PhD defense

Modeling and estimation of pedestrian flows in train stations

Flurin S. Hänseler


Lausanne, February 11, 2016
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

Animation: https://youtu.be/HHMXTJJ1Q1kY
Outline

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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 1

- 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 $\kappa \in \mathcal{K}$, $\kappa = (\nu_O, \nu_D)$
- OD demand $\textbf{d} = [d_{\kappa, \tau}]$
- link flow $\textbf{f} = [f_{\lambda, \tau}]$
Notation II

- platform $\pi \in P$
- train $\zeta \in Z$
  - platform $\pi_\zeta$
  - boarding and alighting volumes $e_{\zeta}^{\text{on}}$, $e_{\zeta}^{\text{off}}$
  - arrival and departure times $t_{\zeta}^{\text{arr}}$, $t_{\zeta}^{\text{dep}}$
Structural model: Traffic assignment

Flow assignment

\[ f = \Sigma_f(d; y) + \eta_f \]

where

\( \Sigma(\cdot) \) : pedestrian DTA

\( y \) : parameter vector

\( \eta(\cdot) \) : structural error

Example specification (→ 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

→ alighting flows

⋯⋯ platform exit flows

D C B A
Structural model: Platform exit flows II

\[ f_{\text{arr}} = \varphi(e_{\text{off}}; y) + \varepsilon\varphi \]

where

\[ f_{\text{arr}} = \sum f_{\text{arr}}(d; y) + \eta_{f,\text{arr}} \text{ (from DTA)} \]

\[ \varphi = [\phi_{\lambda,\tau}] \text{ (from alighting volumes; empirical model)} \]

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

![Graph showing demand in pedestrian underpasses](image)

- **(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]
Traffic assignment: Overview

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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 $\xi$: range of interaction
- stream $\lambda$: uni-directional flow
- node $\nu$: flow valve

- flow on uni-directional stream $= \text{density} \times \text{velocity}$
- 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, \(\vartheta, \beta\): parameters

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

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

\(\gamma\): shape parameter, \(k_{\text{jam}}\): 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
Case studies

• isotropic case studies
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Cross-flow experiment (Plaue et al., 2014)
Cross-flow experiment: Results

**Table: Performance of various fundamental diagrams**

<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><strong>1062.6</strong></td>
<td>1098.8</td>
</tr>
<tr>
<td>$v_f$ [m/s]</td>
<td>1.307 ± 0.005</td>
<td>1.308 ± 0.001</td>
<td>1.308 ± 0.006</td>
<td>1.332 ± 0.002</td>
</tr>
<tr>
<td>$\mu$ [-]</td>
<td>1.16 ± 0.03</td>
<td>1.39 ± 0.02</td>
<td>2.64 ± 0.41</td>
<td>2.05 ± 0.20</td>
</tr>
<tr>
<td>$\vartheta$ [m$^4$]</td>
<td>0.139 ± 0.004</td>
<td>0.143 ± 0.004</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\beta$ [m$^2$]</td>
<td></td>
<td></td>
<td>0.300 ± 0.008</td>
<td></td>
</tr>
<tr>
<td>$\gamma$ [m$^{-2}$]</td>
<td></td>
<td></td>
<td></td>
<td>1.76 ± 0.15</td>
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<tr>
<td>$k_j$ [m$^{-2}$]</td>
<td></td>
<td></td>
<td></td>
<td>5.99 ± 0.61</td>
</tr>
</tbody>
</table>
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

PhD defense:

**Modeling and estimation of pedestrian flows in train stations**

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