TME192 - Active Safety

Project Report:

Driver behavior and active safety systems in critical rear-end situations

Group 14
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Abbreviations

Denotation	Declaration
AEB	Automatic Emergency Braking
FCW	Forward Collision Warning
NaN	Not a Number
TTC	Time-To-Collision

Introduction

The aim of this project was to propose a forward collision warning (FCW) and an autonomous emergency braking (AEB) system by analyzing the kinematics of a rear-end situation and by processing and using experimental data to understand drivers' braking behavior in a critical rear-end situation. The different tasks carried out are:

- Analyse and visualize a hypothetical rear-end conflict situation.
- Study critical braking behavior with experimental data.
- Driver behavior analysis using the safety metrics table.
- Active safety system (simple FCW and AEB systems) design.

Task 1: A hypothetical rear-end conflict situation

In this first task, the following hypothetical rear-end conflict was studied.

A driver, who is on the way home from work, is following a lead vehicle at a constant distance on the highway at a constant speed of 90 km/h. The driver is engaged in distracted driving: looking down on the phone reading a text message from a friend. The consequence of the distraction is that the driver does not realize that the lead vehicle is changing lane and uncovers a stationary vehicle which the driver is now approaching. The driver has a reaction time of 1.5 s and the vehicle brakes with a constant deceleration of 5 m/s2 when the brakes are applied by the driver.

- The minimum range (the distance between the driver's car and the stationary vehicle) at which the driver needs to start braking to avoid a collision is 62.5m

$$min\_range = -V^2/(2*a) = 62.5\ m$$

where, V = Velocity(m/s)
a = acceleration(m/s^2)

- The TTC for the above mentioned moment can be calculated using the formula,

$$TTC = (min\_range)/V = 2.5\ seconds$$

This means that the driver will need a TTC of 2.5 seconds to avoid the collision.

- Taking into consideration the driver's reaction time, a distance of 100 m is needed for the driver to stop the car. As the stationary vehicle is just 90 meters ahead(<100 m), the collision cannot be avoided.

$$range = 90m;\ react\_dist = (V * react\_time) = 37.5\ m$$

$$dist\_req = \ react\_dist + min\_range = 37.5 + 62.5 = 100\ m$$

where,
react_dist = reaction distance (m)
react_time = reaction time (s)

(d) An animation of the hypothetical rear-end conflict was made containing the information about the travelled distance or distance to the lead vehicle,the speed of the driver, and when a crash occurs. The animation is included in the attached .m file.

