Models and Control Strategies of a Multimodal Transportation Network

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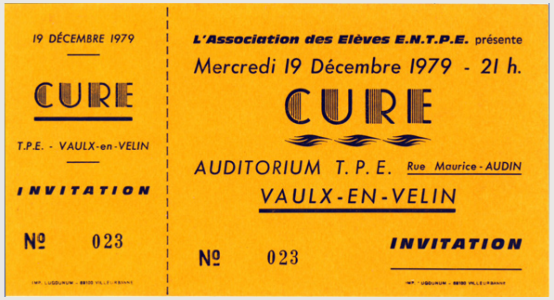
ENTPE

- Engineering School established in 1954:
  - Civil engineering;
  - Environmental;
  - Transports;
- Several Master of Sc.
- 700 students

- First shows of ***U2*** and ***The Cure*** in France!



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My background

- M.S. CEE-Transportation (ENTPE):
  - LWR model calibration;
- M.S. Operational Research (Uni. of Grenoble):
  - Cellular automata;
- Ph.D. CEE-Transportation (Uni. of Lyon):
  - Fundamental Diagram estimation methods;
- Assistant Prof. at ENTPE (Licit) since 2009:
  - Multimodal and Multiscale models for urban traffic management.

Motivations (1/2)

Optimizing the global performance of the network

Control strategies that combine actions targeted at

Infrastructure

- **Intermittent Bus Lanes** — X. Xie *(PhD)*
- **Perimeter control** — Z. Hua *(Post Doc)*

Bus line control

- **Dynamic control** — E. Hans *(PhD)*

Global evaluation & Optimization

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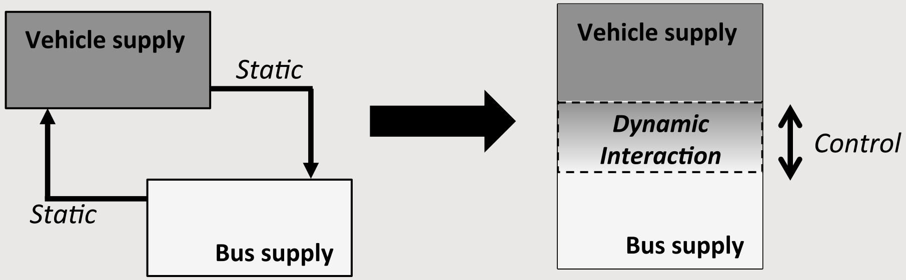
Global evaluation & Optimization

Motivations (2/2)

- **To shift attention from movement of vehicle to movement of people:**
  - Vehicle-based models, e.g. KW model;
  - Bus-based models;



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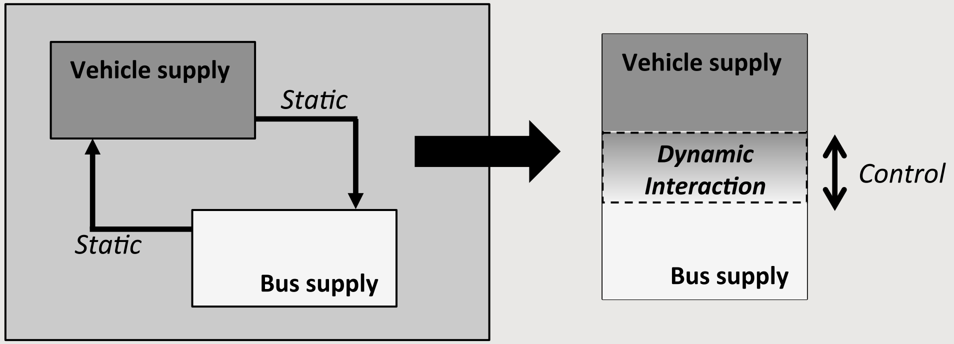


- First step:
  - A common evaluation function of the performance of a multimodal network;

Overview

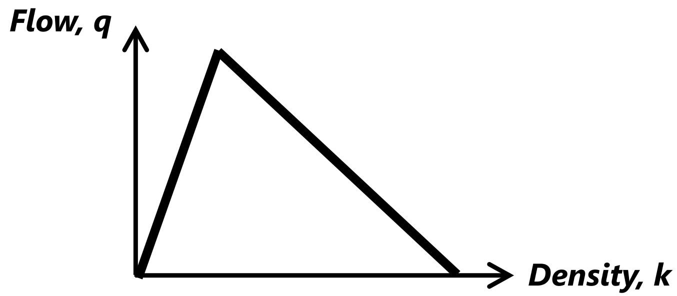
1. **Macroscopic Fundamental Diagram**
   Background
2. **Extensions to assess to the number of passengers and modal choice**
   Definition
   Impact of mode choices
3. **Evaluation of IBL strategies**
   Analytical considerations
   Full comparison

Macroscopic Fundamental Diagram

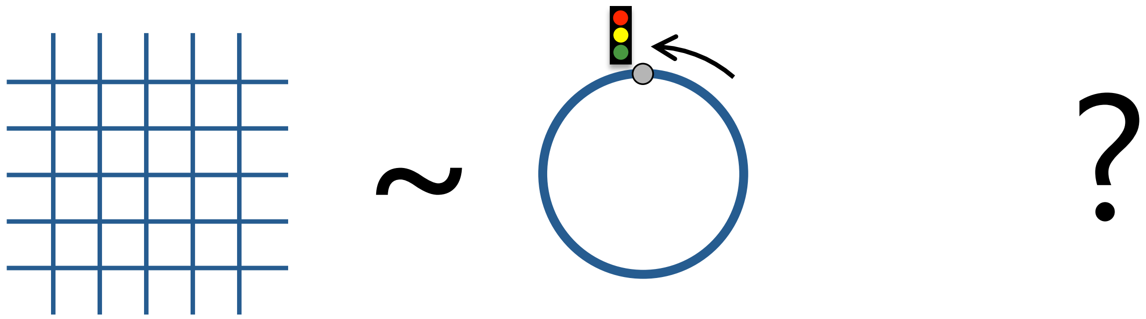
Macroscopic Fundamental Diagram

Single Road Link

Fundamental Diagram (q-k)



Homogeneous Network, Represented as a Ring

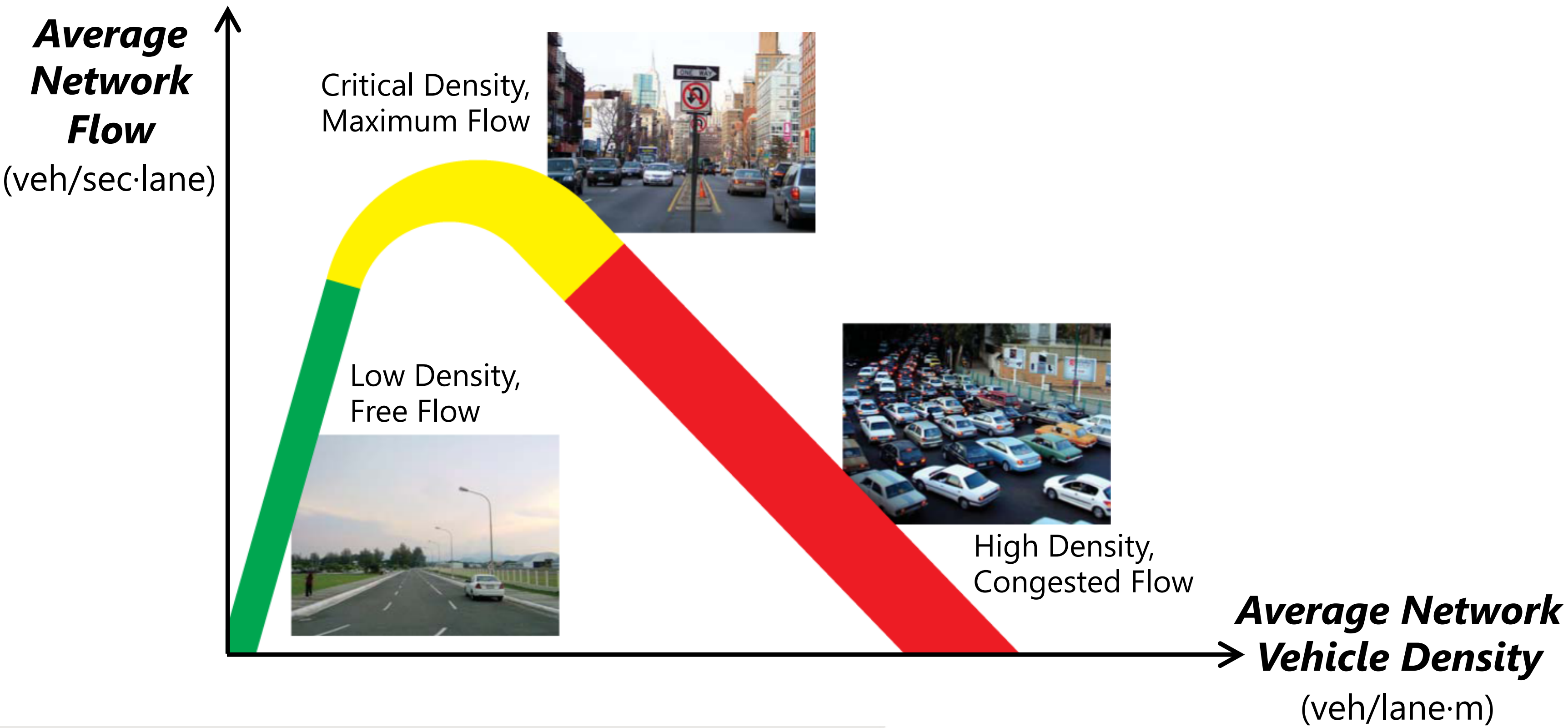


Thanks to E. Gonzales, uMass.

