PhD defense

Modeling and estimation of pedestrian flows in train stations

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Introduction

- optimal design and operation of pedestrian facilities
- particular importance of rail access facilities

Pedestrian flows in train stations

Objectives

1. collect and analyze **data** of a case study train station
2. **model** the usage and level-of-service of rail access facilities
3. **apply** modeling framework to case study

Context

Data [DMA91, LCL99, LC00, GCDC14, vdHH14]

- link/OD counts, traffic conditions, timetable/ridership, ...

Models [CL98, LLW01, Daa04, HB04, KHEM07, ZHL08, XLLH14]

- demand estimation: facility usage assessment
- traffic assignment: level-of-service assessment

Applications [HD04, RK07, SBBR08, JDH+09, SVvdH14]

- many case studies

Outline

1. Case study
2. Demand estimation
3. Traffic assignment
4. Application and practical guidance
5. Conclusions

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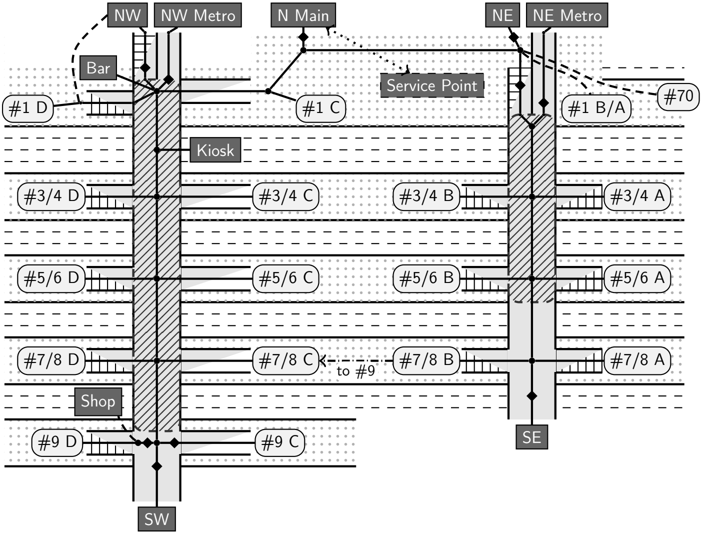
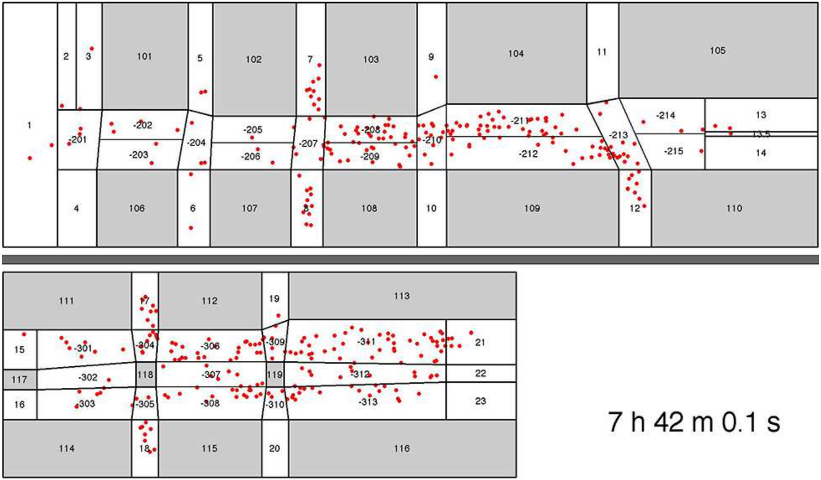
Lausanne railway station: Aerial view

Lausanne railway station: Pedestrian network



Pedestrian movements on January 16, 2013



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Demand estimation

- demand indicators
  - pedestrian counts
  - ridership data, train timetable
  - sales/survey data
  - trajectories
- assignment map: OD demand $\rightarrow$ demand indicators
- find OD demand such that resulting demand indicators match actual observations as closely as possible

Notation I

- discrete time $\tau \in \mathcal{T}$, e.g. $\Delta t = 1$ min
- walking network $\mathcal{G} = (\mathcal{N}, \mathcal{L})$
  - nodes $\nu \in \mathcal{N}$, links $\lambda \in \mathcal{L}$
- OD pair $\kappa \in \mathcal{K}$, $\kappa = (\nu_{\mathsf{O}}, \nu_{\mathsf{D}})$
- OD demand $\boldsymbol{d} = [d_{\kappa,\tau}]$
- link flow $\boldsymbol{f} = [f_{\lambda,\tau}]$

