Lund University

2022 | AUTONOMOUS DRIVING SYSTEMS- GENERATING CRITICAL DRIVING SCENARIOS FOR TESTING AUTONOMOUS EMERGENCY BRAKING SYSTEMS (AEBS).

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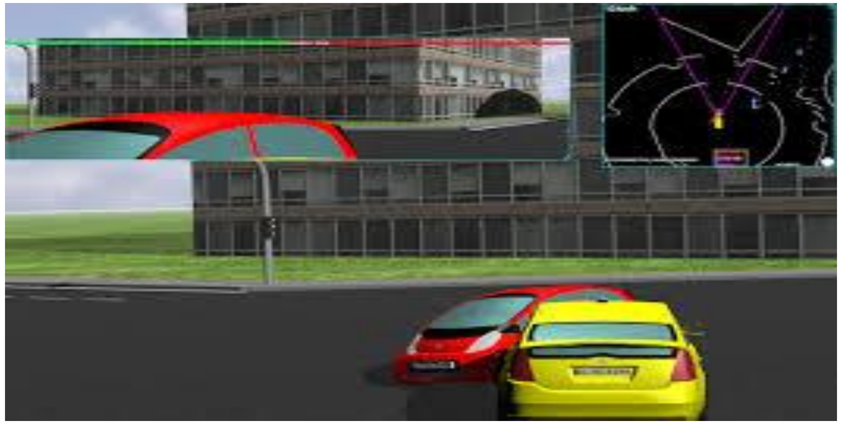
Definition of Critical Driving Scenarios (CDS)

Importance of Testing CDS

- ADAS has become increasingly popular.
- Ensure reliability and safety of ADAS.
- Discover potential defects & misbehavior in the system.
- Cover rare traffic situations. (Uber’s case in USA 2018)
- Avoid relaying on substantial real-world testing or collecting real driving data at scale.
- Regular road traffic is considered non-critical.



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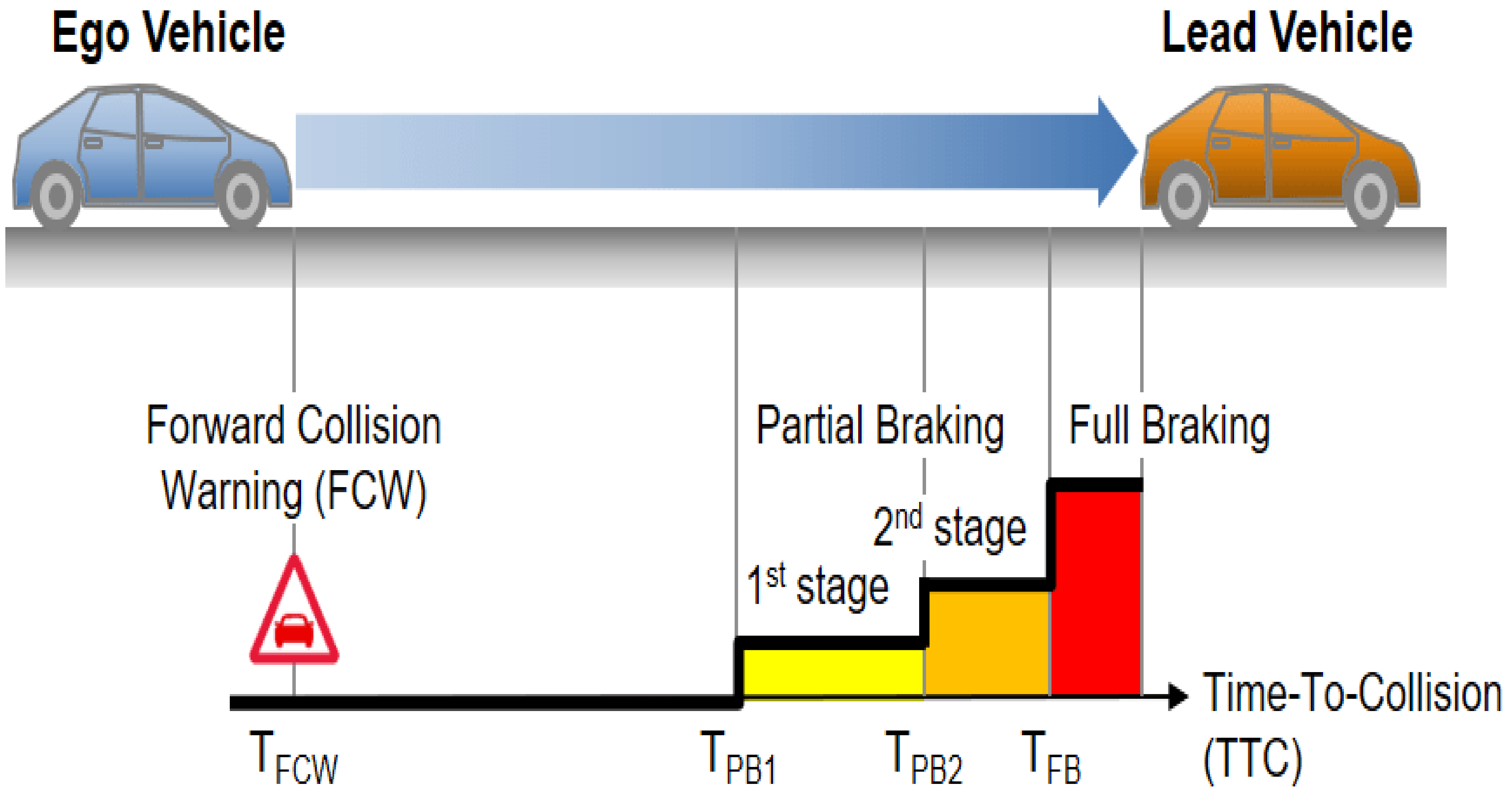
Autonomous Emergency Braking System (AEBS)



