Assessment of Autonomous Braking System in Simulated Driving Scenarios Generated Based on Real World Accident Data

Palash Chhabra, B S Vishak Nandan Aathresh, Avinash Penumaka, Muthukumar Muthanandam

Abstract

The objective of this study is to create simulated scenarios that resemble the real-world Indian accident scenarios and evaluate the Autonomous Emergency Braking (AEB) system in those new scenarios. The dataset considered is from the RASSI (Road Accident Sampling System – India) database. A total of 120 real-world cases are queried using relevant parameters where AEB system will be applicable and for each case PC-Crash reconstructed data is obtained.

In a given real-world case, a new test vehicle is introduced apart from the vehicles involved in the crash in order to create a simulated scenario and the test vehicle follows the crashed passenger car. The simulated scenarios are parameterised based on distance gap and relative velocity between the test vehicle and passenger car vehicle and also braking threshold of test vehicle.

For every simulated scenario, AEB system is integrated to test vehicle which can intervene fully by applying braking at 1*g*. The benefit assessment is captured either by collision avoidance or collision mitigation. In 2017, authors evaluated the benefit assessment of the AEB system in real-world scenarios. In the present study, for wider applicability, AEB system is evaluated in complex simulated scenario which are generated based on real-world accident data.

Keywords Autonomous Emergency Braking, benefit assessment, collision avoidance, real world accident data, simulated scenario.

I. INTRODUCTION

In India, 147,913 road traffic fatalities are reported in 2017 [1]. Driver fault is the primary contributing factor that accounts for about 80% of all fatalities. Of that, 61% of fatalities are a result of speeding over the limits. Also, the number of rear-end accidents accounted to about 77,540 accident which resulted in 22,446 fatalities. This research aims to conduct in-depth investigation of the accident cases where the driver is involved in rear-end crashes and generate multiple simulated scenarios from each case. In such simulated scenarios, potential benefit of driver assistance system like Automatic Emergency Braking (AEB) system [2] has been assessed.

There has been a lot of literature on benefit assessment of safety systems based on real world accident data. This kind of literature is both available for passenger cars [2, 3, 4, 5] and also for powered two wheelers [6]. In 2017, authors evaluated the benefit assessment of three different AEB systems based on real-world scenarios [7]. For these real world scenarios, the function effectiveness (collision avoidance) varied from 19% - 48% depending on the system specification. Though there has been continuous improvement in the AEB function itself, the challenge is to establish the system effectiveness in different accident scenarios [8]. In the present study, for wider applicability, AEB system was further evaluated in complex simulated scenarios generated based on real world scenarios.

II. METHODS

Data Source

Real world passenger car accident data is essential to understand characteristics of the accidents and to identify countermeasures to reduce the frequency and the severity of accidents. The analysis of pre-crash dynamics of a passenger car prior to the impact is a way to thoroughly investigate accident causation.

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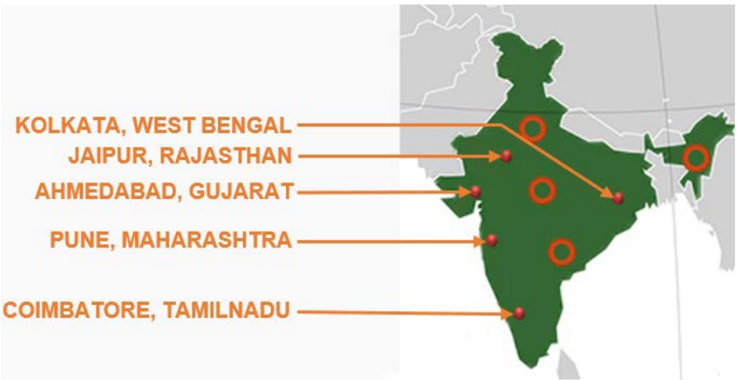

Fig. 1. RASSI sampling locations across India (Source: RASSI).

