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Drivers' overtaking of bicycles with oncoming traffic: decision making process and safety margins towards cyclists

Master's thesis in Mechanical Engineering

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Department of Applied Mechanics
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2017

MASTER’S THESIS IN APPLIED MECHANICS

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Drivers' overtaking of bicycles with oncoming traffic: decision making process and safety margins towards cyclists

Master's thesis in Automotive Engineering

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ABSTRACT

The use of bicycles is getting popular to go to work and school due to all the environmental issues, such as climate change. Furthermore, using a bicycle brings several advantages from a health as well as from an environmental point of view. However, the increasing usage of the bicycles has brought to an increase of situations when a motorist may need to overtake a slower bicycle. Consequently the likelihood to lead to severe injuries is increased.

Several studies were carried out to investigate how drivers overtake cyclists, but more research is needed to assess the comfort zone boundaries during the overtaking maneuver of a cyclist in order to support the design of autonomous vehicles and countermeasures to road crashes. In fact, autonomous vehicles have to take into account every aspect that can occur during the driving, including safely overtaking a cyclist. A driving simulator study was conducted at the University of Tsukuba in Japan. The participants were requested to overtake the simulated bicycle with the presence of oncoming traffic in the opposite lane. Seven overtaking maneuvers were taken into account to simulate different values of time to collision (TTC) between the participant's vehicle and the oncoming traffic.

The results show that TTC significantly influences the overtaking strategy and the comfort zone boundaries chosen by the drivers during the overtaking maneuver. Besides, by comparing the current analyses with a previous study focusing on overtaking maneuvers without oncoming traffic, it was found that the participants reduced their safety margins to the bicycle due to the presence of oncoming traffic in the opposite lane.

Further research is suggested to understand the factors affecting the decision making process during the overtaking maneuver. Furthermore, additional research should be conducted to evaluate how the lateral distance between the passing vehicle and the oncoming vehicle influences the choice of the comfort zone boundaries chosen by the driver towards the cyclist.

Keywords: traffic safety, human factors, driving simulator, crash prevention

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Acknowledgment

The analyses were carried out at SAFER, Division of Vehicle Safety, Research Group of Accident Prevention - Lindholmen Science Park, Göteborg, Sweden. The driving simulator study was conducted at the University of Tsukuba in Japan. Special thanks to Prof. Makoto Itoh, Dr. Xuiping Zhou and Ahmad Khushairy Makhtar from University of Tsukuba for helping transferring data. I would also like to thank my supervisor, Giulio Piccinini, who led me during the thesis project and my examiner, Marco Dozza, who let me develop this thesis project.

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1 INTRODUCTION

Due to the climate change and the growing temperature of the planet earth, the usage of high polluting vehicles should be limited when possible. The usage of bikes is increasing nowadays because it is an inexpensive transportation mode, it is not affected by gasoline price, lack of parking space or air pollution and it is healthy (Koike, 2014).

Kobayashi et al. (2014) reported the increasing number of bicycle's owners in Japan. As a consequence, accidents and fatalities grew as well: in 2014 cyclists faced 109.269 accidents and 542 fatalities (Kameda, 2015). Hence, more relevance should be given to cycling safety in order to reduce fatalities and injuries and, therefore, produce a further increase in bicycles' use and the development of sustainable urban and rural areas (Loo, et al., 2010; Pucher et al., 2011; Koike, 2014). In addition to the increase of cycling safety, research on vulnerable road users safety is also fundamental for an appropriate setting of automatic warnings of active safety systems (Schindler & Bast, 2015).

The objective of this thesis is to assess the comfort zone boundaries - thus the minimum safety margins - which drivers choose towards the bicycle during car to bicycle overtaking maneuvers in presence of oncoming traffic in the opposite lane. In order to determine those boundaries, a driving simulator study was conducted at the University of Tsukuba, Japan with 42 participants. The study aimed to answer the following research questions:

- How does the presence of oncoming traffic influence the choice of the comfort zone boundaries?
- How does the TTC, calculated between oncoming traffic and subject vehicle (vehicle driven by the participant), influence the driver's choice to perform the overtaking of a cyclist?
- How does the TTC affect the choice of comfort zone boundaries during the overtaking?

2 LITERATURE REVIEW

This chapter gives an overview over the relevant literature on overtaking maneuvers (Section 2.1), driver behaviour (Section 2.2), comfort zone boundaries (Section 2.3) and TTC (Section 2.4).

2.1 OVERTAKING MANEUVER

The overtaking maneuver can be described through a variety of variables and parameters. This thesis will focus on cars overtaking cyclists with the presence of oncoming traffic. Before describing the study, it is important to define the overtaking phases and identify the factors that could influence the overtaking maneuver.

2.1.1 OVERTAKING PHASES

An overtaking maneuver is a long and complex process. Different authors suggested that an overtaking comprises multiple phases: some authors (Shamir, 2004 and Petrov and Nashashib, 2011, Chuang et al., 2013) suggested a three phases classification while Hegeman et al. (2005) proposed a five phases division which also included the driver's intentions and actions.

In the current study, the classification elaborated by Dozza et al. (2016) has been used to guarantee continuity and allow comparison with previous Master's theses performed by Schindler and Bast (2015) and Fatahtooei Nejad (2017). According to the classification described by Dozza et al. (2016), the first phase is the approaching phase with the motorized vehicle reaching the bicycle from behind (Figure 1). This phase ends when the driver starts to steer away to avoid the collision and it corresponds to the start of phase 2, named steering away phase (Figure 1). Once the driver enters the passing zone (an area which starts 2 m behind the bike and finish 2 m in front of the bike, for a total of about 5.7 m, Dozza et al., 2016) the steering away phase ends and the passing phase begins (Figure 1). In conclusion, the returning phase begins with the driver leaving the passing zone (Figure 1). The returning phase, and the overtaking maneuver, is over when the vehicle returns to the same lane position it had at the beginning.

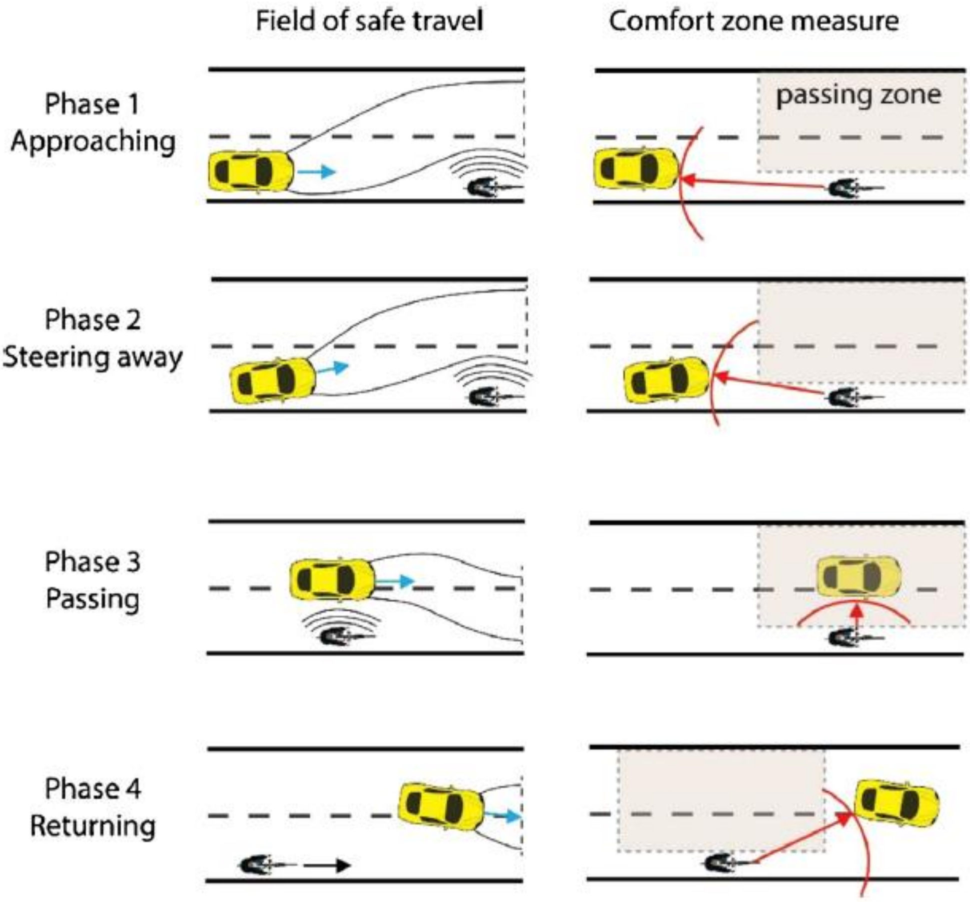

Figure 1: Comfort zone boundaries for each phase (Dozza et al., 2016)

2.2 Comfort Zones

The overtaking of a vehicle against oncoming traffic involves subjective risk which is a key aspect in the decision making process according to the zero risk theory (Näätänen & Summala, 1974). This theory postulates that individuals try to minimize their risk by choosing sufficient margins to potential hazards in order to increase safety and comfort. Those margins within which drivers feel comfortable and safe are defined as comfort zones and can be seen as a dynamic spatiotemporal envelope surrounding the vehicle (Bärgman et al., 2015). The comfort zones can be measured in both time and space and, when they are not enough wide, they can generate a feeling of discomfort for the driver (Summala, 2007). This concept was already introduced by Hall (1966) who attributed different zones around people depending on who is approaching such as the intimate zone, only for closest people, and personal or social and public zones for the others. Thus, humans have safety or comfort zone around them in all environments, with strong emotional characteristics: intrusion is equal to discomfort.

A typical overtaking between a motorized vehicle and a bicycle may take several seconds. In each of the 4 phases defined by Dozza et al. (2016), the driver comfort zone may be measured as the distance between the bicycle and the vehicle. The *minimum distance* is used to define the driver comfort zone boundaries (CZB) (Dozza et al. 2016).

2.3.1 INFLUENCE OF ONCOMING TRAFFIC ON OVERTAKING MANEUVER AND COMFORT ZONE BOUNDARIES

Overtaking a lead vehicle or a bicycle against oncoming traffic in the opposite lane, is a highly complex task that is affected both by the overtaking driver's initial judgment about whether there is sufficient time to complete a driving maneuver (Gray & Regan, 2005; Hills, 1980), and the continuous presence of different hazards during the overtaking (Clarke et al., 1998, 1999). Also, the size of the gap between vehicles in the oncoming flow seem to influence the overtaking process, together with vehicles' speed, the own car's acceleration and the driver's estimation skill (Summala, 2007).

Regarding the influence of oncoming traffic on comfort zone boundaries, Papakostopoulos et al. (2015) studied overtaking maneuvers in real traffic focusing on different traffic scenes - such as the case with no oncoming car, the case where the oncoming car suddenly appeared or the case where a car was already present during the overtaking. They found that overtakers adapt their accepted gaps for passing depending on the traffic situation with respect to type of overtaking maneuver, traffic volume in the opposite traffic and waiting time for an opportunity to overtake. In their results, they found that drivers, in general, decreased their lateral distance to the overtaken vehicle when the Time Headway to the oncoming traffic was reduced, possibly to ensure safe passing of all three cars involved by means of lane sharing. In essence, in this condition the drivers opted to actively get close to the overtaken car in an attempt to minimize as far as possible any interaction with the opposite traffic. Thus, the different scenarios affected directly the overtaking in terms of safety margins to the overtaken vehicle.

2.4 TIME TO COLLISION

Car control is also extensively based on time margins such as TTC, time headway and time to line crossing. Montogomery et al. (2014) defined TTC as a metric that indicates the time until a collision would take place if neither driver in a 2-car scenario changes their velocities or path. This definition is in agreement with the one by Minderhoud and Bovy (2001) stating that "TTC value at an instant t is defined as the time that remains until collision between two vehicles would have occurred if the collision course and speed difference are maintained".

As described by Lee (1976), Time To Collision is based on visual information and this information is available during the overtaking maneuver because the driver of the subject vehicle can always see the oncoming traffic. This characteristic makes the TTC a suitable independent variable to assess how the presence of oncoming traffic influences the overtaking maneuver. In addition, TTC is a variable that has been already previously used to operationalize safety margins between vehicles (Engström & Lijung Aust, 2011)

3 APPROACH AND METHODOLOGY

This chapter shows how the collected data are processed and analyzed in order to calculate the comfort zone boundaries. Afterwards, some variables are used to distinguish the different overtaking maneuvers.

In this experiment oncoming traffic was considered in order to study its effect on the decision of starting the overtaking maneuver. Due to its presence, TTC was evaluated.

3.1 DATA COLLECTION AND EXTRACTION

The data were collected during a driving simulator study conducted at the University of Tsukuba, Japan, in 2015. The driving simulator used for the study is shown in Figure 2.

Figure 2: Driver simulator at University of Tsukuba

In total, 42 participants took part in the study but 6 of them were eliminated due to getting sick and become dizziness during the experimental test by the driving simulator. Therefore, 36 participants including 21 males (58.33%) and 15 females (41.67%) by the average age of 48 years old (standard deviation: ±19.39) were employed. They all met the following requirements:

- Own a driving license;
- Have a minimum mileage of 30.000km, since getting the driving license;
- Drive, at least, once per week;

The average years of holding driving license was 24.49 (standard deviation: ±15.31) and 56.76% of the participants were driving every day.

During the whole study, the participants underwent a trial test – to get accustomed with the driving simulator - and two experimental tests, one without oncoming traffic and one with oncoming traffic during the overtaking maneuver (for more details, please see the description reported in Fatahtooei Nejad, 2017. For the present work, only the latter has been considered since the data from the former have already been analyzed by Fatahtooei Nejad (2017). The route designed for the trial with oncoming traffic can be seen in Figure 3 and it reproduces a two-lanes rural road (one for each direction of travel), without divider, with lane width equal to 3.2 m and shoulder equal to 0.4 m.. During the whole route, the participants were requested to keep their speed as close as possible to 70 km/h and to behave as they would do in reality when there is a bicycle on the road. On the other hand, the bicycle had a speed of 22 km/h and maintained a distance of 0.3 m from the curb. Along the route, the participants were requested to carry out 7 overtaking maneuvers, as reported in Figure 3. The driver would overtake the bike in a way that he/she was comfortable with, thus he/she could choose to overtake the bike before meeting the vehicle on the opposite lane or wait until the vehicle passed.

As shown in Figure 3, all overtaking maneuvers occurred in straight stretches of road with visibility of 400 m and with dashed center line.

In each overtaking, the bicycle and the oncoming vehicle were started to move when the ego vehicle reached a distance of 100 m from the bike. However, the distance between the subject and the oncoming vehicle was different in each overtaking as well as the corresponding TTC (Table 1: Variable settings).

Table 1: Variable settings

Overtaking	1	2	3	4	5	6	7
Distance subject–oncoming vehicle [m]	500	350	480	450	520	400	380
Time To Collision desired	9	6	8,5	8	9,5	7	6,5

Through the software AutoCAD 2010 all the drawings were represented in order to represent all the possible cases in a more detailed way.

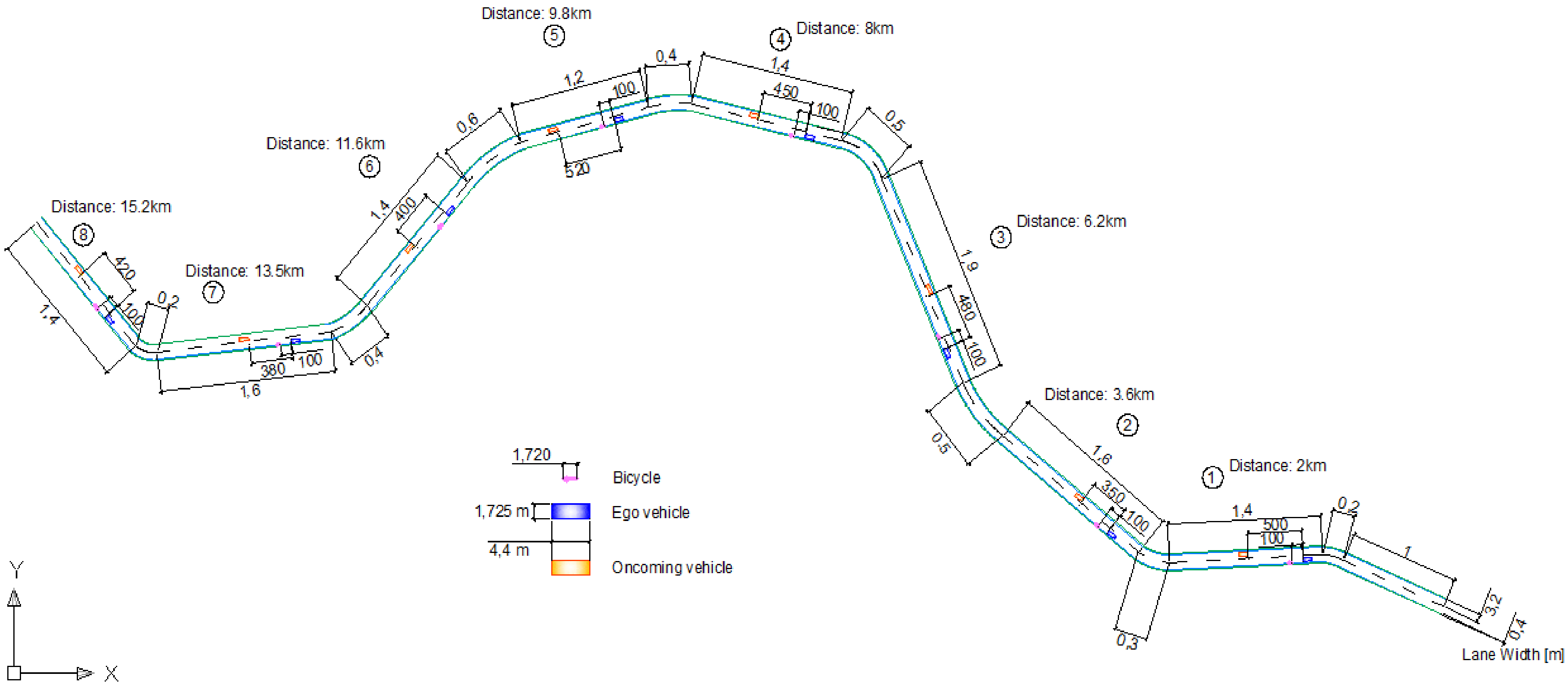

Figure 3:Layout of the experimental route, including vehicle's positions

All data were collected in DAT format and then converted to MAT files with the software TpConv whose interface is represented in Figure 4. Not all the variables collected were extracted but only those useful for the study.

