Pedestrian flow characteristics based on individual trajectories

Marija Nikolić Bilal Farooq Michel Bierlaire

TRANSP-OR, Ecole Polytechnique Fédérale de Lausanne

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Content

- Interest & Motivation
- Methodology
- Preliminary results
- Conclusions and future work

Interest & motivation

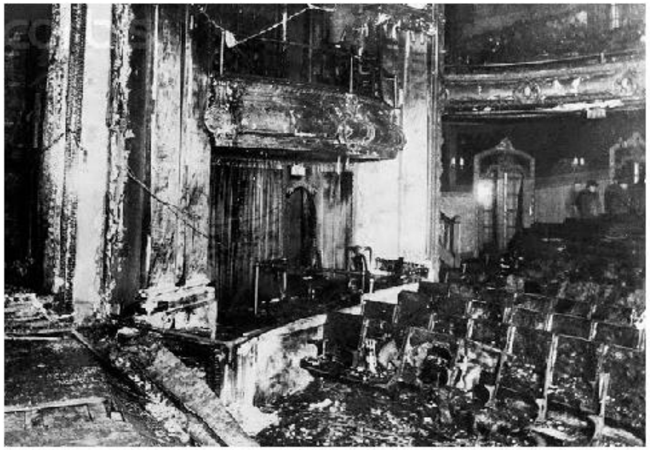
- Mathematical modeling of pedestrian dynamics
- Understanding and predicting the evolution of pedestrians
  - Efficient design of new facilities
  - Large events gathering a high number of people
  - Travel guidance
  - **Congestion**

Evacuation

More Than 950 Iraqis Die in Stampede on Baghdad Bridge

The New York Times

Iroquois Theatre fire, 605 people died



WIKIPEDIA
The Free Encyclopedia

1989: Football fans crushed at Hillsborough

BBC News

Congestion
Lausanne railway station

Related work

- Modeling approaches inspired by physics, artificial intelligence, biology, traffic flow theory
- Microscopic vs. macroscopic
  - Social force model (Helbing and Molnár, 1995)
  - Continuum models (Hughes, 2002)
- Aggregated vs. disaggregated
  - Social force model; Queuing model (Løvås, 1994)
    Discrete choice models (Antonini et al., 2006)
- Discrete vs. continuous
  - Cellular automata (Blue and Adler, 2001)
  - Continuum models (Hughes, 2002)

    …

Missing – detailed representation of congestion based on recent data

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Strategy
Step by step

- Evaluation of data potential
- Good estimation of congestion indicators
  - Density, flow, speed

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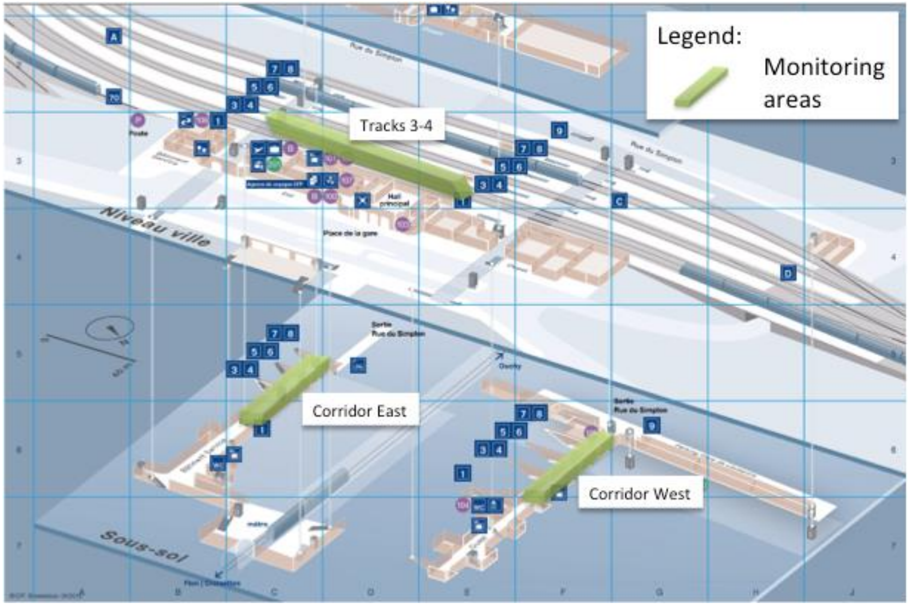
Step by step

- **Evaluation of data potential**
- Good estimation of congestion indicators
  - Density, flow, speed

Data collection



Source: (Alahi et al., 2013)

- 76 smart sensors capture flow at Lausanne train station
  - Corridors West (PIW) and East (PIE)
  - Tracks 3-4
- People are automatically:
  - Located in 3D
  - Tracked across time

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Data potential

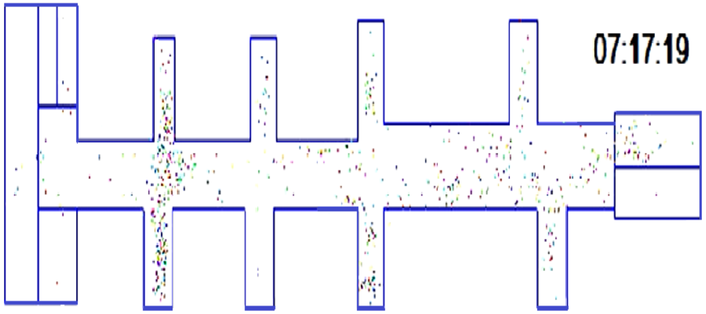
- Trajectory

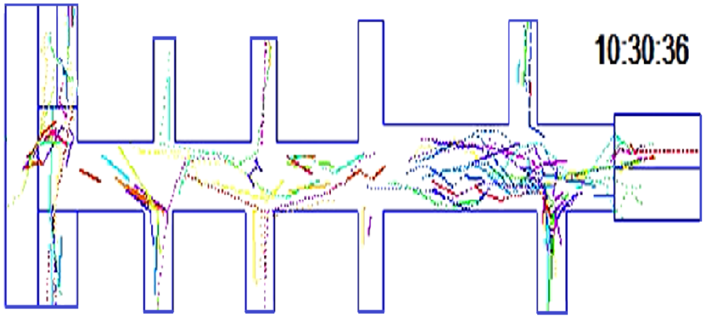
$$[time, x, y, pedestrian_{id}]$$

- Describe the essential parts of the pedestrian motion behavior
  - Interaction with moving and static objects (other pedestrians, obstacles)
  - Collective behavior and self-organization of pedestrian groups
  - Flow characteristics
- Model calibration and validation

