Active Safety Project

Group number 6

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Introduction

This assignment report reflects our learning and understanding of the concepts learned throughout the Active Safety course. As described in the assignment instructions, the report is divided into tasks. This report specifically analyses safety-critical events in case of a rear-end collision.

Task 1: A hypothetical rear-end conflict situation

a) Minimum range

From given data,
Initial velocity, $u = 90km/h = 25\,m/s$
Acceleration, $a = -5\,m/s2$
Final velocity, $v_t = 0$
Using equation of motion,

$$v_t = u + at = \frac{v_t - u}{a} = \frac{0 + 25}{5} = 5s \quad (1)$$

$$S = ut + \frac{1}{2}at^2 = 62.5m \quad (2)$$

Therefore, minimum range, **S = 62.5 m**

b) Time-to-collision (TTC)

TTC is a metric used to assess traffic safety and driving risk. It is used to estimate the time it takes for a vehicle to collide with an obstacle in front of it.
The time to a collision occurs between the involved vehicles is known as TTC.

$$TTC = \frac{x}{v_{con}} = \frac{62.5}{25} = 2.5s \quad (3)$$

c) Stopping Distance

The driver's reaction time is **1.5s**, so the distance travelled under reaction time is $1.5 \times 25 = \mathbf{37.5m}$
From part B, the distance travelled by the car from an initial speed of constant deceleration to 0 m/s is **62.5m**. So, the stopping distance with reaction time

$$62.5 + 37.5 = \mathbf{100m} > 90m$$

Therefore, the 90m distance to the target vehicle means that a collision **cannot be avoided**

d) Kinematics of the event overtime.

Solution:
When the distance to obstacle is 0, there has been a car crash.

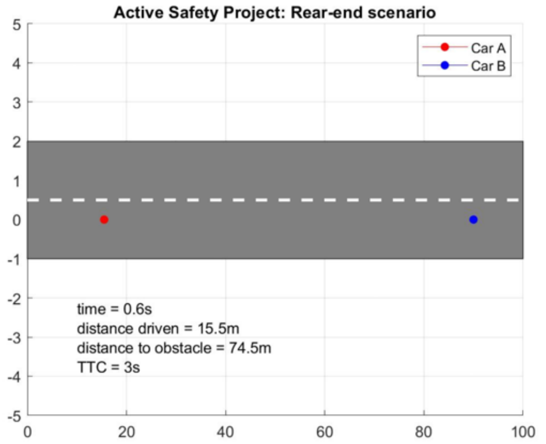


Figure 1.2 Kinematics of the event (no crash)

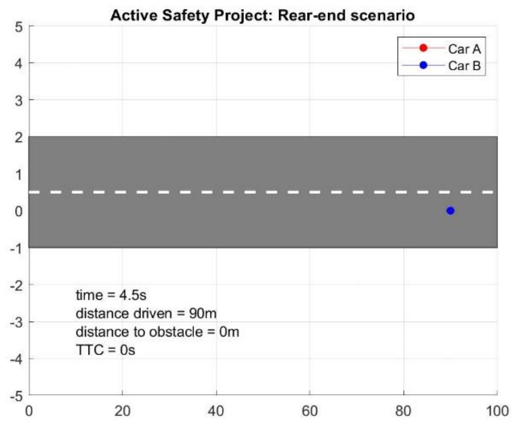


Figure 1.3 Kinematics of the event (crash)

Task 2: Study critical braking behaviour with experimental data

In this part, we have designed an algorithm for automatic recognition of vehicle braking behaviour through MATLAB, which is able to identify the vehicles' braking and calculate the relevant parameters related to braking of these vehicles.

a) Data processing

To make it easier and secure to process the data, we create a new data structure called "***new_data***" to save the processed data.

In the next step, we use a loop to traverse the original data and extract the data into a new data structure based on certain conditions. In this loop, we check if the radar range data contains a NaN value, and if it has no NaN value, the data will be extracted into a new structure and the radar time will be time-synchronised by minus 0.2 seconds from the radar time to make the radar data and the vehicle kinematics time aligned.

