A-L-V

Automating the Left Side of the V

Presenters, Ford Chassis Controls:

Nate Rolfes **John Broderick** **Jeff Cotter**

With Ford MBSE Tools & Methods:

Kyu Sohn **Yuping Jiang** **Tapan Kasaragod**

May 2, 2018

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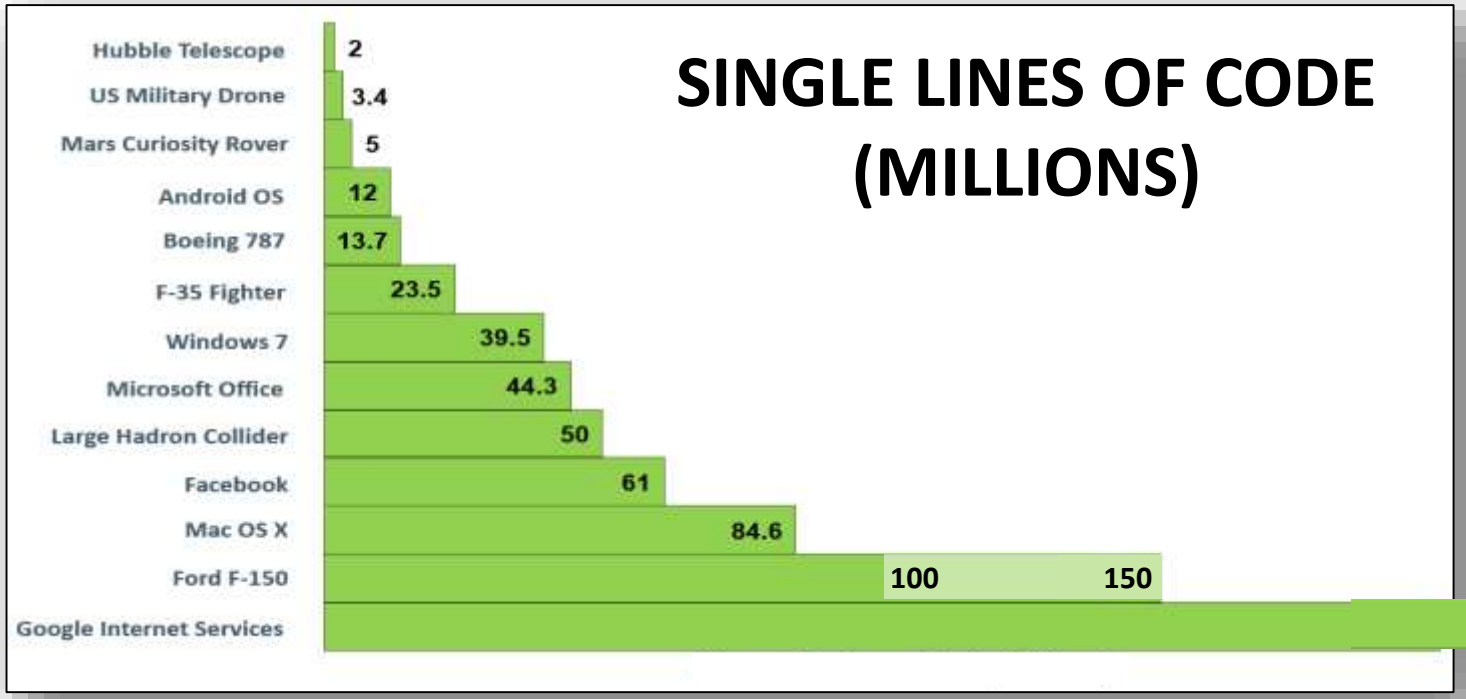
MODERN SOFTWARE COMPLEXITY



Modern automotive vehicles contain between 100-150 million lines of code across 30-80 networked ECU's with up to 30,000 physical parts, making them one of the most complex engineered systems in the modern world.

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Sources:
https://informationisbeautiful.net/visualizations/million-lines-of-code/
https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/rethinking-car-software-and-electronics-architecture
http://sites.ieee.org/futuredirections/2016/01/13/guess-what-requires-150-million-lines-of-code/

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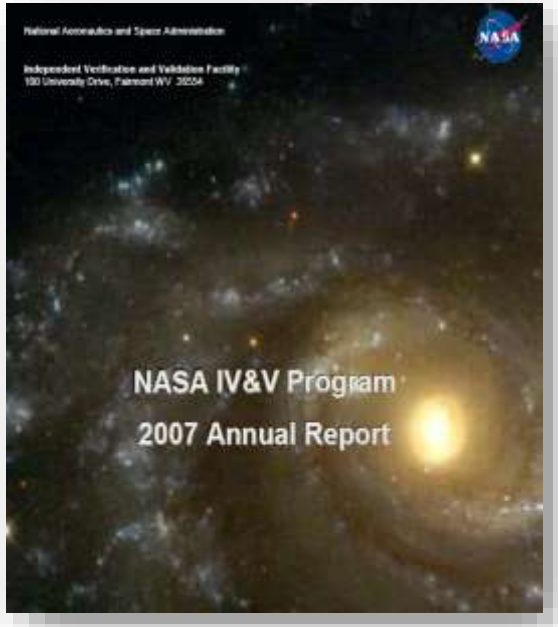
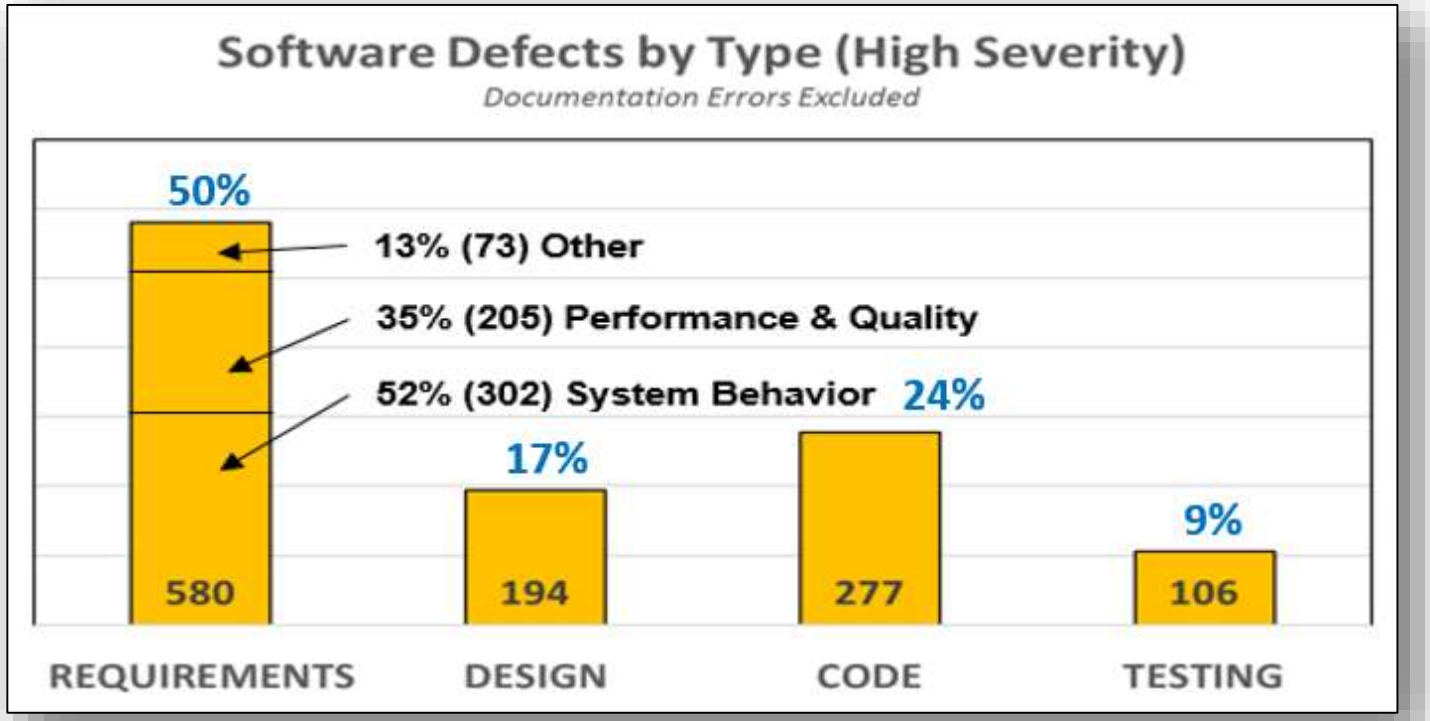
THE SOURCE OF SOFTWARE ISSUES



*"The IV&V Program documented **10,677 software artifact defects on 22 NASA projects in 2007**…The IV&V Program analyzed the defects sorting them by severity and type of defect."*



Requirements are the leading source of software defects. System requirements are the leading source of requirement defects.

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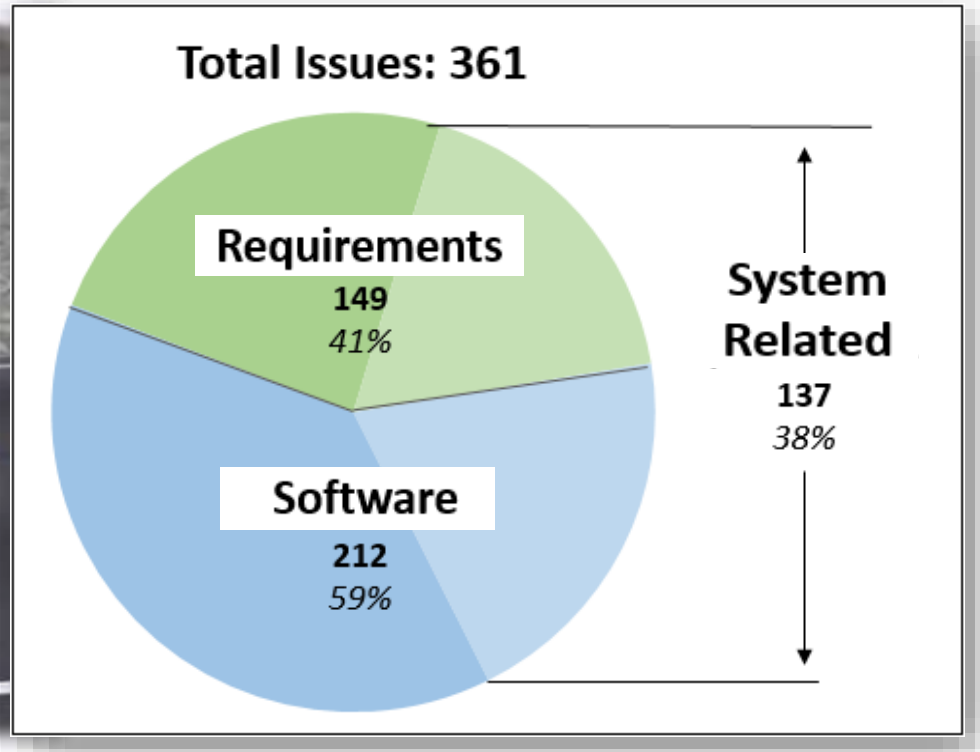
THE SOURCE OF SOFTWARE ISSUES



41% of Software issues found during development of the 2016MY F-150 Pro Trailer Backup Assist Feature were related to the requirements, and 38% of all software issues were system-related.

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Source:
Rolfes, N., "Requirement Modeling of Pro Trailer Backup Assist™," SAE Int. J. Passeng. Cars – Electron. Electr. Syst. 10(1):2017, doi:10.4271/2017-01-0002.

