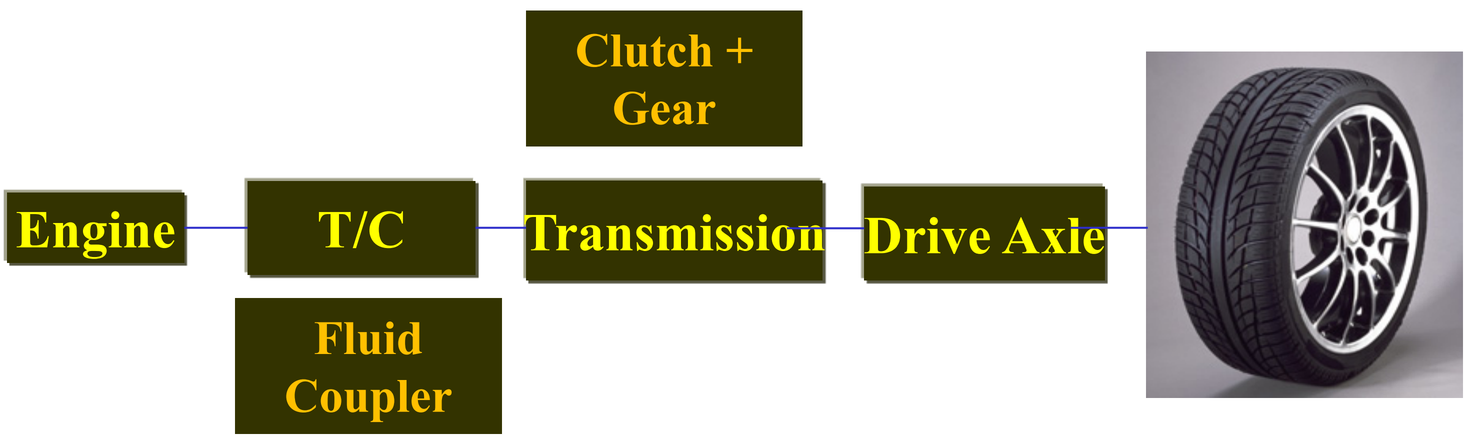
Powertrain Control Feature Development Through Model Based Design

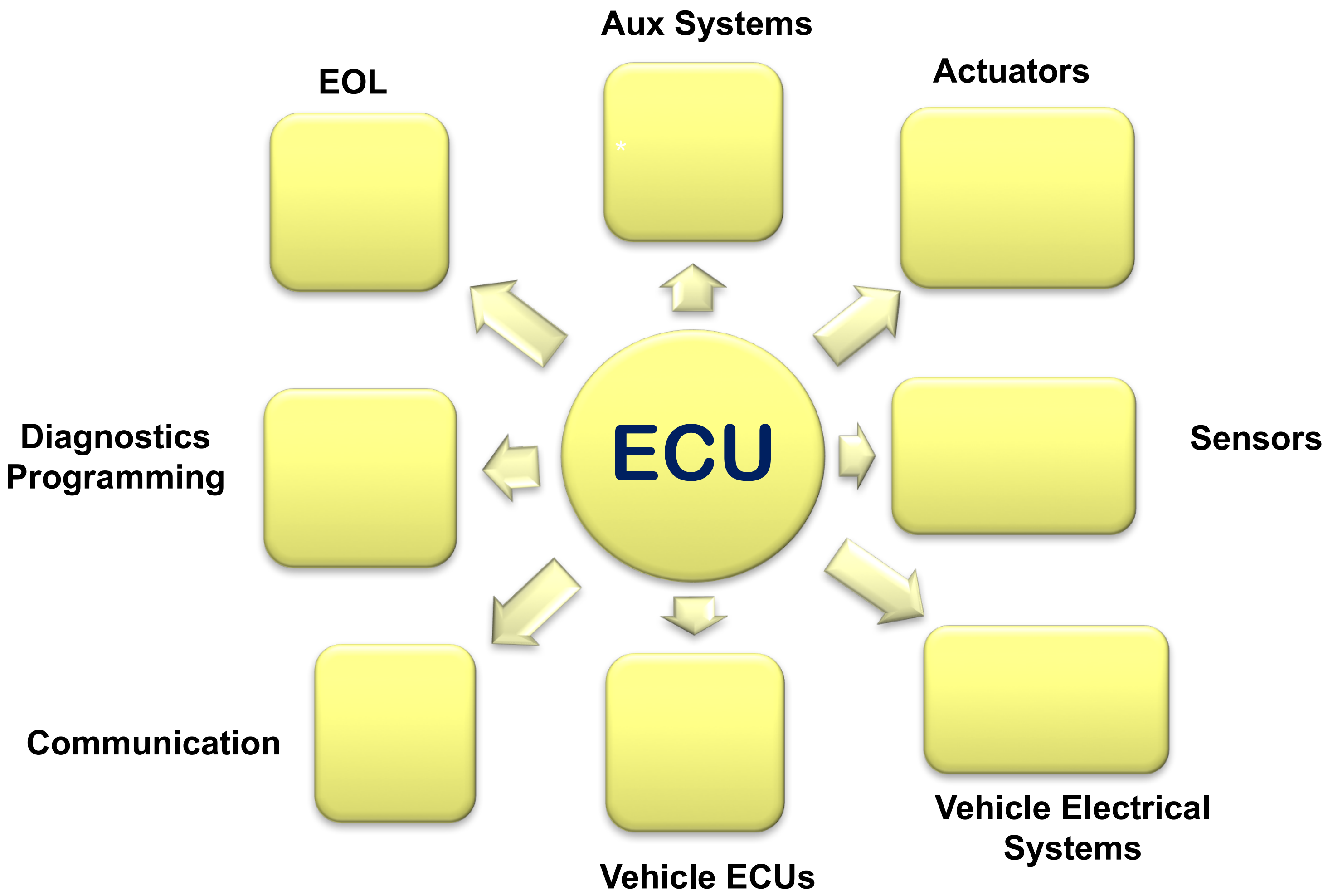
- Introduction to Powertrain
- Powertrain feature – Clutch Control
- Requirements
- Function Development
- Model verification
- Design verification & Coverage analysis
- Software in loop checking
- Auto code generation
- Concluding points

Outline

- This presentation describes how Model Based Design (MBD) concept is successfully deployed to address problem and challenges associated in designing complex powertrain control system



Engine Electronics Interfaces



Integrated Powertrain Control

- Coolant thermo sensor
- Throttle position sensor
- Knock sensor
- Airflow sensor
- Lambda sensor
- Engine RPM sensor

