Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Lecture with Computer Exercises:

Modelling and Simulating Social Systems with MATLAB

Project Report

Modelling the Interaction of Pedestrians and Bikers using the Social Force Model

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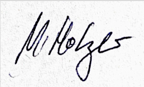
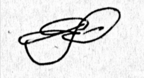
Abstract

Attempt to apply the social force model to simulating cyclists among a crowd of pedestrians in a narrow corridor using Matlab. Effect on capacity and safety of line separation was investigated and concluded, that it can have a positive effect on capacity.

Individual contributions

Group member	general conception	programming	report & presentation	individual contribution	Signature
Sandro Giacomuzzi	33%	62%	5%	100.00%	
Hannes Heller	35%	5%	60%	100.00%	
Manuel Holzer	32%	33%	35%	100.00%	
	100%	100%	100%		

1 Introduction and Motivations

1.1 Motivation

The primary motivation to simulate the interaction pedestrian and bikers was the idea to implement a simulation that can reproduce an every day situation and therefore be verified by ones every day experience. The authors were fascinated by the simplicity of abstracting individuals as physical particles as the social force model introduced by Dirk Helbing proposes it. As they are also passionate bicyclists it suggested itself to extend the model and apply it to a simple, familiar geometry and see how well it matches their expectations.

As the Social Force model has been successfully applied in order to improve the safety and performance of pedestrian traffic, it was studied how this could be done for mixed traffic zones, as their becoming are more and more common in many cities. A simple geometry was chosen inspired by the railroad underpass of the Langstrasse in Zurich, which is a perfect example for such circulation. It is a long and narrow corridor with a bike lane road marking.

The main goal was to achieve a qualitatively reasonable simulation of cyclist among pedestrians. The authors tried to answer the question whether the applied model is suitable for simulating cyclist. For this, they quantified "dangerous situations" as well as the capacity of the system by counting the individuals that came within 10m of their desired destination at the end of each simulation. The influence of separating traffic was simulated in order to investigate the influence on capacity as well as security. This was done to simulate a condition that also exists in reality. This also allowed investigating the effectiveness of the self-organizing bias of the social force model versus planned organization.

Figure 1: Underpass at Langstrasse in Zurich

2 Description of the Model and code framework

2.1 The Model

The social force model simply explained: each individual is simulated as particle which exerts and experiences physical forces, which will make it accelerate or slow down in certain directions. In reality, these physical forces correspond to motivation to move to a certain position. Following forces add up to the so-called social force:[1]

1. There is a driving force, the attraction to the desired destination of each individual, which it wants to reach directly and with a desired speed.
2. Each person has a certain private sphere and when other individuals enter this area, they will felt repelled by them. This private sphere is round. There is a second part to this force, which has an asymmetric shape, as seen in Figure 1, which accounts to the field of vision. Upcoming impediments are much more relevant than the ones behind. The pedestrian is also subject to repulsive forces by trying to avoid physical objects as walls. These forces increase reversed proportionally to the distance of their source.
3. Attractive forces to objects as street artists, window displays or areas as designated traffic lanes.

The authors want to refer to [1] and [2] for detailed explanation of the model and its parameters.

An "Avoidance Force" for individuals moving directly towards each other was introduced at an early stage in order to avoid the strong resulting collisions. Later it was removed for bikers, since there was interference with the introduced slipstreaming. It was implemented only for the longitudinal direction for simplicity, what makes it only applicable for similar geometries as chosen by the authors.

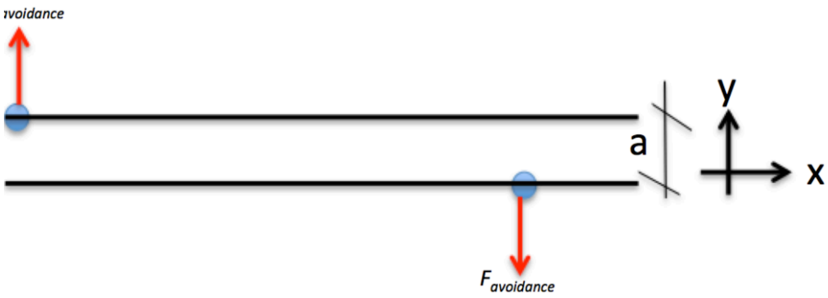


Figure 2: Displaying the avoidance force

If $a < \varepsilon$, there is a perpendicular force moving particles away from each other to the side which they are closer to. The influence and effect of this force was not adequately investigated, the authors estimate it to be relatively low.