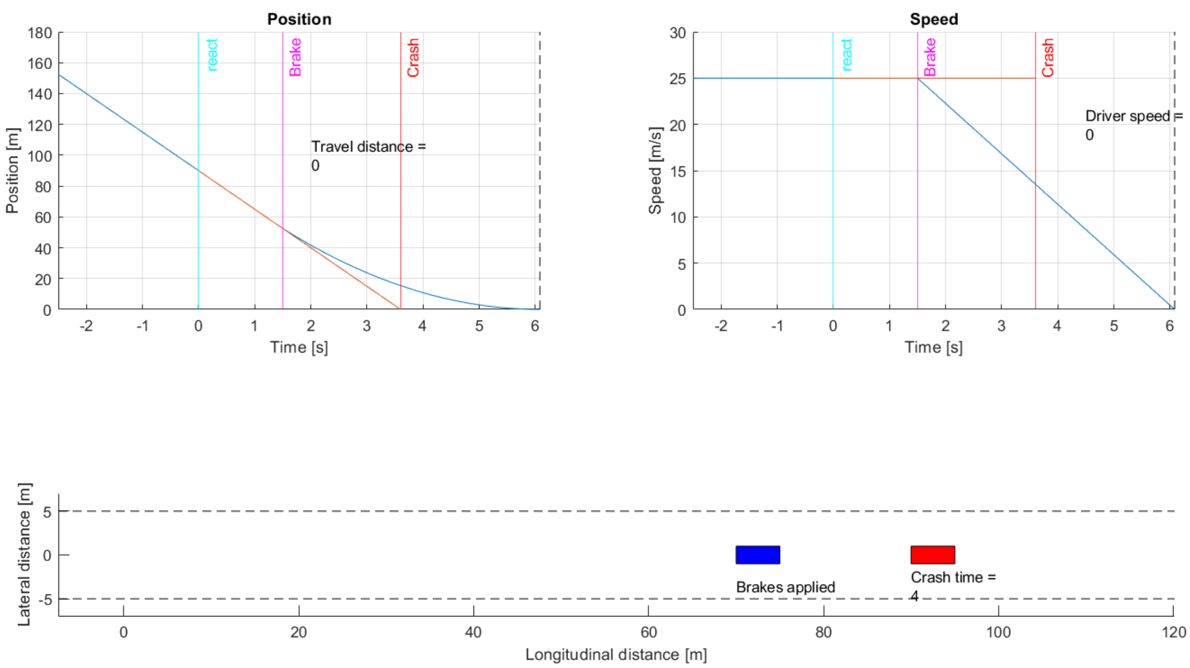


Figure 1: Animation of the conflict

Task 2: Study critical braking behavior with experimental data

In this task, drivers' braking preferences in a critical rear-end situation was studied using experimental data provided. The following steps were carried out:

- The data was imported into MATLAB and the structure containing the data was studied.
- A new struct(RadarData_edit) is created for editing purposes.
- The empty test runs were removed by finding runs with only NaNs by comparing whether the number of NaN elements present in the test run(using MATLAB function called *isnan*) and the size of the test run(using MATLAB function called *size*) are the same in the new struct created and the radar and vehicle kinematics time were synchronized as the radar time is 200 ms delayed compared to the vehicle time by subtracting radar time vector by 0.2 seconds.
- Unwanted extra values which are present within vehicle speed, yaw rate and vehicle time values (Appx. 3 per data) are removed to make the vector length consistent.
- The NaN elements present inside the radar range and radar acceleration values of the test runs were filled with data using interpolation function *fillmissing*.
- The NaN elements present inside the radar range rate was filled with values from vehicle speed as Radar range rate is very similar to the vehicle speed values(which makes sense).

Identifying Braking Maneuvers

- An Algorithm was created which automatically identifies the braking maneuvers.
- Each test run was plotted for the start and end of the braking maneuvers and were plotted to verify how the automatic algorithm works.
- The test runs manually removed were Test run 7(Due to Very low speed at brake onset), Test run 20(Due to abrupt changes in yaw rate which indicates steering action performed by the driver), Test run 46(Due to Very high range and very low speed at brake onset which outputs very high TTC values) and Test run 51(Due to Very high range and very low speed at brake onset which outputs very high TTC values).
- Excluding the above manually removed 4 test runs, the rest of the 78 test runs were included in the safety metrics table(Table 1).
- The mean acceleration and minimum acceleration for each braking maneuver were calculated and recorded. The mean acceleration was found between the two abrupt change points(beginning and end of the acceleration trough) using the MATLAB function called *mean*. The TTC was calculated at the start of the braking maneuver using the formula,

$$TTC\_at\_BO = \frac{Range\_at\_BO}{Speed\_at\_BO} \tag{1}$$

- The safety metric results were stored into a table named Safety_Metrics.mat and is present in the APPENDIX section.

In the above figure, The Radar Range, Radar Range Rate, Vehicle Speed, Acceleration and Yaw Rate versus time. The brake onset and brake release points are calculated by an algorithm which uses threshold points and finds abrupt change points(point at which the acceleration value changes rapidly) of acceleration. The vehicle acceleration is found using the formula,

