ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

TRANSP-OR

Workshop on Pedestrian Models

Schedule-based pedestrian demand estimation in railway stations

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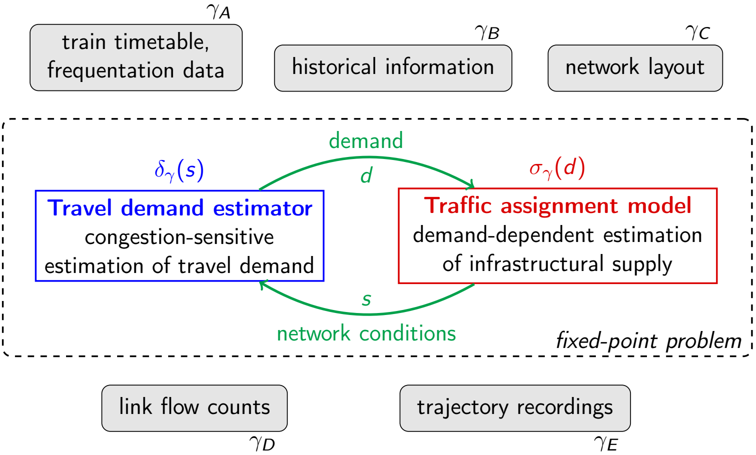
Pedestrian flows in train stations

Joint estimation of demand and supply



Literature review: Pedestrian flows in railway stations

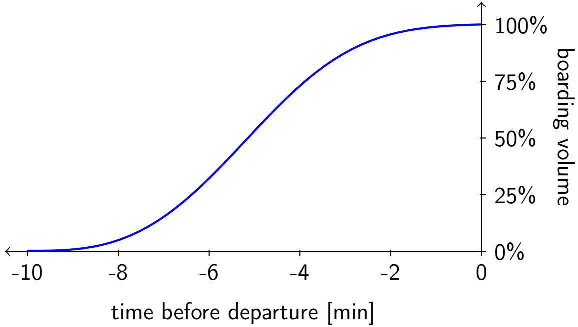
- flow characterization
  - empirical fundamental diagrams [LCL99, LC00]
- route choice
  - discrete choice models [CL98, Daa04]
- flow modeling
  - empirical flow-travel time relationships, queueing networks, CAs, Petri nets [LLW01, Daa04, KHEM07, ZHL08, XLLH14]
- case studies [HD04, RK07, DGM+13]
  - demand estimation: field surveys, regulatory load cases

⇒ estimation of schedule-based, station-wide pedestrian demand

- analogy to car traffic/transit networks [CIM93, WT98]

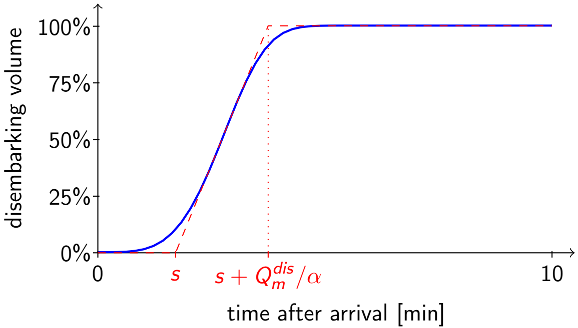
Train-induced arrival and departure flows

- departure flow: outbound passengers reaching platform
  - parameter vector γ_m associated with train m
  - generic flow rate $y_{dep}(t|\gamma_m, Q_m^{bord}, t_m^{dep})$
  - sample pattern of cumulated departure flow [HDGHA10, BW08]



Train-induced arrival and departure flows

- arrival flow: inbound passengers reaching platform exit ways
  - flow capacity of access way α_m
  - generic flow rate $y_{arr}(t|\alpha_m, Q_m^{dis}, t_m^{arr})$
  - sample pattern of cumulated arrival flow [BDK+11, Mol13]



General framework: Space, time and demand

- discrete time-intervals $\tau \in \mathcal{T}$ of uniform length
  - 'micro-peaking' (highly variable demand)
- network of pedestrian facilities $\mathcal{G} = (\mathcal{N}, \mathcal{L})$
  - nodes $\nu \in \mathcal{N}$, edges $\lambda \in \mathcal{L}$
  - subset of centroids $\mathcal{C} \subset \mathcal{N}$
    centroid type $u_\nu = (\text{platform}, \text{non-platform})$
- pedestrian origin-destination (OD) pairs $\zeta \in \mathcal{Z}$
  - $\zeta = (\nu_o, \nu_d)$, $\nu_o, \nu_d \in \mathcal{C}$
- demand $d_{\zeta,\tau} \in \mathbb{R}_0^+$ between OD pair ζ during time interval τ
  - independent single-destination trips