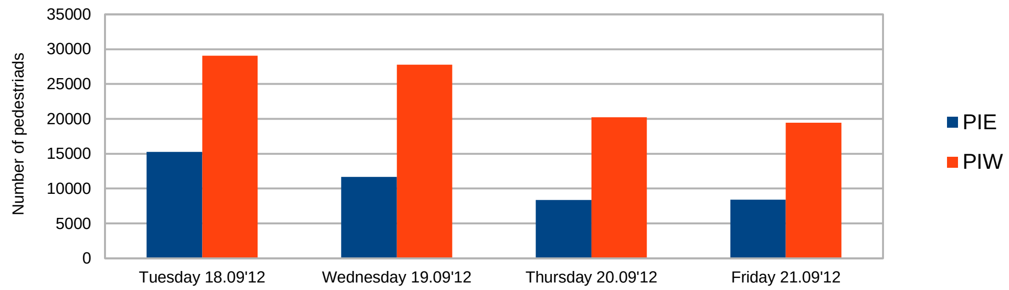
Exploratory data analysis

- Time-space patterns
- Qualitative analysis
  - Visualization tool
  - Macroscopic and microscopic aspects
- Quantitative analysis
  - Effects of congestion on pedestrian dynamics
  - Effects of different spatial aggregation levels on observables

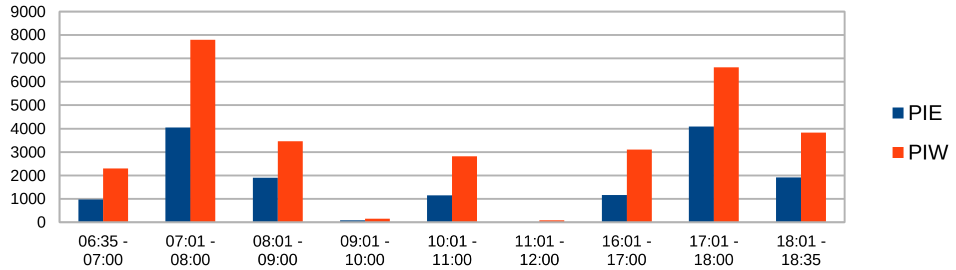




Critical time periods

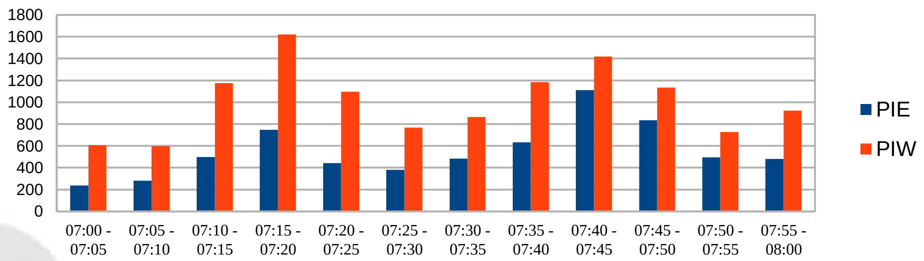


Decrease in traffic over the week days for PIE and PIW
Higher rate of traffic observed for PIW



Two critical periods of time:

- 7am - 8am
- 5pm - 6pm



The most critical time:

- From 7:10 am to 7:25 am
- From 7:35 am to 7:50 am

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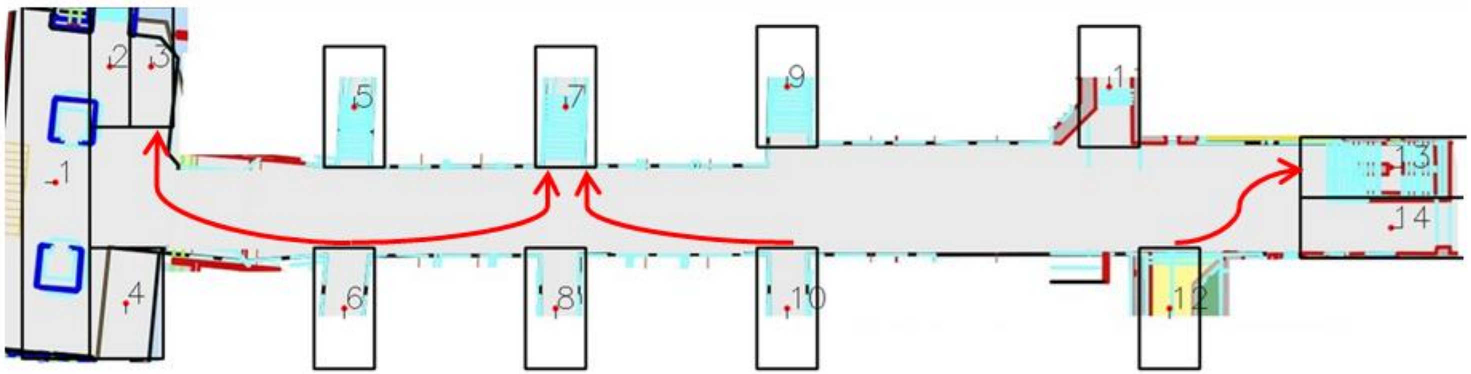
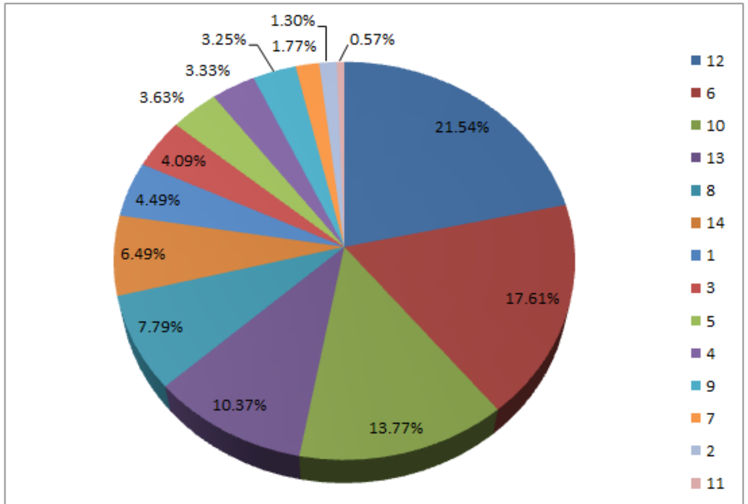
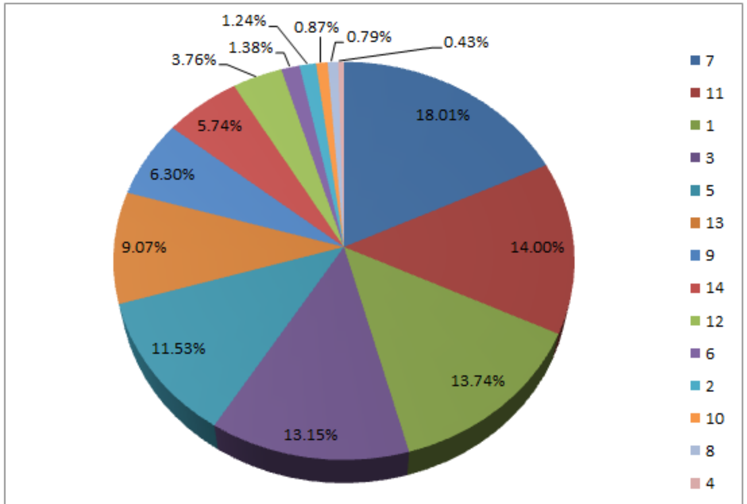
Frequently used paths and areas
PIW - peak day





