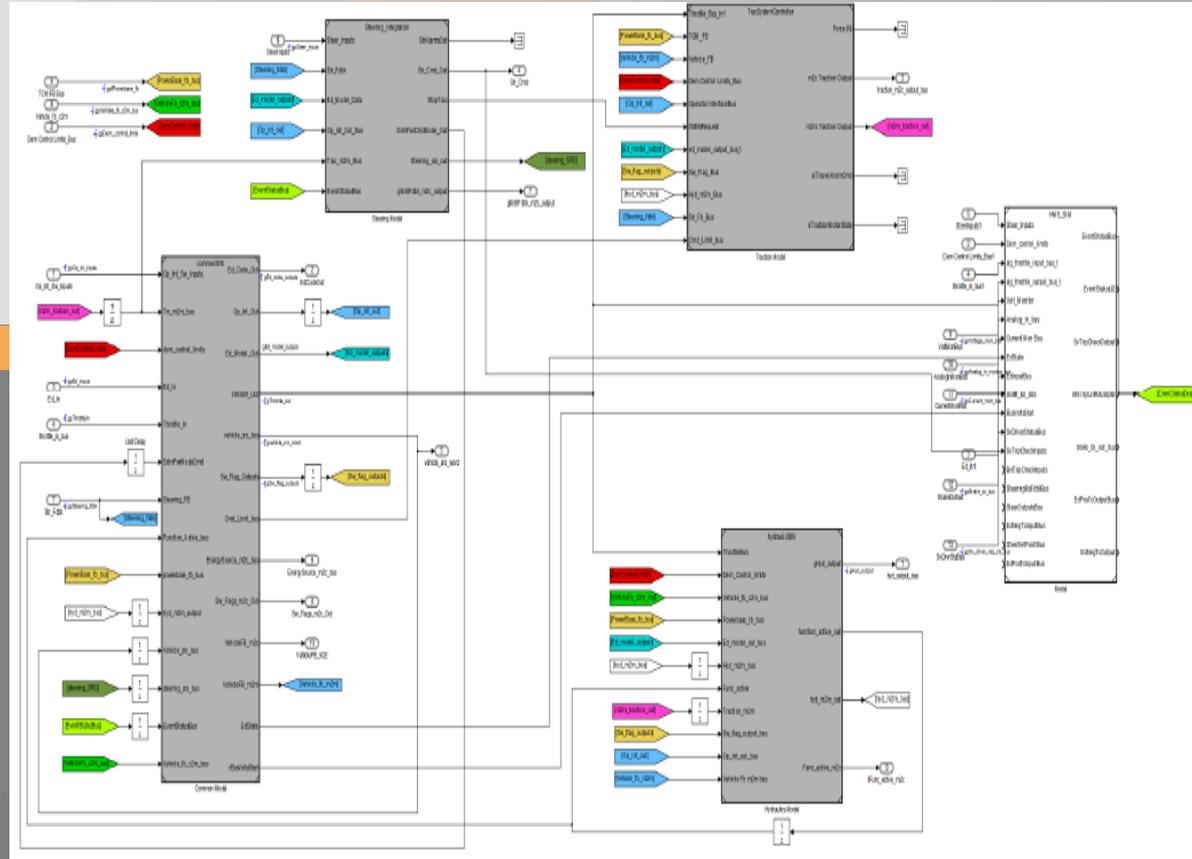
R2011b

R2012b

## Initial MBS Version:

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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

