EPFL

Spring 2025

11 Park & Ride First/Last-mile Service

CIVIL-324 Urban public transport systems

École polytechnique fédérale de Lausanne

Single vs inter-modal transport

Single-modal

Mass transit

Flexible transit

Personal mobility service

Inter-modal

Park & ride

First/last-mile

Mobility-as-a-service

Co-modality

Single vs inter-modal transport

Single-modal

Mass transit

Flexible transit

Personal mobility service

Inter-modal

Park &

Topic of this lecture

Mobility-as-a-service

Co-modality

Single vs inter-modal transport

Single-modal

Mass transit

Flexible transit

Personal mobility service

Inter-modal

Park & ride

First/last-mile

Mobility-as-a-service

Co-modality

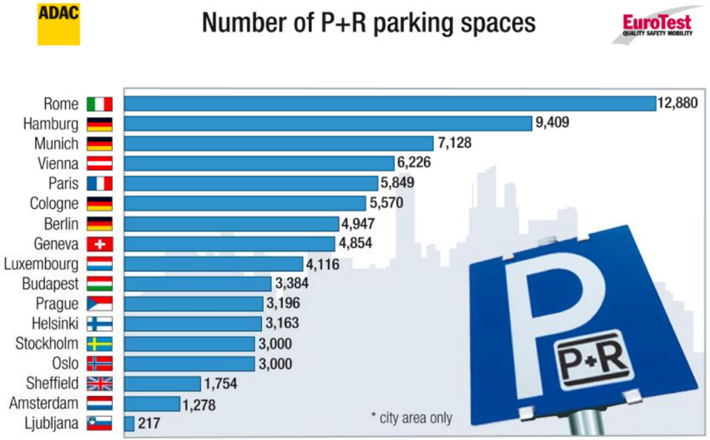
Topic of next week

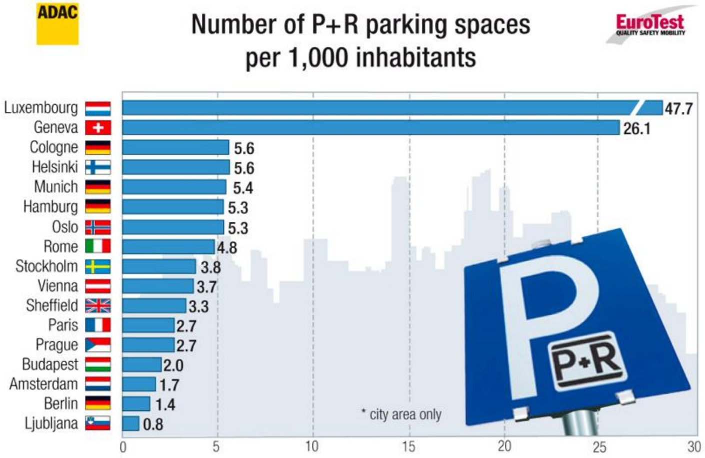
What is park & ride (P&R)?

- Parking facilities distributed at the city perimeter
  - Connection points to transfer from driving to public transport (e.g., train)
    - Discounted parking price is introduced as financial incentives
  - Target at car users who commute between the suburbs and the city centers
    - Suburb: without access to public transport
    - City center: lack of parking spaces

What is park & ride (P&R)?

- Parking facilities distributed at the city perimeter
  - Connection points to transfer from driving to public transport (e.g., train)
    - Discounted parking price is introduced as financial incentives
  - Target at car users who commute between the suburbs and the city centers
    - Suburb: without access to public transport
    - City center: lack of parking spaces
  - Emerged in the 1920s in the U.S. and widely implemented in Europe

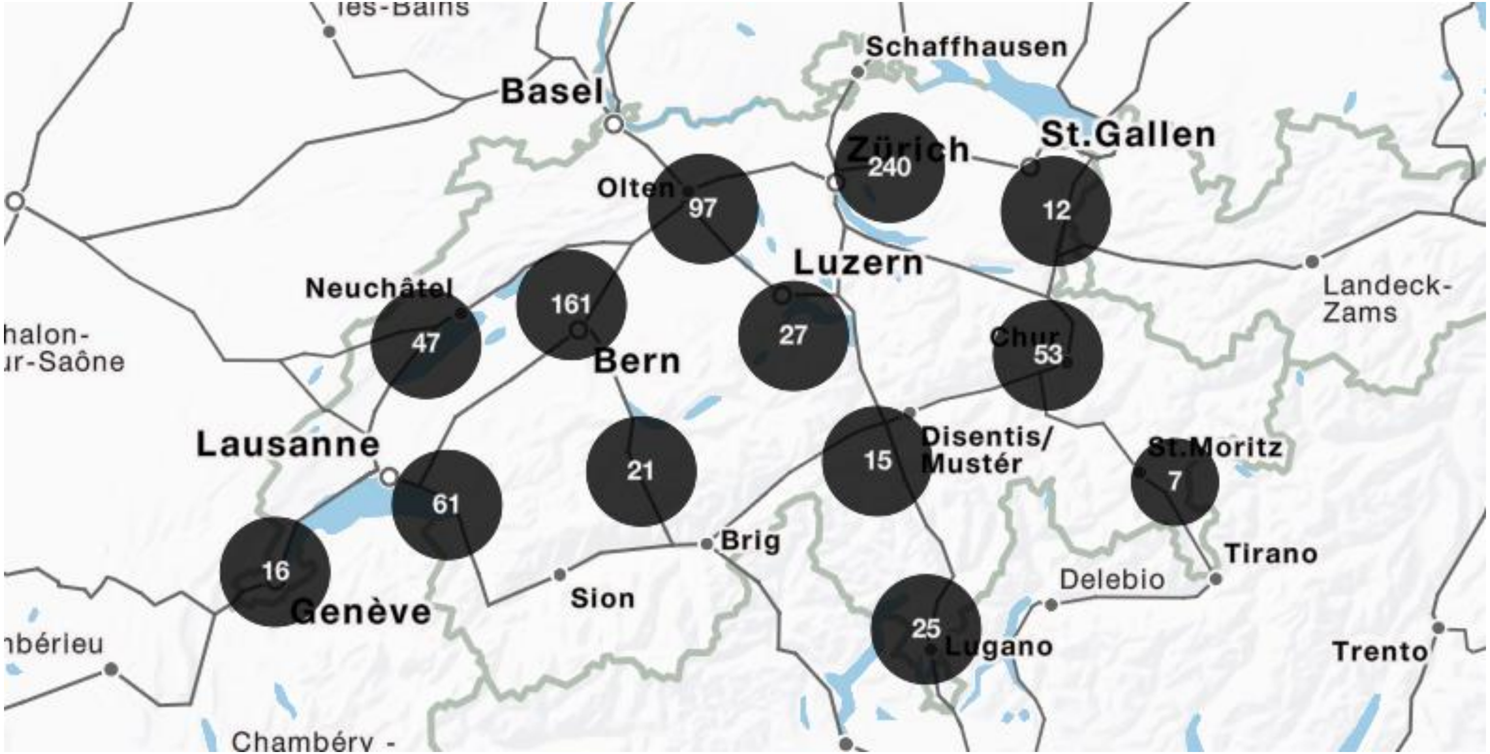




Park & Ride: State of the Art in Europe. EuroTest, FiA

Practice in Switzerland

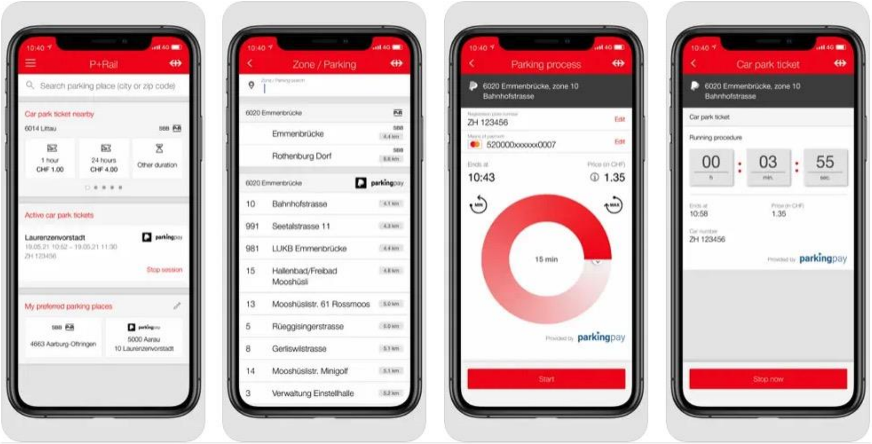
- P&R as “park and rail”