Origins



Destinations

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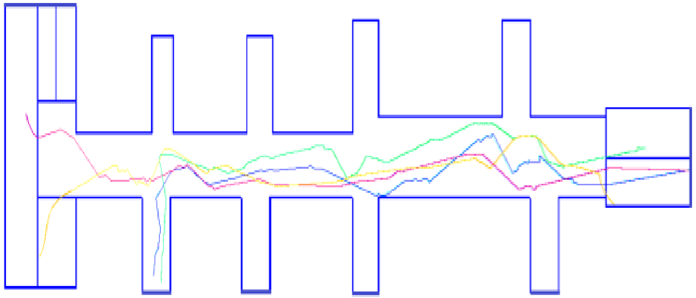
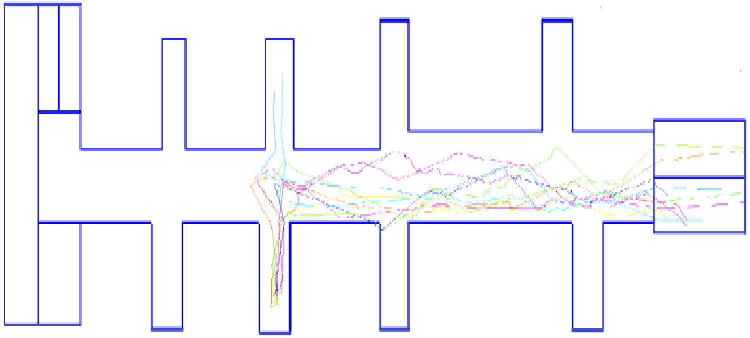
Qualitative data analysis
Microscopic

PIW corridor



18.09.2012. 10:30-10:32



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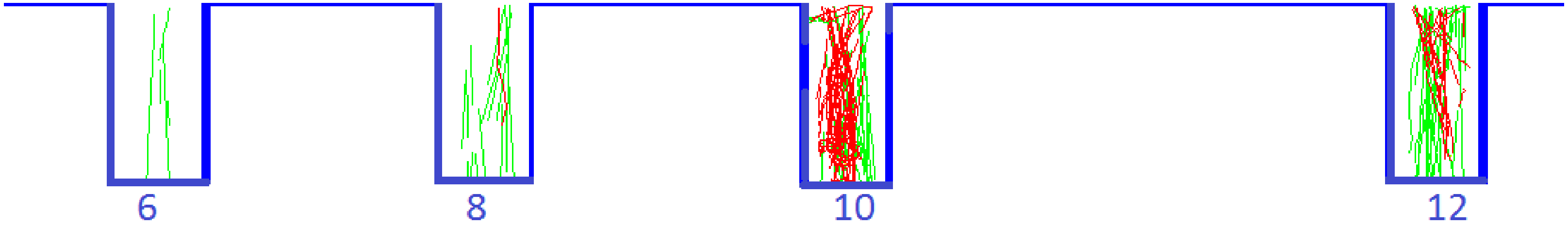
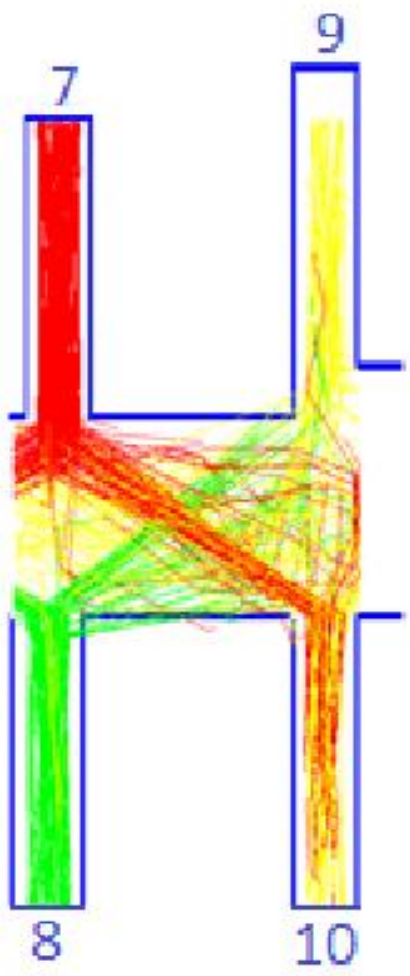
PIW stairs/ramps



