Traffic congestion in networks, and alleviating it with public transportation and pricing

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In collaboration with

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References

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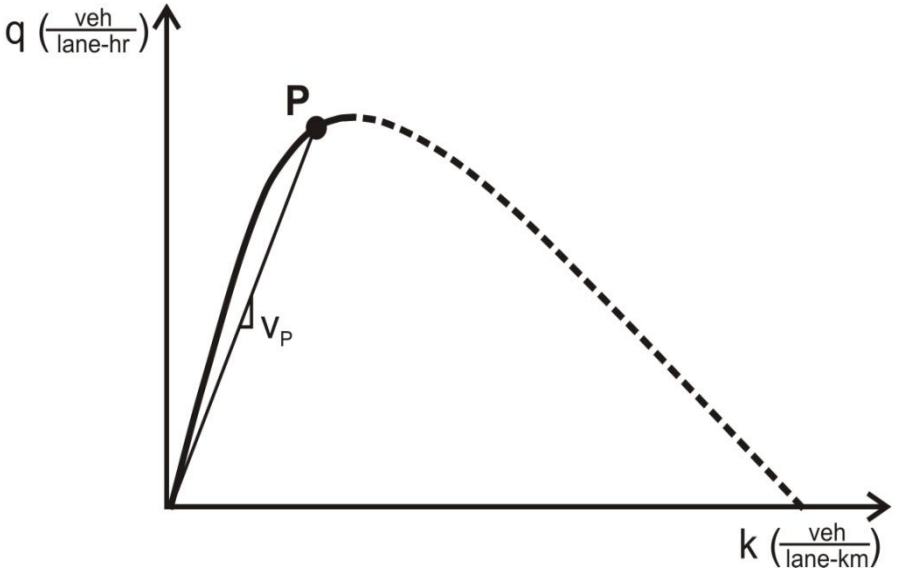
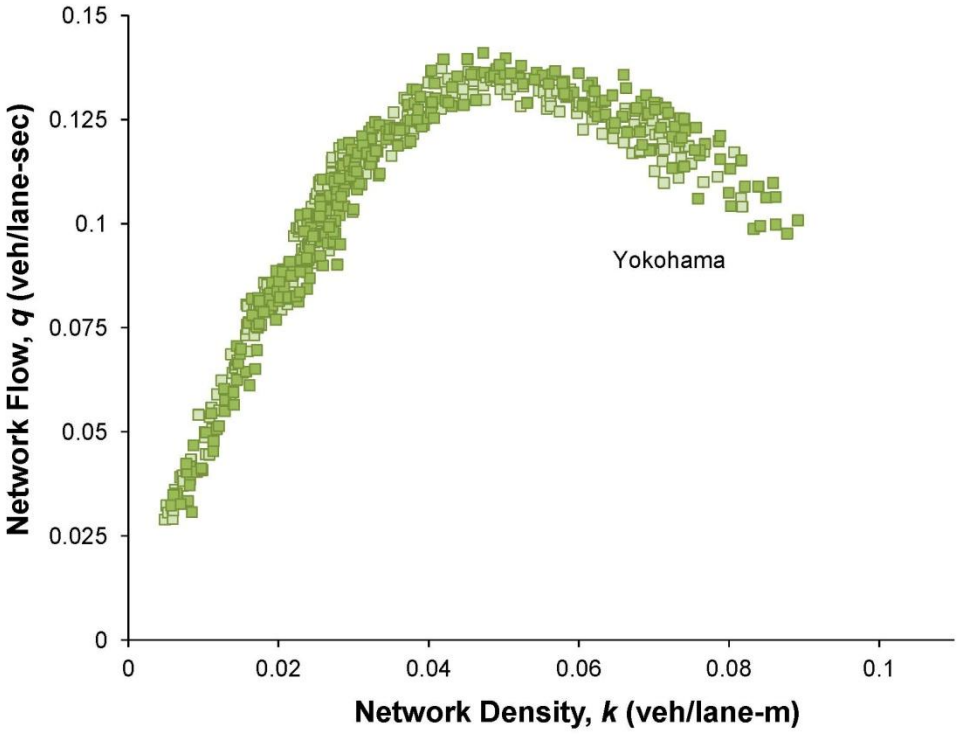
Outline

- Building blocks
  - City-wide traffic model
  - City-wide transit model
- Putting them together
  - How modes should share street space
  - City scale analysis

