STRC 2013

A mesoscopic dynamic flow model for pedestrian movement in railway stations

F. Hänseler, B. Farooq, T. Mühlematter and M. Bierlaire

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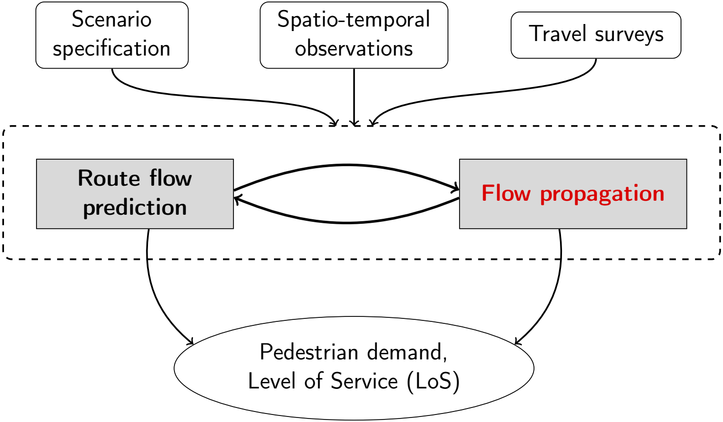
Pedestrian flows in train stations

Framework for pedestrian flow estimation



Scenario specification

Spatio-temporal observations

Travel surveys

Route flow prediction

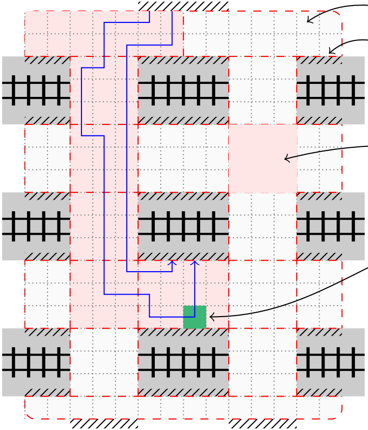
Flow propagation

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

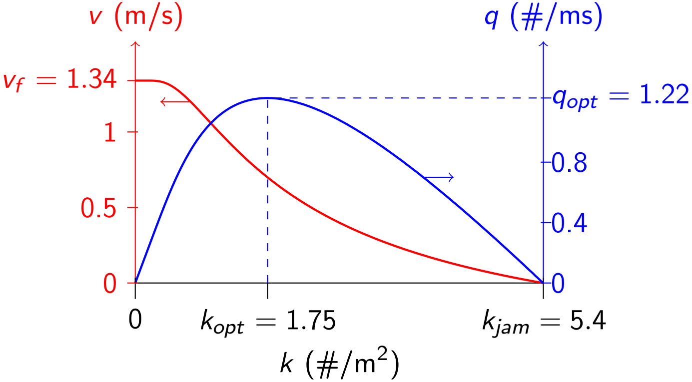
Representation of pedestrian facilities



- walkable area
- entry/exit points
- route $R = (r_0, r_1, \ldots)$
  - topological area r
- path $\Gamma = (\xi_1, \xi_2, \ldots)$
  - discretization cell ξ

Framework of pedestrian propagation model

- pedestrian fundamental diagram [Wei93]



Framework of pedestrian propagation model

- pedestrian fundamental diagram [Wei93]
  - isotropic density-velocity relation
  - hydrodynamic flow $q(k) = kv(k)$
- space: network of cells $\mathcal{G} = (\mathcal{V}, \mathcal{E})$
  - cells $\xi \in \mathcal{V}$, edges $g \in \mathcal{E}$
  - in- and outflow edges of cell ξ: $\mathcal{I}(\xi)$, $\mathcal{O}(\xi)$
- time: discrete intervals $\tau \in \mathcal{T}$
  - uniform length $\Delta t = \Delta L / v_f$, ΔL^2: cell size
- pedestrians: groups $\ell \in \mathcal{L}$
  - path Γ or route R, departure interval τ_0, size m_0
  - $m_\ell(\xi, \tau)$: size of group ℓ in cell ξ during interval τ

Advancement of group ℓ along path Γ

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

$$S_g^{\ell}(\tau) = \min\left\{ m_\ell(i,\tau),\ \frac{m_\ell(i,\tau)}{\sum_{\ell\in\mathcal{L}} m_\ell(i,\tau)} Q_i(\tau) \right\}$$

- ‘receiving capacity’ of cell j during interval τ

$$R_j(\tau) = \min\left\{ \delta\left(N - \sum_{\ell\in\mathcal{L}} m_\ell(i,\tau)\right),\ \hat{Q}_j(\tau) \right\}$$

