Recent trends in pedestrian modeling at EPFL

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Outline

1. Introduction
2. Data
3. Indicators
   - Density
   - Fundamental diagram
   - Flow
4. Demand analysis
   - OD flows
   - Activity chains
5. Flow propagation
6. Conclusion

Pedestrians

Context

Swiss railway authority

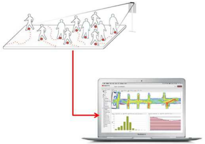
- Increasing demand
- Increased capacity of the trains
- More and more pedestrian congestion in train stations
- Need for decision aid tools

SBB CFF FFS

Research projects at EPFL

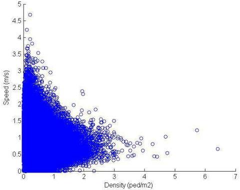
Data collection and analysis

- Trajectories
- WiFi traces



Performance indicators

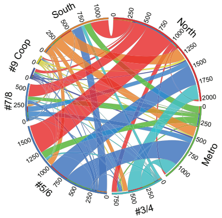
- Density
- Speed
- Flow
- Fundamental relationships



Research projects at EPFL

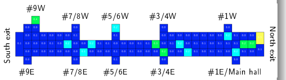
Demand analysis

- Origin-destination matrices
- Activities



Flow propagation

- Assignment
- Congestion
- Cell transmission model



Outline

Traditional data collection

Real life data

- Video surveillance
- Manual extraction of relevant data

Experimental data

- Controlled environment
- Video analysis

TU Delft

New technology

Visiosafe

- Spin-off of EPFL
- Anonymous tracking of pedestrians
- Thermal and range sensors

VISIOSAFE

Short movie

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Pervasive technology: smartphones