$F_{avoidance} = const.$

2.2 Code Framework

The Matlab code was based on an existing implementation by Gareth William Parry for his master thesis. [2] His implementation allowed only the same number of pedestrians coming from left or right. The program allowed five different geometries to choose from, each one with different starting conditions.

2.3 Bikers

Bikers were based on the model for pedestrians. Following modifications were made to simulate bikers.

Bikers need a higher mass to account for the bicycle and following higher inertia. This also reflects the lower capability of altering directions on this vehicle.

The anisotropic influence of view is not changed, for the biker a semi elliptic sphere is assumed. This accounts for that a biker typically does not mind other bikers slipstreaming and enables simple variation of the biker's attention field, which is longer due to his higher speed. Helbing and other authors have proposed elliptic spheres before. [3]

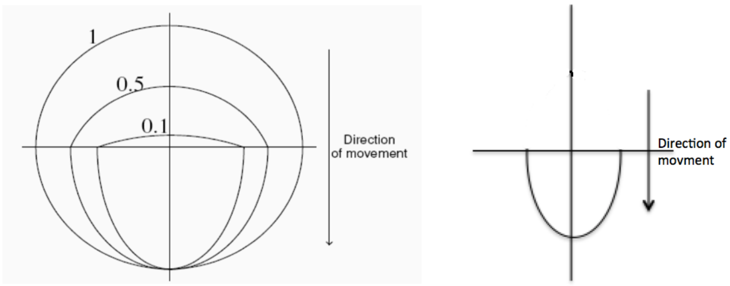


Figure 3: Shape of anisotropic character of interaction in the original model [2] (left) for pedestrians and semi elliptical for bikers (right).

It was assumed, that bikers are subject to an attracting force to bike lanes. This urge is supposed constant at all times and comes from the experience that they are able to move along faster and are better anticipated by traffic using them. The bike lane was based on boundaries. A biker located inside the bike lane experiences an exponentially inclining, but relatively week force, that keeps him inside. If he finds himself on the lane it reaches it's maximum. Outside of the lane he experiences this maximal force pointing in the opposite direction, pulling him back in.

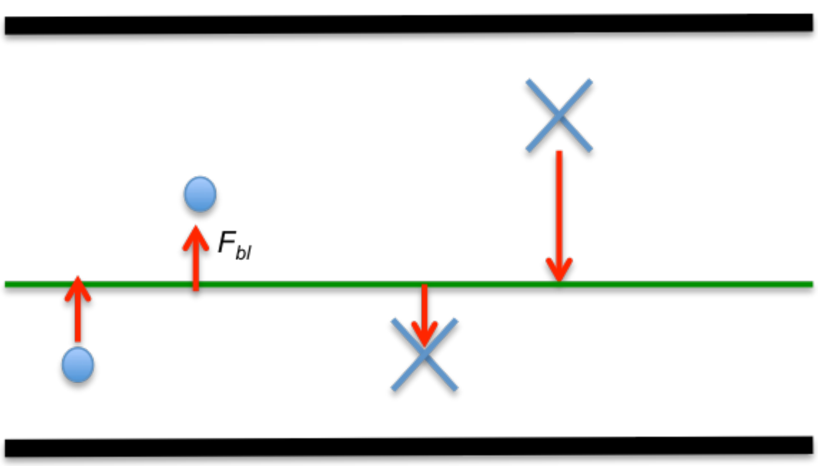


Figure 4: The bike lane force acts differently for bikers and pedestrians

As it was assumed that bikers are attracted, it was modelled that pedestrians are slightly repelled by bike lanes, as they are aware of potential higher danger of an accident, but still using it if density gets higher. Both these forces are displayed in figure 3.

Bikers enjoy slipstreaming. This means to get behind the closest biker in order to profit not only from wind shielding but also channelling. This was modelled as displayed in figure 4.