REQUIREMENT MODELING

"Requirement models … capture the functional requirement in a **clear** and **executable** manner that can be used to evaluate the **interaction** and **compatibility** of requirements from **disparate sources**"

Lee/Friedman, The Mathworks, SAE 2013-01-2237

REQUIREMENT MODELING

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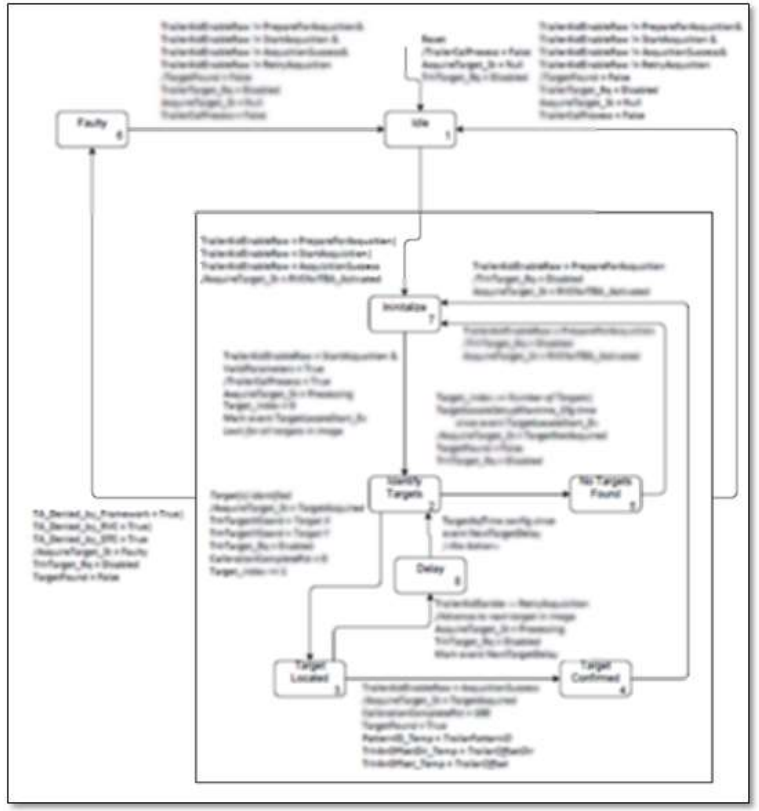
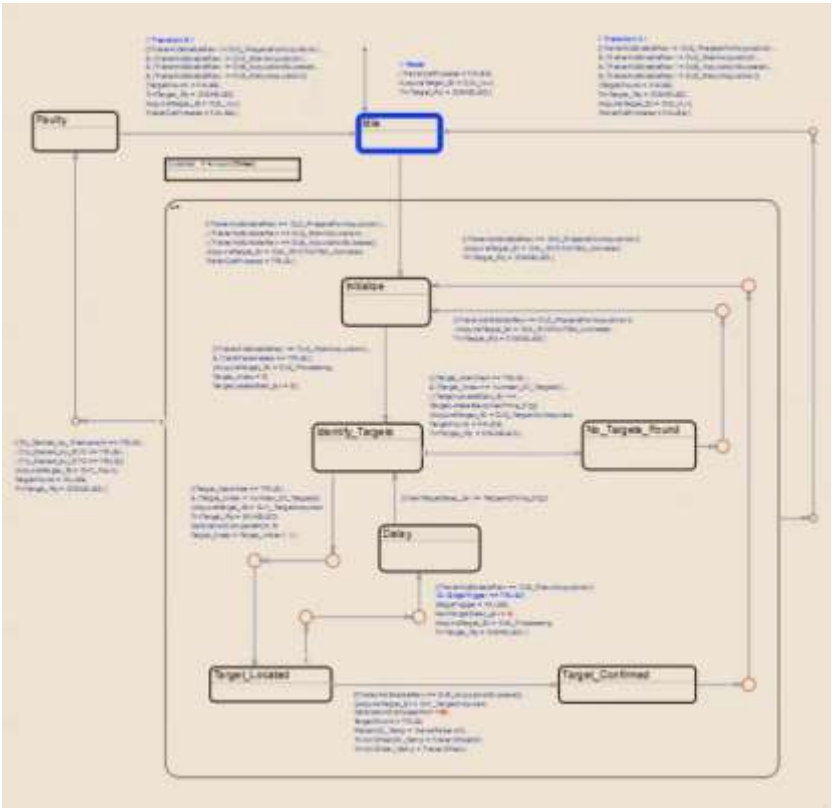
Lee/Friedman, The Mathworks, SAE 2013-01-2237

Requirement Specification



Requirement Models



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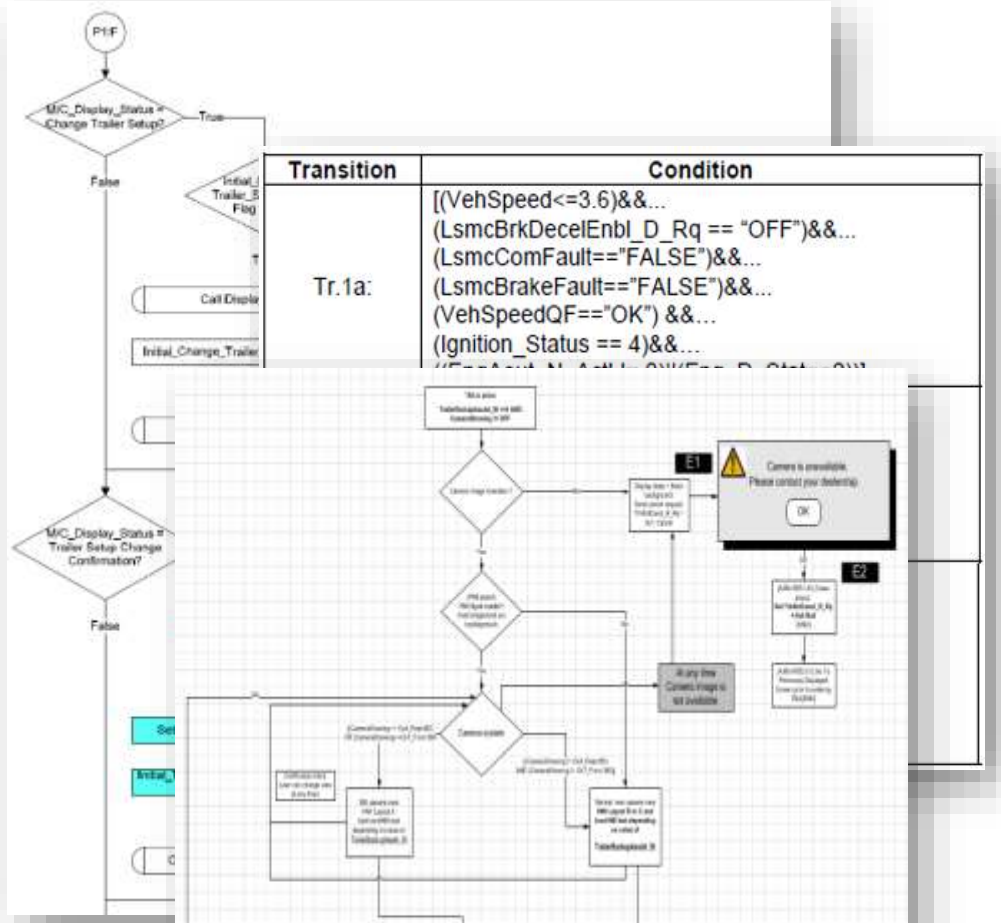
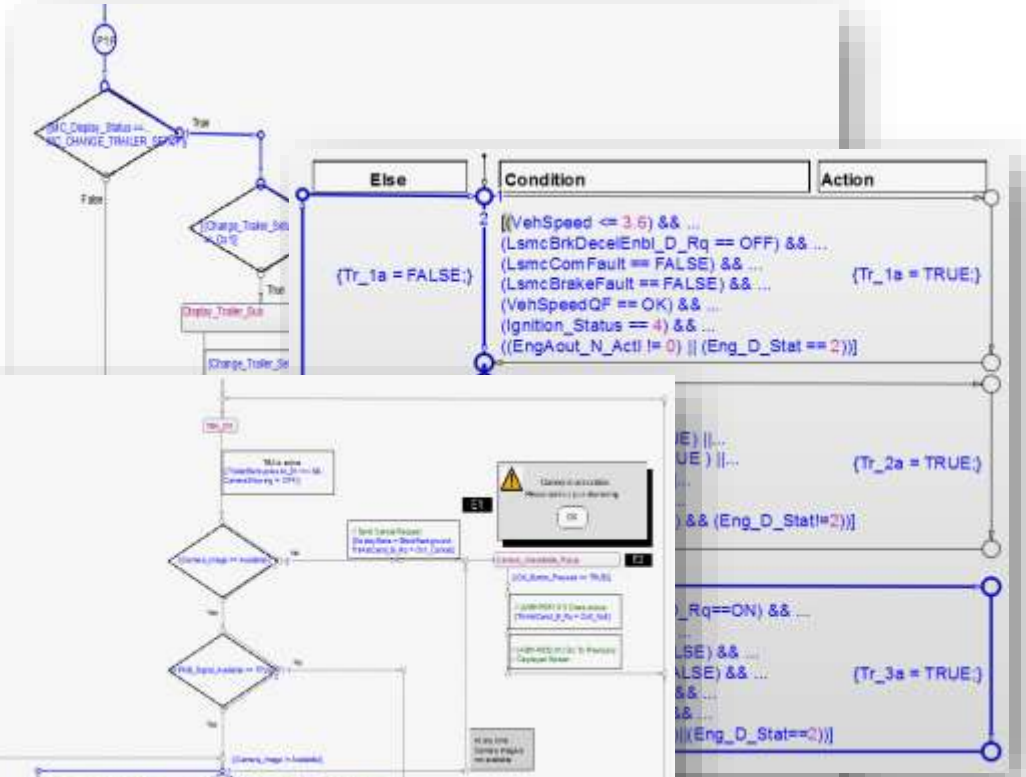
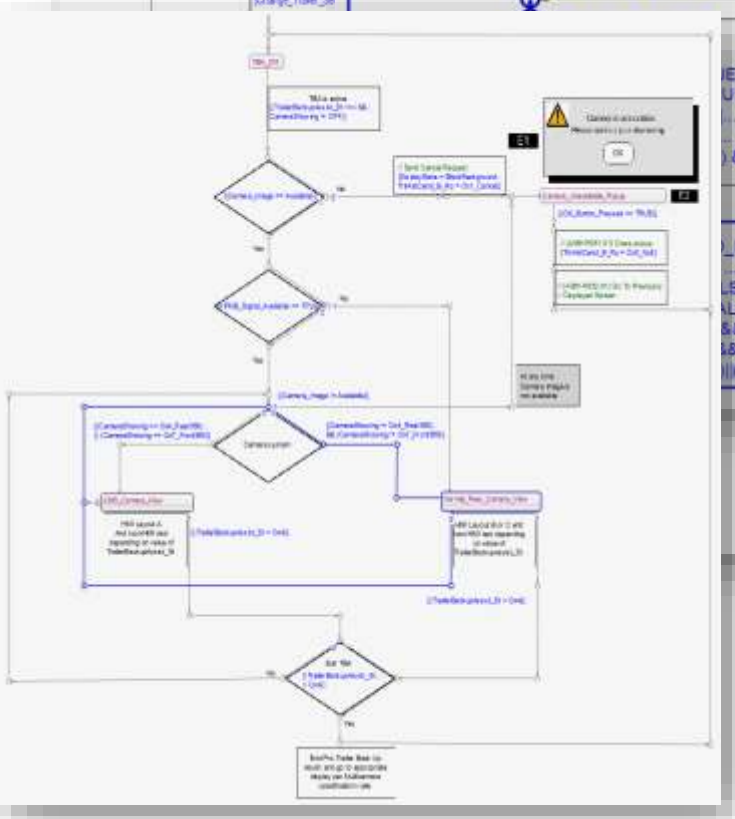
REQUIREMENT MODELING



Transition	Condition
Tr.1a:	[(VehSpeed<=3.6)&&... (LsmcBrkDecelEnbl_D_Rq == "OFF")&&... (LsmcComFault=="FALSE")&&... (LsmcBrakeFault=="FALSE")&&... (VehSpeedQF=="OK") &&... (Ignition_Status == 4)&&...





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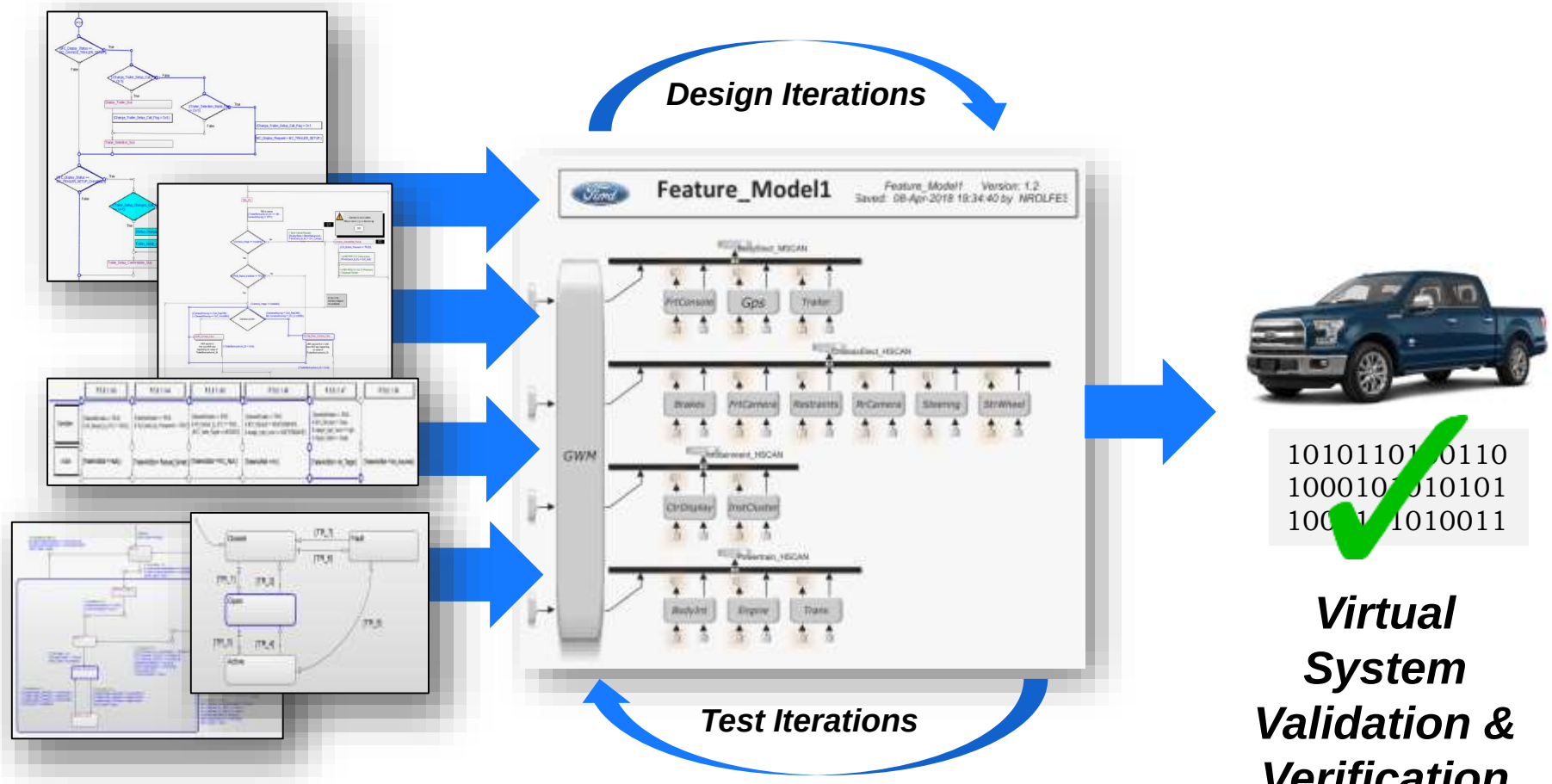
DISTRIBUTED SYSTEM MODEL

The collection of requirement models can be collected into a larger system model which enables up-front design and testing to ensure the system behaves as intended.