Framework for traffic assignment

- pedestrian routes $\rho \in \mathcal{R}$
  - sequence of edges $\rho = (\lambda_1^\rho, \lambda_2^\rho, \dots)$
  - route choice fraction $\delta_{\rho,\zeta}$, $\Delta(d) = [\delta_{\rho,\zeta}(d)]$
- flow on link λ during time interval τ
  - $f_{\lambda,\tau} = \sum_{\kappa \in \mathcal{T}} \sum_{\zeta \in \mathcal{Z}} \sum_{\rho \in \mathcal{R}} \Pr(\lambda, \tau, \rho, \kappa | d)\, \delta_{\rho,\zeta}(d)\, d_{\zeta,\kappa}$
  - $f = A(d)\Delta(d)d$ where $A_{(\lambda,\tau),(\rho,\kappa)}(d) = \Pr(\lambda, \tau, \rho, \kappa | d)$
- further indirect measures of demand
  - subroute flows: $m = B(d)\Delta(d)d$
  - area occupation: $n = S(d)\Delta(d)d$
  - velocities, travel times, ...

Framework for demand estimation

- direct and indirect demand measurements
  - historical demand estimate $\hat{d}$
  - flow observations $\hat{f}_{\lambda,\tau}$ on subset of links $\mathcal{E}_f \subset \mathcal{E}$
  - train-induced arrival/departure flows, sales data, ...
- demand reproducing available measurements at best

$$d = \arg\min_{x \geq 0} ||\hat{d} - x||_2^2 + \mu_f ||\hat{f} - \hat{A}_f(x)\hat{\Delta}_f(x)x||_2^2 + \ldots$$

$\mu_i \in \mathbb{R}_0^+$: relative weight of information source i

Train-induced arrival and departure flows

- flows towards and from platform p
  - M_p trains during time horizon $\mathcal{T}$
  - linear superposition of flows
- cumulated arrival flow on platform p during time interval τ

$$\hat{g}_{p,\tau} = \int_{t=t_\tau^-}^{t_\tau^+} \sum_{m=1}^{M_p} y_{arr}(t|\gamma_{p,m}^{arr}, Q_m^{arr}, t_m^{arr}) \, \mathrm{d}t$$

  - similarly for cumulated departure flow $\hat{h}_{p,\tau}$

Variance of demand

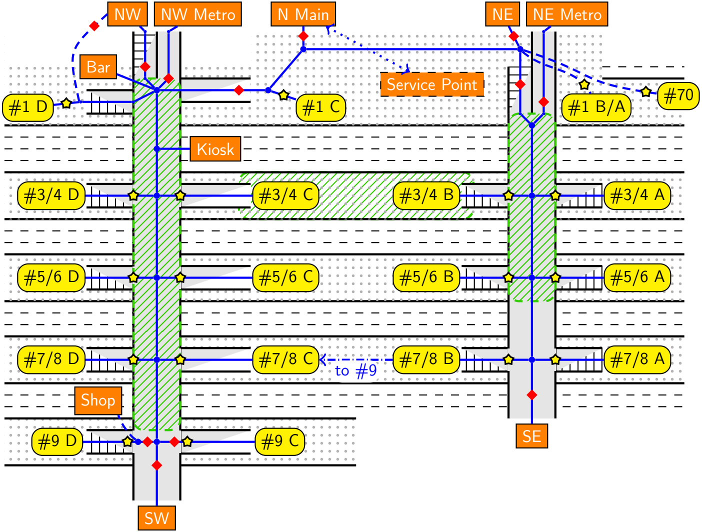
- distribution of measurements
  - day-specific observations (e.g. link flows, timetable)
  - day-generic distributions (e.g. no. of boardings per train)
  - information with unknown distribution (e.g. historical data)
- distribution of demand estimate $\pi(d)$
  - day-specific distribution (e.g. for validation)
  - day-generic distribution (for planning/dimensioning)
- Monte Carlo integration

Case study: Lausanne railway station

Case study: Lausanne railway station

- trip types: inbound, outbound, transfer and local users
  - conditional choice of destination type
    - $\beta(\text{platform}|\text{non-platform}) = 95\%$ [BDK+11, LAB13]
    - $\beta(\text{non-platform}|\text{platform}) = 91.3\% \pm 4.55\%$ [AHB12]
- facility types: walking, waiting and service areas
  - focus on walking areas
- traffic assignment model
  - signposted routes: $|\mathcal{R}_\zeta| = 1 \; \forall \, \zeta \in \mathcal{Z}$
  - demand-independent propagation [Wei93]
    $v \sim \mathcal{N}(1.34 \text{ m/s}, 0.34 \text{ m/s})$

