TME 192 Active Safety
Project Report

Group number: 16

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Course	TME 192 – Active Safety Project Chalmers University of Technology Academic year 2019/20
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1. Introduction

In this project we deal with a specific type of crash called 'Rear-end collision" where one vehicle hits another from behind due to inactive/distracted driver (our area of focus) or panic braking of the leading car. We start with using the equations of motion to predict the outcome of a hypothetical longitudinal rear-end scenario, process the experimental data and use the same to understand the driver behavior in critical rear-end situation and with the gained knowledge, develop simple threat assessment and decision making algorithms to propose a Forward Collision Warning (FCW) system and Automatic Emergency Braking (AEB) system and discuss the effectiveness and limitations of the proposed systems.

2. Task-1: A hypothetical rear-end conflict situation

This task involves a hypothetical situation where a driver of a vehicle moving at a constant speed of 90 kmph who is following a lead vehicle, the driver is involved in distracted driving, the lead vehicle changes the lane due to the presence of a stationary vehicle in front, now which the distracted driver's car is approaching fast. Reaction time for the driver to start braking after seeing the stationary vehicle is 1.5 seconds and the brakes will be applied at constant deceleration of 5 m/s^2.

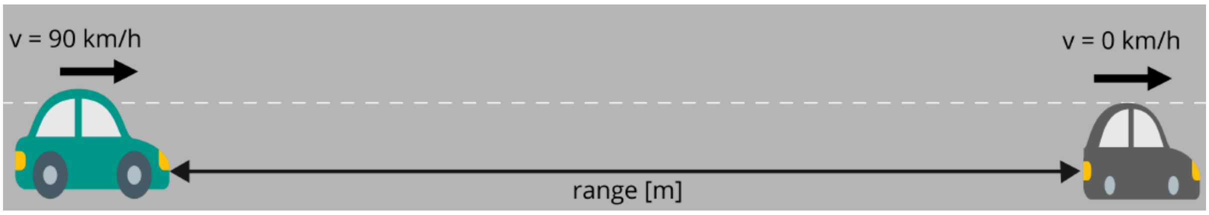

Fig. 1. Scenario illustration

With the above situation in hand, we need to find:

i. The minimum range between the approaching car and the stationary vehicle required in order to avoid the collision, which essentially means the final velocity of the vehicle is zero.

Initial velocity: u = 90 kmph

Final velocity: v = 0 kmph

Acceleration (when brakes applied): a = -5 m/s^2

The time required for the final velocity to reach zero with the brakes being applied,

$$Time = \frac{Final\ velocity - Initial\ velocity}{Acceleration} \tag{1}$$

The minimum distance required for the car to avoid collision with the stationary vehicle can be calculated using newton's laws of motion,

$$Minimum\ range = (Initial\ velocity\ x\ Time) + (0.5\ x\ Acceleration\ x\ Time^2) \tag{2}$$

The minimum range required in this scenario would be **62.5 meters**.

ii. Time to collision (TTC) : It can be defined as "time required for the collision if the current situation persists", it means if the brakes are not applied. With respect to above situation TTC can be written as,

$$Time\ to\ collision = \frac{Distance}{Initial\ velocity} \tag{3}$$

From, the above case, the distance would be equivalent to minimum range, which results in TTC to be **2.5 seconds**.

iii. In this case, there is a slight variation which the distance at which the stationary vehicle is seen by the approaching driver which happens to be 90m. With the reaction time taken into consideration we need to answer that, whether the driver will be able to avoid the collision or not.

For this we take an approach of finding out the minimum distance required to stop the car considering reaction time and check with the distance he has ahead (90m) and if its possible to stop within that distance.

We will break the distance required as,

a. Distance covered before reacting, that is in the time 1.5 (between when the driver sees the stationary vehicle and applies break).

$$Distance_1 = Initial\ speed\ x\ Reaction\ time \tag{4}$$

b. Distance covered with the application of brakes, which happens to be the minimum range.

$$Distance_2 = Minimum\ Range \tag{5}$$

So, the minimum distance required to avoid the collision comes down as,

$$Distance_{ac} = Distance_1 + Distance_2 \tag{6}$$

When calculated, $\text{Distance}_{\text{ac}}$ turns out to be 100 m, but the distance ahead of the driver is only 90 m, which tells us that the **collision cannot be avoided**.

