UNIVERSITY OF Southampton

Towards Simulation Tools for Innovative Street Designs

Dr Bani Anvari

Lecturer in Intelligent Mobility

Pedestrian Dynamics: Modeling, Validation and Calibration, *Brown University*, 22 August 2017

University of Southampton Campuses at a Glance

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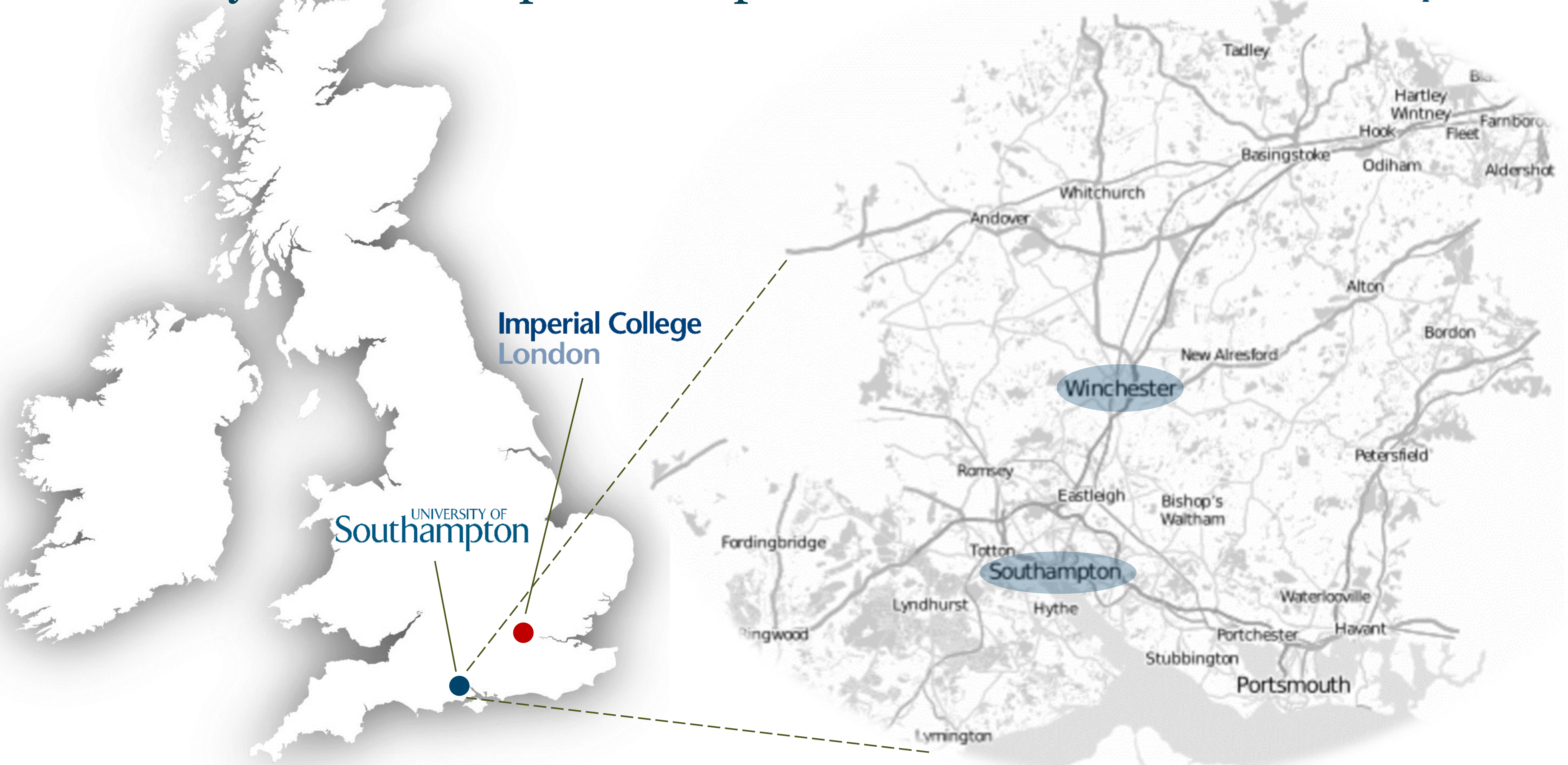

Boldrewood Innovation Campus

Highfield Campus

Research ranking in the UK:

- REF 2014: First in the “power” and “quality” indicators.
- Second best University in Civil Engineering.
- One of the longest established and leading centres for engineering-related transport teaching and research.

Transport Research Group (TRG)

Civil, Maritime and Environmental Engineering and Science Academic Unit

Faculty of Engineering and the Environment

Transportation Research Group (TRG) in Brief

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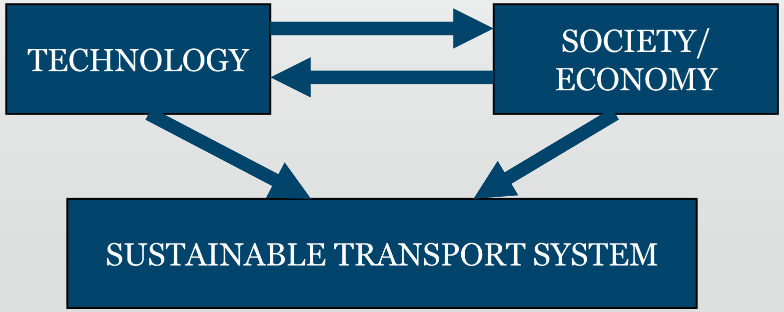
- Around 9 lecturers, 25 core staff, 20 PGR students and 35 PGT students.
- Current research awards: ~£8m:

  ~£4m from EPSRC
  ~£1m from EC
  ~£3M from other Governmental Bodies (incl. Innovate UK)

- International links include Cornell, Delft, Gothenburg, MIT, Monash, Ningbo, Sydney and Tsinghua.
- Areas of research activity and expertise:



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Intelligent Mobility

focussing on improving mobility, safety & quality of life.

Intelligent Traffic Control Systems

Green Adaptive Control for Future Interconnected Vehicles

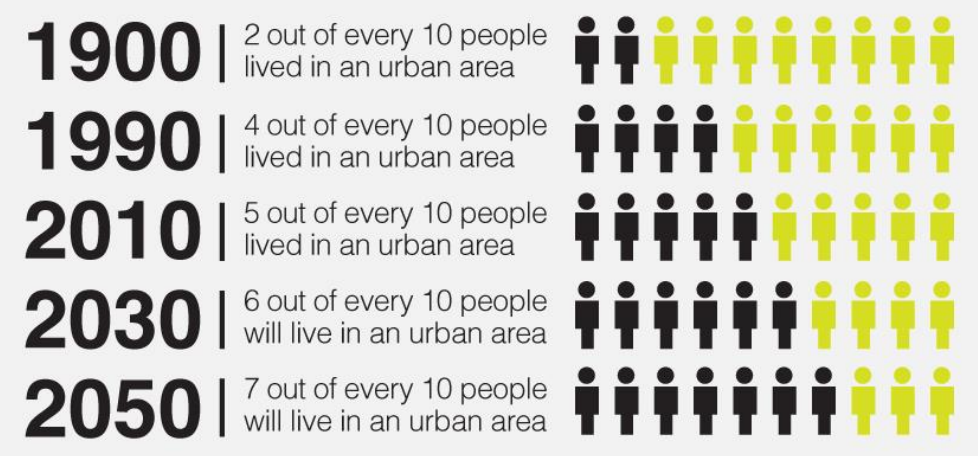
Integrating Connected & Autonomous Vehicles

Road Safety

Sustainable Mobility

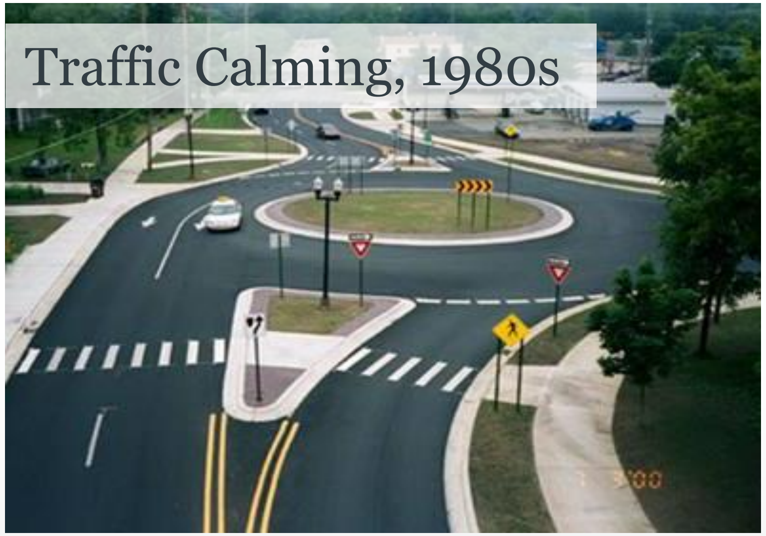
“The majority of people will be living in cities by 2050.”

United Nations report, 2016



Separation Concept, 1960s

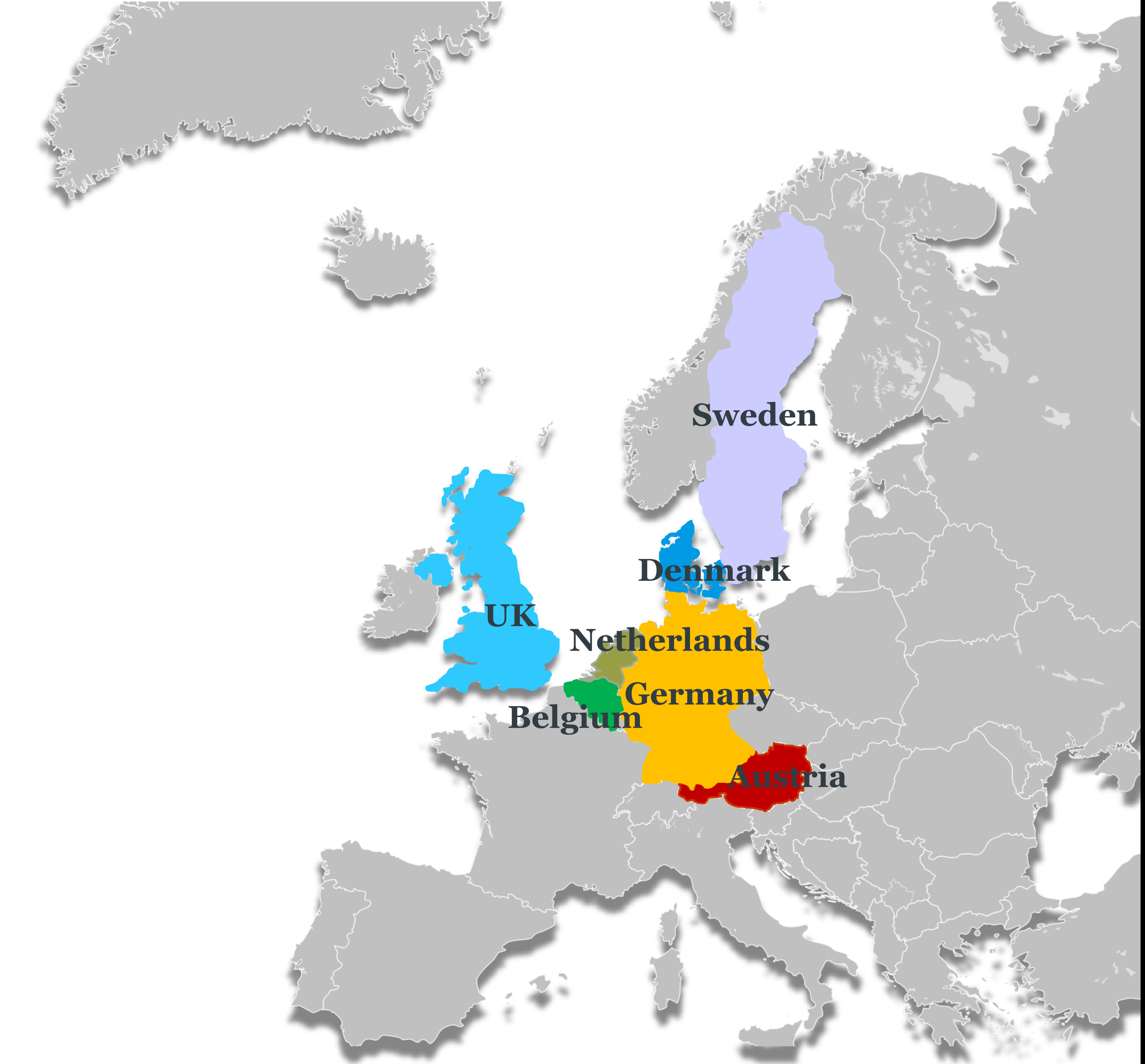
Woonerf, 1960s



Traffic Calming, 1980s


Shared Space, 1991
An entrance threshold
Irregular parking
Single surface environments
Green space and trees

Video available here: https://www.youtube.com/watch?v=qgYzyGvMqjo



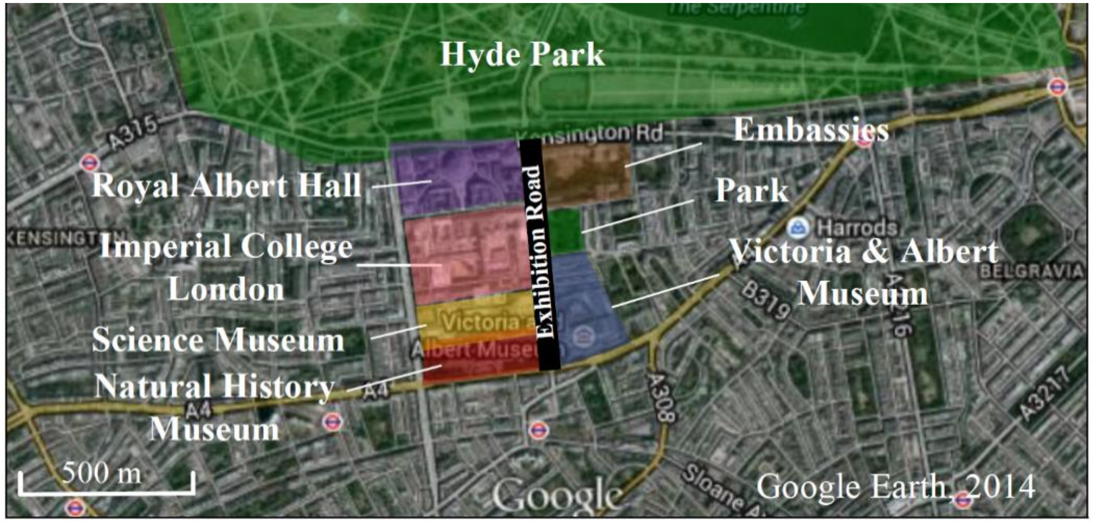
Shared Space Schemes:

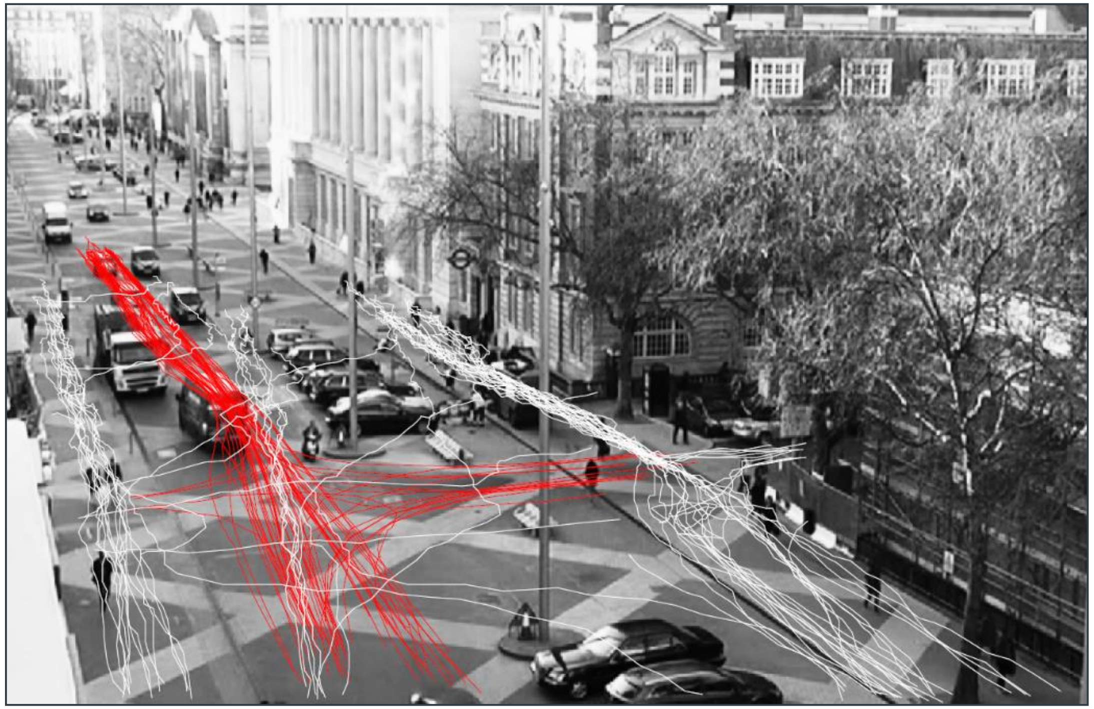
Austria
Belgium
Denmark
Germany
Netherlands
Sweden
United Kingdom

How can we evaluate new shared spaces before implementation?