Notation II

- platform $\pi \in \mathcal{P}$
- train $\zeta \in \mathcal{Z}$
  - platform π_ζ
  - boarding and alighting volumes e_ζ^{on}, e_ζ^{off}
  - arrival and departure times t_ζ^{arr}, t_ζ^{dep}

Structural model: Traffic assignment

flow assignment

$$\boldsymbol{f} = \Sigma_f(\boldsymbol{d}; \boldsymbol{y}) + \boldsymbol{\eta}_f$$

where

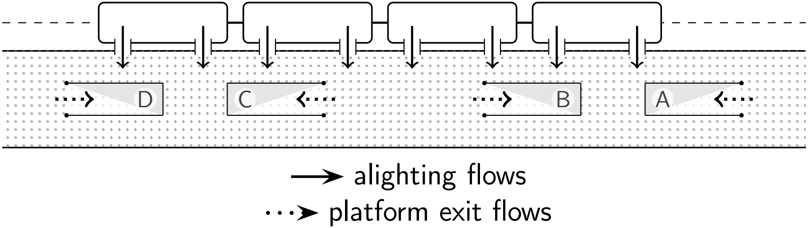
$$\begin{aligned} \boldsymbol{\Sigma}_{(.)} &: \text{ pedestrian DTA} \\ \boldsymbol{y} &: \text{ parameter vector} \\ \boldsymbol{\eta}_{(.)} &: \text{ structural error} \end{aligned}$$

example specification ($\rightarrow$ case study):

[A1] route choice: shortest route

[A2] walking speed $v = \mathcal{N}(1.34 \text{ m/s}, 0.34 \text{ m/s})$ [Wei92]

Structural model: Platform exit flows I



Structural model: Platform exit flows II

$$\boldsymbol{f}_{\text{arr}} = \boldsymbol{\varphi}(\boldsymbol{e}_{\text{off}}; \boldsymbol{y}) + \boldsymbol{\varepsilon}_{\varphi}$$

where

$$\boldsymbol{f}_{\text{arr}} = \boldsymbol{\Sigma}_{\text{f,arr}}(\boldsymbol{d}; \boldsymbol{y}) + \boldsymbol{\eta}_{\text{f,arr}} \quad \text{(from DTA)}$$
$$\boldsymbol{\varphi} = [\phi_{\lambda,\tau}] \quad \text{(from alighting volumes; empirical model)}$$

example specification:

[A3] empirical exit flows $\phi_{\lambda,\tau}$ as superposition of independent train contributions (next slide)

Structural model: Platform exit flows III

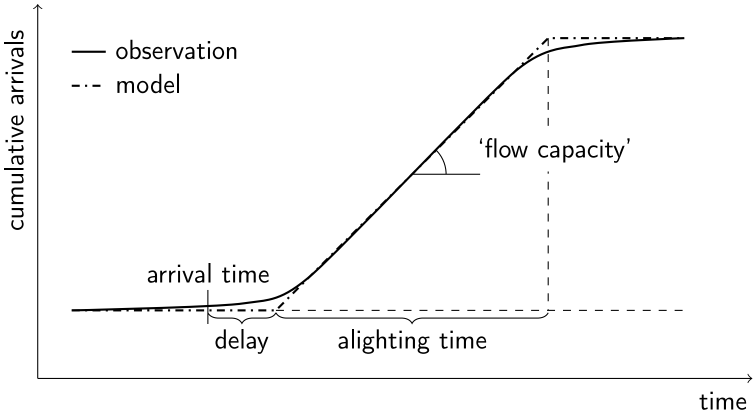
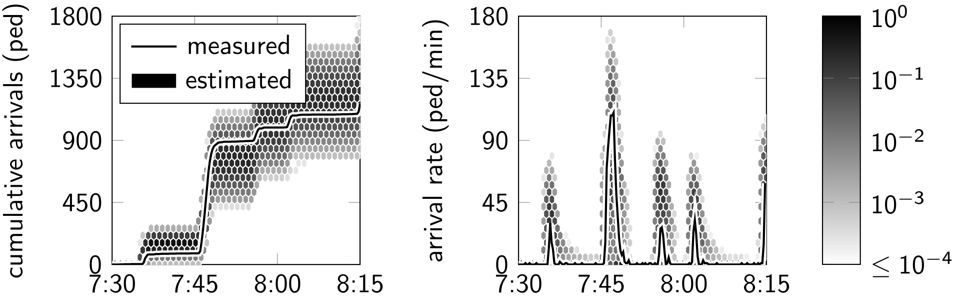


