用Simulink开发分布式汽车控制器

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特别感谢：

美国福特汽车

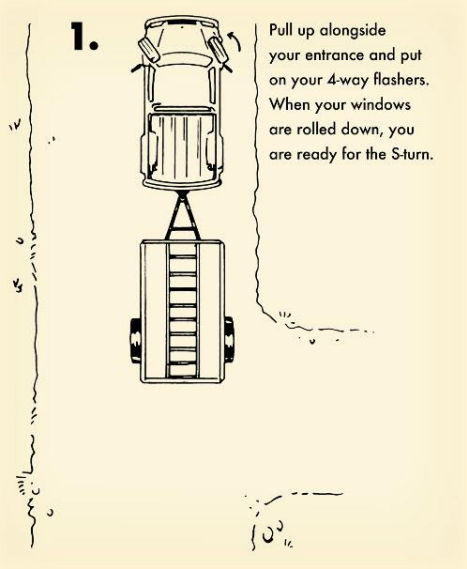
Go Further

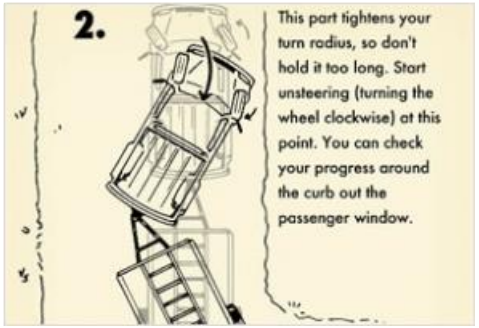
Nate Rolfes

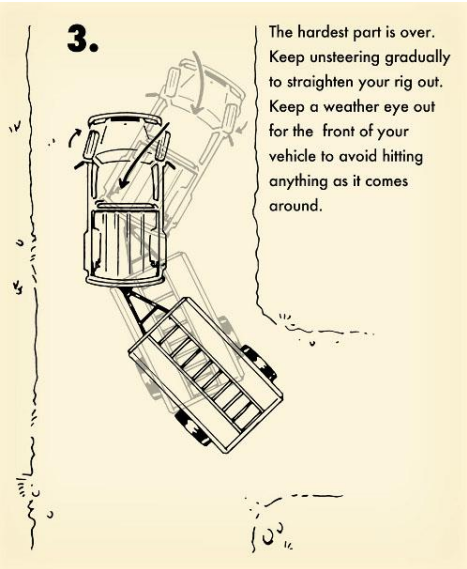
- 内容来自Rolfes先生在今年美国MAC上的演讲
- 产品及架构设计由美国福特公司原创
- MathWorks从工具以及MBD层面支持了开发过程
- 在MathWorks技术咨询帮助下，优化了验证流程并开发了自动化验证工具

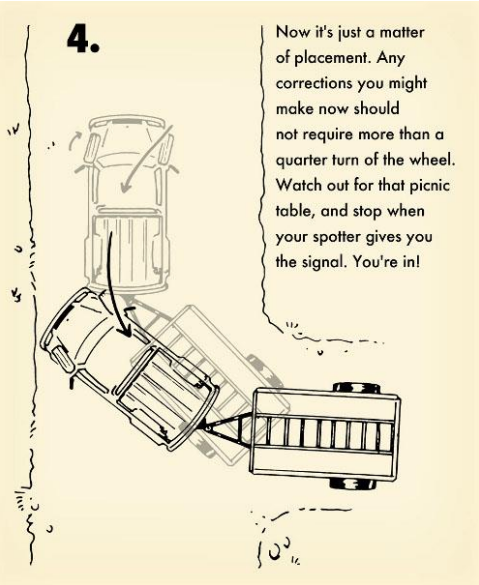
Pro Trailer Backup Assist (TBA)

拖车倒车控制难点


1.
Pull up alongside your entrance and put on your 4-way flashers. When your windows are rolled down, you are ready for the S-turn.

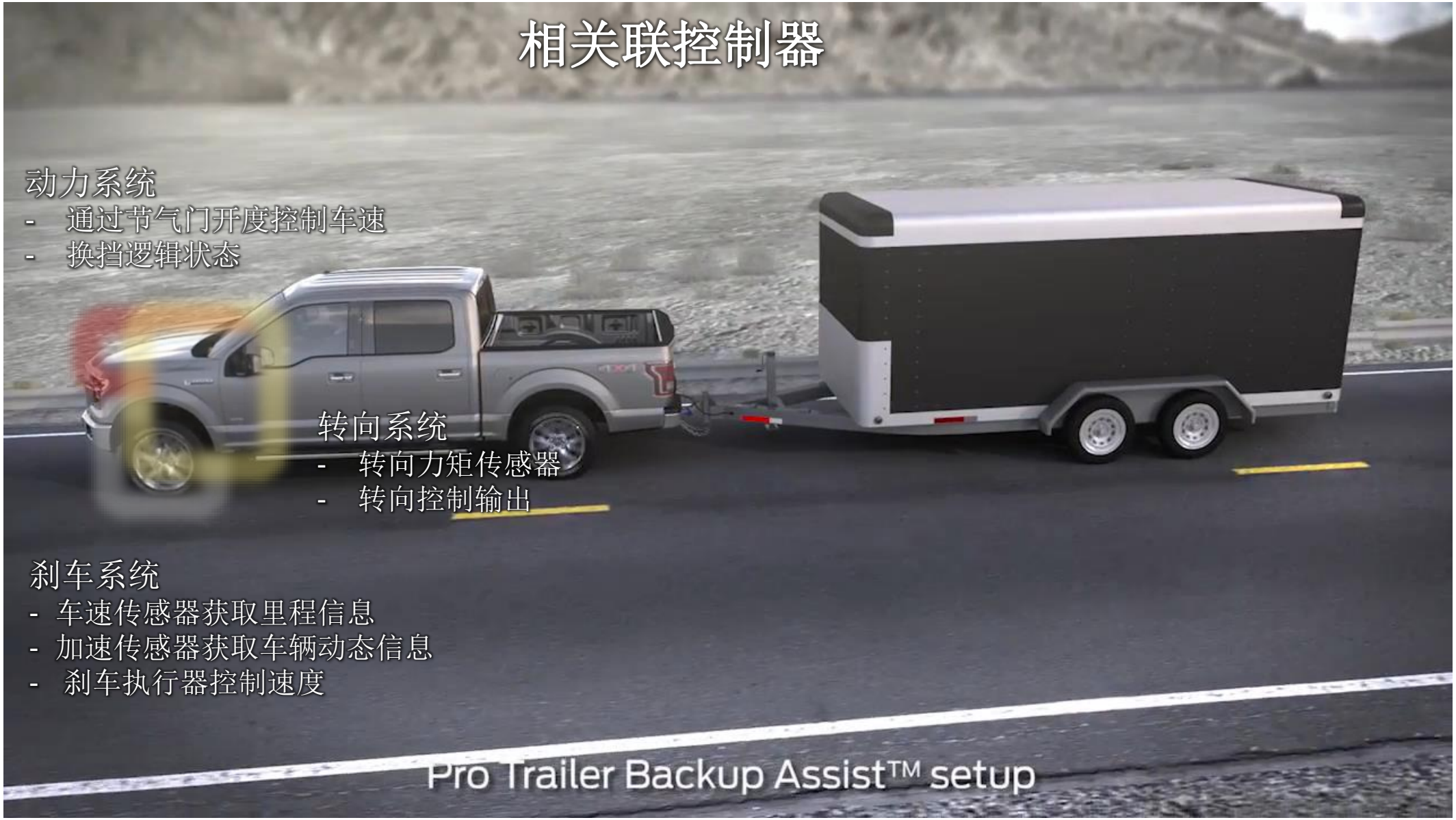

2.
This part tightens your turn radius, so don't hold it too long. Start unsteering (turning the wheel clockwise) at this point. You can check your progress around the curb out the passenger window.


3.
The hardest part is over. Keep unsteering gradually to straighten your rig out. Keep a weather eye out for the front of your vehicle to avoid hitting anything as it comes around.

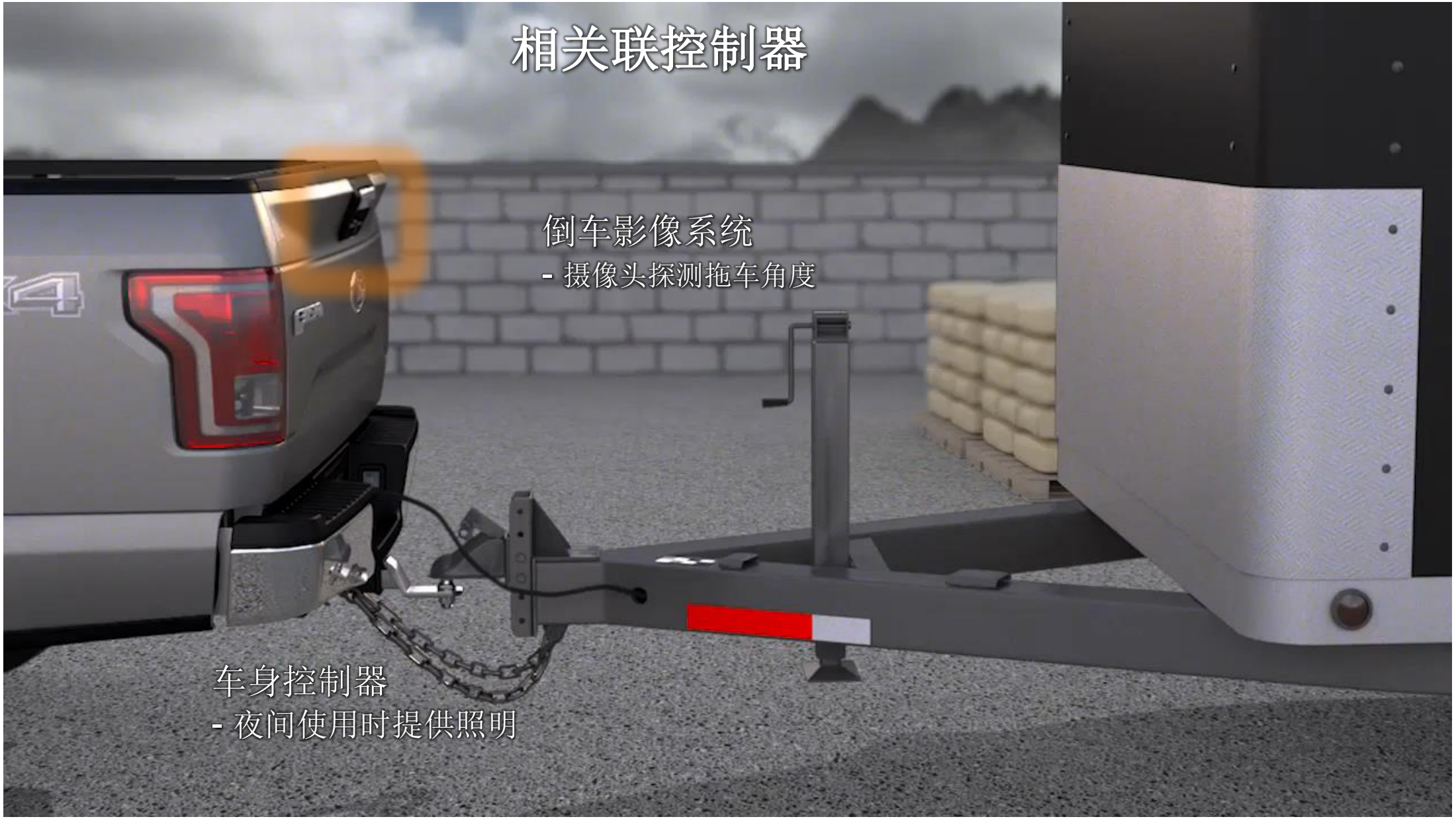

4.
Now it's just a matter of placement. Any corrections you might make now should not require more than a quarter turn of the wheel. Watch out for that picnic table, and stop when your spotter gives you the signal. You're in!


CWD

相关联控制器


动力系统
- 通过节气门开度控制车速
- 换挡逻辑状态
转向系统
- 转向力矩传感器
- 转向控制输出
刹车系统
- 车速传感器获取里程信息
- 加速传感器获取车辆动态信息
- 刹车执行器控制速度
Pro Trailer Backup Assist™ setup

