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Analysis of Automated Emergency Braking System to Investigate Forward Collision Condition Using Scenario-Based Virtual Assessment

Lee Kah Onn[1], Colin Rei[1], Vimal Rau Aparow[1,2*], Cheok Jun Hong[1] Alex Au Yong Lup Wai[1], Zulhaidi Mohd Jawi[3]

[1]Automated Vehicle Engineering System (AVES) Research Group,
Department of Electrical and Electronics Engineering, Faculty of Science and Engineering,
University of Nottingham Malaysia, 43500, Jalan Broga, Semenyih, Selangor, MALAYSIA

[2]Centre of Excellence for Testing & Research of Autonomous Vehicles NTU (CETRAN),
Energy Research Institute @ NTU (ERI@N). CleanTech One (CTO), 1 CleanTech Loop, 637141 SINGAPORE

[3]Malaysian Institute of Road Safety Research (MIROS), Taman Kajang Sentral, 43000 Kajang, Selangor, MALAYSIA

*Corresponding Author

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Abstract: In the recent trend of automotive technologies, active safety systems for vehicles have become one of the key elements to reduce road traffic conditions. Automated vehicles are known as one of the active safety systems to minimize road traffic congestion and unwanted road hazardous situations. Generally, automated vehicles are designed using advanced driving assistance system (ADAS) technology to enhance the safety capability of the vehicles. Moreover, automated vehicles are designed to adopt multiple scenarios with different types of traffic situations. Generally, the performance of automated vehicles is evaluated to adapt with various road conditions and different type of traffic conditions, autonomously. Nonetheless, most of the safety testing was conducted in a controlled environment and with less traffic conditions. Moreover, this technology is tested in developed countries and mostly evaluated for highway driving scenarios, with less pedestrians and motorist's road users. On the other hand, in developing countries such as Malaysia, most of the automotive researchers have initiated research related to automated vehicle based on controlled environment only. One of the primary focuses for the current automotive researchers is to reduce road accidents due to frontal collision. Thus, automated emergency braking systems have been heavily investigated by most developers to minimize road accidents. Most of the researchers analyze the system in terms of theoretical based simulation and tested using actual vehicle for physical testing. However, this type of testing is not sufficient to optimize the performance of automated emergency braking systems for developing countries. Therefore, this study focuses on scenario-based virtual assessment to evaluate the capability of autonomous vehicles using automated emergency braking system without causing road casualties with the distance range is 4.5m to 0.5m depending on vehicle speed.

Keywords: Virtual safety testing, automated emergency braking, Malaysian road and traffic environment

1. Introduction

In recent years, human population growth in most developing countries has increased the demand for using ground transportation [1][2]. This causes a bottleneck on road traffic networks, resulting in major traffic congestion in the

*Corresponding author: Vimal.Rau@nottingham.edu.my

developing countries. In these developing countries, roads are crowded with many various road users and mixed modes of transportation, and the road infrastructure and traffic are not well designed or coordinated to deal with them [3][4]. Studies have demonstrated that deployment of autonomous vehicles has a high possibility to minimize the traffic congestion by not only enhancing the traffic flow but also reducing the unwanted hazardous conditions that impact other road users [5].

Since its first introduction, AV has been beneficial for drivers around the world. According to the Insurance Institute for Highway Safety, partially autonomous technology such as, forward collision and lane departure warning systems, side view assist, and adaptive headlights will potentially prevent or mitigate crashes, and the reduction in injuries and fatalities can be up to 33% [6]. A Swedish study based on insurance claims indicated a 23% reduction of rear‐end crashes involving Volvo XC60 fitted with City Safety, while a study by the Highway Loss Data Institute in the USA showed a 20% reduction in crash involvement risk for the Volvo XC60 and 33% reduction in bodily injury liability [7]. Another study that analyzed AEB system in China also states that AEB system can greatly reduce the number of road traffic collisions by 3.12% to 7.98%, while the associated injury reduction ranges from 2.72% to 5.47% [8]. These studies prove that AV has been involved in reducing road accidents and has the potential to be involved more in the future. Other researchers also studied the Berkeley Algorithm for the forward collision avoidance system but focusing on the two-wheeler bike system which is conducted in simulation study [9].

It must be noted that deployment of an autonomous vehicle in developing countries is quite complex due to large human population and their excessive use of transportation with a lack of traffic management [1][10]. Use of vehicles has become one of the major forms of human mobility, but since it also inevitably causes major traffic congestion, an efficient traffic management system is required. Therefore, deployment of autonomous vehicles in developing countries can be one of the potential solutions since technologies of automated vehicle focus more on safety and sustainable transportation [11]. One of the main priority systems for an autonomous vehicle is automated emergency braking (AEB) system to reduce frontal collision during critical condition [12]. However, safety testing of AEB for autonomous vehicle in developing countries is one of the major challenges, given that driving conditions and pedestrian movements in these countries are not similar to those developed countries where a large part of autonomous vehicle testing is carried out. The road conditions and pedestrian movements in the developing countries differ remarkably from developed countries which creates hurdle for most of testing autonomous vehicle in developing countries.

Currently, Malaysian government is quite keen in adopting the autonomous vehicle technology as part of the new automotive policy in Malaysia [13]. Several government agencies such as Futurise Sdn Bhd, Malaysian Automotive, Robotics and IoT Institute (MARii), MRANTI are exploring the possibilities to initiative the autonomous vehicle technology to be deployed in Malaysia. Recently, Futurise has published "Guidelines for Public Road Trials of Autonomous Vehicle" with support from Ministry of Transport which is emphasizing the autonomous vehicle trial procedures, testing requirement location for testing and reporting process. However, several challenges have been identified for testing and deployment of autonomous vehicles in Malaysia, as stated by Futurise, Malaysia. The major challenges highlighted by Futurise are focusing on the open road physical testing and regulations [14]. Even though certain regulation is currently in place, there are no published document focusing on safety testing frameworks for autonomous vehicles in Malaysia that analyze avoidance of frontal collision.

It can be noted that the initiatives from Malaysian government, government agencies, local startup companies and universities show that Malaysia is already moving forward towards the deployment and testing of autonomous vehicles. Nevertheless, an appropriate safety testing framework is required to evaluate the capability of automated vehicle technologies such as the automated emergency vehicle (AEB) before proceeding to on-road testing. Moreover, various type of test cases referring to Malaysian road and traffic conditions need to be evaluated before the on-road testing. Therefore, an adequate safety testing procedure is designed in this study using virtual simulation testing to evaluate the performance of AEB system. The testing procedure is designed by integrating several aspects such as data collection from actual scenarios in Malaysia, scenario identification and classification based on severity level, test cases development, configuration of vehicle models, virtual environment models, traffic models and control algorithms which is automated emergency braking. The detailed testing procedure and analysis of the automated emergency braking system is discussed in the next section.