Qualitative data analysis
Macroscopic

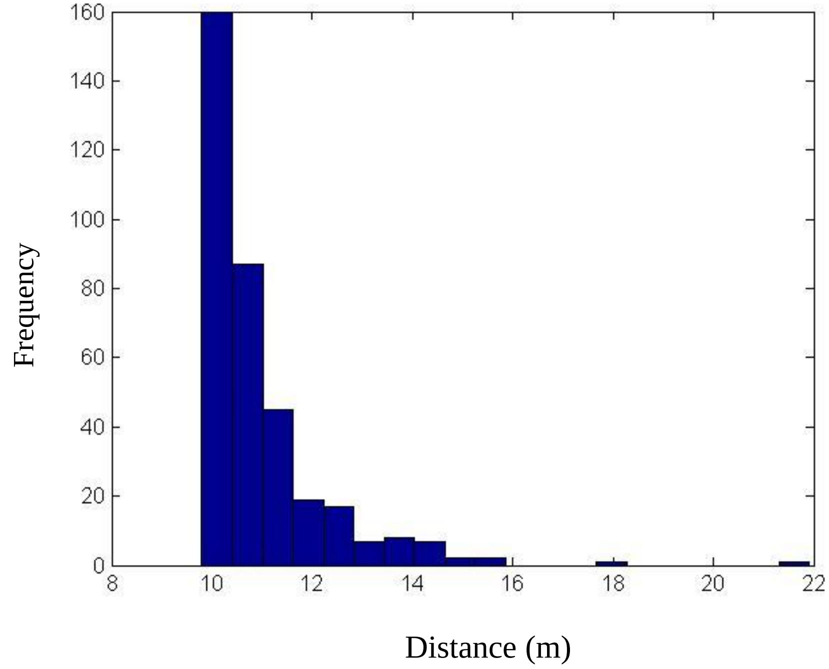


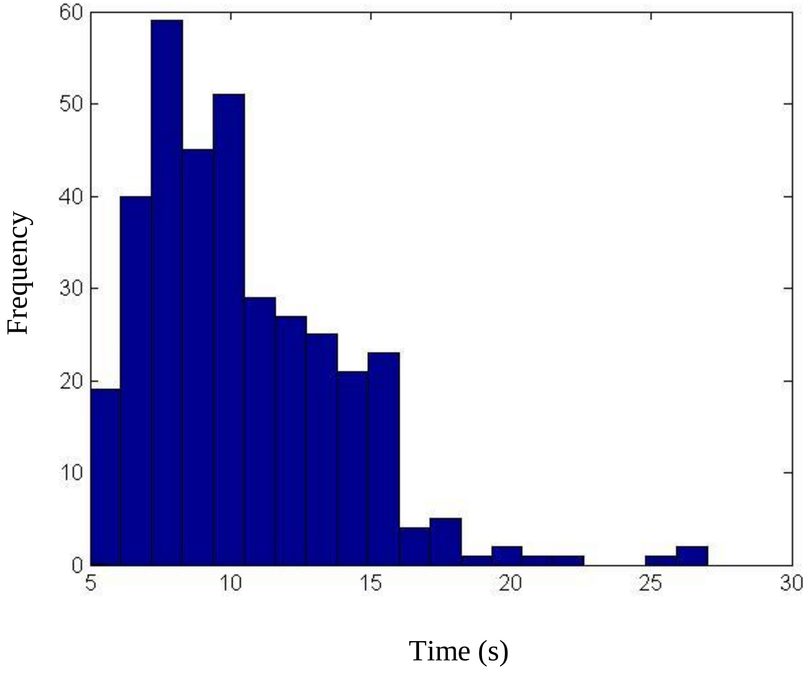
Lane formation

Hypothesis

– Lane allows for a more comfortable flow for people who walk in the same direction

Distance & time observables





For more details (Nikolic et al., 2013)

Strategy
Step by step

- Evaluation of data potential

- **Good estimation of congestion indicators**
  - **Density, flow, speed**

Pedestrian flow characteristics

- Density (k) – number of pedestrians present at some instant per unit of space
- Flow (q) – number of pedestrians passing a fixed point per unit of time
- Speed
  - Space mean speed (v_s) - average speed of pedestrians at some instant per unit of space
  - Time mean speed (v_t) - average speed of pedestrians passing through a given point per unit of time

Fundamental diagram: $q = v_s \cdot k$

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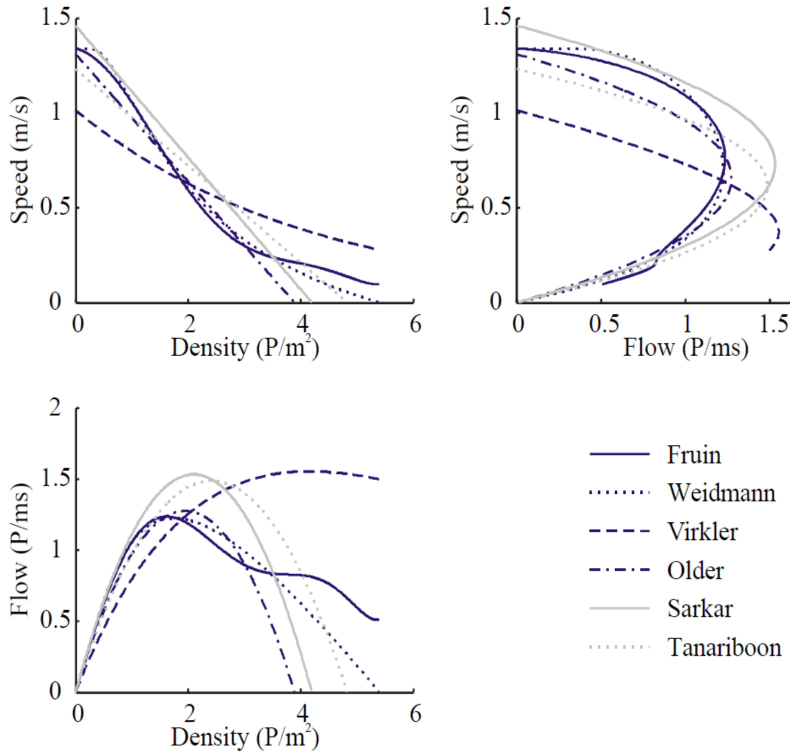
Fundamental diagram
Literature



Complex nature of pedestrian interactions

External factors

Social and psychological aspects

Different types of facilities

Different types of pedestrian flow

Measurement methods

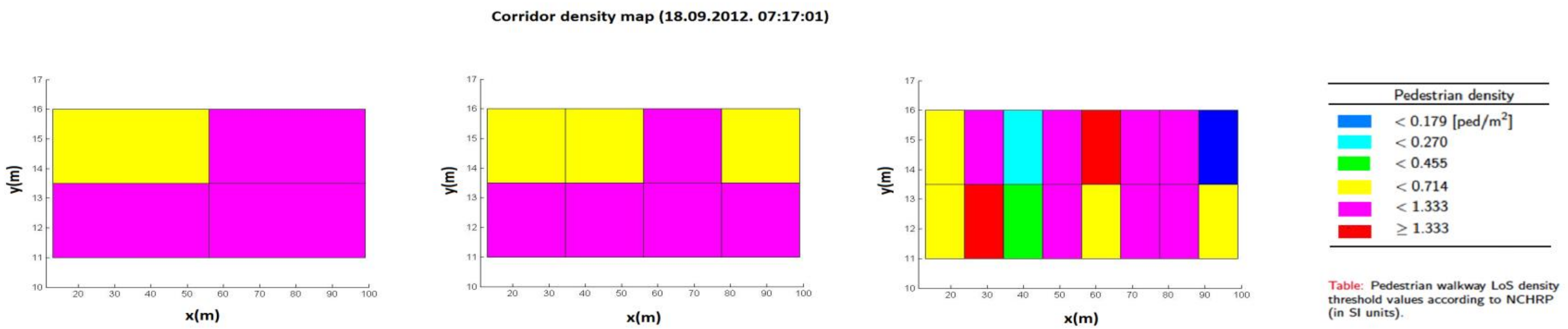
Source: (Daamen et al., 2005)

Fundamental diagram
Measurement methods

- Methods based on time aggregation
  - Mean value of flow
  - Time mean speed
- Methods based on space aggregation
  - Mean value of density
  - Space mean speed
- Time and space discretization