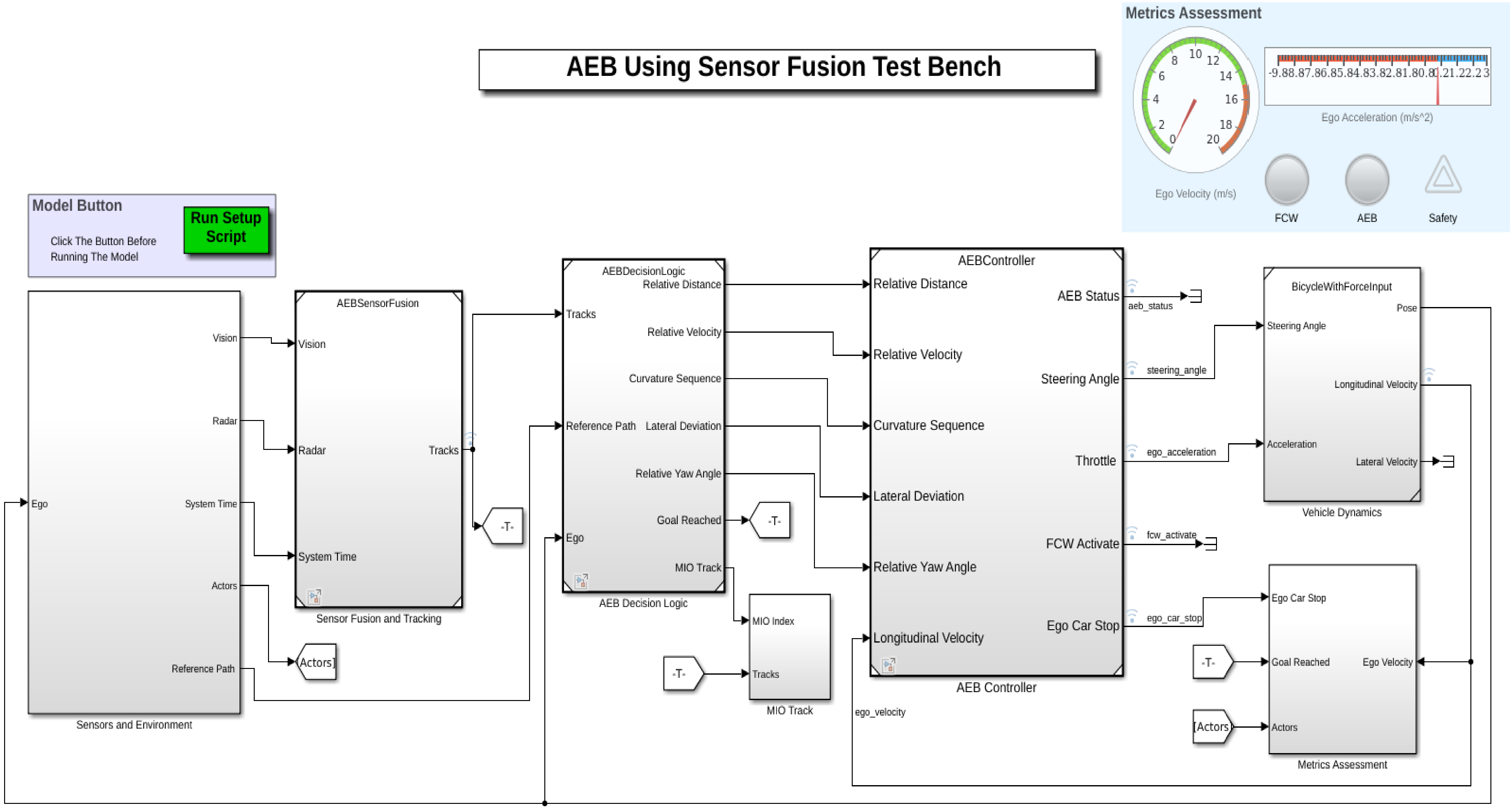
Ego Vehicle
Lead Vehicle
Forward Collision Warning (FCW)
Partial Braking
Full Braking
2nd stage
1st stage
Time-To-Collision (TTC)
T_{FCW}
T_{PB1}
T_{PB2}
T_{FB}

Methods

- Simulating AEBS
- Optimizing Critical Scenarios

Simulating AEBS:

- Using MATLAB AEBS model.
- Using AEBTestBench and a dataset consists of 26 important scenario categories from Euro NCAP.
- Using 6 sub-models each one of them based on an algorithm written in MATLAB.
- Using test requirements set.
- Using Parallel Automate Testing to increase the overall automate execution speed.



