Transforming the Software Development Paradigm to Meet Unique Needs of Our Industry and Customers

Jeff Daiker
Executive Director
Global Dynamic Systems and Controls
May 5, 2021
Agenda

- Who we are: Cummins history and key data
- The Industry Background: Key enablers for AUTOSAR based architecture
- Cummins Approach:
  - High level overview of C-SAR
  - Model-based development and virtual validation
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Our history

For more than 100 years, we have defined ourselves by our unwavering values and our promise of innovation and dependability. In the next 100, we will continue to challenge the impossible. Here’s a look at some highlights from our past 100 years:

1919: Clessie Cummins creates the Cummins Engine Company based in Columbus, Indiana (U.S.A.). William G. Irwin, who employed Cummins as a driver, supplies nearly all of the $50,000 in startup capital.

1929: Cummins takes Irwin for a ride in a used Packard limousine that he equipped with a diesel engine on Christmas Day, convincing Irwin of the engine’s potential. Irwin invests a much-needed infusion of cash.

1932: Cummins barnstorms across the country, demonstrating the power and fuel efficiency of the diesel engine in his Coast to Coast Cummins Diesel Test Bus.

1937: Cummins earns its first profit.

1944: Miller becomes Executive Vice President of Cummins.

1949: Miller becomes Chairman of the Cummins Board.

1951: Cummins begins operations in India, first as a joint venture with one plant in Pune.

1962: Cummins purchases 86 percent of the Onan Corporation in Minneapolis, Minnesota (USA), which would become the basis for its Power Generation Business.

1962: Miller becomes Chairman of the Cummins Board.

1975: Cummins enters China as part of a deal involving heavy construction equipment with Cummins engines.

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1990: Cummins celebrates 100-year anniversary.

2000: Cummins Engine Company becomes Cummins Inc. to acknowledge it is also a leader in global markets including filtration and power generation.

2017: Cummins redefines Our Story including the Mission and Values around its Vision of “Making people’s lives better by powering a more prosperous world.”

2019: Cummins celebrates 100-year anniversary.

2019: Cummins redefines Our Story including the Mission and Values around its Vision of “Making people’s lives better by powering a more prosperous world.”
## Powering a more prosperous world in 2020

<table>
<thead>
<tr>
<th>Countries &amp; territories*</th>
<th>Global employees</th>
<th>Engines built in 2020**</th>
</tr>
</thead>
<tbody>
<tr>
<td>190</td>
<td>57,825</td>
<td>1.3M</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cummins certified dealer locations</th>
<th>Invested in research &amp; technology in 2020</th>
<th>Years of industry leadership</th>
</tr>
</thead>
<tbody>
<tr>
<td>9,000</td>
<td>$903M</td>
<td>102</td>
</tr>
</tbody>
</table>

*Approximation of countries and territories with Cummins service
**This includes engines from both our custodial plants and unconsolidated joint ventures.
As published in the 2020 10K found on cummins.com
Five operating segments

Cummins has a 102-year-long track record of delivering leading power solutions. As we look ahead, we know our industries and markets will continue to change, and we are committed to bringing our customers the right technology at the right time.
We serve many markets and applications

Heavy-duty Truck  Medium-duty Truck  Bus  Construction  Oil & Gas  Fire & Emergency  Power Generation  Electrolysis  Marine  Mining  Light-duty Automotive & Recreational Vehicle  Defense  Agriculture  Rail

This is not an exhaustive display of Cummins-powered markets. Please refer to cummins.com for the most updated product information.
Global partnerships

Companies listed on this slide reflect a view of top customers globally but is not an exhaustive list of global partnerships. Companies are listed in no particular order.
Controls Software and Platform evolution at Cummins

**Reducing cycle time, Improving Quality, Increased Reuse**

- **Pre-Core 1980s**
  - ECM development
  - SW development on HW platform
  - Controls system testing
  - Common workflow
  - Common tools
  - Software reuse

- **Core I 1990s**
  - ECM development
  - SW Porting Integration
  - Controls system testing
  - Controls tuning
  - New architecture
  - Improved workflow
  - Improved tools
  - Improved reuse concept

- **Core II 2000s**
  - ECM development
  - Controls system testing
  - Controls tuning
  - System testing

- **Future**
  - Cycle time = f(Reuse, quality, portability, flexibility, integratibility, complexity, …)

The Future is now
Model-Based Design at Cummins

Collaboration with 3rd party Collaborator

Application Support

Model Based Design

Controls Prototyping

Component Modeling

Early 2000s

Automatic Code Generation

Graphical Coding

2006

System Level Generation

Gap in Integration

2016

Simulation Based Development

AUTOSAR

2019

Simulation drives ROI of Model-Based Design

Developing the future
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“Our industry is in a transition. Technology, regulations and customer expectations are changing rapidly, requiring our teams to innovate so they can deliver the value our customers expect.”