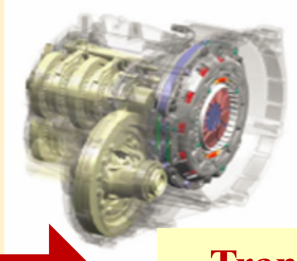
ECU → Fuel Control

Engine Management system

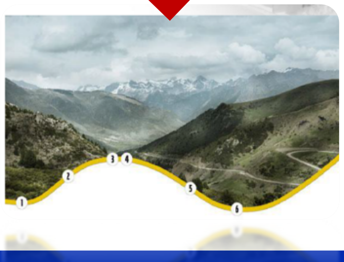
Integration

TCU → Gearshift

- Selector lever switch
- Mode selection switch
- Brake switch
- Trans oil temp sensor
- Trans oil pr sensor
- Vehicle speed



Transmission control system



GPS

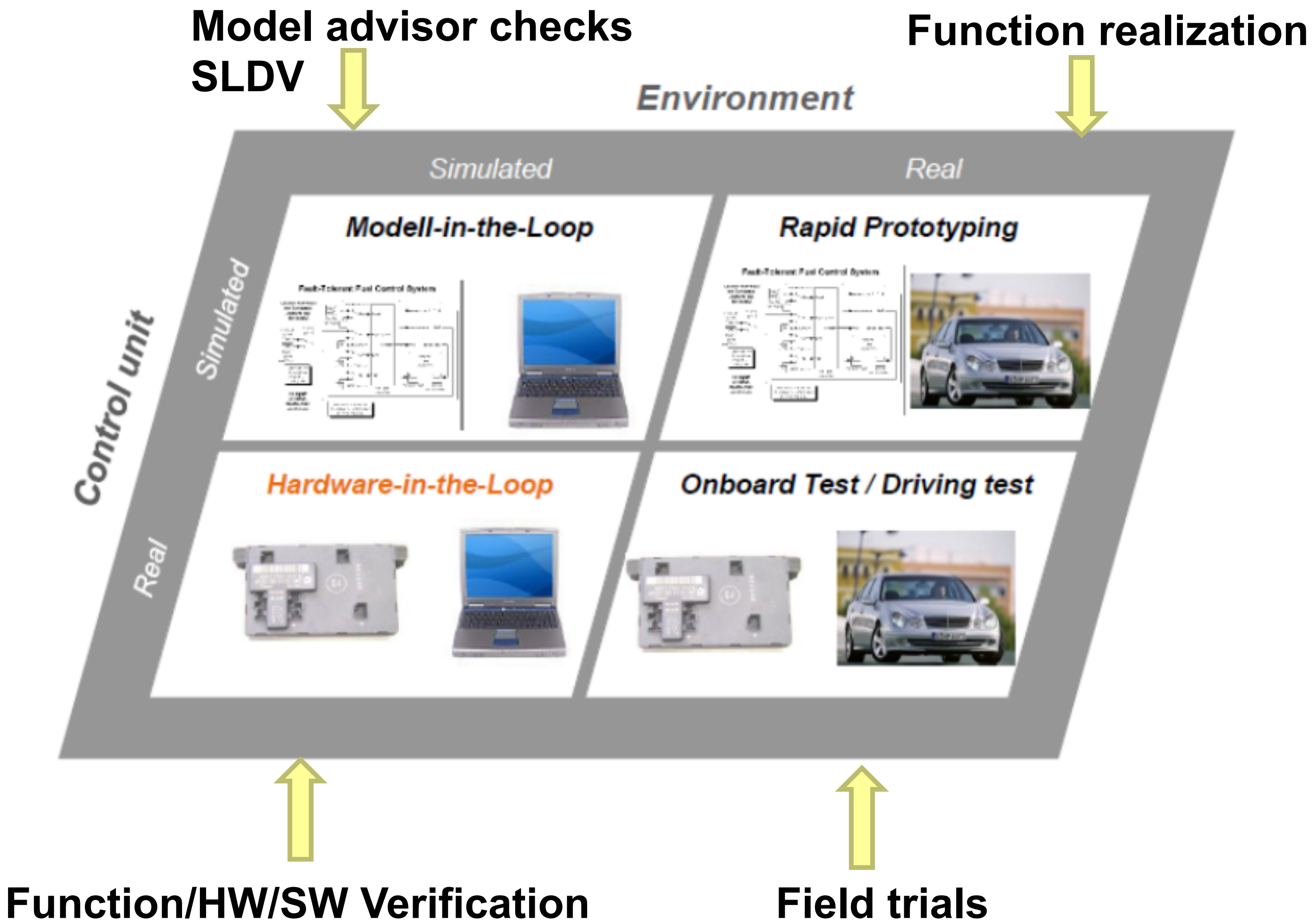
Control Design Challenges

- Powertrain requires to deliver best - performance, emission, Fuel economy, drivability, safety etc.
- Capable of handling Multi-domain tasking
- Respond to tight coupling of powertrain components
- Manage lot of interdependencies and exchange of huge no. of parameters
- Ensure reliable working under all operating scenarios