City-wide traffic:
MFD evidence

- MFD
  - Network flow (q) vs. network density (k);
    $q = Q(k)$

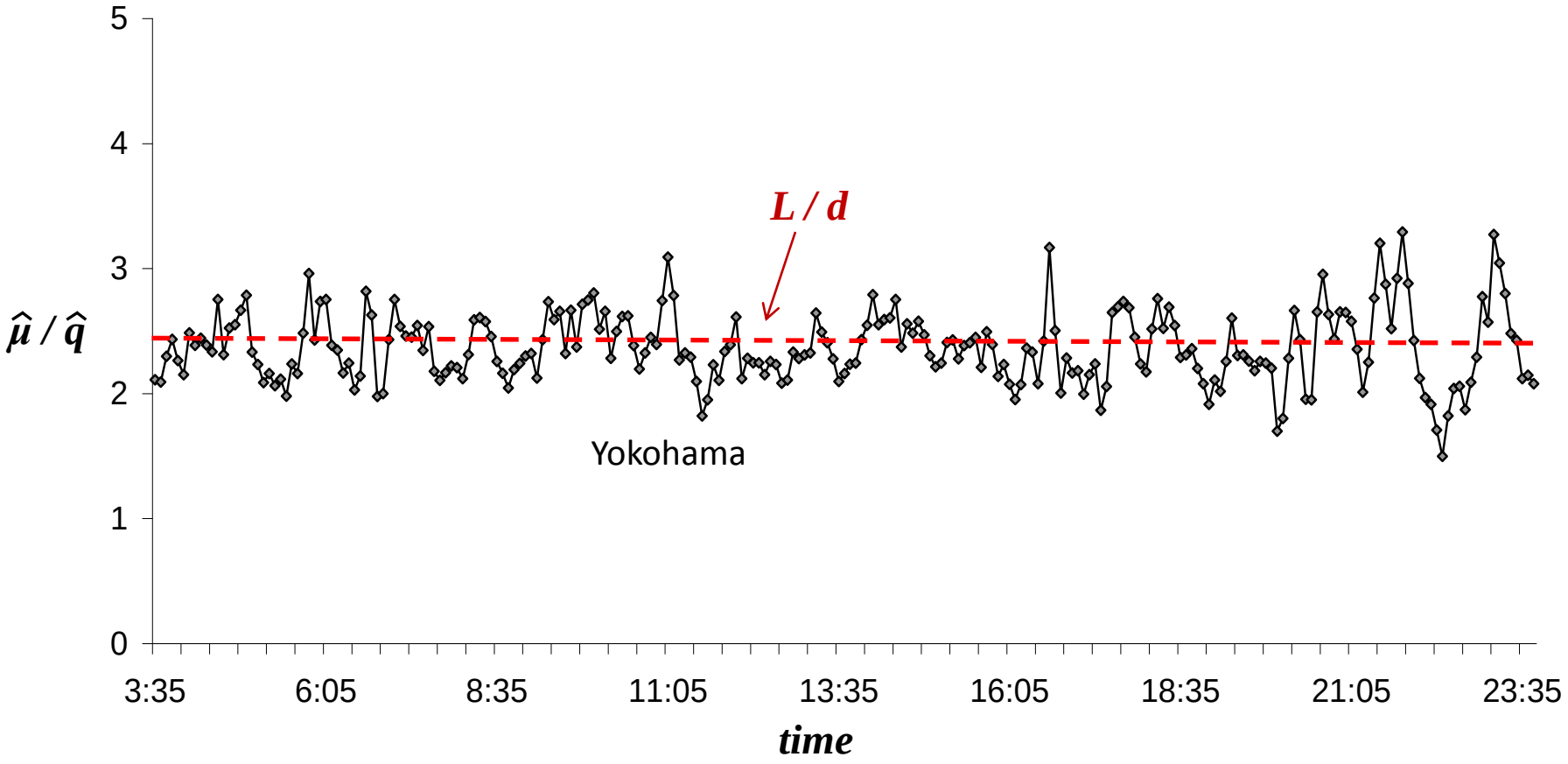




Source: Geroliminis and Daganzo (2008)

