Recent advances in traffic flow theory

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ETH, July 1 2016

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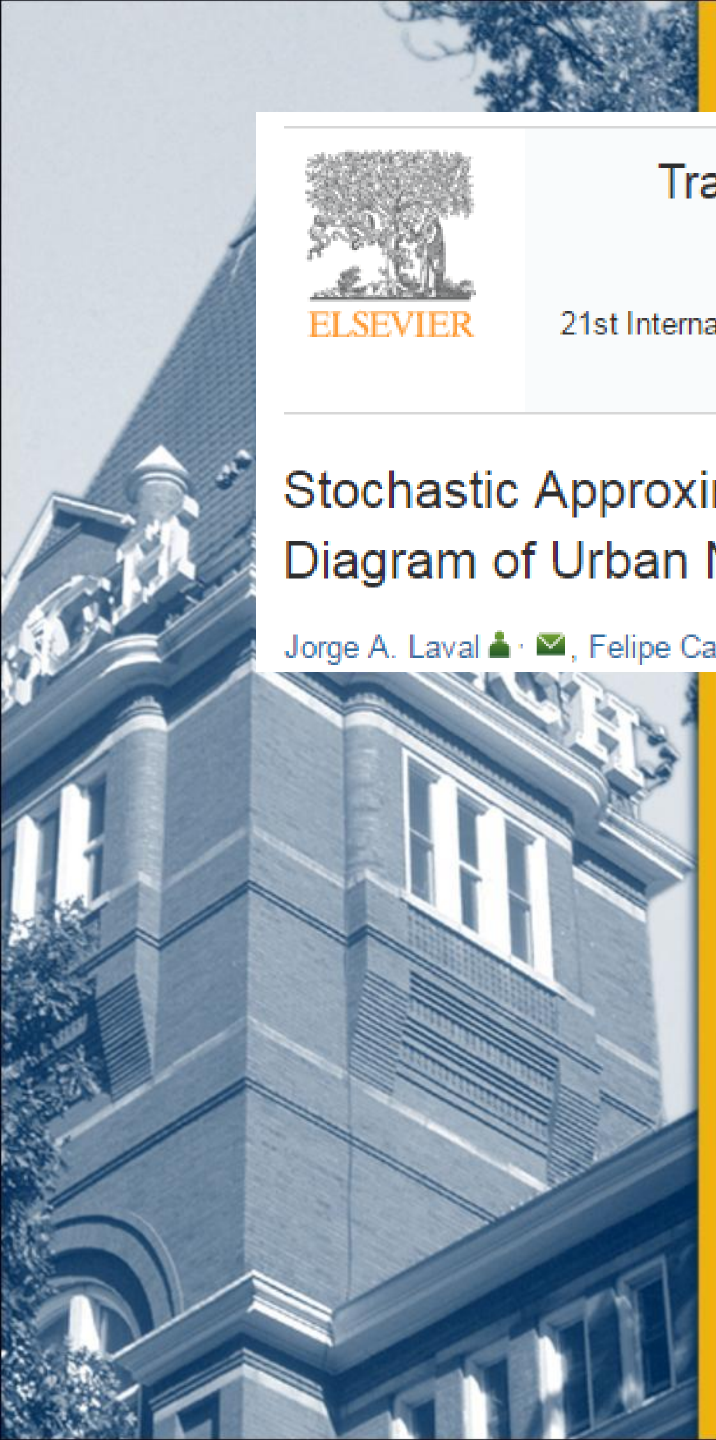
Content

- Stochastic Approximations for the Network MFD
  - MFD mostly depends on 2 parameters
    - mean segment length to mean green ratio
    - mean red to mean green ratio
- Symmetry in traffic flow
  - parameter-free representation of LWR model
  - capacity and delay are invariant: choose fundamental diagram that simplifies the problem the most
- Realistic oscillations in car-following models
  - random error in drivers free-flow accelerations explains formation and propagation of oscillations



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Stochastic Approximations for the Macroscopic Fundamental Diagram of Urban Networks ☆

Jorge A. Laval, Felipe Castrillón

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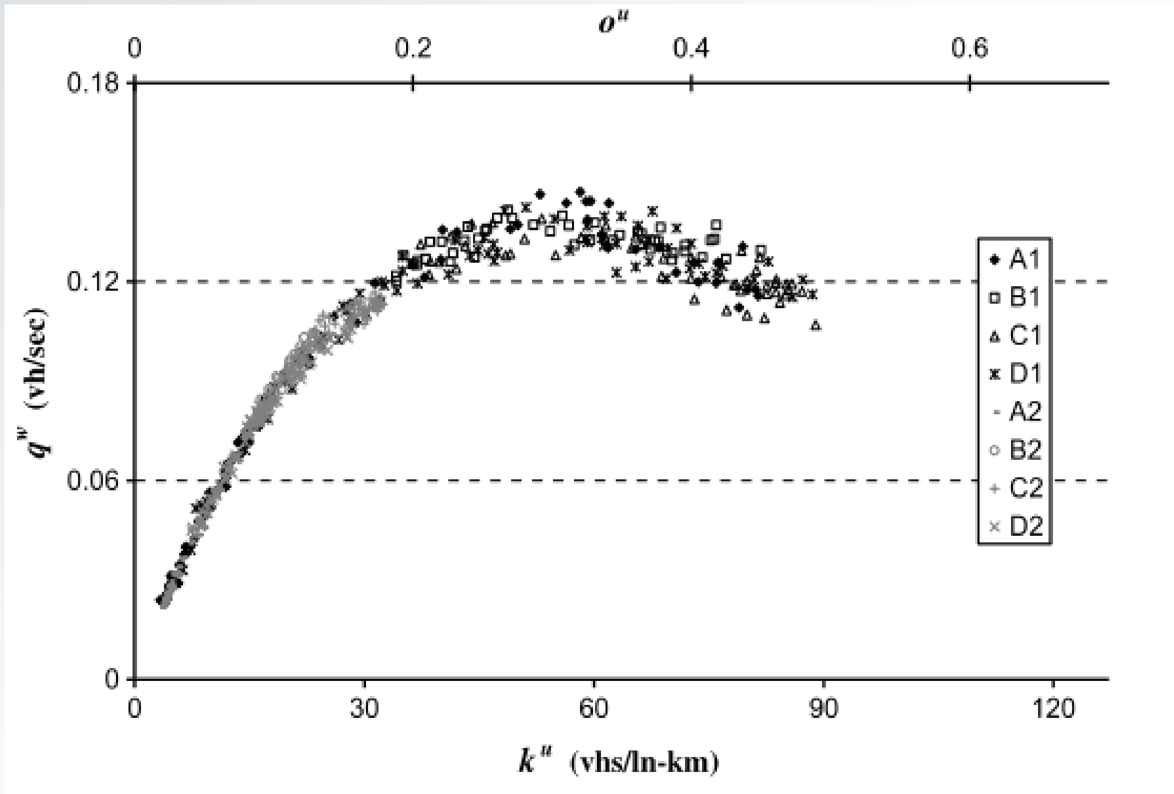
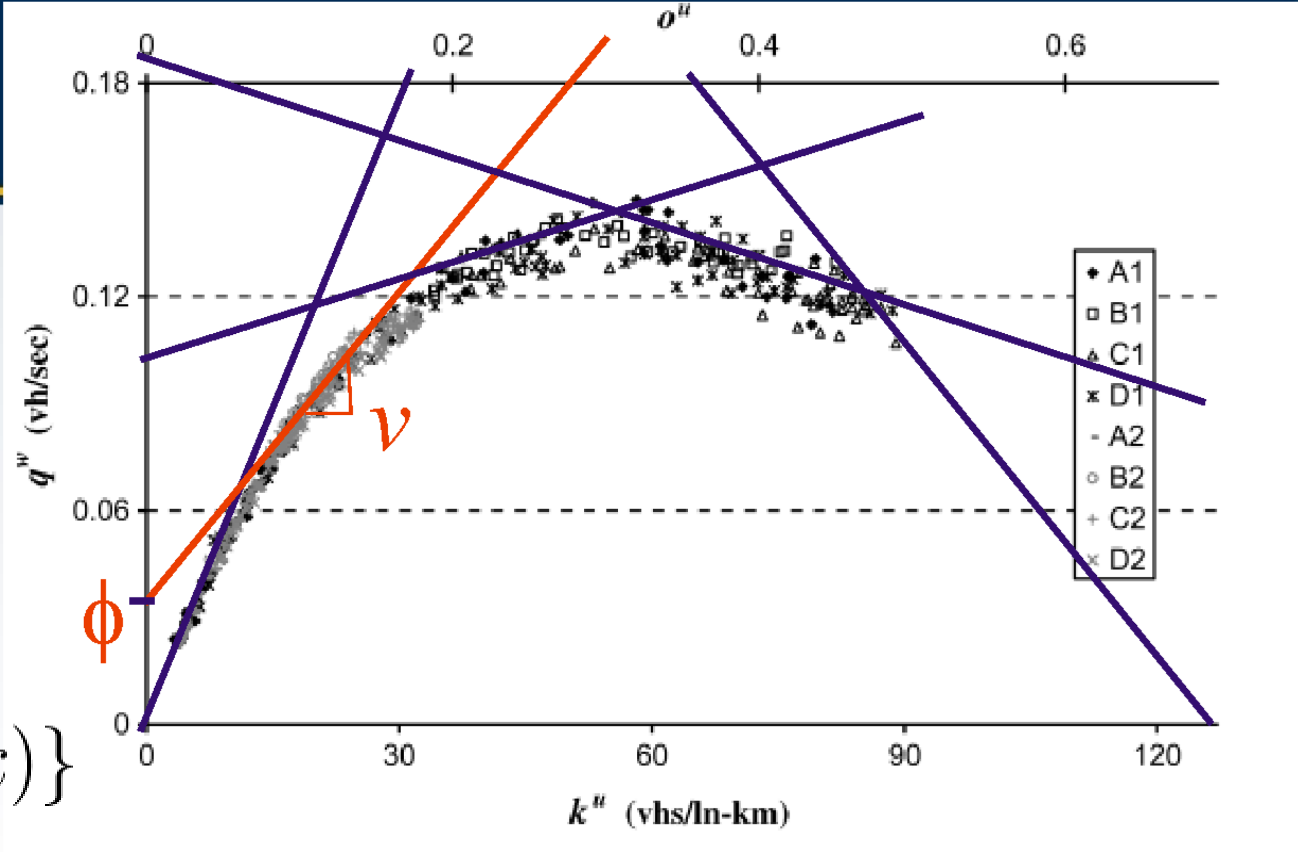
The Yokohama MFD



- **Insensitive to O-D demands and route choice**
- **Tool for macroscopic feedback monitoring and control**

C. F. Daganzo, "Urban gridlock: Macroscopic modeling and mitigation approaches," *Transp. Res. Part B Methodol.*, vol. 41, no. 1, pp. 49–62, Jan. 2007.
N. Geroliminis, C. F. Daganzo, "Existence of urban-scale macroscopic fundamental diagrams: some experimental findings," *Transp. Res. Part B*

Method of Cuts



- φ = maximum passing rate
- *v* = average observer speed

$$q(k) = \min_s\{q_s(k)\}$$

- analytical for homogeneous* corridors
- intractable for heterogeneous corridors ⇒ numerical methods (Leclercq and Geroliminis, 2013)

*homogeneous = same segment length and signal timing

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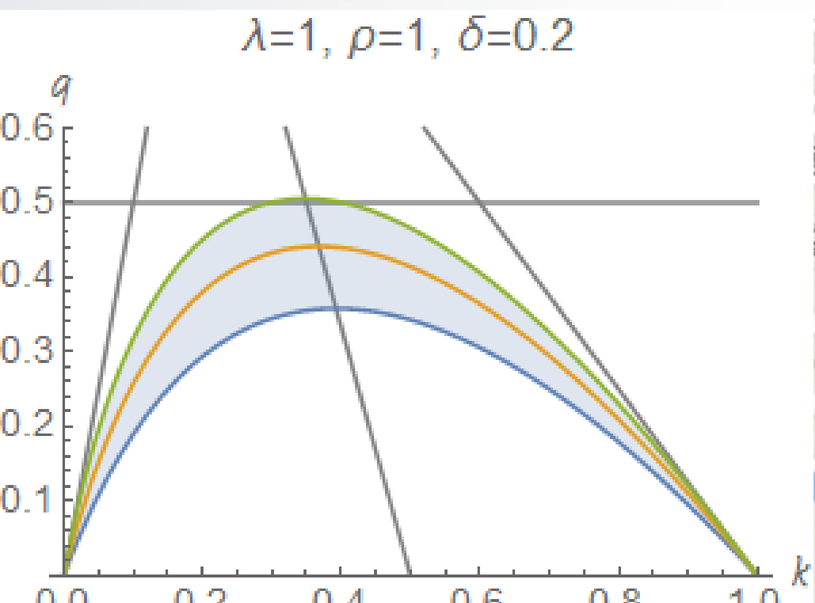
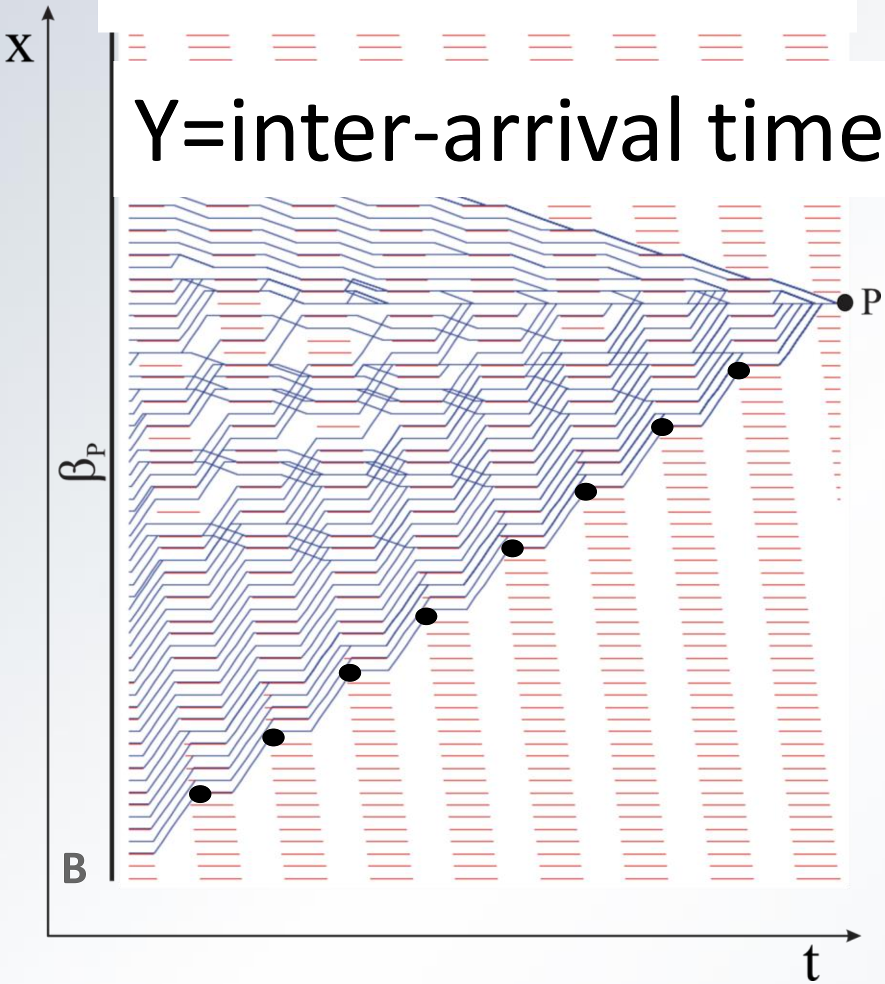
Findings

