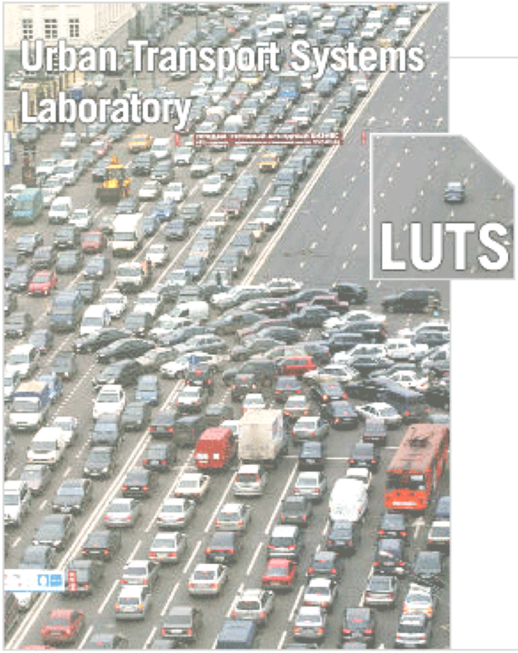


CIV-455: Transport economics

Modeling and Optimization of multimodal urban networks with MFD

Prof. Nikolas Geroliminis

Urban Transport Systems Laboratory

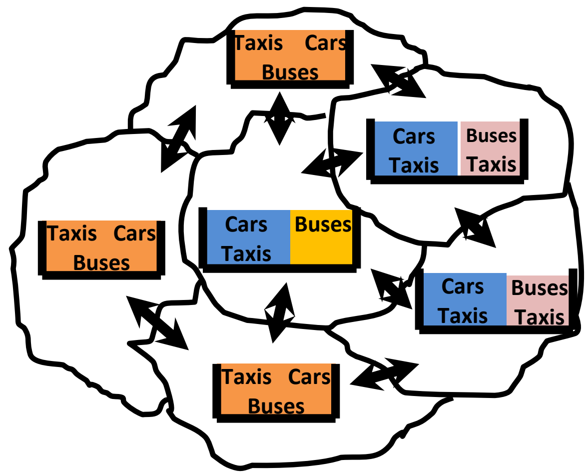
EPFL | ENAC
ENVIRONNEMENT NATUREL, ARCHITECTURAL ET CONSTRUIT

LUTS

M³ : Multimodal Modeling and Management

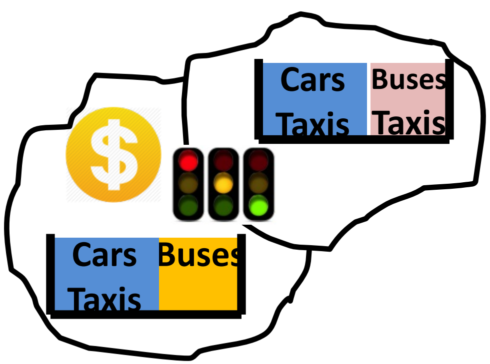
Multimodal
&
Management

Modal competition
Passenger mobility

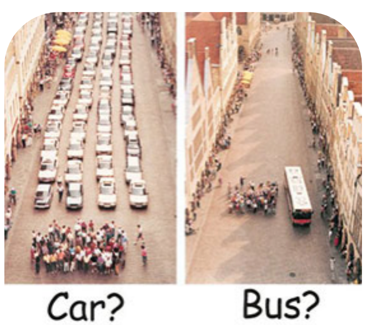


Space competition

Mode conflict



Smart controls



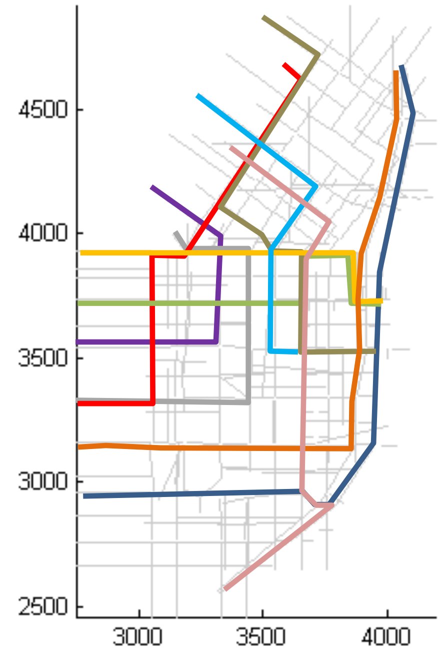