The selection of an appropriate accident database that includes in-depth information on the pre-crash phase of the accidents in addition to the crash and post-crash phase of the accidents is crucial. The Road Accident Sampling System – India (RASSI) database has been used for this research. Accident data were collected from five different sampling locations across India as shown in Figure 1. A total of 3,046 real world accidents from three different sampling locations were examined by means of in-depth accident reports consisting of about 700 variables per accident case. Accident characteristics prior to collision were derived using technical reconstruction.

Data Querying

Data querying is performed using python scripts. The rationale behind querying the RASSI database is to obtain relevant data about the pre-crash, crash and post-crash phase. The three phases of the crash are captured in 15 separate tables. The RASSI Structured Query Language (SQL) database contains several relational tables which contain several keys that could be used for linking the variables.

Following merging of the data tables *Accident*, *Vehicle Recon* and *Vehicle General Documents*, initial query on the vehicle type, i.e., body type relevant for passenger cars, is conducted. Following this merging, 1,393 cases are extracted where at least one passenger car is involved in these accidents. The description of the tables is shown in Table I.

TABLE I

DESCRIPTION OF THE DATA TABLES: BELOW TABLES USED FROM RASSI DATABASE TO MERGE AND QUERY

Data Tables	Description
Accident	General info about the scene and environmental conditions
Accident event sequence (AccEventSeq)	Specific info for each event (impact) in the crash sequence
Vehicle general documents (VGD)	Vehicle information that was gathered from police documents and from OEM specific documents
Vehicle reconstruction (VehicleRecon)	Info on the reconstruction of the first and the most harmful crash events per vehicle

A total of 199 accidents resulted in a query where the first event is Rear-End crash configuration. The vehicle movement prior to critical event, i.e., vehicle going in a straight line path, and pre-impact stability, i.e., vehicle skidding longitudinally but yaw angle less than 30 deg., resulted in 181 cases. In 147 cases, accident reconstruction status is complete. However, only 135 reconstruction cases are done using PC-Crash and the remaining cases are reconstructed using hand-calculations. Finally, a total of 120 cases are selected for this study after eliminating 15 cases in which accidents happened due to vision obstruction.

System Definition

The System considered for the present study is a hypothetical Autonomous Emergency Braking (AEB) system. The AEB System has one radar sensor that would support the driver in case of an emergency situation. With the support of the radar, the AEB system would give a headway warning 2.6s prior to the collision. In spite of the warning, if there is no reaction from the driver, the AEB system would intervene with complete braking at 1.0g deceleration provided the time to collision is less than or equal to 0.6s. However, post the warning, if driver reacts by braking, the AEB system would intervene with complete braking at 1.0g deceleration only if time to collision is less than or equal to 0.6s. If the driver applies braking of 0.5g and the time to collision is more than 0.6s, then the AEB system would not intervene. However, if the time to collision is less than or equal to 0.6s, then the AEB system would ramp-up to complete braking at 1.0g deceleration. In order to achieve the maximum deceleration, the maximum frictional coefficient value considered is 1.0. The considered AEB system is not designed to provide partial braking (0.4*g*) which most traditional AEB systems would assist the driver with. The rationale behind not considering this partial braking was to evaluate the AEB system in the worst case scenario. The characteristics of the AEB System are shown in the below Table II.

TABLE II
CHARACTERISTICS OF SYSTEM

System Parameter	Value
Detection range	60 m
Detection angle	80°
Time delay for activation of Full Braking	0.3s
AEB Full Braking deceleration value	1.0g
System warning to driver prior to TTC	TTC – 2.6s
Full Braking activation priori to TTC	TTC – 0.6s

System Application

For each accident in the database, there would be a reconstruction file (.pro file reconstructed in PC-Crash) associated with the case. This section illustrates the method adopted to reconstruct the exemplary accident case by integrating the AEB system. Apart from the original reconstruction file, there would be an additional reconstruction file showing the impact of the AEB system in the case.