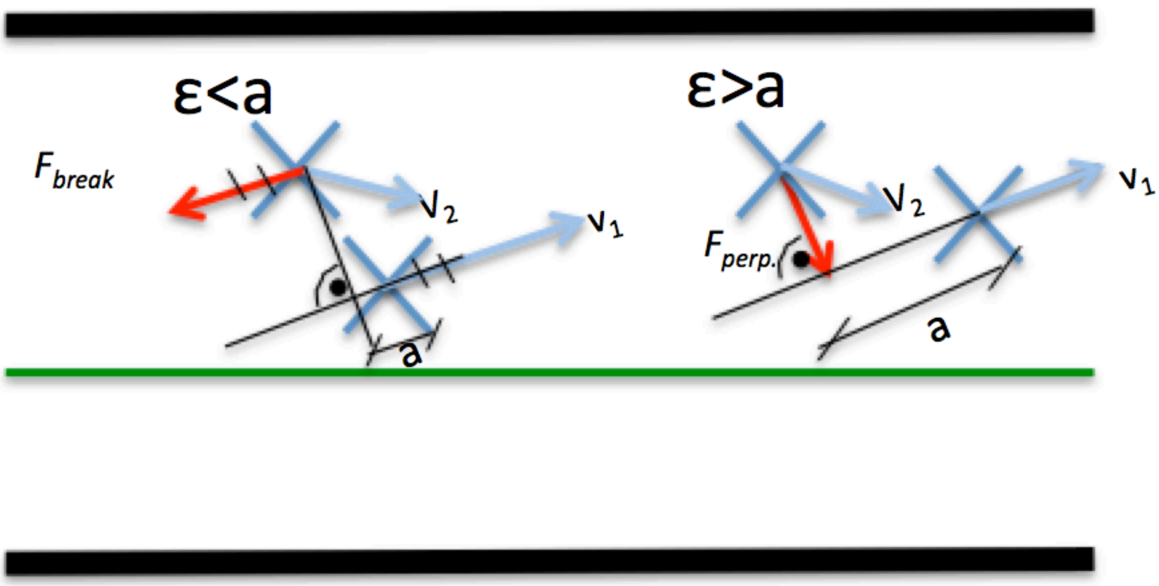


Figure 5: Model of the slipstreaming force

a is the distance between the one biker to another, projected on the direction of movement. If a is below ε, the biker behind is slowed down by F_{break}. When the distance a is bigger than ε, there is a perpendicular force pulling the biker behind the one in front.

$F_{break} = const.$

$F_{perp.}$ is analogue to the boundary interaction force, explained in [2] with opposite sign.

3 Implementation

The initial goal was to only add bikers and tools for statistics to the code by Perry. But it showed to have the severe defect that all particles had the same speed at every time step. Was one pedestrian impeded, all others slowed down as well. This is shown in Video1.avi. The authors were quite discouraged when they found out that the code they have been working with had severe defects as well as minor bugs, as missing numbers or false labelling of rooms.

Social_Force.m is the main program. It holds all parameters, sets the initial conditions and geometry and plots the results in the end. It calls up the function iteration.m, which uses fun5.m to calculate the forces at the given constellation and updates the position depending on them. It returns returns a matrix with the positions of all particles at each time step.

3.1 Starting constellations

The five boundary maps were reduced to one: "the counterflow", which conveniently equated the geometry on which we wanted to simulate our model.

The code was changed in order to also allow asymmetric starting constellations to have more freedom regarding our simulations. The number of pedestrians and bikes starting left or right can be selected, what required modifications throughout the code.

If there is a line separating traffic, bikers start in the designated lane, pedestrians outside. This in order to have a more already levelled starting situation.

3.2 Integration of time steps

It turned out that the system solver was the error source. Parry uses a Matlab in-built ODE solver, what we found resulted in the same speed for all particles at each time step. This was discovered only after intense studying of the code and first tries at extending it for simulating bikers, which certainly troubled the authors and forced them to implement a function for the correct numerical integration of the time steps.

The proposed function `iteration.m` simply adds up the vectors of the different forces for each individual time step to the social force. The force equivalents to the acceleration, which multiplied by time step equals to the change of speed. The change of speed is added to the current speed and the new location derived.

A damping perpendicular to the y direction was introduced so that individuals evading others do not move too far around and do not oscillate as much. A more natural behaviour can be observed this way.