Brighton and Hove City Council

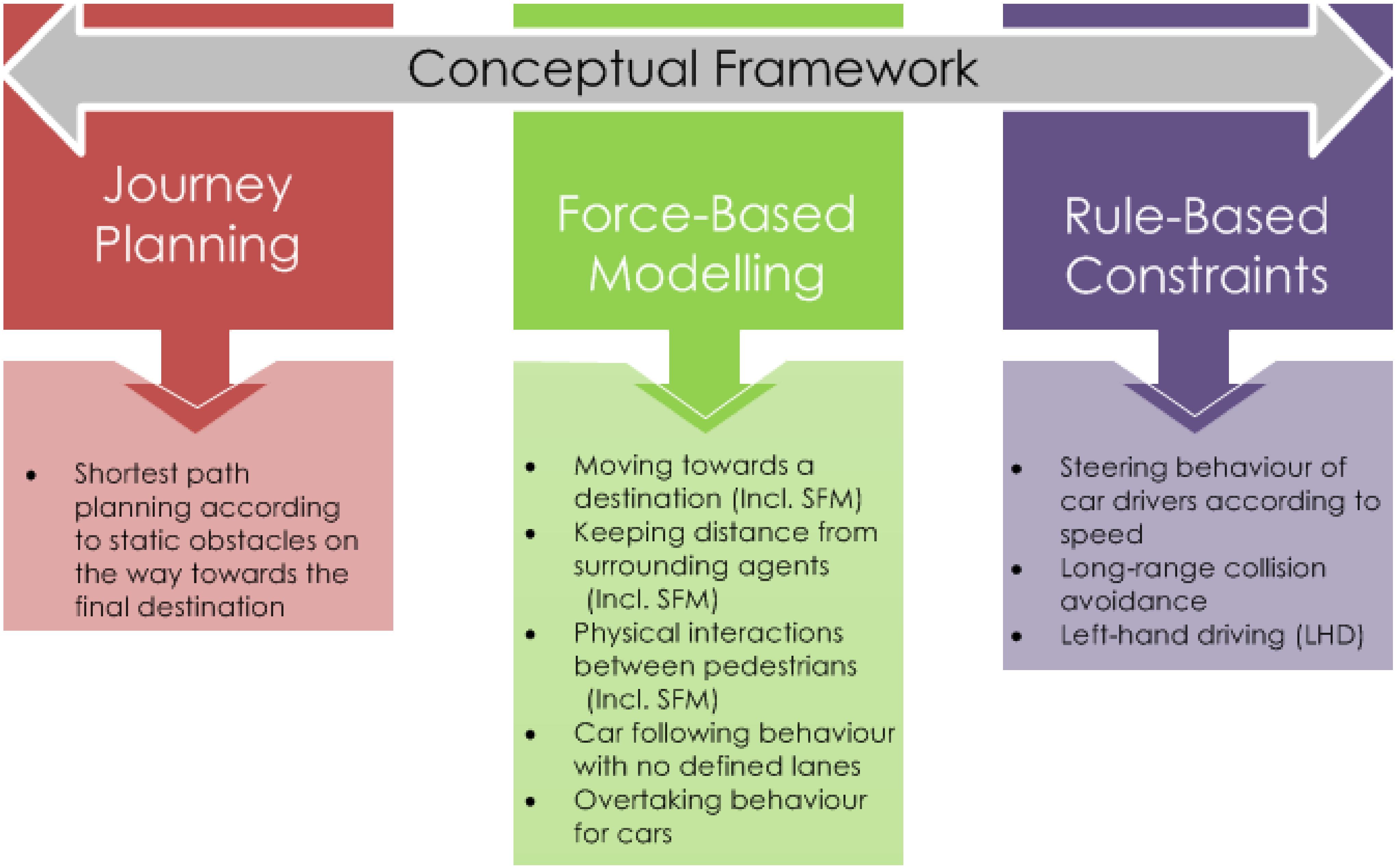
Royal Borough of Kensington and Chelsea





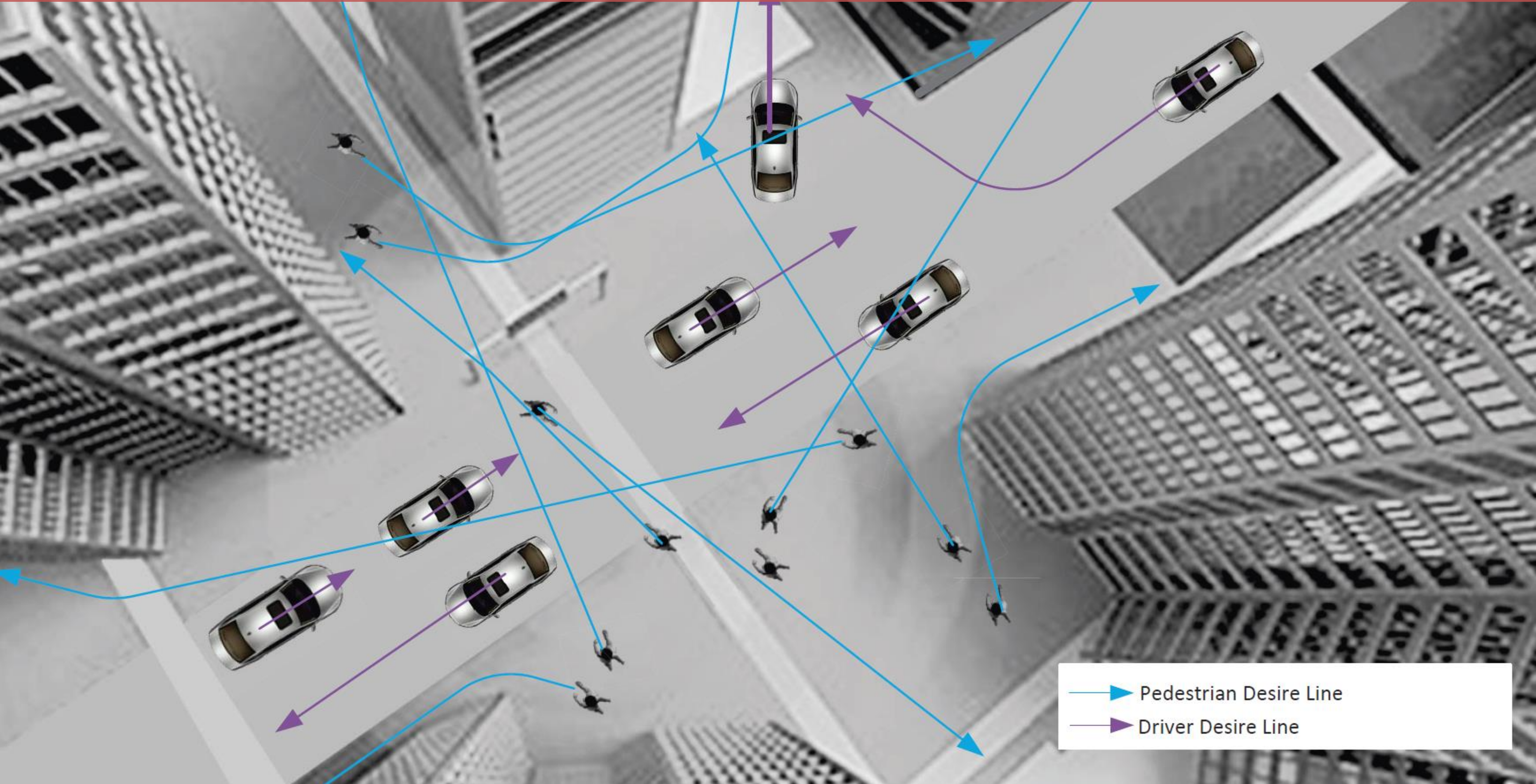
B. Anvari, W. Daamen, V.L. Knoop, S.P. Hoogendoorn & M.G. Bell,"Shared Space Modelling Based on Social Forces and Distance Potential Field“, *Pedestrian and Evacuation Dynamics*, 2012.

Video available here: https://www.youtube.com/watch?v=Hql8sutWFxs



B. Anvari, M.G.H. Bell, A. Sivakumar, W.Y. Ochieng, "Modelling Shared Space Users Via Rule-based Social Force Model", *Transportation Research Part C: Emerging Technologies*, 2015.

Journey Planning Layer



Journey Planning Layer

Flood Fill Methods (1/2)

- Euclidean Distance

  $\Delta x = \sum_i |\delta x_i|$ and $\Delta y = \sum_i |\delta y_i|$

  $D^E = \sqrt{\Delta x^2 + \Delta y^2}$

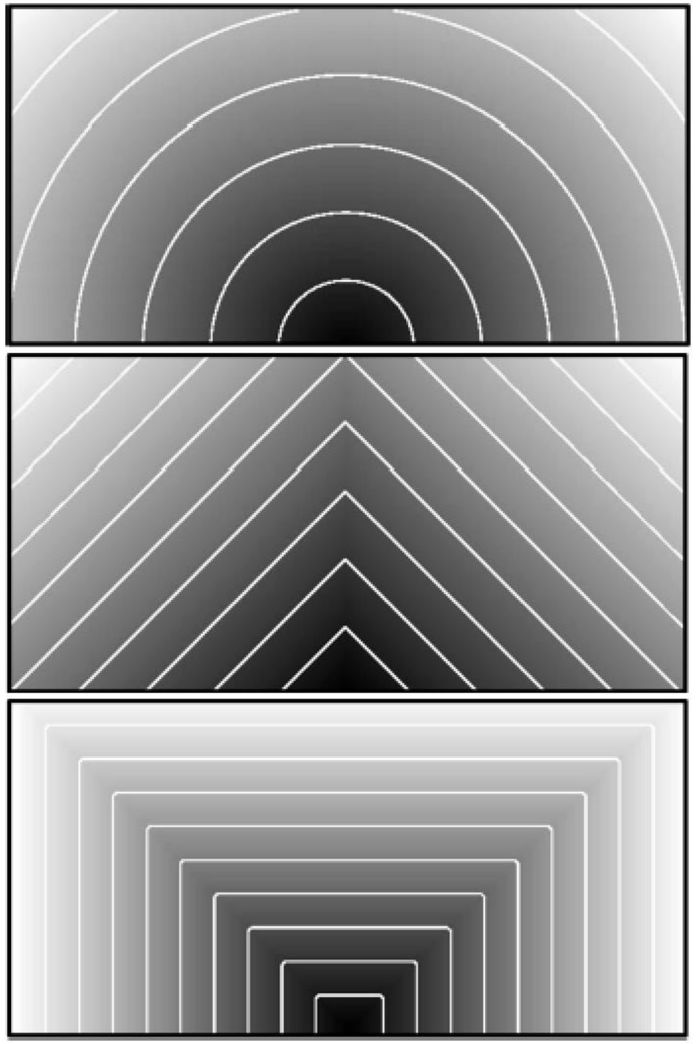
- Manhattan Metric

  $D^M = \sum d_i^M = \Delta x + \Delta y$

- Chessboard Metric

  $d_i^C = max(|\delta x_i|, |\delta y_i|)$

  $D^C = \sum d_i^C$



T. Kretz, C. Bonisch, and P. Vortisch. "Comparison of Various Methods for the Calculation of the Distance Potential Field". Pedestrian and Evacuation Dynamics, 2008.

Journey Planning Layer

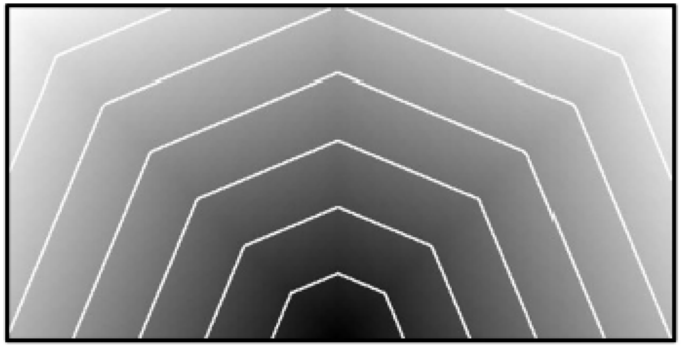
Flood Fill Methods (2/2)

- Combination

$$d_i^m = d_i^M - d_i^C = min(|\delta x_i|, |\delta y_i|)$$

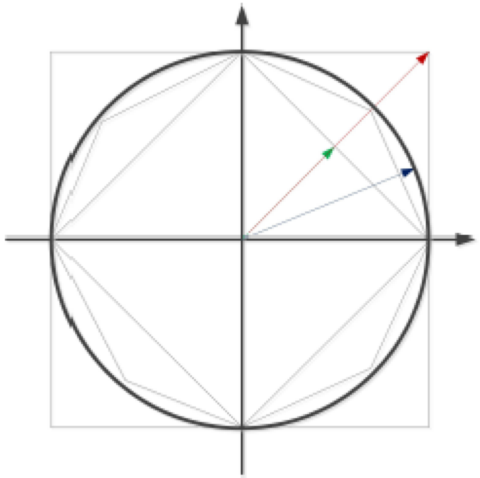
$$D^m = \sum d_i^m = D^M - D^C$$

$$(D^{\sqrt{2}}) = (\sqrt{2} - 1)(D^m) + (D^C)$$



- Relative Error

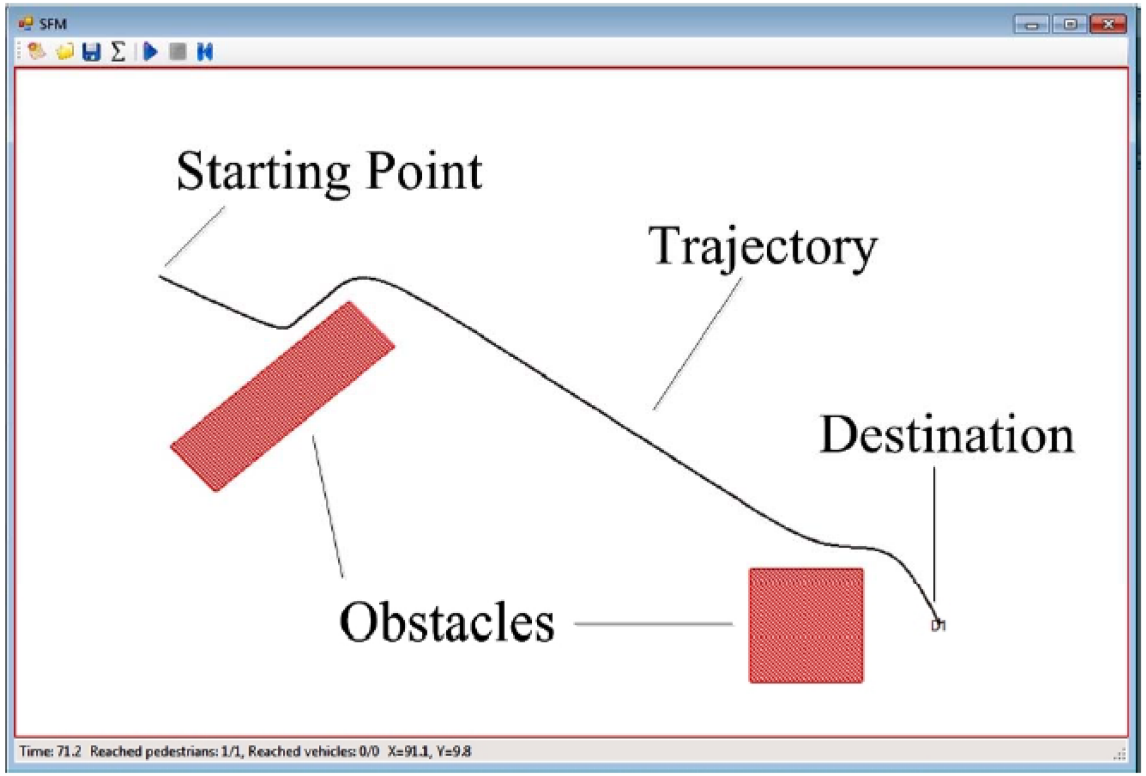
$$\epsilon_{Relative} = \left| \frac{\mathbf{D} - D^E}{D^E} \right|$$



T. Kretz, C. Bonisch, and P. Vortisch. ”Comparison of Various Methods for the Calculation of the Distance Potential Field”. Pedestrian and Evacuation Dynamics, 2008.

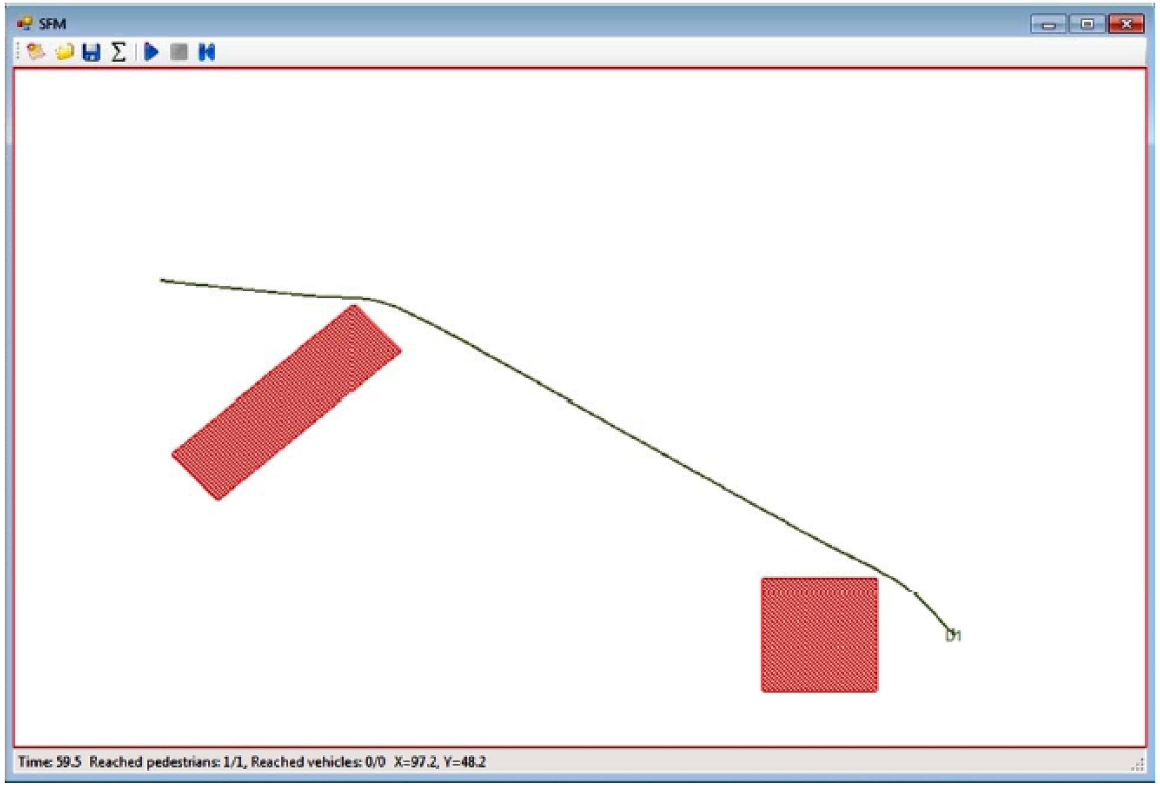
Journey Planning Layer

Obstacle Avoidance and Way-finding Simulation:



(a) Without Distance Map

Obstacle Avoidance and Way-finding Simulation:



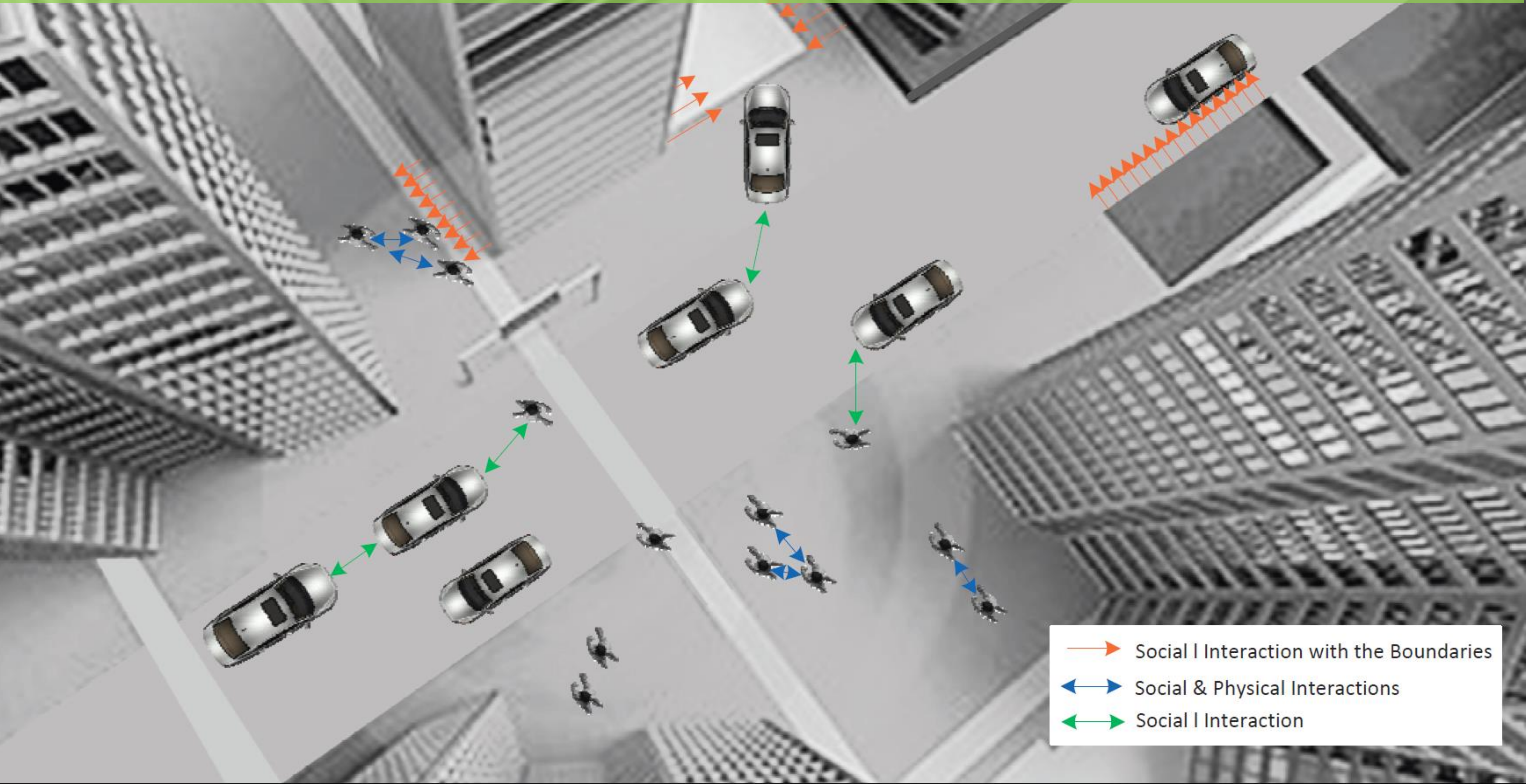
(b) With Distance Map

TU Delft

Nearctis
Network of Excellence for Advanced Road Cooperative Traffic management in the Information Society