3. Task-2: Study critical breaking behavior with experimental data

A dataset obtained from an experiment conducted to study the drivers braking preferences in a critical rear-end situation which included nine drivers and were given a certain specific speed to be maintained and were asked to break as late as possible to avoid a collision with a stationary “balloon vehicle”. This dataset contained kinematic data and radar data which required processing before the analysis.

3.1. Data Cleaning

- We created a new dataset ‘RadarDataCorrected’ to move all the required data, after cleaning is done.
- With the use of function ‘isnan’ we identified the number of ‘Nan’ i.e. empty test run values, in the arrays of all the fields (RadarRange, RadarRangeRate, VehicleSpeed, etc)
- All the arrays containing more than 80% of ‘Nan’ were not assigned to new struct. So, the data assigned to the ‘RadarDataCorrected were cells with less than 80%of ‘Nan’ and some of them had very less test runs after the removal of Nan.
- All the arrays with empty cells were removed from the new dataset.
- As mentioned above if any arrays contained very little data, in this case less than 30 values per cell were removed from ‘RadarDataCorrected’ as well.
- The delay in ‘RadarTime’ is fixed by removing 200ms from it and synchronizing it with the ‘VehicleTime’.
- Among the dataset remaining, all the missing values in the cells were linearly interpolated using the function ‘fillmissing’.
- A new field named ‘VehicleAcceleration’ was created and filled with values using the following equation (gradient),

$$Time\ to\ collision = \frac{\Delta\ Vehicle\ Speed}{\Delta\ Vehicle\ Time} \tag{7}$$

- After cleaning up the data, we were left with 62 cells of all the fields which initial was 89 cells.

3.2. Break Maneuvers

- We have defined braking to be recognized as an event if the acceleration goes less than -0.5 m/s^2 and remains so for at least 2 seconds.

- All the cells of 'VehicleAcceleration' values which goes beyond -0.5 m/s^2 for at least 20 time-steps (because, each time-step is known to be 0.1 second)which happens to be 2 seconds is recorded, if the value of acceleration increases more than -0.5, the record is terminated.
- In the recorded data, the time-steps are checked if they are of consecutive order or not, all the non-consecutive time-step data is cleaned only to retain consecutive time-step acceleration, which is what we require as per our definition of breaking.
- The time of starting and ending of breaking is recorded in the 'start' and 'endtime' respectively.

4. Task-3: Driver behavior analysis

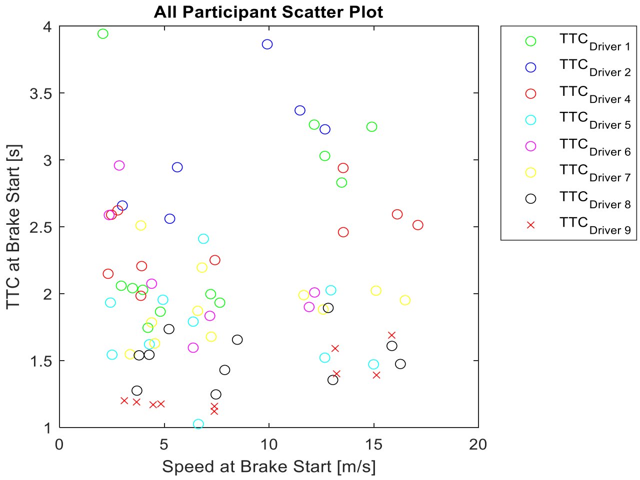

Fig. 2. TTC vs Speed All Participant Plot

In task 3, we are tasked to plot the TTC at brake onset vs Speed at brake onset for each participant. However, firstly we would like to take an overall look at the whole data's plot. As we can observe from Fig. 2. It is shown that the plot is scattered through different data points. For each driver, there are several patterns of behavior that we can take conclusion from.

If we would like to cluster the whole plot, the plot will look like Fig. 3. The method used in order to find this is the *spectral clustering*. This method works by finding clusters in a data set, based on a specified search radius for creating a similarity graph. It is shown that each cluster represent the speed that the brake event is happening. Clustering will result in 3 different colors of cluster. The red cluster shows the ***1st cluster*** which can be interpreted as the *highest speed level*. The 1st cluster could be approximated as the speed ranging from 15 m/s until 17.5 m/s which could be translated to 54 km/h until 63 km/h.