dx = change in vehicle speed

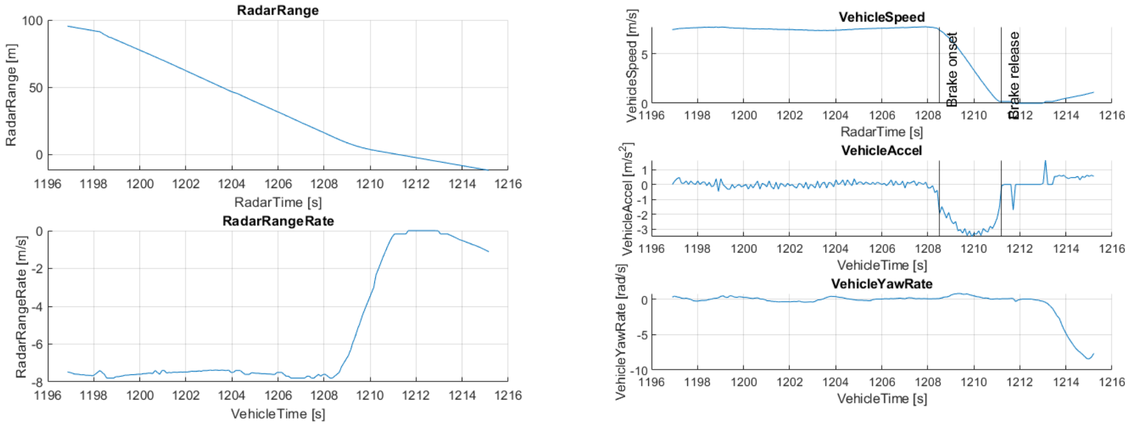


Figure 2: (a)Radar Range and Range rate vs time (b)Vehicle speed, Acceleration and Yaw Rate vs Time

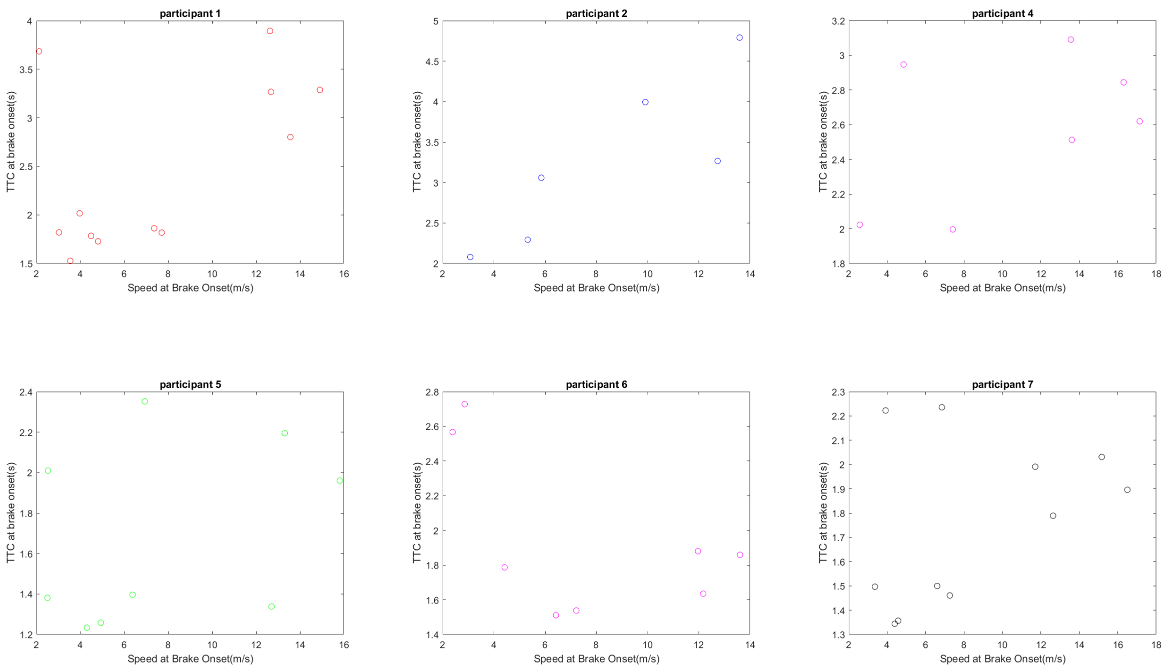
dt = change in time

$$Vehicle\_Accel = \frac{dx}{dt} \tag{2}$$

Task 3: Driver behavior analysis

For this task, the provided safety metrics table from Task 2 (TableTask2.mat) was used to study the driver behaviour.

- The speed at brake onset (x-axis) vs. TTC at brake onset (y-axis) for each participant was plotted as shown in Fig.5.



- From the graphs, it can be seen that the different drivers have both high and low TTC values and clusters are present either at high TTC and high speed or at low TTC and low speed.

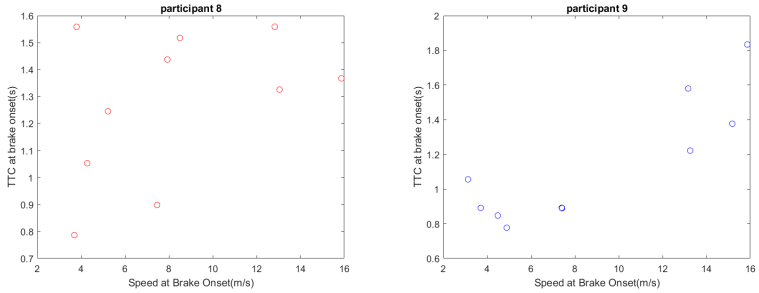


Figure 5: speed at brake onset (x-axis) vs. TTC at brake onset (y-axis) for all participants

- Which type of statistical distribution would you say best describes your data (e.g. normal, skewed)? What are the 5th and 95th percentiles?