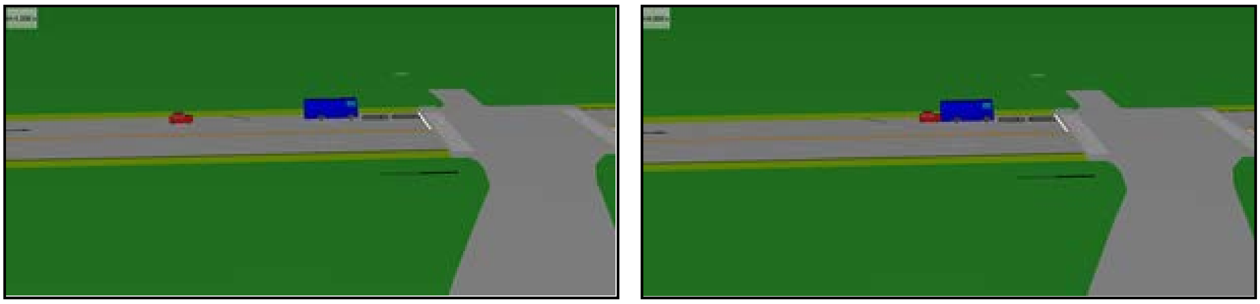

Figure. 2. Schematic representation of actor and ego vehicle engagement at impact in PC-Crash during original Reconstruction (Source: PC-Crash Images).

In the exemplary case (Figure 2), the ego vehicle passenger car (red vehicle) and the actor vehicle truck (blue vehicle) are approaching an uncontrolled intersection. The travelling speeds of ego vehicle and actor vehicle are 50 km/h (V_e) and 10 km/h respectively. At the point of impact, the collision speeds of ego vehicle and actor vehicle are 50 km/h and 0 km/h. There is an uninvolved vehicle ahead of the actor vehicle (blue vehicle) and hence the actor vehicle had braked and almost stopped prior to the impact. There is a misjudgment of the situation by the ego vehicle which ended up with rear-end collision with actor vehicle. There is no collision avoidance manoeuvre from the ego vehicle. In the original crash reconstruction, t=0 would be the point of impact.

To the given real-world case, a new test vehicle would be introduced apart from the vehicles involved in the crash in order to create a simulated scenario. The test vehicle would be following the ego vehicle (as shown in Figure 3). The simulated scenarios would be parameterized based on distance gap, braking threshold of the test vehicle and relative velocity.

In Figure 3, the collection of schematics shows the different phases of the simulation:

- Fig 3.1 (top-left): Schematic represents the position of ego and actor vehicle along with the introduction of the test vehicle in the PC-Crash Environment.
- Fig 3.2 (top-right): Schematic represents the triggering of AEB system in the new test vehicle. Due to PC-Crash OLE limitation, authors have removed actor vehicle i.e., stopped truck, which has no relevance in the evaluation scenario as new test vehicle is not having any collision with actor vehicle. The focus was on the new test vehicle and the ego vehicle.
- Fig 3.3 (bottom left): Schematic represents the application of AEB system in the new test vehicle.
- Fig 3.4 (bottom right): Schematic represents the final stopped positions of the new test vehicle and ego vehicle.