The green cluster shows the ***2nd cluster*** which can be interpreted as the *middle speed level*. The 2nd cluster could be approximated as the speed ranging from 10 m/s until 14 m/s which could be translated to 36 km/h until 50 km/h. Moreover, the blue cluster shows the ***3rd cluster*** which can be interpreted as the *lowest speed level*. The 3rd cluster could be approximated as the speed ranging from 0 m/s until 8 m/s which could be translated to 0 km/h until 28.8 km/h.

The individual plot of the TTC vs Speed at brake onset is shown in the Fig. 4 and Fig. 5 in the next page. From these graphs, similarly we could infer that each participant has different speed at brake onset and TTC at brake onset. The spectral clustering can only result in the clustering based on speed, not based on TTC value.

Assuming that the average TTC is 2 s as it is the most dense TTC point, we could conclude that participant 2 and 4 has the highest TTC tendency that might indicate these participants tend to drive carefully by having mostly early start of brake onset regardless of the speed at brake onset. On the other hand, we could also categorize participant 8 and 9 as a relatively reckless since they have the average of TTC far below 2s by simple observation of the plots. In addition, the rest of the drivers (participant 1,5,6,7) could be concluded as an average person whose TTC average hovering +/- 0.5 second from the determined average point of 2 second. In addition, through analysis of individual plots, we could see the general trend that the TTC increase with respect to vehicle speed even though this is not true for all cases. This indicates that normal average person will tend to be more careful when they drive on a higher speed as shown by the increase in TTC.

