



# Requirement Modeling

of Distributed Automotive Control Systems

*Presented by:*

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*Material prepared for the Mathworks Automotive Conference, May 12, 2016*





# Pro Trailer Backup Assist

## Distributed Control System Overview

### Powertrain System

- Throttle Speed Controller for Speed Limiting
- Gear Shift Lever for State Logic

### Steering System

- Steering Torque Sensing
- Steering Controller Actuation and Logic

### Brake System

- Wheel Speed Sensors for Odometry
- Accelerometers for Vehicle Dynamics State Estimation
- Braking Controller Actuation for Speed Limiting



# Pro Trailer Backup Assist

## Distributed Control System Overview



### Camera System

- Rearview Camera for Trailer Angle Detection



# Pro Trailer Backup Assist

## Distributed Control System Overview

### Camera System

- Rearview Camera for Trailer Angle Detection
- Lighting for Night Usage

# Pro Trailer Backup Assist

## Distributed Control System Overview

### HMI System: Driver Inputs

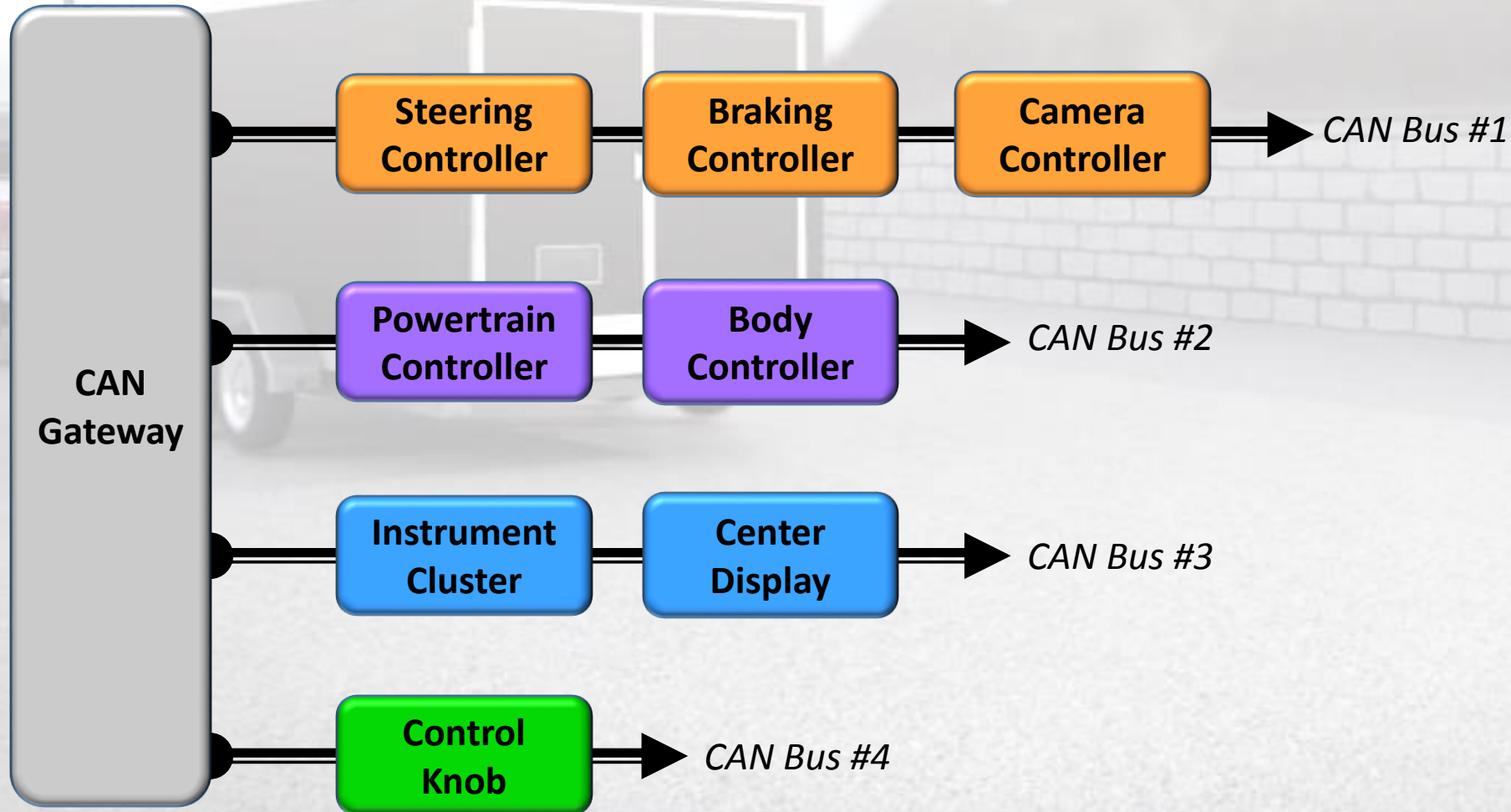
- Activation Switch and Control Knob
- Five-Way Buttons for Driver Inputs
- Cluster Display for Menu Selection and Instructions
- Center Console Display for Trailer View & Warnings





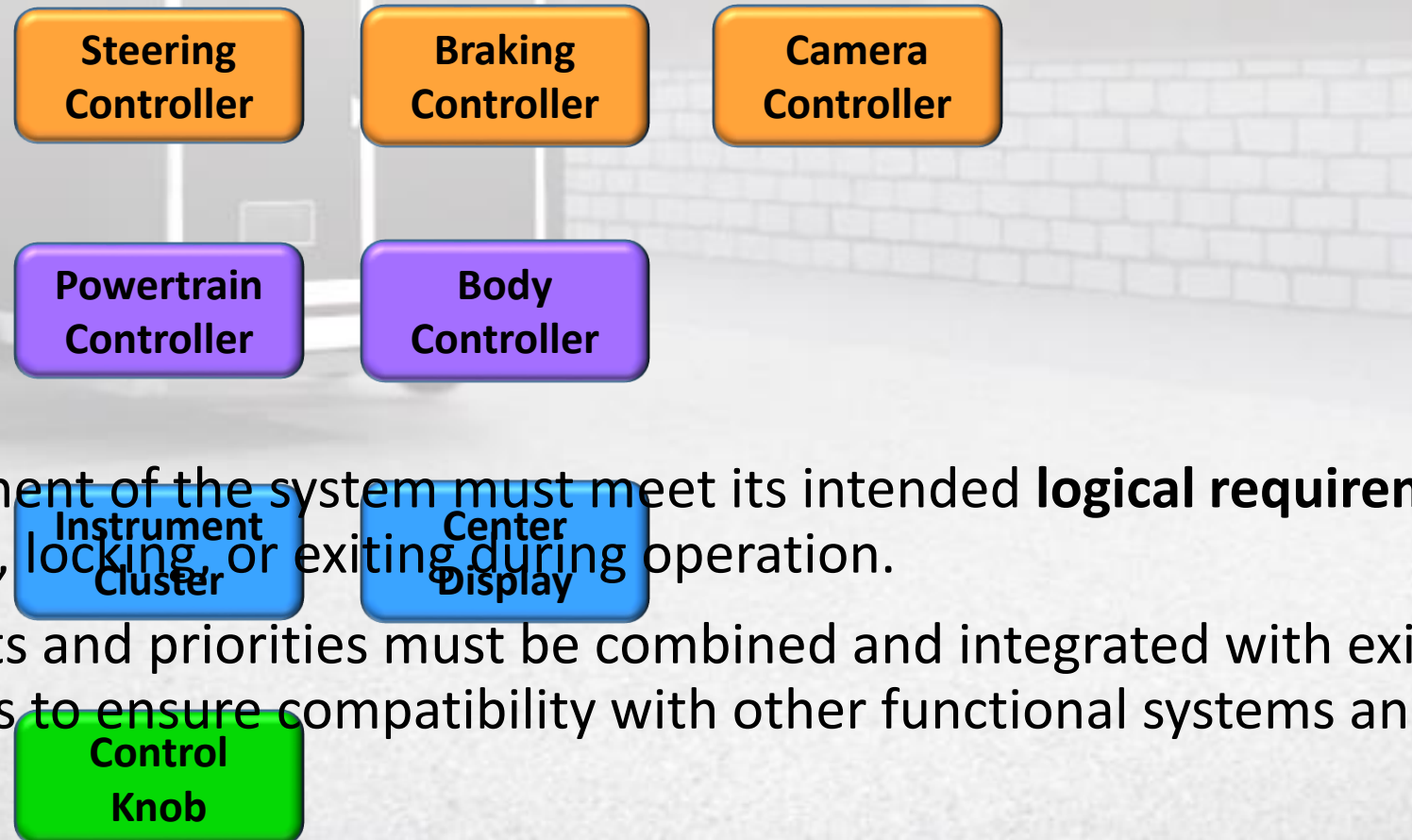
# Challenges of Pro Trailer Backup Assist

- There is not a standalone “Pro Trailer Backup Assist” Module
- The feature is a Distributed Logic Control System containing Eight ECU’s on four CAN buses connected through a CAN Gateway



# Challenges of Pro Trailer Backup Assist

- The control logic is designed based on engineering considerations, e.g.
  - Optimizing and sharing new functionality
  - Leveraging and adapting carryover functionality
  - Minimizing communication bandwidth



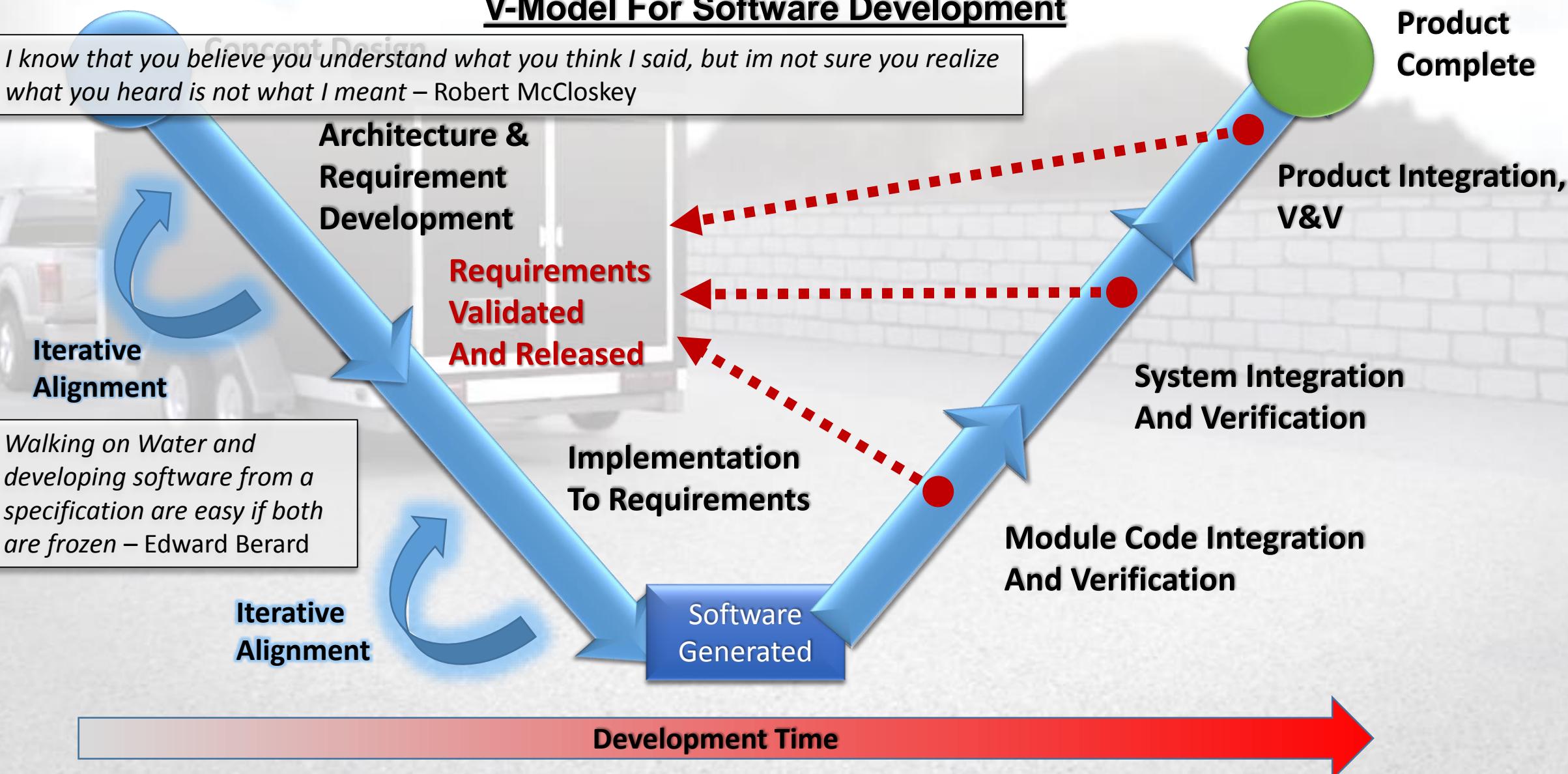
- Each component of the system must meet its intended **logical requirements** to prevent logic looping, locking, or exiting during operation.
- Requirements and priorities must be combined and integrated with existing functional requirements to ensure compatibility with other functional systems and interfaces.