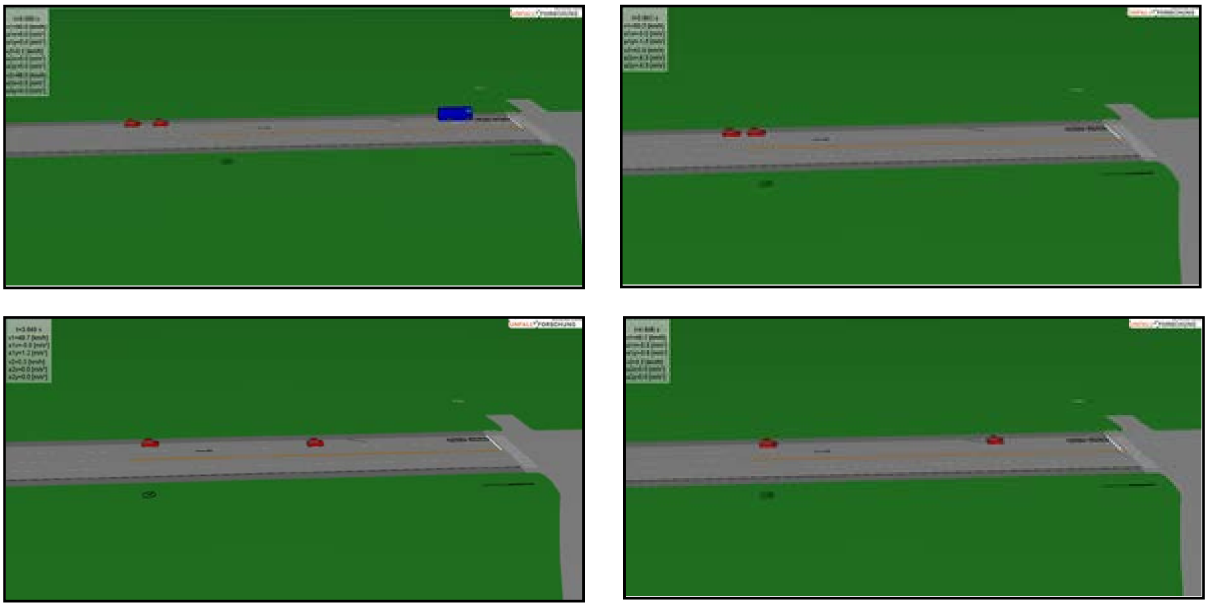

Figure 3. Schematic representation of actor and ego vehicle engagement at impact in PC-Crash during original reconstruction (Source: PC-Crash Images).

For the exemplary case, twenty-four re-recons that are done are shown in the Table III. For every simulation the following steps are carried out:

1. Load the re-recon file (one-of the twenty-four re-recons)
2. Load the Active Safety function block with the System into the new test vehicle
3. Run the simulation

4. Capture the results for the new test vehicle (impact speed, delta v, time of collision, etc.)

The System successfully avoided the collision in 21 scenarios out of 24 scenarios. The three scenarios where the System is not able to avoid the collision where relative velocity is 10m/s and the distance between the two vehicles is the least (6.9 m). Of all the 24 scenarios, the three scenarios which resulted in collision are the worst scenarios for the exemplary case as the relative velocity is high (10 m/s) and the least distance gap (6.9m). Hence, irrespective of the test vehicle driver braking (either no braking or 0.1g or 0.2g braking), the system has intervened as soon as time to collision is below the threshold and applied complete braking at 1.0g deceleration. However, in the three worst scenarios, the collision mitigation is achieved with impact speed reduction by 30% and kinetic energy reduction by 50%.

TABLE III
EXEMPLARY CASES RE-RECONSTRUCTIONS WITH SYSTEM INTERVENTION

Reconstructions	Traveling speed (km/h)	Deceleration	Distance Gap (m)	Impact Speed (km/h)	Impact Speed Reduction	Kinetic Energy Reduction
Recon1	68.0	0.1	6.9	Collision Avoided	-	-
Recon2	68.0	0.2	6.9	Collision Avoided	-	-
Recon3	68.0	0	6.9	Collision Avoided	-	-
Recon4	68.0	0.1	20.8	Collision Avoided	-	-
Recon5	68.0	0.2	20.8	Collision Avoided	-	-
Recon6	68.0	0	20.8	Collision Avoided	-	-
Recon7	68.0	0.1	13.9	Collision Avoided	-	-
Recon8	68.0	0.2	13.9	Collision Avoided	-	-
Recon9	68.0	0	13.9	Collision Avoided	-	-
Recon10	68.0	0.1	27.8	Collision Avoided	-	-
Recon11	68.0	0.2	27.8	Collision Avoided	-	-
Recon12	68.0	0	27.8	Collision Avoided	-	-
Recon13	86.0	0.1	6.9	60.4	-30%	-51%
Recon14	86.0	0.2	6.9	60.4	-30%	-51%
Recon15	86.0	0	6.9	60.4	-30%	-51%
Recon16	86.0	0.1	20.8	Collision Avoided	-	-
Recon17	86.0	0.2	20.8	Collision Avoided	-	-
Recon18	86.0	0	20.8	Collision Avoided	-	-
Recon19	86.0	0.1	13.9	Collision Avoided	-	-
Recon20	86.0	0.2	13.9	Collision	-	-