In order to complete the case where *RadarRange* is *NAN*, we first calculate the distance of vehicle by integrating *VehicleTime* and *VehicleSpeed*, and then calculate the corresponding integral values for the *RadarRange* which is not *NAN*, and subtract them, then take the average value of these numbers as offset, and subtract the offset from the range of the integral value, finally we get the completed *RadarRange*.

We use the vehicle's acceleration and speed changes to determine if the vehicle has brake behaviour. The average deceleration of a car should be 3-4 m/s², but in practical vehicle braking, except in emergencies, the braking deceleration should not normally be greater than 1.5-2.5 m/s². So, we first calculated the deceleration of the car and added a new column ***Brake*** after ***new_data*** to count whether the car has performed braking or not. We have decided the data with acceleration value less than 1.4 m/s². as having braking situation and given its ***Brake*** value as 1.

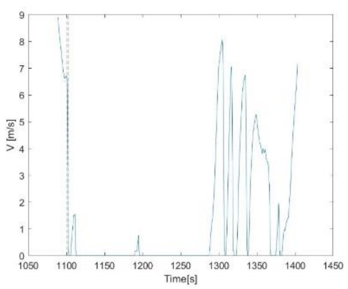
Next, we set the brake zone. When the car's deceleration is first less than 1.4 m/s², record it as start time. Then, when the speed is less than 0.3m/s and the acceleration remain less than 0, it is set as the braking end time. Finally, we plotted the time-velocity curve for each vehicle and manually filtered out a few unsuitable images and removed them.

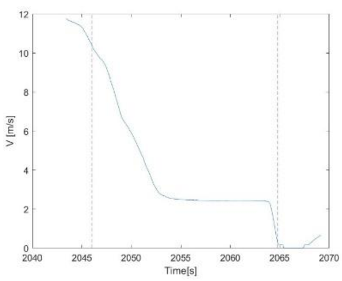
In the loop, we also calculate the relevant parameters: Mean acceleration, Minimum acceleration, Speed at brake onset, Range at brake onset and TTC at brake onset. Finally, we save this data in a new table ***results_table***

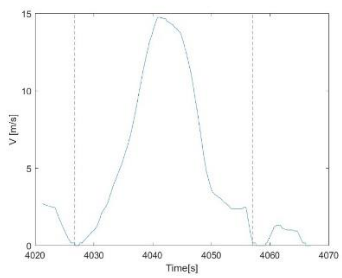
b) Data discard

We performed a two-step data discard. Firstly, we determine whether in ***RadarRange***, at ***start_i*** the ***RadarRange*** is NaN or not, if the data is NaN at this point, then this set of data will be discarded.

The second step is manual selection. We manually remove this data when the curve has the following conditions:







1.The Timeframe is too tight	**2.The car experienced two braking processes with a period of constant speed**	**3.Misidentification of algorithms**
Figure 2.1 Case 1	Figure 2.2 Case 2	Figure 2.3 Case 3

Through data selection, our algorithm successfully passed the test with **55** sets of data.

c) Result table

1.Mean Acceleration

Mean acceleration is the average of the vehicle's acceleration throughout the braking process. It indicates the average deceleration of the vehicle during braking. A higher value of average acceleration means that the vehicle is subjected to greater deceleration during braking, which is usually higher for emergency braking or driving in dangerous situations.

In the table, we can see that the mean deceleration of some cars reaches 6 m/s^2, which is a very emergency braking situation, if the driver can be warned to brake in advance, the mean deceleration will be lower, and the possibility of crash will be reduced.

2. Minimum Acceleration

Minimum acceleration is often important in assessing the most dangerous braking situations, s it reflects the maximum load the driver can tolerate in a potentially dangerous situation. As we can know from the table, some of the cars minimum acceleration reached 11 m/s^2, which means that they experience emergency braking.

3. Speed at Brake Onset

The speed at brake onset is the speed of the vehicle when the driver begins to perform the braking manoeuvre. Braking at higher speeds may require longer braking distances, while braking at lower speeds may be easier to control. This metric can be used to calculate braking strategy and TTC time. In the table we can know that nearly 70% cars brake at speeds higher than 6m/s, which means they are exposed to a higher risk of collision.