CFF P+Rail

Practice in Switzerland

- CFF P+Rail
  - Hourly/daily parking
    - Reserve and buy ticket via mobile app
    - Daily pass between CHF3-20
  - Monthly/annual pass
    - Monthly pass between CHF 30-160
    - Annual pass between CHF 300-1600



Practice in Switzerland

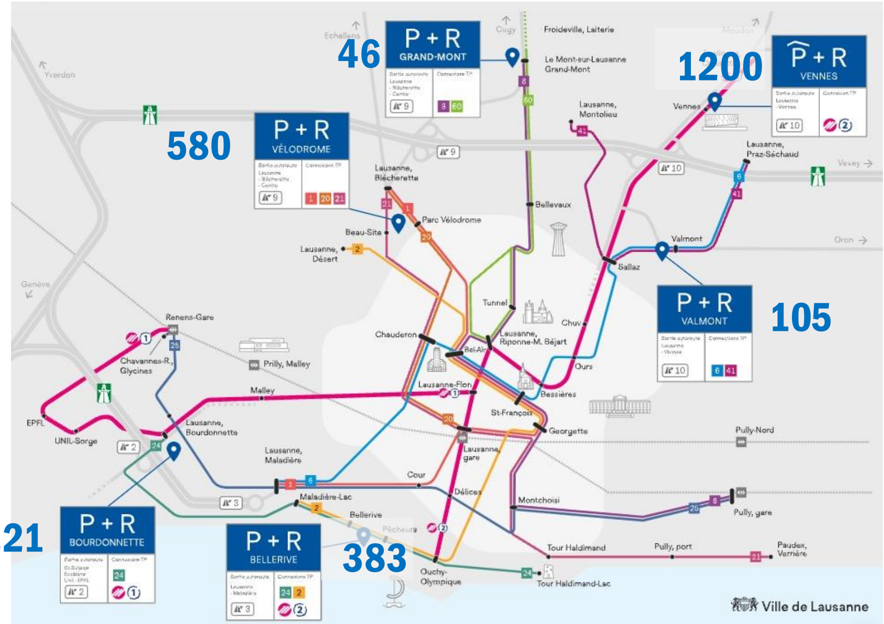
- Regional P+Rail
  - Lausanne
    - 2500 spots across six facilities
    - Close to highway exits, metro stations, and bus stops
  - Geneva
    - 4500 spots across 24 facilities
    - Subscriptions for bike parking
      - P + B and P + R + B

Geneve P+R

- ***Q: What are key design variables of P&R?***

Design of P&R

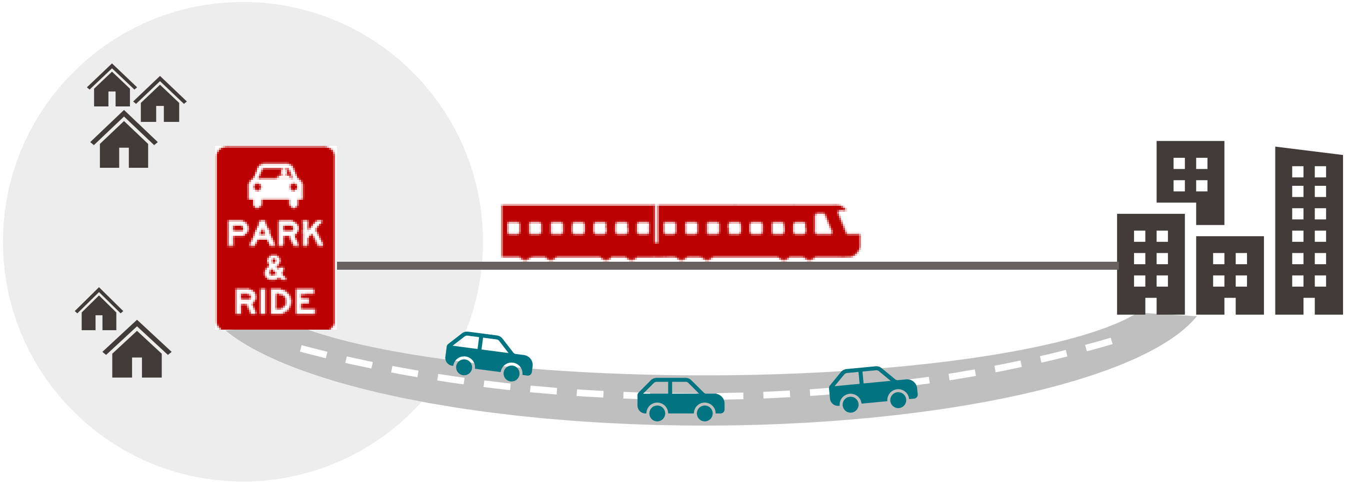
- Location and capacity
  - Align with the distribution of potential users
- Pricing
  - Competitive with other travel modes
    - e.g., driving



[Lausanne P+R](#)

Design of P&R

- Stylized model with single origin-destination
  - Demand from the residential area to the city center at rate λ_0 (pax/hr)
    - Driving through highway at cost c_{drv} (CHF)
    - P&R at cost $c_{\mathrm{P\&R}}$ (CHF)
  - Sufficient P&R capacity
  - Congestible highway with limited capacity κ (veh/hr)



Design of P&R

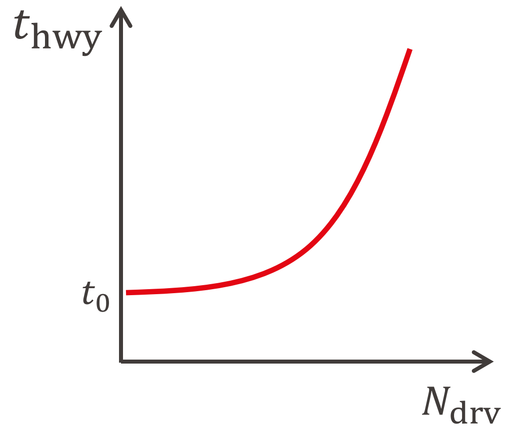
- Total travel time per trip
  - Driving

$$t = t_a + t_{\mathrm{hwy}}$$

    - t_a driving time from home to highway
    - t_{hwy} highway travel time
  - P&R

$$t = t_a + \tau + t_{\mathrm{rail}}$$

    - t_a driving time from home to P&R
    - τ parking/transfer time
    - t_{rail} riding time of train



$$t_{\mathrm{hwy}} = t_0 \left[1 + \gamma \left(\frac{\lambda_{\mathrm{drv}}}{\kappa}\right)^{\alpha}\right]$$

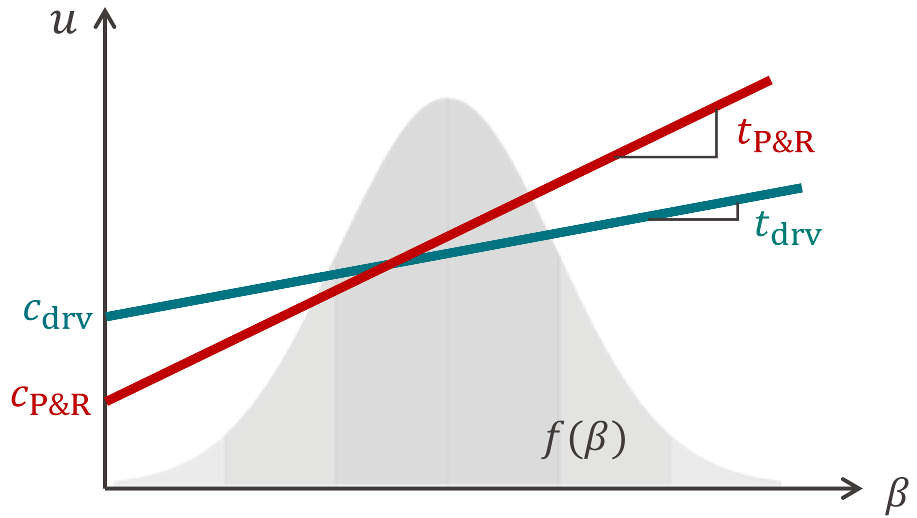
- t_0 free-flow travel time on highway
- λ_{drv} driving demand
- κ highway capacity
- α, γ parameters in highway travel time function