3.3 Parameters

Following parameters were used for the simulation. The parameters of pedestrians were first adopted of the base code and then recalibrated for simulation with cyclers. Parameters were estimated iteratively, since statistical data is scarce. The authors found that there is a lack of such calibration throughout existing simulation models for bikers. [3] For explanation of the parameter in the first partition of table 1, the authors would like to reference to [2]. Information on the ones in the second is found in the

The mass values need to be interpreted as relation pedestrians to bikers.

Parameter	Pedestrian	Biker
Initial Desired Velocity - $v_\alpha^0(0)$	1.34 ms^{-1}	4.02 ms^{-1}
Relaxation Time - τ_α	0.5 s	.5 s
Maximum Speed - $v_\alpha^{\max}$	1.742 ms^{-1}	5.226 ms^{-1}
Territorial Sphere Pedestrian Interaction Strength - A_α^1	1.5	0
Territorial Sphere Pedestrian Interaction Range - B_α^1	1	10
Anisotropic Character - λ_α	0.3	-
Physical Pedestrian Interaction Strength - A_α^2	1.5	1.5
Physical Pedestrian Interaction Range - B_α^2	0.5 m	0.2 m
Boundary Interaction Strength - $A_{\alpha\beta}$	5	5
Boundary Interaction Range -$B_{\alpha\beta}$	0.1 m	0.1 m
Radius of Pedestrians - r_α	0.3 m	0.3 m
Mass - M	1	2
Attractive force slipstream A_v	-	16
Attractive force slipstream B_v	-	4
Horizontal Damping k	0.4	0.4
Radius of Verlet Sphere r	4	-
Bike Lane Force Linear Vv $(\sim A_{\alpha\beta})$	0.02	0.01
Bike Lane Interaction Range Vf $(\sim B_{\alpha\beta})$	0.3	0.3
Avoiding Force Parameter	10	-

Table 1: Parameters of bikers and pedestrians.

4 Simulation Results and Discussion

For the simulation a time step dt of .06 seconds was chosen. This allowed relatively fast simulations with relatively few mistakes. Setting the time step too high allows particles to get too close to each other, resulting in absurd forces catapulting them into space.

4.1 Simulations

Simulation #		Left	Right	Lane	Comment
10	Ped	20	20	yes	
	Bike	5	5	no	
11	Ped	20	20	yes	
	Bike	5	5	no	
20	Ped	20	20	yes	No slipslide
	Bike	5	5	no	No slipslide
21	Ped	20	20	yes	No slipslide
	Bike	5	5	no	No slipslide
22	Ped	26	14	yes	No slipslide
	Bike	7	3	no	No slipslide
30	Ped	10	10	yes	
	Bike	10	10	no	
31	Ped	10	10	yes	
	Bike	10	10	no	