Passenger measures

Parking limitation

Revision from FTOC course

Geroliminis, Zheng and Aboudoulas (2014), *Trans. Res. Part C*

Three-dimensional MFD for Mixed Bi-modal Networks



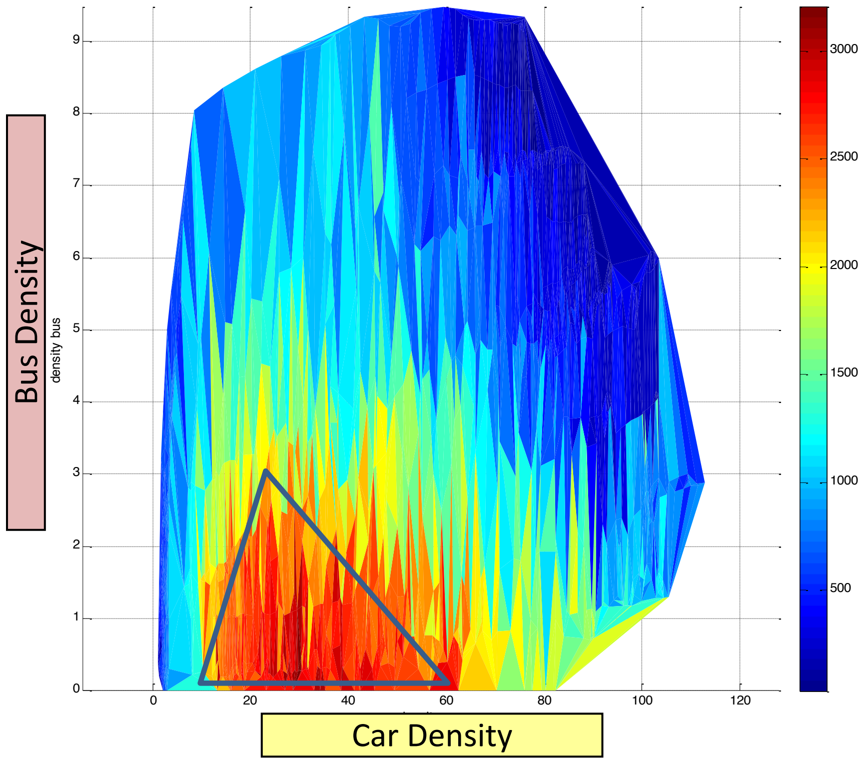
Motivations:

- Individual modal impact & global performance
- Bi-modal traffic dynamics and heterogeneity
- Real-time traffic management for multi-modal systems

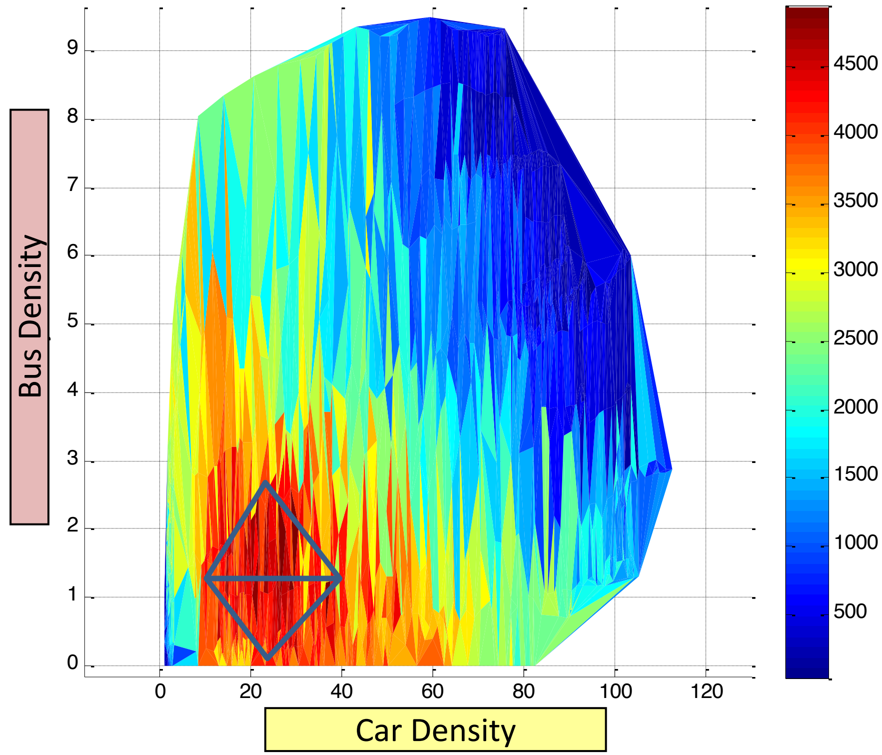
MFD review: MOOC Week 4 https://www.edx.org/course/intro-to-traffic-flow-modeling-and-intelligent-tra (Choose the free version – no certificate)

