TGF’ 15

A dynamic network loading model for anisotropic and congested pedestrian flows

Flurin S. Hänseler, William H.K. Lam, Michel Bierlaire, Gael Lederrey, Marija Nikolić

Delft, October 30, 2015
Unsteady, anisotropic and congested flow

Figure: Passageway in Central Station (MTR), Hong Kong
Macroscopic pedestrian flow models

- **graph-based models** [CS94, Løv94]
  - interaction between streams entirely neglected

- **cell transmission models** [ASKT07, GHW11, HBFM14]
  - inherent assumption of isotropy

- **continuum models** [Hug02, HWZ^+09, HvWKDD14]
  - expensive, particularly for multi-class applications
Time, space and demand

- discrete time
  - uniform time intervals
- discrete space
  - partitioning into areas
- demand
  - pedestrian ‘groups’
  - aggregated by time interval and route
- route
  - origin/destination area
  - accessible network
Walking network and model principle

- area: range of interaction
- stream: uni-directional flow
- node: flow valve

- flow on uni-directional stream $= \text{density} \times \text{velocity}$

- stream-based pedestrian fundamental diagram (next slide)
Pedestrian fundamental diagram

• specification inspired by research at HKU [WLC+10, XW15]

• stream-based fundamental diagram (SbFD)

\[ V_{\lambda} = V_f \cdot \exp \left\{ -\vartheta k_{\xi}^2 \right\} \prod_{\lambda' \in \Lambda_{\xi}} \exp \left( -\beta (1 - \cos \varphi_{\lambda,\lambda'}) k_{\lambda'} \right) \]

- isotropic reduction (Drake, 1967)
- reduction due to pair-wise interaction of streams
  
  \( V_f \): free-flow speed, \( k_{\{\xi,\lambda}\} \): density, \( \varphi_{\lambda,\lambda'} \): intersection angle, \( \vartheta, \beta \): parameters
Propagation model

1. **receiving capacity of stream**
2. **sending capacity of group fragment to stream**
3. **candidate inflow to stream**
4. **actual flow of group fragment to stream**
Calibration

• \( \theta \): unknown parameter vector

• pedestrian \( i = \{1, \ldots, N\} \)
  – \( tt^\text{obs}_i \): observed travel time
  – \( f_i^\text{est}(tt|\theta) \): estimated travel time probability density

• pseudo maximum likelihood estimation

\[
\hat{\theta} = \arg \max \tilde{\mathcal{L}}(tt_\text{obs}|\theta)
\]

with

\[
\tilde{\mathcal{L}}(tt_\text{obs}|\theta) = \prod_{i=1}^{N} f_i^\text{est}(tt^\text{obs}_i|\theta)
\]
Counter-flow experiment (Wong et al., 2010)
Counter-flow experiment: Observed speeds

<table>
<thead>
<tr>
<th>Exp.</th>
<th>major group</th>
<th>minor group</th>
</tr>
</thead>
<tbody>
<tr>
<td>#84</td>
<td>87 ped</td>
<td>1.08 ± 0.15 m/s</td>
</tr>
<tr>
<td>#85</td>
<td>79</td>
<td>1.19 ± 0.13</td>
</tr>
<tr>
<td>#86</td>
<td>68</td>
<td>0.90 ± 0.10</td>
</tr>
<tr>
<td>#87</td>
<td>61</td>
<td>0.82 ± 0.06</td>
</tr>
<tr>
<td>#88</td>
<td>53</td>
<td>0.83 ± 0.09</td>
</tr>
<tr>
<td>#89</td>
<td>44</td>
<td>0.79 ± 0.10</td>
</tr>
</tbody>
</table>