AEB Using Sensor Fusion Test Bench
Metrics Assessment
Ego Velocity (m/s)
Ego Acceleration (m/s^2)
FCW
AEB
Safety
Model Button
Run Setup Script
Click The Button Before Running The Model
Sensors and Environment
Ego
Vision
Radar
System Time
Actors
Reference Path
AEBSensorFusion
Tracks
Sensor Fusion and Tracking
AEBDecisionLogic
Relative Distance
Relative Velocity
Curvature Sequence
Lateral Deviation
Relative Yaw Angle
Goal Reached
MIO Track
AEB Decision Logic
MIO Index
MIO Track
AEBController
AEB Status
Steering Angle
Throttle
FCW Activate
Ego Car Stop
Longitudinal Velocity
AEB Controller
aeb_status
steering_angle
ego_acceleration
fcw_activate
ego_car_stop
ego_velocity
BicycleWithForceInput
Pose
Acceleration
Lateral Velocity
Vehicle Dynamics
Ego Velocity
Metrics Assessment

Demos:

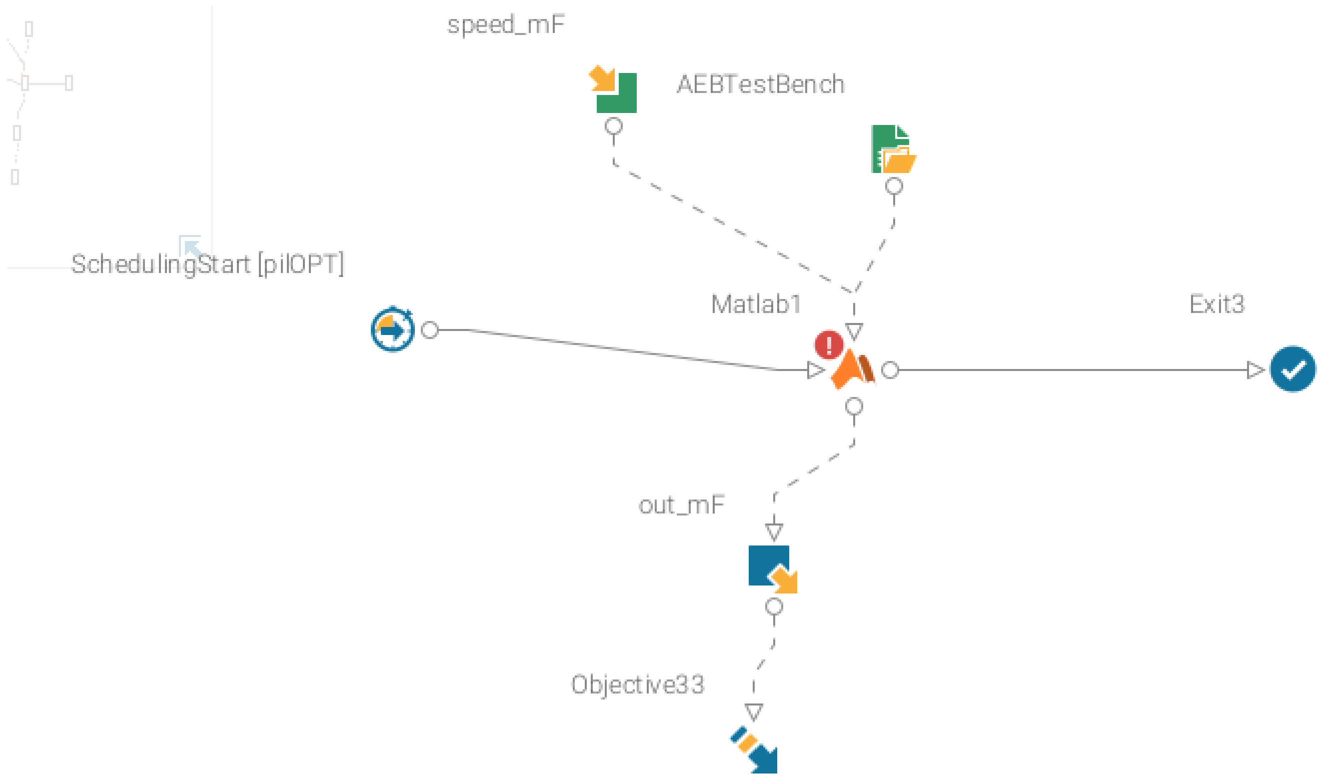
Demo of Scenario "Pedestrian_Child"
https://share.vidyard.com/watch/p3brAMW6kDhSd9x5iinYWn?

Demo of AEBS "Pedestrian_Child"
https://share.vidyard.com/watch/6S6ekdJQSgwM6ddfTzJga7?

Optimizing Critical Scenarios:

- Using modeFrontier tool.
- Using multi-strategy self-adapting algorithm that combines the advantages of local and global search, in self initializing mode, which is called pilOPT.
- Integrating MATLAB node with modeFrontier.
- Creating a workflow of different nodes.
- Define the objective as minimizing TTC while specifying upper & lower bounds for the egoVehicle's velocity as input parameters.
- Run pilOPT with 1000 evaluations.
- Plot the optimized results and define a thresh hold to get extreme CDS.