A 3D-MFD for bi-modal mixed traffic

VEHICULAR FLOW



PASSENGER FLOW



Composition of traffic AFFECTS the shape of the 3D-MFD

Simulated data – Downtown SF

Geroliminis, Zheng and Ampountolas (2014) TR Part C

Methodology – Derivation of Passenger 3D-MFD

The total network passenger flow (the sum of passengers on car and bus flows):

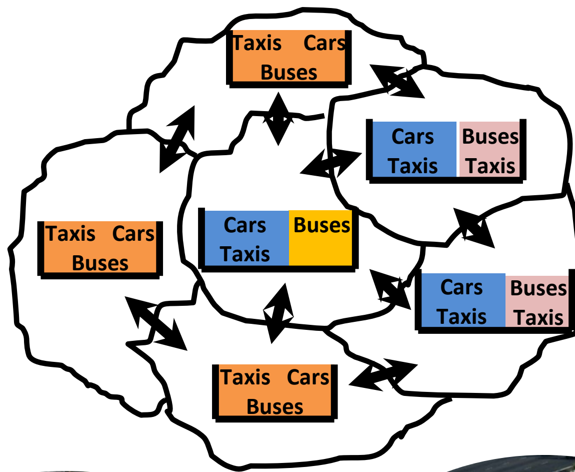
$$P = P(n_c, n_b) = h_c Q_c + h_b Q_b$$

- h_c the occupancy of cars, constant
- h_b the occupancy of buses, dynamic
- $Q_m \overset{\text{def}}{=} v_m n_m / L$
- $v_c \cong v = \frac{Q}{(n_c + n_b)L}, v_b \cong \theta v_c + \beta$

Outline

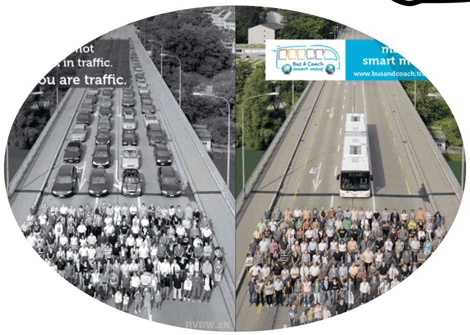
Zheng and Geroliminis (2013), *Trans. Res. Part B – PAPER 1*

Multi-modal Multi-region Modeling Framework for Road Space Allocation

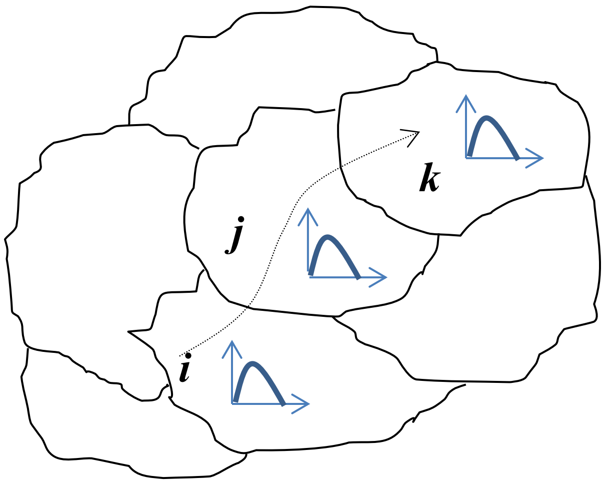


Motivations:

- Road space and performance
- Aggregated system dynamics
- Multi-modal operation
- Road space allocation strategies