2. Virtual Safety Testing Procedure for Automated Emergency Braking System

In order to evaluate the performance of the automated emergency braking system, virtual safety assessment framework as shown in Figure 1 is developed for the scenario-based testing. The virtual safety testing framework is developed mainly to evaluate the performance of autonomous vehicle based on advanced driving assistance system (ADAS) using various scenario based on Malaysian road and traffic environment. In this safety assessment framework, several criteria need to be completed before conducting the virtual safety testing. For the initial work, scenario identification needs to be completed by collecting the video footage from the dashcams. Then, the scenarios are analyzed based on dashcam videos and classified based on different categories and referred to as "test case". Based on the video footage, the road networks will be identified and developed in the virtual simulation tool, which is referred to the second stage development process. Once the virtual environment such as road model is developed, the static and dynamic objects are defined in the road model and configured the routes for the dynamic obstacles for the virtual safety testing, identical to real scenarios. The next stage will be the development of vehicle model based on actual vehicle that used in the real testing which includes the component level details such as powertrain, steering and brake as well as sensors configuration for perception analysis. The final stage will be focusing on the development of collision avoidance algorithms such as the automated emergency braking and adaptive cruise controllers (the longitudinal controllers) as part of the autonomous vehicle controller design. The integrated controller of both AEB and ACC, which is known as part of ADAS technology, are used as the rear-end/frontal collision avoidance system for various test cases in virtual environment model.

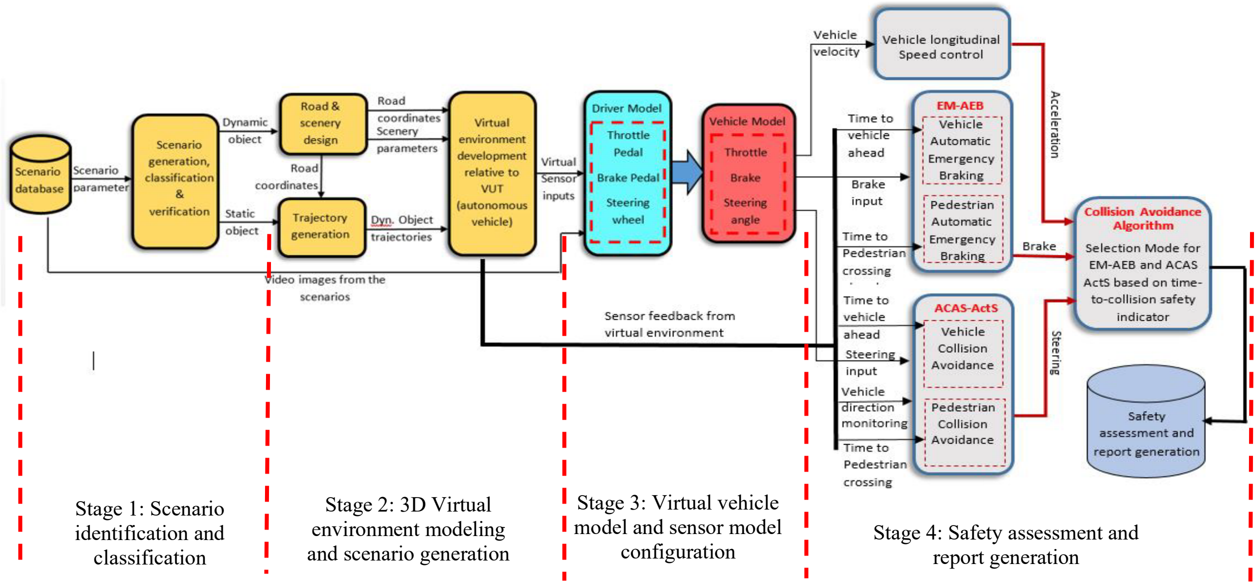

Fig. 1 - Virtual safety assessment framework for ACC and AEB

2.1 Scenario Identification and Classification

In order to conduct the simulation testing, relevant scenarios from Malaysian road and traffic environment are required. The scenarios are required to identify the traffic objects such as dynamic objects (pedestrians, motorbike and vehicles) and static objects (sign board, road marker, traffic lights and etc.). In order to obtain the information, data recording from actual environment is required in this research. Thus, an instrument vehicle is designed using the system architecture as shown in Figure 2 for data collection from multiple sensors as shown in Figure 3. The instrumented vehicle is equipped with multiple camera sensors (front, rear and side views), pedal sensors, steering angle sensors, IMU sensor, GPS sensor and data acquisition board (acting as Host PC for data collection). The relevant information will be used to develop the virtual environment and integrated with vehicle models integrated with sensor models and control algorithm as well traffic modules.

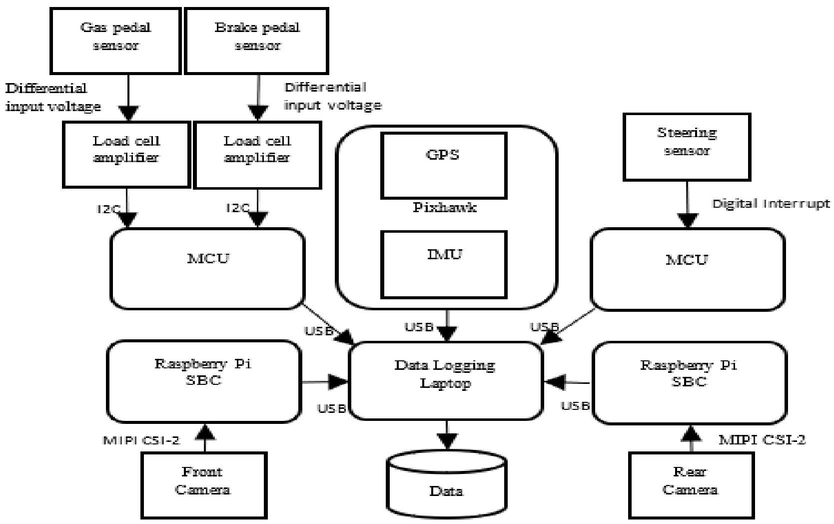

Fig. 2 - System architecture of data acquisition system [15]

