

# Rapid Control Prototyping using Simulink Real-Time™

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**Abstract:** This paper delves into Cummins' innovative strategy for engine control prototyping, underscoring the critical role of rapid prototyping in navigating the escalating complexity of engine systems, spurred by a variety of applications and more stringent emission standards. It chronicles Cummins' evolution through an array of prototyping tools and hardware, culminating in the strategic choice of MathWorks & Speedgoat offerings for cutting-edge rapid prototyping endeavors. This pivotal decision was influenced by the necessity for sophisticated hardware that accommodates the demands for multicore microcontrollers, augmented memory, and enhanced processing capabilities. Moreover, the manuscript elucidates the meticulous selection process for this hardware, leveraging 6-Sigma methodologies and internal critiques, with a focus on criteria such as compatibility with Simulink, comprehensive hardware capabilities, and user-friendliness. It further explores prospective applications, including Hardware-in-the-Loop (HIL) configurations, component-specific models, and the integration of cloud-connected vehicles with digital twins, showcasing Cummins' relentless pursuit of innovation in the realm of engine control prototyping.

**Keywords:** Cummins, engine control, rapid prototyping, MathWorks, Speedgoat

## 1. Introduction

The Automobile & Powertrain sector is currently experiencing a surge in growth and stands at a critical juncture [1]. Diesel engines have traditionally held sway over the commercial powertrain landscape. Yet, the tightening of emission norms globally is complicating the development of engine control systems, a scenario further intensified by the varied applications and rigorous emissions benchmarks. Concurrently, as the cost associated with energy storage sees a decline, there's a significant shift in investment towards alternative, environmentally friendly powertrain solutions, notably in electrification.

Cummins Inc. [2] is no excuse for this. Cummins Inc. designs, manufactures, sells and services diesel and alternative fuel engines from 2.8 to 95 liters, diesel and alternative-fueled electrical generator sets from 2.5 to 3,500 kW. Figure 1. Cummins Product Portfolio. Cummins sells engines worldwide under many different emissions limits and other localized requirements. The complexity of the product portfolio has increased greatly during the past decade. This has resulted in increasing complexity in management of the control system development. The other complexity with Cummins' business is the diversity of applications of its products. [Figure 2. Cummins Diverse Product Applications]. Although each of the applications has a need for power and torque, they all have some variation in the way they integrate in those applications.

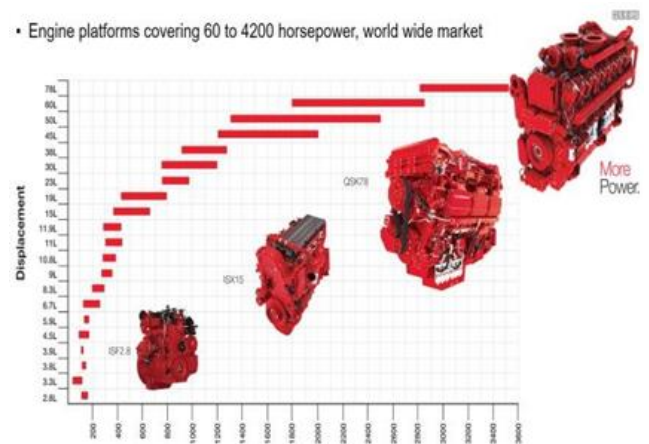


Figure 1: Cummins Product Portfolio



Figure 2: Cummins Diverse Product Applications

That brings the challenge to prototype engine control systems, quickly, and test it in various applications. For this an organization requires a good infrastructure of modeling tools and prototyping hardware. Best way to achieve this is to have "Common Integration Tools & Methods" that can serve all the phases of the product development cycle, including simulation, rapid control prototyping and production.

## 2. Model-Based Design

Like any technology company, Cummins uses a variety of modeling tools that are typically highly specialized for the problem domain [Figure 3. Cummins Powertrain Simulation Framework]. Leveraging decades of experience, over the years Cummins has developed a streamlined process and framework for its product development. In general modeling tools provide the capability we need for predicting subsystem performance. However, Effective integration of these complex subsystems requires integration of the MBD tools and workflows.