Design of P&R

- Mode choice of commuters

$$u = c + \beta t$$

  - u generalized cost
  - c, t monetary cost and total travel time
  - β value of time with probability density function $f(\beta)$

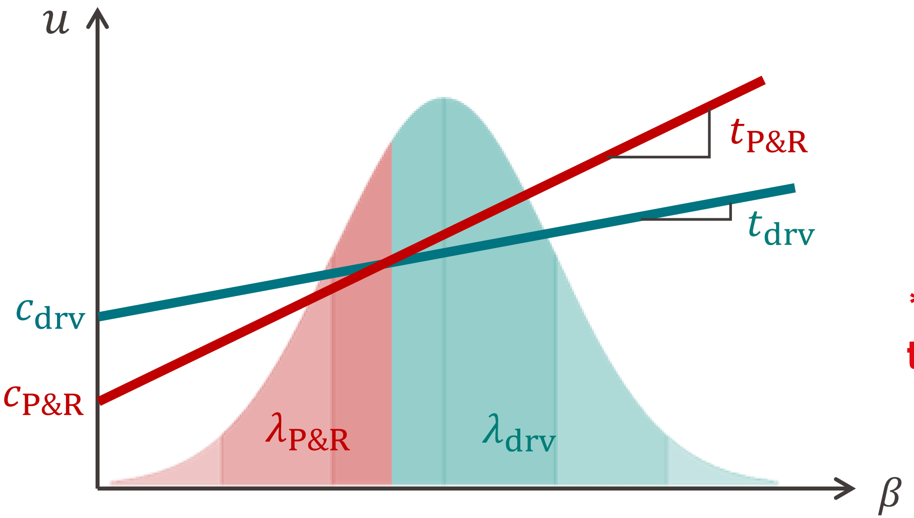


Design of P&R

- Mode choice of commuters

$$u = c + \beta t$$

- u generalized cost
- c, t monetary cost and total travel time
- β value of time with probability density function $f(\beta)$



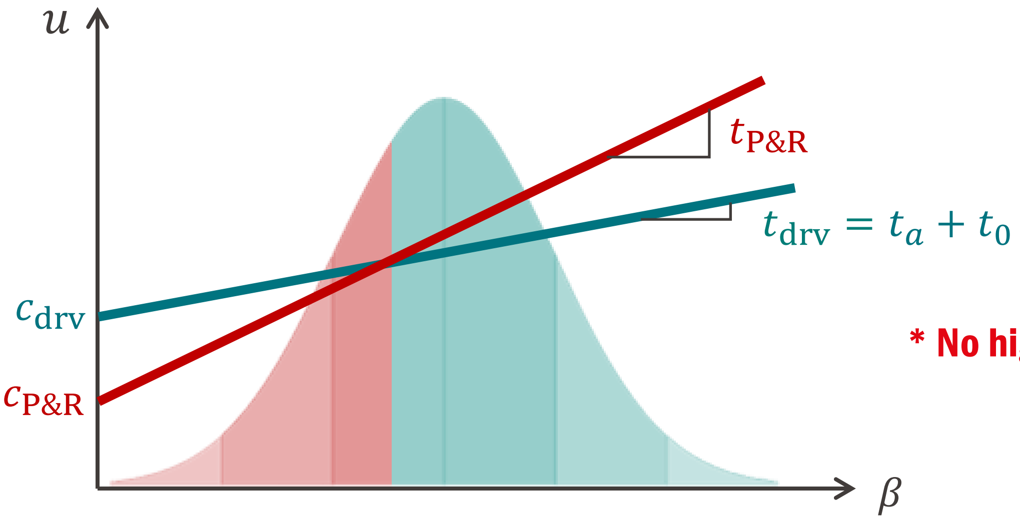
*** t_{drv} is affected by λ_{drv} due to highway congestion**

Design of P&R

- Mode choice of commuters

$$u = c + \beta t$$

- u generalized cost
- c, t monetary cost and total travel time
- β value of time with probability density function $f(\beta)$



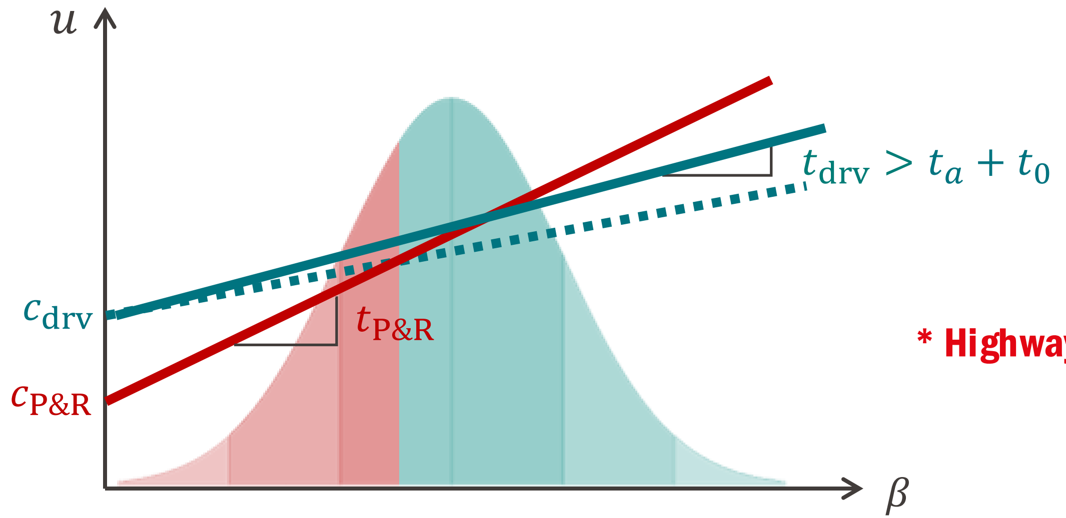
*** No highway congestion**

Design of P&R

- Mode choice of commuters

$$u = c + \beta t$$

  - u generalized cost
  - c, t monetary cost and total travel time
  - β value of time with probability density function $f(\beta)$



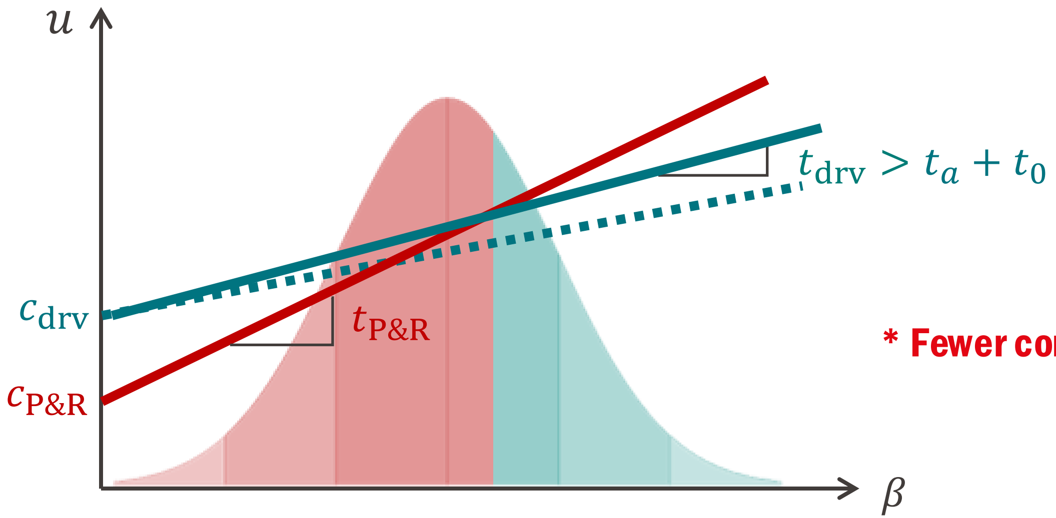
* Highway becomes congested

Design of P&R

- Mode choice of commuters

$$u = c + \beta t$$

- u generalized cost
- c, t monetary cost and total travel time
- β value of time with probability density function $f(\beta)$