Fig. 3 - System configuration of instrumented vehicle for data collection [15]

On the other hand, the critical scenarios which cannot be identified through the online video resources referring to Malaysian road scenarios. The data collection of test material is obtained through online sources due to the risk for the driver to collect high hazard scenarios. Data collection was done via YouTube compilation videos of traffic scenarios in Malaysian road environments. The videos collected from the instrumented vehicle and online sources are then edited into separate scenarios from the compilation. These scenarios are compiled and categorized as "Malaysian Road Scenarios Database" which is referred as scenario database in creating the virtual simulation test cases. This video inputs and sensor inputs data are classified into three sub- scenarios which is emphasizing on vehicle driving direction (moving straight, left turn and right turn), vehicle speed (High speed, medium speed and low speed) and traffic light conditions (signalized and unsignalized). In term of location, each of the scenarios are mapped to different location such as:

i. Bridge
ii. Highway
iii. Intersection
iv. Junction
v. Outskirt road
vi. Mountain path
vii. Parking lot
viii. Roundabout
ix. Secondary road
x. T-junction
xi. Toll gate
xii. Village road
xiii. Y-junction

Then, each scenario is mapped to different actors for each sub-scenario focusing on direction, speed and signalized or unsignalized. Other than that, each sub-scenario also mapped into day or night conditions and whether conditions referring to Malaysia. The actors can be classified into various category such as:

i. Pedestrian
ii. Animals
iii. Bicycle
iv. Bus
v. Car
vi. Motorcycle
vii. Van
viii. Truck
ix. Tanker

For each mapped scenario with location, actor, day/night and whether conditions, the variation for each scenario is identified based on the actor's response from the video inputs and data collected from the sensors. Based on the actor responses, an expected behavior characteristic has been identified to minimize road accidents. All the mapping was conducted in terms of qualitative analysis for the first layer of scenario identification and classification. The overall framework analysis is tabulated in Figure 4. Based on the scenario identification and classification, the video footage has been analyzed and classified as shown in Figures 5 to 8. Based on the recorded video stream data, the simulation environment is developed in Scenario Editor using the virtual simulation platform called IPG CarMaker. Traffic information such as the dynamic and static objects are included in the simulation analysis to re-create similar traffic conditions with actual scenario [17] [18].

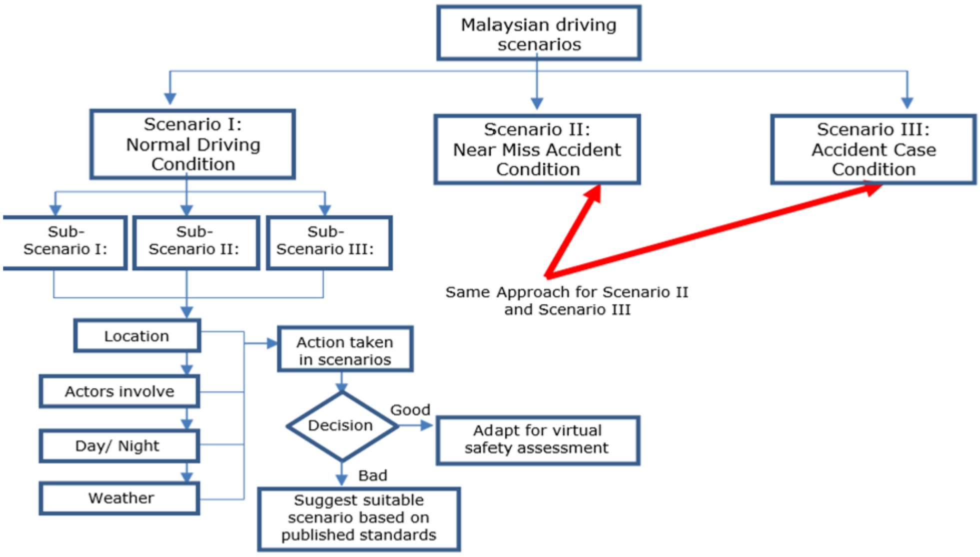

Fig. 4 - Framework analysis for the scenario identification and classification for autonomous vehicle safety testing [16]