### Powerplant Level Simulation Framework

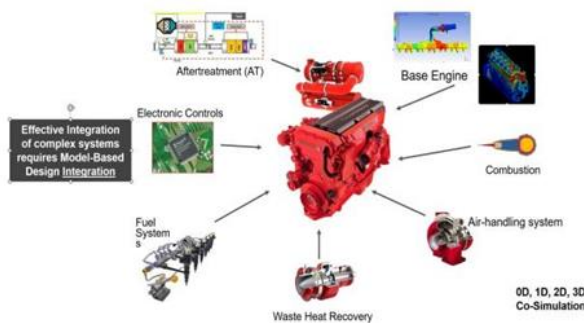


Figure 3: Cummins Powertrain Simulation Framework

Engine development typically starts with the simulation of the 3d combustion system using highly specialized Combustion modeling software. Then this data is used to calibrate a 1D simulation of the entire engine system that will include Air-Handling, Waste Heat recovery, Fuel injection system, the after-treatment system, and the base engine system.

Simulink is used as a system simulation integration environment. Simulink is also used for Control system development. Simulink inherently provides the capabilities for prototype new algorithms and electronic components.

At Cummins, Model-Based Development (MBD) workflow is followed at various stages of the product development lifecycle [Figure 4. Model-Based Development at Cummins]. In classical, V diagram, MBD workflow starts from concept generation to all the way through post product support. Left side of the V represents the Research, Incubation & Prototyping work whereas the Right side represents production development and post productsupport. Control System is given special emphasis in MBD and modeled and simulated in close-loop fashion practically at every phase of product development. At times, open-loop detailed Control System simulation is used for Regression testing and feature enhancements. Each control engineer leverages Unit or Component level simulation for validating the concept. Since Simulink is the tool for modeling Control Systems, its Code Generation technology is leveraged for embedded controllers. As per V-diagram, Rapid Control Prototyping is performed mainly during the Research phase for Minimum Viable Product (MVP) demonstration and occasionally used during the production phase.

## Model-Based Development at Cummins

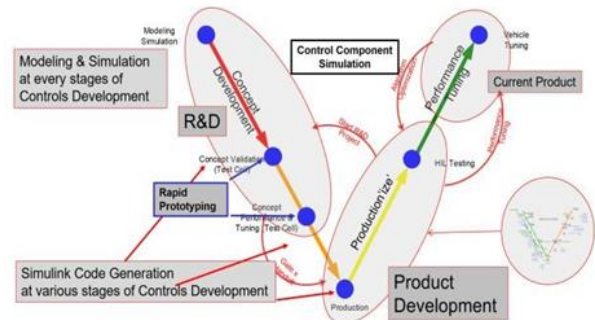


Figure 4: Model-Based Development at Cummins

## 3. Approach to Rapid Control Prototyping

In the essence of faster innovation and time to market, controls researchers need the capability to develop and validate their concepts early enough to gain confidence to proceed for MVP demonstration. In such a case, Rapid Control Prototyping (RCP) provides the crucial capability to control engineers where they can focus on core algorithm development and not get distracted by the nitty gritty of tools used.

At Cummins, RCP has been leveraged since late 90' utilizing various tools and hardware. Since then, this capability has evolved. In the late 90s or 2000 ADI's prototyping hardware and tools. Later, around 2003, Cummins developed the homegrown first version of the prototyping system utilizing our production ECU. Later in 2008, Cummins replaced all ADI solutions with commercial-off-the-shelf (COTS) solutions from dSPACE [3] and National Instruments [4] Woodward [5]. With recent enhancements in the homegrown RCP solution, the question was... Why do they need the Next Generation RCP Environment? [Figure 5. Rapid Control Prototyping History at Cummins]