Methodology - General representation of multimodal system

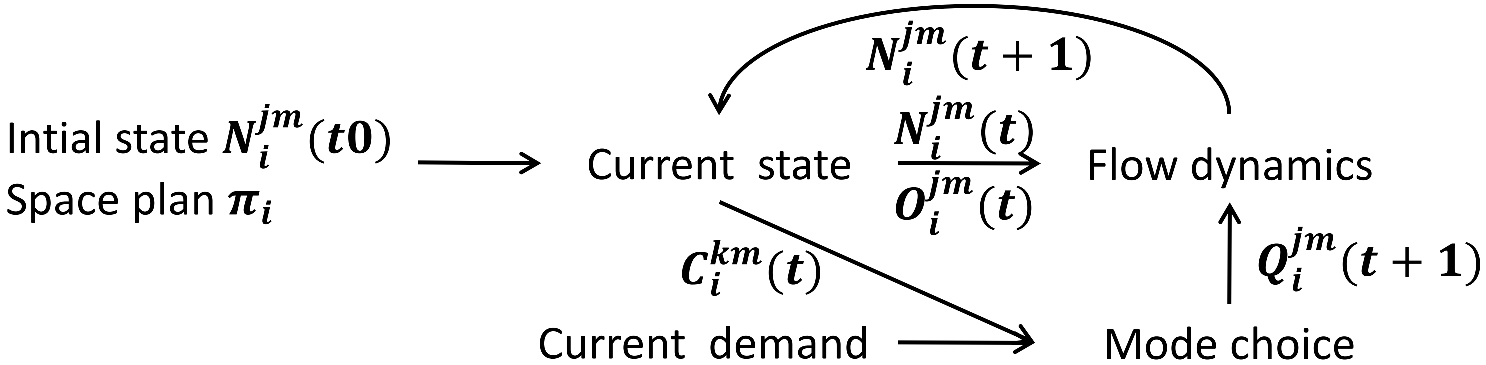


- Urban system partitioned into multiple regions (Ji and Geroliminis, 2012): congestion and mode usage

- Mode and space-specific MFD

$$O_i^m(t) = G_i^m(N_i^m(t), \pi_i)$$

- Given route choice (region sequence)



$\boldsymbol{\pi_i}$: space allocation plan in region i

$\boldsymbol{Q_i^{jm}(t)}$: demand generated in region i traveling to destination region j with mode m at time t

$\boldsymbol{C_i^{km}(t)}$: cost of travel in the region i by traveling to final destination k with mode m at time t

$\boldsymbol{N_i^{jm}(t)}$: accumulation of vehicle mode m in region i with destination region j at time t

$\boldsymbol{O_i^{jm}(t)}$: transfer flow of vehicle mode m in region i to region j at time t

Methodology - Traffic flow dynamics (1)

Vehicle flow dynamics (discritized):

$$N_i^{jm}(t+1) = N_i^{jm}(t) + Q_i^{jm}(t+1) + I_i^{jm}(t) - O_i^{jm}(t)$$

- $N_i^{jm}(t)$: accumulation of vehicle mode m in region i with final destination region j at time t
- $O_i^{jm}(t)$: transfer flow, $O_i^{jm}(t) = O_i^m(t) \cdot \frac{N_i^{jm}(t)}{N_i^m(t)}$
- $I_i^{jm}(t)$: total incoming flow of mode m from neighbor regions, $\sum_l O_{l\to i}^{jm}(t)$, with final destination j at time t
- $Q_i^{jm}(t)$: demand generated in region i traveling to final destination region j with mode m at time t

Methodology - Traffic flow dynamics (1)

- Conservation of vehicles:

$$n_i^{kc}(t+1) = n_i^{kc}(t) + \frac{Q_i^{kc}(t+1)}{ob_i^c} - \sum_{j=1}^{N} O_{i\to j}^{kc}(t) + \sum_{l=1}^{N} O_{l\to i}^{kc}(t),$$

$$n_i^{kb}(t+1) = n_i^{kb}(t) - \sum_{j=1}^{N} O_{i\to j}^{kb}(t) + \sum_{l=1}^{N} O_{l\to i}^{kb}(t),$$

$n_i^{km}(t)$: accumulation of mode *m* in region i with final destination region *k* at time *t*
$O_{i\to j}^{km}(t)$: transfer flow of mode *m* from region i to *j* with final destination *k* at time *t*
$Q_i^{km}(t)$: demand generated *k* at time *t* in region i with final destination region *k*, choosing mode
ob_i^c *m* : average number of passengers per car in region i

- Assumptions:

(1) Intra-regional route choice not relevant, inter-regional route choice fixed for trips with the same OD
(2) Transfer flow $O_{i\to j}^{km}(t)$ determined by the corresponding MFD and the boundary capacity of a region
(3) Each region has a well defined MFD estimated by variational theory (space distribution as one input)
(4) Non-circular route for cars; fixed route and fixed number of operating vehicles for buses

Methodology - Traffic flow dynamics (2)

Passenger flow dynamics:

$$NP_i^{jm}(t+1) = NP_i^{jm}(t) + Q_i^{jm}(t+1) + IP_i^{jm}(t) - OP_i^{jm}(t)$$

- $NP_i^{jm}(t)$: number of on-board passengers of mode m in region i with destination region j at time t
- $IP_i^{jm}(t)$: incoming passenger flow on mode m from neighbor regions , $\sum_l OP_{l\to i}^{jm}(t)$, with destination region j at time t
- $OP_i^{jm}(t)$: transferring passenger flow from mode m to region j at time t
  - $j \neq i : O_i^{jm}(t) \cdot ob_i^{jm}(t)$
  - $j = i$: $O_i^{im}(t) \cdot ob_i^{im}(t) \cdot (1-(1-\theta_i)^z)$

    z : nr. of passing stops during interval t

    θ_i: probability of reaching destination (trip length, spacing)

$$\theta_i = \left(\frac{\bar{L}'_{ib}}{s_i}\right)^{-1}$$

$ob_i^{jm}(t)$: passenger occupancy on mode m in region i with destination region j at time t, $ob_i^{jm}(t) = \frac{NP_i^{jm}(t)}{N_i^{jm}(t)}$

Methodology – Multimodal travel time estimation

- Speed estimation for mode m usage only region

$$V_i^m(t) \stackrel{\text{def}}{=} \frac{P_i^m(t)}{N_i^m(t)} \overset{*}{=} \frac{O_i^m(N_i^m(t)) \cdot L_i^m}{N_i^m(t)} \; {}^{**}$$

* Edie (1963)'s definition

** Little (1961)'s formula

$P_i^m(t)$: production of mode *m* in region i, veh-km travelled

$N_i^m(t)$: accumulation of mode *m* in region i, $\sum_j N_i^{jm}(t)$

L_i^m: : average trip length of mode *m* traveling in region i

- Speed estimation for mixed-mode region

$$V_i^{PT}(t) = V_i^c(t) \cdot \frac{TT_i^c(t)}{TT_i^c(t) + TT_d^{PT}(t)}$$

$TT_i^c(t)$: travel time of cars in region i at time *t* (PT travel time without dwelling)

$TT_d^{PT}(t)$: average time spent by PT dwelling for passengers during time interval *t*

- Travel time estimation

$$TT_i^m(t) = \frac{L_i^m}{V_i^m(t)}$$

Methodology – Aggregated mode choice

- The "disutility" of traveling at time t from region i to final destination region k using mode m

$$U_i^{km}(t) = -\sum_{j \in \{S_i^k\}} \left(TT_j^m(t) + c_j^m(t)\right)$$

$c_j^m(t)$: other cost of traveling with mode m in region j at time t
S_i^k : the passing-over regions from region i to k

- Mode share percentage at time $t+1$ for mode m:

$$p_i^{km}(t+1) = p_i^{km}(t) + \beta_1 \cdot \Delta U_i^k(t) + \beta_2 \cdot \left(\Delta U_i^k(t) - \Delta U_i^k(t-1)\right)$$

$\Delta U_i^j(t)$: difference in disutility between traveling with cars and mode m from region i to k at time t
β_1, β_2 : mode choice parameters

- Assumptions:

(1) Mode choice happens only at the start of a trip, remain fixed afterwards
(2) Disutility of using a mode at a certain time is identical within the same region
(3) Demand generated at time *t+1* have perfect information of the traffic condition at time *t*

Optimization framework

- System performance measure: total passenger hours travelled (PHT)