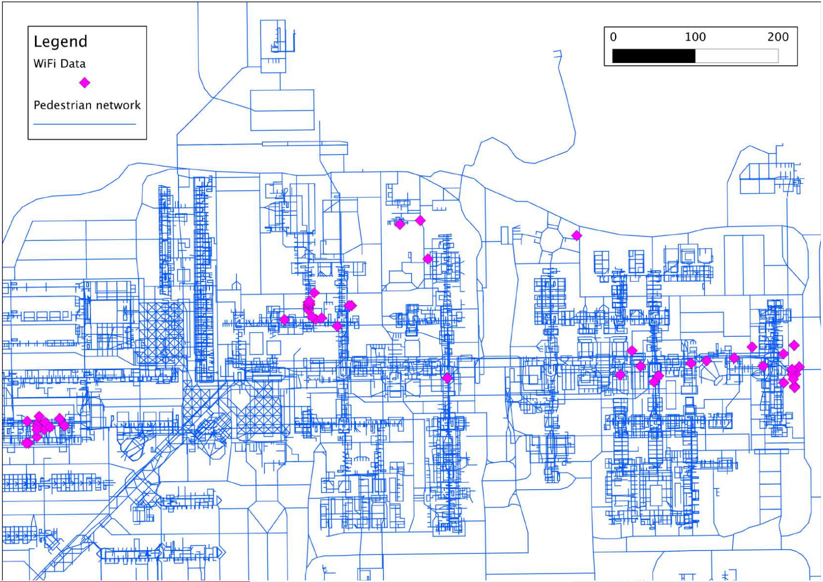
WiFi traces

- Media Access Control (MAC) address tracked
- Sometimes, login is required

Bluetooth

- Track surrounding devices
- Tracking devices are mobile

EPFL campus

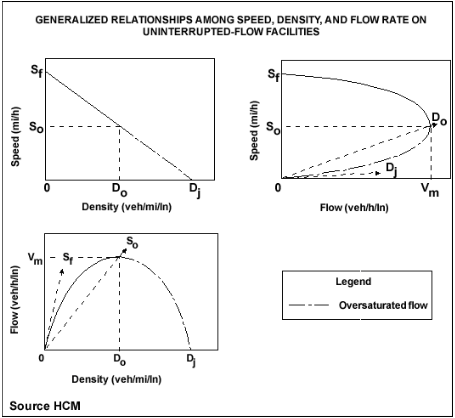


Outline

Indicators

Traffic flow theory

- Density
- Speed
- Flow
- Fundamental relationships



Density

Vehicular traffic

At a given time, number of cars per meter

Pedestrians

At a given time, number of pedestrians per square meter

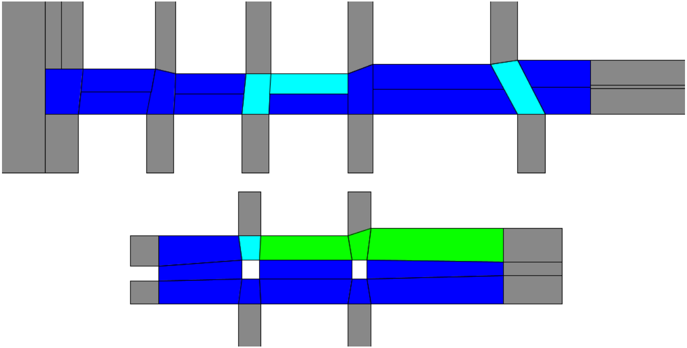
Pedestrian walkway LoS density threshold values according to NCHRP

	LOS	Pedestrian density
(blue)	A	< 0.179 [ped/m^2]
(cyan)	B	< 0.270
(green)	C	< 0.455
(yellow)	D	< 0.714
(orange)	E	< 1.333
(red)	F	≥ 1.333

Data analysis: Heat map January 22, 2013

Aggregation: $\Delta t = 60$ s, $A = 8 \ldots 75$ m^2

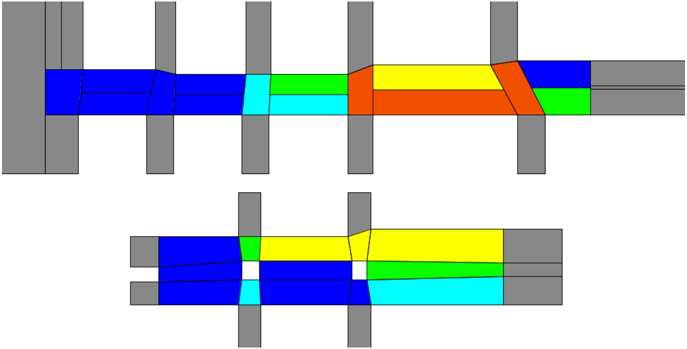
7:40–7:41: Low occupation, no train arrivals



Data analysis: Heat map January 22, 2013

Aggregation: $\Delta t = 60$ s, $A = 8 \ldots 75$ m^2

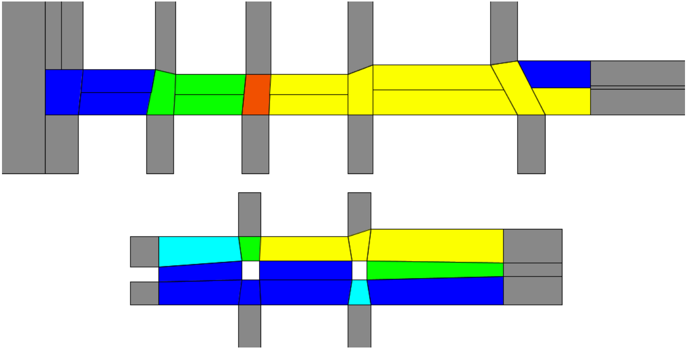
7:41–7:42: Arrival of train IR 1606 at 7:40:20 on platform 3/4



Data analysis: Heat map January 22, 2013

Aggregation: $\Delta t = 60$ s, $A = 8 \dots 75$ m^2

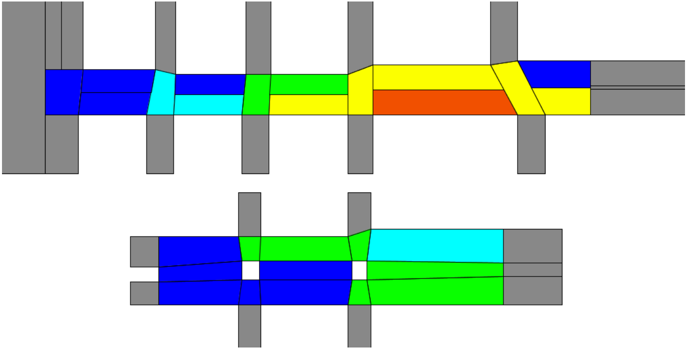
7:42–7:43: Arrival of train IR 706 at 7:41:24 on platform 5/6