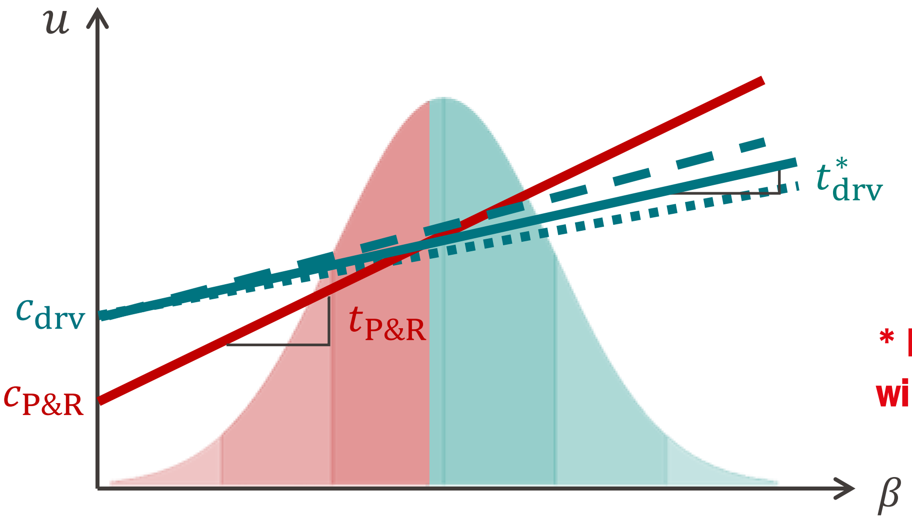
* Fewer commuters choose to drive

Design of P&R

- Mode choice of commuters

$$u = c + \beta t$$

- u generalized cost
- c, t monetary cost and total travel time
- β value of time with probability density function $f(\beta)$



*** Reach equilibrium when no one wishes to further change mode**

Design of P&R

- Optimal pricing of P & R

$$\min_{c_{\mathrm{P\&R}}} \quad \lambda_{\mathrm{P\&R}}\left(c_{\mathrm{P\&R}} + \bar{\beta}_{\mathrm{P\&R}} t_{\mathrm{P\&R}}\right) + \lambda_{\mathrm{drv}}\left(c_{\mathrm{drv}} + \bar{\beta}_{\mathrm{drv}} t_{\mathrm{drv}}\right)$$

*** Min total travel cost of all commuters**

$$s.t. \quad t_{\mathrm{drv}} = t_a + t_0\left[1 + \gamma\left(\frac{\lambda_{\mathrm{drv}}}{\kappa}\right)^{\alpha}\right]$$

$$t_{\mathrm{P\&R}} = t_a + \tau + t_{\mathrm{rail}}$$

$$\beta_{\mathrm{thres}} = \frac{c_{\mathrm{drv}} - c_{\mathrm{P\&R}}}{t_{\mathrm{P\&R}} - t_{\mathrm{drv}}}$$

$$\lambda_{\mathrm{P\&R}} = \lambda_0 \int_0^{\beta_{\mathrm{thres}}} f(\beta)\, \mathrm{d}\beta$$

$$\lambda_{\mathrm{drv}} = \lambda_0 - \lambda_{\mathrm{P\&R}}$$

$$\bar{\beta}_{\mathrm{P\&R}} = \int_0^{\beta_{\mathrm{thres}}} \beta f(\beta)\, \mathrm{d}\beta$$

$$\bar{\beta}_{\mathrm{drv}} = \int_{\beta_{\mathrm{thres}}}^{\infty} \beta f(\beta)\, \mathrm{d}\beta$$

*** Average VOT of P&R and driving commuters**

Design of P&R

- Optimal pricing of P & R

$$\min_{c_{\mathrm{P\&R}}} \quad \lambda_{\mathrm{P\&R}}\left(c_{\mathrm{P\&R}} + \bar{\beta}_{\mathrm{P\&R}} t_{\mathrm{P\&R}}\right) + \lambda_{\mathrm{drv}}\left(c_{\mathrm{drv}} + \bar{\beta}_{\mathrm{drv}} t_{\mathrm{drv}}\right)$$

$$s.t. \qquad t_{\mathrm{drv}} = t_a + t_0\left[1 + \gamma\left(\frac{\lambda_{\mathrm{drv}}}{\kappa}\right)^{\alpha}\right]$$

$$t_{\mathrm{P\&R}} = t_a + \tau + t_{\mathrm{rail}}$$

$$\beta_{\mathrm{thres}} = \frac{c_{\mathrm{drv}} - c_{\mathrm{P\&R}}}{t_{\mathrm{P\&R}} - t_{\mathrm{drv}}}$$

*** Equilibrium condition** $c_{\mathrm{P\&R}} + \beta_{\mathrm{thres}} t_{\mathrm{P\&R}} = c_{\mathrm{drv}} + \beta_{\mathrm{thres}} t_{\mathrm{drv}}$

$$\lambda_{\mathrm{P\&R}} = \lambda_0 \int_0^{\beta_{\mathrm{thres}}} f(\beta)\,\mathrm{d}\beta$$

$$\lambda_{\mathrm{drv}} = \lambda_0 - \lambda_{\mathrm{P\&R}}$$

$$\bar{\beta}_{\mathrm{P\&R}} = \int_0^{\beta_{\mathrm{thres}}} \beta f(\beta)\,\mathrm{d}\beta$$

$$\bar{\beta}_{\mathrm{drv}} = \int_{\beta_{\mathrm{thres}}}^{\infty} \beta f(\beta)\,\mathrm{d}\beta$$

Design of P&R

- Optimal pricing of P & R

$$\min_{c_{\mathrm{P\&R}}} \quad \lambda_{\mathrm{P\&R}}\left(c_{\mathrm{P\&R}} + \bar{\beta}_{\mathrm{P\&R}} t_{\mathrm{P\&R}}\right) + \lambda_{\mathrm{drv}}\left(c_{\mathrm{drv}} + \bar{\beta}_{\mathrm{drv}} t_{\mathrm{drv}}\right)$$

$$s.t. \qquad t_{\mathrm{drv}} = t_a + t_0\left[1 + \gamma\left(\frac{\lambda_{\mathrm{drv}}}{\kappa}\right)^{\alpha}\right]$$

$$t_{\mathrm{P\&R}} = t_a + \tau + t_{\mathrm{rail}}$$

$$\beta_{\mathrm{thres}} = \frac{c_{\mathrm{drv}} - c_{\mathrm{P\&R}}}{t_{\mathrm{P\&R}} - t_{\mathrm{drv}}}$$

$$\lambda_{\mathrm{P\&R}} = \lambda_0 \int_0^{\beta_{\mathrm{thres}}} f(\beta)\,\mathrm{d}\beta$$

$$\lambda_{\mathrm{drv}} = \lambda_0 - \lambda_{\mathrm{P\&R}}$$

*** Demand split at equilibrium**

$$\bar{\beta}_{\mathrm{P\&R}} = \int_0^{\beta_{\mathrm{thres}}} \beta f(\beta)\,\mathrm{d}\beta$$

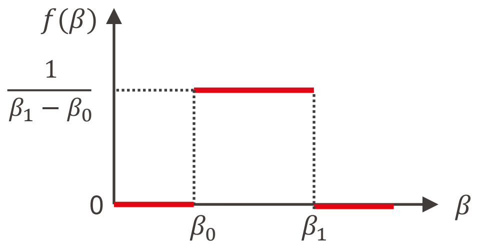
$$\bar{\beta}_{\mathrm{drv}} = \int_{\beta_{\mathrm{thres}}}^{\infty} \beta f(\beta)\,\mathrm{d}\beta$$

Design of P&R

- Case study
  - Uniform distribution of value of time

$$f(\beta) = \begin{cases} \frac{1}{\beta_1 - \beta_0}, & \beta_0 \le \beta \le \beta_1 \\ 0, & \text{otherwise} \end{cases}$$

