Individual cyclist behavior

Characteristics of the steering angle from an individual cyclist in a controlled laboratory experiment

Bachelor thesis

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Preface

First I want to thank supervisors, Dr. ir. Y. Yuan and Ir. Rolf Koster, for giving me feedback and a lot of helpful tips. Than I want to thank my fellow students, L. Andringa, L, Heijenrath, E. Molier and M. Poppe, for giving me feedback during the group meeting. I also want to thank B. van de Krol for helping me out with MATLAB problems and proofreading my writing.

Abstract

In most urban areas the active modes of traffic are growing. It is important that the infrastructure can accommodate more cyclists and pedestrians in a space efficient and safe way. In this research the focus lies on the bicycle mode of transportation. Bicycle flow models are used to model the flow of cyclists. With these models the optimal situation in terms of infrastructure for cyclists can be found. These models use cyclist data to make a prediction about the traffic flow. To make the most accurate prediction of the reality microscopic data about how individual cyclists behave is needed. This research is about the steering angle of individual cyclists in a face to face encounter because no earlier research is done about the steering angle of an cyclist. The data that is used comes from a controlled laboratory experiment(Yuan, 2016). The data is processed in MATLAB to come to results. The main question of this research is "What is the interaction behavior of cyclists in bidirectional encounters related to steering angle and longitudinal interaction?". The on average steering angle of a cyclist in bidirectional encounter is 2 degrees, witch means that all cyclist are steering 2 degrees more to the left than to the right. The smoothed steering angle of a cyclist in a bidirectional encounter movement always look like an S-curve due to the fact that a cyclist always need to steer back again to follow the road. To confirm this result more research is needed also for different movements to see if this a typical result for bidirectional encounter. If the results of this research can be confirmed, the numbers can be used as an extra parameter or parameter boundary in bicycle flow models.

Contents

1 Introduction

The modal split in the Netherlands is changing, especially in large cities more people are choosing for the bike. This modal shift occurs due to the changing composition of city residents and the changing of infrastructure (Harms, 2016). The disadvantages of having a car in big cities also plays a role in this change. In Amsterdam the modal share of cyclists in 1986 was 21 percent, in 2014 this has grown to 32 percent, see figure 1.

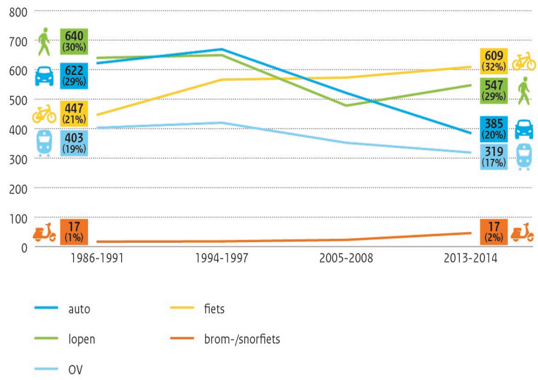

Figure 1: Modal Split Amsterdam, number of trips (x 1.000) (Harms, 2016).

1.1 Relevance of the research

This growing use of bicycles is good for the environment, however in Amsterdam the cycling paths are too narrow for big flows of cyclists. This leads to cyclist congestions during peak hour (Obbink, 2013). With a big investment the city of Amsterdam wants to change this. However, the best way to adjust the infrastructure is not figured out yet (Obbink, 2013). With bicycle traffic flow simulations the best way of improving the infrastructure can be proposed. To make these models more accurate, more information about individual cyclists must be implemented. In this thesis, microscopic research about individual cyclist behavior related to the steering angle are obtained. The results of this research can possibly be implemented in the bicycle traffic flow simulations to improve the models.

This research is about individual cyclist behavior in a bidirectional encounter to enlarge the knowledge for bicycle traffic flow models. The data is obtained from a controlled laboratory experiment (Yuan, 2016). This experiment took place on the campus of Delft University of Technology. Twelve participants did three different interactions: bidirectional, crossing and overtaking. Moreover, there were three different interaction types: one to one, one to two and two to two. In this research, the data of the bidirectional interaction between two individuals are used. In current publications there are no behavior rules related to individual steering angle. A lot of research about the dynamic modeling and stability of an individual cyclist has been done, or on an individual cyclist steering in a curve (such as: Zhang, 2010; Vansteenkiste, 2014; Iuchi, 2005). With more microscopic research about cyclist interaction the macroscopic bicycle flow models can be further developed.

1.2 Research questions

The main question to be answered in this research is: "What is the interaction behavior of cyclists in bidirectional encounters related to steering angle and longitudinal interaction?" The sub-questions to answer the main questions are the following;

- What is the minimum, maximum and average steering angle of a cyclist?
- What is the difference in steering angles between evading and steering back after maximum lateral deviation (see figure 2)?

- What is the longitudinal interaction distance, the distance between the two cyclists when the first cyclist starts steering (see figure 2)?

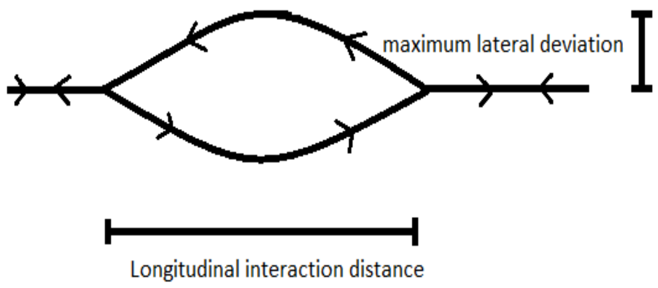

Figure 2: Longitudinal length in bidirectional encounter of two cyclists.

Along with the lateral distance the space needed for a bi-directional interaction of two cyclists can be determined. The minimum and maximum steering angle in this situation are some restrictions that can be used in further developing cyclist flow models.

In the second chapter, the methodology, is explained how the answers to the sub-questions are derived. In chapter three the data set on which the results are based is interpreted. Then the results are shown in the fourth chapter. Eventually, the main research question is answered in the conclusion.

2 Methodology

This chapter describes how the research questions will be answered. The data about bidirectional encounter from the paper of Yuan are used to answer the sub-questions (Yuan, 2016). All the data has been processed in MATLAB. The data is from a controlled laboratory research where two persons approaching each other in a bidirectional encounter (see figure 2). The bidirectional encounter experiment is repeated 48 times, 24 times in the morning session and 24 times in the afternoon session. So in total there is data from 96 individual cyclists.

2.1 Measuring points

In the data there are four measuring points of each cyclist, called blobs; the most right and the most left side of the steeling wheel (the handles), the head of the person and the luggage carrier (rear). See figure 3.

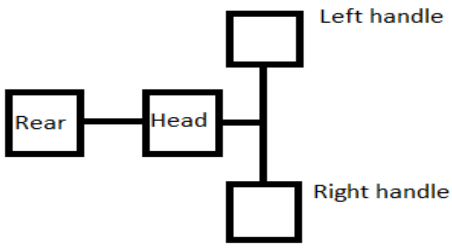

Figure 3: The Four measuring points of one cyclist.

2.2 Deriving the Steering angle

The steering angle will be determined as a function of time and position (x coordinate in m). If the lateral vector is not 90 degrees to the longitudinal vector the cyclist is evading. After deriving the steering angle the minimum, maximum and average angle can be determined and the difference between evading and steering back can be studied.