Ans: A histogram was plotted showing the TTC data for all drivers which shows a right skewed statistical distribution as shown in Fig.6 describing the data. The 5th and 95th percentiles of TTC are calculated using the MATLAB function *prctile* whose values are 0.8903 s and 3.6246 s respectively.

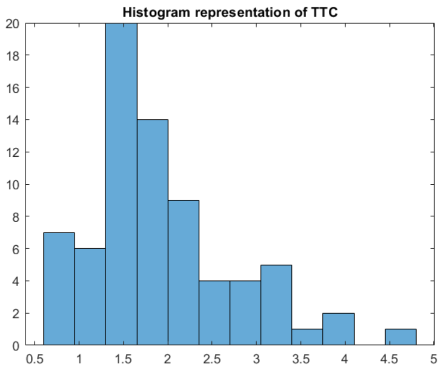


Figure 6: Histogram representation of TTC

- Assume that you are asked to design an active safety system (e.g. a warning or intervention system)that uses TTC to assess the criticality of the situation. Which TTC would you use to design such a system?

Ans: We would design an active safety system for the 90th percentile TTC i.e., 3.12 s since most of the drivers are conservative(from Table 1) in case of a warning system(as he needs some time to react as well).

- What happens if you design your system only for the average person and/or only for the most careful (i.e. a more conservative system) or sensation-seeking drivers (i.e. a more aggressive system)?

Ans: If the system is designed only for the average person there are possibilities of more conservative drivers to panic and not intervene in time when the warning is published.

If the system is only designed only for the sensation seeking drivers then its hard for most of the drivers(atleast in our case using TableTask2.mat data) wont be able to react and brake well on time since there are only a very few cases of drivers braking at high speed and low TTC values.

If the system is designed only for the most careful drivers (where most of the data are clustered), all of the drivers will be able to react on time for the warning and prevent the vehicle from crashing. The only disadvantage of this system is that it might be a bit too early for more aggressive drivers(Which might frustrate them).

• The distributions for mean and minimum acceleration (results from Table 1) were plotted as shown in Fig.7. The information about driver behavior that we can obtain from these are both the distributions are left skewed(which indicates that most of the values are at the right side of the distribution) which projects the driving behaviour of the drivers to be more conservative than aggressive.

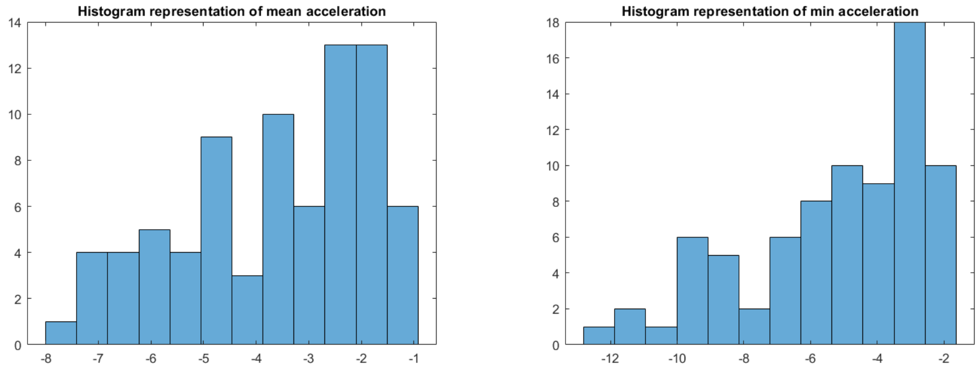


Figure 7: Distributions for mean and minimum acceleration

Task 4: Active safety system design

The aim of this final task was to use the calculated safety metrics to estimate upper and lower limits of driver braking behavior in critical rear-end situations and propose simple FCW and AEB systems. The proposed systems was then tested on the hypothetical scenario described in Task 1 to see if they can help avoiding the collision.

• In this first step, two FCW systems - a conservative and an aggressive FCW system was proposed based on obtained knowledge from the driver behavior analysis.