Macroscopic Fundamental Diagram

Macroscopic relationship between trip completion rate and density

(Daganzo and Geroliminis, 2008)



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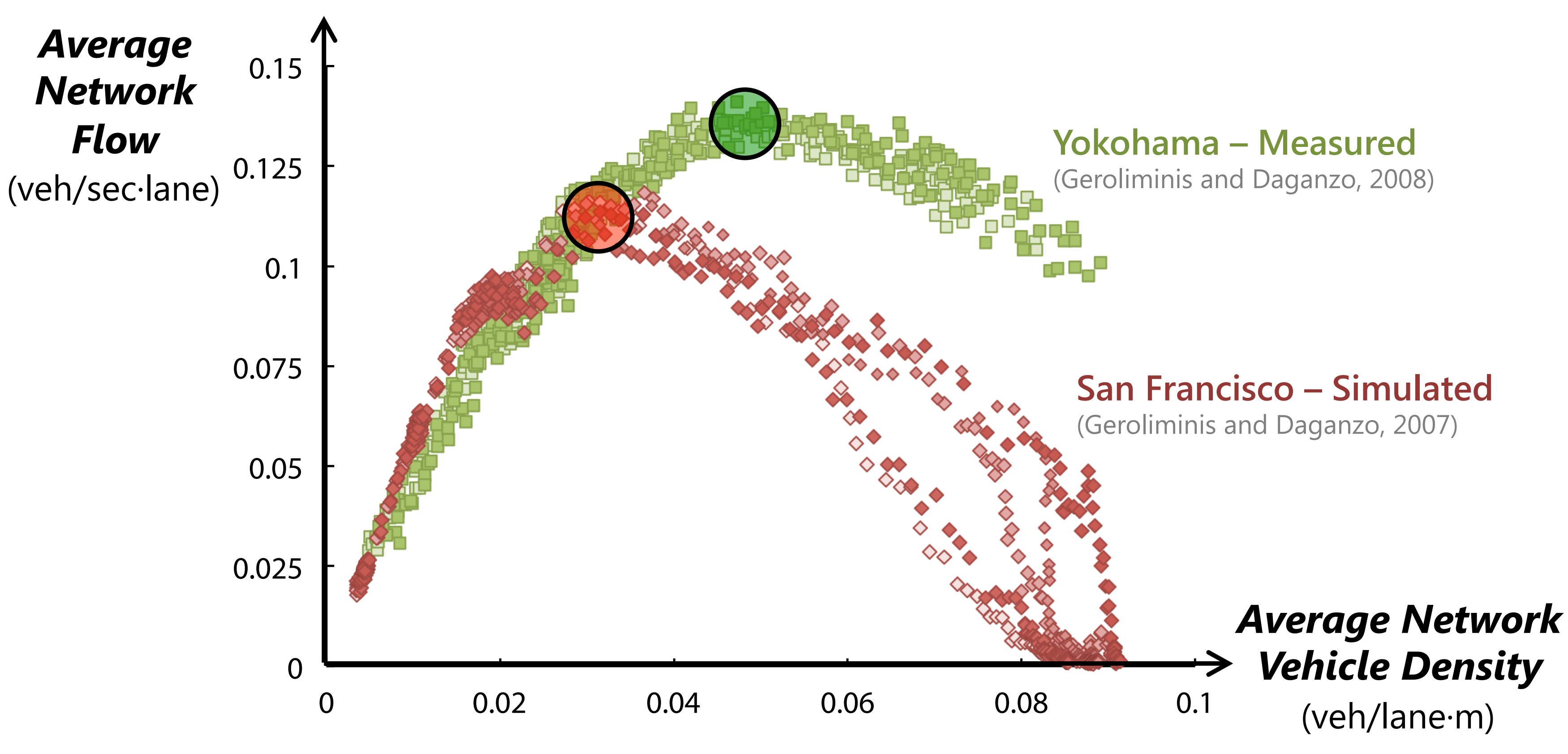
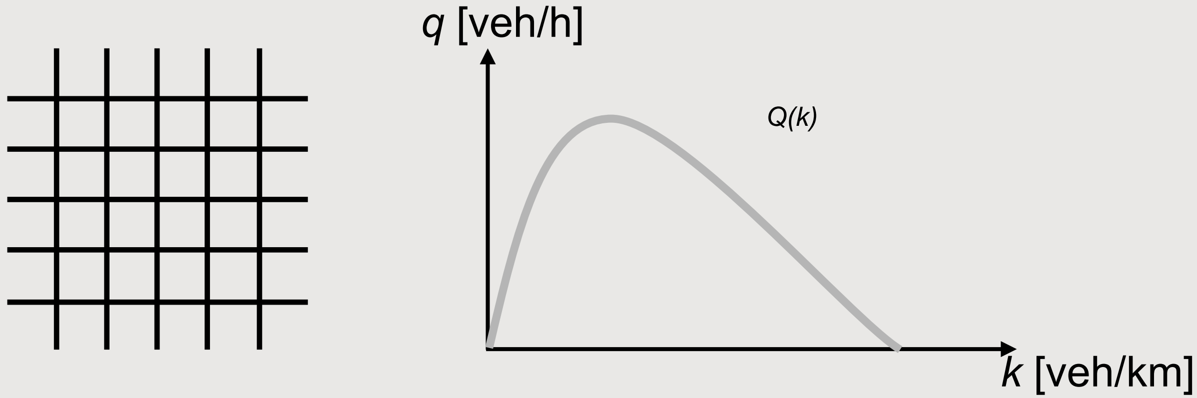
Macroscopic Fundamental Diagram



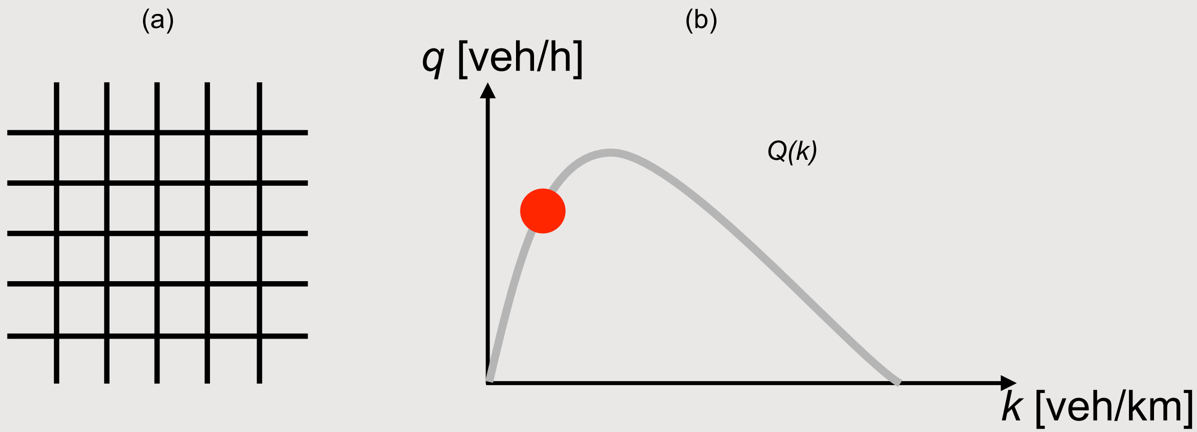
Thanks to E. Gonzales, uMass.

Macroscopic Fundamental Diagram

(a) (b)

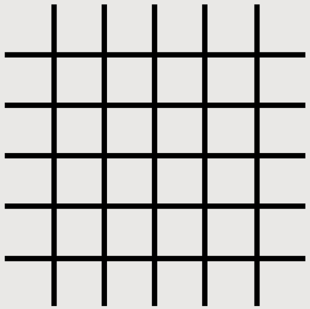


Macroscopic Fundamental Diagram

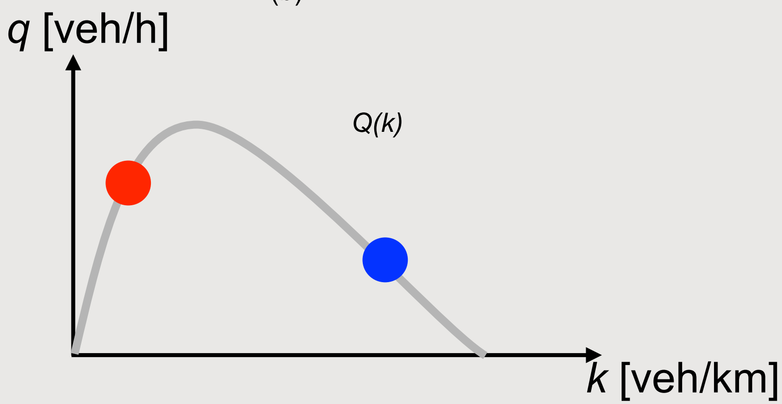


Macroscopic Fundamental Diagram

(a)



(b)



MFD background (1/2)

- Reproduces traffic dynamics:
  - At an aggregated scale (arterial, part of a city, city, etc.)
  - As an uniform reservoir (same traffic conditions on each link);
  - By linking the average density to the average flow (give access to the average speed);
- Very convenient:
  - Still captures traffic flow dynamics;
  - But with few parameters.

MFD background (2/2)

- Various approaches to estimate MFDs:
  - Account for traffic signals, control strategies and impacts of multimodality (public transport, trucks);
- Makes it possible to:
  - Compare different traffic management strategies;
  - Evaluate ex ante the network performance;
- However, MFD only expresses the performance in term of number of vehicles:
  - **Need to extend to account for the number of passenger!**

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N. Chiabaut, 2015.
Evaluation of a multimodal urban arterial: the passenger MFD.
Tr. Res. Part B, *in press*.

Passenger-MFD

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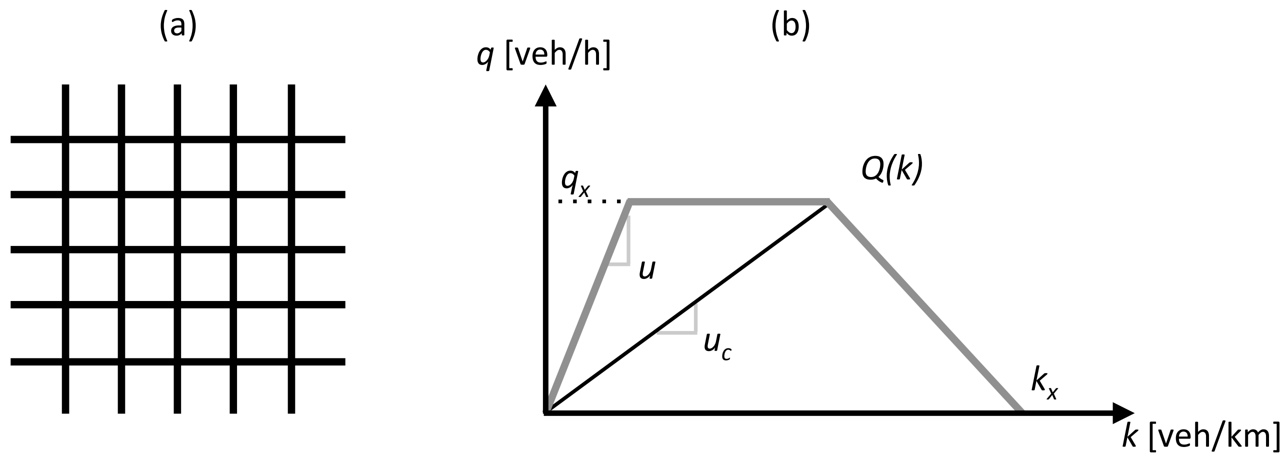
Objectives

- To provide a framework for the global evaluation of a transportation network:
  - Passenger MFD;
  - Impacts of modal choice;
- To apply this new method to design and compare traffic management strategies:
  - Optimal time-headway;
  - Introduction of dedicated bus lanes;
  - Intermittent bus lanes.

