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Master's thesis in Mechanical Engineering

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ABSTRACT

After the great earthquake in 2011, the number of bicycles owners in Japan increased significantly and the use of bicycles is getting popular to go to work and school. Although bicycles are non-motorized vehicles and there are several advantages in using bikes (for example, health and environmental benefits), in 2015, cyclists faced 109,269 accidents and 542 fatalities. Several crashes occurred in rural areas where there was no bicycle path and the collisions happened when a motorized vehicle overtook a slower bike. A number of studies were carried out on this topic, but more research is needed to assess the comfort zone boundaries during drivers’ overtaking of cyclists in order to support the design of autonomous vehicles. A driving simulator study was conducted with 37 participants at the University of Tsukuba in Japan. The participants were divided into two groups of age (standard drivers: 25-40 years old; elderly drivers: 65-75 years old) and two groups of gender (22 males and 15 females). The results show statistically significant differences between standard and elderly drivers only for comfort zone boundaries (CZB)1 in overtaking maneuver 2 (small effect size) and statistically significant differences between male and female drivers. However the significant differences between naturalistic versus driving simulator study was only in CZB1 (large effect size) and CZB4 (small effect size).

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

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PREFACE

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The analyses were carried out at SAFER premises in Gothenburg. The driving simulator study was conducted at 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 examiner Prof. Aki Mikkola and my supervisor, Giulio Piccinini, who led me during the thesis project.

NOTATIONS

Acronym	**Definition [unit]**
a	The line from the vehicle's center extreme point and perpendicular [m]
b	The line from the rear extreme point of the bikes and perpendicular in x axis [m]
C	The line from the vehicle's extreme center point to the bikes' center extreme point [m]
d	The line the from the center extreme point of the vehicle to the front left extreme point of the vehicle [m]
e	The line from the front left extreme point of the vehicle to the perpendicular line of the bike in x axis [m]
e_f	The line from the front left extreme point of the vehicle to the perpendicular line of the bike in x axis [m]
e_r	The line from rear left extreme point of the vehicle to the perpendicular line of the bike in x axis [m]
f	The line between q and the perpendicular line at the rear extreme point of the bike in x axis [m]
f_f	The line between q_f and the perpendicular line at the front extreme point of the bike in x axis [m]
f_r	The line between q_f and the perpendicular line at the front extreme point of the bike in x axis [m]
g	The line from the front left extreme point of the vehicle to the perpendicular line of the bike in the bike axis [m]
g_f	The line from front left extreme point of the vehicle to the perpendicular line in the bike axis [m]
g_r	The line from rear left extreme point of the vehicle to the perpendicular line in the bike axis [m]
h	The line from the front left extreme point of the vehicle and perpendicular in y axis [m]
k	The line from the center extreme point of the bikes and perpendicular in y axis [m]

L_{bike}	Length of the bikes [m]
$L_{vehicle}$	Length of the vehicle [m]
p	The line from the front left extreme point of the vehicle and perpendicular [m]
p_f	The line from front left extreme point of the vehicle and perpendicular x axis [m]
p_r	line from rear left extreme point of the vehicle and perpendicular in x axis [m]
psi	The angle between *C* and Δx [degree]
q_f	The line from the front extreme point of the bike and perpendicular in y axis [m]
q_r	The line from the rear extreme point of the bike and perpendicular in y axis [m]
q	The line from the rear extreme point of the bike and perpendicular [m]
x_{bike}	The *x* coordinate of the center extreme point of the bikes [m]
$x_{f_{bike}}$	The *x* coordinate of the front extreme point of the bikes [m]
$x_{fl_{vehicle}}$	The *x* coordinate of the front left extreme point of the vehicle [m]
$x_{ml_{vehicle}}$	The *x* coordinate of the middle left extreme point of the vehicle [m]
$x_{r_{bike}}$	The *x* coordinate of the rear extreme point of the bikes [m]
$x_{rl_{vehicle}}$	The *x* coordinate of the rear left extreme point of the vehicle [m]
$x_{vehicle}$	The *x* coordinate[1] of the center extreme point of the vehicle [m]
y_{bike}	The *y* coordinate of the center extreme point of the bikes [m]
$y_{f_{bike}}$	The *y* coordinate of the front extreme point of the bikes [m]
$y_{fl_{vehicle}}$	The *y* coordinate of the front left extreme point of the vehicle [m]
$y_{ml_{vehicle}}$	The *y* coordinate of the middle left extreme point of the vehicle [m]
$y_{r_{bike}}$	The *y* coordinate of the rear extreme point of the bikes [m]
$y_{rl_{vehicle}}$	The *y* coordinate of the rear left extreme point of the vehicle [m]
$y_{vehicle}$	The *y* coordinate[2] of the center extreme point of the vehicle [m]

[1] The x coordinate refers to an absolute coordinate system

[2] The y coordinate refers to an absolute coordinate system

$w_{vehicle}$	Width of the vehicle [m]
z	The line from the front left extreme point of the vehicle and it is the subtraction/sum of *y_vehicle* and *h* [m]
$\propto$	The angle between the longitudinal axis of the vehicle and the x coordinate axis of the system [degree]
β	The angle between *d* and the center extreme point of the vehicle [degree]
γ	The difference between alpha and beta [degree]
Δx	The difference between $x_{vehicle}$ and x_{bike} [m]
Δy	The difference between $y_{vehicle}$ and y_{bike} [m]
ϵ	The difference between *psi* and θ [degree]
θ	The angle between the longitudinal axis of the bikes and the x coordinate axis of the system [degree]
φ_{bike}	Heading angle of the bikes [degree]
$\varphi_{vehicle}$	Heading angle of the vehicle [degree]
CZB	Comfort zone boundaries [m]
CZB1	Comfort zone boundaries 1 [m]
CZB2	Comfort zone boundaries 2 [m]
CZB3	Comfort zone boundaries 3 [m]
$CZB3_a$	Comfort zone boundaries 3(a) [m]
$CZB3_b$	Comfort zone boundaries 3(b) [m]
$CZB3_c$	Comfort zone boundaries 3(c) [m]
CZB3_min	Minimum value of comfort zone boundaries 3(a, b, c) [m]
CZB4	Comfort zone boundaries 4 [m]

1 INTRODUCTION

As claimed by UN anticipation, the population of the world will be more than 9 billion inhabitants in the mid-21st century (Koike 2014, p. 32). Also due to global warming and growing temperature of the planet earth, the usage of motorized vehicle should be limited. To counteract the negative effects of global warming, governments made some efforts to attract people to use bikes by advertisement in media and municipalities supplied rental bicycles - called city bike - to facilitate citizens' access to bikes. (Loo & Tsui 2010, p. 1903; Pucher, Buehler & Seinen 2011, p. 451; Koike 2014, p. 33.) In addition, the usage of bikes is getting popular nowadays as an inexpensive mode of transportation due to several reasons such as high traffic, air pollution, gasoline price, lack of parking space, health and exercise. (Koike 2014, p. 33.)

In Japan, the number of bicycle owners is increasing and approximately 11% of people use bicycles to travel to school or work (Kobayashi, Honda & Yoshida 2014, p. 268). As stated by the National Police Agency (NPA), there were 71.551 million bicycles in Japan in 2013. (Kameda 2015.) In particular, bicycle became more popular as a transportation mean instead of motorized vehicles after the Great East Japan Earthquake in 2011. (Koike 2014, p. 34.) As a consequence of bicycle use, in 2014, cyclists faced 109,269 accidents and 542 fatalities. (Kameda 2015.) Figure 1.1 shows a motorized vehicle while overtaking of a bicycle.

Figure 1.1. Overtaking a bicycle (Wakefield 2015).

An effort to increase cycling safety is required to reduce fatalities and injuries and to stimulate the use of bikes and the development of sustainable urban and rural areas (Loo et al. 2010, p. 1904; Pucher et al. 2011, p. 453; Koike 2014, p. 35). Although helmets might help to decrease accident severity, in many cases helmets are not sufficient to prevent severe injuries. (Walker 2007, p. 420.) For this reason, the prevention of crashes assumes a relevant role in increasing cycling safety. More investigation is needed to evaluate the most suitable distance for drivers and cyclists during overtaking maneuver, particularly for the appropriate setting of automatic warnings of active safety systems. (Schindler & Bast 2015, p. 42.)

A driving simulator was conducted at the University of Tsukuba, in Japan, in order to assess the comfort zone boundaries during the overtaking of cyclists, without the presence of oncoming traffic. The study aimed to answer the following research question:

- What are the comfort zone boundaries (CZB) maintained by drivers during the overtaking of cyclists in a driving simulator, without oncoming traffic?
- What is the effect of age and gender on the choice of CZB?
- What is the difference between the CZB assessed in driving simulator and naturalistic settings?

The above research questions will be investigated in the chapters and will be determined that whether the results are significant or not and what are the possibilities and implications in future.

2 LITERATURE REVIEW

Previous research was focused on how to improve the safety of riders in natural driving and not in a driving simulator situation. Also there was no information about the drivers' age and gender (Dozza & Werneke 2014, p. 85; Schramm et al. 2014, p. 3). Recently, a naturalistic data collection in Gothenburg investigated the comfort zone boundaries during the overtaking of cyclists. (Schindler & Bast 2015, p. 22; Dozza et al. 2016, p. 32.) This work is a continuation of the latter study and focuses on the overtaking of cyclists in a simulated environment, with Japanese participants.

This chapter illustrates previous research on overtaking maneuvers and comfort zone boundaries and also discuss the factors which might influence the overtaking maneuver.

2.1 Overtaking Maneuver

Collisions between bikes and vehicles terminate in mortality for cyclists (Bil, Bílová & Müller 2010, p. 1634; Dozza et al. 2014, p. 85). When the interaction happens, probably it leads to severe injuries for cyclists. Overtaking can be defined as the maneuver of a faster vehicle passing a slower vehicle through the same driving lane or using the opposite lane. Figure 2.1 shows an overtaking maneuver.

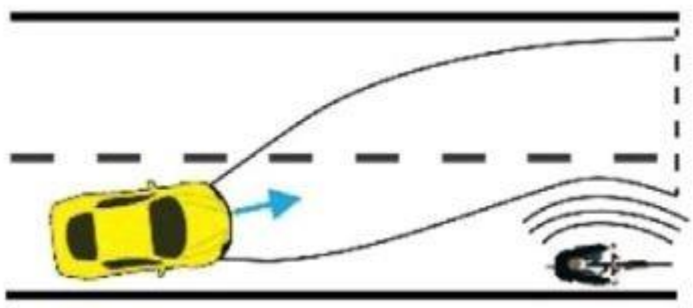

Figure 2.1. Overtaking maneuver (modified Dozza et al. 2016, p. 30).

According to previous literature, the overtaking maneuver can be divided in four different strategies; accelerative, flying, piggy backing and 2+ overtaking maneuver (Schindler & Bast 2015, p. 15) and described as the following: Accelerative; the overtaking vehicle has not enough space to overtake the object (a vehicle) and therefore has to adjust the speed by braking. Flying overtaking; the overtaking vehicle has sufficient speed and space to overtake without regulating the velocity (Wilson & Best 1982, p. 181). Piggy backing; when the slower vehicle will be overtaken by two or more vehicles. 2+ overtaking maneuver; when a vehicle overtakes 2 or more slower vehicles in one row simultaneously. In this thesis study, the only type the overtaking maneuver which will be considered is flying as there is no oncoming traffic.