Conservative FCW system

The conservative FCW system is proposed at TTC=7s equal to the sum of reaction time(Task 1), Time to collision(Task 1) and 2.5s (based on the obtained knowledge from the driver behavior analysis (Task 3)). The warning is published at a distance of 162.5 meters from the lead vehicle.

Aggressive FCW system

The aggressive FCW system is proposed at TTC=5s equal to the sum of reaction time(Task 1), Time to collision(Task 1) and 0.5s (based on the obtained knowledge from the driver behavior analysis (Task 3)).The warning is published at a distance of 112.5 meters from the lead vehicle(because atleast 100 m is needed to avoid the crash).

• Among the conservative and the aggressive FCW system, The conservative one is better because it has more possibilities of preventing the crash (irrespective of whether the driver is more careful or sensation seeking or an average driver).

• The FCW system can only warn the driver when it encounters a slowing down or stationary lead vehicle and a FCW system cannot alone avoid a crash. However, the outcome is totally based on driver reaction. Hence inorder to increase the possibility to avoid collision, the FCW system needs to be combined with an AEB system.

```
while Velocity > 0 % (DRIVING)
    Monitor TTC values %threat assessment
    if TTC value == TTC_conservative %decision making
        issue warning
    end
end
while Velocity > 0 % (DRIVING)
    Monitor TTC values %threat assessment
    if TTC value == TTC_aggressive %decision making
        issue warning
    end
end
```

AEB system with threat assessment metric ’acceleration’

- In the next step, an AEB system was proposed, that uses the required acceleration to stop the car as the “threat-assessment” metric. A maximum braking capability was assumed to be $-10m/s^2$. This value is selected because the braking will be very harsh and rapid if the acceleration value is reduced further.

```
while Velocity > 0 % (DRIVING)
    Monitor TTC values %threat assessment
    if TTC value == TTC_avail_AEB_1 %decision making
        brake intervention %decision making
    end
end
```

- The AEB system performs conservatively in the situation in Task 1. Assuming the determined maximum braking capability which is $-10m/s^2$, a minimum TTC of 1.25 s is required and a distance of 31.25 m to the lead vehicle for the AEB to intervene to avoid a collision. The distance to the lead vehicle when the car comes to a full stop is 7.8125 m.

AEB system with threat assessment metric ’TTC’

- Another AEB system was proposed by defining a TTC at which the system would trigger an AEB intervention. The value of TTC chosen is 1.0220 s.

This value is chosen based on the 10th percentile of TTC at Brake onset from the given Table-Task2.mat file. A distance of 25.55 m from the lead vehicle is required to avoid a collision.

```
while Velocity > 0 % (DRIVING)
    Monitor TTC values %threat assessment
    if TTC value == TTC_AEB_2 %decision making
        brake intervention %decision making
    end
end
```

The distance to the lead vehicle when the car comes to a full stop is 6.3875 m. The benefit of this system is that though being aggressive the vehicle stops well ahead of the stationary lead vehicle and the drawback is that an acceleration of $12.23 m/s^2$

- A simple AEB system(i.e. that only consider one threat-assessment metric) may brake a car unexpectedly in urban situations while driving in traffic. AEB should not intervene when the speed is less than specific value to encounter such a case. Hence the velocity of the vehicle can also be additionally given as input along with TTC to better assess the situation and make the right decision.

- In the visualization (or simulation) created in Task 1 (d) information about when the four systems (two FCW and two AEB systems) would warn the driver or start to autonomously brake the car was added assuming the driver to not act. The time when the autonomous braking was enabled for the four systems are as seen in Table 1.