The steering angle of a bicycle is the angle between the lateral and the longitudinal vector minus 90 degrees (angle A - 90), see figure 4. Steering to the right defines a negative steering angle and steering to the left gives a positive steering angle. The position of the rear and the position of the rear minus one time step are used to determine the longitudinal vector. Only the rear is used to determine the longitudinal vector due to the fact that the head of a person can move a little bit more to the right or the left than the bicycle itself. When moving straight ahead, the lateral vector always makes 90 degrees with the rear and the rear minus one-time step.

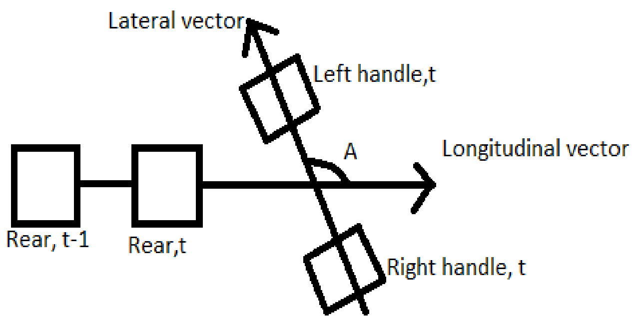

Figure 4: The vectors and steering angle (A) of a cyclist.

The steering angle angle is calculated in MATLAB with the function atan2d. This function returns the four-quadrant inverse tangent which result to the angle in degrees between two vectors in counterclockwise direction. As shown in figure 4 in this case the inputs of the atan2d function are the longitudinal vector and the lateral vector. The steering angle is the outcome of the atan2d function minus 90 degrees.

2.3 Concluding calculation operations

An overview of the different calculation steps that are given in table 1, all the step will be executed in MATLAB. The data analysis column shows how the factors will be determined and the last column shows how the data will be presented in this report.

Table 1: Calculation operations.

Factor	**Data analysis**	**Plot**
The rear, left handle and right handle position with X and Y, time(t) coordinates	Split the data in different measuring points and different experiments.	Trajectory of rear (X,Y)
The steering angle	Make vectors, lateral vector and longitudinal vector. Measure the angle between the vectors.	Steering angle as a function of the time (angle, t)
Maximum, minimum and average steering angle	Define maximum, minimum and average steering angle from the different sessions and directions	Overview of results in a boxplot and a table
Angle of evading and steering back	Split up the different experiments and determine the maximal lateral deviation to split up the evading and steering back parts	Overview of results in a boxplot and a table
Longitudinal interaction distance	Define the point and time where the first cyclist starts to turn their steer (smoothed S-curve of the steering angle). Find how far the other cyclist is away in longitudinal direction at the same time.	Boxplot of longitudinal interaction distance

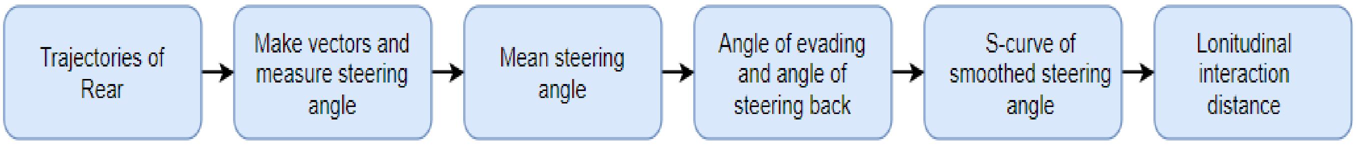

Figure 5: Overview of operations.

3 Data description

In this chapter the data that is used will be explained. An advanced video processing software, Moving Object Detection and Tracking (Yuan, 2016), was used to obtain the raw data of the four measuring points from every cyclist. The raw data are read by a software package called TrajectoyViewer (Yuan, 2016), developed at the TU Delft, to remove double counts and add missing trajectory points. Two cameras were used in the laboratory experiment so the data is merged from two camera measurements. In the end the data is stored in MATLAB, this is already done by Yuan (Yuan, 2016). In this research all the results will be obtained with MATLAB using the already existed data.

3.1 The data

There are two data sets, one from the morning session and one from the afternoon session. In both sessions 24 experiments are done but with another instruction. In the morning session both participants started on the middle line, in the afternoon session they just started somewhere random most of the times more to the right. The data is stored in a big matrix (coordinates) where all the blobs (four different measuring points) have different numbers per session (column 1), see figure 5. The other interesting columns in the matrix are the ID numbers of the blobs (column 5), the x coordinates (column 2), the y coordinates (column 3) and the time (column 8).

	1	2	3	4	5	6	7	8	9
1	7535	292.8000	1.0156e+03	0	1084	149.5851	122.1962	7.3646e+05	515.9610
2	7536	315.8333	1.0138e+03	0	1084	170.7254	128.5516	7.3646e+05	516.0190
3	7537	326.8333	1.0118e+03	0	1084	181.0978	130.8651	7.3646e+05	516.0820
4	7538	351.2500	1010	0	1084	203.3141	137.6459	7.3646e+05	516.1490
5	7539	376	1.0062e+03	0	1084	226.4768	143.3113	7.3646e+05	516.2050
6	7540	412	1004	0	1084	259.0137	153.9634	7.3646e+05	516.2860
7	7541	441.8000	1.0046e+03	0	1084	284.8750	164.5564	7.3646e+05	516.3460
8	7542	468.8000	1.0046e+03	0	1084	308.3912	173.9259	7.3646e+05	516.4050
9	7543	486.2000	1.0054e+03	0	1084	323.1850	180.6587	7.3646e+05	516.4750
10	7544	500.5000	1.0055e+03	0	1084	335.6482	185.6410	7.3646e+05	516.5460

Figure 6: First ten row of big matrix with all the data.

3.2 Different measuring points

The blob numbers used per experiment are stored in a different matrix. First, the blob numbers are split up in the different directions: from left to right (direction one) and from right to left (direction two). Then the different measuring points of one cyclist are defined: head, rear, left handle and right handle. Now it is defined which blob numbers measures which point. Then the coordinates and the time from every blob number can be found from the big coordinates matrix. With a loop the blob numbers from the four different measuring points and the different directions can be found. For example, in figure 6 you see the trajectory of the rear blobs in the morning session in one direction, from left to right.

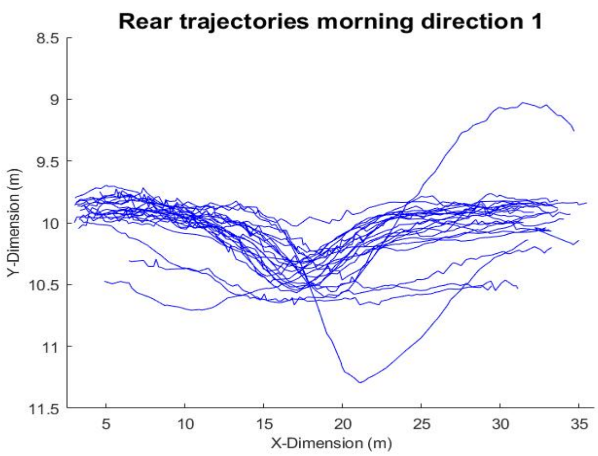

Figure 7: Rear trajectories from morning session in direction one.

4 Results

In this chapter, the results are shown and explained. First, the results of the trajectories are treated. After that, the characteristics of the steering angle are shown in a table and a box plot. Then a closer look at the different trajectories according to the steering angle is executed, the difference of the steering angle between evading and steering back and the smoothed steering angle. In the end all the results together are discussed.