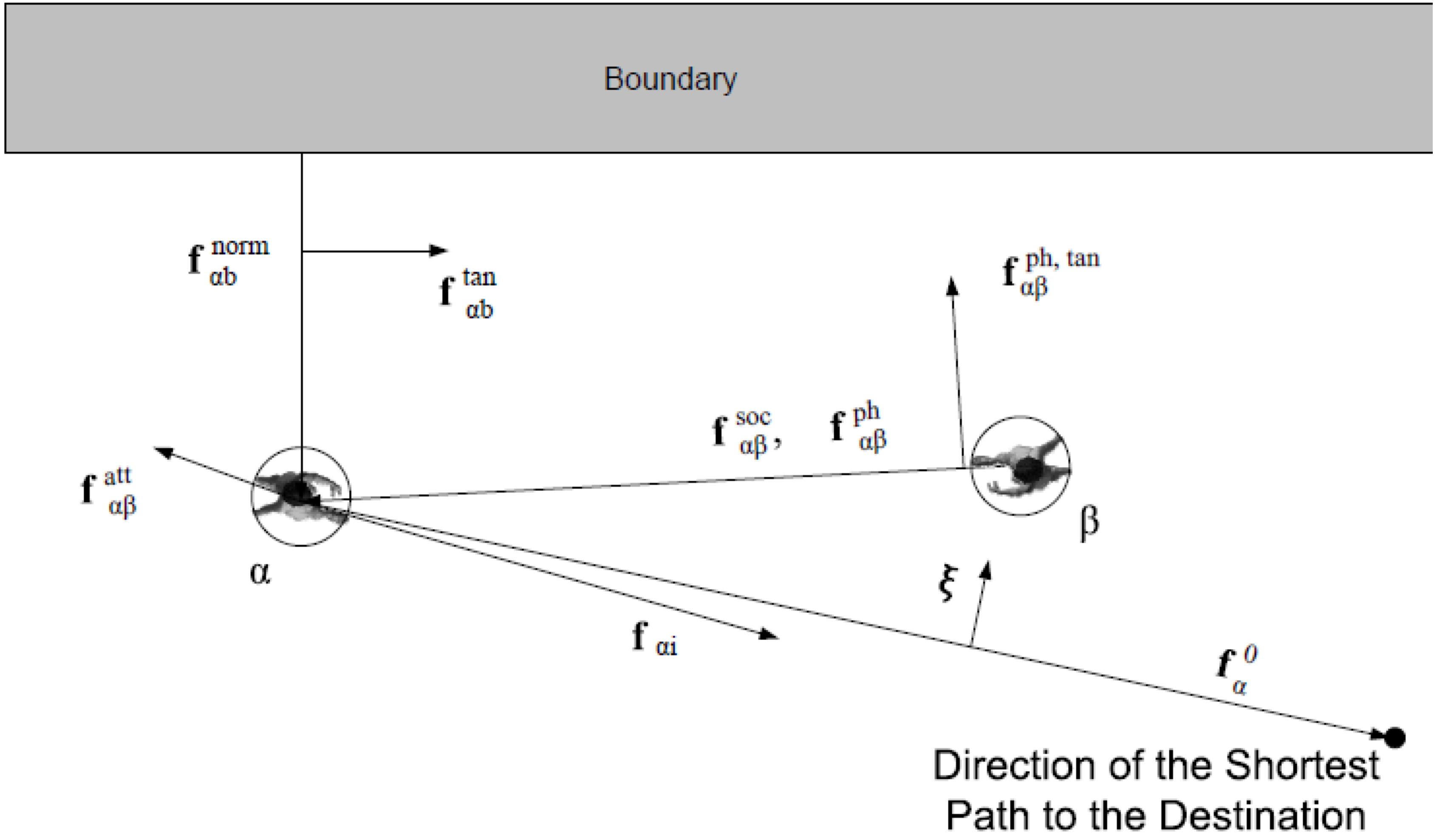
B. Anvari, W. Daamen, V.L. Knoop, S.P. Hoogendoorn & M.G. Bell,"Shared Space Modelling Based on Social Forces and Distance Potential Field." *Pedestrian and Evacuation Dynamics*, 2012.

Operational Force-based Layer



Operational Force-based Layer

$$\frac{d\boldsymbol{v}_\alpha(t)}{dt} = \boldsymbol{f}^0_\alpha + \sum_\beta \boldsymbol{f}_{\alpha\beta} + \sum_b \boldsymbol{f}_{\alpha b} + \sum_\beta \boldsymbol{f}^{\text{att}}_{\alpha\beta} + \sum_i \boldsymbol{f}_{\alpha i} + \boldsymbol{\xi}$$

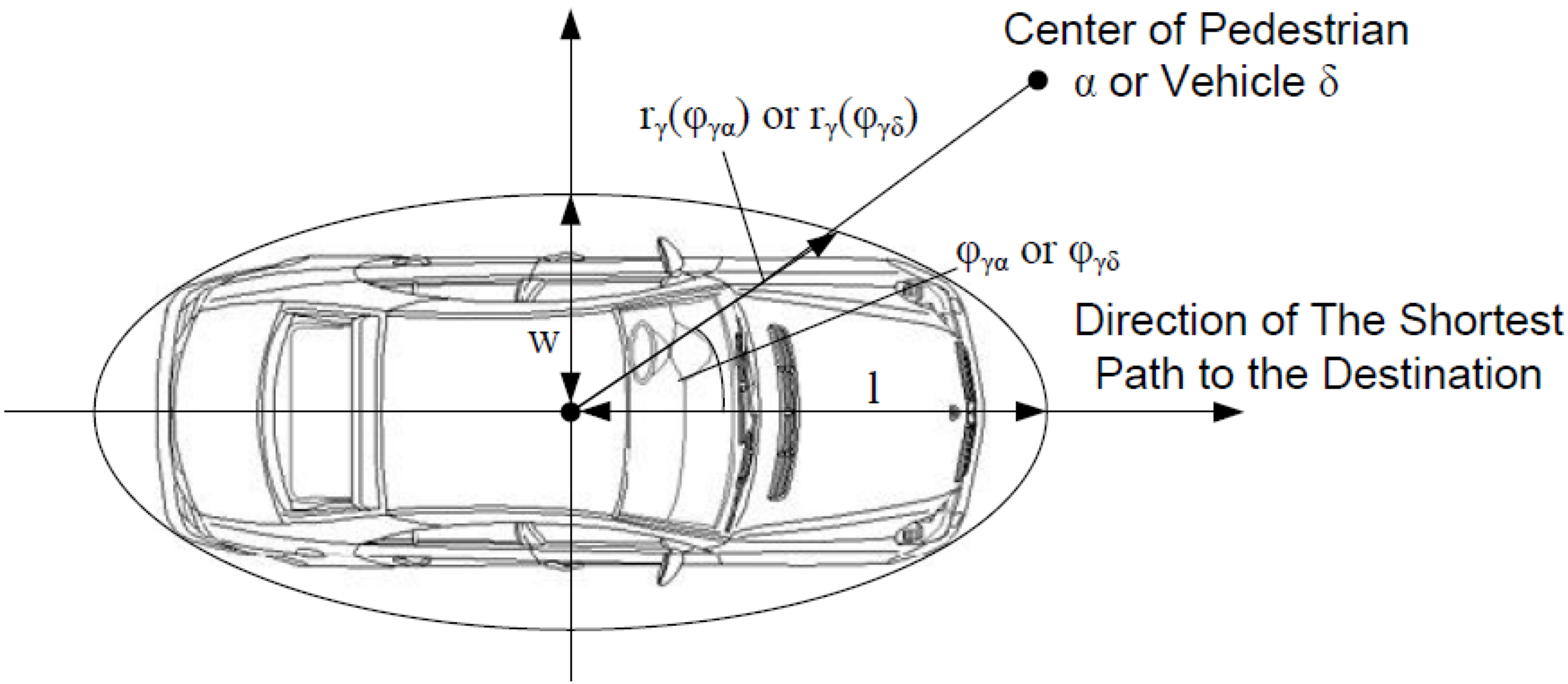


Helbing et al., "Simulating Dynamical Features of Escape Panic". Nature, vol. 407, pp. 487 - 490, 2000.

Geometrical Car Modelling

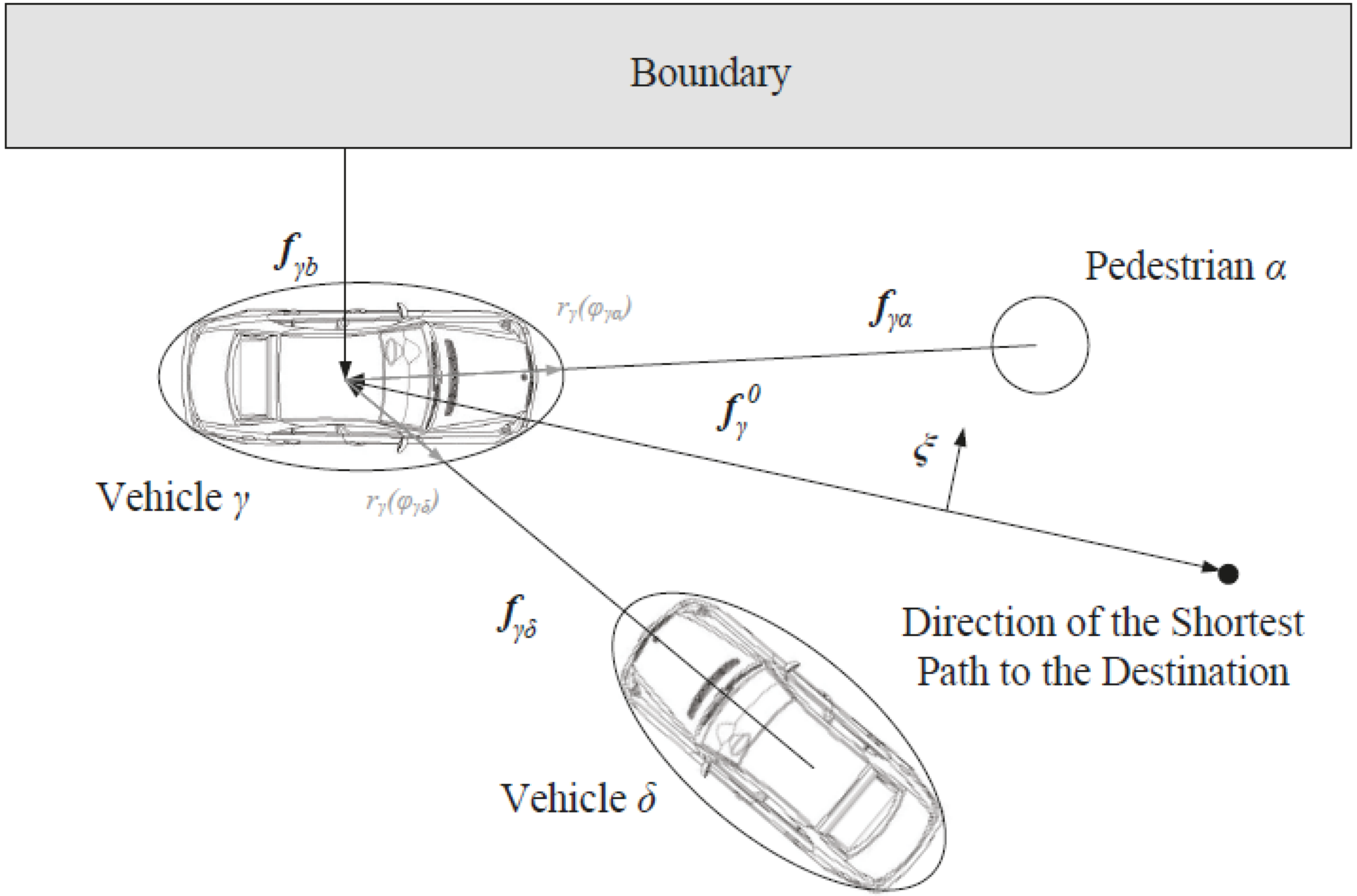
Car Modelling using a Geometrical Approximation of an Ellipse

$$r_\gamma(\varphi_{\gamma U}) = \frac{w}{\sqrt{1-\epsilon^2 \cos^2(\varphi_{\gamma U})}}, \text{ where } \epsilon = \frac{\sqrt{l^2 - w^2}}{l}$$



Social Force Model for Cars

$$\frac{d\boldsymbol{v}_\gamma(t)}{dt} = \boldsymbol{f}^0_\gamma + \sum_{\delta(\delta\neq\gamma)} \boldsymbol{f}_{\gamma\delta} + \sum_{\alpha} \boldsymbol{f}_{\gamma\alpha} + \sum_{b} \boldsymbol{f}_{\gamma b} + \boldsymbol{\xi}$$



Social Force Model for Cars

Driving Force:

$$\boldsymbol{f}_\gamma^0 = \frac{v_\gamma^0 \cdot \boldsymbol{e}_\gamma(t) - \boldsymbol{v}_\gamma(t)}{\tau_\gamma}, \text{ where } \boldsymbol{e}_\gamma(t) = \frac{\boldsymbol{r}_\gamma^k - \boldsymbol{r}_\gamma}{|\boldsymbol{r}_\gamma^k - \boldsymbol{r}_\gamma|}$$

Interaction Forces Considering the Geometric Model of Cars:

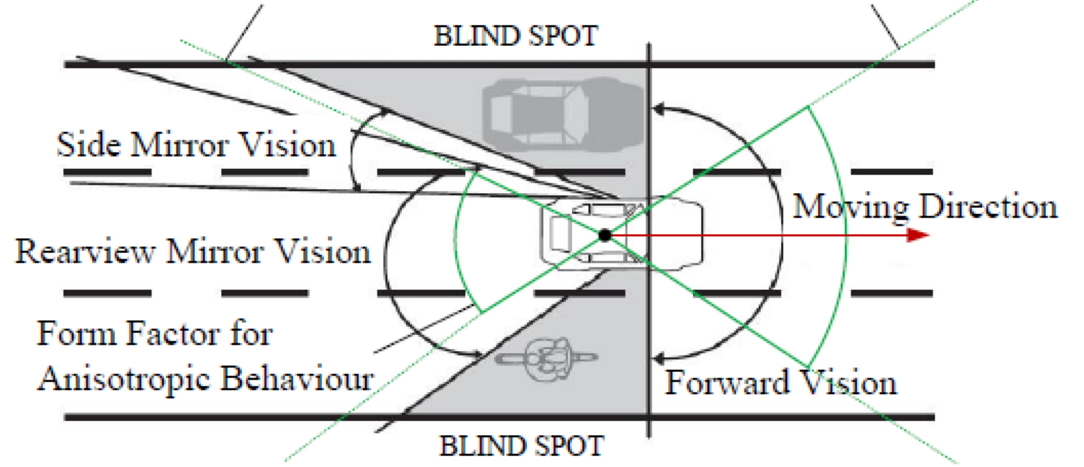
$$\boldsymbol{f}_{\gamma U}(t) = \boldsymbol{f}_{\gamma U}^{\text{soc}}(t) + \boldsymbol{f}_{\gamma\delta}^{\text{following}}(t)$$

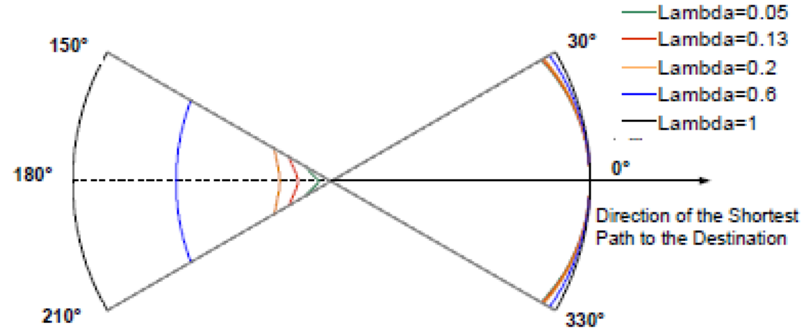
Socio-psychological Force:

$$\boldsymbol{f}_{\gamma U}^{\text{soc}} = A_{\gamma U} e^{\frac{r_{\gamma U} - d_{\gamma U}}{B_{\gamma U}}} \boldsymbol{n}_{\gamma U} F_{\gamma U} \qquad F_{\gamma U} = \left(\lambda_\gamma + (1 - \lambda_\gamma) \frac{1 + cos(\varphi_{\gamma U})}{2}\right) \cdot q$$

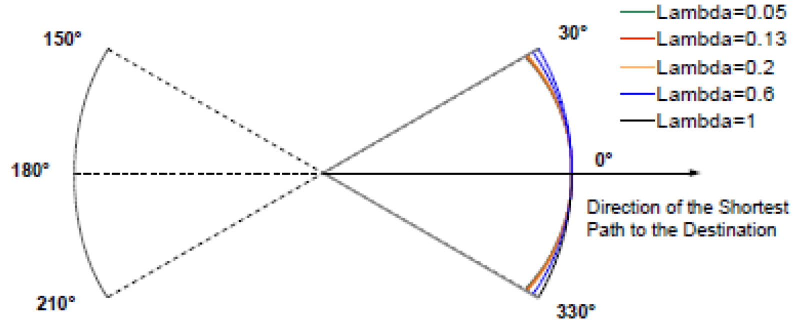
Social Force Model for Cars

Form Factor and Effective Factor





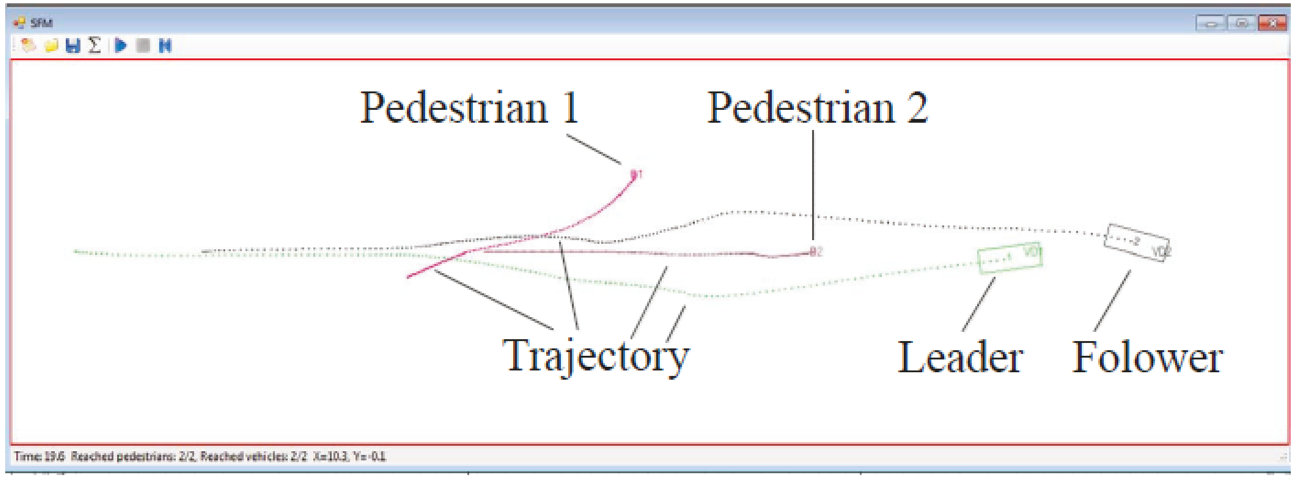
$q = 1$, *if* $-\vartheta^{o} \leq \varphi_{\gamma\alpha} \leq \vartheta^{o}$ *and*
$(180^{o} - \vartheta^{o}) \leq \varphi_{\gamma\alpha} \leq (180^{o} + \vartheta^{o})$
$q = 0$, *otherwise*



