The Hong Kong Polytechnic University
香港理工大學

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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

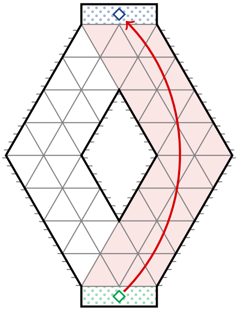
Unsteady, anisotropic and congested flow

Figure: Passageway in Central Station (MTR), Hong Kong

Macroscopic pedestrian flow models

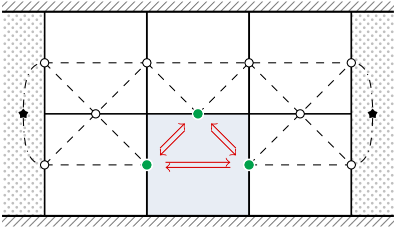
- graph-based models [CS94, Løv94]
  - interaction between streams entirely neglected
- cell transmission models [ASKT07, GHW11, HBFM14]
  - inherent assumption of isotropy
- continuum models [Hug02, HWZ+09, HvWKDD14]
  - expensive, particularly for multi-class applications

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 = density × velocity
- stream-based pedestrian fundamental diagram (next slide)

Pedestrian fundamental diagram

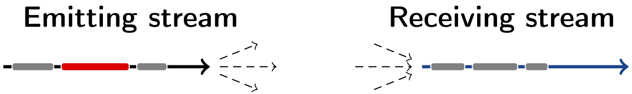
- specification inspired by research at HKU [WLC+10, XW15]
- stream-based fundamental diagram (SbFD)

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

  - 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, ϑ, β: 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

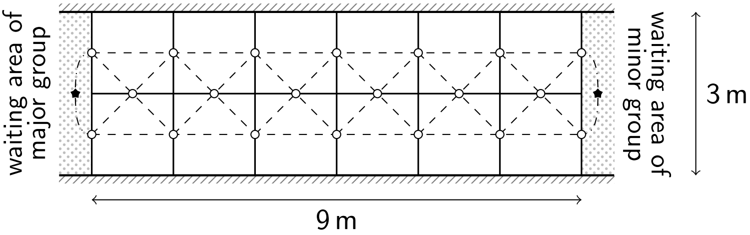
- $\boldsymbol{\theta}$: unknown parameter vector
- pedestrian $i = \{1, \ldots, N\}$
  - tt_i^{obs}: observed travel time
  - $f_i^{\text{est}}(tt|\boldsymbol{\theta})$: estimated travel time probability density
- pseudo maximum likelihood estimation

$$\hat{\boldsymbol{\theta}} = \arg\max \tilde{\mathcal{L}}(\boldsymbol{tt}_{\text{obs}}|\boldsymbol{\theta})$$

with

$$\tilde{\mathcal{L}}(\boldsymbol{tt}_{\text{obs}}|\boldsymbol{\theta}) = \prod_{i=1}^{N} f_i^{\text{est}}(tt_i^{\text{obs}}|\boldsymbol{\theta})$$

Counter-flow experiment (Wong et al., 2010)



Counter-flow experiment: Observed speeds

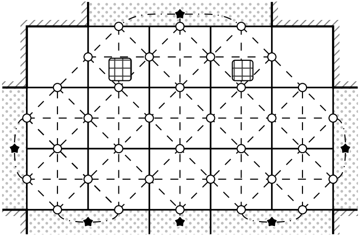
Exp.	major group		minor group	
#84	87 ped	1.08 ± 0.15 m/s	–	–
#85	79	1.19 ± 0.13	9 ped	0.80 ± 0.14 m/s
#86	68	0.90 ± 0.10	18	0.74 ± 0.15
#87	61	0.82 ± 0.06	26	0.67 ± 0.10
#88	53	0.83 ± 0.09	30	0.79 ± 0.15
#89	44	0.79 ± 0.10	44	0.79 ± 0.18

Extracted from Wong et al., 2010 [WLC+10]