Case study



- A meshed urban network with signalized intersections
- Two transportation modes: individual car and bus.
- Traffic is supposed to obey a MFD:
  - Average flow and density of cars in the road of the network;
  - Average occupancy $\boldsymbol{\rho_c}$;
- Bus system characteristics:
  - Free-flow speed $\boldsymbol{u_t}$;
  - Time-headway $\boldsymbol{h}$;
  - Average occupancy $\boldsymbol{\rho_t}$.

The passenger MFD (p-MFD)

- It combines both modes (cars and buses):
  - p-MFD relates the average density of pax within the network with the average flow of pax;

$$P(K) = F_c(K_c) + F_t(K_t)$$
$$K = K_c + K_t$$

  - K_c & Q_c: density and flow of cars (pax)
  - K_t & Q_t: density and flow of transit (pax)
- A crucial variable:
  - the mode choice.

$$\tau = {K_c}/{K}$$

- Equilibrium has a strong impact on the p-MFD shape.

Static modal ratio (1/3)

- It does not depend on traffic conditions:
  - τ is exogenously given;

$$P(K) = \tau F_c(K_c) + (1 - \tau).F_t(K_t)$$

- $F_c(K_c)$ is given by the MFD weighted by the average occupancy;
- $F_t(K_t)$ directly comes from the bus system characteristics:
  - Free-flow: easy – $F_t(K_t) = \rho_t / h$.
  - Congestion: more difficult.

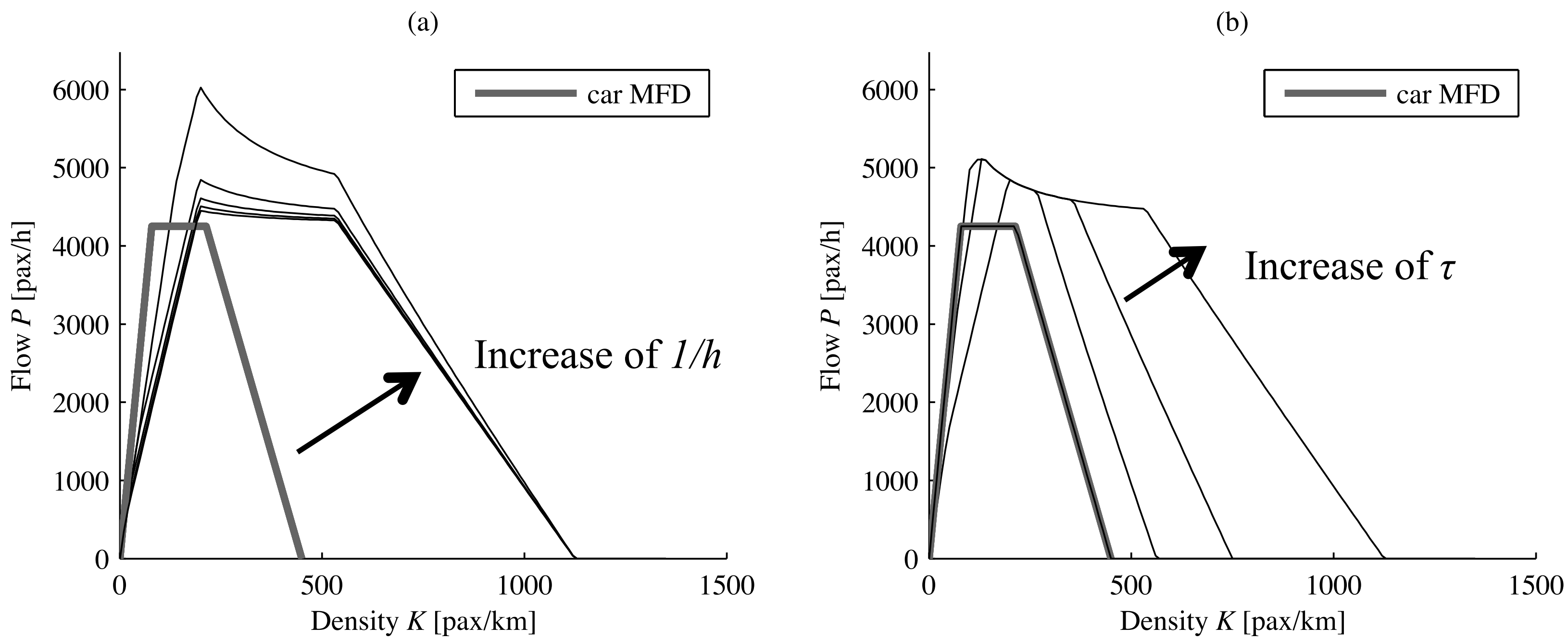
Static modal ratio (2/3)

- Traffic flow constrains the bus when:
  - $v_c < u_t$;
- We assume that the number of buses in operation is constant:
  - Time-headway has to be updated based on traffic conditions;
  - $h = L/(n_{bus}.v_c)$ where L is the average length of the transit lines.
- It comes:

$$P(K) = \rho_c q \left(\frac{\tau K}{\rho_c}\right) + \frac{1}{L}.\min\big((1-\tau)K.L, \rho_t n_{bus}/L\big).\min(u_t, v_c)$$

Static modal ratio (3/3)

- Sensitivity to:
  - Bus time-headways;
  - Mode choice ratio.



Dynamical mode ratio

- ***τ*** can now depend on traffic conditions;
- We focus on two equilibriums:
  - User equilibrium (UE);
  - System optimum (SO).
- **UE:** each driver seeks to minimize his travel time, i.e. maximize his average speed;
- **SO:** the average travel time is minimized, i.e. the average speed is maximized.

System Optimum (1/3)

- P-MFD is now given by:

$$P(K) = \max_{\tau}[\tau . F_c(K_c) + (1-\tau) . F_t(K_t)]$$

- Free-flow:
  - Switch of mode when:

$$\frac{\delta K_c}{\delta F_c}(F_c^*) = \frac{1}{u_t}$$

- Congestion:
  - Bus time-headway have to be dynamically changed.

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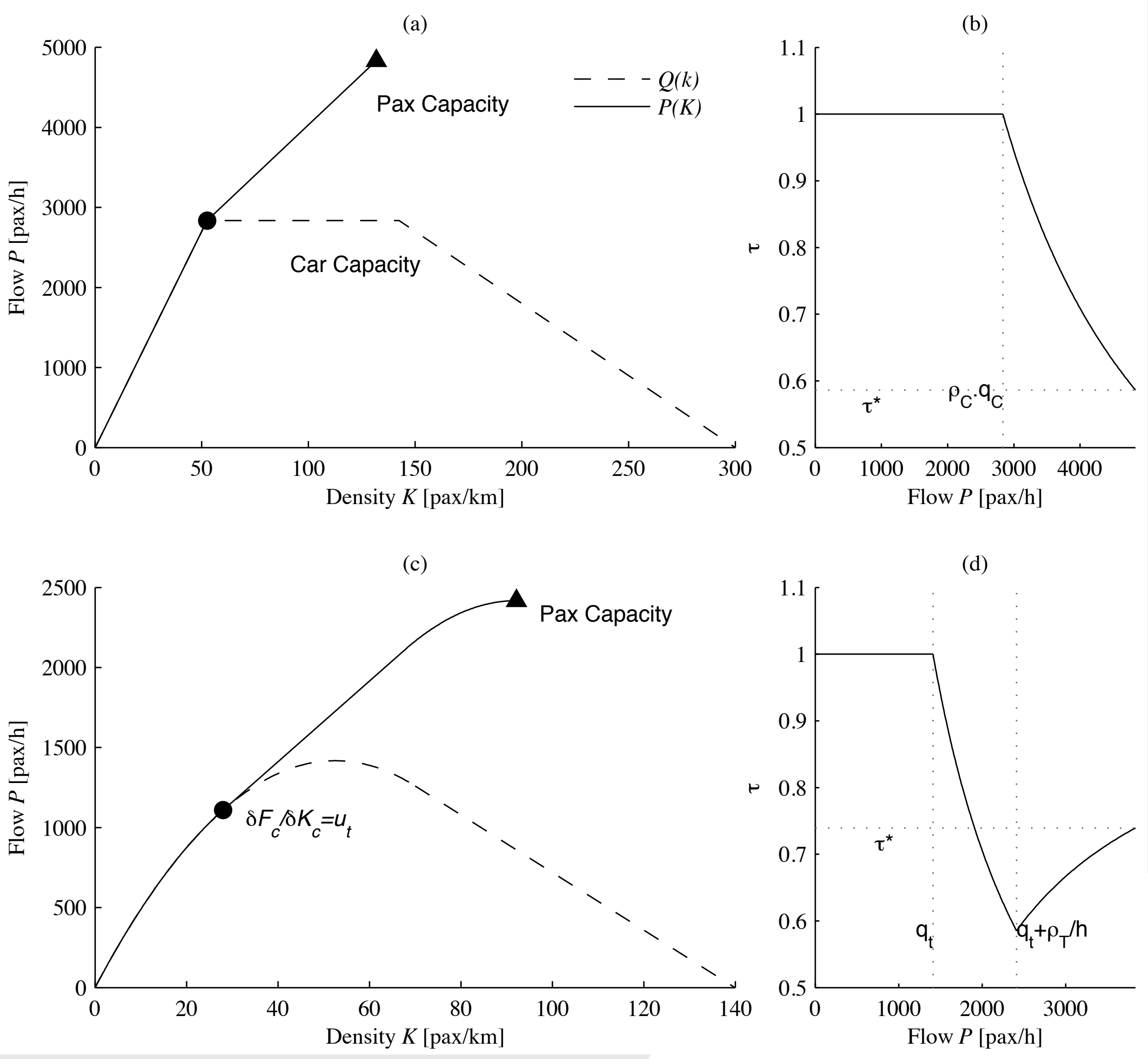
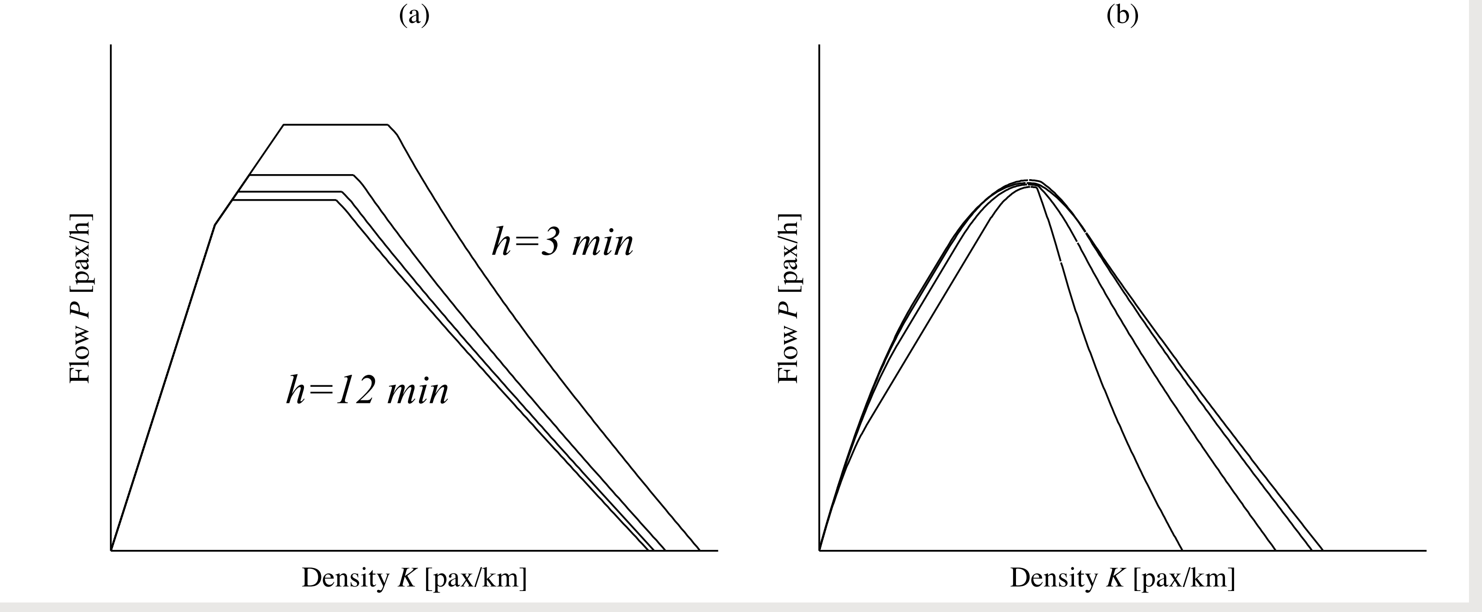
System Optimum (2/3)