Walking areas in Lausanne railway station

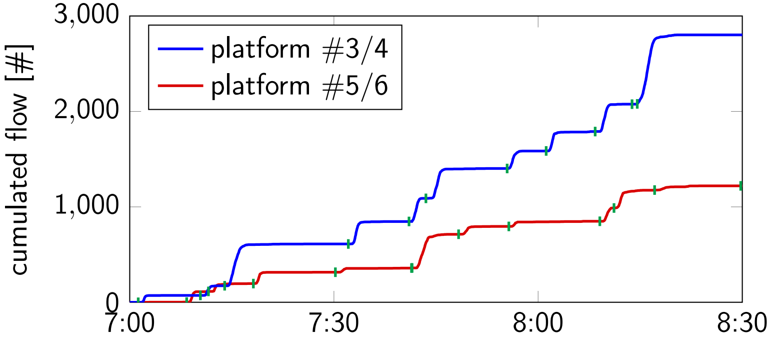


Walking areas in Lausanne railway station

	pedestrian walking network
entrance	centroid with historical information
platform	centroid without historical information
	link with a priori flow estimate based on timetable
	link equipped with directed flow counter
	area covered by pedestrian tracking system

Train-induced arrival flow in Lausanne railway station

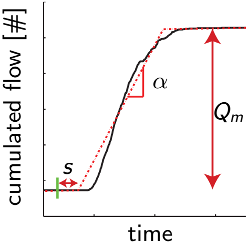
- afflux of passengers and train arrivals on April 9, 2013



Train-induced arrival flow in Lausanne railway station

- afflux of passengers and train arrivals on April 9, 2013
- piecewise-constant flow rate [BDK+11]

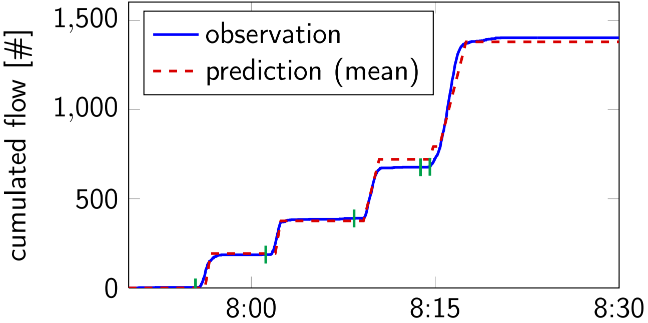
$$y(t|\alpha, s, Q_m, t_m) = \begin{cases} \alpha & t \in (t_m + s, t_m + s + Q_m/\alpha) \\ 0 & \text{otherwise} \end{cases}$$



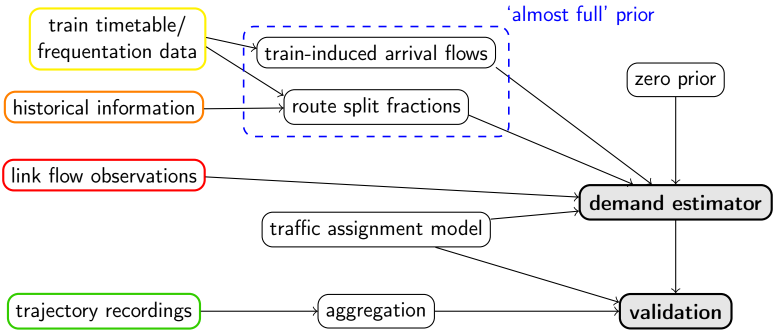
- arrival of train m at t_m
- dead time: $s \sim \mathcal{N}(38.7\text{ s}, 14.6\text{ s})$
- capacity flow rate: $\alpha \sim \mathcal{N}(3.9\text{ s}^{-1}, 1.1\text{ s}^{-1})$
- disembarkations of train m: $Q_m \sim \mathcal{N}(\mu_m, 0.2\mu_m)$

Train-induced arrival flow in Lausanne railway station

- afflux of passengers and train arrivals on April 9, 2013
- piecewise-constant flow rate [BDK+11]
- prediction for platform #5/6 (April 9, 2013, HOP data)



Case study: Estimation methodology



Conclusions

- methodology for estimating pedestrian OD demand in railway stations lent from car traffic
  - use of various direct and indirect measurements
- integration of train timetable and train frequentation data
  - train-induced arrival and departure flows
- variance of demand
  - day-to-day variability, ‘micro-peaking’
- case study of Lausanne railway station
  - simplest possible traffic assignment model
  - to be estimated and validated

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