The Workflow:

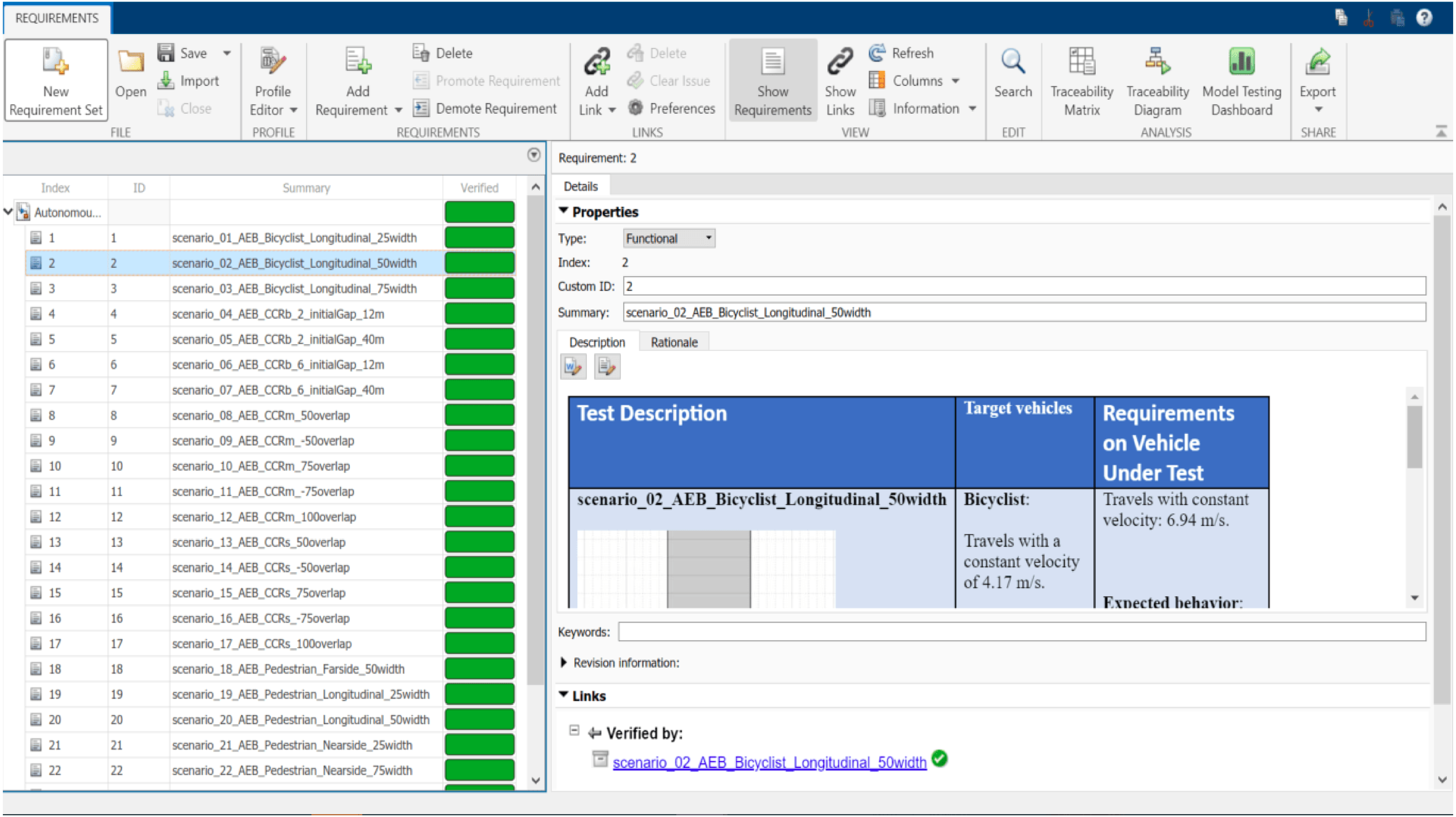


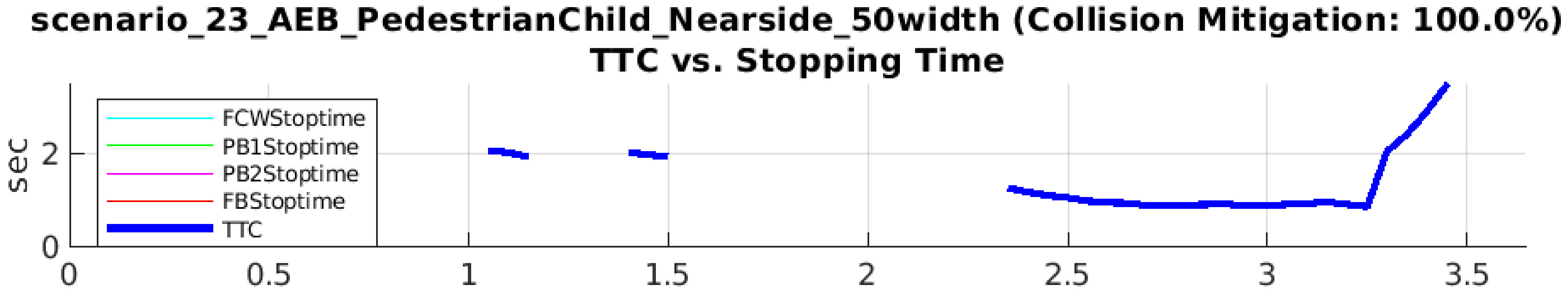
Results

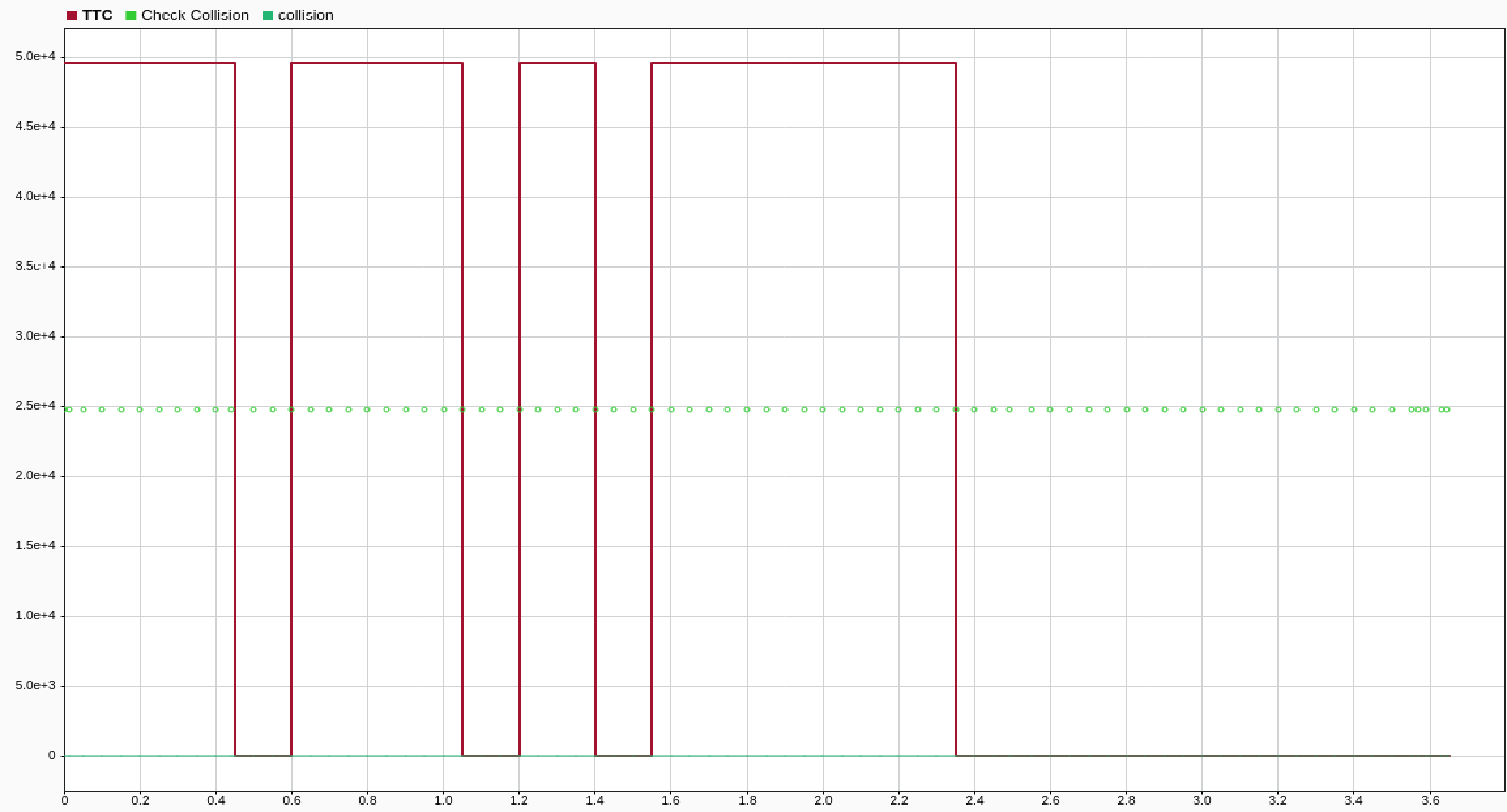
- First Phase:

1) The entire dataset, that is, the 26 CDS imported from Euro NCAP, is passed and verified by AEBS. In each one of them, the check safety goal is achieved and the collisions are mitigated.

2) All test requirements are met.


REQUIREMENTS
New Requirement Set
Open
Save
Import
Close
FILE
Profile Editor
PROFILE
Add Requirement
Delete
Promote Requirement
Demote Requirement
REQUIREMENTS
Add Link
Delete
Clear Issue
Preferences
LINKS
Show Requirements
Show Links
Refresh
Columns
Information
VIEW
Search
EDIT
Traceability Matrix
Traceability Diagram
Model Testing Dashboard
ANALYSIS
Export
SHARE
Index
ID
Summary
Verified
Autonomou...
1 1 scenario_01_AEB_Bicyclist_Longitudinal_25width
2 2 scenario_02_AEB_Bicyclist_Longitudinal_50width
3 3 scenario_03_AEB_Bicyclist_Longitudinal_75width
4 4 scenario_04_AEB_CCRb_2_initialGap_12m
5 5 scenario_05_AEB_CCRb_2_initialGap_40m
6 6 scenario_06_AEB_CCRb_6_initialGap_12m
7 7 scenario_07_AEB_CCRb_6_initialGap_40m