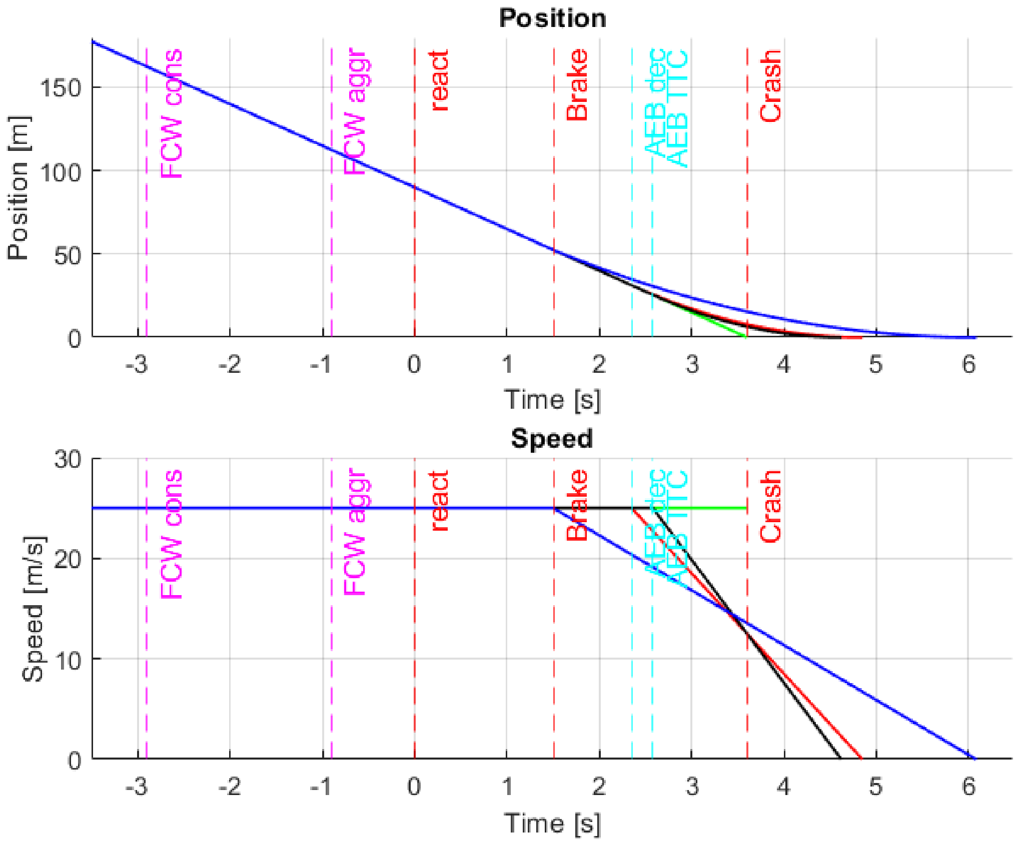


Figure 8: Graphs plotted for the proposed warning and intervention systems

Table 1: TTC Thresholds for the active safety systems proposed

Active safety system	TTC Threshold
Conservative FCW system	6.5 s
Aggressive FCW system	4.5 s
AEB system with threat assessment metric 'acceleration'	1.25 s
AEB system with threat assessment metric 'TTC'	1.0220 s

Conclusion

In conclusion, we have developed simple threat assessment and decision making algorithms for active safety system. We have studied about the driver behavior and designed simple FCW and AEB active safety systems. The work division between the group members is shown in the Table 2. The features of this project like precise and to the point explanation helped us a lot to understand about active safety systems and its design process.

Table 2: Work Load division

Group Member Name	Coding	Report sections
Aparna Ram	Task1	Task1, Appendix, Conclusion
Elizabeth	Task3	Task3, Introduction, Report layout
Sundar	Task2, Task4	Task2, Task4

APPENDIX

Table 3: Safety metrics

Test Runs	**Mean Acceleration**	**Min Acceleration**	**Speed at Brake Onset**	**Range at Brake Onset**	**TTC**
1	-2.6562	-3.5152	7.4140	12.4	1.6724
2	-2.3842	-3.2809	12.382	36.9096	2.9807
3	-2.9114	-3.8273	13.117	32.6	2.4852
4	-1.8531	-2.9696	4.7578	8.3	1.7444
5	-2.5752	-3.2809	6.9687	11.3	1.6215
6	-1.6447	-2.1097	3.1250	4.3	1.376
8	-1.5656	-2.1116	3.8125	8	2.09836
9	-2.3958	-3.5159	2.0312	3.9	1.92
10	-1.6156	-2.3439	4.1562	6.2	1.4917
11	-2.0554	-3.0477	11.890	40.3726	3.3953
12	-1.2961	-1.7968	2.9921	5.8	1.9383
13	-2.7194	-3.5933	14.726	47.3	3.2118
14	-1.4679	-1.8753	5.6171	16.7	2.9730
15	-1.3711	-1.7990	2.7656	6.5	2.3502
16	-1.4606	-2.1087	9.7421	37.9	3.8902
17	-1.5151	-2.1093	5.0625	11.2	2.2123
18	-1.8951	-3.4371	12.578	52.8607	4.2025
19	-2.3437	-3.2037	12.437	39.2	3.1517
21	-0.9593	-1.7182	2.5078	5.2	2.0735
22	-2.8866	-3.9039	13.281	38.8	2.9214
23	-1.6169	-2.5778	15.554	70.4801	4.5311
24	-4.1666	-6.0925	16.523	38.2390	2.3142