				Avoided		
Recon21	86.0	0	13.9	Collision Avoided	-	-
Recon22	86.0	0.1	27.8	Collision Avoided	-	-
Recon23	86.0	0.2	27.8	Collision Avoided	-	-
Recon24	86.0	0	27.8	Collision Avoided	-	-

Of the 120 cases, 30 cases are selected for this study to demonstrate the AEB system effectiveness. For the 30 cases, a total of 720 simulations (30 cases x 24 scenarios/case) are carried out. All these simulations are carried out using Object Linking Embedded (OLE) with Python and PC-Crash. The rationale behind the selection of 30 cases instead of 120 cases is because of challenges attributed towards usage of PC-Crash Object Linking Embedded (OLE) which has been discussed in the limitations section.

III. RESULTS

For a total of 120 cases, about 2,880 simulated scenarios are simulated (24 re-recons per case). Of the 120 cases, 30 cases are selected for this study to demonstrate the System effectiveness. For these 30 cases, a total of 720 simulations (30 cases x 24 re-recons/case) are carried out. All these simulations are carried out using Object Linking Embedded (OLE) with Python and PC-Crash ensuring there is no manual effort. But, due to limitation with PC-Crash OLE, the present study is evaluated only for 30 cases.

TABLE IV
IMPACT SPEED REDUCTION ACHIEVED FOR DIFFERENT RELATIVE VELOCITIES

System Parameter	Relative Velocity (5 m/s)	Relative Velocity (10 m/s)
10th percentile	27.5%	22.8%
25th percentile	34.1%	27.0%
50th percentile	51.5%	30.0%
75th percentile	73.5%	32.7%
90th percentile	84.4%	55.5%

As shown in Table IV, about 360 simulations with relative velocity 5 m/s resulted in 9.4% (34 collision out of 360 scenarios) of collision occurrence rate. While in the 360 simulations with relative velocity 10 m/s resulted in 16.7% (60 collision out of 360 scenarios) of collision occurrence rate. In 10% of the collisions with relative velocity of 5m/s, the AEB system managed to get more the 84% impact speed reduction and in 90% of the collisions, AEB system managed to get more than 27.5% impact speed reduction.

*Distance Gap (V_e*0.5)*

In 180 simulations with Distance gap of V_e*0.5, only one collision occurred when relative velocity was 5 m/s, but braking is 0.2*g*. It is an anomaly as the system triggered braking late as risk of collision is not high due to driver braking. In the 90 simulations when relative velocity is 10 m/s, 38 scenarios have resulted in a collision.

⇨ 0.0*g* deceleration: 12 cases when collision occurred with relative velocity of 10 m/s, average impact speed reductions is 30%. The 10th percentile impact speed reduction is 26% while the 90th percentile is 32%, i.e., 80% of the impact speed reduction achieved are between 26% and 32%; all collisions are avoided when relative velocity between both the vehicles is 5m/s.

⇨ 0.1*g* deceleration: 13 cases when collision occurred with relative velocity of 10 m/s, average impact speed reduction is 30%. The 10th percentile impact speed reduction is 25% while the 90th percentile is 32%, i.e., 80% of the impact speed reduction achieved are between 26% and 32%; all collisions are avoided when relative velocity between both the vehicles is 5m/s.