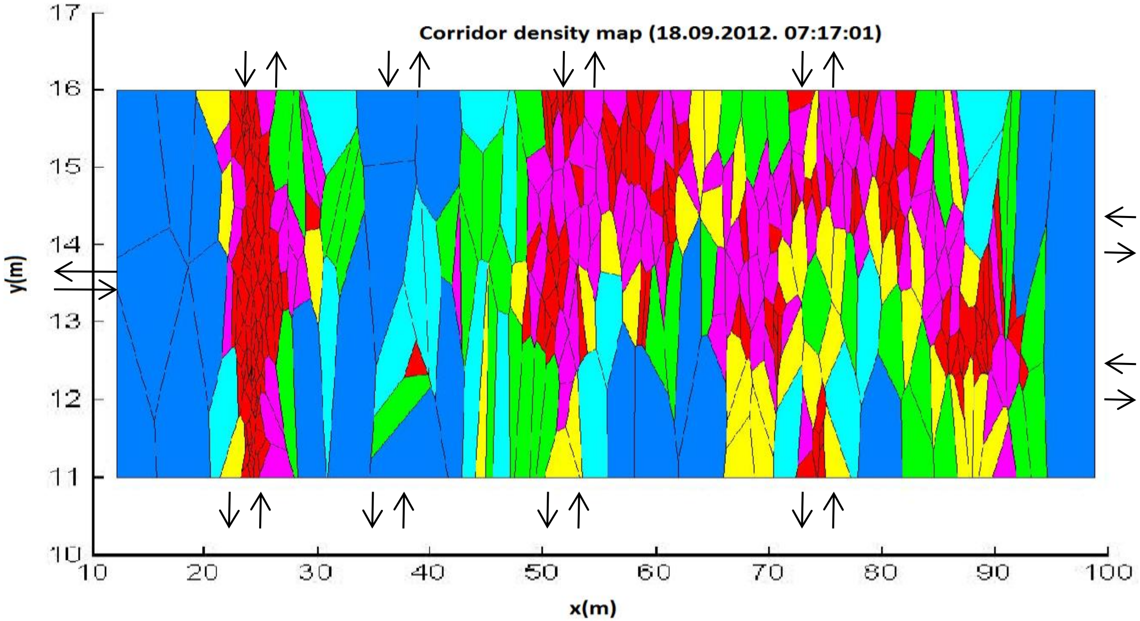
Grid space representation
Density

- The grid based method transforms the space into cell regions
  - Each cell is seen as entirely homogenous



- Cell sizes: 2.5m ×43m, 2.5m ×21.5m, 2.5m×10.75m
- *Modifiable areal unit problem*

Voronoi space representation
Density



Pedestrian density	
(blue)	< 0.179 [ped/m^2]
(cyan)	< 0.270
(green)	< 0.455
(yellow)	< 0.714
(magenta)	< 1.333
(red)	≥ 1.333

Table: Pedestrian walkway LoS density threshold values according to NCHRP (in SI units).

Voronoi space discretization

$$V_p(p_i) = \{p \mid \|p - p_i\| \leq \|p - p_j\|, j \in \{1, \dots, N_p\} \backslash \{i\}\}$$

N_p - number of pedestrians

p_i and p_j - pedestrians' position

- ✓ Flexible
- ✓ Better resolution in space

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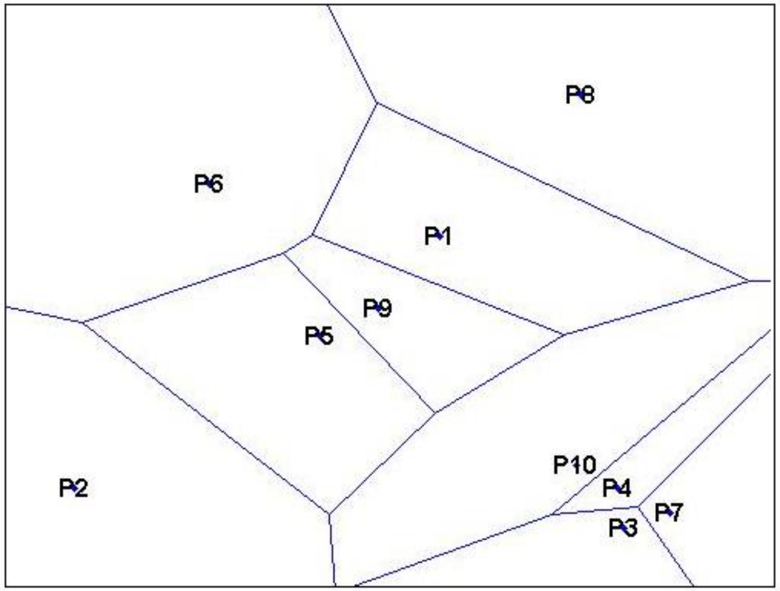
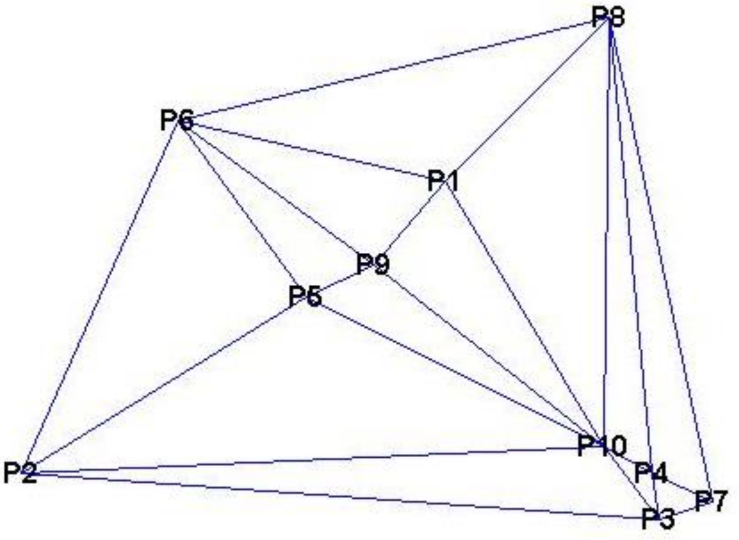
Voronoi space representation
Issues

- Small polygons allocated to pedestrians in very dense areas
  - Clustering based on Delaunay triangulation
  - Threshold distance: 0.1915m