2.2 Comfort Zone

Comfort zone can be defined as an area which the driver feels comfortable and gets away from the collision path. (Bärgman, Smith & Werneke 2015, p. 172.) Drivers tend to pass the collision path by steering in order to overtake a vehicle and returning to the comfort zone as fast as possible (Summala 2007, p. 192). Comfort zone boundaries are shown in Figure 2.2.

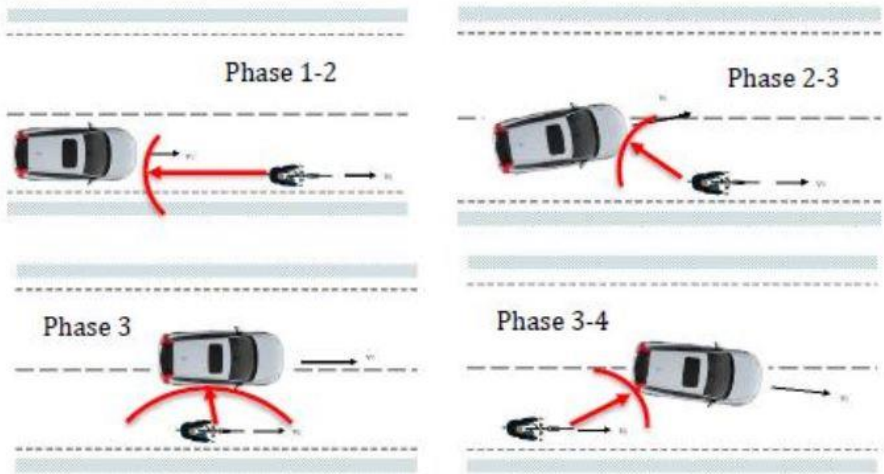

Figure 2.2. Comfort zone boundaries (modified Schindler & Bast 2015, pp. 15-17).

The opposite term of comfort zone is dread zone. It is a new concept which describes an area where drivers desire not to enter due to high risk of collision. But in some occasions, for example, when drivers are in hurry, then they take the risk and go through the dread zone. (Bärgman et al. 2015, p. 173.) Comfort zone or comfort zone boundaries (CZB) depends on some parameters such as driver, vehicle, and environment:

Age and gender can impact on the driver's CZB chosen. Also, vehicle type and size can influence. Environment is also important. The weather condition or the type of a road can affect the CZB.

2.3 Factors influencing drivers’ behavior

There are several factors which can influence the drivers’ choice of CZB. For instance, Llorca et al (2013, p. 177) proposed that young (standard age) drivers had 1s shorter overtaking and 4 km/h faster than elderly drivers. (Llorca et al. 2013, p. 177.) Walker noted that gender can also influence drivers’ speed during overtaking of cyclists. (Walker 2007, p. 420.) More details about gender group will be illustrated in the chapter 3.1. The other influencing factor such as the weather condition (dor example different kind of weather), type of the route, personality, physical and mental wellbeing, vehicle size (ex. truck, bus), the effect of road markings and signs on roads were investigated in previous studies (Shackel & Parking 2014, p. 102). However, in this master thesis study, only the age and gender factors were considered and it will be explained in the next chapter.

3 METHODS

In this chapter, the way of data collection will be presented. In addition the tools which used for data analyzing will be explained. Furthermore, the definition of phases and the methods which is used to analyze CZBs will be illustrated.

3.1 Test plan

The objective of this study was to conduct a driving simulator study with numbers of participants in order to compare the results with naturalistic results by considering the age and gender factors.

3.2 Data collection

The data was collected from the driving simulator of the University of Tsukuba (Figure 3.1), in Japan between October and December 2015. Overall, 42 Japanese participants took part in the study. Before the study, the participants filled out a questionnaire which included demographic information that was used to make sure that the participants met the following requirements; be a Japanese national, own a driving license, have a minimum mileage of 30.000 km, since getting the driving license and drive, at least, once per week.

Figure 3.1. Driving simulator at the University of Tsukuba.

There were 42 participants and 5 of them were eliminated due to dizziness arising as a result of simulation sickness during the experiment. Therefore, in total, 37 participants including 22 males (59.46%) and 15 females (40.54%) by the average age of 48 years old (standard deviation: ±19.39) were employed. The participants with the age range of 25-40 years old categorized into the standard group and the participants with the age range of 65-75 years old categorized into the elderly group. The average years of holding driving license was 24.49 (standard deviation: ±15.31) and 56.76% of the participants were driving every day.

The driving simulator was equipped with five screens to display the simulated route and the traffic environment. The drivers were able to control the vehicle through the steering wheel, the accelerator and brake pedals. There was no clutch pedal since the transmission was automatic. Besides, two cameras were used to record the driver and the simulated route. During the study, the participants underwent three trials in the driving simulator: a trial test, a trial without oncoming traffic during the overtaking maneuvers and a trial with oncoming traffic during the overtaking maneuvers. It was asked the participants to drive normally as they drive in real life.

The trial test was conducted to make the participants familiar with the task and the driving simulator. The length of the trial route was 12 km long and the participants were requested to perform eight overtaking maneuvers, four with oncoming traffic and four without oncoming traffic. The routes were designed based on the routes in naturalistic study (2 routes in Gothenburg, Sweden) in order to be compared farily. Table 3.1 shows the information about the route without oncoming traffic which was considered for the current study. Each driver was requested to perform four overtaking maneuvers of bicycles without traffic coming from the opposite direction. The four bicycles to be overtaken were located at 0.3 m from the curb of the road and travelled at 22 km/h. The bike was visible for the drivers from 200m behind the bike.

Table 3.1. Route without oncoming traffic information.

Length of the route	9006 m
No. of overtaking	4
Location of bike in overtaking maneuver 1	590 m

Table 3.1 continues. Route without oncoming traffic information.

Location of bike in overtaking maneuver 2	5040 m
Location of bike in overtaking maneuver 3	6536 m
Location of bike in overtaking maneuver 4	7888 m

3.3 Tools

All data were collected in DAT format and were converted to MAT files by a software called TpConv. MATLAB software was employed for analyzing the data and calculation of CZB. Also AutoCAD was used to draw overtaking sketches.

3.4 Phases

Based on previous work (Schindler & Bast, 2015; Dozza et al., 2016), the driver's overtaking of a cyclist can be divided in four phases named respectively approaching, steering away, passing and returning (Figure 3.2).

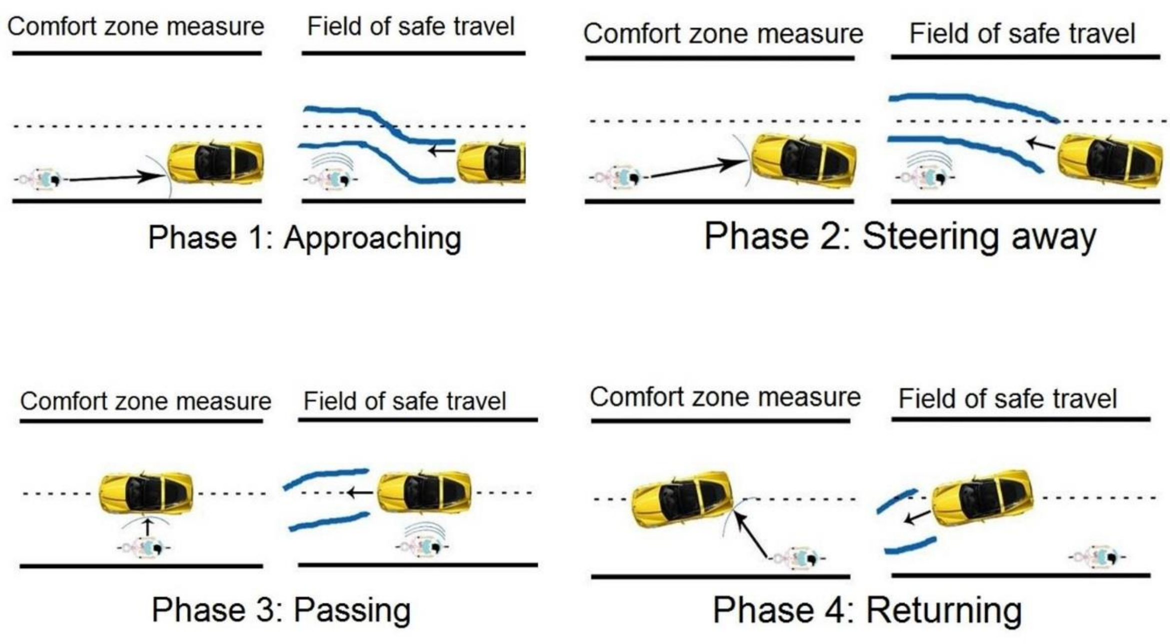

Figure 3.2. Overtaking phases (modified Dozza et al. 2016, p. 30).

The approaching phase starts when the vehicle reaches the bicycle and it ends when the vehicle steers to avoid the collision path with the bike. The steering away starts when phase 1 is ended and it ends when the overtaking vehicle enters the passing zone, defined as an area about 5.7 m long and extending from 2 meters behind the bicycle to 2 meters in front of the bicycle. (Dozza et al. 2016, p. 30.) The passing phase starts with the conclusion of phase 2 and it ends when the vehicle moves away from the passing zone. Finally, the returning phase starts when the phase 3 ends and it is completed when the vehicle returns to the original lateral position maintained before the start of the overtaking.

Although most participants had similar style to get away from the collision path in phase 1, some of them disclosed a different behavior. For instance, some participants had several steering adjustments before starting the actual overtaking. Therefore, it was difficult to find a similar pattern for all participants and it was complicated to determine the end of phase 1. The videos of all participants during the four overtaking maneuvers were watched in order to determine the end of phase 1. By plotting the steering angle of all participants, it was possible to clarify when the drivers had a steering maneuver (see Figure 3.3, the steering marked with oval). The end of phase 1 was considered when the steering angle was constant for at least 3s and then changed by at least 0.2º.