8 8 scenario_08_AEB_CCRm_50overlap
9 9 scenario_09_AEB_CCRm_-50overlap
10 10 scenario_10_AEB_CCRm_75overlap
11 11 scenario_11_AEB_CCRm_-75overlap
12 12 scenario_12_AEB_CCRm_100overlap
13 13 scenario_13_AEB_CCRs_50overlap
14 14 scenario_14_AEB_CCRs_-50overlap
15 15 scenario_15_AEB_CCRs_75overlap
16 16 scenario_16_AEB_CCRs_-75overlap
17 17 scenario_17_AEB_CCRs_100overlap
18 18 scenario_18_AEB_Pedestrian_Farside_50width
19 19 scenario_19_AEB_Pedestrian_Longitudinal_25width
20 20 scenario_20_AEB_Pedestrian_Longitudinal_50width
21 21 scenario_21_AEB_Pedestrian_Nearside_25width
22 22 scenario_22_AEB_Pedestrian_Nearside_75width
Requirement: 2
Details
Properties
Type: Functional
Index: 2
Custom ID: 2
Summary: scenario_02_AEB_Bicyclist_Longitudinal_50width
Description
Rationale
Test Description
Target vehicles
Requirements on Vehicle Under Test
scenario_02_AEB_Bicyclist_Longitudinal_50width
Bicyclist:
Travels with a constant velocity of 4.17 m/s.
Travels with constant velocity: 6.94 m/s.
Expected behavior:
Keywords:
Revision information:
Links
Verified by:
scenario_02_AEB_Bicyclist_Longitudinal_50width