Fig. 5 - Scenario 1: signalized junction

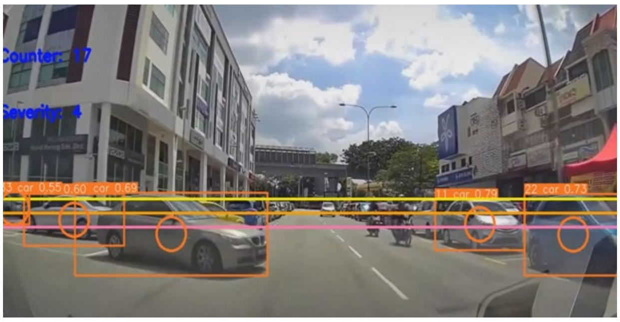

Fig. 6 - Scenario 2: Vehicle crossing unsignalized

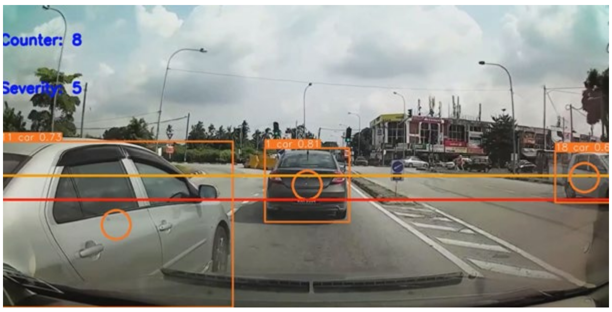

Fig. 7 - Scenario 3: traffic vehicle cut-in

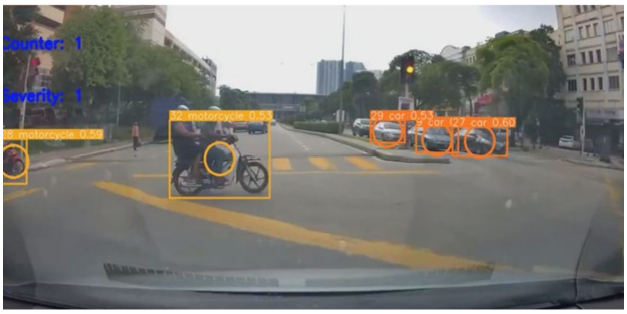

Fig. 8 - Scenario 4: motorist crossing unsignalized

2.2 Creation of Virtual Environment Model Based on Malaysian Road

The methodology for this study is developing the test scenarios and simulating it inside the IPG Carmaker software to assess the AEB system. Scenario generation is developed inside IPG Carmaker with the scenario/road function. Mitsubishi iMiEV vehicle model is used as the desired vehicle model in simulation and the parameters is developed inside the car parameter function. The test scenarios are developed based on standard regulations, such as Euro NCAP [20], ASEAN NCAP, CTU-C, NHTSA Test [21], Europe Commission Test, and previous study from [6]. These test scenarios are referred as the benchmark in creation of the scenario framework and test cases for Malaysia road environment. The selected map for this study is located in Kajang, Malaysia and the intended route starts from KTM Kajang station to McDonald's Kajang Perdana DT. This map is selected because the route covers both urban roads and highway road. The urban road covers the KTM Kajang station road to the intersection that led to the entrance of the highway. It was chosen because it is a busy road on a regular day basis. It has many intersections, crosswalks, and bus stop that can be useful to the generation of test scenarios around the area which covers most of the edge test cases that happen in Kalng Valey area. The highway road covers the end of the urban road until the round flyovers near McDonald's Kajang Perdana DT. This route was chosen because it has a lot of elements that can be useful to test scenarios such as intersections, flyovers, and toll gates. Figures 9 and 10 show the intended route of Kajang map in Maps and IPG Carmaker.

The scenario/road function in IPG Carmaker helps on recreating the intended route of Kajang map. Using the Background tool, road pictures can be inserted inside the function. The road pictures are the references for the length of the road, road curves, and sceneries. Using the Road and Accessories tool, the road curves, road markings, traffic barriers, trees, and buildings from the road pictures can be recreated. Variations of routes are created using the Traffic tool. Road elevation is one of the key elements for Kajang map. There are some parts of the road that need more elevation. The urban road is considered to be the datum for the road elevation. At the end of the urban road, a 10 meters elevation is needed since the end of the urban road is the intersection that leads to the entrance of a higher elevated highway road. The highway road elevation goes higher, and its elevation is up until 67 meters at the end of the road. The flyover near the start of the highway road is elevated 4 meters higher than the highway road, while the round flyover elevation is about 10 meters.

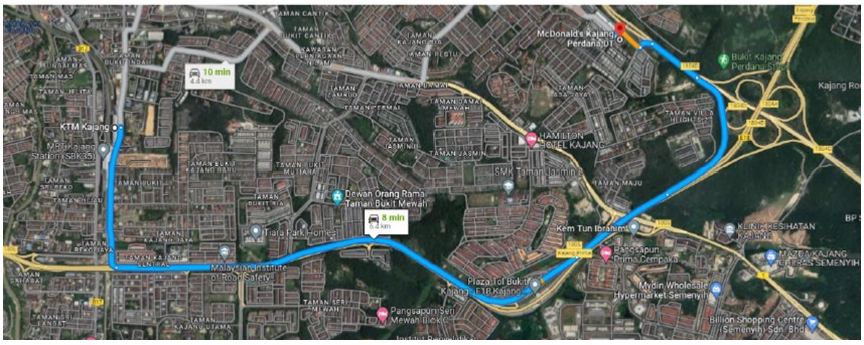

Fig. 9 - Kajang map in Google Maps

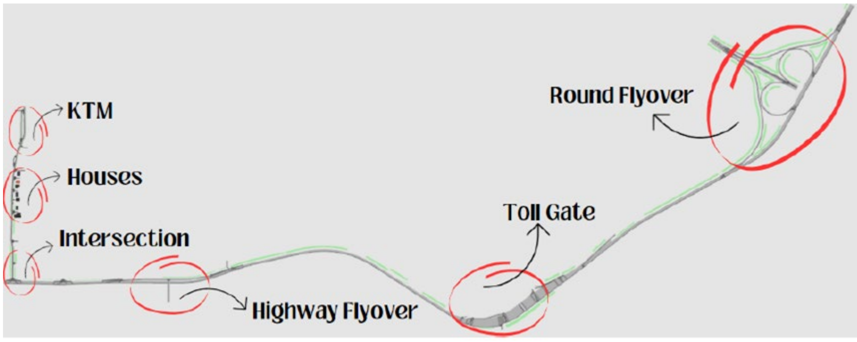

Fig. 10 - Kajang map in IPG CarMaker

2.3 Creation of Virtual Vehicle Model in IPG CarMaker

In the development procedure of the autonomous vehicle (AV), the development of vehicle model, parameters configuration according to the actual vehicle design and validation of the vehicle model is essential. The vehicle model needs to represent the actual vehicle configuration to ensure that model accuracy and behavior responses after implementing the autonomous driving system (ADS) in the vehicle. This section describes in detail the process of the development of the vehicle model. For the test case simulation in 3D virtual environment, the Mitsubishi IMiEV vehicle model has been used for the testing purpose as shown in Figure 11. The 3D design can be downloaded via open source or purchased online. The 3D models need to be updated by adjusting the colors, logos and vehicle lighting effect. Also, the tire model from the vehicle 3D model needs to be removed and uploaded separately in IPG CarMaker as shown in Figure 12. This is mainly because tires play an important role in translating the electric power source to the rotational motion to drive the vehicle on the road in both lateral and longitudinal direction.

Then, the 3D model is uploaded in IPG CarMaker and calibrated according to the dimensions and detail configuration of the chassis design. The sample configuration defined in IPG CarMaker is shown in Figure 13. The configuration mainly focusing on the alignment of the vehicle model in the IPG CarMaker virtual environment, using the reference coordinate of the Malaysian road model. Then, the vehicle 3D model is adjusted in terms of suspension profile, electric motor and braking system, rack and pinion steering system of the actual vehicle based on the parameter given by the third-party manufacturers and via validation analysis. Since this vehicle is designed using a single motor to operate the vehicle using basic hydraulic brake system with rack and pinion steering system, the virtual 3D model is configured using a similar configuration. The configuration of the powertrain model using electrical power source is shown in Figure 14.

Based on the configuration, the IMiEV vehicle model is established in IPG CarMaker as shown in Figure 15. However, the configured IMiEV vehicle model needs to be validated with the actual IMiEV vehicle in order to ensure the accuracy of the vehicle behavior in lateral and longitudinal direction. Therefore, an actual IMiEV vehicle is used as an instrumented vehicle for the validation process based on SAE testing standards for lateral and longitudinal direction. Once the vehicle model is validated with the actual vehicle, then the vehicle model is used as an "ego-vehicle" for the virtual test case with ADAS system (AEB and ACC) configuration.