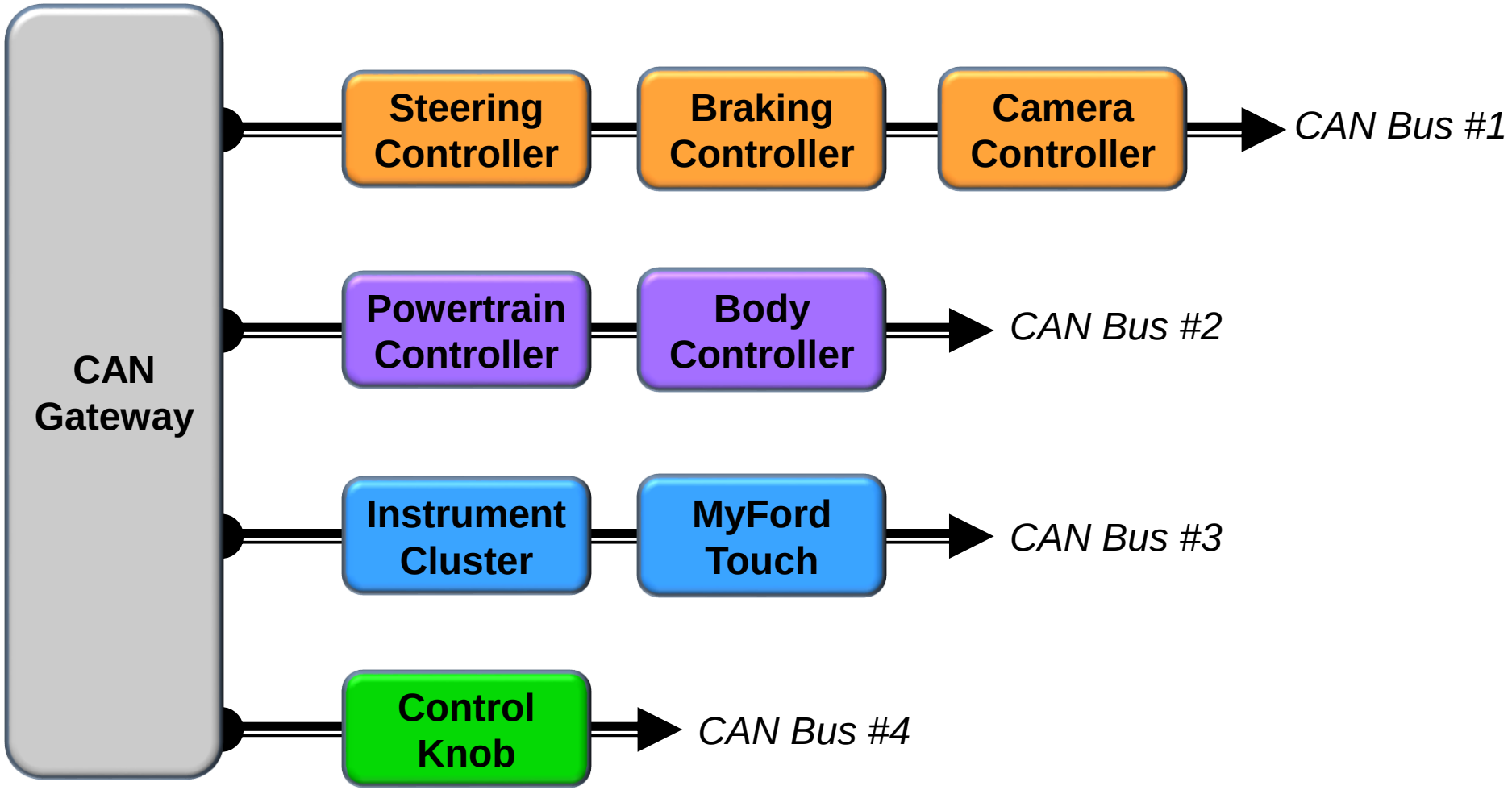
相关联控制器



相关联控制器

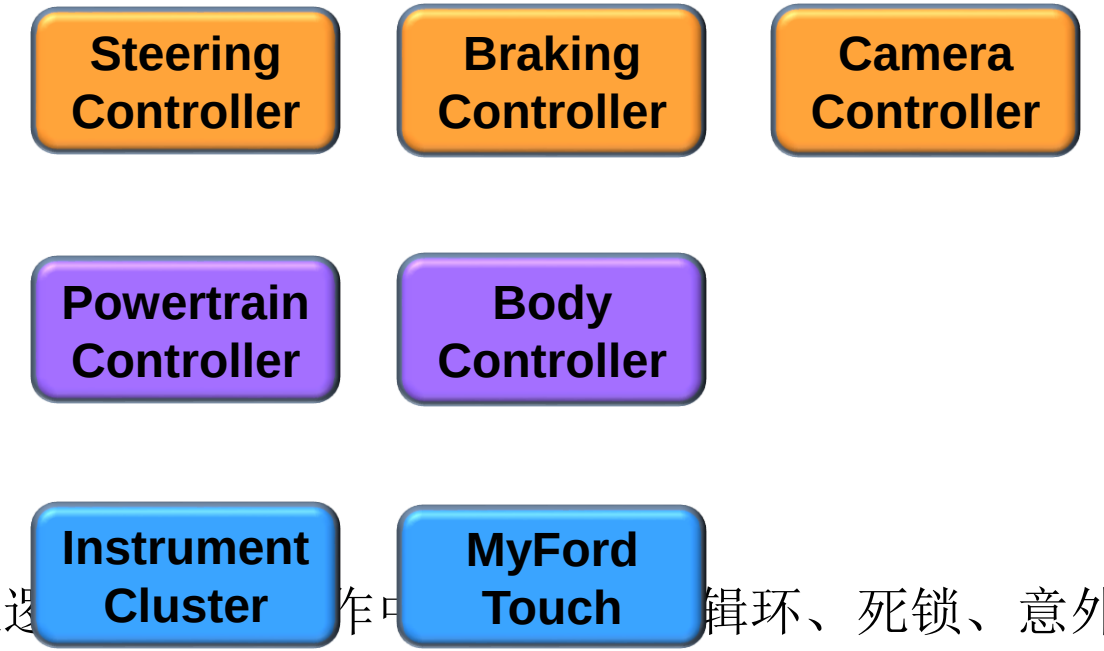
TBA 系统开发面临的挑战

- 没有一个独立的TBA控制模块
- 所需的功能分散在由4路CAN总线连接的8个控制器当中



TBA 系统开发面临的挑战

- 控制逻辑的设计要充分考虑到
  - ✓ 新功能的优化分配及共享
  - ✓ 对已有功能的充分利用
  - ✓ 尽量减少各模块间的通讯
  - ✓ 工程进度



- 系统的每个模块必须满足逻 作中 辑环、死锁、意外退出等
- 新功能及其优先级必须与已有的功能相结合，要保证其兼容性

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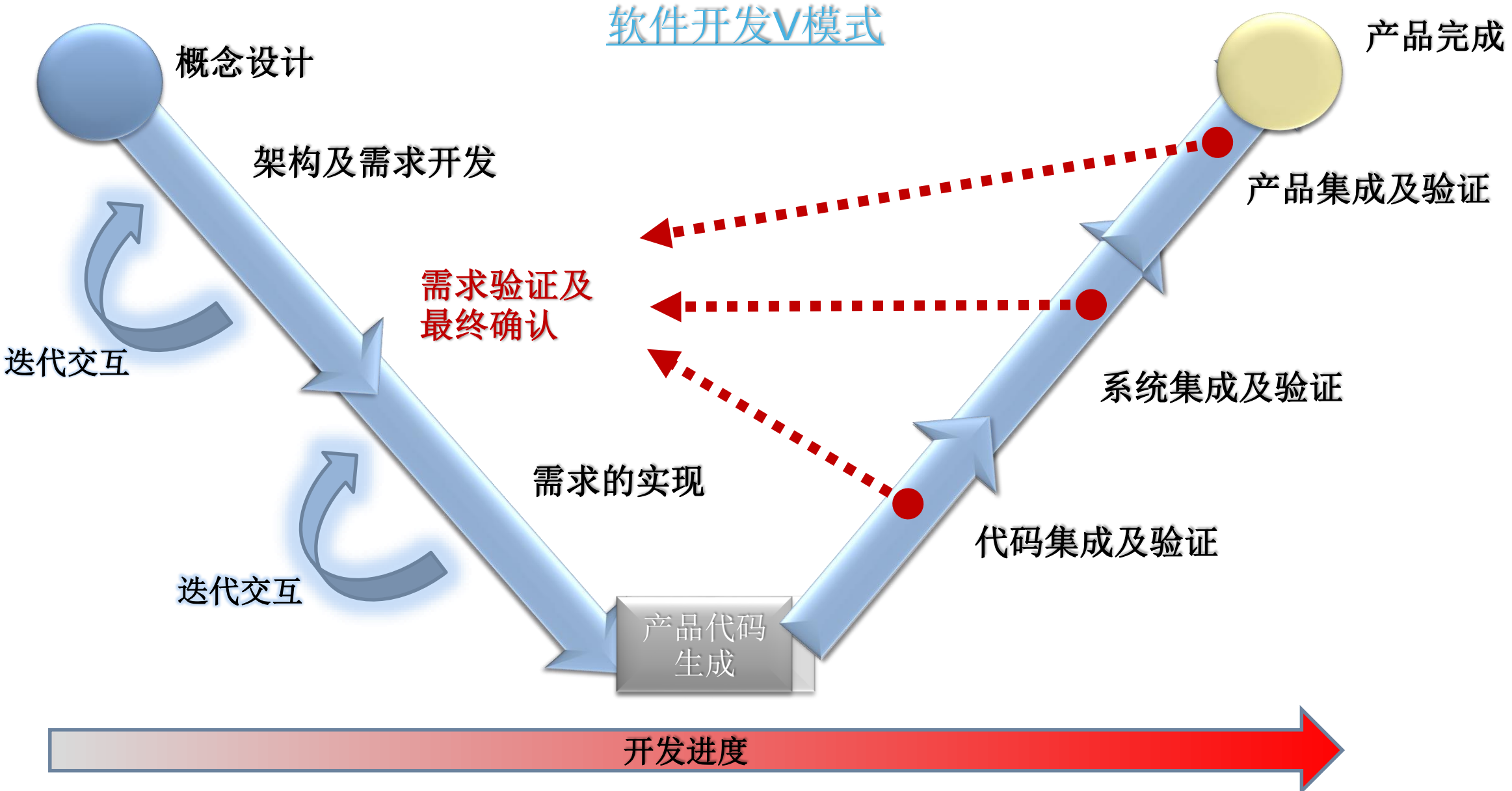

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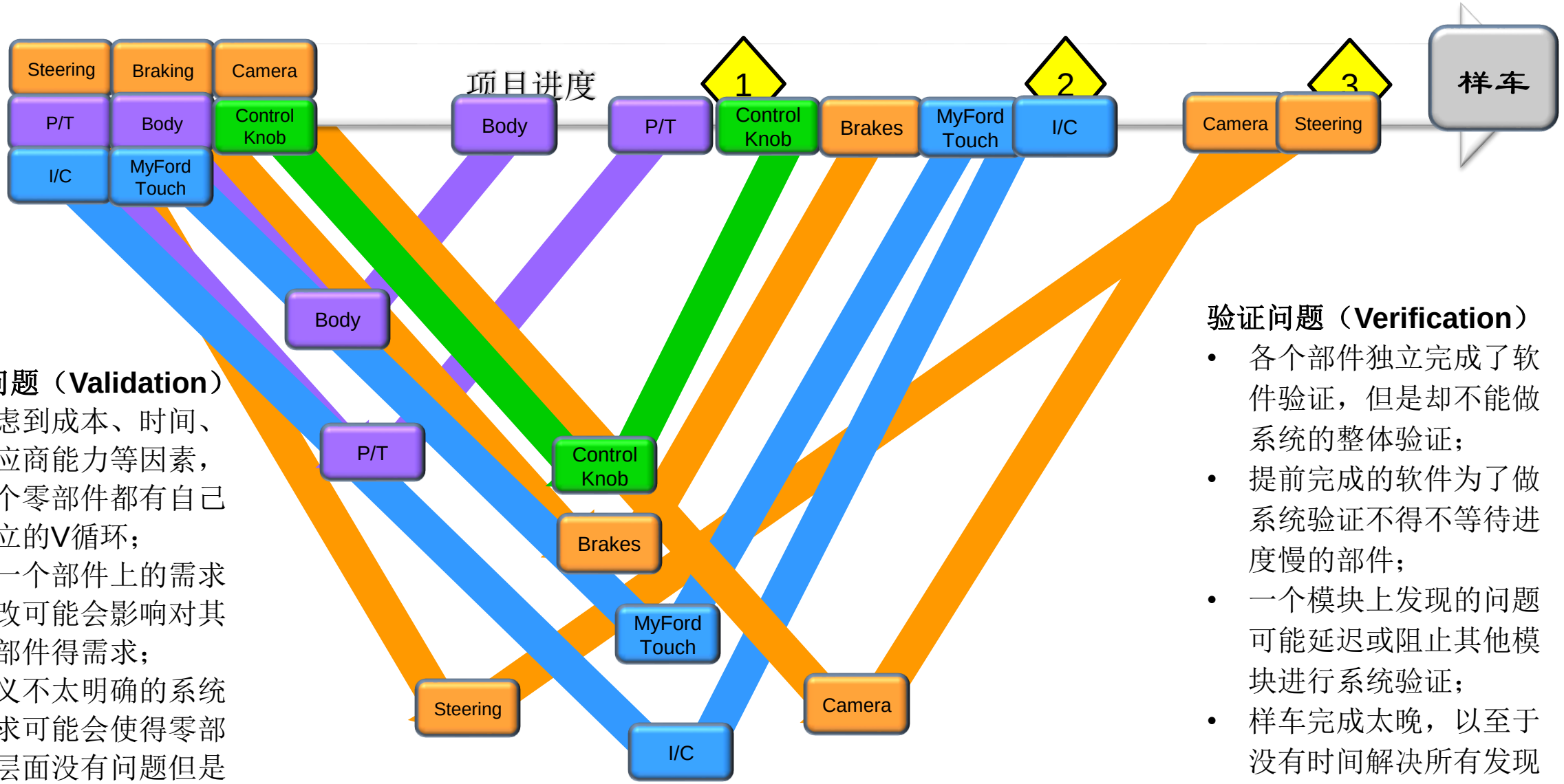

确认问题（Validation）

- 考虑到成本、时间、供应商能力等因素，每个零部件都有自己独立的V循环；
- 在一个部件上的需求更改可能会影响对其他部件得需求；
- 定义不太明确的系统需求可能会使得零部件层面没有问题但是最终系统却无法工作

验证问题（Verification）

- 各个部件独立完成了软件验证，但是却不能做系统的整体验证；
- 提前完成的软件为了做系统验证不得不等待进度慢的部件；
- 一个模块上发现的问题可能延迟或阻止其他模块进行系统验证；
- 样车完成太晚，以至于没有时间解决所有发现的问题

解决方案

1. **需求建模**:
   - 在交给下游进行软件实现之前，对需求进行建模、仿真从而保证分布式控制逻辑满足系统功能需求
2. **分布式网络仿真**:
   - 创建的仿真环境，连接各个控制器、CAN网络、司机控制输入、车辆交互信息等；
   - 该仿真环境既可以运行MIL（虚拟）也可以运行实时的HIL（硬件），而且每个控制器都可以在MIL与HIL间方便切换；
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3. **确认及验证工具:**
   - 创建的验证工具可以有效地应用于软件开发V流程:
     - ✓测试及确认需求模型 (V的左半边，由上而下)
     - ✓验证软件功能模块输出满足需求模型要求 (V的又半边，由下而上)

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什么是需求建模?