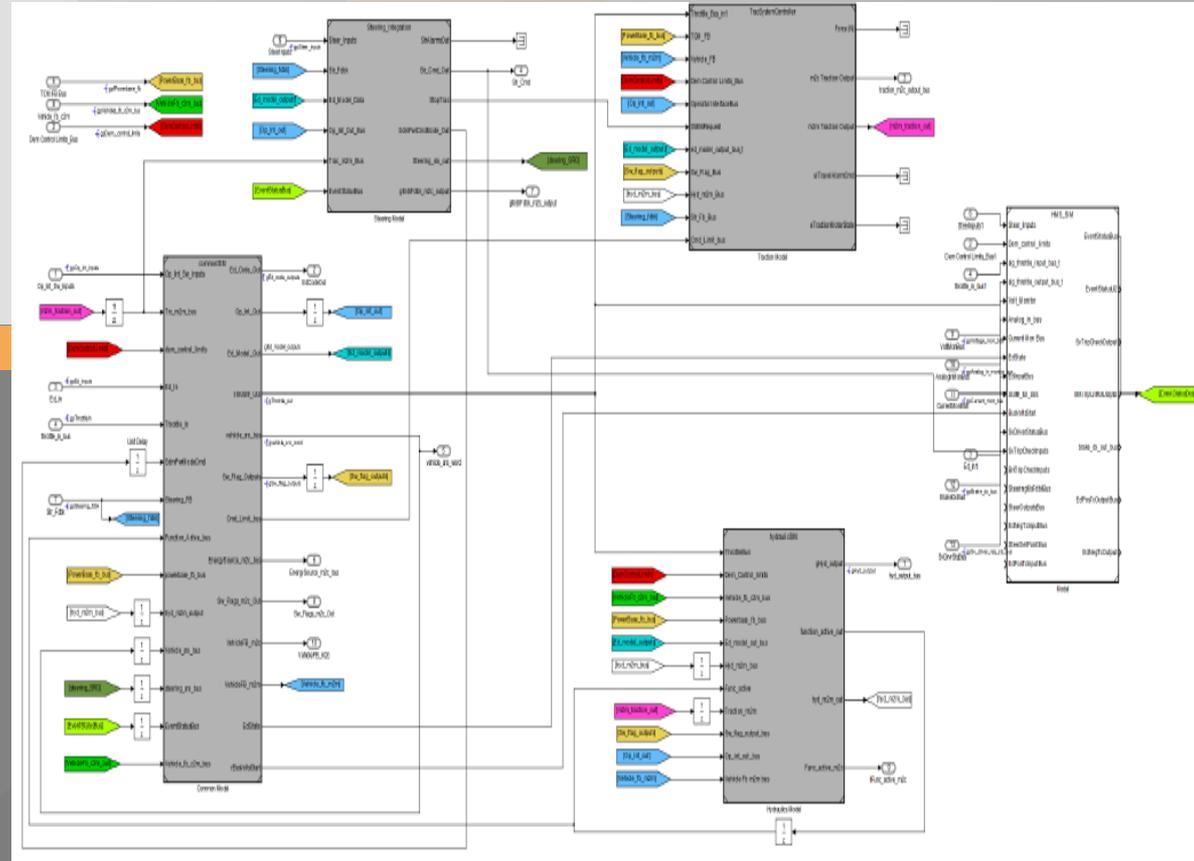
R2011b

R2012b

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# III. Model Based Software – Code Generation

## Initial Code Gen:

- MATLAB Coder
  - Simulink Coder
  - Embedded Coder
- (4) System Developers

## Software environment

Code replacement library:

Shared code placement:

R2011b

R2012b

R2014a

## Initial MBS Version:

- MATLAB
  - Simulink
  - Stateflow
- Data Dictionary Concept  
Shared Network Files  
(8) Legacy MATLAB Users

## Individual Builds:

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

- Normal
- Normal
- Accelerator
- Rapid Accelerator
- Software-in-the-Loop (SIL)
- Processor-in-the-Loop (PIL)
- External

commonSIMbuild

- Model Workspace
- Reference (Active)

# III. Model Based Software – Code Generation

## Initial Code Gen:

- MATLAB Coder
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R2011b

R2012b

R2014a

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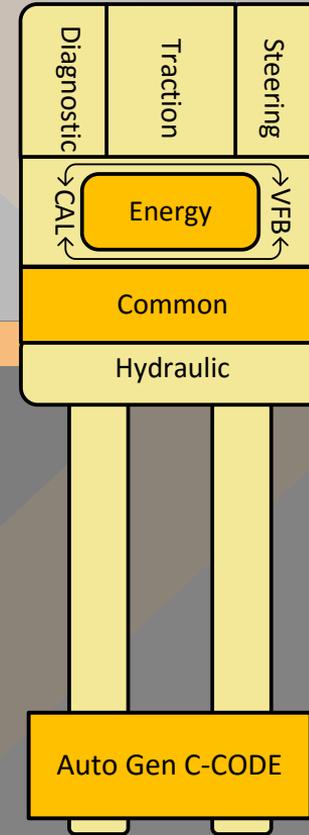
- Simscape
- MATLAB Report Generator
- Simulink Report Generator