Fig. 11 - Actual vehicle IMiEV

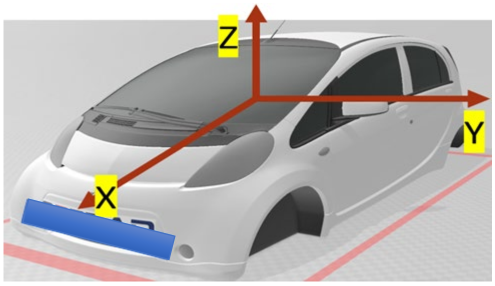

Fig. 12 - 3D vehicle of IMiEV (Body Design)

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FileCreator = CarMaker 10.2.1


## Assembly ##############################################################

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Description:
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        FileCreator CarMaker/Vehicle Data Set Generator 2023-01-09 19:46:28
        driveline front drive
        engine power 72.0 kW (98 PS) at 4900.0 rpm
        max. torque 175.0 Nm at 2750.0 rpm
        unloaded weight 1085.0 kg
        length x width x height 3475.0 mm x 1475.0 mm x 1610.0 mm
        wheel base 2550.0 mm
        track width front 1310.0 mm
        track width rear 1720.0 mm
        rear overhang 425.0 mm
        tire 175/55 R15

Eng.Kind = Rigid
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Eng.Orientation = 0.0 0.0 0.0

