Local performance measures of pedestrian traffic

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Outline

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Research motivation

Example: Public transport interchange stations

- Well functioning stations are important for the performance of the traffic system.
- An increasing number of people travel by public transport. (Or: We would like more people to do so)
- For efficient and comfortable transfers small stations are needed.

The Problem:

Small station + lots of people ⇒ **congestion**.

Congestion causes:

- Delay
- Discomfort

Where? How much? Why? Can we prevent it?

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Microsimulation

Microsimulation is a good tool for this problem since:

- People are different
  - Preferred speed and other characteristics,
  - Path preferences & limitations,
  - May perceive similar traffic situations differently.
- The infrastructure geometry can be almost arbitrary.
- The granularity and dynamics of pedestrian traffic is important in several situations.

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Output of microsimulation of pedestrian traffic

To answer Where? How much?, we must define measures describing the traffic situation

- We need to aggregate
  - Over time
  - Over replications
  - Over space (But not too much!)
- We need suitable measures of discomfort and delay
  - Theses should be localized in space to make it possible to find problems with the infrastructure.
- Nice to have mathematically convenient measures, e.g. continuous.

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Density in a fixed area

If the output of a microscopic simulation is seen as a sum of delta functions, the density in an area A is

$$\rho_A(t) = \frac{1}{A} \int_A \sum_i \delta\left(\mathbf{x}_i\left(t\right) - \mathbf{x}\right) d\mathbf{x}, \tag{1}$$

where $\mathbf{x}_i$ is the position of pedestrian i.

This measure is (possibly strongly) dependent on the choice of A.

Local density

Another possible definition of the density is

$$\rho_\sigma(\mathbf{x}, t) = \int_{\mathbb{R}^2} \sum_i w_\sigma\left(\mathbf{x} - \mathbf{x}'\right) \delta\left(\mathbf{x}' - \mathbf{x}_i(t)\right) d\mathbf{x}', \tag{2}$$

where $w_\sigma(\mathbf{x})$ is some normalized smoothing function, for example a Gaussian

$$w_\sigma(\mathbf{x}) = \frac{1}{2\pi\sigma^2} e^{-\mathbf{x}^2/2\sigma^2}, \tag{4}$$

with spatial scale σ.

The measure is still arbitrary, since σ is arbitrary.

But, we propose that there is a choice of σ that is more suitable than others.

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$$\rho(\mathbf{x}, t) = \sum_i w_\sigma(\mathbf{x} - \mathbf{x}_i(t)) \quad (3)$$

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Calibrations of the SFM

We are aware of two attempts to calibrate a complete model based on the SFM

– Zanlungo, F., Ikeda, T., and Kanda, T. (2011). "Social force model with explicit collision prediction". *Europhysics Letters* 93.6, p. 68005. DOI: 10.1209/0295-5075/93/68005.
– Johansson, A., Helbing, D., and Shukla, P. K. (2007). "Specification of the social force pedestrian model by evolutionary adjustment to video tracking data". *Advances in Complex Systems* 10.SUPPL. 2, pp. 271–288. DOI: 10.1142/S0219525907001355.

Both resulted in a spatial scale of the repulsive forces, $\sigma \approx 0.6\,\mathrm{m}$.

– Pedestrians closer than this interacts strongly.
– σ is a natural aggregation scale.

Local measures of delay and discomfort

We can also use this to define local measures of delay and discomfort:

Discomfort density

$$\Delta(\mathbf{x},t) = \int_{\mathbb{R}^2} \sum_{ij} F_{ij}(\mathbf{x}_i(t),\mathbf{x}_j(t))\delta(\mathbf{x}' - \mathbf{x}_i(t))w(\mathbf{x}-\mathbf{x}')\,\mathrm{d}^2\mathbf{x}'.$$

Acceleration density

$$A(\mathbf{x},t) = \int_{\mathbb{R}^2} \sum_{i} a_i\delta(\mathbf{x}' - \mathbf{x}_i(t))w(\mathbf{x}-\mathbf{x}')\,\mathrm{d}^2\mathbf{x}',$$

Delay rate density

$$\Gamma(\mathbf{x},t) = \int_{\mathbb{R}^2} \sum_{i} \left(1 - \frac{\mathbf{v}_i^p \cdot \mathbf{v}_i}{(v_i^p)^2}\right)\delta(\mathbf{x}' - \mathbf{x}_i(t))w(\mathbf{x}-\mathbf{x}')\,\mathrm{d}^2\mathbf{x}'$$