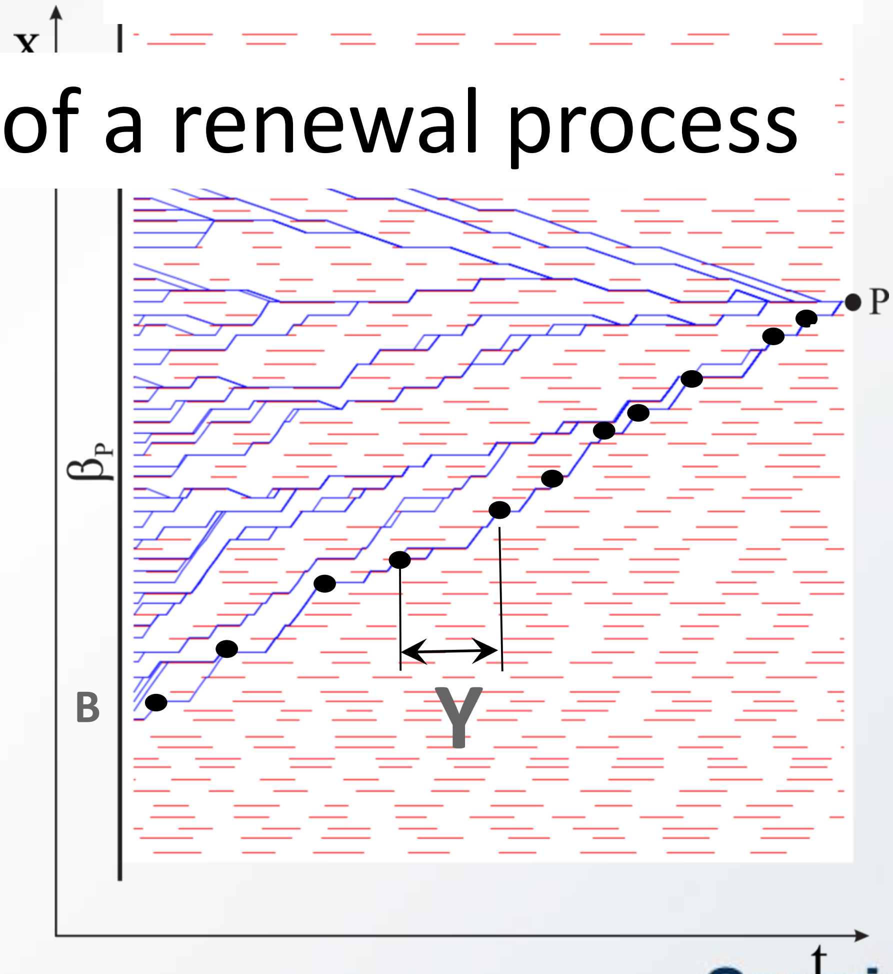
- stochastic method of cuts
- "stochastic corridor" MFD mostly depends on 2 parameters
  - λ = mean dimensionless segment length
  - ρ = mean red to green ratio
- matches well simulation of a corridor
- matches well Yokohama MFD using average λ and ρ



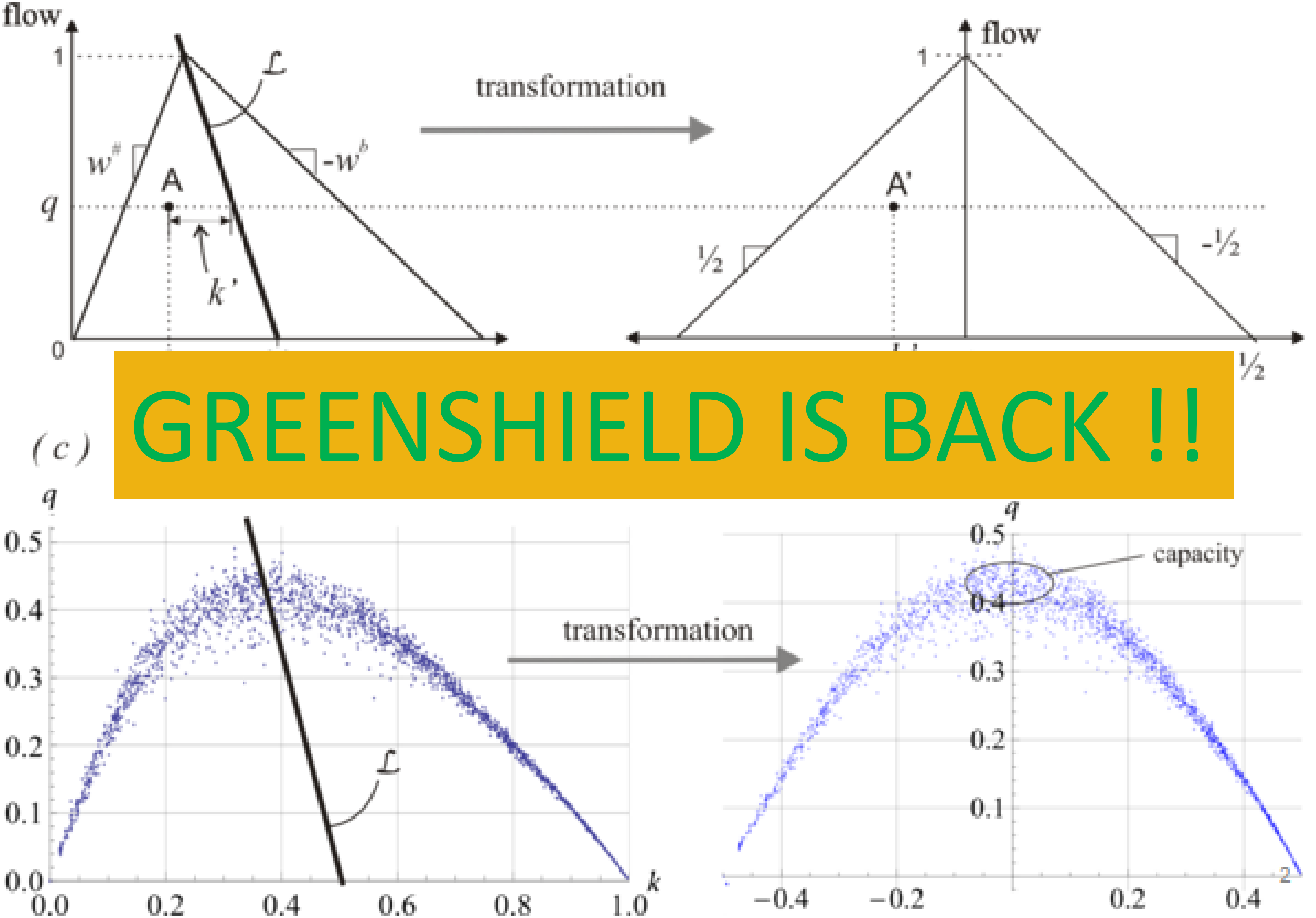
Minimum paths



Y=inter-arrival time of a renewal process



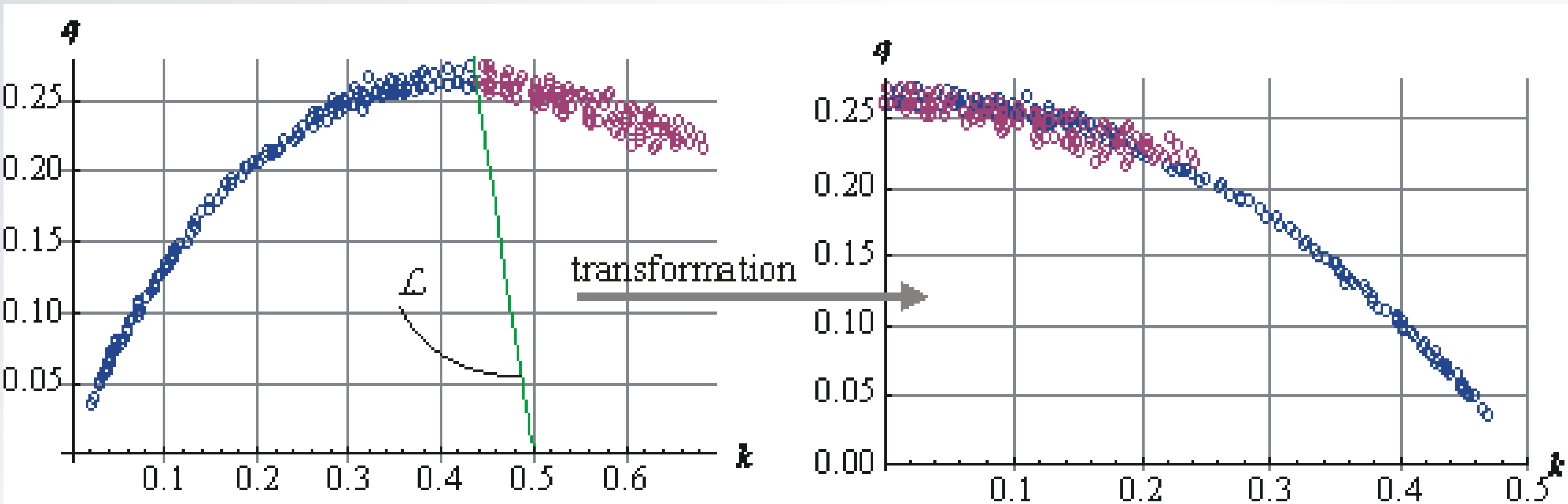
Density Transformation



GREENSHIELD IS BACK !!

Yokohama MFD: symmetry

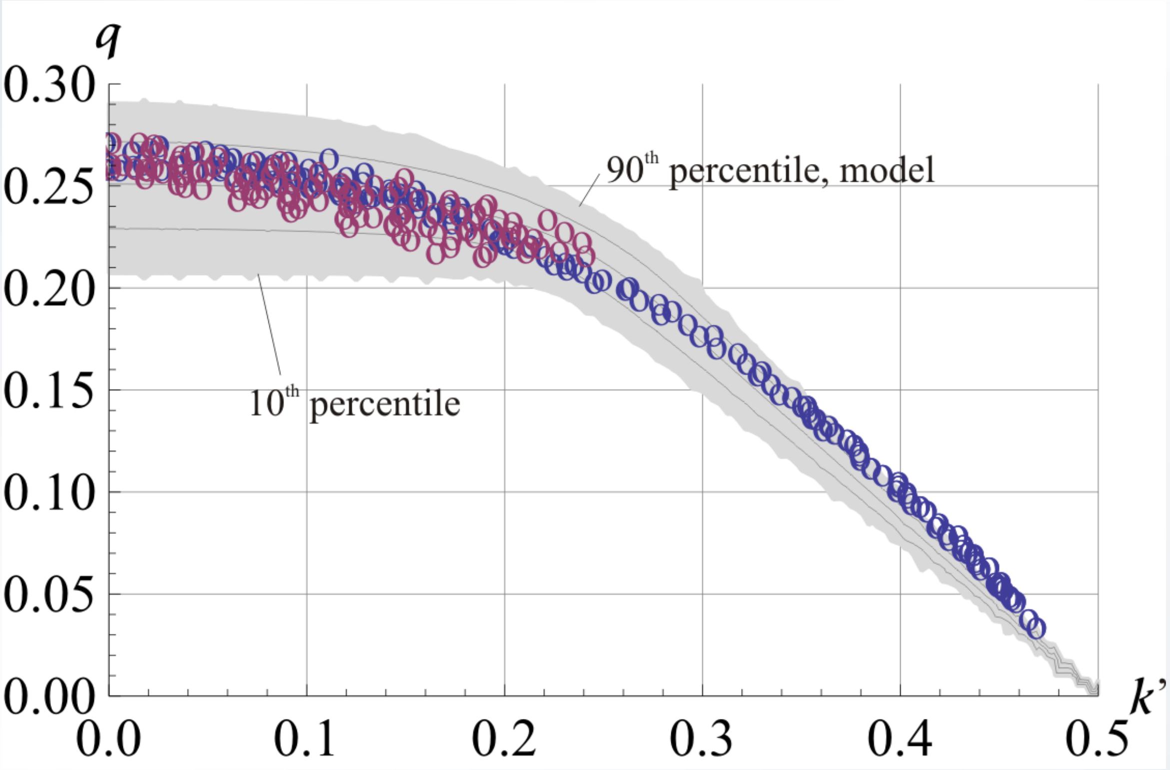
Empirical data from Yokohama city center (Geroliminis and Daganzo, 2008)



conjecture: the distribution of network MFD is symmetric
⇒ The congested branch is a reflection of the free-flow branch with respect to *L*

Yokohama MFD: fit

Table 1 in (Geroliminis and Daganzo, 2008) was used to derive avg λ=0.8 and avg ρ=1.65. We use δ=0.2.



conjecture network MFD ≈ stoch. corridor MFD with avg λ and ρ

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Recap

The MFD of urban networks :

- mostly depends on 2 parameters

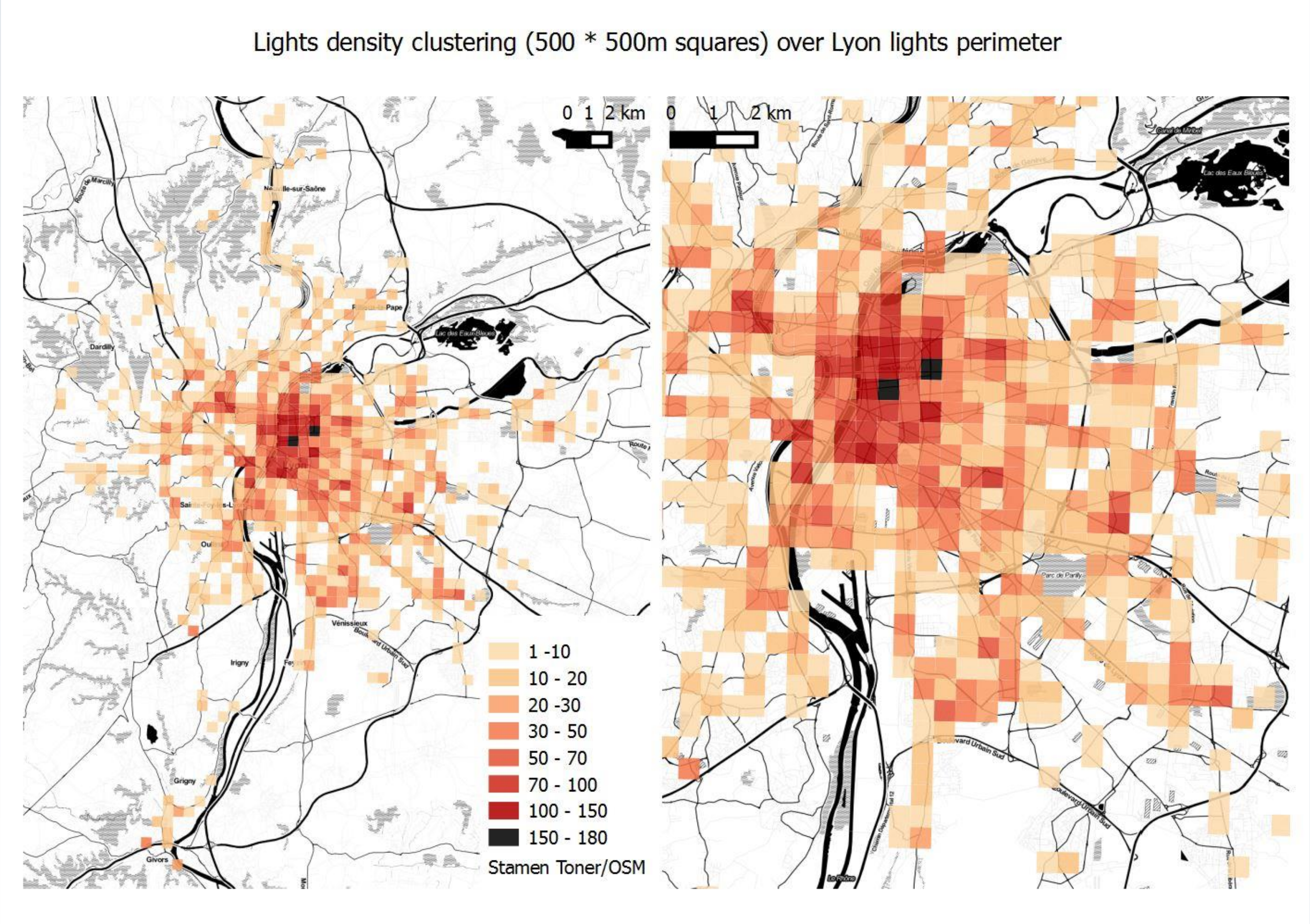
  $1/\lambda$ = density of traffic lights