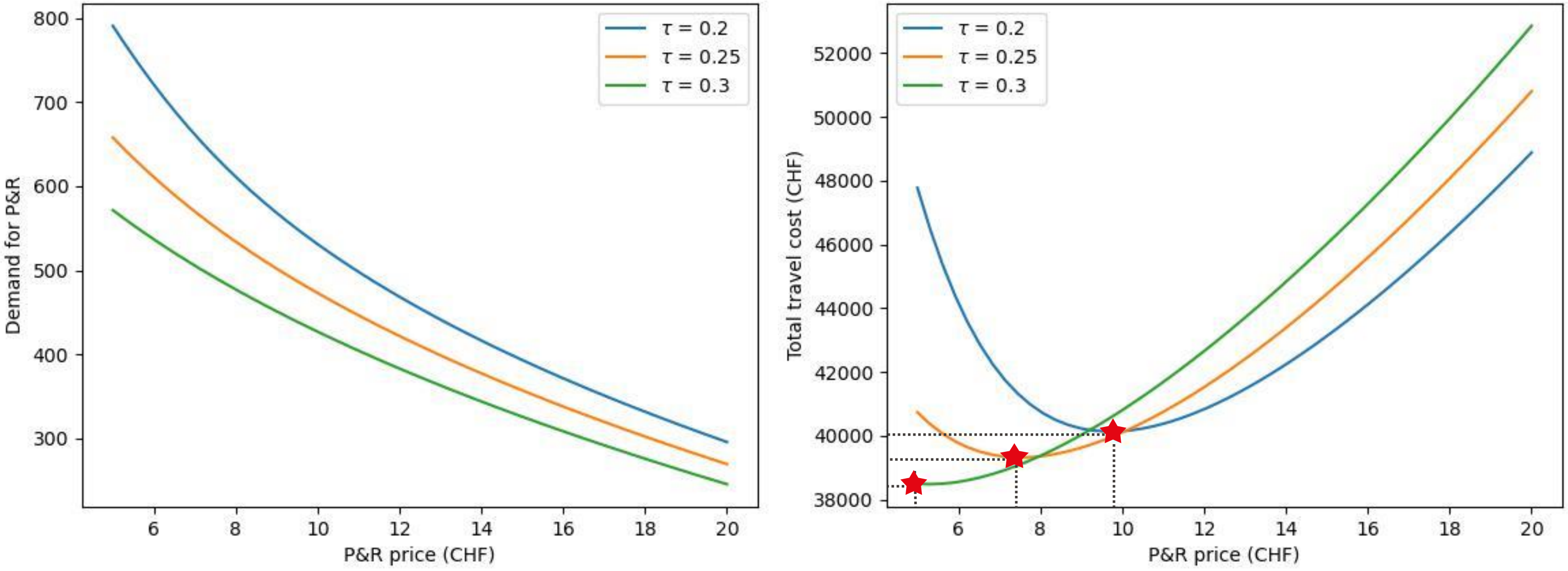
    - $\beta_0 = 25$ (CHF/hr); $\beta_1 = 50$ (CHF/hr)



  - Total demand $\lambda_0 = 1000$ (pax/hr)
  - Cost of driving $c_{\mathrm{drv}} = 25$ (CHF)
  - Driving time to highway/P&R $t_a = 0.25$ (hr)
  - Transfer time $\tau \in \{0.2, 0.25, 0.3\}$ (hr)
  - Riding time on train $t_{\mathrm{rail}} = 0.75$ (hr)
  - Highway free-flow travel time $t_0 = 0.5$ (hr)
    - capacity $\kappa = 400$ (veh/hr);
    - parameters $\alpha = 4, \gamma = 0.15$

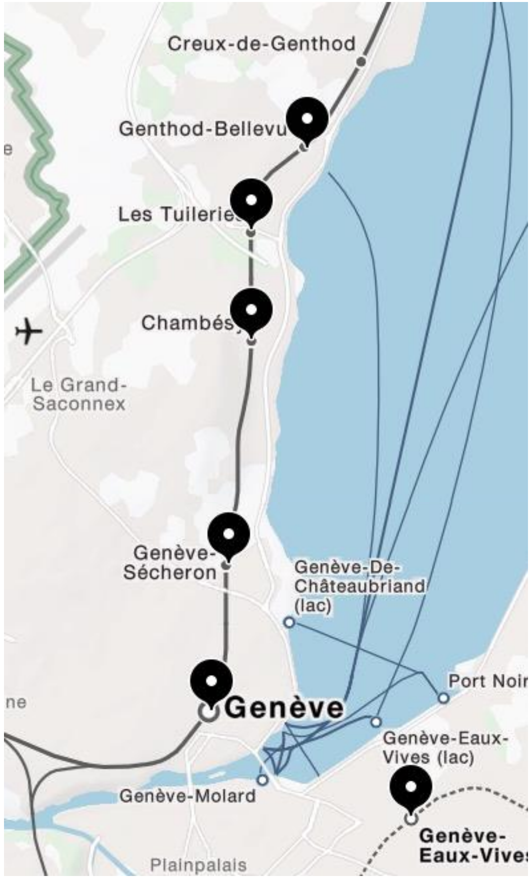
Design of P&R

- Case study
  - Both demand and optimal pricing for P&R are highly sensitive to parking/transfer time τ



Design of P&R

- Factors not considered
  - “Congestion” in P&R
    - parking/transfer time τ increases with $\lambda_{\mathrm{P\&R}}$
  - Last-mile travel time ω and parking fee c_{park} in the city center
    - $\omega_{\mathrm{P\&R}} > \omega_{\mathrm{drv}} \approx 0$ in general
    - expensive parking $c_{\mathrm{park}} \gg 0$ in the city encourages P&R
  - Multiple P&R facilities along the transit line
    - correlated choice of parking location



Questions?

The first/last-mile challenge

- From trip origin/destination to the closest transit stop
  - Always exist in fixed-route transit system
  - Main obstacle of promoting public transit
    - on average, people are willing to walk about 400m to a bus stop and about 1km to a rapid transit station[1]
    - also depend on walkability and sociodemographic

[1] Human Transit

First/last-mile solutions

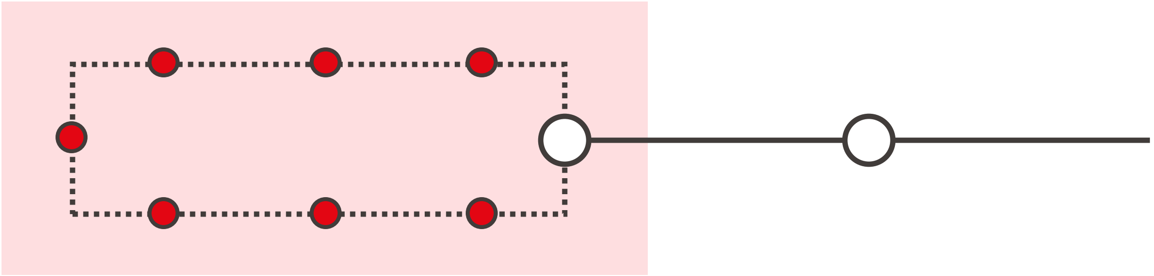
- Active modes
  - walking
  - personal micro-mobility (e.g., bike)
- Vehicular sharing
  - shared micro-mobility (e.g., bike-sharing)
  - ride-hailing
- Public transit
  - feeder bus (e.g., hierarchical corridor)
  - demand responsive transit (DRT)

