STRC 2012

Preliminary ideas for dynamic estimation of pedestrian origin-destination demand within train stations

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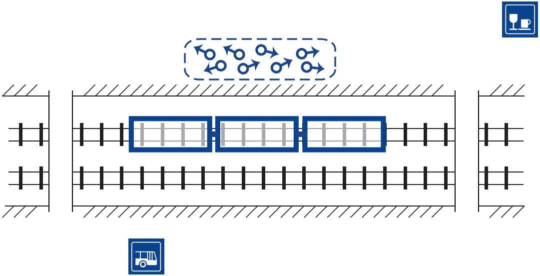
May 3, 2012

Context & Motivation

- Importance of pedestrian flows in transportation hubs for public transportation system as a whole
  - congestion of pedestrian facilities at peak hours
  - large increase in number of passengers
- Pedestrian flows key for level of service
  - performance: travel time, timetable stability
  - comfort: ‘degree of crowdedness’
  - safety: in case of evacuation, stampede
- Models needed for better understanding of pedestrian flows
  - optimize pedestrian facilities & their operation

Pedestrian flow modeling in train stations



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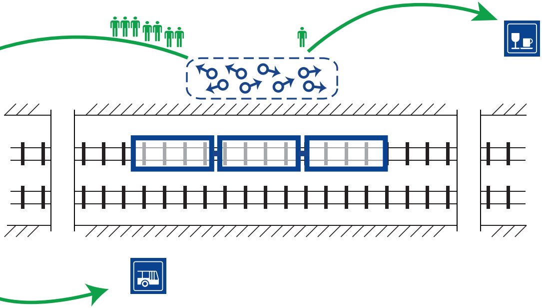
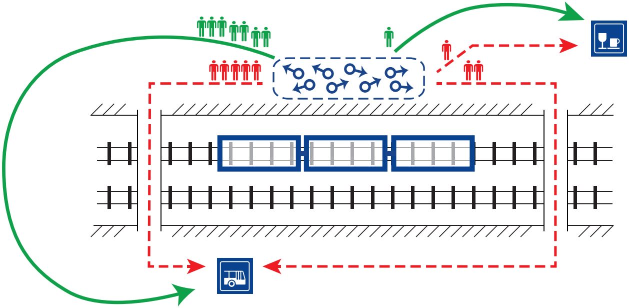


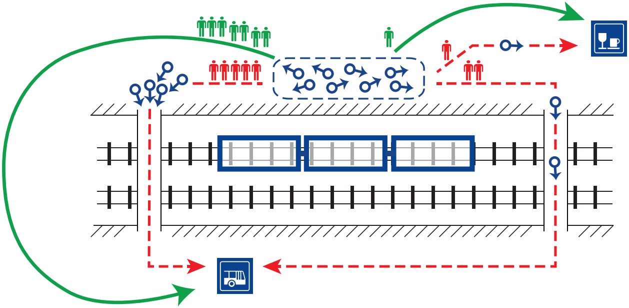
Pedestrian OD demand (strategical)

Pedestrian flow modeling in train stations



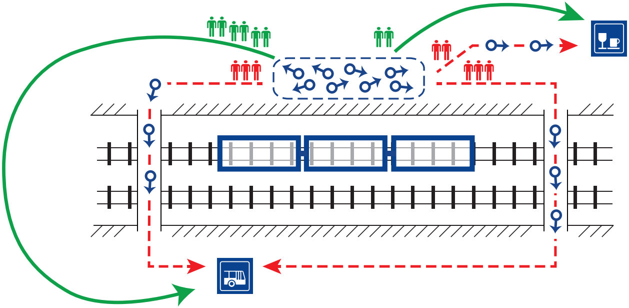
Pedestrian OD demand (strategical)
Pedestrian route choice (tactical)

Pedestrian flow modeling in train stations



Pedestrian OD demand (strategical)
Pedestrian route choice (tactical)
Pedestrian dynamics (operational)

Pedestrian flow modeling in train stations



Pedestrian OD demand (strategical)
Pedestrian route choice (tactical)
Pedestrian dynamics (operational)

back coupling

Pedestrian origin-destination (OD) demand in train stations

- Pedestrian waves due to train arrivals or upcoming departures
  - OD demand fluctuations on a minute-by-minute basis
  - superposition of waves leading to congestion

$\rightsquigarrow$ high temporal resolution needed

- Literature
  - Daamen, W. (2004), Ph.D. Thesis, TU Delft
  - Cascetta, E. and Nguyen, S. (1988), Transp. Res. B