Data analysis: Heat map January 22, 2013

Aggregation: $\Delta t = 60$ s, $A = 8 \dots 75$ m^2

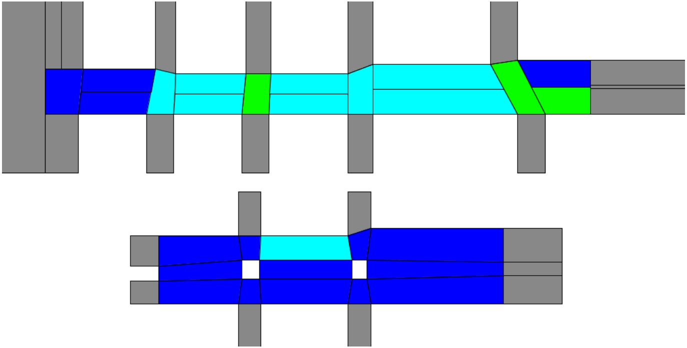
7:43–7:44: Arrival of train IR 1407 at 7:42:20 on platform 3/4



Data analysis: Heat map January 22, 2013

Aggregation: $\Delta t = 60$ s, $A = 8 \ldots 75$ m^2

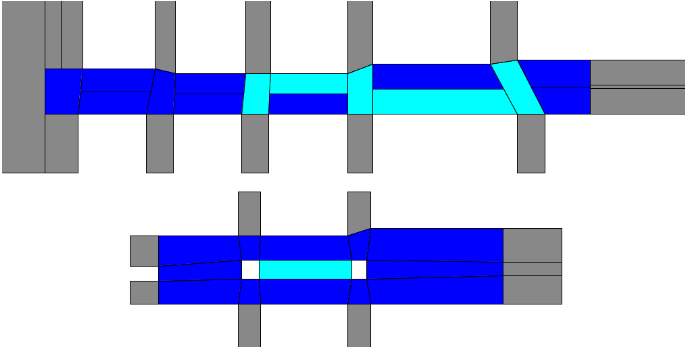
7:44–7:45: Gradual decrease in pedestrian occupation



Data analysis: Heat map January 22, 2013

Aggregation: $\Delta t = 60$ s, $A = 8 \ldots 75$ m^2

7:45–7:46: Return to low level of occupation



New developments

Issues

- Spatial discretization is arbitrary
- Results may be highly sensitive
- If cells are too small, many are empty
- If cells are too large, loss of heterogeneity

Solution investigated

- Visiosafe data: detailed trajectories
- Position of every single individual over time

$$(t, x(t), y(t), \text{pedestrian}_{id})$$

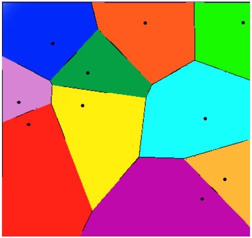
- Idea: data driven spatial discretization

Voronoi tessellations

Partitioning of space

- Consider a finite set of points p_1, p_2, ... in space.
- The Voronoi cell of point p_i is defined as

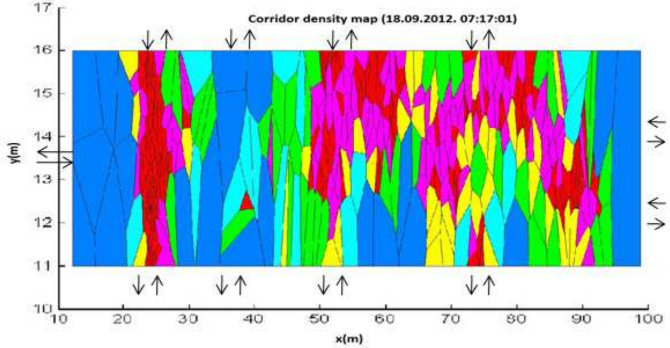
$$V(p_i) = \{p | \|p - p_i\| \leq \|p - p_j\|, i \neq j\}$$



Illustrations: Wikipedia

Voronoi tessellations

Set of points: pedestrians



Pedestrian density	
(blue)	< 0.179 [ped/m²]
(cyan)	< 0.270
(green)	< 0.455
(yellow)	< 0.714
(magenta)	< 1.333
(red)	≥ 1.333

Table: Pedestrian walkway LoS density threshold values according to NCHRP (in SI units).