System Optimum (3/3)

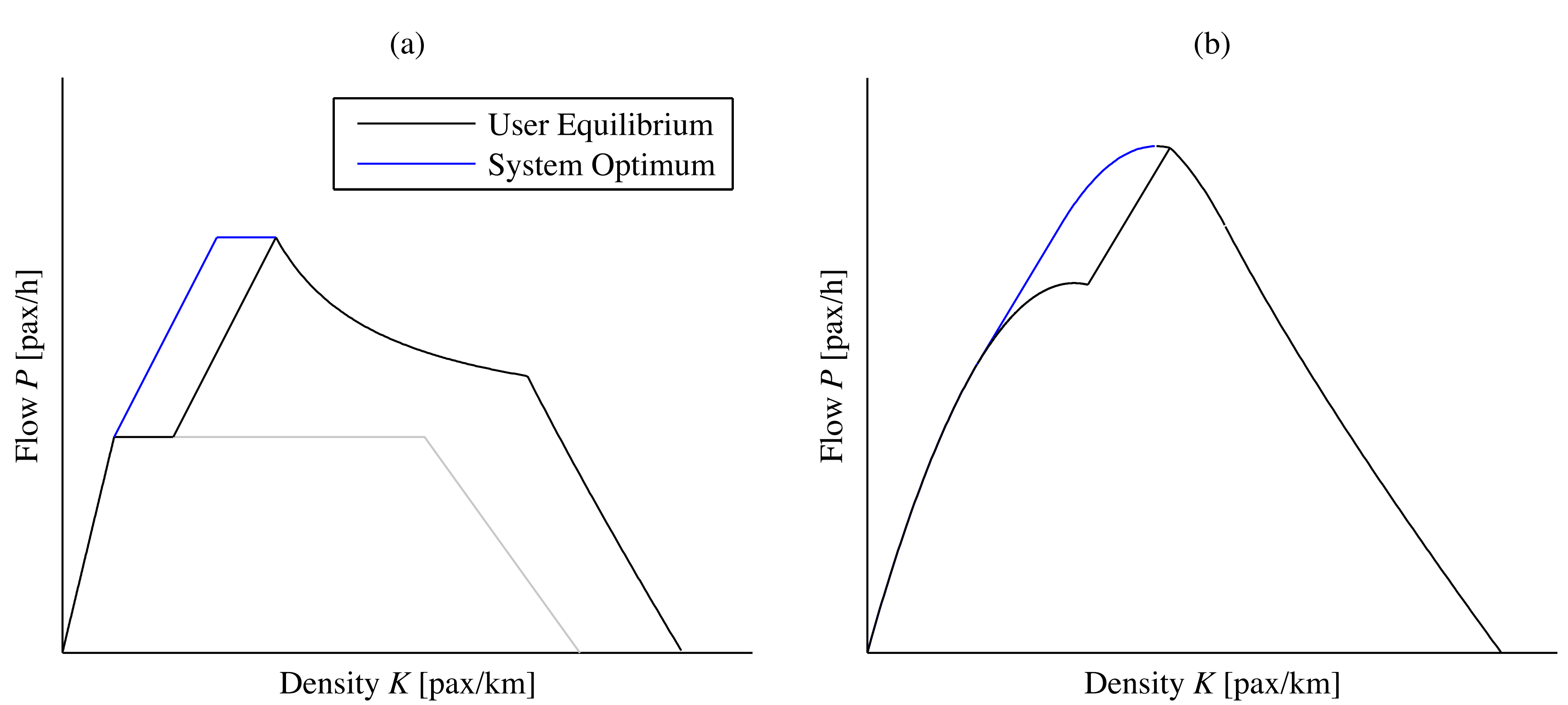
- Sensitivity to bus time-headway:



User Equilibrium (1/4)

- Individual optimal solution:
  - pax seeks to minimize their travel time;
  - First Wardrop principle;
- Only one mode until speed of the car is equal to the bus free-flow speed:
  - Very easy to calculate.

User Equilibrium (2/4)



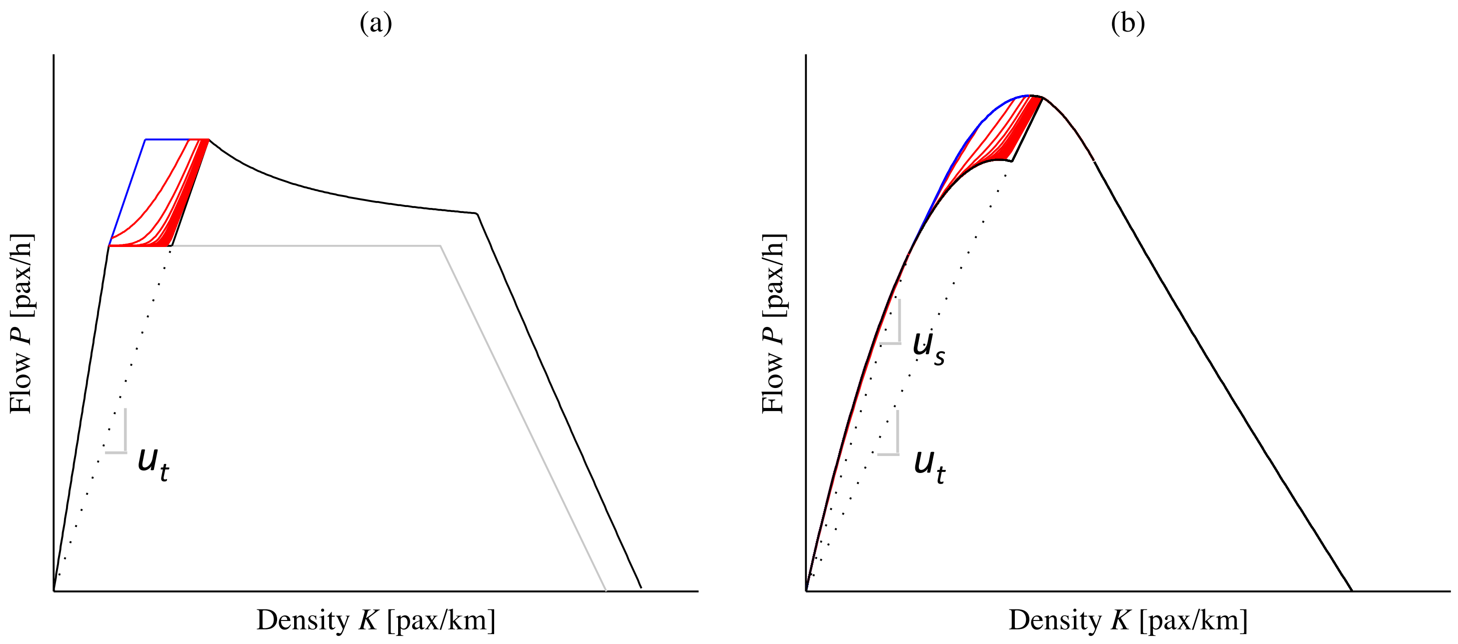
User Equilibrium (3/4)

- We can also test probabilistic mode choice model:
  - Ex: Logit model;
- Mode ratio depends on the travel time difference:

$$\frac{F_t}{F_c} = e^{-\theta\left(\frac{L}{v_t} - \frac{L}{v_c}\right)}$$

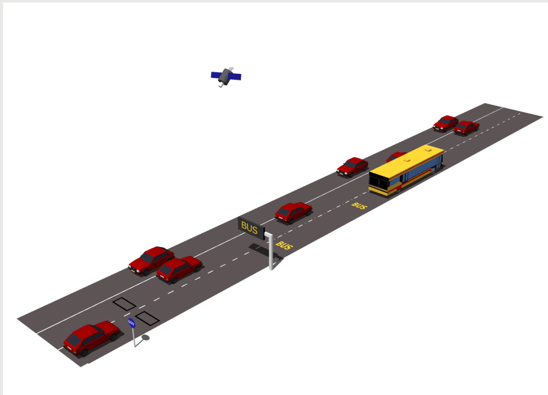
- Sensitivity to the theta parameter.