2013-01-2237

Requirements Modeling and Automated Requirements-Based Test Generation

John Lee and Jon Friedman
MathWorks

"...需求建模的目的是通过**清晰、精确、可分析**并**可执行**的方式获得功能性需求，而这个目的往往无法用**自然语言**来实现。

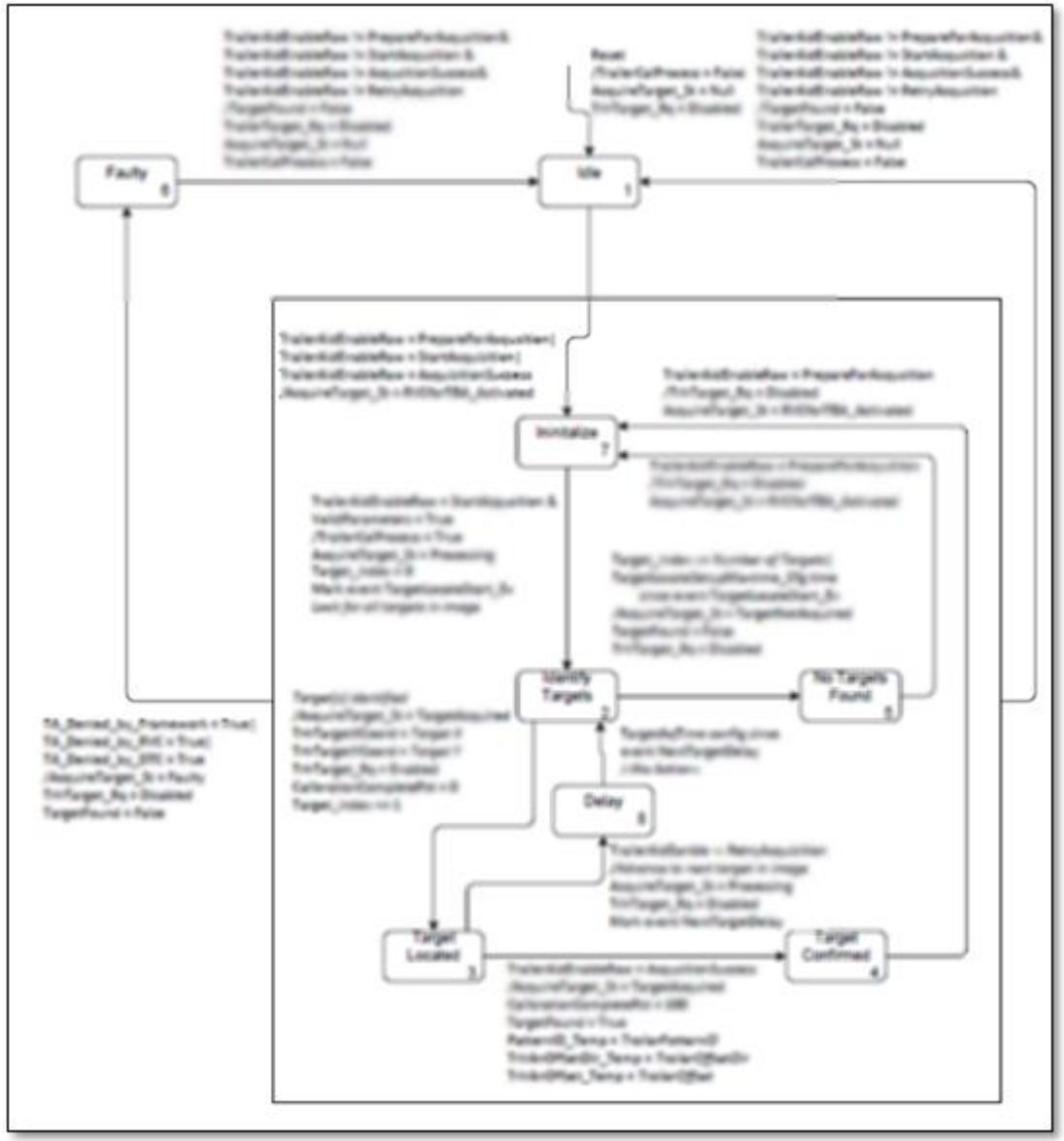
需求模型可以用来评估多种来源获取的需求的交互性和兼容性，

以及开发**测试用例及验收判据（或期望输出）**。

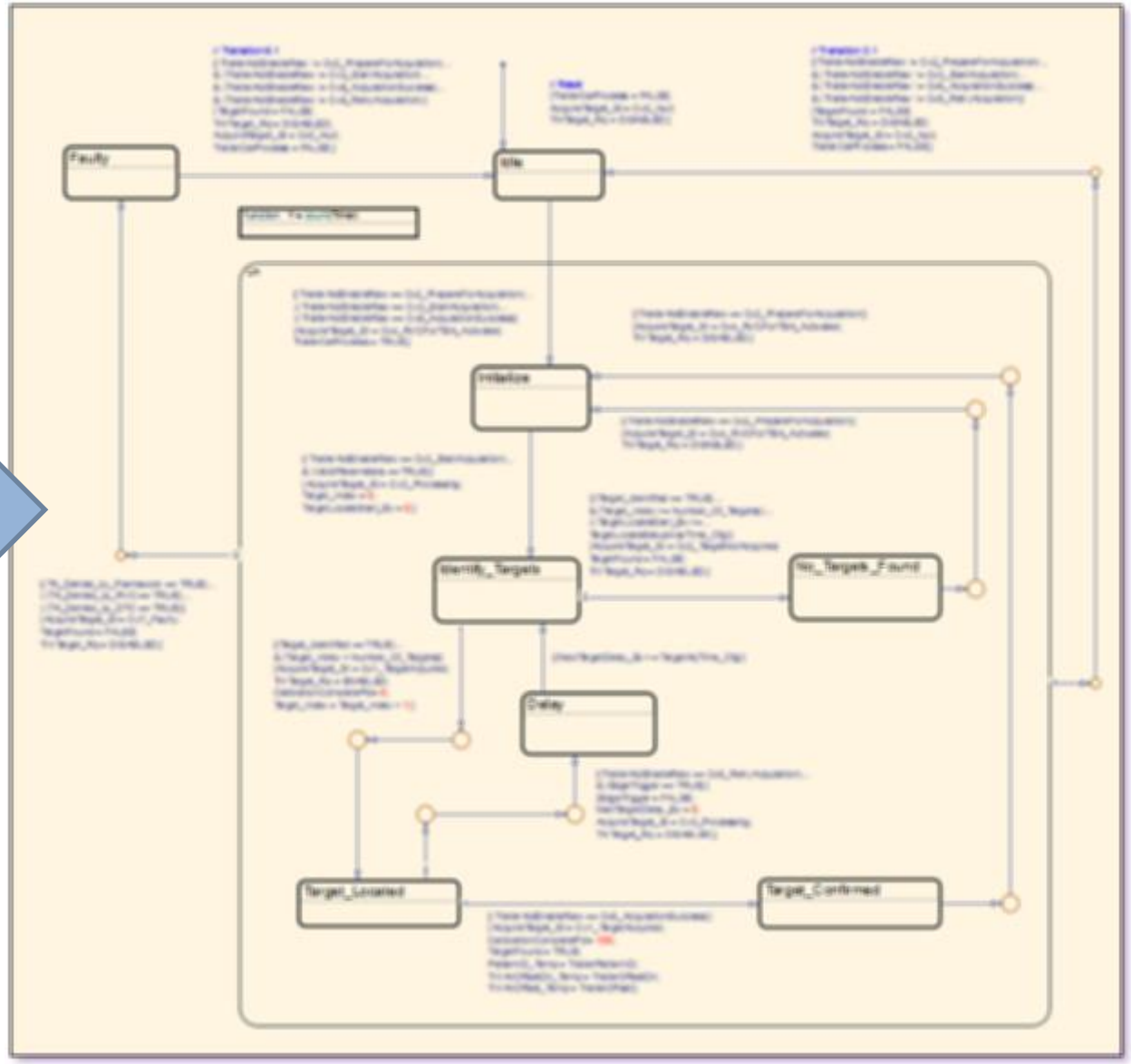
用需求模型建立测试用例可以让工程师根据需求模型的各种覆盖度概念评估测试是否完善..."

需求建模

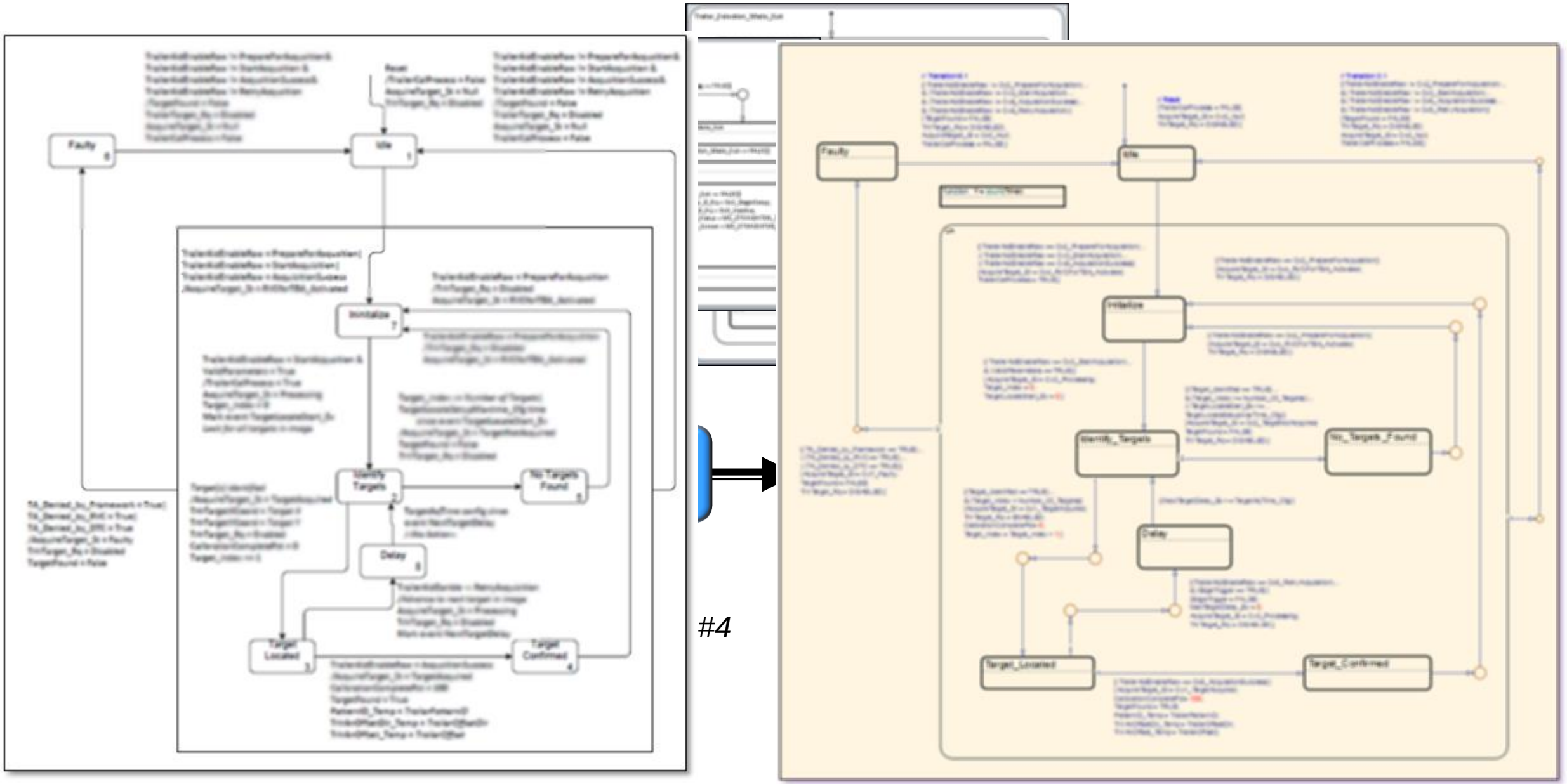
状态机需求文档:



Stateflow 需求模型:



需求建模


Faulty
Idle
Initialize
Identify Targets
No Targets Found
Delay
Target Located
Target Confirmed
#4
Faulty
Idle
Initialize
Identify_Targets
No_Targets_Found
Delay
Target_Located
Target_Confirmed

解决方案

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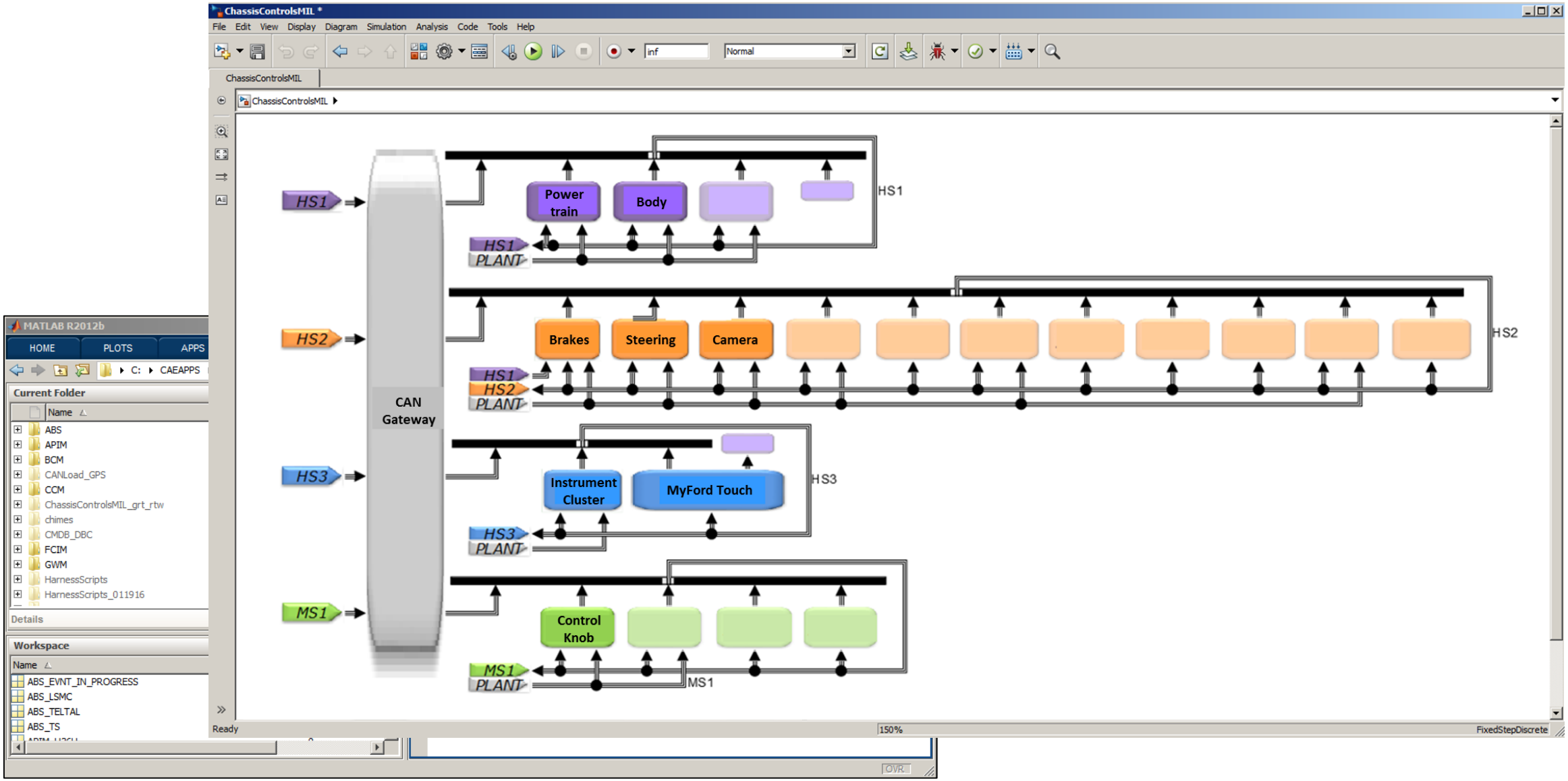
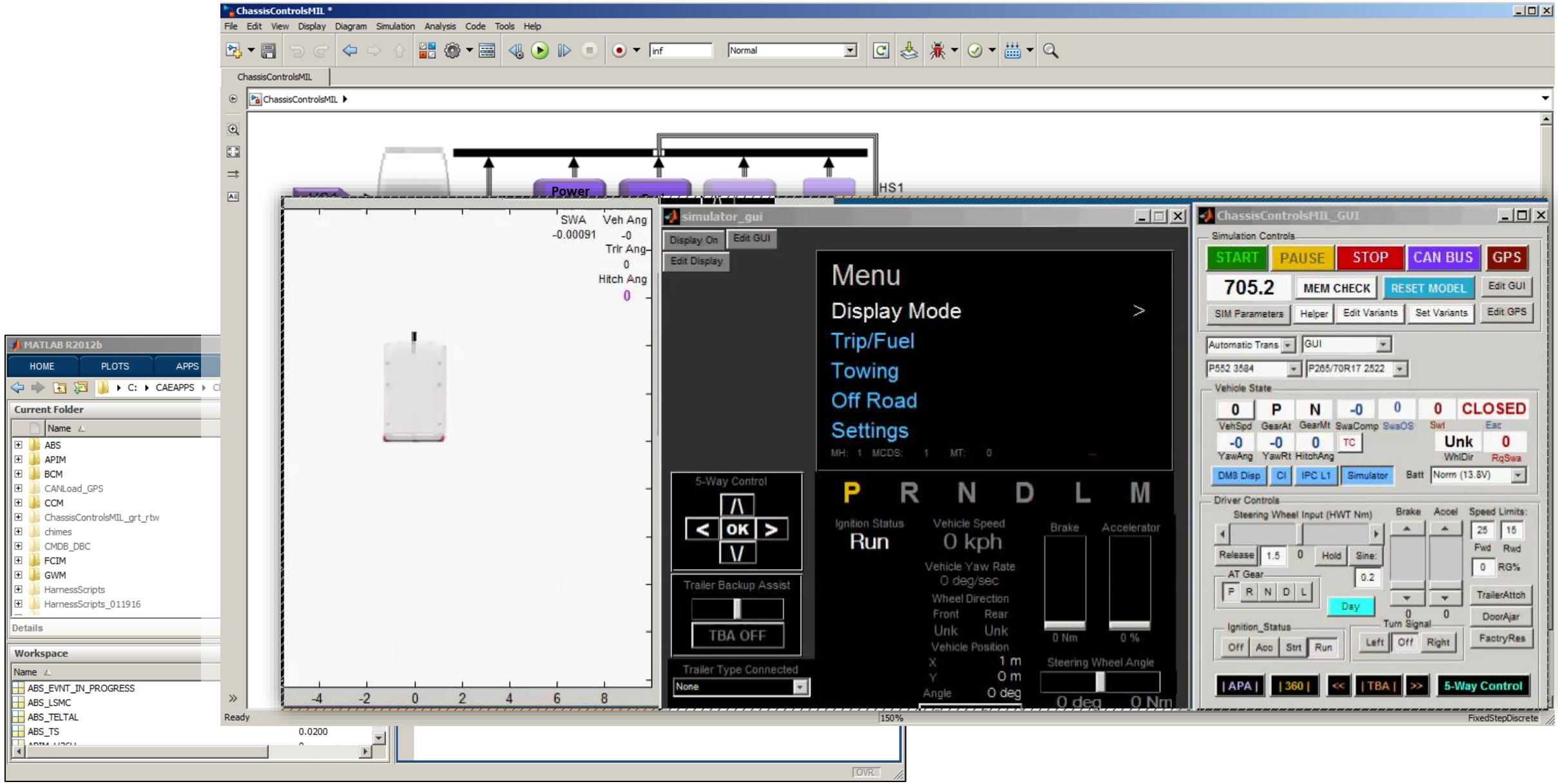