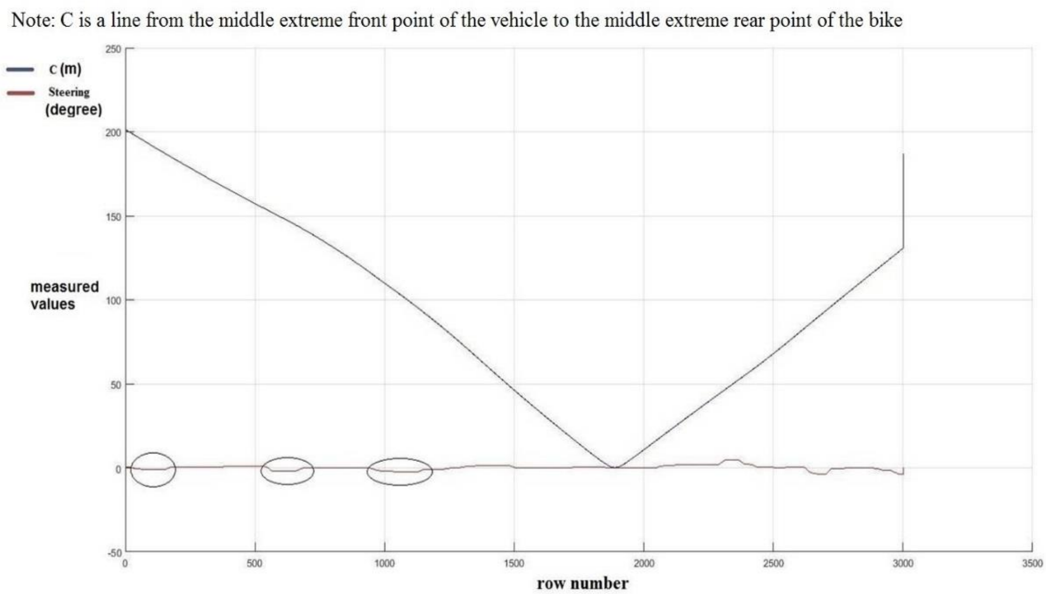

Figure 3.3. Participant 42. C versus steering.

In order to distinguish the steering maneuver which starts the overtaking, the line from the middle extreme front point of the vehicle to the middle extreme rear point of the bike (*C*) was calculated and plotted simultaneously with the steering angle (see Figure 3.4). When *C* is close to 0, the vehicle is getting close to the bike (approx. 2m far from the bike).

Accordingly, the last steering maneuver before *C*≈0 meters (that is, before the vehicle reached the bicycle) was considered as the end of phase 1.

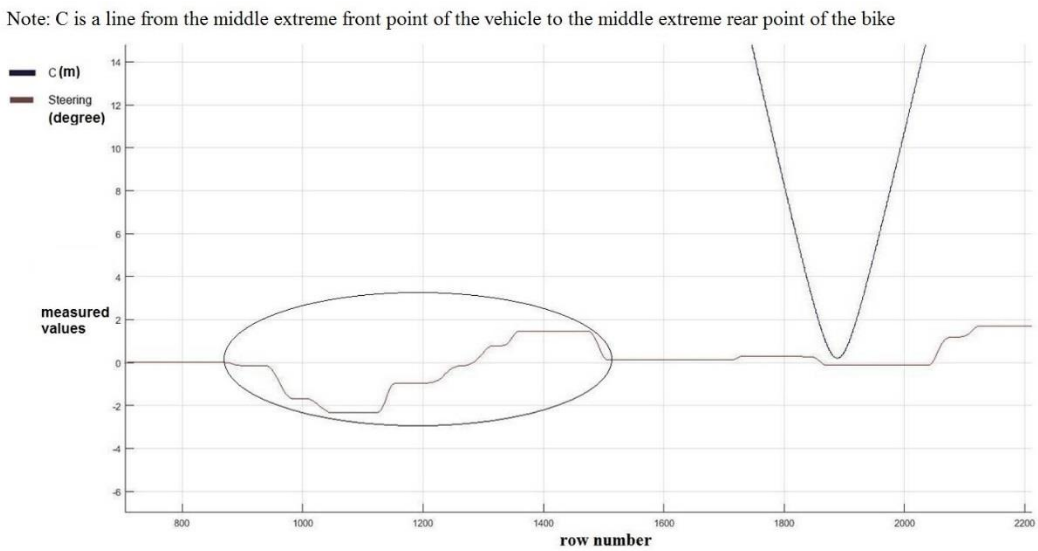

Figure 3.4. Participant 42. C versus steering (steering starts at row no. 875).

3.5 CZB calculations

The CZBs were calculated using the relative position between the bike and the vehicle, as shown in the next sections. The bike was stopped until the car did not reach a distance of 200m from the bike. The length of vehicle ($L_{vehicle}$), the width of the vehicle ($w_{vehicle}$) and the length of the bikes (L_{bike}) are reported below (the width of the bike was assumed to be negligible);

$$L_{vehicle} = 4.4\ m$$
$$w_{vehicle} = 1.725\ m$$
$$L_{bike} = 1.62\ m$$

The heading angle of the vehilce ($\varphi_{vehicle}$) abd the bicycle (φ_{bike}) varies during the course of the route. However, the heading angle of the bike before starting to move was as reported below in the different overtaking:

$\varphi_{bike} = 151.5°$ in overtaking maneuver 1

$\varphi_{bike} = -174.1°$ in overtaking maneuver 2

$\varphi_{bike} = 175.8°$ in overtaking maneuver 3

$\varphi_{bike} = -140.9°$ in overtaking maneuver 4

3.5.1 CZB1 calculations

Comfort zone boundaries 1 (CZB1) represents the comfort zone boundary corresponding to the approaching phase.

$$\propto = 180 - \varphi_{vehicle} \tag{1}$$

$\propto$ represents the angle between the longitudinal axis of the vehicle and the x axis of the frame of reference are calculated for overtaking manuevers 1 and 3. In overtaking manuevers 2 and 4 will be:

$$\propto = 360 - (180 - \varphi_{vehicle}) \tag{2}$$

$$\theta = 180 - \varphi_{bike} \tag{3}$$

θ represents the angle between the longitudinal axis of the bike and the x axis of the system in overtaking manuever 1. In overtaking manuevers 2, 3 and 4:

$$\theta = 360 - (180 - \varphi_{bike}) \tag{4}$$

$$psi = atan(abs\left(\frac{\Delta y}{\Delta x}\right)) \times \frac{180}{\pi} \tag{5}$$

$$\epsilon = psi - \theta \tag{6}$$

$$\Delta x = x_{bike} - x_{vehicle} \tag{7}$$

$$\Delta y = y_{bike} - y_{vehicle} \tag{8}$$

$$c = \sqrt{\Delta x^2 + \Delta y^2} \tag{9}$$

psi represents the angle between C and the difference between $x_{vehicle}$ and x_{bike} (Δx) in the triangle. It is necessary in order to calculate the comfort zone boundaries 1 (*CZB1*). ϵ is the the difference between psi and θ. The difference between the x coordinate of the center extreme point of the vehicle ($x_{vehicle}$) and the x coordinate of the center extreme point of the bikes (x_{bike}), called Δx and the difference between the y coordinate of the center extreme point of the vehicle ($y_{vehicle}$) and the y coordinate of the center extreme point of the bikes

(y_{bike}) called Δy are shown below. By applying Euclidean equation, the distance between the vehicle's center extreme point to the bike's center extreme point (*C*) will be calculated as in the equation (9) and it is essential in order to obtain *CZB1*.

$$CZB1 = \left(c \times cos\left(\epsilon \times \frac{\pi}{180}\right)\right) - \frac{L_{bike}}{2} - \left(\frac{L_{vehicle}}{2} \times cos\left((\propto - \theta) \times \frac{\pi}{180}\right)\right) \quad (10)$$

Finally, in order to calculate CZB1, half of the length of the vehicle and half of the length of the bike should be subtracted from the side of triangle as CZB is defined as the minimum distance between the car and the bike, as reported in equation (10).

The start of phase 1 was determined as it stated in the previous chapter. Then, by equation (10), CZB1 results for all participants were obtained. Figure 3.5 is shown below and it represents the schematic view of CZB1.

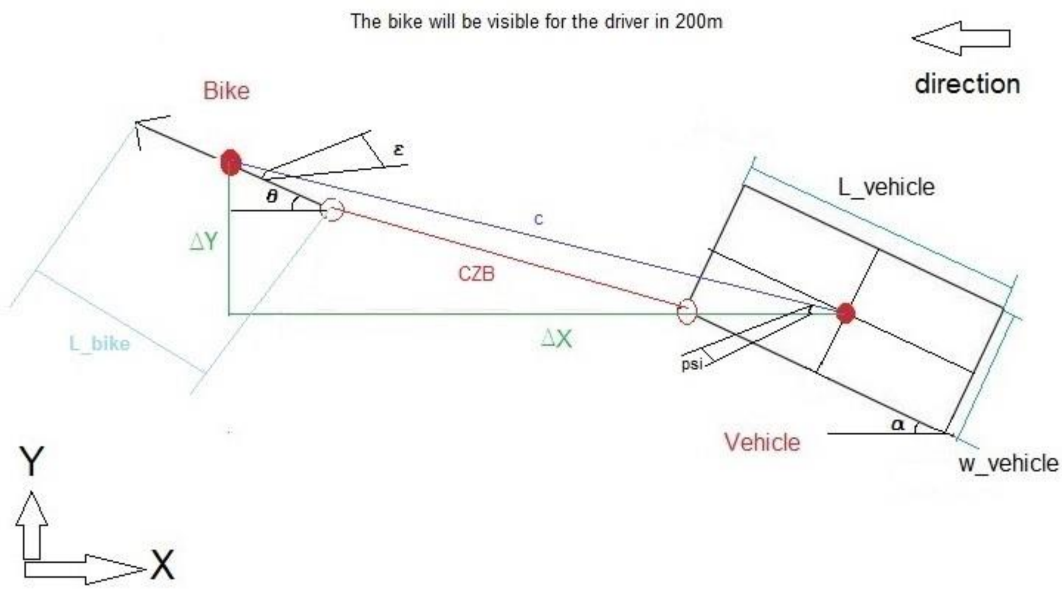

Figure 3.5. CZB1 – Schematic view.

3.5.2 CZB2 calculations

Comfor zone boundaries 2 (CZB2) represents the comfort zone boundary corresponding to the steering away phase. The schematic drawing for CZB2 calculation is reported in Figure 3.6.

$$b = \frac{L_{bike}}{2} \times cos\left(\theta \times \frac{\pi}{180}\right) \tag{11}$$

b is a line from the rear extreme point of the bikes and perpendicular in x axis with angle θ was defined.

$$d = \sqrt{\frac{L_{vehicle}{}^2}{2} + \frac{w_{vehicle}{}^2}{2}} \tag{12}$$

By Euclidean equation, a line from the center extreme point of the vehicle to the front left extreme point of the vehicle defined as *d*.

$$\beta = arctan\left(\frac{\frac{w_{vehicle}}{2}}{d}\right) \tag{13}$$

β is the angle between *d* and the center extreme point of the vehicle.

$$k = sin\left(\theta \times \frac{\pi}{180}\right) \times \frac{L_{bike}}{2} \tag{14}$$

The line from the center extreme point of the bikes and perpendicular in y axis, called *k*, is obtained as it is presented above. Due to several different overtaking maneuvers by participants, various conditions were applied. The conditions make the calculations more accurate. Because during an overtaking several variables change as it is different for each participant. The first condition for CZB2 calculation is;

if $\propto \geq \beta$, then;

$$\gamma = \beta - \alpha \tag{15}$$

$$a = d \times cos\left((\gamma) \times \frac{\pi}{180}\right) \tag{16}$$

$$h = d \times sin\left((\gamma) \times \frac{\pi}{180}\right) \quad (17)$$

$$z = y_{vehicle} - h \quad (18)$$

γ is an angle which is obtained by the difference of β and $\propto$. a is a line with angle γ and it is from the vehicle's center extreme point and perpendicular in x axis. h is a line from the front left extreme point of the vehicle and perpendicular in y axis. z is a line from the front left extreme point of the vehicle which is obtained by the difference of $y_{vehicle}$ and h and it is in y axis. The above condition will not happen in overtaking maneuvers 2 and 4, because α is always bigger than β.