PubliBike at bus stop

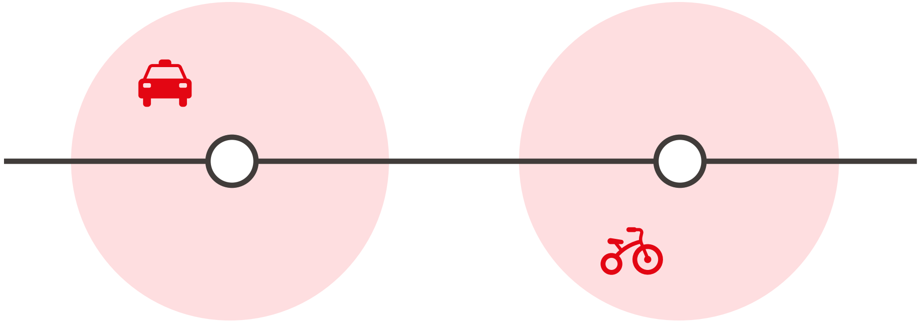
PostBus at train station

Design of first/last-mile service

- Without coordination
  - Fixed/flexible-route transit



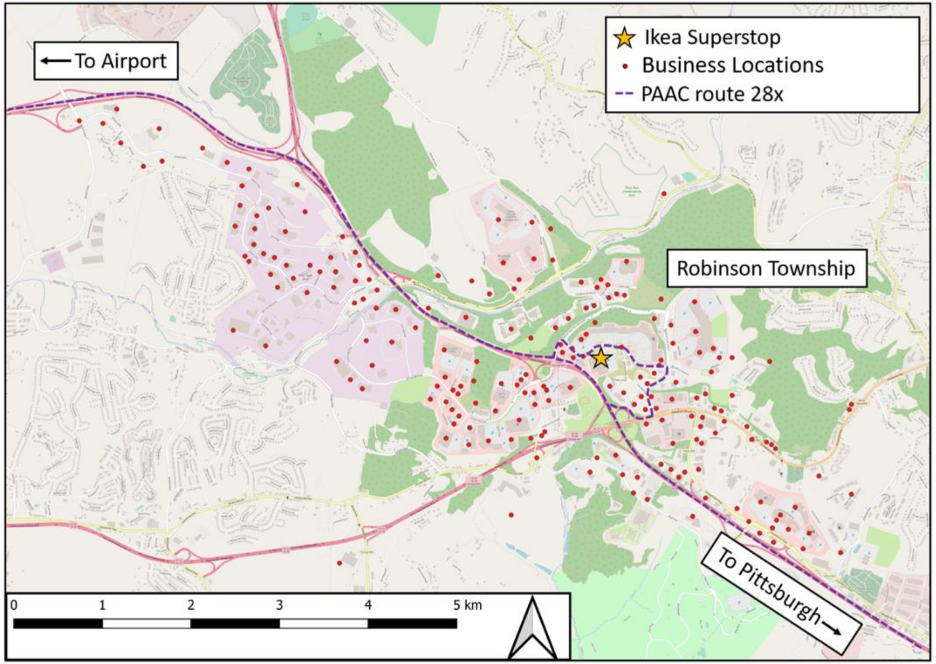
  - On-demand mobility
    - Ride-hailing and micro-mobility

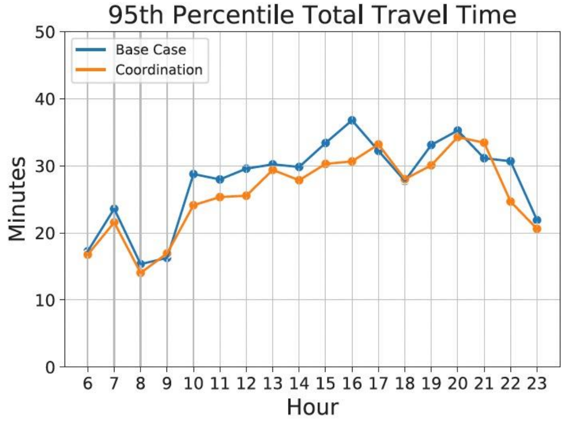


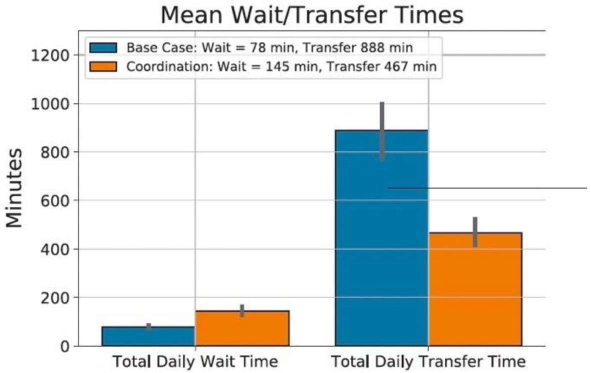
Design of first/last-mile service

- With coordination

Robinson Township near Pittsburgh[1]



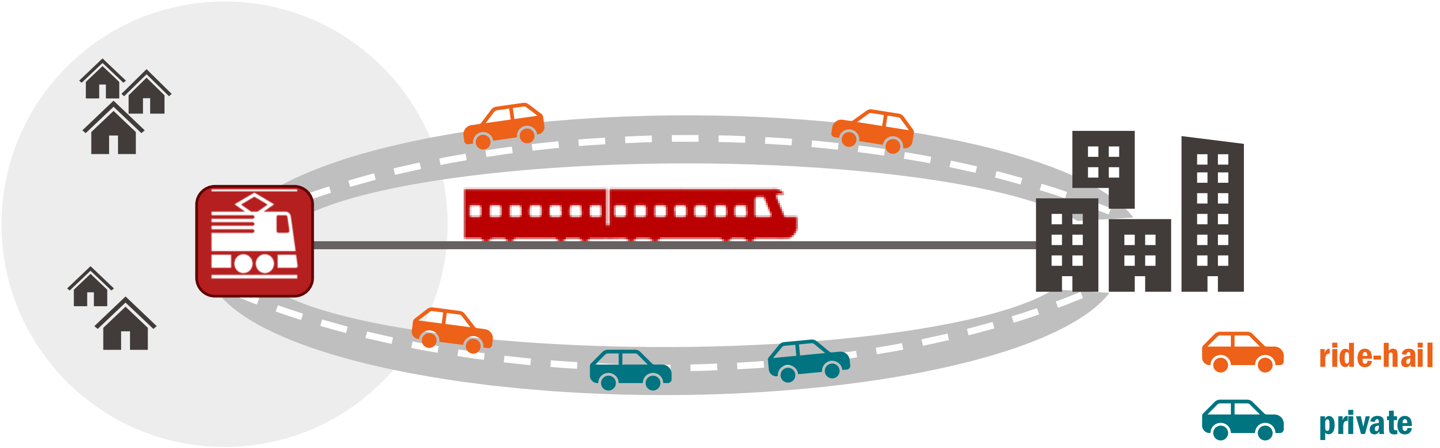




[1] Grahn, Qian, & Hendrickson. TR-C. 2021.

Benefit of first-mile service

- Stylized model with single origin-destination
  - Demand from the residential area to the city center at rate λ_0 (pax/hr)
    - Driving through highway at cost c_{drv} (CHF)
    - Ride-hailing trip through highway at price c_{hail} (CHF)
    - First-mile ride-hailing trip + train at price c_{1st} (CHF)
  - Congestible highway with capacity κ (veh/hr)
  - Ride-hailing service with fleet size M (veh)



Benefit of first-mile service

- Total travel time per trip
  - Driving

    $$t = t_a + t_{\text{hwy}}$$

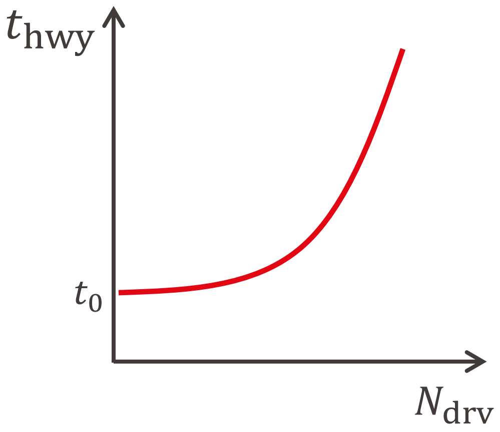
    - t_a driving time to highway
    - t_{hwy} travel time on highway
  - Ride-hailing

    $$t = w + t_a + t_{\text{hwy}}$$

    - w waiting time
  - First-mile + Rail

    $$t = w + t_a + \tau + t_{\text{rail}}$$

    - τ transfer time
    - t_{rail} riding time of train



$$t_{\text{hwy}} = t_0 \left[1 + \gamma \left(\frac{\lambda_{\text{drv}} + \lambda_{\text{hail}}}{\kappa} \right)^{\alpha} \right]$$