Virtual Truck, HiL,

Shared Code Placement

Reference Config Sets

(8) System Developers



# III. Model Based Software – Code Generation

## Initial Code Gen:

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R2011b

R2012b

R2014a

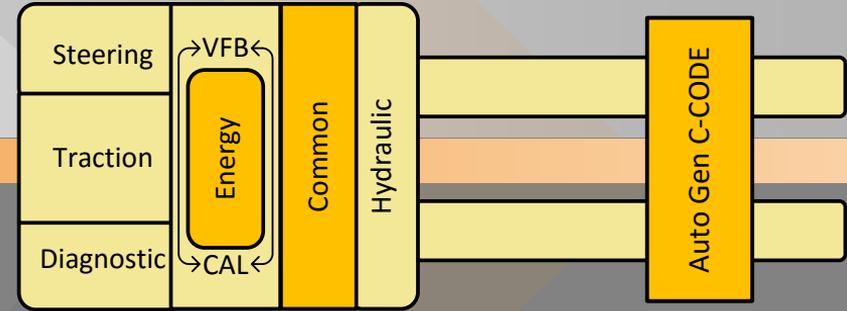
## Initial MBS Version:

- MATLAB
- Simulink
- Stateflow

Data Dictionary Concept  
Shared Network Files  
(8) Legacy MATLAB Users

## Individual Builds:

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



# Vehicle Apps

20

System Apps

200

Simulink Models

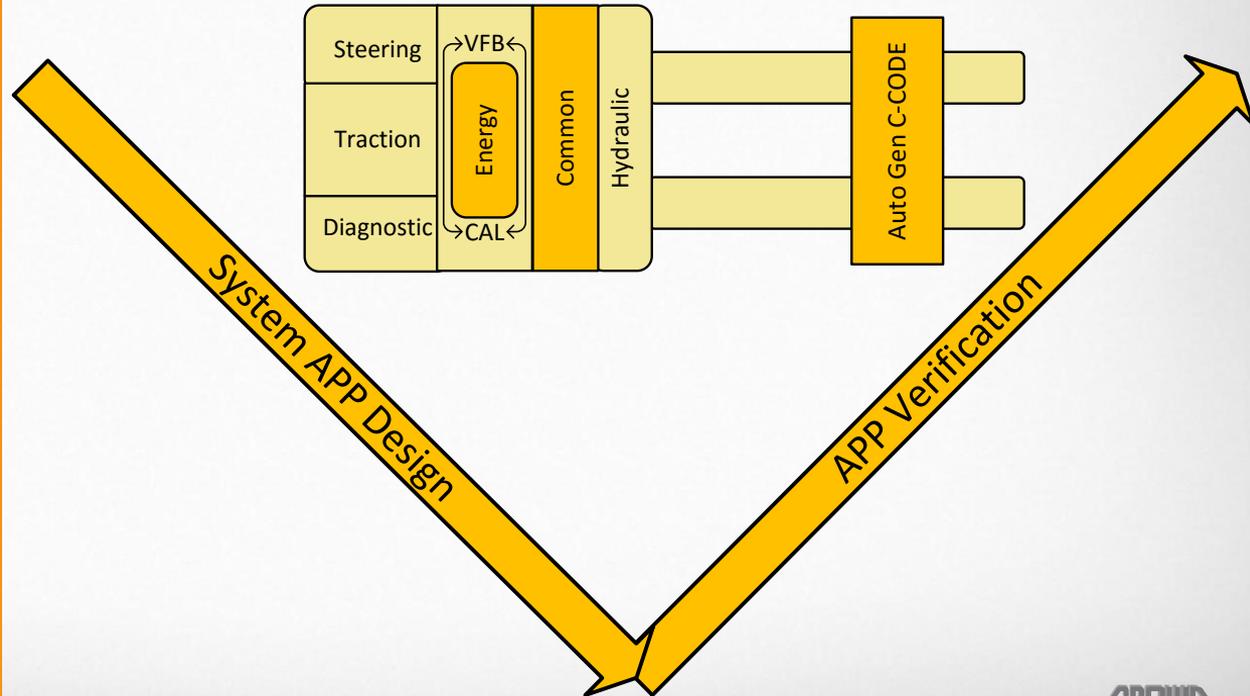
2000

Model Parameters

1

Auto Gen C-Code  
325K Lines of Code

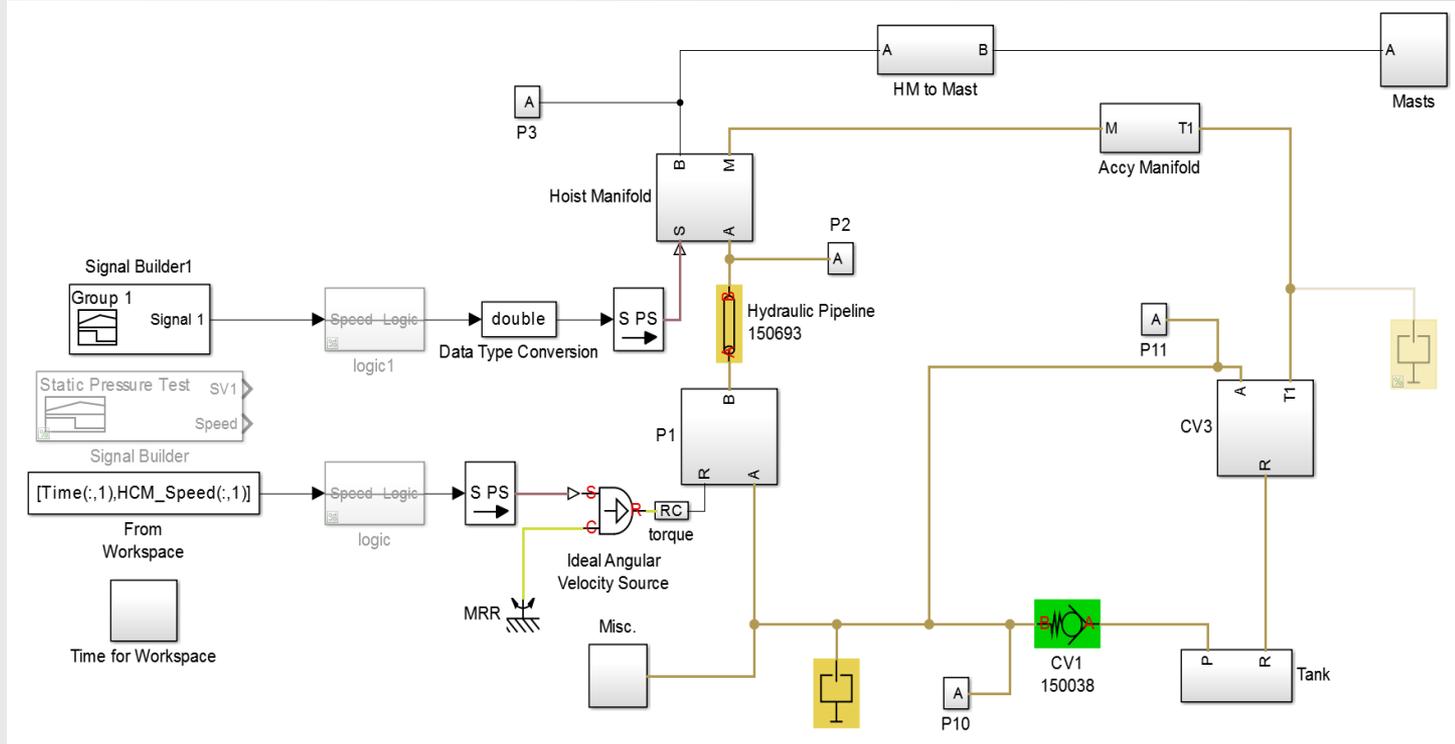