4. Range at Brake Onset

The range at brake onset is the distance between the vehicle and the obstacle in front of it when the driver starts braking. It indicates the distance between the vehicle and a potential collision object at the onset of braking. A shorter distance at the onset of braking means that the driver needs to react faster to avoid a collision. From the table, we know that some vehicles have a very short braking distance, which means that the driver needs to make a braking manoeuvre very quickly.

5. TTC at Brake Onset

TTC is the time interval between the vehicle and the obstacle ahead when braking begins. A lower TTC indicates an increased risk of crash with the obstacle in front because the driver needs to act more quickly to avoid a collision. From the table we can clearly know that the TTC for these drivers is between 1s and 4s, which means that the driver is at high risk of crashing.

d) Example of a brake maneuver

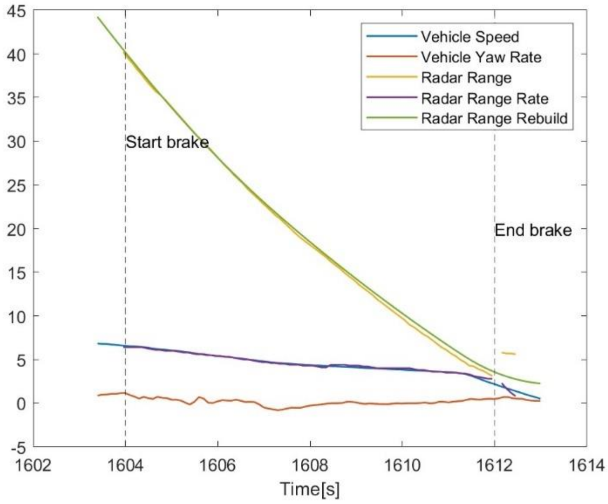


Figure 2.4 Brake maneuver

Task 3: Driver behavior analysis

a) Plot speed at brake onset (x-axis) vs. TTC at brake onset (y-axis) for each participant.

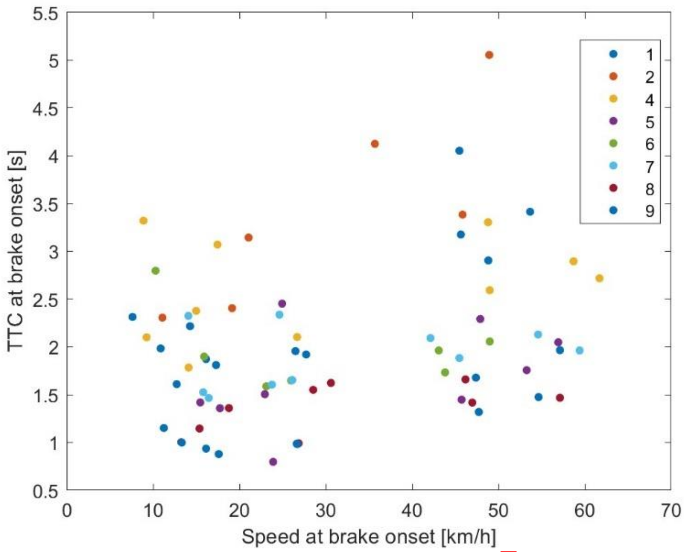


Figure 3.1 Speed vs. TTC

b) Use the graph to describe if the different drivers have both high and low TTC values or are there clusters in the data?

The Figure 3.1 illustrates a varied distribution of Time-to-Collision (TTC) values among different drivers. Some drivers exhibit both high and low TTC values, indicating fluctuations in their driving behavior. For instance, Participant 2 demonstrates a wide range of TTC values, ranging from a high of 5.05 seconds to a low of 2.3 seconds.