Voronoi tessellations

Methodology

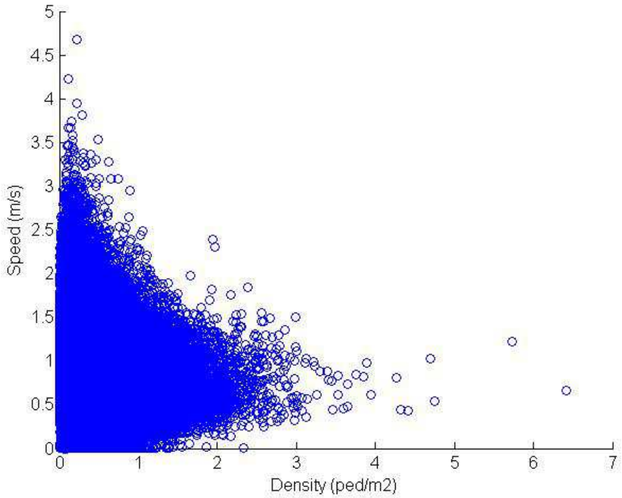
- Consider pedestrian p
- V_p is the Voronoi cell associated with p
- $|V_p|$ is the area of cell V_p (in m^2)
- Density associated with the cell: $d_p = 1/|V_p|$.

Issues

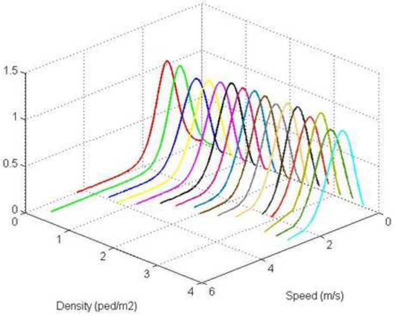
- Numerical instability if pedestrians are very close.
- Time discretization: a new tessellation is computed at each point in time.
- Dealing with obstacles.

Fundamental diagram

Empirical



Probabilistic speed-density model



$$V \sim f\left(\alpha\left(k\right), \beta\left(k\right), l\left(k\right), u\left(k\right)\right)$$

- f - Kumaraswamy pdf
- V - speed
- k - density level
- α, β - shape parameters
- l, u - boundary parameters

Other research topics

Definition of flow

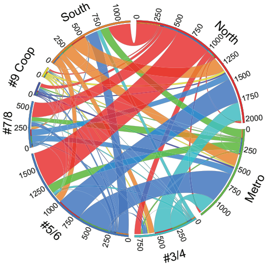
- Vehicular traffic: number of vehicles crossing a given location per unit of time.
- Pedestrian case: how do we define the location?
- Well defined instances: unidirectional flow through gates, doors, corridors, stairs.
- Ill defined instances: open spaces, multidirectional flow.

Outline

Origin destination matrices

Data

- Visiosafe data
- Train timetable
- Train occupation



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Demand estimation: timetable induced demand

- correlation between train schedule and pedestrian flows

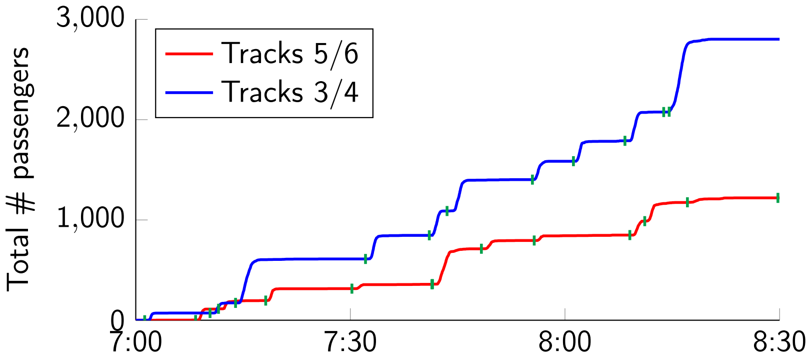
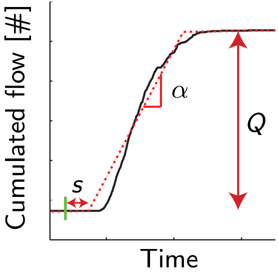


Figure: Train unloading flow and train arrivals, April 9, 2013

Demand estimation: timetable induced demand

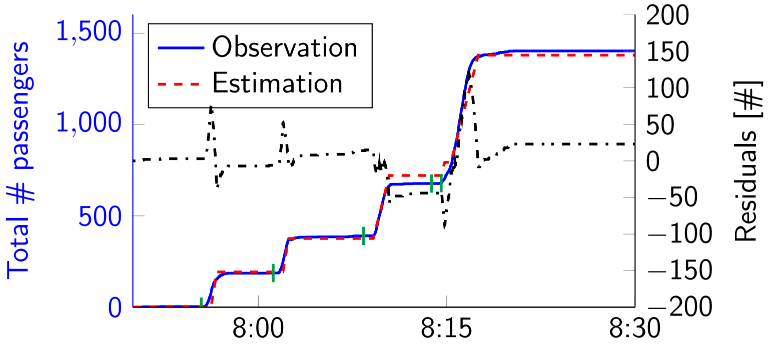
- correlation between train schedule and pedestrian flows
- ‘unloading flow’ as superposition of train-induced events