scenario_23_AEB_PedestrianChild_Nearside_50width (Collision Mitigation: 100.0%)
TTC vs. Stopping Time
sec
0
2
0
0.5
1
1.5
2
2.5
3
3.5
FCWStoptime
PB1Stoptime
PB2Stoptime
FBStoptime
TTC



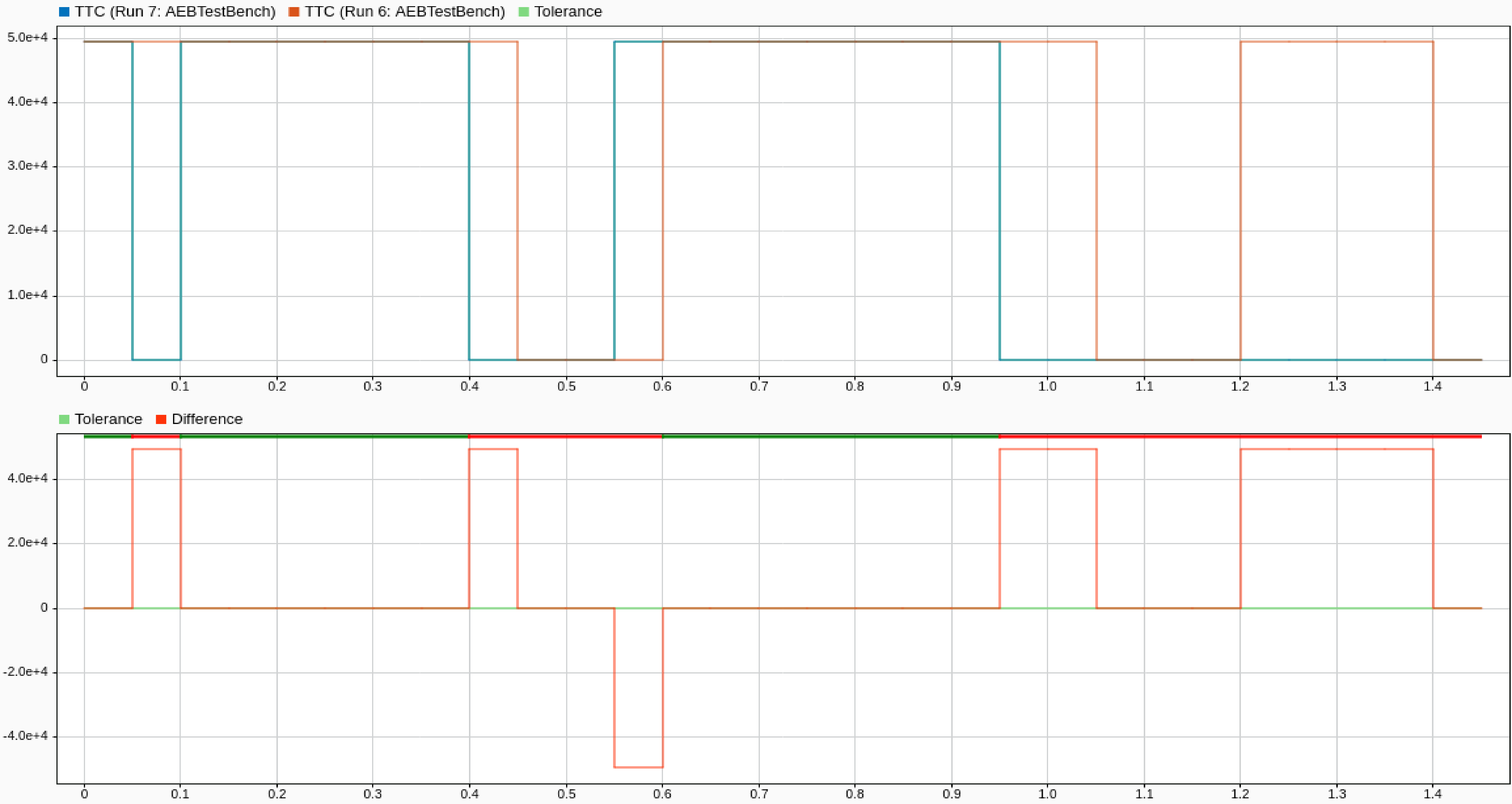
TTC
Check Collision
collision
5.0e+4
4.5e+4
4.0e+4
3.5e+4
3.0e+4
2.5e+4
2.0e+4
1.5e+4
1.0e+4
5.0e+3
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6