  ρ = mean red to green ratio

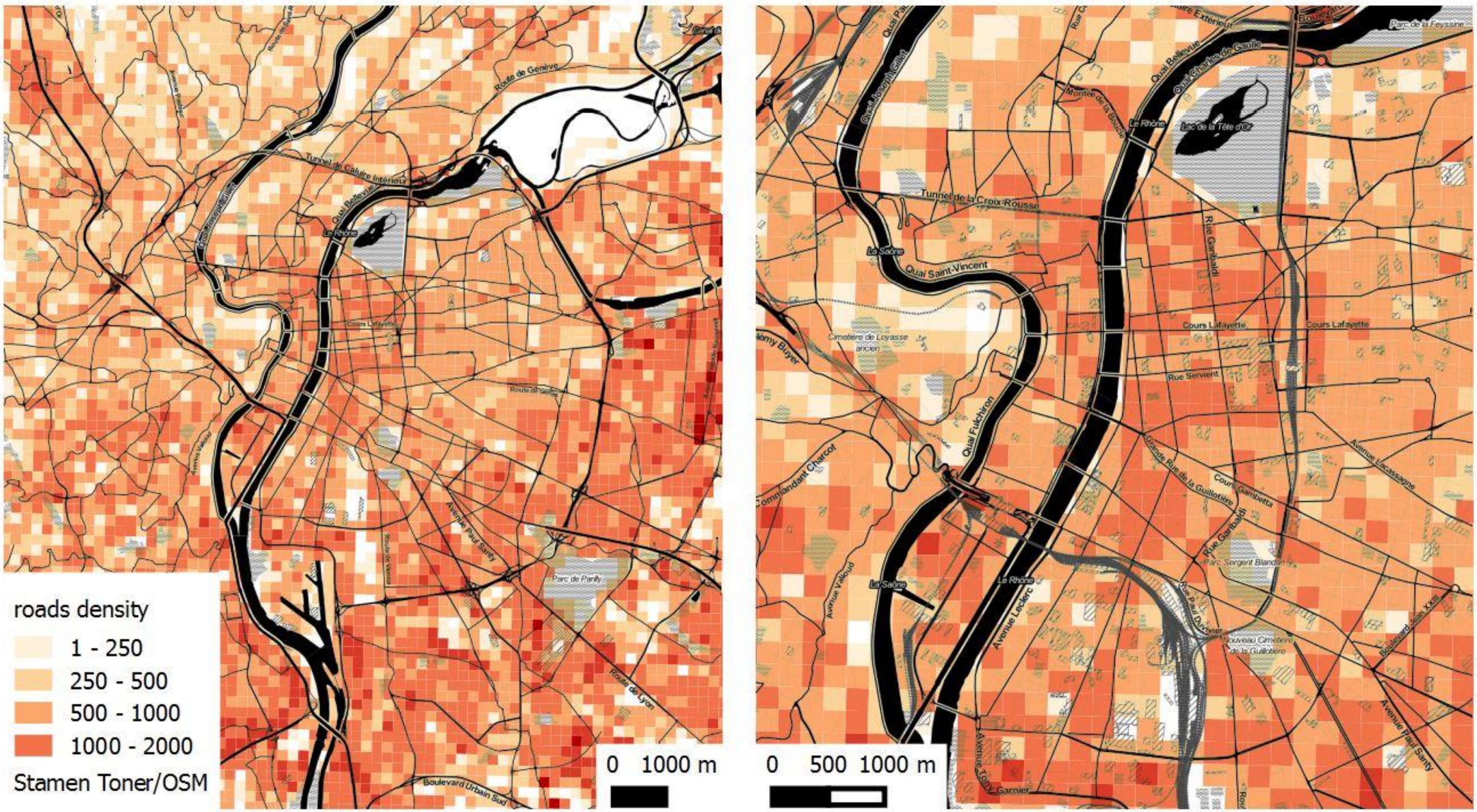
- is symmetric and delay is invariant
  - parabolic MFD should be good approx. *and no need to go back to original cordinates!*
- reduce cycle time on short blocks
- signal coordination might be overrated for some networks

Extensions and outlook

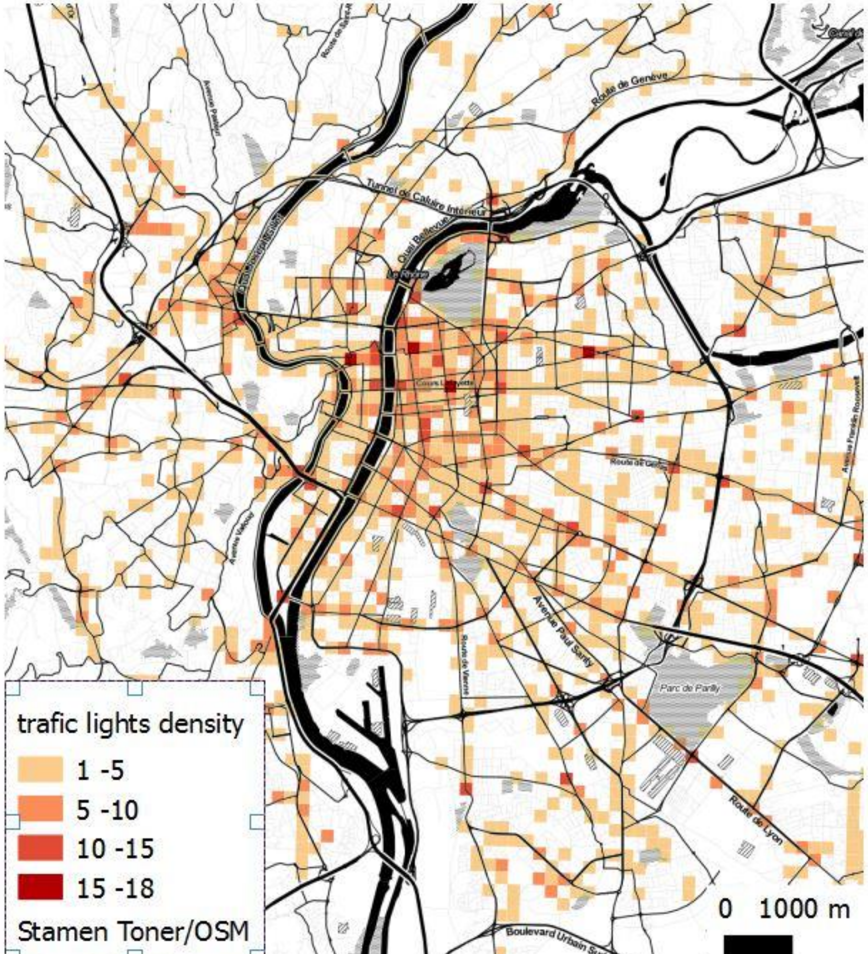
- Impacts of buses
- Validation with more data: MFD Dataquest
- Macroscopic DTA for control

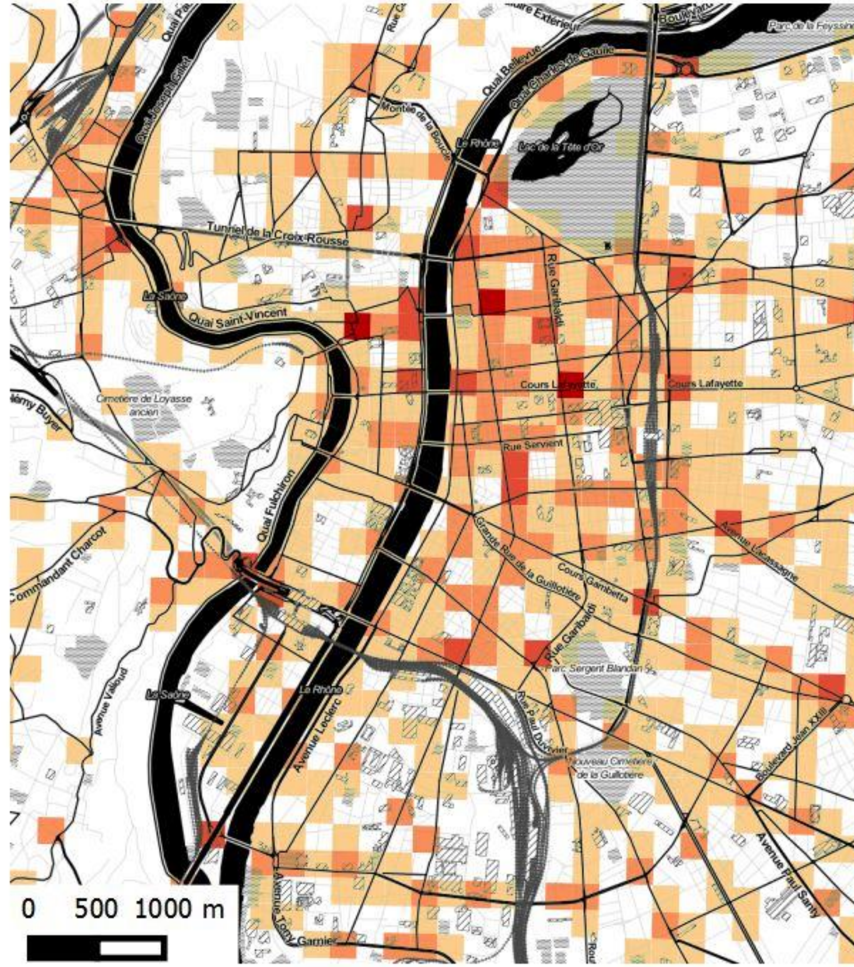


roads (local network only, by direction) density clustering (200m * 200m cells) over Lyon lights perimeter



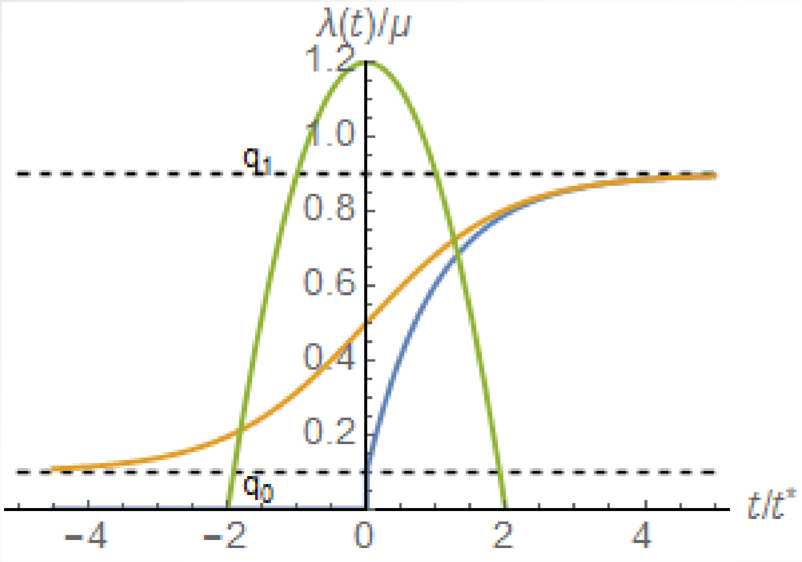
Lights (R11 and R14) density clustering (200m * 200m cells) over Lyon lights perimeter

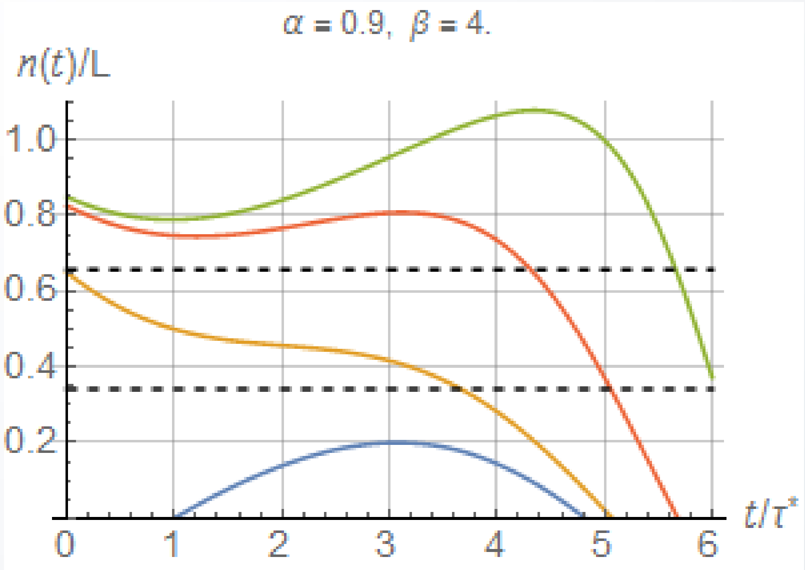




Macroscopic DTA

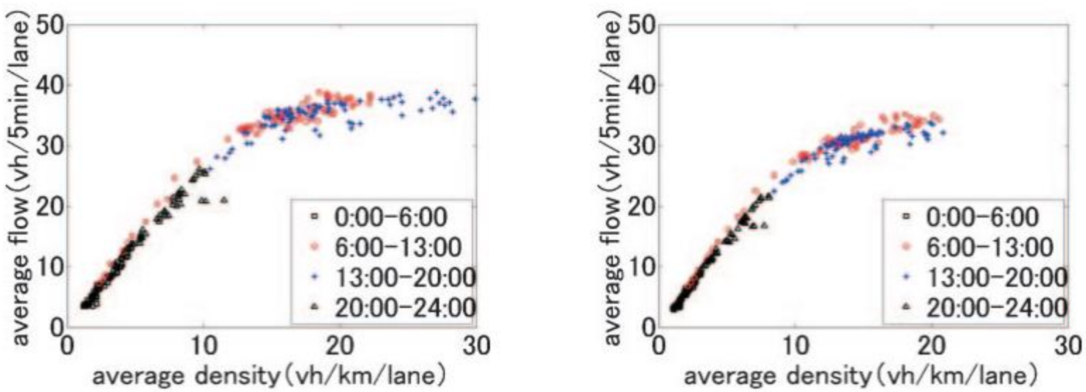
- Greenshield approx anables analytical solutions for MFD densities under important family of demand curves, in the case of:
  - single MFD, parallel MFDs, freeway vs MFD





MFD Dataquest

Sendai, Japan



(a) Area 1 (b) Area 2 (c) Area 3 (d) Area 0

Contributor	Location of data
Henk van Zuylen	Changsha (PR China).
Hesham Rakha	Washington DC.
Serge Hoogendoorn	arterials near A10 motorwa
Nicolas Chiabaut	Lyon.
Ludovic Leclercq	Lyon.
Samer Hamdar	Korea and Washington DC
Jack Haddad	Tel Aviv.
Meng Li	Beijing.
Mohsen Ramezani	Melbourne.
Masao Kuwahara	Japan.
Alessandra Pascale	London and Dublin.
Victor Knoop	The Hague dataset
Nikolas Geroliminis	Geneva
Evangelos Mitsakis	Athens
Weihua Gu	Qingdao, China
Keshuang Tang	Qingdao, China
Robert L. Bertini	Oregon (Portal) or Californi
Christine Buisson	Toulouse
Jiwon Kim	Brisbane
Kentaro Wada	Sendai region
Takashi Akamatsu	Sendai region
Pengfei Wang	Sendai region

Transportation Research Part B: Methodological

Volume 89, July 2016, Pages 168–177

Symmetries in the kinematic wave model and a parameter-free representation of traffic flow

Jorge A. Laval, Bhargava R. Chilukuri

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doi:10.1016/j.trb.2016.02.009