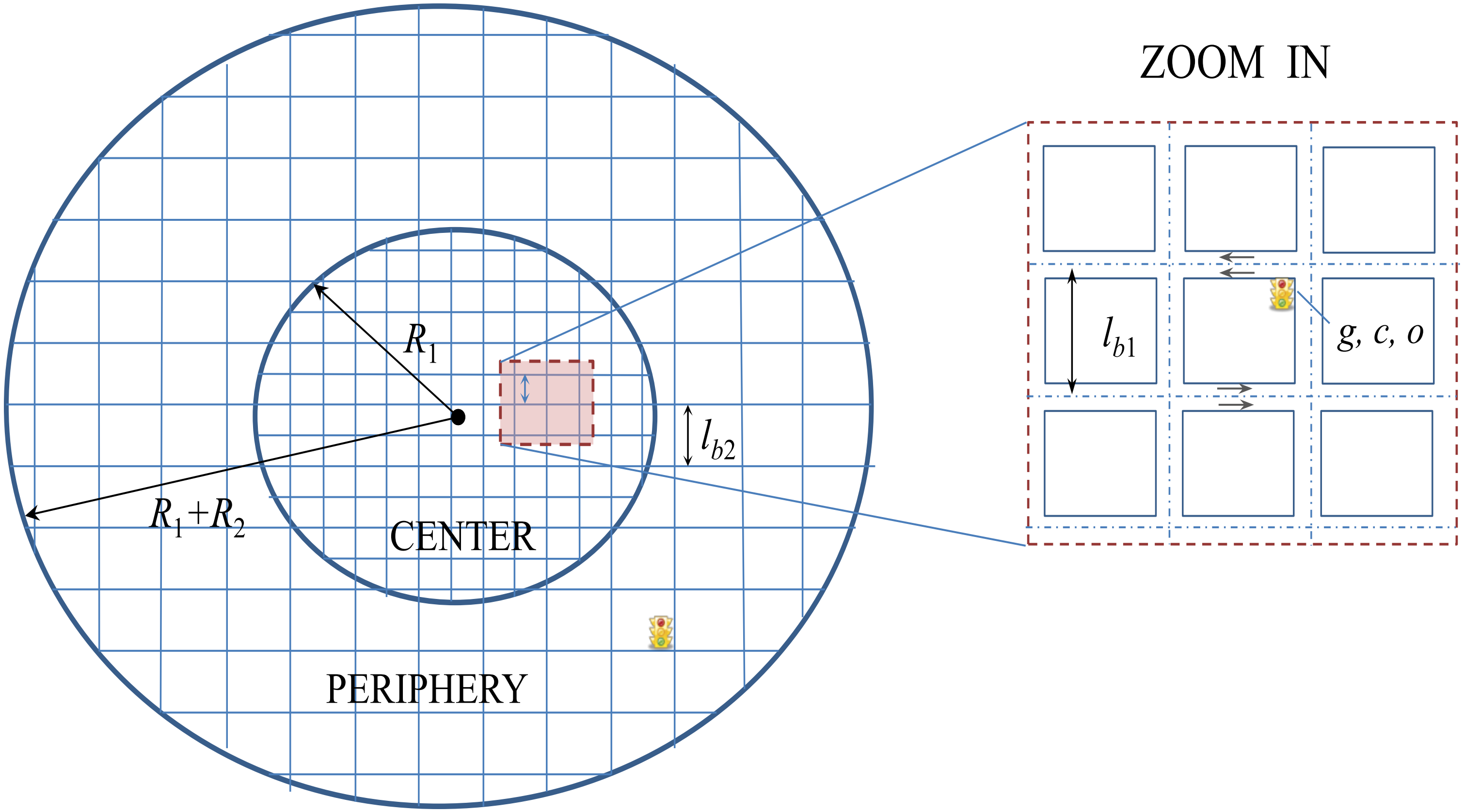
$$PHT(\boldsymbol{\pi}_i) = \sum_t \sum_i \sum_j \sum_m NP_i^{jm}(t) \cdot T$$

- Objective function

$$\min_{\boldsymbol{\pi}_i} Z = \sum\nolimits_{t,i,m} PHT_{t,i,m}(\boldsymbol{\pi}_i)$$

- Optimization algorithm: Lagrangian SQP with multiple initial search

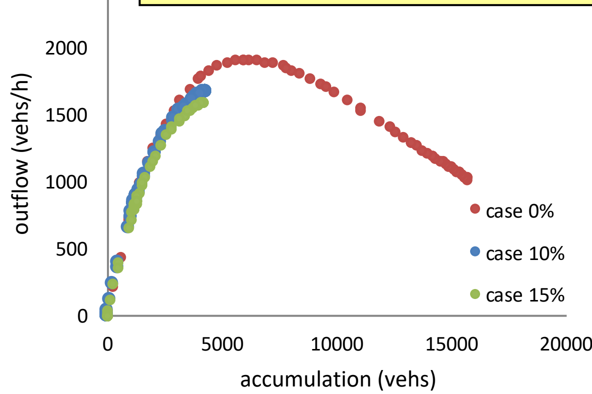
Case study: A bi-modal two-region transport system