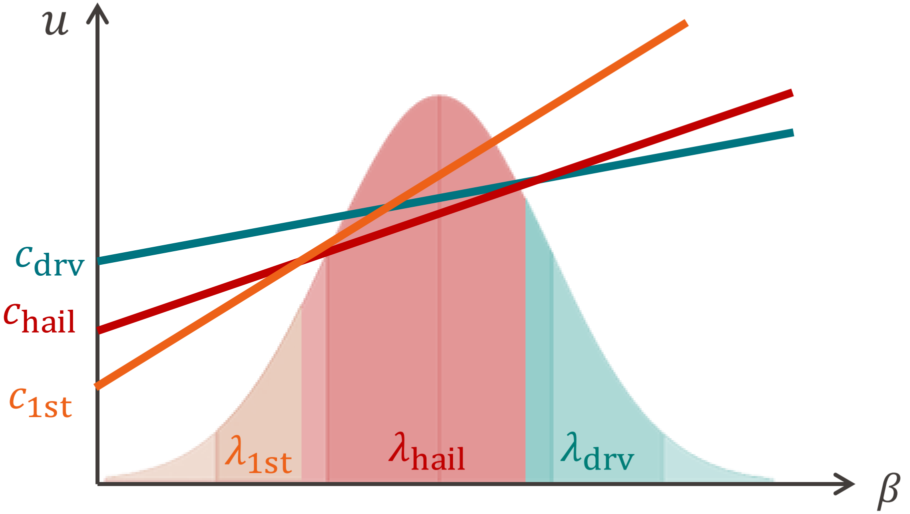
- t_0 free-flow travel time on highway
- $\lambda_{\text{drv}}, \lambda_{\text{hail}}$ driving and ride-hailing demand
- κ highway capacity
- α, γ parameters in highway travel time function

Benefit of first-mile service

- Mode choice of commuters

$$u = c + \beta t$$

  - u generalized cost
  - c, t monetary cost and total travel time
  - β value of time with probability density function $f(\beta)$



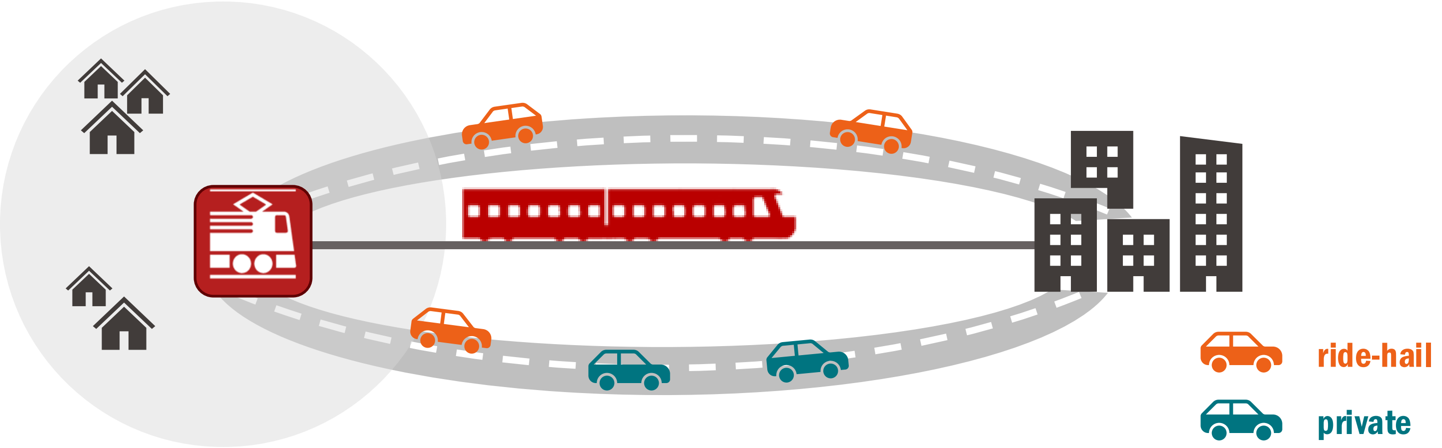
Benefit of first-mile service

- Ride-hailing vehicle conservation

$$M = V + (\lambda_{1st} + \lambda_{hail})(w + t_a) + \lambda_{hail}(t_0 + t_{hwy})$$

* Total trip time to train station

- V vacant vehicle time in residential area
- $\lambda_{1st}/\lambda_{hail}$ demand for first-mile and regular trips
- t_0 relocation travel time



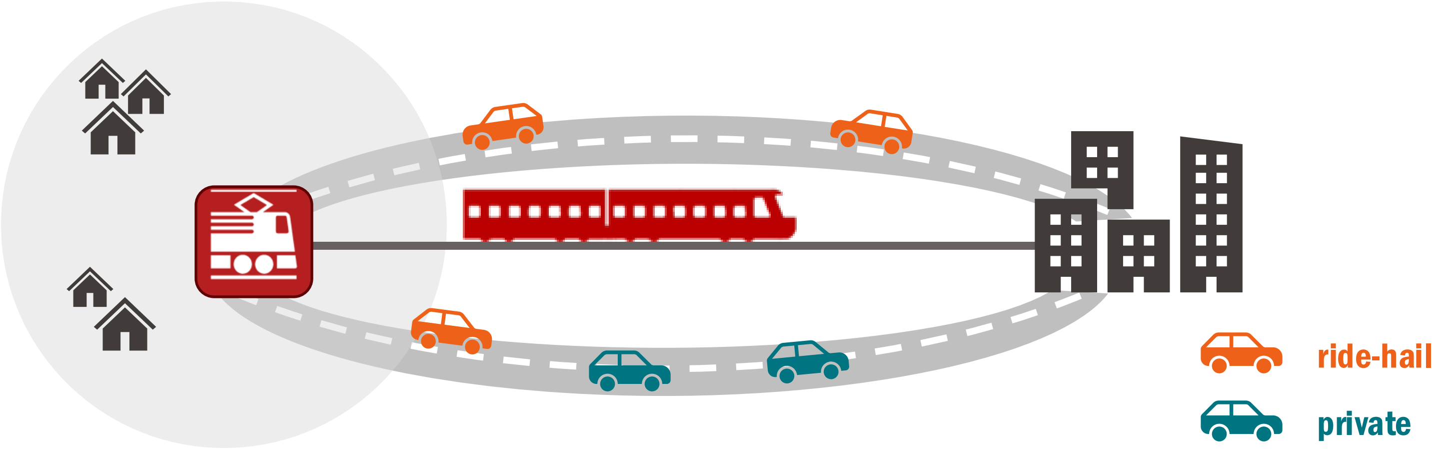
Benefit of first-mile service

- Ride-hailing vehicle conservation

$$M = V + (\lambda_{1st} + \lambda_{hail})(w + t_a) + \lambda_{hail}(t_0 + t_{hwy})$$

* Total vehicle time associated with ride-hailing trips

- V vacant vehicle time in residential area
- $\lambda_{1st}/\lambda_{hail}$ demand for first-mile and regular trips
- t_0 relocation travel time



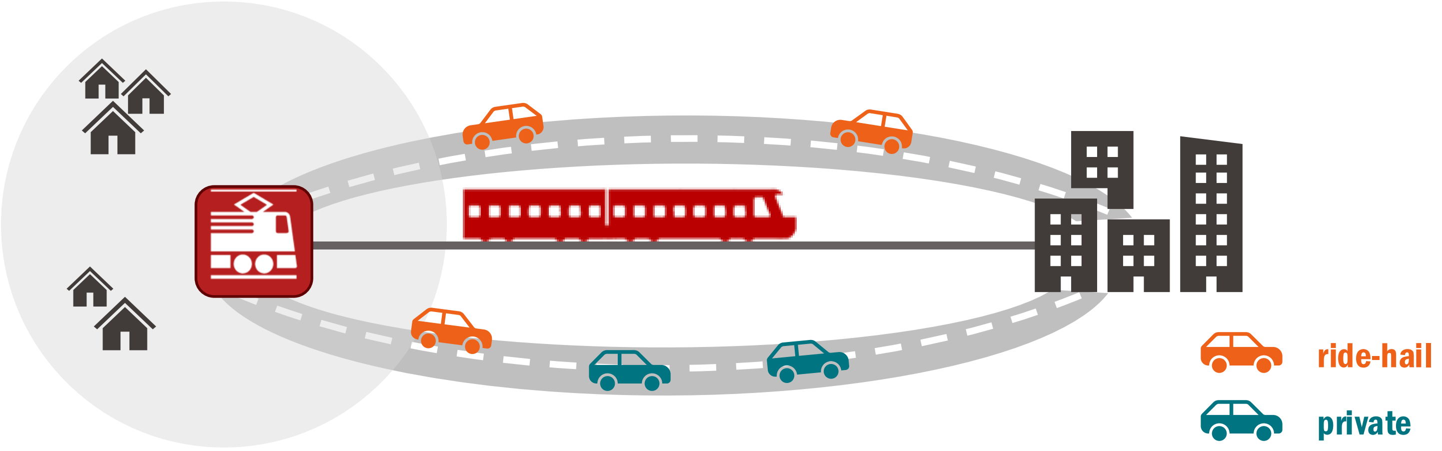
Benefit of first-mile service

- Ride-hailing vehicle conservation

$$M = V + (\lambda_{1st} + \lambda_{hail})(w + t_a) + \lambda_{hail}(t_0 + t_{hwy})$$

