Spatial tessellations of pedestrian dynamics

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Content

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

Interest & motivation

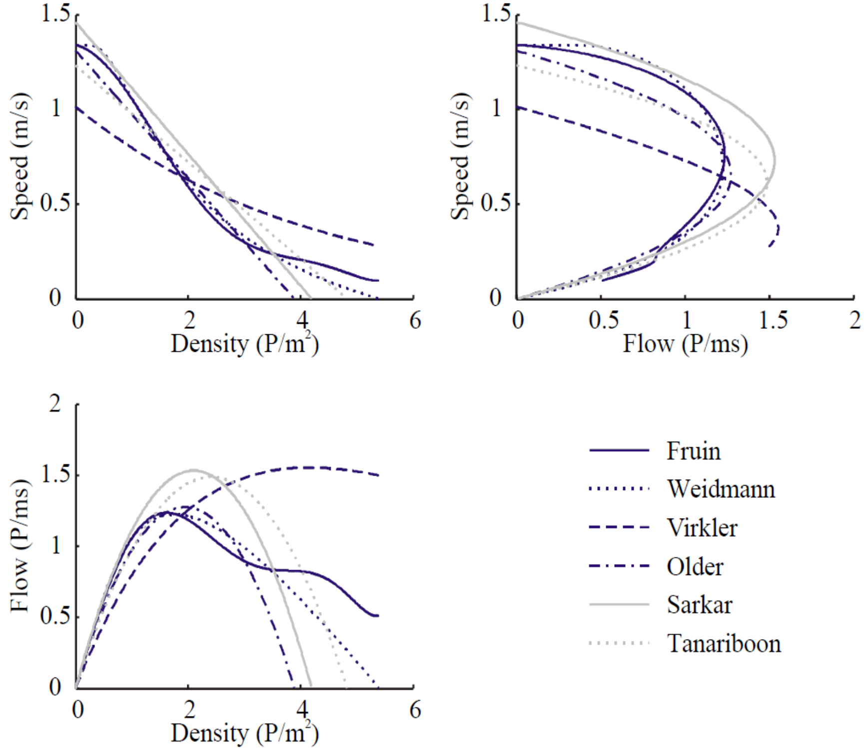
- Mathematical framework for detailed characterization of pedestrian flow indicators
- Understanding and predicting pedestrian flows
  - Efficient design of new facilities
  - Large events gathering a high number of people
  - Travel guidance
  - Congestion

Lausanne railway station

Related work 1/2

- Models of pedestrian flow and behavior
  - Social force model (Helbing and Molnár, 1995)
  - Continuum model (Hughes, 2002)
  - Cellular automata (Blue and Adler, 2001)
- Empirical studies
  - Collective effects and self-organization phenomena
    - (Navin and Wheeler, 1969; Daamen and Hoogendoorn, 2003; Helbing et al., 2007; Schadschneider et al., 2008)
  - Quantitative analyses of pedestrian flow characteristics
    - (Fruin and Strakosch, 1987; Lam and Cheung, 2000; Helbing et al., 2001; Kretz et al., 2006; Wong et al., 2010; Rastogi et al., 2013)
  - Fundamental diagram
    - (Schadschneider et al., 2008; Zhang, 2012)

