Pedestrians: the new kings of smart cities

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Outline

1. Motivation

2. Fundamental quantities
   - Discretization
   - 3D Voronoi
   - Indicators

3. Moving walkways
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
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3 Moving walkways
Fundamental quantities

For pedestrians
- Density $k$ (ped/m$^2$)
- Speed $v$ (m/s)
- Flow $q$ (ped/ms)
Pedestrians ≠ vehicles

Issues
- Scattered fundamental diagram
- Impact of spatial discretization

25603 trajectories, Lausanne train station, February 2013

Source: [Nikolic et al., 2016]
Discretization methods

- Grid-based (GB)
- Range-based (RB)
- Exponentially Weighted (EW)
Discretization methods

Edie (XY-T)

Voronoi-based (VB)
Fundamental quantities

3D Voronoi

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: $\Omega$ 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): $\Gamma_i : \{p_{is} | p_{is} = (x_{is}, y_{is}, t_s)\} , t_s = [t_0, t_1, ..., t_f]$
Definition

- For each point \( p \in \Omega \)
- For each trajectory \( \Gamma_i \)
- 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 $i$:

$$V_i = \{p \in \Omega | \delta_{\Gamma_i}(p, \Gamma_i) = 1\}$$
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 $P_{(0,0,1),p_0}$

Intersection with $P_{(a,b,0),p_0}$
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].
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3 Moving walkways
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
Moving walkways

Paris, 1900

Panoramas de Paris 1900
Moving walkways

Sustainable
- Electric
- No local emission
- Energy efficient

Functional
- Continuous flow
- Speed: accelerated moving walkways
Toronto Airport, today
## Costs

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus</td>
<td>0.1-6.7</td>
<td>1500</td>
<td>0.09-0.95</td>
</tr>
<tr>
<td>Light rail</td>
<td>8.5-83.5</td>
<td>2800</td>
<td>0.07-0.28</td>
</tr>
<tr>
<td>PRT</td>
<td>6.7-25.4</td>
<td>3500</td>
<td>0.07-0.28</td>
</tr>
<tr>
<td>AMW</td>
<td>34.8-54.4</td>
<td>7300</td>
<td>0.08-0.42</td>
</tr>
</tbody>
</table>

✗ High capital costs

✗ High typical costs

✓ Competitive operational costs
### Efficiency

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

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

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

- ✓ Low energy consumption
- ✓ Low noise level
Moving walkways

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].
Pedestrians: new kings of smart cities?

Data
Pedestrian trajectories

Technology
Accelerated moving walkways

Models
Specification, validation, prediction

Urban Systems
Integration
Gardner, C. (2011). We are the 25%: Looking at street area percentages and surface parking.