City-wide traffic:
Trip completion evidence

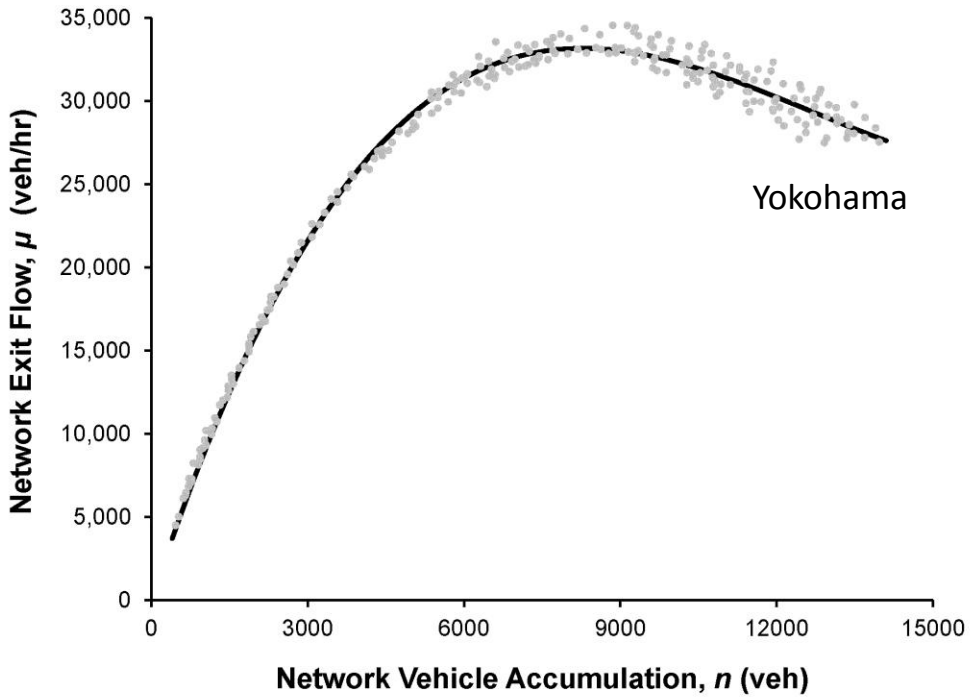
- Ratio of trip completion rate (μ) to network flow (q)



Source: Geroliminis and Daganzo (2008)

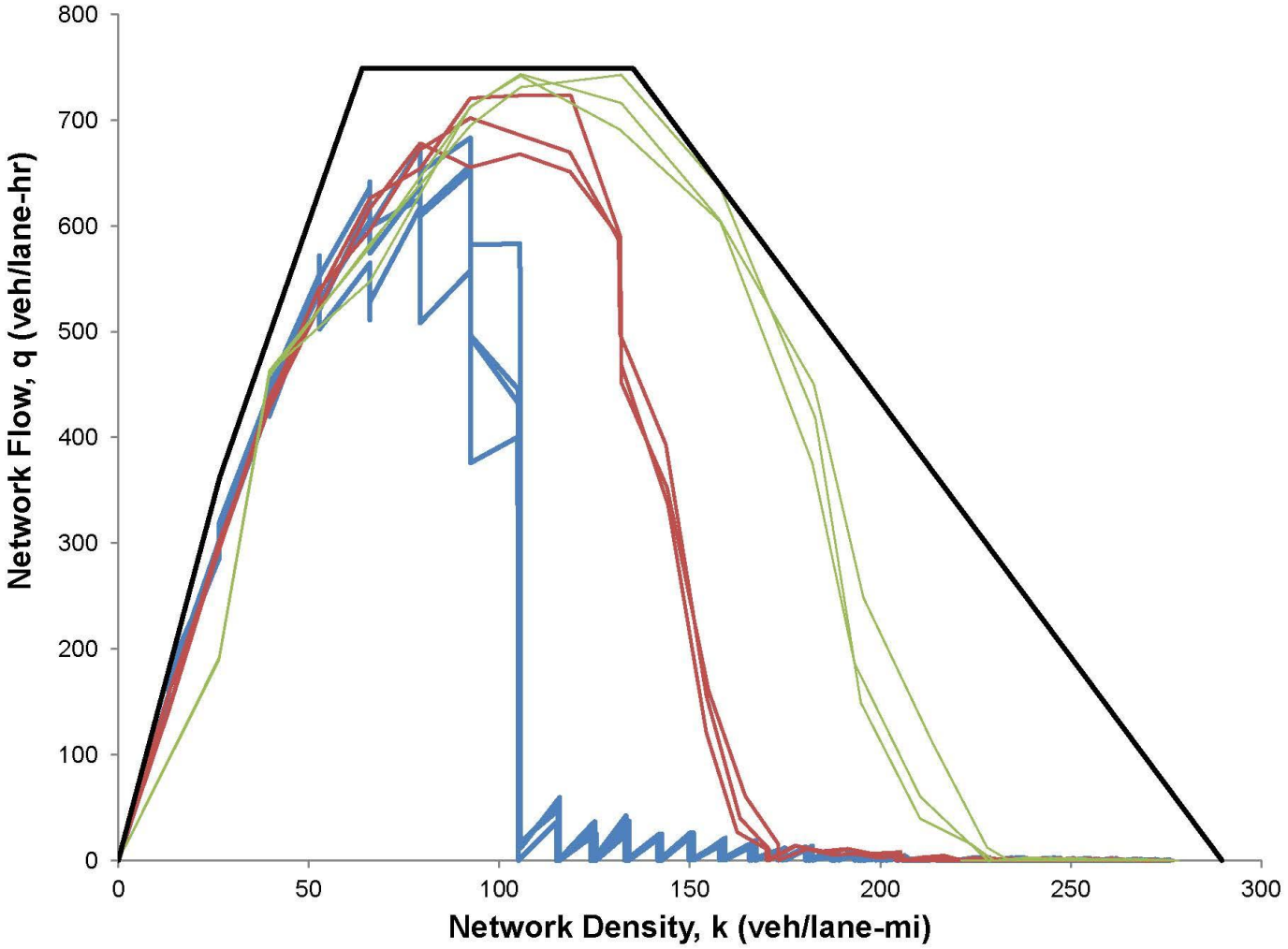
City-wide traffic:
Network Exit Function