if $\propto < \beta$, then;

$$\gamma = \propto - \beta \quad (19)$$

$$a = d \times cos\left((\gamma) \times \frac{\pi}{180}\right) \quad (20)$$

$$h = d \times sin\left((\gamma) \times \frac{\pi}{180}\right) \quad (21)$$

$$z = y_{vehicle} + h \quad (22)$$

The above condition will not happen in overtaking maneuvers 1 and 3, because $\propto$ is always bigger than β. The second condition for overtaking maneuvers 1 and 3 is;

if $y_{bike} - k \geq z$;

if $abs(f) \geq b$, then;

f and q will be demonstrated in the next page.

$$e = abs(\Delta x) - abs(a) - abs(a) + abs(f) - b \quad (23)$$

$$p = abs(e) - abs(f) \quad (24)$$

e is a line which is from the front left extreme point of the vehicle to the perpendicular line of the bike (see Figure 3.6) in x axis. p is a line which is one side of the triangle in order to apply the Euclidean equation and it is in x axis and starts from front left extreme point of the vehicle and perpendicular.

elseif $abs(f) < b$, then e and p will be the same as (23) and (24).

elseif $y_{bike} - k < z$;

$$q = abs(z) - abs(y - k) \tag{25}$$

$$f = q \times tan\left(\theta \times \frac{\pi}{180}\right) \tag{26}$$

$$e = abs(\Delta x) - abs(a) - abs(a) - abs(f) - b \tag{27}$$

$$p = abs(e) + abs(f) \tag{28}$$

The other side of the triangle is q which is in y direction and starts from the rear extreme point of the bike and perpendicular to p. f is a line between q and the perpendicular line at the rear extreme point of the bike in x direction. The conditions for overtaking 2 are:

Always $\propto < \beta$, then,

$$\gamma = \propto + \beta \tag{29}$$

And a, h and z will be the same as overtaking 1. In overtaking 2 and 4, β. is always bigger than ∝. The second condition in overtaking maneuvers 2 and 4 is;

If $y_{bike} + k < z$, then e, p and f will be the same as e, p and f in overtaking maneuver 1.

$$q = abs(z) - abs(y_{bike}) + k \tag{30}$$

In overtaking maneuver 2, $y_{bike} + k \geq z$, this condition is never met.

$$g = cos\left(\theta \times \frac{\pi}{180}\right) \times e \tag{31}$$

$$CZB2 = \sqrt{p^2 + q^2} \tag{32}$$

g is a line from the front left extreme point of the vehicle to the perpendicular line of the bike in the bike axi. The closer view of the angles on the car is shown in the figure 3.7.

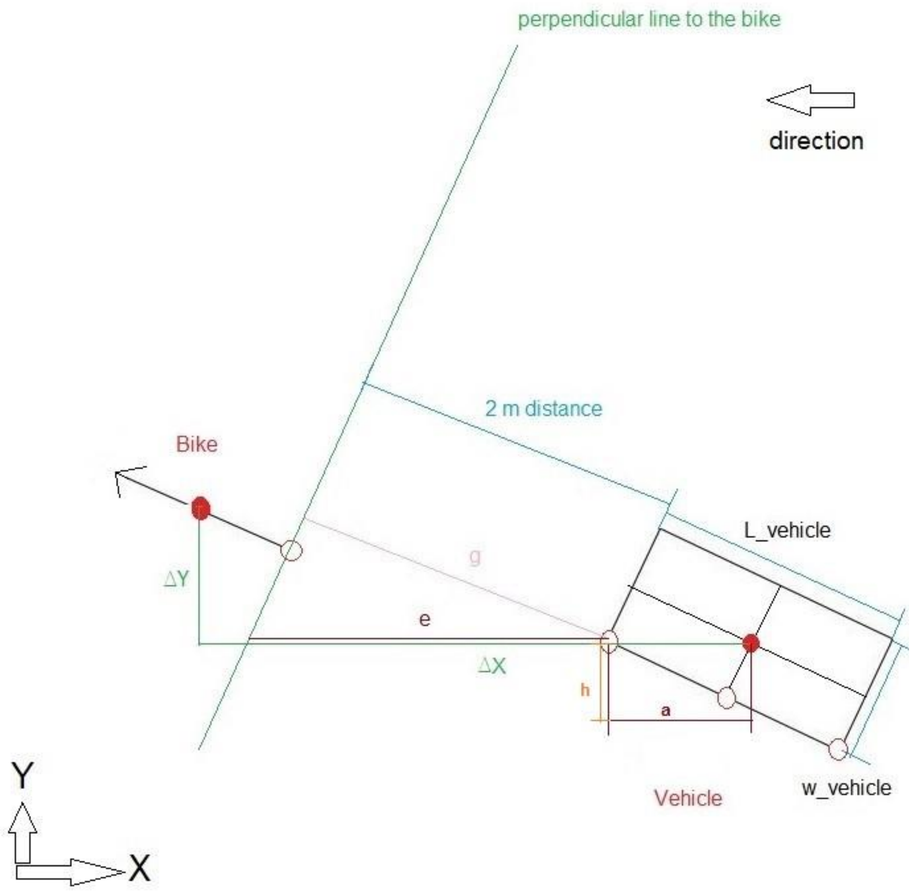

Figure 3.6. CZB2 - Schematic view.

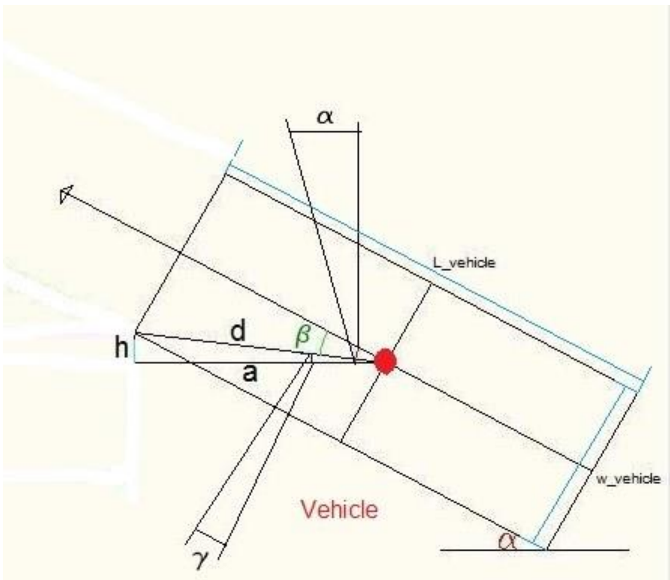

Figure 3.7. CZB2 - Schematic view (closer view).

In order to calculate CZB2 for all participants, an interval which includes the start point and the end point of phase 2 were determined. Start of phase 2 is equal the end of phase 1. The start point of phase 2 was synchronized by the row number in CZB2 mat file in MATLAB. End of phase 2 is g<2 (g is a line from front left of the vehicle to the perpendicular line of the bike in the bike direction). Then, the minimum value in this interval was chosen as CZB2.

3.5.3 CZB3 calculations

Comfort zone boundaries 3 (CZB3) represents the comfort zone boundary corresponding to the passing phase. The same conditions as in CZB2 calculations for ∝ and β were applied to CZB3 calculations (see Figure 3.8). The entire phase 3 is shown below. Phase 3 occurs within the distance around 5.7 m.

If $\propto \geq \beta$;

Then, *a* and *h* are the same with (16) and (17). Also γ same as equation (15). As in phase 3 the vehicle passes the bikes, the start point on the vehicle and the end point on the bikes for calculating the minimum distance between the vehicle and the bikes become different. Some points on the vehicle and the bikes were determined and the following equations were defined.

$$x_{fl_{vehicle}} = x_{vehicle} - a \tag{33}$$

, where $x_{fl_{vehicle}}$ is the *x* coordinate of the front left extreme point of the vehicle.

$$y_{fl_{vehicle}} = y_{vehicle} - h \tag{34}$$

, where $y_{fl_{vehicle}}$ is the *y* coordinate of the front left extreme point of the vehicle.

$$x_{ml_{vehicle}} = x_{fl_{vehicle}} + (\frac{L_{vehicle}}{2} \times cos(\alpha \times \frac{\pi}{180})) \tag{35}$$

, where $x_{ml_{vehicle}}$ is the *x* coordinate of the middle left extreme point of the vehicle.

$$y_{ml_{vehicle}} = y_{fl_{vehicle}} - (\frac{L_{vehicle}}{2} \times sin(\alpha \times \frac{\pi}{180})) \quad (36)$$

, where $y_{ml_{vehicle}}$ is the *y* coordinate of the middle left extreme point of the vehicle.

$$x_{rl_{vehicle}} = x_{fl_{vehicle}} + (L_{vehicle} \times cos(\alpha \times \frac{\pi}{180})) \quad (37)$$

, where $x_{rl_{vehicle}}$ is the *x* coordinate of the rear left extreme point of the vehicle.

$$y_{rl_{vehicle}} = y_{fl_{vehicle}} - (L_{vehicle} \times sin(\alpha \times \frac{\pi}{180})) \quad (38)$$

, where $y_{rl_{vehicle}}$ is the *y* coordinate of the rear left extreme point of the vehicle.

The condition $\propto < \beta$ is never met because $\propto$ is always bigger than β. Therefore, the equations for this condition were not assessed. Furthermore, the rear extreme point and the front extreme point of the bike were calculated.

$$x_{r_{bike}} = x_{bike} + b \quad (39)$$

, where $x_{r_{bike}}$ is the *x* coordinate of the rear extreme point of the bikes.

$$y_{r_{bike}} = y_{bike} - abs(k) \quad (40)$$

, where $y_{r_{bike}}$ is the *y* coordinate of the rear extreme point of the bikes.

$$x_{f_{bike}} = x_{bike} - b \quad (41)$$

, where $x_{f_{bike}}$ is the *x* coordinate of the front extreme point of the bikes.

$$y_{f_{bike}} = y_{bike} + abs(k) \quad (42)$$

, where $y_{f_{bike}}$ is the *y* coordinate of the front extreme point of the bikes.

$$q_f = abs(y_{fl_{vehicle}} - y_{r_{bike}}) \tag{43}$$

$$f_f = q_f \times tan\left(\theta \times \frac{\pi}{180}\right) \tag{44}$$

$$q_r = abs(y_{rl_{vehicle}} - y_{f_{bike}}) \tag{45}$$

$$f_r = q_r \times tan\left(\theta \times \frac{\pi}{180}\right) \tag{46}$$

q_f is a line from the front extreme point of the bike and perpendicular in y axis. f_f is a line between q_f and the perpendicular line at the front extreme point of the bike in x axis. q_r is a line from the rear extreme point of the bike and perpendicular in y axis. f_r is a line between q_f and the perpendicular line at the front extreme point of the bike in x axis. The next condition is to specify when the two points (the rear left of the bike and the front left of the vehicle) meet each other. Since some variables will change when $y_{r_{bike}}$ is bigger or smaller than $y_{fl_{vehicle}}$, then we apply the following condition:

If $y_{r_{bike}} \geq y_{fl_{vehicle}}$;

If abs(f_f) > b;

$$e_f = abs(x_{r_{bike}}) + abs(f_f) - abs(x_{fl_{vehicle}}) \tag{47}$$

$$p_f = abs(x_{r_{bike}}) - abs(x_{fl_{vehicle}}) \tag{48}$$

$$e_r = abs(x_{f_{bike}}) + abs(f_r) - abs(x_{rl_{vehicle}}) \tag{49}$$

$$p_r = abs(x_{f_{bike}}) - abs(x_{rl_{vehicle}}) \tag{50}$$

$$CZB3_a = \sqrt{p_f^2 + q_f^2} \tag{51}$$

$$CZB3_b = \sqrt{(x_{bike} - x_{ml_{vehicle}})^2 + (y_{bike} - y_{ml_{vehicle}})^{\,2}} \tag{52}$$

$$CZB3_c = \sqrt{p_r^2 + q_r^2} \tag{53}$$

e_f is a line from the front left extreme point of the vehicle to the perpendicular line of the bike in x axis. p_f is a line from front left extreme point of the vehicle and perpendicular in x axis. e_r is a line from rear left extreme point of the vehicle to the perpendicular line of the bike in x axis. p_r is a line from rear left extreme point of the vehicle and perpendicular in x axis. $CZB3_a$, $CZB3_b$ and $CZB3_c$ are 3 different comfort zone boundaries based on the position of the vehicle and minimum value of these 3 comfort zone boundaries was taken as the CZB3.

if abs(f_f) < b;

The same calculations were considered for $e_f, p_f, e_r, p_r, CZB3_a, CZB3_b$ $and CZB3_c$.
elseif $y_{bike} - k < y_{fl_{vehicle}}$;

If $abs(x_{fl_{vehicle}}) < abs(x_{r_{bike}}) - abs(f_f)$
$\&\& \, abs(x_{fl_{vehicle}}) < abs(x_{f_{bike}}) - abs(f_r)$

In overtaking maneuver 2, f_f and f_r will be summed. The same calculations were considered for $p_f, p_r, CZB3_a, CZB3_b$ $and CZB3_c$. But e_f and e_r will be different;

$$e_f = abs(x_{r_{bike}}) - abs(f_f) - abs(x_{fl_{vehicle}}) \tag{54}$$

In overtaking maneuver 2, f_f will be summed. The following formula is correct only when the front edge of bicycle is lower than the rear left edge of car.

$$e_r = abs(x_{f_{bike}}) - abs(f_r) - abs(x_{rl_{vehicle}}) \tag{55}$$

In overtaking maneuver 2, f_r will be summed.

$elseif\, abs(x_{fl_{vehicle}}) \geq abs(x_{r_{bike}}) - abs(f_f)$
$\&\& \, abs(x_{fl_{vehicle}}) < abs(x_{f_{bike}}) - abs(f_r)$

In overtaking maneuver 2, f_f and f_r will be summed.

$$e_f = abs(x_{fl_{vehicle}}) - abs(x_{r_{bike}}) - abs(f_f) \tag{56}$$

$$p_f = abs(x_{fl_{vehicle}}) - abs(x_{r_{bike}}) \tag{57}$$

Then, e_r, p_r, $CZB3_a$, $CZB3_b$ and $CZB3_c$ will be the same as (49), (50), (51), (52) and (53).

$$elseif\, abs(x_{fl_{vehicle}}) \geq abs(x_{r_{bike}}) - abs(f_f)$$
$$\&\&\, abs(x_{fl_{vehicle}}) \geq abs(x_{f_{bike}}) - abs(f_r)$$

In overtaking maneuver 2, f_f and f_r will be summed. By the above condition, calculation (49) and (50) were supposed for e_f and p_f, respectively. But for e_r, in overtaking 2, f_f will be summed.

$$If\, abs(x_{rl_{vehicle}}) < abs(x_{f_{bike}}) - abs(f_r)$$
$$\&\&\, abs(x_{rl_{vehicle}}) < abs(x_{f_{bike}})$$

In overtaking maneuver 2, f_r will be summed. Then, e_r and p_r will be determined as (49) and (50). But for e_r in overtaking maneuver 2, f_r will be summed.

$$If\, abs(x_{rl_{vehicle}}) \geq abs(x_{f_{bike}}) - abs(f_r)$$
$$\&\&\, abs(x_{rl_{vehicle}}) < abs(x_{f_{bike}})$$

In overtaking maneuver 2, f_r will be summed.

$$e_r = abs(f_r) - abs(x_{f_{bike}}) - abs(x_{rl_{vehicle}}) \tag{58}$$

In overtaking maneuver 2, f_r will be summed. Then, p_r will be determined as (50).

$$If\, abs(x_{rl_{vehicle}}) \geq abs(x_{f_{bike}}) - abs(f_r)$$
$$\&\&\, abs(x_{rl_{vehicle}}) \geq abs(x_{f_{bike}})$$

In overtaking maneuver 2, f_r will be summed.

$$e_r = abs(f_r) + abs(x_{f_{bike}}) - abs(x_{rl_{vehicle}}) \tag{59}$$

$$g_f = cos\left(\theta \times \frac{\pi}{180}\right) \times e_f \tag{60}$$

$$g_r = cos\left(\theta \times \frac{\pi}{180}\right) \times e_r \tag{61}$$

$$CZB3\_min = min([CZB3_a\ CZB3_b CZB3_c]) \tag{62}$$

$$CZB3 = CZB3\_min \tag{63}$$

In overtaking maneuver 2, f_r will be summed. Then, p_r will be determined as (50). In CZB3 calculations, the definition of some parameters might change as three points of front left, middle left and rear of the vehicle and two points of front and rear of the bike were defined. g_f is a line from front left extreme point of the vehicle to the perpendicular line in the bike axis. g_r is a line from rear left extreme point of the vehicle to the perpendicular line in the bike axis. CZB3_min is the minimum value of $CZB3_a, CZB3_b and\ CZB3_c$.

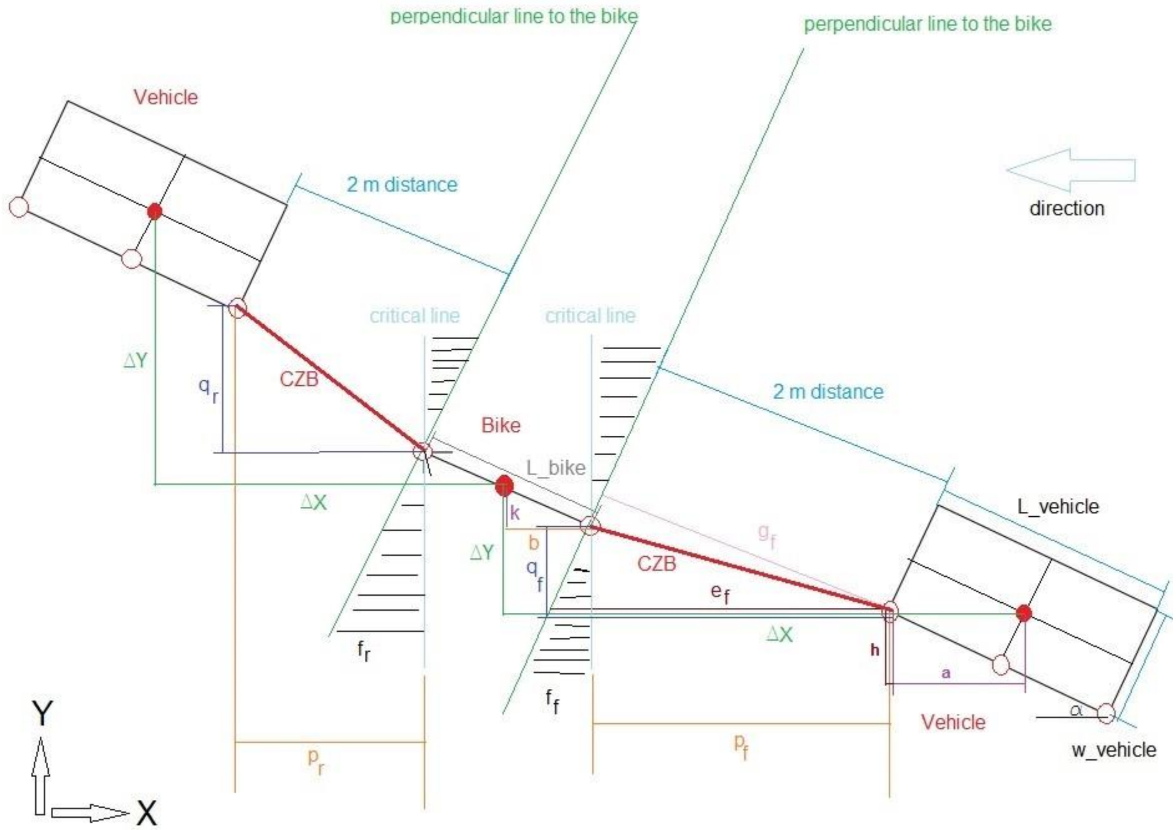

Figure 3.8. CZB3 - Schematic view.

In order to calculate CZB3 for all participants, an interval which includes the start point and the end point of phase 3 were determined. Start of phase 3 is equal the end of phase 2. The start point of phase 3 was synchronized by the row number in CZB3_min mat file in

MATLAB. End of phase 3 is g_r>2 (g_r is a line from front left of the vehicle to the perpendicular line of the bike in the bike direction). Then, the minimum value in this interval was chosen as CZB3. Note that the angles are not shown in Figure 3.8 due to existing many parameters and lines. The angles are defined same as CZB2 and shown in Figure 3.6.

3.5.4 CZB4 calculations

Comfort zone boundaries 4 (CZB4) represents the comfort zone boundary corresponding to the returning phase. The same conditions for α and β were applied here. In addition, the same formula (33), …, (46) were implemented in CZB4 calculations (see Figure 3.9). Then, two more conditions are needed;

If $abs\left(x_{rl_{vehicle}}\right) \geq abs\left(x_{f_{bike}}\right) - abs(f_r)\ \&\&\ abs\left(x_{rl_{vehicle}}\right) < abs\left(x_{f_{bike}}\right)$

The same calculation as (57) and (65) for p_r, e_r were used.

If $abs\left(x_{rl_{vehicle}}\right) \geq abs\left(x_{f_{bike}}\right) - abs(f_r)\ \&\&\ abs\left(x_{rl_{vehicle}}\right) \geq abs\left(x_{f_{bike}}\right)$

The same calculation as (50) and (59) for p_r, e_r were used. The formula (61) was applied for calculating g_r.

Note that in the above figure, the angle are not shown due to existing of many lines and parameters. The angles are defined same as CZB2 and CZB3 and shown in Figure 3.6. Same as CZB3, in CZB4 calculations, the definition of some parameters might change as three points of front left, middle left and rear of the vehicle and two points of front and rear of the bike were defined.

In order to calculate CZB4 for all participants, an interval which include the start point and the end point of phase 4 were determined. Start of phase 4 is g_r>2 (g_r is a line from front left extreme point of the vehicle to the perpendicular line of the bike in the bike direction). The start point of phase 3 was synchronized by the row number in CZB4 mat file in MATLAB. The end point of phase 4 is the maximum value of CZB4. Then, the minimum value in this interval was chosen as CZB4.