$q = 1$, *if* $-\vartheta^{o} \leq \varphi_{\gamma\alpha} \leq \vartheta^{o}$
$q = 0$, *otherwise*

Social Force Model for Cars

Trajectory simulation of an obstructed car and the following car according to:
(a) the social force
(b) the deceleration force

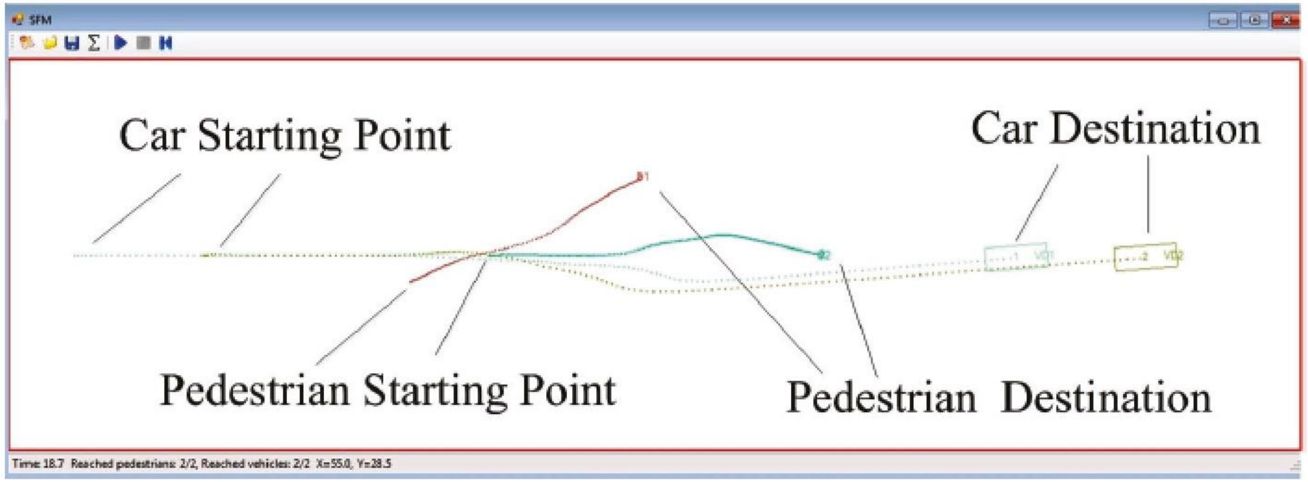


(a)

Deceleration Force:

$$f_{\gamma\delta}^{\text{following}} = -\frac{v_\gamma^0}{\tau_\gamma} e^{\frac{d(v_\gamma) - d_{\gamma\delta}}{B'_{\gamma\delta}}} - \frac{\Delta v_{\gamma\delta} e^{\frac{d(v_\gamma) - d_{\gamma\delta}}{B''_{\gamma\delta}}}}{\tau'_\gamma} \Theta(\Delta v_\gamma),$$

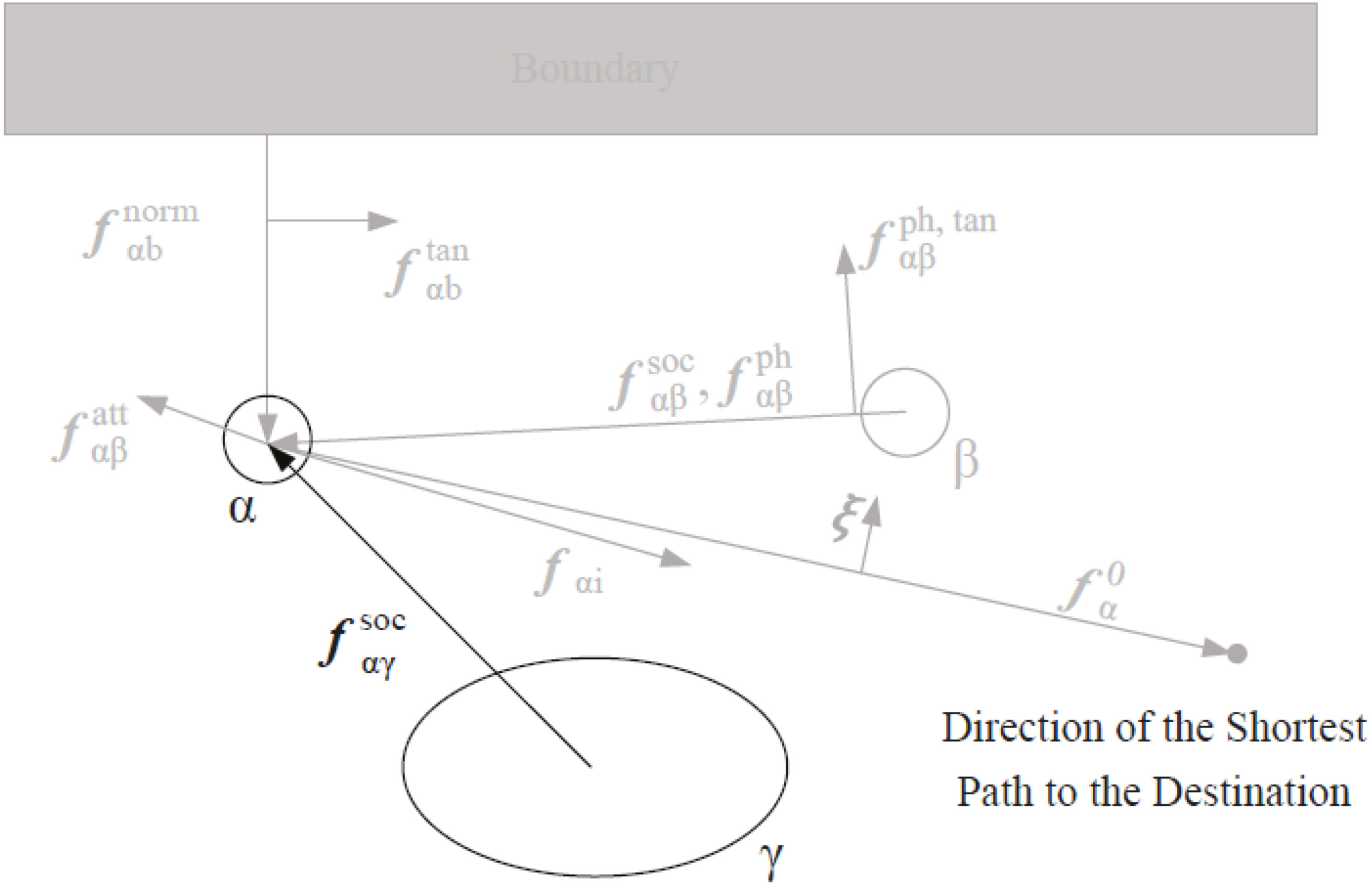
$$\text{where} \begin{cases} \Theta(\Delta v_\gamma) = 1, & \text{if } (\Delta v_\gamma) > 0) \\ \Theta(\Delta v_\gamma) = 0, & \text{otherwise} \end{cases}$$



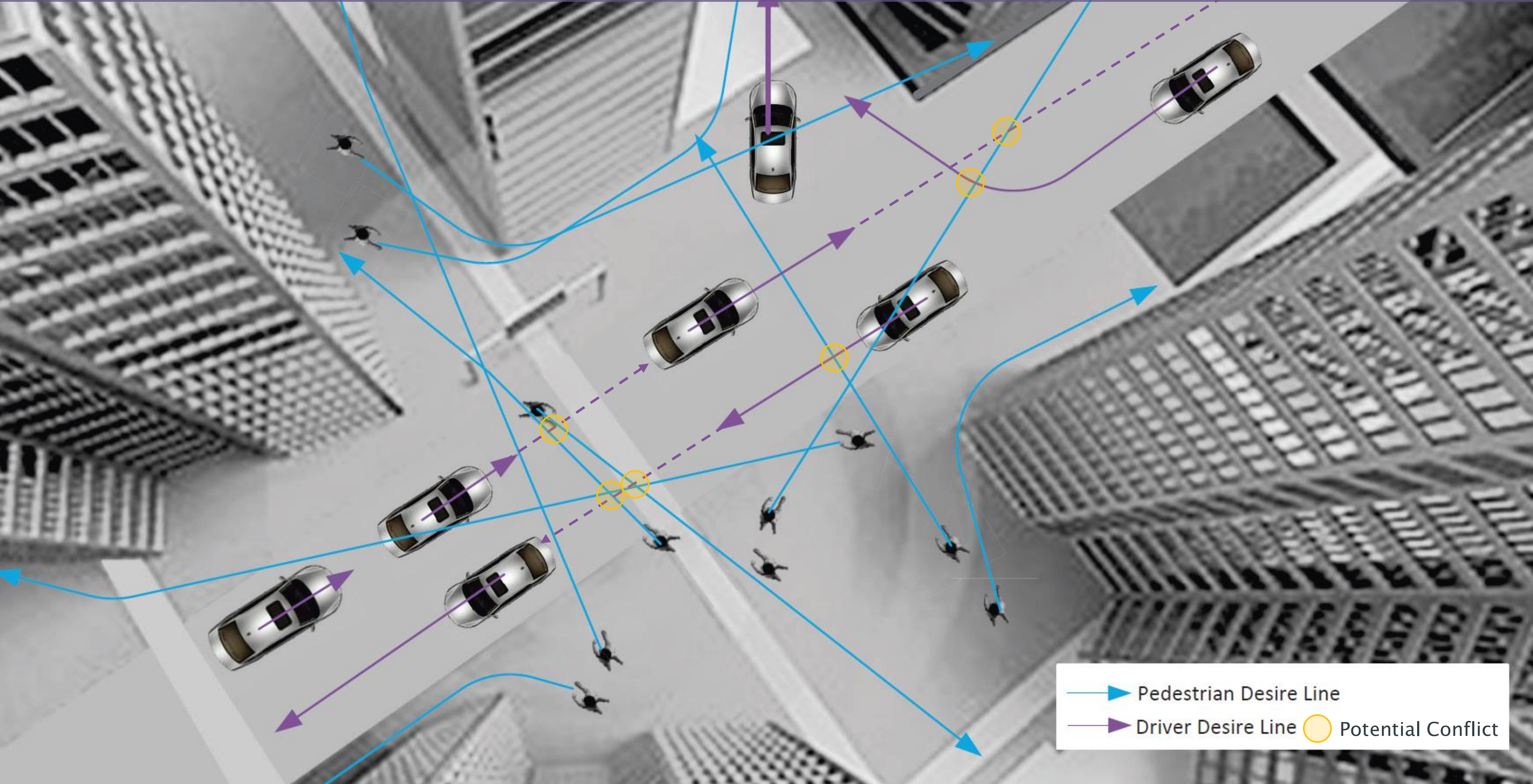
(b)

Social Force Model for Pedestrians in Shared Spaces

$$\frac{d\boldsymbol{v}_\alpha(t)}{dt} = \boldsymbol{f}_\alpha^0 + \sum_{\beta(\beta\neq\alpha)} \boldsymbol{f}_{\alpha\beta} + \sum_b \boldsymbol{f}_{\alpha b} + \sum_\gamma \boldsymbol{f}_{\alpha\gamma} + \boldsymbol{\xi}$$



Rule-based constraints layer



Rule-based constraints layer

Relation between Steering Angle and Moving Speed

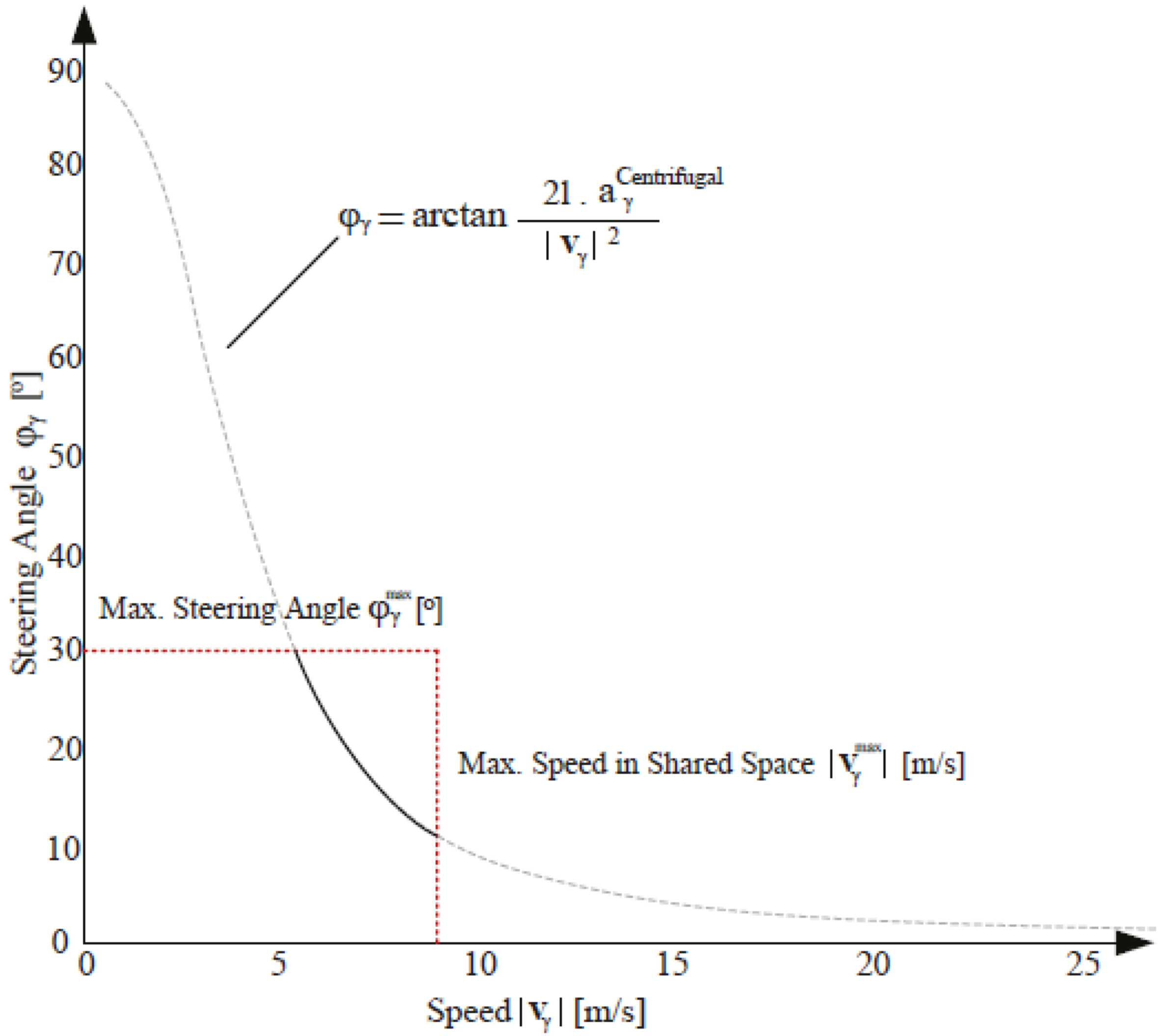
$$\psi_\gamma = \arctan \frac{2l \cdot a_\gamma^{\text{Centrifugal}}}{|\boldsymbol{v}_\gamma|^2}$$

for $0 < |\boldsymbol{v}_\gamma| \leq 5.3\,\frac{\text{m}}{\text{s}}$,

$$\psi_\gamma \leq 30^\circ$$

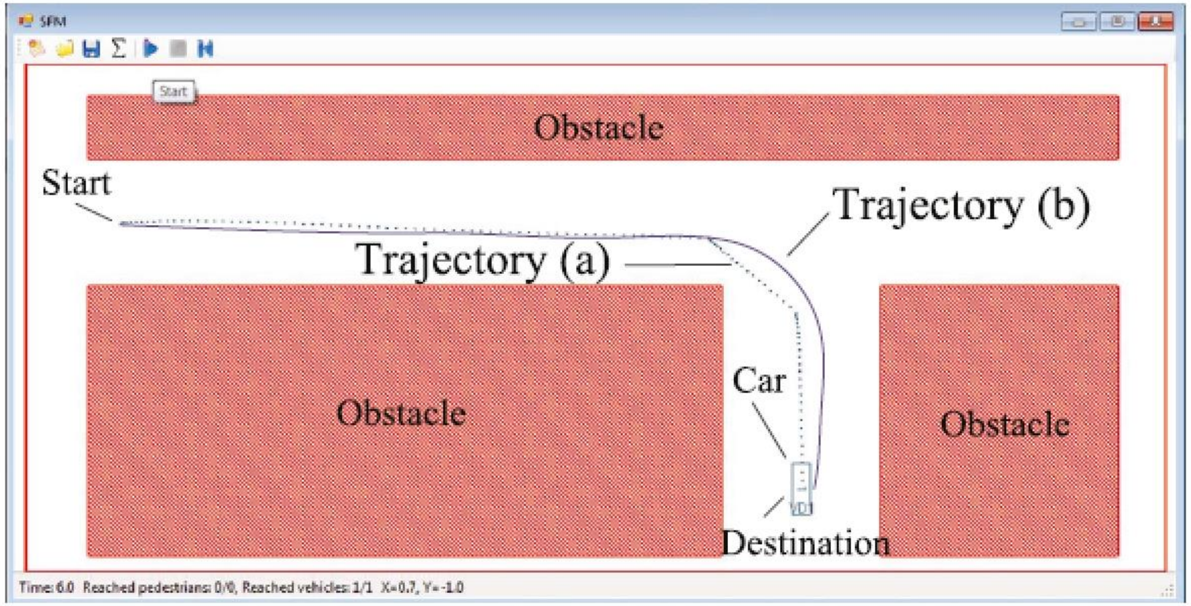
for $5.3\,\frac{\text{m}}{\text{s}} < |\boldsymbol{v}_\gamma| \leq 8.9\,\frac{\text{m}}{\text{s}}$,

$$\psi_\gamma \leq \arctan \frac{2l \cdot a_\gamma^{\text{Centrifugal}}}{|\boldsymbol{v}_\gamma|^2}$$