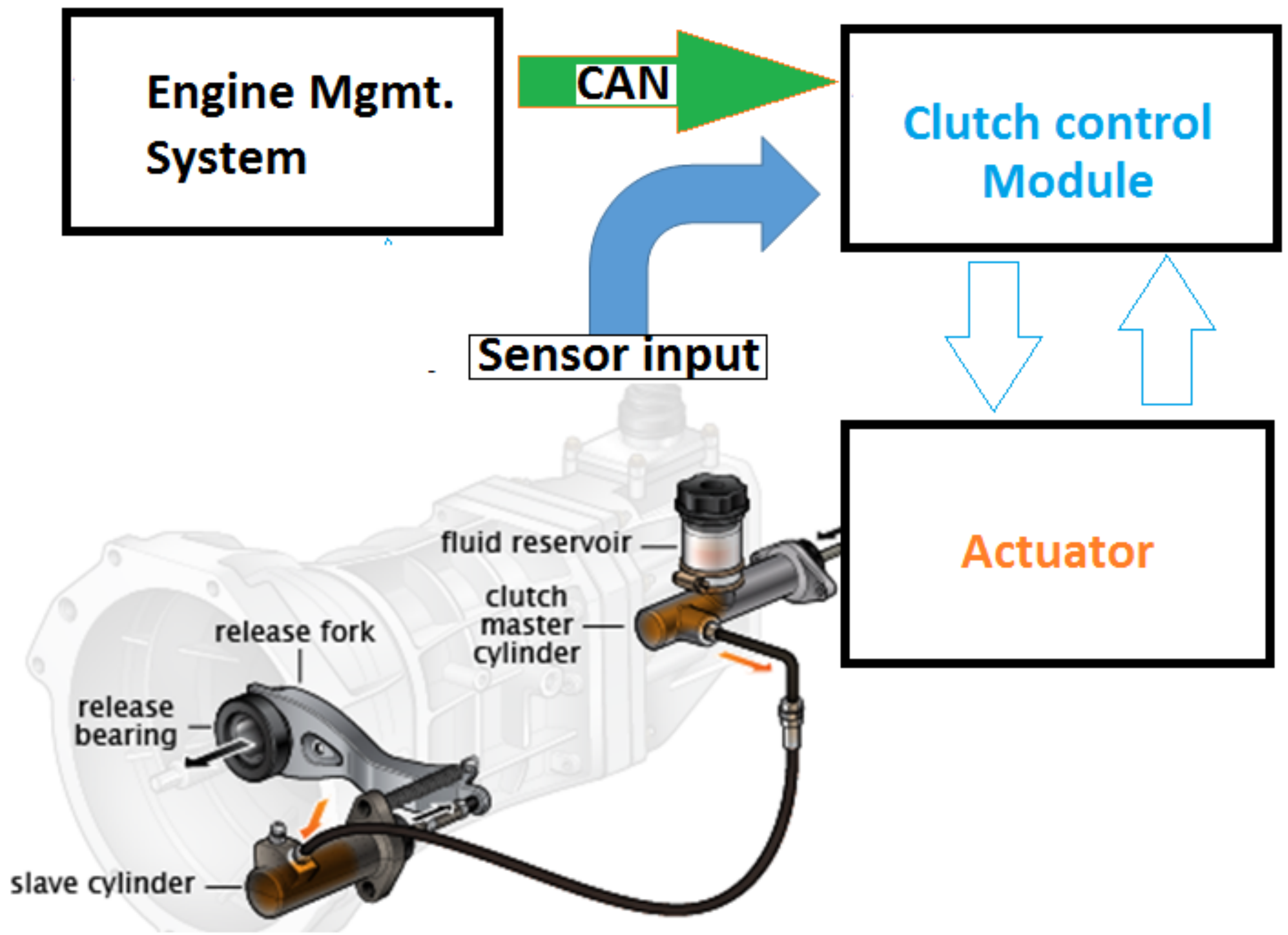
Approach

- Conventional design approach has limitations in terms of analysis, testing, risk mitigation & confidence building
- MBD provides platform for quick building of control design and verification
- Support step by step design integrated with testing throughout the development cycle
- Provide ease of modification to refine algorithm to build optimum system
- Tools used
  - Matlab, Simulink, Stateflow
  - Embedded Coder
  - Simulink Design Verifier
  - Model Advisor

MBDS & Test technologies



Powertrain Control feature-Clutch Control



Key Challenges

- Auto Clutch control is combination of Manual and Automated actions
- Critical success factors
  - To be in sync & respond near real time basis
  - Clutch actuation trigger with driver input
  - Require continuous motoring of clutch movement & act accordingly
  - Fault management & safety
  - Any mismatch in timing may cause component damage and affect drivability
  - Need to incorporate self learning & neural logic to build right control mechanism

Requirements

- Stateflow and Simulink are used for gap analysis
- Multiple iterations of review and discussions were performed
- Requirements were in the form of text / diagrams
- Referencing of interfacing inputs and feedbacks
- Some High level requirement examples –
  - While changing gear clutch should be disengaged
  - While Brake pedal pressed for time-T, then Clutch Should be Disengaged
  - User can select reverse gear ONLY when vehicle speed is zero
  - Current gear & next gear should be identified and clutch shift timings to be varied accordingly

Requirement Reviews & Discussions

- While change in gear Clutch should be disengaged
- While Brake pedal press for T time then Clutch Should be Disengaged
- User can select reverse gear ONLY when vehicle speed is zero

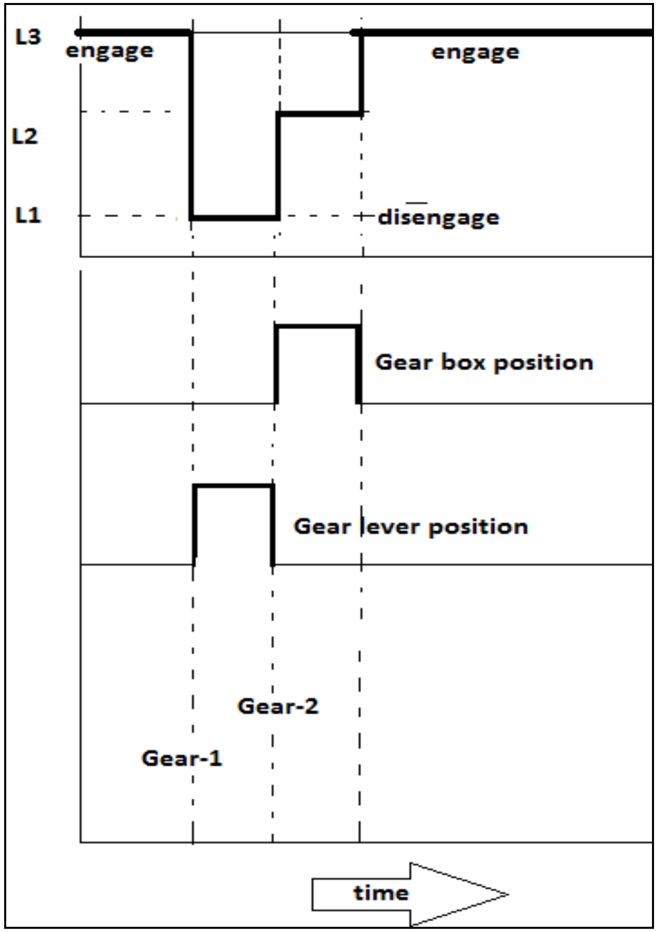
Initial requirements in text

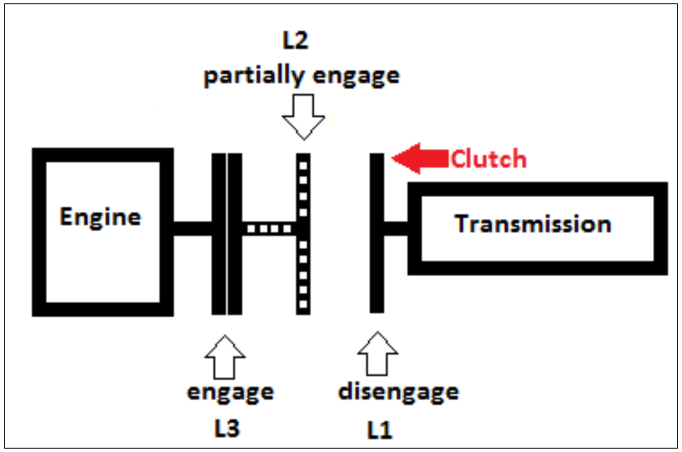
- Added tuning parameters(timing, calibration parameter)