Results

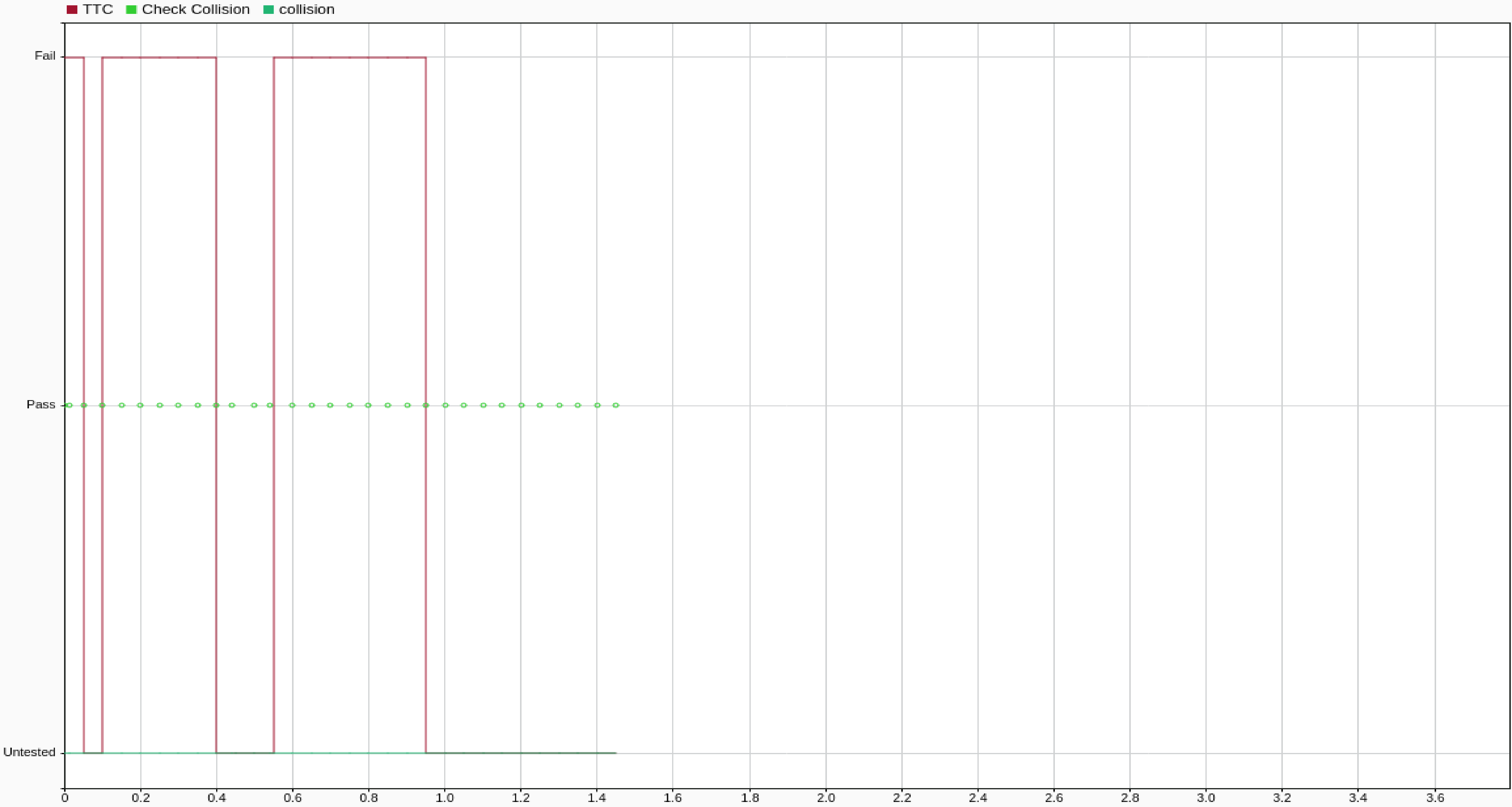
- Second Phase:

1) As part of the integration process, I discovered a bug in modeFrontier, which stuck during the simulation. I have logged the issue, reported it to modeFrontier's team, and they have confirmed it.