For the subject vehicle, the most important were the speed, the acceleration, the initial position and X,Y coordinates referred to the global reference system, turn rate, vehicle mileage and the size of the vehicle (length and width). As regard the bikes and the oncoming traffic, the same variables were extracted and numbered in order to use them in an easier way:

Table 2: Variables extracted for bikes and oncoming vehicles

‘移動物体データ => Moving object data for vehicle (0 to n=8)															
BICYCLES							ONCOMING VEHICLES								
1	6	11	16	21	26	31	36	41	46	51	56	61	66	座標 X [m]	X coordinate: X coordinate of the vehicle n
2	7	12	17	22	27	32	37	42	47	52	57	62	67	座標 Y [m]	Y coordinate: Y coordinate of the vehicle n
3	8	13	18	23	28	33	38	43	48	53	58	63	68	方位角 [rad]	Azimuth angle
4	9	14	19	24	29	34	39	44	49	54	59	64	69	速度 [m/s]	Speed
5	10	15	20	25	30	35	40	45	50	55	60	65	70	加速度 [m/s^2]	Acceleration

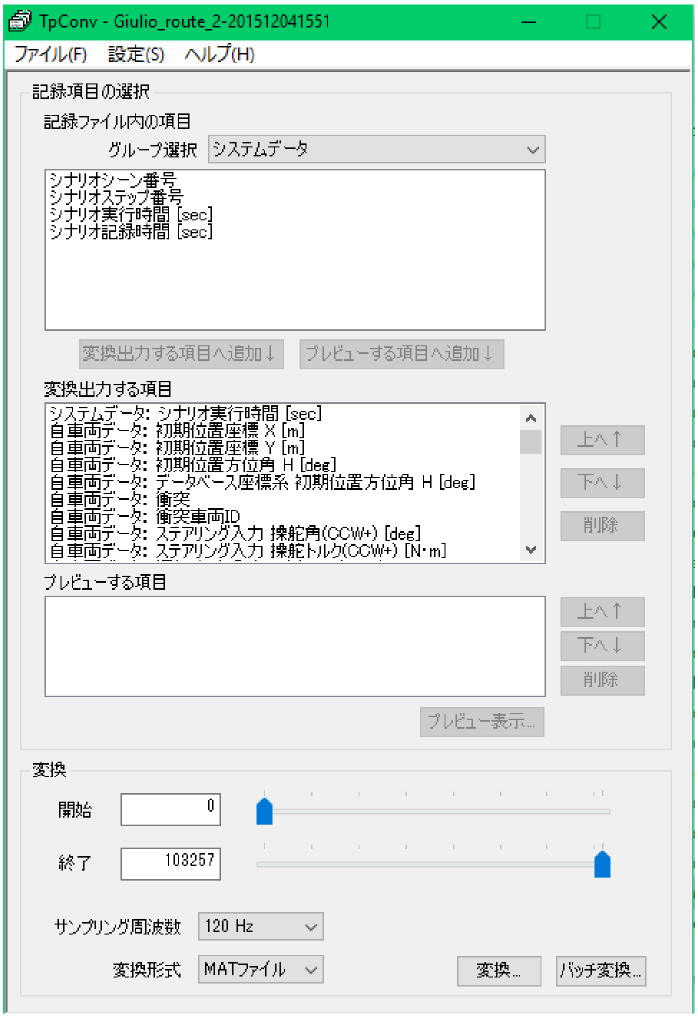

Figure 4: TpConv Software interface

MATLAB was then used for data processing and analyses.

3.2 OVERTAKING PHASES

This section will provide more detailed information about the description and calculation of the overtaking phases mentioned in the literature review chapter and derived from previous studies (Schindler and Bast, 2015; Dozza et al., 2016). As reported earlier, the driver's overtaking of a cyclist can be divided in four phases which are graphically shown in Figure 5:

1) Approaching phase: phase during which the motorized vehicle approaches the bicycle from behind;
2) Steering away phase: phase starting when the driver steers away in order to get out of the collision path. This phase ends when the driver enter the passing zone which extends from 2 meters behind to 2 meters in front of the bicycle;
3) Passing phase: phase during which the driver is in the passing zone;
4) Returning phase: phase starting when the vehicle leaves the passing zone and return to the same lane it had before starting the overtaking.

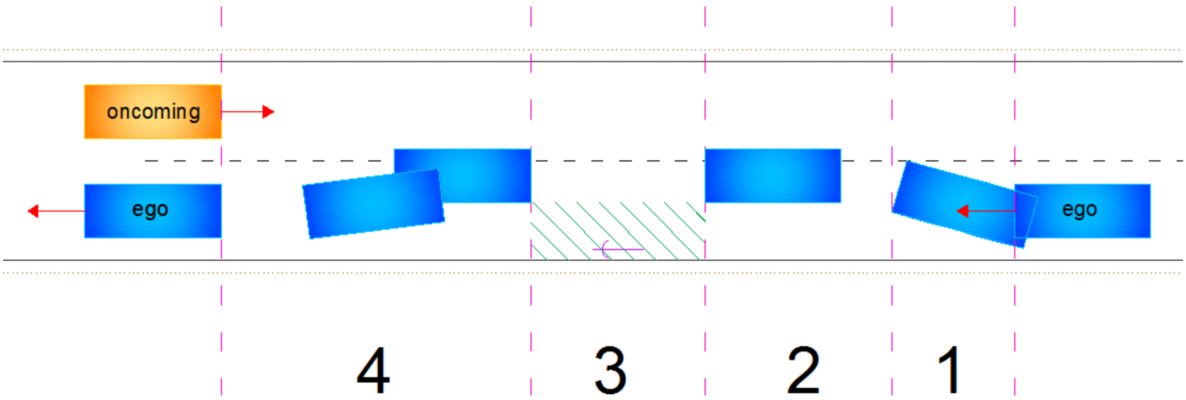

Figure 5: Overtaking's phases

Before calculating the comfort zone boundaries for each phase, a start point and an end point for each phase needs to be determined.

3.2.1 PHASE 1-2

In the reference study (Dozza et al., 2015), phase 1 started when the vehicle was first visible from the LIDAR. However, a different procedure had to be used for the driving simulator experiment since the vehicle was always visible. In particular, the procedure needed to consider both computational requirements (small file size) and experimental requirements (the participants could start the overtaking before the bike moved). The final compromise led the phase 1 to begin 8.3 seconds before the bike started to move (see Appendix). The bike was set to start moving when the subject vehicle (SV) reached 100 m distance from the bike.

For assessing the end of the first phase - corresponding to the start of the second one - it was required to determine when the SV leaves the collision path with the bike. This can be done by calculating the *lateral distance* reported in Figure 6.

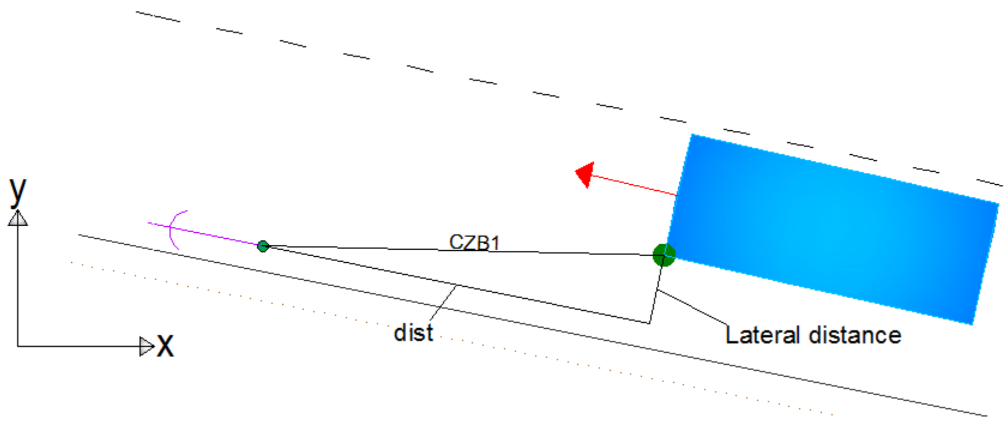

Figure 6: Measurements used to assess the end of phase 1

The calculation of the *lateral distance* is dependent on the road inclination and, looking at the road shown in Figure 3, two different cases exist:

1. Azimuth <0;
2. Azimuth >0.

Hence, in order to assess the *lateral distance*, it was necessary to introduce two angles to distinguish all the cases:

- ε, the angle between the CZB1 and $\Delta X_{egobike}$ calculated as:

$$\varepsilon = arctan\frac{\Delta Y_{egobike}}{\Delta X_{egobike}}$$

- χ, the angle formed by the *lateral distance* and the CZB1. In the calculations, it was considered the angle that the oncoming vehicle makes with the horizontal (azimuth) because it was fixed in the driver simulator's settings.

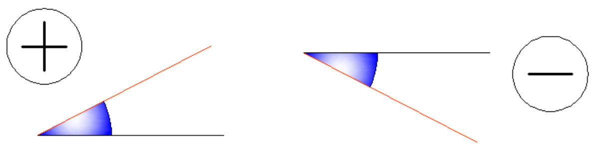

Figure 7: Convention of positivity for the azimuth

The calculations assumed the convention of positivity for the azimuth angles as represented in Figure 7. Once the positivity of the considered angles were determined, the vertical position (respect to absolute coordinate system) of the vehicle and the bike originated different combinations which had an impact on the calculation of the angles ε and χ as described below:

1. $Azimuth < 0$
   - $y_{bb} > y_{fv}$, where 'bb' and 'fv' are respectively used for 'bike's back' and 'front of the vehicle'. These subscript denoting are fundamental to distinguish which points of the bike or of the vehicle were considered for the calculations.

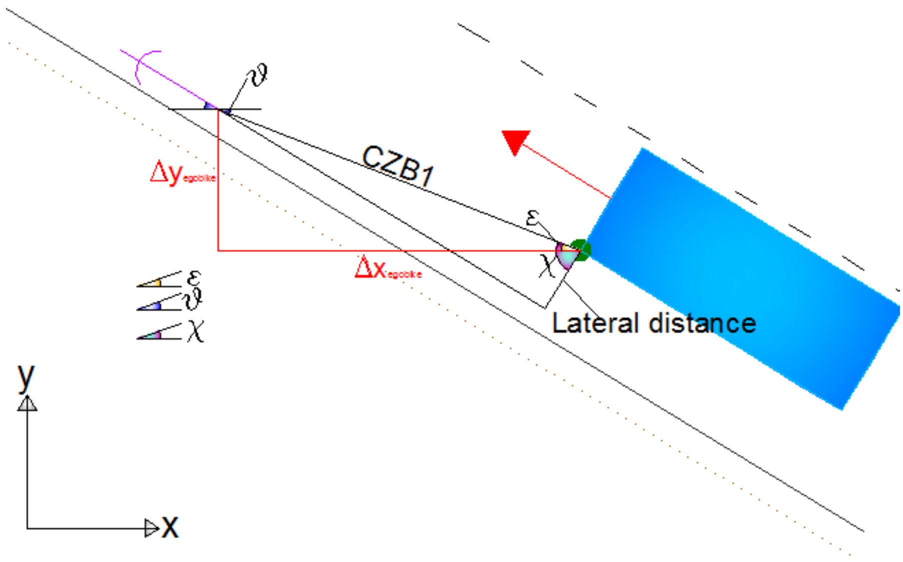

Figure 8: Phase 1-2 calculations, Azimuth < 0, $y_{bb} > y_{fv}$

In this case, χ was defined as follow:

$$\chi = \frac{\pi}{2} + \varepsilon - \vartheta$$

Where ϑ is the angle formed by the bike with the horizontal axis of the absolute coordinate system, and it is equal to the inclination of the road.

- $y_{bb} < y_{fv}$, where 'bb' and 'fv' are respectively used for 'bike's back' and 'front of the vehicle'

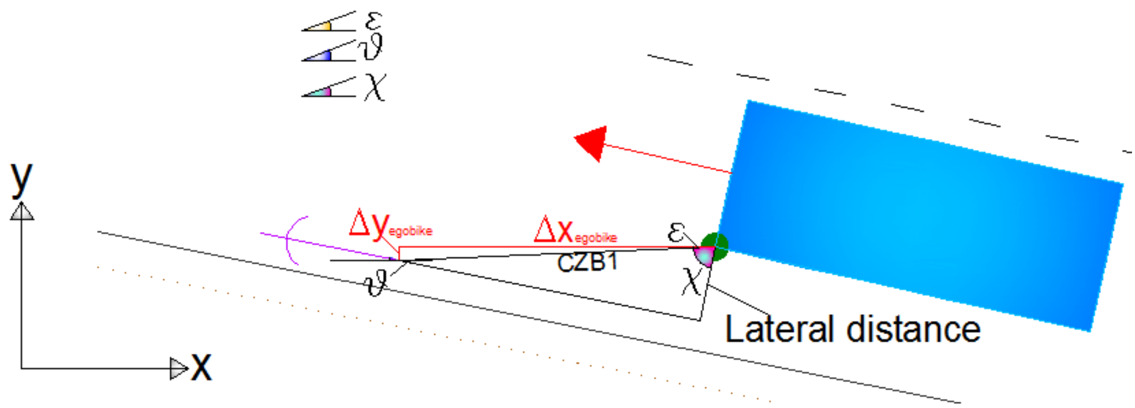

Figure 9: Phase 1-2 calculations, Azimuth < 0, $y_{bb} < y_{fv}$

In this case, χ was defined as follow:

$$\chi = \frac{\pi}{2} - \varepsilon - \vartheta$$

2. $Azimuth > 0$

   In this case, the y coordinates did not affected the final results, thus only one case was considered.

$$\chi = \frac{\pi}{2} - \varepsilon + \vartheta$$

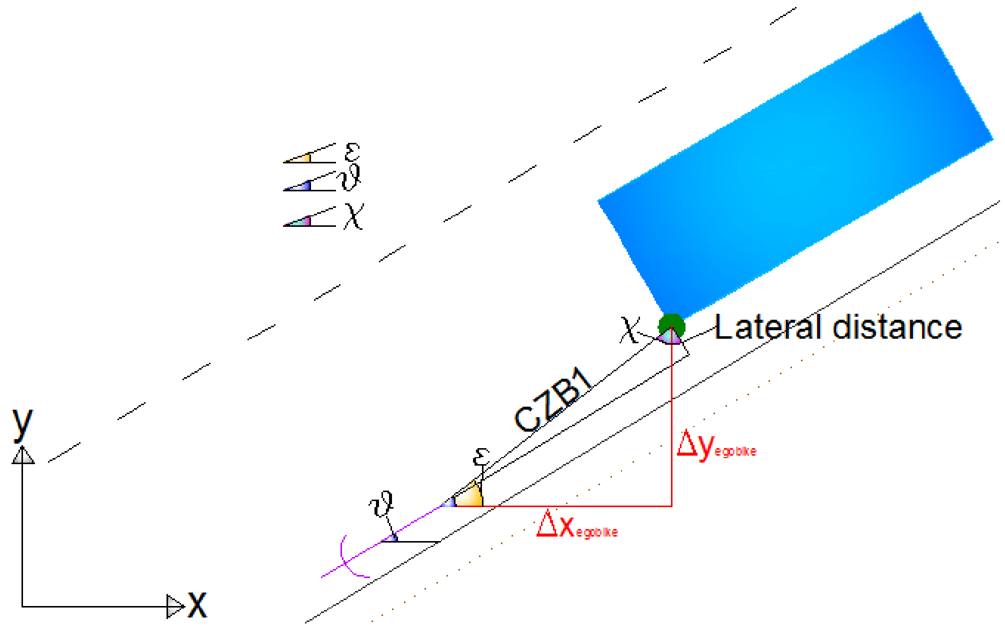

Figure 10: Phase 1-2 calculations, Azimuth > 0

Once all the parameters were calculated, after the evaluation of the comfort zone boundaries, it was possible to determine the *lateral distance* with the formula below.

$$\text{Lateral distance} = \text{abs}(\text{CZB}_{12} * \cos(\chi))$$

Although the calculations of the CZBs will be illustrated in the next chapter, it is relevant to mention here that their assessment was based on the difference between the x and y coordinates of the vehicle and the bike, named as $\Delta X_{egobike}$ and $\Delta Y_{egobike}$ and consequent application of the Pythagorean Theorem.

Once the *lateral distance* was calculated, two conditions were verified to determine the end of phase 1;

The value of the *lateral distance* had to be greater than 0.6 and lesser than 0.8 m. These values were defined after analyzing in detail the overtaking behavior of several participants and observing the minimum and maximum values that this variable assumed during the whole duration of the simulation.

The n value of the *lateral distance* had to increase compared to the n-1 value with the latter being greater than 0.5: this condition was set to guarantee that the vehicle was actually increasing its lateral distance from the bike and, therefore, performing the overtaking.

The first value which respected the two conditions determined the start of phase 1.

3.2.2 PHASE 2-3

With the χ values it was possible to assess the longitudinal distance – on the bike axis direction - between the bike and the vehicle to be used for assessing the beginning of the third phase (see Figure 6):

$$dist = \mathrm{abs}(\mathrm{CZB}_{12} * \sin(\chi))$$

In accordance with Dozza et al. (2015), the end of the second phase, and at the same time the start of phase 3, was fixed when the subject vehicle was 2 meter behind the bike as it can be seen Figure 11. From a computational point of view, once the variable *dist* was calculated, the start of phase 3 corresponded to the first point in time for which *dist* was less than 2 meters.