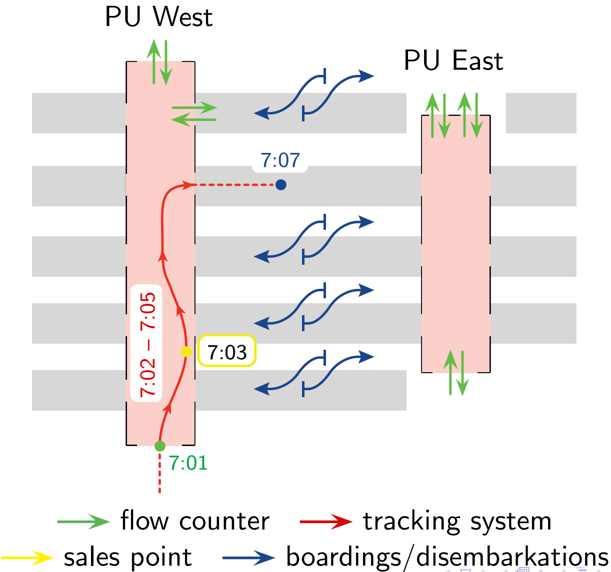
- inflow after train arrival
- dead time: $s \approx 46.3$ s
- flow rate:
  $\alpha_{long} = 6.8 \pm 1$ #/s
  $\alpha_{short} = 4.5 \pm 1$ #/s
- disembarkations per train:
  $Q = 80 \ldots 500$

Demand estimation: timetable induced demand

- correlation between train schedule and pedestrian flows
- ‘unloading flow’ as superposition of train-induced events
- sample prediction (April 9, 2013, based on HOP data)



Pedestrian demand estimation: measurement equation



Pedestrian demand estimation: measurement equation

For route $r \in R$, sensor $s \in S$, time interval $t \in T$:

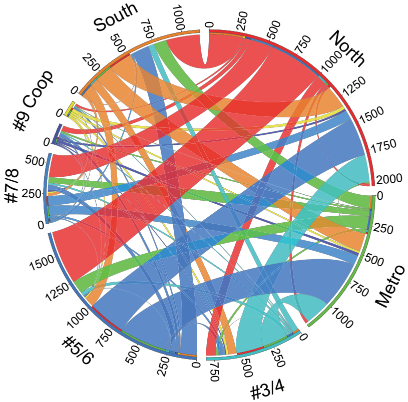
$x_{r,t}$: pedestrian demand on route r during interval t

$y^s_{r,t}$: travel time on route r to sensor s if departing in interval t

Measurement equation for sensor s (time interval t):

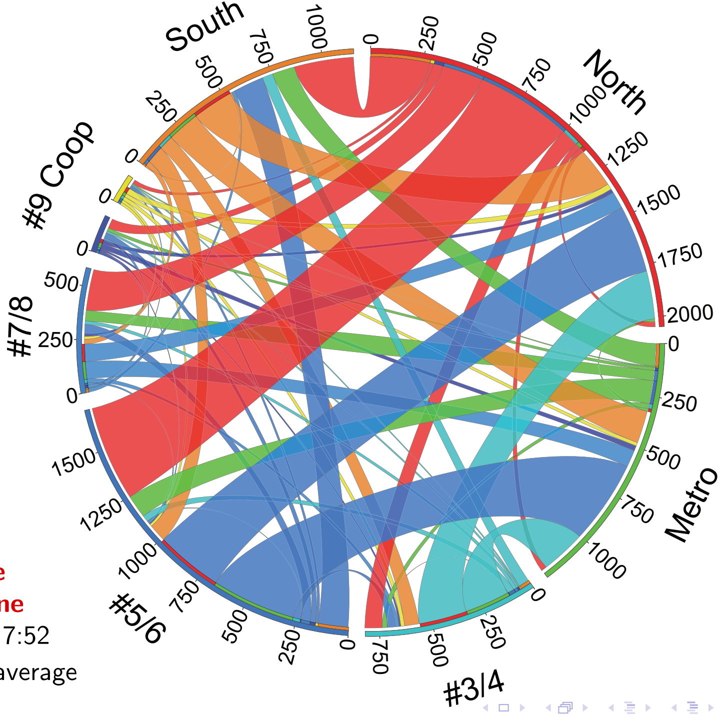
$$\text{sensor flow: } f_{s,t} = \sum_{k=1}^{t} \sum_{r=1}^{R} x_{r,k} \underbrace{\Pr(y^s_{r,k} = t - k)}_{\text{probability term}}$$