Most of the tests conducted resulted in TTC values below 2.5 seconds, which means that they trend towards quick decision-making and responsiveness among the participants. Besides, Participants 8 and 9 consistently displayed lower TTC values, consistently below 2 seconds, indicating their rapid reaction times.

c) **Plot a histogram showing the TTC data for all drivers. Which type of statistical distribution would you say best decribes your data (e.g. normal, skewed)? What are the 5th and 95th percentiles?**

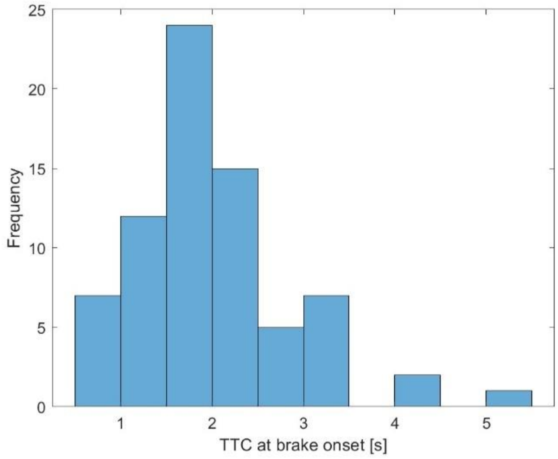


Figure 3.2 TTC for all drivers

From Figure 3.2, the histogram reveals that the distribution of TTC values is **skewed to the right**, indicating that most drivers tend to have lower TTC values, reflecting quicker reaction times.

The 5th percentile, representing the value below which **5%** of the data falls, is **0.985s**. This indicates that 5% of the drivers had a TTC value of 0.985s or lower, suggesting an extremely quick response from this portion of the participants.

On the other hand, the 95th percentile, which represents the value below which **95%** of the data falls, is **3.41s**. This implies that 95% of the drivers had a TTC value of 3.41s or less than it. The presence of a relatively small number of drivers with higher TTC values contributes to the right skewness of the distribution.

d) **Active safety system**

In this dataset, the 5th percentile and the 95th percentile of TTC values are significant metrics to consider. The 5th percentile value of 0.985s represents a very quick response time, indicating that 5% of drivers react exceptionally fast in critical situations. On the other hand, the 95th percentile value of 3.41s suggests that 95% of drivers react within this timeframe.

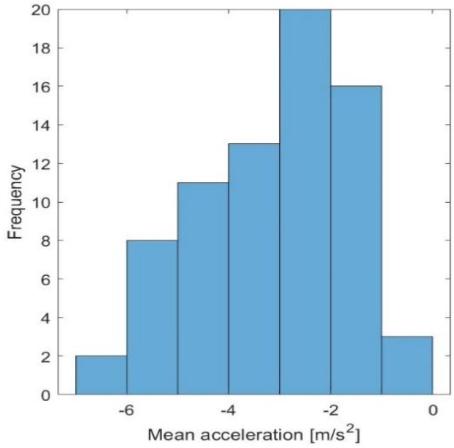
Designing a system only based on the **average TTC** (from the table is 1.89s) might not be optimal. If the system is designed for the average person, it might not be responsive enough for the 5% of drivers who react exceptionally quickly (0.985s). In the emergency situations, such as avoiding crash, this system might not provide adequate warnings or interventions for these drivers.

Conversely, designing the system for the most careful drivers (more conservative system) could result in frequent and unnecessary warnings or interventions for the 95% of drivers who typically react within 3.41s. This could lead to driver annoyance and reduced trust in the system due to constant alerts for situations that might not be genuinely critical.

Designing for sensation-seeking drivers (a more aggressive system) might provide faster warnings, but it could also lead to riskier behaviours as these drivers might become desensitized to frequent alerts, leading them to ignore genuine critical situations.