### Rapid Control Prototyping

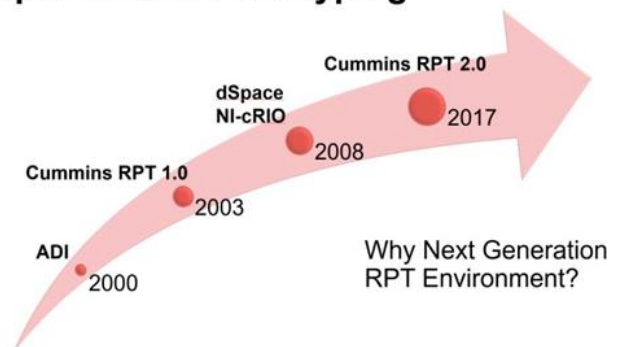


Figure 5: Rapid Control Prototyping History at Cummins

Well, Cummins' investment in COTS solution was almost a decade old and, in that timeframe, technology has advanced vastly. Microcontrollers moved to multicore, Advancements to sensors and actuators technology, Adoption of Wireless technology, Higher demands for memory and processing power for advanced controls algorithms. All this created a need to look for new hardware.

There were various tools & hardware available commercially. To select the right hardware/software for Cummins' needs, engineers used some 6-Sigma tools and processes like Cause & Effect(C&E)/Pugh Matrix. Through an extensive voice of customer (VOC), selection criteria, as represented in this Pi chart, was established and after evaluating half a dozen various systems and scoring through our selection criteria, finally the MathWorks & Speedgoat solution was selected as Next Generation RCP solution. [Figure 6. Selection Criteria for Next Generation RCP]

### NextGen RCP – Selection Criteria an Process



Figure 6: Selection Criteria for Next Generation RCP

### 4.Rapid Prototyping with Simulink Real-Time and Speedgoat

As described above, the MathWorks' MATLAB/Simulink [6] is used as a primary design tool by most of Cummins' engineering community. Model based RCP solution was the natural choice and best if it is Simulink based. The tight integration between Simulink Real-Time and Speedgoat [7] hardware within the MATLAB and Simulink environment enables control engineers to rapidly test new design variants for ECU control algorithms [8]. Typical RCP setup at Cummins looks like Figure 7. Rapid Control Prototyping Framework.

### Rapid Control Prototyping



Figure 7: Rapid Control Prototyping Framework

However, to cater the needs, this is how we configured the setup [Figure 8. ECM Bypassing Topology]. For ECM Bypassing, we used Vectors XCP Hardware and integrated POD inside the ECM. Speedgoat machine is configured with A2L file generated for our ECU and communicating with Vector hardware [9] over XCP [10]. This way Speedgoat got access to our ECM Signals & Parameters. Host Computer is used to Control/Monitor the Speedgoat hardware as well as to monitor ECM over CAN.

### Rapid Control Prototyping - ECM Bypass

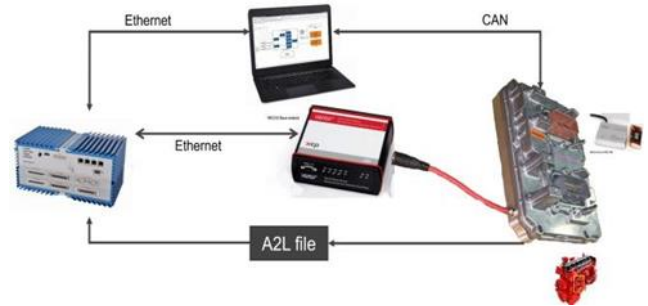


Figure 8: ECM Bypassing Topology

Apart from ECU Bypassing, another use case of Speedgoat hardware for us is Unified, Robust & Fast DataLogging. In this setup, Speedgoat is used to collect data from all the data sources like ECM, Test Cell Controller, extra IO directly connected to the hardware and log data in its internal hard drive. The host computer is used to extract the data for analysis upon test completion.