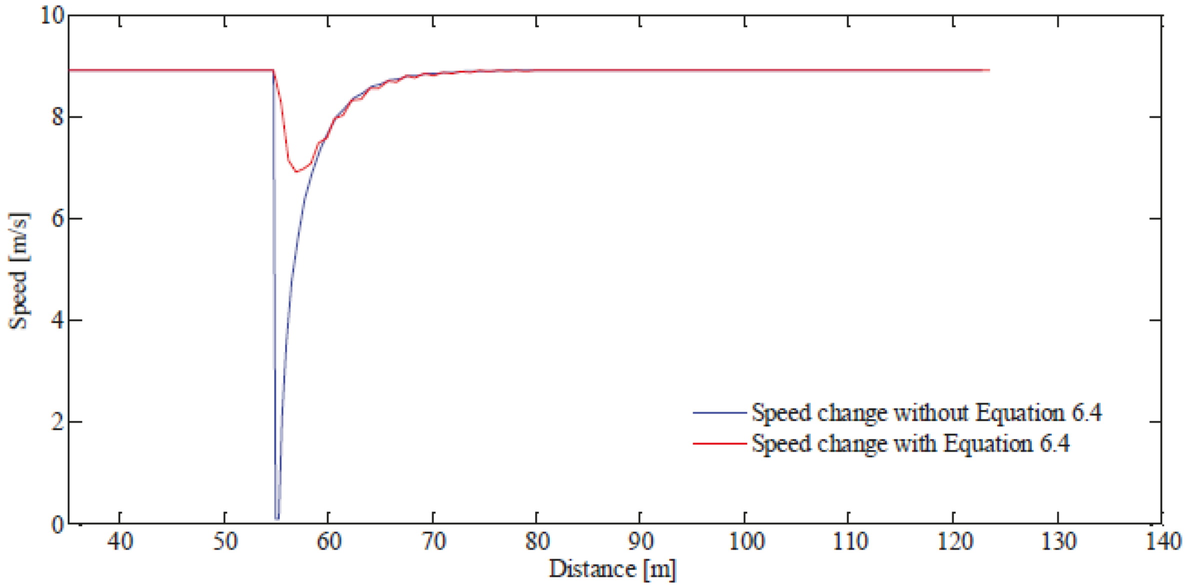


Rule-based constraints layer

Driving trajectory simulation of a turning car:
(a) without steering angle constraints
(b) with steering angle constraints

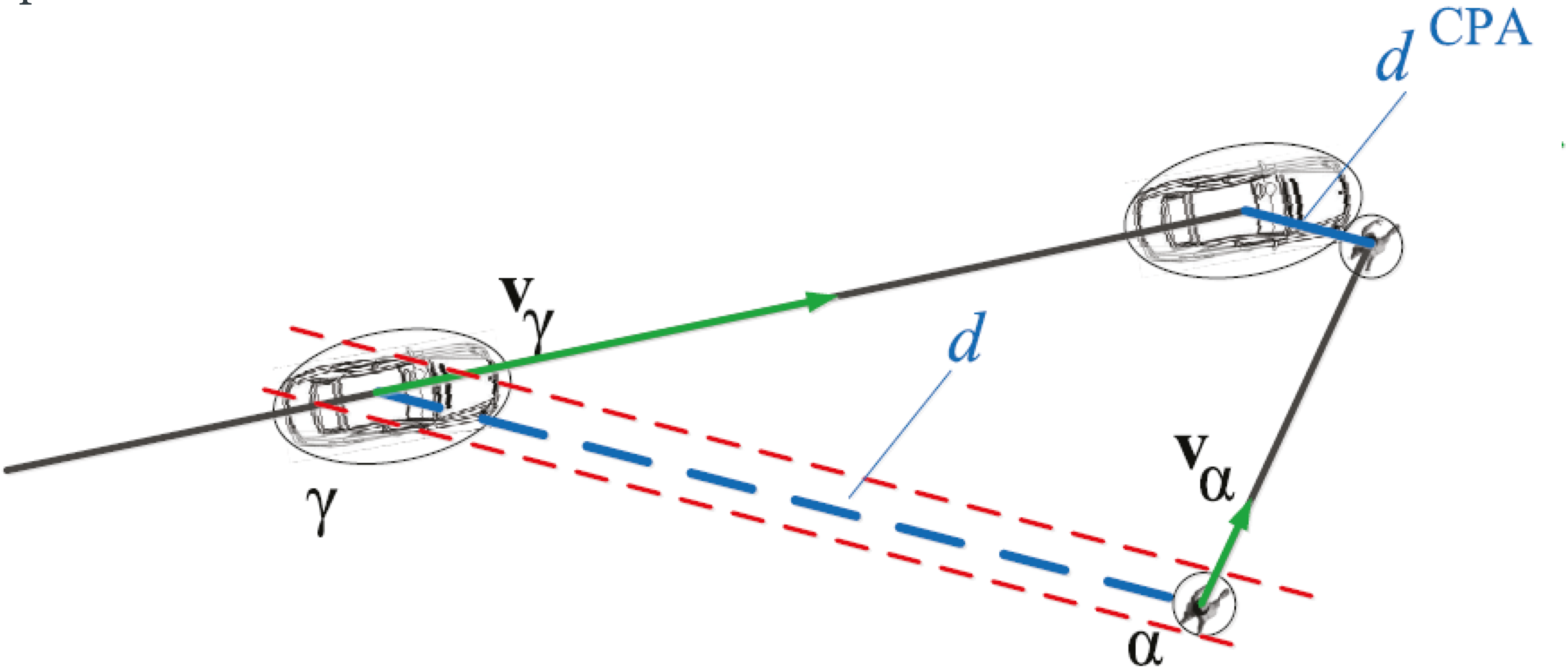


Speed change of a turning car as a result of steering angle constraints



Rule-based constraints layer

Optimal Manoeuvre for Conflict Avoidance:



L. Pallottino and E.M. Feron. ”Conflict Resolution Problems for Air Traffic Management Systems Solved With Mixed Integer Programming”. IEEE Transactions on Intelligent Transportation Systems, vol. 3, pp.1-11, 2002.

Rule-based constraints layer

Adding a minimum velocity change $\Delta\vec{v}^{min} = \vec{v}^{opt}(t) - \vec{v}(t)$ will avoid conflicts.

$$c\left(v_x^{opt}(t), v_y^{opt}(t)\right) = \left(v_x^{opt}(t) - v_{x,q_1}(t)\right)^2 + \left(v_y^{opt}(t) - v_{y,q_1}(t)\right)^2$$

The optimisation problem incorporating all these constraints can be formulated as follows:

Minimize $c\left(v_x^{opt}(t), v_y^{opt}(t)\right)$

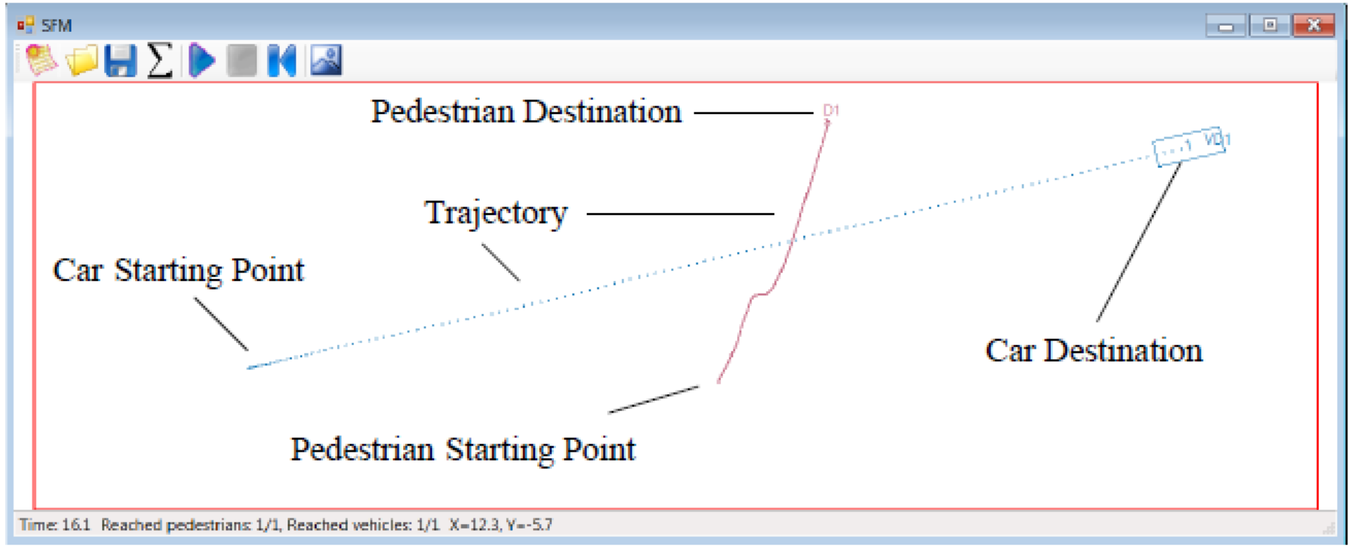
Subject to $v_U^{min} < v_U^{opt} < v_U^{max}$

$d_{\gamma\alpha}^{CPA} > r_\alpha + r_\gamma(\varphi_{\gamma\alpha})$

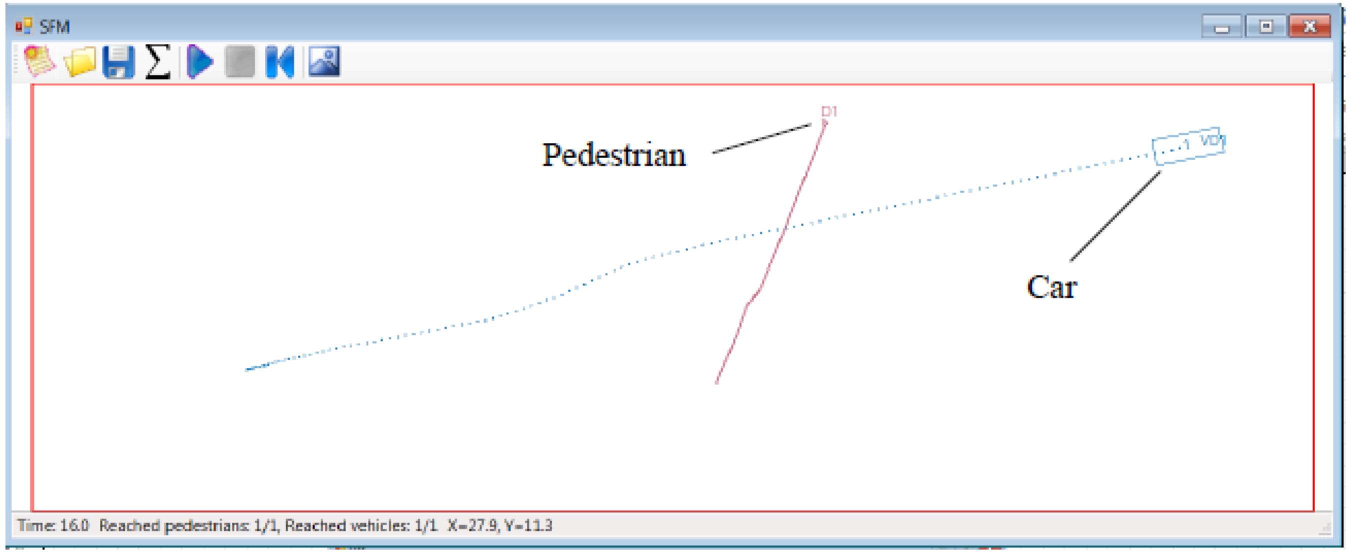
Distance to reach the CPA $>$ Minimum acceptable distance

A conflict avoidance force $\vec{f}_U^{conflict} = \frac{\Delta\vec{v}^{min}}{\tau_U}$ is calculated and added to the sum of forces

Rule-based constraints layer

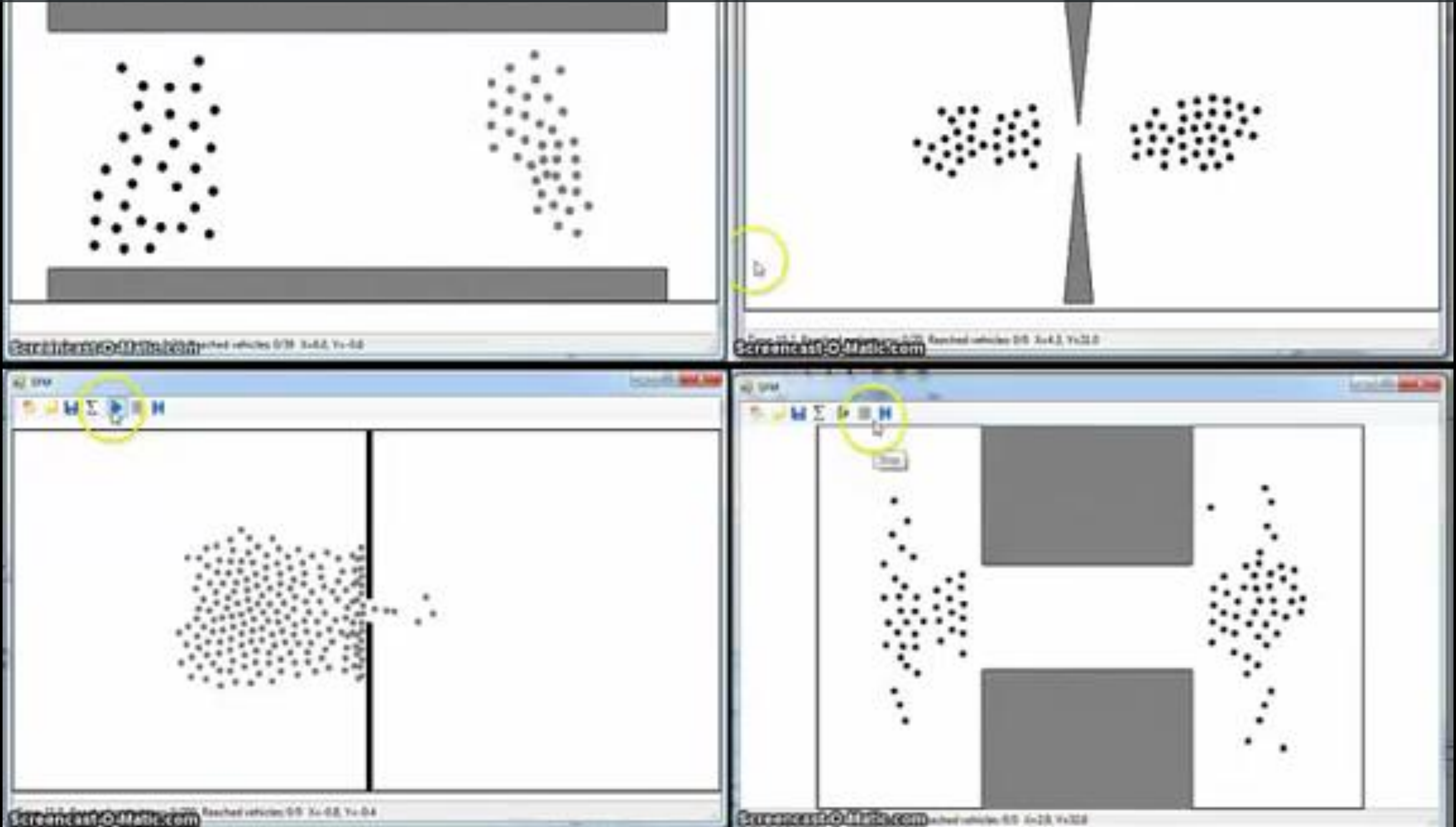


(a) Simulation of the interaction between a car and pedestrian without conflict avoidance force



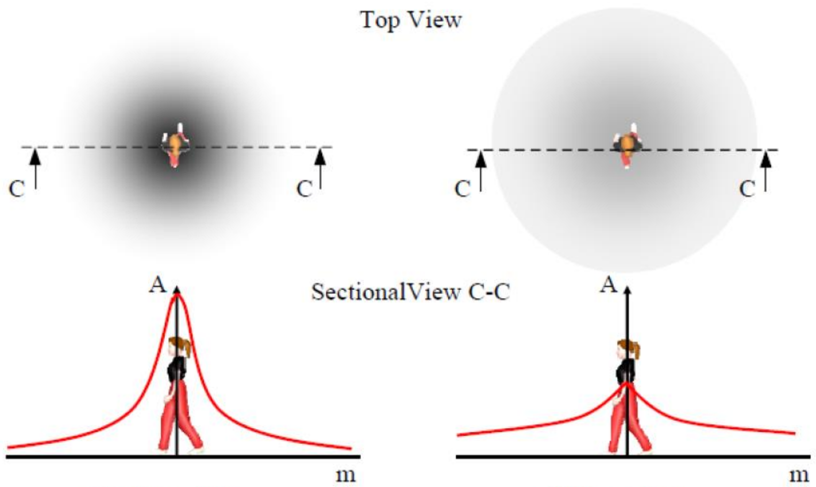
(b) Simulation of the interaction between a car and pedestrian with conflict avoidance force

Video available here: https://www.youtube.com/watch?v=c3ITUMLz6KI



Specification of Parameters for Calibration

Determination of the Interaction Strength A:



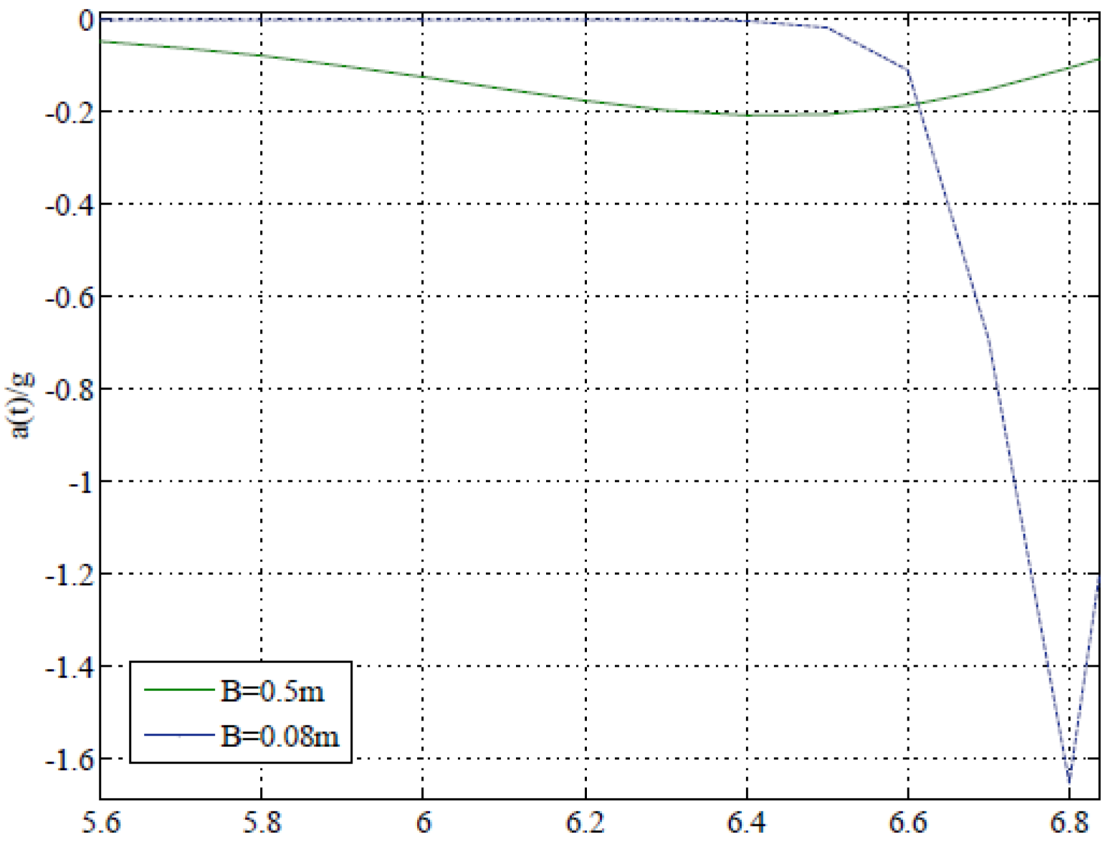
(a) Physical Force (b) Social Force

Determination of the Interaction Range B:

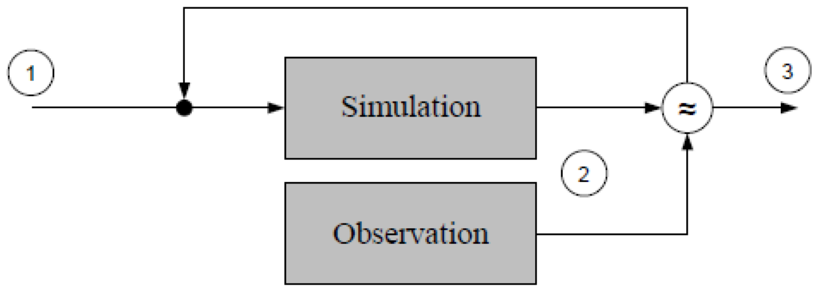
$$\frac{d\vec{v}}{dt} = \frac{\vec{v}_\alpha - v^0_\alpha \cdot \vec{e}^0_\alpha(t)}{\tau_\alpha} - \frac{A_\alpha}{m} e^{d_{\alpha b}/B_\alpha}$$

Maximum deceleration of human beings:

$$0.2g(g = 9.8\frac{m}{s^2}) \Rightarrow B_\alpha = 0.5$$



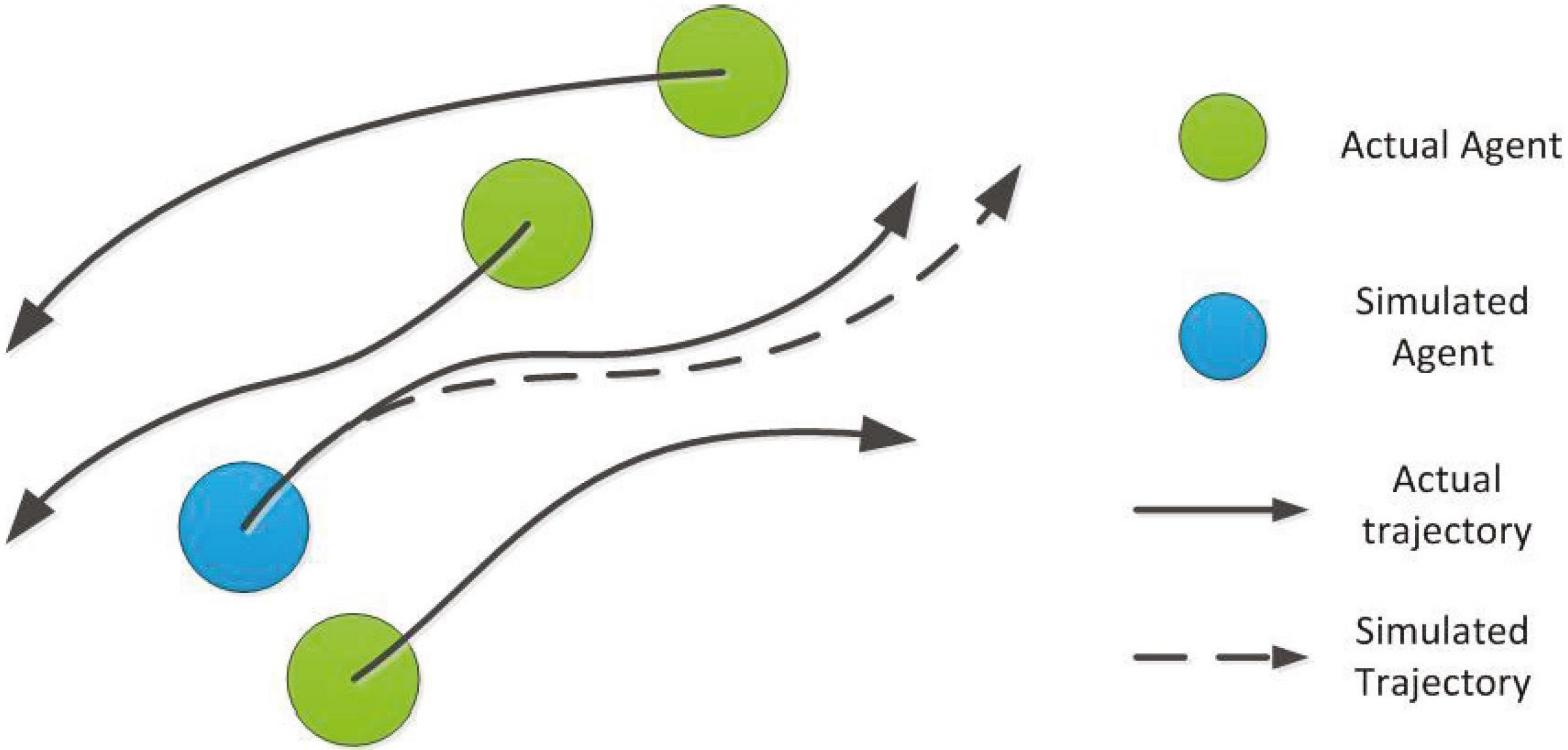
Calibration and Validation



1.	Input:	Initial Parameters for *A* and *B*.
2.	Output:	Trajectories
		Velocities
		Accelerations and Decelerations
3.	Output:	Calibrated parameters for *A* and *B*.

- Using the hybrid model, an error measure related to deviation from our simulated position to the actual position from the observation will be calculated
- With this error measure we can iterate a calibration process that will find an optimal set of simulation parameters

Calibration and Validation



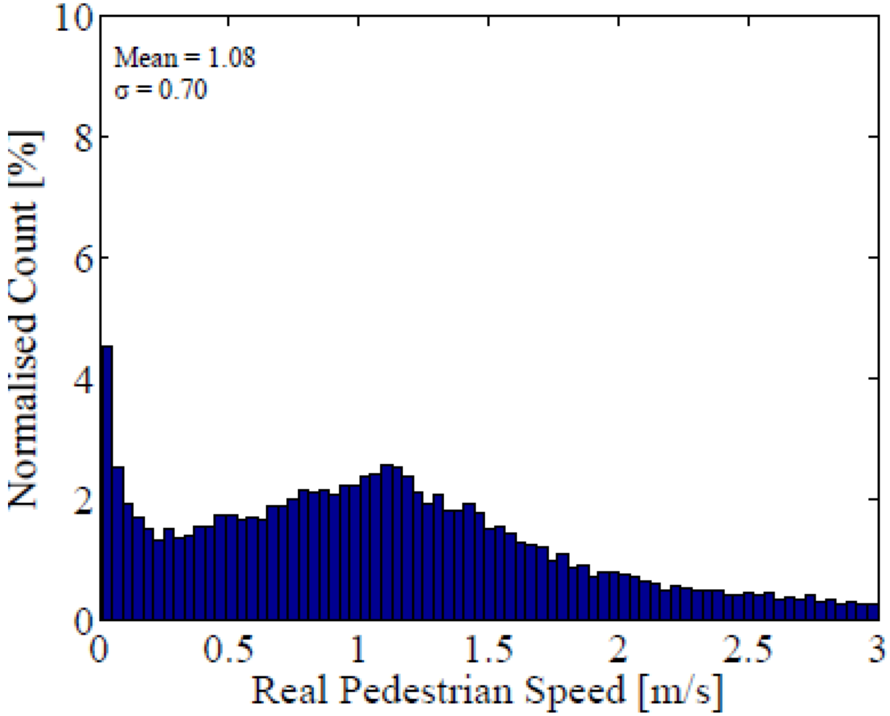
$$E = \frac{\left\| r_U^{simulated}(t+T) - r_U^{tracked}(t+T) \right\|}{\left\| r_U^{tracked}(t+T) - r_U^{tracked}(t) \right\|}$$

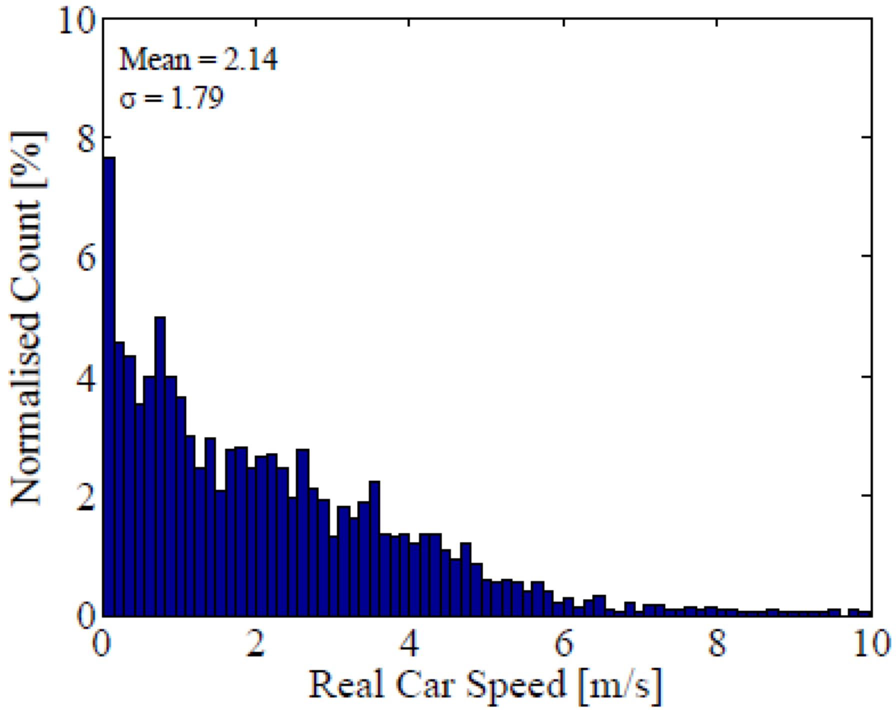
Observation Results

Trajectories of pedestrians (in white) and cars (in red) in New Road, Brighton

Observation Results

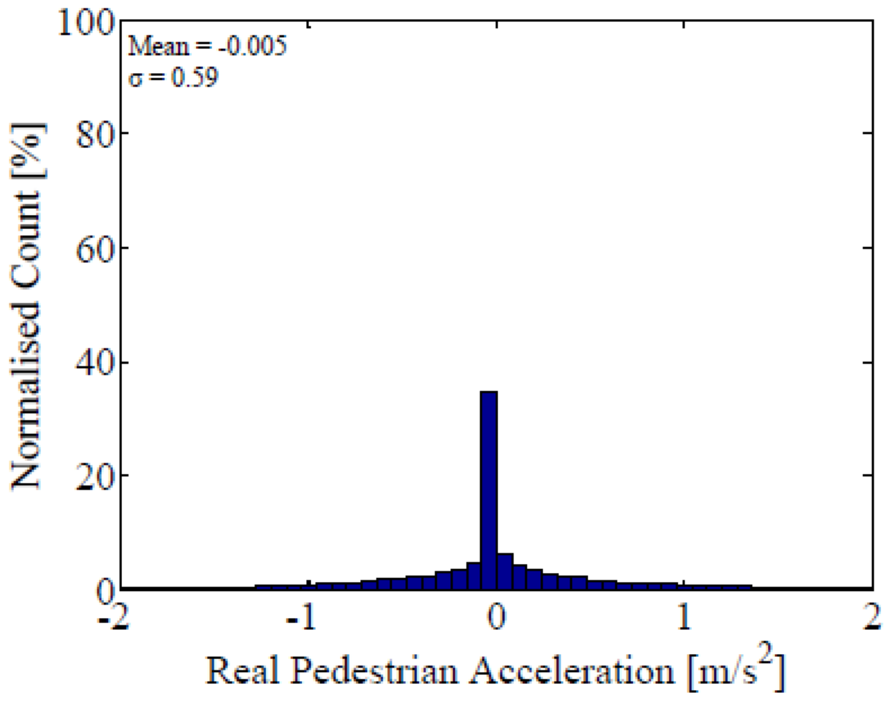
- The mean speed of pedestrians is 1.08 $\frac{m}{s}$ (σ = 0.70$\frac{m}{s}$)that is close to the Weidmann estimation of 1.38 $\frac{m}{s}$ for the 'optimal energy level'.
- The mean speed of cars on New Road is about 2.14 $\frac{m}{s}$ (σ = 1.79$\frac{m}{s}$) and drivers do not speed up more than 10. $\frac{m}{s}$

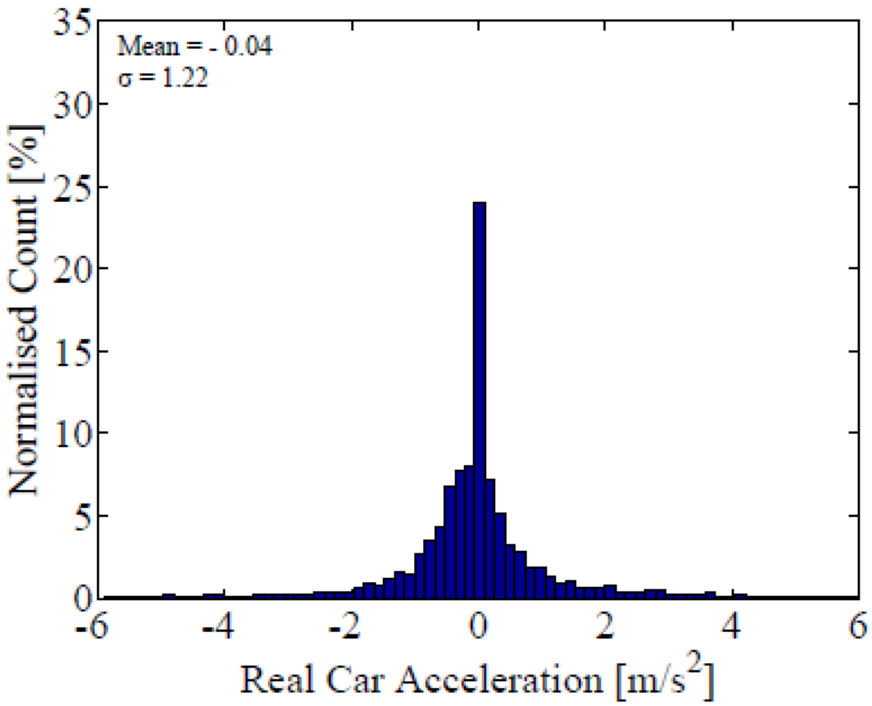




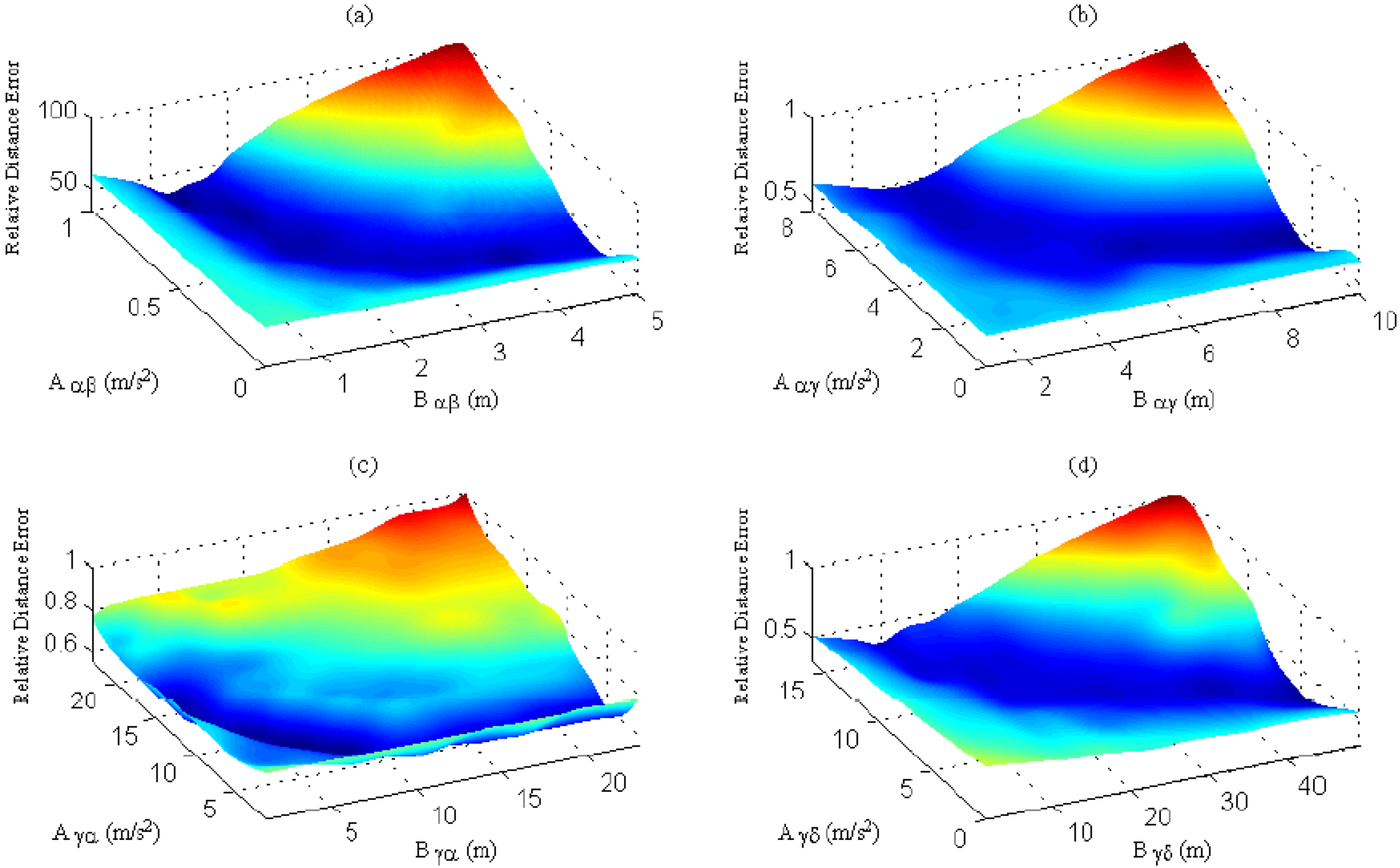
Observation Results

- Pedestrians accelerate and decelerate at the rate of -0.005 $\frac{m}{s^2}$ ($\sigma = 0.59 \frac{m}{s}$) which is matching Weidmann estimation for the immediate change of acceleration (less than 20% of the g-force)
- Acceleration and deceleration rate is about -0.04 $\frac{m}{s^2}$ ($\sigma = 1.22 \frac{m}{s}$) for cars.