4.1 Trajectories of the cyclists in a bidirectional encounter

In figure 7 and 8, the rear trajectories in the two directions are shown: from left to right and from right to left. In Appendix A, the trajectories of the left handle and the right handle are added. Due to the fact that the head trajectories are not used to reach the results, the head trajectories are not obtained. Since the results of the morning and the afternoon session are different they are in a different plot. The reason for this big difference is that in the afternoon session the participants of the experiment were instructed differently than in the morning session as described in section 3.1. In the following steps, the results are obtained separately from the morning session and the afternoon session. In the end, in the morning session results are compared with the afternoon session results to see the influence of the different experiment process.

In figure 7 it is visible that the maximum lateral deviation of the two directions is not in the same place in the X dimension. Most of the time the cyclists have their maximal lateral deviation after they pass each other. Which means these cyclists are still interacting after passing each other and do not steer back directly after passing.

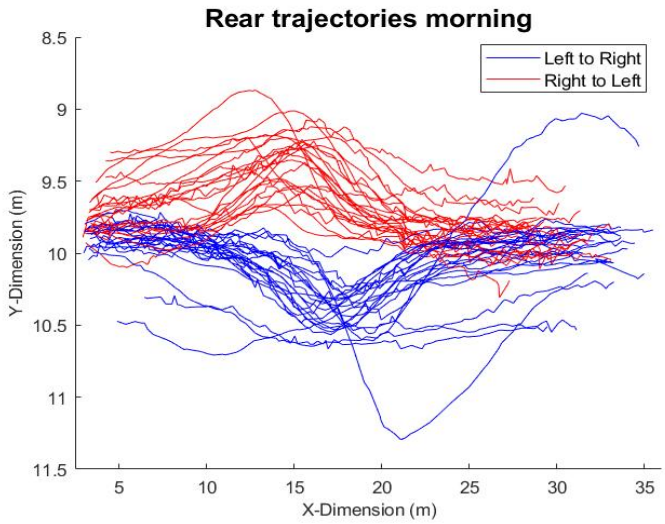

Figure 8: Rear trajectories from the morning session.

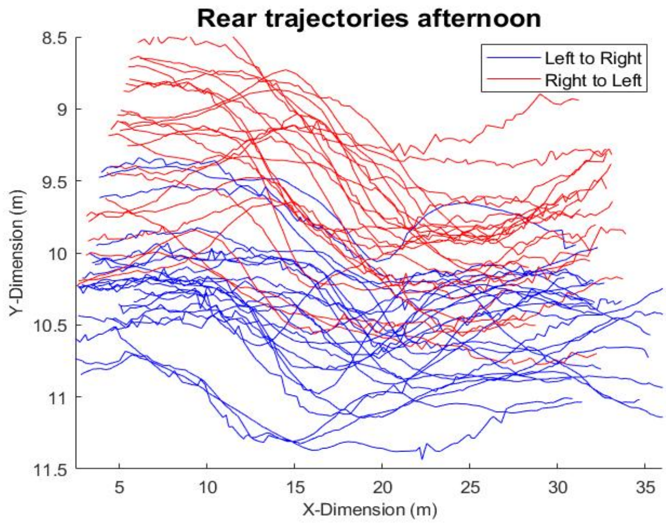

Figure 9: Rear trajectories from the afternoon session.

4.2 The mean steering angle

After obtaining the lateral en longitudinal vector the steering angle is computed as described in the methodology (section 2.2). The three different blobs; the rear, the left handle, and the right handle, do not have the same amount of data. At some time steps there is not a measurement from all the blobs. So those time steps are filtered out due to the fact that only on time steps with all three measurement points the steering angle can be calculated. For example, in figure 9 all the steering angles from the morning session of the cyclist cycling from left to right (direction 1) are shown. The figures with the steering angles from all the sessions and directions are shown in Appendix B.

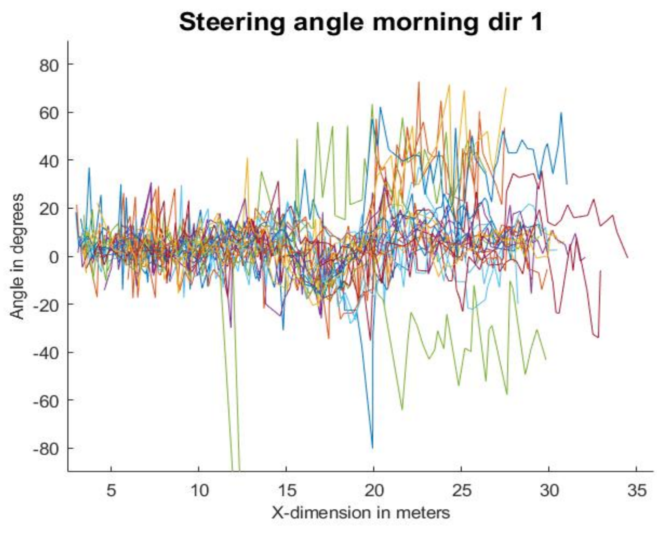

Figure 10: Steering angles from the morning session in direction one.

In the figures is clearly visible that on the higher x dimensions there are more outliers in the steering angle than on the lower x dimensions. The reason for this is that in the last part of direction 1 (from left to right) and the first part of direction 2 (from right to left) some differences in time are visible. On some time steps, the three different measurements are not taken exactly at the same time. These differences are in orders of milliseconds to seconds, so in most cases it makes no difference but in some cases it leads to outliers. For example one outlier is clearly visible in figure 9, the extremely low steering angle of an X-dimension of 20 meters.

In the afternoon session at a point of time, the sign of the lateral vector from some trajectories changes from negative to positive. This means that there is a sudden change in the right and left handle measurements. The steering angle jumps from around zero degrees to around minus one hundred eighty degrees, see figure 10. This change of hundred eighty degrees is obviously if the vector changes from direction. This change of sign happens probably due to a change in how the data is measured and stored. This discontinuity is solved by adding one hundred eighty degrees to all the extremely low results. The sudden change in measurements for the left and right handle is also visible in the trajectory figures of the right and left hand from the afternoon session. For example in figure 11 the right handle trajectories are shown. There are jumps in the Y-dimension which lead to almost vertical lines in the graphs around an X-dimension of 22 meters.

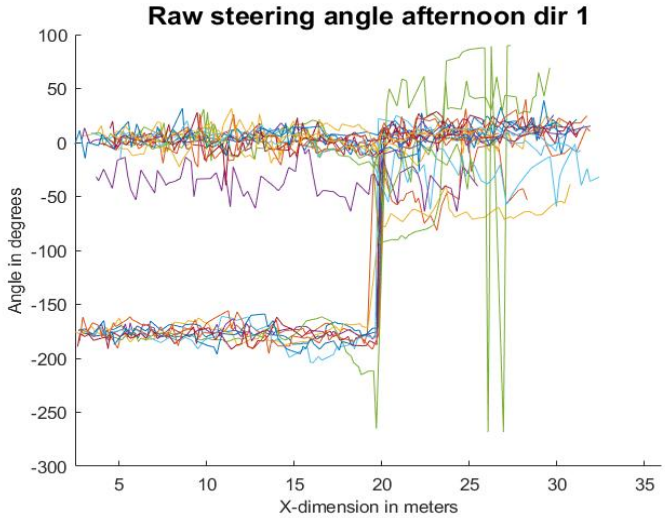

Figure 11: Steering angles from the afternoon session in direction one before correcting the outliers.