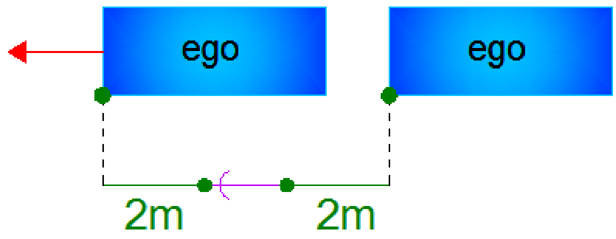

Figure 11: Phase 3

3.2.3 Phase 3-4

As defined by Dozza et al. (2015), phase 3 ends when the longitudinal distance – on the bike axis direction – is longer than 2 meters (Figure 11). This longitudinal distance was determined as:

$$dist4 = \text{abs}(\text{CZB}_4 * \sin(\chi_4))$$

Where CZB_4 is the CZB in phase 4 and its calculation will be explained in chapter 3.3.4.

The procedure to identify the end of phase 3 is symmetric to the one described earlier to determine the start of phase 3.

Like in section 3.2.1., χ_4 is the angle formed by the perpendicular to longitudinal distance and the CZB_4. For its calculation, it was used a similar procedure to the one explained in chapter 3.2.1. Therefore, in order to define this angle, and thus the variable "dist4", a new angle ε_4 was defined as the angle between the CZB_4 and $\Delta X_{egobike}$:

$$\varepsilon_4 = arctan \frac{\Delta Y_{egobike}}{\Delta X_{egobike}}$$

Where $\Delta X_{egobike}$ and $\Delta Y_{egobike}$ are the differences between the coordinates of the vehicle and the bike as shown in Figure 12 (back of the vehicle and front of the bike).

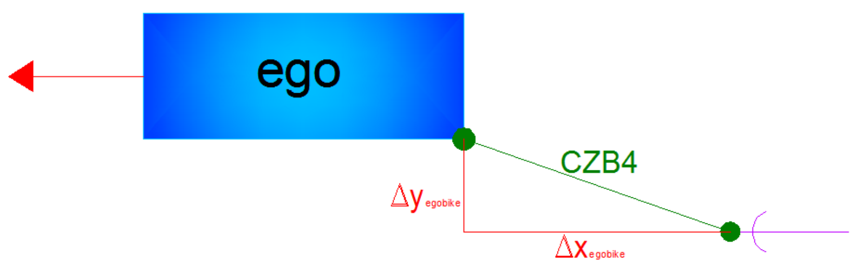

Figure 12: Points of interest for phase 4

The definition of the chi4 angle was analogue to the one followed to define chi. Thus, it varied with the inclination of the road and with the y coordinates of the bicycle and the subject vehicle.

1. $Azimuth > o;$

- $y_{bb} < y_{fv};$

$$\chi_4 = \frac{\pi}{2} - \varepsilon_4 - \vartheta$$

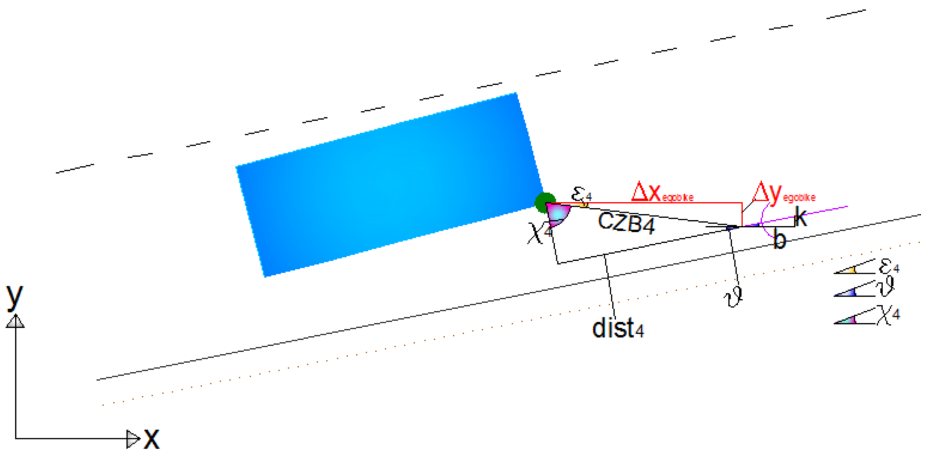

Figure 13:Dist$_4$ calculations, Azimuth > 0, y_{bb} < y_{fv}

- $y_{bb} > y_{fv};$

$$\chi_4 = \frac{\pi}{2} + \varepsilon_4 - \vartheta$$

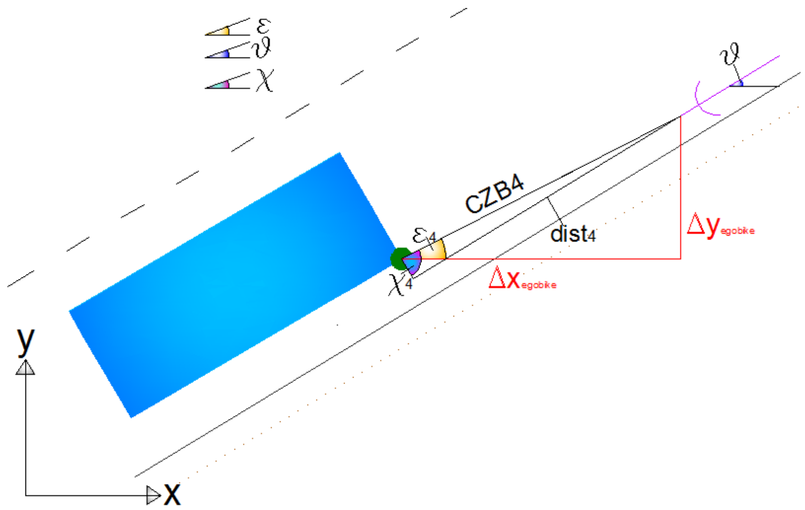

Figure 14: Dist$_4$ calculations, Azimuth > 0, y_{bb} > y_{fv}

2. $Azimuth < 0$;

In this case, no distinctions were made between the y coordinates because it did not affected the results.

$$\chi_4 = \frac{\pi}{2} - \varepsilon_4 + \vartheta$$

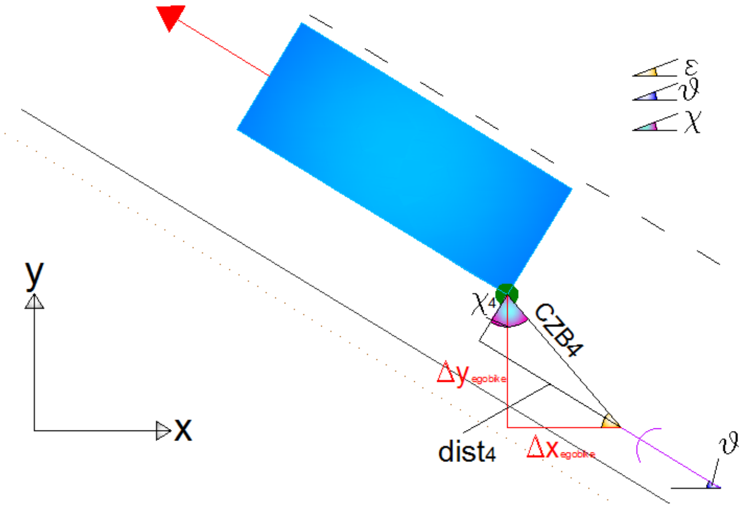

Figure 15: Dist$_4$ calculations, Azimuth < 0

Once calculated χ_4 and $dist4$, the end of phase 3 – corresponding to the start of phase 4 – was fixed as the time when the vehicle first reached 2 m far in front of the bike.

For the end of phase 4, Dozza et al. (2015) considered the moment in which the vehicle was not visible anymore from the LIDAR. However, since no LIDAR was used here, the end of phase 4 was established 40 seconds after the first moment the bike started moving. The decision about the 40 seconds was driven by the fact that no overtaking maneuvers lasted more than that period of time.

3.3 CZBs: Calculations

For the assessment of the Comfort Zone Boundaries, the following information was retrieved from the simulation output file about the vehicle and the bike:

- Length vehicle = 4,4m
- Width vehicle = 1,725m;
- Length bike = 1,72m.
- The width of the bike was assumed to be negligible.

The Comfort Zone Boundaries were calculated using the relative position between the bike and the vehicle. The simulation output file supplied provided the coordinates for the center of gravity of the vehicles and the center of gravity of the bike. Those coordinates were referred to the global coordinate system and, therefore, particular attention had to be paid to the angle of inclination of the road (ϑ), the angle representing the direction of ego vehicle (α), oncoming vehicles ($azimut$) and bike (ϑ) on the horizontal axis.

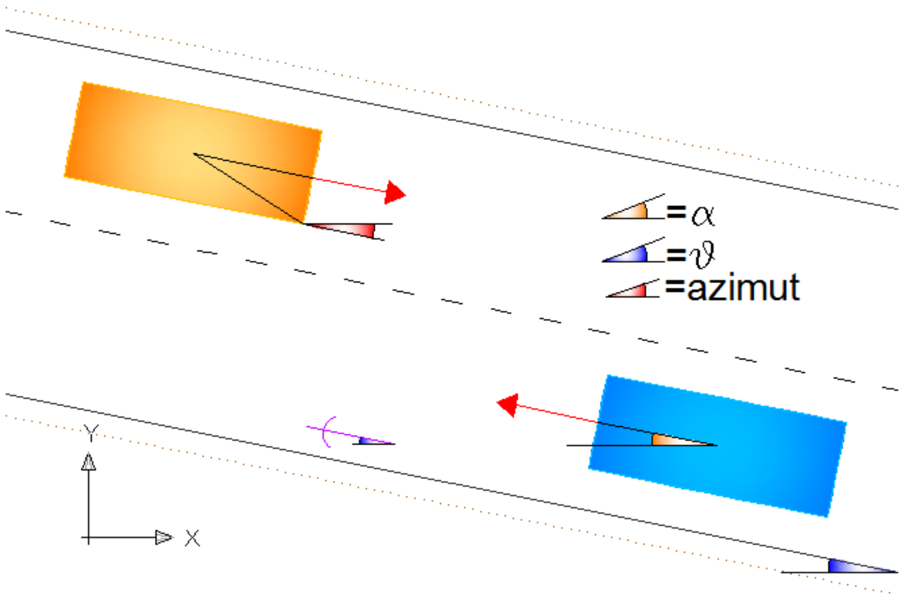

Figure 16: Angles

Since the oncoming vehicles and the bike were programmed to travel on a straight line, their direction on the horizontal axis did not change during the overtaking maneuver.

Table 3: Oncoming vehicles' and bicycles' angles

Overtaking	Azimuth (oncoming vehicles’ angles) [deg]	ϑ (bicycles’ angles) [deg]
1	2,9	-117,2
2	-40,5	139,4
3	-65,8	114,1
4	-13,1	166,9
5	16,5	-164
6	50,4	-129,7
7	5,9	-174,2

This was not the case for the ego vehicle which was driven by the participants as it can be seen from the following chart:

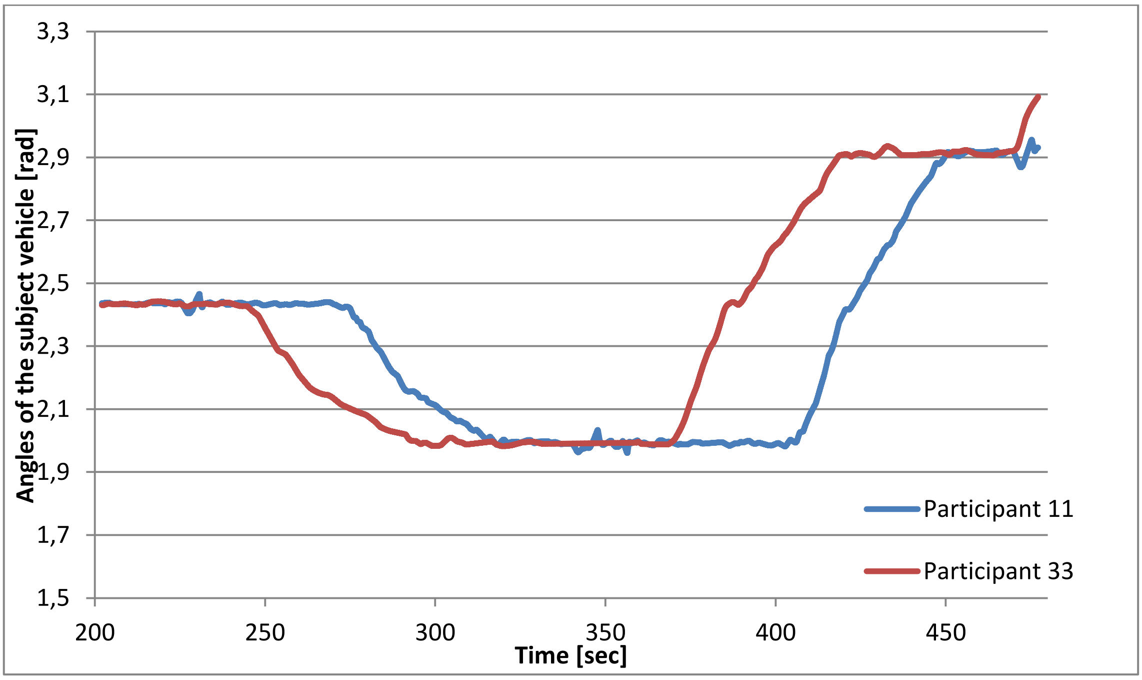

Figure 17: Angle’s differences between participants

From the angles reported in Table 3, new variables were defined in order to evaluate all the comfort zone boundaries that are needed for the study.

- β angle:

$$\beta = \operatorname{asin}\left(\frac{\frac{width_{vehicle}}{2}}{diag}\right)$$

Where:

$$diag = \sqrt{\left(\frac{length_{vehicle}}{2}\right)^2 + \left(\frac{width_{vehicle}}{2}\right)^2}$$

Once β is calculated, two cases were distinguished:

- $\alpha > \beta$;
- $\alpha < \beta$.

For each case, the different sign of the azimuth was considered.

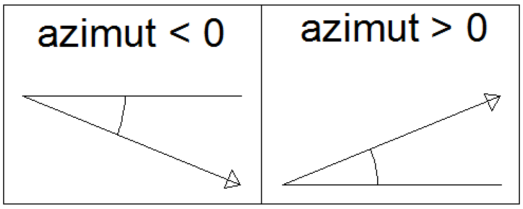

Figure 18: Different cases depending on the inclination of the road

In order to obtain the parameters useful for the definition of the new coordinates, a new angle was defined: γ, whose value is different in the two cases reported in Figure 14 and according to the comfort zone boundaries that we are calculating. All the differences between the cases will be explained in the next sections.

3.3.1 CZB1 CALCULATIONS

The points useful to evaluate the comfort zone boundaries of the first phase are shown in Figure 19.

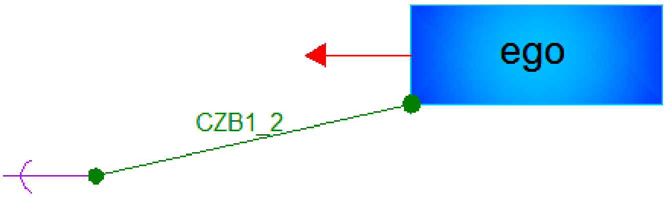

Figure 19: Useful points for CZB1 and CZB2

The calculations of CZB1 was different if the inclination of the subject vehicle (α) was greater or lesser than β. Furthermore, the cases of negative and positive inclination of the road (azimuth) have to be specified.

1. $Azimuth < 0$;
   - $\alpha > \beta$;

In this case, γ can be defined as follow:

$$\gamma = \alpha - \beta$$

The first parameters evaluated were the projections of half of the bike and half of the diagonal of the subject vehicle on the x and y axes of the global reference system. In order to calculate them, trigonometric functions were used.

$$a = \cos(\gamma) * diag$$

$$h = \sin(\gamma) * diag$$

$$b = \cos(\vartheta) * \frac{length_{bike}}{2}$$

$$k = \sin(\vartheta) * \frac{length_{bike}}{2}$$

Here, what is matter is the front extreme left point of the subject vehicle (fv) and the back of the bicycle (bb).