Calibration Results for Shared Space in New Road, Brighton



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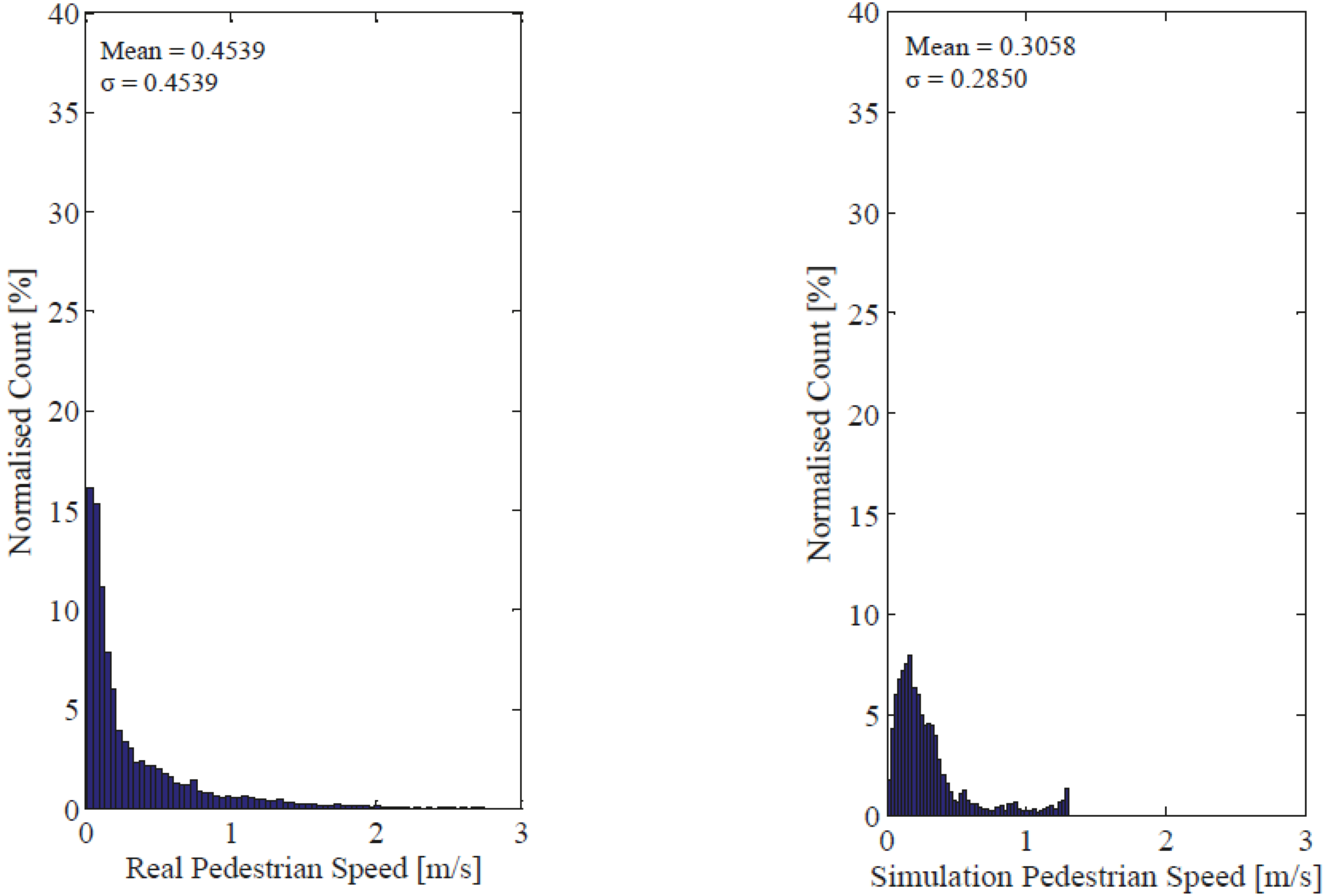

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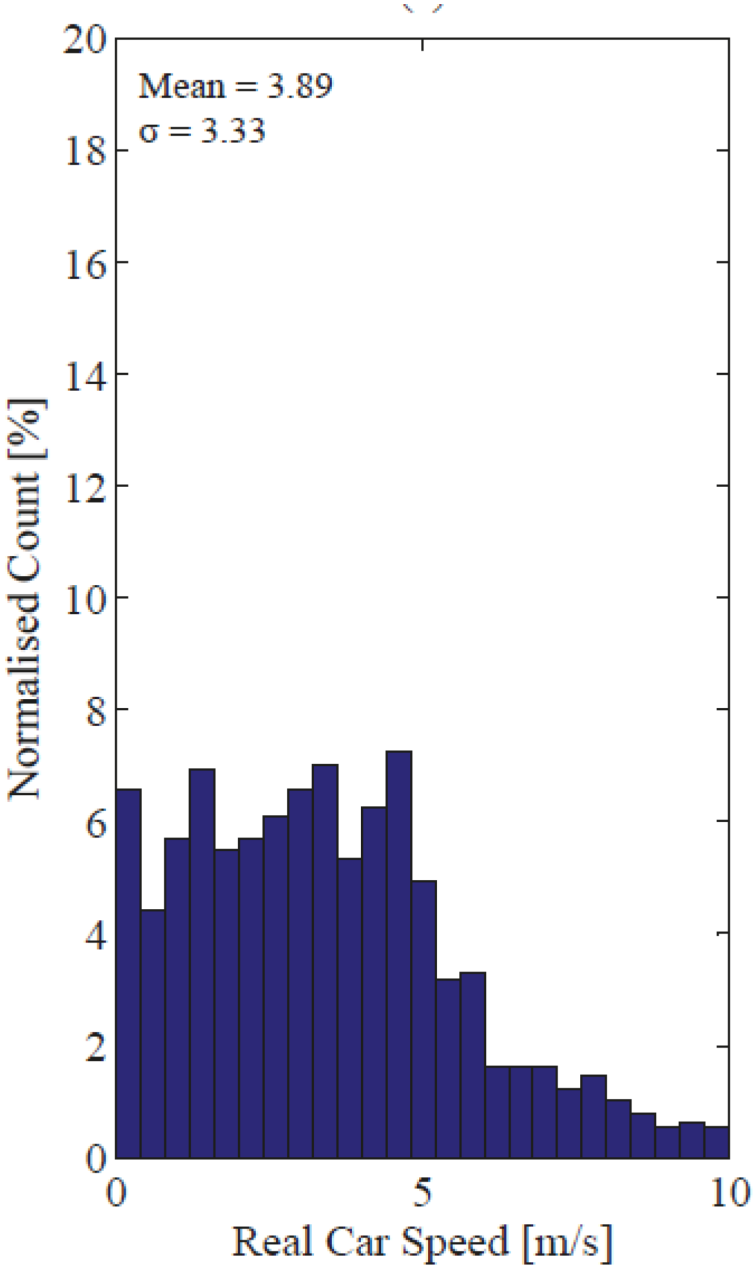
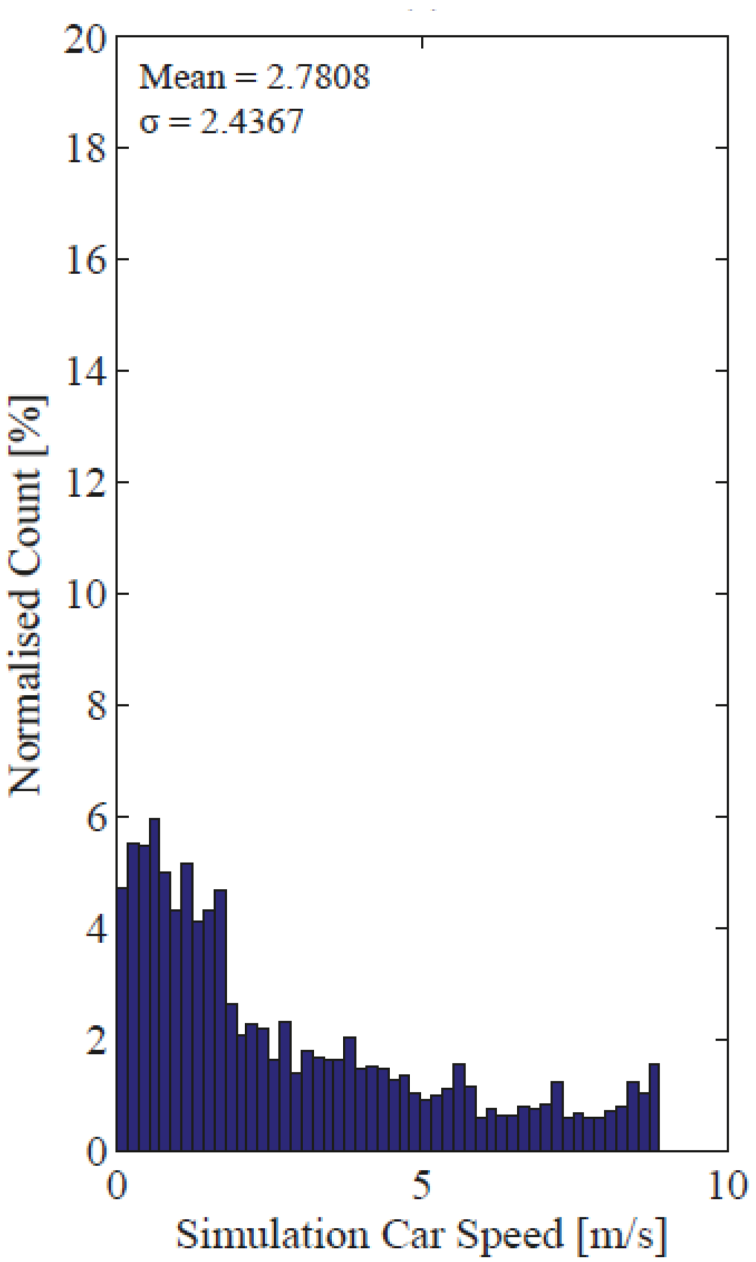
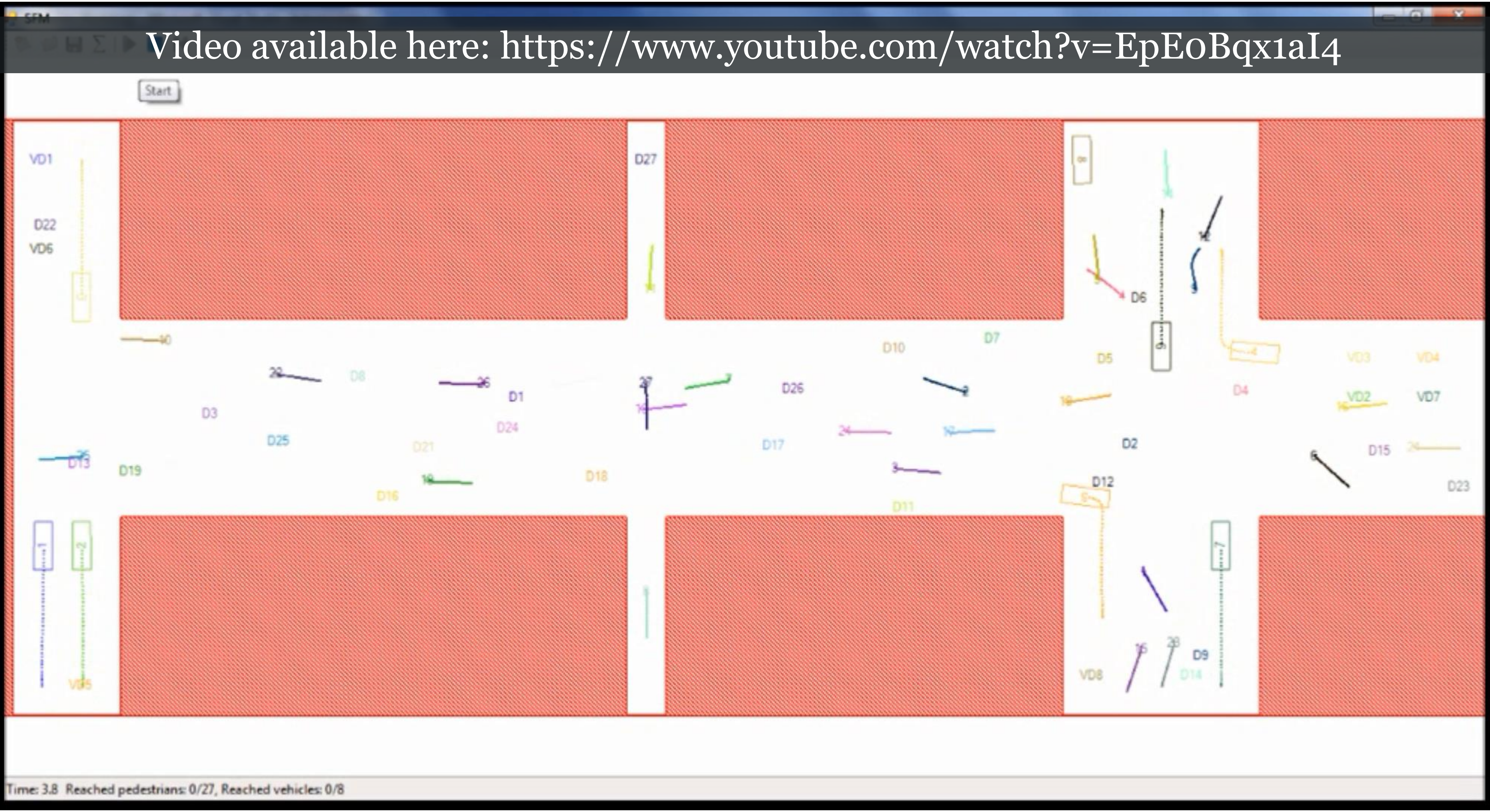


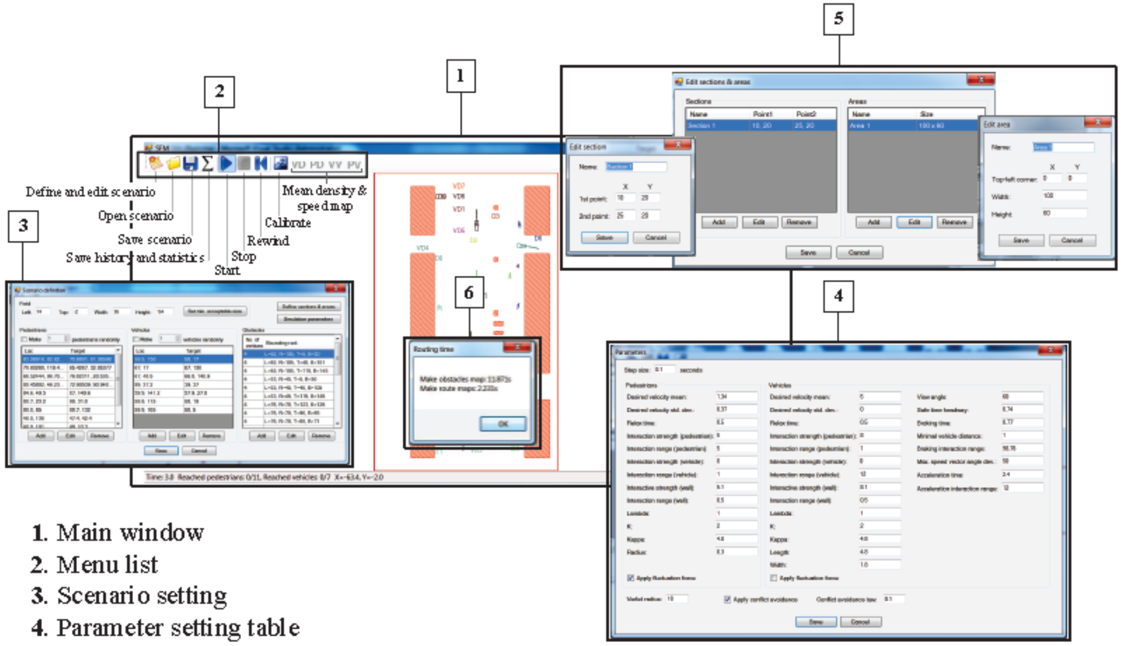


Video available here: https://www.youtube.com/watch?v=EpE0Bqx1aI4



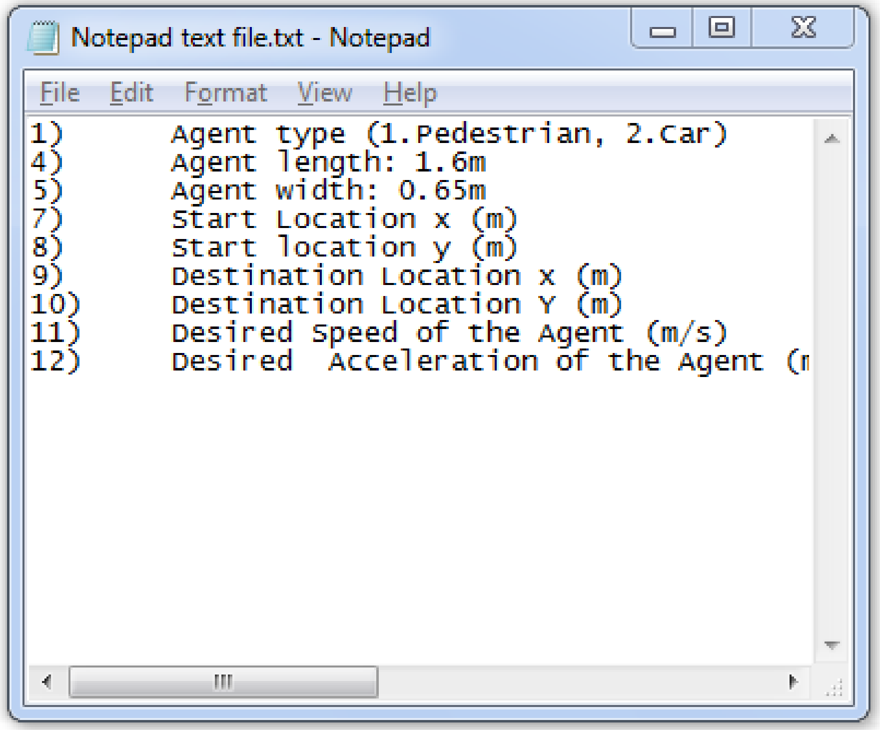
Inputs

- Street plan: an outline of desirable design elements with their dimensions in the street space.
- Start and destination point of all users (e.g. pedestrians, drivers).
- Desired speed and acceleration for all agents.
- Max speed and acceleration for all agents.