ChassisControlsMIL *
File Edit View Display Diagram Simulation Analysis Code Tools Help
ChassisControlsMIL
HS1
HS2
HS3
MS1
CAN Gateway
Power train
Body
Brakes
Steering
Camera
Instrument Cluster
MyFord Touch
Control Knob
HS1
HS2
HS3
MS1
PLANT
Ready
150%
FixedStepDiscrete
MATLAB R2012b
HOME
PLOTS
APPS
Current Folder
Name
ABS
APIM
BCM
CANLoad_GPS
CCM
ChassisControlsMIL_grt_rtw
chimes
CMDB_DBC
FCIM
GWM
HarnessScripts
HarnessScripts_011916
Details
Workspace
ABS_EVNT_IN_PROGRESS
ABS_LSMC
ABS_TELTAL
ABS_TS

分布式网络仿真


ChassisControlsMIL *
File Edit View Display Diagram Simulation Analysis Code Tools Help
ChassisControlsMIL
Power
HS1
SWA
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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
5-Way Control
OK
Trailer Backup Assist
TBA OFF
Trailer Type Connected
None
P R N D L M
Ignition Status
Run
Vehicle Speed
0 kph
Vehicle Yaw Rate
0 deg/sec
Wheel Direction
Front Rear
Unk Unk
Vehicle Position
X 1 m
Y 0 m
Angle 0 deg
Brake
Accelerator
0 Nm
0 %
Steering Wheel Angle
0 deg 0 Nm
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
P265/70R17 2522
Vehicle State
CLOSED
VehSpd GearAt GearMt SwaComp SwaOS Swf Eac
YawAng YawRt HitchAng
WhlDir RqSwa
DM3 Disp
Cl
IPC L1
Simulator
Batt
Norm (13.6V)
Driver Controls
Steering Wheel Input (HWT Nm)
Brake
Accel
Speed Limits:
Release
Hold
Sine:
AT Gear
P R N D L
Day
TrailerAttch
DoorAjar
FactryRes
Ignition_Status
Off Acc Strt Run
Turn Signal
Left Off Right
APA
360
TBA
5-Way Control
MATLAB R2012b
HOME PLOTS APPS
Current Folder
Name
ABS
APIM
BCM
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chimes
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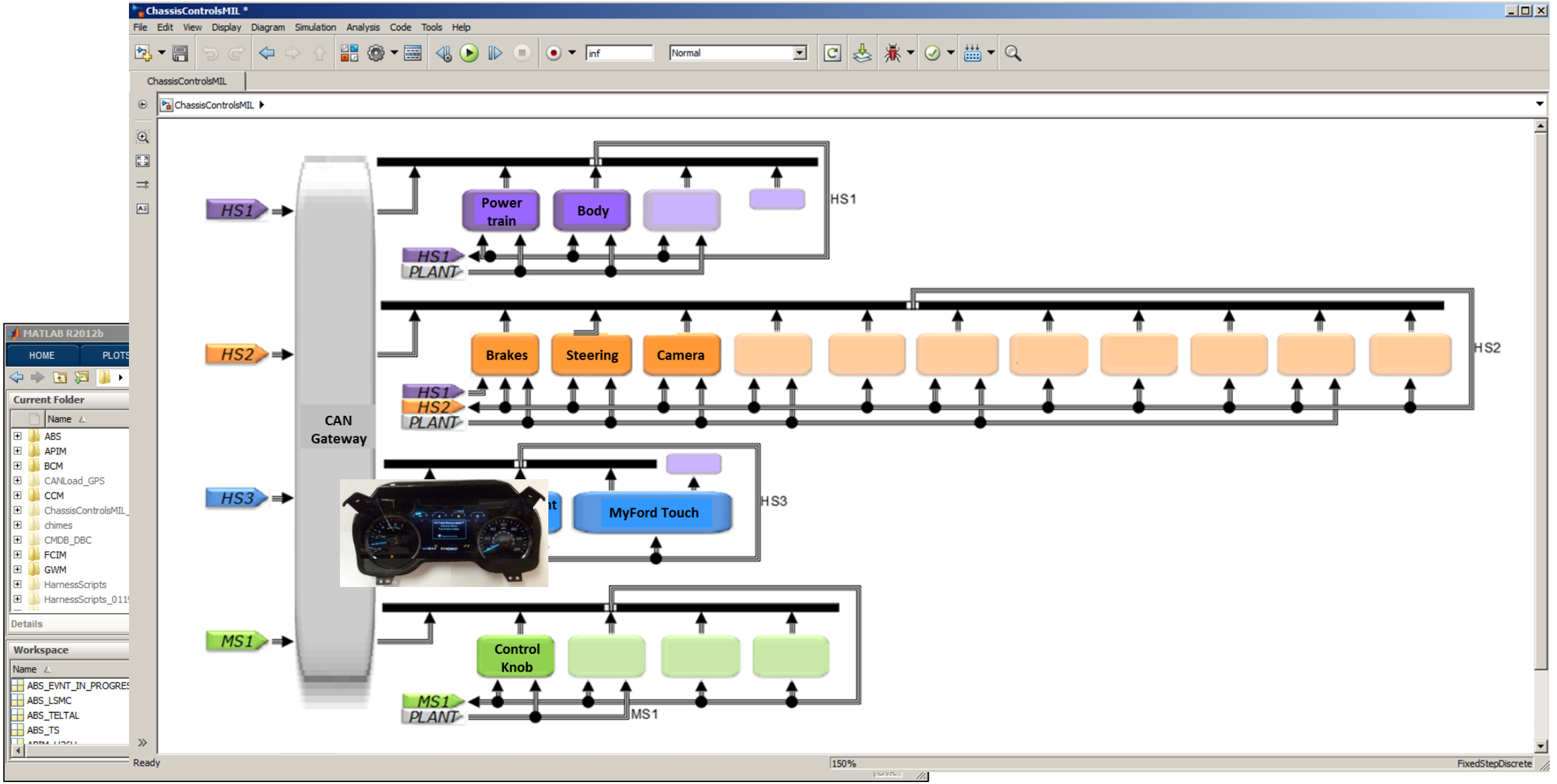
HarnessScripts_011916
Details
Workspace
ABS_EVNT_IN_PROGRESS
ABS_LSMC
ABS_TELTAL
ABS_TS
0.0200
Ready
150%
FixedStepDiscrete
OVR

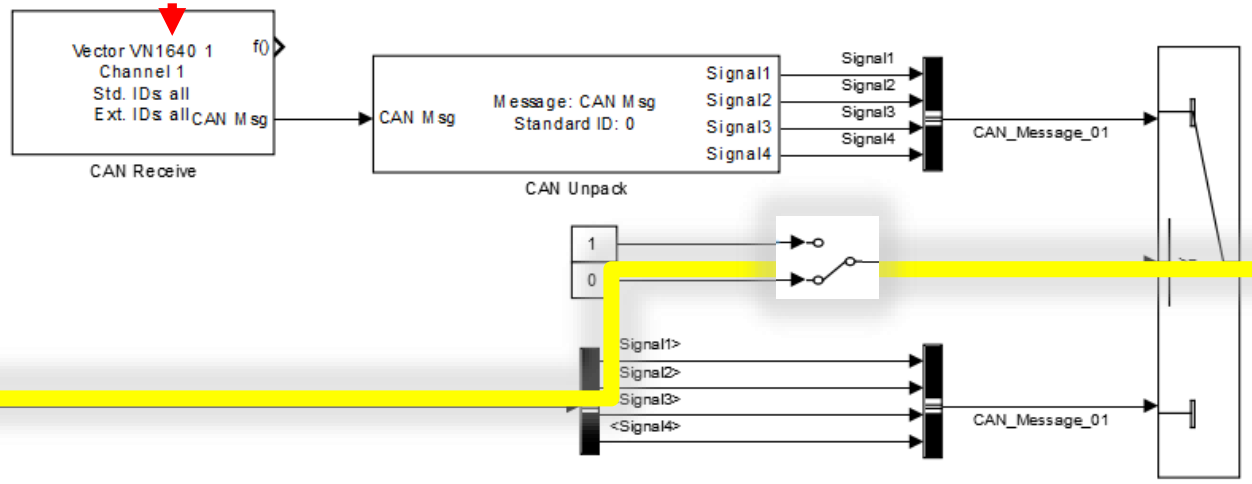
带有HIL的分布式网络仿真



利用Vehicle Network Toolbox实现HIL切换

硬件

Vehicle Network Toolbox



Instrument Cluster Requirement Model (MIL)

CAN Gateway (MIL)

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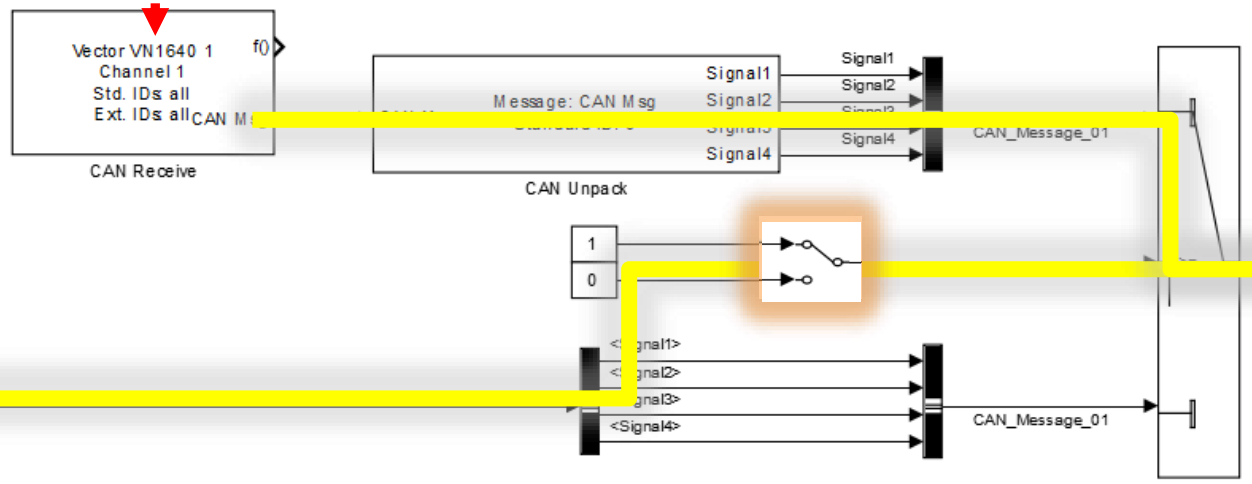
硬件