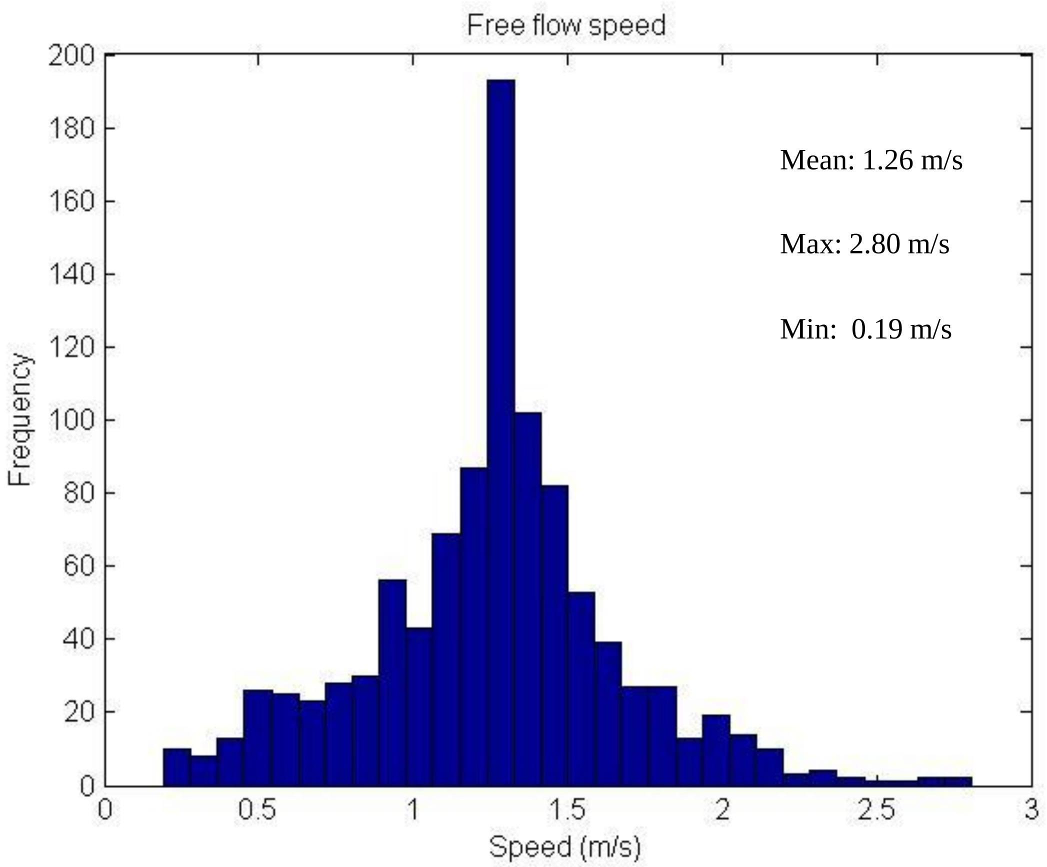


Voronoi diagram



Delaunay triandulation

Free flow speed
Empirical observations

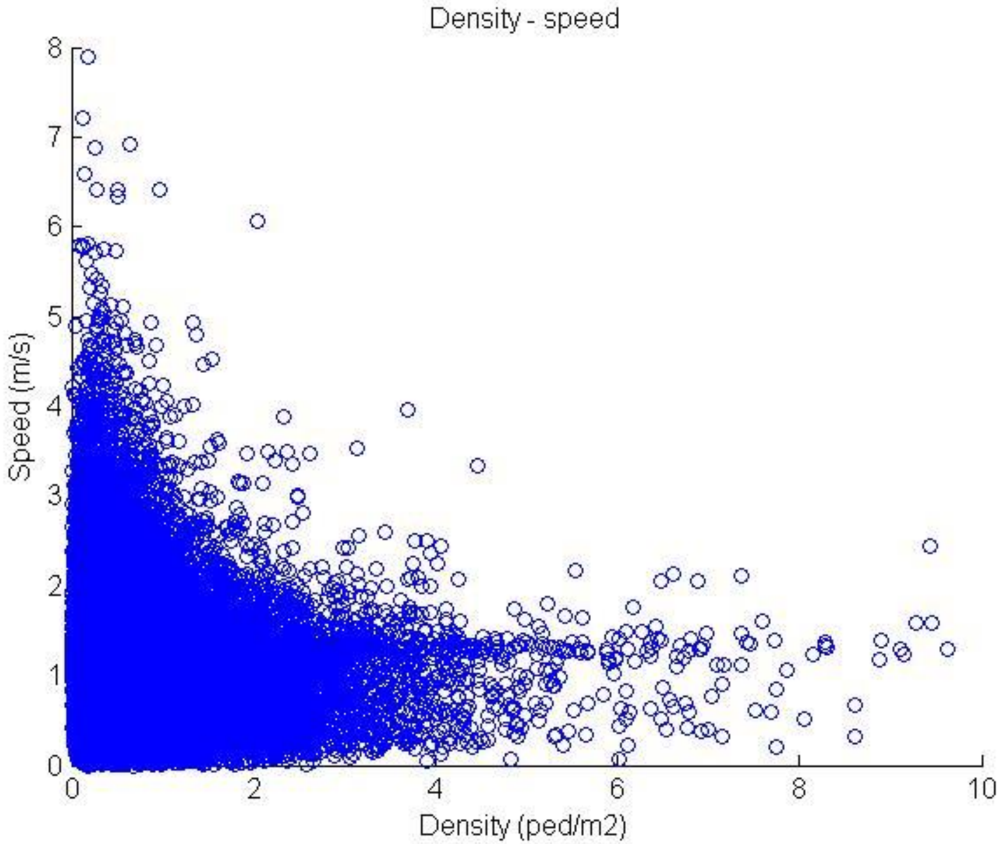


- The speed pedestrians walk with when they are not constrained
- Voronoi based personal region - density less than 0.05 ped/m^2

$$\overrightarrow{v_i}(t) = \frac{\overrightarrow{x_i}(t+\Delta t) - \overrightarrow{x_i}(t-\Delta t)}{2 \cdot \Delta t}$$

- Literature (Daamen et al., 2006)
  - Mean: 1.34 m/s
  - Max: 1.65 m/s
  - Min: 0.97 m/s