Hence, the following coordinates were defined:

$$x_{fv} = x_{ego} - a$$

$$y_{fv} = y_{ego} + h$$

$$x_{bb} = x_{bike} + b$$

$$y_{bb} = y_{bike} - k$$

- $\alpha < \beta$;

In this case γ is given by the difference between the β angle and the inclination of the vehicle on the horizontal axis, α.

$$\gamma = \beta - \alpha$$

Thus, the points of interest are given by:

$$x_{fv} = x_{ego} - a$$

$$y_{fv} = y_{ego} - h$$

$$x_{bb} = x_{bike} + b$$

$$y_{bb} = y_{bike} - k$$

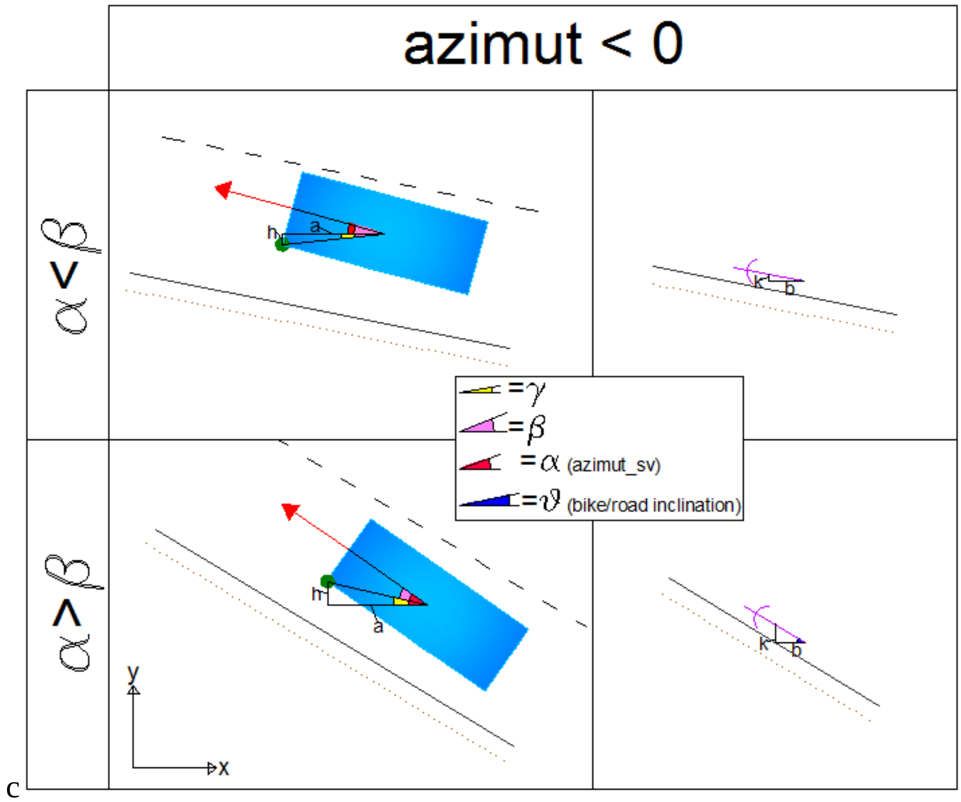

Figure 20: CZB1_2 calculations, azimuth < 0

2. $Azimuth > 0;$
   - $\alpha > \beta;$

In this case the angle γ is given by the sum of the two angles α and β: $\gamma = \alpha + \beta$

Thus,

$$x_{fv} = x_{ego} - a$$

$$y_{fv} = y_{ego} - h$$

$$x_{bb} = x_{bike} + b$$

$$y_{bb} = y_{bike} + k$$

   - $\alpha < \beta;$

For this case, the calculations were the same as the case above:

$$\gamma = \alpha + \beta$$

$$x_{fv} = x_{ego} - a$$

$$y_{fv} = y_{ego} - h$$

$$x_{bb} = x_{bike} + b$$

$$y_{bb} = y_{bike} + k$$

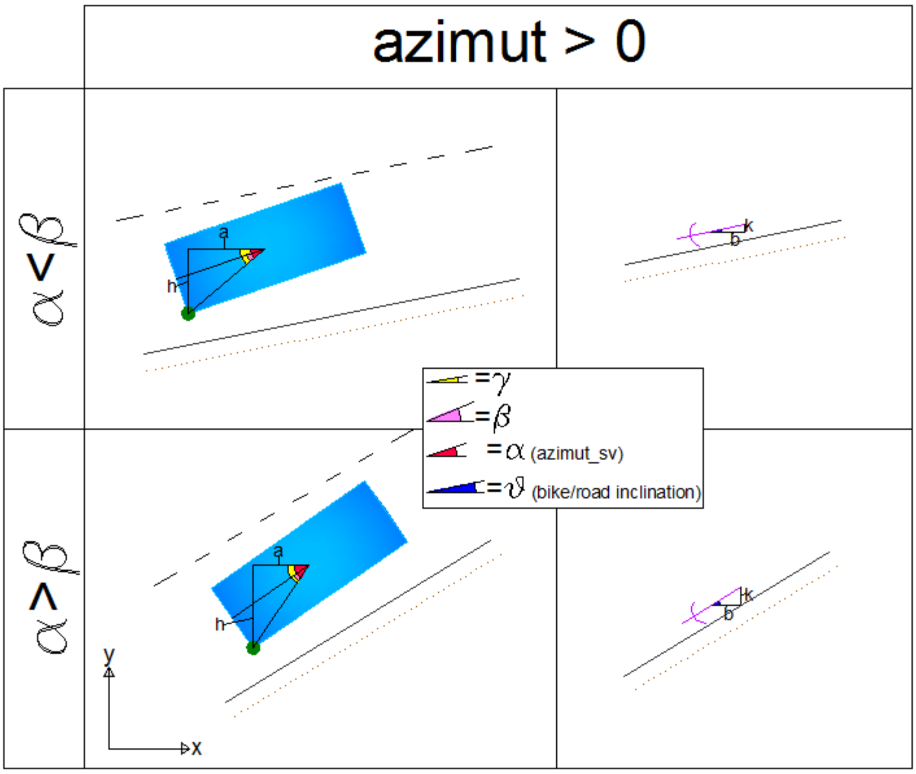

Figure 21:CZB1_2 calculations, azimuth > 0

Once the coordinates were defined, the following distances were evaluated:

$$\Delta x_{egobike} = |x_{bb} - x_{fv}|$$

$$\Delta y_{egobike} = |y_{bb} - y_{fv}|$$

Finally, according to the Pythagorean Theorem:

$$CZB1 = \sqrt{\Delta x_{egobike}{}^2 + \Delta y_{egobike}{}^2}$$

3.3.2 CZB2 CALCULATIONS

For the calculations of CZB2, the same procedure was used due to the fact that the points of interest were the same of CZB1 (Figure 19).

$$CZB2 = \sqrt{\Delta x_{egobike}{}^2 + \Delta y_{egobike}{}^2}$$

3.3.3 CZB3 CALCULATIONS

In this case, the minimum distance between the vehicle and the bike varied in time. At the beginning of the third phase, the minimum distance was from the front left of the vehicle to the back of the bike. In the middle of the phase, so the actual passing phase, the minimum distance was given by the middle left of the vehicle to the center of the bike. Finally, at the end of the third phase the rear left of the vehicle and the front of the bike were considered.

In this section, only the passing phase will be analyzed because the beginning and the end of the third phase were already taken into account in the calculations of CZB2 and CZB4.

For the calculations of the comfort zone boundaries of the third phase, only one distinction was taken into account: the different inclination of the road. The value of the α or β angle was not relevant for the calculation because it did not affect the results.

To begin, the following two distances were defined:

$$pt_{3x} = \frac{width_{vehicle}}{2} * \sin(\alpha)$$

$$pt_{3y} = \frac{width_{vehicle}}{2} * \cos(\alpha)$$

- $Azimuth > 0$

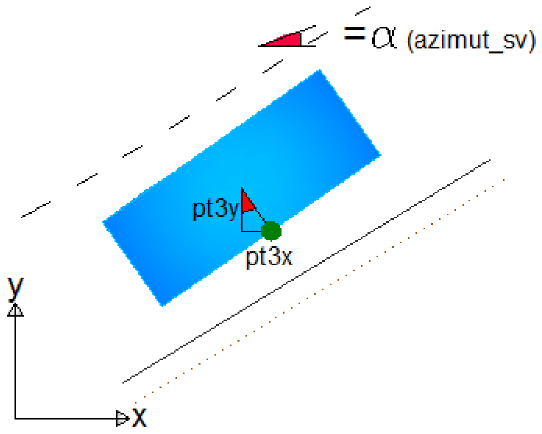

Figure 22: CZB3 calculations, azimuth > 0

$$x_{mv} = x_{ego} + pt_{3x}$$

$$y_{mv} = y_{ego} - pt_{3y}$$

Where ‘mv’ is the abbreviation used for ‘middle of the vehicle’.

- $Azimuth < 0$

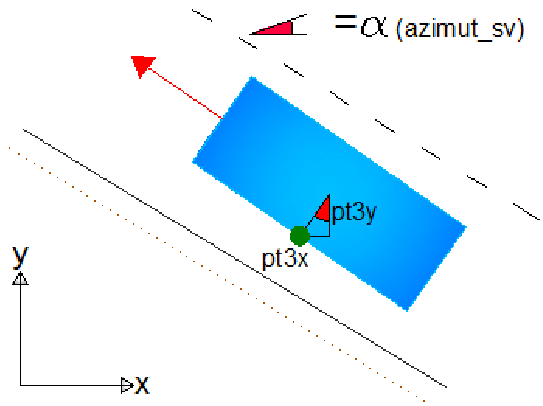

Figure 23:CZB3 calculations, azimuth < 0

$$x_{mv} = x_{ego} - pt_{3x}$$

$$y_{mv} = y_{ego} - pt_{3y}$$

Once all the coordinates were calculated, it was possible to determine the distances from the bicycle, $\Delta x_{egobike}$ and $\Delta y_{egobike}$. Afterwords, with the Pythagorean Theorem, the hypotenuse was determined.

$$\Delta x_{egobike} = |x_{bike} - x_{mv}|$$

$$\Delta y_{egobike} = |y_{bike} - y_{mv}|$$

$$CZB3 = \sqrt{\Delta x_{egobike}{}^2 + \Delta y_{egobike}{}^2}$$

3.3.4 CZB4 CALCULATIONS

In the fourth phase, the minimum CZBs were calculated from the front of the bike to the rear left extreme point of the vehicle. Thus we will refer to two these points with: ‘rv’ for the vehicle and with ‘fb’ for the front of the bike.

As in the calculations of the CZB1 and CZB2, different cases have to be distinguished:

1. $Azimuth < 0$;
   - $\alpha > \beta$;
   - $\alpha < \beta$;

These firsts two cases are geometrically different but are characterized by the same equations:

$$\gamma = \alpha + \beta$$
$$a = diag * \cos(\gamma)$$
$$h = diag * \sin(\gamma)$$
$$x_{rv} = x_{ego} + a$$
$$y_{rv} = y_{ego} - h$$

As well as, for the bike:

$$b = \frac{length_{bike}}{2} * \cos(\vartheta)$$
$$k = \frac{length_{bike}}{2} * \sin(\vartheta)$$
$$x_{fb} = x_{bike} - b$$
$$y_{fb} = y_{bike} + k$$

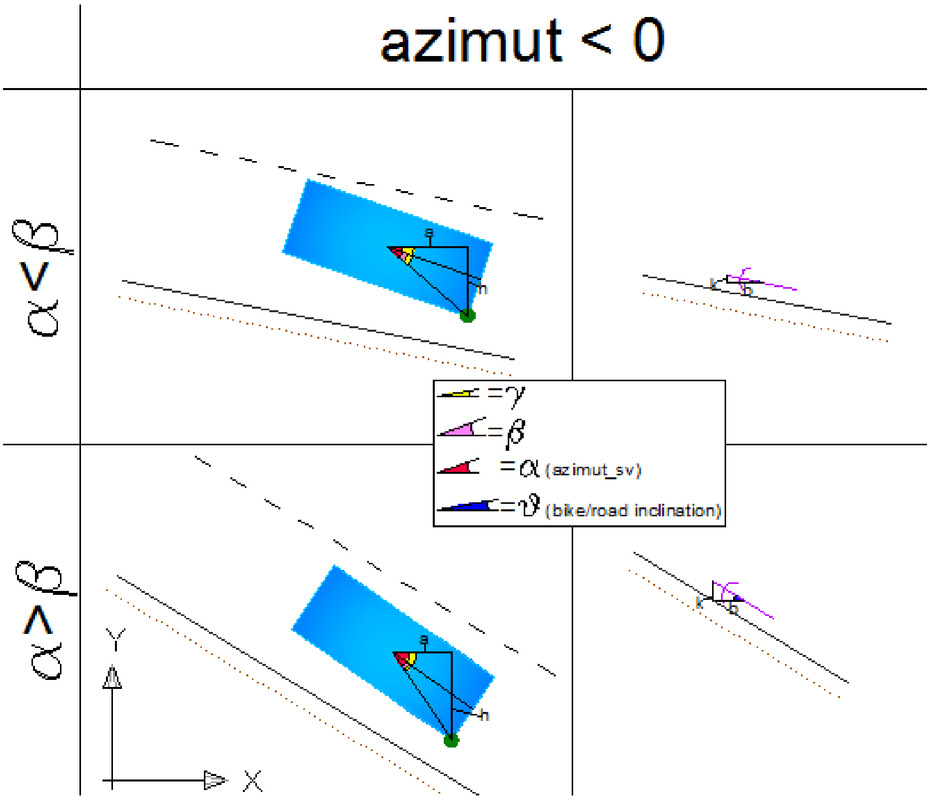

Figure 24:CZB4 Calculations, azimuth < 0

2. $Azimuth > 0$;
   - $\alpha > \beta$;

$$\gamma = \alpha - \beta$$

$$x_{rv} = x_{ego} + a$$

$$y_{rv} = y_{ego} + h$$

Where a and h are evaluated as in the previous case.

As regards the calculation to determine the front point of the bike, the only value that changes is the y value:

$$y_{fb} = y_{bike} - k$$

This value is the same even for the following case.

- $\alpha < \beta$;

$$\gamma = \beta - \alpha$$

$$x_{rv} = x_{ego} + a$$

$$y_{rv} = y_{ego} - h$$

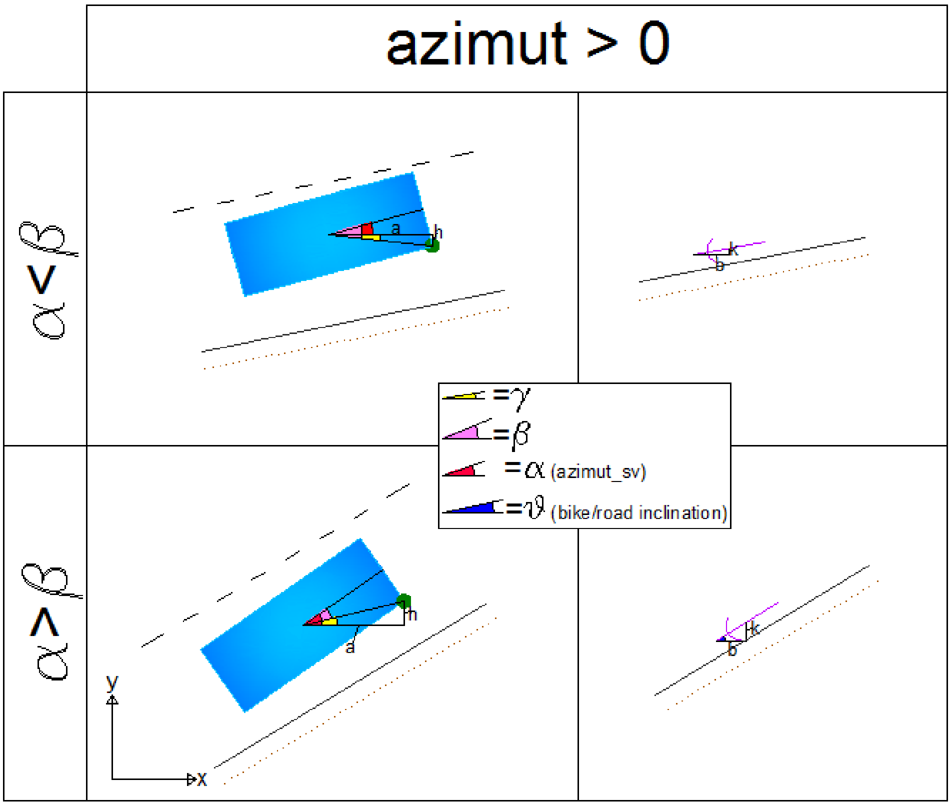

Figure 25: CZB4 Calculations, azimuth > 0

Once all the coordinates are determined, the distances Δx and Δy between the vehicle and the bike can be evaluated as in the previous calculations:

$$\Delta x_{egobike} = |x_{fb} - x_{rv}|$$

$$\Delta y_{egobike} = |y_{fb} - y_{rv}|$$

$$CZB4 = \sqrt{\Delta x_{egobike}{}^2 + \Delta y_{egobike}{}^2}$$

3.3.5 TOTAL COMFORT ZONE BOUNDARIES

For every overtaking it was considered a matrix with as many rows as the duration of the whole simulation and three columns, one for each CZBs calculation. With a Matlab function, it was found the minimum for each row (green, blue and red boxes in Figure 26). With these value a new array with all the minimum values of the Comfort Zone Boundaries was built as shown in the figure below:

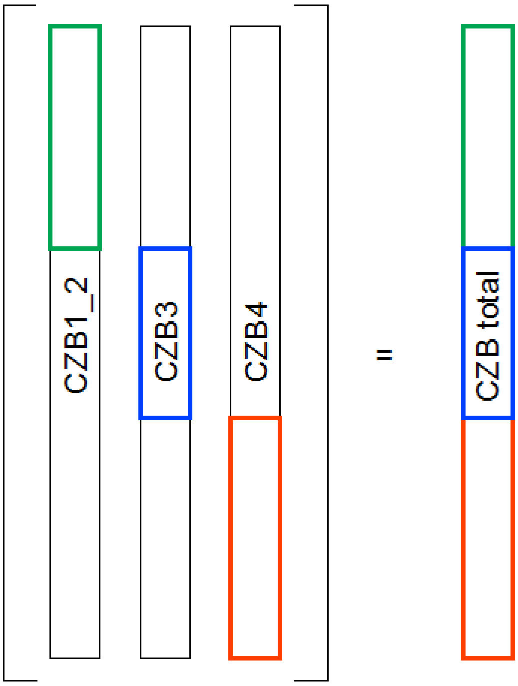

Figure 26: Schematic procedure description to find CZB total

This procedure was followed for every overtaking, resulting in 7 arrays which were put together in a final matrix (see Appendix for the Matlab code).

3.4 TIME TO COLLISION: CALCULATIONS

The TTC is calculated by the following ratio:

$$TTC = \frac{\Delta D}{\Delta V}$$

Where:

- ΔD is the perpendicular distance between the ego and oncoming vehicle (see Figure 30, Figure 31 and Figure 32). In order to evaluate this distance two points were considered: for both vehicles it was considered the point on the front right of the vehicle.
- ΔV is the difference between the speed of the two vehicles. The speed had opposite directions, thus ΔV was evaluated as follow:

$$\Delta V = Speed_{egovehicle} - (-Speed_{oncvehicle})$$

Even in these calculations it was necessary to distinguish different cases depending on the inclination of the road and on the β angle, already introduced before. The cases were necessary in order to calculate the angle γ.