Generally, the driver's reaction time is about 1.2 s. We decided to set **the aggressive TTC** of the active safety system is 1.89s + 1.2s = 3.1s, the **conservative** one is **3.4s + 1.2 = 4.6s**

e) Mean and minimum acceleration



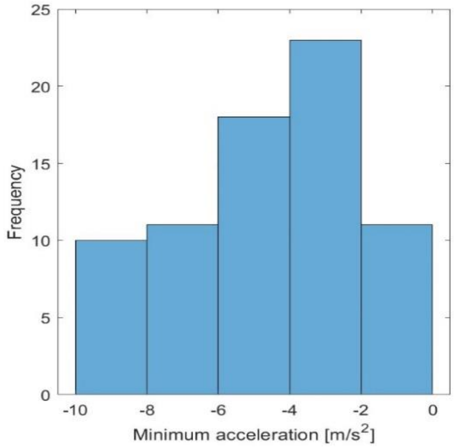


Figure 3.3 Mean acceleration Figure 3.4 Minimum acceleration

From Figure 3.3 we can know that most drivers have an average deceleration of between 2 m/s^2 ~ 3 m/s^2, and only a small percentage of drivers are able to achieve 6 m/s^2 ~ 7 m/s^2. This means that most of the participants had conservative driving strategies.

From figure 3.4, the majority of drivers will not achieve the minimum deceleration greater than 6 m/s^2, but there is a significant proportion of drivers with aggressive driving strategies, which demonstrates the different levels of threat perception by drivers.

Task 4: Active safety system design and evaluation

a) TTC based on Task 3

The first system is an aggressive one which would give the driver a warning when TTC is less than 3.1s. The second one is more conservative to cover most of the drivers' cases with a threshold of 4.6s. Both systems use TTC as the threat-assessment. When TTC is less than the given threshold, the system will give an audible or visual warning which is a decision.

b) FCW system test and new TTC for FCW

We set a series of thresholds for the FCW system and test each of them in the scenarios described in Euro NCAP CCRs. If the threshold tested currently can not help the driver avoid a collision in one scenario, the threshold will not be a valid threshold. Based on that, the series of thresholds are set to be *5:-1:1*. The most aggressive threshold is the minimum one among all the valid thresholds that will not let even one collision happen. The most aggressive TTC threshold is 4.1s. It has a higher threshold than that of the aggressive FCW in task 3, and it's more aggressive than the most conservative FCW in task 3. Since 4.1s is the most aggressive threshold that can ensure no collision happen, the aggressive FCW in task 3 will fail to prevent the driver from a collision. The lower FCW works for the slowest speed has a threshold of 3.2s. The difference of the threshold 4.1s and 3.2s is caused by the different velocity of the vehicle. A lower speed would allow higher TTC threshold.

c) Limitations of an FCW system

An FCW system may rely too much on the reaction time of the driver. If the driver does not react in time after the FCW gives a warning, and if the threshold is set too aggressively, a collision could still happen. Moreover, an FCW system that can handle high speed scenarios may not be convincible enough for the driver when the speed is low. Therefore, it is better to have an AEB system to help the driver if the warning given by the FCW system is ignored.

d) AEB system based on acceleration

In our design, we set the threshold of -7 m/s^2. We get this result in Automotive Theory, Tsinghua University, Zhisheng Yu [1]. He came to the conclusions based on the HongQi CA770, which uses a compressed air-hydraulic braking system to conduct experiments.

The threat assessment is performed by calculating the required acceleration needed to stop the car based on the current range and range rate. If this calculated acceleration exceeds the maximum braking capability of the car, the system identifies it as a potential threat.

For the decision making, if the acceleration calculated is less than or equal to the maximum braking capability, the AEB system remains inactive (activate = 0), indicating that there is no immediate threat. However, if the acceleration exceeds the maximum braking capability, the AEB system activates (activate = 1), initiating emergency braking to prevent a potential collision.

e) AEB test on Euro NCAP CCRs

Since the maximum braking speed of AEB is set differently by different car manufacturers, according to the description of CNCAP [2], the braking deceleration of AEB is 8 m/s^2~10 m/s^2 in general, so we set the maximum deceleration of AEB to $9m/s^2$. We tested the system with the speeds of the different Euro NCAP scenarios and calculated the remain distance from the vehicle in front,

AEB is triggered at all speeds except at 10km/h and the remaining distance is greater than 0 within the distance interval of $0 \sim 100\text{m}$, which indicates that the AEB system is working well and can prevent collisions.

f) AEB system based on low/high speed TTC

Generally, the speed limit on city streets is 40km/h, so we use 40km/h to distinguish between high and low speed conditions. Firstly, we first calculate the TTC for the limiting operating condition.