Related work 2/2

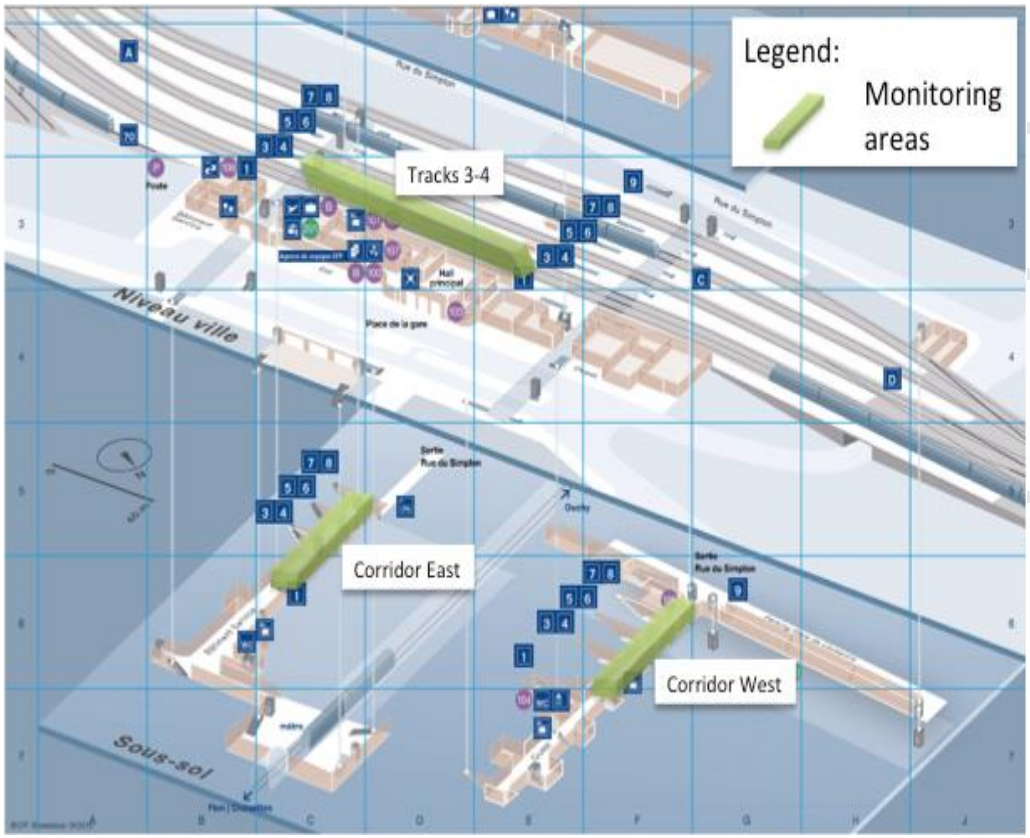


Source: (Daamen et al., 2005)

Contradictory empirical data base

- Complex nature of pedestrian interactions
- External factors
- Social and psychological aspects
- Different types of facilities
- Different types of pedestrian flow
- Measurement methods

Data collection



Source: (Alahi et al., 2013)

- Case study: Gare de Lausanne
- Depth sensors based pedestrian tracking
- Vision processing outcome

$(t, x(t), y(t), pedestrian_{id})$

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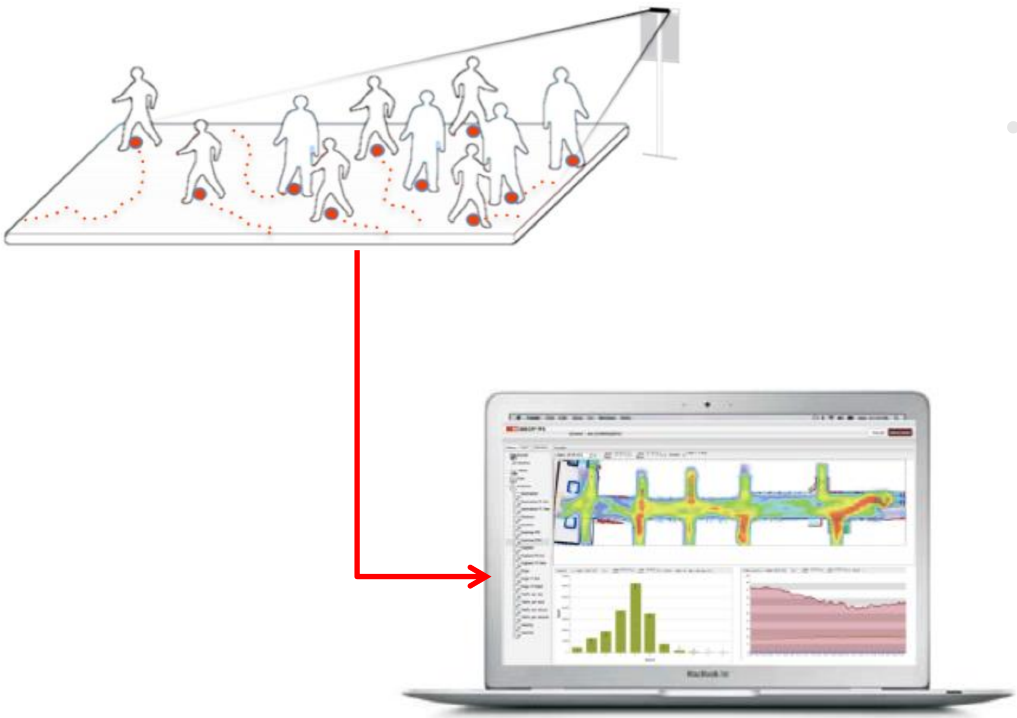
Data potential



- Pedestrian flow characteristics
- Pedestrian behavior
  - Interaction with moving and static objects
  - Collective behavior
  - Self-organization of pedestrian groups