## Model Based Vehicle System Apps



# OnTrac™ Traction Control

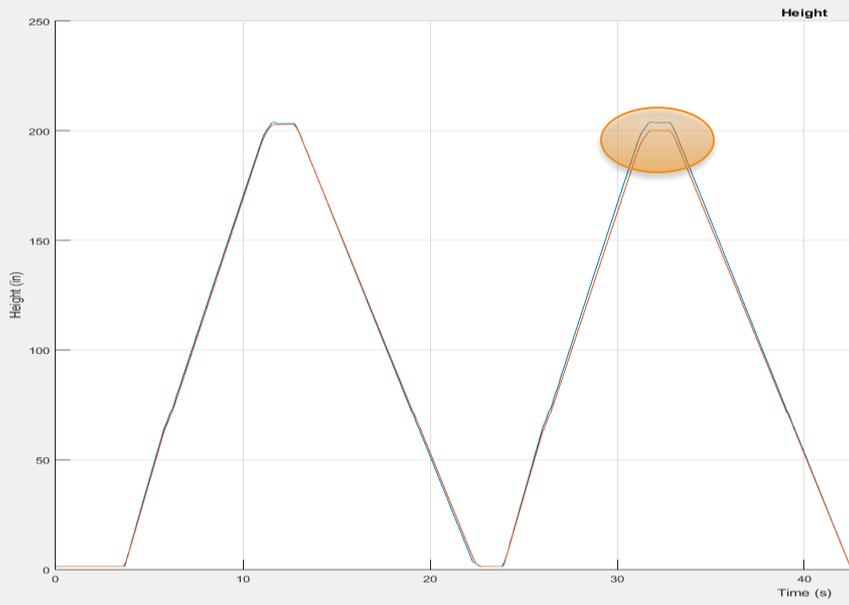


# IV. Model Based Software – Virtual Truck

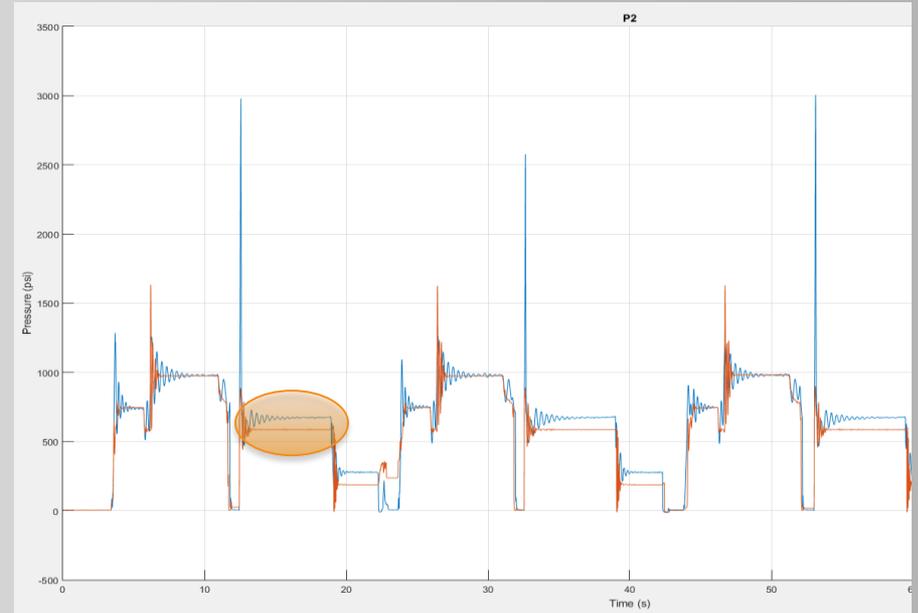


# IV. Model Based Software – Virtual Truck

## Lift Speed Correlation (test vs model)



## Pressure Correlation (test vs model)



# V. Model Based Software – Improved Performance

## Initial Code Gen:

- MATLAB Coder
  - Simulink Coder
  - Embedded Coder
- (4) System Developers

## Parallel Builds:

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

R2011b

R2012b

R2014a

R2015b

## Initial MBS Version:

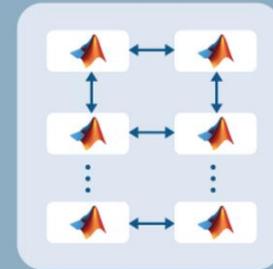
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  - Simulink Report Generator
- Virtual Truck, HiL,  
Shared Code Placement  
Reference Config Sets  
(8) System Developers

## Desktop

### Parallel Computing Toolbox



Simulink,  
Blocksets, and  
Other Toolboxes

MATLAB®

# V. Model Based Software – Improved Performance

R2011b

## Initial Code Gen:

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

R2012b

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R2014a

## Individual Builds:

10-20 Minute Code Gen  
Single Core - 16 GB RAM  
IBM's RTC Source Control  
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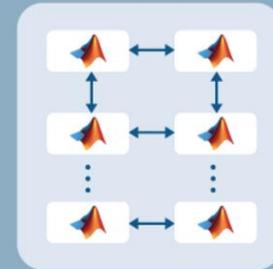
R2015b

