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

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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)
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Pedestrian route choice (tactical)
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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
  \[\implies\] high temporal resolution needed

- Literature
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 $i \rightarrow j$ at time $t$
- $y_{i,j,t}$: travel time $i \rightarrow j$ if leaving node $i$ at time $t$

Structural equations for centroids $i, j$ at time $t$:

**Origin flow:** $f_{i,t} = \sum_{j=1}^{R} x_{i,j,t}$

**Destination flow:** $g_{j,t} = \sum_{k=1}^{t} \sum_{i=1}^{R} x_{i,j,k} \Pr(y_{i,j,k} = t - k)$
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 $j$:

- number of alighting passengers: $\phi_{j,z} = q_{j,z}o_{j,z} + \varepsilon_{j,z}$
- 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:

\[
\tilde{B}_p(\tilde{t}, \tilde{\gamma}, \tilde{\delta}, \tilde{t}_p) = \gamma = 5, \delta = 2
\]

\[
\int_{\tilde{t}_p}^{\tilde{t}} \tilde{B}_p(\tilde{u}, \tilde{\gamma}, \tilde{\delta}, \tilde{t}_p) d\tilde{u}
\]
Pedestrian arrival/departure pattern on platform

Beta distribution:

pattern preceding train departure: $\tilde{B}_p(\tilde{t}; \tilde{\gamma}, \tilde{\delta}, \tilde{t}_p)$

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:

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

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

\( N_j \) : 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:
  - Origin flow: \( \hat{f}_{i,t} = f_{i,t} + \xi_{i,t} \quad \forall i \in F, t \)
  - Destination flow: \( \hat{g}_{j,t} = g_{j,t} + \nu_{j,t} \quad \forall j \in G, t \)

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

- For train platform nodes:
  - Passenger arrival flow: \( \hat{d}_{i,t} = f_{i,t} + \zeta_{i,t} \quad \forall i \in I, t \)
  - Passenger departure flow: \( \hat{e}_{j,t} = g_{j,t} + \lambda_{j,t} \quad \forall j \in J, t \)

  \( I, J \): 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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Centroids

Intersection nodes
Case Study: Renens CFF (simplified)

\[ \ell_{5,6,t} = \sum_{k=1}^{t} \left\{ \left( x_{1,3,k} + x_{1,4,k} \right) \cdot Pr(y_{1,5,k} = t - k) + \left( x_{2,3,k} + x_{2,4,k} \right) \cdot Pr(y_{2,5,k} = t - k) \right\} \]

\[ \ell_{6,5,t} = \sum_{k=1}^{t} \sum_{m=3}^{4} \sum_{n=1}^{2} \left\{ x_{m,n,k} \cdot Pr(y_{m,6,k} = t - k) \right\} \]
Trip travel time and transition probability

Velocity-density relation: link flows $\rightarrow$ link travel times

\[
\begin{array}{c|c|c|c|c|c|c}
\rho [1/m^2] & 0 & 1 & 2 & 3 & 4 & 5 & 6 \\
\hline
v [m/s] & 1.5 & 1 & 0.5 & 0.25 & 0.1 & 0.05 & 0.025 \\
\end{array}
\]

uniform flow (Weidmann, 1993)
Trip travel time and transition probability

Estimating the transition probability:

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

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

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

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

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

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

$\tau_{m,n,t}$: 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
  $\Rightarrow$ optimization studies
Thank you

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