Model calibration and validation

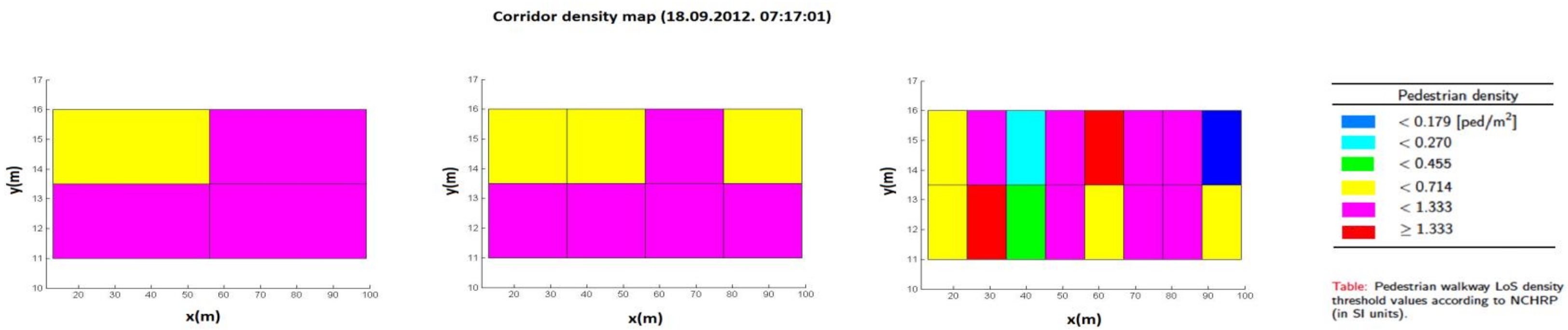
Flow characteristics

- Density (k) – number of pedestrians present at some instant per unit of space
- Flow (q) – number of pedestrians passing a fixed cross-section 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: $q = v_s \cdot k$

Grid space representation
Density map

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



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

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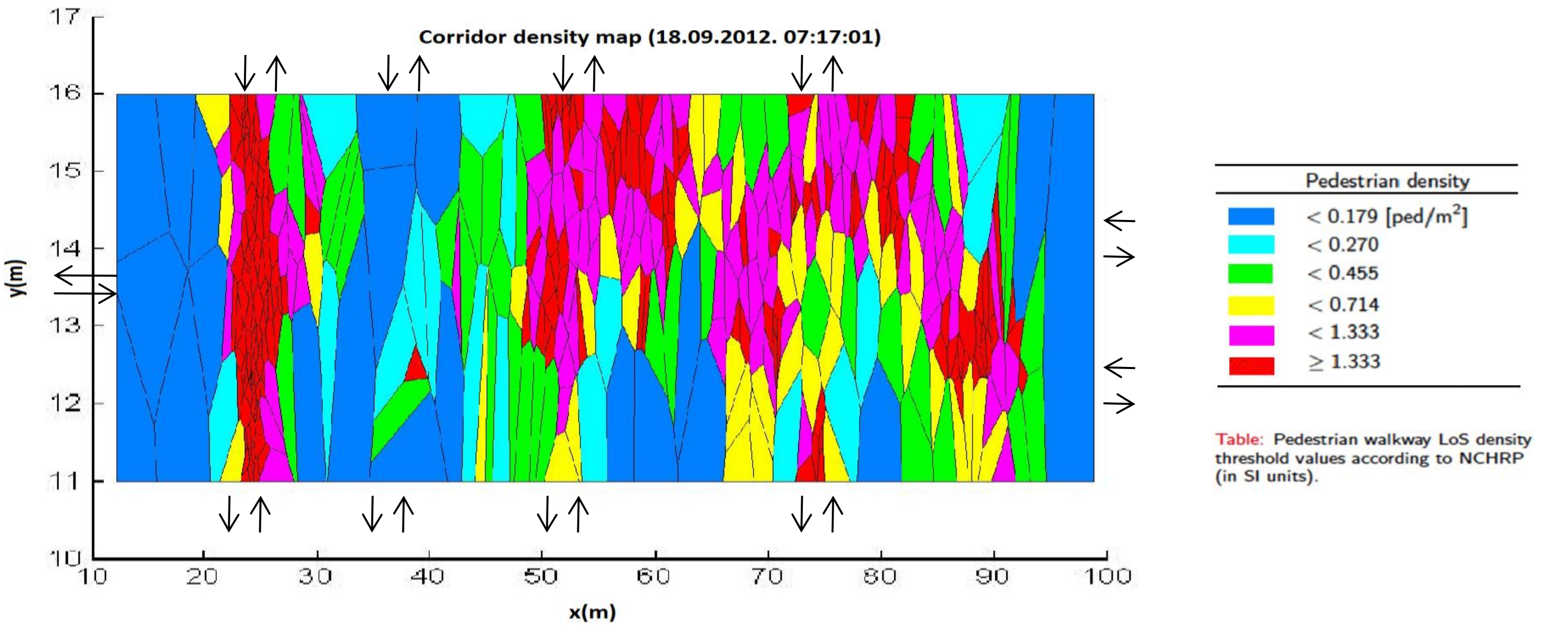
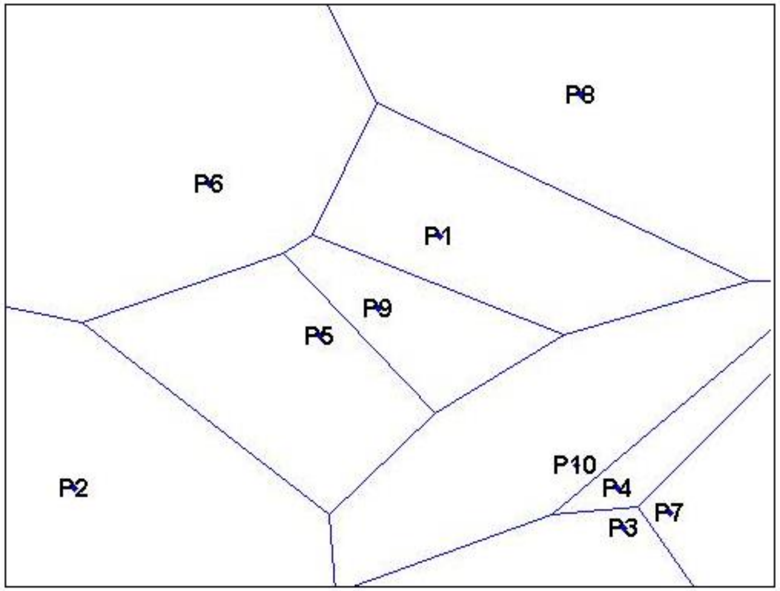
Voronoi space representation
Density map