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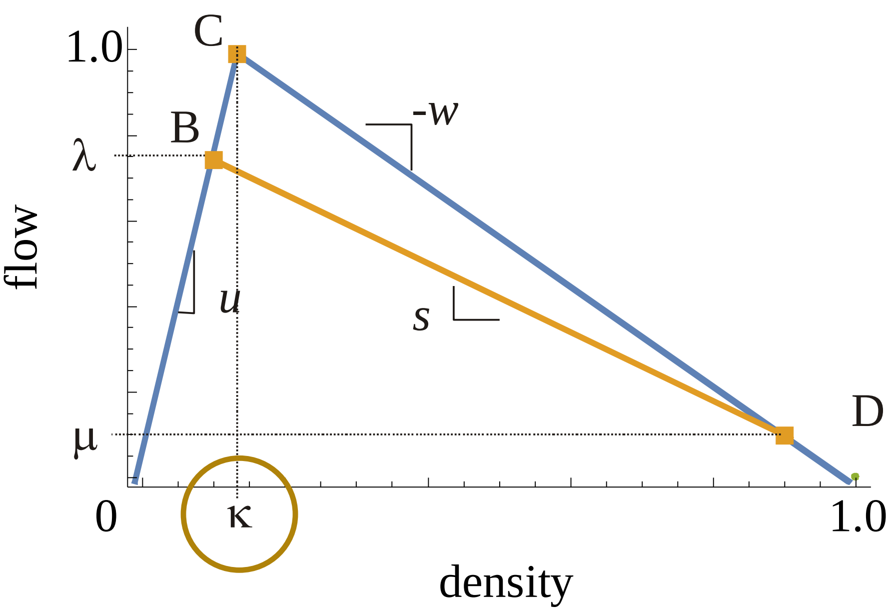
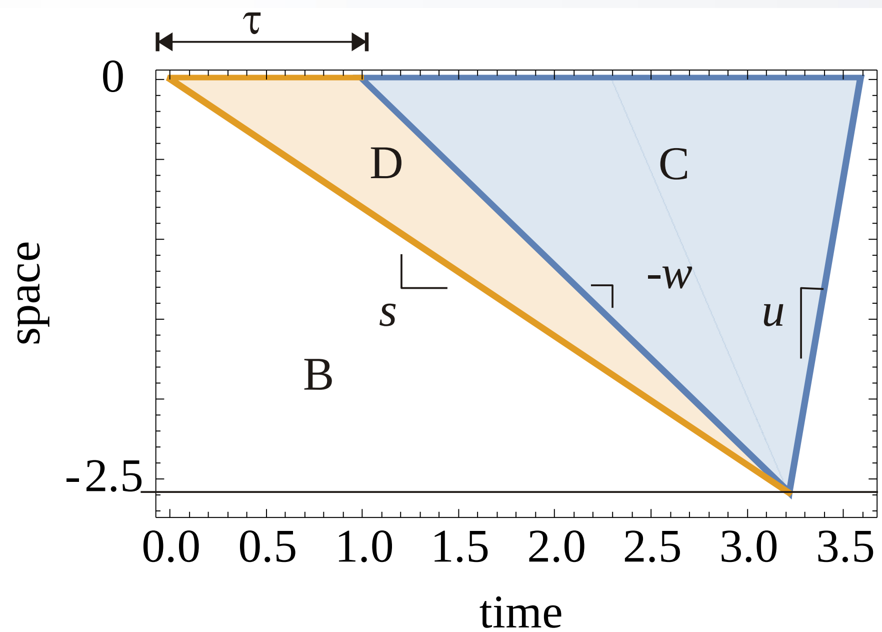
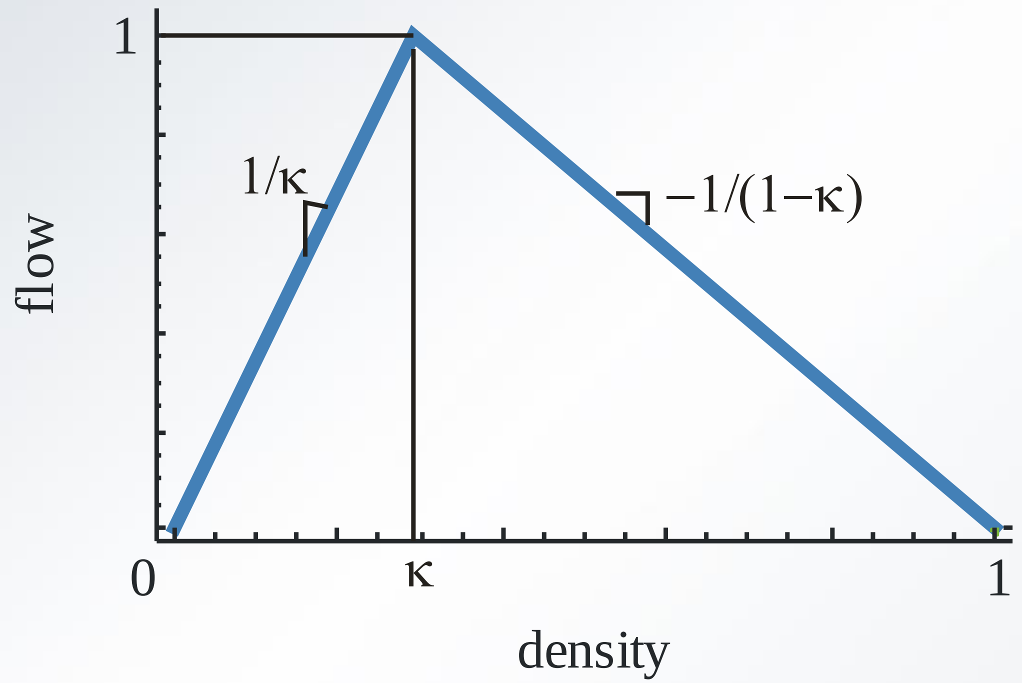
Example: An incident bottleneck

- uncongested freeway with a constant flow λ when a bottleneck of capacity $\mu < 1$ appears for a duration τ.
- $\kappa =$ critical density





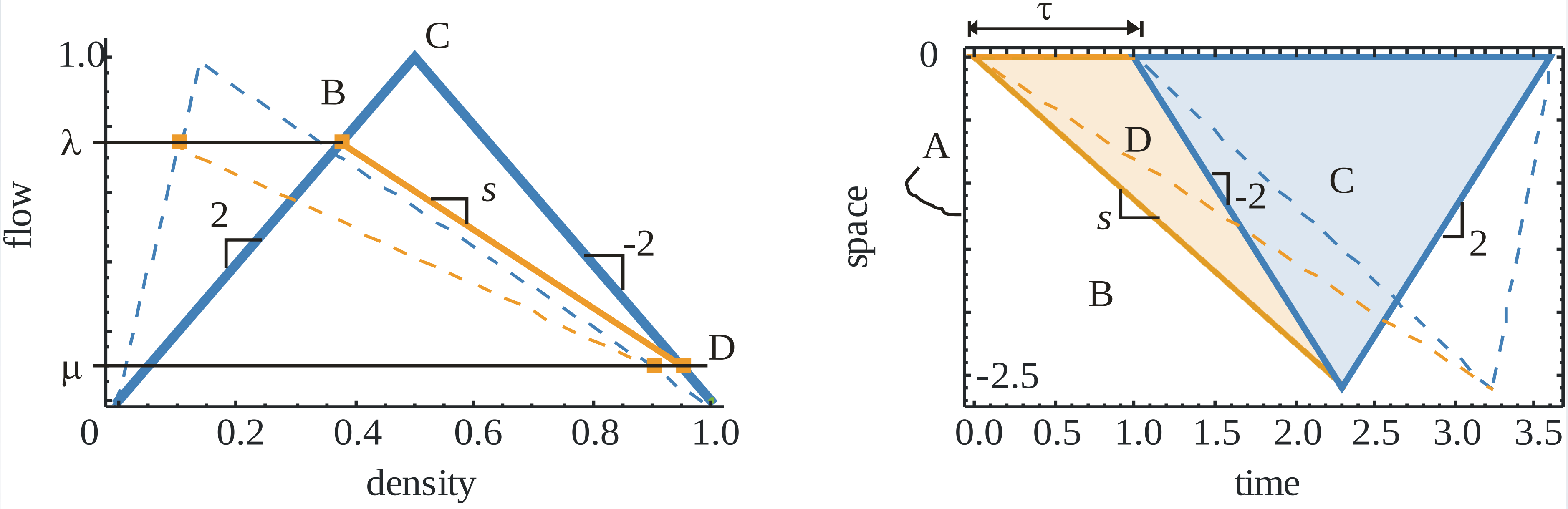
Triangular FD



Parameter-free representation of traffic flow

Example: An incident bottleneck

- uncongested freeway with a constant flow λ when a bottleneck of capacity $\mu < 1$ appears for a duration τ.
- κ = critical density



Same queue length and areas!

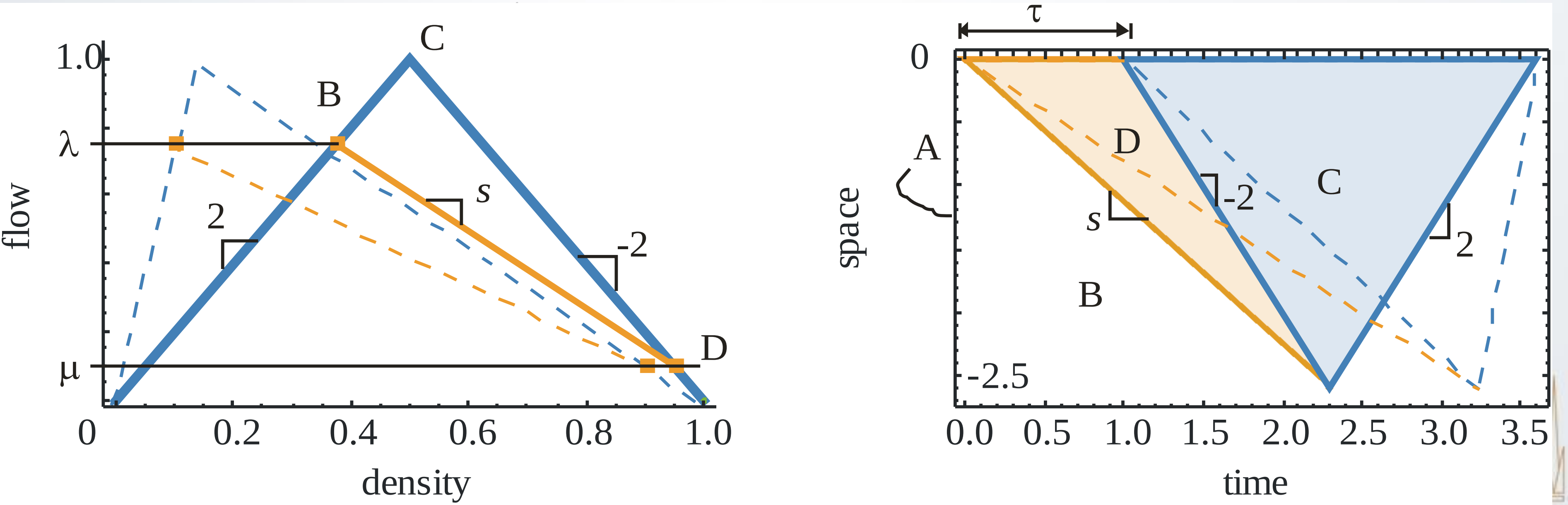
An incident bottleneck

- uncongested freeway with a constant flow λ when a bottleneck of capacity $\mu < 1$ appears for a duration τ.

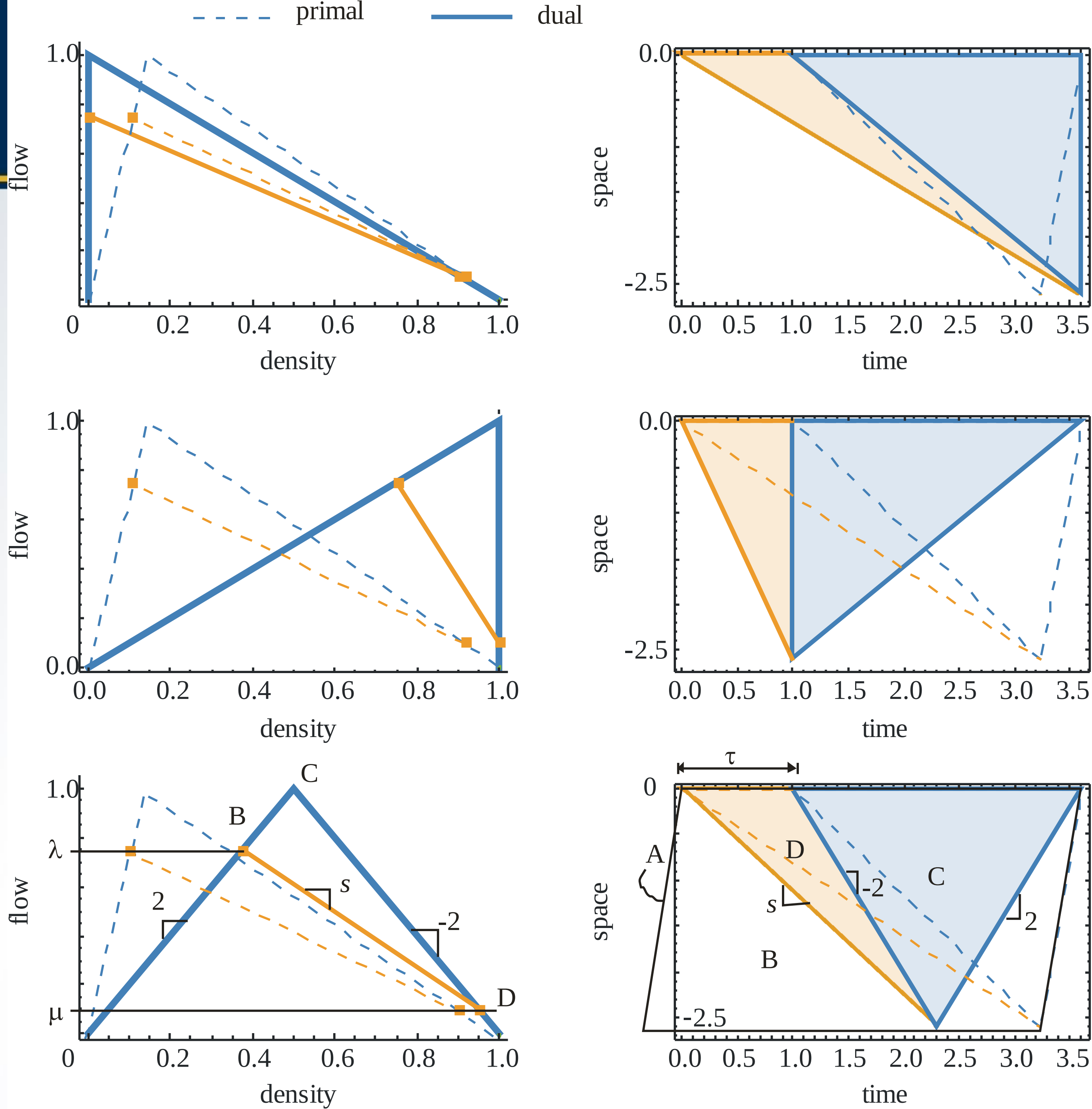
$$\Psi = \int_A k(t,x)\, dA = A/2 - (1/2 - \kappa)A\lambda, \qquad \Phi = \int_A q(t,x)\, dA = A\lambda \tag{1a}$$

$$\Delta = (1-\lambda)A/2, \qquad A = \frac{(1-\mu)(\lambda-\mu)\tau^2}{(1-\lambda)^2} \tag{1b}$$