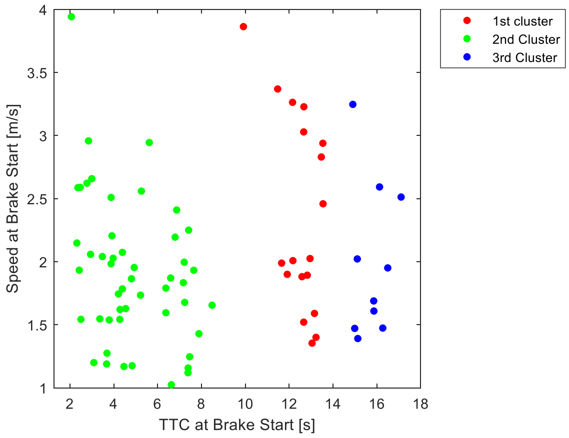

Fig. 3. TTC vs Speed All Participant Plot

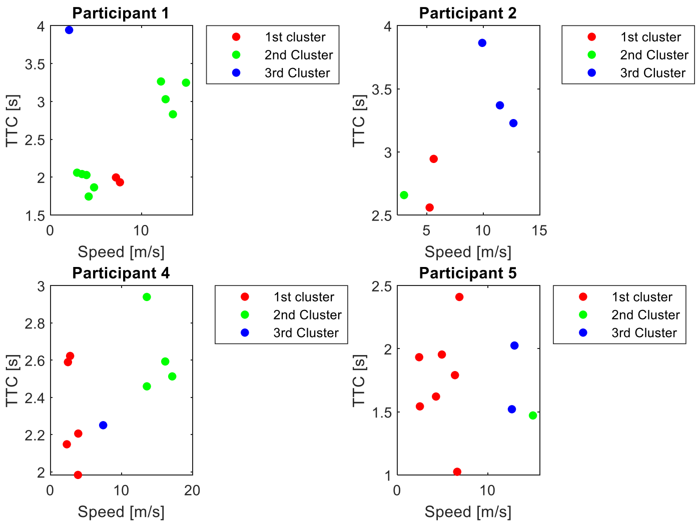

Fig. 4. Participant (1,2,4,5) Individual Plot with Clustering

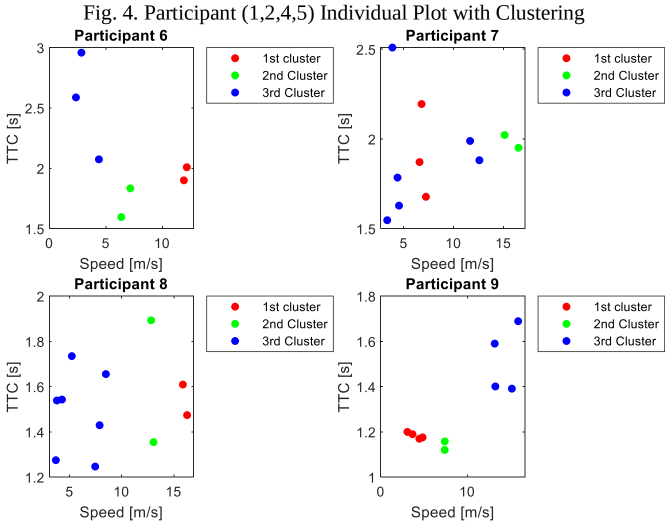

Fig. 5. Participant (6,7,8,9) Individual Plot

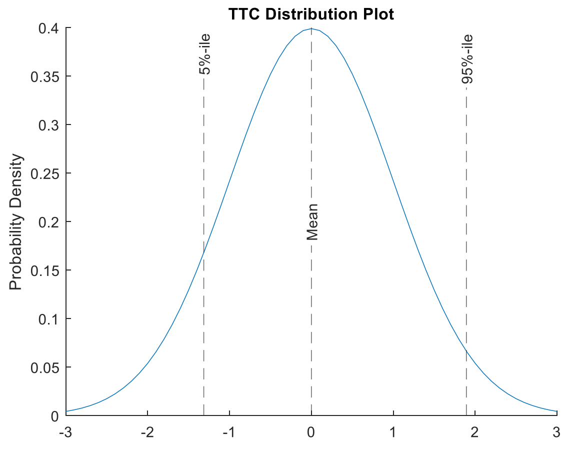

Fig. 6. TTC Normal Distribution Plot

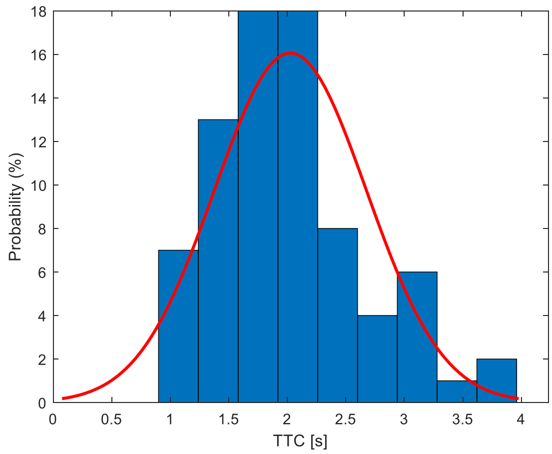

Fig. 7. TTC Histogram Distribution Plot

Table 1. TTC Statistical Parameters

μ (Mean)	σ (Standard Deviation)	95th Percentile	5th Percentile
2.02632	0.650244	3.2574	1.1713

In order to plot the TTC distribution plots above (Figure 4), we used Normal Distribution (Gaussian Distribution) method which uses the equation shown below.

$$y = f(x|\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-\mu)^2}{2\sigma^2}} \tag{8}$$

where x = Individual TTC data, μ = Mean of all data, σ = Standard Deviation of data, y = Probability

Using the Gaussian Distribution, sum of independent samples from any distribution with finite mean and variance converges to the normal distribution as the sample size goes to infinity. Based on table 1, the average of the TTC data is calculated as 2.02632 and the Standard Deviation is 0.650244. In addition, 95th Percentile and 5th Percentile point is calculated as 3.2574 and 1.1713 respectively. *The 5th Percentile* point indicates that only 5% of the population of TTC data has value which is below that point whereas the *95th percentile* point indicates that only 5% of the population of TTC data has the value which is above that point.

In Fig. 5, μ is defined as 0 point in the x-axis and σ is defined as the 1 incremental step to the left or the right of the 0 point. It shows that the only 5% of the driver has the value of TTC below 1.1713 and only 5% of the driver has the value of TTC below 3.2574. This shows that the assumption that we use is somehow valid since their average value are very much less than the average value of TTC.