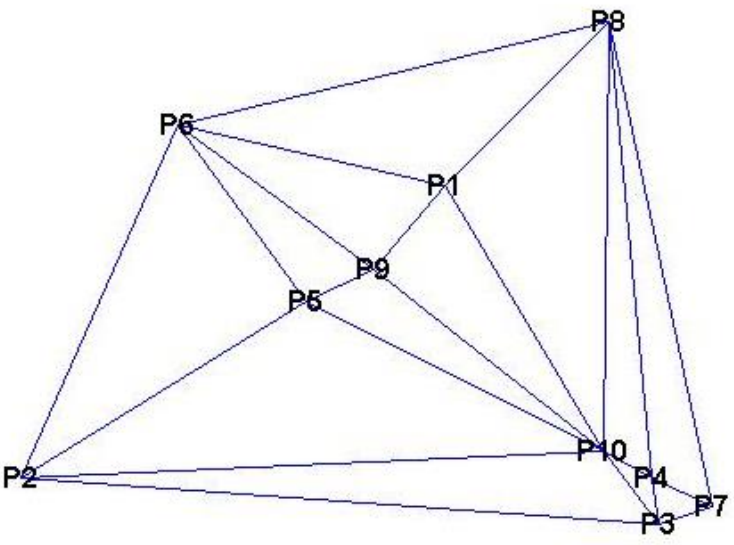
- Voronoi cell
  - $V(p_i) = \left\{ p \,\middle|\, \|p - p_i\| \leq \|p - p_j\|, i \neq j \right\}$
- Voronoi diagram
  - $V = \{V(p_1) \cap RoI, V(p_2) \cap RoI, \ldots, V(p_n) \cap RoI\}$

Merging cells

- Issue: small polygons allocated to pedestrians in very dense areas
  - Clustering based on Delaunay triangulation $d(pi, pj) < \delta, \forall i, j$
  - Weight associated to the corresponding space w_i

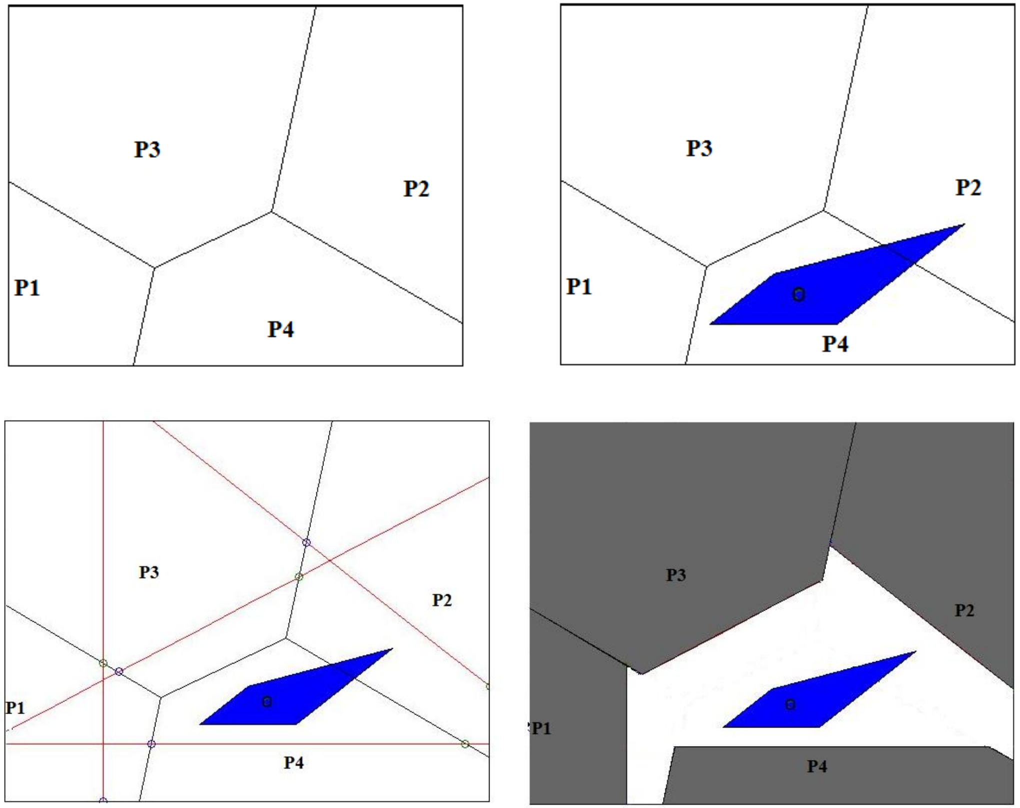


Voronoi diagram



Delaunay triandulation

Dealing with obstacles



- Voronoi assumption
  - It is possible to connect two generator points by a straight line
- Voronoi diagram for points & Voronoi diagrams for areas