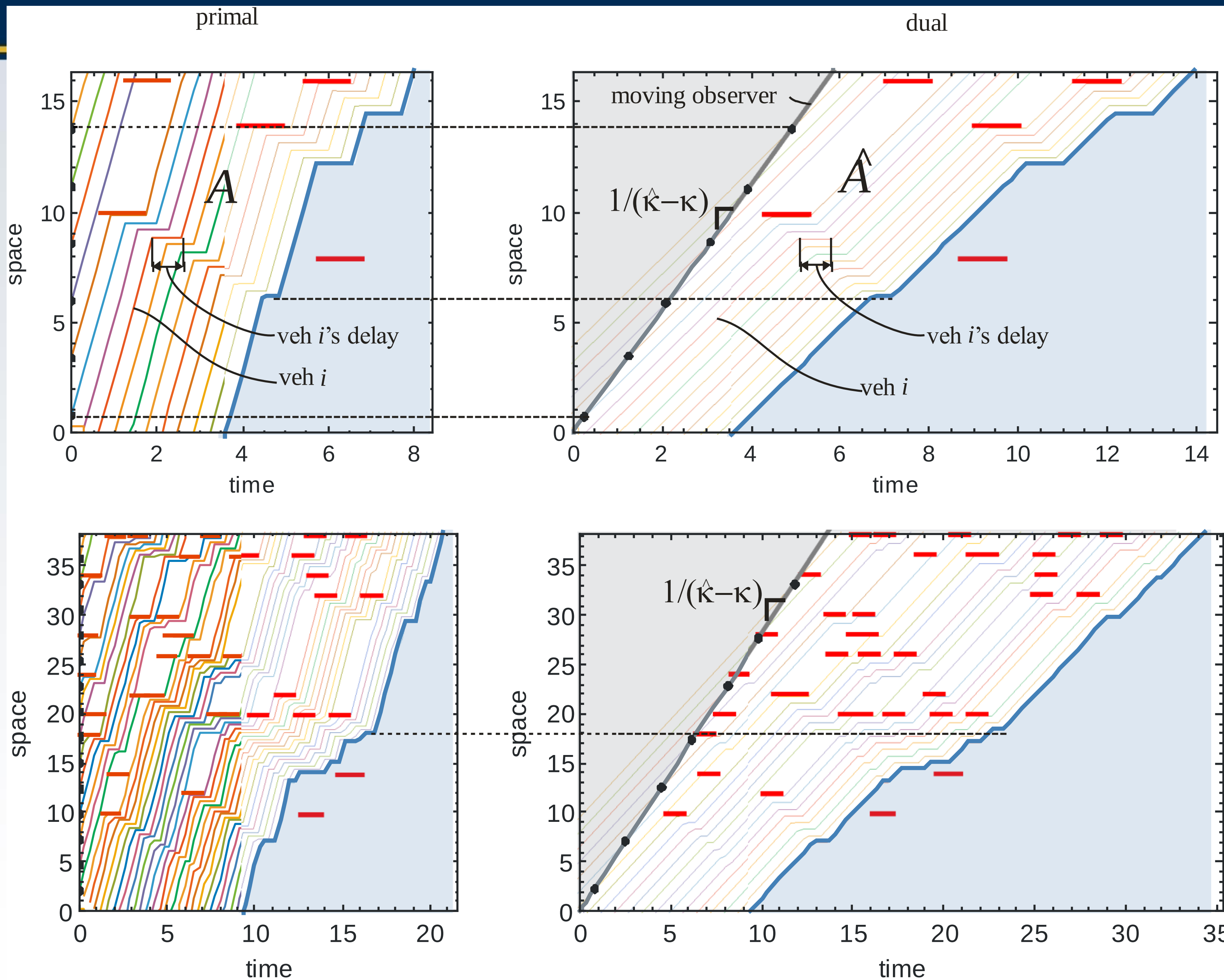
κ = critical density, Ψ = total time traveled and Φ = total distance traveled



An incident bottleneck



More Bns



primal
dual
moving observer
A
Â
1/(κ̂−κ)
veh i's delay
veh i
space
time

Main ideas

- Symmetry: *An object is symmetrical if one can subject it to a certain operation and it appears exactly the same after the operation. The object is then said to be invariant with respect to the given operation.* (Weyls)
- Conservation laws are invariant w.r.t. linear transformations of time and space
- TTT, TTD and delay can be invariant
  - one may choose the FD that simplifies the problem the most
  - does not require knowing the actual FD

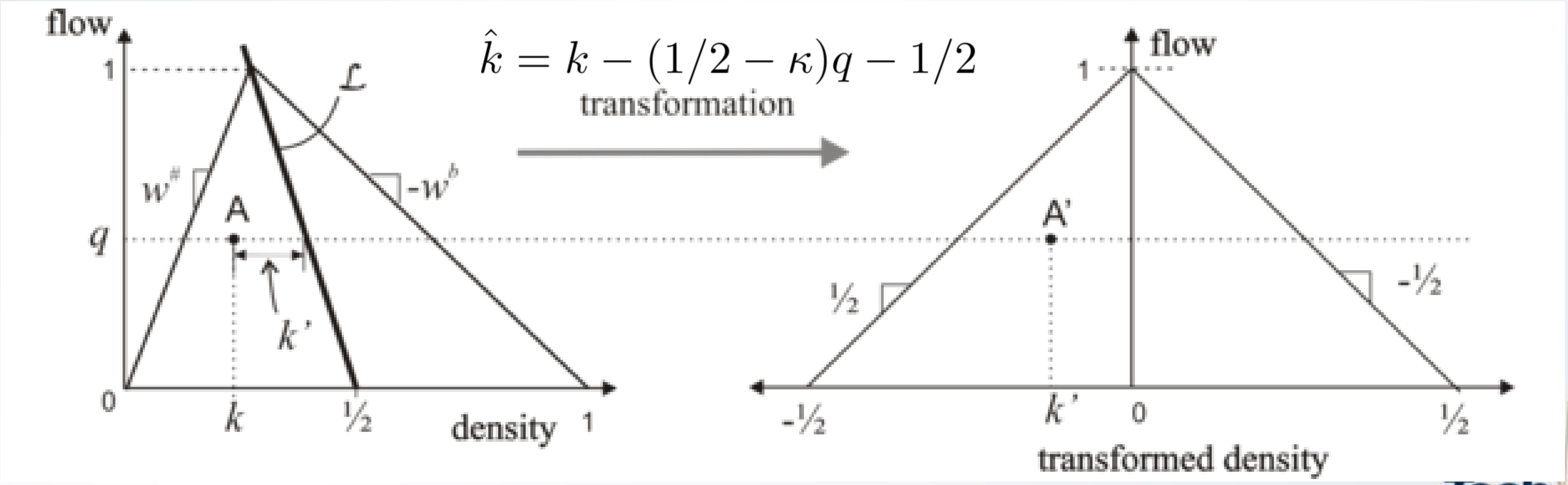
Transformations for Triangular FD

- Flow conserving transformations:

$$\hat{t} = t + (\hat{\kappa} - \kappa)x, \qquad \hat{x} = x, \tag{1a}$$

$$\hat{k} = k + (\hat{\kappa} - \kappa)q, \qquad \hat{q} = q. \tag{1b}$$

- TTD and delay are invariant.
- Special case: isoceles transformation:



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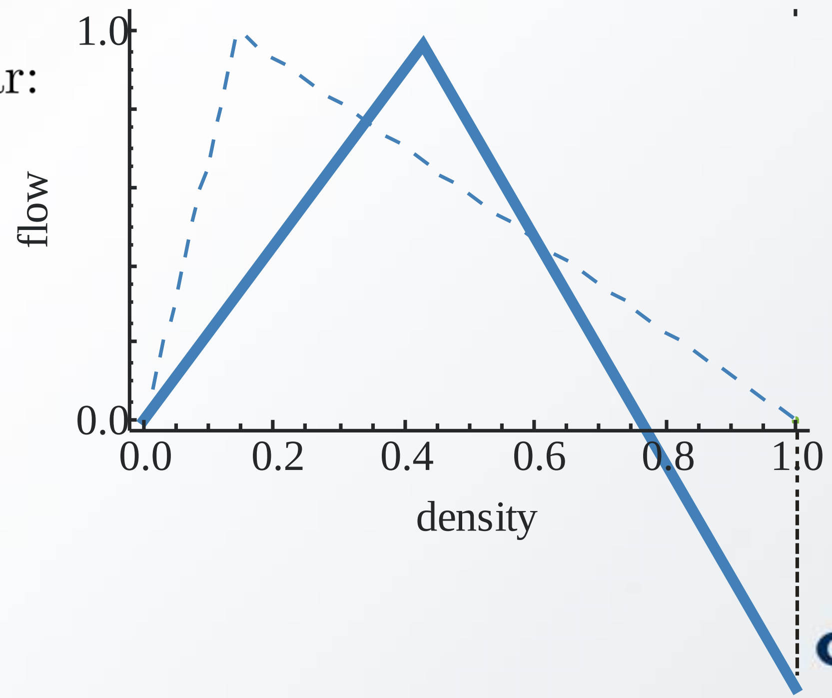
Triangular transformations

- Density conserving transformations:

$$\hat{x} = x + (\hat{\kappa} - \kappa)t, \qquad \hat{t} = t, \tag{1a}$$

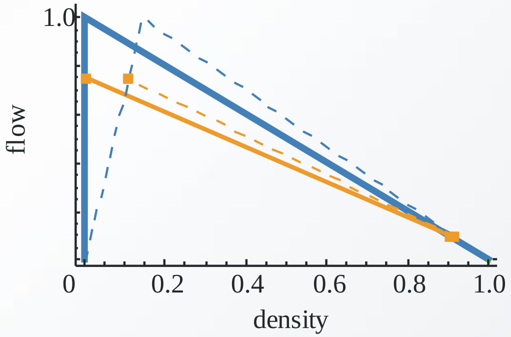
$$\hat{q} = q + (\hat{\kappa} - \kappa)k, \qquad \hat{k} = k. \tag{1b}$$

- TTT and delay are invariant.
- transformed FD is not triangular:

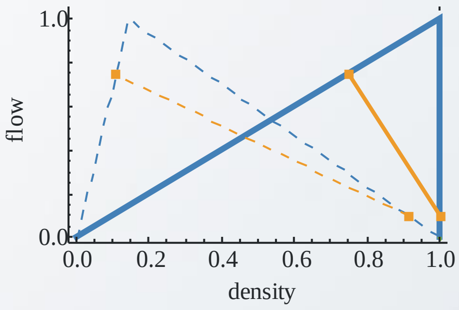


Triangular transformations

- Newell's (1993) transformation : $\kappa = 0$
  - infinite free-flow speed
  - standard method for calculating delays

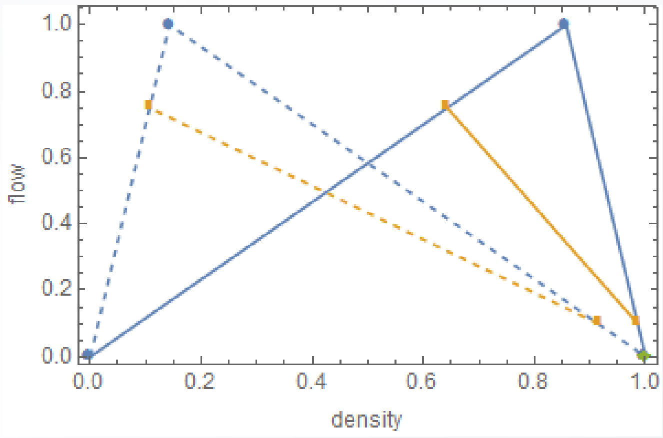


- Mirror image of Newell's : $\kappa = 1$
  - in congestion, waves travel infinitely fast upstream
  - congested departure curves can be shifted vertically upwards by the jam accumulation between the two locations

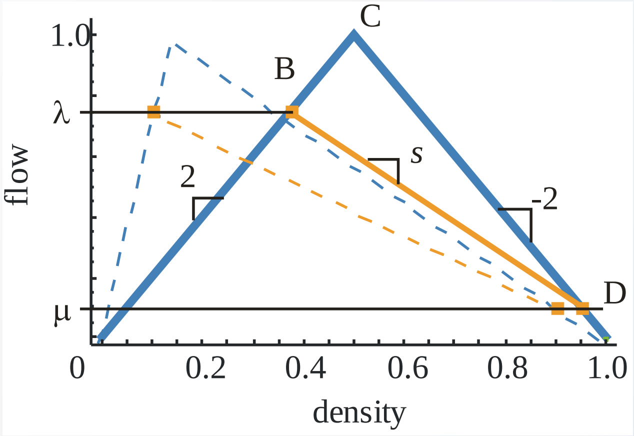


Triangular transformations

- Motion of "holes" : κ'= 1- κ
  - Newell (1993): inhomogeneous freeway solution
  - Daganzo and Geroliminis (2008): MFD cuts in congestion



- Isosceles transformations : κ = 1/2
  - fast numerical solution
  - CTM becomes exact
  - No memory



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A parsimonious model for the formation of oscillations in car-following models Original Research Article

Transportation Research Part B: Methodological, Volume 70, December 2014, Pages 228-238

Jorge A. Laval, Christopher S. Toth, Yi Zhou

Abstract | Research highlights | PDF (3338 K)

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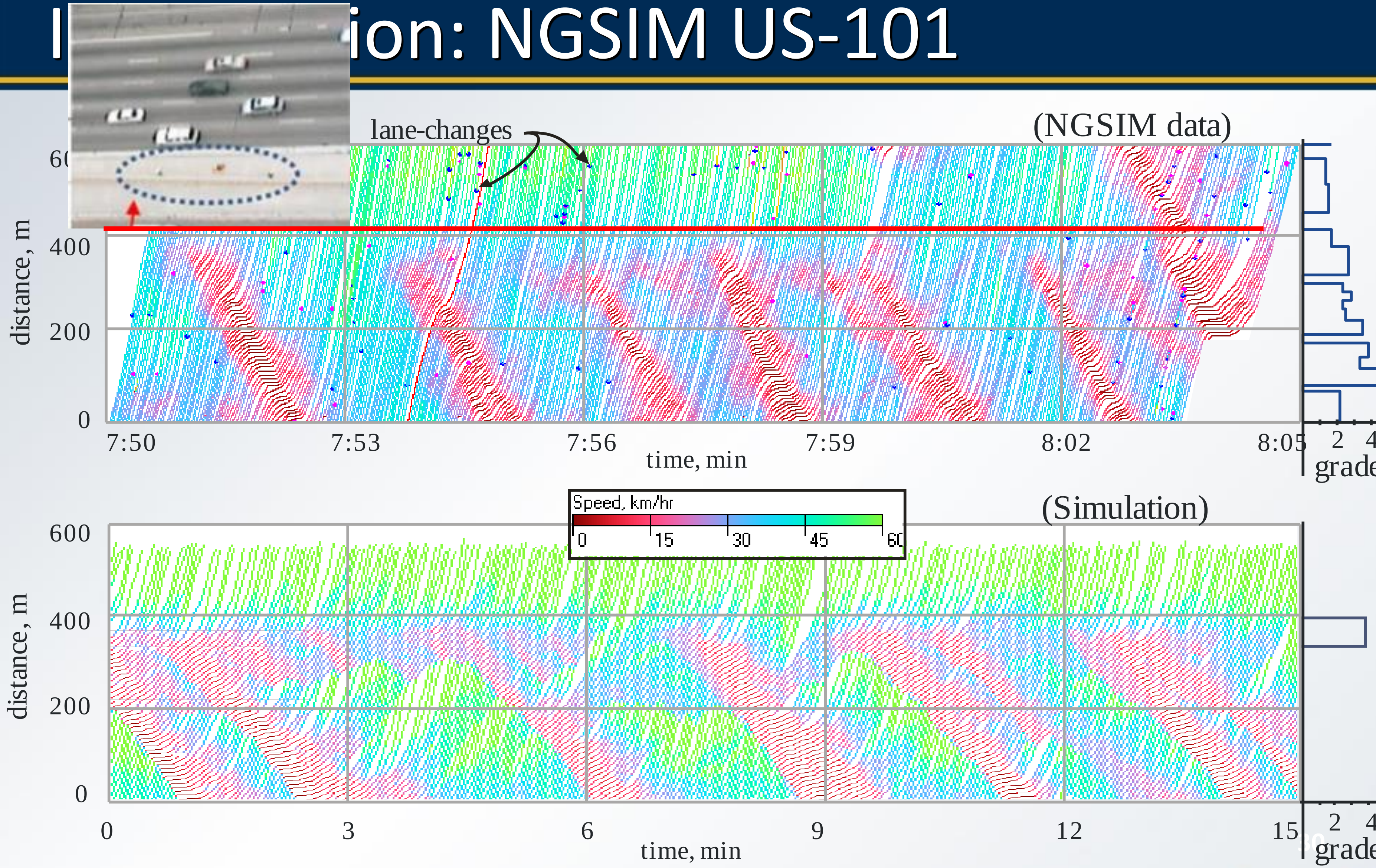