Vehicle Network Toolbox



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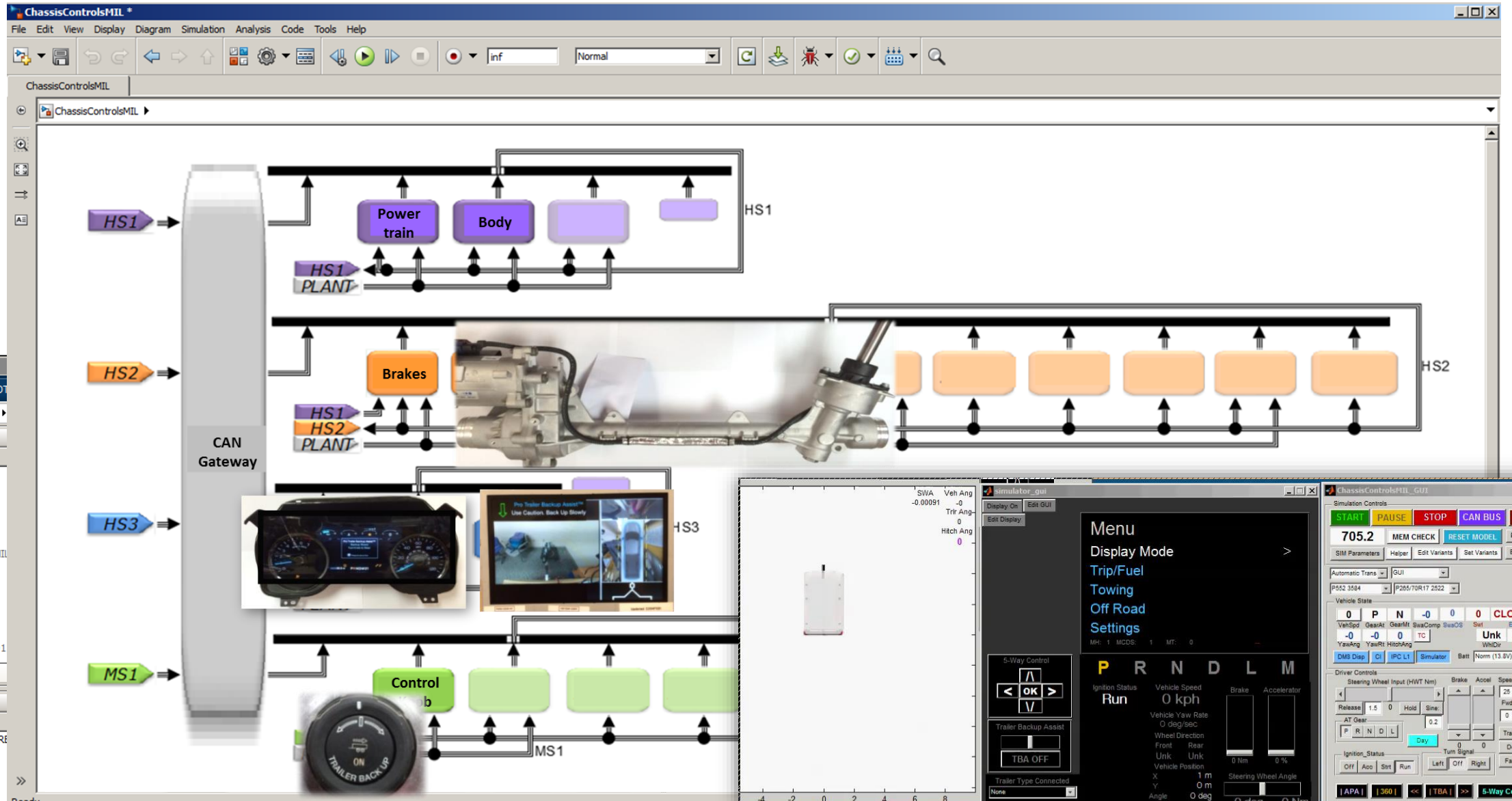

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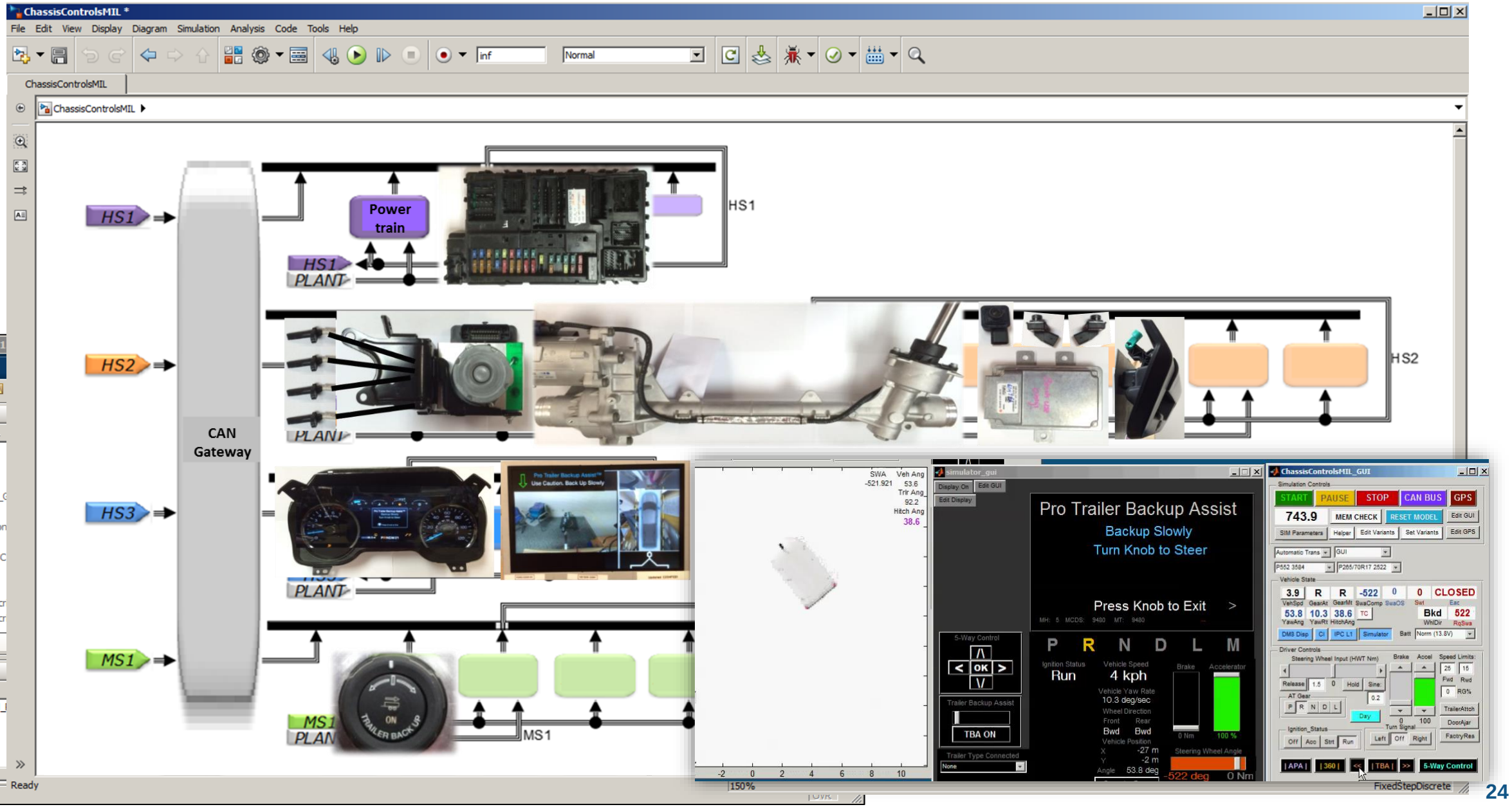
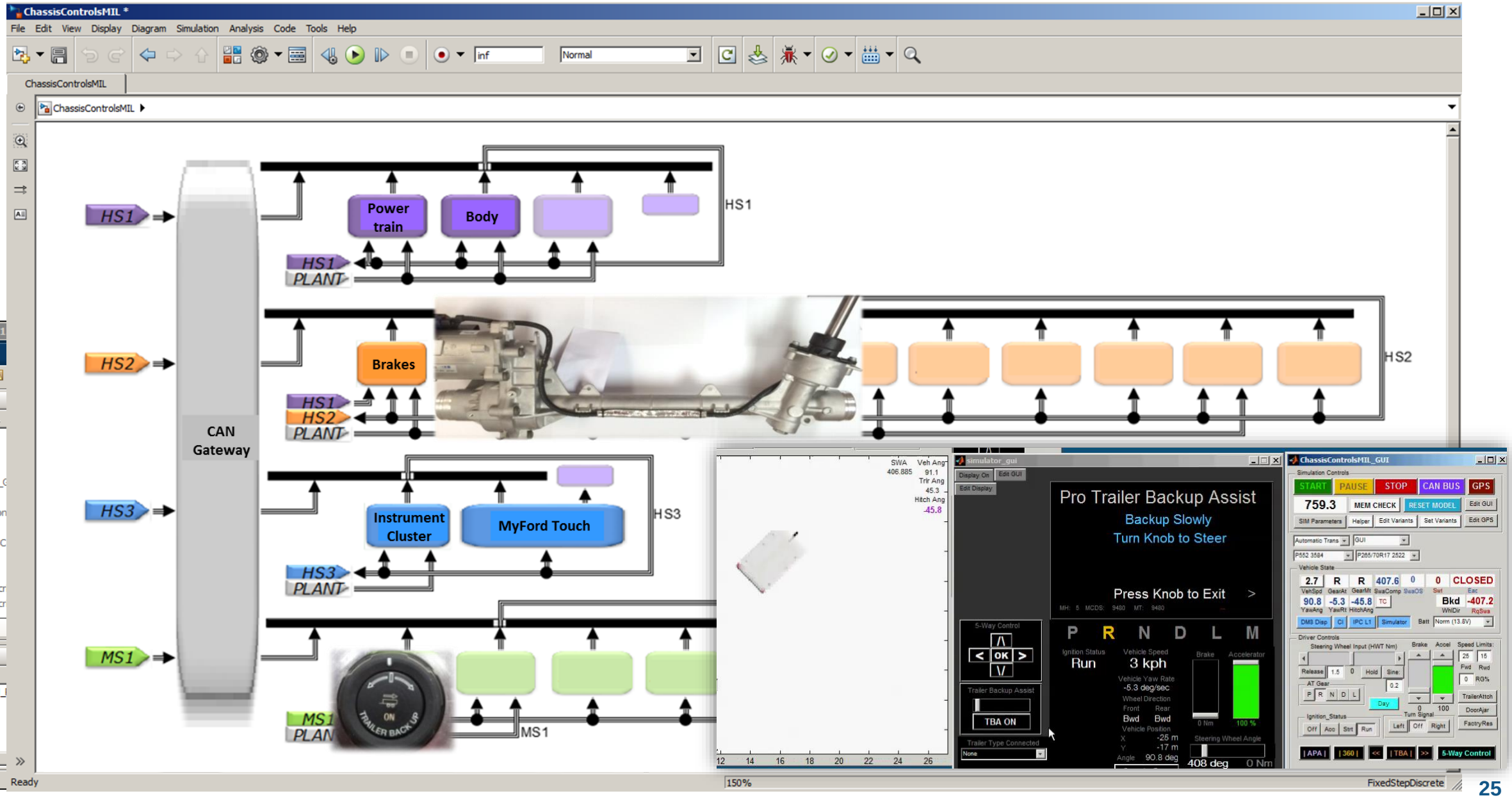


分布式网络仿真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MyFord Touch
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HS2 PLANT
HS3 PLANT
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Pro Trailer Backup Assist
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Press Knob to Exit
ChassisControlsMIL_GUI
Ready
150%
FixedStepDiscrete

解决方案

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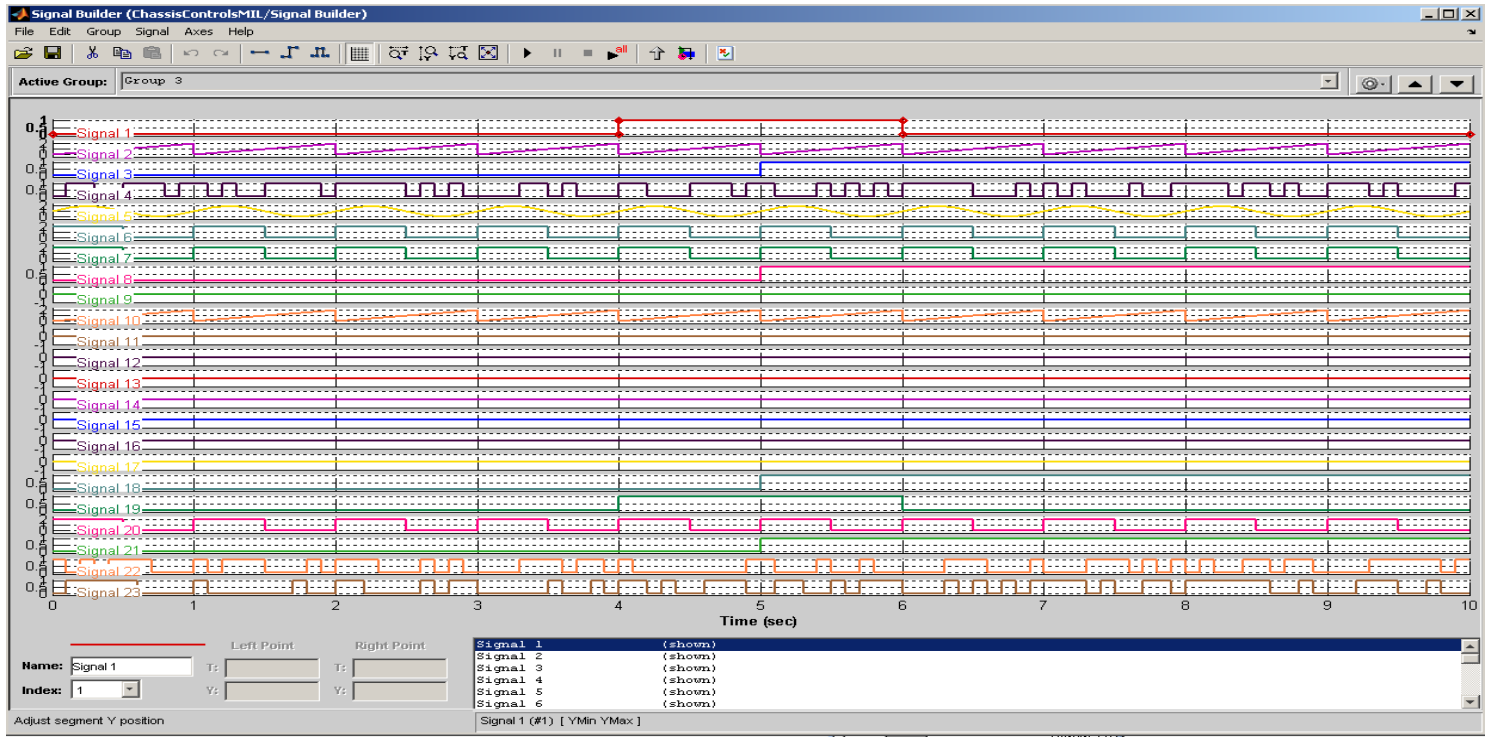
确认与验证工具

- 大多数验证工具主要是完成单元级测试验证，很少采用司机在环（driver-in-the-loop）的方式来仿真验证整个系统；
- Simulink 信号生成工具只适合于模型简单、测试用例较少、输入输出数量较少的单元测试；
- 对于有上百个输入输出（而且要测哪一个预先不确定）的分布式逻辑控制模型，修改维护信号生成工具会非常繁杂；
- 测试复杂导致推广困难。