Extracted from Wong et al., 2010 [WLC^+10]
## Counter-flow experiment: Results 1

<table>
<thead>
<tr>
<th></th>
<th>Zero-Model</th>
<th>Drake</th>
<th>SbFD</th>
<th>Weidmann</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{AIC}_{85,87}^{\text{calib}}$</td>
<td>837.7</td>
<td>754.0</td>
<td>704.5</td>
<td>729.4</td>
</tr>
<tr>
<td>$v_f$ [m/s]</td>
<td>1.166 ± 0.001</td>
<td>1.170 ± 0.001</td>
<td>1.115 ± 0.000</td>
<td>1.169 ± 0.001</td>
</tr>
<tr>
<td>$\mu$ [-]</td>
<td>1.43 ± 0.06</td>
<td>12.15 ± 0.29</td>
<td>10.18 ± 2.02</td>
<td>14.84 ± 0.30</td>
</tr>
<tr>
<td>$\vartheta$ [m$^4$]</td>
<td>0.078 ± 0.000</td>
<td>0.001 ± 0.004</td>
<td>0.210 ± 0.005</td>
<td></td>
</tr>
<tr>
<td>$\beta$ [m$^2$]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\gamma$ [m$^{-2}$]</td>
<td></td>
<td></td>
<td></td>
<td>4.92 ± 0.20</td>
</tr>
<tr>
<td>$k_j$ [m$^{-2}$]</td>
<td></td>
<td></td>
<td></td>
<td>6.58 ± 0.46</td>
</tr>
<tr>
<td>$\text{AIC}_{84}^{\text{valid}}$</td>
<td>355.2</td>
<td>338.4</td>
<td>311.4</td>
<td>348.2</td>
</tr>
<tr>
<td>$\text{AIC}_{86}^{\text{valid}}$</td>
<td>381.7</td>
<td>371.3</td>
<td>355.3</td>
<td>401.4</td>
</tr>
<tr>
<td>$\text{AIC}_{88}^{\text{valid}}$</td>
<td>400.3</td>
<td>384.6</td>
<td>364.0</td>
<td>435.3</td>
</tr>
<tr>
<td>$\text{AIC}_{89}^{\text{valid}}$</td>
<td>458.2</td>
<td>408.8</td>
<td>396.8</td>
<td>454.6</td>
</tr>
</tbody>
</table>
Cross-flow experiment (Plaue et al., 2014)
Cross-flow experiment: Results I

**Table:** Results of calibration on cross-flow experiment.

<table>
<thead>
<tr>
<th></th>
<th>Zero-Model</th>
<th>Drake</th>
<th>SbFD</th>
<th>Weidmann</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIC</td>
<td>1160.0</td>
<td>1101.0</td>
<td>1062.6</td>
<td>1098.8</td>
</tr>
<tr>
<td>$v_f$ [m/s]</td>
<td>$1.307 \pm 0.005$</td>
<td>$1.308 \pm 0.001$</td>
<td>$1.308 \pm 0.006$</td>
<td>$1.332 \pm 0.002$</td>
</tr>
<tr>
<td>$\mu$ [-]</td>
<td>$1.16 \pm 0.03$</td>
<td>$1.39 \pm 0.02$</td>
<td>$2.64 \pm 0.41$</td>
<td>$2.05 \pm 0.20$</td>
</tr>
<tr>
<td>$\vartheta$ [m$^4$]</td>
<td>$0.139 \pm 0.004$</td>
<td>$0.143 \pm 0.004$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\beta$ [m$^2$]</td>
<td></td>
<td></td>
<td>$0.300 \pm 0.008$</td>
<td></td>
</tr>
<tr>
<td>$\gamma$ [m$^{-2}$]</td>
<td></td>
<td></td>
<td></td>
<td>$1.76 \pm 0.15$</td>
</tr>
<tr>
<td>$k_j$ [m$^{-2}$]</td>
<td></td>
<td></td>
<td></td>
<td>$5.99 \pm 0.61$</td>
</tr>
</tbody>
</table>
Zero-Model ($L^2$-error: 53.3 s)

Drake ($L^2$-error: 47.6 s)

Weidmann ($L^2$-error: 47.4 s)

SbFD ($L^2$-error: 39.2 s)
Illustration: Walking speed in counter-flow

Parameters:

- $V_f = 1.308$ m/s
- $\vartheta = 0.143$ m$^4$
- $\beta = 0.300$ m$^2$

(Berlin data set)
Concluding remarks

- macroscopic model for congested, anisotropic flow
  - stream-based pedestrian fundamental diagram
  - freely available on GitHub

- counter- and cross-flow experiments
  - significant improvement for anisotropic formulation

- future work
  - applications within DTA-framework, demand estimation
TGF’ 15:

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R. L. Hughes.  
A continuum theory for the flow of pedestrians.  

