Pedestrians: the new kings of smart cities

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Outline

Motivation

Motivation

A world of cities

- 2014: 54% of the world's population lives in cities Source: UN

Share of walking trips in cities

- Bangalore 2011: 26%
- Beijing, 2011: 21%
- Bogota, 2008: 15%
- Delhi, 2011: 21%
- London, 2011: 30%
- New-York, 2010: 39%
- Barcelona 2006: 38%
- Berlin, 2010: 29%
- Chicago, 2008: 19%
- Madrid, 2006: 36%
- Singapore, 2011: 22%
- Mumbai, 2011: 27%

Source: [LTA Academy, 2011]

Research challenges

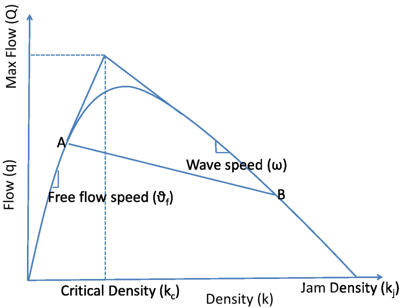
- Understand, describe and predict
- Design of facilities
- Management and control
- Information and guidance

In this talk...

1. Characterization of fundamental quantities
2. A futuristic transportation system: a network of moving walkways

Outline

Fundamental quantities

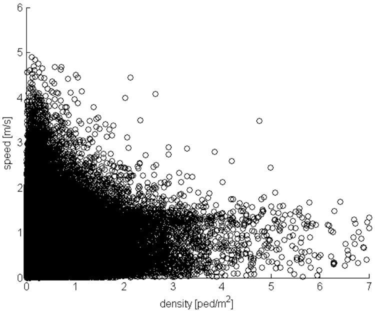


Flow Density Relationship

For pedestrians

- Density k (ped/m^2)
- Speed v (m/s)
- Flow q (ped/ms)

Pedestrians $\neq$ vehicles



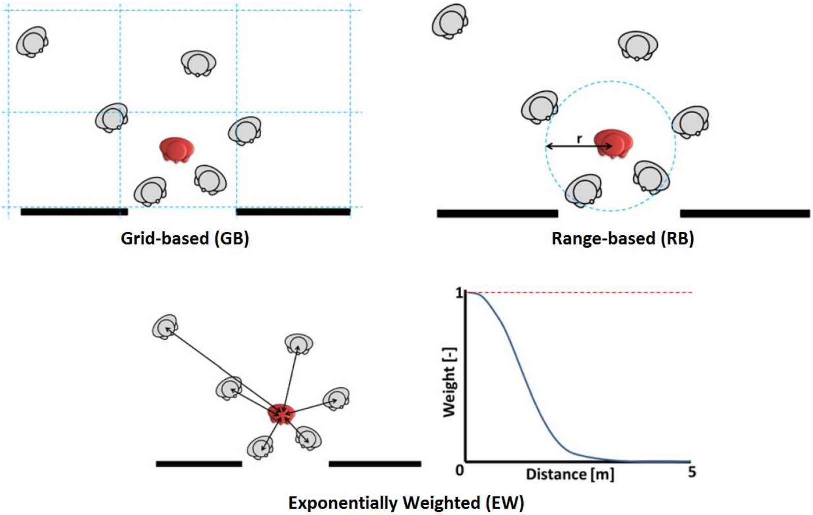
25603 trajectories, Lausanne train station, February 2013

Source: [Nikolic et al., 2016]

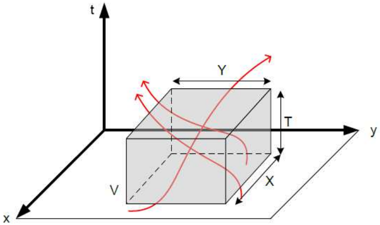
Issues

- Scattered fundamental diagram
- Impact of spatial discretization

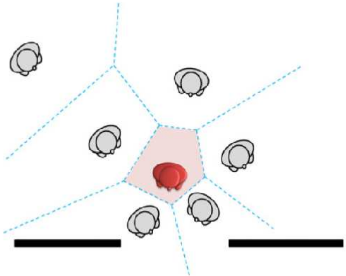
Discretization methods



Discretization methods



Edie (XY-T)



Voronoi-based (VB)