Low speed TTC threshold:

$$x = \frac{v_0^2 - v_t^2}{2 \cdot a} = \frac{(40/3.6)^2}{2 \cdot 9} = 6.85\, m$$

$$TTC = \frac{x}{v} = \frac{6.85}{40/3.6} = 0.62\, s$$

High speed TTC threshold:

$$x = \frac{v_0^2 - v_t^2}{2 \cdot a} = \frac{(80/3.6)^2}{2 \cdot 9} = 27.43\, m$$

$$TTC = \frac{x}{v} = \frac{27.43}{80/3.6} = 1.3\, s$$

We tested our system under Euro NCAP CCRs, the AEB system was triggered, and we avoided the crash.

Speed (km/h)	TTC threshold (s)	Activate Distance (m)	Remain Distance (m)
10	0.62	1.72	1.29
15	0.62	2.58	1.65
20	0.62	3.44	1.75

25	0.62	4.3	1.62
30	0.62	5.16	1.30
35	0.62	6.02	0.76
40	0.62	14.44	7.58
45	1.3	16.25	7.56
50	1.3	18.05	7.33
55	1.3	19.86	6.89
60	1.3	21.66	6.23
65	1.3	23.47	5.36
70	1.3	25.27	4.26
75	1.3	27.08	2.97
80	1.3	28.88	1.46

Table 4.1 AEB based on TTC results

g) AEB false trigger

AEB systems can be triggered incorrectly when identifying speed bumps These speed bumps are often designed as a more abrupt section of road surface height change, and a basic AEB system may misinterpret this sharp road surface change as a potential collision threat, triggering the emergency braking.

In addition, AEB may be triggered by mistake when entering a tunnel. In this scenario, the AEB system may incorrectly perceive the edges of the tunnel, walls or light shadows as obstacles, which could trigger the braking system in the mistaken belief that the vehicle is going to crash.

To solve this problem, we can change the radar mounting height and find the best position for it. Besides, we have to combine the AEB system with multiple sensors (e.g., camera, radar, LIDAR, etc.) to obtain more information about the environment. With these sensors, the system can more accurately identify obstacles on the road and be able to distinguish between actual dangerous obstacles.

h) FCW & AEB in Task 1

We tried a variety of TTCs to stop the vehicle, and finally used AEB set by acceleration, which successfully stopped the vehicle when it hit the front vehicle. However, it collided when using aggressive FCW. We also tried AEB set by TTC, however, our test before the maximum speed is 80km/h and in Task1 its speed is 90km/h, so the collision is also triggered in our TTC-based AEB system.

In the Task 1 visualization tool, we try different TTCs

For aggressive FCW system, we set 4.1s calculated by our function.

For conservative FCW system, we set 4.35s.

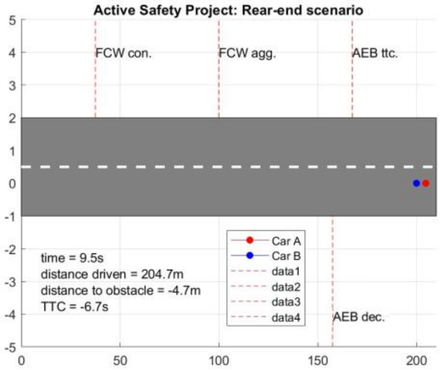


Figure 4.1 AEB TTC Kinematics of the event (Crash)

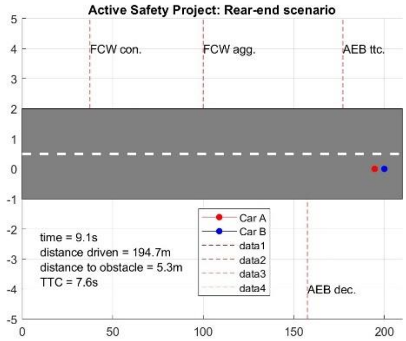


Figure 4.2 AEB ACC Kinematics of the event (No Crash)