- Exit flow, $\mu = qL/d$; accumulation, $n = kL$;
- NEF: $\mu = F(n)$



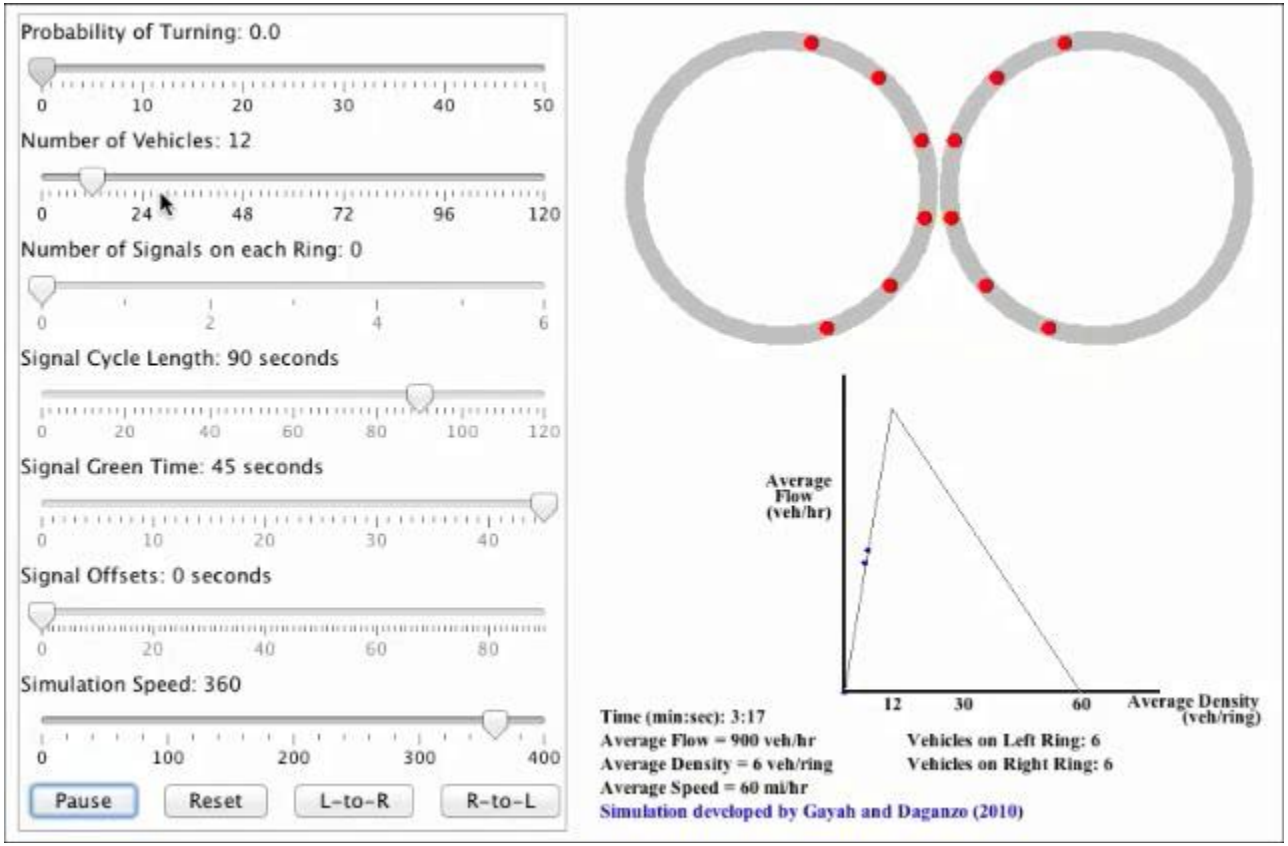
Source: Geroliminis and Daganzo (2008)