$$d(p_i, O) = \min_{o_j}\{\|p_i - o_j\| | o_j \in O\}$$

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Pedestrian flow indicators

- Space-time representation

$$p_i = (x_i, y_i, t_i)$$

- Density

$$k(p_i) = \frac{w_i}{|V(p_i)|}$$

- Speed

$$v_s(p_i) = \frac{\|p_i(t_i - \Delta t) - p_i(t_i + \Delta t)\|}{2 \cdot \Delta t}, \Delta t = 0.5s$$

w_i - weight corresponding to the group of pedestrians

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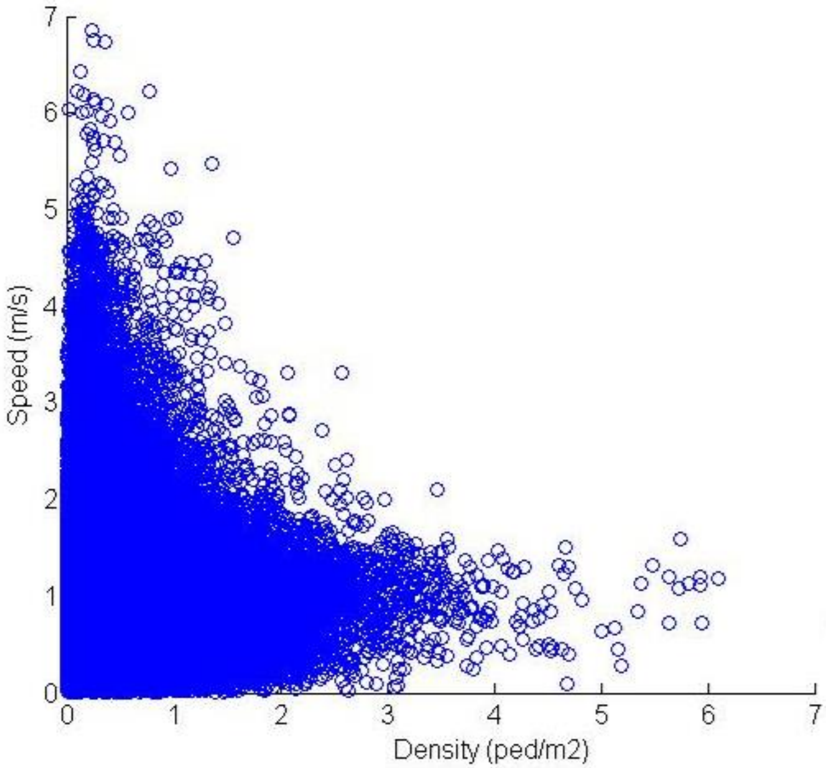
Empirical speed-density relationship



