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A mesoscopic dynamic flow model for pedestrian movement in railway stations

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Pedestrian flows in train stations
Framework for pedestrian flow estimation

- Scenario specification
- Spatio-temporal observations
- Travel surveys

Route flow prediction

Flow propagation

Pedestrian demand, Level of Service (LoS)
Network-based pedestrian propagation models

- graph-based representation of space
- cell-transmission model (CTM) [Dag94, ASKT07]
  - mesoscopic: aggregate group of pedestrians
  - deterministic: 1st order flow theory
  - system dynamics: macroscopic fundamental diagram
- queueing network based model [CS94, Løv94, Daa04]
  - disaggregate: individual agents
  - stochastic: random queues
Representation of pedestrian facilities

- walkable area
- entry/exit points
- route $R = (r_0, r_1, \ldots)$
  - topological area $r$
- path $\Gamma = (\xi_1, \xi_2, \ldots)$
  - discretization cell $\xi$
Framework of pedestrian propagation model

- pedestrian fundamental diagram [Wei93]

\[ v(m/s) \]

\[ k(#/m^2) \]

\[ q(#/ms) \]

\[ v_f = 1.34 \]

\[ k_{opt} = 1.75 \]

\[ k_{jam} = 5.4 \]

\[ q_{opt} = 1.22 \]
Framework of pedestrian propagation model

- pedestrian fundamental diagram [Wei93]
  - isotropic density-velocity relation
  - hydrodynamic flow $q(k) = kv(k)$

- space: network of cells $G = (V, E)$
  - cells $\xi \in V$, edges $g \in E$
  - in- and outflow edges of cell $\xi$: $I(\xi)$, $O(\xi)$

- time: discrete intervals $\tau \in T$
  - uniform length $\Delta t = \Delta L/v_f$, $\Delta L^2$: cell size

- pedestrians: groups $\ell \in L$
  - path $\Gamma$ or route $R$, departure interval $\tau_0$, size $m_0$
  - $m_\ell(\xi, \tau)$: size of group $\ell$ in cell $\xi$ during interval $\tau$
Advancement of group $\ell$ along path $\Gamma$

- ‘sending capacity’ of gate $g : i \rightarrow j$, $g \in \Gamma$ during interval $\tau$

$$S^\ell_{g}(\tau) = \min \left\{ m^\ell(i, \tau), \frac{m^\ell(i, \tau)}{\sum_{\ell \in \mathcal{L}} m^\ell(i, \tau)} Q^i(\tau) \right\}$$

- ‘receiving capacity’ of cell $j$ during interval $\tau$

$$R^j(\tau) = \min \left\{ \delta (N - \sum_{\ell \in \mathcal{L}} m^\ell(i, \tau)), \hat{Q}^j(\tau) \right\}$$

- cellular capacity ($N = k_{jam} \Delta L^2$)
- hydrodynamic inflow capacity

$$\hat{Q}^\xi(\tau) = \begin{cases} Q^\xi_{\text{opt}} & \text{if } \sum_{\ell \in \mathcal{L}} m^\ell(\xi, \tau) \leq k_{opt} \Delta L^2 \\ Q^\xi(\tau) & \text{otherwise} \end{cases}$$

Ref: [ASKT07]
Advancement of group $\ell$ along path $\Gamma$

- actual flow along gate $g : i \to j$, $g \in \Gamma$ during interval $\tau$

\[
y^\ell_g(\tau) = \begin{cases} 
S^\ell_g(\tau) & \text{if } \sum_{h \in \mathcal{I}(j)} \sum_{\ell \in \mathcal{L}} S^\ell_h(\tau) \leq R_j(\tau) \\
X^\ell_g(\tau) R_j(\tau) & \text{otherwise}
\end{cases}
\]

- cell congestion: demand proportional supply distribution

\[
X^\ell_g(\tau) = \frac{S^\ell_g(\tau)}{\sum_{k \in \mathcal{I}(j)} \sum_{\ell \in \mathcal{L}} S^\ell_k(\tau)}
\]

- recursion for group $\ell$ in cell $i$

\[
m^{\ell}(i, \tau + 1) = m^{\ell}(i, \tau) + y^\ell_f(\tau) - y^\ell_g(\tau)
\]

- $\Gamma = (\ldots, f, g, \ldots)$, where $f : h \to i$, $g : i \to j$

Ref: [ASKT07]
Cell potentials for en-route path choice

- route $R = (r_0, r_1, \ldots)$
  - topological area $r$
  - $G_R = (\mathcal{V}_R, \mathcal{E}_R)$
- path $\Gamma = (\xi_1, \ldots, \xi_\star)$
  - discretization cell $\xi$
- route-specific potentials
  - $P_\xi = \min$ if $\xi = \xi_\star$
  - $P_\xi = \infty$ if $\xi \notin \mathcal{V}_R$
- generalized potential
  - distance to destination $\star$
  - connectivity

Ref: [HG08]
Advancement of group $\ell$ along route $R$

- turning proportion: edge $g : i \rightarrow j$, $g \in \mathcal{E}_R$, interval $\tau$

$$D^R_g(\tau) = \begin{cases} 
(P^R_i - P^R_j) \left[ N_j(\tau) - \sum_{\ell \in \mathcal{L}} m_{\ell}(j, \tau) \right] \\
\sum_{k \in \Theta^R_i} \left\{ (P^R_i - P^R_k) \left[ N_j(\tau) - \sum_{\ell \in \mathcal{L}} m_{\ell}(k, \tau) \right] \right\},
\end{cases} \quad g \in \Theta^R_i$$

- sending capacity: edge $g : i \rightarrow j$, interval $\tau$

$$S^\ell_g(\tau) = D^R_g(\tau) \min \left\{ m_\ell(i, \tau), \frac{m_\ell(i, \tau)}{\sum_{l \in \mathcal{L}} m_\ell(i, \tau)} Q_i(\tau) \right\}$$

- recursion for group $\ell$ in cell $\xi \in \mathcal{V}_R$

$$m_\ell(\xi, \tau + 1) = m_\ell(\xi, \tau) + \sum_{h \in \Phi^R_\xi} y^\ell_h(\tau) - \sum_{g \in \Theta^R_\xi} y^\ell_g(\tau)$$
Uniform 1D corridor with peak load ($m_0/N = 75\%$)
Conclusions

- congestion in pedestrian facilities of railway stations
- demand estimation ↔ flow propagation
  - space: route, path ↔ areas, cells
  - pedestrians: groups with same route & departure time
- cell-based pedestrian propagation model
  - 1\textsuperscript{st} order pedestrian flow theory
  - multi-directionality
  - en-route path choice
    ~ route-specific cell potentials & local traffic conditions
- next: test cases and case study
Thank you

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W. Daamen.  
*Modelling passenger flows in public transport facilities.*  

C.F. Daganzo.  
The cell transmission model: A dynamic representation of highway traffic consistent with the hydrodynamic theory.  
*Transportation Research Part B: Methodological,*  

John J Fruin.  
Pedestrian planning and design.  


BD Hankin and RA Wright. 
Passenger flow in subways.  

G.G. Løvås.  
Modeling and simulation of pedestrian traffic flow.  

Masamitsu Mōri and Hiroshi Tsukaguchi.  
A new method for evaluation of level of service in pedestrian facilities.  
FP Navin and RJ Wheeler. 
Pedestrian flow characteristics. 

Detlef Oeding. 

SJ Older. 
Armin Seyfried, Bernhard Steffen, Wolfram Klingsch, and Maik Boltes.