Context

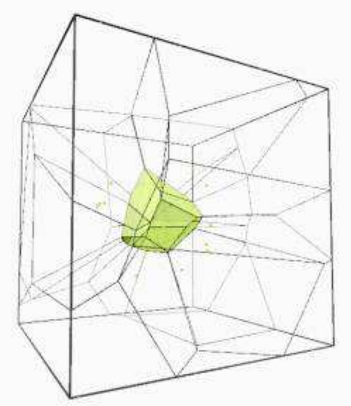
Model

- Space-time representation: $\Omega \subset \mathbb{R}^3$
- Units: meters and seconds
- $p = (x, y, t) \in \Omega$: physical position (x, y) in space at a specific time t
- Assumption: Ω is convex (obstacle-free and bounded)

Data: trajectories

- Continuous: $\Gamma_i : \{p_i(t) | p_i(t) = (x_i(t), y_i(t), t)\}$
- Discrete (sample): $\Gamma_i : \{p_{is} | p_{is} = (x_{is}, y_{is}, t_s)\}, t_s = [t_0, t_1, ..., t_f]$

3D Voronoi diagram



Definition

- For each point $p \in \Omega$
- For each trajectory Γ_i
- Define a distance $D(p, \Gamma_i)$
- Associate p with the closest trajectory: $\delta_\Gamma(p, \Gamma_i) =$

$$\begin{cases} 1, & D(p, \Gamma_i) \leq D(p, \Gamma_j), \forall j \neq i \\ 0, & \text{otherwise} \end{cases}$$

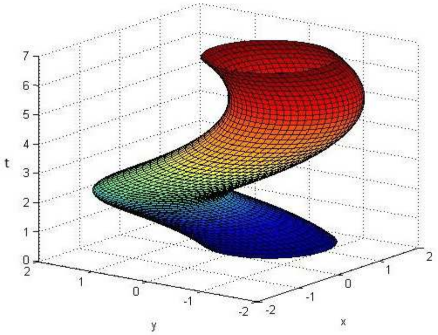
3D Voronoi diagram

Distance

$$D(p, \Gamma_i) = \min_{p_i \in \Gamma_i} \{d(p, p_i)\},$$

- Various definitions of $d(\cdot, \cdot)$ are possible. [Nikolic and Bierlaire, 2016]
- Voronoi cell for trajectory i:

$$V_i = \{p \in \Omega | \delta_\Gamma(p, \Gamma_i) = 1\}$$



Intersection with a plane

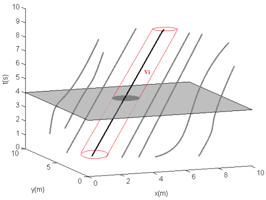
Notation

$\mathcal{P}_{(a,b,c),p_0}$: plane through p_0 with normal vector (a, b, c)

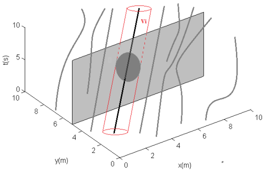
Intersection with a plane

Intersections

Intersection with $\mathcal{P}_{(0,0,1),p_0}$



Intersection with $\mathcal{P}_{(a,b,0),p_0}$



Voronoi-based traffic indicators

Consider $(x, y, t) \in \Omega$, and i such that $(x, y, t) \in V_i$.

Density indicator

$$k(x, y, t) = \frac{1}{|V_i \cap \mathcal{P}_{(0,0,1),(x,y,t)}|}$$

Flow indicator

$$\vec{q}_{(a,b,0)}(x, y, t) = \frac{1}{|V_i \cap \mathcal{P}_{(a,b,0),(x,y,t)}|}$$

Velocity indicator

$$\vec{v}_{(a,b,0)}(x, y, t) = \frac{\vec{q}_{(a,b,0)}(x, y, t)}{k(x, y, t)} = \frac{|V_i \cap \mathcal{P}_{(0,0,1),(x,y,t)}|}{|V_i \cap \mathcal{P}_{(a,b,0),(x,y,t)}|}$$

Main findings

- Data driven discretization.
- Well defined and flexible.
- Robust to noise in the data.
- Robust to sampling of trajectories.
- Details in [Nikolic and Bierlaire, 2016].