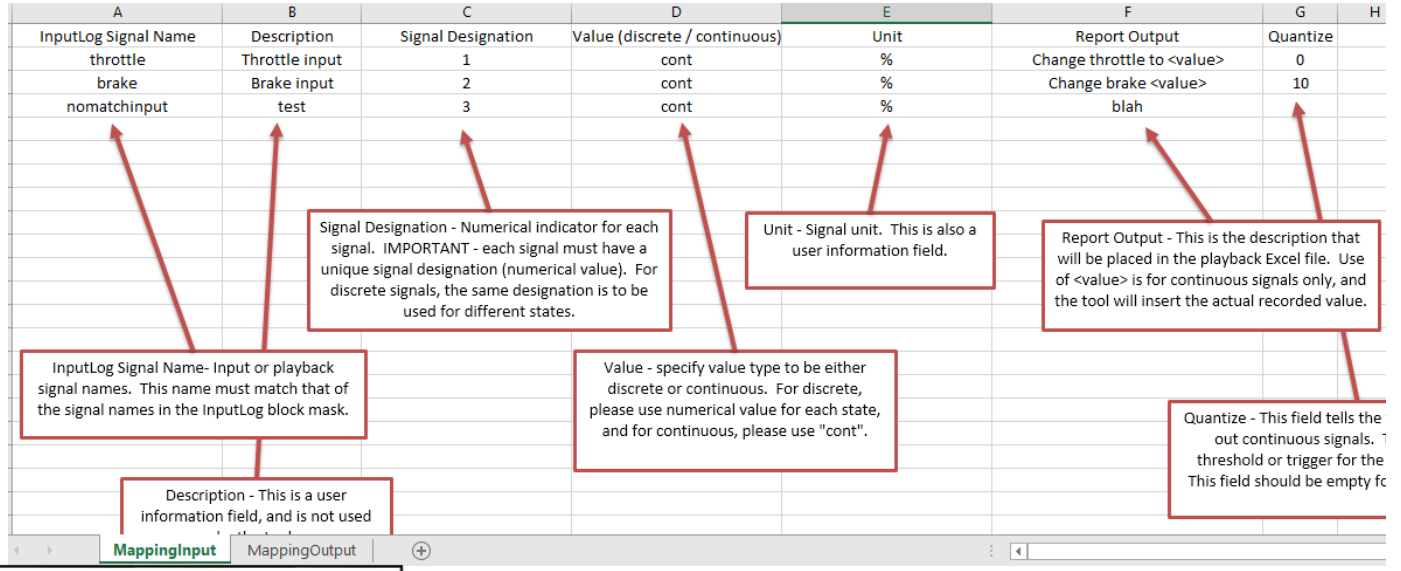


确认与验证工具

- 在MathWorks技术咨询帮助下重新设计验证工具
- 测试过程简化、人工干预减少、过程实现自动化，测试人员工作量大幅减少：
  - 选择被测信号、定义测试模式
  - 模拟实际工作环境，自动记录测试过程，并生成结构化的测试用例语言描述
  - 方便回放测试过程
  - 结果自动对比
- 整个解决方案得以顺利推广，而且正在应用到其他类似项目

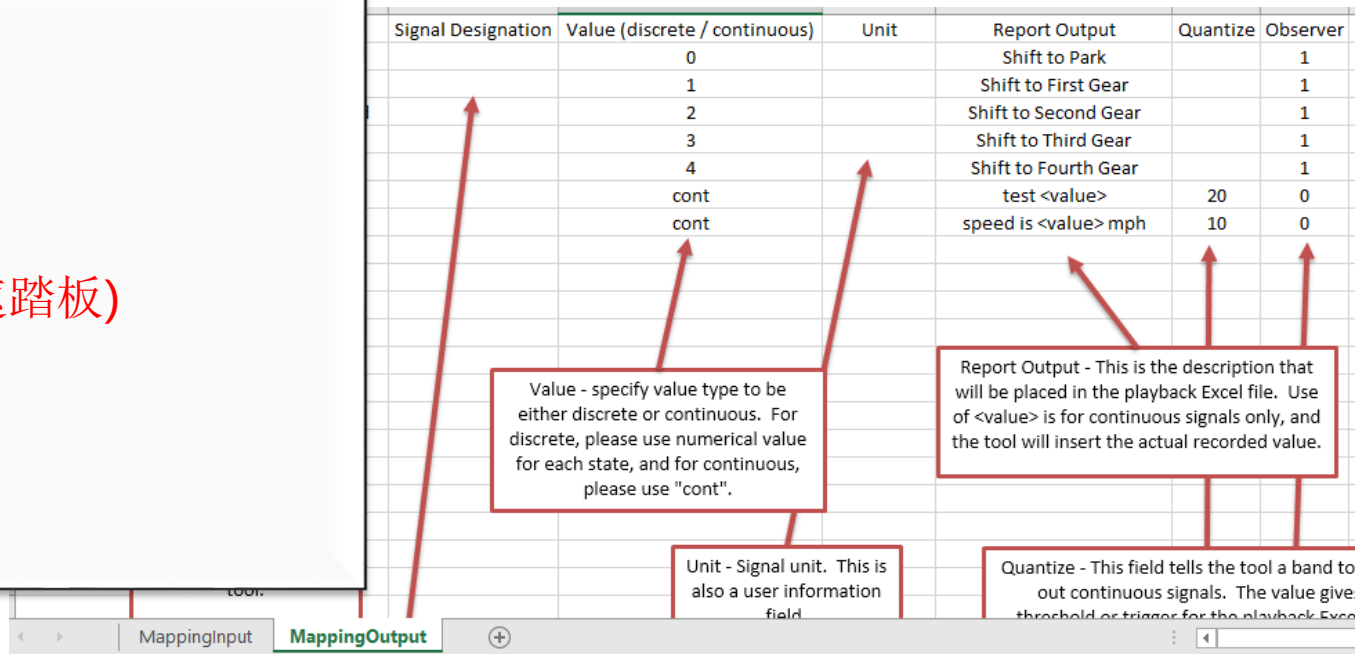
确认与验证工具

步骤 1: 定义测试用例



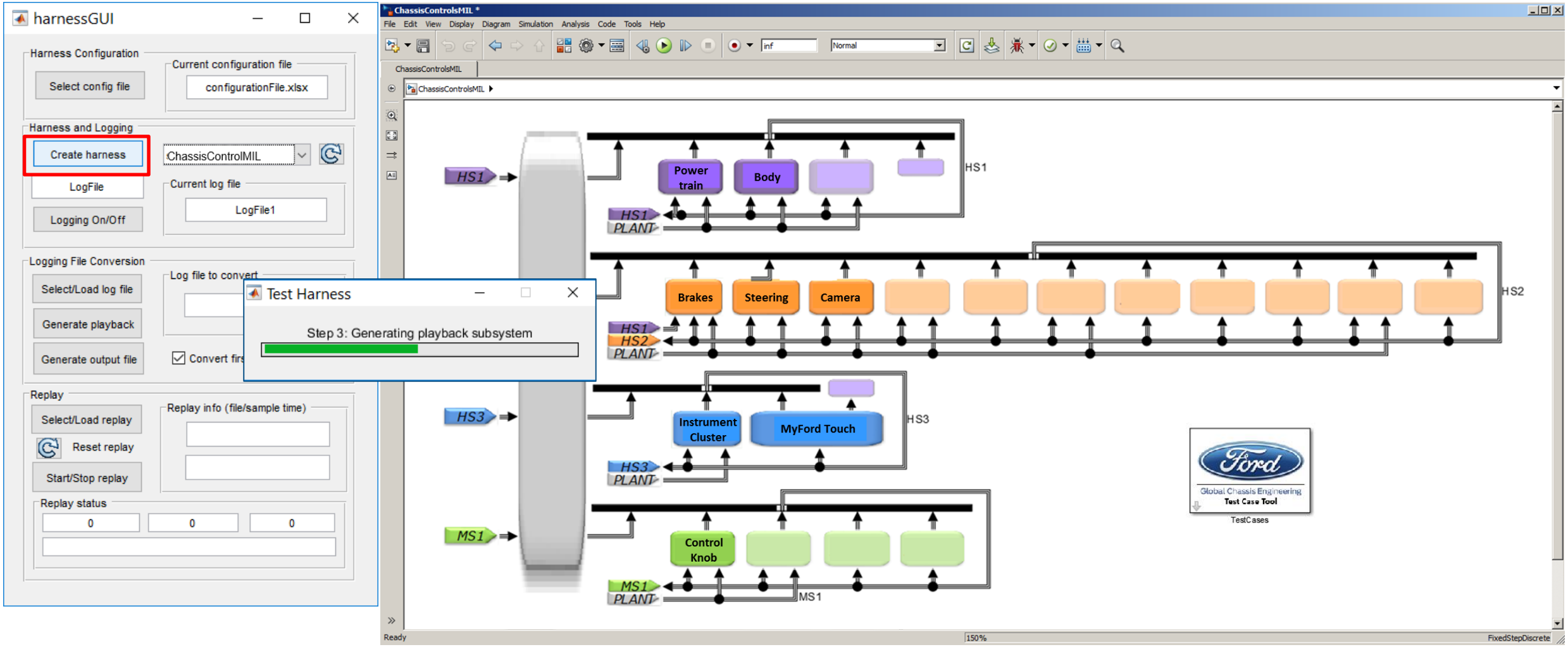
一个简单的TBA测试用例

1. 司机启动TBA功能 (按控制按钮)
2. 司机几秒种后开始倒车 (挂倒挡，踩加速踏板)
3. 司机停车 (踩刹车踏板)
4. 司机关闭TBA功能 (按控制按钮)



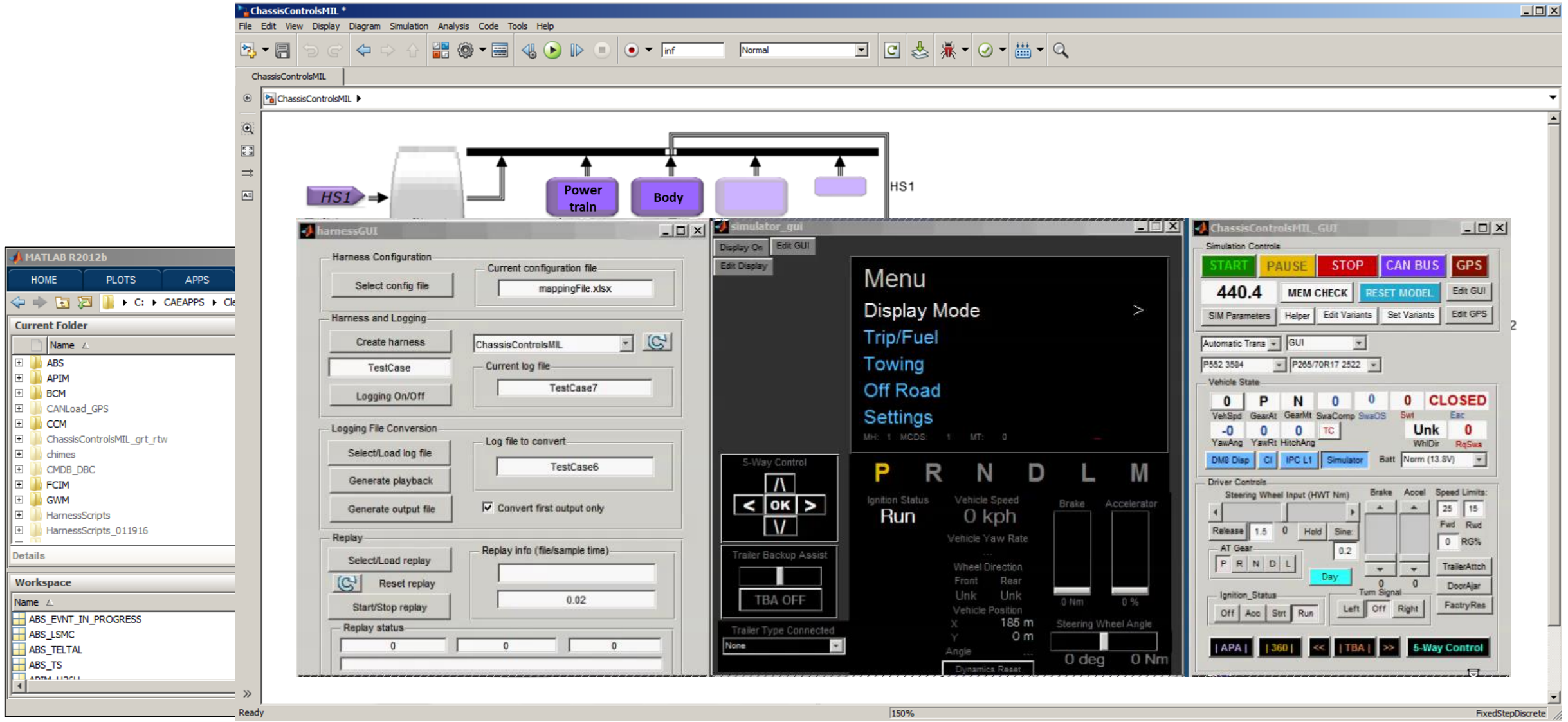
确认与验证工具

步骤2：自动生成测试框架



确认与验证工具

步骤3：仿真并记录测试用例



确认与验证工具

步骤4: 生成测试用例回放文件（Excel）

自动生成的测试用例回放文件

	A	B
1		
2	Time	Driver Input
3	0	
4	2.82	TBA Button Pressed
5	3.14	TBA Button Not Pressed
6	4.26	Down Pressed
7	4.5	Down Not Pressed
8	5.54	Up Pressed
9	5.78	Up Not Pressed
10	6.86	Ok Pressed
11	7.06	Ok Not Pressed
12	16.94	Shift gear to Reverse
13	18.78	Accel pedal 25 %
14	19.14	Accel pedal 50 %
15	19.66	Accel pedal 75 %
16	20.98	Accel pedal 50 %
17	21.3	Accel pedal 25 %
18	21.72	Accel pedal 0 %
19	22.34	Brake Pedal 25 %
20	22.76	Brake Pedal 50 %
21	23.16	Brake Pedal 75 %
22	24.12	Brake Pedal 50 %
23	24.46	Brake Pedal 25 %
24	24.82	Brake Pedal 0 %
25	26.64	TBA Button Pressed
26	26.9	TBA Button Not Pressed
27	30.1	Ok Pressed
28	30.42	Ok Not Pressed
29	38.86	Shift gear to Park
30		