Hitch.System =
Hitch.pos = -0.1 0.0 0.4
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Jack.fr.pos = 2.583 -0.652 0.261
Jack.rl.pos = 0.817 0.854 0.261
Jack.rr.pos = 0.817 -0.854 0.261
Virtual.PoA = 0.0 0.0 0.0
```

Fig. 13 - Configuration of 3D vehicle model in IPG CarMaker

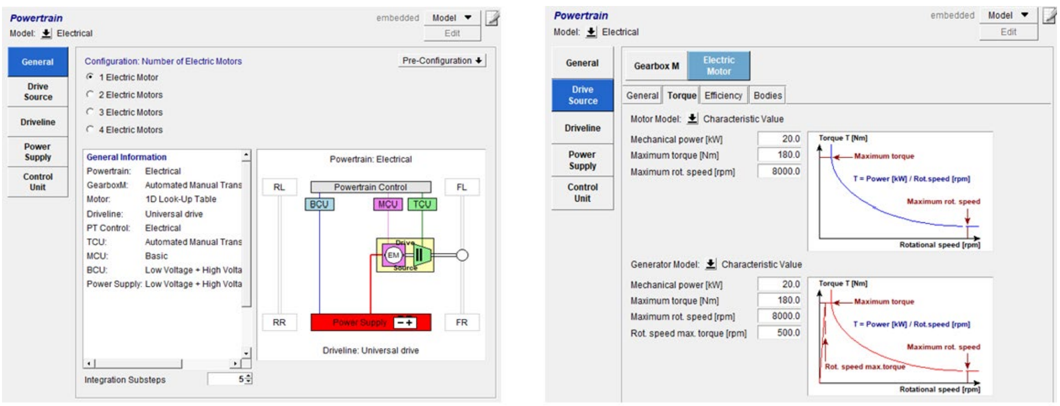


Fig. 14 - The power source configuration for IMiEV a. Single electric power source b. Torque and RPM Requirements

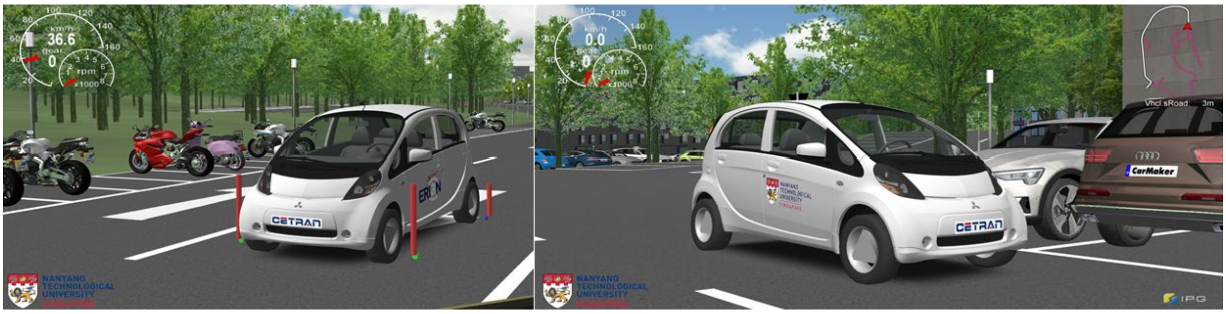


Fig. 15 - Mitsubishi IMiEV vehicle 3D model used in the simulation as "ego-vehicle".

2.4 Control Algorithm for Adaptive Cruise Control and Automated Emergency Braking System

This section describes about the driver profile which is required for an autonomous vehicle to travel on the defined road network using the route created in Scenario editor. Both lateral and longitudinal controllers were explored to implement the speed control using Adaptive Cruise Control (ACC), vehicle distance control using Autonomous Emergency Braking (AEB), lane keeping using Lane Keeping Assistance System (LKAS) and evasive maneuver using Autonomous Emergency Steering (AES) system. These algorithms are basically falls under the advance driving assistance systems (ADAS) which is used as autonomous driving systems (ADS) for the simulation testing as shown in Figure 16. However, in this study, the main focus will be on the application of AEB algorithm to evaluate the performance of the vehicle for various test cases. The required acceleration of the ego vehicle in ACC algorithm is obtained by using equation (1). The algorithm of the AEB was designed along with the ACC using Simulink model. Simulink coder interface was used in this study to implement the developed algorithm as vehicle control plug-in model.

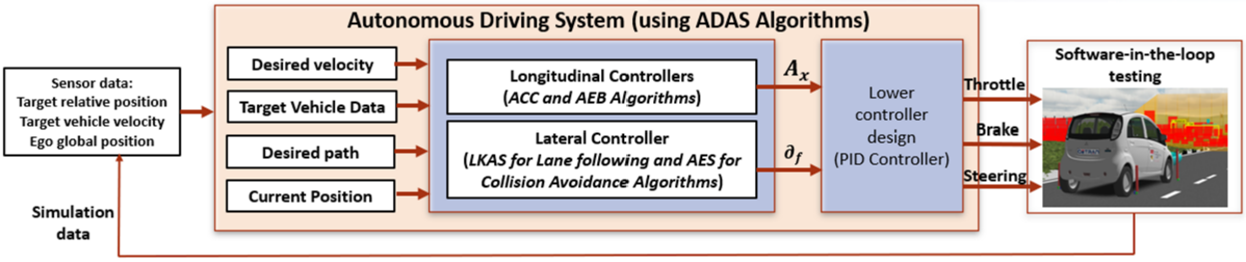


Fig. 16 - Overall configuration of the autonomous driving system using IPG CarMaker

In the ACC/AEB algorithm, the brake and gas parameters are the main concern to halt the ego vehicle. In the algorithm, there are subsystems including Sensor, User Input, ACC/AEB Control and AccelCtrl in ACC/AEB block. The Sensor subsystem is used to provide the data collected from the sensor and the User Input subsystem contains the brake input from the driver. Meanwhile, the ACC/AEB enabled block contains the logic of the controller and AccelCtrl subsystem contains the P-I controller which controls the desired acceleration of the system as shown in Figure 17. The time-to-collision (TTC) is calculated in the algorithm by using the data collected from the sensor to decide the switching between ACC and AEB which is revealed in equation (2).

$$desired\ a_x = \frac{(target.ds - desired\ distance)}{kd} + \frac{target.dv}{kv} \tag{1}$$

which a_x is the acceleration, $target.ds$ is the distance to the target, *kd* is the distance gain, $target.dv$ is the difference with the velocity of target and *kv* is the velocity gain.

$$TTC = -\frac{d_{rel}}{v_{rel}} \tag{2}$$

which d_{rel} is the relative distance and v_{rel} is the relative velocity between the ego vehicle and the target object. In sensor model configuration of the virtual simulation platform, there is a sensor subsystem which radar and object sensors model that are used to detect the obstacle. Moreover, the relative distance between the ego vehicle and the target object are evaluated in this system. Besides, the relative velocity of the target object also evaluated in this system. These quantities are applied for the calculation of the desired acceleration of the vehicle which can be used to control the gas and brake pedals.

In Distance Control Algorithm subsystem, ACC and AEB logics are used to control the acceleration of the vehicle. Based on ACC algorithm, the desired distance is required to be compared with the actual distance with a gain parameter (*kd*) for the distance controller and sum it with the target velocity with *kv* gain. These quantities are then merged into one acceleration value with limit between -2.5m^2/s to 1m^2/s. The desired acceleration calculated is the output of ACC subsystem. In AEB mode, there are two types of braking which are partial braking and full braking can be applied. The ACC is switched to AEB and the desired acceleration will be -3.5m^2/s, which partial braking is applied when the TTC is below 2.4s. If the TTC goes below 1s, the full braking is required and so the desired deceleration increases to 9.5m^2/s. The deceleration values of AEB are selected based on the rates provided by NHTSA technical paper and other studies [19]. The maximum acceleration/deceleration rates were illustrated in Table 1. For the AccelCtrl subsystem, it is created to control the desired acceleration of the vehicle and convert it into the value of the gas or brake required to assist the driver. In this situation, the PI controller is used to provide control to the actual acceleration to reach the desired acceleration with the minimal delay and overshoot. The values of proportional gain and integral gain are both 0.001 which are the default values used by virtual simulation platform.