1. $Azimuth < 0$;

In this case there is no distinction between $\alpha > \beta$ and $\alpha < \beta$ because the different cases did not produce any differences in the calculations. Thus, in every case γ was given by the sum of the two angles: $\gamma = \alpha + \beta$

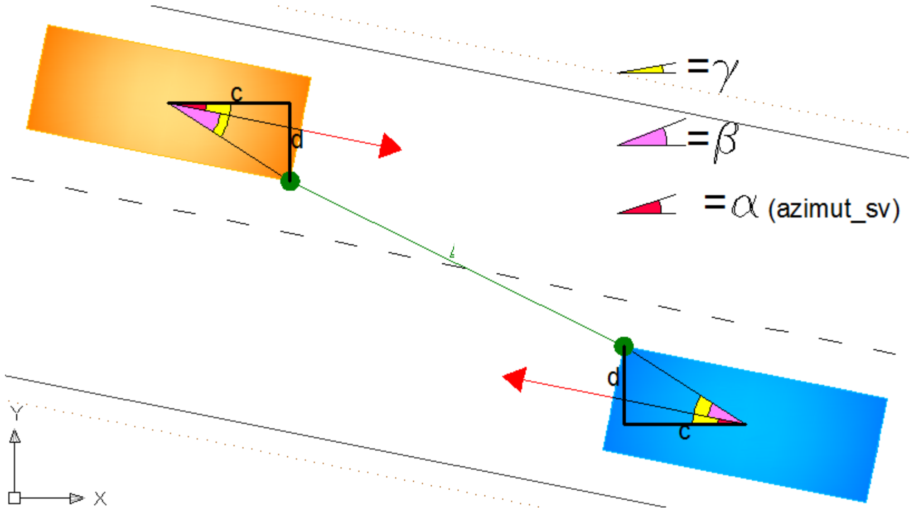

Figure 27: γ calculation for TTC, azimuth < 0

2. $Azimuth > 0$;

- $\alpha > \beta$;

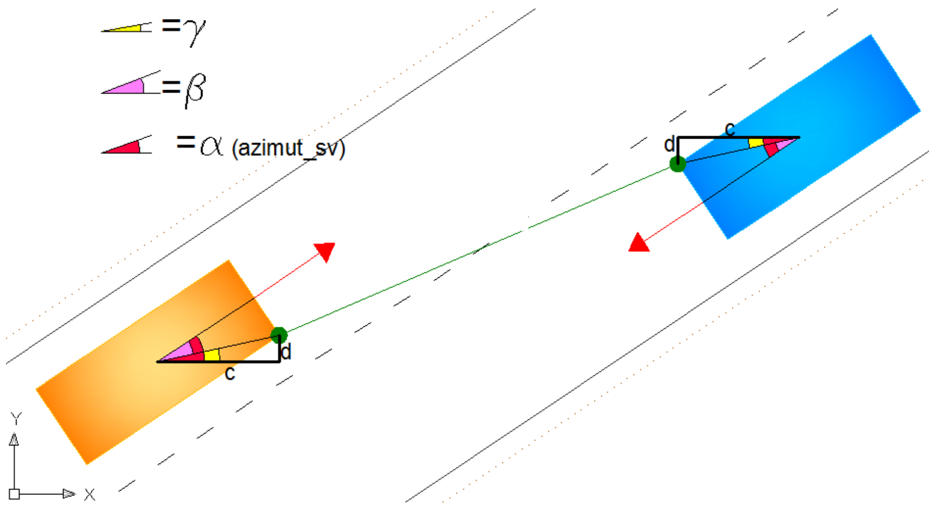

Figure 28: γ calculation for TTC, azimuth > 0, $\alpha > \beta$

In this case γ was given by the difference between α and β: $\gamma = \alpha - \beta$.

- $\alpha < \beta$;

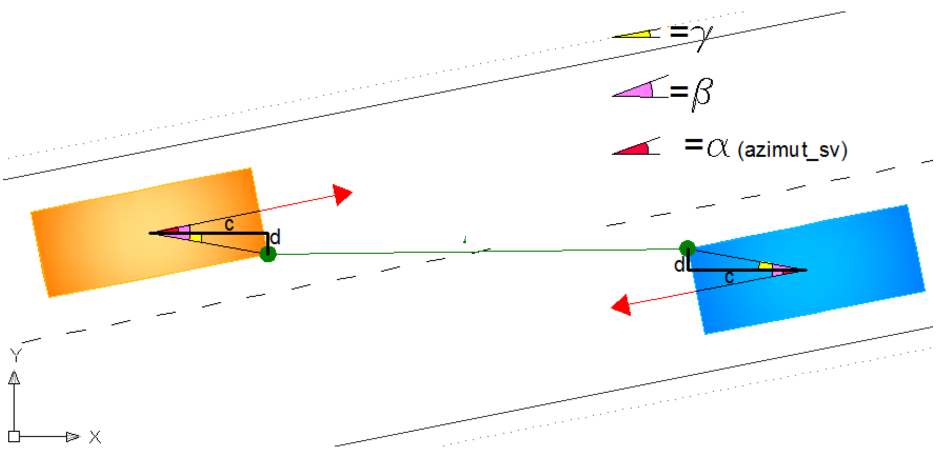

Figure 29: γ calculation for TTC, azimuth > 0, $\alpha > \beta$

Thus, γ was calculated as: $\gamma = \beta - \alpha$.

After defining γ for every case, it was possible to determine the parameters c and d that can be seen in Figure 27 - Figure 28 and Figure 29.

$$c = |diag * \cos(\gamma)|$$

$$d = |diag * \sin(\gamma)|$$

With these values it was possible to finally determine the coordinates of the points of interest of the subject and the oncoming vehicle (signed in green in the pictures).

$$x_{fev} = x_{ego} - c$$

$$y_{fev} = y_{ego} + d$$

$$x_{fov} = x_{onc} + c$$

$$y_{fov} = y_{onc} - d$$

Where the denoting mean:

- ‘fev’ = ‘front right of the ego vehicle’;
- ‘fov’ = ‘front right of the oncoming vehicle’.

Once all the parameters were calculated, it was possible to evaluate the difference between the x and y coordinates of the two vehicles:

$$\Delta x_{egoonc} = |x_{ego} - x_{onc}|$$

$$\Delta y_{egoonc} = |y_{ego} - y_{onc}|$$

To conclude, the distance between the two vehicles was assessed using the Pythagorean Theorem:

$$dist_{vehic} = \sqrt{{\Delta x_{egoonc}}^2 + {\Delta y_{egoonc}}^2}$$

It was then calculated the distance used to determine the TTC between the oncoming traffic and the subject vehicle, ΔD. This required an *if function* because the angle ω to consider varied if the y coordinate of the subject vehicle was greater or lesser then the one of the oncoming vehicle and if the azimuth was positive or negative.

1. $Azimuth > 0$;

When the azimuth was positive, two cases were distinguished. Otherwise only one case was considered because the y coordinate of the oncoming traffic was always greater than the y coordinate of the subject vehicle.

- $y_{onc} > y_{ego}$;

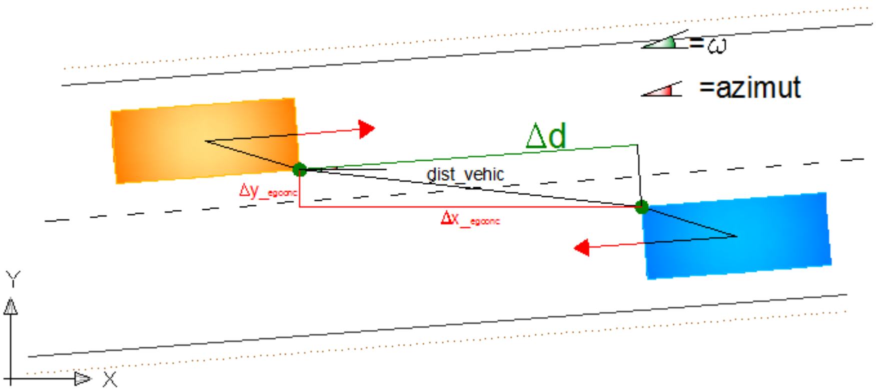

Figure 30: ΔD calculation, azimuth > 0, $y_{onc} > y_{ego}$

$$\omega = azimut + atan\frac{\Delta y_{egoonc}}{\Delta x_{egoonc}}$$

- $y_{onc} < y_{ego}$;

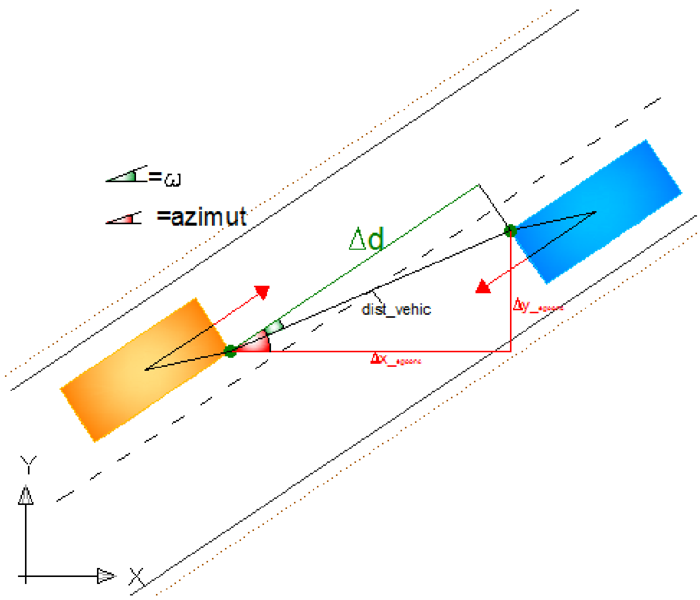

Figure 31: ΔD calculation, azimuth > 0, $y_{onc} < y_{ego}$

$$\omega = azimut - atan\frac{\Delta y_{egoonc}}{\Delta x_{egoonc}}$$

2. $Azimuth < 0$

As mentioned above, here no cases based on the y coordinates were distinguished.

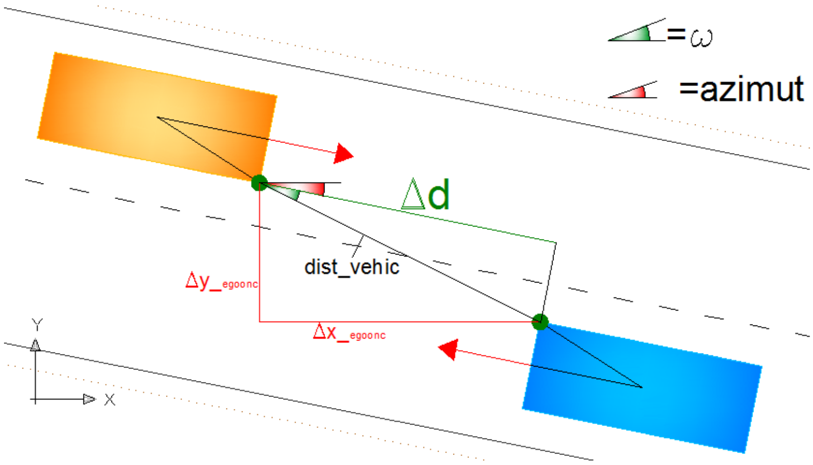

Figure 32: Δ*D* calculation, azimuth < 0

$$\omega = \frac{\pi}{2} - azimut - atan\frac{\Delta y_{egoonc}}{\Delta x_{egoonc}}$$

At this point it was possible to determine ΔD:

$$\Delta D = dist_{vehic} * \cos(\omega)$$

Once all the calculation were done, the TTC was evaluated with the ratio introduced at the beginning:

$$TTC = \frac{\Delta D}{\Delta V}$$

3.5 FLYING AND ACCELERATIVE MANEUVERS

With the presence of the oncoming traffic, there is the possibility to have two different overtaking maneuvers:

- Flying maneuver: speed is kept approximately constant (Dozza et al. 2016)
- Accelerative maneuver: the participant slows down for a while following the cyclist i.e. to wait for the oncoming traffic to pass (Dozza et al. 2016).

Hence, in order to distinguish these maneuvers two conditions were used. The former on the distance between the two vehicles and between the subject vehicle and the bicycle, the latter on the speed.

For the first condition it was found the first moment (distfind) when the subject vehicle reached a distance from the bike greater than 0 and lesser than 2.2 m . This second value was chosen after analyzing different participants and observing that the minimum value registered for one of them in one of the overtaking was 2.2 m, for the other overtaking maneuvers and participants was less than 2.2 m, thus it satisfied the condition. Afterwards, the minimum ΔD between the two vehicles was researched (findmindeltad in the code) and here an if function was used: if the minimum between the two vehicles was reached *before* the minimum between the subject vehicle and the bike, then it meant that the participant let the oncoming traffic pass and he/she was in an *accelerative maneuver* (with even the second condition satisfied). Otherwise, it was a *flying maneuver*.

The second condition was on the speed. It can be assumed that the driver decreased his/her velocity up to a value of 10m/s = 36 km/h or below. This value was taken into account observing the trend of the speed of different participants during the first three phases of the overtaking maneuver.

Thus if both conditions were satisfied then the overtaking was an accelerative maneuver, otherwise, it was a flying maneuver.

4 RESULTS

This section presents the results from the calculation of CZBs in each phase and the analyses of the possible correlations between them and TTC. All the following analyses were conducted with IBM SPSS software, Microsoft EXCEL and MATLAB.

Before assessing all the possible associations between TTC and CZBs, a description of the trends for the most relevant variables from the moment the bike starts moving to the end of the overtaking maneuver can be made (Figure 33). The results taken into account are of the participant 33, 7th overtaking.

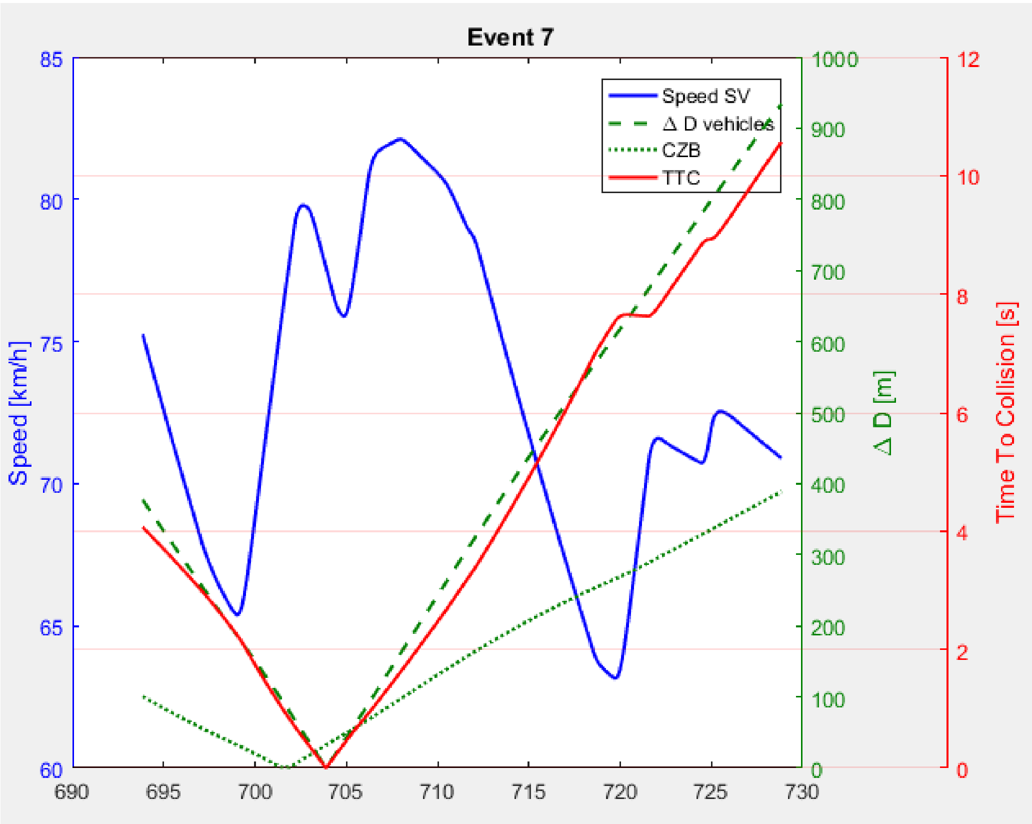

Figure 33: Output TTC and CZBs calculation, participant 33, event 7

In Figure 33, it can be spotted the moment when the subject vehicle (SV) overtook the bike from the trend of the CZB which decreases gradually towards zero and then, after a few seconds, starts growing again. Simultaneously, the trend of the TTC and ΔD decreases as well, but it reaches the zero after the CZBs' zero value. This is because the minimum distance, and thus the minimum TTC, happens right after the overtaking of the bike. From this information, it may be concluded that the 7th event of the 33rd participant is a flying overtaking maneuver, because the driver did not wait for the oncoming traffic to pass before carrying out the overtaking maneuver.

For participant 11 in the second event, an accelerative overtaking maneuver was performed instead, because the TTC, and ΔD as well, reached the zero before the minimum value of the comfort zone boundaries (see Figure 34).

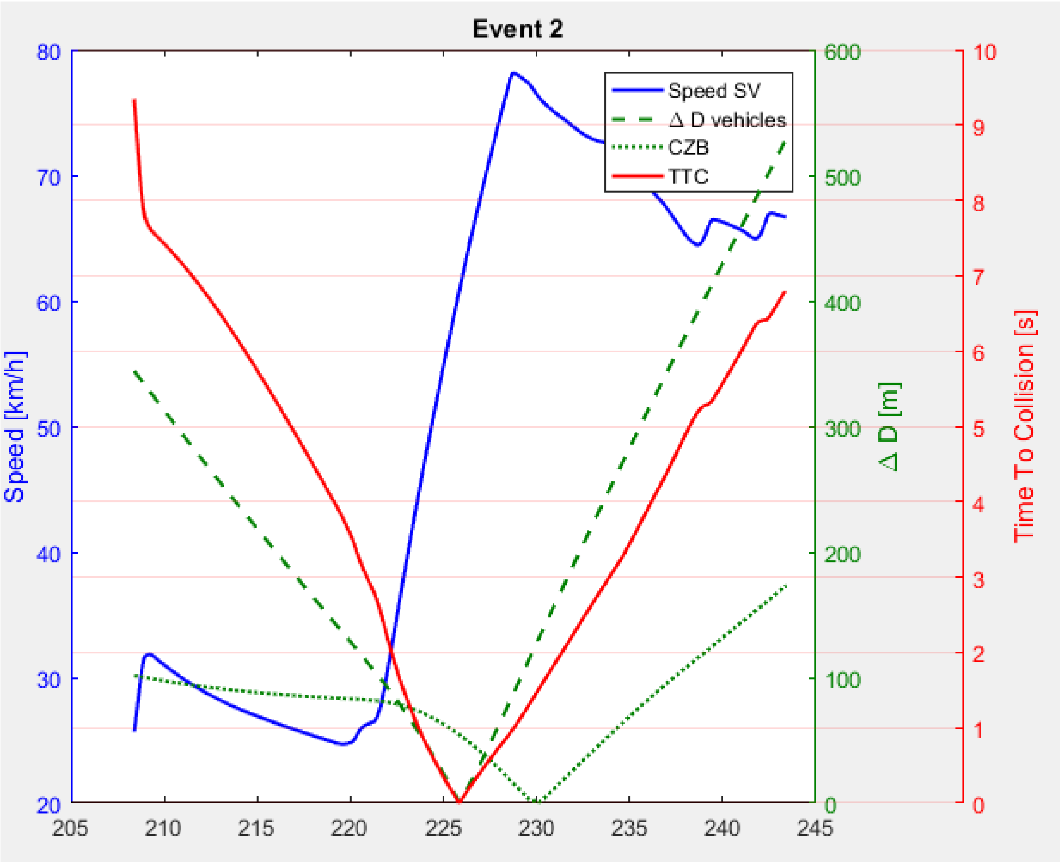

Figure 34: Output TTC and CZBs calculation, participant 11, event 2

4.1 CZB VS NOMINAL TTC

In order to observe how the different TTC influences the choice of the comfort zone boundaries, the mean values (and the standard deviation) of CZB are reported in Table 4 for each overtaking maneuvers.