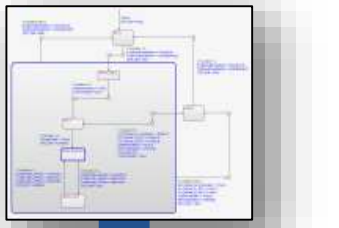


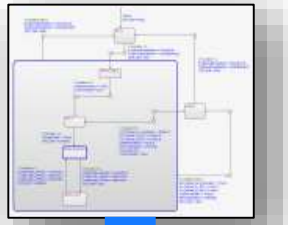
DISTRIBUTED SYSTEM MODEL TYPES

Model-in-the-Loop (MIL)

Software-in-the-Loop (SIL)

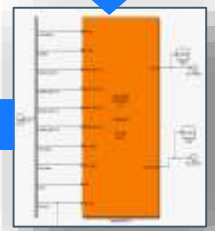
Hardware-in-the-Loop (HIL)

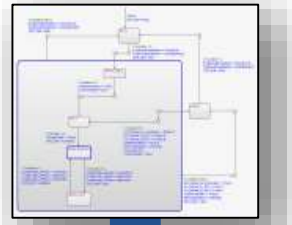




Code Gen

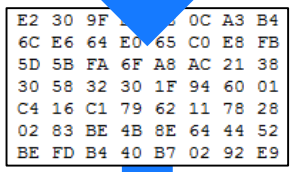
Code Wrapper





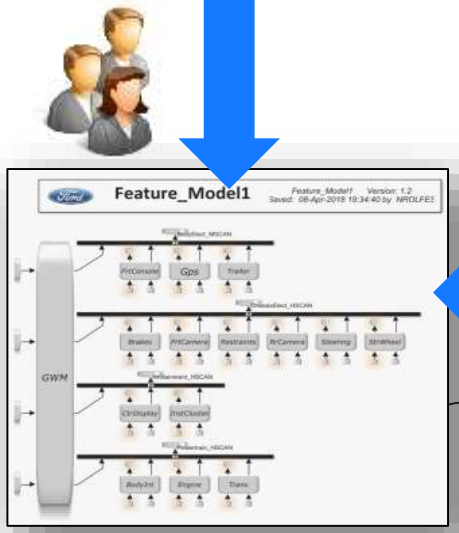
Code Gen

Code Build for Target



Hex file

Upload to Hardware



Simulate!

Power and Connect Hardware

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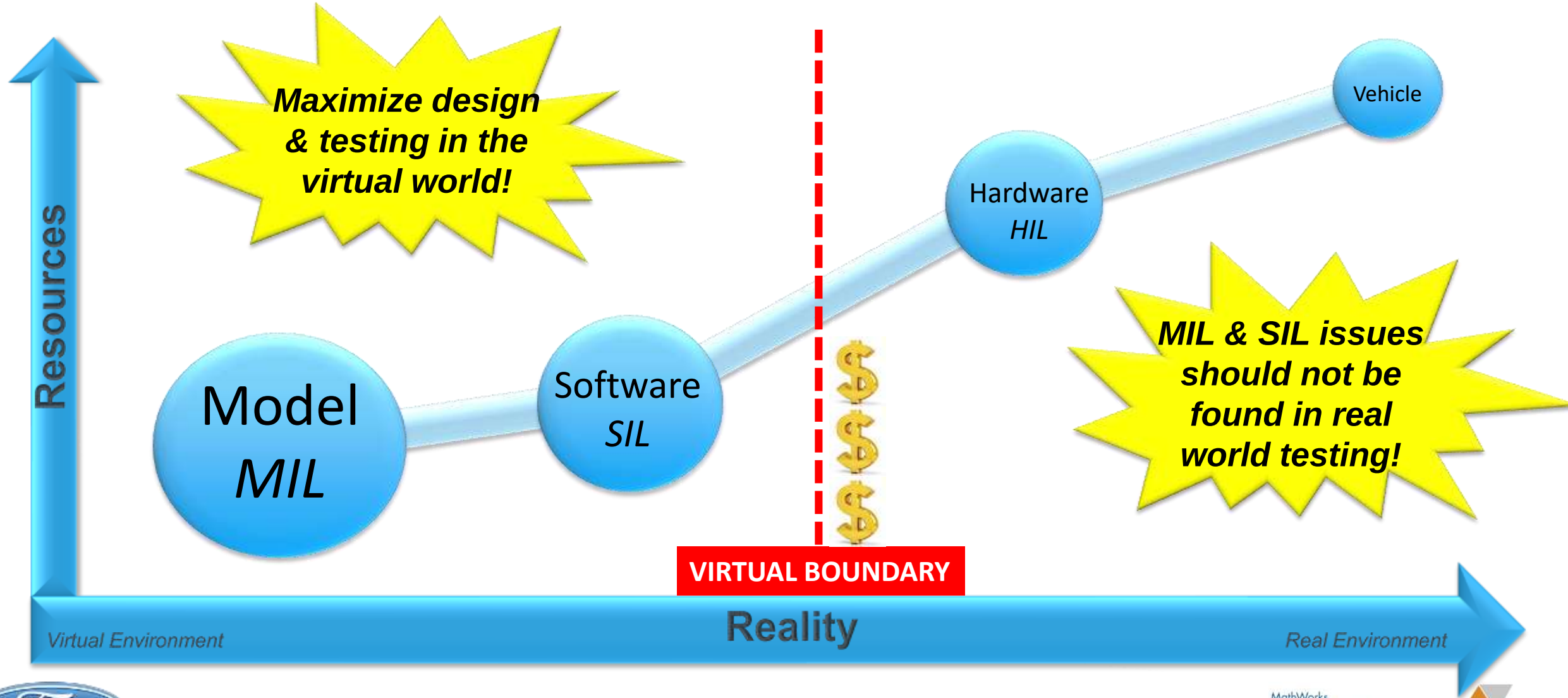
DISTRIBUTED SYSTEM MODEL TESTING



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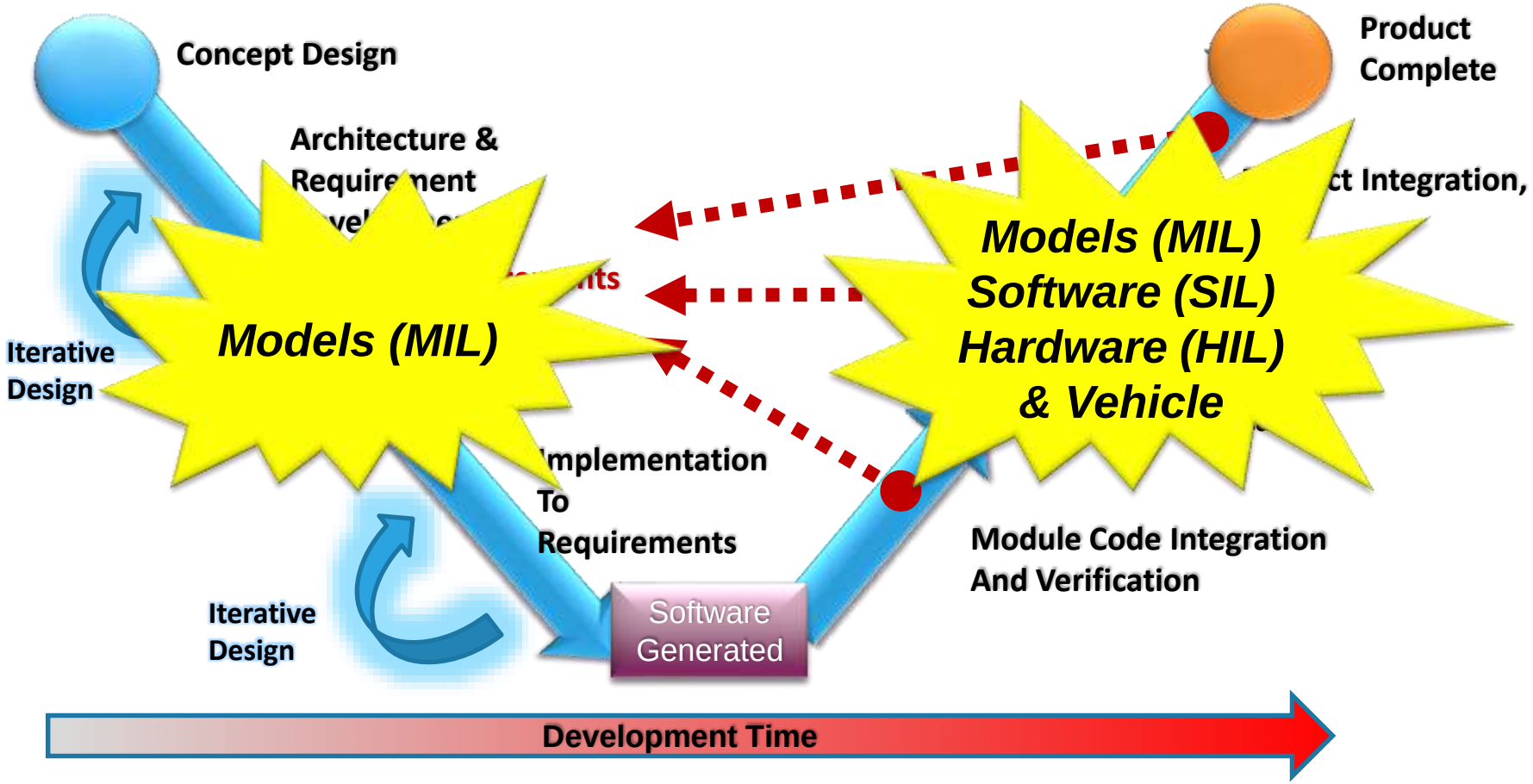
THE SYSTEM V


Concept Design
Architecture &
Product
Complete
Models (MIL)
Models (MIL)
Software (SIL)
Hardware (HIL)
& Vehicle
Iterative
Design
Implementation
To
Requirements
Module Code Integration
And Verification
Iterative
Design
Software
Generated
Development Time

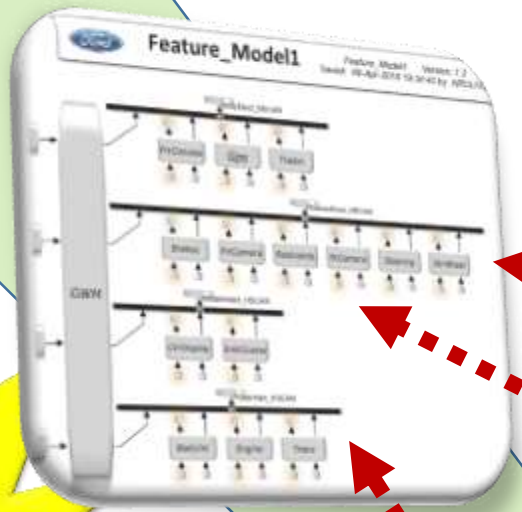
THE REAL WORLD SYSTEM V

Weeks before Production

180 140 100 80 40 0

Kickoff

Production



MIL can be used as the oracle to check SIL and HIL Testing

80 weeks of Development Time prior to Software availability!