S. P. Hoogendoorn, F. L. M. van Wageningen-Kessels, W. Daamen, and D. C. Duives.  
Continuum modelling of pedestrian flows: From microscopic principles to self-organised macroscopic phenomena.  
Revisiting Hughes’ dynamic continuum model for pedestrian flow and the development of an efficient solution algorithm.

G. G. Løvås.
Modeling and simulation of pedestrian traffic flow.
Bidirectional pedestrian stream model with oblique intersecting angle.  

S. Xie and S. C. Wong.  
A Bayesian inference approach to the development of a multidirectional pedestrian stream model.  
Counter-flow experiment: Results II

Table: Travel times for counter-flow validation experiments.

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Groups</th>
<th>$t_{t_{obs}}$ [s]</th>
<th>$t_{t_{Zero}}$ [s]</th>
<th>$t_{t_{Drake}}$ [s]</th>
<th>$t_{t_{SbFD}}$ [s]</th>
<th>$t_{t_{Weidmann}}$ [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>#84</td>
<td>87 / 0</td>
<td>8.5 / -</td>
<td>9.5 / -</td>
<td>9.1 / -</td>
<td>8.1 / -</td>
<td>8.3 / -</td>
</tr>
<tr>
<td>#86</td>
<td>68 / 18</td>
<td>10.1 / 12.7</td>
<td>9.5 / 9.5</td>
<td>10.0 / 10.8</td>
<td>9.4 / 12.5</td>
<td>8.8 / 9.5</td>
</tr>
<tr>
<td>#88</td>
<td>53 / 31</td>
<td>10.9 / 11.8</td>
<td>9.5 / 9.5</td>
<td>10.0 / 10.6</td>
<td>10.3 / 11.7</td>
<td>8.9 / 9.2</td>
</tr>
<tr>
<td>#89</td>
<td>44 / 44</td>
<td>11.8 / 11.6</td>
<td>9.5 / 9.5</td>
<td>11.6 / 11.4</td>
<td>11.7 / 11.6</td>
<td>9.7 / 9.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L$^2$-error (weighted, [s])</td>
<td>21.4 / 23.4</td>
<td>9.0 / 10.5</td>
<td><strong>7.9 / 0.7</strong></td>
<td>22.3 / 23.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- The table shows travel times for counter-flow validation experiments, with columns for observed, zero, Drake, SbFD, and Weidmann times.
Cross-flow experiment: Results II

Table: Travel times along major routes in Berlin case study.

<table>
<thead>
<tr>
<th>$N_{\text{ped}}$</th>
<th>$tt_{\text{obs}}$ [s]</th>
<th>$tt_{\text{Zero}}$ [s]</th>
<th>$tt_{\text{Weidmann}}$ [s]</th>
<th>$tt_{\text{Drake}}$ [s]</th>
<th>$tt_{\text{SbFD}}$ [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>118</td>
<td>12.4 (base)</td>
<td>10.8 (-12.7%)</td>
<td>14.0 (+12.6%)</td>
<td>13.3 (+7.2%)</td>
<td>12.6 (+1.8%)</td>
</tr>
<tr>
<td>46</td>
<td>10.6 (base)</td>
<td>8.4 (-21.3%)</td>
<td>9.9 (-6.8%)</td>
<td>10.0 (-6.2%)</td>
<td>10.9 (+2.2%)</td>
</tr>
</tbody>
</table>