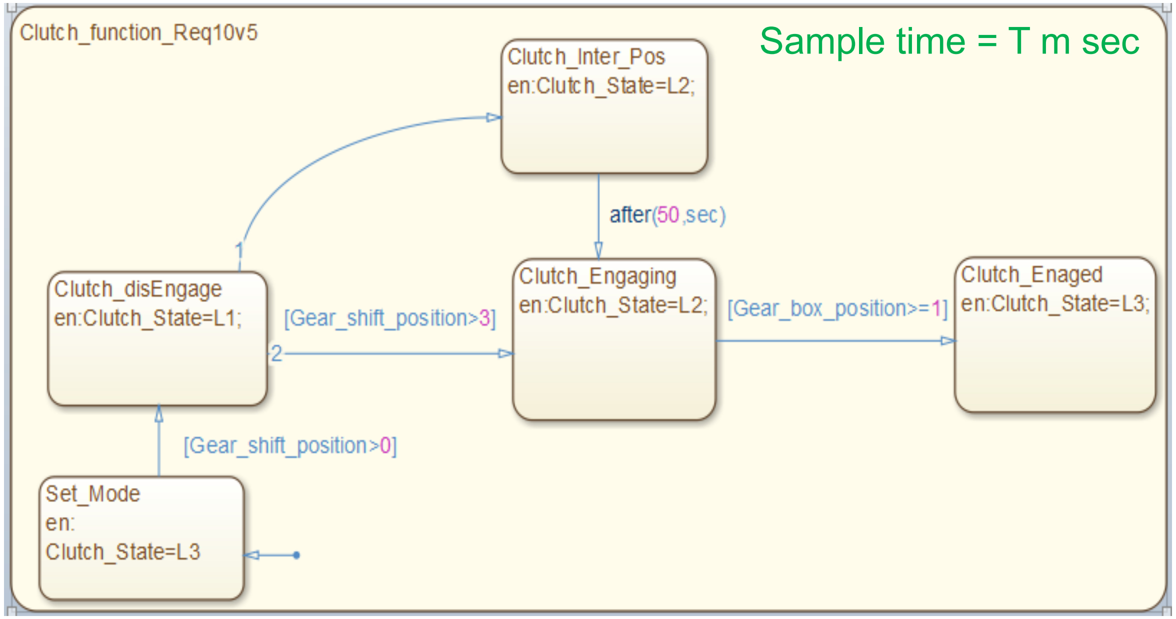
Modeling & Requirement refinements

- While modeling missing parameters, relationships, interfaces were identified and corrected.
- Stateflow enabled to define transition, conditions and actions in the control logic