Multi ECU HIL

Single ECU HIL

SIL Testing

Software Available

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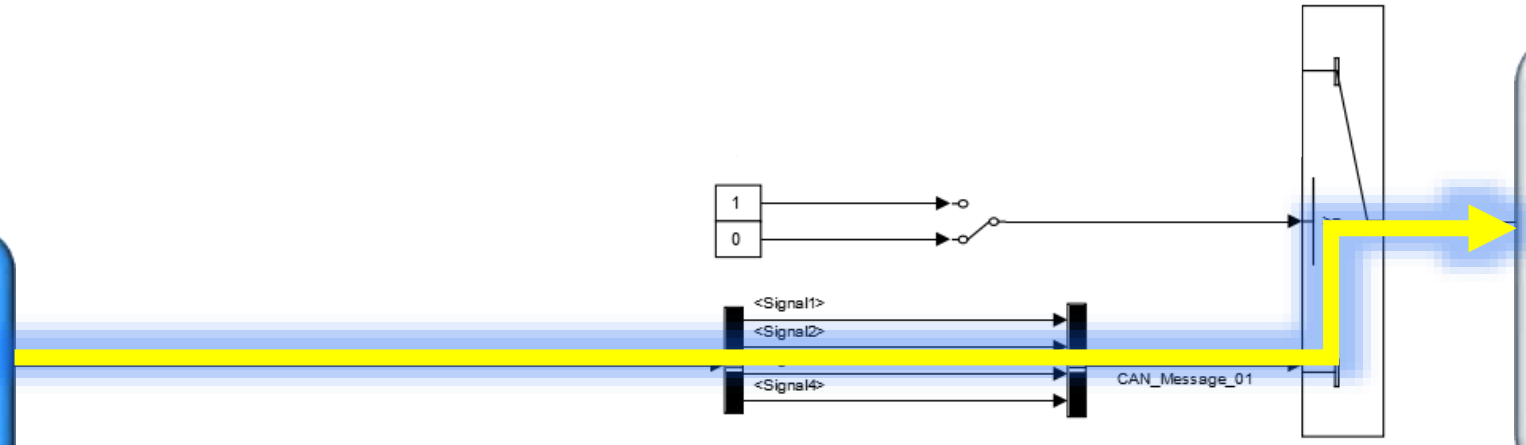
MIL TO HIL SWITCH

Instrument Cluster Hardware (HIL)

Vehicle Network Toolbox

Instrument Cluster Requirement Model (MIL)



CAN Gateway (MIL)

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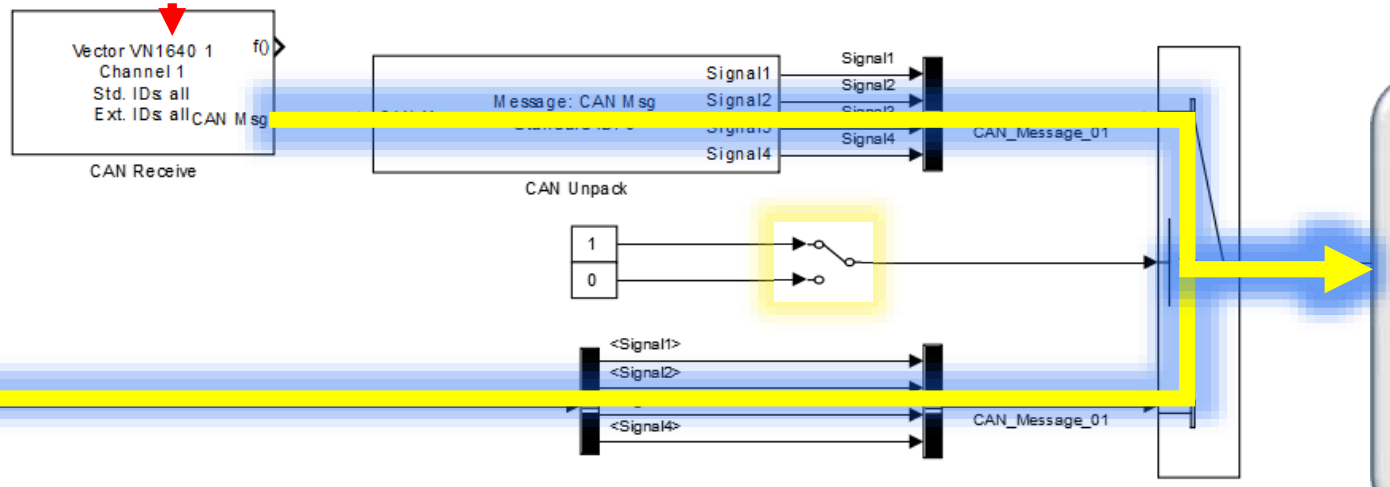
MIL TO HIL SWITCH

Instrument Cluster Hardware (HIL)

Vehicle Network Toolbox



Instrument Cluster Requirement Model (MIL)

CAN Gateway (MIL)

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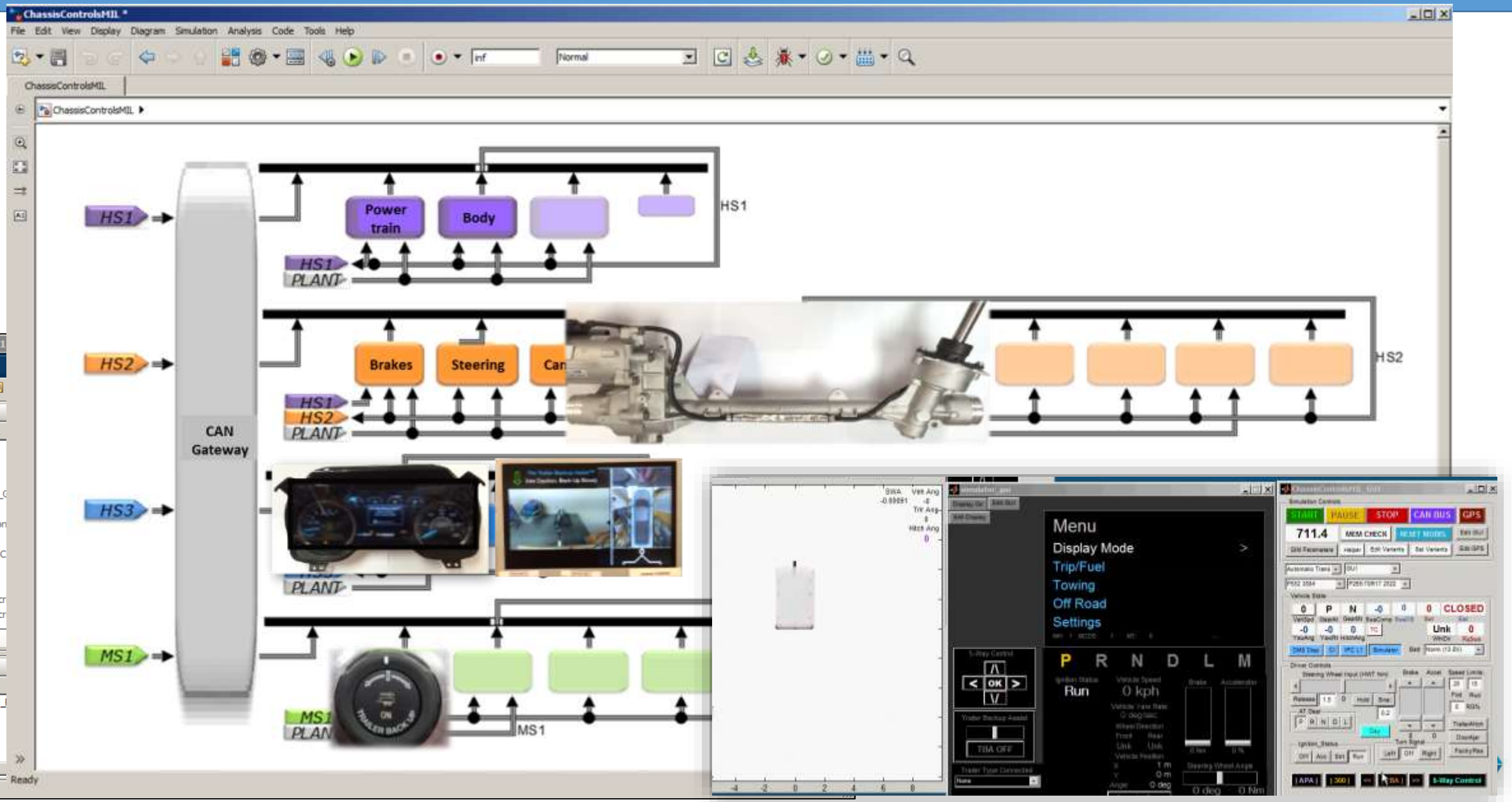
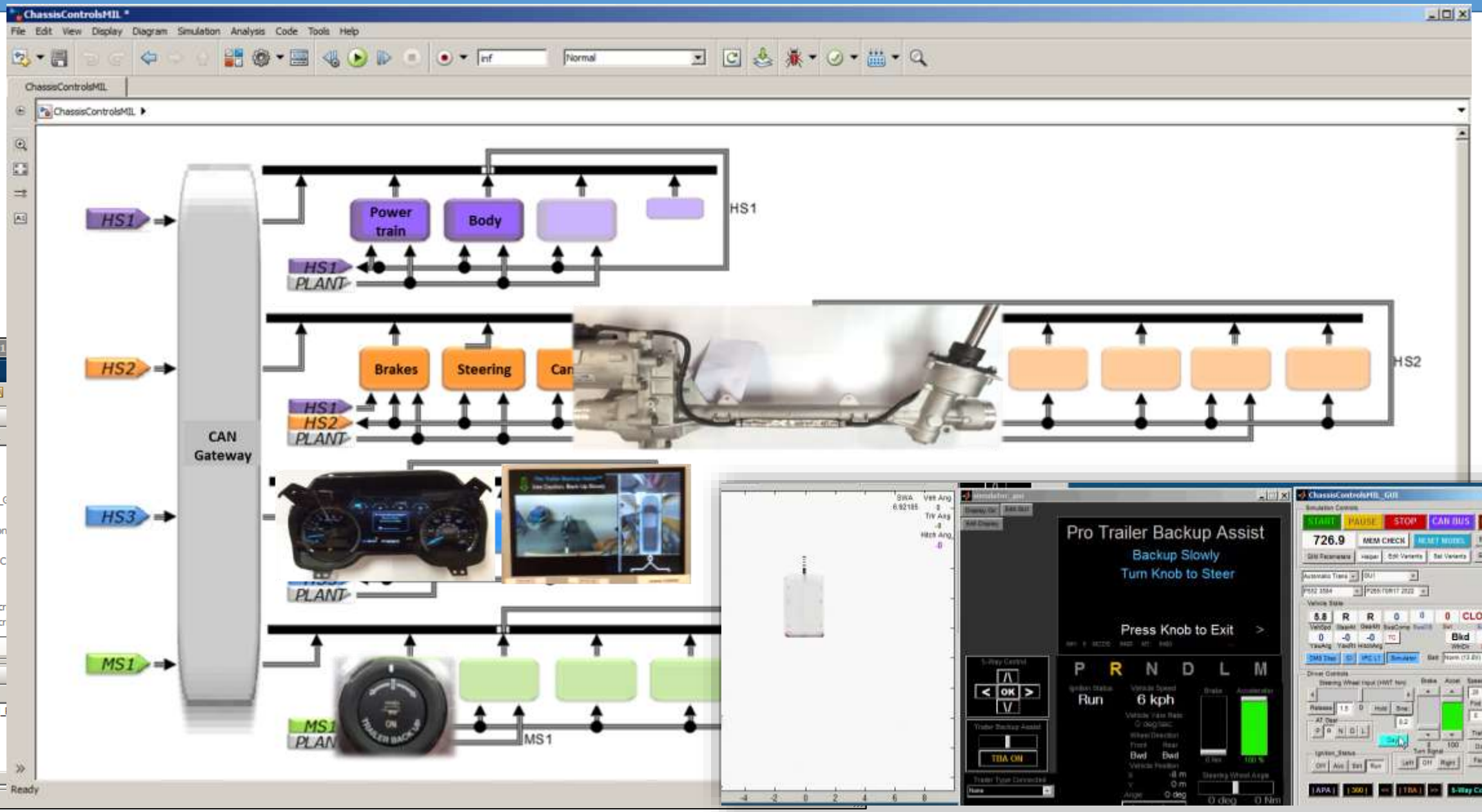
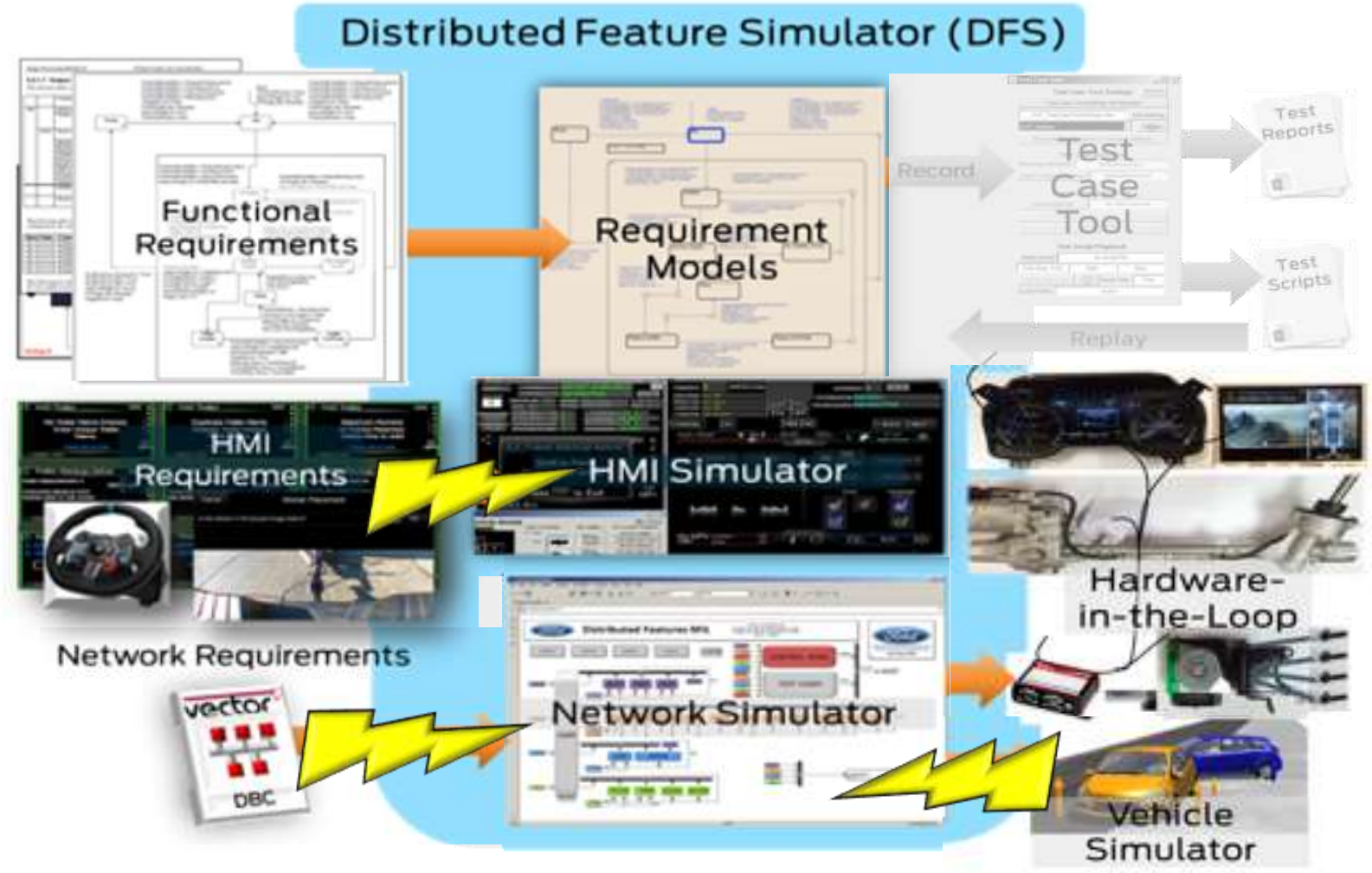
DISTRIBUTED SYSTEM TESTING