# Challenges of Pro Trailer Backup Assist

## V-Model For Software Development

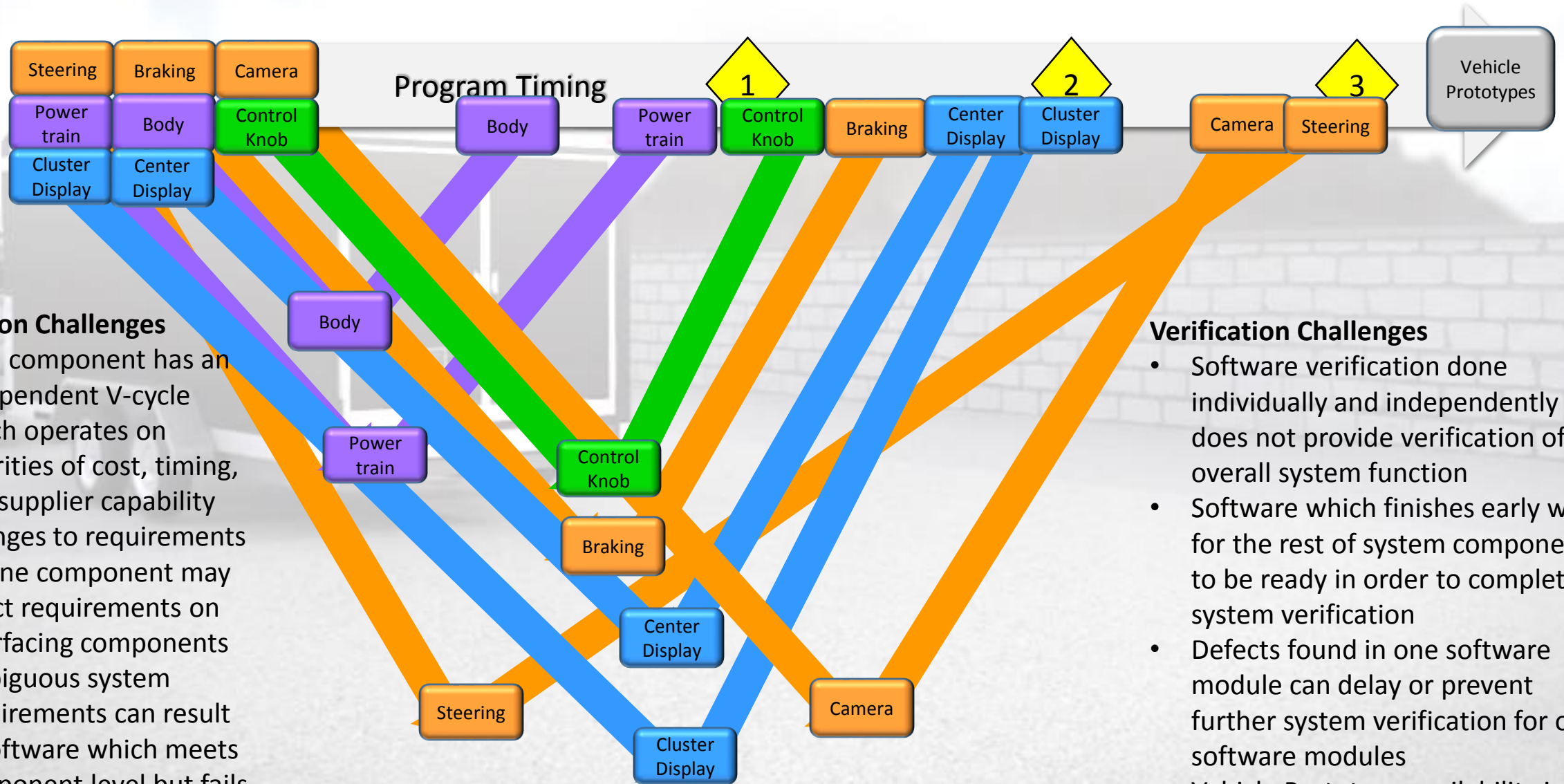
*I know that you believe you understand what you think I said, but im not sure you realize what you heard is not what I meant – Robert McCloskey*



*Walking on Water and developing software from a specification are easy if both are frozen – Edward Berard*

**Development Time**

# Challenges of Pro Trailer Backup Assist



## Validation Challenges

- Each component has an independent V-cycle which operates on priorities of cost, timing, and supplier capability
- Changes to requirements on one component may affect requirements on interfacing components
- Ambiguous system requirements can result in software which meets component level but fails the system level

## Verification Challenges

- Software verification done individually and independently does not provide verification of the overall system function
- Software which finishes early waits for the rest of system components to be ready in order to complete system verification
- Defects found in one software module can delay or prevent further system verification for other software modules
- Vehicle Prototype availability is too late to resolve critical defects



# Solutions of Pro Trailer Backup Assist

## 1. REQUIREMENT MODELING:

- A modeling methodology for Requirements which captures and simulates the logical parts to ensure the distributed control logical design of requirements works as intended prior to release for software implementation

## 2. DISTRIBUTED NETWORK SIMULATION:

- A simulation environment which can link multiple Controller modules, CAN Networks, Driver and Vehicle Interactions.
- It can simulate both MIL (Virtual) and HIL (Hardware) in real-time and each controller can be switched in real-time to either the MIL or HIL version. It can test all systems together or target systems individually at the system engineer's discretion

## 3. VALIDATION AND VERIFICATION TOOL:

- A tool that can work effectively throughout the Software V process to:
  - ✓ Test and validate requirement models (Down the System V)
  - ✓ Verify that software components and module outputs match the requirement model behavior (Up the System V)

# What is Requirement Modeling?

**TIME**

## Remembering the Apollo 11 Moon Landing With the Woman Who Made It Happen

Lily Rothman @lilyrothman | July 20, 2015



“...Part of what had made Hamilton’s work so effective was that she tested everything so rigorously, **in a simulator that could demonstrate the “system of systems” at work,** and the relationship between the software, the hardware and the astronaut. “We couldn’t run something up to the moon,” she says. But they could run lots of tests on the ground.

**Hamilton’s team found that nearly three-quarters of them were interface errors, like conflicts in timing or priority...”**



Margaret Hamilton



# What is Requirement Modeling?

2013-01-2237

## Requirements Modeling and Automated Requirements-Based Test Generation

John Lee and Jon Friedman  
MathWorks

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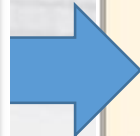
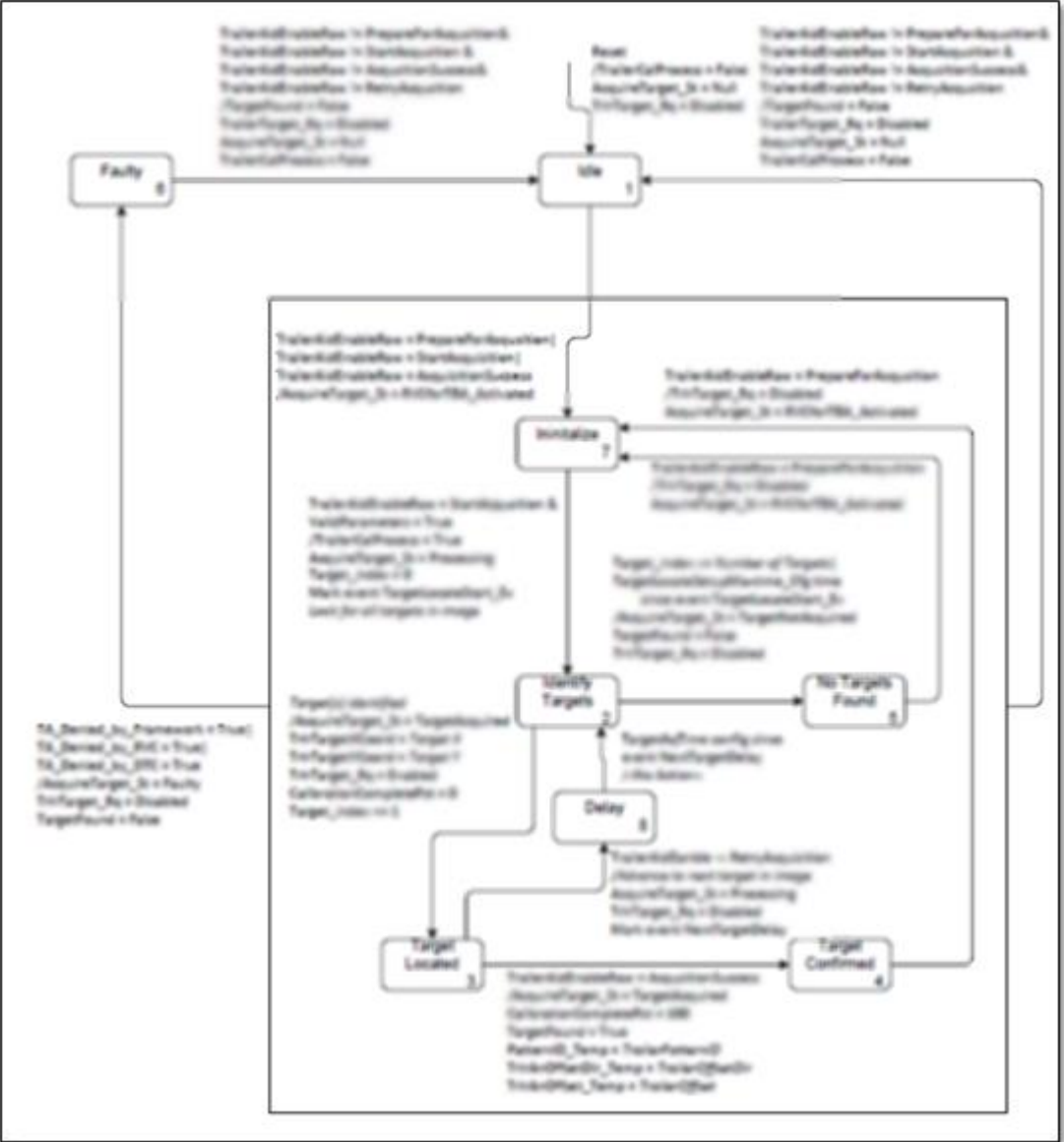
“...The goal of requirements models is **to capture the functional requirement in a clear, concise, analyzable and executable manner, which is typically not possible with natural language.**

The requirements models can then be used to **evaluate the interaction and compatibility of requirements from disparate sources as well as to develop tests and acceptance criteria (or expected outputs).**