1. Main window
2. Menu list
3. Scenario setting
4. Parameter setting table
5. Section and area setting
6. Routing time report

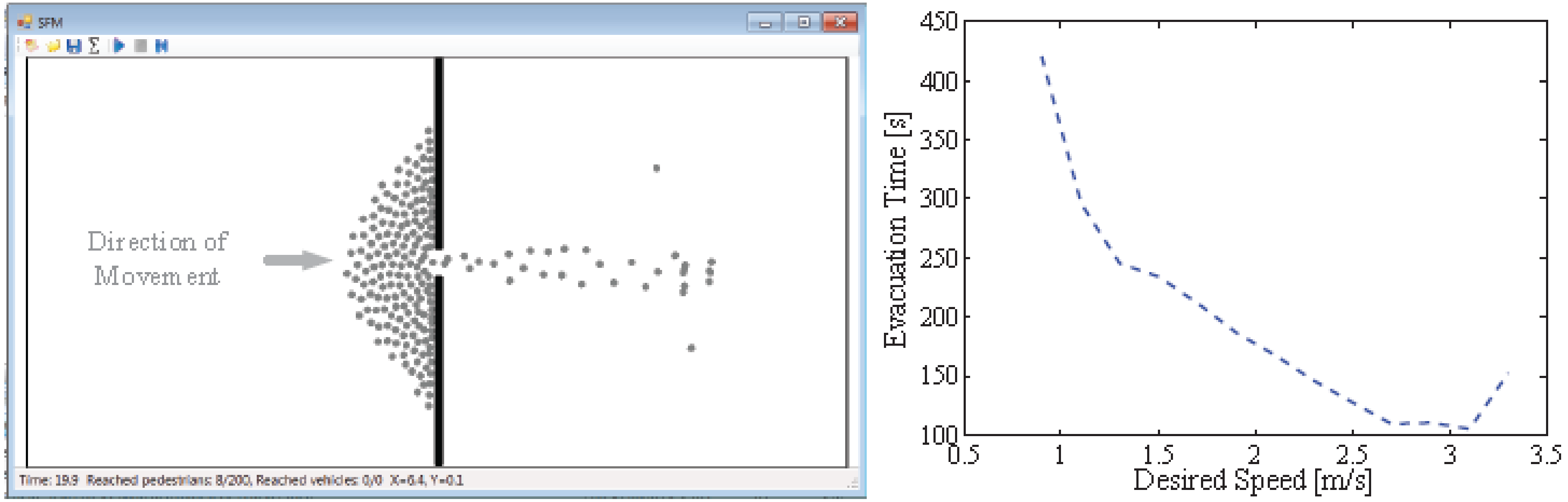
GUI of the simulation tool



Text and excel files

Outputs (1/5)

- Evacuation time and desired speed relationships in the design stage so as to achieve solutions for optimal design features before implementation

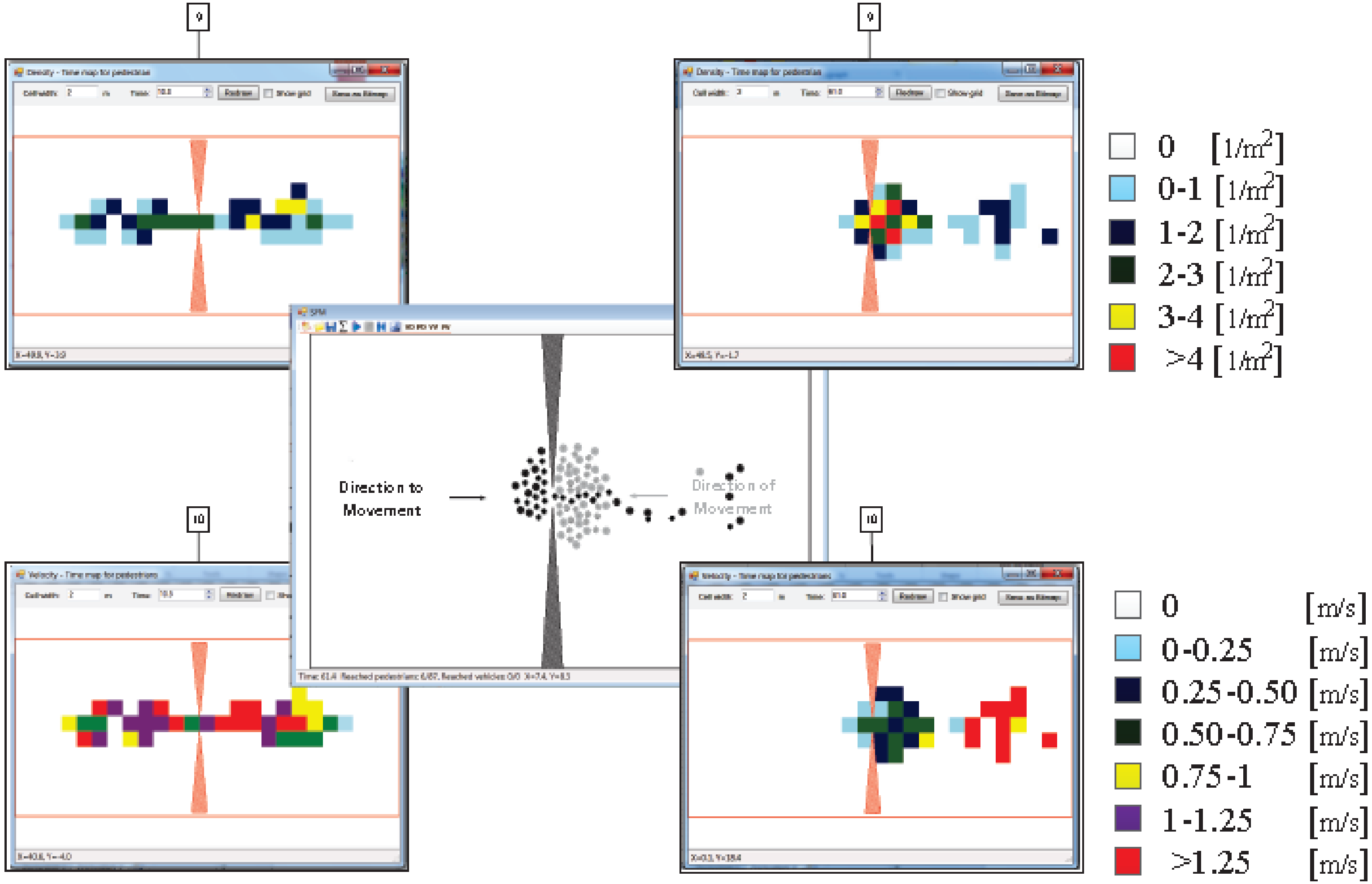


(a) (b)

Faster-Is-Slower simulation: (a) clogging at the exit and (b) evacuation time of 200 people versus desired velocity

Outputs (2/5)

- Potential spots for conflicts in order to avoid peaks of density and pressure at critical locations

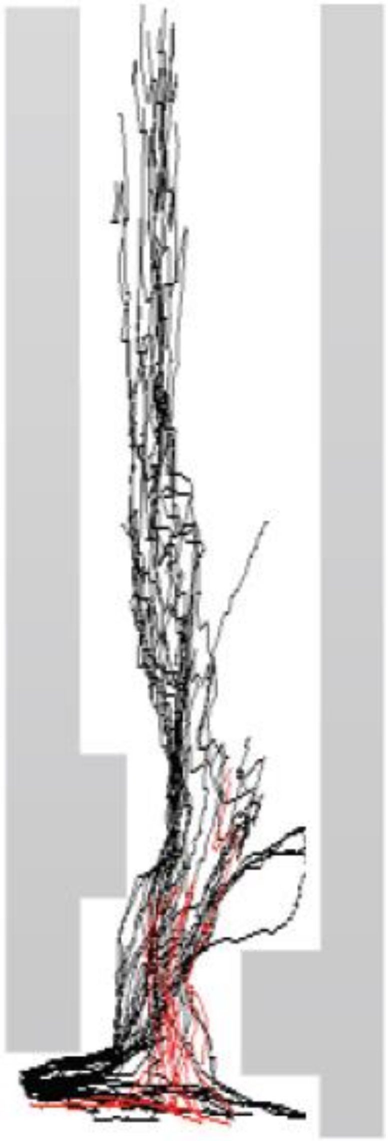


9. Density map at different time steps
10. Mean speed map at different time steps

Outputs (3/5)

- Visualising the trajectories of pedestrians and cars

(b)

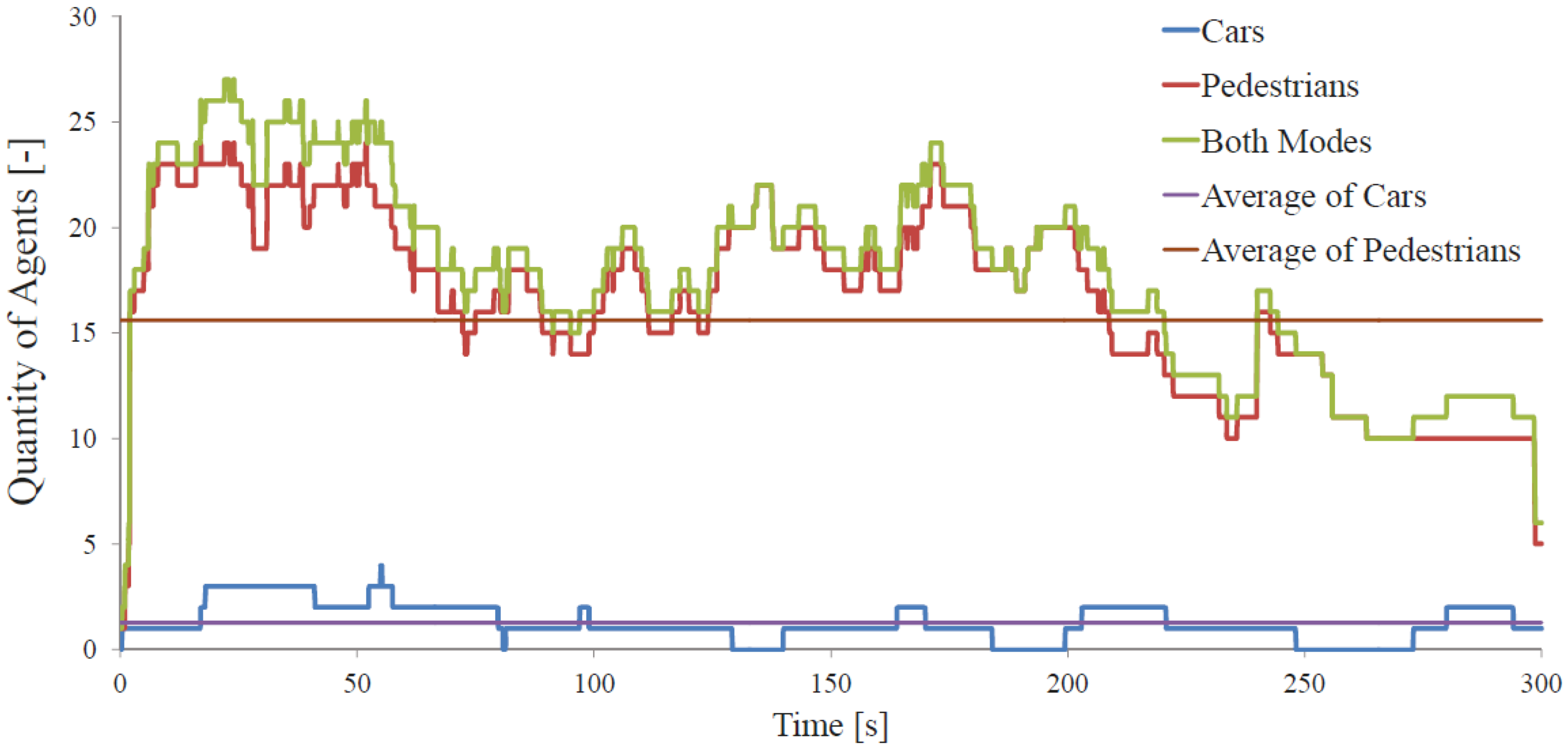


(a)

Trajectories of 150 pedestrians and 26 cars (a) perspective view and (b) top view

Outputs (4/5)

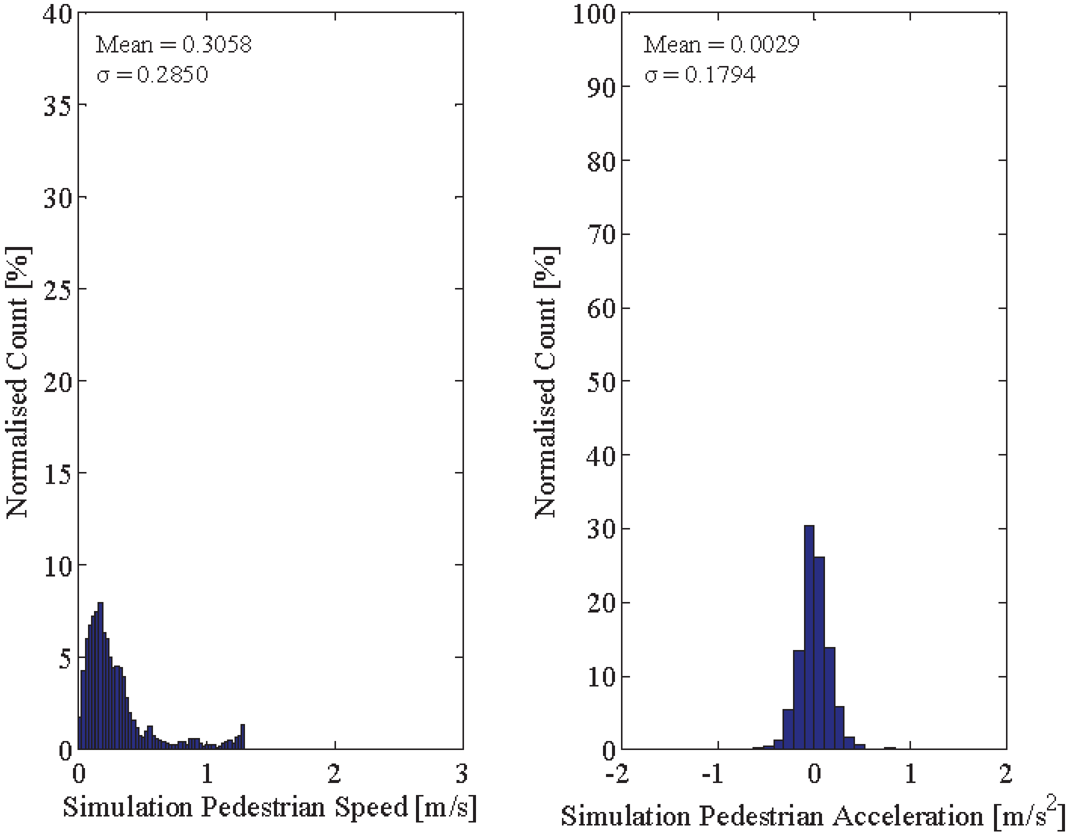
- Traffic demand of all road users



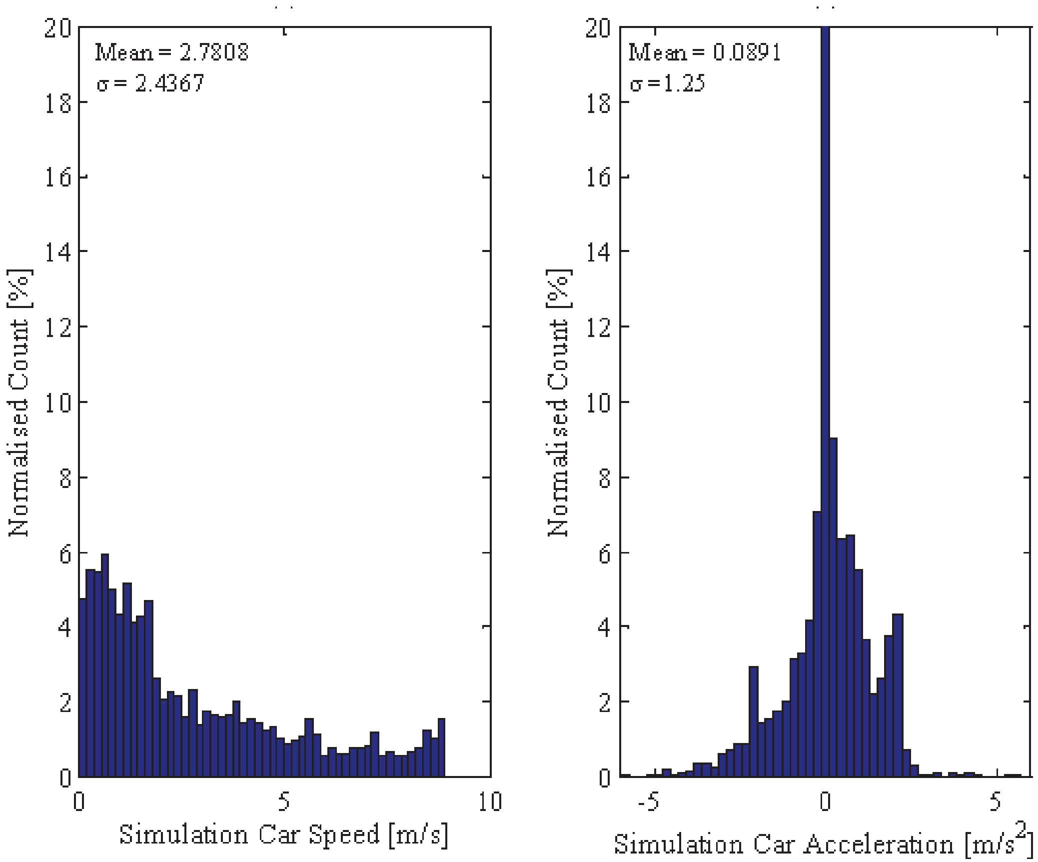
Traffic demand of road users on New Road (Brighton, UK)

Outputs (5/5)

- Road users' speed and acceleration histograms



(a)

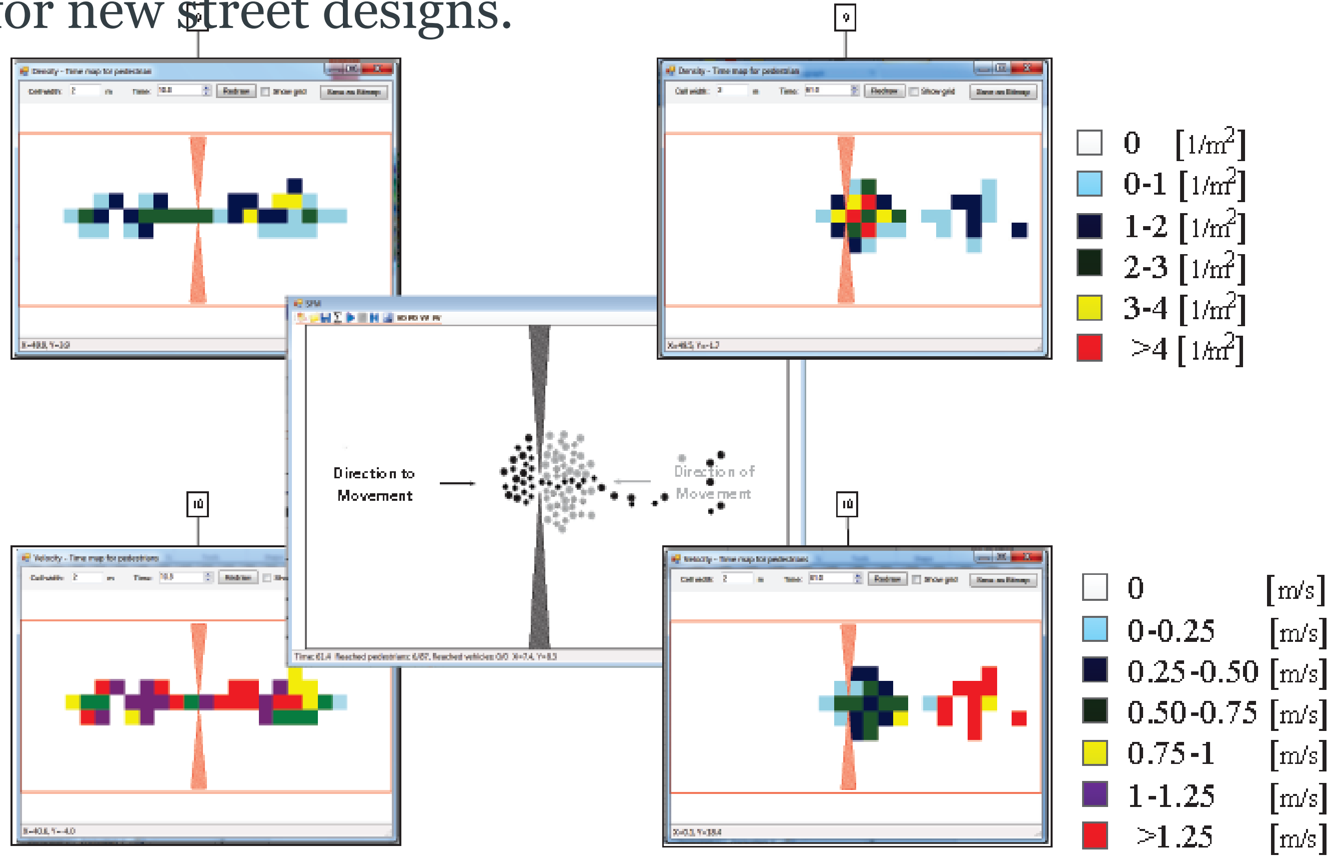


(b)

Speed and acceleration histograms of (a) Pedestrians and (b) Cars on New Road (Brighton, UK)

Development of **a new microscopic model for the simulation of shared space schemes** to:

- achieve solutions for optimal design features;
- gain knowledge about efficiency or safety challenges;
- make emission and exposure assessments for new street designs.



B. Anvari, M.G.H. Bell, P. Angeloudis, W.Y. Ochieng, "Calibration and Validation of A Shared space Model: A Case Study", *Transportation Research Record*, 2016.

What is next?

Safety investigation of the shared space model.

Modelling cyclists behaviours in shared spaces.

Modelling human-autonomous cars interactions.

Video mapping and spatial augmented reality.

UNIVERSITY OF Southampton

Many thanks for your attention.

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