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

$$\hat{Q}_\xi(\tau) = \begin{cases} Q_{\xi,opt} & \text{if } \sum\limits_{\ell\in\mathcal{L}} m_\ell(\xi,\tau) \le k_{opt}\Delta L^2 \\ Q_\xi(\tau) & \text{otherwise} \end{cases}$$

Ref: [ASKT07]

Advancement of group ℓ along path Γ

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

$$y_g^\ell(\tau) = \begin{cases} S_g^\ell(\tau) & \text{if } \sum_{h\in\mathcal{I}(j)} \sum_{\ell\in\mathcal{L}} S_h^\ell(\tau) \le R_j(\tau) \\ X_g^\ell(\tau) R_j(\tau) & \text{otherwise} \end{cases}$$

  - cell congestion: demand proportional supply distribution

$$X_g^\ell(\tau) = \frac{S_g^\ell(\tau)}{\sum_{k\in\mathcal{I}(j)} \sum_{\ell\in\mathcal{L}} S_k^\ell(\tau)}$$

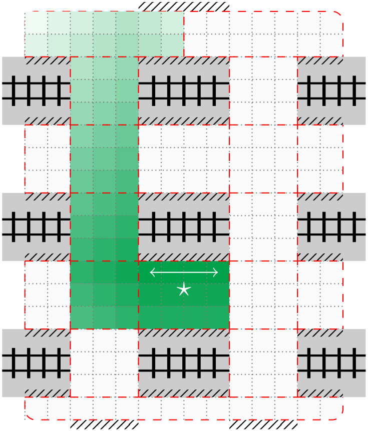
- recursion for group ℓ in cell i

$$m_\ell(i,\tau+1) = m_\ell(i,\tau) + y_f^\ell(\tau) - y_g^\ell(\tau)$$

  - $\Gamma = (\dots, f, g, \dots)$, 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
    - $\mathcal{G}_R = (\mathcal{V}_R, \mathcal{E}_R)$
- path $\Gamma = (\xi_1, \ldots, \xi_\star)$
    - discretization cell ξ
- route-specific potentials
    - $P_\xi = \min$ if $\xi = \xi_\star$
    - $P_\xi = \infty$ if $\xi \notin \mathcal{V}_\mathcal{R}$
- generalized potential
    - distance to destination $\star$
    - connectivity

Ref: [HG08]

Advancement of group ℓ along route R

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

$$D_g^R(\tau) = \begin{cases} \dfrac{(P_i^R - P_j^R)\left[N_j(\tau) - \sum_{\ell \in \mathcal{L}} m_\ell(j,\tau)\right]}{\sum_{k \in \Theta_i^R}\left\{(P_i^R - P_k^R)\left[N_j(\tau) - \sum_{\ell \in \mathcal{L}} m_\ell(k,\tau)\right]\right\}}, & g \in \Theta_i^R \\ 0, & \text{otherwise} \end{cases}$$

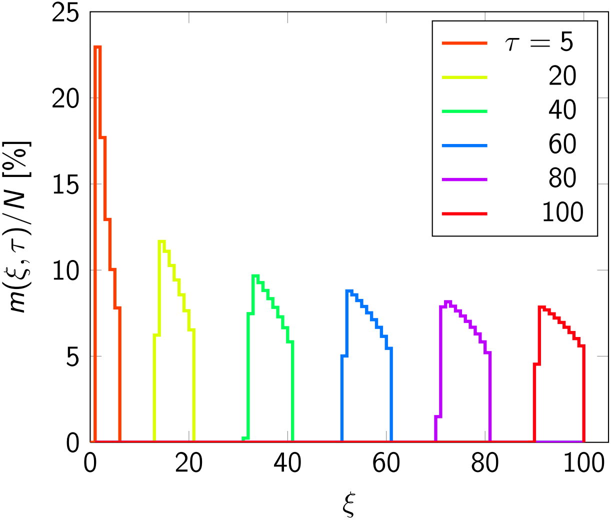
- sending capacity: edge $g : i \to j$, interval τ

$$S_g^\ell(\tau) = D_g^R(\tau) \min\left\{ m_\ell(i,\tau), \frac{m_\ell(i,\tau)}{\sum_{l \in \mathcal{L}} m_\ell(i,\tau)} Q_i(\tau) \right\}$$

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

$$m_\ell(\xi, \tau+1) = m_\ell(\xi,\tau) + \sum_{h \in \Phi_\xi^R} y_h^\ell(\tau) - \sum_{g \in \Theta_\xi^R} y_g^\ell(\tau)$$

Uniform 1D corridor with peak load ($m_0/N = 75\%$)



Conclusions

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

Thank you

STRC 2013:

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