DISTRIBUTED SYSTEM TESTING



DISTRIBUTED FEATURE SIMULATOR



Network Interface Builder

Vehicle Interface Builder

Qt HMI Integration

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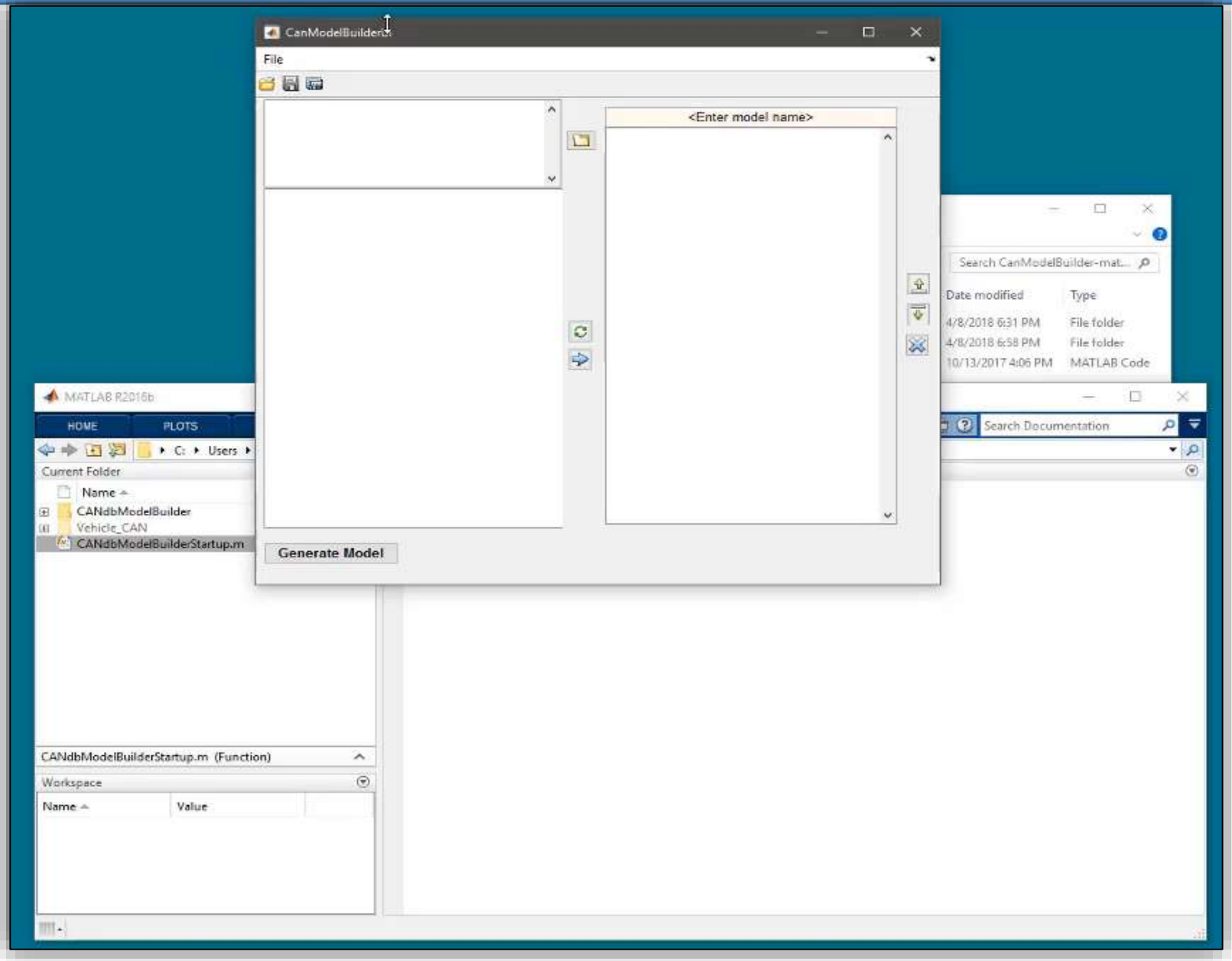
NETWORK INTERFACE BUILDER

Manually creating a Simulink model from a network architecture file can take a lot of time and effort. Each network model is different depending on feature, vehicle, and build configuration.

Building the model also requires the time and effort of an engineer who is skilled in Simulink and the Vehicle Network Toolbox in order to robustly build and debug that the model is working correctly.

NETWORK INTERFACE BUILDER



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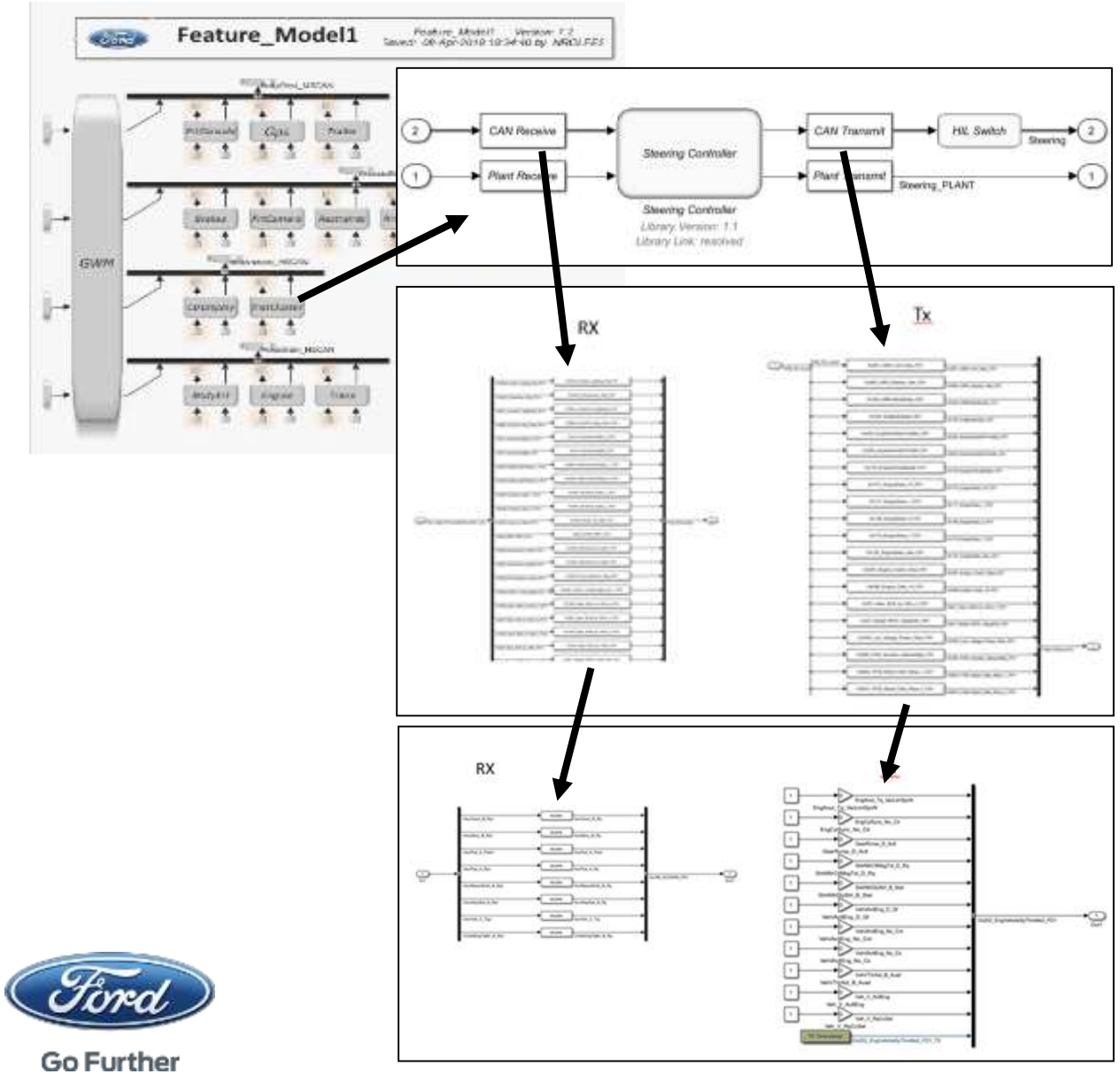
NETWORK INTERFACE BUILDER



Feature Model Example

15 ECUs

13,801 Simulink Blocks

218 CAN Messages

1,397 CAN Signals

It takes 4 minutes to manually model a CAN Message in Simulink…
…and would take 14 hours to build this model by hand!

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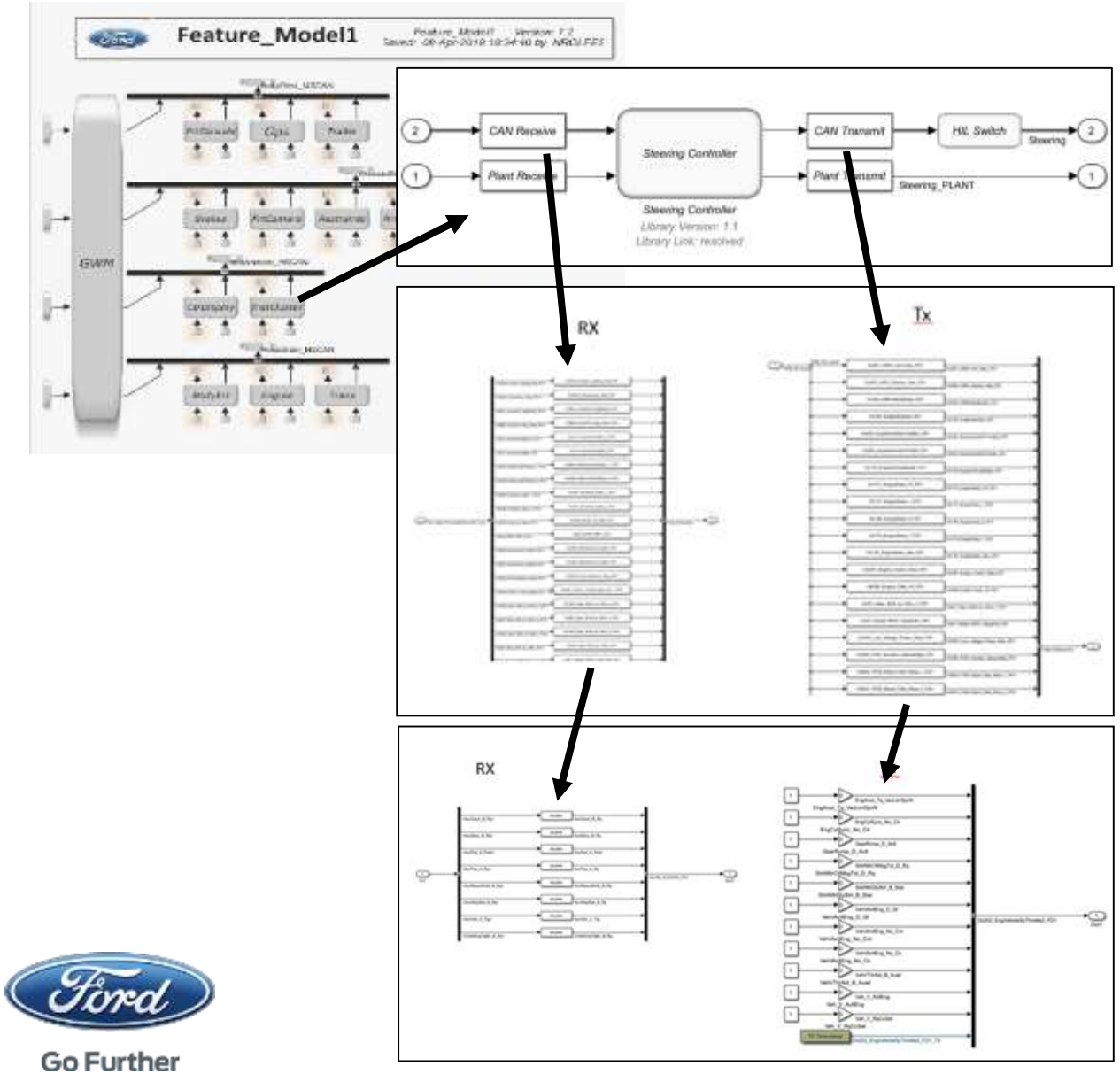
NETWORK INTERFACE BUILDER



By automating the Feature Model build process, we open up new possibilities to improve design, testing, and validation results.