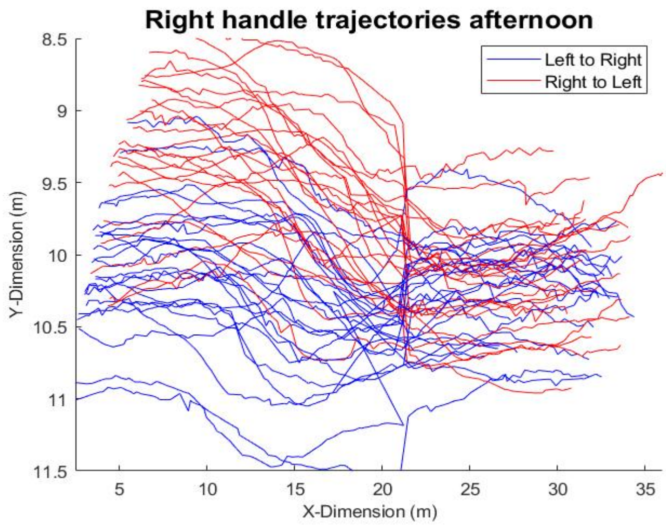

Figure 12: Right handle trajectories from the afternoon session.

Then the mean of the the different sessions is calculates. Due to the fact that there are outliers in this data, the trimmed mean witch exclude a percentage of the highest and lowest data values is obtained. In figure 12 is shown that with a trimmed mean of 40 percent the steering angle is stable so the outliers do not have influence anymore. In table 2, the mean and the trimmed mean of 40 percentage is presented. In figure 13 the box plots of the steering angles in different situations are shown. The mean of all the steering angles together is 2.55 degrees. This means that on average the cyclists are all steering a little bit more to the left than to the right. A small difference in the steering angle in the two directions is also seen, the participants cycling from right to left (direction 1) are more steering to the left in both the morning and the afternoon session. These are small differences, in the morning session this is a difference from 2.98 degrees and in the afternoon session 3.64 degrees. The reason can probably be a difference in surroundings between the left and right side of the experiment but also the outliers or the measuring method can have an influence.

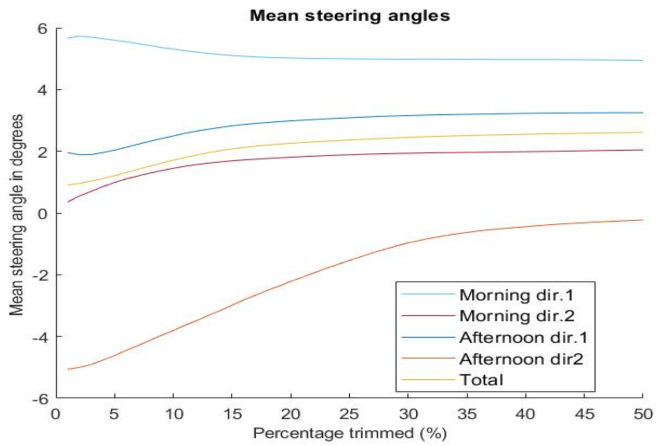

Figure 13: Mean steering angle with upward percentage trimmed.

Table 2: Mean steering angles in degrees.

	Mean	**Trimmed mean 40%**
Morning dir.1	5.66	4.97
Morning dir.2	0.36	1.99
Afternoon dir.1	1.95	3.23
Afternoon dir.2	-5.06	-0.41
Total	0.91	2.55

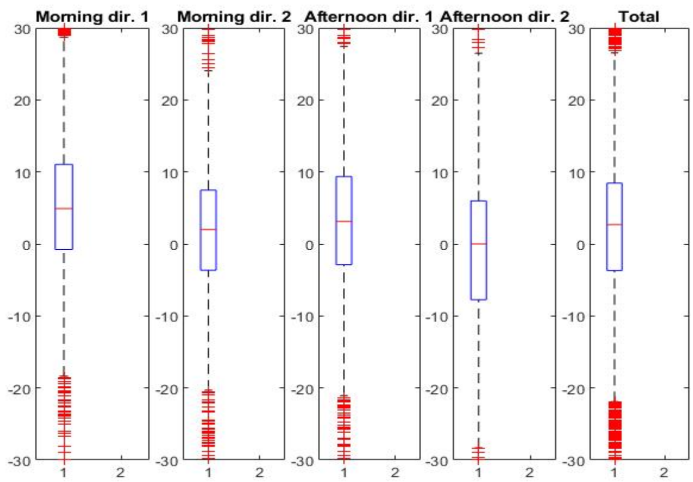

Figure 14: Box plots of the steering angles in the different situations.

4.3 Difference in angles between evading and steering back movement from the morning session

To derive the difference in steering angle between evading and steering back the data set needs to be split up after maximum lateral deviation. The first part of the trajectory is the evading part and after the maximum lateral deviation it is the steering back part, see figure 14.

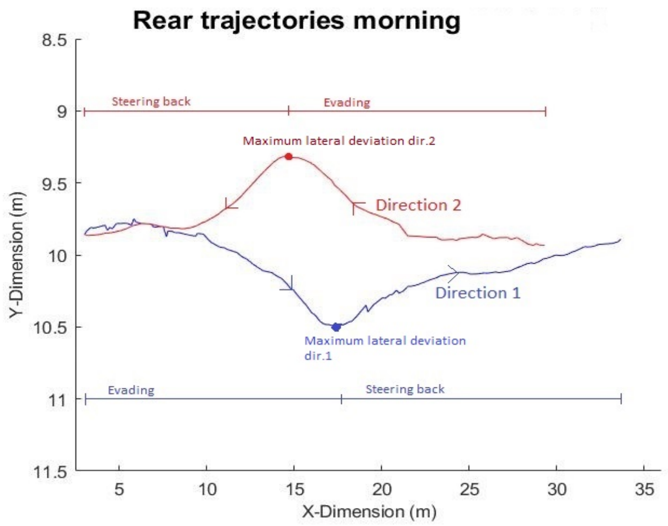

Figure 15: Evading and steering back parts in the two directions.

For all the 24 experiments of the morning session in the two directions, the maximum lateral deviation is determined and the dataset is split up in evading and steering back. Then the steering angle is derived as explained in section 2.2. The trimmed mean is used to filter out the outliers, in figure 15 is shown that from a trimmed mean of 40 percent all the mean values are constant. In table 3 the mean and trimmed mean of 40 percent of this data is presented. In figure 16 the box plots of the results are shown. From the results can be concluded that the evading goes with a lower angle than steering back. This is a logical result because for evading you need to steering to the right which give a negative steering angle, so lower. To steer back to the middle line cyclists need to steer to the left witch gives a positive steering angle, so a higher value is logical. The average difference between the steering angle from the two directions in evading of steering back is 2.2 degrees. This is not a big difference the reason for this is that the displacement is not big and to make a lateral displacement cyclists need to steer to the right and than to the left to continue in a straight way.

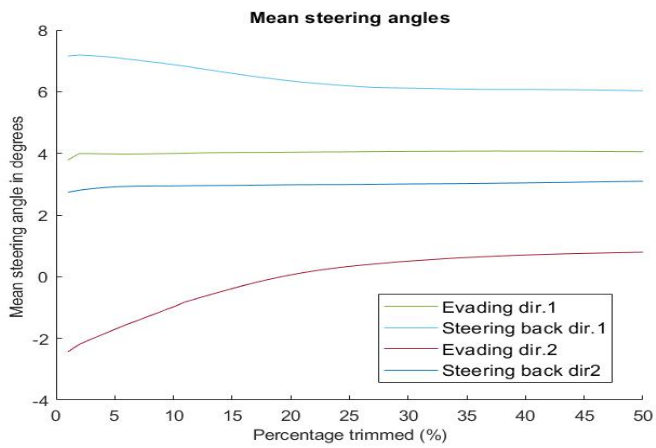

Figure 16: Mean steering angle from evading and steering back parts from the morning session with upward percentage trimmed.