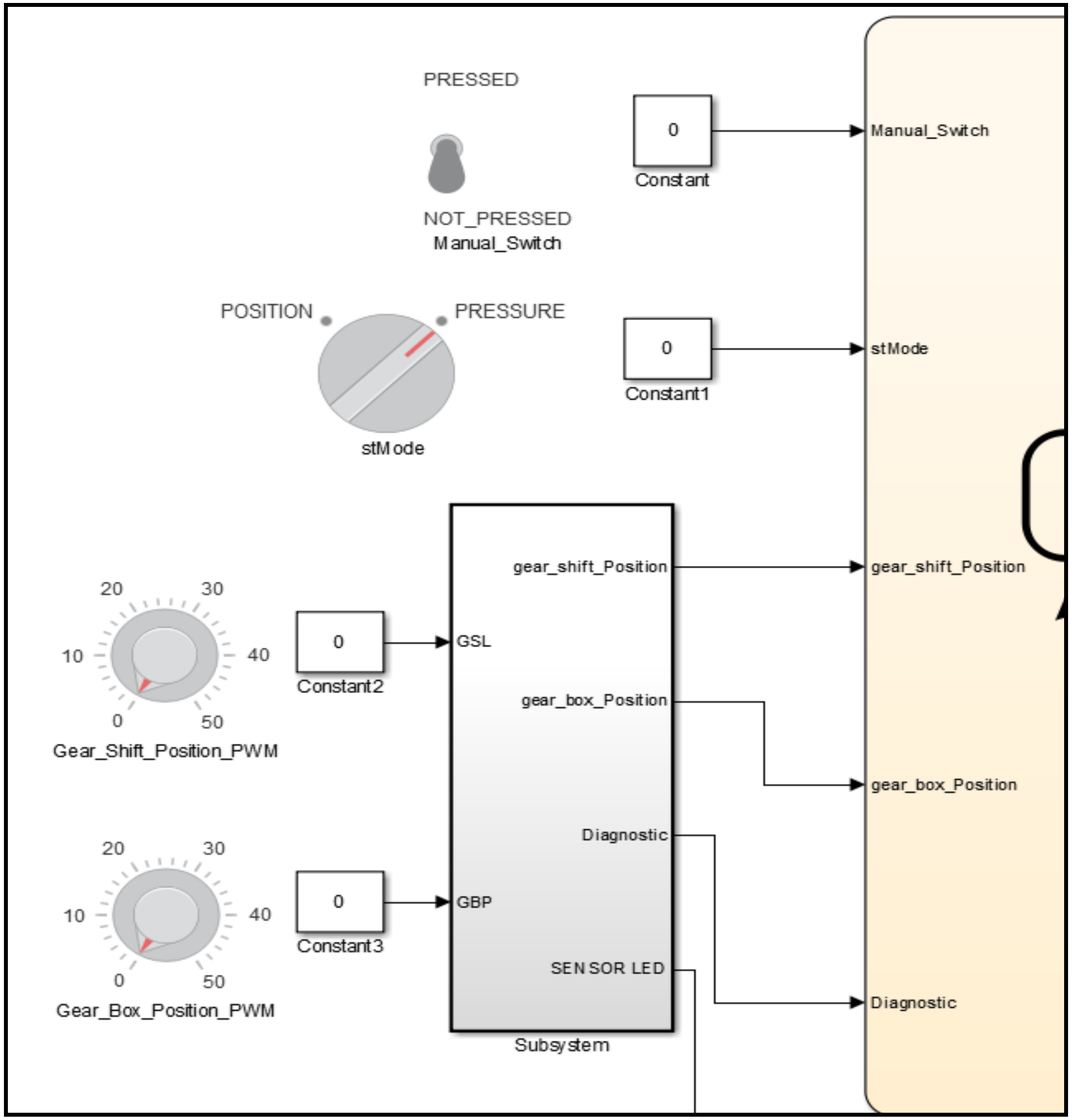
Derived Control Logic



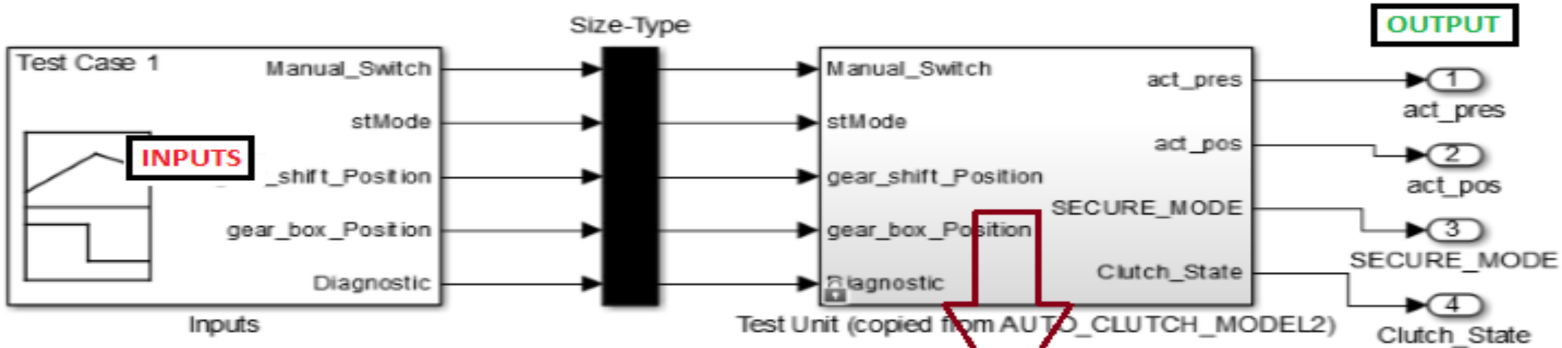




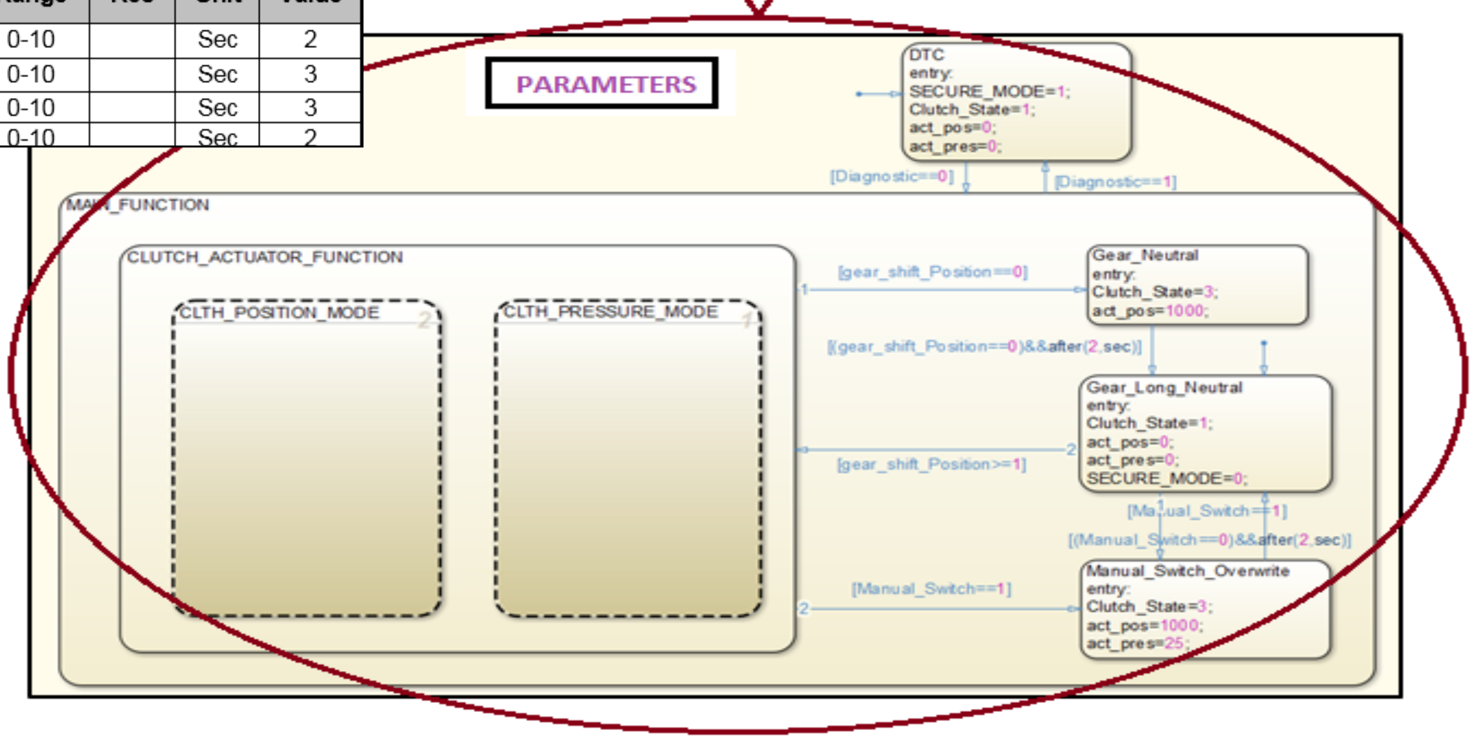
Inputs simulation



Function developement



Local parameter	Range	Res	Unit	Value
T1	0-10		Sec	2
T2	0-10		Sec	3
T3	0-10		Sec	3
T4	0-10		Sec	2