New System models can be generated at each Program Milestone on demand, or whenever new DBC files are released.

Eliminates the bottleneck of needing an expert at Simulink to generate feature models and update them.

Eliminates errors in manual build and the tedious updates of the model when changes to network message or signal designs are changed.

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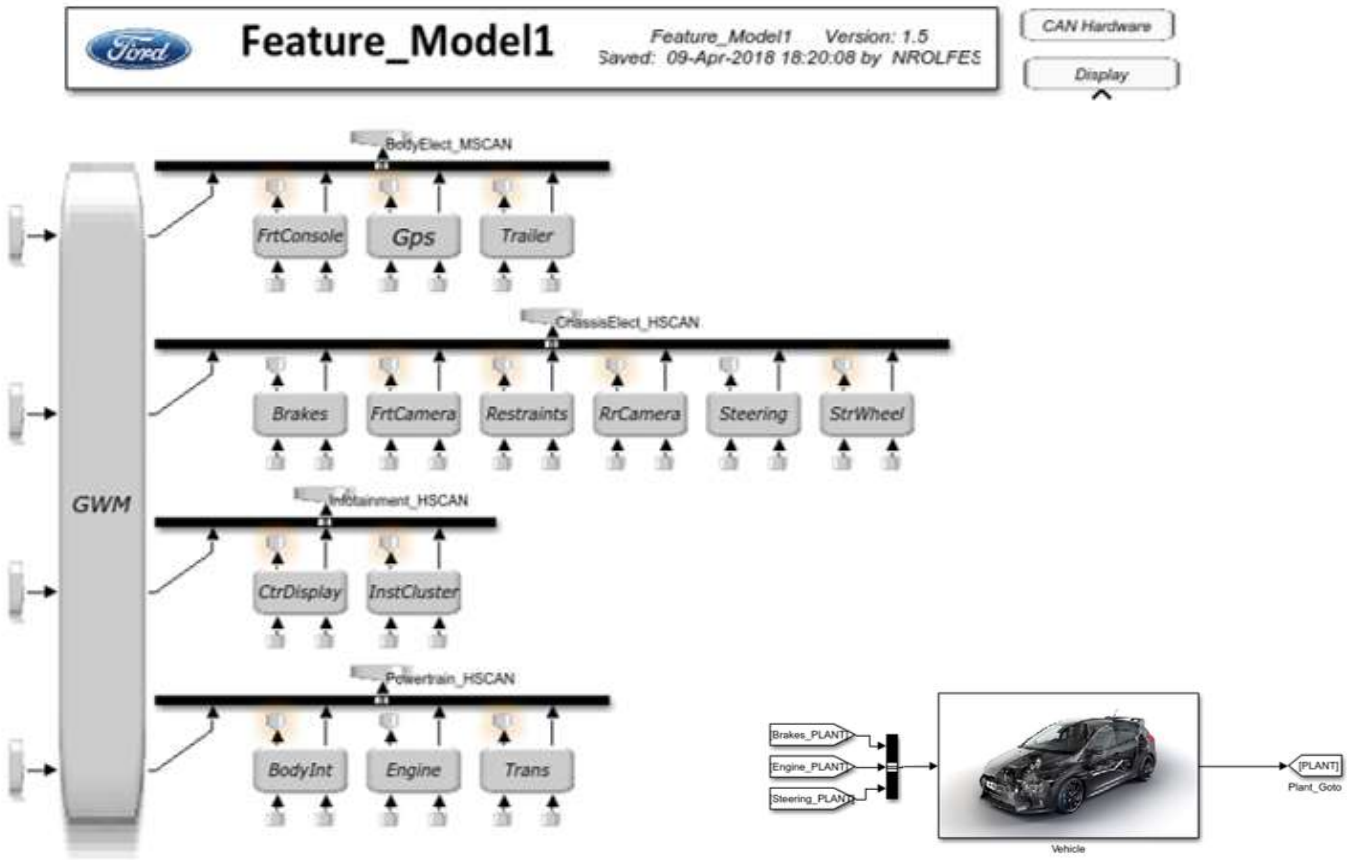
VEHICLE INTERFACE BUILDER



Testing the network ECU model helps to identify and resolve issues with functional logic, state machines, and interfaces.

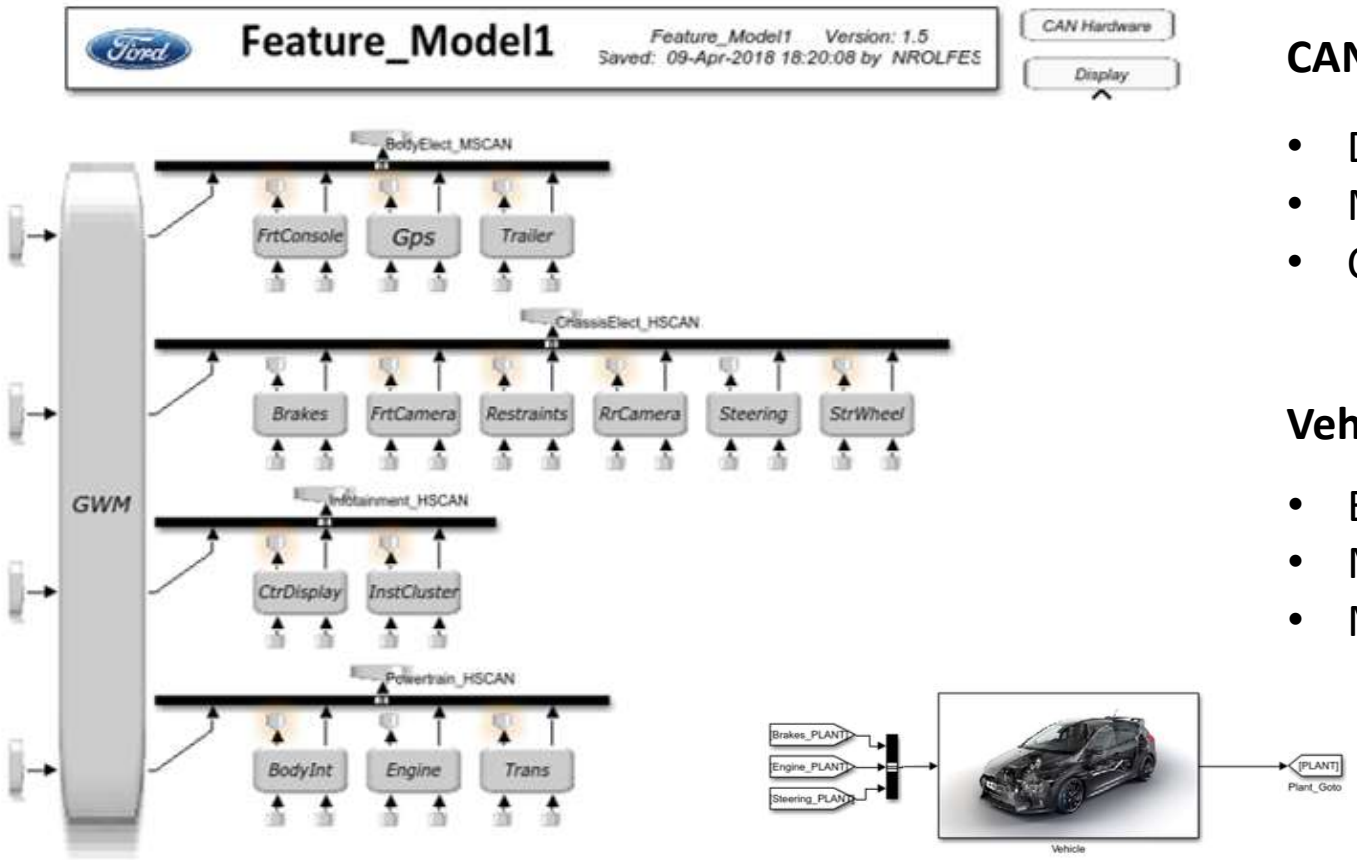
However, for more realistic dynamic testing of the control systems it is helpful to connect a vehicle model simulator which can provide realistic virtual feedback for sensors and actuators that the functional ECU's control. Several "out of the box" simulators exist on the market, such as CarSim, CarMaker, and the Vehicle Dynamics Blockset.

Manually setting up the interface to a vehicle model simulator is tedious and error-prone as it can involve mapping up to hundreds of actuation and sensing signals between the ECU controls model and the Vehicle Model.

It also requires an engineer who has expertise in both Simulink and the Vehicle Model tool.

Developing a way to automatically generate this interface is a key efficiency step to eliminate time

VEHICLE INTERFACE BUILDER



CAN Interface

- Defined by vehicle program in DBC file
- Minimal updates only when DBC files updated
- Completely modeled in Simulink

Vehicle Model Interface

- ECU-dependent interfaces
- Model interfaces may change based on model fidelity
- Must accommodate different 3rd Party vehicle models

Vehicle model interface must be modular and flexible

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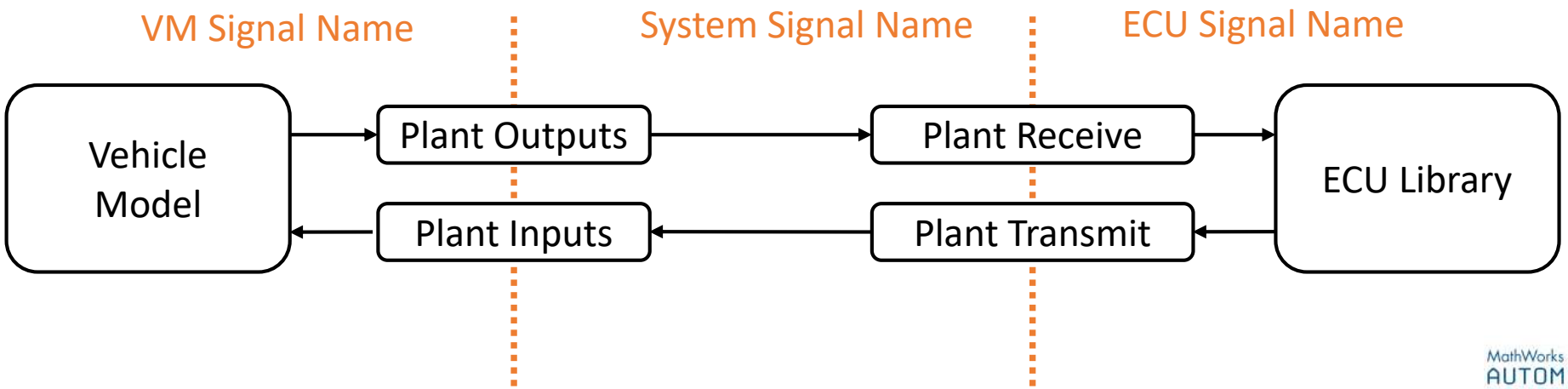
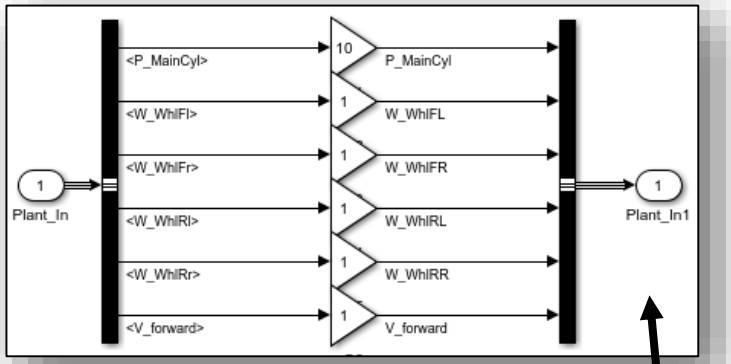
VEHICLE INTERFACE BUILDER

- Example Specification (Subset of Brake ECU Interface)

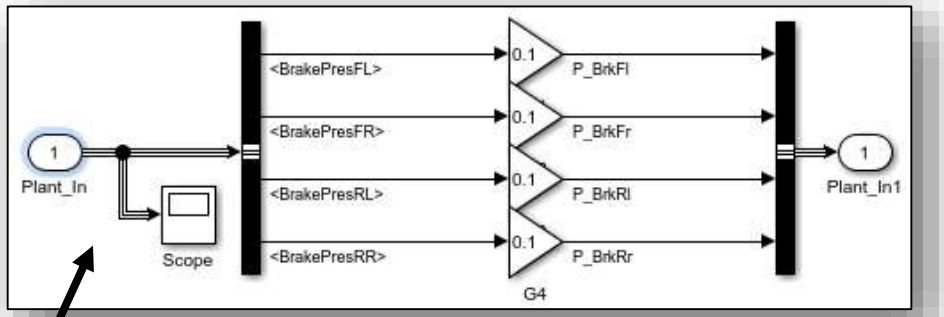
Input/Output	ECU Signal Name	System Signal Name	Vehicle Model (VM) Signal Name	Unit Gain (ECU)	Unit Gain (VM)	VM Specific Parameters
Output	WheelSpeed_FL	W_WhlFl	AVY_L1	1	2π/60	
Input	BrakeTorqueFL	Tq_BrkFL	IMP_MYBK_L1	1	1	