Table 3: Mean steering angles in degrees from evading and steering back parts from the morning session in the two directions.

	Mean	**Trimmed mean 40%**
Dir.1 Evading	3.79	4.07
Dir.1 Steering back	7.16	6.07
Dir.2 Evading	-2.43	0.72
Dir.2 Steering back	2.74	3.05

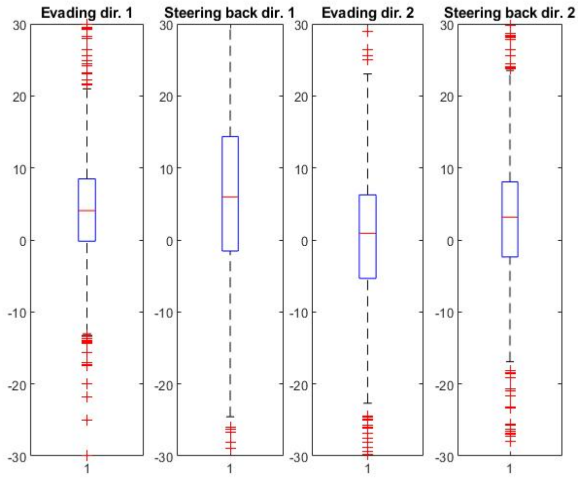

Figure 17: Boxplot of angles in evading and steering back in the morning session in two directions

For the afternoon session, it is not possible to perform this method because the cyclists did not start on the middle line. The maximum lateral deviation does not go together with the point where the cyclist stops evading and start steering back.

4.4 S-curve of the smoothed steering angle from the morning session

Cyclists who are following a straight line are always steering in one direction and then steer back to come back to the middle line. So the steering angle of a cyclist following a straight line will always go up and then down again around zero degrees. If the deriving steering angles from the bidirectional interaction experiment are smoothed the S-curve of a cyclist is visible with an extra high S-curve around the bidirectional interaction. The steering angle is smoothed with the fit function using the smoothing spline, the smoothing spline works with a parameter p. If p is zero the smoothing spline produces a least-squares-line fit to the data, while p is one it produces a cubic spline interpolant. For the smoothed line of the steering angle in this research, a value of p is 0.7 is used because then the S-curve is most visible. In figure 17 an example of one experiment is shown, within the upper figures the smoothed steering angle and in the lower figures the trajectories of the rear. From the upper left plot is clearly visible that the steering angle of the cyclist results in an S-curve. It is also visible that the cyclist is steering to the right with a bigger angle to evade (big minus angles around an x-dimension of 17 meters) and then steer to the left to come back to the middle line again (higher steering angles around an x-dimension of 22 meters).

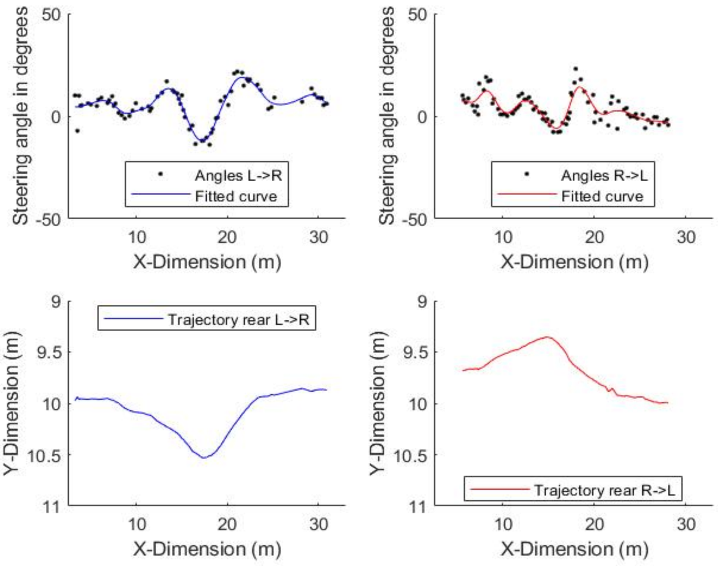

Figure 18: Experiment 3 of the morning session, the two trajectories and the fitted steering angle as a function of x dimension.

To create a better view of an average S-curve in a bidirectional encounter where the two cyclists starts on the same line as in the morning session the smoothed steering angles of two directions are plotted. In figure 18 the smoothed steering angles from the 24 experiments in the morning from one direction are shown, see appendix C for direction two. In this figure is shown that some of the cyclists have the same steering pattern which is probably a typical pattern for a bidirectional encounter. To have a better view on the S-curves the steering angle runs from -30 degrees to 30 degrees (vertical axis) assumed that the higher and lower values are outliers. From this figure, some rough things about the steering angle to evade for bidirectional encounter can be made. The average angle to evade or steer back is around 10 degrees, see dashed green line, and the maximum angle to evade lies probably somewhere between 10 or 20 degrees.

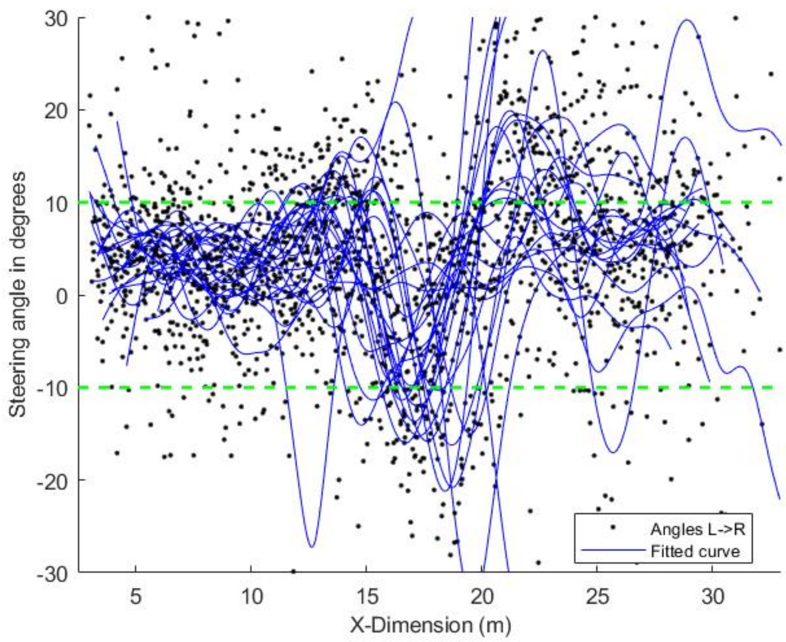

Figure 19: Smoothed steering angles of direction one from the 24 experiments of the morning session

4.5 Point where a cyclist starts steering to evade

To determine the lateral interaction distance the point where the cyclist starts to steer to evade needs to be found. Nevertheless, in the results of the steering angle, the cyclist is always steering also to stay on the middle line. Since the maximum deviation of the cyclists in this experiment is 1.2 meters (Bon, 2017) it is difficult to see if a cyclist is steering to stay on the middle line or to evade.