Table 4: Mean value and Standard Deviation for all participants

Overtaking	CZB1 [m]	CZB2 [m]	CZB3 [m]	CZB4 [m]
1 (TTC = 9 sec)	86,69 ±56,02	2,52 ±0,18	1,27 ±0,40	2,70 ±0,23
2 (TTC = 6 sec)	76,27 ±66,62	2,58 ±0,33	1,32 ±0,60	2,74 ±0,38
3 (TTC = 8,5 sec)	63,52 ±34,12	2,54 ±0,27	1,27 ±0,50	2,48 ±0,10
4 (TTC = 8 sec)	111,41 ±67,86	2,58 ±0,28	1,33 ±0,51	2,72 ±0,31
5 (TTC = 9,5 sec)	76,95 ±23,24	2,63 ±0,24	1,46 ±0,42	2,48 ±0,32
6 (TTC = 7 sec)	90,74 ±64,02	2,43 ±0,16	1,36 ±0,55	2,79 ±0,33
7 (TTC = 6,5 sec)	64,21 ±44,41	2,60 ±0,37	1,35 ±0,63	2,74 ±0,40

The mean values are also represented in the boxplots reported in Figure 35, Figure 36, Figure 37 and Figure 38. The boxplots used in these analysis report, at the bottom of the box, the first quartile and, at the top of the box, the third quartile. The line inside the box is the second quartile, thus the median. Furthermore, the whiskers represent the minimum and the maximum of all data. The values which are not in this interval are represented as outliers with a circle, instead the starts represent the values which are "far out".

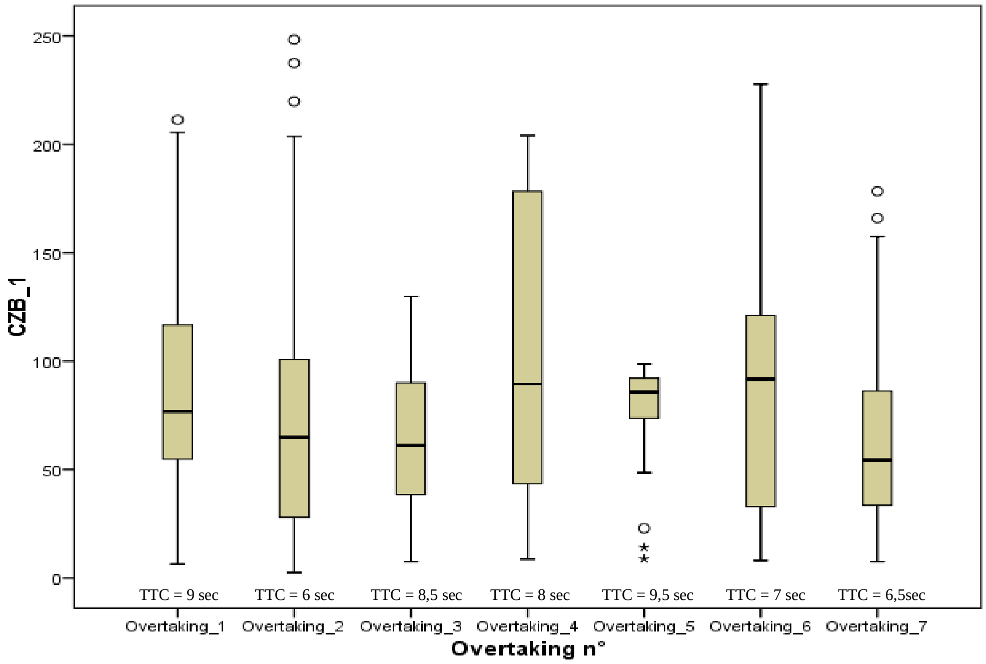

Figure 35: Box Plot CZB1, Overtaking 1-7

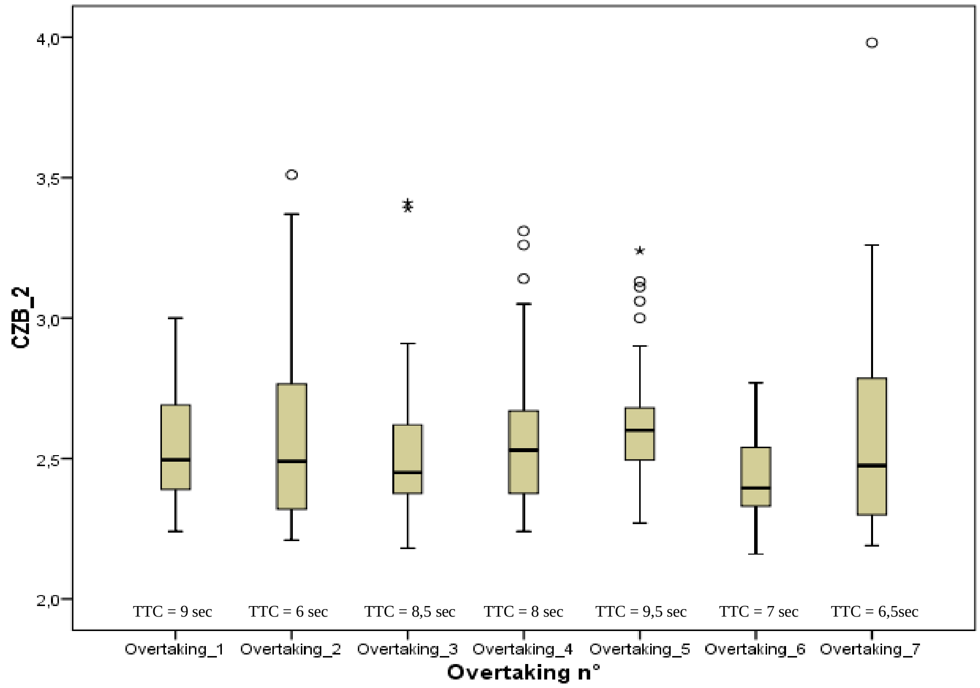

Figure 36: Box Plot CZB2, Overtaking 1-7

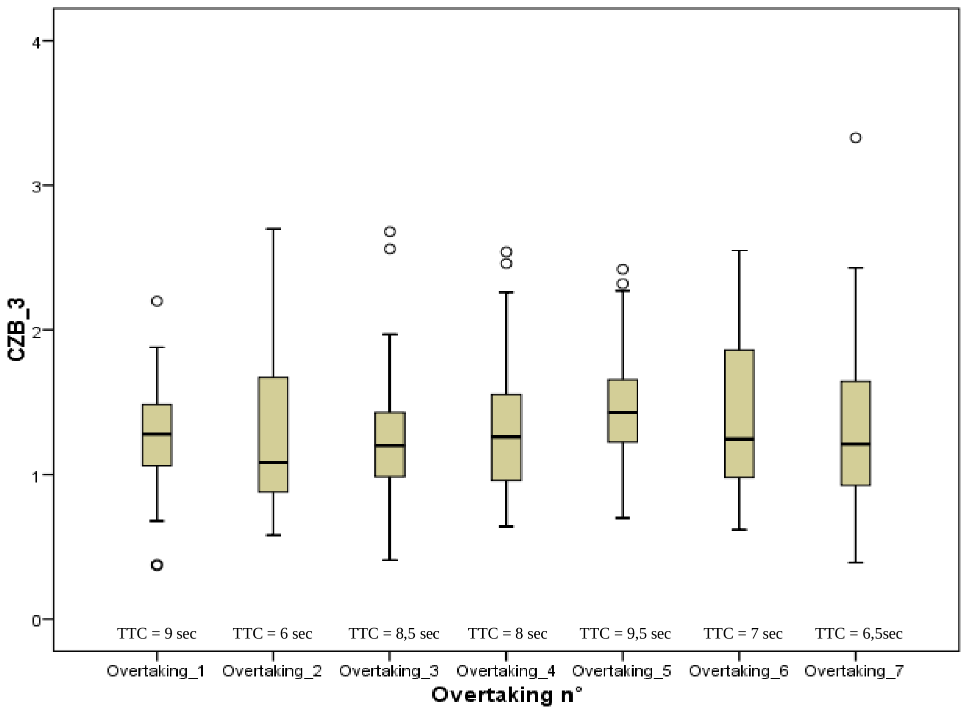

Figure 37: Box Plot CZB3, Overtaking 1-7

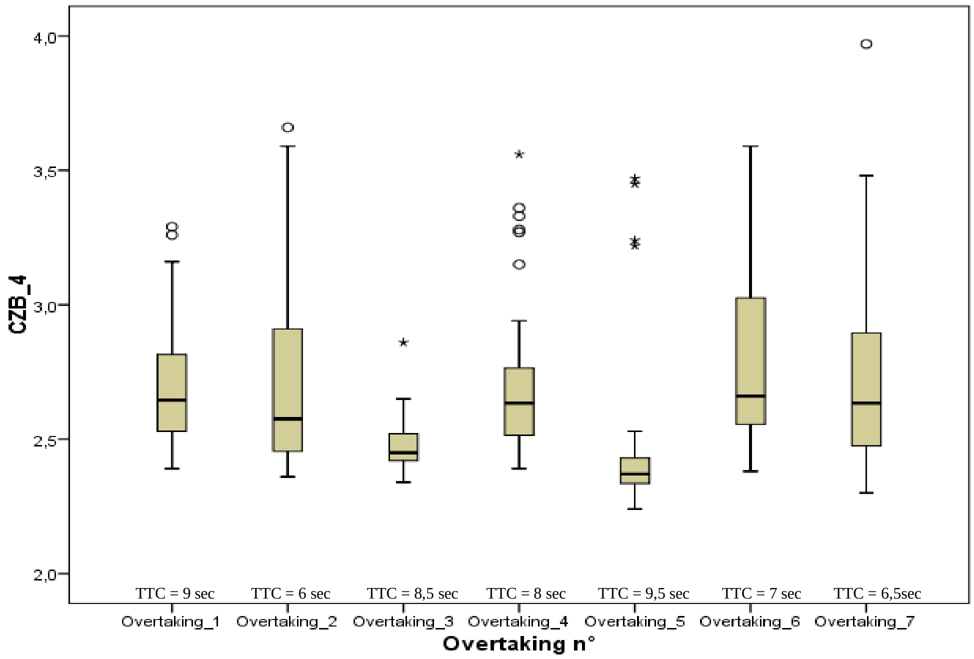

Figure 38: Box Plot CZB4, Overtaking 1-7

To understand how important is the role of TTC in influencing the CZBs choice, a t-test analysis was performed. The t-test analysis is used to determine if a significant difference exists between two sets of data: the CZB values for the minimum and maximum nominal TTC (respectively, 6 and 9.5 sec). Since the analysis considers two experimental conditions with the same group of participants, the dependent t-test (the so-called Paired Sample T-Test) was used. Before using the t-test, it was required to verify that the sampling distribution is normally distributed and that the homogeneity of variance is respected. The statistic tests the Null Hypothesis, which is the assumption that there is no significant change in the CZBs for the different values of the independent variables (different TTC values). If the significance is less than 0,05 ($p<0,05$), then the Null Hypothesis is rejected which means that the different conditions affect the results.

The results of the t-test analysis are reported in Table 5 and show that there is a significant difference for CZB4, meaning that the value of nominal TTC influenced the driver's choice of CZBs during phase 4, which is the phase in which the driver returns to the original lane.

Table 5: Paired Simple T-Test, CZBs - TTC

		t	Correlation Coefficient	Sig. (2-tailed) (p)
Pair 1	CZB1_TTC6 - CZB1_TTC9	-,063	,258	,950
Pair 2	CZB2_TTC6 - CZB2_TTC9	-1,068	,511	,293
Pair 3	CZB3_TTC6 - CZB3_TTC9	-1,769	,608	,086
Pair 4	CZB4_TTC6 - CZB4_TTC9	4,744	,548	,000

In order to understand the relevance of the t-statistic, it was evaluated the Pearson's effect size applying the formula retrieved from Rosenthal (1991) and Rosnow & Rosenthal (2005).

$$r = \sqrt{\frac{t^2}{t^2 + df}}$$

Where:

t = t – test value;

df = degrees of freedom = 35;

The results are reported in Table 6 and show a large effect size for CZB4 (r=0.626)

Table 6: Effect Size t-test

		Effect Size (r)
Pair 1	CZB1_TTC6 - CZB1_TTC9	0,0106
Pair 2	CZB2_TTC6 - CZB2_TTC9	0,1776
Pair 3	CZB3_TTC6 - CZB3_TTC9	0,2865
Pair 4	CZB4_TTC6 - CZB4_TTC9	**0,6256**

4.2 OVERTAKING STRATEGIES VS TTC

The Pearson's χ^2 square was used to determine if an association between type of overtaking (flying and accelerative) and TTC was significant. However, with the χ^2 test was not possible to assess how strong the association was between the variables. For this aim, it was used the effect size.

The assumption of the χ^2 test is that there is no association between the analyzed variables (Null Hypothesis). The significance value, even called the asymptotic significance, is the *p value* and if it is small enough (*p<0,05*), the hypothesis that the variables are independent will be rejected. In order to check if the assumptions are violated, we use the expected count, thus what it is expected if there was no association and the χ^2 test assesses if those observed counts are different enough for the test to be significant or for association to be significant:

$$\chi^2 = \frac{(observed - expected)^2}{expected}$$

The values of the TTC considered for the analyses are the minimum and the maximum nominal TTC during the test for each participant:

- TTC = 6 seconds, which is it the value of TTC set for the second overtaking;
- TTC = 9,5 seconds, which is the value of TTC set for the fifth overtaking.

Before running the analyses, another assumption has to be met for the χ^2 test: in a 2x2 table, all the expected counts should be at least 10 and this assumption was verified as shown in Table 7.

Table 7: Expected and observed counts for Chi-Square test

			Type_of_overtaking		
			Accelerative	Flying	Total
TTC	6,0	Count	18	18	36
		Expected Count	12,5	23,5	36,0
	9,5	Count	7	29	36
		Expected Count	12,5	23,5	36,0
Total		Count	25	47	72
		Expected Count	25,0	47,0	72,0

The results of the χ^2 test are reported in Table 8 and show a significant association between the type of overtaking and the TTC ($\chi^2(1) = 7.414, p = .006$): a decrease in nominal TTC produces a reduction of flying overtaking maneuver – that is driver prefers to wait for the oncoming traffic before performing the overtaking maneuver.

Table 8: Result of Chi-Square test

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	7.414[a]	1	.006
N of Valid Cases	72		

a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 12,50.

In order to evaluate the strength of association between the variables, SPSS can produce another table of output (Table 9) containing some measures taking into account the sample size and the degrees of freedom (df). The obtained value is the effect size and it is a correlation coefficient with a value between 0 and 1 (Field, 2009). The value 0.321 obtained from the analysis indicates a medium association between the type of overtaking and TTC.

In this case the phi effect size was used because the obtained contingency table is a 2x2. If more than 2 variables were used, a Cramer's V effect would have been used.

SPSS table (Table 9) reports both effects that, in this case, are the same.

Table 9: Effect Size

		Value	Approximate Significance
Nominal by Nominal	Phi	,321	,006
	Cramer's V	,321	,006
N of Valid Cases		72	

4.3 CZB BY OVERTAKING STRATEGY

In this section, the focus is to understand the influence of the overtaking strategy adopted by the participant on the choice of the comfort zone boundaries. In order to study this association, a dependent t-test was conducted since the participants are the same for both set of data considered in the analyses. The test was conducted only for the second overtaking maneuver because this maneuver is the most challenging, given that the nominal TTC has its smallest value (TTC = 6 seconds). The results of the t-test are reported in Table 10.

Table 10: T-Test CZB by Overtaking Strategy

		CZB1 [m]	CZB2 [m]	CZB3 [m]	CZB4 [m]
Flying Maneuver (N=18)	Mean Value	92,22	**2,39**	**0,93**	**2,50**
	Standard Deviation	±57,88	±0,15	±0,27	±0,11
Accelerative Maneuver (N=18)	Mean Value	**60,32**	2,77	1,71	2,99
	Standard Deviation	±72,45	±0,36	±0,59	±0.39
T-Test	Test Statistic	t(18)=1,469	t(18)=-3,774	t(18)=-4,709	t(18)=-4,804
	Scalar Value	0,16	**0,002**	**p<0.001**	**p<0.001**
Effect Size			0,665	0,743	0,750

As it can be observed in Table 10, there is a strong association between the choice of the comfort zone boundaries and the type of overtaking strategy adopted for three out of four phases: drivers choosing a flying overtaking strategy decreased their comfort zones to the bicycle compared to drivers choosing an accelerative overtaking strategy.

Moreover, the effect size is particularly large for the comfort zone boundaries calculated in the third and in the fourth phase.