Density

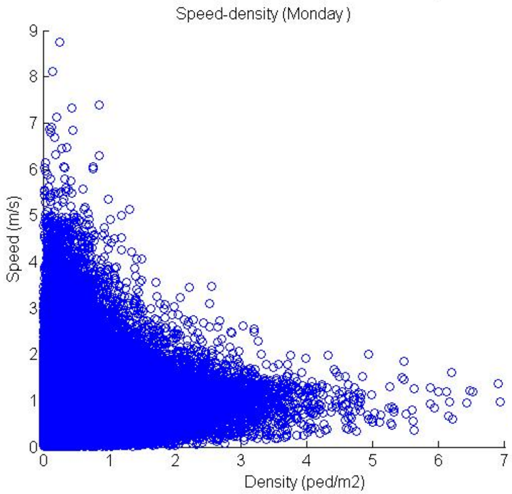
$$k(p_i) = \frac{w_i}{|V(p_i)|}$$

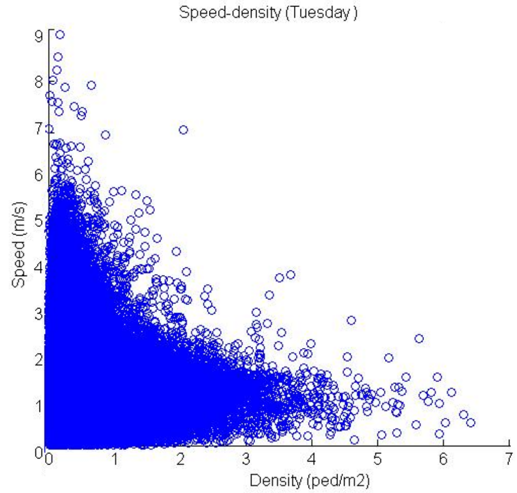
Speed

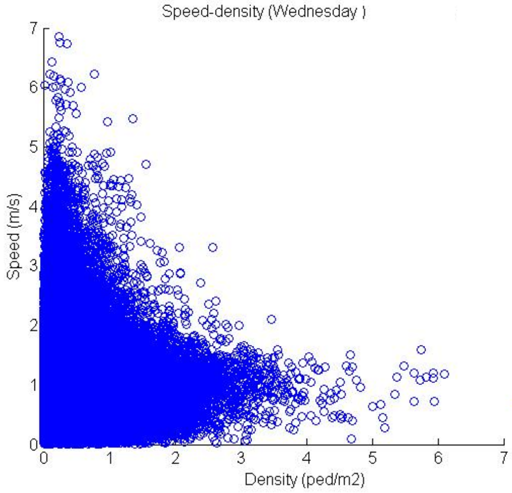
$$v_s(p_i) = \frac{\|p_i(t_i - \Delta t) - p_i(t_i + \Delta t)\|}{2 \cdot \Delta t}$$