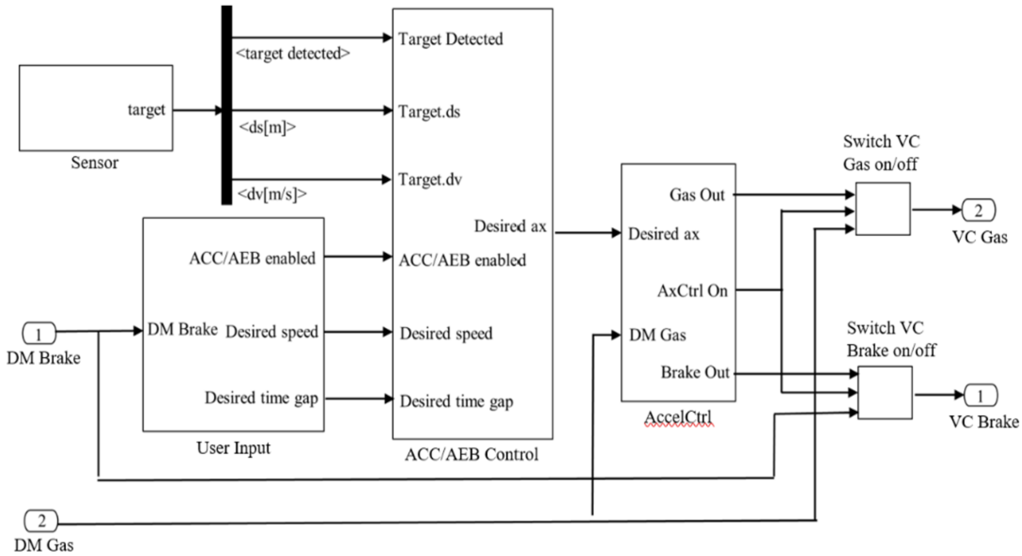


Fig 17 - Simulink ACC/AEB subsystem

Table 1 - ACC and AEB acceleration/deceleration rates

Specifications	ACC	AEB	
Maximum deceleration [m^2/s]	-2.5	TTC ≤ 2.4s	-3.5
		TTC ≤ 1s	-9.5
Maximum acceleration [m^2/s]	1		

3. Simulation Results and Discussion

The Severity rating of each test scenario is determined by the initial ego vehicle and traffic vehicle's speed. The Controllability rating of each test scenario is determined by the average values of deceleration, distance to traffic vehicle, TTC, and ego vehicle speed when the AEB system is active. The Exposure rating is always at E4 because these test scenarios can be experienced daily by the Malaysian drivers. Combining all of these ratings, the ASIL classification system level can be determined [22]. Table 2 shows the ASIL classification system of the toll gate traffic scenario while Table 3 shows the ASIL classification system of the traffic scenario.

3.1 Euro NCAP: CCRs - Toll Gate Traffic

The toll gate traffic scenario is determined by ego-vehicle approaching a traffic vehicle that stops at the toll gate at the speed of 50 km/h, 60 km/h, 70 km/h, and 80 km/h. The traffic vehicle speed is considered 0 km/h during the start of simulation. Table 4 shows the average simulation result values for the toll gate traffic scenario. Figures 16 to 19. show the overall simulation results values for each ego-vehicle speed. Figures 18 until 21 show that the ego-vehicle speed is decreasing as the distance between ego-vehicle and traffic vehicle decreases. The AEB system is active during the decreasing ego-vehicle speed. The desired deceleration takes control of the ego-vehicle acceleration when the AEB system is active. This is affecting the speed differences between ego-vehicle and traffic vehicle as the ego-vehicle speed decreases to match the traffic vehicle's speed as shown in Figures 18 until 21. The AEB system in this scenario is consistent too. Table 4.1. shows that the average distance between ego-vehicle and traffic vehicle for all of the ego-vehicle speeds are almost the same. The average TTC for all ego-vehicle speeds is really high. The average ego-vehicle speed for all ego-vehicle speeds is 0 km/h. Figures 18 to 21 show that there are no collisions between the ego-vehicle and traffic vehicle. These can be seen in the distance between ego-vehicle and traffic vehicle, which always in the positive values. Figure 22 shows the 3D simulated toll gate traffic scenario using IPG CarMaker. By using the initial conditions of the toll gate traffic scenario, the Severity ratings for all of the various ego-vehicle's speeds are the same, which is S1. The Controllability ratings are determined by the average simulation results values. The Controllability ratings for all of the various ego-vehicle's speeds are the same, which is C1. Combining all the ratings, the ASIL classification system level for all ego-vehicle speeds is the same, which is level QM.

Table 2 - CCRs - Toll gate traffic ASIL classification system

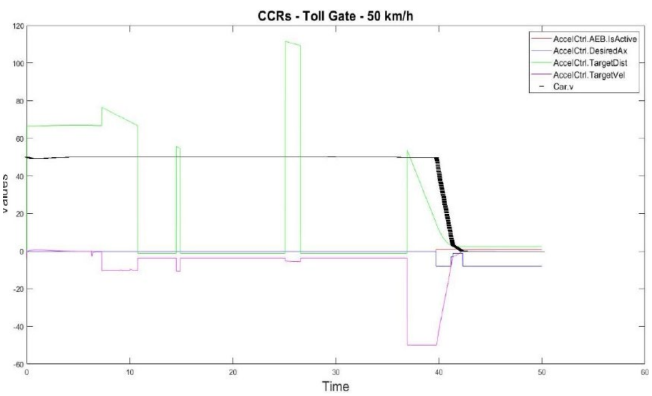
Test Scenario	VUT Speed (km/h)	Severity	Exposure	Controllability	ASIL Classification System
CCRs - Toll Gate Traffic	50	S1	E4	C1	QM
	60	S1	E4	C1	QM
	70	S1	E4	C1	QM
	80	S1	E4	C1	QM

Table 3 - Cut out traffic ASIL classification system

Test Scenario	VUT Speed (km/h)	Severity	Exposure	Controllability	ASIL Classification System
Cut Out - Traffic	30	S1	E4	C2	A
	40	S1	E4	C1	QM
	50	S1	E4	C1	QM

Table 4 - CCRs - Toll gate traffic average simulation results values

VUT Speed (km/h)	TV Speed (km/h)	Deceleration Average (g)	Target Distance Average (meters)	TTC Average (seconds)	Car Speed Average (km/h)
50	0	0.8155	2.4774	115,890	0
60	0	0.8155	2.5087	433,040	0
70	0	0.8155	2.9657	390,640	0
80	0	0.8155	3.3612	163,660	0



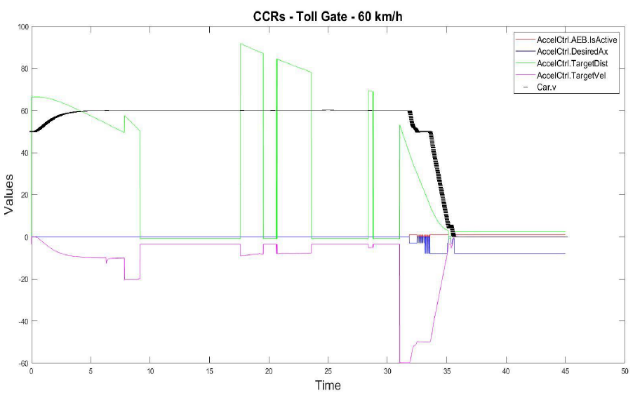


Fig. 18 - CCRs: Toll gate, ego-vehicle speed of 50 km/h **Fig. 19 - CCRs: Toll gate, ego-vehicle speed of 60 km/h**