Pedestrian demand estimation: Circos diagram



Example of OD demand:

- pedestrian underpasses, Gare de Lausanne
- busiest 15-min period
- extracted from tracking data



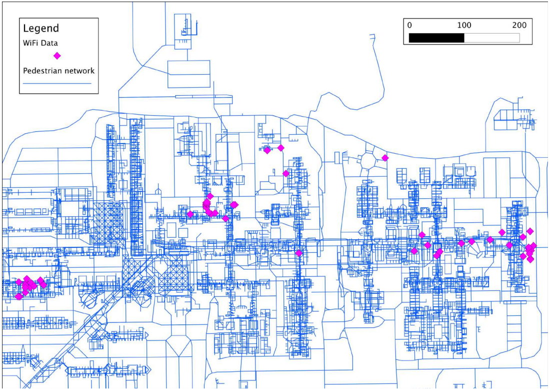
Gare de Lausanne

07:37 – 7:52

10-day average

Activity chains

- Visiosafe data not always available.
- How can we exploit WiFi traces?
- Case study: EPFL campus



Methodology

Goal

Extract the possible activity episodes performed by pedestrians from digital traces from communication networks

Input

- Network traces
- Semantically-enriched routing graph
- Potential attractivity measure

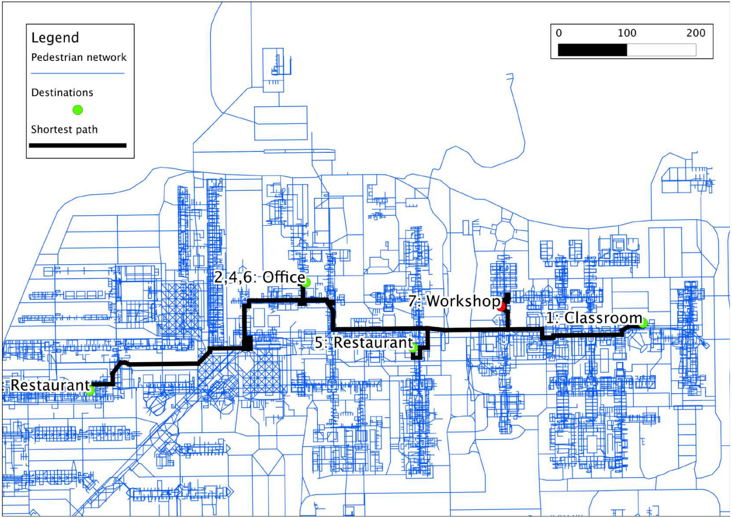
Output

Set of candidate activity-episode sequences associated with the likelihood to be the true one

Bayesian approach

$$P(a_{1:m}|\hat{s}_{1:n}) \propto P(\hat{s}_{1:n}|a_{1:m}) \cdot P(a_{1:m})$$

Case study


Legend
Pedestrian network
Destinations
Shortest path
0
100
200
2,4,6: Office
7: Workshop
1: Classroom
5: Restaurant
Restaurant

Outline

Propagation model

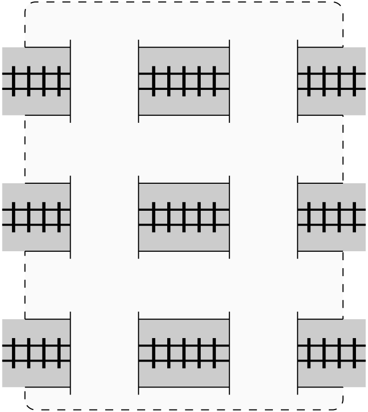
Hierarchical discretization of space

- One discretization for route choice
- One discretization for flow propagation

Cell transmission model

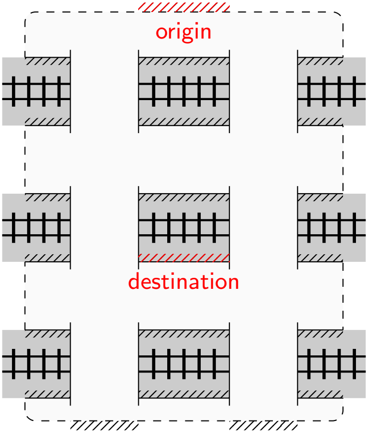
- mesoscopic: aggregate group of pedestrians
- deterministic: 1^{st} order flow theory
- system dynamics: macroscopic fundamental diagram