Speed-density relationship
Empirical observations



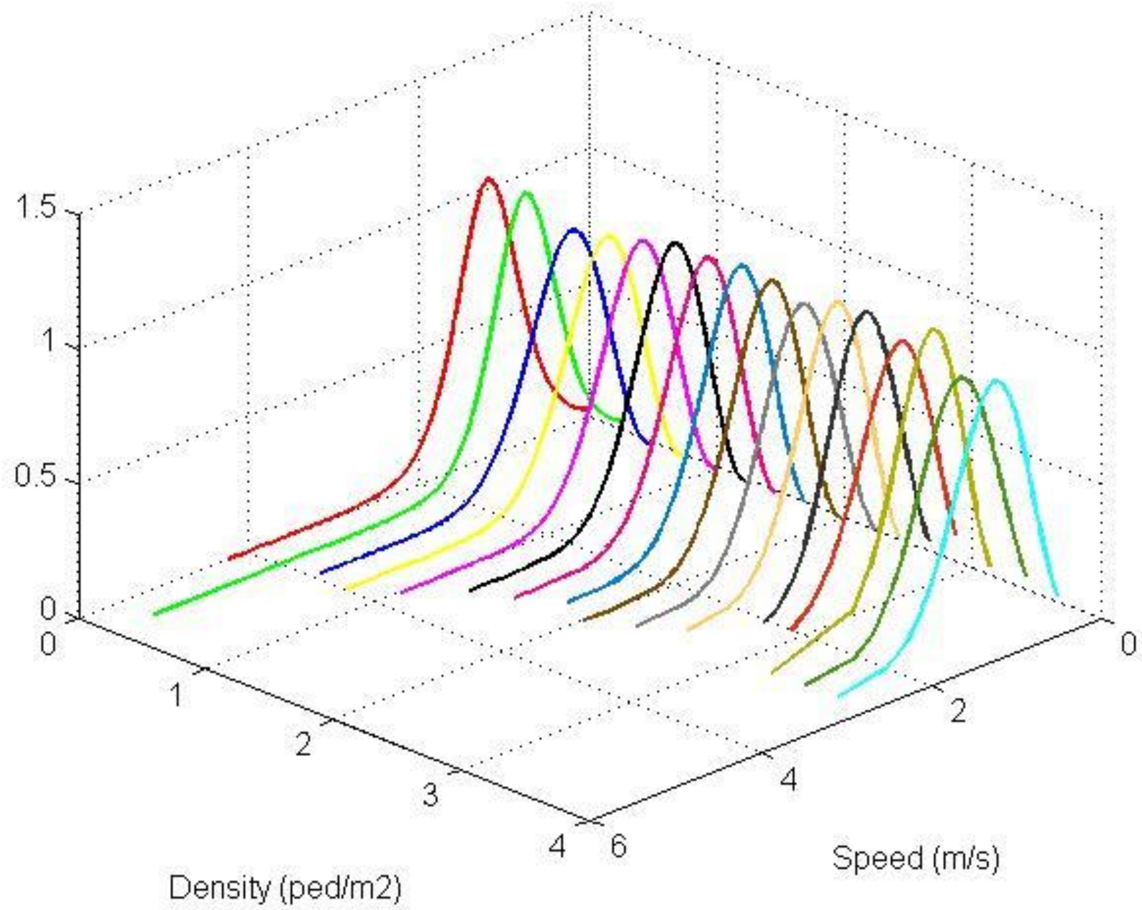
Density: $\frac{1}{A_i}$

A_i-personal area assigned to pedestrian i

Speed: $\vec{v_i}(t) = \frac{\vec{x_i}(t+\Delta t) - \vec{x_i}(t - \Delta t)}{2 \cdot \Delta t}$

$\Delta t = 0.5s$

Probabilistic speed-density model



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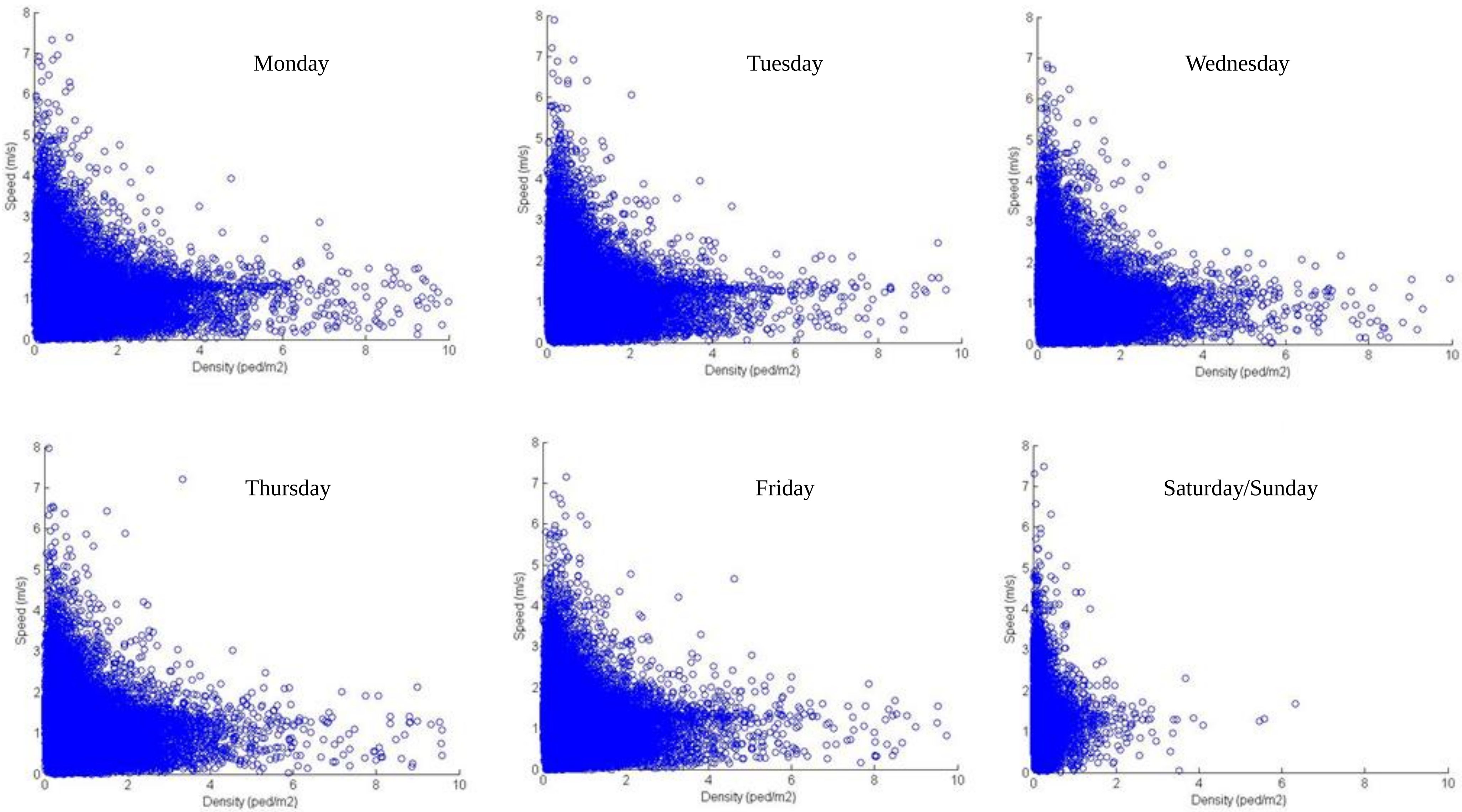
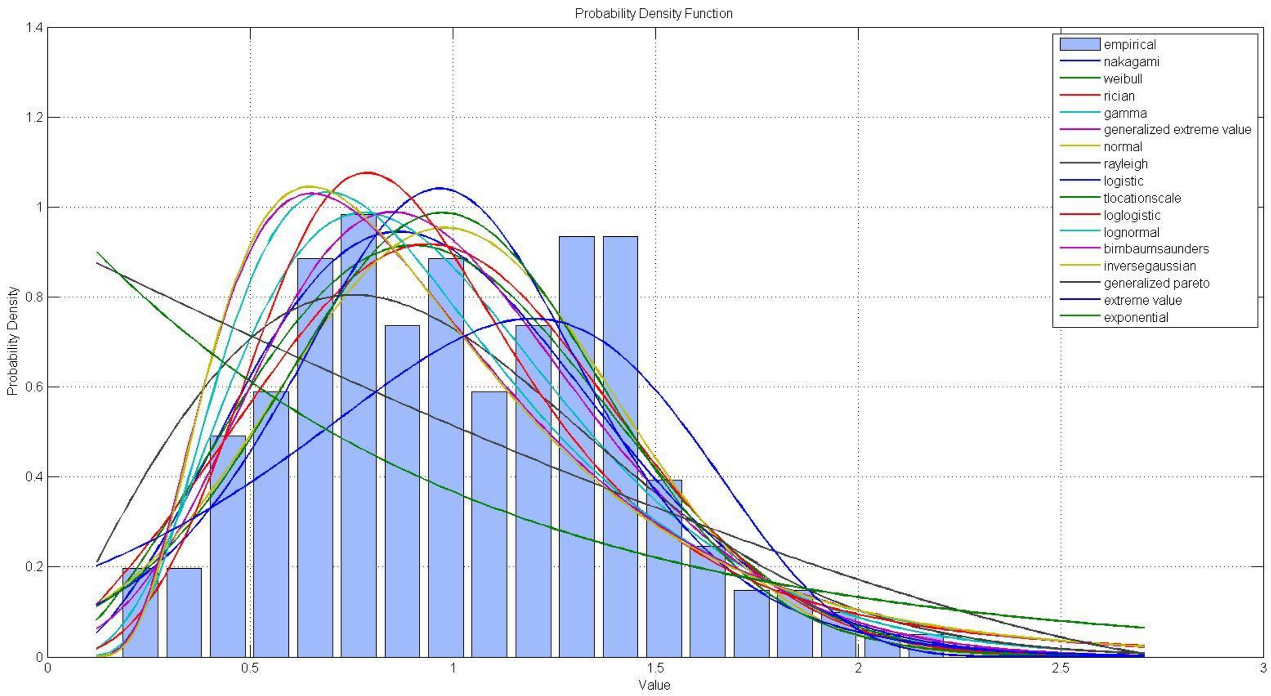
Weekly change of speed-density relationship