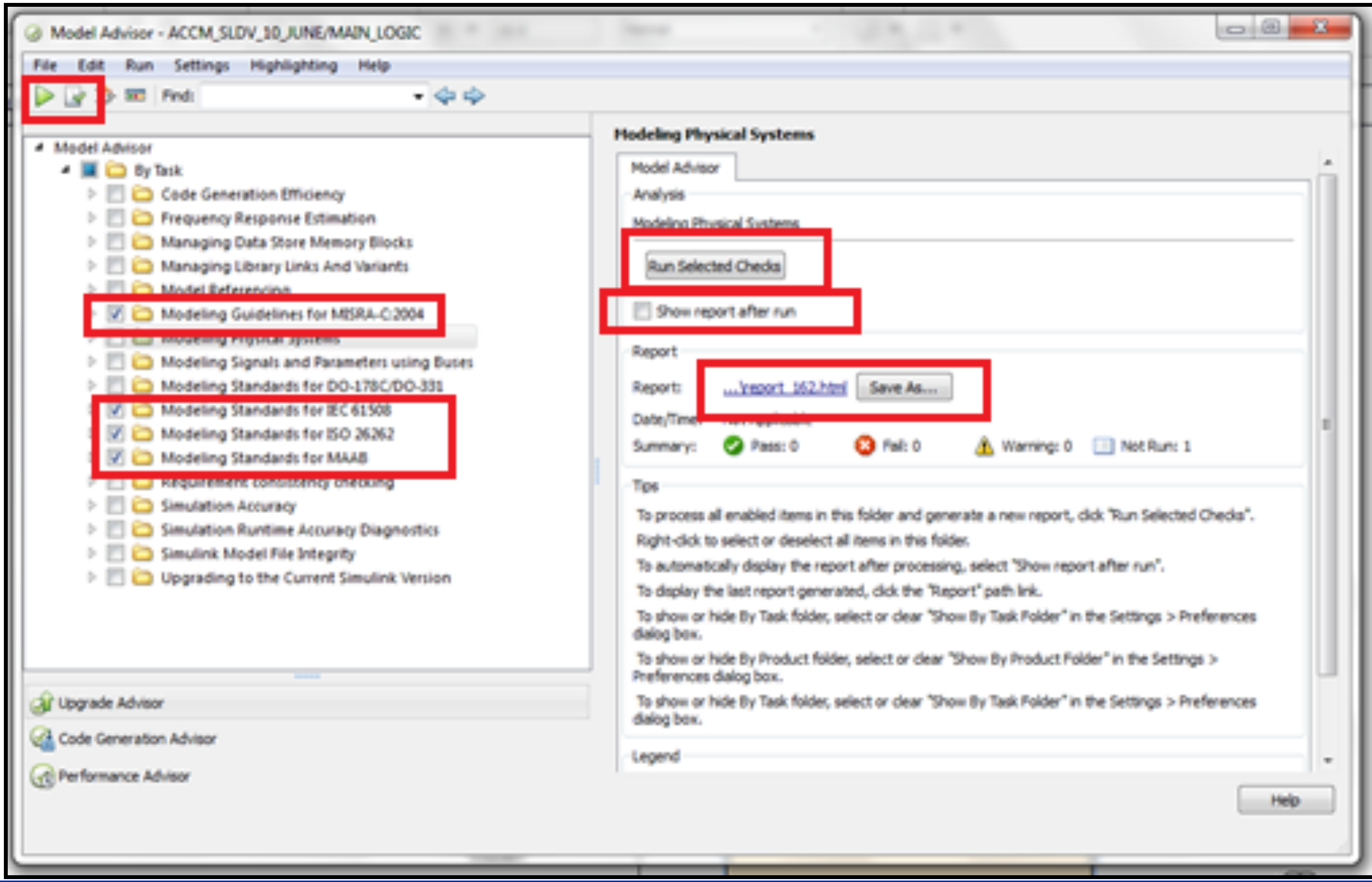


Design Verification

- Requires to check following
  - Individual function
  - Possible real time failure
  - Impact of calibration limits
  - Diagnostics
  - Safety functions
- Following tools were used as part of design verification:
  - Model Advisor
  - Simulink Design Verification
  - Software in Loop

Model Analysis

- Following standard guideline checks were performed:
  - MATHWORKS Automotive Advisor Board
  - MISRA 2004
  - ISO 26262
  - IEC 61582



Model Advisor-Report

Model Advisor Report - Clutch_Eng_DEngage_1_dec_2015.mdl

Simulink version: 8.5 **Model version:** 1.96

System: Clutch_Eng_DEngage_1_dec_2015/AUTO_CLUTCH MODEL **Current run:** 12-Dec-2015 11:14:29

Run Summary

Pass	Fail	Warning	Not Run	Total
125	2	42	47	216

Check for blocks not recommended for MISRA-C:2004 compliance

Identify blocks that are not supported or recommended for MISRA-C:2004 compliant code generation.

Passed
Blocks that are not supported or recommended for MISRA-C:2004 compliant code generation were not found i subsystem.

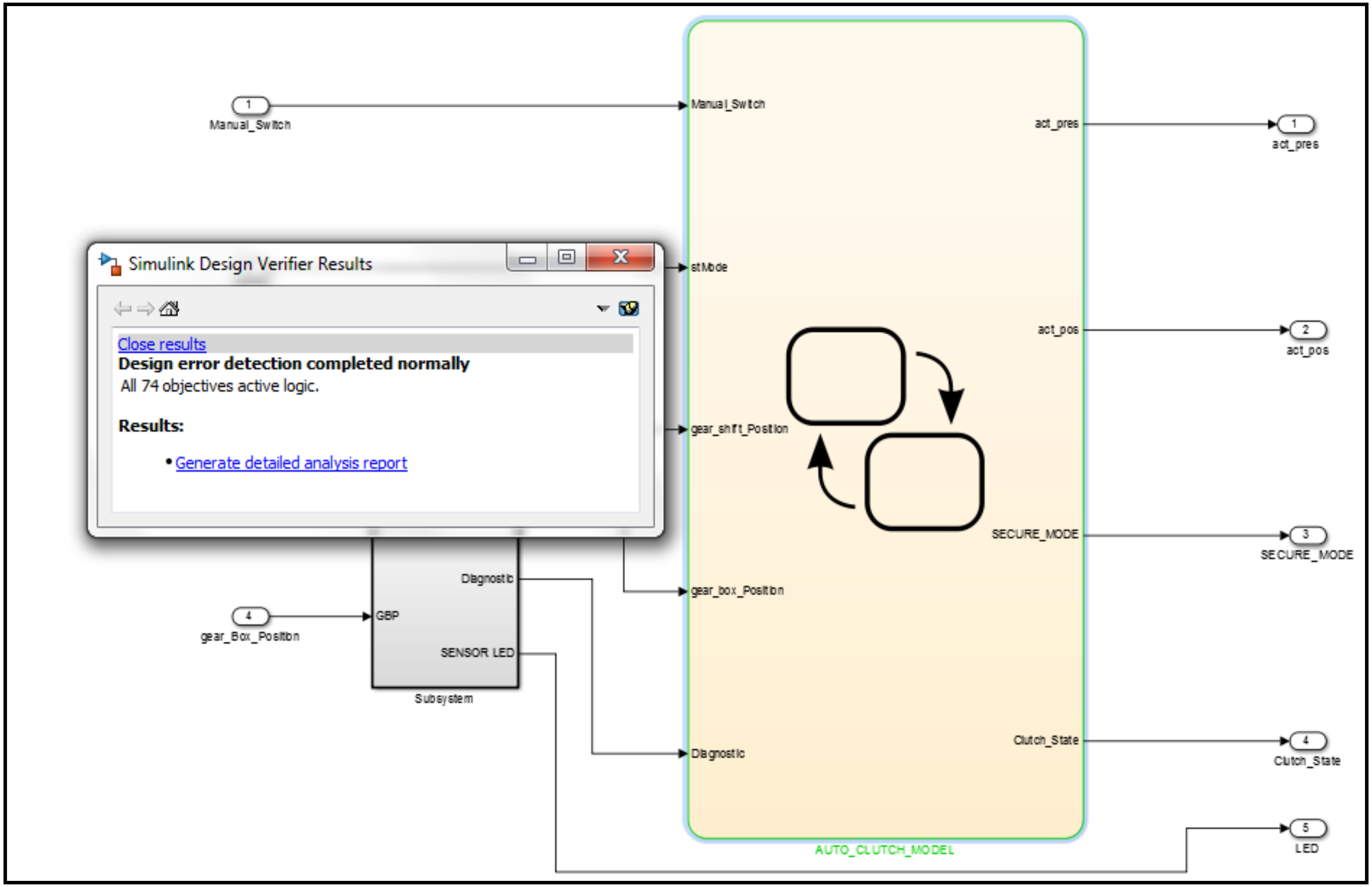
Check for Lookup Table blocks using cubic spline interpolation or extrapolation methods.