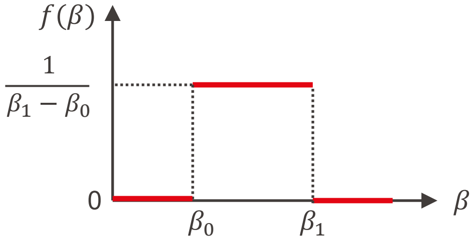
*** Trade-off between fare revenue per trip and vehicle utilization**

- V vacant vehicle time in residential area
- $\lambda_{1st}/\lambda_{hail}$ demand for first-mile and regular trips
- t_0 relocation travel time



Benefit of first-mile service

- Case study
  - Uniform distribution of value of time
    - $\beta_0 = 25$ (CHF/hr); $\beta_1 = 50$ (CHF/hr)
  - Demand rate $\lambda_0 = 1000$ (pax/hr)
  - Cost of driving $c_{\text{drv}} = 25$ (CHF)
  - Driving time to highway/train station $t_a = 0.25$ (hr)
  - Transfer time $\tau = 0.2$ (hr)
  - Riding time on train $t_{\text{rail}} = 0.75$ (hr)
  - Highway free-flow travel time $t_0 = 0.5$ (hr)
    - capacity $\kappa = 400$ (veh/hr);
    - other parameters $\alpha = 4, \gamma = 0.15$
  - Ride-hailing fleet size $M = 500$ (veh)
  - Ride-hailing waiting time

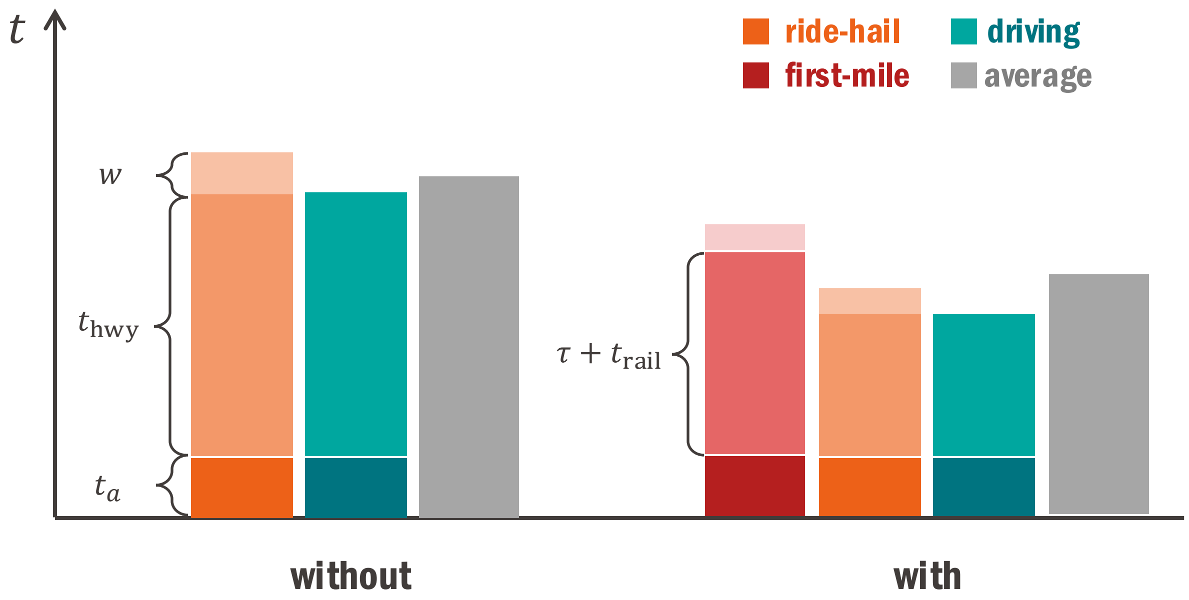


$$w = \frac{\delta}{2v}\sqrt{A/V}$$

- residential area $A = 40$ (km²);
- cruising vehicle speed $v = 20$ (km/hr)
- network detour ratio $\delta = 1.4$

Benefit of first-mile service

- Inclusion of first-mile service
  - Ride-hailing price $c_{\text{hail}} = 20$ (CHF), $c_{1\text{st}} = 10$ (CHF)



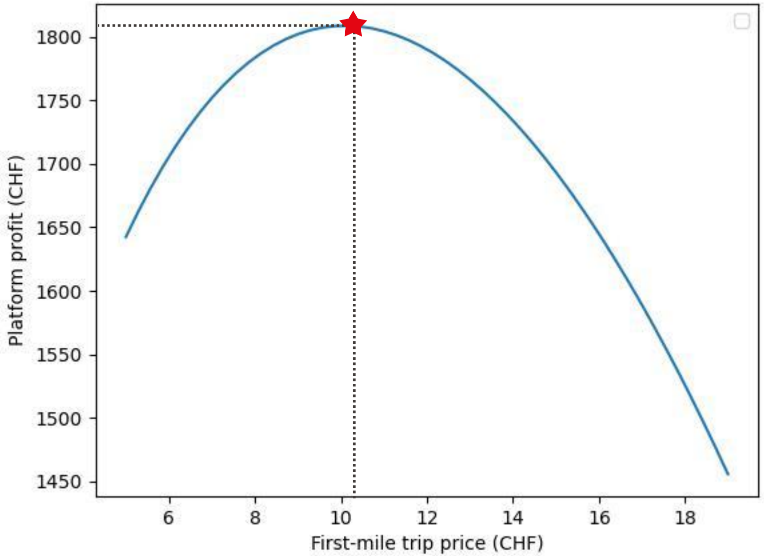
*** Introducing first-mile service leads to both shorter travel time and less congestion**

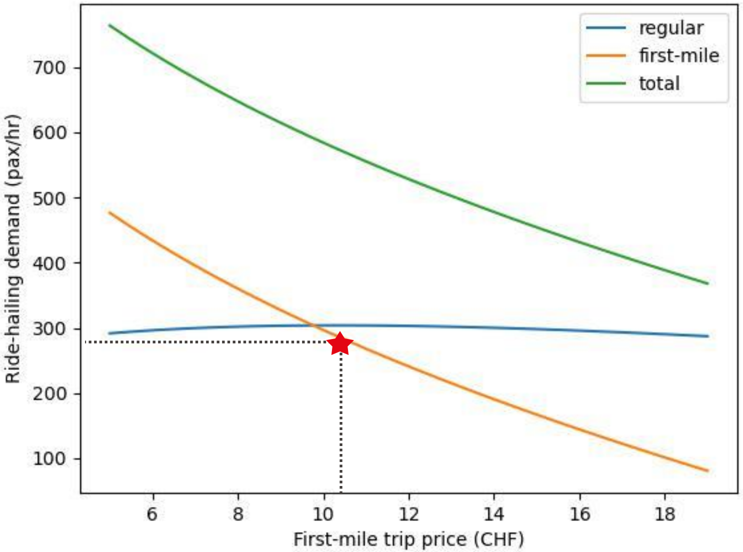
Benefit of first-mile service

- Ride-hailing platform profit

$$\Pi = \eta(c_{1\text{st}}\lambda_{1\text{st}} + c_{\text{hail}}\lambda_{\text{hail}})$$

  - Fixed regular trip price $c_{\text{hail}} = 20$ (CHF) and commission rate $\eta = 0.2$





*** Providing first-mile service is also profitable**

Questions?