Vice President and Chief Technical Officer Jim Fier
### Industry Trends

<table>
<thead>
<tr>
<th>Safety</th>
<th>(Cyber) Security</th>
<th>Integration</th>
</tr>
</thead>
<tbody>
<tr>
<td>• ISO 26262</td>
<td>• Ethernet, CAN FD</td>
<td>• OEM tools support</td>
</tr>
<tr>
<td>• SQA</td>
<td>• Gateway compliance</td>
<td>• Industry protocols</td>
</tr>
<tr>
<td>• CMMI</td>
<td>• Industry development practices</td>
<td>• OEM protocols</td>
</tr>
<tr>
<td>• ASPICE</td>
<td>• Regulations</td>
<td>• AUTOSAR</td>
</tr>
<tr>
<td></td>
<td>• Newer SAE standards for OBD Port</td>
<td></td>
</tr>
</tbody>
</table>

1. How can Cummins best position itself in times when OEMs are driving vertical integration to meet the market demands?  
2. Are our electronics and digital architectures and plans in place to meet the future needs?

**AUTOSAR**

Software Architecture

- Safety
- Powertrain
- Functional Safety
- Cyber Security
- Autonomous Driving
- Network Architecture
- V2X
- Transmission
- E/E System Complexity

1. How can Cummins best position itself in times when OEMs are driving vertical integration to meet the market demands?  
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### System Design Options Evaluation

Needs of customers translated into product needs and potential solutions

<table>
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<tr>
<th>Customer Needs</th>
<th>Product Needs</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasingly demanding product requirements (fuel economy, performance, emissions)</td>
<td>Physics model-based controls</td>
<td>▪ Expand hardware capacity with distributed modules</td>
</tr>
<tr>
<td></td>
<td>Machine learning</td>
<td>▪ New hardware technologies for safety and security.</td>
</tr>
<tr>
<td></td>
<td>Greater ECM processing power</td>
<td>▪ Leveraging System Simulation for feature design.</td>
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System Design Options Evaluation
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<tbody>
<tr>
<td>Increasing machine integration needs and changing powertrain technology portfolio</td>
<td>Module-agnostic software residence</td>
<td>▪ Adopt off-the-shelf industry standard OS for increased compatibility and interoperability.</td>
</tr>
<tr>
<td></td>
<td>Open vs. closed optionality</td>
<td>▪ A mix of Classic AUTOSAR and Adaptive AUTOSAR based on application needs.</td>
</tr>
<tr>
<td></td>
<td>Flexibility in scope of controls</td>
<td></td>
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System Design Options Evaluation
Needs of customers translated into product needs and potential solutions

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<tr>
<td>Faster software release and update time</td>
<td>More modular software architecture</td>
<td>▪ Design modular S/W architecture.</td>
</tr>
<tr>
<td></td>
<td>Component-level test capability</td>
<td>▪ Redesign controls processes to better balance quality and speed from end-</td>
</tr>
<tr>
<td></td>
<td>Faster end-to-end processes</td>
<td>to-end.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Leveraging System Simulation for virtual validation.</td>
</tr>
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</table>
Implement These Changes under One Initiative: C-SAR

- AUTOSAR and Model-Based Processes to enable Agile Development
- Tools that are commercially available and based on industry standards
- Infrastructure to support ISO26262/CMMI/ASPICE, Cybersecurity and industry expectations
- Transition to AUTOSAR-based Architecture using model-based principles
# C-SAR Drives Changes in Many Functional Areas