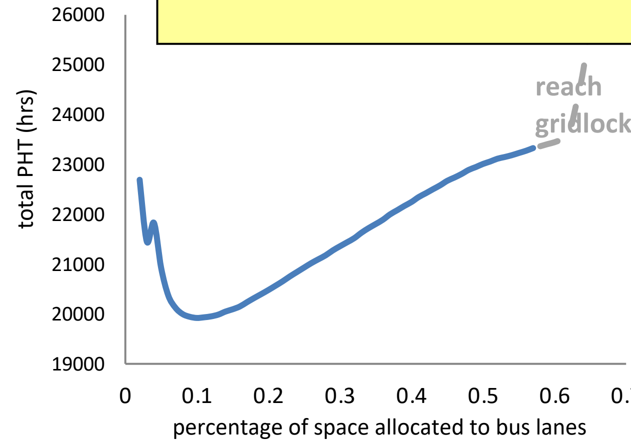
- Regional demands and average trip lengths are given
- MFDs estimated given the network properties (Boyaci and Geroliminis, 2012)
- Space allocation implemented in center, Mixed traffic in periphery `

Case study: STATIC and DYNAMIC bus-lane allocations

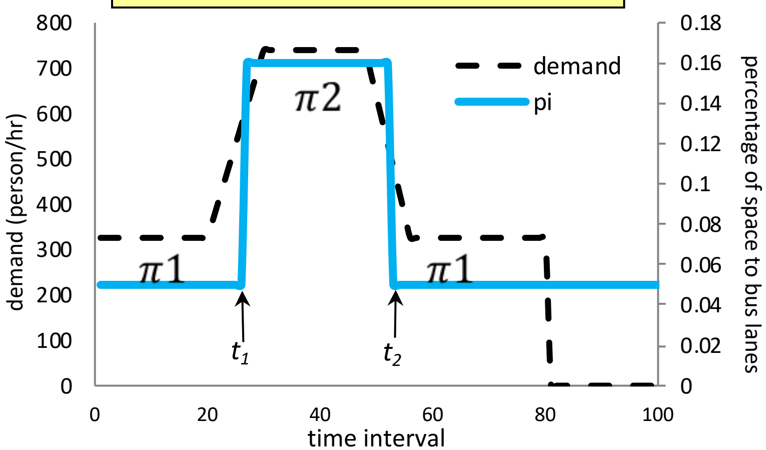
MFD, static allocation
0%, 10%, 15%

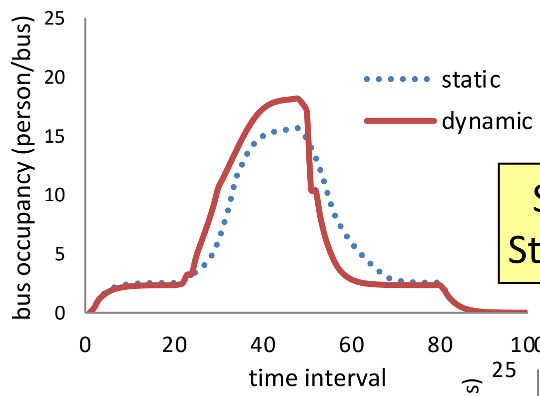


PHT over static allocation %

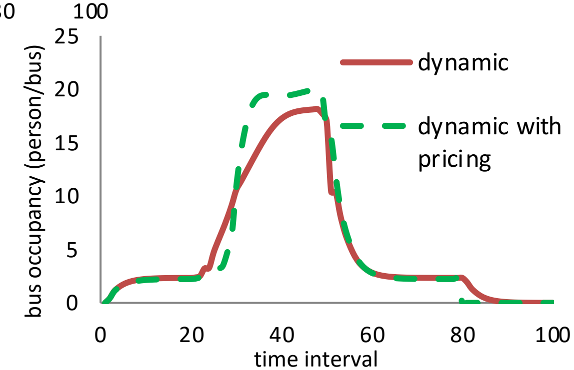


Optimal dynamic allocation
by 4 variables: $\pi 1$, $\pi 2$, t_1, t_2





Space utilization improve
Static vs. Dynamic vs. Pricing



Results – Effect of demand fluctuations