Challenges in modelling bicycle flow
Background

- Increasing urbanisation
- Growing attractiveness of cycling
- Higher mode share

- Yet, little scientific attention
Background

- Complex behavioural dimensions
- More sensitive to environment
- Knowledge on cyclist behaviour
- Development of theories and models to describe behaviour
Background

I. Walking and cycling behaviour

- Intended routes
- Desired walking speeds
- Geometry, infra char.

II. Activity scheduling
Route and destination choice

- Subjective choice set
- Experience, survey knowledge

III. Knowledge acquisition

- Network information
- Route conditions
- Traffic conditions, levels-of-service
- Real-time info and guidance

Physical network infrastructure

- Perceptron

ICT
Literature on cycling

- Size: 1.90 x 0.75m

Richard, 1981
Literature on cycling

- Speeds depend on
  - Bicycle facility type (off vs on street)
  - Gender (2.5 km/h)
  - Presence of a barrier (with 18.2 km/h, without 13.9 km/h)

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Average speed in [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;12</td>
<td>18.72</td>
</tr>
<tr>
<td>13-18</td>
<td>20.45</td>
</tr>
<tr>
<td>19-45</td>
<td>17.10</td>
</tr>
<tr>
<td>46-60</td>
<td>13.68</td>
</tr>
<tr>
<td>&gt;60</td>
<td>12.55</td>
</tr>
</tbody>
</table>
Literature on cycling

Schacht, 1934
Literature on cycling

<table>
<thead>
<tr>
<th>Study</th>
<th>Critical Density [bicycles/m²]</th>
<th>Jam density [bicycles/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Navin, 1994)</td>
<td>0.11</td>
<td>0.33</td>
</tr>
<tr>
<td>(Yang, 1985)</td>
<td>0.10</td>
<td>0.45</td>
</tr>
<tr>
<td>(Homburger, 1976)</td>
<td>0.05</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Homburger, 1976

Navin, 1994
Empirical facts of cycling
Empirical facts of cycling

<table>
<thead>
<tr>
<th></th>
<th>First day</th>
<th>Second day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition</td>
<td>812 bicycles, 28 mopeds (3.3%)</td>
<td>497 bicycles, 23 mopeds (4.2%)</td>
</tr>
<tr>
<td>Flow</td>
<td>736 b/h/m</td>
<td>522 b/h/m</td>
</tr>
<tr>
<td>Density</td>
<td>0.04 b/m²</td>
<td>0.03 b/m²</td>
</tr>
<tr>
<td>Speed</td>
<td>18.4 km/h</td>
<td>17 km/h</td>
</tr>
<tr>
<td>Saturation flow</td>
<td>2494 b/h</td>
<td></td>
</tr>
<tr>
<td>Jam density</td>
<td>0.36 b/m²</td>
<td></td>
</tr>
</tbody>
</table>
Empirical facts of cycling

- Intensity vs. Density graph
  - Free flow measurements (blue dots)
  - Saturation flow measurements (red dots)
  - Jam density measurements (green dots)
Empirical facts of cycling

<table>
<thead>
<tr>
<th></th>
<th>Model</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity [b/h/m]</td>
<td>2380</td>
<td>2494</td>
</tr>
<tr>
<td>Free flow speed [km/h]</td>
<td>18.5</td>
<td>17.9</td>
</tr>
<tr>
<td>Critical density [b/m²]</td>
<td>0.14</td>
<td>0.36</td>
</tr>
<tr>
<td>Jam density [b/m²]</td>
<td>0.36</td>
<td>0.36</td>
</tr>
</tbody>
</table>
Empirical facts of cycling

![Graph showing the relationship between density (bicycles/m²) and the number of bicycles in the queue.](image)
Literature on cyclist models

• Numerous studies on bicycle operation and path design

• Bicycle flow theory is in its infancy

• First steps in establishing theory and empirically underpinned models
Literature on cyclist models

- CA model
Literature on cyclist models

- CA model
Modelling bicycle flows

Different modelling approaches

• Microscopic
  • CA
  • Social forces
  • Game theory
  • Optimal control

• Macroscopic
  • Continuum models
Modelling bicycle flows

- Aim to optimise behaviour
- Continuous monitoring of the system
- Anisotropic particles
- Predicting behaviour of others
- Limited prediction capabilities
- Follow optimal trajectory to destination
- Perform limited effort in control
Modelling bicycle flows

• Control
  • Putting power on the pedals
    • Acceleration $a$
  • Turning the steer
    • Change in steering angle $\omega$

• Dynamics
  • $v = a$
  • $\varphi = \omega$
  • $x = v \cos \varphi$
  • $y = v \sin \varphi$
Optimal control

- Find the control where cycling behaviour is desired, and preferable optimal

Identify cycling ‘costs’

- Straying from the optimal path
  - $L_{stray} = \frac{1}{2} c^1 \nabla^2 \left( v \nu - v_0 \right) + \frac{1}{2} c^1 \nabla^2 \left( \phi \nu - \phi_0 \right)$

- Maintain current speed and cycling direction
  - $L_{eff} = \frac{1}{2} ( c^2 a - c^2 \omega )$

- Proximity costs
  - $L_{prox} = c^3 \sum b^\exists \exp(-\|r_c - r_b\|/\|v_c \cdot R_0\|)$
Modelling bicycle flows

![Graphs showing bicycle movement metrics](image)

- **x (m)**: Distance travelled as a function of time.
- **v**: Speed as a function of time.
- **phi (rad)**: Angular displacement as a function of time.

Destination
Conclusions

• Limited knowledge on cyclist behaviour
• Even less on cyclist models
• On all behavioural levels
  • Cycling behaviour
  • Activity scheduling
  • Route choice
  • Knowledge acquisitions