Representation of pedestrian facilities



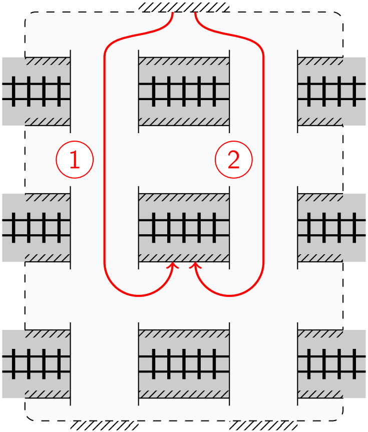
- walkable area

Representation of pedestrian facilities



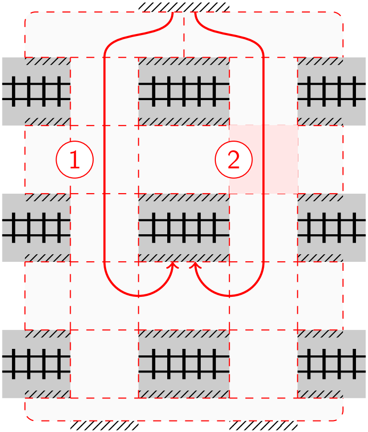
- walkable area
- entry/exit points

Representation of pedestrian facilities



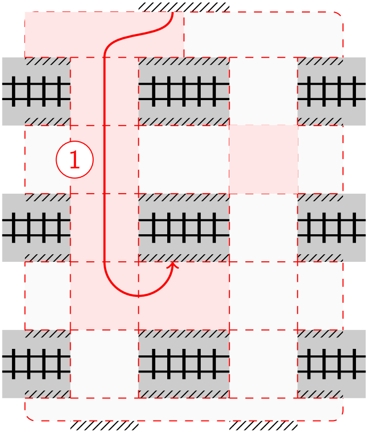
- walkable area
- entry/exit points
- route R

Representation of pedestrian facilities



- walkable area
- entry/exit points
- route $R = (r_0, r_1, \ldots)$
  - topological area r

Representation of pedestrian facilities



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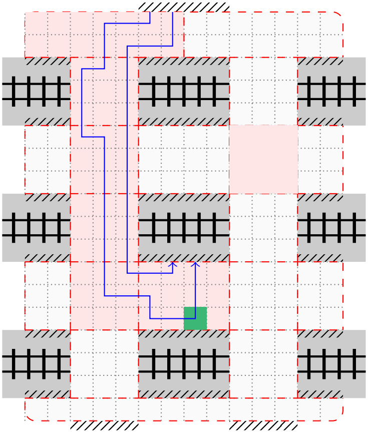

- walkable area
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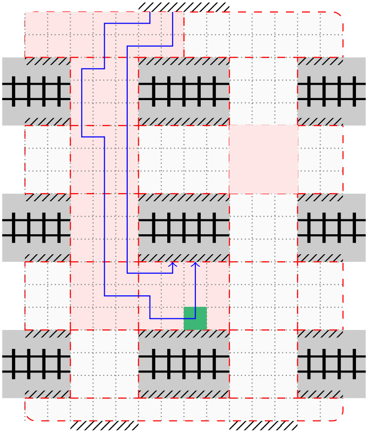
- route $R = (r_0, r_1, \ldots)$
  - topological area r
- path $\Gamma = (\xi_1, \xi_2, \ldots)$
  - discretization cell ξ

Representation of pedestrian facilities



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

Advancement of group ℓ along path Γ

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

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

  - free flow: all agents proceed
  - congestion: demand-proportional supply
  - hydrodynamic outflow capacity

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

$\rightsquigarrow$ $Q_\xi(\tau)$: cumulated hydrodynamic cell flow

Advancement of group ℓ along path Γ

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- 'receiving capacity' of cell j during interval τ