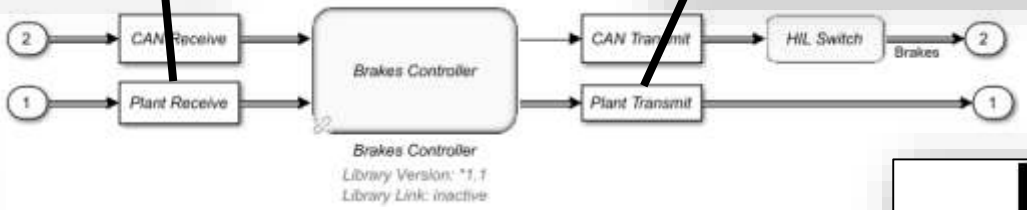
VEHICLE INTERFACE BUILDER

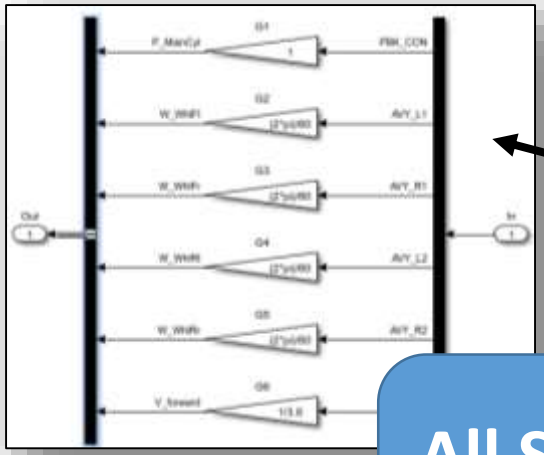


System to Controller conversion

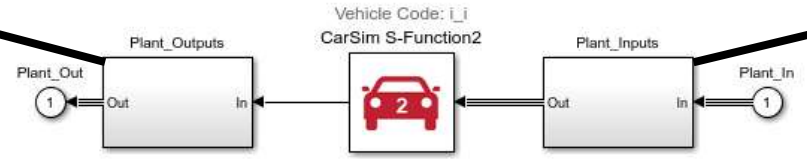


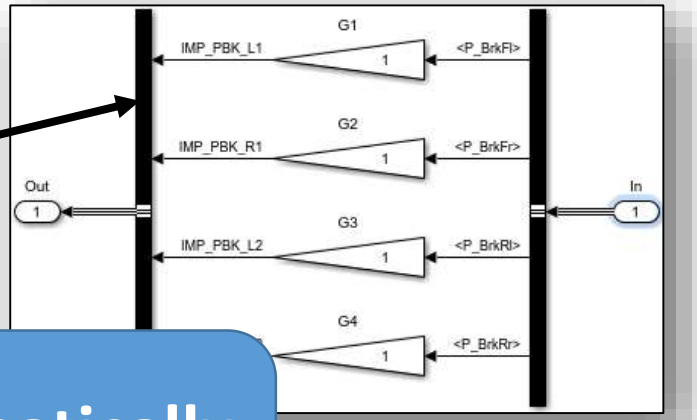
Controller to System conversion





Vehicle Model to S





cle Model Conversion

All Signal Routing and Gains automatically generated from specification files

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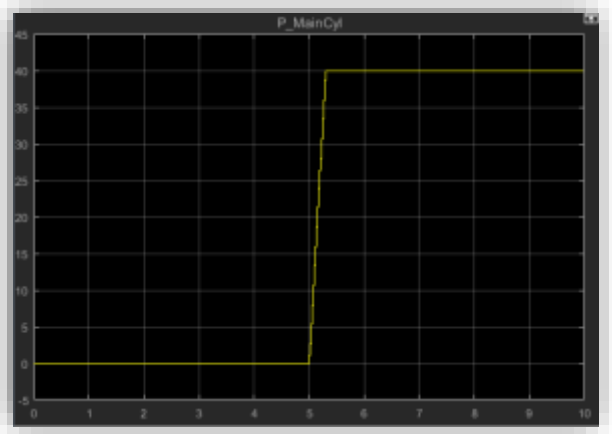
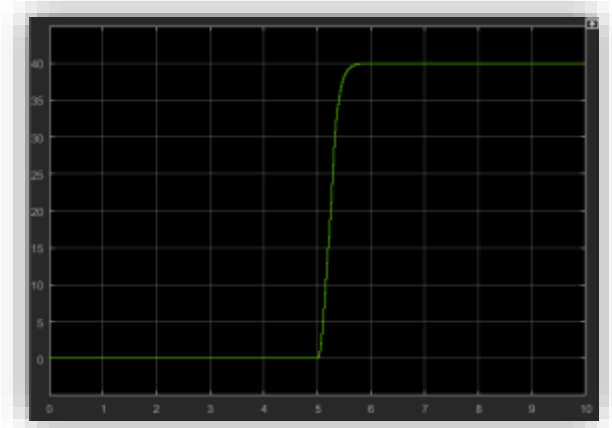
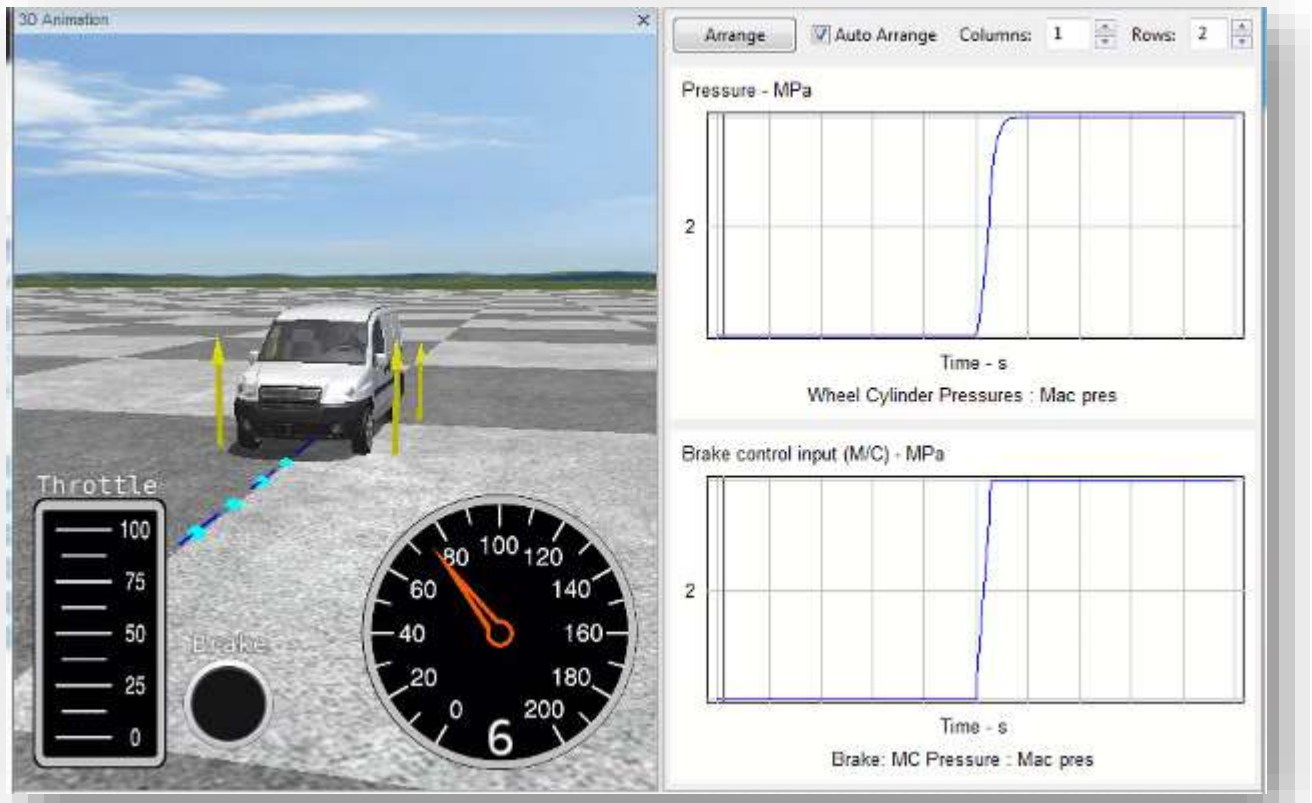
VEHICLE INTERFACE BUILDER



Input to Brakes



Output from Brakes



Vehicle Inputs/Outputs

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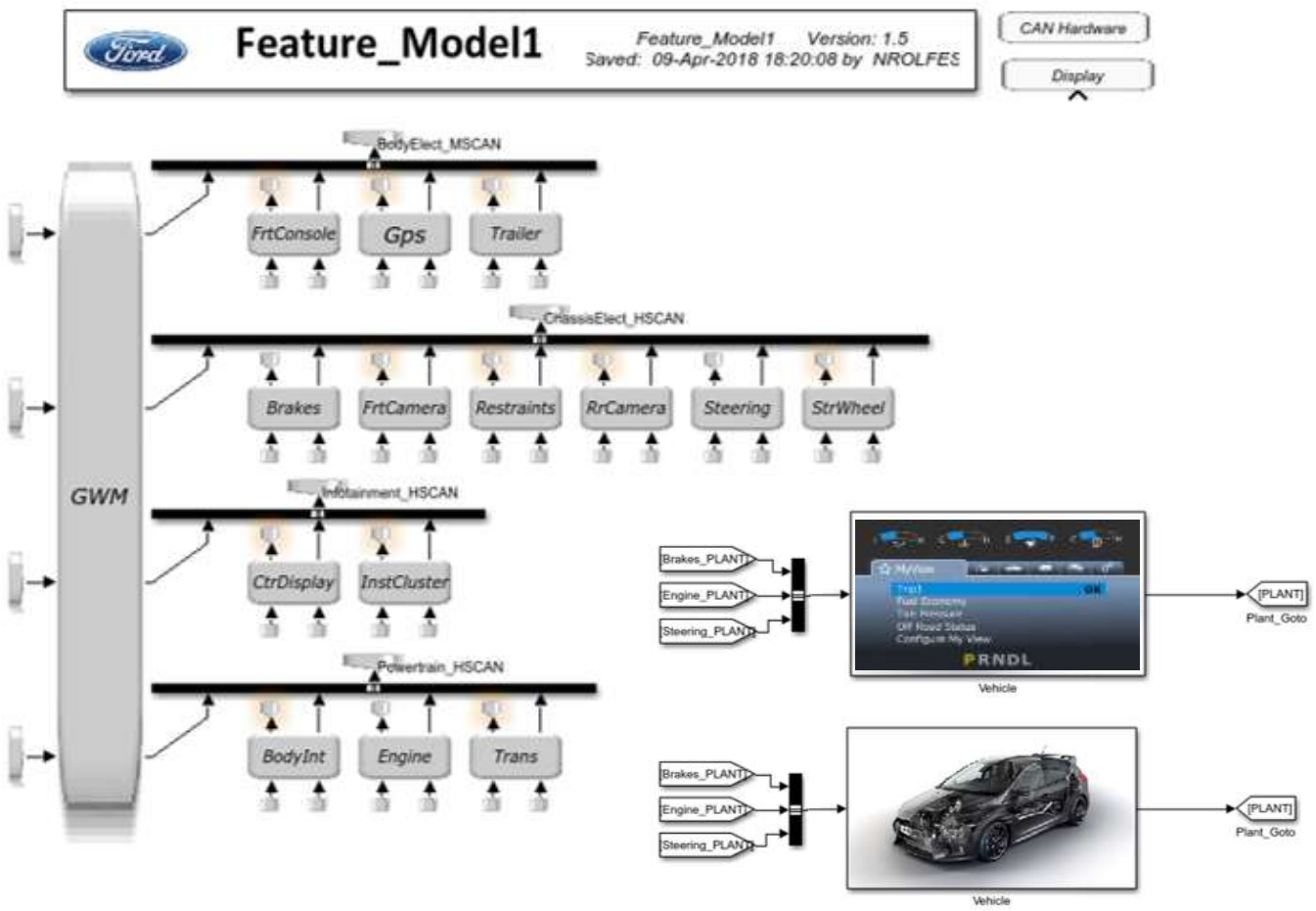
QT HMI INTEGRATION



- Most features have “Driver in the Loop” test scenarios
- HMI simulators help improve the quality and robustness of a feature
- The more realistic the HMI displays and simulators can be made, the better testing results can be achieved.
- Developing high quality HMI displays and interactions is tedious and is not a typical skillset of a controls or simulation engineer.
- Integrating HMI systems such as Qt with the Distributed Feature Simulator helps overcome this.