Fig. 7 shows a more detailed explanation of the TTC distribution. It is shown that 36% of the driver start the brake by TTC of 1.6-2.2 seconds, around 50% by TTC of 1.2-2.2 seconds, around 21% by TTC of 2.2-4 seconds as well as around 20% by TTC of 0.9-1.6 seconds. This shows most of the driver in this experiment regarded the TTC of 1.2-2.2 seconds as the critical instant time to start braking. Hence, as a designer of Active Safety system, it is preferable to use the average of value of TTC of **2 seconds** as *general reference point*. Moreover, if we would like to rather personalize the design to the *relatively sensation seeking* driver, we could take the high point between 0.9-1.6 seconds which is **1.6 seconds** in order to keep a safety margin for the *most sensation seeking driver*. In addition, for drivers with the relatively cautious driving characteristic, we prefer to set the value of **3 seconds** as the TTC value as it is the mid-point between 2.2-4 seconds which represents trade-off between safety and comfort of the driver since taking too high TTC value for the design of the system will sacrifice the comfort by braking the vehicle more frequently.

In Fig. 8, we obtained the maximum deceleration normal distribution plot by the same method that we used in obtaining TTC normal distribution plot. This plot shows that the average of the maximum driver deceleration at the start of the braking is nearly -1.7969 m/s^2. This data also showed that only 5% of the driver decelerate more than -10.4063 m/s^2. Based on Fig. 10 plot, we could observe that around 62% of the driver has maximum deceleration of between -2 until -6 m/s^2. On the other hand, only 15% of the driver could actually achieve the level between -8 until -12 m/s^2. Similarly, we could use the data in Table 3 in order to get the average of the mean deceleration as -3 m/s^2 during the whole braking event. Consequently, from these data, we could use them as a reference of driver maximum braking deceleration capability in order to design the Automated Emergency Braking (AEB). The AEB as a mitigating crash or as a crash avoidance measure could be used by adding the braking deceleration capability on top of driver deceleration capability.

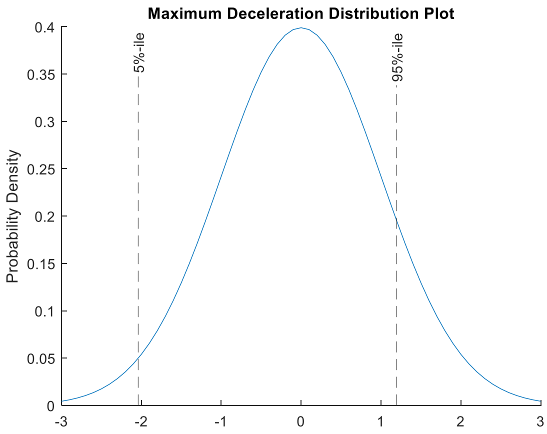

Fig. 8. Maximum Acceleration Normal Distribution Plot

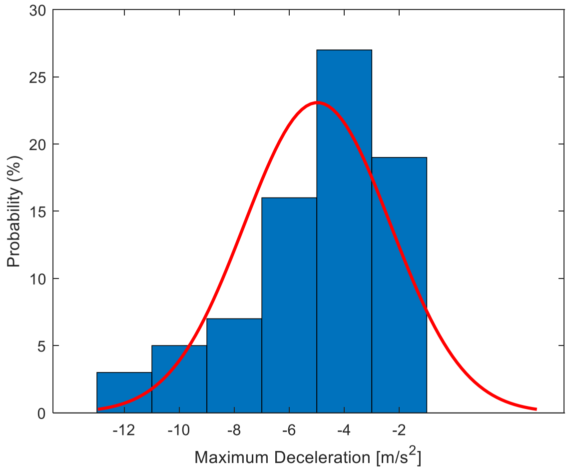

Fig. 9. Maximum Deceleration Histogram Normal Distribution Plot

Table 2. Maximum Acceleration Statistical Parameters

μ (Mean)	σ (Standard Deviation)	95th Percentile	5th Percentile
-4.97971	2.66164	-1.7969	-10.4063