Outline

Cars: kings of our cities

Surface used by streets and parkings

- Houston, TX: 64.7%
- Little Rock, AR: 61.2%
- Milwaukee, WI: 54.1%
- Washington, DC: 44.4%

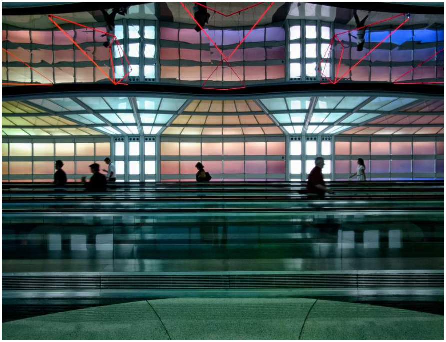
Source: [Gardner, 2011]

What about a “post car” world?

- Cars are banned from cities.
- The surface of streets is claimed for pedestrians.
- Problem: speed.
- Possible solution: moving walkways

Paris, 1900

Moving walkways



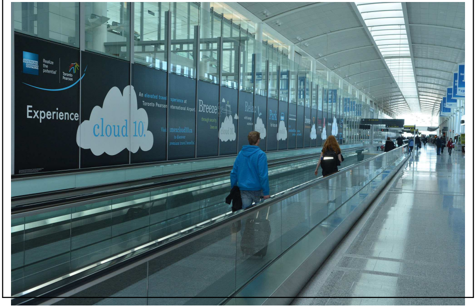
Sustainable

- Electric
- No local emission
- Energy efficient

Functional

- Continuous flow
- Speed: accelerated moving walkways

Toronto Airport, today



Costs

System	Capital cost [M EUR/km]	Typical costs [EUR/pax-km]	Operational cost [EUR/pax-km]
Bus	0.1- 6.7	1500	0.09-0.95
Light rail	8.5-83.5	2800	0.07-0.28
PRT	6.7-25.4	3500	0.07-0.28
AMW	34.8-54.4	7300	0.08-0.42

- ✗ High capital costs
- ✗ High typical costs
- ✓ Competitive operational costs

Efficiency

System	Average speed [km/h]	Capacity [pax/h]	Corridor width [m]
Bus	15-20	1,000-4,500	3.0-4.2
Light rail	15-45	1,000-30,000	2.5-3.2
PRT	20-25	1,800-7,200	2.5-3.2
AMW	5-12	4,500-7,500	1.2-2.3

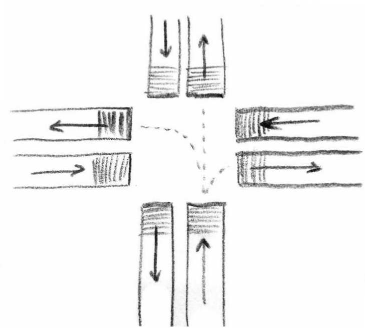
- ✓ Competitive speed
- ✓ High capacity
- ✓ Low space usage

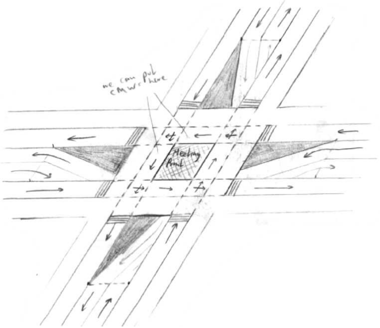
Energy

System	Energy use [MJ/pax-km]	Noise level [dB(A)]
Bus	0.30-1.56	70-84
Light rail	0.70-2.50	60-74
PRT	0.55	35-65
AMW	0.11	54

- ✓ Low energy consumption
- ✓ Low noise level

Network design





Case study; Geneva

- Two objectives: mobility and costs.
- Good trade off with 44 AMWs.
- Details in [Scarinci et al., 2014] and [Scarinci et al., 2016].

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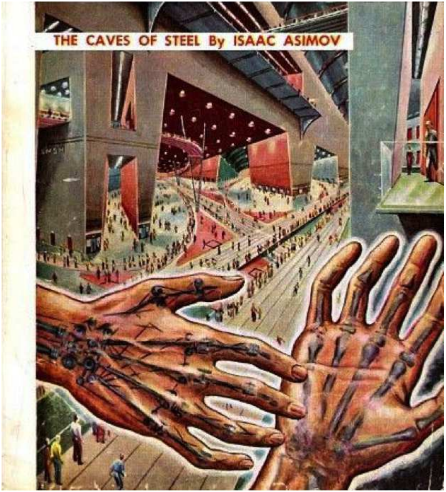

Data
Pedestrian trajectories

Technology
Accelerated moving walkways

Models
Specification, validation, prediction

Urban Systems
Integration

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