User Equilibrium (4/4)

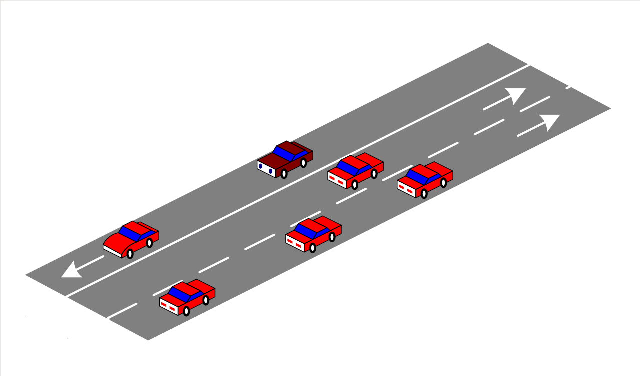


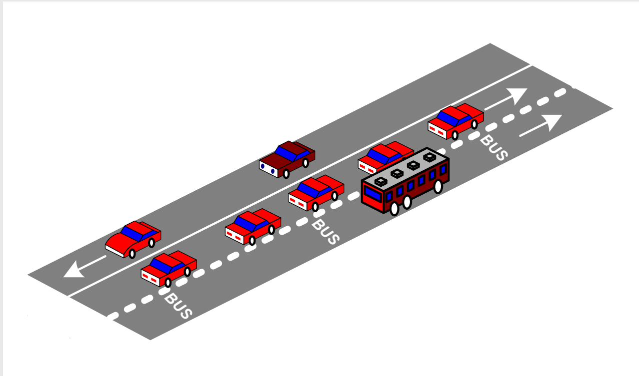
N. Chiabaut, X. Xie, L. Leclercq, 2014.
Performance analysis for different designs of a multimodal urban arterial.
Transportmetrica B: Transport Dynamics, 2(3), 229-245.

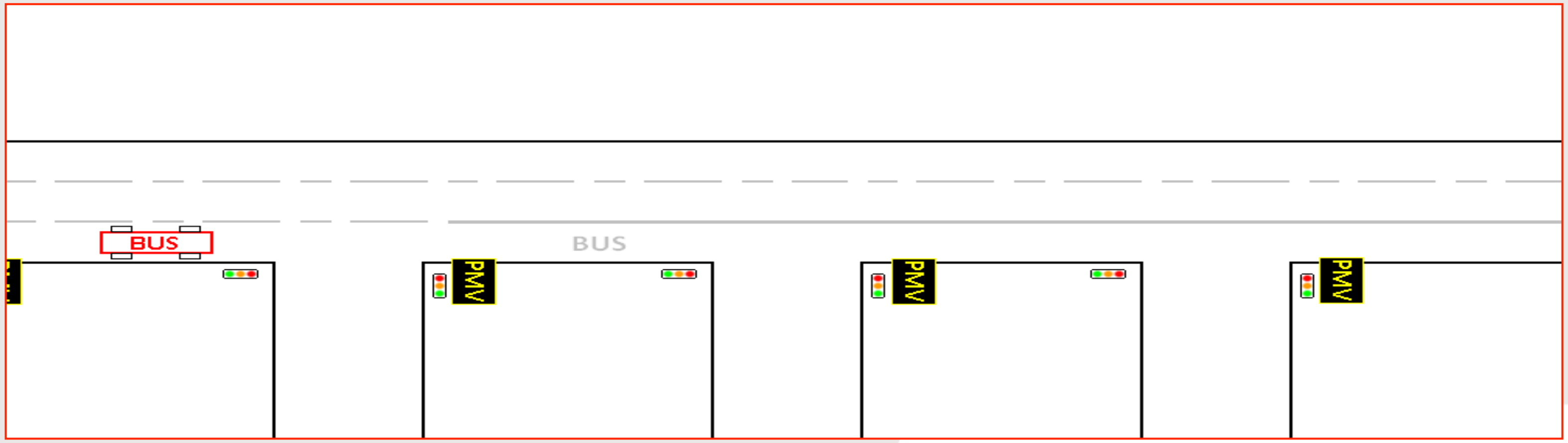
Application:
Evaluation of IBL strategies



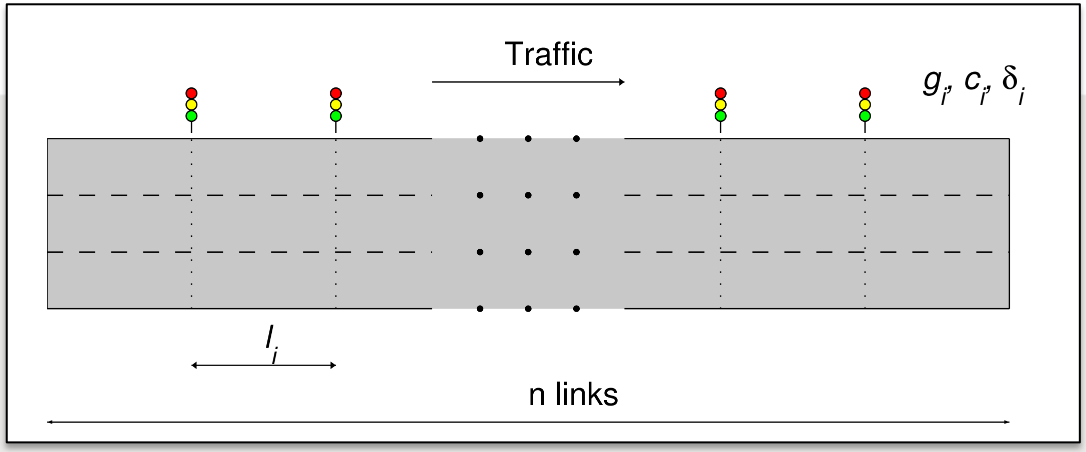
Intermittent Bus Lane (IBL)







Case study



- Idealized urban arterial:
  - *3* lanes;
  - ***n*** links separated by traffic signals;
  - No turning movement;
- Bus system:
  - Bus time headway: ***h***;
  - No station;
  - Reduced speed u_b (smaller than free-flow vehicles speed ***u***);
- Traffic is supposed to obey triangular FD:
  - Free-flow speed ***u***;
  - Congested wave speed ***w***;
  - Jam density ***κ***.

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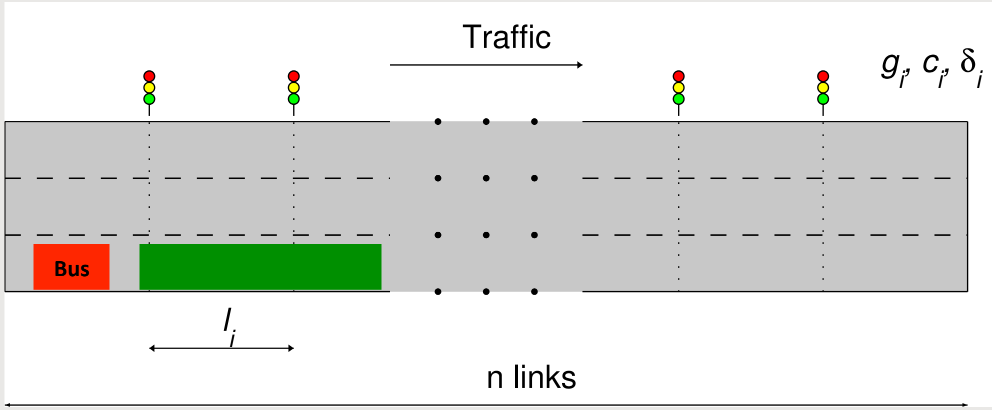
IBL design

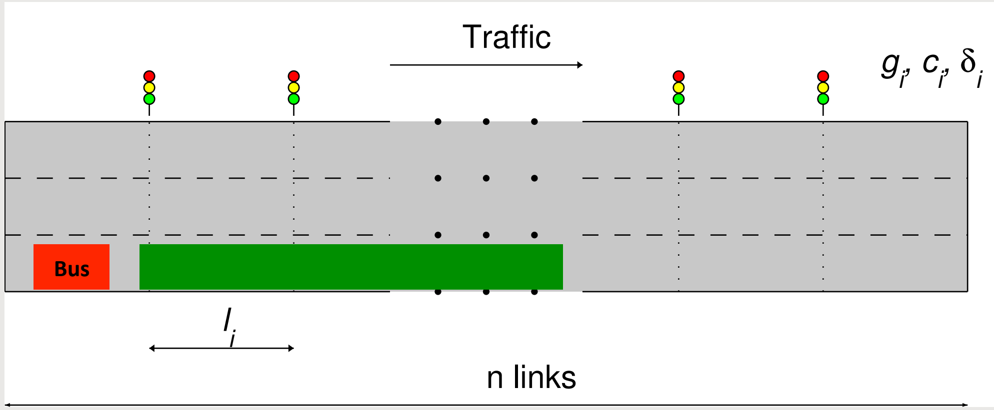
- When a bus is detected, right lane is dedicated for *i* successive links



2 links

IBL design

- When a bus is detected, right lane is dedicated for *i* successive links



3 links

IBL design

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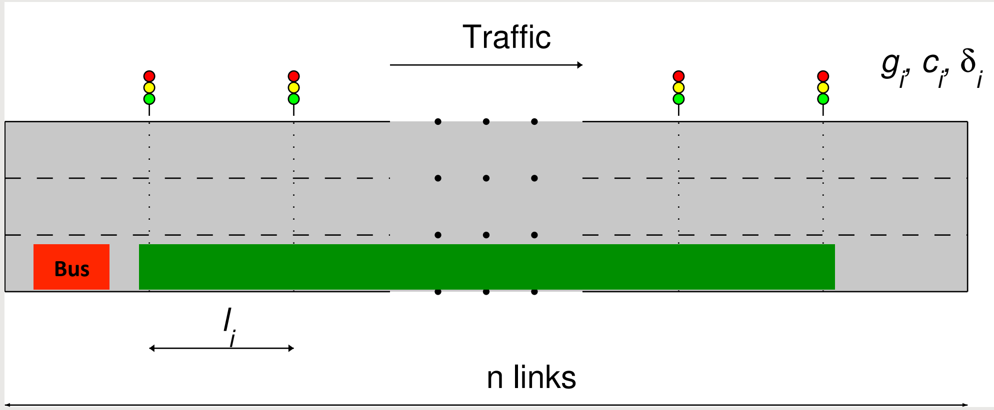