- ⇨ 0.2*g* deceleration: 13 cases when collision occurred with relative velocity of 10 m/s, average impact speed reduction is 29%. The 50th percentile speed reduction is 30% and the 90th percentile speed reduction is 32%. In the one case with relative velocity of 5m/s, the average impact speed reduction was 86%.

Distance Gap (V_e*1.0)

In 180 simulations with Distance gap of V_e*1.0 ➔ a total of 10 collision occurred overall.

- ⇨ 0.0*g* deceleration: two cases with relative velocity of 10 m/s, impact speed reduction is between 23% and 29%; all collisions are avoided when relative velocity between both the vehicles was 5m/s.
- ⇨ 0.1*g* deceleration: in the one case with relative velocity of 10 m/s, the maximum impact speed reduction observed is 22%; in the remaining five cases with relative velocity of 5 m/s, average impact speed reduction is 36% and the 50th percentile speed reduction is 29%.
- ⇨ 0.2*g* deceleration: in the one case with relative velocity of 10 m/s, the average impact speed reduction observed is 22%. In the one case with relative velocity of 5m/s, the average impact speed reduction is 88%.

TABLE V

SUMMARY OF ALL RE-RECONS WITH SYSTEM INTERVENTION (V_e*0.5)

Relative Velocity (km/h)	Distance Gap (m)	Deceleration Applied (g)	Collisions Occurred	Collisions Avoided	Collision Occurrence Rate	Average Impact Speed Reduction (%)
18	V_e*0.5	0	0	30	0%	-
18	V_e*0.5	0.1	0	30	0%	-
18	V_e*0.5	0.2	1	29	3%	86%
36	V_e*0.5	0	12	18	67%	30%
36	V_e*0.5	0.1	13	17	76%	30%
36	V_e*0.5	0.2	13	17	76%	29%

TABLE VI

SUMMARY OF ALL RE-RECONS WITH SYSTEM INTERVENTION (V_e*1.0)

Relative Velocity (km/h)	Distance Gap (m)	Deceleration Applied (g)	Collisions Occurred	Collisions Avoided	Collision Occurrence Rate	Average Impact Speed Reduction (%)
18	V_e*1.0	0	0	30	0%	-
18	V_e*1.0	0.1	5	25	20%	36%
18	V_e*1.0	0.2	1	29	3%	88%
36	V_e*1.0	0	2	28	7%	26%
36	V_e*1.0	0.1	1	29	3%	22%
36	V_e*1.0	0.2	1	29	3%	22%

TABLE VII

SUMMARY OF ALL RE-RECONS WITH SYSTEM INTERVENTION (V_e*1.5)

Relative Velocity (km/h)	Distance Gap (m)	Deceleration Applied (g)	Collisions Occurred	Collisions Avoided	Collision Occurrence Rate	Average Impact Speed Reduction (%)
18	V_e*1.5	0	4	26	15%	28%
18	V_e*1.5	0.1	6	24	25%	67%
18	V_e*1.5	0.2	0	30	0%	-
36	V_e*1.5	0	2	28	7%	28%
36	V_e*1.5	0.1	1	29	3%	27%

36	V_e*1.5	0.2	4	26	15%	46%

*Distance Gap (V_e*1.5)*

In 180 simulations with Distance gap of V_e*1.5 ➔ 17 collision occurred overall; 7 cases 0.1g deceleration; 4 cases 0.2g deceleration

⇨ 0.0g deceleration: two cases with relative velocity of 10 m/s, average impact speed reduction was 28%; in the remaining four cases with relative velocity of 5 m/s, average impact speed reduction was 28%.

⇨ 0.1g deceleration: in the one case with relative velocity of 10 m/s, the average impact speed reduction observed was 27%; in the remaining six cases with relative velocity of 5 m/s, the average impact speed reduction is 67%. The 50th percentile speed reduction was 66%.