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Table 3 – Safety metrics

Test Runs	Mean Acceleration	Min Acceleration	Speed at Brake Onset	Range at Brake Onset	TTC
25	-1.2562	-1.9531	4.7812	13.8	2.8862
26	-3.2460	-4.7656	13.179	30.1	2.2838
27	-1.8456	-2.7346	13.687	33.883	2.4754
28	-2.1211	-3.3597	7.2421	14	1.9331
29	-3.8435	-5.0045	15.656	39.0375	2.4934
30	-4.1503	-5.5479	6.5078	14.9	2.2895
31	-5.0454	-6.5611	5.8593	8.4	1.4336
32	-2.5683	-4.4540	1.9921	2.6071	1.3087
33	-5.2115	-6.8743	12.367	18.6	1.5039
34	-3.5392	-5.1562	4.5312	5.1	1.1255
35	-6.9157	-9.2215	14.296	16.4	1.1471
36	-3.5724	-4.6865	3.8750	4.4	1.1354
37	-5.8927	-9.2205	12.242	14.3	1.1680
38	-1.6852	-2.6554	2.5234	6.1154	2.4234
39	-4.5814	-5.8605	6.3203	3.3	0.5221
40	-6.7539	-9.7646	13.367	17.3	1.2942
41	-4.5251	-5.4692	5.8125	6.1	1.0494
42	-5.8289	-7.5811	10.343	8.8	0.8507
43	-2.0169	-3.0459	2.3593	5.5019	2.3319
44	-6.0467	-9.2205	11.914	15	1.2590
45	-4.5912	-6.8750	5.8203	7.8	1.3401
47	-2.1614	-3.3597	2.625	7.2	2.7428
48	-4.8063	-6.5618	11.007	16.6	1.5080
49	-2.5833	-3.6722	3.875	6.7	1.7290
50	-3.4027	-4.2183	6.031	7.3	1.2103
52	-2.0217	-2.6567	6.7968	15.3	2.2510
53	-3.4922	-4.9228	6.9453	9.9	1.4254
54	-2.1874	-2.8903	3.0390	3.1990	1.0526
55	-4.8186	-7.4248	12.046	17.6	1.4609
56	-1.5101	-2.6565	4.2578	5.9	1.3856
57	-5.7254	-8.8272	16.023	27.484	1.7152
58	-2.1562	-2.8909	4.3671	5.3	1.2135
59	-3.5741	-4.8442	11.375	20.9	1.8373
60	-2.6922	-3.2815	3.5390	7.5	2.1192
61	-4.5702	-5.6244	14.5	26.2	1.8068
62	-5.5858	-8.4375	6.851	5.2	0.7589
63	-4.0144	-5.6250	7.914	11.1	1.4025
64	-3.8194	-6.1718	3.335	7.36	2.2073
65	-6.9573	-11.015	12.039	13.4	1.1130
66	-3.2447	-4.1406	4.7812	5.9	1.2339
67	-7.2058	-10.6218	15.562	19.5	1.2530
68	-2.4126	-5	4.2109	4.5	1.0686
69	-4.6183	-6.2481	12.382	17.4	1.4051
70	-3.3671	-4.1410	3.2265	2.6	0.8058
71	-5.2341	-6.6472	7.2656	9.1	1.2524

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Table 3 – Safety metrics

Test Runs	Mean Acceleration	Min Acceleration	Speed at Brake Onset	Range at Brake Onset	TTC
72	-6.5521	-12.030	15.289	19.4	1.2688
73	-6.8045	-9.3740	6.5859	4.4	0.6680
74	-6.4557	-8.6640	6.9218	5	0.7223
75	-2.5780	-3.3590	2.8125	2.7	0.96
76	-5.4245	-8.5937	12.578	16.8	1.3356
77	-4.5780	-6.4062	4.4531	2.8	0.6287
78	-7.1912	-9.9980	14.296	16.3	1.140
79	-3.8352	-5.0791	4.125	2.9	0.7030
80	-7.5409	-11.094	12.570	12.3	0.9784
81	-3.6544	-4.7641	3.0546	2.20	0.7202
82	-6.2272	-8.4476	15.070	23.7	1.5726