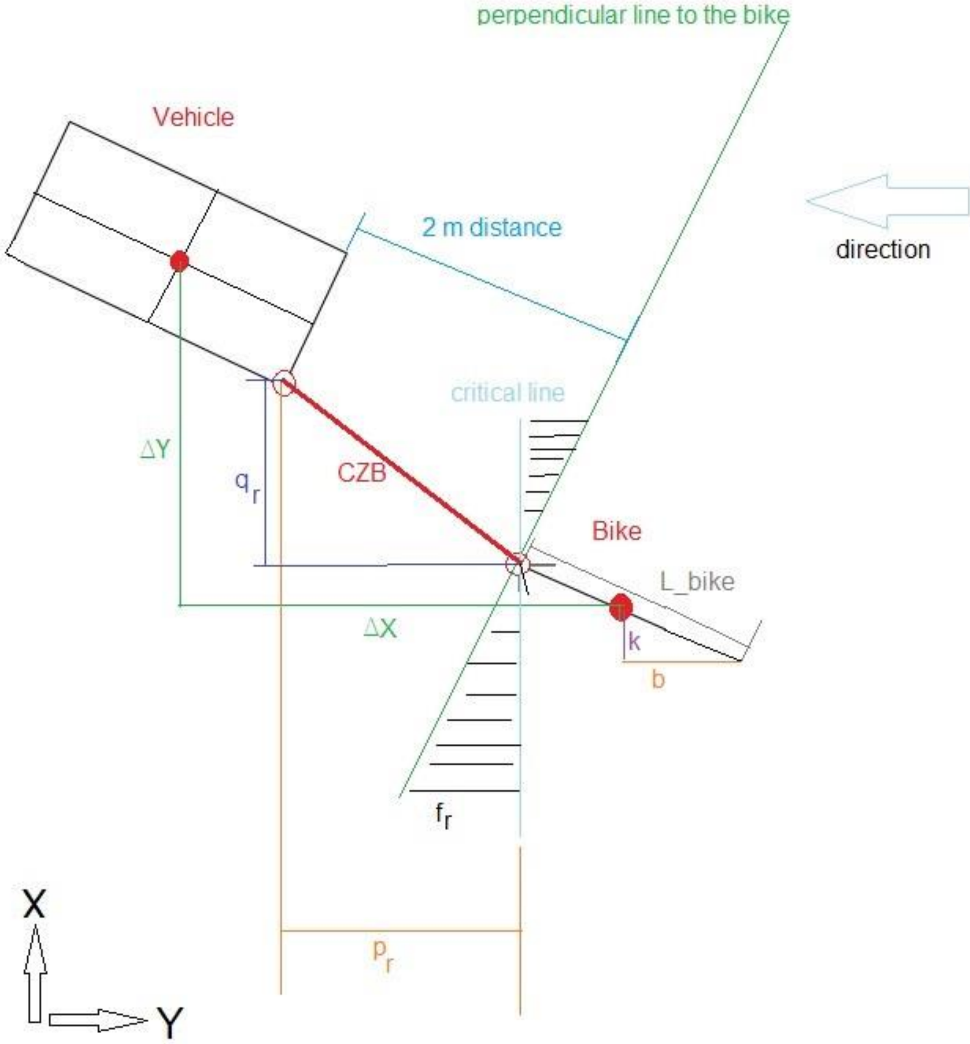

Figure 3.9. CZB4 - Schematic view.

CZB or the minimum distance between the vehicle and the bike during an overtaking maneuver represents the area where the driver feel comfort with the lowest risk of collision and can be influenced by several factors. Eventually, all CZBs values were evaluated and the results will be presented in the chapter 4.

4 RESULTS

This chapter presents the values resulting from the calculation of CZB. As mentioned in section 3.1, the analysis covers 37 out of the 42 participants.

Table 4.1 reports the mean values for all population for each CZB in 4 overtaking maneuver, based on the calculation performed in chapter 3 Method. It is shown that the mean values in CZB1 are large numbers comparing to CZB2, CZB3 and CZB4. The mean values of CZB2 have the smallest values and the mean values in CZB2 and CZB4 have similar values

Table 4.1. Mean value and standard deviation for all population.

	Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4
CZB1	80.96 ±32.99	79.69 ±27.77	74.01 ±29.90	63.56 ±18.34
CZB2	2.58 ±0.41	2.61 ±0.30	2.62 ±0.41	2.62 ±0.34
CZB3	1.71 ±0.57	1.71 ±0.43	1.75 ±0.57	1.77 ±0.47
CZB4	2.77 ±0.41	2.69 ±0.29	2.73 ±0.41	2.73 ±0.23

The same values are represented in the boxplots reported in
Figure 4.1, Figure 4.2, Figure 4.3, and Figure 4.4: boxplots report the lower quantile (25% quantile), median (50% quantile), upper quartile (75% quantile), whisker and outliers. Outliers are indicated with (+) in the boxplots (Field 2009, p. 101).
Figure 4**.1** represents the range of values in CZB1 for 4 overtaking maneuvers. In overtaking maneuver 1, the range of values are between 60-10m with 2 outliers, in overtaking maneuver 2, the range of values are between 65-90m with 2 outliers, in overtaking maneuver 3, the range of values are between 50-85m with 1 outlier and in overtaking maneuver 4, the range of values are between 48-80m without outlier.

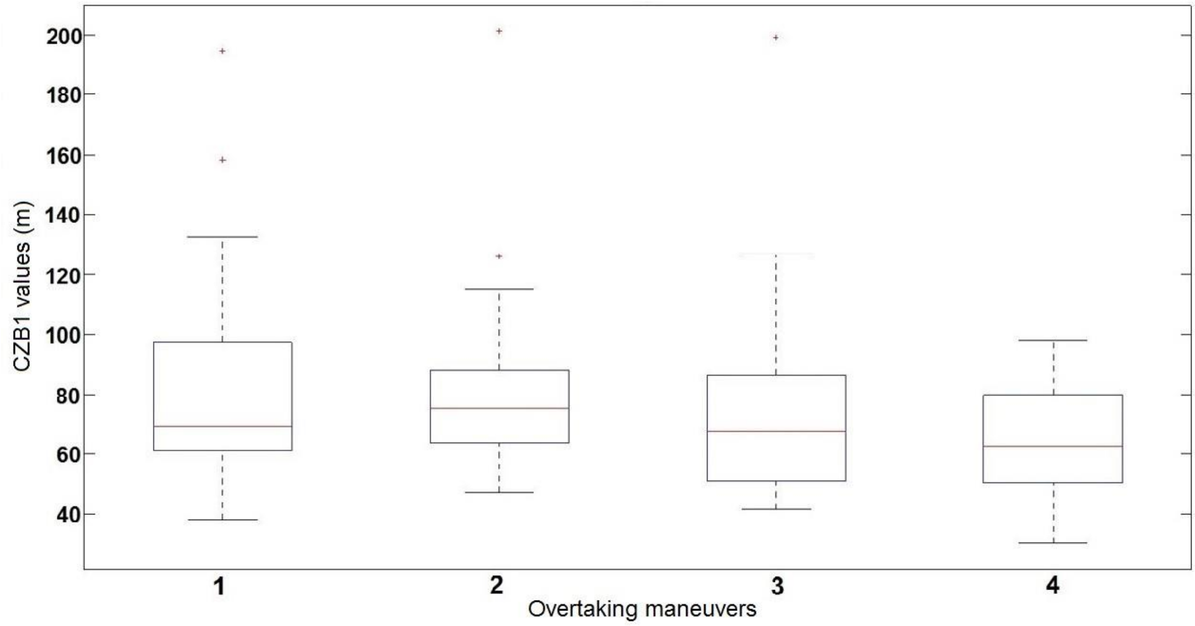

Figure 4.1. Box plot – CZB1, overtaking maneuvers 1-4.

Figure 4.2 represents the range of values in CZB2 for 4 overtaking maneuvers. In overtaking maneuver 1, the range of values are between 2.25-2.8m with 1 outlier, in overtaking maneuver 2, the range of values are between 2.4-.2.7m with 1 outlier, in overtaking maneuver 3, the range of values are between 2.3-2.8m with 2 outliers and in overtaking maneuver 4, the range of values are between 2.3-2.8m with 2 outliers.

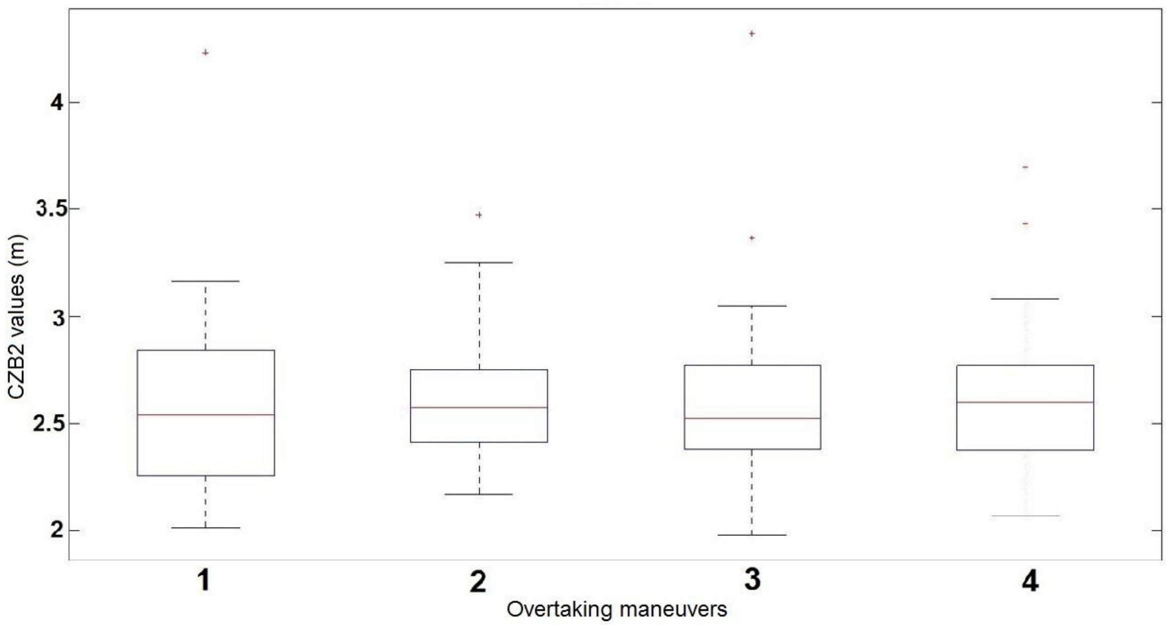

Figure 4.2. Box plot – CZB2, overtaking maneuvers 1-4.

Figure 4.3 represents the range of values in CZB3 for 4 overtaking maneuvers. In overtaking maneuver 1, the range of values are between 1.3-2.1m with 1 outlier, in overtaking maneuver 2, the range of values are between 1.4-2m without outlier, in overtaking maneuver 3, the range of values are between 1.45-2m with 1 outlier and in overtaking maneuver 4, the range of values are between 1.45-2.2m with 1 outlier.