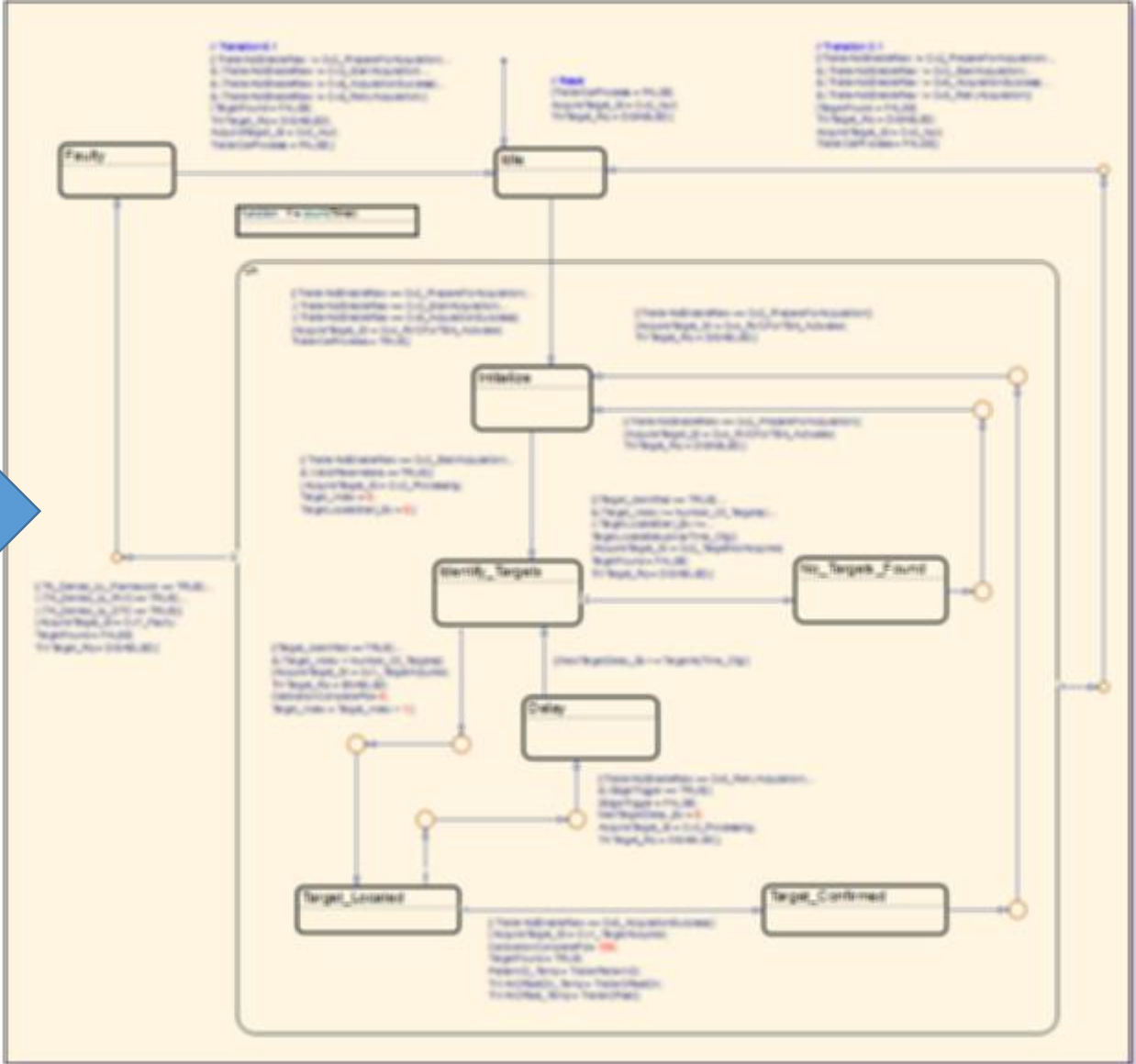
The use of the requirements models for test creation enables engineers to assess the completeness of the tests **using different notions of coverage on the requirements model...**”

# Requirement Modeling Example

Paper Specification State Machine:

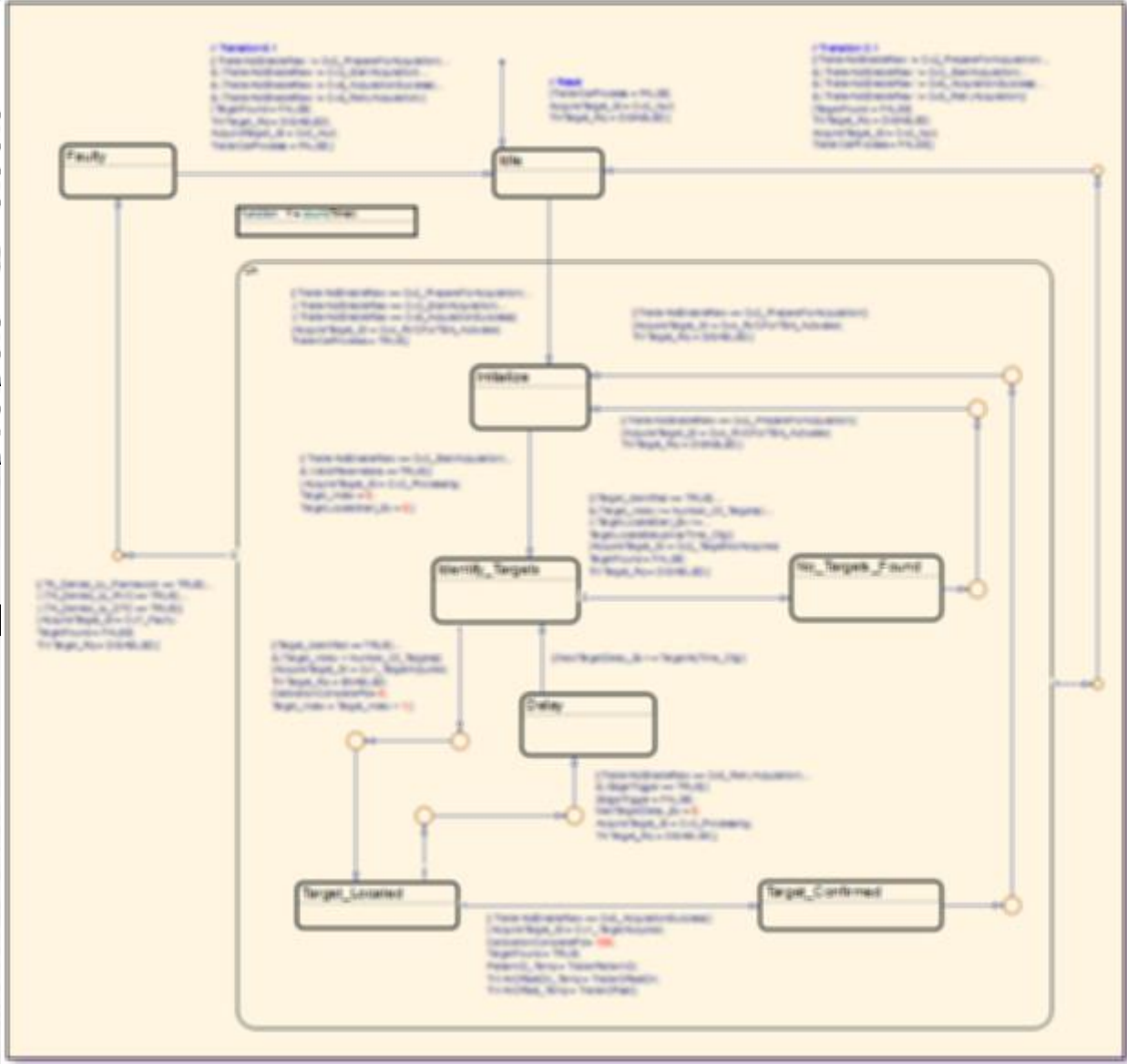
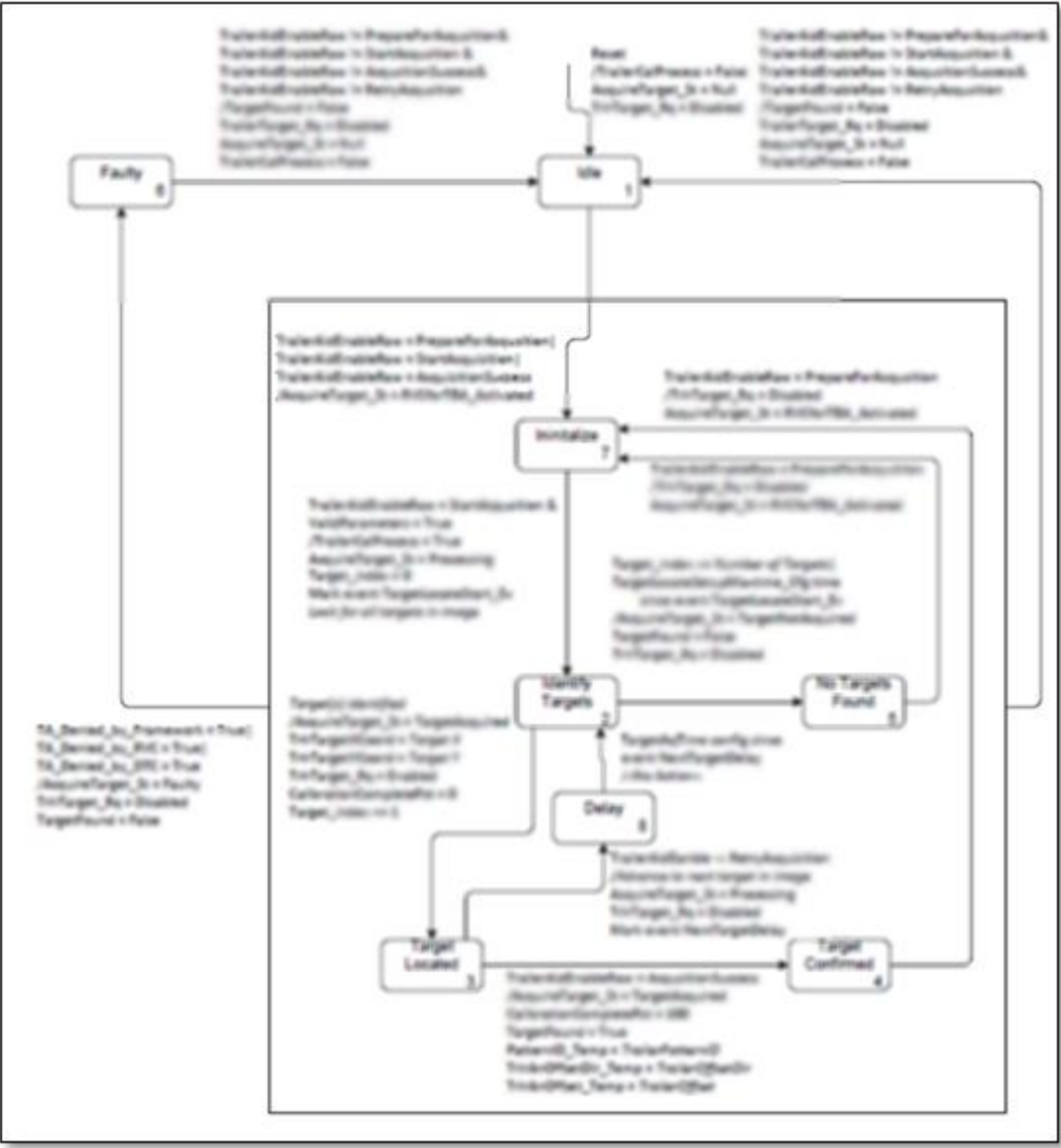


Stateflow Requirement Model:





# Requirement Modeling Example



# Solutions of Pro Trailer Backup Assist

## 1. REQUIREMENT MODELING:

- A modeling methodology for Requirements which captures and simulates the logical parts to ensure the distributed control logical design of requirements works as intended prior to release for software implementation