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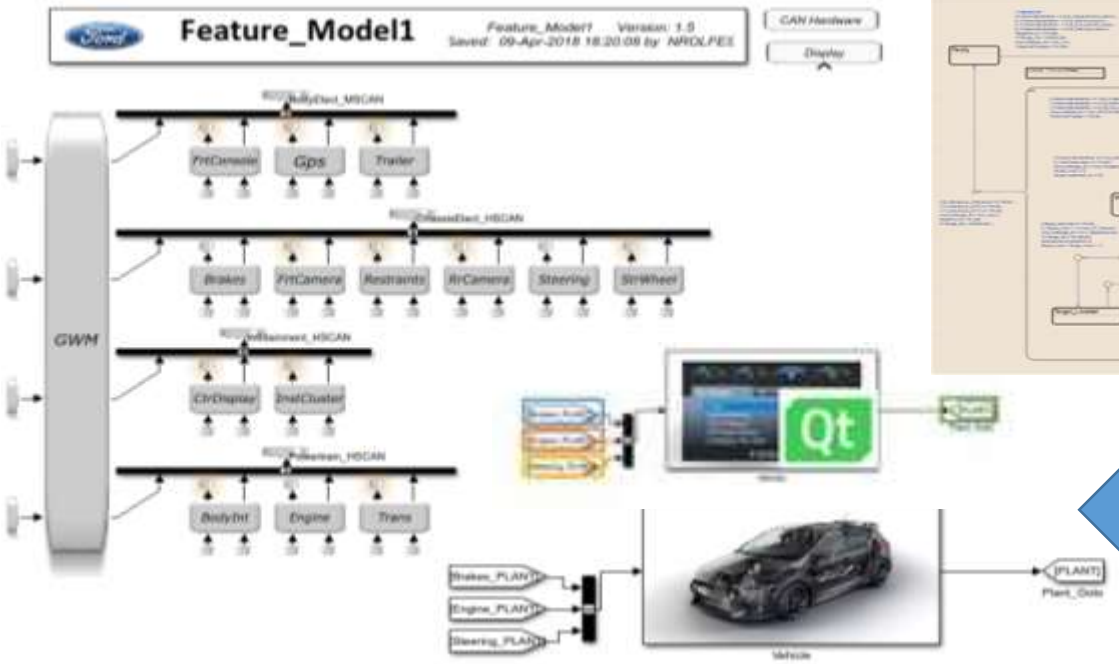
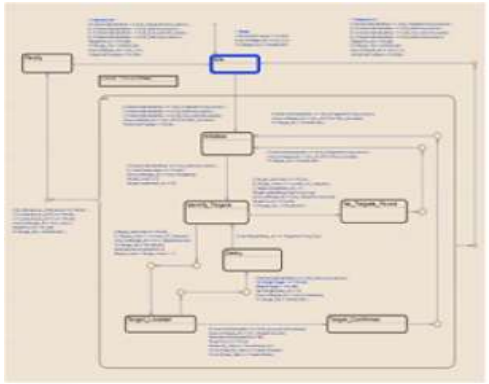
QT HMI INTEGRATION

- Connect ECU's to HMI Model for Vehicle Simulator Experience
- Co-simulation with Qt model over Virtual CAN or physical device (e.g. Raspberry Pi)



Simulink Logic



+

QT Graphics

QT Logic + Graphics

Virtual CAN

Physical CAN

Embedded Device

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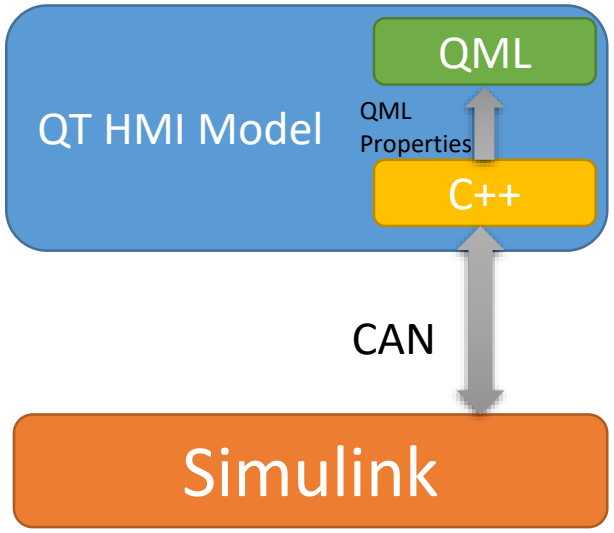
QT HMI INTEGRATION

QT HMI Model and Simulink Integration

- Virtual CAN / Physical CAN Communication
- QT C++ Reads/Writes CAN Messages
- QT C++ Sets QML Properties



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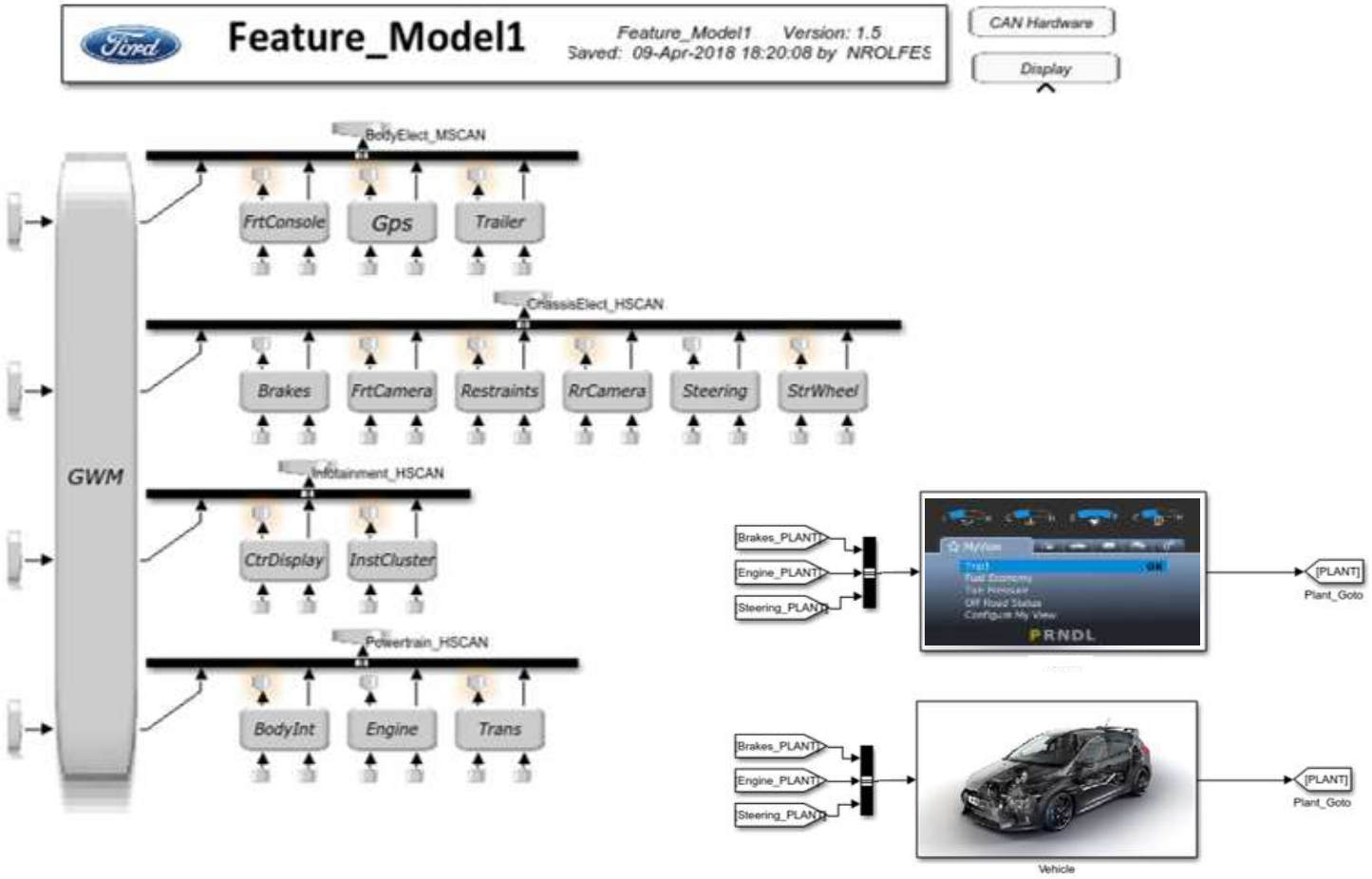
QT HMI INTEGRATION



- Re-use of work already being done by HMI teams
- Enables co-simulation of production-quality HMI development tools with production-quality controls and software development tools
- Saves controls engineer time of having to develop a Simulink replication of already existing HMI models.

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A-L-V RESULTS

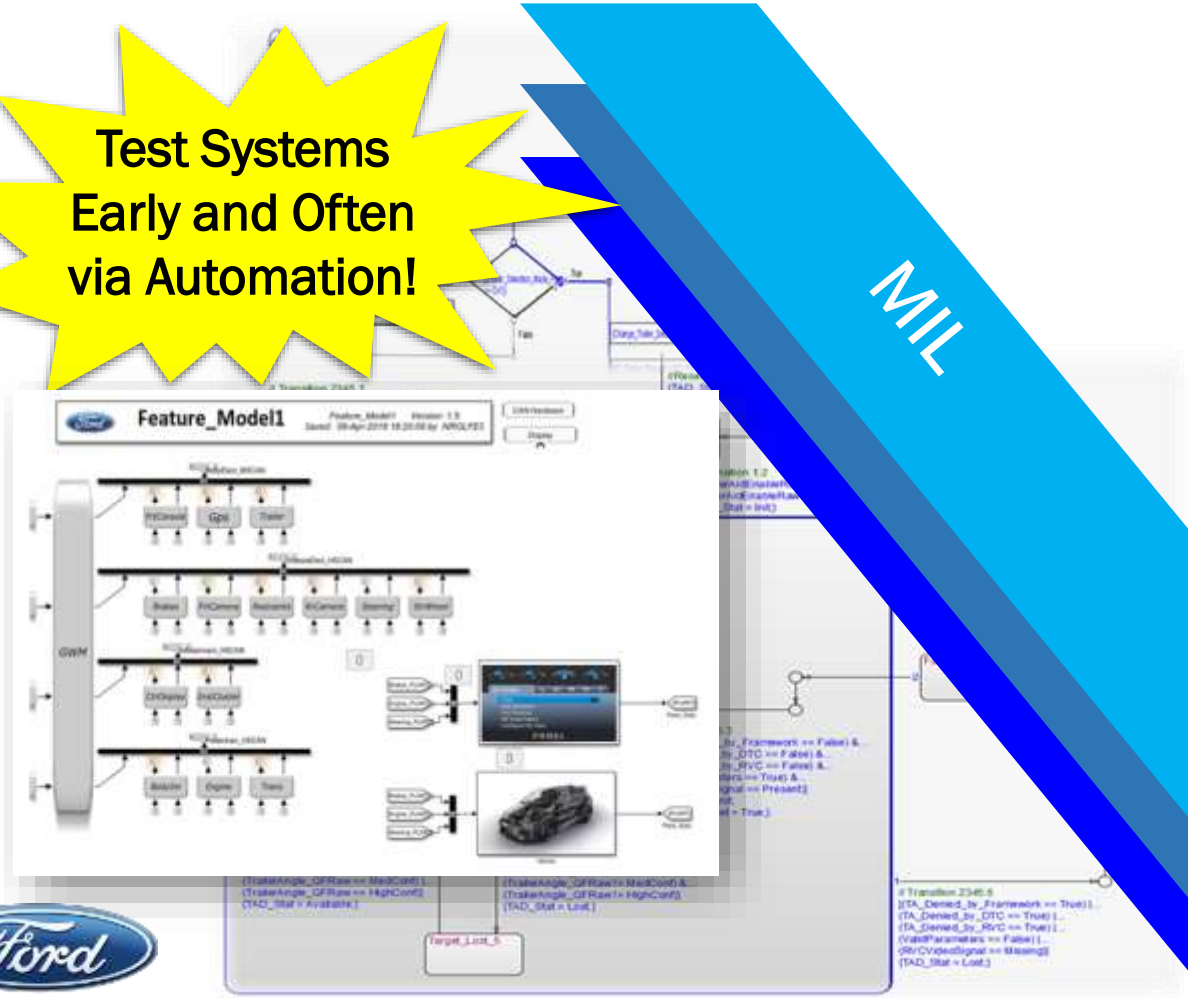
Feature	Initial Build Hours	Milestone 1 Update Hours	Milestone 2 Update Hours	Milestone 3 Update Hours	Milestone 4 Update Hours	Total Hours
Network Interface	15	10	5	5	3	38
Vehicle Interface	6	4	4	4	4	22
HMI Integration	8	2	2	2	2	16
Total	29	16	11	11	9	**76**

- 76 engineering hours (9 days) saved per feature model
- For a program concurrently developing 10 features, this equates to 90 days of saved engineering time!
- In addition to saving time, the automated processes eliminate modeling mistakes
- Lastly, the automated methods frees up the time of valuable simulation engineers to focus on simulating and testing to improve our quality and robustness rather than tedious model-building tasks.

AUTOMATING THE LEFT SIDE OF THE V

"The problem is that we are attempting to build systems that are beyond our ability to intellectually manage." -- *Nancy Leveson (MIT), The Coming Software Apocalypse (The Atlantic, September 2017)*

Test Systems Early and Often via Automation!



HIL is not a Silver Bullet!

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SPECIAL THANKS

THANK YOU FOR YOUR ATTENTION ☺

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