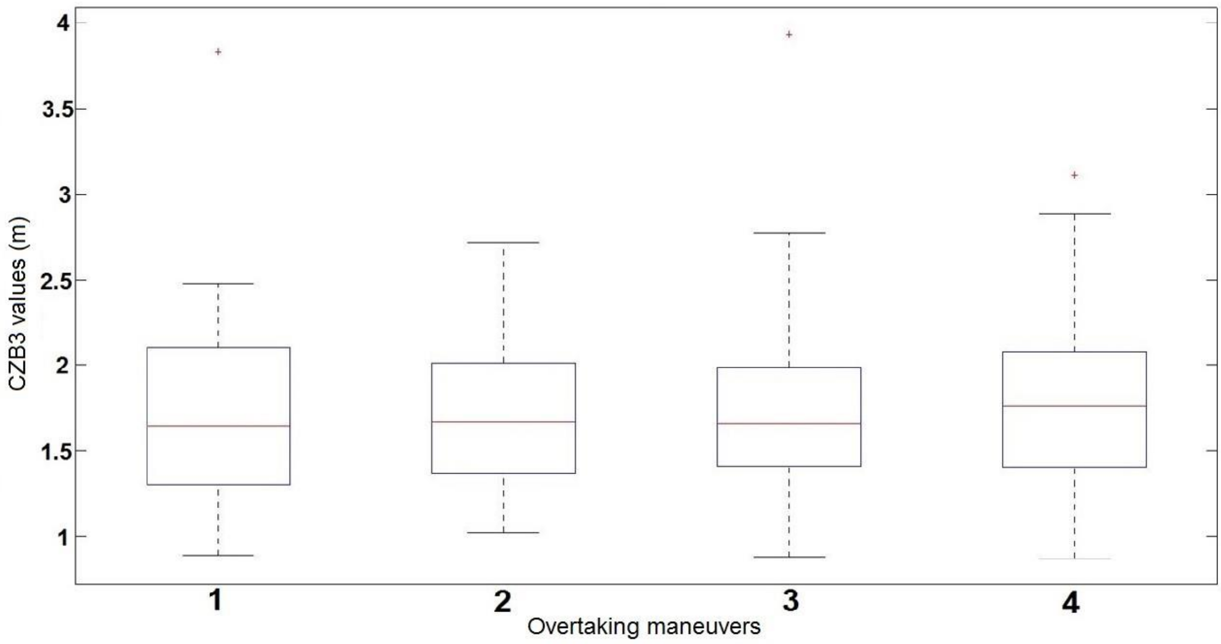

Figure 4.3. Box plot – CZB3, overtaking maneuvers 1-4.

Figure **4**.4 represents the range of values in CZB4 for 4 overtaking maneuvers. In overtaking maneuver 1, the range of values are between 2.5-3m with 1 outlier, in overtaking maneuver 2, the range of values are between 2.4-2.9m without outlier, in overtaking maneuver 3, the range of values are between 2.5-2.8m with 2 outliers and in overtaking maneuver 4, the range of values are between 2.6-3m without outlier.

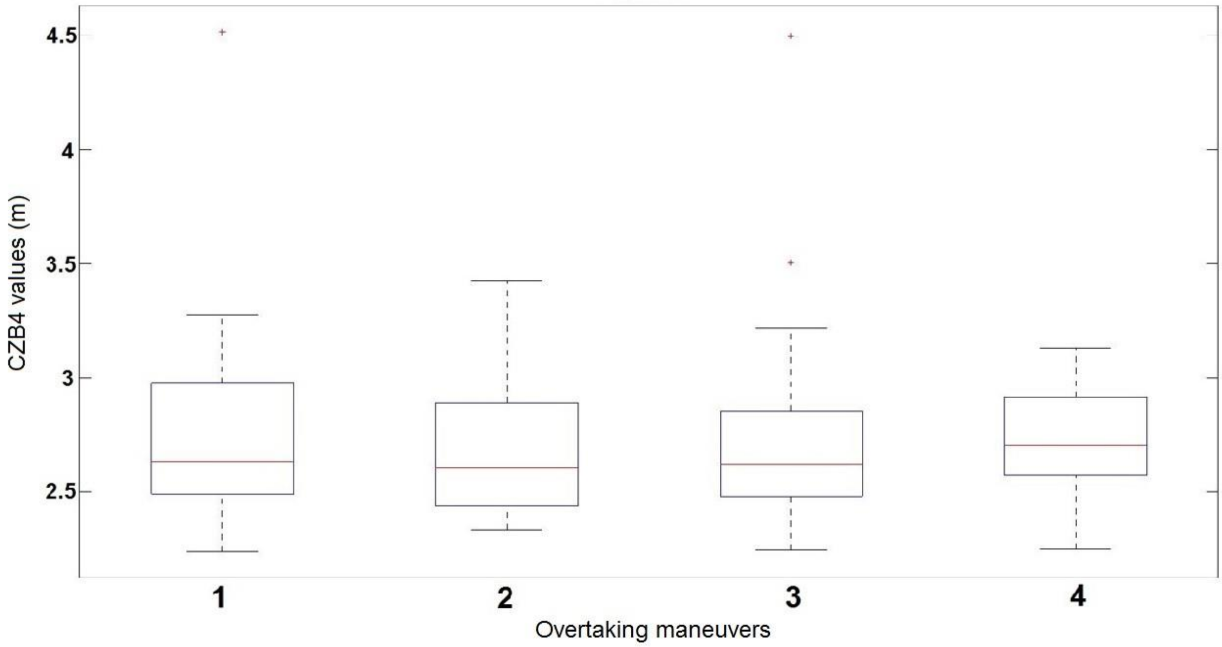

Figure 4.4. Box plot – CZB4, overtaking maneuvers 1-4.

Table 4.2 reports the mean value and standard deviation of CZBs for 4 overtaking maneuvers by considering the gender groups which were defined earlier. It is obvious that the mean values in CZB1 are large values and the standard deviation shows that how the values are vary and distributed in a large scale in CZB1 due to the definition of phase 1 (approaching). Also, it is illustrated that the male participants had various overtaking maneuver in overtaking maneuver 1, 2 and 3 while the female group had various overtaking maneuver in overtaking maneuver 4. The mean values in CZB2 and CZB4 are similar values and the standard deviation declares that the values are in a smaller scale. CZB3 has the smallest mean values.

Table 4.2. Mean value and standard deviation regarding for the two gender groups.

		Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4
CZB1	Male	79.59 ±36.82	78.03 ±32.21	74.06 ±33.86	61.31 ±16.20
	Female	82.98 ±27.53	82.12 ±20.42	73.95 ±24.05	66.86 ±21.25

Table 4.2 continues. Mean value and standard deviation regarding for the two gender groups.

		Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4
CZB2	Male	2.60 ±0.48	2.59 ±0.30	2.65 ±0.46	2.65 ±0.40
	Female	2.54 ±0.29	2.56 ±0.31	2.57 ±0.33	2.57 ±0.21
CZB3	Male	1.74 ±0.66	1.69 ±0.41	1.80 ±0.62	1.82 ±0.56
	Female	1.66 ±0.41	1.75 ±0.48	1.67 ±0.49	1.70 ±0.30
CZB4	Male	2.82 ±0.48	2.67 ±0.26	2.76 ±0.47	2.75 ±0.25
	Female	2.70 ±0.27	2.72 ±0.33	2.68 ±0.31	2.71 ±0.20

Table 4.3 describes the mean values and the standard deviation for the two age groups (standard drivers versus elderly). Same as table 4.2, there are large values in CZB1 for 4 overtaking maneuvers with high standard deviation, which means in CZB1, the participants had various overtaking maneuvers with various CZBs. Moreover, the mean values in CZB2 and CZB4 are close to each other with low standard deviation. CZB3 consists of the smallest mean values.

Table 4.3. Mean value and standard deviation for the two age groups.

		Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4
CZB1	Standard drivers	76.67 ±34.46	72.15 ±19.24	69.95 ±23.72	63.36 ±17.66
	Elderly drivers	87.27 ±30.76	90.74 ±34.76	79.98 ±37.29	63.86 ±19.92

Table 4.3 continues. Mean value and standard deviation for the two age groups.

		Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4
CZB2	Standard drivers	2.55 ±0.32	2.57 ±0.31	2.56 ±0.36	2.56 ±0.32
	Elderly drivers	2.61 ±0.52	2.67 ±0.29	2.69 ±0.47	2.70 ±0.35
CZB3	Standard drivers	1.69 ±0.49	1.68 ±0.47	1.69 ±0.53	1.72 ±0.47
	Elderly drivers	1.75 ±0.69	1.76 ±0.38	1.82 ±0.62	1.85 ±0.48
CZB4	Standard drivers	2.76 ±0.31	2.68 ±0.31	2.73 ±0.34	2.72 ±0.24
	Elderly drivers	2.79 ±0.53	2.69 ±0.27	2.73 ±0.51	2.75 ±0.22

The values of the test statistic (t-test) and scalar value (p) which is in parenthesis were calculated to assess statistically significant differences in CZB between the two age groups and between the two gender groups. The results are reported in table 4.4 and table 4.5. As it is bolded, the only significant result which was occurred is in the age group, CZB1, overtaking maneuver 2. When the scalar value is less than 0.1, it means the result is remarkable.

Table 4.4. Value of the test statistic (t test) and Scalar value (p) for the age variables. All the t-tests calculated consider 35 degrees of freedom.

	Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4
CZB1	0.95 (0.34)	2.08 **(0.04)**	1.00 (0.32)	0.08 (0.93)
CZB2	0.44 (0.65)	0.96 0.33	0.94 0.35	1.19 (0.24)

Table 4.4 continues. Value of the test statistic (t test) and Scalar value (p) for the age variables. All the t-tests calculated consider 35 degrees of freedom.

	Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4
CZB3	0.28 (0.77)	0.55 (0.58)	0.65 (0.51)	0.81 (0.42)
CZB4	0.20 (0.83)	0.12 (0.90)	-0.01 (0.99)	0.42 (0.67)

Table 4.5. Value of the test statistic (t test) and Scalar value (p) for the gender variable. All the t-tests calculated consider 35 degrees of freedom.

	Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4
CZB1	-0.30 (0.76)	-0.43 (0.66)	0.01 (0.99)	-0.90 (0.37)
CZB2	0.42 (0.67)	-0.49 (0.62)	0.53 (0.59)	0.65 (0.51)
CZB3	0.41 (0.68)	-0.38 (0.70)	0.63 (0.53)	0.73 (0.46)
CZB4	0.82 (0.41)	-0.49 (0.62)	0.55 (0.58)	0.44 (0.65)

Table 4.6 shows the effect sizes for the t-tests calculated in table 4.4 and table 4.5. As it is shown, the largest effect size is belong to CZB1, overtaking maneuver 2 for the age group and it proves that the result is notable.

Table 4.6. Effect size.

		Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4
CZB1	age	0.16	0.33	0.16	0.01
	gender	0.05	0.07	0.00	0.15
CZB2	age	0.07	0.16	0.15	0.19
	gender	0.07	0.08	0.08	0.11

Table 4.6 continues. Effect size.

		Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4
CZB3	age	0.04	0.09	0.11	0.13
	gender	0.06	0.06	0.10	0.12
CZB4	age	0.03	0.02	0.00	0.07
	gender	0.13	0.08	0.09	0.07

4.1 Comparison with naturalistic data

Table 4.7 shows the comparison between the CZB calculated in the current thesis and the ones obtained from the previous study conducted by Dozza et al. (2016) in naturalistic driving settings. The results show statistically significant differences in both CZB1 and CZB4 but, only for CZB1, the effect size is large. The differences in the results for CZB1 between naturalistic driving and simulator setting is probably due to the fact that, in the simulator, it was not possible to determine the start of the steering away as precisely as in the naturalistic driving setting.

Table 4.7. CZB in naturalistic driving versus simulator.

		CZB1	CZB2	CZB3	CZB4
Driving simulator (N=37)	Mean value	74.56	2.62	1.73	2.73
	Standard deviation	±17.72	±0.34	±0.47	±0.30
Naturalistic study (N=99)	Mean value	16.64	2.73	1.71	2.60
	Standard deviation	±5.23	±0.34	±0.47	±0.31
t test	Test statistic	t(134)= -29.418	t(134)=1.657	t(134)= -0.208	t(134)= -2.276
	Scalar value	**p < 0.001**	p = 0.100	p = 0.836	**p = 0.024**
Effect size		**0.93**			0.19

5 CONCLUSIONS

37 participants took part in a driving simulator study at the University of Tsukuba in Japan in order to assess CZB without oncoming traffic. The participants were divided into two groups based on age (standard drivers: 25-40 years old; elderly drivers: 65-75 years old) and gender (22 males and 15 females). Each overtaking was spit up in 4 phases, defined as approaching, steering away, passing and returning. All data extracted from the driving simulator, was converted from DAT files to MAT files through TpConv software and analyzed in MATLAB.

The comfort zone boundaries were calculated for each overtaking maneuvers and boxplots were drawn. The statistical analysis shows that only a small significant difference was found in overtaking maneuver 2 for the age group whereas not significant difference was found based on gender. By comparing the current results with a previous naturalistic study, it was found that significant differences between exist for CZB1 (large effect size) and CZB4 (small effect size).

It is obvious that the values of CZB1 in driving simulator are much more than the values of CZB1 in the naturalistic study. One hypothesis is that the determination of approaching phase in driving simulator was difficult and in naturalistic study, it was more accurate due to that the bicycles equipped with LIDAR. The second hypothesis is that difference is because of the different situation and atmosphere between driving simulator and realistic driving. The third hypothesis is that usually participants get used to drive and get familiar and with the atmosphere of the simulator and become more accurate after the first overtaking maneuver.

The current results can be used to support the design of automated driving by defining average comfort zone boundaries which should be maintained between the vehicle and the cyclist during the overtaking process. Although more research is needed on the topic, the outcome of this study does not suggest any significant difference in the overtaking process between standard and elderly drivers and between male and female drivers.

5.1 Future work

Further studies need to be conducted to gain more knowledge in the field of cyclist safety. In this project, only overtaking maneuvers without oncoming traffic were considered. In the future, the same analyses should take into account oncoming traffic to understand how the overtaking maneuver will be affected by vehicles coming from the opposite direction.

Also, other influencing factors on drivers' overtaking process such as the vehicle type/size, the weather conditions and the lane width should be investigated. Furthermore, it is a good idea if a similar study with more participants be done.

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CZB1 values.

Participants	Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4
1	72.97	67.27	96.88	67.44
2	104.01	84.21	67.21	98.11
3	55.77	56.99	95.83	38.06
4	38.31	55.02	51.10	49.07
5	56.68	47.09	57.25	95.76
6	60.85	84.70	66.35	30.12
7	65.46	91.52	42.29	46.28
8	N/A	N/A	N/A	N/A
9	84.99	201.14	199.19	49.05
10	N/A	N/A	N/A	N/A
11	75.66	76.40	79.54	75.45
12	67.70	64.52	92.06	62.79
13	78.19	80.76	84.60	82.91
14	111.03	98.86	81.27	86.83
15	132.40	81.42	74.30	33.18
16	N/A	N/A	N/A	N/A
17	62.67	94.71	85.93	57.19
18	96.61	63.51	41.66	64.99
19	71.12	102.16	84.87	73.41
20	64.91	70.00	51.84	53.00
21	66.43	109.39	53.73	88.07
22	194.68	76.49	67.69	79.57
23	71.11	53.25	50.16	51.34
24	57.92	80.45	85.84	57.80
25	103.52	64.45	50.61	86.42
26	67.28	56.32	70.87	50.11
27	158.40	66.01	73.56	83.83

CZB1 values.

Participants	Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4
28	40.57	71.97	93.55	75.39
29	N/A	N/A	N/A	N/A
30	61.09	86.84	61.74	51.54
31	69.35	65.74	42.34	50.66
32	46.02	75.46	46.79	54.55
33	56.95	55.68	59.32	53.73
34	69.21	66.92	46.32	72.17
35	74.62	115.28	96.22	86.73
36	94.38	51.15	50.16	34.66
37	66.34	63.71	46.98	66.43
38	N/A	N/A	N/A	N/A
39	99.97	99.49	88.29	5179
40	49.09	62.02	126.65	42.54
41	125.67	81.68	63.68	70.46
42	123,73	125.97	111.84	80.33

CZB2 values.

Participants	Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4
1	2.40	2,21	2.30	2.19
2	2.17	2.18	2.14	2.20
3	2.86	2.25	2.09	2.15
4	2.19	2.41	2.52	2.46
5	2.25	2.45	2.52	2.38
6	2.60	2.73	2.38	2.71
7	2.47	2.71	2.68	2.63
8	N/A	N/A	N/A	N/A
9	2.35	2.49	2.75	2.95
10	N/A	N/A	N/A	N/A
11	2.42	2.54	2.87	2.62
12	2.16	2.57	2.65	2.91
13	2.01	2.67	2.44	2.45
14	2.80	2.63	2.65	2.74
15	2.89	2.86	2.77	2.87
16	N/A	N/A	N/A	N/A
17	2.14	2.31	2.31	2.39
18	2.15	2.41	2.36	2.06
19	2.96	2.67	2.70	2.96
20	2.63	2.70	2.77	2.77
21	2.66	2.78	2.96	2.72
22	2.93	3.17	3.03	3.08
23	3.16	2.79	2.95	3.43
24	2.55	2.44	2.50	2.76
25	2.54	2.41	2.45	2.50
26	2.53	2.41	2.46	2.27
27	2.32	2.56	2.49	2.45

CZB2 values.

Participants	Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4
28	2.24	2.63	2.50	2.72
29	N/A	N/A	N/A	N/A
30	2.45	2.49	2.46	2.50
31	2.62	2.38	2.25	2.33
32	2.96	2.69	2.69	2.57
33	2.43	2.69	2.39	2.59
34	2.20	2.16	1.97	2.27
35	2.73	3.09	2.53	2.59
36	2.83	2.91	3.04	2.66
37	2.24	2.28	2.32	2.35
38	N/A	N/A	N/A	N/A
39	4.23	3.47	4.31	3.69
40	2.28	2.38	2.30	2.31
41	2.91	3.00	2.92	2.60
42	3.07	3.24	3.36	2.95

CZB3 values.

Participants	Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4
1	1.45	1.21	1.24	1.32
2	1.20	1.02	0.97	1.15
3	2.18	1.19	0.96	0.98
4	1.31	1.49	1.70	1.68
5	1.29	1.40	1.57	1.52
6	1.57	1.68	1.41	1.73
7	1.42	1.71	1.65	1.80
8	N/A	N/A	N/A	N/A
9	1.50	1.54	1.83	2.12
10	N/A	N/A	N/A	N/A
11	1.55	1.51	2.15	1.74
12	1.08	1.66	1.89	2.10
13	0.93	2.01	1.41	1.68
14	2.01	1.88	1.80	2.00
15	2.09	2.13	1.91	2.23
16	N/A	N/A	N/A	N/A
17	1.00	1.31	1.39	1.39
18	0.88	1.18	1.23	0.87
19	2.29	1.88	1.94	2.22
20	1.82	2.02	2.11	2.21
21	1.83	1.89	2.28	1.90
22	2.31	2.57	2.33	2.36
23	2.47	2.02	2.30	2.88
24	1.64	1.57	1.9	1.75
25	1.80	1.49	1.53	1.58
26	1.73	1.59	1.62	1.34
27	1.55	1.37	1.57	1.40

CZB3 values.

Participants	Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4
28	1.23	1.80	1.72	2.06
29	N/A	N/A	N/A	N/A
30	1.67	1.47	1.61	1.54
31	1.80	1.29	1.15	1.51
32	2.25	1.91	1.87	1.91
33	1.44	1.85	1.47	1.75
34	0.98	1.16	0.87	1.22
35	1.82	2.46	1.67	1.81
36	2.14	2.24	2.36	1.99
37	1.27	1.26	1.33	1.27
38	N/A	N/A	N/A	N/A
39	3.83	2.51	3.93	3.11
40	1.30	1.20	1.22	1.36
41	2.35	2.13	2.24	1.78
42	2.38	2.71	2.77	2.25

CZB4 values.

Participants	Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4
1	2.49	2.49	2.36	2.61
2	2.50	2.38	2.37	2.56
3	3.08	2.33	2.24	2.69
4	2.55	2.55	2.69	2.71
5	2.44	2.40	2.52	2.79
6	2.62	2.55	2.59	2.69
7	2.44	2.55	2.46	2.70
8	N/A	N/A	N/A	N/A
9	2.68	2.60	2.61	2.83
10	N/A	N/A	N/A	N/A
11	2.54	2.61	2.88	2.64
12	2.42	2.57	2.81	2.72
13	2.23	3.01	2.44	2.67
14	2.93	2.71	2.69	2.74
15	2.93	2.90	2.84	2.99
16	N/A	N/A	N/A	N/A
17	2.42	2.40	2.59	2.63
18	2.35	2.33	2.34	2.24
19	3.14	2.81	2.78	2.78
20	2.89	2.94	3.07	3.07
21	2.75	2.69	3.03	2.76
22	3.16	3.31	3.08	3.02
23	3.27	2.88	3.12	3.56
24	2.57	2.52	2.61	2.62
25	2.89	2.51	2.44	2.81
26	2.82	2.69	2.61	2.73
27	2.63	2.40	2.48	2.53

CZB4 values.

Participants	Overtaking 1	Overtaking 2	Overtaking 3	Overtaking 4
28	2.47	2.72	2.70	3.04
29	N/A	N/A	N/A	N/A
30	2.62	2.60	2.75	2.74
31	2.78	2.40	2.35	2.73
32	3.14	2.79	2.83	2.85
33	2.52	2.81	2.57	2.64
34	2.44	2.44	2.31	2.56
35	2.81	3.26	2.58	2.93
36	3.09	3.06	3.21	2.94
37	2.40	2.38	2.51	2.63
38	N/A	N/A	N/A	N/A
39	4.51	3.12	4.49	3.25
40	2.61	2.36	2.49	2.57
41	3.14	2.95	3.06	2.85
42	3.24	3.42	3.50	3.15