Passed
No Lookup Table blocks using cubic spline interpolation or extrapolation methods found.

Warnings are Corrected after analysis(e.g.)

- Identify signal labels that are not correct for C variable names.
- Check Simulink block or Stateflow objects that do not link to a requirement documents
- Identify mismatches between names of Stateflow ports and the associated signals.

Design verification



SLDV - Results

- Dead Logic Detection

Objectives Status	
Number of Objectives:	**98**
Dead Logic:	11
Active Logic:	87

- Division by zero

Objectives Status	
Number of Objectives:	**0**

- Integer Overflow

Objectives Status	
Number of Objectives:	**2**
Objectives Proven Valid:	1
Objectives Undecided when the Analysis was Stopped:	1

- Check Specified Intermediate Minimum and Maximum Values

Objectives Status	
Number of Objectives:	**0**

- Out of bound Array

Objectives Status	
Number of Objectives:	**0**

Model Coverage Analysis

- **Generated Input data**

Generated Input Data

Time	0-1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Step	**1-2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Manual_Switch	0	0	1	1	0	1	1	1	1	2	1	0	0	2	1	0	2	0	1	0	2	0	1
stMode	0	0	0	0	0	0	0	0	0	0	1	0	0	0.5	0	0	0	0	0	0	0.5	1	1
gear_shift_Position	0	0	3	3	0	0	3	3	3	1	1	3	1	-1	3	3	0	3	3	3	2	3	3
gear_box_Position	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diagnostic	0	1	1	0	2	0	0	1	0	2	0	0	0	1	0	0	2	1	0	0	2	0	0

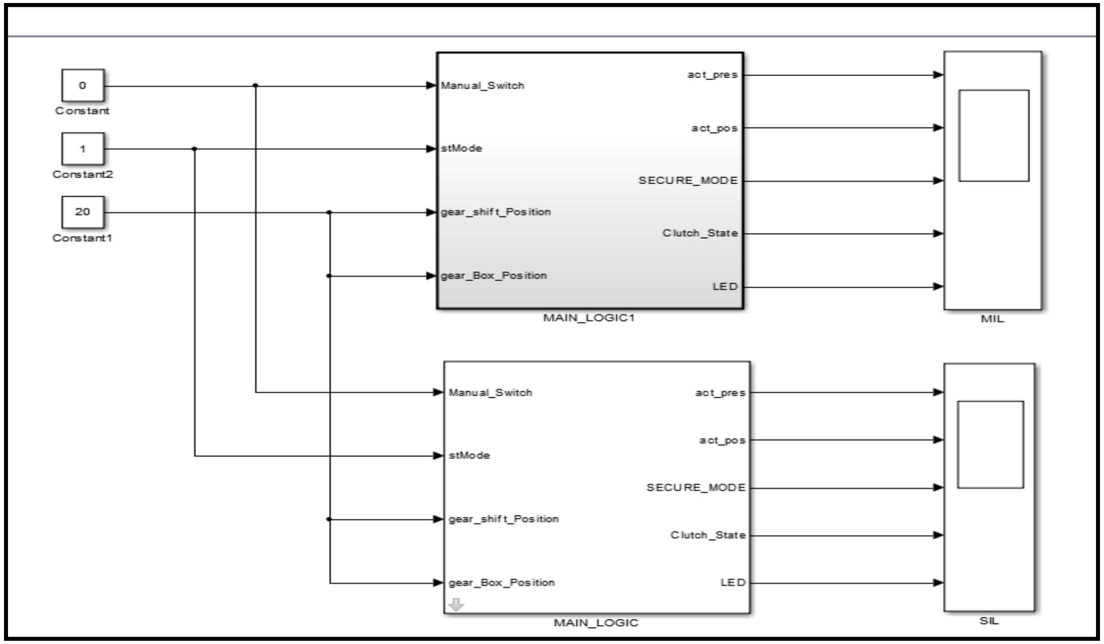
Time	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
Step	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**
Manual_Switch	0	0	0	1	0	0	2	2	0	0	0.5	2	1	0	0	0.5	2	1	0	0	0.5	2	1
stMode	0	0.5	0	0	0	0.5	0	0	0	0	1	0	0	0	0.5	0	0	1	0	0.5	0	0	0
gear_shift_Position	3	3	1	1	3	3	0	1	0	1	3	2	1	3	3	3	2	1	3	3	3	3	3
gear_box_Position	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Diagnostic	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