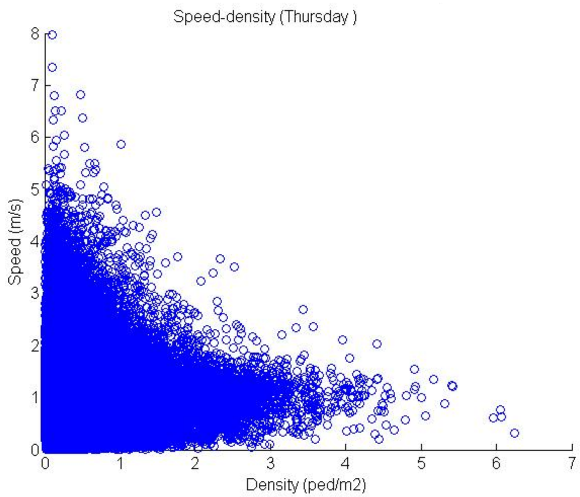
$$\Delta t = 0.5s$$

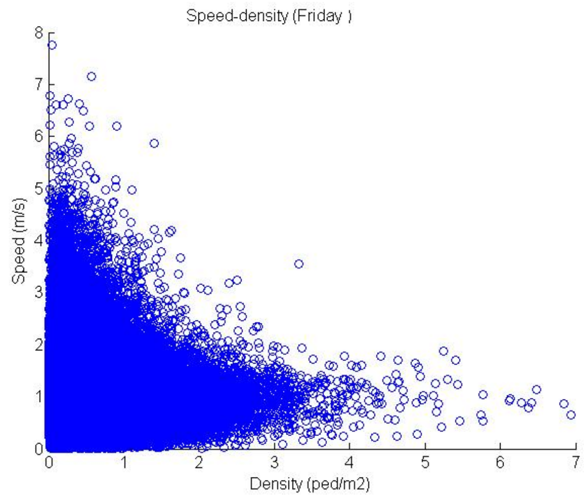
Speed-density profiles



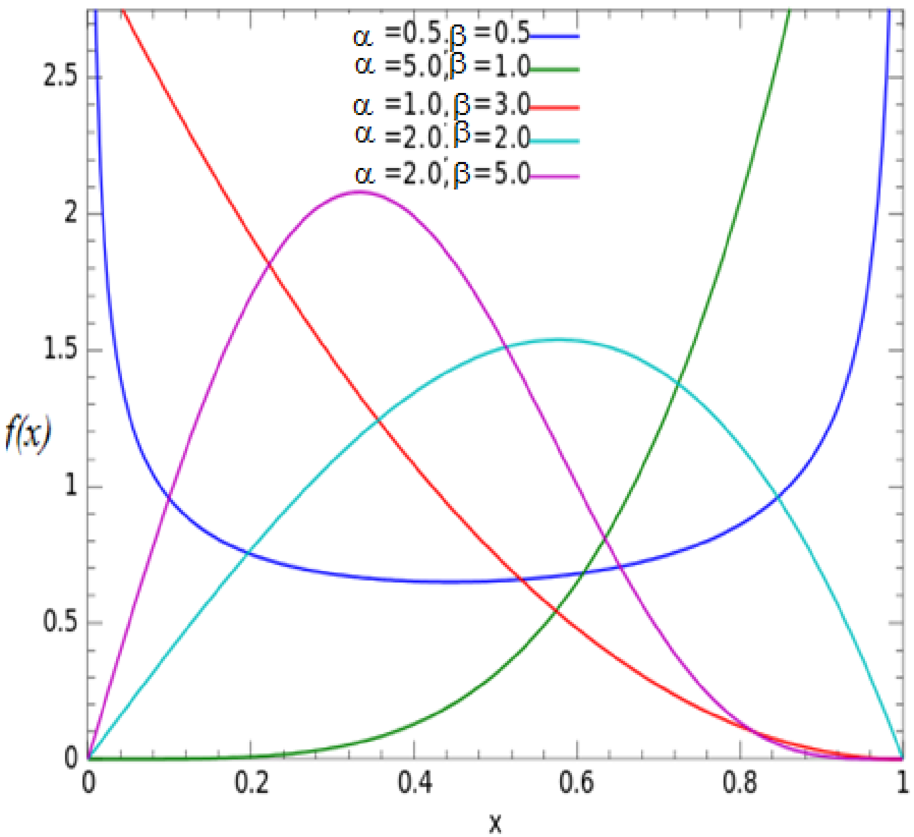








Kumaraswamy distribution

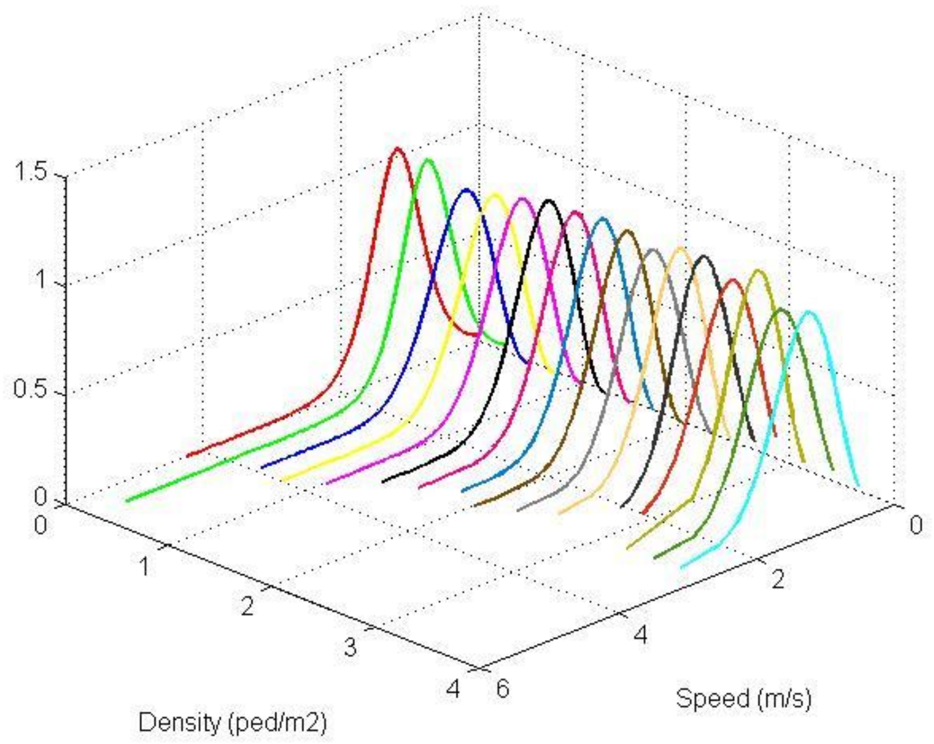


- Defined on the bounded region $[l, u]$
- Two non-negative shape parameters α and β
- The simple closed form of pdf $f(x)$ and cdf $F(x)$

$$f(x) = \frac{\alpha \cdot \beta \cdot (x-l)^{\alpha-1} \cdot ((u-l)^{\alpha} - (x-l)^{\alpha})^{\beta-1}}{(u-l)^{\alpha\beta}}$$