Counter-flow experiment: Results I

	Zero-Model	Drake	SbFD	Weidmann
$AIC^{calib}_{85,87}$	837.7	754.0	704.5	729.4
v_f [m/s]	1.166 ± 0.001	1.170 ± 0.001	1.115 ± 0.000	1.169 ± 0.001
μ [-]	1.43 ± 0.06	12.15 ± 0.29	10.18 ± 2.02	14.84 ± 0.30
ϑ [m^4]		0.078 ± 0.000	0.001 ± 0.004	
β [m^2]			0.210 ± 0.005	
γ [m^{-2}]				4.92 ± 0.20
k_j [m^{-2}]				6.58 ± 0.46
AIC^{valid}_{84}	355.2	338.4	311.4	348.2
AIC^{valid}_{86}	381.7	371.3	355.3	401.4
AIC^{valid}_{88}	400.3	384.6	364.0	435.3
AIC^{valid}_{89}	458.2	408.8	396.8	454.6

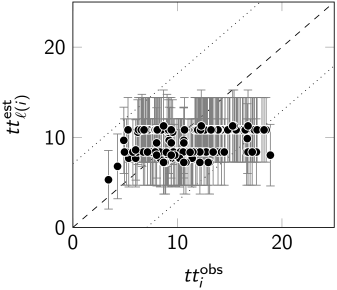
Cross-flow experiment (Plaue et al., 2014)



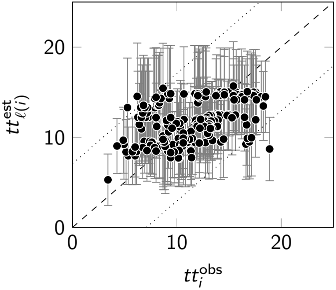
Cross-flow experiment: Results I

Table: Results of calibration on cross-flow experiment.

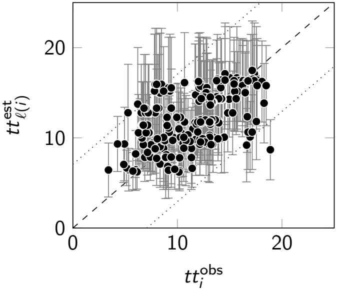
	Zero-Model	Drake	SbFD	Weidmann
AIC	1160.0	1101.0	1062.6	1098.8
v_f [m/s]	1.307 ± 0.005	1.308 ± 0.001	1.308 ± 0.006	1.332 ± 0.002
μ [-]	1.16 ± 0.03	1.39 ± 0.02	2.64 ± 0.41	2.05 ± 0.20
ϑ [m^4]		0.139 ± 0.004	0.143 ± 0.004	
β [m^2]			0.300 ± 0.008	
γ [m^{-2}]				1.76 ± 0.15
k_j [m^{-2}]				5.99 ± 0.61



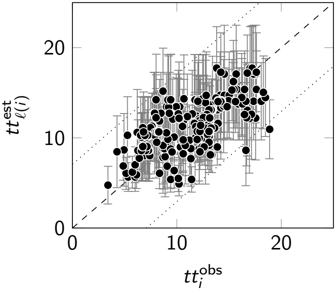
(a) Zero-Model (L^2-error: 53.3 s)



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

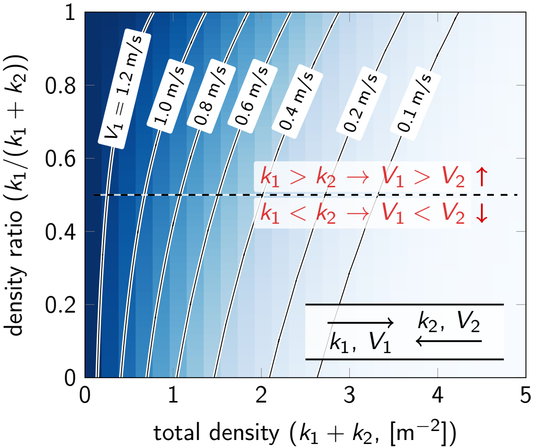


(c) Weidmann (L^2-error: 47.4 s)



(d) 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

Thank you

TGF' 15:

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Counter-flow experiment: Results II

Table: Travel times for counter-flow validation experiments.

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

Cross-flow experiment: Results II

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

N_{ped}	tt_{obs} [s]	tt_{Zero} [s]	$tt_{Weidmann}$ [s]	tt_{Drake} [s]	tt_{SbFD} [s]
118	12.4 (base)	10.8 (-12.7%)	14.0 (+12.6%)	13.3 (+7.2%)	12.6 (+1.8%)
46	10.6 (base)	8.4 (-21.3%)	9.9 (-6.8%)	10.0 (-6.2%)	10.9 (+2.2%)