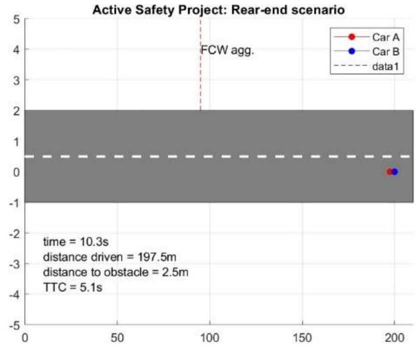


Figure 4.3 FCW aggressive Kinematics of the event (No Crash)

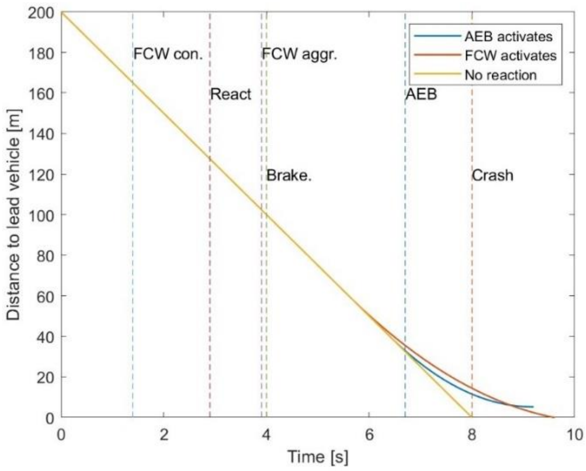


Figure 4.4 Distance to lead vehicle by different active safety system

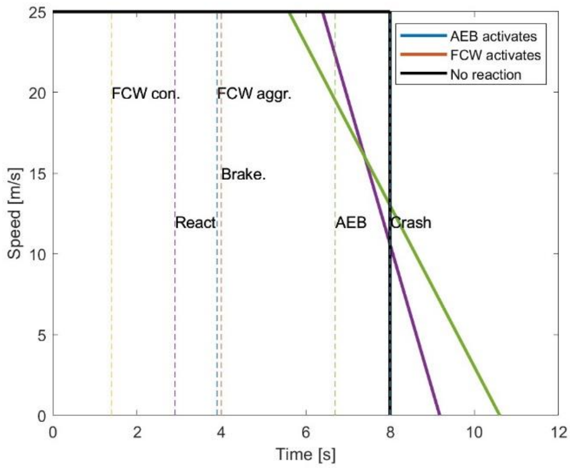


Figure 4.4 Vehicle speed by different active safety system

Conclusion

In this project, we start with the basic kinematic model, which gives us a preliminary understanding of the concept and use of TTC. Then, we processed different NDS through Matlab and plot the TTC of different drivers based on the processed data. Next, we selected the appropriate TTC from previous task to set up the FCW system through the principle of statistics. Based on the TTC, we set up the AEB system at different speeds and tested the EURO-NCAP protocol. Finally, we applied this system to the previous problems to verify whether our system was effective. All in all, we gained a lot from these tasks and learned more about active safety.

Yahui Wu	Task 1 Task 2 Task 3 Task 4 (FCW) Report writing
Tianshuo Xiao	Task 1 Task 2 Task 3 Task 4 (AEB) Report writing
Nishanth Suresh	Task 1 Task 3 Report writing

Table 5.1 Work load

Reference

[1] Yu, C.S.. (2006). Theory of Automobiles, Fourth Edition. Beijing: Mechanical Engineering Press, 5.

[2] China New Car Assessment Program. CNCAP. (n.d.). https://www.c-ncap.org.cn/

[3] Euro-ncap-aeb-c2c-test-protocol-v42. EuroNCAP. (n.d.). https://www.euroncap.com/en/for-engineers/protocols/