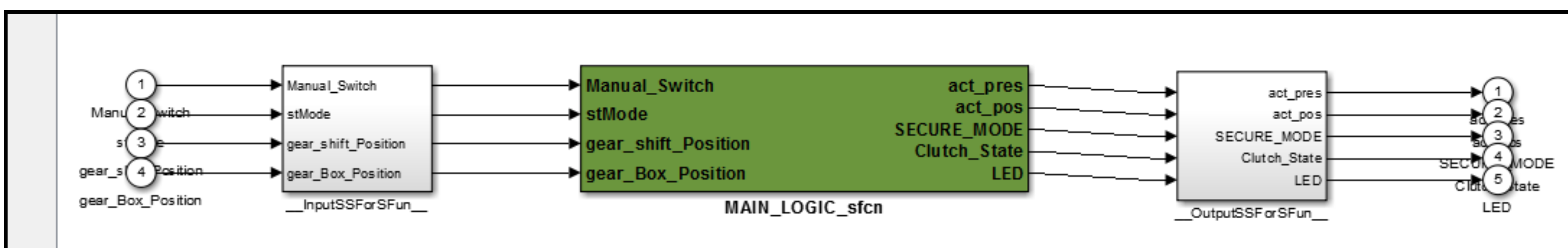
- **Coverage Report**

Model Hierarchy/Complexity:		Test 1		
		D1	C1	MCDC
AUTO_CLUTCH_MODEL5	**51**	97%	69%	38%
. . . AUTO_CLUTCH_MODEL	**50**	97%	69%	38%
. . . . . . SF: AUTO_CLUTCH_MODEL	49	97%	69%	38%
. . . . SF: MAIN_FUNCTION	46	97%	69%	38%
. . . . SF: CLUTCH_ACTUATOR_FUNCTION	32	95%	67%	33%
. . . . SF: CLTH_POSITION_MODE	16	95%	67%	33%
. . . . SF: CLTH_PRESSURE_MODE	16	95%	67%	33%

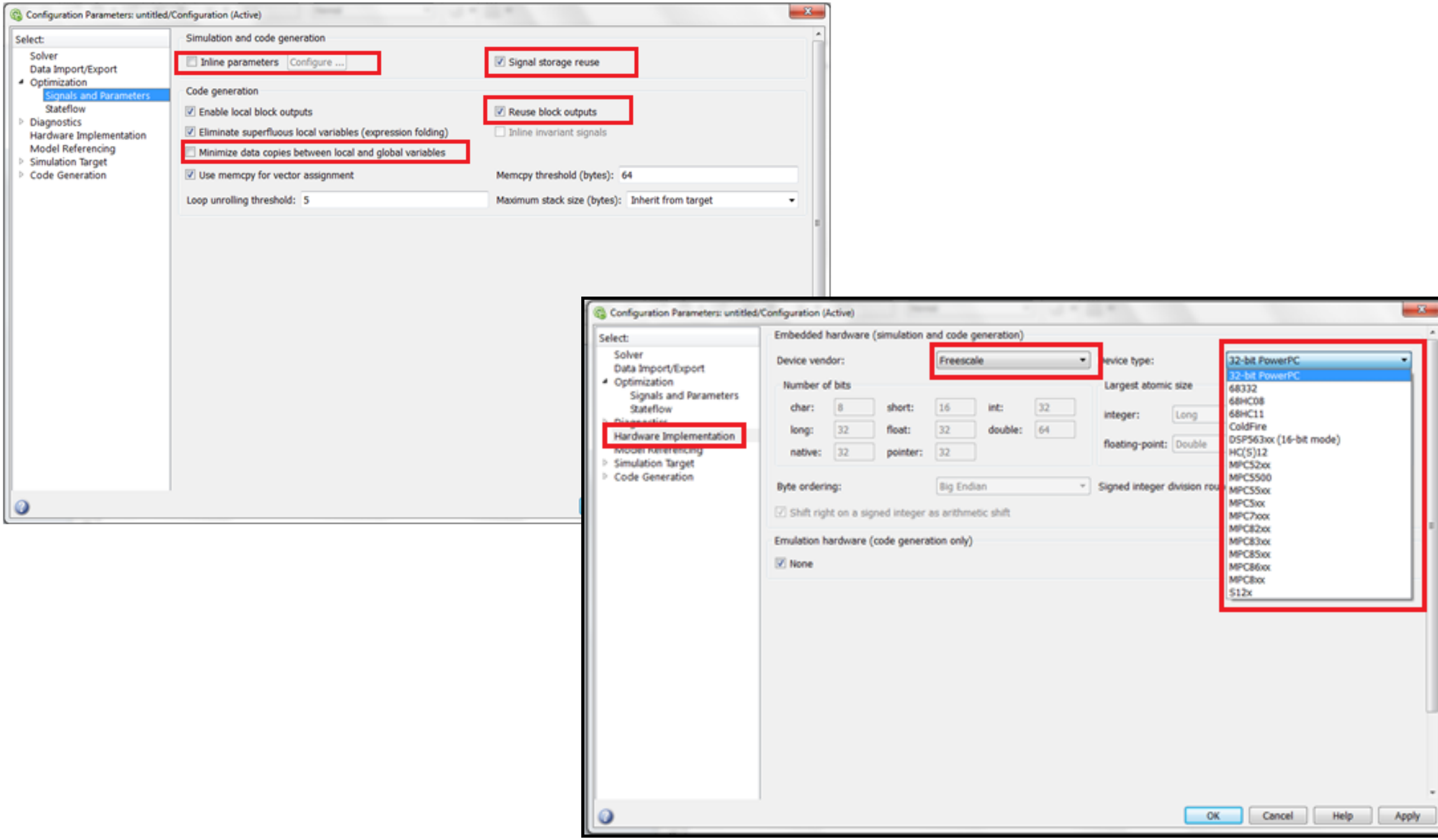
Software in Loop

- Results of SIL are compared with Model test results
- Same test cases can be used
- Test source code on development computer





Auto code Generation



Concluding points

- ✓ Automotive Electronics has become competitive necessity to stay ahead of competitors
- ✓ Increased risk of product defects due to Complex E/E architecture ,large number of ECU & seamless networking
- ✓ Test & development strategies to ensure flawless functioning of individual and all ECU's together
- ✓ Way forward is to deploy robust development process, In depth testing, V&V
- ✓ Use of qualified and proven tools & services

Thanks for your attention

Summary

- As on now, attempt is made to check proof of concept
- Require thorough checking on testbed & on vehicle to firm up control strategies
- Important benefit derived is identifying gaps while modeling and same were addressed and verified
- Evolved model around 10 times to reach final executable requirements
- Realized: Timings, State transition sequence is a key parameter to achieve synchronization
- Need to incorporate self learning & neural logic to build right control mechanism