Table 2: Settings of in Figure 6 displayed simulations

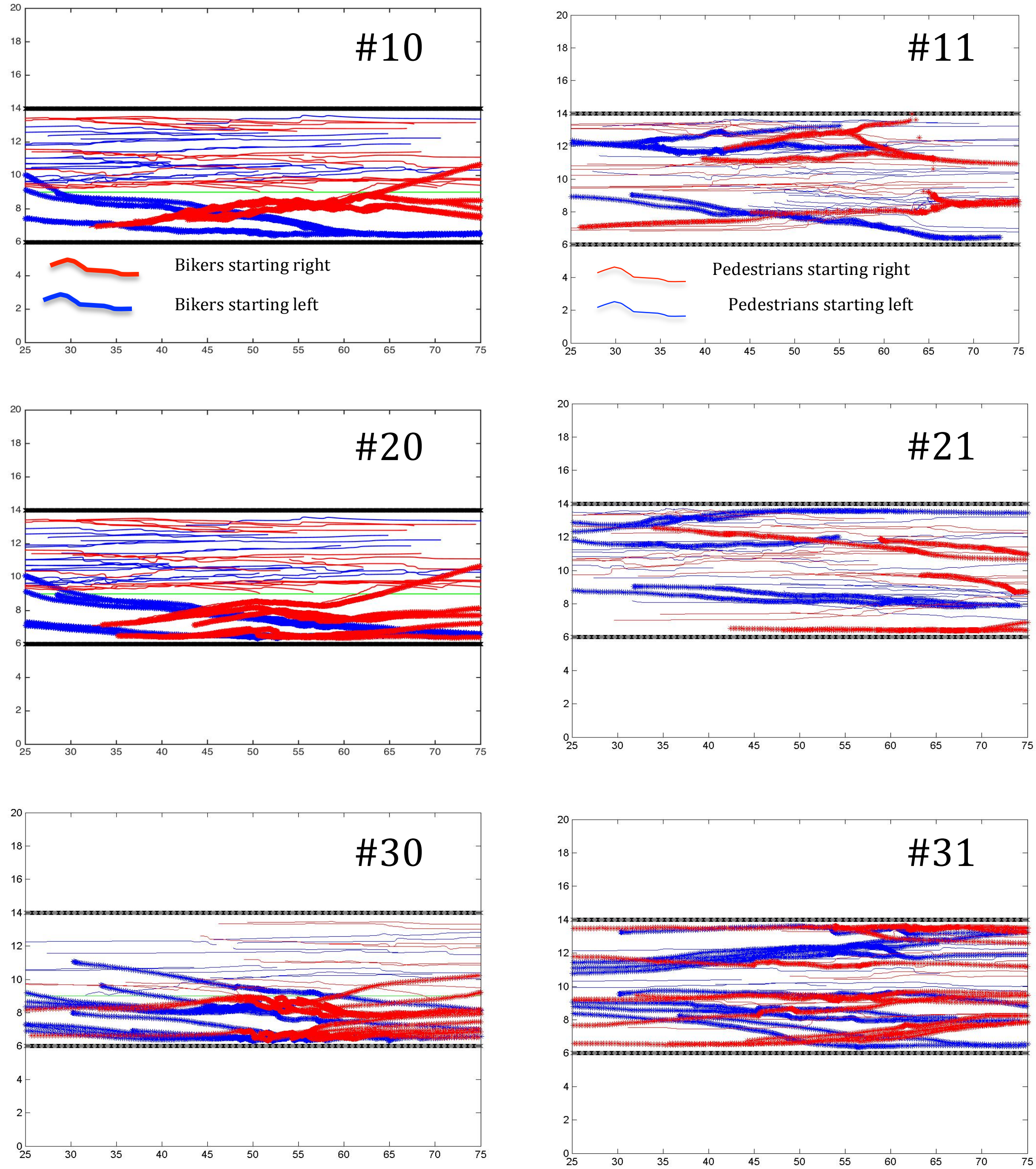


Figure 6: Displaying pathway plots of pedestrians and bikers, labels refer to table 2

The exact configurations for each simulation in this chapter are found in the appendix. Starting positions were evenly, randomly distributed along horizontal as well as vertical for the simulations without bike lane separating traffic (green). For the case with line, the bikers started evenly distributed along the horizontal axis but only in the lower two thirds of the vertical axis. This because we wanted to get closer to an already levelled situation, where bikers would be closer to the bike lane.

Comparing #10 and #11, it can be stated that both pedestrians and bikers clearly profited from traffic separation. This was to be expected due to better organization and also corresponds to a biker's every day experience.

Comparing #11 and #21 shows that the slipstreaming force does proof to be as beneficial as density increases and self-organizing effects are strong among bikers. This might be due to the identical reaction sphere amongst them.

#30 and #31 were simulated to have a comparison with more and less pedestrians in the system. Here it can be seen that the bake lane even has a negative effect on capacity, since bikers are attracted to it independent of its use to capacity.

4.2 Statistics

Simulations displayed and discussed in this chapter have the same parameters as in the chapter above, but starting positions were only distributed in displayed part of the corridor, which reaches horizontally from value 0 to 100. The number of 40 simulations were made and accumulated. Five different scenarios, each with different starting conditions were conducted 8 times. The five scenarios were 10, 20, 30, 40 and 50 participants, evenly distributed left and right with a pedestrian to biker ratio of 4:1.