### Unified, Robust, Fast Logging

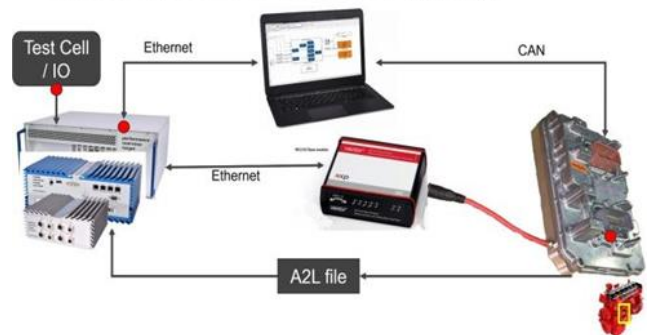


Figure 9: Datalogging Use case

This setup provided various advantages over Cummins' previous RCP platform. Along with cost advantages, this setup demonstrated robust performance over the period of 48 hours with no connection lost or data lost. With this setup, all the simulation and control development are consolidated in the unified Simulink solution which provides the fastest path to production capable software solution. Team created the standardized modeling guideline and template model so that the implementation process is standardized, and production intent software implementation is seamless. With Simulink Real-Time, engineers could easily integrate plant models developed using Simscape [11] or GT Power [12], also they could integrate any open-source C/C++ code to enhance the capabilities.

### 5.Future Directions and Innovations

Looking at the immediate advantages of utilizing

Simulink Real-Time and Speedgoat hardware, Cummins engineers are considering future use cases and scalability of this solution. In collaboration with MathWorks & Speedgoat, some of the future use cases that engineers currently working on:

### A. Hardware-in-the-Loop (HiL) Setup

For HiL setup, system plant model developed using Gamma Technologies' GT-Power or The MathWorks' Simscape/Simulink can easily be deployed on Speedgoat machine and different I/O cards, various types of signals, required for ECM, can be emulated.

### B. Multiple ECM Bypassing

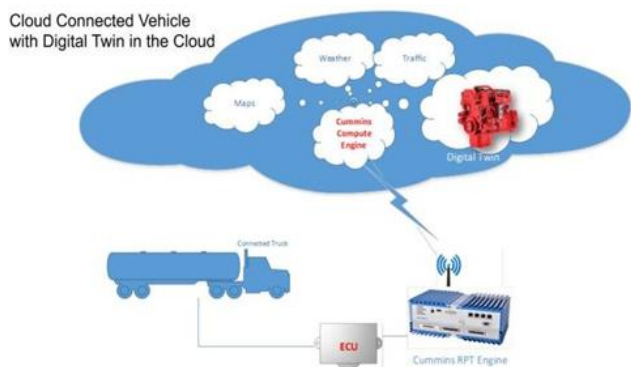
There are systems that utilize more than one ECM, in such setups, following the similar setup of single ECM bypassing, user can bypass more than one ECM because of Speedgoat's multiple ethernet availability.

### C. Test Automation

The MathWorks has developed Simulink Test as product to automate simulation-based testing. Same test framework can be used with Speedgoat hardware and automation overall simulation and HiL testing framework.

### D. Cloud Connected Vehicle

In this use case, Speedgoat could be used as an Edge device and run performance analytics on Cummins Compute Engine with Digital Twin in the cloud. [Figure 10. Future Use case of Speedgoat] Cummins commitment to innovation in engine control development and further innovation in electrification areas, with the immediate success in establishing the set and enabling Cummins' control engineer community for innovation, Cummins is committed to strengthen its collaboration with MathWorks and Speedgoat.



**Figure 10:** Future Use case of Speedgoat

## 6. Conclusion

In summary, after thorough analysis by Cummins engineers, and excellent support from MathWorks & Speedgoat, Cummins has established a good Rapid Prototyping framework to be used across the company.

With the tight integration of MATLAB/Simulink, Simulink Real-time and Speedgoat hardware this will enable Cummins research organization to realize the goal of Digital Twin in the early development phase and cater to provide robust validate requirements for production solutions. This solution scales beyond RCP and across the automotive industry to innovate cleaner, environment

friendly, autonomous & connected solutions.

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