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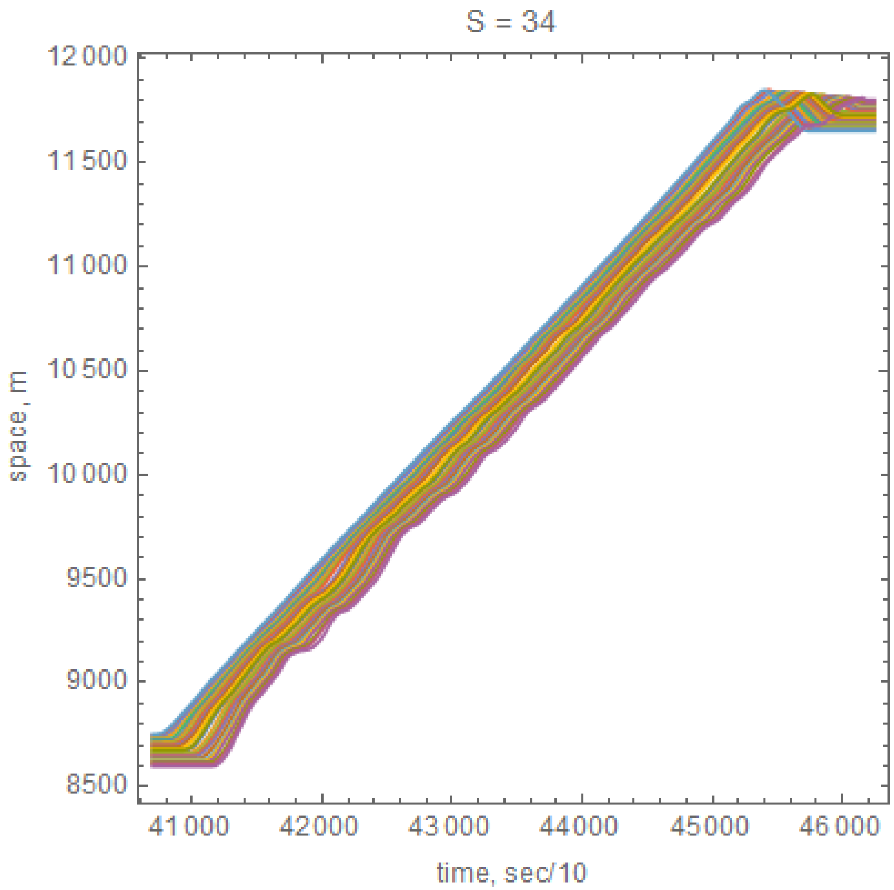
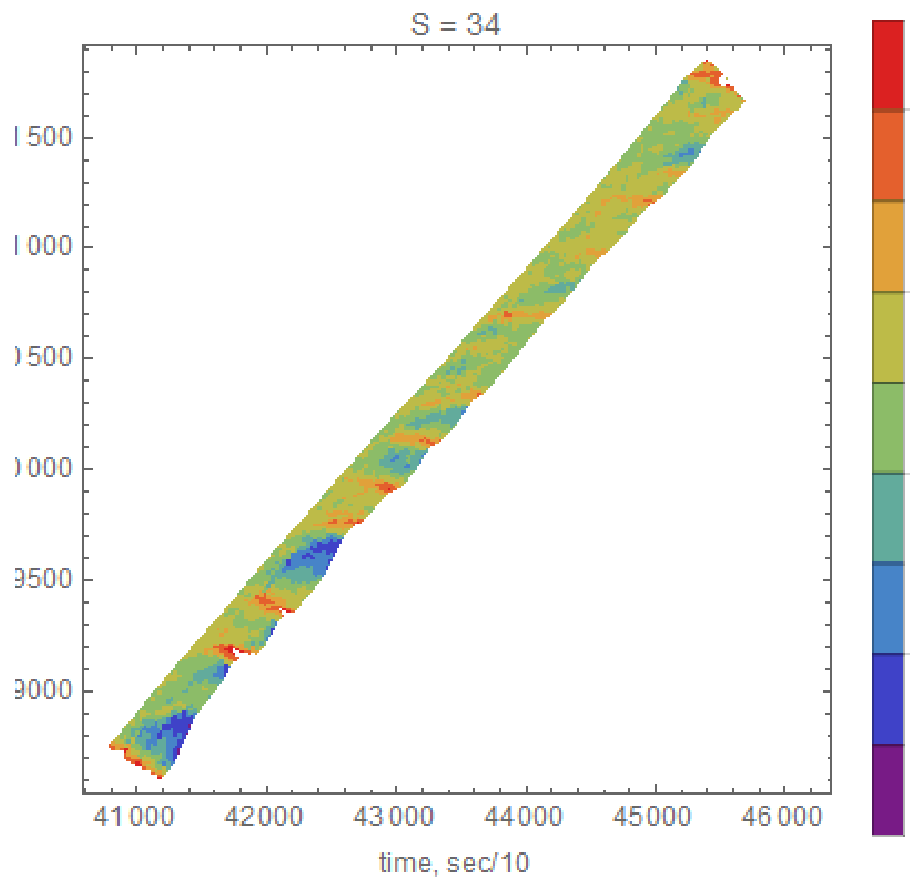
Introduction: China CF experiment

- Tian et al, Trans. Res. B (2015)
- Jian et al, PloS one (2014)





Introduction: China CF experiment

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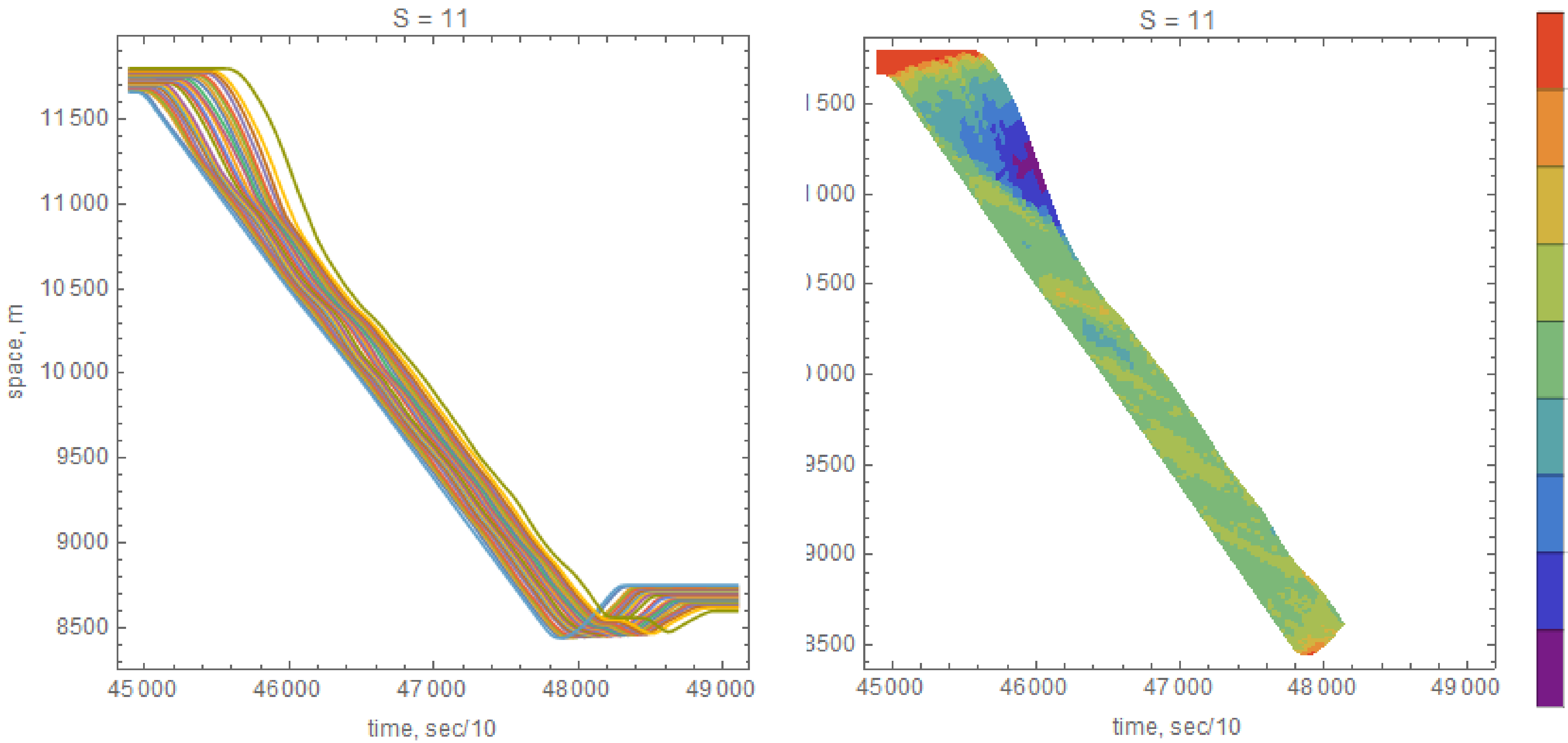
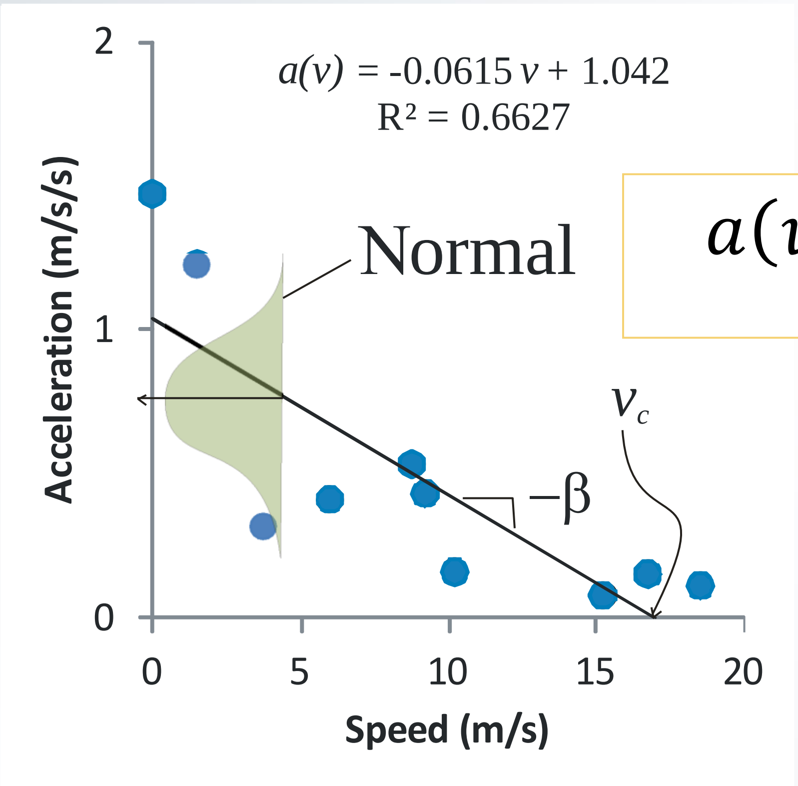


Stochastic desired accelerations

- desired acceleration ⇔ vehicle downstream does not constrain the motion



$$a(v) = (v_c - v)\beta + \text{white noise}$$

The SODE

$\xi(t)$ = position at time t
$v(t)$ = speed at time t
$W(t)$ = standard Brownian motion,
σ^2 = diffusion coefficient, units of $[\text{distance}]^2[\text{time}]^{-3}$

$$\begin{cases} d\xi(t) = v(t)dt, & \xi(0) = 0, \\ dv(t) = (v_c - v(t))\beta dt + \sigma dW(t), & v(0) = v_0, \end{cases}$$

Plugin to Newell's car-following model

$$x_{i+1}(t) = \min\{\underbrace{x_{i+1}(t-\tau) + \xi_{i+1}(\tau)}_{\text{free-flow}}, \underbrace{x_i(t-\tau) - \delta}_{\text{congestion}}\}$$

where:

τ = wave trip time between two cars

δ = jam spacing,

$x_{i+1}(t)$ = position of vehicle $i+1$ at time t

$\xi_{i+1}(\tau)$ = vehicle displacement between $t-\tau$ and t

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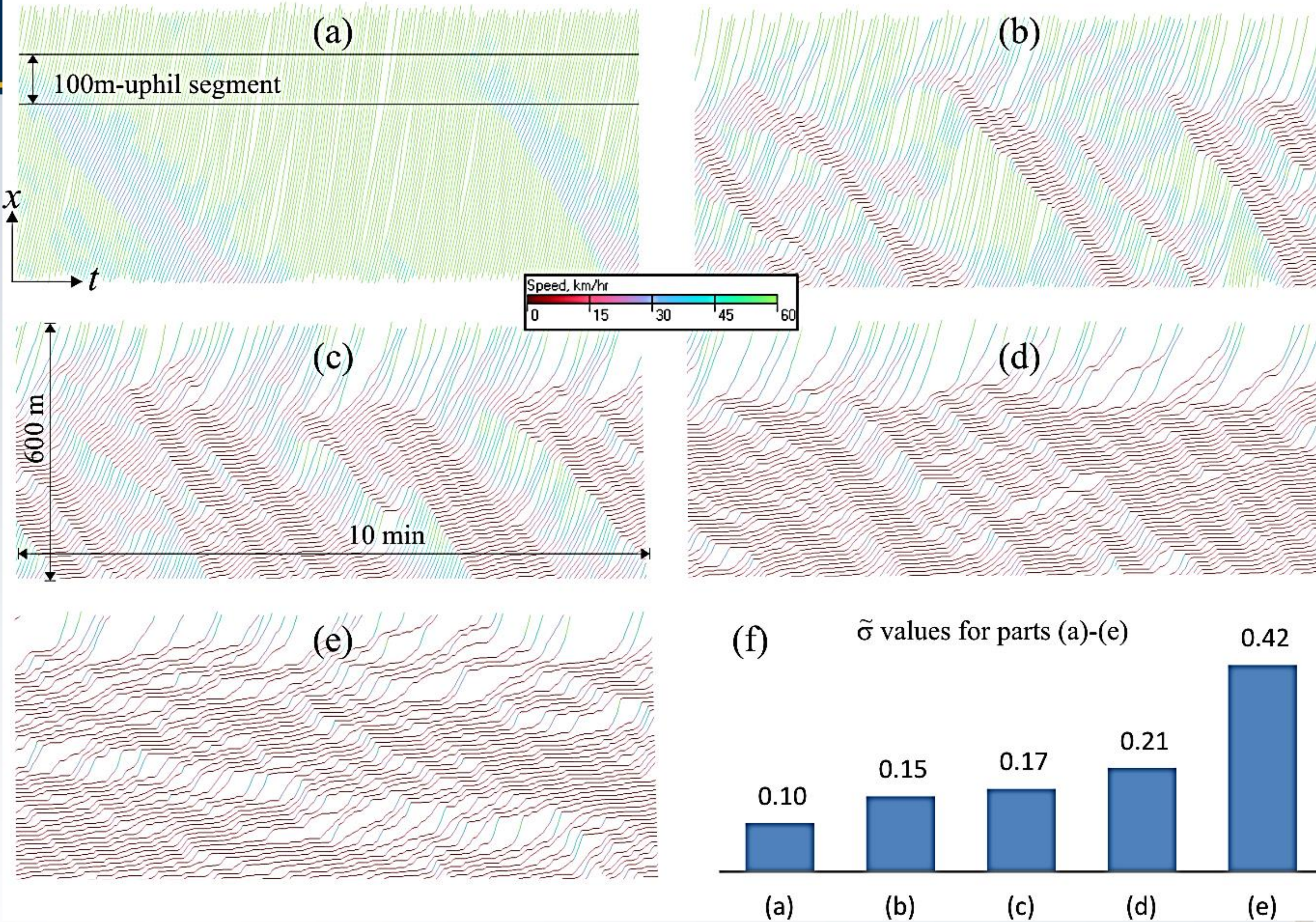
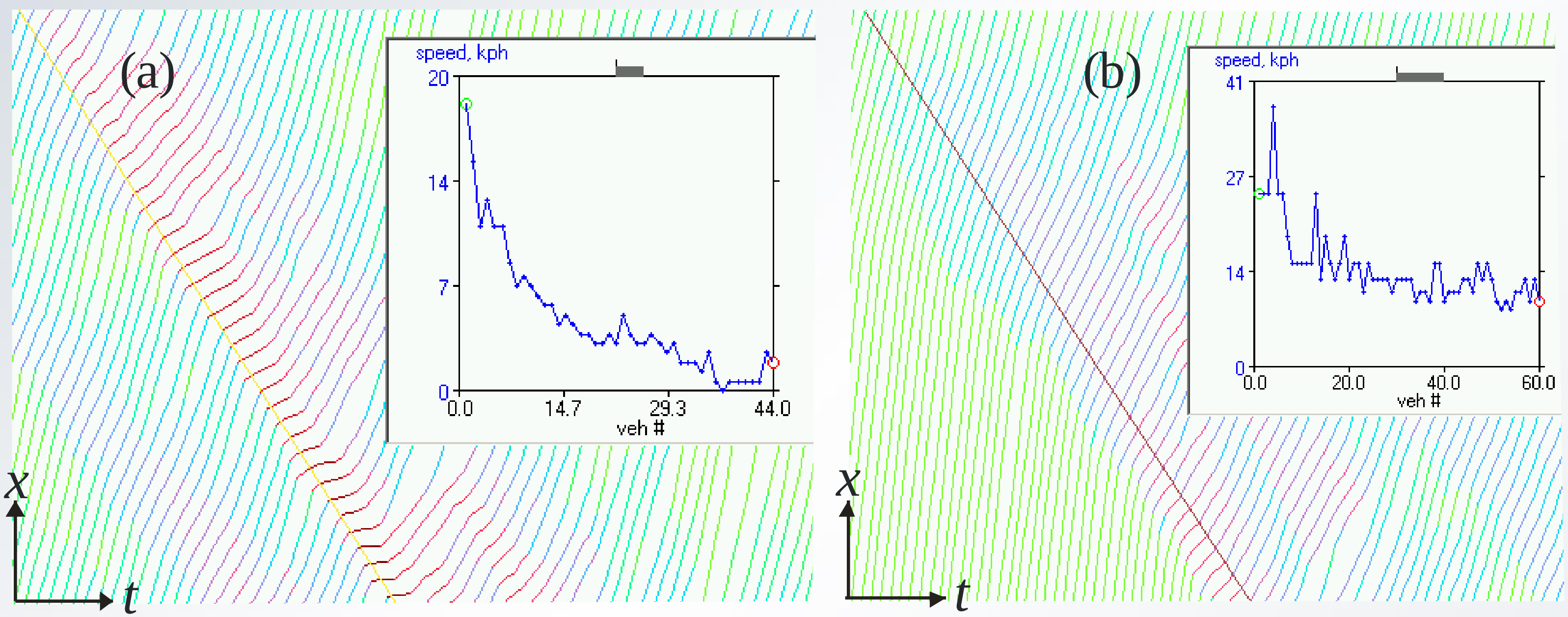
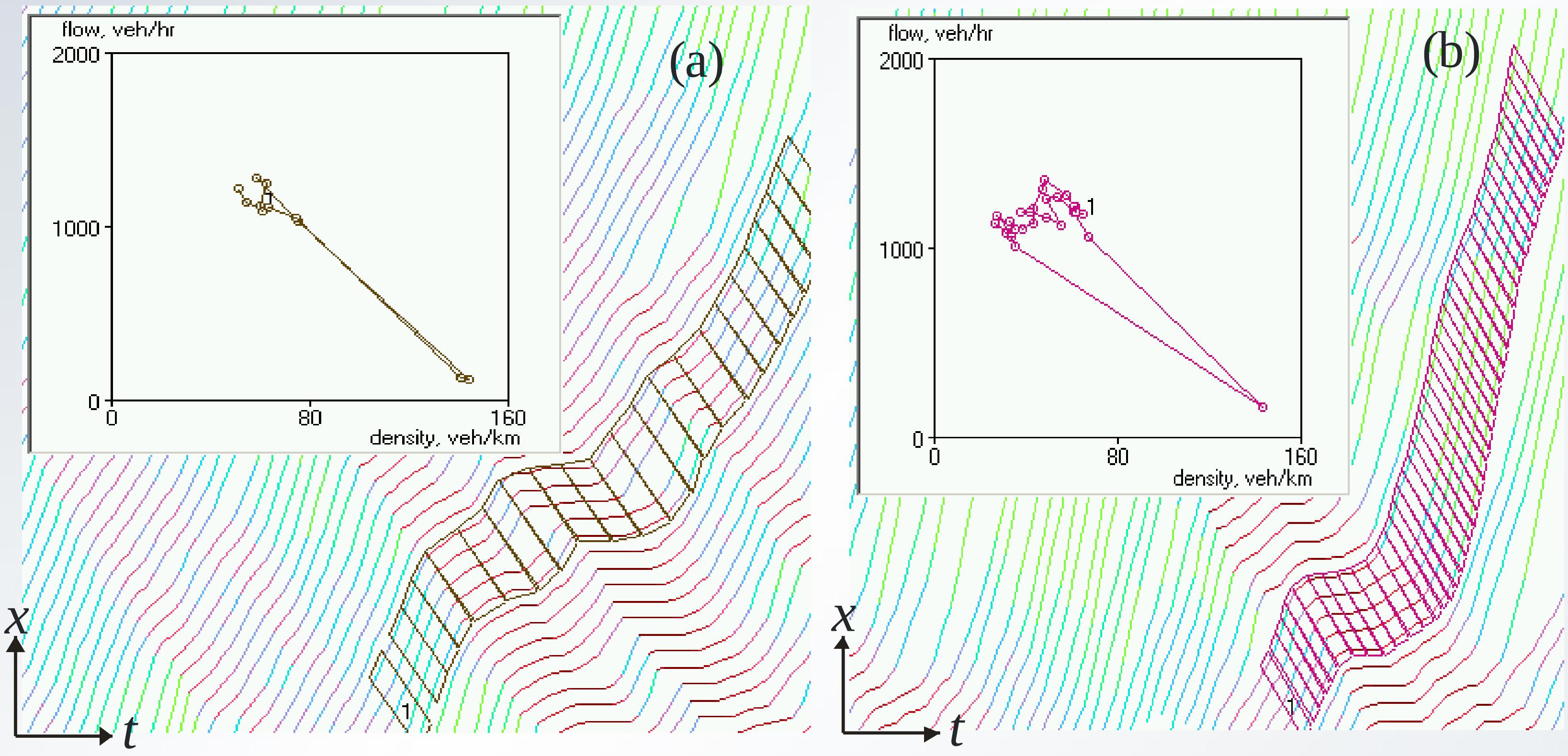

(a)
100m-uphil segment
x
t
(b)
Speed, km/hr
0
15
30
45
60
(c)
600 m
10 min
(d)
(e)
(f)
σ̃ values for parts (a)-(e)
0.10
0.15
0.17
0.21
0.42
(a)
(b)
(c)
(d)
(e)

Model captures oscillation growth

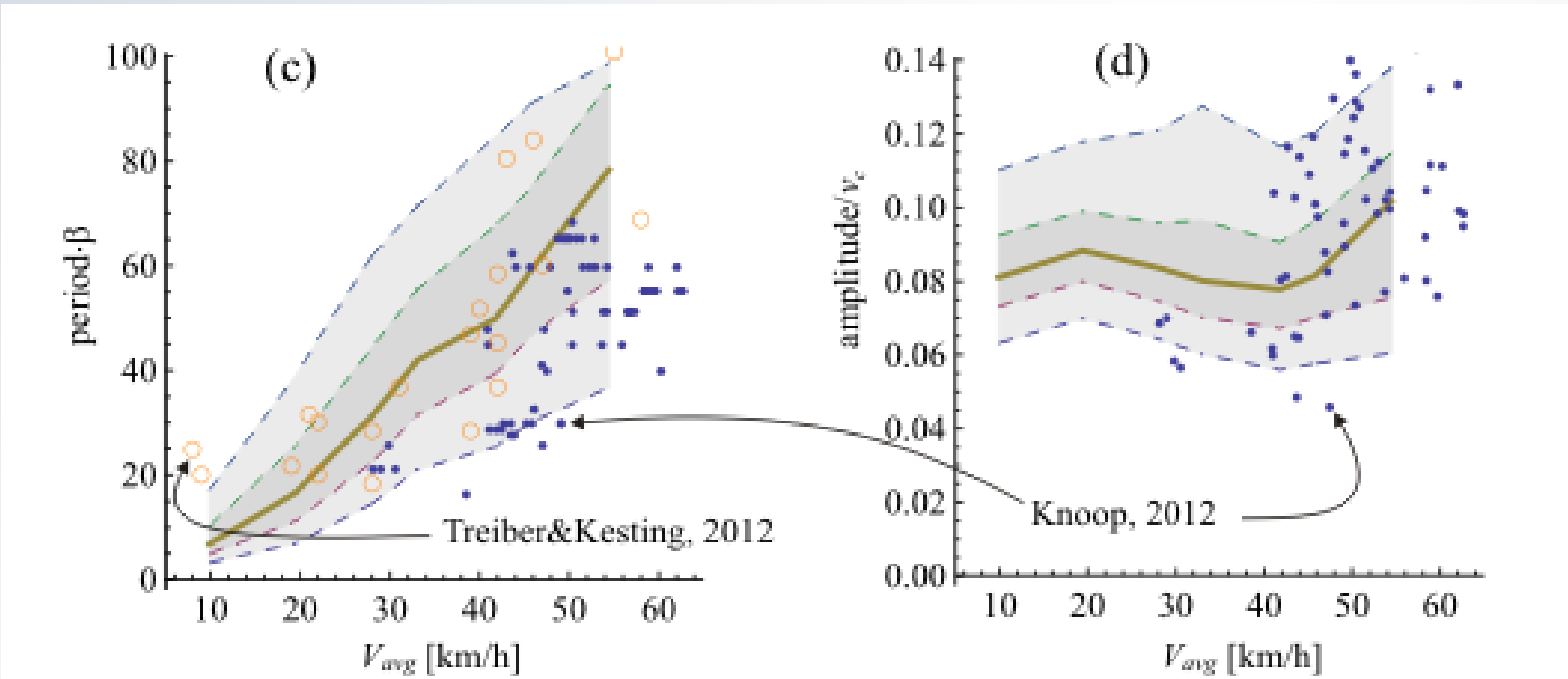


Model captures hysteresis

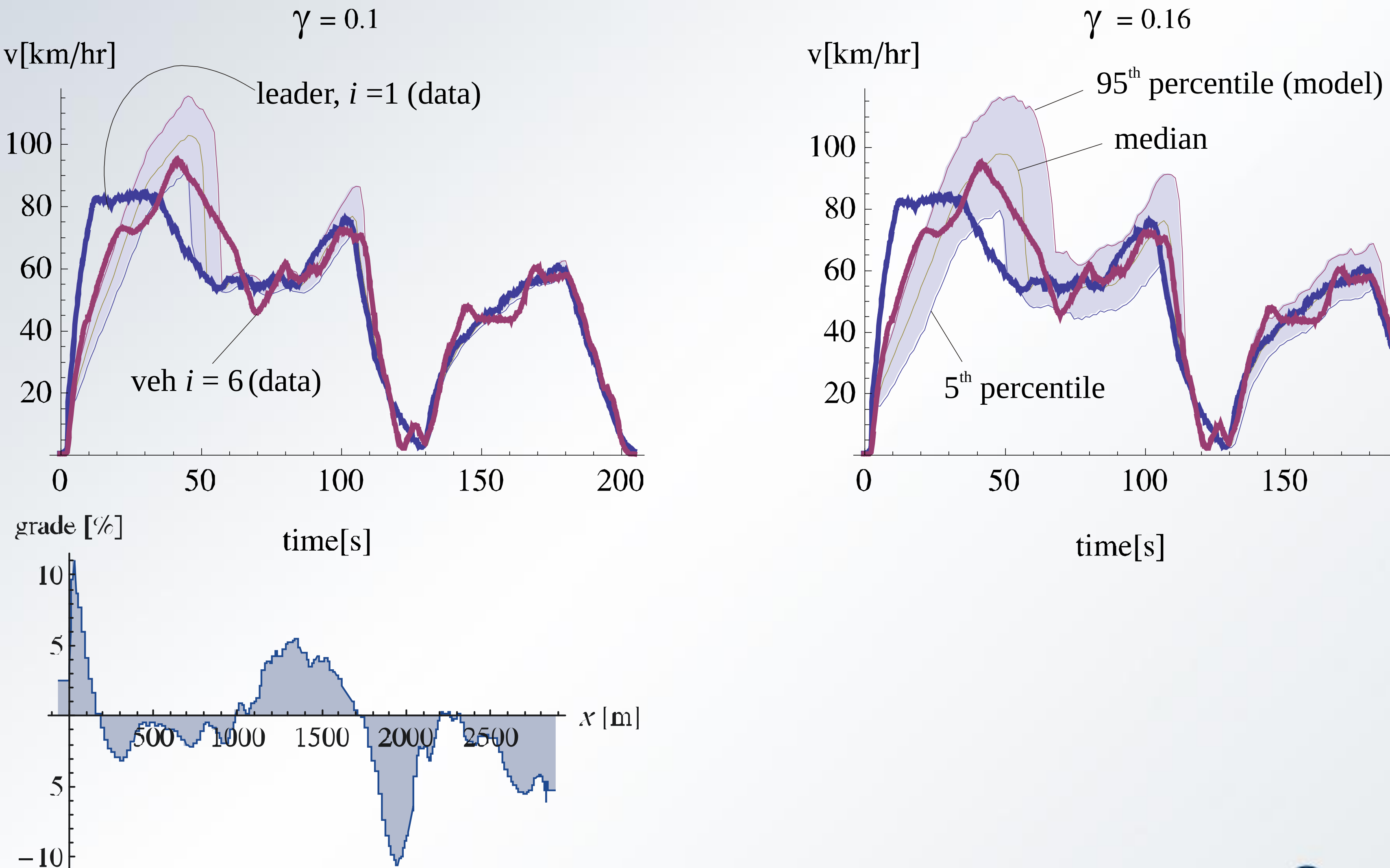


Trajectory Explorer (trafficlab.ce.gatech.edu)