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

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

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

Advancement of group ℓ along path Γ

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

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

  - cell congestion: demand proportional supply distribution

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

Advancement of group ℓ along path Γ

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

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  - cell congestion: demand proportional supply distribution

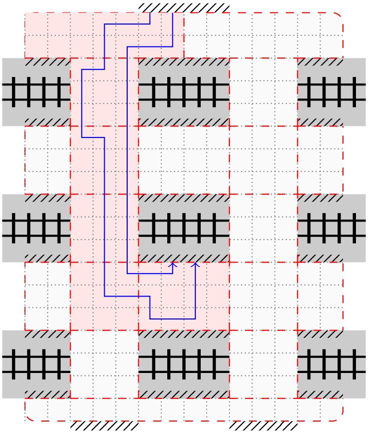
$$X_g^\ell(\tau) = \frac{S_g^\ell(\tau)}{\sum_{k\in\mathcal{I}(j)} \sum_{\ell\in\mathcal{L}} S_k^\ell(\tau)}$$

- recursion for group ℓ in cell i

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

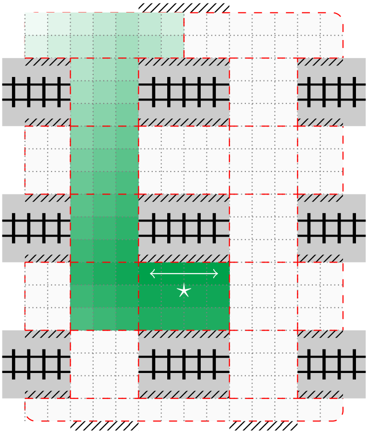
  - $\Gamma = (\ldots, f, g, \ldots)$, where $f : h \to i$, $g : i \to j$

Cell potentials for en-route path choice



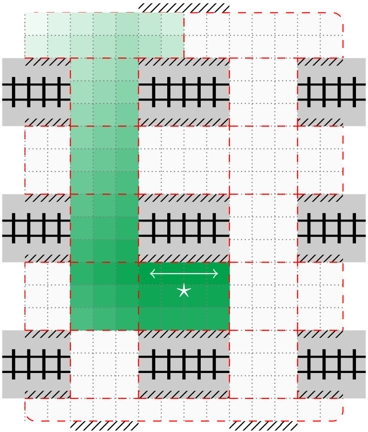
- route $R = (r_0, r_1, \ldots)$
- path $\Gamma = (\xi_1, \ldots, \xi_\star)$

Cell potentials for en-route path choice



- route $R = (r_0, r_1, \ldots)$
- path $\Gamma = (\xi_1, \ldots, \xi_\star)$
- route-specific floor field F^R
  - distance to destination $\star$
  - $F^R_\xi = \min$ if $\xi = \xi^R_\star$

Cell potentials for en-route path choice



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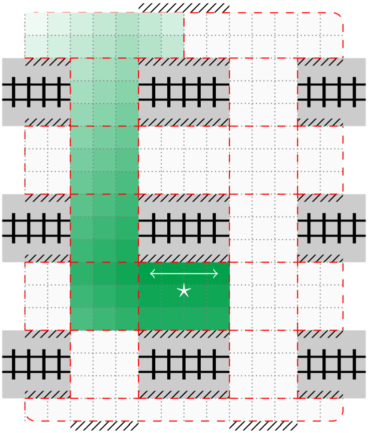
- route-specific floor field F^R
  - distance to destination $\star$
  - $F^R_\xi = \min$ if $\xi = \xi^R_\star$
- traffic-dependent floor field
  - prevailing speed $v_\xi(\tau)/v_f$

Cell potentials for en-route path choice



- route $R = (r_0, r_1, \dots)$
- path $\Gamma = (\xi_1, \dots, \xi_\star)$
- route-specific floor field F^R
  - distance to destination $\star$
  - $F^R_\xi = \min$ if $\xi = \xi^R_\star$
- traffic-dependent floor field
  - prevailing speed $v_\xi(\tau)/v_f$
- potential of cell ξ
  - $P^R_\xi(\tau) = F^R_\xi - \alpha \frac{v_\xi(\tau)}{v_f}$
  - lower is 'closer' to destination
  - route R, interval τ

Outline

Conclusion

Pedestrian movements in open facilities

- Train stations
- Campus
- Airport
- etc.

From data to behavior

- Advanced tracking data
- Smartphone data

From traffic to pedestrians

- Important analogies
- Major differences