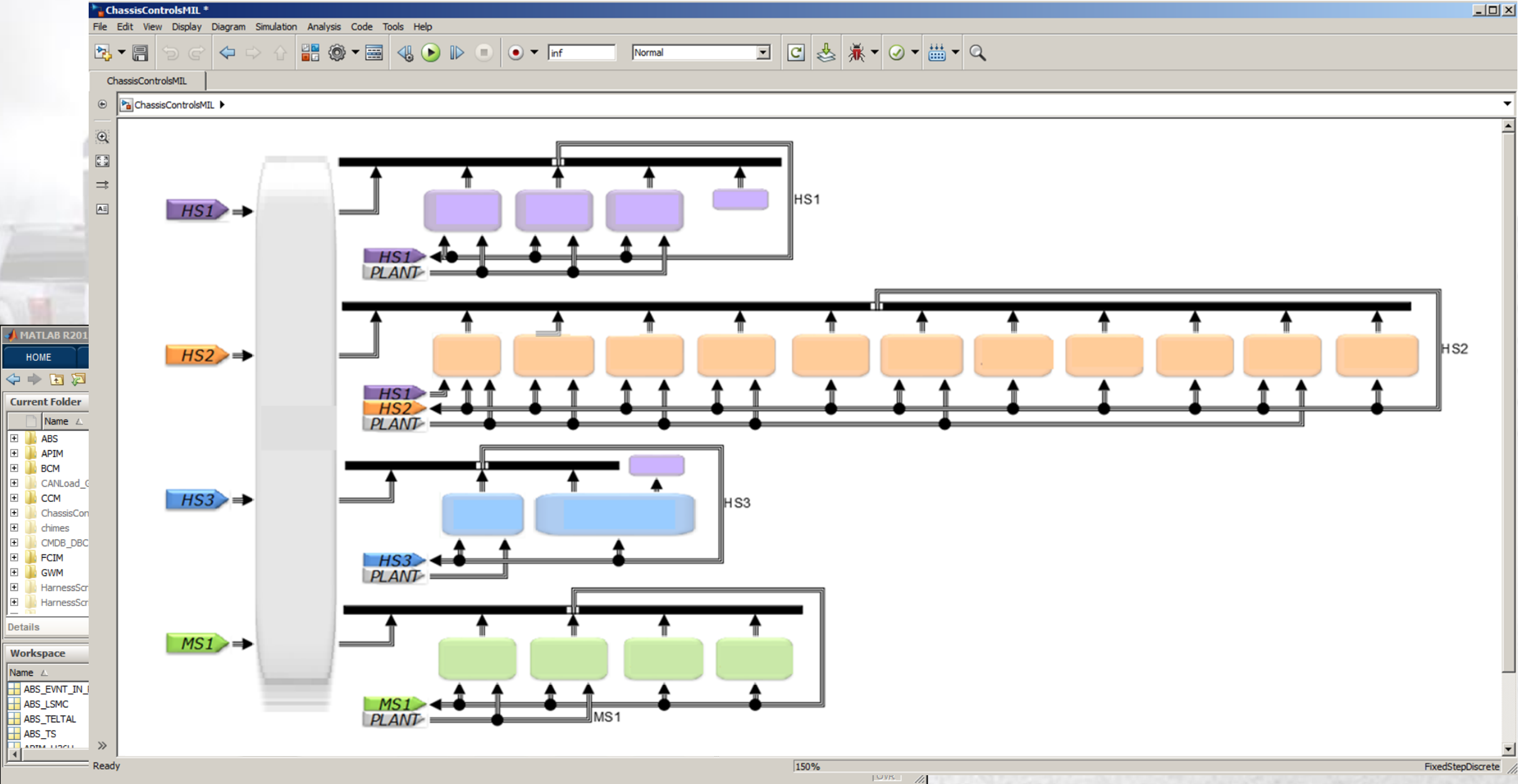
## 2. DISTRIBUTED NETWORK SIMULATION:

- A simulation environment which can link multiple Controller modules, CAN Networks, Driver and Vehicle Interactions.
- It can simulate both MIL (Virtual) and HIL (Hardware) in real-time and each controller can be switched in real-time to either the MIL or HIL version. It can test all systems together or target systems individually at the system engineer's discretion

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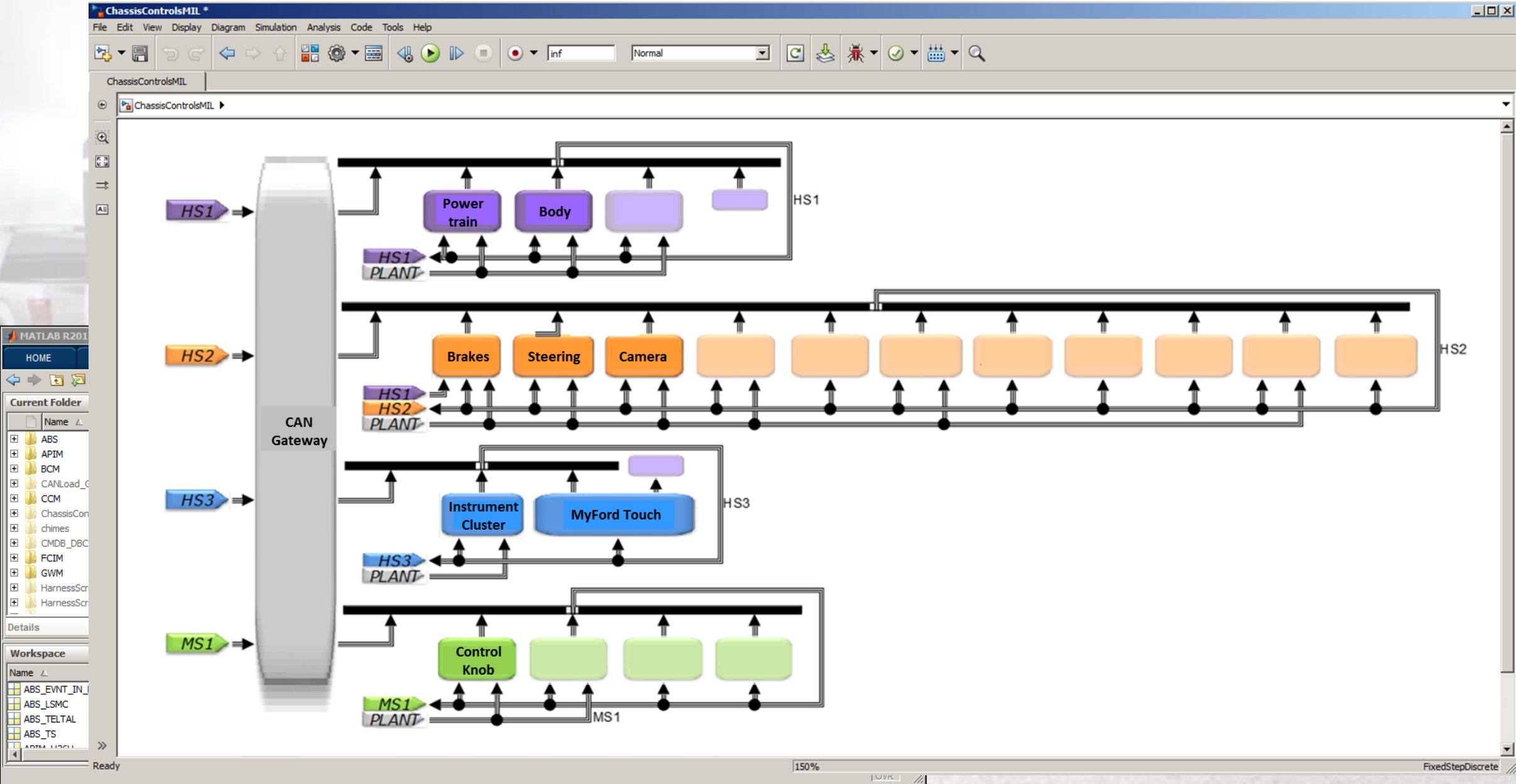
- A tool that can work effectively throughout the Software V process to:
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# Distributed Network Simulation MIL





# Distributed Network Simulation MIL



# Distributed Network Simulation MIL

The image shows a screenshot of the ChassisControlsMIL simulation software interface. A large red text overlay with a yellow glow reads "Simulator of Systems". The interface includes a MATLAB R201x workspace on the left, a central simulation area with a vehicle model, and several control panels on the right. The simulation area displays vehicle parameters: SWA: -0.00091, Veh Ang: -0, Trlr Ang: 0, Hitch Ang: 0. The simulator\_gui panel shows a menu with options like Trip/Fuel, Towing, Off Road, and Settings, along with a 5-Way Control pad and Trailer Backup Assist controls. The ChassisControlsMIL\_GUI panel features simulation controls (START, PAUSE, STOP, CAN BUS, GPS), a speedometer showing 705.2, and various vehicle state indicators (P, R, N, D, L, M) and driver controls (Steering Wheel Input, Brake, Accel, Speed Limits).

ChassisControlsMIL

File Edit View Display Diagram Simulation Analysis Code Tools Help

ChassisControlsMIL

ChassisControlsMIL

SWA -0.00091 Veh Ang -0 Trlr Ang 0 Hitch Ang 0

simulator\_gui

Display On Edit GUI Edit Display

Menu

Display Mode >

Trip/Fuel

Towing

Off Road

Settings

MH: 1 MCDS: 1 MT: 0

5-Way Control

Trailer Backup Assist

TBA OFF

Trailer Type Connected

None

ChassisControlsMIL\_GUI

Simulation Controls

START PAUSE STOP CAN BUS GPS

705.2 MEM CHECK RESET MODEL Edit GUI

SIM Parameters Helper Edit Variants Set Variants Edit GPS

Automatic Trans GUI

P552 3584 P285/70R17 2522

Vehicle State

0 P N -0 0 0 CLOSED

VehSpd GearAt GearMt SvaComp SvaOS Swt Eac

-0 -0 0 TC Unk 0

YawAng YawRt HitchAng WhlDir RqSwa

DM3 Disp Cl IPC L1 Simulator Batt Norm (13.8V)

Driver Controls

Steering Wheel Input (HWT Nm) Brake Accel Speed Limits:

Release 1.5 0 Hold Sine: 0.2

AT Gear F R N D L Day

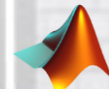
Ignition\_Status Turn Signal

Off Acc Strt Run Left Off Right

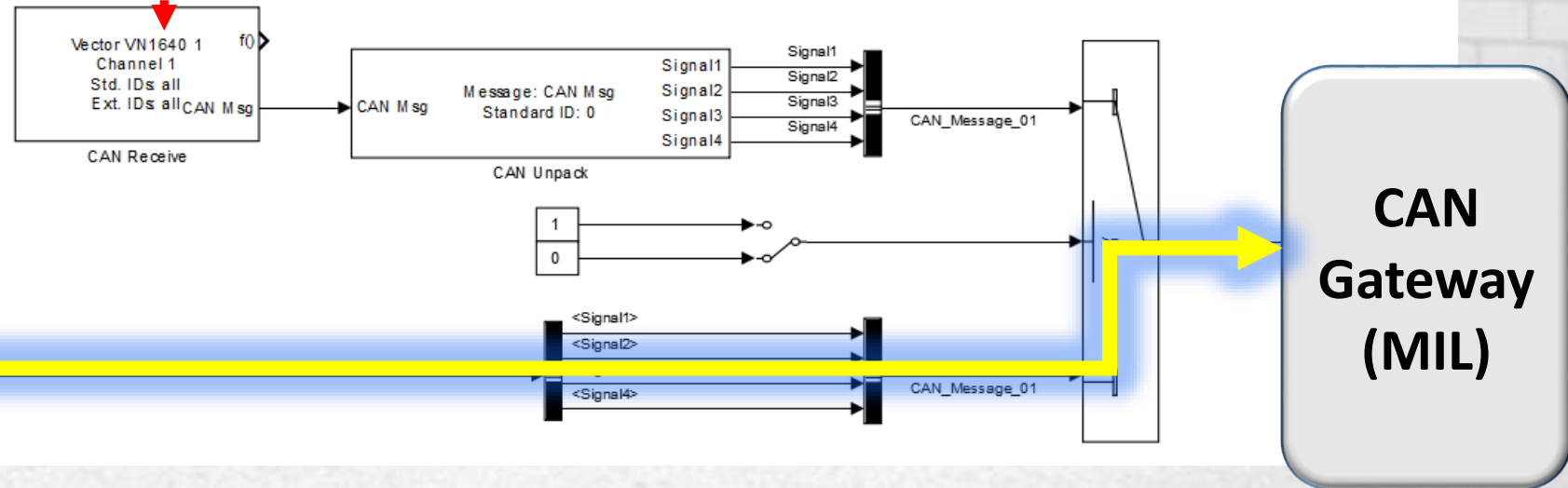
APA 360 TBA 5-Way Control

# Adding Hardware using Vehicle Network Toolbox

Instrument Cluster  
Hardware (HIL)



Vehicle Network Toolbox



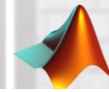
Instrument Cluster  
Requirement Model  
(MIL)