⇨ 0.2g deceleration: in the four cases with relative velocity of 10 m/s, average impact speed reduction is 46% , the minimum impact speed reduction observed was 27%, however, in the remaining three cases the impact speed reduction was more than 42% and a maximum upto 62%; all collisions were avoided when relative velocity between both the vehicles was 5m/s.

TABLE VIII
SUMMARY OF ALL RE-RECONS WITH SYSTEM INTERVENTION (V_e*2.0)

Relative Velocity (km/h)	Distance Gap (m)	Deceleration Applied (g)	Collisions Occurred	Collisions Avoided	Collision Occurrence Rate	Average Impact Speed Reduction (%)
18	V_e*2.0	0	9	21	43%	38%
18	V_e*2.0	0.1	8	22	36%	79%
18	V_e*2.0	0.2	0	30	0%	-
36	V_e*2.0	0	2	28	7%	19%
36	V_e*2.0	0.1	4	26	15%	36%
36	V_e*2.0	0.2	5	25	20%	80%

*Distance Gap (V_e*2.0)*

In 180 simulations with Distance gap of V_e*2.0 ➔ 28 collision occurred overall; 11 collision 0.0g deceleration; 12 cases 0.1g deceleration; five cases 0.2g deceleration

⇨ 0.0g deceleration: two cases with relative velocity of 10 m/s, average impact speed reduction was 19%; in the remain 9 cases with relative velocity of 5 m/s, average impact speed reduction was 38%.

⇨ 0.1g deceleration: in the four cases with relative velocity of 10 m/s, average impact speed reduction is 36%, the maximum impact speed reduction observed was 50%; in the remain eight cases with relative velocity of 5 m/s, average impact speed reduction is 79% , the minimum impact speed reduction achieved was 67%. The 50th percentile speed reduction was 82%.

⇨ 0.2g deceleration: in the five cases with relative velocity of 10 m/s, average impact speed reduction is 80%, the minimum impact speed reduction observed was 69% and the 50th percentile speed reduction was 78%; all collisions were avoided when relative velocity between both the vehicles was 5m/s.

IV. DISCUSSION

The context of the research work primarily emphasized on two aspects: creation of simulated scenarios based on real world data and evaluation of the feasibility of the AEB System assessment based on these simulated scenarios. For the passenger car accidents which resulted in rear-end crash configuration, the present study resulted in creation of 720 simulated scenarios based on 30 real world accident cases. This is achieved by introducing a new test vehicle following the ego vehicle. The roadmap for this research activity is to create a Synthetic Scenario Database (SSD) with at least 50,000 simulated scenarios which could be used to evaluate various active safety systems and the functioning of automated driving vehicles. In the past, some simulated scenarios are already generated which would eventually add to the vision of 50,000 Synthetic Scenario Database [7].

Among the 720 simulations, there are particularly two types of accident scenarios categories which are found to be challenging for AEB system effectiveness. The two categories are:

(a) Abrupt high braking by ego vehicle: Test vehicle integrated with AEB system could not avoid the collision when following an ego vehicle which did abrupt high braking (mostly > 0.7*g*). Among the 720 simulations, in 94 scenarios collision occurrence (13%) is observed. At least 20 scenarios resulted in collision because of abruptly high braking (> 0.7g) by the ego vehicle. However, the AEB system implemented in this present study is for the worst case scenario. There is no partial braking and also there is no braking ramp-up when driver applied the brake after warning. The only criteria for braking ramp-up to 1*g* is when the time to collision is less than or equal to 0.6s. For these kind of specific scenarios, different kinds of AEB system should be designed and performance evaluation could be conducted.