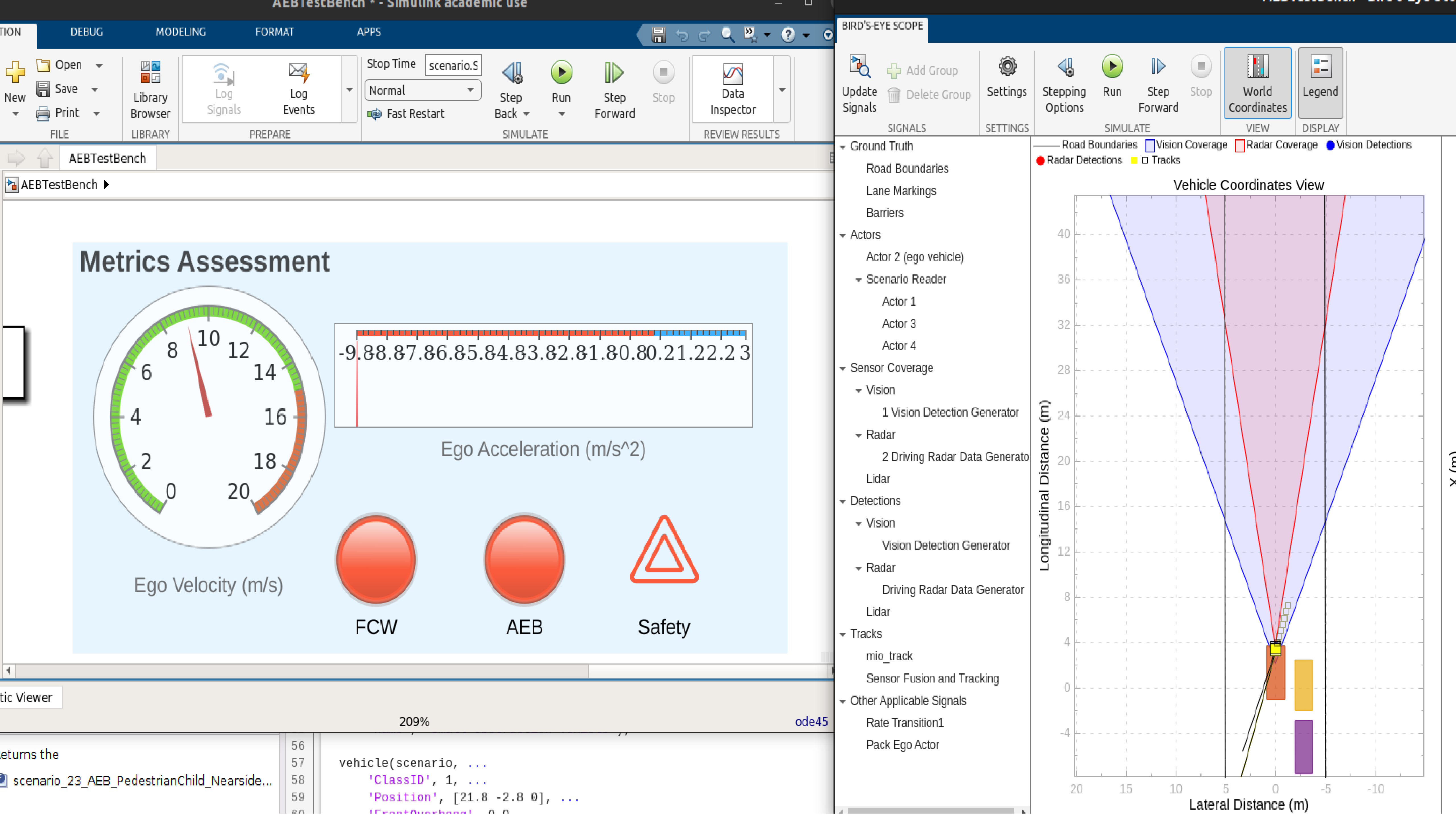
2) Due to the bug, the optimization could not be carried out as planned. However, manually checking the AEBS through manual optimization, revealed a defect in which the collision could not be mitigated, and the car collided with the pedestrian/child.



TTC (Run 7: AEBTestBench)
TTC (Run 6: AEBTestBench)
Tolerance
5.0e+4
4.0e+4
3.0e+4
2.0e+4
1.0e+4
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
Tolerance
Difference
4.0e+4
2.0e+4
0
-2.0e+4
-4.0e+4
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4



TTC
Check Collision
collision
Fail
Pass
Untested
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6


AEBTestBench * - Simulink academic use
DEBUG
MODELING
FORMAT
APPS
New
Open
Save
Print
FILE
Library Browser
LIBRARY
Log Signals
Log Events
PREPARE
Stop Time
scenario.S
Normal
Fast Restart
Step Back
Run
Step Forward
Stop
SIMULATE
Data Inspector
REVIEW RESULTS
AEBTestBench
Metrics Assessment
Ego Velocity (m/s)
Ego Acceleration (m/s^2)
FCW
AEB
Safety
209%
ode45
scenario_23_AEB_PedestrianChild_Nearside...
vehicle(scenario, ...
'ClassID', 1, ...
'Position', [21.8 -2.8 0], ...
BIRD'S-EYE SCOPE
Update Signals
Add Group
Delete Group
SIGNALS
Settings
SETTINGS
Stepping Options
Run
Step Forward
Stop
SIMULATE
World Coordinates
VIEW
Legend
DISPLAY
Ground Truth
Road Boundaries
Lane Markings
Barriers
Actors
Actor 2 (ego vehicle)
Scenario Reader
Actor 1
Actor 3
Actor 4
Sensor Coverage
Vision
1 Vision Detection Generator
Radar
2 Driving Radar Data Generato
Lidar
Detections
Vision
Vision Detection Generator
Radar
Driving Radar Data Generator
Lidar
Tracks
mio_track
Sensor Fusion and Tracking
Other Applicable Signals
Rate Transition1
Pack Ego Actor
Road Boundaries
Vision Coverage
Radar Coverage
Vision Detections
Radar Detections
Tracks
Vehicle Coordinates View
Longitudinal Distance (m)
Lateral Distance (m)

Conclusion

For autonomous vehicles, safety and reliability are essential attributes. In addition, due to the complexity of driving scenarios and the uncertainty of the operational environment, traditional requirements-driven testing approaches are impeded. Thus, it is necessary to identify the most critical scenarios for testing the autonomous driving systems and to uncover defects and misbehaviors. As we have seen in Uber's case, it is a life or death matter.

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