Speed distribution
Maximum likelihood

Density levels (ped/m²)

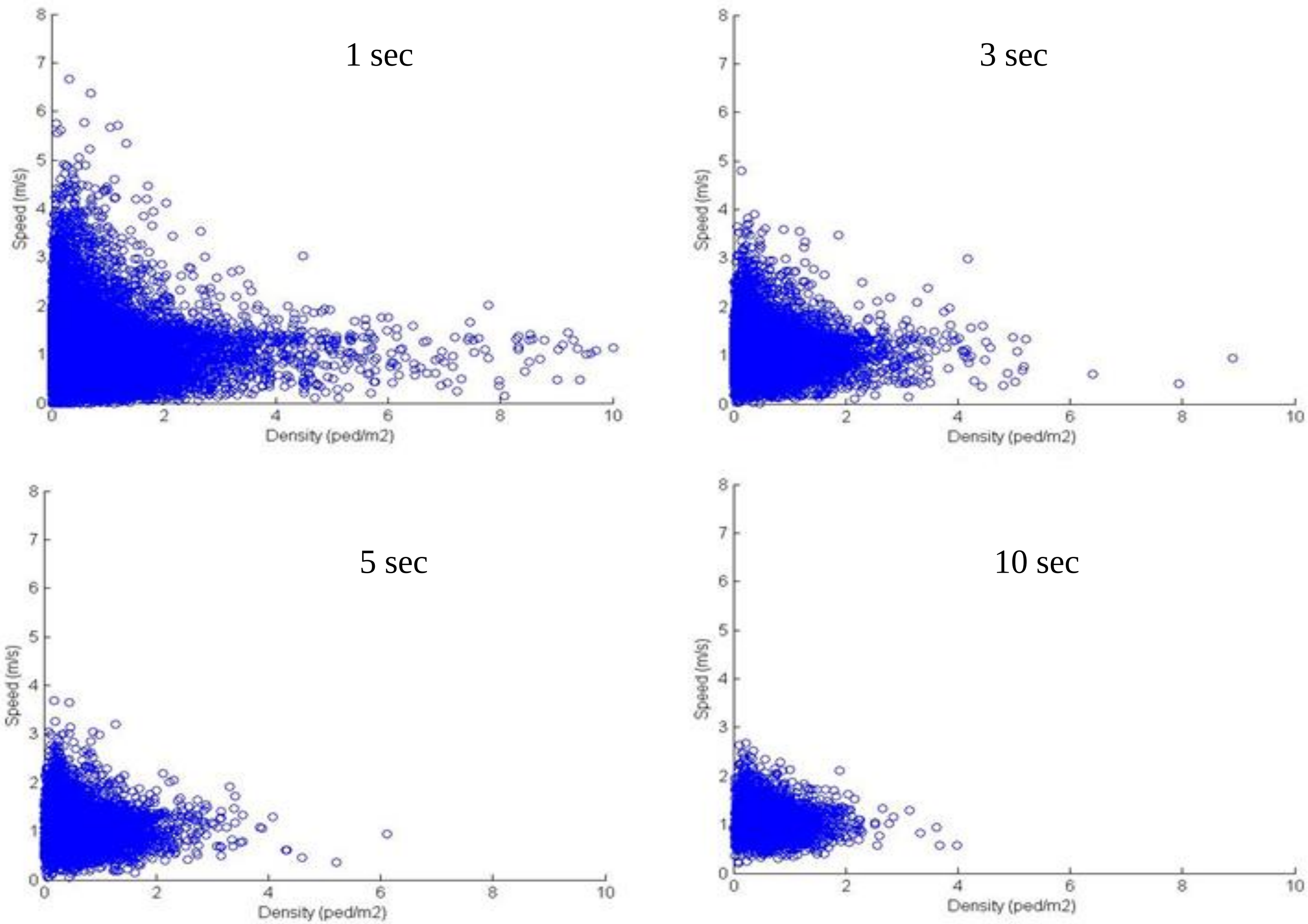
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1
1 - 1.25
1.25 - 1.5
1.5 - 1.75
1.75 - 2
2 - 2.25
2.25 - 2.5
2.5 - 2.75
2.75 - 3
3 - 3.25
3.25 - 3.5
3.5 - 3.75
≥ 3.75



Goodness of fit

- Chi-squared test
  - $\mathcal{X}^2 = \sum_i [(O_i - E_i)^2 / E_i]$
  - Null hypothesis: a statistical (theoretical) model fits a set of empirical observations
  - Result: rejected at 0.05 level of significance
- Fitting does not explain!
  - Addition of explanatory variables

Speed-density relationship
Effects of time aggregation



Time discretization

- Voronoi based
  - Fixed number of pedestrians within each time interval
- Motivation
  - Consistent with the philosophy of space decomposition
  - Observables have comparable statistical accuracy
  - Independent of the occurring flow

Conclusion

- High data potential
  - Behavioral and flow aspects
- Voronoi representation of space and time
  - Consistent philosophy for time and space decomposition
  - Good space resolution
  - Independent of the occurring flow
- Probabilistic fundamental diagram
- Lot of work need to be done!

Future work

- Voronoi based space representation
  - Dealing with obstacles

- Voronoi based time representation
  - Investigation of appropriate time discretization

- Probabilistic fundamental diagram

THANK YOU

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