Figure: Train-induced platform exit flow

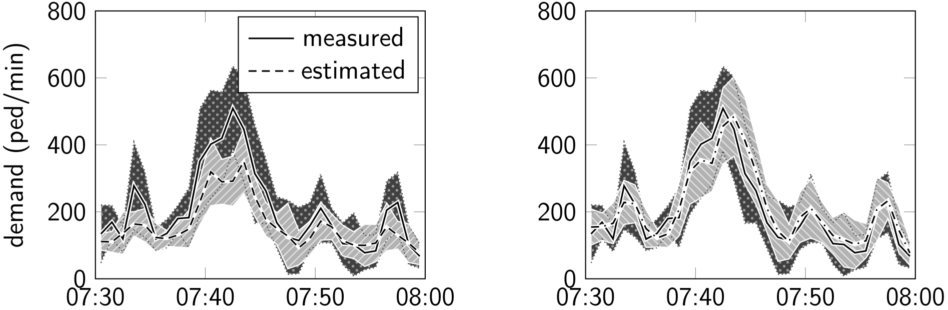
Structural model: Platform exit flows IV



(a) CDF (b) PDF

Figure: Exit flow, platform #5/6, Lausanne, April 10, 2013

Lausanne railway station: Results



(a) Base estimate (RMSE = 70.47)

(b) Full estimate (RMSE = 37.56)

Figure: Demand in pedestrian underpasses

Demand estimation: Conclusions

- estimation model for pedestrian OD demand in train stations
- within-day and natural day-to-day demand variation
- good agreement of case study results with tracking data

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Traffic assignment: Overview

- route choice
  - mostly utility-based approaches [Dia71, CL98, HB04]
  - high maturity of available models
- network loading
  - wide range of approaches [Løv94, HM95, BA01, Hug02]
  - lack of accurate *and* efficient models [DDH13]

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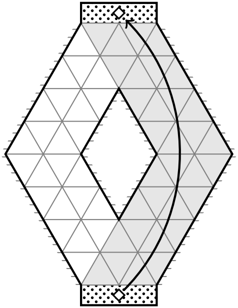
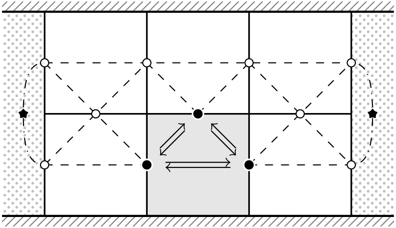
  input: 'route demand'
  output: traffic conditions (travel times, density, . . .)

Framework



- discrete time
  - uniform time intervals
- discrete space
  - partitioning into areas
- demand
  - aggregate by time interval and route
  - pedestrian ‘groups’

Walking network and model principle



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

- flow on uni-directional stream = density $\times$ velocity
- stream-based pedestrian fundamental diagram (next slide)

Pedestrian fundamental diagram

- stream-based fundamental diagram (SbFD) [WLC+10, XW15]

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

  - 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

- state-of-the-practice: Weidmann, 1992 [Wei92]

$$v_\lambda = v_f \left\{1 - \exp\left[-\gamma\left(\frac{1}{k_\xi} - \frac{1}{k_{\text{jam}}}\right)\right]\right\}$$

  γ: shape parameter, k_{jam}: jam density

Case studies

- isotropic case studies
  - pedestrian underpass, Lausanne railway station
  - bottleneck experiment, Delft
- anisotropic case studies
  - cross-flow experiment, Berlin
  - counter-flow experiments, Hong Kong

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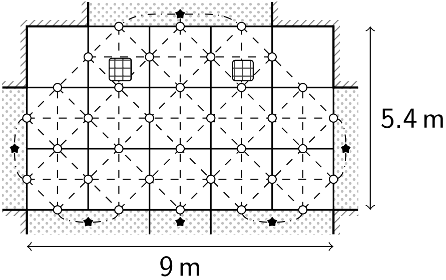
Cross-flow experiment (Plaue et al., 2014)



Cross-flow experiment: Results

Table: Performance of various fundamental diagrams

	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

Traffic assignment: Conclusions

- loading model for dynamic, multi-directional pedestrian flows
- explicit consideration of anisotropy
- accurate reproduction of travel times and density

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Application and practical guidance

- application of modeling framework to Lausanne railway station
  - current usage
  - current level-of-service
- practical guidance for planning of rail access facilities
  - 6-step planning process [BW08]

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Conclusions: Contributions

- rich data set of large Swiss train station
- demand estimation for pedestrian OD demand in train stations
- loading model for large, congested walking facilities
- case-study application and planning guidelines

Conclusions: Future research directions

- Data
  - new collection techniques, real sites
- Models
  - activity-based demand estimation
  - loading model for non-walking behavior
- Applications
  - crowd management (active and passive)

Thank you

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