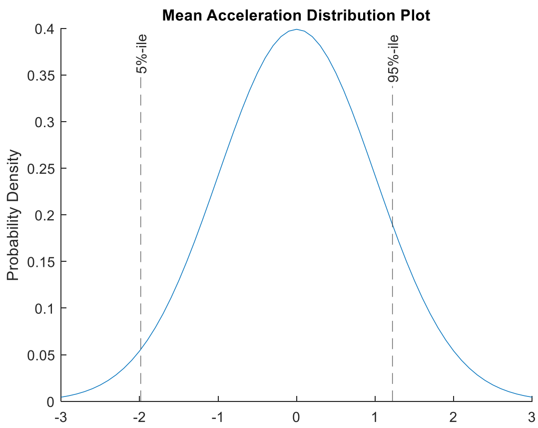

Figure 9. Mean Deceleration Normal Distribution Plot

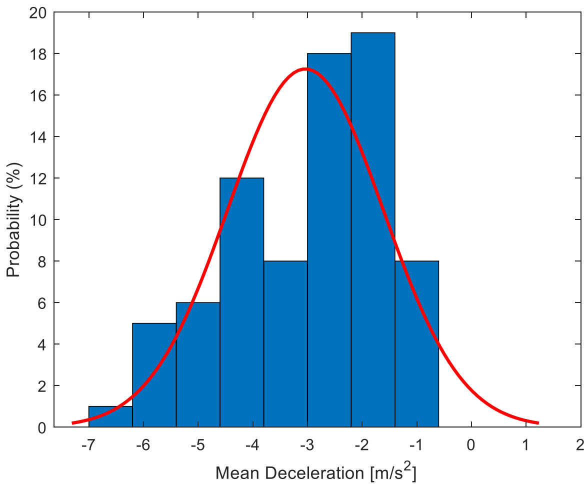

Figure 10. Mean Deceleration Histogram Normal Distribution Plot

Table 3. Mean Deceleration Statistical Parameters

μ (Mean)	σ (Standard Deviation)	95th Percentile	5th Percentile
-3.03818	1.42419	-1.3001	-5.8660

5. Task-4: Active safety system design

1. The two FCW systems suitable for scenario proposed in task 1 are,
    a) Audio, visual warning
    b) Haptic warning

    In both cases the threat assessment and decision-making processes follow the same algorithm, threat in this case is a stationary car which is revealed when the lead car departs lane and the driver is distracted. Main aim of any algorithm in an FCW system (threat assessment) is to estimate the distance to collision and TTC, if the calculated values when compared to pre-set standards show that they are in comfort zone (decision making)i.e. the collision can be avoided by driver action (braking, steering) the warnings are given. AEB, AES are used when the calculated values are past the comfort zones. {1}

    a) In this case the driver is engaged in reading a text on his phone which proves us that he is awake and can heed attention to any audio, visual warning from the car. Visual warnings can be lights on dashboard and simulated brake lights on windshield.
    b) Haptic warnings include tightening of seatbelt against the body and vibration of steering wheel, seats. Both can be sensed easily by the driver although he is distracted.

2. Both systems perform well in the given scenario, i.e. serve the purpose of alerting the distracted driver.

But, when a number of different scenarios are considered where the driver is distracted to a great extent such that the audio and visual warnings could pass unnoticed, haptic warning comes in handy. There might be situations where haptic warnings like steering vibration and seat belt tightening could not be useful if the driver is not in contact with steering and not wearing a seat belt at the right time, which is very unlikely, but the seat vibration proves to be the most prioritized option to alert the driver of the impending danger. An integrated system of audio-visual and haptic warning could be the ultimate solution for the warning not to go unnoticed and get the attention of driver as soon as possible.

3. The limitations of a FCW system are,
    a) These warnings can be ignored when the driver is heavily distracted or asleep.
    b) The warning systems are fruitless when the scenarios like task 1 occur i.e. when the obstacle or collision probability is detected without enough time for action to avoid.
    c) They just detect the collision and do not act on it i.e. they only alert the driver of possible imminent collision but cannot avoid it.

    As said above front collision warning systems cannot avoid collision on their own when the driver action or reaction time is slow. Hence, we need automatic emergency braking (AEB) systems or automatic emergency steering systems (AES) in the vehicles to stop or change lanes to avoid collision.

4. An AEB system comes into action when the calculated distance to collision and TTC are past the comfort zone of alerting the driver and have enough time for him to stop the car.

An AEB system must be suitable for all the driving conditions i.e. whether in highway or in urban driving conditions. Hence for this system to work the algorithm should not be based on the speed, but rather on range and TTC. This gives better chance of survival in urban conditions where usually the driving speed is around 30kmph and has lot of factors affecting or obstructing the vehicle such as jay walkers, distracted cyclists with earphones or distracted drivers.