4.4 Comparison CZB with and without oncoming traffic

Another t-test analysis was performed to compare the comfort zones chosen by the drivers with and without oncoming traffic. The results used for the analysis without oncoming traffic were derived from the Master's thesis written by Fatahtooei Nejad (2017).

For both analyses the mean and the standard deviation for all participants and for all the overtaking maneuvers considered were calculated.

The results of the t-test analysis are reported Table 11 and show that the presence of oncoming traffic affects the driver's choice of comfort zone boundaries for the third phase: the presence of oncoming traffic reduced the lateral comfort zones between the subject vehicle and the bicycle.

Table 11: Paired Simple T-Test, CZBs with and without oncoming traffic

		CZB1 [m]	CZB2 [m]	CZB3 [m]	CZB4 [m]
With Oncoming Traffic (N=36)	Mean Value	81,40	**2,55**	**1,34**	**2,66**
	Standard Deviation	±16,719	±0,066	±0,065	±0,129
Without Oncoming Traffic (N=37)	Mean Value	**74,56**	2,62	1,73	2,73
	Standard Deviation	±17.72	±0.34	±0.47	±0.30
T-Test	Test Statistic	t(35)=0,955	t(35)=-1,248	t(35)=-5,664	t(35)=-1,927
	Scalar Value	0,346	0,22	**p<0.001**	0,62
Effect Size				0,692	

5 DISCUSSION

The present Master's thesis aimed to assess driver behaviour during overtaking maneuvers of cars towards bicycles, in presence of oncoming traffic. The tool used for the data collection was the driving simulator of the University of Tsukuba and the detailed focus was the influence of TTC on the choice of the type of overtaking maneuver and on the choice of the comfort zone boundaries and the difference between the case with and without oncoming traffic.

The influence of TTC on the overtaking maneuver was studied with respect to the minimum comfort zone boundaries and the overtaking strategy chosen by the drivers. By comparing the overtaking maneuvers with minimum and maximum nominal TTC (respectively 6 and 9.5 seconds), a significant difference was found for CZB4. This means that a decrease in the nominal minimum TTC induced the participants to keep a smaller safety margin to the bike. As well, a decrease in the nominal minimum TTC produced a change in the overtaking strategy adopted by the drivers: more participants preferred to wait for the oncoming traffic to pass before performing the overtaking maneuver. Overall, it is clear from the results that the decrease in TTC to the oncoming traffic influenced the decision making process associated to the overtaking maneuver.

The comparison between comfort zone boundaries with and without oncoming traffic – the latter assessed in a previous Master's thesis – was also conducted: the results showed that the presence of oncoming traffic influenced driver's behavior during the overtaking maneuver. In particular, drivers maintained smaller safety margins during the passing phase, probably due to the necessity to complete the overtaking maneuver as fast as possible, due to the presence of oncoming traffic on the opposite lane.

6 CONCLUSIONS

The study aimed to answer the following research questions:

- How does the TTC influence the driver's choice to perform the overtaking of a cyclist?

In order to answer to this research question a chi-square test was performed. A strong association between the time to collision and the type of overtaking was found. This means that the TTC influences the driver's choice of how to perform the overtaking of the cyclist. In particular, if the driver chose to perform a flying overtaking strategy, the comfort zone boundaries evaluated were lesser than the ones kept in the accelerative maneuver.

- How does the TTC affect the choice of comfort zone boundaries during the overtaking?

It was found that the TTC affected the CZBs above all in the fourth phase. Thus, the driver is affected by the presence of the oncoming traffic –above all— at the end of the overtaking maneuver, when the driver return in the original lane.

Finding a relation between TTC and CZB is fundamental in order to design autonomous vehicles able to perform an overtaking maneuver in total safety and without going beyond the limit of the drivers' discomfort.

- How does the presence of oncoming traffic influence the choice of the comfort zone boundaries?

The presence of oncoming traffic was studied in comparison with the results obtained in the previous work by Fatahtooei Nejad (2017). Through a t-test it was found a strong difference in the third phase, the one characterized by the minimum distances between the subject vehicle and the overtaken bike. In this phase, in fact, the comfort zone boundaries were greater without oncoming traffic, than the ones calculated with the presence of oncoming traffic.

7 FUTURE ANALYSES

Overall, the results of this Master's thesis can provide relevant information for the design of active safety systems and automated driving which could mimic at best the behaviour of the driver during the overtaking maneuver.

Further analyses should be performed on the dataset to understand if the decision making process was actually driven by temporal information (e.g. TTC) or by distance to the oncoming traffic. As well, additional research should be conducted to evaluate how the lateral distance between the subject vehicle and the oncoming vehicle influences the choice of the comfort zone boundaries chosen by the driver towards the cyclist.

The current study presents some limitations. First, the experiment was conducted in a simulated environment and the results might differ for on road driving due to the different perception of subjective risk. Besides, the sample included only drivers aged either 25-40 years old or 65-75 years old and this might have had an influence on the final results.

The study of the overtaking maneuver is really important in order to design autonomous vehicles which are able to overtake a bicycle or another vehicle safely. Thus, it can be interesting to conduct more studies on the overtaking maneuver of different types of vehicles and study the Comfort Zone Boundaries for each of them with or without the presence of oncoming traffic. The results will be implemented in the active safety systems of an autonomous vehicle allowing it to overtake any road users.

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APPENDIX

SECTION A: MATLAB CODE

```
for i=1:7
```
→Loop for every i-th overtaking, where i = (1,…,7)

Definition of start and end of each overtaking maneuver.

```
    Start(i)=find(speed_cp(:,i)>0,1,'first');
    Start1000(i)=Start(i)-1000;
```
→ 1000*0.0083s = 8.3 s

```
    StartTime(i)=time(Start1000(i));
    fine(i)=time(Start(i))+35;
    End(i)=find(Data(:,1)<fine(i),1,'last');
    EndTime(i)=time(End(i));
    vehicle_mileage(i)=Data(Start1000(i),26);
```

In this section all the variables for the assessing of the distances between bike and vehicle will be defined.

```
b(Start1000(i):End(i),i)=abs(cos(AZIMUT(Start1000(i):End(i),i)).*(1.72
/2));
k(Start1000(i):End(i),i)=abs(sin(AZIMUT(Start1000(i):End(i),i)).*(1.72
/2));
   %CZB3
   pt_3x(:,i)=abs((Data(:,28)./2).*abs(sin(Data(:,14))));
   pt_3y(:,i)=abs((Data(:,28)./2).*abs(cos(Data(:,14))));

   if rad2deg(AZIMUT(Start1000(i),i))>0
      if abs(AZIMUT(Start1000(i),i))<beta(Start1000(i))
          % CZB1 - CZB2
          %Front left of the vehicle
          gamma(:,i)=beta(Start1000(i))+abs(AZIMUT(Start1000(i),i));
          a(:,i)=abs(cos(gamma(:,i)).*diag);
          h(:,i)=abs(sin(gamma(:,i)).*diag);
          % CZB4
          %Rear left extreme point of the vehicle
          gamma2(:,i)=beta(:)-abs(AZIMUT(:,i));
          a2(:,i)=abs(cos(gamma2(:,i)).*diag);
          h2(:,i)=abs(sin(gamma2(:,i)).*diag);
          x_rv(:,i)=X_egoglob(:)+a2(:,i);
          y_rv(:,i)=Y_egoglob(:)-h2(:,i);
      else
          % CZB1 - CZB2
          %Front left of the vehicle
```

```
        gamma(:,i)=abs(AZIMUT(Start1000(i),i))+beta(Start1000(i));
        a(:,i)=abs(cos(gamma(:,i)).*diag);
        h(:,i)=abs(sin(gamma(:,i)).*diag);
        % CZB4
        %Rear left extreme point of the vehicle
        gamma2(:,i)=abs(AZIMUT(:,i))-beta(:);
        a2(:,i)=abs(cos(gamma2(:,i)).*diag);
        h2(:,i)=abs(sin(gamma2(:,i)).*diag);
        x_rv(:,i)=X_egoglob(:)+a2(:,i);
        y_rv(:,i)=Y_egoglob(:)+h2(:,i);
    end

    % CZB1 - CZB2
    x_fv(:,i)=X_egoglob(:)-a(:,i);
    y_fv(:,i)=Y_egoglob(:)-h(:,i);
    %Back of the bike
    x_bb(:,i)=x_bikeglob(:,i)+b(:,i);
    y_bb(:,i)=y_bikeglob(:,i)+k(:,i);

    %CZB3
    x_mv(:,i)=X_egoglob(:)+pt_3x(:,i);
    y_mv(:,i)=Y_egoglob(:)-pt_3y(:,i);

    %CZB4
    %front of the bike
    x_fb(:,i)=x_bikeglob(:,i)-b(:,i);
    y_fb(:,i)=y_bikeglob(:,i)-k(:,i);

    %Paramters useful to the calculation of the distance between the
    %vehicles
    c(:,i)=abs(cos(gamma2(:,i)).*diag);
    d(:,i)=abs(sin(gamma2(:,i)).*diag);
else
    % CZB1 - CZB2
    %Front left of the vehicle

    if abs(AZIMUT(Start1000(i),i))<beta(Start1000(i))
        % CZB1 - CZB2
```

```
    %Front left of the vehicle
    gamma(:,i)=beta(Start1000(i))-abs(AZIMUT(Start1000(i),i));
    a(:,i)=abs(cos(gamma(:,i)).*diag);
    h(:,i)=abs(sin(gamma(:,i)).*diag);
    x_fv(:,i)=X_egoglob(:)-a(:,i);
    y_fv(:,i)=Y_egoglob(:)-h(:,i);
 else
    % CZB1 - CZB2
    %Front left of the vehicle
    gamma(:,i)=abs(AZIMUT(Start1000(i),i))-beta(Start1000(i));
    a(:,i)=abs(cos(gamma(:,i)).*diag);
    h(:,i)=abs(sin(gamma(:,i)).*diag);
    x_fv(:,i)=X_egoglob(:)-a(:,i);
    y_fv(:,i)=Y_egoglob(:)+h(:,i);
end

%CZB3
x_mv(:,i)=X_egoglob(:)-pt_3x(:,i);
y_mv(:,i)=Y_egoglob(:)-pt_3y(:,i);

% CZB4
gamma2(:,i)=abs(AZIMUT(:,i))+beta(:);
a2(:,i)=abs(cos(gamma2(:,i)).*diag);
h2(:,i)=abs(sin(gamma2(:,i)).*diag);

x_rv(:,i)=X_egoglob(:)+a2(:,i);
y_rv(:,i)=Y_egoglob(:)-h2(:,i);

%Back of the bike
x_bb(:,i)=x_bikeglob(:,i)+b(:,i);
y_bb(:,i)=y_bikeglob(:,i)-k(:,i);

%front of the bike
x_fb(:,i)=x_bikeglob(:,i)-b(:,i);
y_fb(:,i)=y_bikeglob(:,i)+k(:,i);

%Parameters for distances between ego and oncoming vehicles
```

```
        c(:,i)=abs(cos(gamma2(:,i)).*diag);
        d(:,i)=abs(sin(gamma2(:,i)).*diag);
    end

    %% CZB1 - CZB2
    DeltaX_egobike1(:,i)=abs(x_bb(:,i)-x_fv(:,i));
    DeltaY_egobike1(:,i)=abs(y_bb(:,i)-y_fv(:,i));

CZB1_2(:,i)=sqrt((DeltaX_egobike1(:,i).^2)+(DeltaY_egobike1(:,i).^2));

    %% CZB3 - middle phase
    DeltaX_egobike3(:,i)=abs(x_mv(:,i)-x_bikeglob(:,i));
    DeltaY_egobike3(:,i)=abs(y_mv(:,i)-y_bikeglob(:,i));

CZB_3(:,i)=sqrt((DeltaX_egobike3(:,i).^2)+(DeltaY_egobike3(:,i).^2));

    %% CZB4
    DeltaX_egobike4(:,i)=abs(x_rv(:,i)-x_fb(:,i));
    DeltaY_egobike4(:,i)=abs(y_rv(:,i)-y_fb(:,i));

CZB_4(:,i)=sqrt((DeltaX_egobike4(:,i).^2)+(DeltaY_egobike4(:,i).^2));

        %% Parameters for TIME TO COLLISION
        %ego vehicle
        x_fev(:,i)=X_egoglob(:)-c(:,i);
        y_fev(:,i)=Y_egoglob(:)+d(:,i);

        %oncoming vehicle
        x_fov(:,i)=x_oncglob(:,i)+c(:,i);
        y_fov(:,i)=y_oncglob(:,i)-d(:,i);

        %Delta D
    DeltaX_egoonc(:,i)=abs(x_fov(:,i)-x_fev(:,i));
    DeltaY_egoonc(:,i)=abs(y_fov(:,i)-y_fev(:,i));

dist_vehic(:,i)=sqrt((DeltaX_egoonc(:,i).^2)+(DeltaY_egoonc(:,i).^2));
    if AZIMUT(:,i)>0
```

```
        if y_fov(:,i)>y_fev(:,i)
omega(:,i)=AZIMUT(:,i)+atan(DeltaY_egoonc(:,i)./DeltaX_egoonc(:,i));
        else
            omega(:,i)=AZIMUT(:,i)-
atan(DeltaY_egoonc(:,i)./DeltaX_egoonc(:,i));
        end
   else
        omega(:,i)=pi/2-abs(AZIMUT(:,i))-
atan(DeltaY_egoonc(:,i)./DeltaX_egoonc(:,i));
   end
   DELTAD(:,i)=abs(dist_vehic(:,i).*cos(omega(:,i)));
   DeltaVkm(:,i)=speed_sv+speed_cp(:,i);
   DeltaV(:,i)=speed_sv+speed_cp(:,i)./3.6;
   minDELTAD(:,i)=min(DELTAD(:,i));
   findmindeltad(:,i)=find(DELTAD(:,i)==minDELTAD(:,i),1);
   %Calculation of Time To Collision
   TTC(:,i)=DELTAD(:,i)./DeltaV(:,i);
   %% End of phase 1
epsilon(:,i)=abs(atan(DeltaY_egobike1(:,i)./DeltaX_egobike1(:,i)));
%[rad]
epsilon4(:,i)=abs(atan(DeltaY_egobike4(:,i)./DeltaX_egobike4(:,i)));
%[rad]

if rad2deg(AZIMUT(Start1000(i),i))>0        →Positive road's inclination

        for j=Start1000(i):End(i)          →Interval of interest
            chi(j,i)=abs(pi/2-epsilon(j,i)+abs(AZIMUT(j,i)));
        end
```

When the azimuth was positive, it was not considered the condition on the y coordinates. This is because the y coordinate of the vehicle was always greater than y coordinate of the bike.

```
 else                                       →Negative road's inclination
        for j=Start1000(i):End(i)          →Interval of interest
```

In this case, it was considered the differences between the y coordinates in order to evaluate the chi angle which will be used to calculate the distance used for the start of the third phase:

```
           if y_bb(j,i)<y_fv(j,i)
```

```
                chi(j,i)=abs(pi/2-epsilon(j,i)-abs(AZIMUT(j,i)));
            else
                chi(j,i)=abs(pi/2+epsilon(j,i)-abs(AZIMUT(j,i)));
            end
        end
end

   Delta_y_phase1(:,i)=abs(CZB1_2(:,i).*cos(chi(:,i)));
   dist(:,i)=abs(CZB1_2(:,i).*sin(chi(:,i)));
   dist4(:,i)=abs(CZB_4(:,i).*sin(chi4(:,i)));
   for z=2:length(time)
       if Delta_y_phase1(z,i)>0.6 && Delta_y_phase1(z,i)<0.80 &&
Delta_y_phase1(z,i)>Delta_y_phase1(z-1,i) && Delta_y_phase1(z-1,i)>0.5
           Temp(z,i) = Delta_y_phase1(z,i);
       else
           Temp(z,i) = 0;
       end
   end
   End_1(i)=find(Temp(:,i)>0,1,'first');
end
   %% Parameters for phase 3
dist3_start=zeros(length(Start1000(2):End(2)),7);
dist3_end=zeros(length(Start1000(2):End(2)),7);
```

For some of the participants the array's length from the start point of the overtaking (Start1000) to the end point (End) was different in the first overtaking: the length was 5200 and not 5201, probably due to the fact that all the data were collected every 0,0083s and some approximation were different.

Hence, an *if condition* was used in order not to have a mismatch in the dimensions of the arrays considered:

```
for i=1:7
    if length(Start1000(i):End(i))==5200
       %Start phase 3
       dist3_start(:,i)=dist(Start1000(i):(End(i)+1),i);
       %End phase 3
       dist3_end(:,i)=dist4(Start1000(i):(End(i)+1),i);
```

In order to agree with the array dimension

```
    else
        %Start phase 3
        dist3_start(:,i)=dist(Start1000(i):End(i),i);
        %End phase 3
        dist3_end(:,i)=dist4(Start1000(i):End(i),i);
    end
```

These two vectors, dist3_start and dist3_end, were defined in order to have an array for the duration of the overtaking maneuver and not for the whole duration of the experiment.