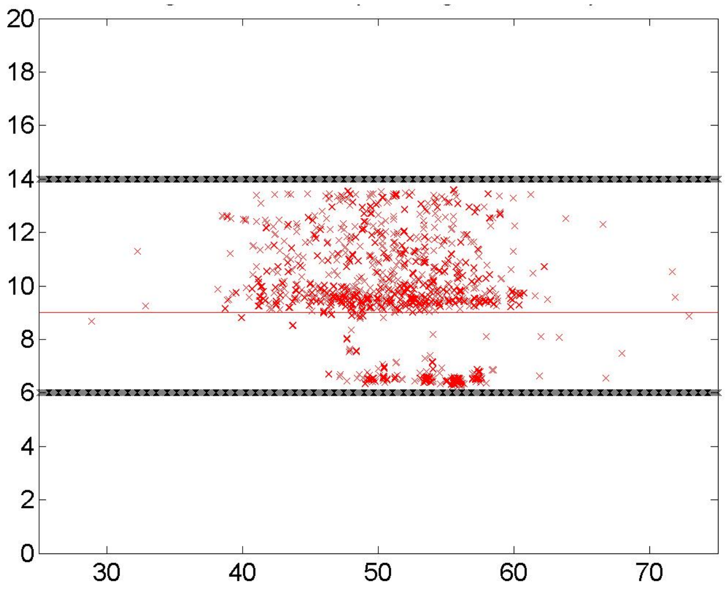


Figure 7: Display of dangerous situation in 40 simulations

With the starting conditions it is clear that dangerous situations accumulate in the center as displayed in figure 7. But it shows a clear concentration of such events along the bike lane, where pedestrians and bikers interact most. A dangerous situation is recorded when two particles get to close to one another.

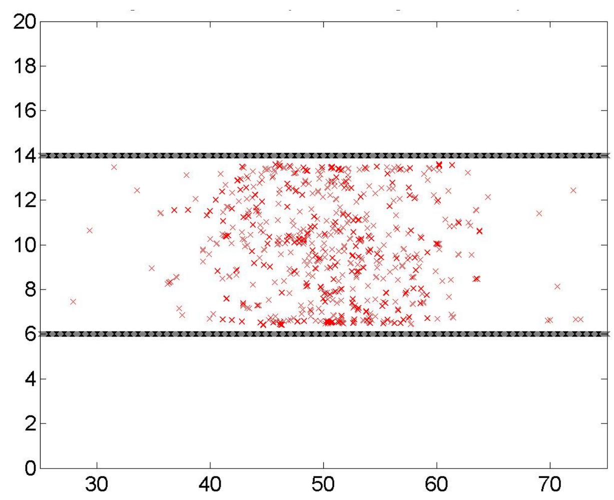


Figure 8: Dangerous situations without bike lane

Figure 8 shows how dangerous situations are more evenly distributed, with certain bulks along the corridor walls. This is due to higher forces along boundaries, which can force particles to close to one another. This phenomenon can be found in reality. The street curb is a great potential danger to cyclists.

Following plots are based on simulations with a ration of 2:1 individuals coming from left. Other conditions stay the same.

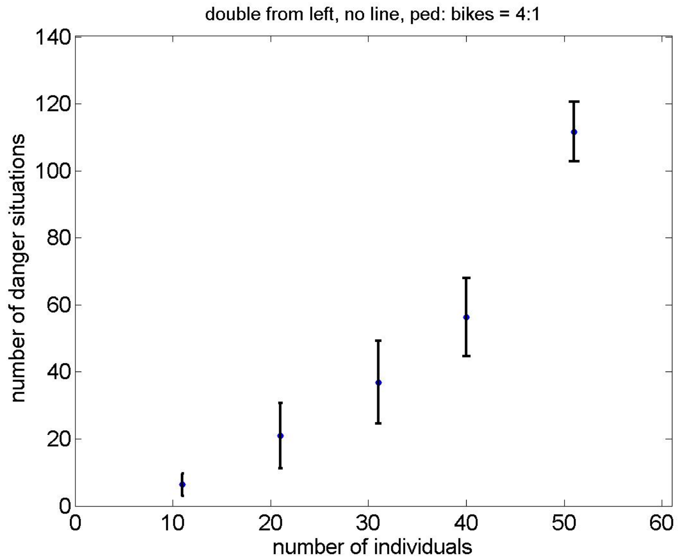


Figure 9: Displaying number of dangerous situations and standart deviation without bike lane