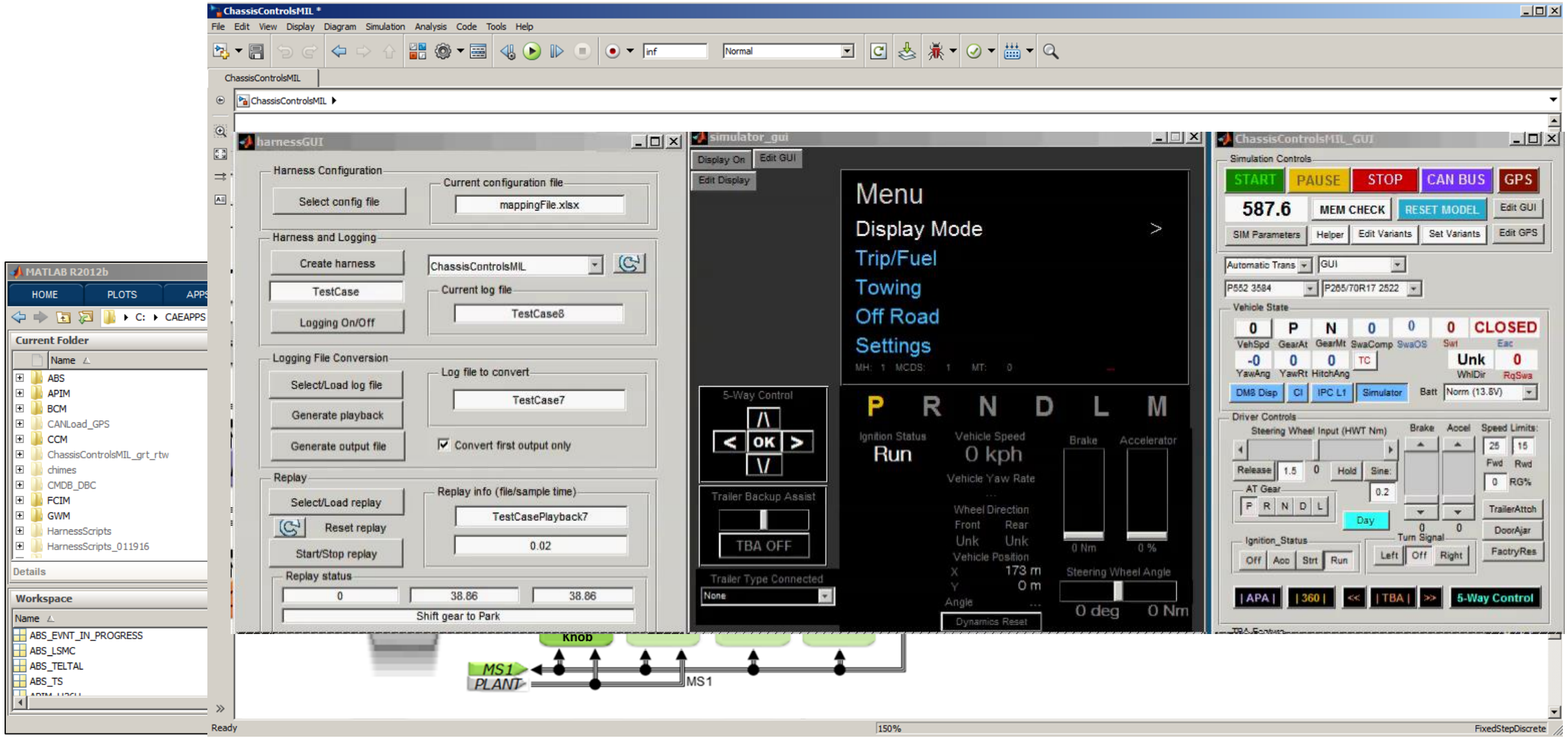
测试用例报告

TestCaseOutput7.xls [Compatibility Mode] - Excel

	A	B	F	G	H	I	J	K	L
1									
2	Time	Driver Input	HMI Request	HMI Status	Camera Status	Setup Status	Steering Angle	Vehicle Speed	
3	0		1 HMI	Inactive	Null	Inactive	0 deg	0 kph	
4	2.82	TBA Button Pressed	1 HMI	Inactive	Null	Inactive	0 deg	0 kph	
5	3.14	TBA Button Not Pressed	1 HMI	Inactive	Null	Inactive	0 deg	0 kph	
6	3.26		2 HMI	Inactive	Null	Inactive	0 deg	0 kph	
7	4.26	Down Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph	
8	4.5	Down Not Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph	
9	5.54	Up Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph	
10	5.78	Up Not Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph	
11	6.86	Ok Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph	
12	7.06	Ok Not Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph	
13	7.24		2 HMI	ActivateTba	Null	Inactive	0 deg	0 kph	
14	7.32		2 HMI	ActivateTba	TbaActive	Inactive	0 deg	0 kph	
15	7.46		2 HMI	DeactivateTba	TbaActive	Inactive	0 deg	0 kph	
16	7.58		4 HMI	DeactivateTba	TbaActive	Inactive	0 deg	0 kph	
17	7.84		4 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
18	15.46		14 HMI	Inactive			0 deg	0 kph	
19	16.94	Shift gear to Reverse	14 HMI	Inactive			0 deg	0 kph	
20	17.5		5 HMI	Inactive			0 deg	0 kph	
21	18.78	Accel pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
22	19.14	Accel pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.004036 kph	
23	19.66	Accel pedal 75 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	1.1564 kph	
24	20.98	Accel pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	6.101 kph	
25	21.3	Accel pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.9395 kph	
26	21.72	Accel pedal 0 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.7276 kph	
27	22.34	Brake Pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.4148 kph	
28	22.76	Brake Pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	3.9163 kph	
29	23.16	Brake Pedal 75 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.98992 kph	
30	24.12	Brake Pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
31	24.46	Brake Pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
32	24.82	Brake Pedal 0 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
33	26.64	TBA Button Pressed	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
34	26.9	TBA Button Not Pressed	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
35	27.02		13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
36	30.1	Ok Pressed	13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
37	30.42	Ok Not Pressed	13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph	
38	32.04		1 HMI	Inactive	Null	Inactive	0 deg	0 kph	
39	38.86	Shift gear to Park	1 HMI	Inactive	Null	Inactive	0 deg	0 kph	
40									
41									

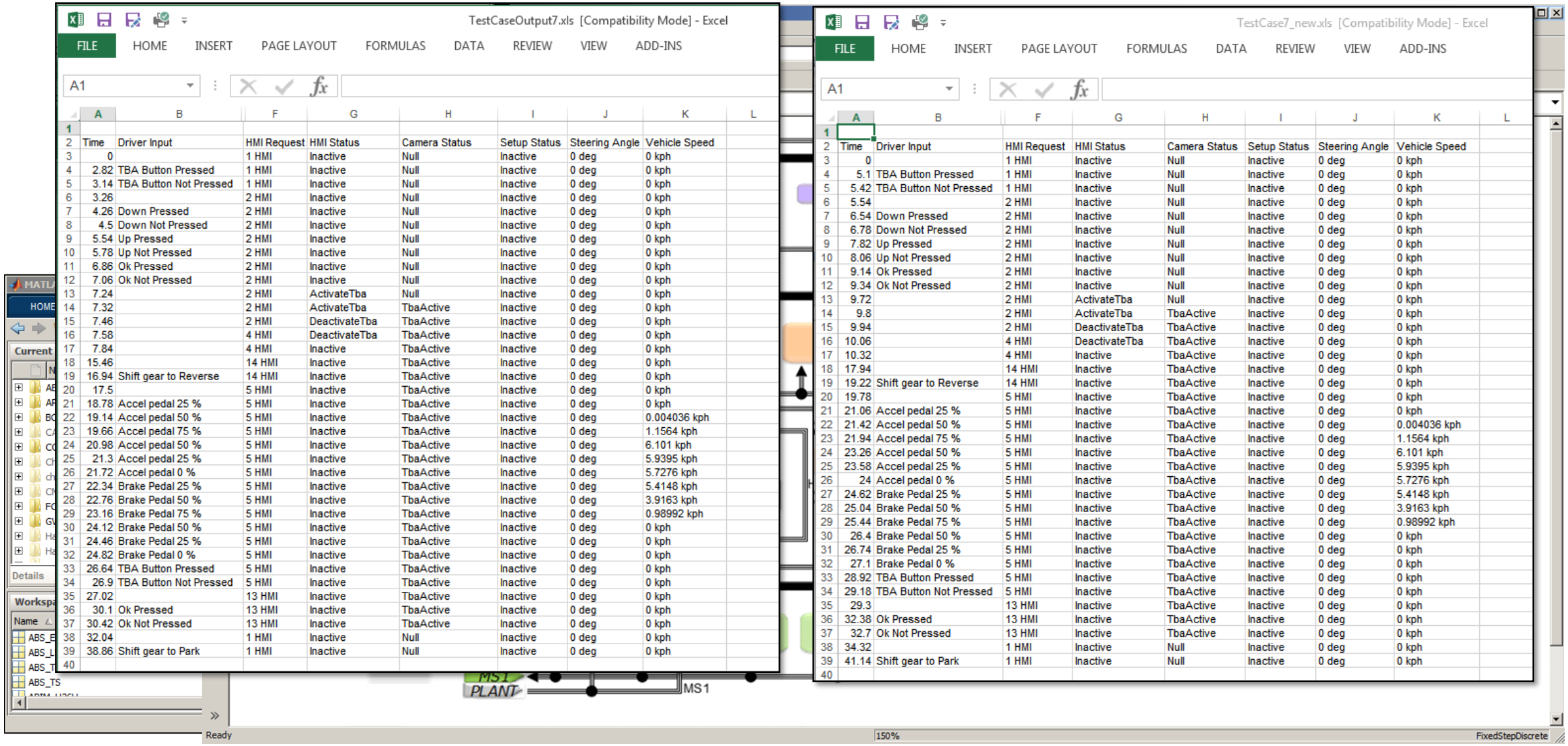
确认与验证工具

步骤5：测试用例的回放及记录



确认与验证工具

步骤6：测试结果自动比较 (最初测试结果与回放结果)



TestCaseOutput7.xls [Compatibility Mode] - Excel

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
3.26		2 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
7.24		2 HMI	ActivateTba	Null	Inactive	0 deg	0 kph
7.32		2 HMI	ActivateTba	TbaActive	Inactive	0 deg	0 kph
7.46		2 HMI	DeactivateTba	TbaActive	Inactive	0 deg	0 kph
7.58		4 HMI	DeactivateTba	TbaActive	Inactive	0 deg	0 kph
7.84		4 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
15.46		14 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
16.94	Shift gear to Reverse	14 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
17.5		5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
18.78	Accel pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
19.14	Accel pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.004036 kph
19.66	Accel pedal 75 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	1.1564 kph
20.98	Accel pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	6.101 kph
21.3	Accel pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.9395 kph
21.72	Accel pedal 0 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.7276 kph
22.34	Brake Pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.4148 kph
22.76	Brake Pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	3.9163 kph
23.16	Brake Pedal 75 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.98992 kph
24.12	Brake Pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
24.46	Brake Pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
24.82	Brake Pedal 0 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
26.64	TBA Button Pressed	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
26.9	TBA Button Not Pressed	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
27.02		13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
30.1	Ok Pressed	13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
30.42	Ok Not Pressed	13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
32.04		1 HMI	Inactive	Null	Inactive	0 deg	0 kph
38.86	Shift gear to Park	1 HMI	Inactive	Null	Inactive	0 deg	0 kph

TestCase7_new.xls [Compatibility Mode] - Excel

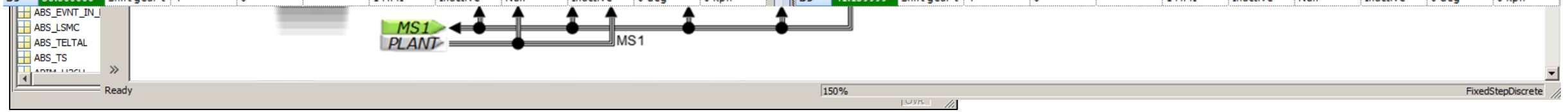
Time	Driver Input	HMI Request	HMI Status	Camera Status	Setup Status	Steering Angle	Vehicle Speed
0		1 HMI	Inactive	Null	Inactive	0 deg	0 kph
5.1	TBA Button Pressed	1 HMI	Inactive	Null	Inactive	0 deg	0 kph
5.42	TBA Button Not Pressed	1 HMI	Inactive	Null	Inactive	0 deg	0 kph
5.54		2 HMI	Inactive	Null	Inactive	0 deg	0 kph
6.54	Down Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
6.78	Down Not Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
7.82	Up Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
8.06	Up Not Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
9.14	Ok Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
9.34	Ok Not Pressed	2 HMI	Inactive	Null	Inactive	0 deg	0 kph
9.72		2 HMI	ActivateTba	Null	Inactive	0 deg	0 kph
9.8		2 HMI	ActivateTba	TbaActive	Inactive	0 deg	0 kph
9.94		2 HMI	DeactivateTba	TbaActive	Inactive	0 deg	0 kph
10.06		4 HMI	DeactivateTba	TbaActive	Inactive	0 deg	0 kph
10.32		4 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
17.94		14 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
19.22	Shift gear to Reverse	14 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
19.78		5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
21.06	Accel pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
21.42	Accel pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.004036 kph
21.94	Accel pedal 75 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	1.1564 kph
23.26	Accel pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	6.101 kph
23.58	Accel pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.9395 kph
24	Accel pedal 0 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.7276 kph
24.62	Brake Pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.4148 kph
25.04	Brake Pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	3.9163 kph
25.44	Brake Pedal 75 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.98992 kph
26.4	Brake Pedal 50 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
26.74	Brake Pedal 25 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
27.1	Brake Pedal 0 %	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
28.92	TBA Button 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
29.3		13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
32.38	Ok Pressed	13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
32.7	Ok Not Pressed	13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
34.32		1 HMI	Inactive	Null	Inactive	0 deg	0 kph
41.14	Shift gear to Park	1 HMI	Inactive	Null	Inactive	0 deg	0 kph

确认与验证工具

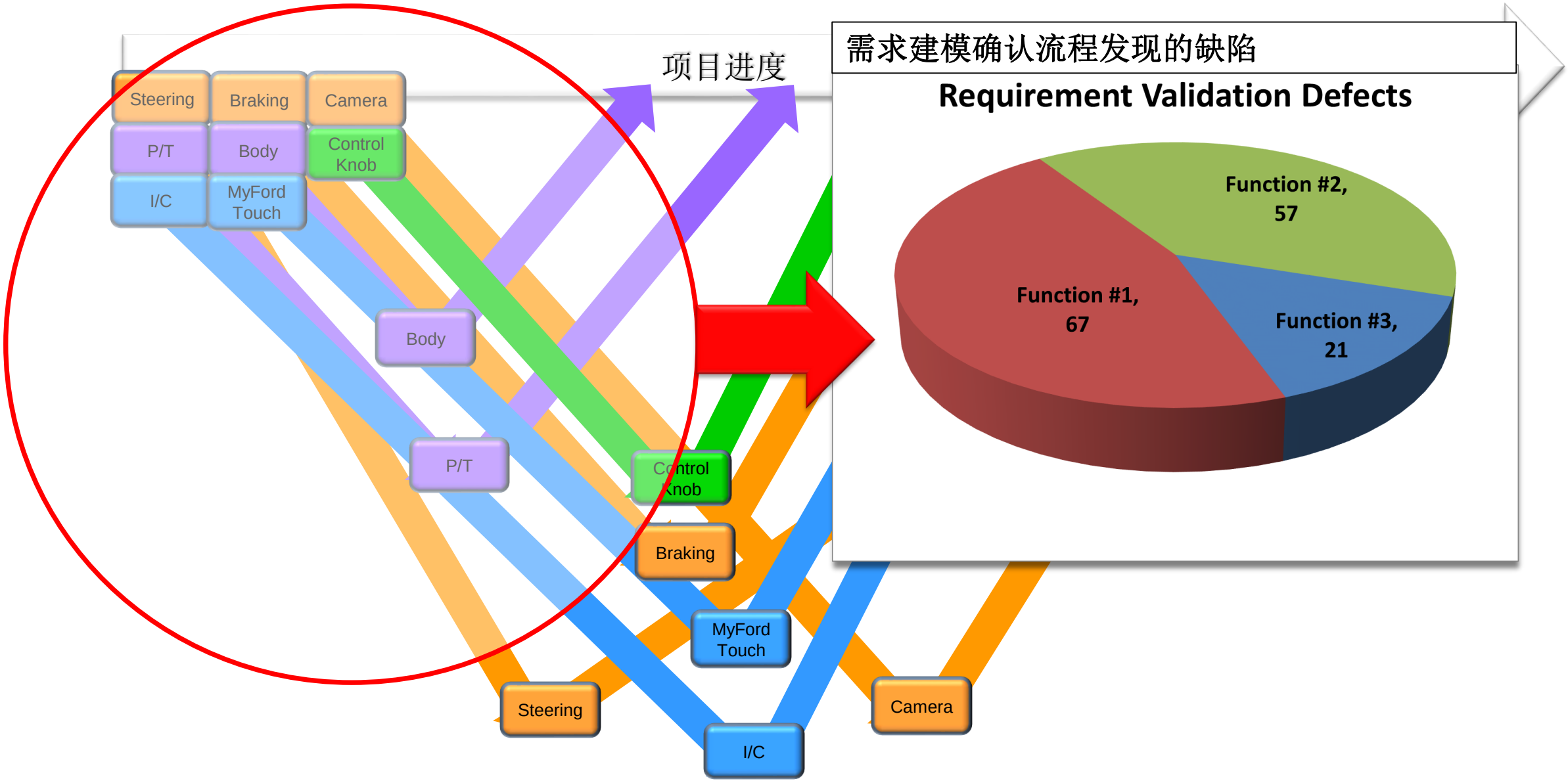
步骤6：测试结果自动比较 (最初测试结果与回放结果)