<table>
<thead>
<tr>
<th>Development process and tools</th>
<th>Controls Architecture</th>
<th>POC &amp; Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Define optimal end to end development process and tools for model centric controls development while ensuring AUTOSAR, Functional Safety and Cybersecurity compliance.</td>
<td>Establish a multi-platform architecture capable of supporting future Cummins products.</td>
<td>Define and implement a plan to demonstrate the “next gen” concept as well as the initial delivery to application teams.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diagnostics</th>
<th>Machine Communication Protocols</th>
<th>Electronic Tools Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deliver an architecture and a plan to transition Cummins proprietary diagnostics approach into the AUTOSAR implementation.</td>
<td>Deliver an architecture and a plan to transition Cummins communications protocols to the AUTOSAR implementation.</td>
<td>Re-architect the existing tool interfaces and related infrastructure and tools. Includes replacing proprietary protocols with UDS and XCP, adding ethernet, security updates, support for non-CMI devices.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Simulation Ecosystem</th>
<th>Strategy and Planning</th>
<th>Plant Modeling and Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deliver an embedded controls validation environment that enables simulation processes for the Next Generation Controls.</td>
<td>Define overall direction and ensure alignment of resources. Responsible for the overall schedule and priorities.</td>
<td>Deliver requirements to Next Gen design in order to enable efficient PureSim plant modeling and system simulation capability.</td>
</tr>
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A Clean-Sheet Multi-platform Architecture
Model Centric, Distributed Computing, Standard-Based, Off-the-Shelf Tools

AUTOSAR & Model-Based Design

Agile Development

AUTOSAR and Model Based Processes to enable Agile Development

Application Authoring

BSW Configuration

Tools that are commercially available and based on industry standards

AUTOSAR BSW & MCAL

Modeling in Simulink

Infrastructure to support ISO26262/CMMI/ASPICE, Cybersecurity and industry expectations

Top-Down Workflow

Multi-Platform Architecture

Transition to AUTOSAR-based Architecture using MBD principles
Enable Agile Development
with AUTOSAR and Model Based Processes

Traditional Pluggable Functions

AUTOSAR SW Components

Modern Pluggable Components

AUTOSAR & MBD

Agile Development

AUTOSAR and Model Based Processes
to enable Agile Development
Leverage Synergy Across AUTOSAR, ISO 26262, Model-Based Design

### Table 3 – Principles for Software Architectural Design

<table>
<thead>
<tr>
<th>1a</th>
<th>1b</th>
<th>1c</th>
<th>1d</th>
<th>1e</th>
<th>1f</th>
<th>1g</th>
<th>1h</th>
<th>1i</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restricted use of interrupts</td>
<td>Appropriate hierarchical structure of the software components</td>
<td>Restricted size and complexity of software components</td>
<td>Restricted size of interfaces</td>
<td>Strong cohesion within each software component</td>
<td>Appropriate management of shared resources</td>
<td>Appropriate scheduling properties</td>
<td>Loose coupling between software components</td>
<td>Appropriate spatial isolation of the software components</td>
</tr>
</tbody>
</table>

**Right-Sizing Components**

- “Restrict size…” of components
- De-couple components
- “Isolation” and partitioning

**ISO 26262 Reference Workflow**

#### Unit-Based Testing

- Back-to-back MIL/SIL/PIL
- Model = Design
- Maximize Testing at Unit Level

**Infrastructure** to support ISO26262/CMMI/ASPICE, Cybersecurity and industry expectations
Implement Top-Down Workflow: Architecture - Design – Code

Authoring – Top Down
Define Architecture
1. Application Software Components, Internal Behavior
2. Software Component interaction
   Application to Application
   Application to BSW

Downstream Export I - Simulink MBD:
Application SWC/Component import
1. Implement Controls based on software description
2. Individual component Simulation
3. Auto generation of Production code

Downstream Export II – BSW Configuration:
ECU Extract Import
1. Task Mapping
2. BSW configuration/consideration
3. RTE Generation

Transition to AUTOSAR-based Architecture using MBD principles
Connect Software Workflow with System Simulation

Seamless integration of controller models and plant models to enable efficient pure simulation plant modeling and system simulation capability.

Integration of ECU and Plant Models

Enabling an efficient and robust system simulation capability utilizing Model-Based Design and C-SAR will allow us to fully realize our total system simulation concept.
Next steps

• Process refinement
  • Reuse and product line
  • Agile methodologies
  • CI/CD

• Application software creation
  • Content migration, new content creation
  • Functional safety compliance