CAN  
Gateway  
(MIL)

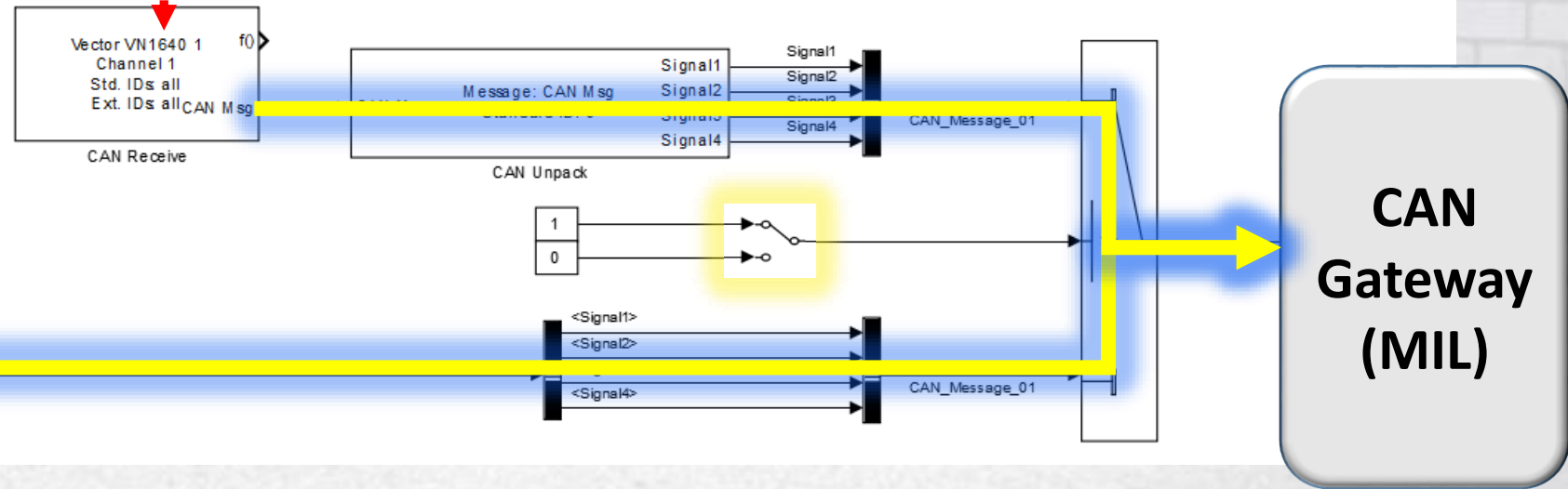


# Adding Hardware using Vehicle Network Toolbox

Instrument Cluster  
Hardware (HIL)



Vehicle Network Toolbox



Instrument Cluster  
Requirement Model  
(MIL)

# Distributed Network Simulation MIL & HIL

The screenshot displays the ChassisControlsMIL simulation environment. The main workspace shows a distributed network architecture centered around a CAN Gateway. The network is divided into four hierarchical levels:

- HS1 (Host Simulation 1):** Contains high-level functional blocks such as Power train, Body, and other vehicle systems.
- HS2 (Host Simulation 2):** Contains more detailed control blocks like Brakes, Steering, and Chassis.
- PLANT:** A central physical representation of the vehicle chassis and drivetrain.
- MS1 (Master Simulation 1):** Includes a driver's perspective with a steering wheel, instrument cluster, and a video feed of the vehicle's interior.

External nodes are connected to the CAN Gateway via HS1, HS2, HS3, and MS1. The interface includes a menu for simulation control (START, PAUSE, STOP, CAN BUS, GPS) and a detailed vehicle state display. The vehicle state panel shows:

- Automatic Trans:** GUI
- Vehicle State:** 0 P N -0 0 0 CLOSED
- Driver Controls:** Steering Wheel Input (HWT Nm), Brake, Accel, Speed Limits (25, 16), AT Gear (P R N D L), Trailer Attach (Day), Ignition\_Status (Off, Acc, Strt, Run), Turn Signal (Left, Off, Right), Door/Arj (Factory/Res).

The simulator GUI also displays a menu with options like Trip/Fuel, Towing, Off Road, and Settings, along with a 5-Way Control interface and a Trailer Backup Assist section.

# Distributed Network Simulation MIL & HIL

The image displays a complex simulation environment for vehicle chassis controls, divided into several key components:

- ChassisControlsMIL (Main Window):** Shows a CAN Gateway connected to four hierarchical simulation levels: HS1 (Power train, Body), HS2 (Brakes, Steering, Cam), HS3 (Instrument cluster), and MS1 (Trailer Backup Assist). Each level is connected to a corresponding hardware-in-the-loop (HIL) plant.
- MATLAB R2019a (Left Panel):** Shows the current folder structure with subfolders for various vehicle systems like ABS, BCM, and ChassisControl.
- simulator\_gui (Bottom Center):** Displays the Pro Trailer Backup Assist interface with a central message: "Pro Trailer Backup Assist Backup Slowly Turn Knob to Steer". It includes a gear selector (P, R, N, D, L, M) and a "Press Knob to Exit" button.
- ChassisControlsMIL\_GUI (Bottom Right):** Provides simulation controls such as START, PAUSE, STOP, CAN BUS, and GPS. It also displays real-time vehicle state data, including speed (6.8 kph), gear (R), and various sensor readings.



# Solutions

## 1. REQUIREMENT MODELING:

- A modeling methodology for Requirements which captures and simulates the logical parts to ensure the distributed control logical design of requirements works as intended prior to release for software implementation

## 2. DISTRIBUTED NETWORK SIMULATION:

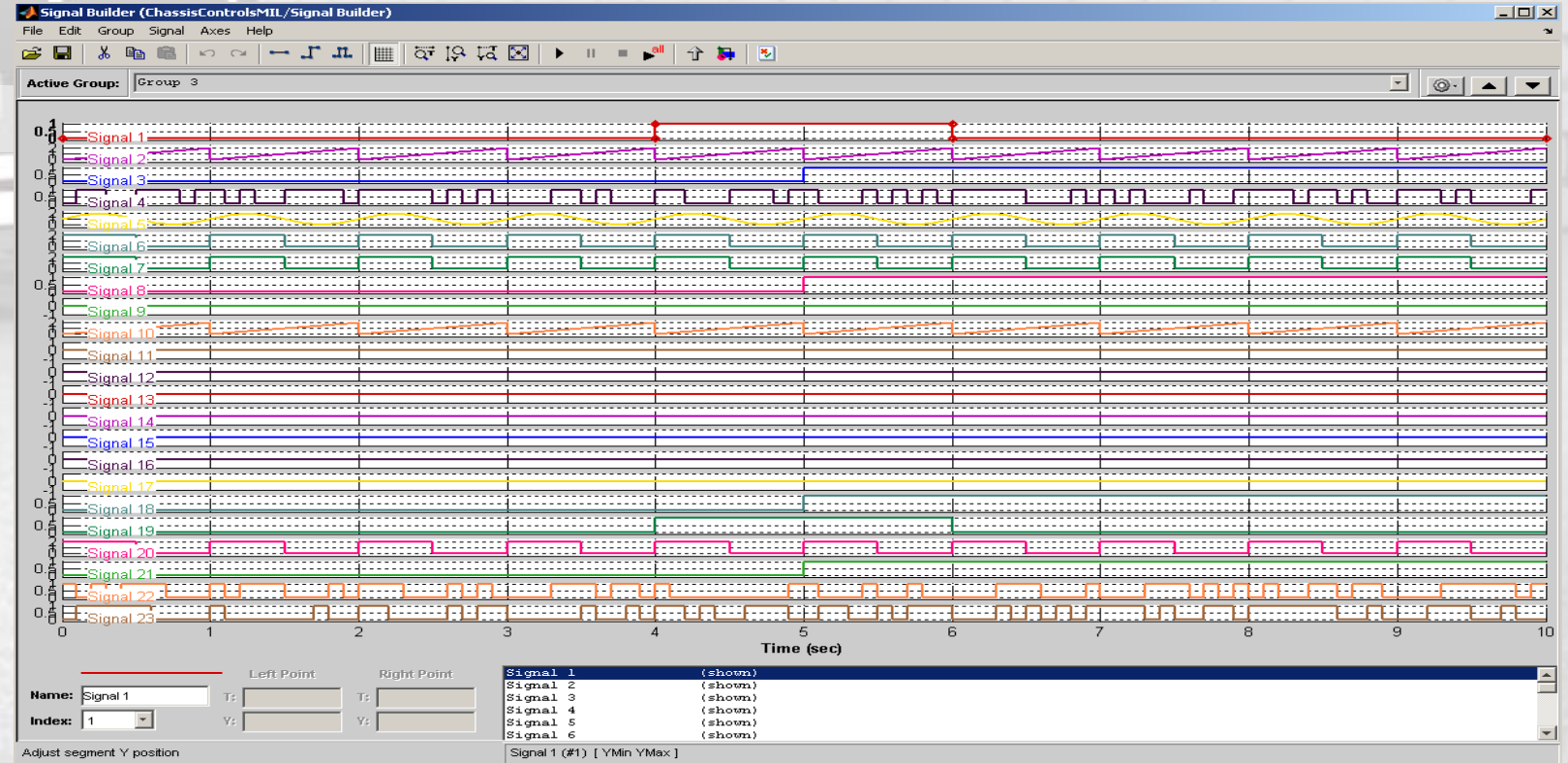
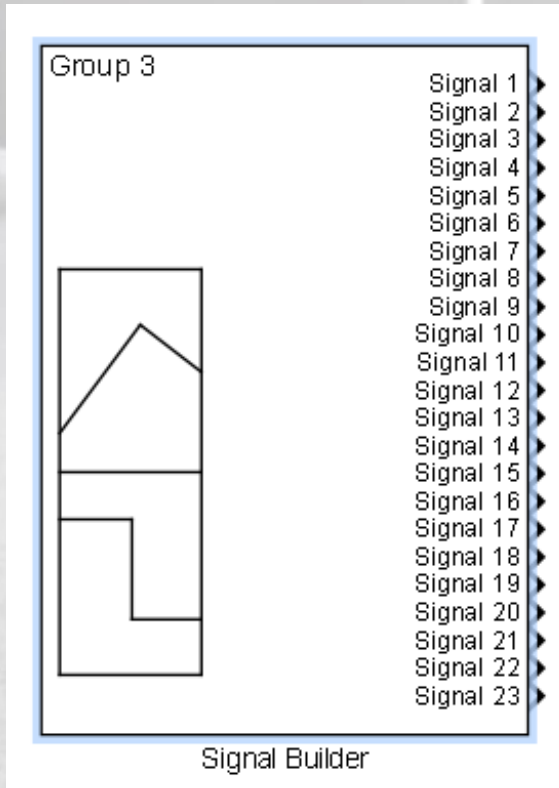
- A simulation environment which can link multiple Controller modules, CAN Networks, Driver and Vehicle Interactions.
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# Validation and Verification Tool

- Most verification tools are not intended to handle “simulation of systems” with driver-in-the-loop. Most are designed and focused for unit-level testing and verification.
- Simulink Signal Generator tool works for unit testing of simple models and test cases with a limited and predictable number of inputs and outputs.
- It becomes cumbersome to modify and maintain Signal Generator for highly complex or distributed logic control models with hundreds of potential inputs and outputs



# Validation and Verification Tool

- Based on previous experience and not-so-successful attempts with existing verification tools, I developed a unique verification tool that would integrate seamlessly into the Distributed Network Simulation environment.