Attachment

Participant	Mean acceleration [m/s^2]	Minimum acceleration [m/s^2]	Speed at brakeonset [m/s]	Range at brake onset [m]	TTC at brake onset [s]
1	-2.751705537	-3.515273473	7.609375	13.2	1.734702259
1	-2.974056427	-3.827359528	13.2734375	33.9	2.553972925
1	-2.120495324	-2.969640892	4.640625	8.2	1.767003367
1	-2.641185328	-3.280921908	7.125	12.1	1.698245614
1	-1.701351081	-2.109796959	3.296875	4.7	1.425592417
1	-1.0547732	-1.40822151	1.96875	7.8	3.961904762
1	-1.674115115	-2.111697868	3.8125	8	2.098360656
1	-2.646517456	-3.515976598	2.328125	4	1.718120805
1	-1.811721443	-2.343984398	4.03125	5.8	1.43875969
1	-2.32264653	-3.593390661	14.8828125	49	3.292388451
2	-1.565020161	-1.875375075	5.1484375	14.4	2.796965099
2	-1.467079092	-1.799033841	2.9140625	6.2	2.127613941
2	-1.481917385	-2.108742377	9.7421875	37.9	3.890296712
2	-1.646405939	-2.109375	4.7109375	9.9	2.101492537
2	-1.972348999	-3.437156284	12.328125	50.5	4.096324461
2	-2.37677089	-3.203765753	12.59375	40.3	3.2
4	-2.545067221	-3.903907655	13.4453125	41.9	3.116327716
4	-3.918913341	-6.092531494	17.046875	43.2	2.534188818
4	-3.201196089	-4.765625	13.375	31.4	2.347663551
5	-4.406220625	-5.547984597	6.8203125	15.6	2.287285223
5	-5.397580066	-6.561187762	6.2265625	9	1.445420326
5	-5.059334525	-6.874312569	12.875	21.2	1.646601942
5	-3.789125652	-5.15625	4.7734375	5.7	1.19410802
5	-5.913370564	-9.221516455	15.59375	26	1.667334669
5	-6.152220706	-9.220594119	12.578125	15.6	1.240248447
5	-6.048202284	-9.764648535	14.7265625	24.4	1.656870027
6	-5.03054878	-7.581157463	11.8046875	16.1	1.36386499
6	-5.25620795	-9.220594119	13.3984375	23.8	1.776326531
6	-4.486333181	-6.561843816	11.875	21.3	1.793684211
7	-3.543115162	-4.218328167	6.296875	7.9	1.254590571
7	-2.225177152	-2.656781356	6.7265625	14.6	2.170499419
7	-3.643053757	-4.922859572	7.15625	10.6	1.481222707
7	-4.89371085	-7.424844938	12.4375	20.1	1.616080402
7	-2.302430337	-2.656515652	4.125	5.4	1.309090909
7	-2.343694854	-2.890914091	4.2421875	4.9	1.155064457
7	-3.091182798	-4.844234423	11.609375	22.1	1.903633917
7	-2.692286982	-3.281578158	3.703125	7.9	2.133333333
7	-4.49334398	-5.624437556	15.0546875	29.2	1.939595226
8	-3.430660812	-5.625	8.4296875	12	1.423540315
8	-6.767949622	-11.015625	13.0390625	15.9	1.219412822
8	-3.134726441	-4.140625	5.1953125	6.5	1.25112782
8	-2.950675759	-5	4.078125	4	0.980842912
8	-4.286054799	-6.248125562	12.703125	18.8	1.4799508
8	-3.3671875	-4.141039104	3.5546875	2.9	0.815824176
8	-4.76044466	-6.647272272	7.875	10.5	1.333333333
8	-6.215550413	-12.030047	15.71875	20.4	1.297813121

9	-6.455965909	-9.374062594	7.375	5.8	0.786440678
9	-6.455555101	-8.66407733	7.3125	5.8	0.793162393
9	-2.578054689	-3.359039096	3.015625	2.9	0.961658031
9	-5.1499588	-8.59375	13.125	19.4	1.478095238
9	-4.95654215	-6.40625	4.7578125	3.3	0.693596059
9	-6.750587489	-9.9980004	15.0625	19.3	1.281327801
9	-7.217480973	-11.09485949	13.1796875	14.9	1.130527564
9	-3.758597031	-4.764195741	3.6328125	3	0.825806452
9	-5.735336059	-8.447637165	15.7734375	27.3	1.730757801