$$F(x) = 1 - (1 - \left(\frac{x-l}{u-l}\right)^{\alpha})^{\beta}$$

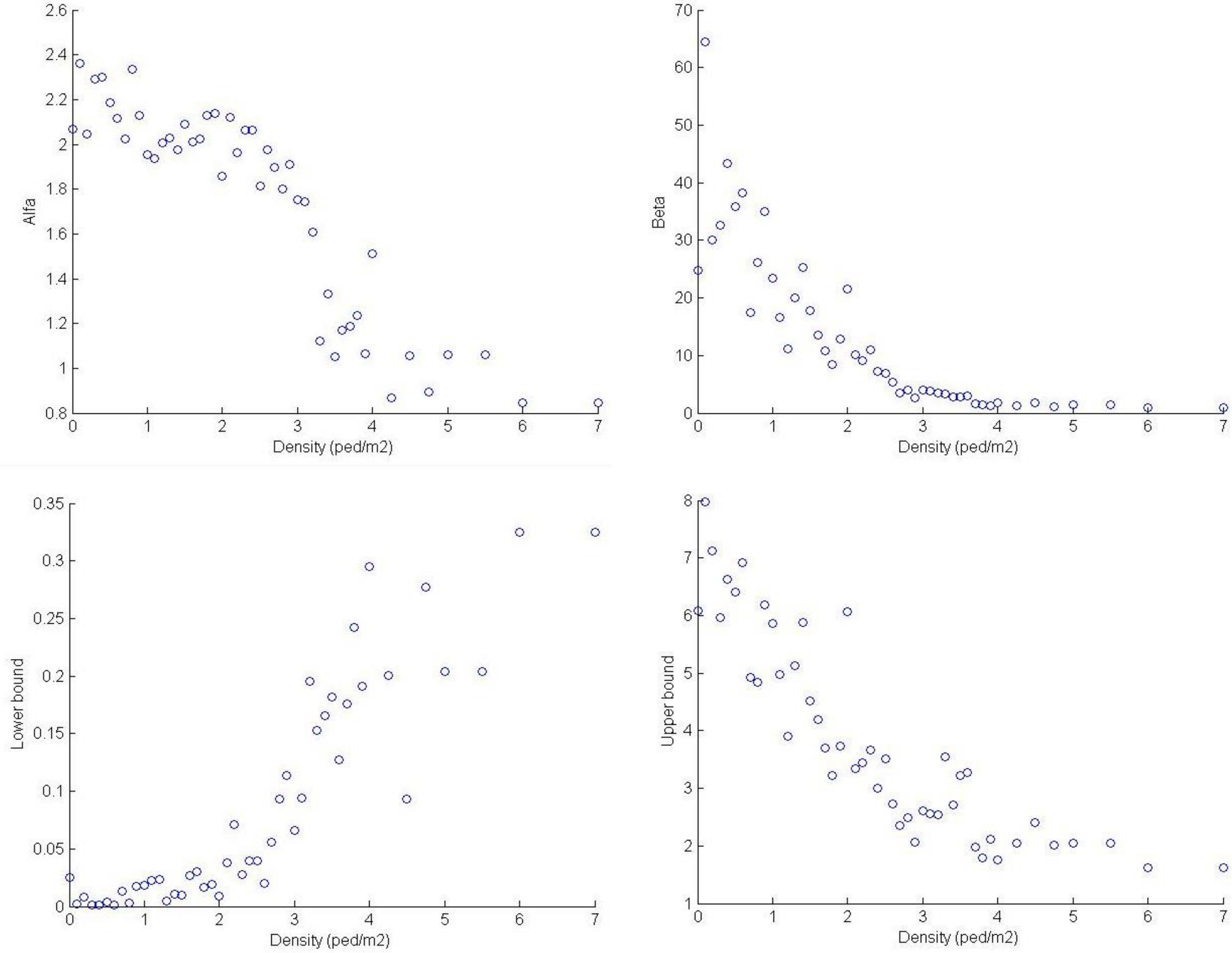
Probabilistic speed-density relationship



$$V \sim f(\alpha(k), \beta(k), l(k), u(k))$$

- f – Kumaraswamy *pdf*
- V – speed
- k – density level
- α, β – shape parameters
- l, u – boundary parameters

Parameters specification



Model specification

- Speed-density relationship

$$V \sim f(\alpha(k), \beta(k), l(k), u(k))$$

Parameter	Specification 1	Specification 2
$\alpha(k)$	$a_\alpha k^3 + b_\alpha k^2 + c_\alpha k + d_\alpha$	$a_\alpha k^3 + b_\alpha k^2 + c_\alpha k + d_\alpha$
$\beta(k)$	$a_\beta \exp(b_\beta k)$	$a_\beta \exp(b_\beta k)$
$u(k)$	$a_u \exp(b_u k)$	$a_u k^3 + b_u k^2 + c_u k + d_u$
$l(k)$	0	0

Model estimation

- Maximum log-likelihood

$$log\mathcal{L} = \sum_{i=1}^{n} \log\big(\alpha(k_i)\big) + \sum_{i=1}^{n} \log\big(\beta(k_i)\big) + \sum_{i=1}^{n} (\alpha(k_i) - 1)\log(v_i - l(k_i)) + \sum_{i=1}^{n} (\beta(k_i) - 1) \log\Big(\big(u(k_i) - l(k_i)\big)^{\alpha(k_i)} - \big(v_i - l(k_i)\big)^{\alpha(k_i)}\Big) - \sum_{i=1}^{n} \alpha(k_i)\beta(k_i) \log(u(k_i) - l(k_i))$$

$$u(k_i) \leq \max(v_i), i = 1, \dots, n$$

	a_α	b_α	c_α	d_α	a_β	b_β	a_u	b_u	c_u	d_u	LL
Specification 1	0.248	-0.6968	0.1603	2.2452	68.894	-0.8751	8.0608	-0.2833			-1.6497e+05
Specification 2	0.0498	-0.2823	-0.0207	2.0089	45.362	-0.5945	0.0002	-0.0002	-0.0010	8.0017	-1.699372e+05

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Conclusion

- High data potential
  - Detailed pedestrian flow studies
- Voronoi representation of space
  - Good space resolution
  - Reveals phenomenon not observable with the other methods
- Pedestrian oriented definitions of flow indicators
- Probabilistic speed-density relationship

Future work

- Validation of the speed-density model
- Time discretization
  - Consistent with the philosophy of space decomposition
- Definition of flow indicator

THANK YOU

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