In the first vector, through a *find function*, it was found the first moment when the distance between the bike and the vehicle was 2.2 m (d3_min2 in the script). Therefore, this value was extracted from the array dist3_start defined before: d3_min2value.

```
        d3_min2(i)=find(dist3_start(:,i)<=2.2,1,'first');
        d3_min2value(i)=dist3_start(d3_min2(i),i);
```

Finally, in order to find the location in the whole array, another *find function* was used and thus it was possible to determine the location of the first moment of phase 3:

```
        d3_start(i)=find(dist(:,i)==d3_min2value(i),1,'first');
```

In order to identify the *last* moment when the distance between the vehicle and the bike was lesser than 2.4 m, a second condition was added. Otherwise, when the first condition in the if function reported above was satisfied, the output value would have been the last value of the whole overtaking maneuver. This is because the "+1" in the code added a zero at the end of the array. Hence:

```
d3_last2(i)=find(dist3_end(:,i)>0 & dist3_end(:,i)<2.4,1,'last');
        d3_last2value(i)=dist3_end(d3_last2(i),i);
        d3_end(i)=find(dist4(:,i)==d3_last2value(i),1,'last');
end
%% Start and End times
Start_1=Start1000;
StartTime_1=time(Start1000);
Start_2=End_1;
EndTime_1=time(End_1);
StartTime_2=EndTime_1;
End_2=d3_start;
EndTime_2=(time(End_2))';
Start_3=End_2;
```

```
StartTime_3=EndTime_2;
End_3=d3_end;
EndTime_3=time(End_3);
Start_4=End_3;
StartTime_4=EndTime_3;
EndTime_4=EndTime;
%% Minimum Comfort zone boundaries and other parameters

%For each matrix, the minimum czb for each row is considered, in order to obtain a matrix (length(time),1) with all the minimum values of CZBs.
A1=[CZB1_2(:,1) CZB_3(:,1) CZB_4(:,1)];
AA1=min(A1,[],2);
A2=[CZB1_2(:,2) CZB_3(:,2) CZB_4(:,2)];
AA2=min(A2,[],2);
A3=[CZB1_2(:,3) CZB_3(:,3) CZB_4(:,3)];
AA3=min(A3,[],2);
A4=[CZB1_2(:,4) CZB_3(:,4) CZB_4(:,4)];
AA4=min(A4,[],2);
A5=[CZB1_2(:,5) CZB_3(:,5) CZB_4(:,5)];
AA5=min(A5,[],2);
A6=[CZB1_2(:,6) CZB_3(:,6) CZB_4(:,6)];
AA6=min(A6,[],2);
A7=[CZB1_2(:,7) CZB_3(:,7) CZB_4(:,7)];
AA7=min(A7,[],2);
%All the matrix are then concatenated in one matrix.
CZBtotal=[AA1 AA2 AA3 AA4 AA5 AA6 AA7];

for i=1:7
    minCZB_1(i)=min(CZBtotal(Start_1(i):End_1(i),i));
    minCZB_2(i)=min(CZBtotal(Start_2(i):End_2(i),i));
    minCZB_3(i)=min(CZBtotal(Start_3(i):End_3(i),i));
    minCZB_4(i)=min(CZBtotal(Start_4(i):End(i),i));

    minDELTAD_1(i)=min(DELTAD(Start_1(i):End_1(i),i));
    minDELTAD_2(i)=min(DELTAD(Start_2(i):End_2(i),i));
    minDELTAD_3(i)=min(DELTAD(Start_3(i):End_3(i),i));
    minDELTAD_4(i)=min(DELTAD(Start_4(i):End(i),i));
```

```
    instantTTC(i)=TTC(Start_3(i),i);
    minCZBtotal(:,i)=[minCZB_1(i); minCZB_2(i); minCZB_3(i);
minCZB_4(i)];
    minDELTADphases(:,i)=[minDELTAD_1(i); minDELTAD_2(i);
minDELTAD_3(i); minDELTAD_4(i)];
    StartPhases(:,i)=[StartTime_1(i); StartTime_2(i); StartTime_3(i);
StartTime_4(i)];
    EndPhases(:,i)=[EndTime_1(i); EndTime_2(i); EndTime_3(i);
EndTime_4(i)];
End
%% Plot of the different events
 for i=1:7
%plot three y axes
x=time(Start1000(i):End(i));
%y1=speed_cp(Start(i):End(i),i);
%y2=speed_sv(Start(i):End(i));
y3=DELTAD(Start1000(i):End(i),i);
y4=TTC(Start1000(i):End(i),i);
y5=DeltaVkm(Start1000(i):End(i),i);
y6=CZBtotal(Start1000(i):End(i),i);
ylabels{1}='Speed [km/h]';
ylabels{2}='\Delta D [m]';
ylabels{3}='Time To Collision [s]';
[ax,hlines] = multiplotyyy({x,y5},{x,[y3,y6]},{x,y4},ylabels);
xlabel('time[s]')

grid on
%legend(cat(1,hlines{:}),'Speed Oncoming vehicle','Speed Ego
vehicle','\Delta V','\Delta D vehicles','\Delta D
ego_bike','TTC','location','ne')
legend(cat(1,hlines{:}),'\Delta V','\Delta D
vehicles','CZB','TTC','location','ne')
    title(['Event ' num2str(i) ])
end

%% Plot in order to define the type of overtaking and the end/start of
phase 1/2
figure(9)
```

```
suptitle('Time- Speed(left)- CZB(right)')
for i=1:4
    subplot(2,2,i)
    x=time(Start1000(i):End_2(i));

plotyy(x,speed_sv(Start1000(i):End_2(i)),x,CZBtotal(Start1000(i):End_2
(i),i))
    grid on
    title(['Event ' num2str(i) ])
end
figure(10)
suptitle('Time - Speed(left) - CZB(right)')
for i=5:7
    subplot(2,2,i-4)
    x=time(Start1000(i):End_2(i));

plotyy(x,speed_sv(Start1000(i):End_2(i)),x,CZBtotal(Start1000(i):End_2
(i),i))
    grid on
    title(['Event ' num2str(i) ])
end
% % plot about the steering angle, to analize it better, I put the end
of the
% % plot at the end of phase 3.
figure(11)
suptitle('Time - Acceleration(left)- CZB(right)')
for i=1:4
    subplot(2,2,i)
    x=time(Start1000(i):End_2(i));

plotyy(x,Data(Start1000(i):End_2(i),21),x,CZBtotal(Start1000(i):End_2(
i),i))
    grid on
    title(['Event ' num2str(i) ])
end
figure(12)
suptitle('Time - Acceleration(left) - CZB(right)')
for i=5:7
    subplot(2,2,i-4)
```

```
    x=time(Start1000(i):End_2(i));

plotyy(x,Data(Start1000(i):End_2(i),21),x,CZBtotal(Start1000(i):End_2(
i),i))
    grid on
    title(['Event ' num2str(i) ])
end
figure(13)
suptitle('Time - Steering angle(left)- CZB(right)')
for i=1:4
    subplot(2,2,i)
    x=time(Start1000(i):End_2(i));

plotyy(x,Data(Start1000(i):End_2(i),8),x,CZBtotal(Start1000(i):End_2(i
),i))
    grid on
    title(['Event ' num2str(i) ])
end
figure(14)
suptitle('Time - Steering angle(left) - CZB(right)')
for i=5:7
    subplot(2,2,i-4)
    x=time(Start1000(i):End_2(i));

plotyy(x,Data(Start1000(i):End_2(i),8),x,CZBtotal(Start1000(i):End_2(i
),i))
    grid on
    title(['Event ' num2str(i) ])
end

%% Flying and accelerative maneuvers
```

The first loop was on the overtaking maneuver, so i=1,…,7. The second loop considered a variable j which allowed to consider an interval from the beginning of the first phase until the end of the third phase. It was considered such a huge interval because some of the participants decided at the very last moment to brake and to let the oncoming traffic pass.

```
for i=1:7
```

```
    distfind(i)=find(dist(:,i)>0 & dist(:,i)<2.2,1,'first');

for j=Start_1(i):End_3(i)
```

If both the conditions on the distances and on the speed (Data(j,15)) were satisfied then an index ‘zero’ was assigned, otherwise a ‘one’ was assigned.

```
if (findmindeltad(i)<distfind(i)) && (Data(j,15)>0) && (Data(j,15)<10)
    index(j,i)=0;
else
    index(j,i)=1;
end
end
end
```

SECTION B: CZBS' VALUES

Table 12: CZB1 values

ID	Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4	Overtaking 5	Overtaking 6	Overtaking 7
1	58,16	40,14	40,51	74,44	48,6	45,34	49,85
2	73,7	64,41	62,86	42,9	66,75	48,49	57,38
3	6,52	50,74	10,52	27,55	90,18	8,53	7,99
4	169,84	122,84	81,83	85,31	81,68	170,9	78,11
5	52,87	59,78	71,47	177,17	74,64	82	84,91
6	205,5	203,65	126,57	184,77	98,62	227,68	54,98
7	88,97	68,88	86,32	162,26	98,49	188,92	52,89
9	192,49	119,82	92,94	40,89	94,15	97	157,41
11	25,32	31,26	124,65	8,75	92,01	21,16	24,13
12	58,16	40,14	40,51	74,44	48,6	45,34	49,85
13	59,96	87,12	38,37	84,83	75,55	49,96	53,97
14	67,78	155,76	112,9	178,38	80,15	177,31	104,65
15	93,92	248,27	129,78	55,47	77,4	97,39	100,23
17	28,86	2,5	17,87	33,82	81,95	23,82	10,25
18	62,12	16,1	29,93	191,82	86,94	91,1	69,47
19	102,72	142,96	83,54	93,38	95,35	91,95	44,37
20	13,07	12,99	7,57	14,22	14,11	17,59	13,75
21	13,37	25,37	45,07	43,92	80,57	24,36	80,63
22	27,73	30,43	32,61	31,79	22,93	24,61	100,89
23	56,79	13,32	59,22	201,48	97,06	217,09	63,58
24	75,38	78,03	57,72	23,62	8,89	12,55	37,8
25	140,2	219,73	100,71	175,43	86,97	167,83	165,92
26	82,13	5,69	42,12	203,96	87,7	8,06	41,94
27	18,73	33,48	20,7	143,65	76,99	33,96	87,25
28	91,04	75,09	66,06	162,45	95,15	201,98	12,57
30	211,31	71,36	57,09	200,14	92,06	173,29	29,2
31	60,96	41,1	63,91	190,88	92,62	99,47	37,74
32	200,46	10,05	38,62	178,04	52,08	71	10,48
33	133,39	80,18	87,16	118,54	91	99,21	88,49
35	112,61	65,28	96,67	73,73	57,93	117,72	75,33
36	86,14	114,51	72,58	161,58	91,58	91,98	85,26
37	42,45	67,98	40,09	184,61	96,07	124,56	44,55
39	120,96	237,43	102,26	83,5	88,49	96,08	178,29
40	87,87	69,4	92,7	199,34	84,9	88,41	130,7
41	78,41	16,25	33,17	74,74	72,74	97,93	7,61
42	120,77	23,62	19,97	29,04	89,21	31,97	19,13

Table 13: CZB2 values

ID	Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4	Overtaking 5	Overtaking 6	Overtaking 7
1	2,38	2,32	2,41	2,58	2,47	2,33	2,39
2	2,31	2,26	2,37	2,37	2,33	2,27	2,19
3	2,28	2,22	2,23	2,3	2,27	2,25	2,28
4	2,7	2,43	2,34	2,59	2,66	2,39	2,69
5	2,4	2,49	2,54	2,5	2,36	2,42	2,29
6	2,74	2,88	2,79	2,68	2,62	2,77	2,88
7	2,64	2,75	2,75	2,43	2,59	2,7	2,74
9	2,33	2,32	2,67	2,41	2,68	2,38	2,56
11	2,24	2,53	2,52	2,4	2,52	2,34	2,6
12	2,38	2,32	2,41	2,58	2,47	2,33	2,39
13	2,73	2,86	2,91	2,98	3,13	2,61	3,14
14	2,53	2,37	2,58	2,85	2,68	2,62	2,61
15	2,75	3,37	2,32	2,32	2,62	2,4	3,26
17	2,4	2,21	2,37	2,34	2,54	2,42	2,29
18	2,26	2,49	2,18	2,24	2,28	2,27	2,23
19	2,72	3,51	2,47	3,14	2,65	2,53	3,98
20	2,44	2,59	2,47	2,67	2,79	2,7	2,88
21	2,76	3,2	3,39	3,05	3,11	2,45	2,85
22	3	3,2	3,41	3,26	3	2,49	3,21
23	2,72	2,78	2,87	3,31	3,24	2,77	2,83
24	2,46	2,66	2,4	2,46	2,6	2,38	2,74
25	2,29	2,3	2,48	2,35	2,41	2,34	2,43
26	2,36	2,24	2,43	2,3	2,9	2,31	2,3
27	2,6	2,62	2,61	2,6	2,72	2,16	2,68
28	2,4	2,35	2,38	2,38	2,54	2,3	2,23
30	2,48	2,28	2,4	2,36	2,45	2,35	2,3
31	2,47	2,34	2,58	2,4	2,56	2,47	2,48
32	2,73	2,72	2,63	2,67	2,68	2,55	2,57
33	2,51	2,51	2,48	2,53	2,6	2,4	2,37
35	2,55	2,5	2,34	2,57	2,52	2,2	2,42
36	2,4	2,42	2,4	2,53	2,67	2,41	2,38
37	2,52	2,46	2,4	2,54	2,62	2,56	2,44
39	2,68	2,38	2,4	2,48	2,36	2,33	2,26
40	2,44	2,3	2,33	2,26	2,53	2,25	2,25
41	2,55	2,9	2,33	2,6	2,58	2,7	2,47
42	2,53	2,84	2,74	2,94	3,06	2,36	2,95

Table 14: CZB3 values

ID	Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4	Overtaking 5	Overtaking 6	Overtaking 7
1	1,06	0,88	1,13	1,28	1,23	0,98	1,04
2	0,89	0,63	0,88	0,85	0,74	0,63	0,61
3	0,68	0,71	0,59	0,72	0,7	0,64	0,62
4	1,58	1,24	1,09	1,33	1,52	1,24	1,46
5	1,14	1,15	1,21	1,17	1,17	1,24	1,02
6	1,32	1,72	1,7	1,28	1,55	1,39	1,72
7	1,3	1,41	1,42	1,21	1,31	1,63	1,57
9	0,87	1,06	1,41	0,95	1,25	1	1,23
11	0,38	1,09	1,29	0,96	1,08	1,02	1,48
12	1,06	0,88	1,13	1,28	1,23	0,98	1,04
13	1,42	1,62	1,97	1,86	1,9	2,55	2,3
14	1,43	0,69	1,26	1,81	1,43	1,43	1,14
15	1,83	2,7	0,41	0,72	1,52	2,55	2,39
17	1,03	0,88	0,97	1,12	1,22	1,25	0,92
18	0,37	1,06	0,42	0,64	0,91	0,62	0,39
19	1,48	2,6	0,98	2,19	1,43	1,88	3,33
20	1,39	1,56	1,44	1,78	1,99	1,97	2,04
21	1,82	2,41	2,56	2,26	2,12	1,98	1,74
22	2,2	2,5	2,68	2,54	2,27	1,98	2,43
23	1,88	1,94	1,96	2,46	2,42	1,97	2,03
24	1,19	1,62	0,99	1,09	1,47	1,1	1,47
25	0,75	0,66	0,94	0,65	1,07	0,72	1,01
26	1,09	0,72	1,35	0,96	1,96	0,97	0,81
27	1,54	1,51	1,49	1,46	1,67	0,69	1,5
28	1,1	1,02	1,15	1,15	1,48	1,05	0,81
30	1,26	1,01	1,13	1,06	1,15	1,05	0,89
31	1,21	1,08	1,39	1,25	1,44	1,35	1,23
32	1,65	1,87	1,47	1,52	1,64	1,47	1,5
33	1,39	1,31	1,24	1,26	1,46	1,27	1,19
35	1,28	0,99	0,55	1,43	1,24	2,04	0,95
36	0,93	0,89	1,19	1,28	1,75	1,02	0,93
37	1,28	0,98	1,28	1,26	1,42	1,38	1,26
39	1,8	0,67	1,13	0,64	0,93	0,78	0,72
40	1,1	0,58	0,99	0,87	1,3	0,84	0,64
41	1,49	2,03	0,96	1,59	1,42	1,84	1,19
42	1,41	1,95	1,86	2,09	2,32	2,46	2,09

Table 15: CZB4 values

ID	Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4	Overtaking 5	Overtaking 6	Overtaking 7
1	2,49	2,45	2,44	2,64	2,36	2,55	2,48
2	2,5	2,46	2,44	2,4	2,49	2,38	2,33
3	2,46	2,37	2,46	2,39	2,38	2,38	2,38
4	2,83	2,72	2,37	2,71	2,4	2,77	2,66
5	2,56	2,58	2,57	2,58	2,33	2,64	2,55
6	2,71	2,86	2,34	2,62	2,4	2,72	2,9
7	2,61	2,67	2,48	2,69	2,33	2,87	2,82
9	2,52	2,57	2,48	2,47	2,32	2,56	2,63
11	2,42	2,5	2,52	2,5	2,39	2,51	2,74
12	2,49	2,45	2,44	2,64	2,36	2,55	2,48
13	2,67	2,82	2,38	2,94	2,47	3,42	3,19
14	2,7	2,37	2,54	2,81	2,37	2,77	2,46
15	3,1	3,66	2,45	2,41	2,37	3,59	3,29
17	2,59	2,66	2,51	2,53	2,32	2,6	2,47
18	2,39	2,48	2,42	2,44	2,44	2,44	2,38
19	2,66	3,42	2,45	3,15	2,36	3	3,97
20	2,94	2,96	2,38	3,27	3,22	3,25	3,34
21	3,16	3,35	2,65	3,28	2,53	3,15	2,89
22	3,29	3,59	2,86	3,56	3,45	3,13	3,48
23	3,26	3,33	2,4	3,33	3,24	3,39	3,43
24	2,6	2,8	2,56	2,61	2,42	2,64	2,66
25	2,43	2,4	2,45	2,46	2,4	2,42	2,44
26	2,49	2,43	2,41	2,54	2,48	2,66	2,37
27	2,75	2,7	2,4	2,75	2,36	2,56	2,76
28	2,63	2,53	2,44	2,44	2,32	2,56	2,53
30	2,7	2,52	2,56	2,57	2,26	2,6	2,52
31	2,75	2,6	2,44	2,63	2,34	2,71	2,64
32	2,9	3,18	2,42	2,73	2,37	2,97	2,94
33	2,67	2,57	2,51	2,65	2,38	2,69	2,57
35	2,54	2,55	2,57	2,78	2,24	3,05	2,51
36	2,55	2,44	2,47	2,58	2,37	2,59	2,56
37	2,59	2,55	2,39	2,66	2,29	2,66	2,65
39	2,89	2,44	2,6	2,46	2,33	2,49	2,35
40	2,62	2,36	2,52	2,57	2,37	2,5	2,3
41	2,8	3,17	2,44	2,75	2,35	3,15	2,65
42	2,93	3,27	2,45	3,36	3,47	3,48	3,4