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	15.460000				14 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
19	16.940000	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	18.780000	Accel pedal	3	25	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
22	19.140000	Accel pedal	3	50	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.004036 k
23	19.660000	Accel pedal	3	75	5 HMI	Inactive	TbaActive	Inactive	0 deg	1.1564 kph
24	20.980000	Accel pedal	3	50	5 HMI	Inactive	TbaActive	Inactive	0 deg	6.101 kph
25	21.300000	Accel pedal	3	25	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.9395 kph
26	21.720000	Accel pedal	3	0	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.7276 kph
27	22.340000	Brake Peda	2	25	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.4148 kph
28	22.760000	Brake Peda	2	50	5 HMI	Inactive	TbaActive	Inactive	0 deg	3.9163 kph
29	23.160000	Brake Peda	2	75	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.98992 kp
30	24.120000	Brake Peda	2	50	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
31	24.460000	Brake Peda	2	25	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
32	24.820000	Brake Peda	2	0	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
33	26.640000	TBA Button	11	1	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
34	26.900000	TBA Button	11	0	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
35	27.020000				13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
36	30.100000	Ok Pressed	10	1	13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
37	30.420000	Ok Not Pre	10	0	13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
38	32.040000				1 HMI	Inactive	Null	Inactive	0 deg	0 kph
39	38.860000	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	10.060000				4 HMI	Deactivate	TbaActive	Inactive	0 deg	0 kph
17	10.320000				4 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
18	17.940000				14 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
19	19.220000	Shift gear t	4	1	14 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
20	19.780000				5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
21	21.060000	Accel pedal	3	25	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
22	21.420000	Accel pedal	3	50	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.004036 k
23	21.940000	Accel pedal	3	75	5 HMI	Inactive	TbaActive	Inactive	0 deg	1.1564 kph
24	23.259999	Accel pedal	3	50	5 HMI	Inactive	TbaActive	Inactive	0 deg	6.101 kph
25	23.580000	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	24.620000	Brake Peda	2	25	5 HMI	Inactive	TbaActive	Inactive	0 deg	5.4148 kph
28	25.040000	Brake Peda	2	50	5 HMI	Inactive	TbaActive	Inactive	0 deg	3.9163 kph
29	25.440000	Brake Peda	2	75	5 HMI	Inactive	TbaActive	Inactive	0 deg	0.98992 kp
30	26.400000	Brake Peda	2	50	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
31	26.740000	Brake Peda	2	25	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
32	27.100000	Brake Peda	2	0	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
33	28.920000	TBA Button	11	1	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
34	29.180000	TBA Button	11	0	5 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
35	29.300000				13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
36	32.379999	Ok Pressed	10	1	13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
37	32.700000	Ok Not Pre	10	0	13 HMI	Inactive	TbaActive	Inactive	0 deg	0 kph
38	34.320000				1 HMI	Inactive	Null	Inactive	0 deg	0 kph
39	41.139999	Shift gear t	4	0	1 HMI	Inactive	Null	Inactive	0 deg	0 kph

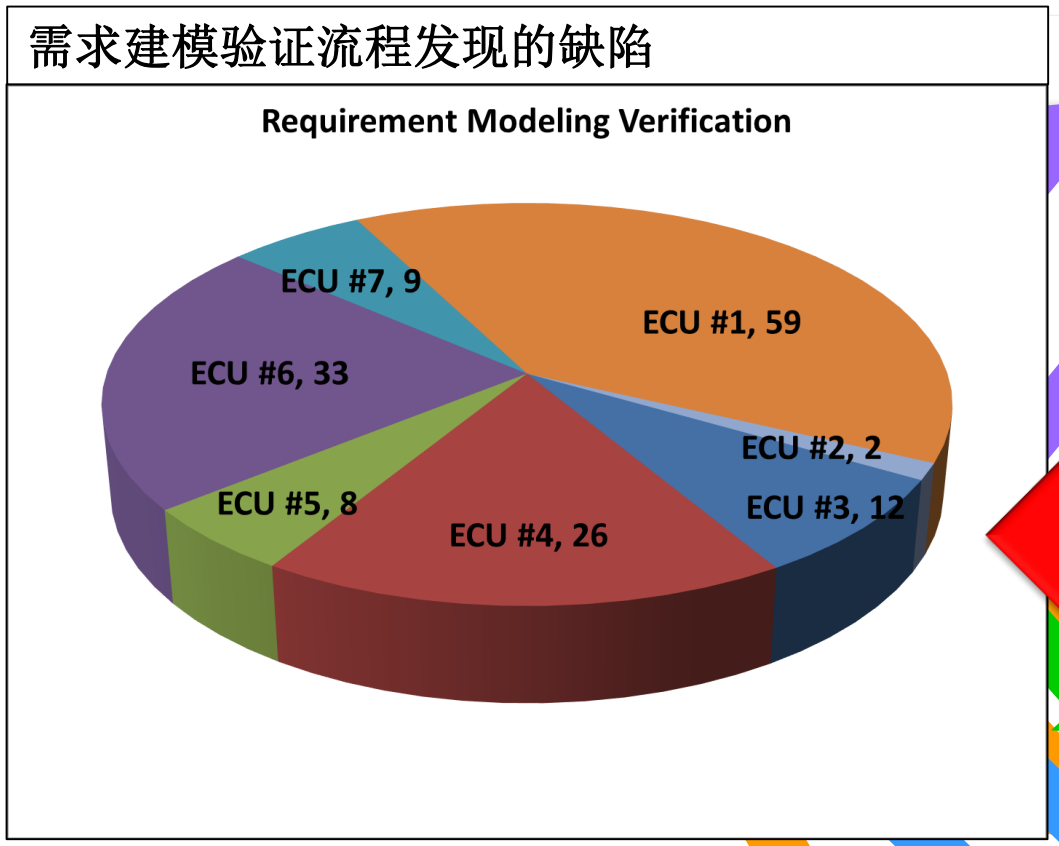


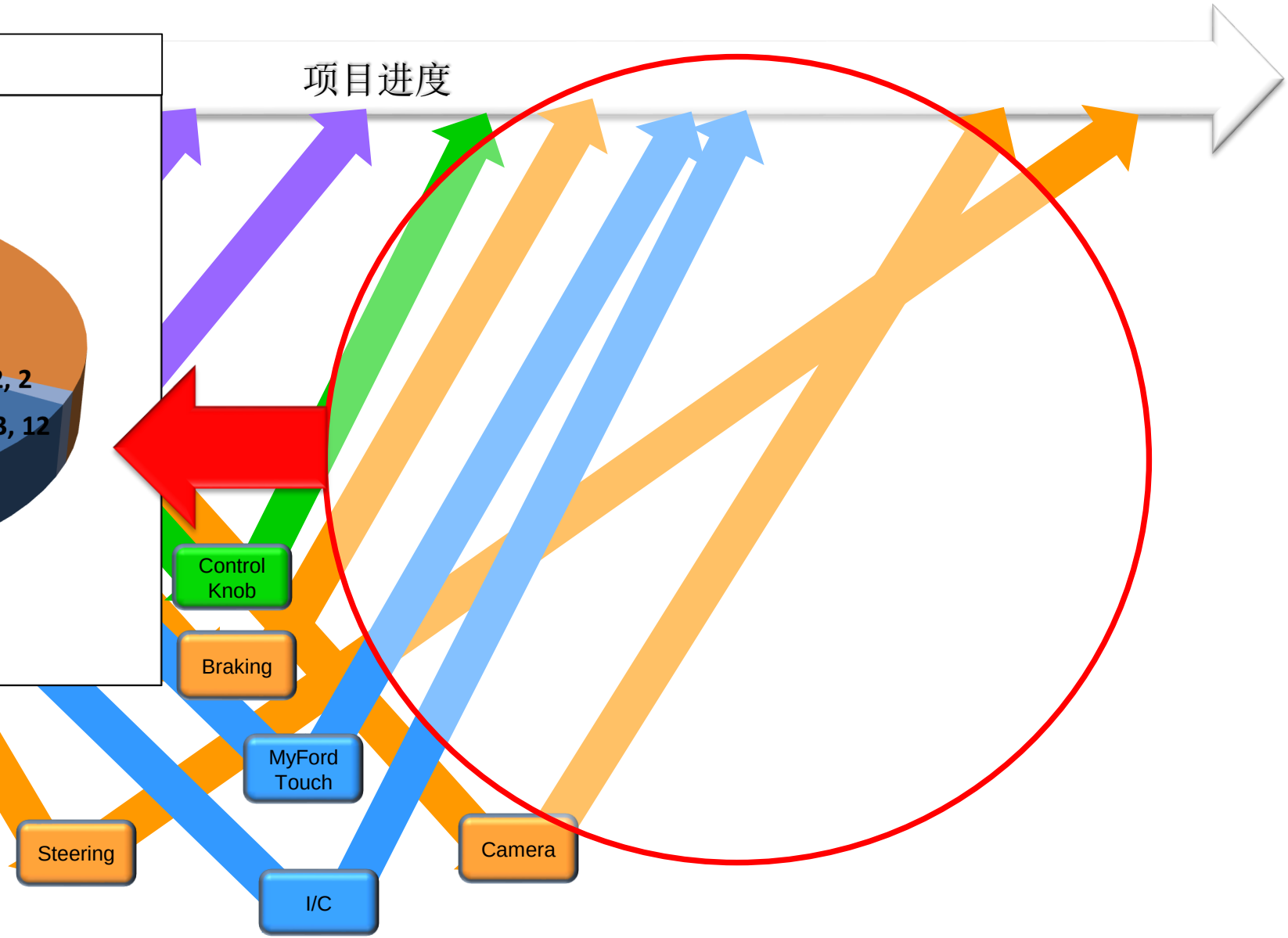
确认结果


项目进度
Steering
Braking
Camera
P/T
Body
Control Knob
I/C
MyFord Touch
Body
P/T
Control Knob
Braking
MyFord Touch
Steering
Camera
I/C
需求建模确认流程发现的缺陷
Requirement Validation Defects
Function #2, 57
Function #1, 67
Function #3, 21

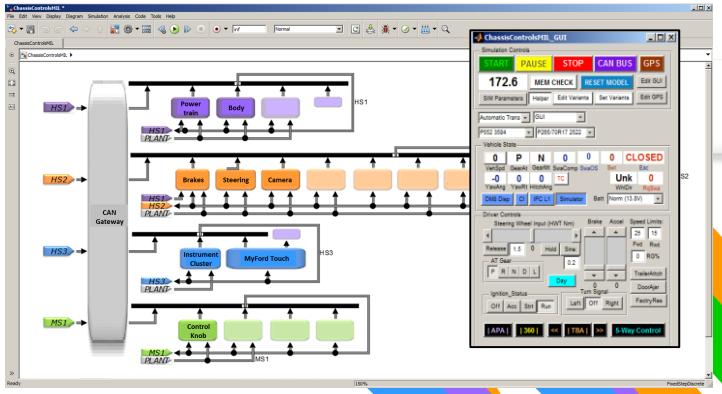
验证结果

需求建模验证流程发现的缺陷





解决方案

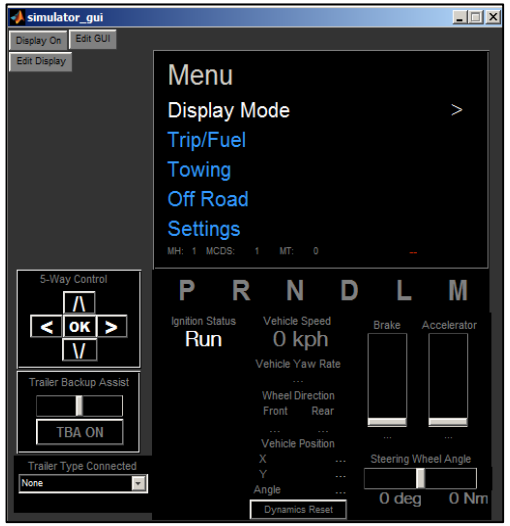


集成仿真环境：
用需求模型测试所有功能需求

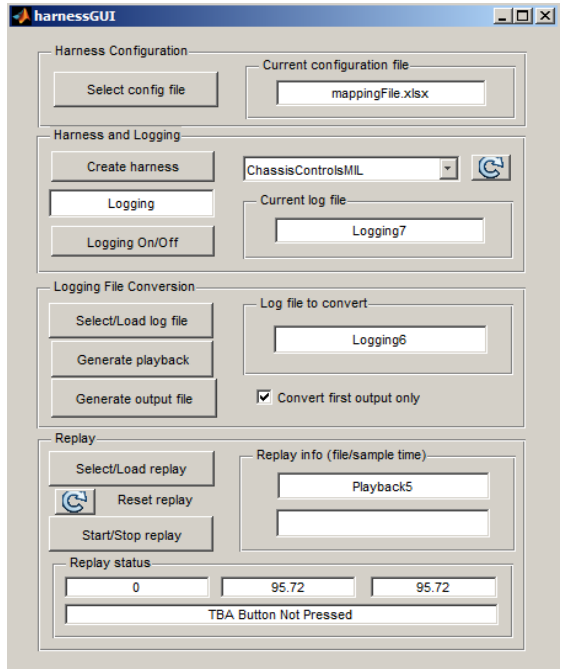
项目进度

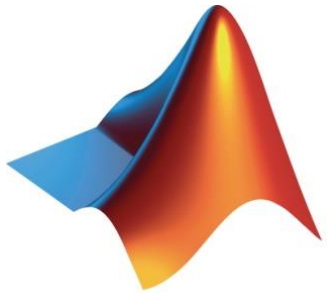
样车完成

验证工具：
测试用例记录与回放，
生成可重复验证脚本，
自动重复执行
MIL/HIL 测试



车辆及司机模拟器：
确认所有需求与设计符合





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