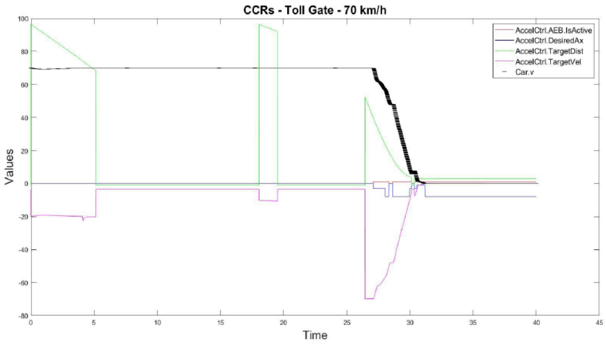


Fig. 20 - CCRs: Toll gate, ego-vehicle speed of 50 km/h

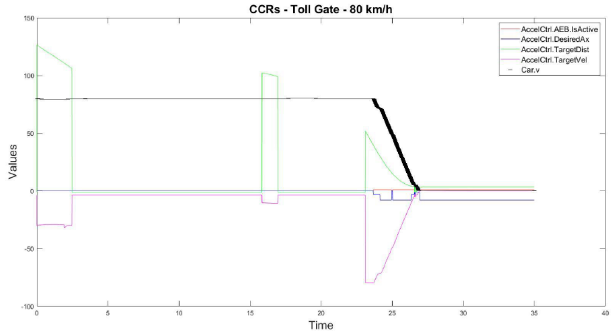


Fig. 21 - CCRs: Toll gate, ego-vehicle speed of 60 km/h

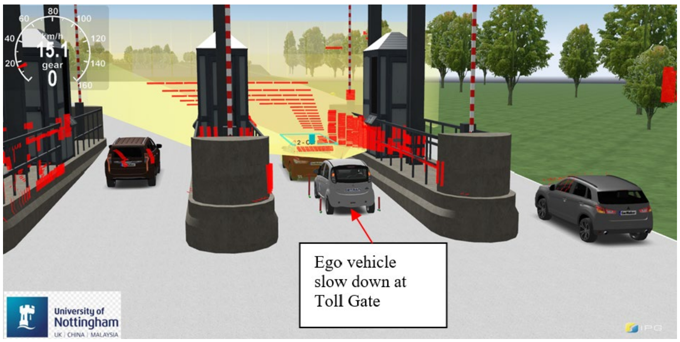


Fig. 22 - CCRs - Toll gate traffic 3D simulation using ego-vehicle

3.2 CTU- C: Cut Out - Traffic

The traffic scenario is determined by ego-vehicle following a traffic vehicle that suddenly cuts out and traffic vehicle needs to brake to the stationary traffic vehicle near the KTM at the urban road at the speed of 30 km/h, 40 km/h, and 50 km/h. The traffic vehicle's speed is considered at 0 km/h during the initial stage of testing. Table 5 shows the average simulation result values for the traffic scenario. Meanwhile, Figures 23 until 25 show the overall simulation results values for each ego-vehicle speed. Figures 23 to 25 show that the ego-vehicle speed is decreasing when the distance between ego-vehicle and traffic vehicle decreases. The AEB system is active during the decreasing ego-vehicle speed. The desired deceleration takes control of the ego-vehicle acceleration when the AEB system is active. This is affecting the speed differences between ego-vehicle and traffic vehicle as the ego-vehicle speed decreases to avoid collision as shown in Figures 23 to 25.

The AEB system in this scenario is consistent too. Table 4 shows that the average distance between ego-vehicle and traffic vehicle for all of the ego-vehicle's speeds are almost the same. The average TTC for ego-vehicle speed of 30 km/h is lower than both 40 km/h and 50 km/h. This is because the distance of ego-vehicle and traffic vehicle for ego-vehicle's speed of 30 km/h is higher before the activation of AEB system. In result, The AEB system just needs to be active for a short time and the desired deceleration needed is less. The average ego-vehicle speed for ego-vehicle's speed of 30 km/h is also higher because of this short activation of AEB system and less desired deceleration. Figures 23 to 25 show that there are no collisions between the ego-vehicle and traffic vehicle. These can be seen in the distance between ego-vehicle and traffic vehicle, which always in the positive values. Figure 26 shows the 3D simulated traffic scenario.

By using the initial conditions of the traffic scenario, the Severity ratings for all of the various ego-vehicle speeds are the same, which is S1. The Controllability ratings are determined by the average simulation results values. The Controllability ratings for the ego-vehicle speed of 30 km/h is C2. The Controllability ratings for the ego-vehicle's speed of 40 km/h and 50 km/h are C1. Combining all the ratings, the ASIL classification system level for the ego-vehicle's speed of 30 km/h is level A and the VUT speed of 40 km/h and 50 km/h are level QM.

4. Conclusion

In this study, safety assessment of automated emergency braking system for autonomous vehicles has been investigated. The performance of the autonomous vehicle has been investigated using two types of test cases based on actual scenarios. The actual scenarios are recorded using an instrumented vehicle for the purposes of re-creation of the virtual environment and traffic models. The vehicle model in IPG CarMaker is configured based on actual vehicle model for the scenario-based testing using ACC and AEB. From the test cases, it can be observed that the autonomous vehicle's velocity is able to follow the desired ACC and AEB velocities which is calculated based on trajectory profile of the pedestrian movements in lateral direction. Thus, the developed autonomous vehicle model using ACC and AEB is able to follow the desired velocity to avoid frontal impact due to traffic motions with minimum distance is 0.5m and maximum distance is 4.5m.

Table 5 - Cut Out - traffic average simulation results value

VUT Speed (km/h)	TV Speed (km/h)	Deceleration Average (g)	Target Distance Average (meters)	TTC Average (seconds)	Car Speed Average (km/h)
30	0	0.1019	4.3267	19.6803	0
40	0	0.8155	3.8184	7,090	0
50	0	0.8155	0.9296	2,090	0

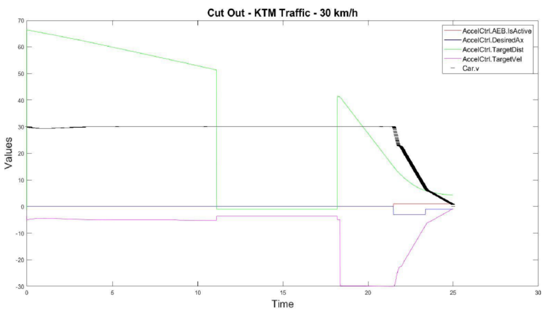


Fig. 21 - Cut Out - Traffic Case Ego Vehicle Speed of 30 km/h

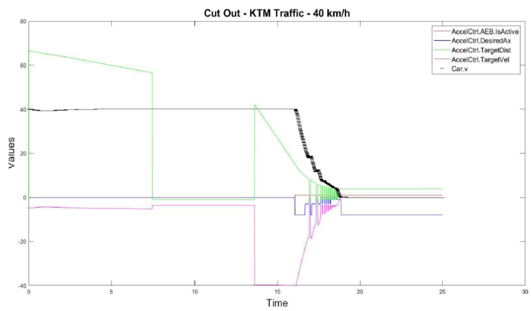


Fig. 22 - Cut Out - Traffic Case Ego Vehicle Speed of 40 km/h

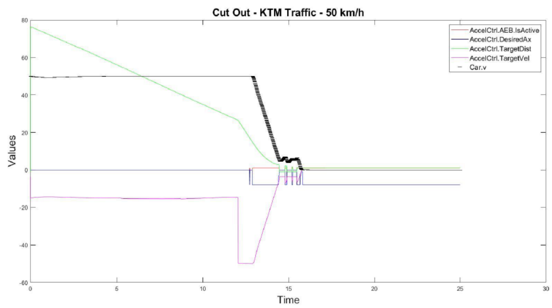


Fig. 23 - Cut Out - Traffic Case Ego Vehicle Speed of 50 km/h

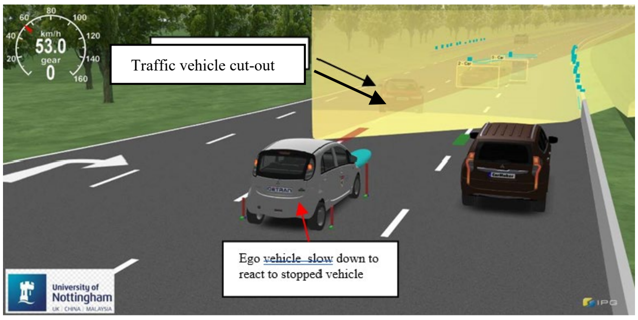


Fig. 26 - CTU-C: cut out - traffic

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