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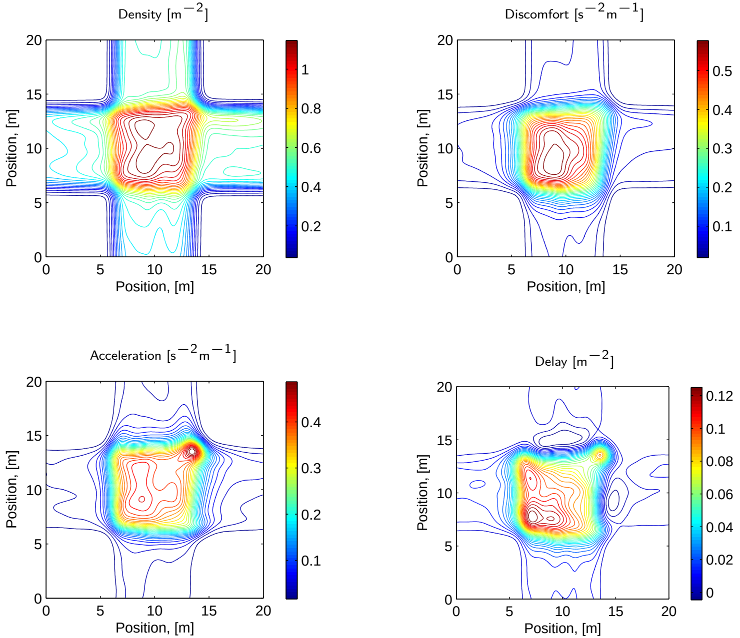
Crossing flows



Conclusions

- The proposed measures
  - Clearly expose structures in pedestrian traffic.
  - Contain different information.
- The measures reveal structural predictions of the social force model:
  - Significant negative delay downstream of intersecting flows.
  - Drifting of walkers along the intersecting flow.

Of course, only observations of real pedestrian traffic can determine if this is a problem or a success of the SFM.

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The preferred force

$$\mathbf{F}_i^p = \frac{1}{\tau}\left(\mathbf{v}_i^p\left(\mathbf{x}_i\right) - \dot{\mathbf{x}}_i\right), \tag{5}$$

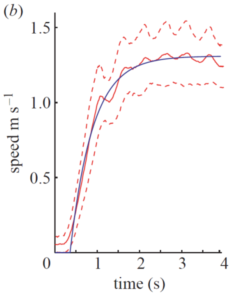
where

τ: Relaxation time

$\mathbf{v}_i^p(\mathbf{x}_i)$: Preferred velocity

$\dot{\mathbf{x}}_i$: Actual velocity

Role 1: Acceleration time scale

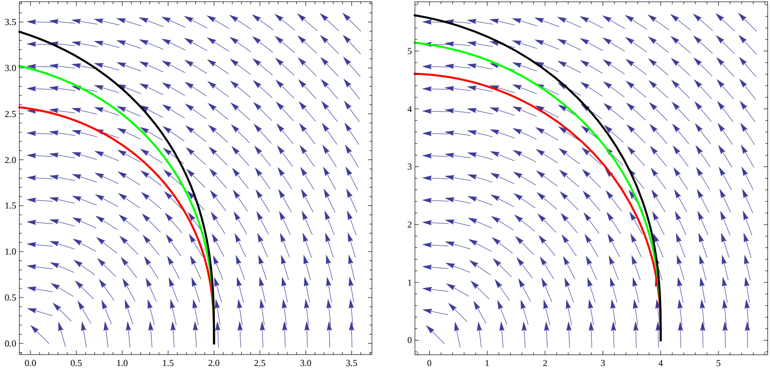


Moussaïd, M., Helbing, D., Garnier, S., Johansson, A., Combe, M., and Theraulaz, G. (2009). "Experimental study of the behavioural mechanisms underlying self-organization in human crowds". *Proceedings of the Royal Society B: Biological Sciences* 276.1668, pp. 2755–2762. DOI: 10.1098/rspb.2009.0405.

Role 2: Aggressiveness

In case of conflicts the evasive maneuvers are suppressed by a large $\mathbf{F}_i^p$.
A small τ gives a more aggressive agent compared to a large τ.

Role 3: Adapt to changes in the preferred direction



$\tau = \color{red}{0.3}, \color{green}{0.6}, 0.9\,\mathrm{s}$, $\mathbf{v}_i^p = 1.34\,\mathrm{m/s}$.

How important is the problem?

- Observe three scenarios where each of the roles are dominant.
- Calibrate the model using data from each of the scenarios separately.
- Compare.
- How much worse is the fit when more than one scenario is included in the calibration data?

Provide the agent with more information

In the Nomad model by Hoogendorn et al., the preferred force is instead

$$\mathbf{F}_i^{\mathrm{P}} = \left(I - \frac{1}{\eta} \frac{\partial \mathbf{v}_i^{\mathrm{P}}}{\partial \mathbf{x}}^T \right) \frac{1}{\tau} \left(\mathbf{v}_i^{\mathrm{P}} - \dot{\mathbf{x}}_i \right), \tag{6}$$

which provides the agent with local first order information on the spatial variation of the preferred velocity field.

- Can this help solving the problem?
- Does this improve the crossing flows situation?

Conclusions

- The relaxation time parameter has many seemingly conflicting roles, connected to:
  - Linear acceleration,
  - Aggressiveness,
  - Adapting to changes in the preferred direction.
- The importance of this problem can be estimated by comparing calibration results.
- The Nomad model may have partly solved the problem by providing the agents with more information.

Thank you!