## STEP 1: Define the Test Case

### Simple Trailer Backup Assist Test Case

1. Driver activates Trailer Backup Assist (Press Button)
2. Driver begins to back-up trailer for a few seconds (Shift to Reverse, Accelerator Pedal)
3. Driver stops the vehicle (Depress Brake Pedal)
4. Driver deactivates Trailer Backup Assist (Press Button)



# Validation and Verification Tool

## STEP 2: Simulate and Record the Test Case

The screenshot displays the ChassisControlsMIL GUI interface, which is used for simulating and recording test cases. The interface is divided into several main sections:

- Simulation Controls:** Located at the top right, it includes buttons for START (green), PAUSE (yellow), STOP (red), CAN BUS (purple), and GPS (orange). Below these are numerical displays for 440.4, MEM CHECK, and RESET MODEL, along with buttons for SIM Parameters, Helper, Edit Variants, Set Variants, and Edit GPS.
- Vehicle State:** This section shows the current gear (P), engine status (Run), and various vehicle parameters such as Vehicle Speed (0 kph), Vehicle Yaw Rate, Wheel Direction, and Vehicle Position (X: 185 m, Y: 0 m). It also displays a gear shift indicator (P, R, N, D, L, M) and a 5-Way Control panel.
- Driver Controls:** This section provides a virtual driver's perspective, including a steering wheel input (HWT Nm), Brake and Accelerator pedals, and a gear shift lever. It also shows Ignition Status (Off, Acc, Strt, Run) and Turn Signal controls.
- Simulation Parameters:** On the right side, there are dropdown menus for Automatic Trans (GUI), P552 3584, and P265/70R17 2522.
- Vehicle State Table:** A table showing various vehicle parameters and their current values:

VehSpd	GearAt	GearMt	SwaComp	SwaOS	Swl	Eac
0	P	N	0	0	0	CLOSED
-0	0	0	TC		Unk	0
YawAng	YawRt	HitchAng			WhlDir	RqSwa
DM8 Disp	Cl	IPC L1	Simulator	Batt	Norm (13.8V)	
- Simulation Configuration:** On the left side, there are sections for Harness Configuration (Select config file, Current configuration file: mappingFile.xlsx), Harness and Logging (Create harness, TestCase, Logging On/Off, Current log file: TestCase7), Logging File Conversion (Select/Load log file, Generate playback, Generate output file, Log file to convert: TestCase6, Convert first output only), and Replay (Select/Load replay, Reset replay, Start/Stop replay, Replay info (file/sample time): 0.02, Replay status).
- Workspace:** On the far left, the MATLAB R201 workspace is visible, showing a list of files and folders related to the simulation, including ABS, APIM, BCM, CANLoad\_C, CCM, ChassisCon, chimes, CMDB\_DBC, FCIM, GWM, HarnessScr, and HarnessScr.

# Validation and Verification Tool

## STEP 3: Generate Test Case Replay Script and Master Report

Time	Driver Input	HMI Request	HMI Status	Camera Status	Setup Status	Steering Angle	Vehicle Speed
0		1 HMI	Inactive	Null	Inactive	0 deg	0 kph
2.82	TBA Button Pressed	1 HMI	Inactive	Null	Inactive	0 deg	0 kph
3.14	TBA Button Not Pressed	1 HMI	Inactive	Null	Inactive	0 deg	0 kph
4.26	Down Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
4.5	Down Not Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
5.54	Up Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
5.78	Up Not Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
6.86	Ok Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
7.06	Ok Not Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
16.94	Shift gear to Reverse	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
18.78	Accel pedal 25 %	2 HMI	ActivateTba	Null	Inactive	0 deg	0 kph
19.14	Accel pedal 50 %	2 HMI	ActivateTba	TbaActive	Inactive	0 deg	0 kph
19.66	Accel pedal 75 %	2 HMI	DeactivateTba	TbaActive	Inactive	0 deg	0 kph
20.98	Accel pedal 50 %	4 HMI	DeactivateTba	TbaActive	Inactive	0 deg	0 kph
21.3	Accel pedal 25 %	4 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
21.72	Accel pedal 0 %	14 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
22.34	Brake Pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
22.76	Brake Pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
23.16	Brake Pedal 75 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
24.12	Brake Pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.004036 kph
24.46	Brake Pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	1.1564 kph
24.82	Brake Pedal 0 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	6.101 kph
26.64	TBA Button Pressed	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.9395 kph
26.9	TBA Button Not Pressed	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.7276 kph
30.1	Ok Pressed	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.4148 kph
30.42	Ok Not Pressed	5 HMI	Inactive	TbaActive	Inactive	0 deg	3.9163 kph
32.04	Shift gear to Park	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.98992 kph
30.1	Ok Pressed	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
30.42	Ok Not Pressed	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
32.04	Shift gear to Park	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
38.86	Shift gear to Park	1 HMI	Inactive	Null	Inactive	0 deg	0 kph

# Validation and Verification Tool

## STEP 4: Replay and Record the Test Case

The screenshot displays the ChassisControlsMIL GUI interface, which is used for simulation and testing. The interface is divided into several main sections:

- Simulation Controls:** Located at the top right, it includes buttons for START (green), PAUSE (yellow), STOP (red), CAN BUS (purple), and GPS (red). It also shows a speedometer reading of 587.6 and buttons for MEM CHECK, RESET MODEL, and Edit GUI. Below these are SIM Parameters, Helper, Edit Variants, Set Variants, and Edit GPS.
- Vehicle State:** Located below the simulation controls, it displays various vehicle parameters: VehSpd (0), GearAt (P), GearMt (N), SvaComp (0), SvaOS (0), Swl (0), Eac (CLOSED), YawAng (-0), YawRt (0), HitchAng (0), TC, WhlDir (Unk), and RqSwa (0). It also shows DM8 Disp, CI, IPC L1, Simulator, and Batt (Norm (13.8V)).
- Driver Controls:** Located at the bottom right, it includes controls for Steering Wheel Input (HWT Nm), Brake, Accel, and Speed Limits (25 Fwd, 15 Rwd). It also features AT Gear (P R N D L), Ignition\_Status (Off, Acc, Strt, Run), Turn Signal (Left, Off, Right), and DoorAjar (FactoryRes).
- Menu:** Located in the center, it provides navigation options: Display Mode, Trip/Fuel, Towing, Off Road, and Settings. It also shows a gear selector (P R N D L M) and Ignition Status (Run).
- 5-Way Control:** Located in the center, it includes a 5-Way Control panel with directional arrows and an OK button, and a Trailer Backup Assist (TBA OFF) button.
- Trailer Type Connected:** Located at the bottom center, it shows a dropdown menu set to None.
- harnessGUI:** Located on the left side, it contains sections for Harness Configuration (Select config file, Current configuration file: mappingFile.xlsx), Harness and Logging (Create harness, TestCase, Current log file: TestCase8, Logging On/Off), Logging File Conversion (Select/Load log file, Generate playback, Generate output file, Log file to convert: TestCase7, Convert first output only), and Replay (Select/Load replay, Reset replay, Start/Stop replay, Replay info (file/sample time): TestCasePlayback7, 0.02, Replay status: 0, 38.86, 38.86, Shift gear to Park).
- MS1 PLANT:** Located at the bottom, it shows a green arrow pointing to the MS1 PLANT.

The interface also includes a MATLAB R201x workspace on the left side, showing a list of files and folders such as ABS, APIM, BCM, CANLoad\_C, CCM, ChassisCon, chimes, CMDB\_DBC, FCIM, GWM, HarnessScr, and HarnessScr. The status bar at the bottom indicates 'Ready' and 'FixedStepDiscrete'.



# Validation and Verification Tool

## STEP 5: Compare Test Case Results against Master

A1

	A	B	F	G	H	I	J	K	L		A	B	F	G	H	I	J	K	L
1	Time	Driver Input	HMI Request	HMI Status	Camera Status	Setup Status	Steering Angle	Vehicle Speed			Time	Driver Input	HMI Request	HMI Status	Camera Status	Setup Status	Steering Angle	Vehicle Speed	
2	0		1 HMI	Inactive	Null	Inactive	0 deg	0 kph			0		1 HMI	Inactive	Null	Inactive	0 deg	0 kph	
3	2.82	TBA Button Pressed	1 HMI	Inactive	Null	Inactive	0 deg	0 kph			5.1	TBA Button Pressed	1 HMI	Inactive	Null	Inactive	0 deg	0 kph	
4	3.14	TBA Button Not Pressed	1 HMI	Inactive	Null	Inactive	0 deg	0 kph			5.42	TBA Button Not Pressed	1 HMI	Inactive	Null	Inactive	0 deg	0 kph	
5	3.26		2 HMI	Inactive	Null	Inactive	0 deg	0 kph			5.54		2 HMI	Inactive	Null	Inactive	0 deg	0 kph	
6	4.26	Down Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph			6.54	Down Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph	
7	4.5	Down Not Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph			6.78	Down Not Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph	
8	5.54	Up Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph			7.82	Up Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph	
9	5.78	Up Not Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph			8.06	Up Not Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph	
10	6.86	Ok Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph			9.14	Ok Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph	
11	7.06	Ok Not Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph			9.34	Ok Not Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph	
12	7.24		2 HMI	ActivateTba	Null	Inactive	0 deg	0 kph			9.72		2 HMI	ActivateTba	Null	Inactive	0 deg	0 kph	
13	7.32		2 HMI	ActivateTba	TbaActive	Inactive	0 deg	0 kph			9.8		2 HMI	ActivateTba	TbaActive	Inactive	0 deg	0 kph	
14	7.46		2 HMI	DeactivateTba	TbaActive	Inactive	0 deg	0 kph			9.94		2 HMI	DeactivateTba	TbaActive	Inactive	0 deg	0 kph	
15	7.58		4 HMI	DeactivateTba	TbaActive	Inactive	0 deg	0 kph			10.06		4 HMI	DeactivateTba	TbaActive	Inactive	0 deg	0 kph	
16	7.84		4 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph			10.32		4 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
17	15.46		14 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph			17.94		14 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
18	16.94	Shift gear to Reverse	14 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph			19.22	Shift gear to Reverse	14 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
19	17.5		5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph			19.78		5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
20	18.78	Accel pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph			21.06	Accel pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
21	19.14	Accel pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.004036 kph			21.42	Accel pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.004036 kph	
22	19.66	Accel pedal 75 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	1.1564 kph			21.94	Accel pedal 75 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	1.1564 kph	
23	20.98	Accel pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	6.101 kph			23.26	Accel pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	6.101 kph	
24	21.3	Accel pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.9395 kph			23.58	Accel pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.9395 kph	
25	21.72	Accel pedal 0 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.7276 kph			24	Accel pedal 0 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.7276 kph	
26	22.34	Brake Pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.4148 kph			24.62	Brake Pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.4148 kph	
27	22.76	Brake Pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	3.9163 kph			25.04	Brake Pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	3.9163 kph	
28	23.16	Brake Pedal 75 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.98992 kph			25.44	Brake Pedal 75 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.98992 kph	
29	24.12	Brake Pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph			26.4	Brake Pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
30	24.46	Brake Pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph			26.74	Brake Pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
31	24.82	Brake Pedal 0 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph			27.1	Brake Pedal 0 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
32	26.64	TBA Button Pressed	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph			28.92	TBA Button Pressed	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
33	26.9	TBA Button Not Pressed	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph			29.18	TBA Button Not Pressed	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
34	27.02		13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph			29.3		13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
35	30.1	Ok Pressed	13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph			32.38	Ok Pressed	13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
36	30.42	Ok Not Pressed	13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph			32.7	Ok Not Pressed	13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
37	32.04		1 HMI	Inactive	Null	Inactive	0 deg	0 kph			34.32		1 HMI	Inactive	Null	Inactive	0 deg	0 kph	
38	38.86	Shift gear to Park	1 HMI	Inactive	Null	Inactive	0 deg	0 kph			41.14	Shift gear to Park	1 HMI	Inactive	Null	Inactive	0 deg	0 kph	
39																			
40																			