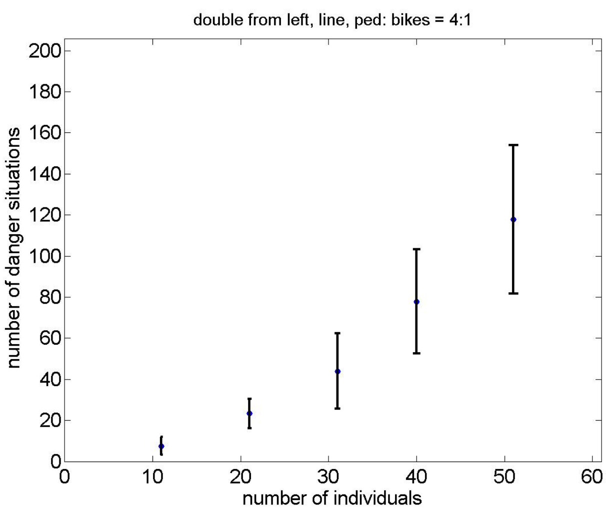


Figure 10: Displaying number of dangerous situations and standart deviation with bike lane

Comparison of figure 10 and 9 shows that traffic separation only influenced standart deviation and not so much the expectancy value of number of accidents in our model.

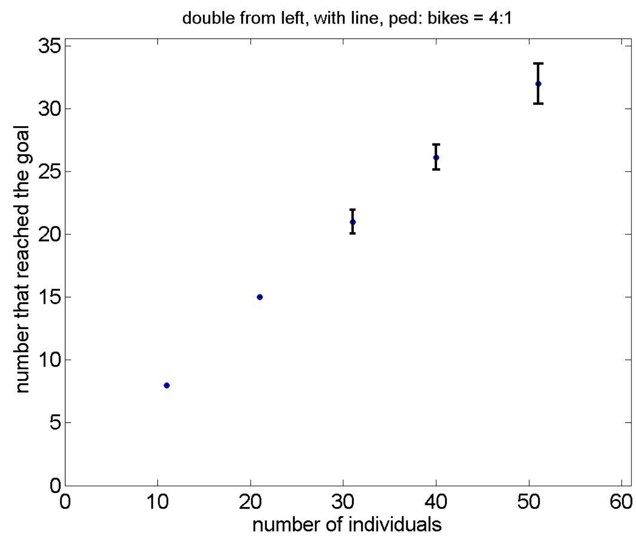


Figure 11: Number of individuals reaching destination within time with line speparation

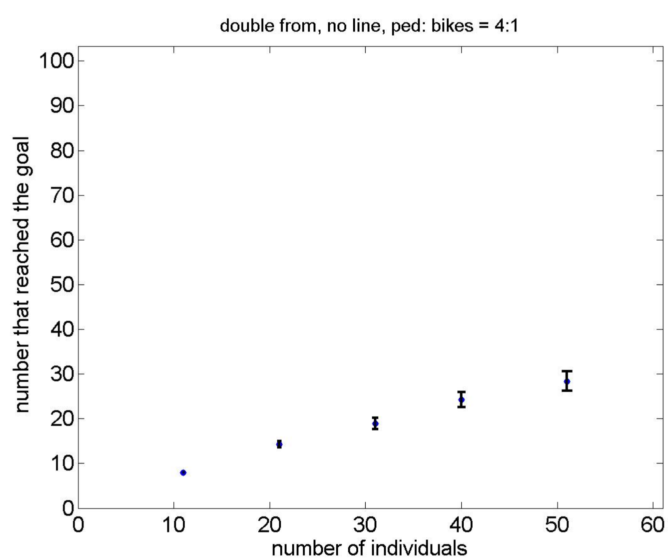


Figure 12: Number of individuals reaching destination within time without line speparation

Comparison of figure 11 and 12 shows that line separation did have a positive effect on capacity as it was to be expected. Surprisingly the increasing density did not have such a severe effect on the number of individuals getting within the distance of 10 to their destination.

Looking at the simulations, it can be qualitatively concluded that the social force model is applicable for modelling cyclists with certain limitations. The drawn statistics showed trends that correlate with the authors real life experience and they show that lane separation has a positive effect at least on capacity.