Coming to task 1 the car should start threat assessment by detecting the slowing of the lead vehicle and charge the brakes, as mentioned above considering range and TTC the decision must be made. The range is 60mts, TTC calculated is 2.5 seconds and driver reaction is 1.5 seconds, it is impossible for the driver to react in time and start braking, avoid collision. Thus, making the system veto on AEB and applying braking with maximum deceleration to avoid collision (in the given scenario the deceleration has a constant value of $5ms^{-2}$, and the collision will not be avoided. It makes sense to have AES in this scenario which could help in changing lanes, which also has a disadvantage of blind spots).

5. The system does not perform well in the task 1 because of the restriction of deceleration, capping it at $5ms^{-2,}$ and having only 90mts to stop, therefore making the collision imminent as it requires 100mts to come to a complete stop even though the brake is applied.

The maximum deceleration of the car can be around $7.84ms^{-2}$, this value is obtained from the assumption that the car is driving under dry road conditions and the which gives us a road friction coefficient above 0.8, since the deceleration is dependent on the mass of the car there are chance where we can assume the downforce on the car is very good with improved aerodynamics in the car, for example in 2017 season f1 racing biggest braking was produced at monza{2} at about 5.2g. Hence in relative terms we can consider the maximum deceleration for a normal passenger car to be about 20% that of f1. And also, we can calculate using the formula,

$$F = m * \mu * g \tag{9}$$

Where, F = braking force
M= mass of car
μ = road friction coefficient

From this equation we can consider that with good dry road conditions of friction coefficient ~0.8 the maximum deceleration can be 7.84ms^{-2}.

Assuming this deceleration rate using equation no (1) & (2) we get new minimum range to brake as 39.86.mts. thus, the AEB should intervene when the distance is at least 50mts and no lesser than 45mts.

6. In the task 1 with fixed deceleration value of 5ms^{-2} it would be unwise to consider TTC as a threat assessment metric. As the TTC calculated is 2.5s and with known deceleration, value we can calculate the final velocity of the car by using equation (1). In an ideal case which should be at least 0, but in this case, it turns out to be 12.5m/s. Thus, making the TTC as threat assessment metric inefficient.

When faced with an obstruction for car, the range should be detected and then the TTC calculated. Thus, for a successful operation of AEB avoiding collision, the system should be activated at a time at least (TTC+1)s thus giving plenty of room for the car to stop.

To avoid collision with the intervention of AEB at (TTC+1) i.e. (2.5+1)s, the deceleration needed is 7.14ms^{-2}, calculated using the equation (1).

7. The deceleration obtained in the previous question is realistic, as these days the legal requirement of the deceleration is >5.8ms^{-2} {3} and achieving 7.14ms^{-2} under extreme conditions is not impossible.

As seen in the maximum deceleration histogram normal distribution plot, the mean deceleration is around -5ms^{-2} and 7.14ms^{-2} remains well inside the realm of possibility for the vehicle.

8. The limitations of AEB are,
    - They are expensive.
    - They cannot detect sudden obstructions like pedestrians, a car coming to lane without the driver noticing it.
    - Not widely available in vehicles, i.e. even after successful stopping from collision there are chances of the car getting into rear end collision from a following car with distracted driver and without AEB.

    Room for improvement,

    - Making them inexpensive thus urging the people to getting the system.
    - Extend the detection from just vehicles in front into detecting vehicles nearby and pedestrians.

6. Conclusion

Starting from the tasks, we analyzed the kinematics of vehicles using equations of motion to solve the hypothetical rear-end conflict situation presented. The experimental data was cleaned to have a clear dataset that was worthy of the use, in order to analyze the breaking maneuvers and driver behavior during the experiment conducted. With the above analysis in hand, we could propose threat assessment and decision making to formulate FCW and AEB systems and discuss the effectiveness and limitations of the proposed system. We learnt a ton on how the data is processed and analysis of the processed data. Coming up with different scenarios in order to develop active safety system that overcomes those was very informative. The contribution of work among the group members is as follows:

Table 4. Contribution of group members

Fikri	Nithin	Subhash
Task 1	Task 1	Task 1
Task 2	Task 2	Task 2
Task 3	Task 4	Task 4

All the group members worked equally in programming and report.

7. Reference

1. Decision making on when to brake and when to steer to avoid a collision(Mattias Brannsrom and Erik Coelingh ,Jonas Sjoberg)
2. Motorsport.com
3. TME121 Engineering of Automotive Systems BRAKE SYSTEMS (Ingemar Johansson)
4. TME192: Active Safety Project;- Active safety system development (Ron Schindler, Linda Pipkorn)