**TEST CASE MASTER**

**TEST CASE ITERATIVE**

MS1 PLANT

MS1

Ready 150% FixedStepDiscrete

# Validation and Verification Tool

## STEP 5: Compare Test Case Results against Master

Time	Value	Component	State	Speed	Component	State	Speed	Component	State	Speed
4	2.8200000	TBA Button	11	1	1 HMI	Inactive	Null	Inactive	0 deg	0 kph
5	3.1400000	TBA Button	11	0	1 HMI	Inactive	Null	Inactive	0 deg	0 kph
6	3.2600000				2 HMI	Inactive	Null	Inactive	0 deg	0 kph
7	4.2600000	Down Pres	7	1	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
8	4.5	Down Not	7	0	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
9	5.5400000	Up Pressed	6	1	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
10	5.7800000	Up Not Pre	6	0	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
11	6.8600000	Ok Pressed	10	1	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
12	7.0600000	Ok Not Pre	10	0	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
13	7.2400000				2 HMI	ActivateTb	Null	Inactive	0 deg	0 kph
14	7.3200000				2 HMI	ActivateTb	TbaActive	Inactive	0 deg	0 kph
15	7.4600000				2 HMI	Deactivate	TbaActive	Inactive	0 deg	0 kph
16	7.5800000				4 HMI	Deactivate	TbaActive	Inactive	0 deg	0 kph
17	7.8400000				4 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
18	15.4600000				14 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
19	16.9400000	Shift gear t	4	1	14 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
20	17.5				5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
21	18.7800000	Accel pedal	3	25	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
22	19.1400000	Accel pedal	3	50	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.004036 k
23	19.6600000	Accel pedal	3	75	5 HMI	Inactive	TbaActive	Inactive	0 deg	1.1564 kph
24	20.9800000	Accel pedal	3	50	5 HMI	Inactive	TbaActive	Inactive	0 deg	6.101 kph
25	21.3000000	Accel pedal	3	25	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.9395 kph
26	21.7200000	Accel pedal	3	0	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.7276 kph
27	22.3400000	Brake Peda	2	25	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.4148 kph
28	22.7600000	Brake Peda	2	50	5 HMI	Inactive	TbaActive	Inactive	0 deg	3.9163 kph
29	23.1600000	Brake Peda	2	75	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.98992 kph
30	24.1200000	Brake Peda	2	50	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
31	24.4600000	Brake Peda	2	25	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
32	24.8200000	Brake Peda	2	0	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
33	26.6400000	TBA Button	11	1	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
34	26.9000000	TBA Button	11	0	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
35	27.0200000				13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
36	30.1000000	Ok Pressed	10	1	13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
37	30.4200000	Ok Not Pre	10	0	13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
38	32.0400000				1 HMI	Inactive	Null	Inactive	0 deg	0 kph
39	38.8600000	Shift gear t	4	0	1 HMI	Inactive	Null	Inactive	0 deg	0 kph
4	5.1000000	TBA Button	11	1	1 HMI	Inactive	Null	Inactive	0 deg	0 kph
5	5.4200000	TBA Button	11	0	1 HMI	Inactive	Null	Inactive	0 deg	0 kph
6	5.5400000				2 HMI	Inactive	Null	Inactive	0 deg	0 kph
7	6.5400000	Down Pres	7	1	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
8	6.7800000	Down Not	7	0	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
9	7.8200000	Up Pressed	6	1	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
10	8.0600000	Up Not Pre	6	0	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
11	9.1399999	Ok Pressed	10	1	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
12	9.3400000	Ok Not Pre	10	0	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
13	9.7200000				2 HMI	ActivateTb	Null	Inactive	0 deg	0 kph
14	9.8000000				2 HMI	ActivateTb	TbaActive	Inactive	0 deg	0 kph
15	9.9400000				2 HMI	Deactivate	TbaActive	Inactive	0 deg	0 kph
16	10.0600000				4 HMI	Deactivate	TbaActive	Inactive	0 deg	0 kph
17	10.3200000				4 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
18	17.9400000				14 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
19	19.2200000	Shift gear t	4	1	14 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
20	19.7800000				5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
21	21.0600000	Accel pedal	3	25	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
22	21.4200000	Accel pedal	3	50	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.004036 k
23	21.9400000	Accel pedal	3	75	5 HMI	Inactive	TbaActive	Inactive	0 deg	1.1564 kph
24	23.2599999	Accel pedal	3	50	5 HMI	Inactive	TbaActive	Inactive	0 deg	6.101 kph
25	23.5800000	Accel pedal	3	25	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.9395 kph
26	24	Accel pedal	3	0	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.7276 kph
27	24.6200000	Brake Peda	2	25	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.4148 kph
28	25.0400000	Brake Peda	2	50	5 HMI	Inactive	TbaActive	Inactive	0 deg	3.9163 kph
29	25.4400000	Brake Peda	2	75	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.98992 kph
30	26.4000000	Brake Peda	2	50	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
31	26.7400000	Brake Peda	2	25	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
32	27.1000000	Brake Peda	2	0	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
33	28.9200000	TBA Button	11	1	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
34	29.1800000	TBA Button	11	0	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
35	29.3000000				13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
36	32.3799999	Ok Pressed	10	1	13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
37	32.7000000	Ok Not Pre	10	0	13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
38	34.3200000				1 HMI	Inactive	Null	Inactive	0 deg	0 kph
39	41.1399999	Shift gear t	4	0	1 HMI	Inactive	Null	Inactive	0 deg	0 kph

- ABS\_EVT\_IN\_I
- ABS\_LSMC
- ABS\_TELTAL
- ABS\_TS
- ARM\_H2CU

Ready

150%

FixedStepDiscrete

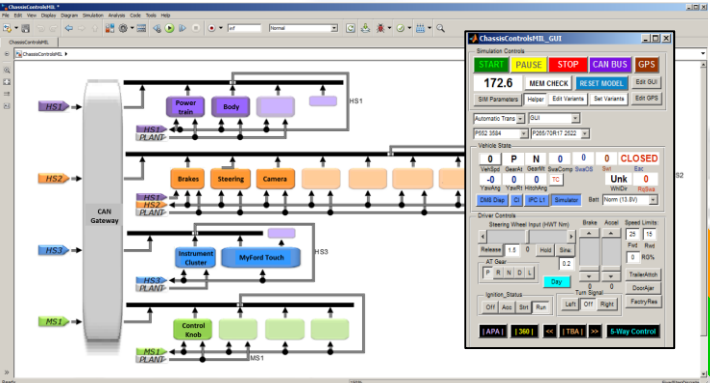


# Validation and Verification Tool

- Recording a Master Test Case and generating a Master Test Report creates a document which captures the system outputs based on the Requirement Models.
- The Master Test Case behavior can be replayed repeatedly to verify the system for new software releases of each module for any MIL/HIL configuration of the Distributed Network Simulation.
- Master Test Reports can be provided to engineers and suppliers to define how their module should react in the system. They can be customized and targeted towards specific modules so that only the relevant test data is generated in the report.
- Iterative Test Reports can be compared against the Master to exactly identify logical defects within the context of Simulation Time and Driver Actions.
- Test Reports can be configured to include any system inputs, outputs, or parameters that exist in the simulation environment
- Can be used in conjunction with Coverage Tool to track coverage metrics.
- In conjunction with Vector CANape (CAN and Video logging), all test case data can be logged into a single synchronous timeline for evidence and review.

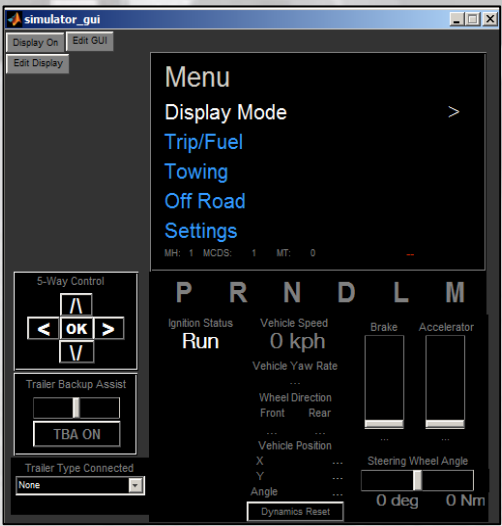
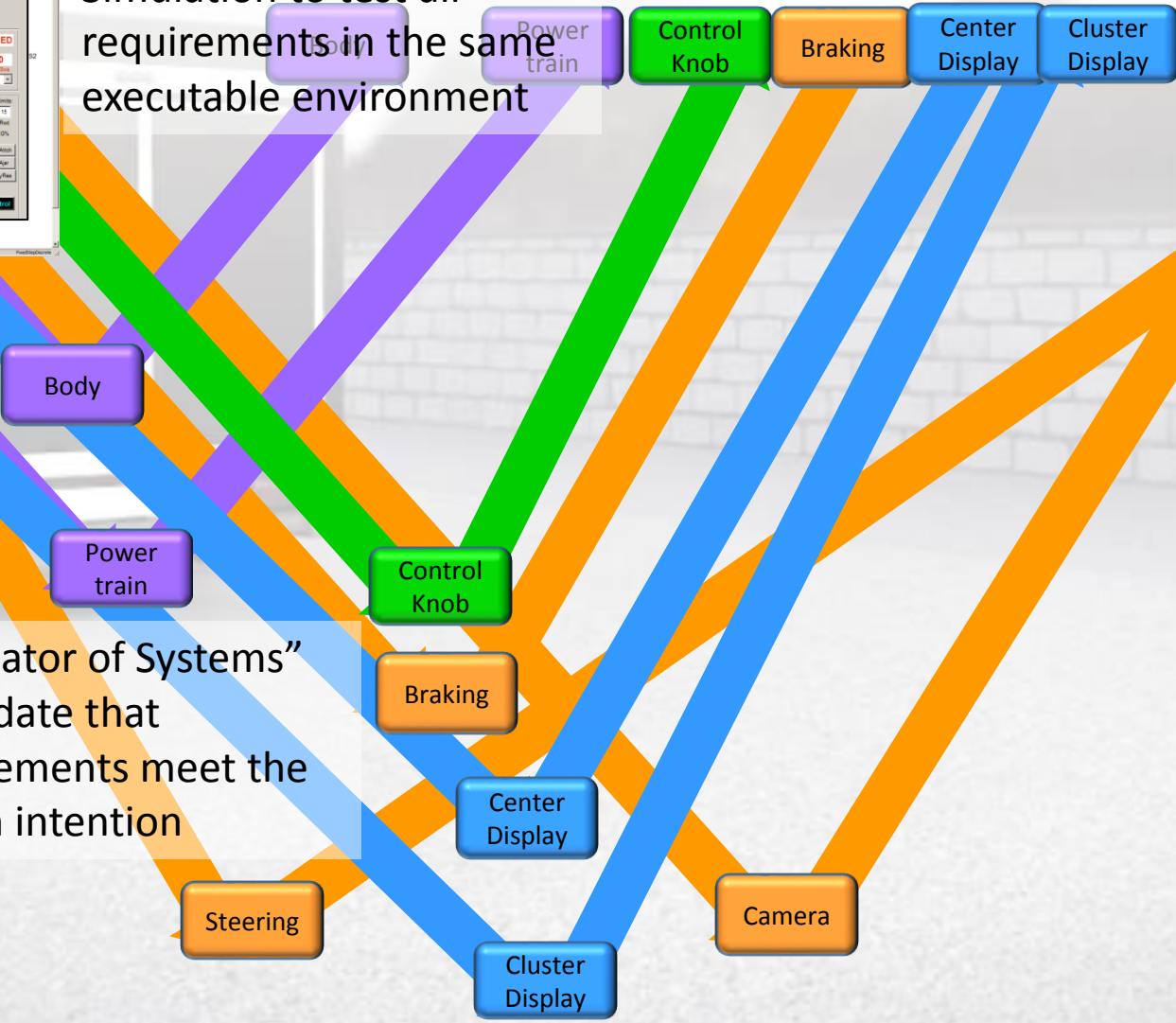


# Solutions Overview

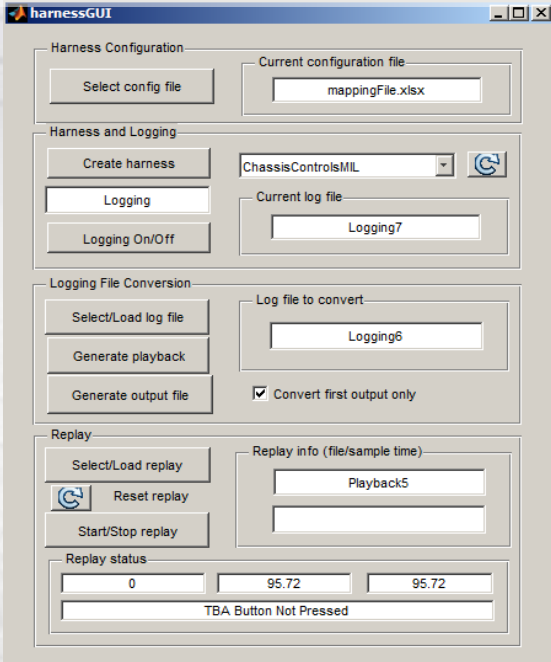


Requirement Model  
Simulation to test all requirements in the same executable environment