Mathematical framework of OD demand model

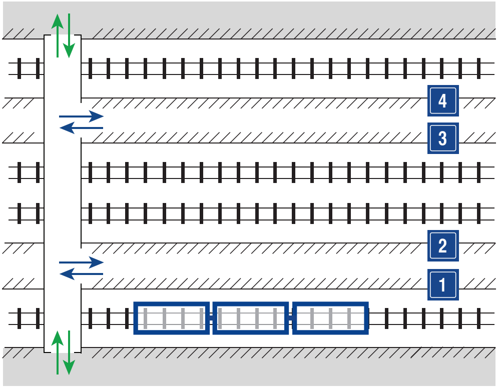
For centroids $i, j = 1, \ldots, R$ and discrete time $t = 1, \ldots, T$:
$x_{i,j,t}$: pedestrian demand rate $i \to j$ at time t
$y_{i,j,t}$: travel time $i \to j$ if leaving node i at time t

Structural equations for centroids i, j at time t:

$$\text{origin flow:} \quad f_{i,t} = \sum_{j=1}^{R} x_{i,j,t}$$

$$\text{destination flow:} \quad g_{j,t} = \sum_{k=1}^{t} \sum_{i=1}^{R} x_{i,j,k} \underbrace{\Pr(y_{i,j,k} = t - k)}_{\text{transition probability}}$$

Data sources for model calibration



Passenger counts   Train related data

Passenger turnover of a train

For a train z using a track adjacent to platform j:

$$\text{number of alighting passengers: } \phi_{j,z} = q_{j,z} o_{j,z} + \varepsilon_{j,z}$$
$$\text{number of boarding passengers: } \pi_{j,z} = q_{j,z} p_{j,z} + \eta_{j,z}$$

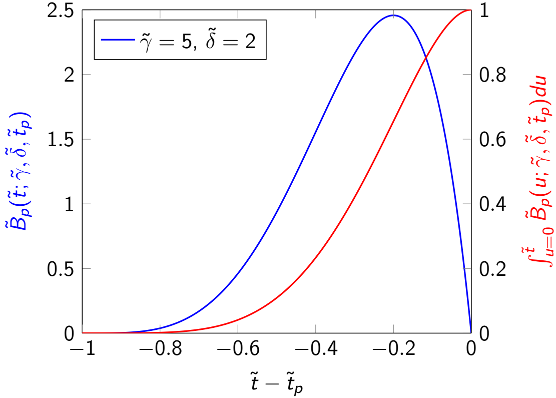
$q_{j,z}$: train capacity

$o_{j,z}, p_{j,z}$: fraction of people alighting/boarding (relative to capacity)

$\varepsilon_{j,z}, \eta_{j,z}$: random variables (r.v.) with known distribution

Pedestrian arrival/departure pattern on platform

Pedestrian arrival pattern on platform preceding train departure:



Pedestrian arrival/departure pattern on platform

Beta distribution:

$$\text{pattern preceding train departure: } \tilde{B}_p(\tilde{t}; \tilde{\gamma}, \tilde{\delta}, \tilde{t}_p)$$
$$\text{pattern following train arrival: } \tilde{B}_o(\tilde{t}; \tilde{\alpha}, \tilde{\beta}, \tilde{t}_o)$$

Similarity assumption:

$$\tilde{B}_o(\tilde{t}; \tilde{\alpha}, \tilde{\beta}, \tilde{t}_o) \sim \tilde{B}_p(-\tilde{t}; \tilde{\gamma}, \tilde{\delta}, -\tilde{t}_p)$$

$\tilde{t}$: continuous time

$\tilde{t}_p, \tilde{t}_o$: time of train departure/arrival

$\tilde{\alpha}, \tilde{\beta}, \tilde{\gamma}, \tilde{\delta}$: shape parameters

Structural equations for train passenger flows

Overall train passenger flows:

$$\text{arrival flow: } d_{i,t} = \sum_{z=1}^{N_i} \phi_{i,z} B_o\left(t; \alpha_{i,z}, \beta_{i,z}, a_{i,z}\right)$$

$$\text{departure flow: } e_{j,t} = \sum_{z=1}^{N_j} \pi_{j,z} B_p\left(t; \gamma_{j,z}, \delta_{j,z}, b_{j,z}\right)$$

N_j : total number of trains docking on platform j

$B_o(\cdot), B_p(\cdot)$: discrete flow patterns corresponding to $\tilde{B}_o$, $\tilde{B}_p$

$\{\alpha, \beta, \gamma, \delta\}_{j,z}$: shape parameters (platform j, train z)

$a_{j,z}, b_{j,z}$: time of arrival and departure (ditto)

Measurement equations

- For nodes with passenger count data:

$$\text{origin flow: } \widehat{f}_{i,t} = f_{i,t} + \xi_{i,t} \qquad \forall i \in F, t$$
$$\text{destination flow: } \widehat{g}_{j,t} = g_{j,t} + \nu_{j,t} \qquad \forall j \in G, t$$