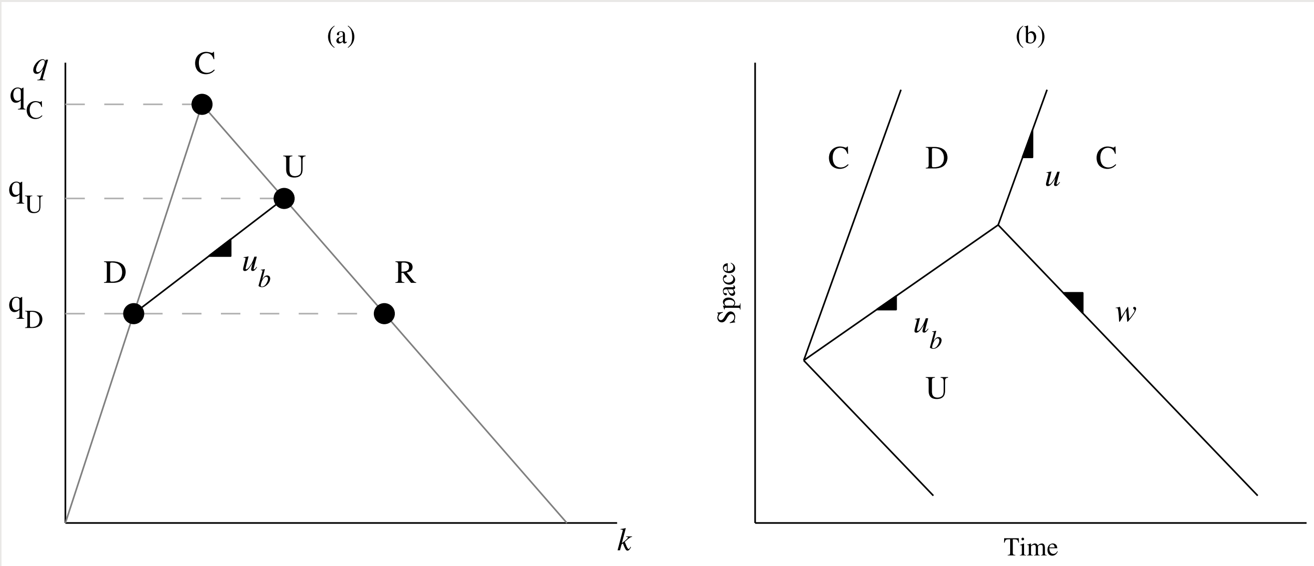
i links

Connections between MB and IBL strategies (1/4)

- *Background*: MB theory (Newell, 1998)

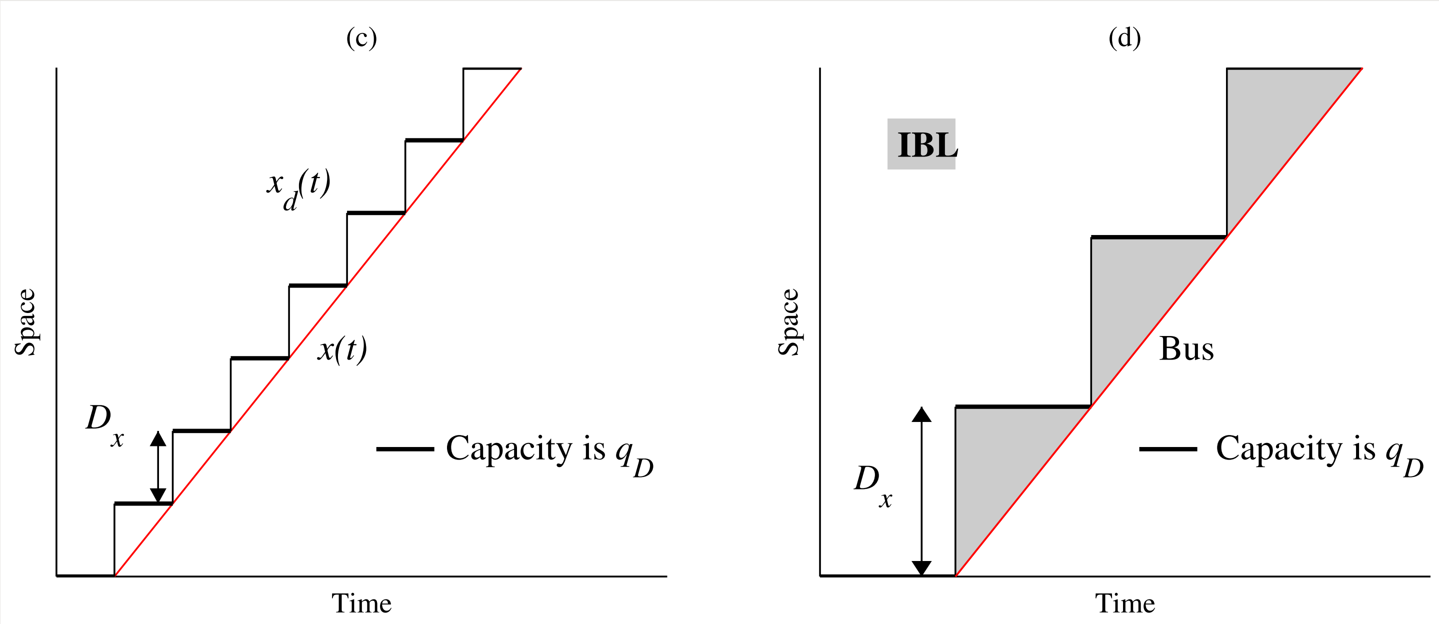
3 lanes

2 lanes



Connections between MB and IBL strategies (2/4)

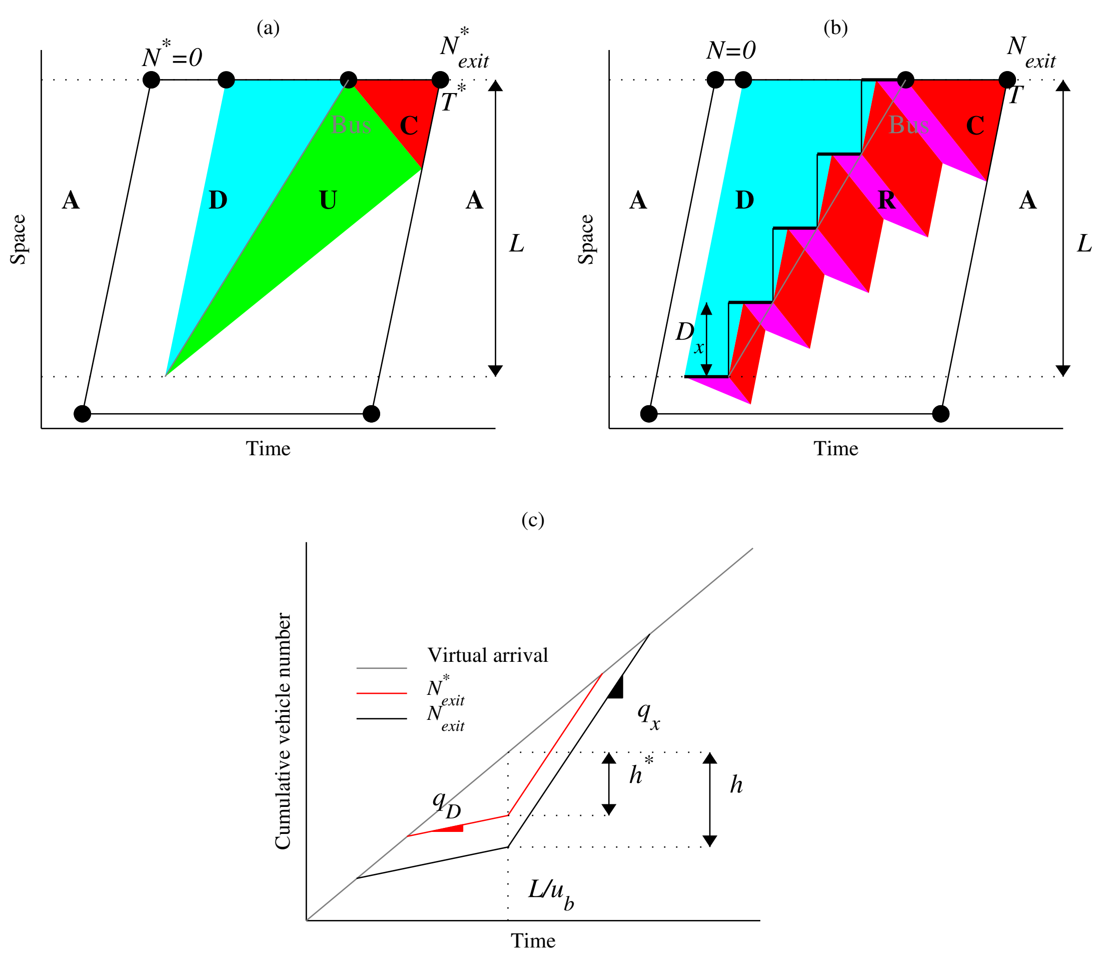
- *Background:* MB discretization (Daganzo & Laval, 2005)



Scaling effect between MB and IBL

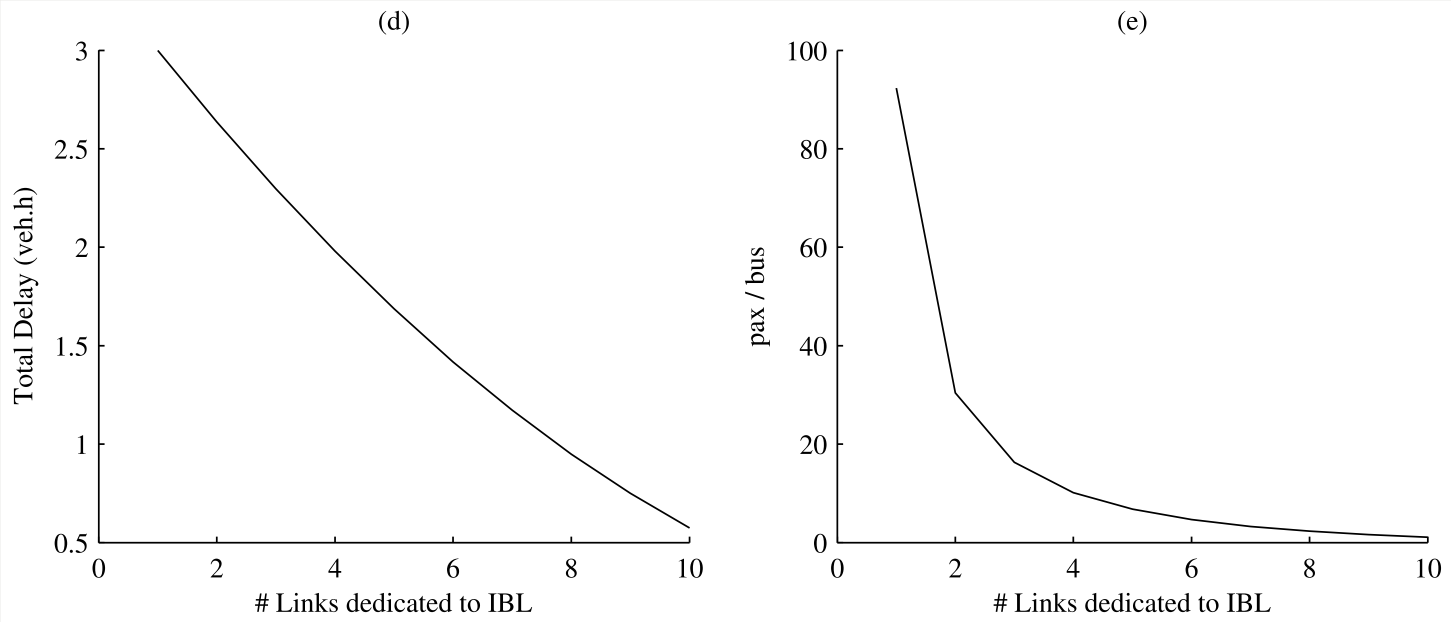
Connections between MB and IBL strategies (3/4)