(b) Abrupt lane cutting of ego vehicle: The new test vehicle integrated with AEB system could not avoid the collision when an ego vehicle abruptly performed a lane cutting manoeuvre into the following test vehicle. One of the primary reasons why the AEB system could not avoid the collision is due to the sensor specifications. The radar field of view considered is 80^{o}, i.e., the half cone angle is 40^{o}. The AEB System is capable of detecting the vehicle only when all the four edges of the ego vehicle are detected. In the 94 scenarios where collision occurrence is observed, at least 16 scenarios resulted in collision due to abrupt lane cutting of ego vehicle. Authors increased the field of view to 110^{o} in these 16 scenarios to evaluate the impact of the AEB System specifications. At least six scenarios resulted in collision avoidance. The remaining 10 scenarios involved abrupt lane cutting along with high braking by ego vehicle.

Limitation

The parametric study is done based on a new test vehicle position relative to ego vehicle in order to create simulated scenarios. More scenarios per case could have been generated as authors have considered relative velocity & distance gap between both the vehicles only. In the future, time headway gap and lateral position could also be considered.

Of the 120 cases, 30 cases are selected for this study to demonstrate the AEB system effectiveness. For the 30 cases, a total of 720 simulations (30 cases x 24 scenarios/case) are carried out. The rationale behind the selection of 30 cases instead of 120 cases is because of challenges attributed towards usage of PC-Crash OLE. Authors have introduced a new test vehicle apart from the ego and actor vehicle, i.e., for every scenario there will always be at least three vehicles involved in the crash.

When a new test vehicle is introduced, the PC-Crash programme assigns the next vehicle sequence number and in this case Unit No. 3. The ego vehicle and actor vehicles are always assigned as either Unit No.1 or Unit No. 2. The PC-Crash tool is also continuously undergoing improvement and authors are hopeful that this issue will be resolved soon. Due to this limitation, in the present study, only 30 cases are considered. For these 30 cases, actor vehicle is not considered there by limiting the number of vehicles in each scenario to two vehicles, i.e., Unit No. 1 would be assigned to ego vehicle and Unit No. 2 would be assigned to new test vehicle. However, the original trajectory of the ego vehicle is retained and is not altered. This resulted in capturing the results of the new test vehicle.

V. CONCLUSIONS

This study presented the benefit assessment of AEB system based on simulated scenarios generated from real world scenarios. A total of 120 cases are considered for this study. For each case, about 24 simulated scenarios are generated by varying the relative velocity, distance gap and braking threshold of the test vehicle. These 120 cases have resulted in 2,880 simulated scenarios. Out of 120 cases, 30 cases are considered for the assessment because of PC-Crash OLE limitation where an AEB system would definitely impact the outcome of the accident either by mitigating or avoiding.

The AEB system is applied in a total of 720 simulated scenarios. The AEB system achieved collision avoidance in 87% of the scenarios and in 94 scenarios (13%) collision mitigation is observed. Out of 94 simulated scenarios, 60 simulated scenarios resulted in collision when the relative speed is 10 m/s and 34 simulated scenarios resulted in collision when the relative speed of 5 m/s.

In the situations when there is no braking by the new test vehicle, the average impact speed reduction are 33% and 26% for relative speeds of 5 m/s and 10 m/s respectively. However, in the situations, when there is braking by the new test vehicle, the average impact speed reduction are 71% and 37% for relative speeds of 5 m/s and 10 m/s. Finally, the average impact speed reduction achieved by AEB system when relative speed is 5 m/s and 10 m/s is about 60% and 33% respectively.

The AEB system found challenging in two specific categories of simulated scenarios where the collision could not be avoided. These two categories add up to 38% of the simulated scenarios where collision occurred. The two categories are: (a) abrupt high braking (> 0.7g) by ego vehicle resulted in 21% of 94 simulated scenarios where collision occurred; (b) abrupt lane change with and without high braking (> 0.7g) of ego vehicle (17% out of 94 simulated scenarios).

To avoid collision in these configurations, the AEB system specification needs to be altered like introducing partial braking, ramp-up to optimal braking level the moment driver applies the brakes after system warning, etc. In the remaining 62% of the simulated scenarios, the test vehicle was following the ego vehicle very closely and with high relative velocity resulting in unavoidable scenarios.

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