5 Summary and Outlook

The results show that it is possible to apply the social force model to bikers. When starting to apply it to an inhomogeneous composition of particles, following problem is faced: one of the difficulties is the different dynamics of bikers. For one they move much faster than pedestrians. Since forces increase exponentially with declining distance, more time steps are needed to avoid particles with high speed getting to close and therefore causing oversize forces. Second, bikers can only move along a line in reality, whereas pedestrians are free to move on the plane, e.g. perform sharp turns. The introduction of mass and damping countered these tendencies quite effectively. The higher the differences in speed, the more complex reasonable simulations become, since traffic participants hitting each other should remain an exceptional happening. The physical model of gases or fluids, such collisions are natural.

Setting the parameters based on empirical data would certainly lead to a much more meaningful result. A way of doing so could be video tracking. The effect of separating traffic on safety could be compared to accident statics of locations where such traffic organisation was established respectively cleared. The authors want to note that the city of Zurich keeps excellent record and statistics of bike related data including accidents and would like to encourage further participants of this course to continue in this matter. [4]

From personal experience the authors know that as a biker, navigating through a moving crowd is quite challenging and in reality, a lot of nonverbal communication as well as sharp observation and experience are used to get ahead. Therefore one does not need to be too disappointed when a comparatively simple model leads to some unnatural situations.

6 References

[1] Dirk Helbing and Peter Molnar, "Social force model for pedestrian dynamics", II. Institute of Theoretical Physics, University of Stuttgart, 70550 Stuttgart, Germany

[2] Gareth William Parry , "The Dynamics of Crowds", Department of Mathematical Sciences, University of Bath, BA2 7AY Bath, United Kindom

[3] Heather Twaddle and Tobias Schendzielorz and Oliver Fakler, "Bicycles in Urban Areas ", Transportation Research Record: Journal of the Transportation Research Board, Volume 2434, Issue 1, Pages 140-146, 2014-12-01

[4] https://www.stadt-zuerich.ch/prd/de/index/statistik/lebensraum/verkehr.html, 2014-10-12

7 Appendix

7.1 Boundary conditions

#10

Number of Pedestrians, coming from left hand: 20

Number of Pedestrians, coming from right hand: 20

Number of Bikers, coming form left hand: 5

Number of Bikers, coming from right hand: 5

Length of the simulation (in seconds): 20

Bikeline? 1 for yes or 0 for no: 1

Seed of random generator:

Type: twister

Seed: 0

State: [625x1 uint32]

#11

Number of Pedestrians, coming from left hand: 20

Number of Pedestrians, coming from right hand: 20

Number of Bikers, coming form left hand: 5

Number of Bikers, coming from right hand: 5

Length of the simulation (in seconds): 20

Bikeline? 1 for yes or 0 for no: 0

Seed of random generator:

Type: twister

Seed: 0

State: [625x1 uint32]

#20

Number of Pedestrians, coming from left hand: 20

Number of Pedestrians, coming from right hand: 20

Number of Bikers, coming form left hand: 5

Number of Bikers, coming from right hand: 5

Length of the simulation (in seconds): 20

Bikeline? 1 for yes or 0 for no: 1

Seed of random generator:

Type: twister

Seed: 0

State: [625x1 uint32]
SLIPSTREAMFORCES TURNED OFF

#21
Number of Pedestrians, coming from left hand: 20
Number of Pedestrians, coming from right hand: 20
Number of Bikers, coming form left hand: 5
Number of Bikers, coming from right hand: 5
Length of the simulation (in seconds): 20
Bikeline? 1 for yes or 0 for no: 0
Seed of random generator:
Type: twister
Seed: 0
State: [625x1 uint32]
SLIPSTREAMFORCES TURNED OFF

#30
Number of Pedestrians, coming from left hand: 10
Number of Pedestrians, coming from right hand: 10
Number of Bikers, coming form left hand: 10
Number of Bikers, coming from right hand: 10
Length of the simulation (in seconds): 20
Bikeline? 1 for yes or 0 for no: 1
Seed of random generator:
Type: twister
Seed: 0
State: [625x1 uint32]
SLIPSTREAMFORCES TURNED OFF

#31
Number of Pedestrians, coming from left hand: 10
Number of Pedestrians, coming from right hand: 10
Number of Bikers, coming form left hand: 10
Number of Bikers, coming from right hand: 10
Length of the simulation (in seconds): 20
Bikeline? 1 for yes or 0 for no: 0
Seed of random generator:
Type: twister

Seed: 0

State: [625x1 uint32]

SLIPSTREAMFORCES TURNED OFF