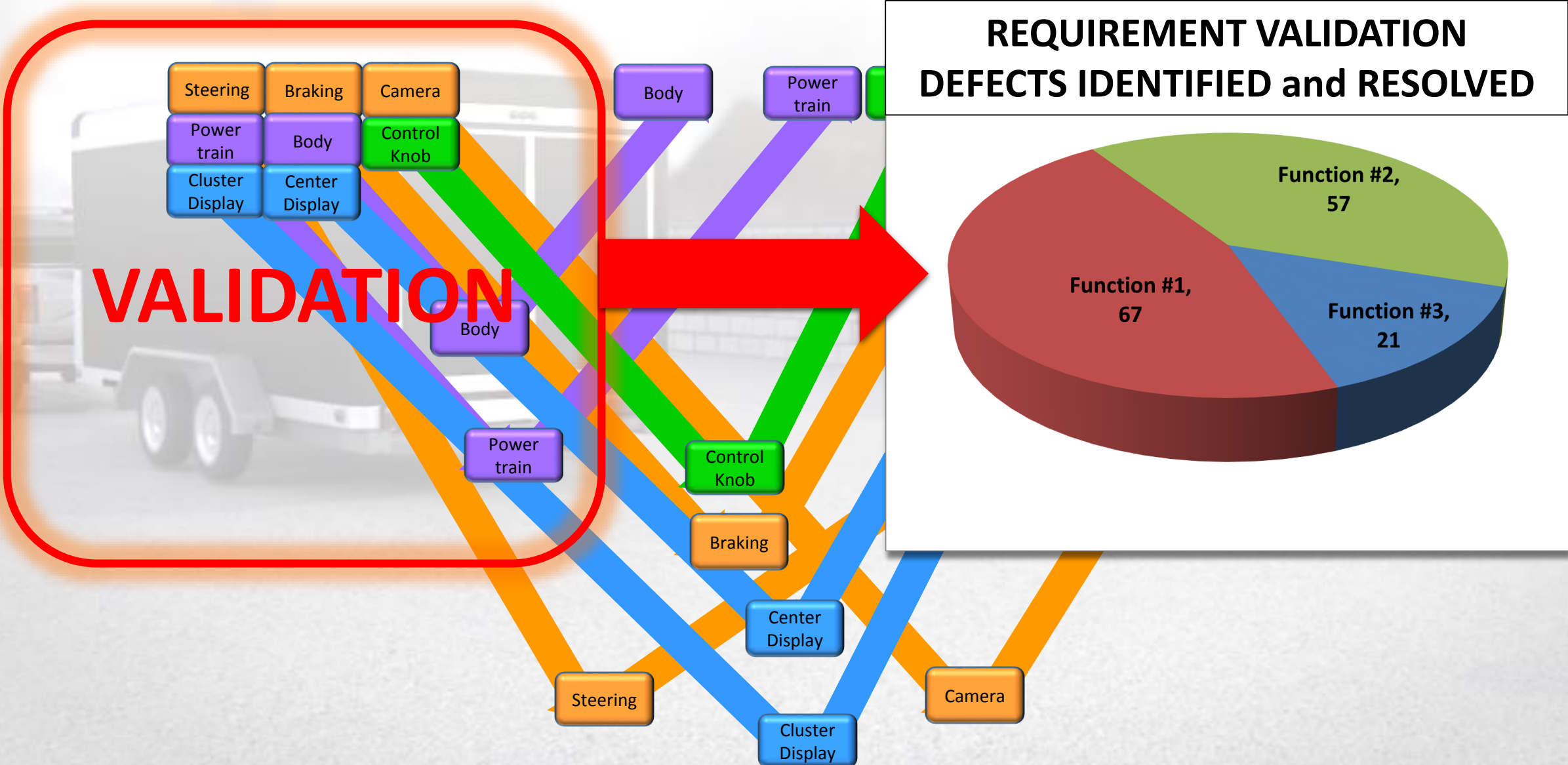
Validation and Verification Tool to record Master Test Cases and generate repeatable test scripts which can be replayed in any MIL/HIL integration configurations



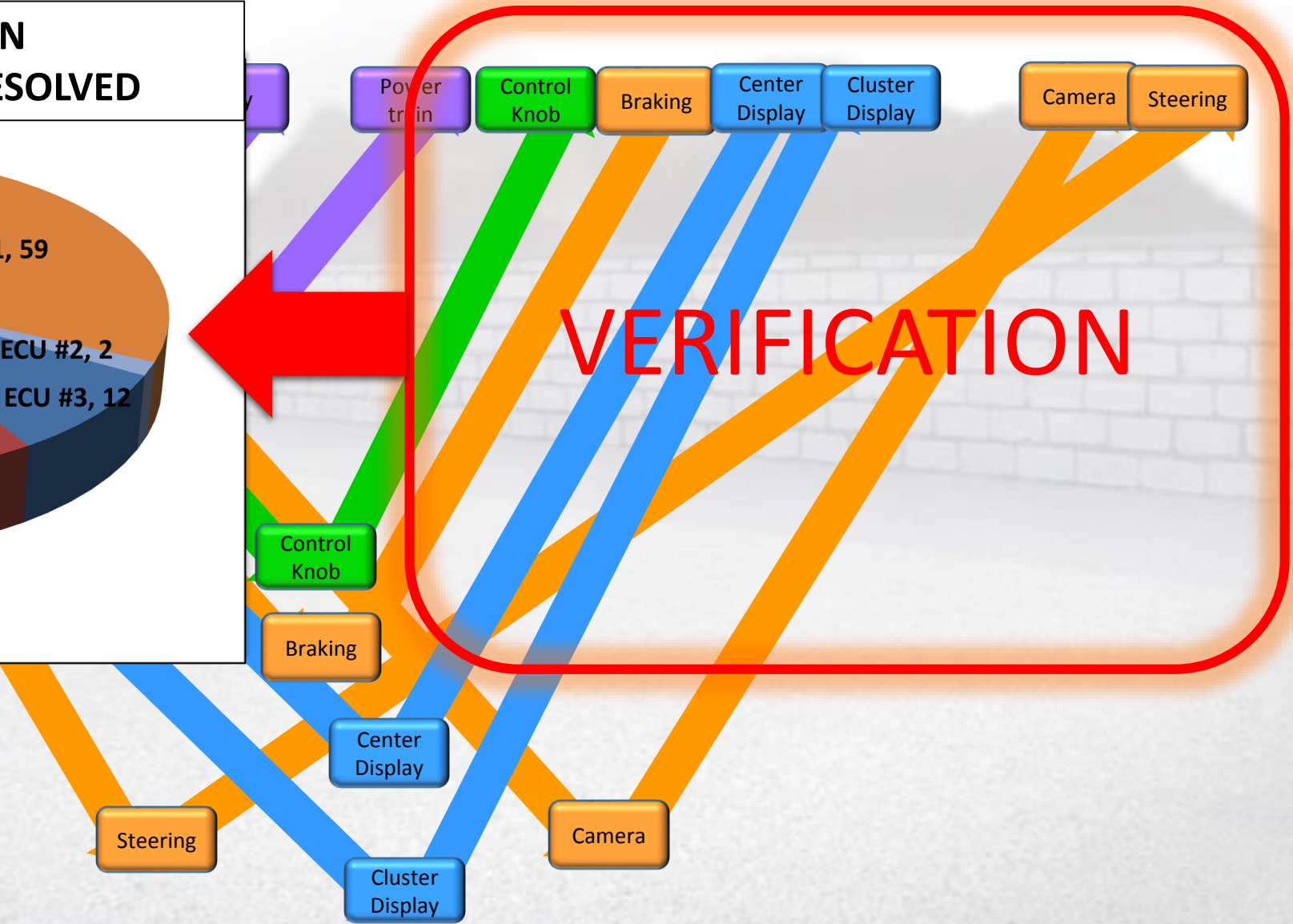
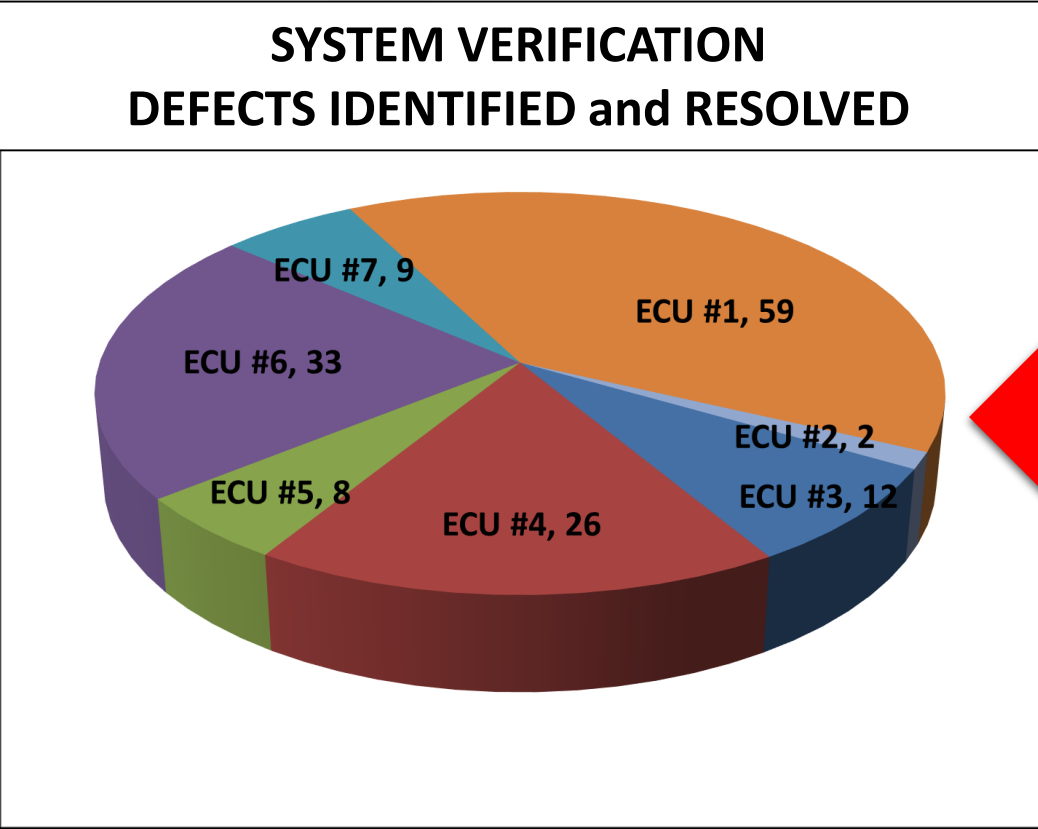
“Simulator of Systems” to validate that requirements meet the Design intention



# Results



# Results





# What's Next?

## Validation

*Concept → MIL*

Emphasis:

*Readability*

Output:

*Requirements*

## Verification

*SIL → HIL*

Emphasis:

*Testability, Traceability*

Output:

*Prototypes*

## Implementation

*MIL → SIL*

Emphasis:

*Efficiency, Compliance*

Output:

*Software*

# What's Next?

## Validation

*Concept → MIL*

Emphasis:

*Readability*

Output:

*Requirements*

- Requirement Validation step is often skipped, overlooked, or misunderstood.
- Requirement Validation skillsets and tools are undeveloped and unrecognized
- Few tools exist to simulate and validate requirements.
- An ideal tool would provide the ability to simulate and generate requirements from a model the same way that tools exist to generate, test, and verify code and hardware from a model.

# What's Next?

## Validation

*Concept → MIL*

Emphasis:

*Readability*

Output:

*Requirements*

- Requirement “modeling” is also done in formats that are non-executable.
- Translation from one tool, language, or format to another takes significant time and resource and introduces errors in translation.
- Requirement Modeling in Matlab is uniquely effective and efficient when code generation and verification is already done in Matlab – there is no translation needed!
- Building an executable model that can be used throughout the System V without translation is a **HUGE** efficiency gain and the essence of Model-Based Design.



**Thank you for your time and attention! 😊**

## **Acknowledgements**

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**Ford Motor Company**

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