## Parallel Builds:

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

## Desktop

### Parallel Computing Toolbox



Simulink,  
Blocksets, and  
Other Toolboxes

MATLAB®

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

## Initial Code Gen:

- MATLAB Coder
  - Simulink Coder
  - Embedded Coder
- (4) System Developers

## 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

R2011b

R2012b

R2014a

R2015b

R2016b

R2017?

## Initial MBS Version:

- MATLAB
  - Simulink
  - Stateflow
- Data Dictionary Concept  
Shared Network Files  
(8) Legacy MATLAB Users

## 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

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

## 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  
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GIT Distributed Source Control  
(12) System Developers

## Test & Report:

Simulink Test,  
MATLAB Compiler,  
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R2011b

R2012b

R2014a

R2015b

R2016b

R2017?

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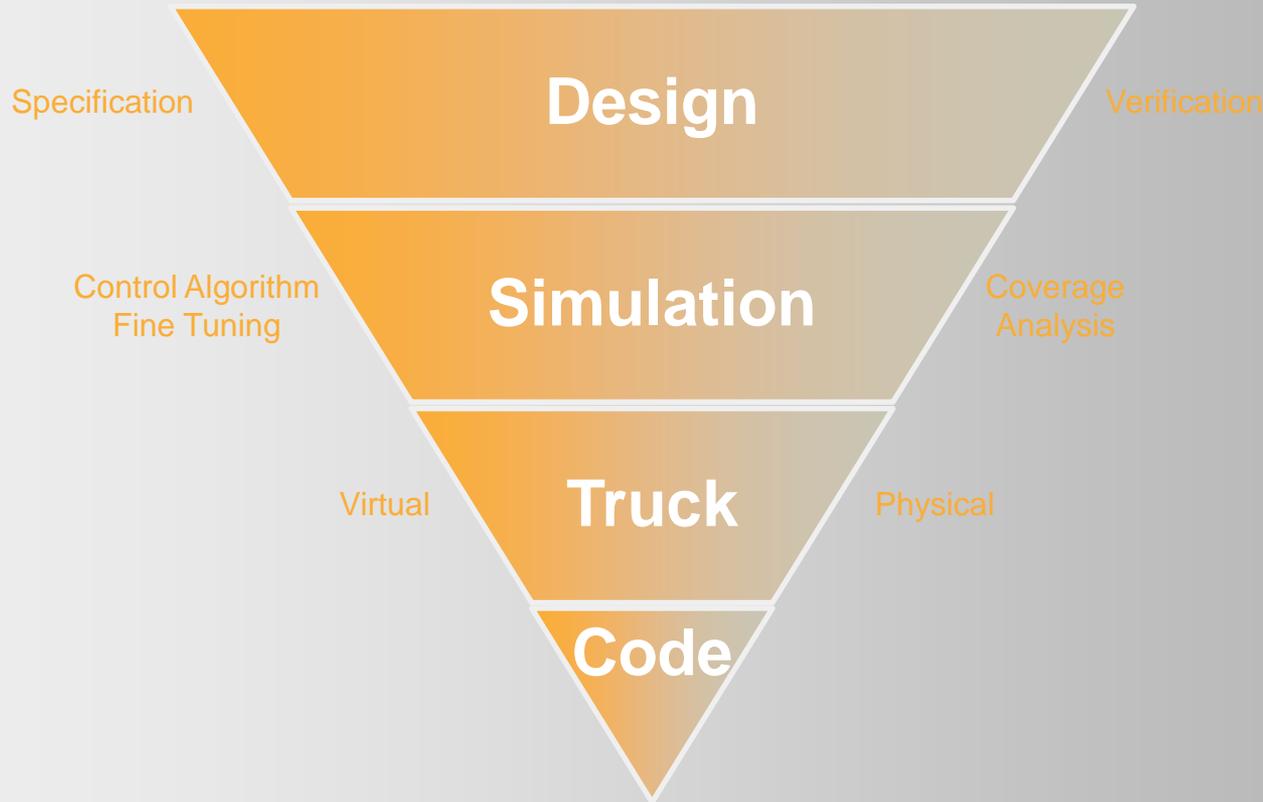
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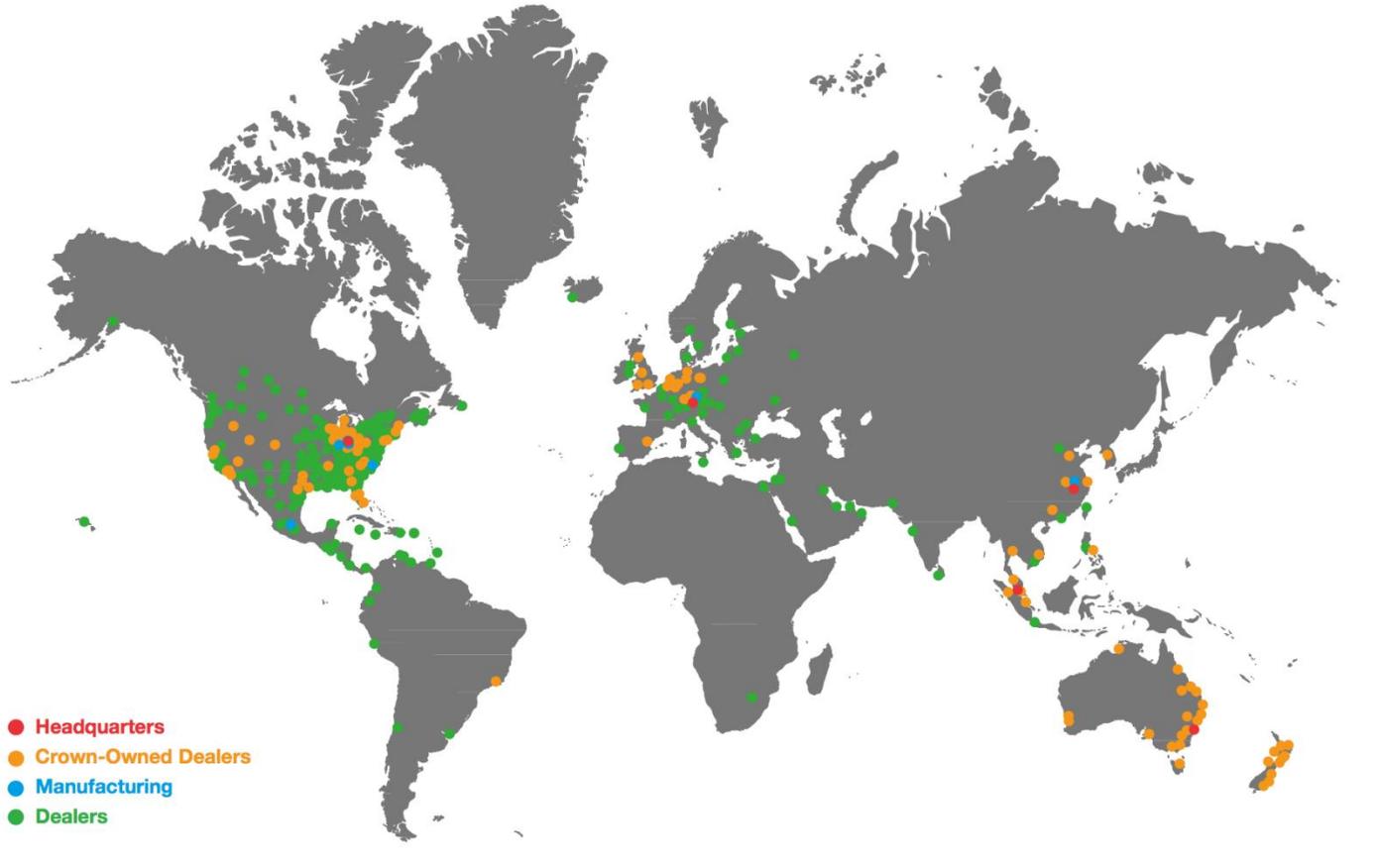
## Verification:

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



# 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  
Suzhou

## AUSTRALIA

Sydney

## SINGAPORE

Singapore

**CROWN**

**IDEAS THAT ADVANCE**