In figure 20 the smoothed steering angles of experiment 5 are shown. With this figure, an example of how the longitudinal interaction distance can be derived is shown. The black horizontal line indicates where the steering angle is zero this means the cyclist is cycling straightforward. The blue line is from the cyclist cycling from left to right and the blue dot is the point where the cyclist starts to steer the right to evade. The red line is from the cyclist steering cyclist from right to left, the red dot is the point where the cyclist starts to steer to the right to evade. To exactly determine the place where the cyclist is steering to evade more knowledge about how big steering angles of a cyclist are to stay on the middle line is needed. The next step is then determining the time when the first cyclist starts steering to evade from an angle of zero degrees. After that, the distance between the two cyclists at that time can be determined, the lateral interaction distance.

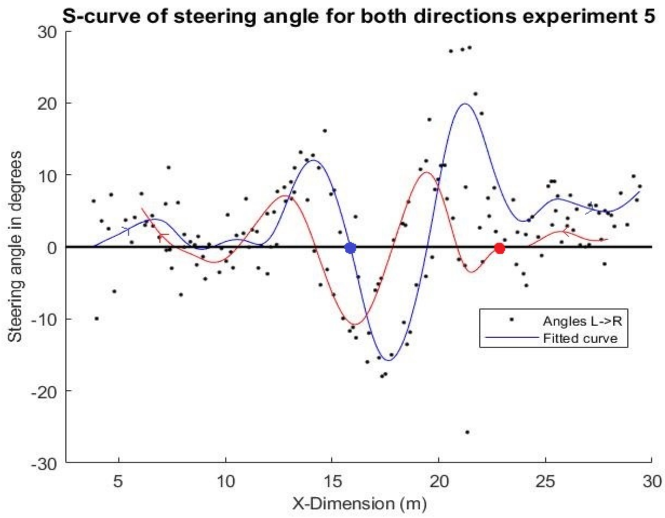

Figure 20: Smoothed steering angles from experiment 5 from the morning session with points where the cyclists start to steer to the right to evade

4.6 Discussion of results

As shown in this chapter the data that is used has some discontinuities, some of them are captured by changes in computing the results. Nevertheless, this discontinuities in the data leads to outliers. Due to these outliers deriving the maximum and the minimum steering angle is not reliable. Therefore, concrete conclusion about the min/max steering angle is not possible for this data.

As discussed in section 5.2 there are a lot of outliers in the steering angles in the last part of direction 1 and the first part of direction 2. This has an influence on the difference in steering angle between evading and steering back. It means that in direction 1 the evading part should be more accurate and in direction 2 the steering back part due to the fact that those part of the trajectories has less outliers than the other parts. Unfortunately, there are no earlier researched to compare this results with to see if they are more accurate or not. The difference between evading and steering back is also only obtained for the morning session, so the results are from 24 experiments with 48 individual cyclists. This is also not enough data to overcome the discontinuities.

5 Conclusion and recommendations

The steering angles from two cyclists in a bidirectional encounter are obtained. The mean of all the steering angles together is 2.6 degrees. This means that all cyclists are steering a little bit more the left than to the right in a bidirectional encounter. The difference in steering angle between evading and steering back is 2.2 degrees. This a very small number so it does not make a lot of a difference in the mean steering angle between a cyclist is making the evading movement or steering back movement. The smoothed steering angle of a cyclist in a bidirectional encounter movement always look like an S-curve due to the fact that a cyclist always need to steer back again to follow the road. The lateral interaction distance cannot yet be obtained from this results. First more knowledge about the steering angle of a cyclist following a straight line is needed. Conclusively, answering the sub-questions, the mean steering angle of a cyclist is 2.6 degrees. The mean of the steering angle of an evading movement is 2.2 degrees more to the right than the mean of the steering angle of a steering back movement. If these findings can be confirmed in the future they can be used as an extra parameter or boundary condition in big bicycle flow models.

There are discontinuities in the data. To draw a firm conclusion about the steering angle of a cyclist more data is needed. More data will overcome the outliers which would be very useful for the reliability of the results. The reason for the difference in steering angle for the two directions needs to be further researched. The mean steering angle from cyclists in bidirectional encounter cycling from left to right is on average 3 degrees more to the left than the mean of the steering angle from cyclists cycling from right to left. More experiments need to be done to see if this usual for a bidirectional encounter or it has something to do with the environment of the experiment. To determine the longitudinal interaction distance more about the steering angle of a cyclist following a straight line needs to be known. The angles witch belongs to the evading movement can then be found. Moreover than the characteristics like the mean of the steering angle to evade can be also be found.

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A Left hand and right hand trajectories

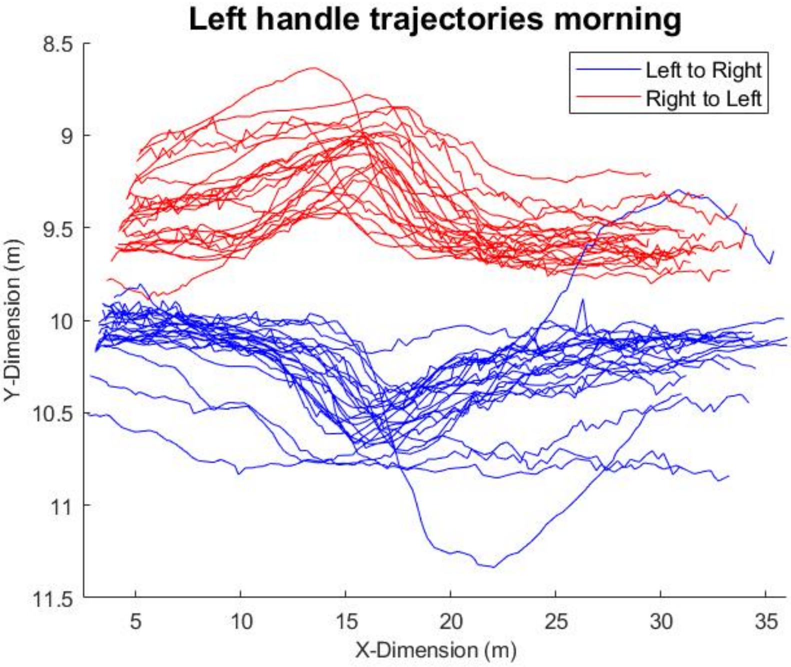


Figure 21:

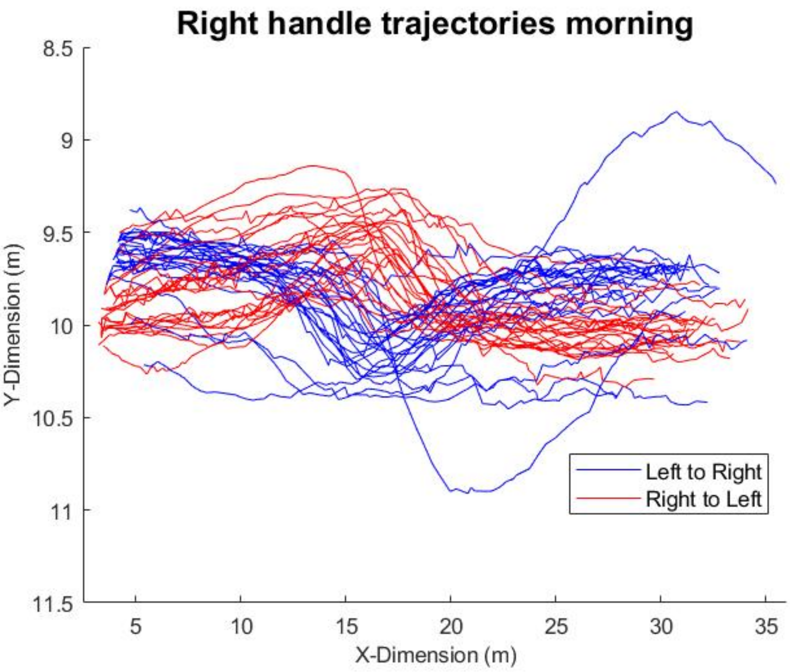


Figure 22:

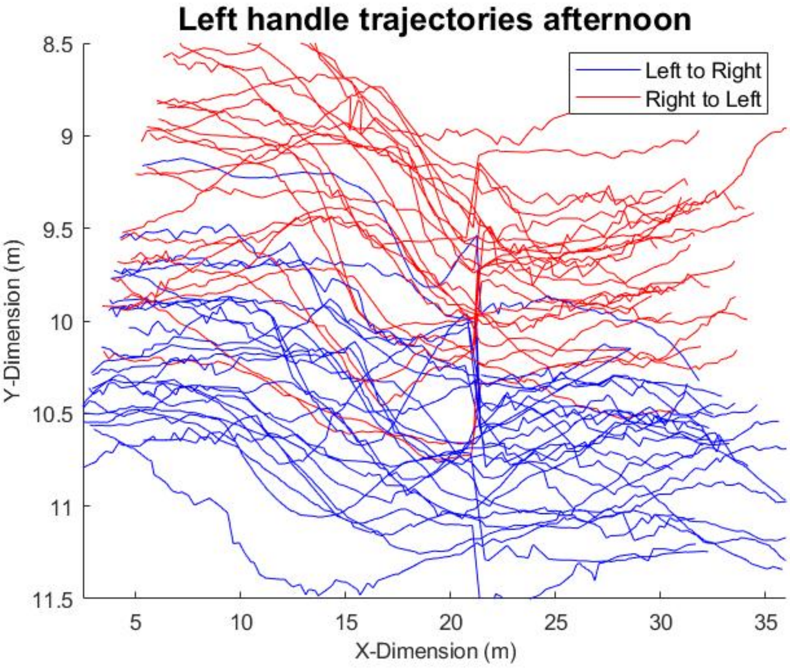
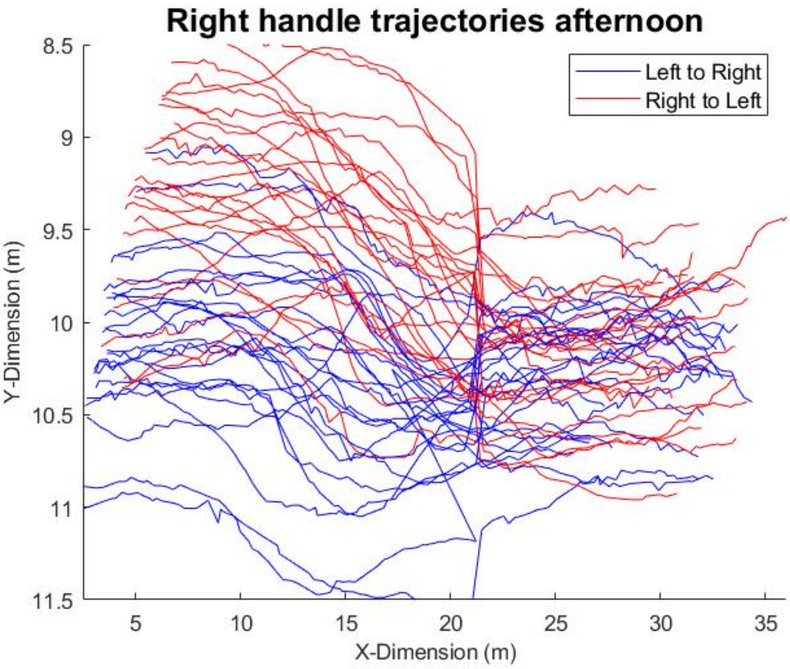

Left handle trajectories afternoon
Left to Right
Right to Left
Y-Dimension (m)
X-Dimension (m)
8.5
9
9.5
10
10.5
11
11.5
5
10
15
20
25
30
35

Figure 23:


Right handle trajectories afternoon
Left to Right
Right to Left
Y-Dimension (m)
X-Dimension (m)
8.5
9
9.5
10
10.5
11
11.5
5
10
15
20
25
30
35

B Steering angles from the four different data sets

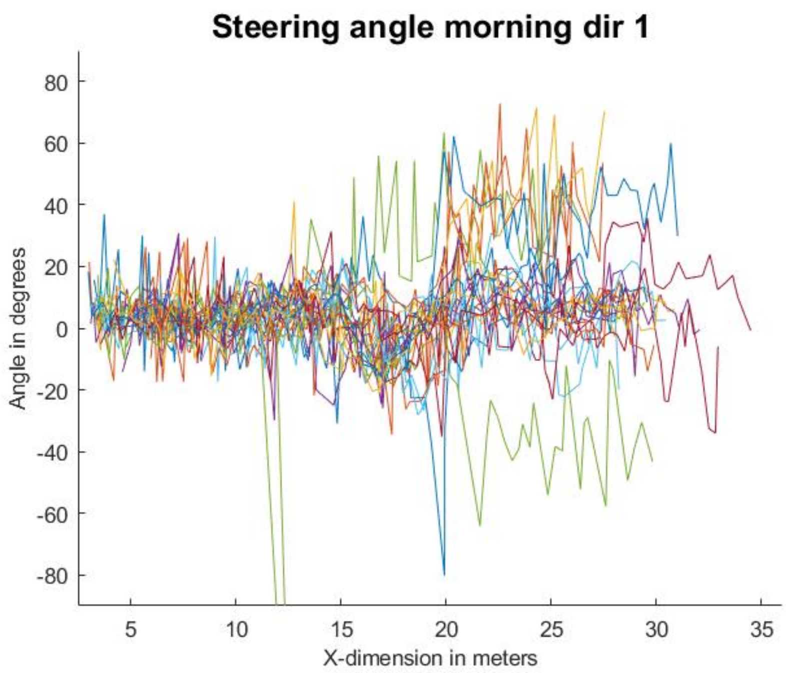


Figure 24:

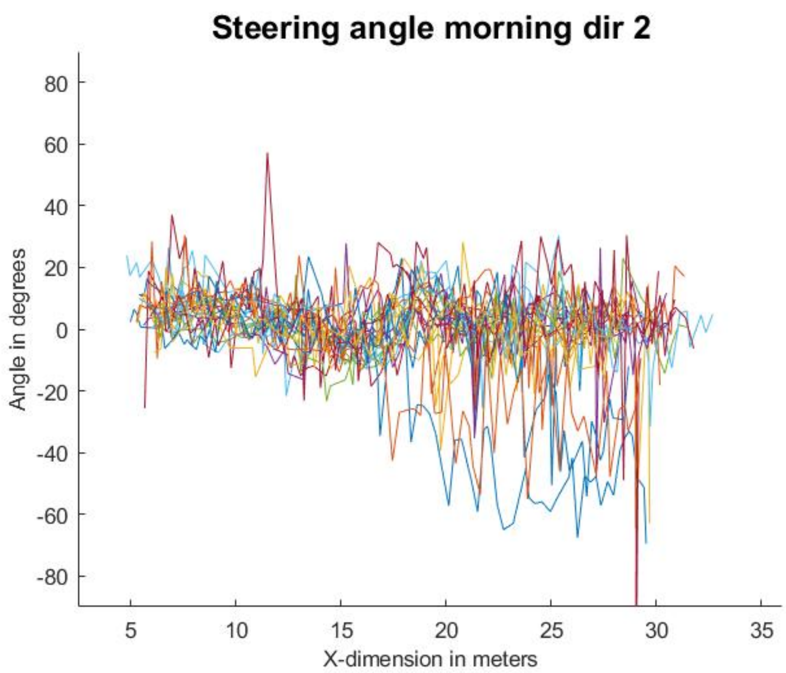


Figure 25:

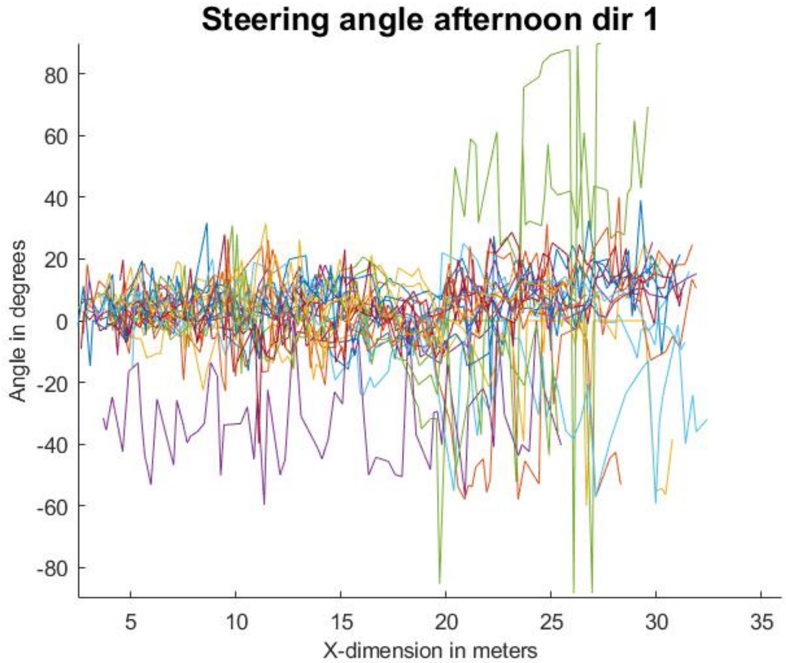


Figure 26:

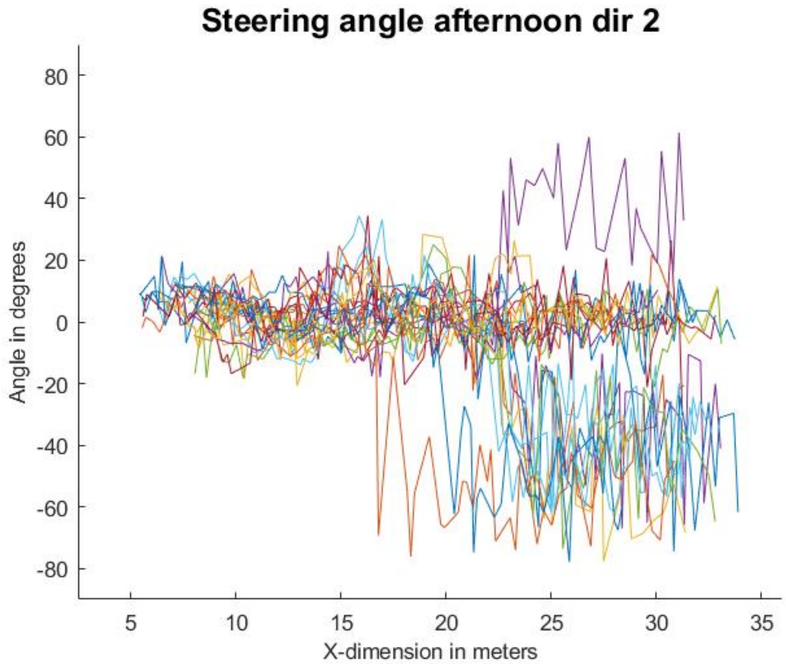


Figure 27:

C Smoothed steering angles of the morning session

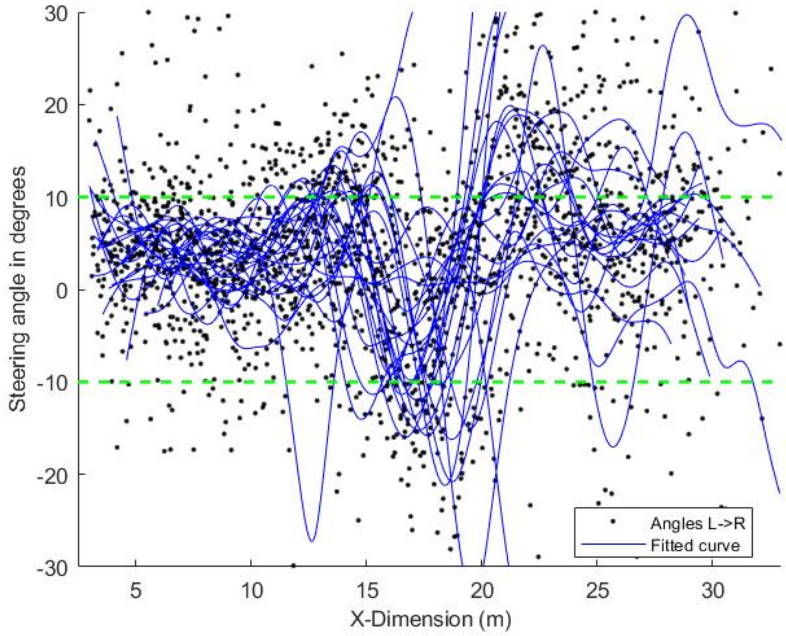


Figure 28: Smoothed steering angles of direction one from the 24 experiments of the morning session

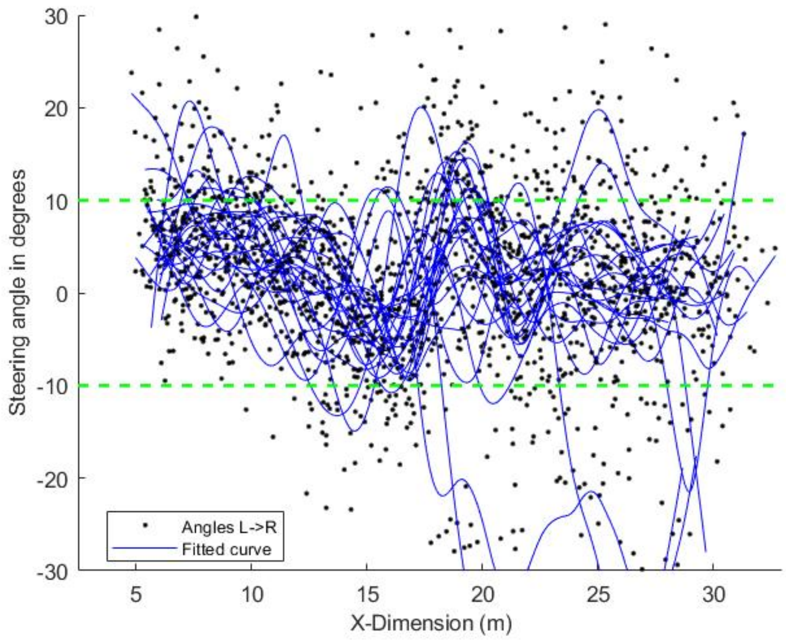


Figure 29: Smoothed steering angles of direction one from the 24 experiments of the afternoon session