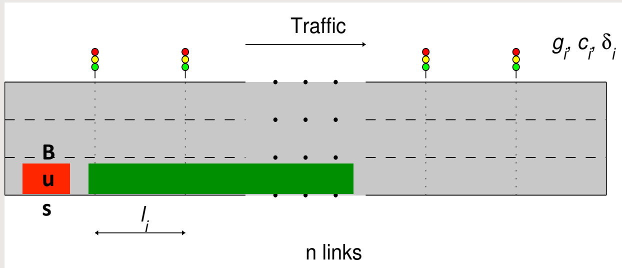
- Calculations of delays



Connections between MB and IBL strategies (4/4)

- Delays introduces by IBLs





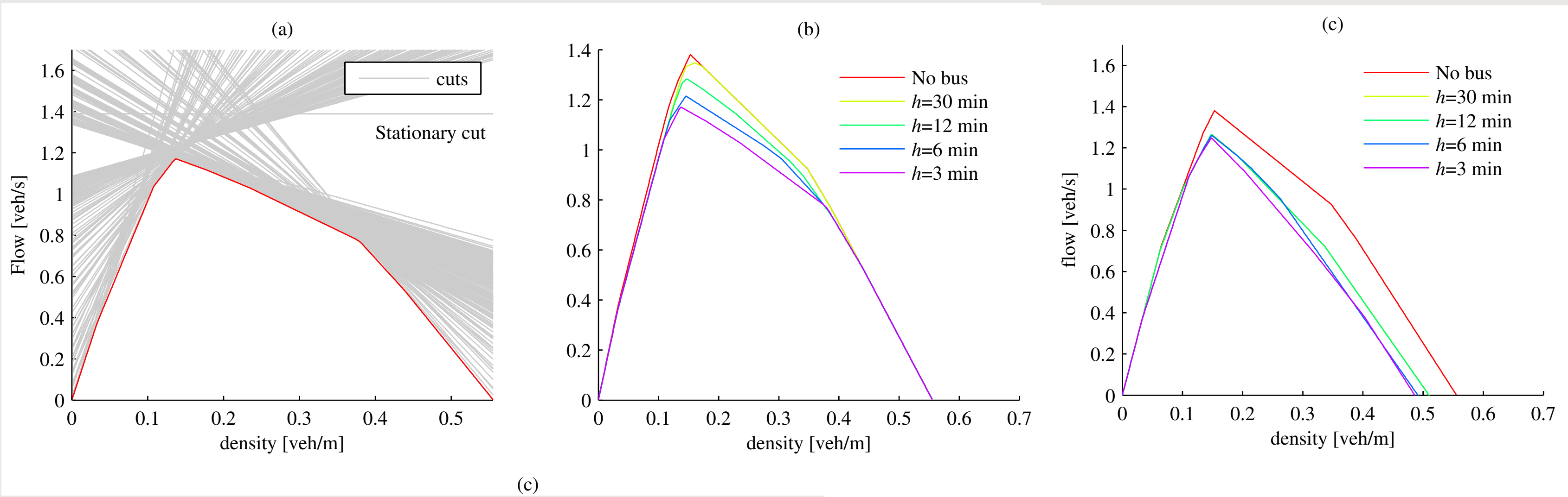
Next

- Limitations:
  - We only focus on free-flow situations ;
  - Influence of traffic signal is not considered ;
- Forthcoming:
  - Estimation of car MFD for MB and IBL cases;
  - Calculation of associated ***passenger MFD;***
  - Comparison of different designs.

Estimation of MFD for MB and IBL cases

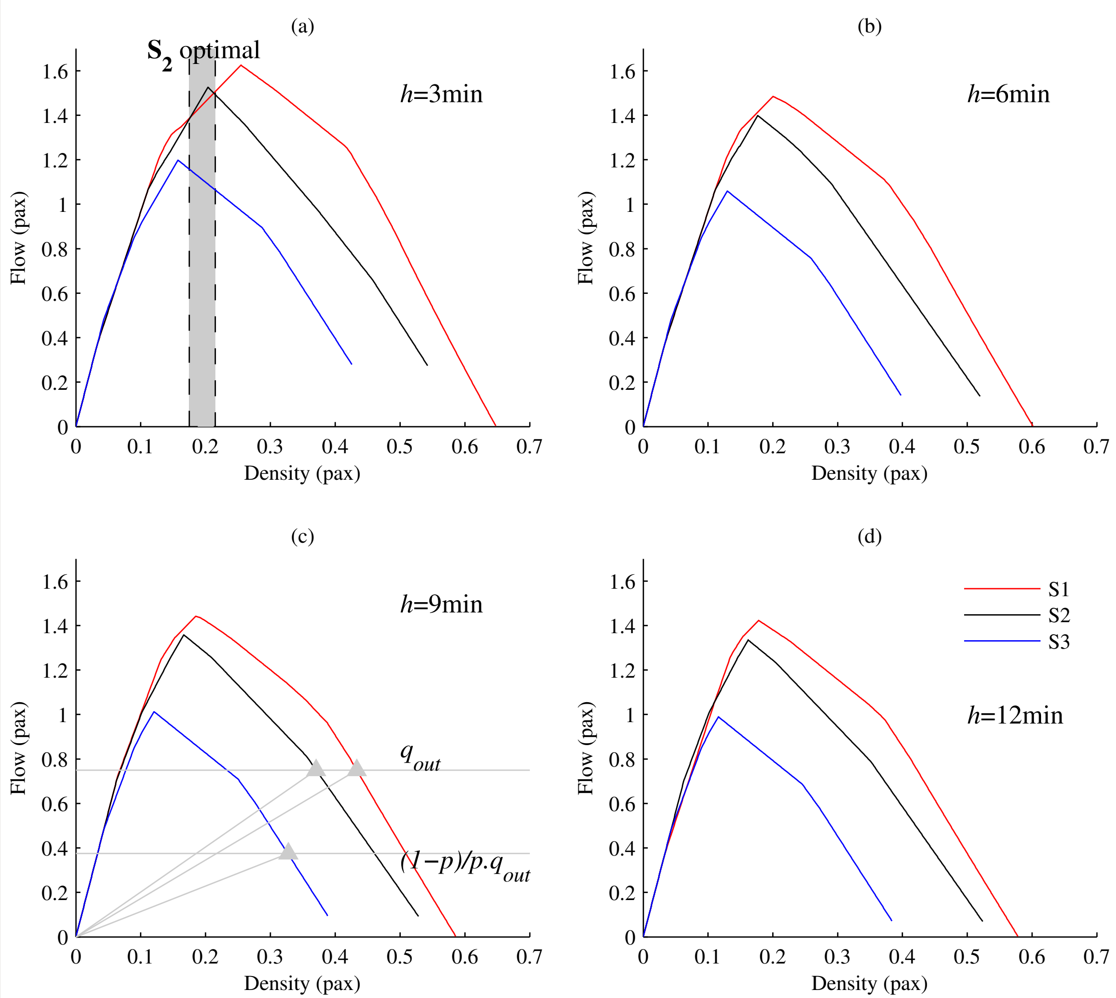
- Semi-analytical method:
  - Based on variational theory;
  - See *Hans, Chiabaut and Leclercq (2015, Tr. Res B)* or *Xie, Chiabaut and Leclercq (2013, TRR)*

All possible cuts for one situation ***MB case*** ***IBL case***



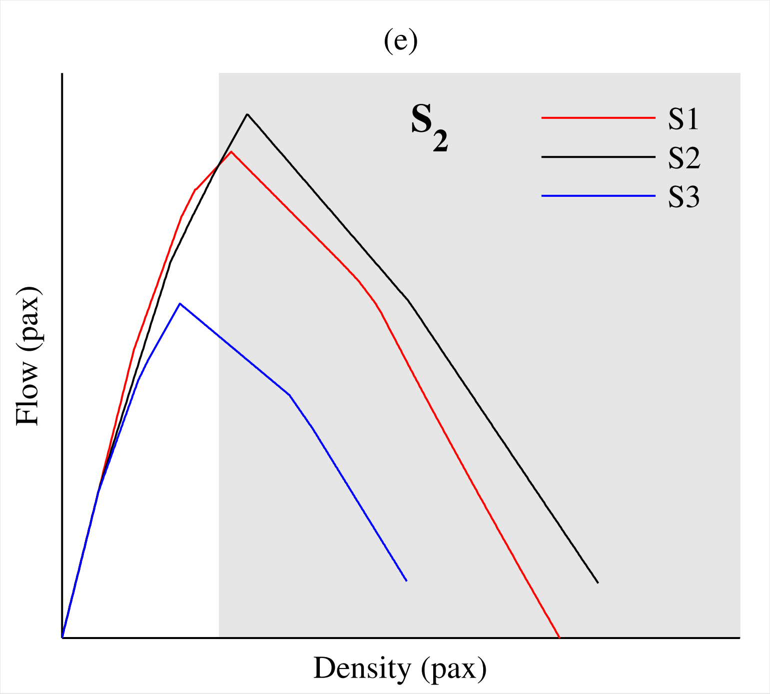
Comparison based on p-MFD

- ***S1***: “do-nothing”
- ***S2***: IBL
- ***S3***: DBL



Domains of application of IBL

- A more realistic case (?)
  - ***S1: h***=9' and $\boldsymbol{u_b}$=8m/s;
  - ***S2-3: h***=6' and $\boldsymbol{u_b}$=10m/s;



Conclusions

- We provided tools to assess and compare various traffic management strategies;
  - Impacts of mode choice equilibrium;
- Applications :
  - Evaluation of IBL;
  - *Optimal bus time-headways;*
  - *Creation of DBL;*
- Future work:
  - Extension to others traffic management strategies (TMS) and comparison of hierarchical network;
  - Feedback between TMS and mode equilibrium;
  - Experimental estimation of p-MFD.