F, G: sets of centroids with outgoing/incoming flow counts

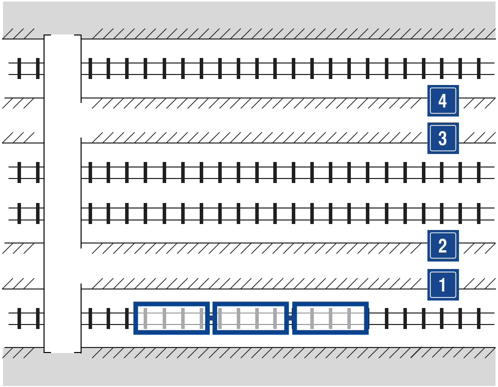
- For train platform nodes:

$$\text{passenger arrival flow: } \widehat{d}_{i,t} = f_{i,t} + \zeta_{i,t} \qquad \forall i \in I, t$$
$$\text{passenger departure flow: } \widehat{e}_{j,t} = g_{j,t} + \lambda_{j,t} \qquad \forall j \in J, t$$

I, J: sets of centroids used as arrival/departure platforms

$\xi_{i,t}$, $\nu_{j,t}$, $\zeta_{i,t}$, $\lambda_{j,t}$: random variables (r.v.)

Case Study: Renens CFF (simplified)



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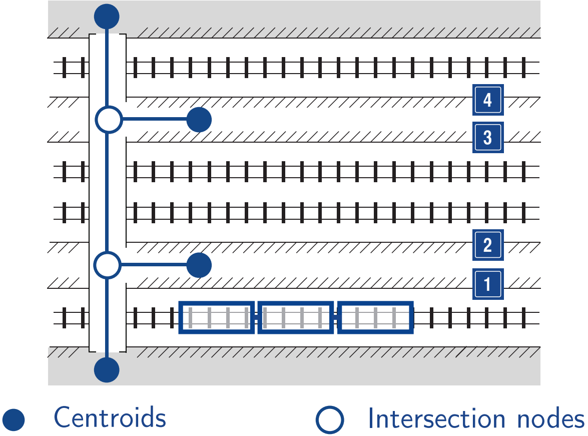

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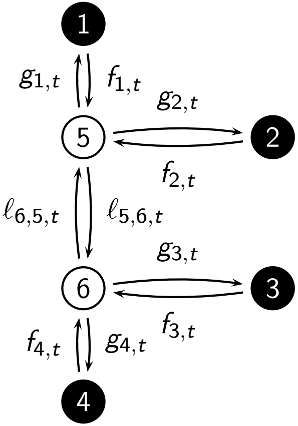
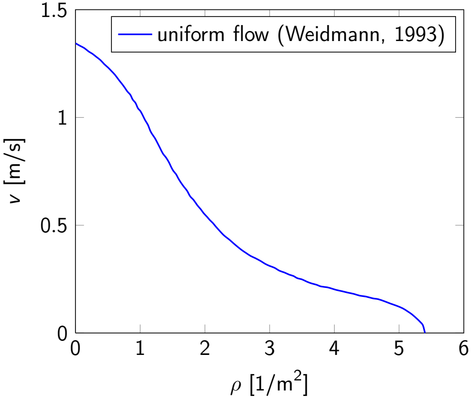


$$\ell_{5,6,t} = \sum_{k=1}^{t} \Big\{ \big(x_{1,3,k} + x_{1,4,k}\big) \cdot \Pr(y_{1,5,k} = t-k) + \big(x_{2,3,k} + x_{2,4,k}\big) \cdot \Pr(y_{2,5,k} = t-k) \Big\}$$

$$\ell_{6,5,t} = \sum_{k=1}^{t} \sum_{m=3}^{4} \sum_{n=1}^{2} \Big\{ x_{m,n,k} \cdot \Pr(y_{m,6,k} = t-k) \Big\}$$

Trip travel time and transition probability

Velocity-density relation: link flows → link travel times



Trip travel time and transition probability

Estimating the transition probability:

- average pedestrian velocity on link $m \to n$ at time t

$$v_{m,n,t} = v\left(c_{m,n}, \ell_{m,n,t}, \ell_{n,m,t}, \tau_{m,n}\right)$$

- trip duration $i \to j$ along $L_{i,j}$

$$y_{i,j,t} = \sum_{(m,n) \in L_{i,j}} \frac{w_{m,n}}{v_{m,n,(t-1+y_{i,m,t})}} \quad \rightsquigarrow \; \Pr(y_{i,j,t} = k)$$

$c_{m,n}$: capacity of link $m \to n$ (m,n neighbors)

$w_{m,n}$: walking length of link $m \to n$

$\tau_{m,n,t}$: r.v. representing fluctuations in avg walking speed

Conclusion & Outlook

Preliminary methodology for dynamic estimation of pedestrian OD demand within a train station as a function of

- incoming, outgoing trains
  - train time table
  - track assignment
  - number of people getting on and off each train

Next steps:

- application on real case study
- consideration of intermediate activities (shopping, eating)
- coupling with pedestrian dynamics simulator
  $\rightsquigarrow$ optimization studies

Thank you

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Funded by SNF grant #200021-141099 ‘Pedestrian dynamics: flows and behavior’

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