Oscillations period and amplitude

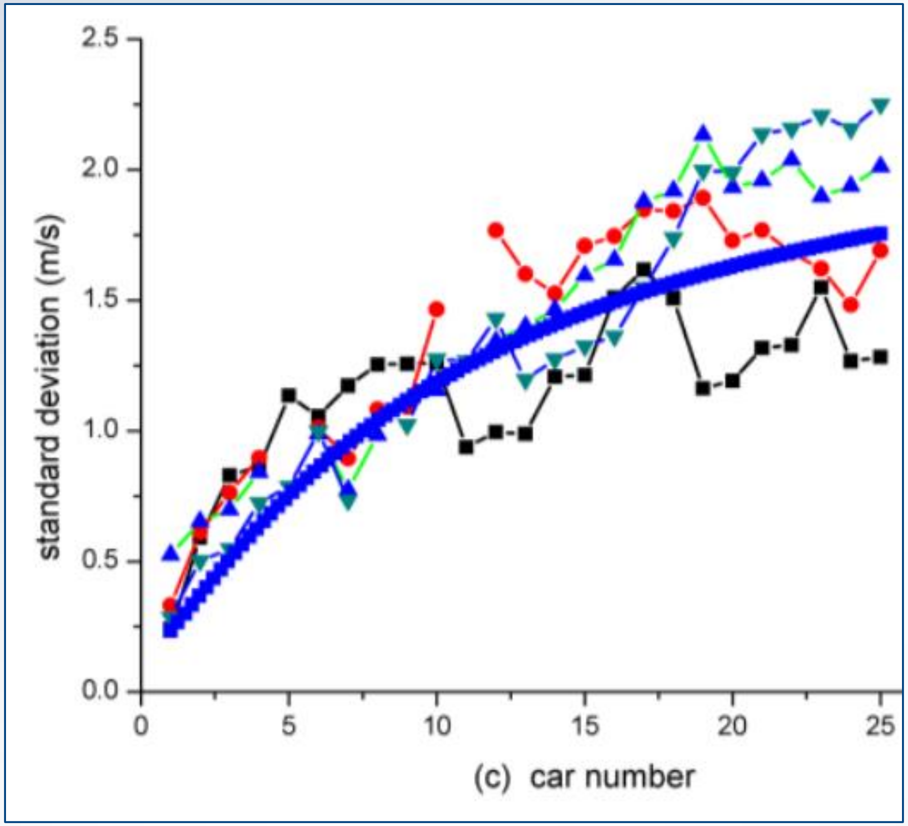


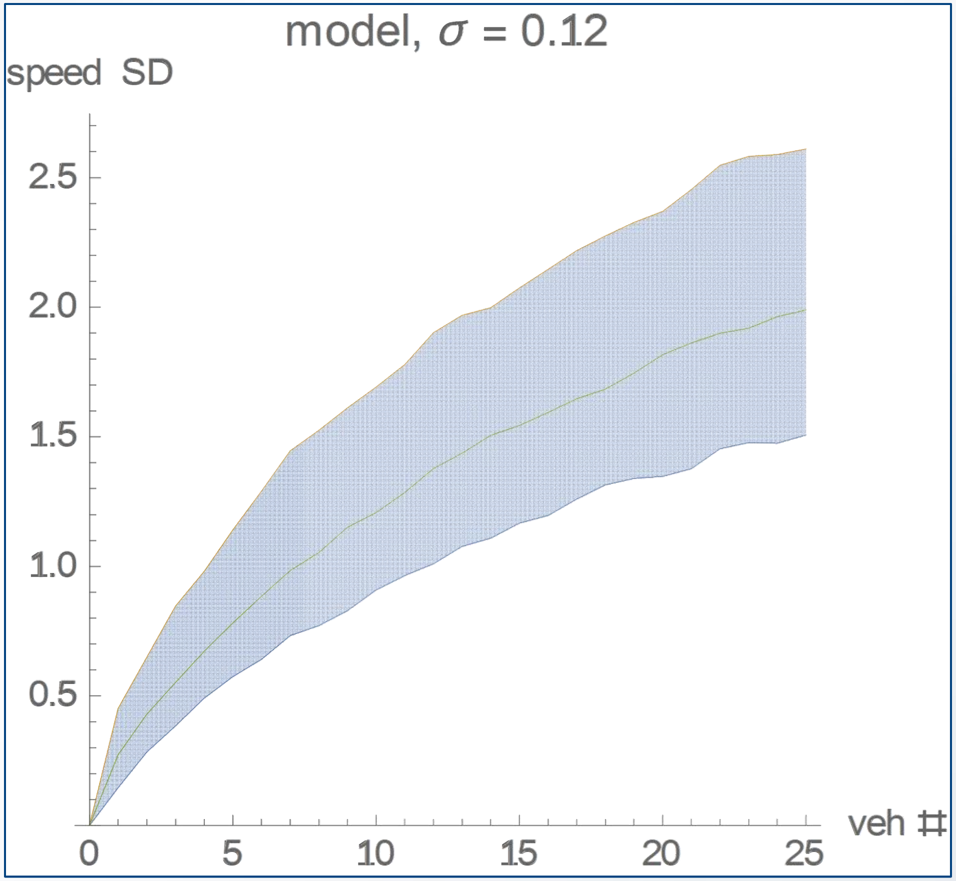
Car-following experiment #1



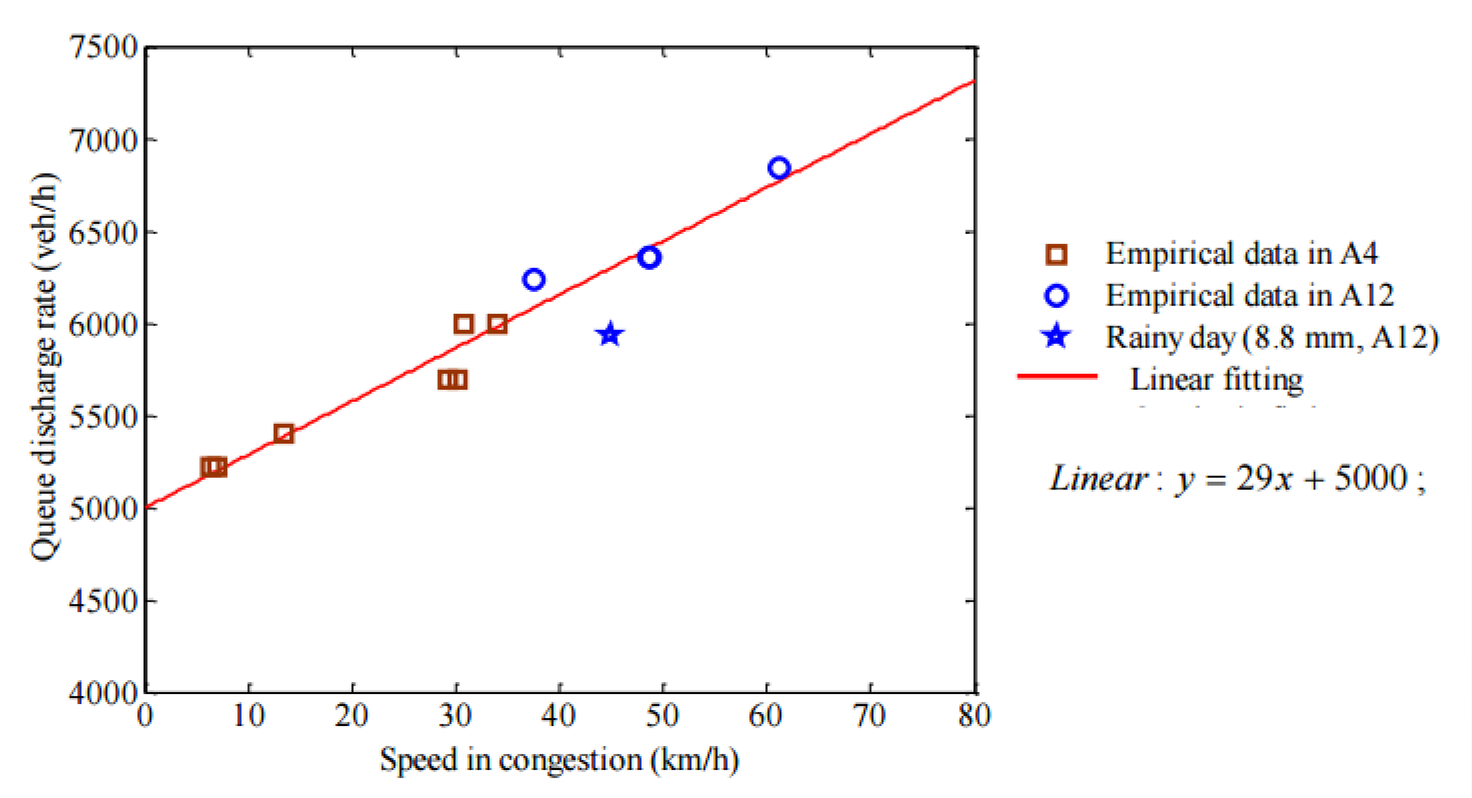
Model captures "concavity"

- Tian et al, Trans. Res. B (2015)
- Jian et al, PloS one (2014)



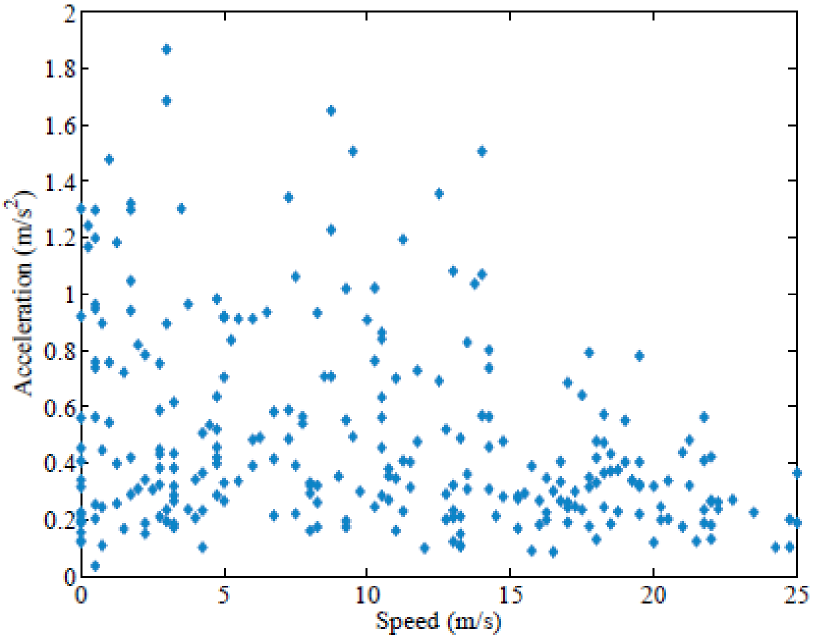


Does not capture capacity-BN speed relation

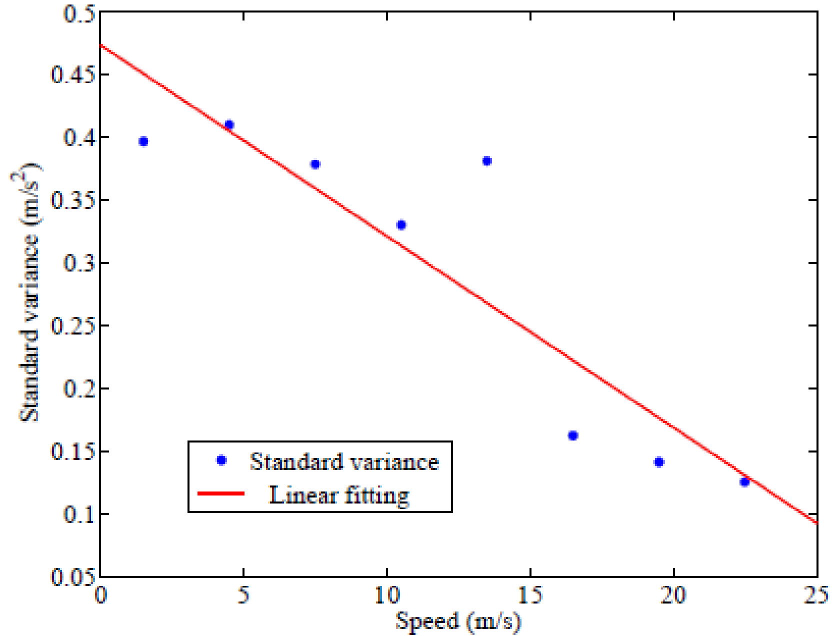


Brownian motion formulation

- desired acceleration ⬄ vehicle downstream does not constrain the motion



(a) Drivers' desired acceleration when traveling at different speed.

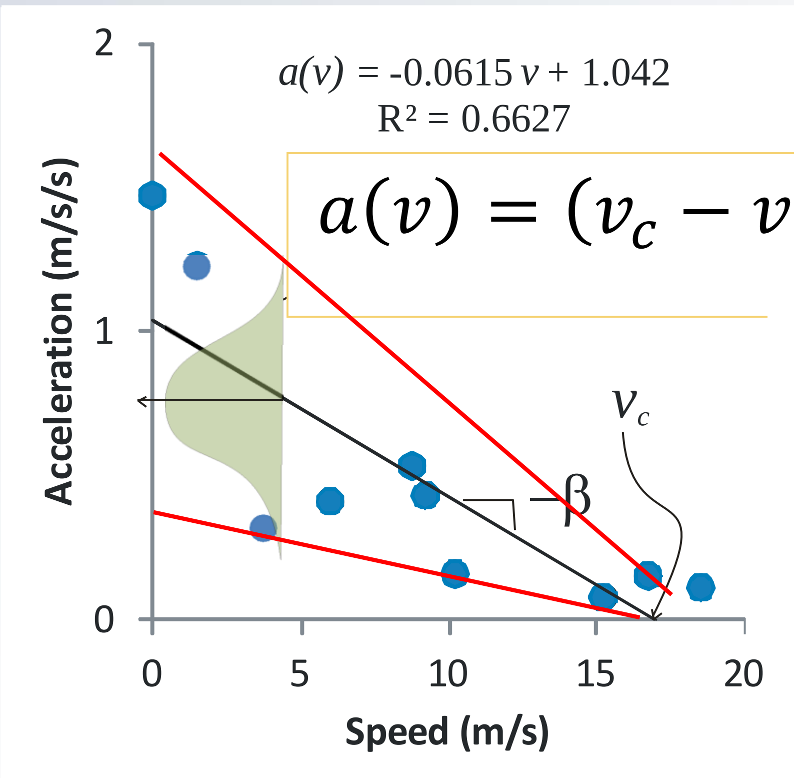


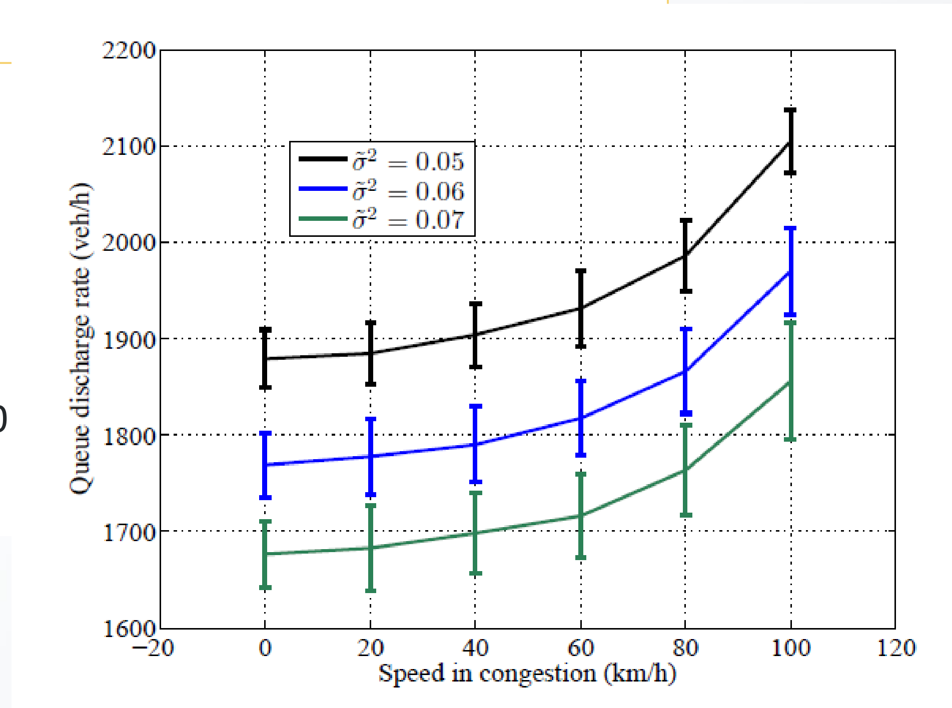
(b) Standard variance of drivers' desired accelerations at different vehicular speeds v.

Speed (m/s)

Geometric Brownian motion formulation

$$a(v) = (v_c - v)\beta + \text{white noise}(v)$$





Q & A

THANK YOU !

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