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Questions ?

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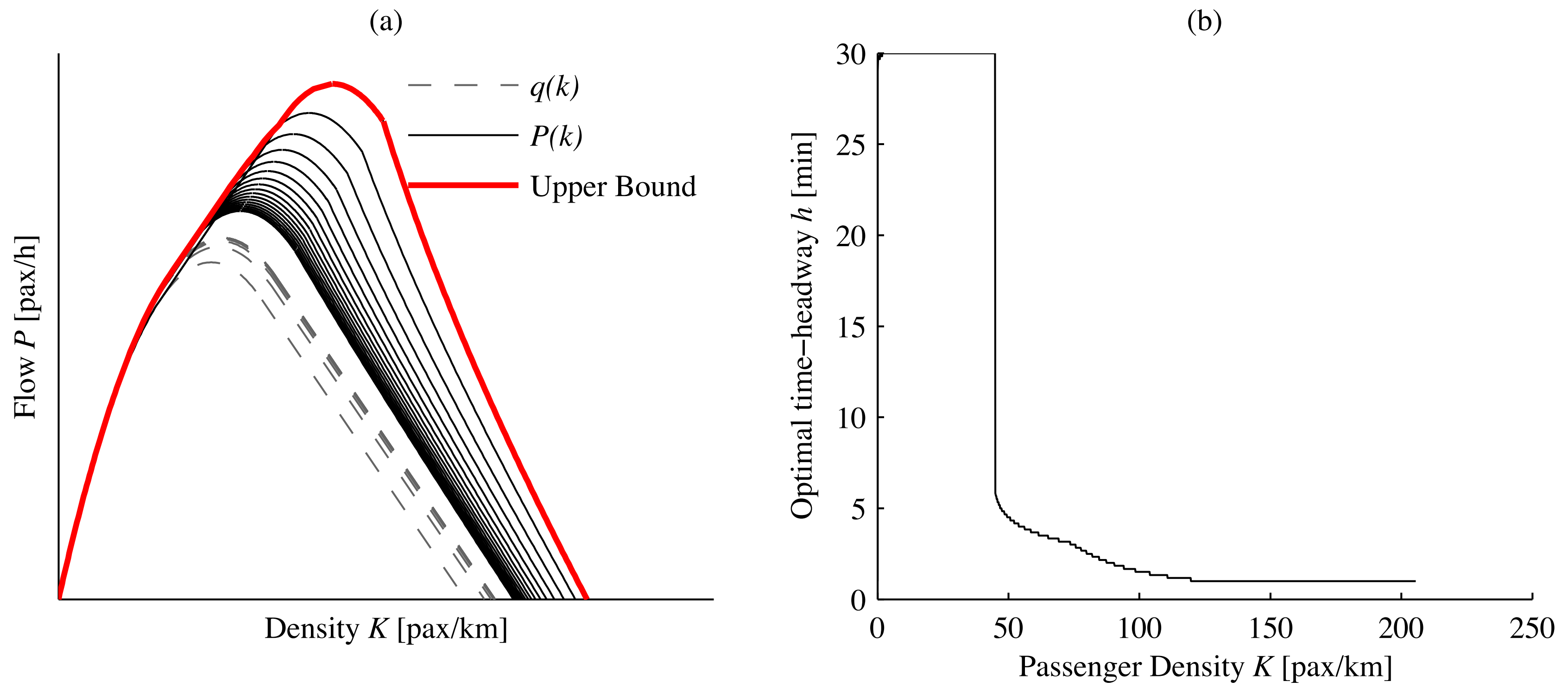
Application (1/5)

- We aim to determine optimal bus time-headway:
  - For a given demand, we determine the headway that leads to the minimal density, i.e. the maximal average speed;
- Impact of buses on individual cars is modeled as a reduction of the maximal capacity:

$$\left(n - e^{1-\frac{h}{h_m}}\right).\, q_x/n$$

Application (2/5)



Application (3/5)

- We aim to determine effect of creating Dedicated Bus Lanes (DBL):
  - α% of the network;
  - Car MFD is homogeneously reduced of α% its original formulation;
- We calculate the upper bound of possible p-MFD:
  - Maximal flow for a given density.

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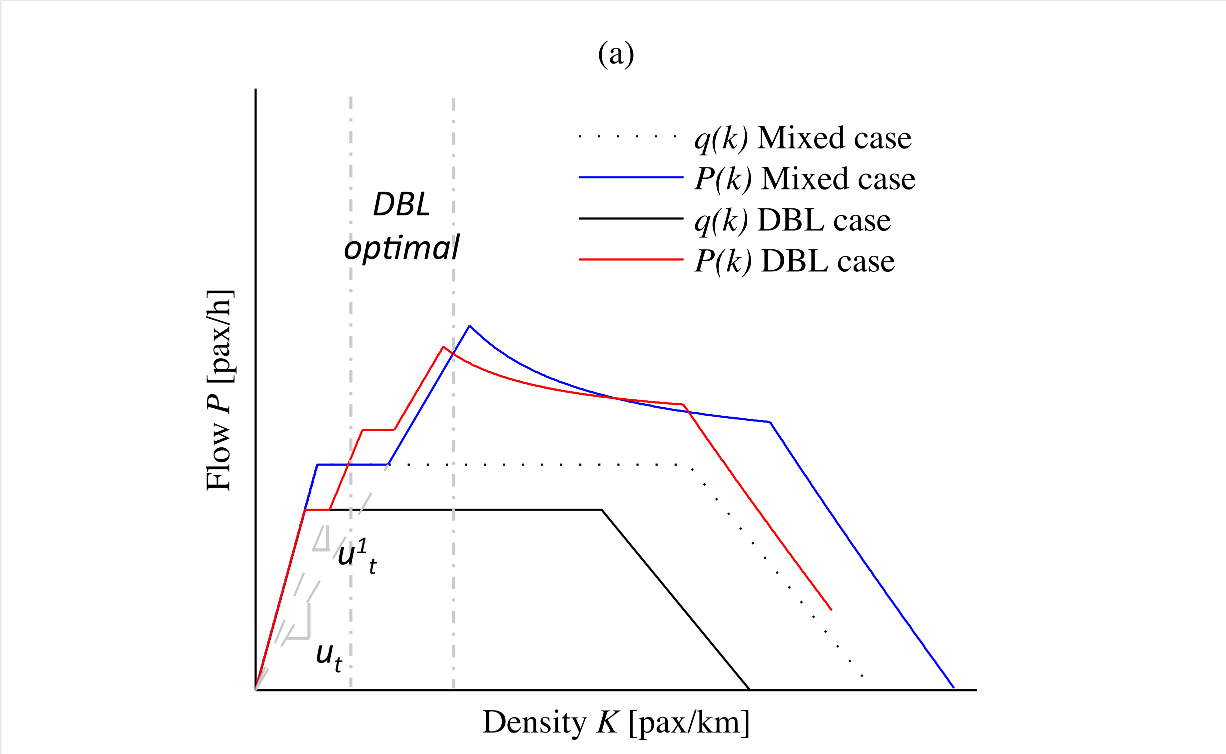
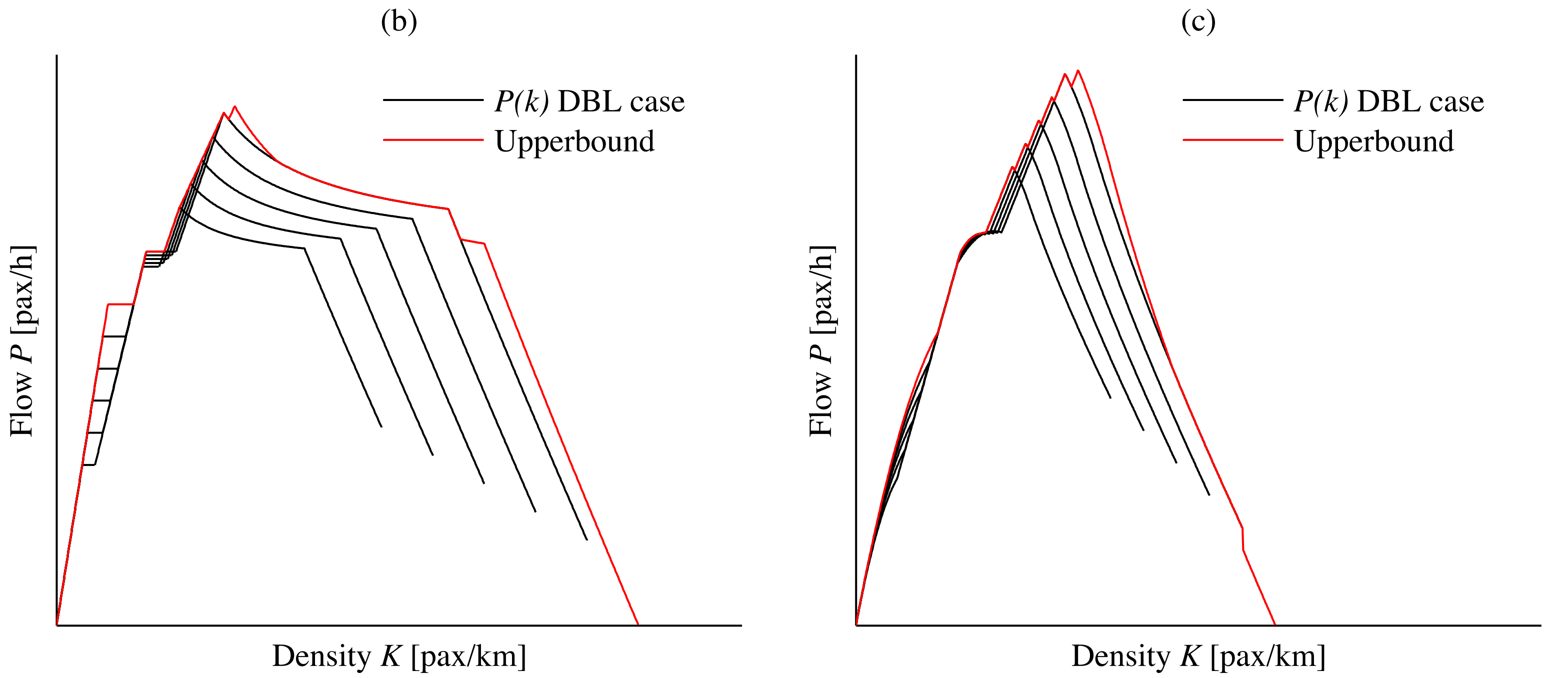
Application (4/5)



Application (5/5)



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