City-wide traffic:
What if drivers do not adapt



Source: Daganzo et al (2011a)

City-wide traffic:
Effect of non-adaptive route choice



Source: Gayah and Daganzo (2011)

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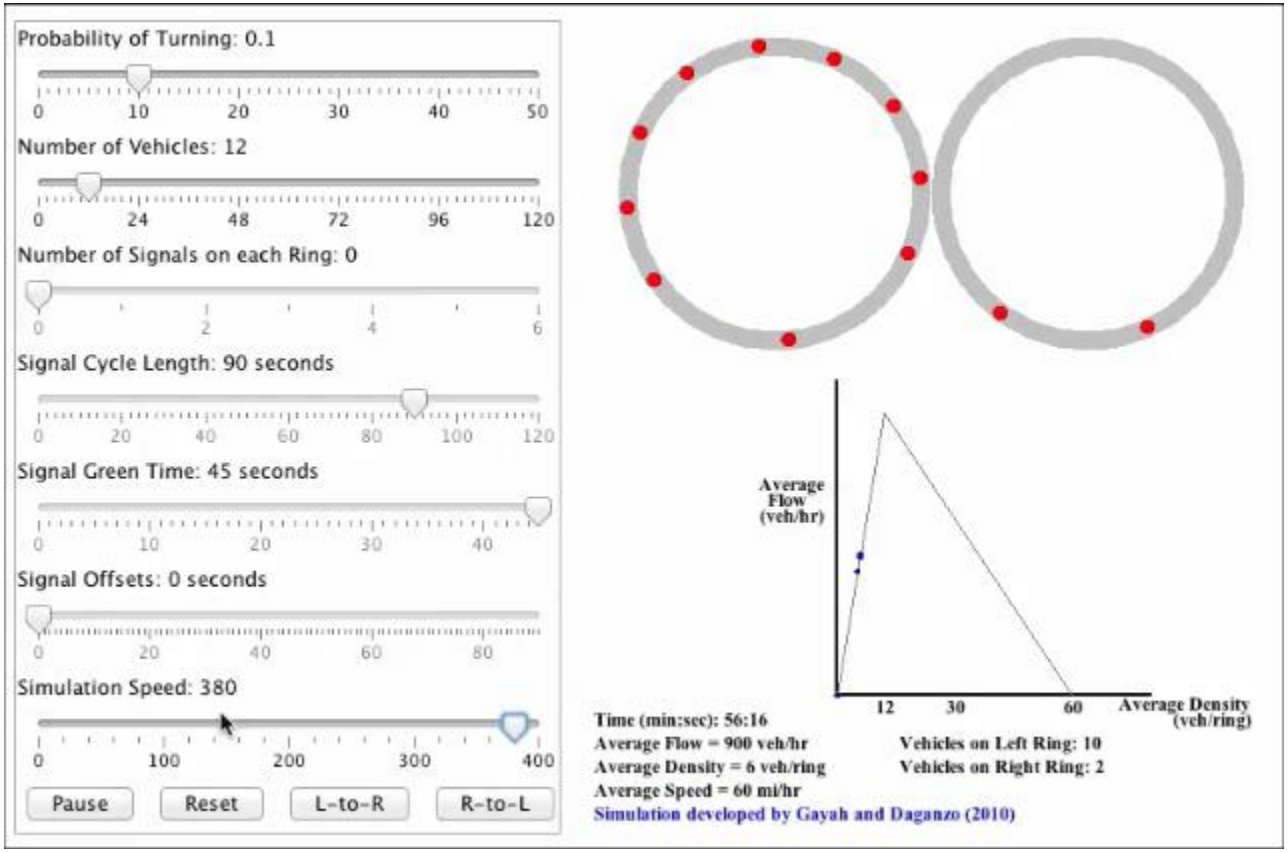

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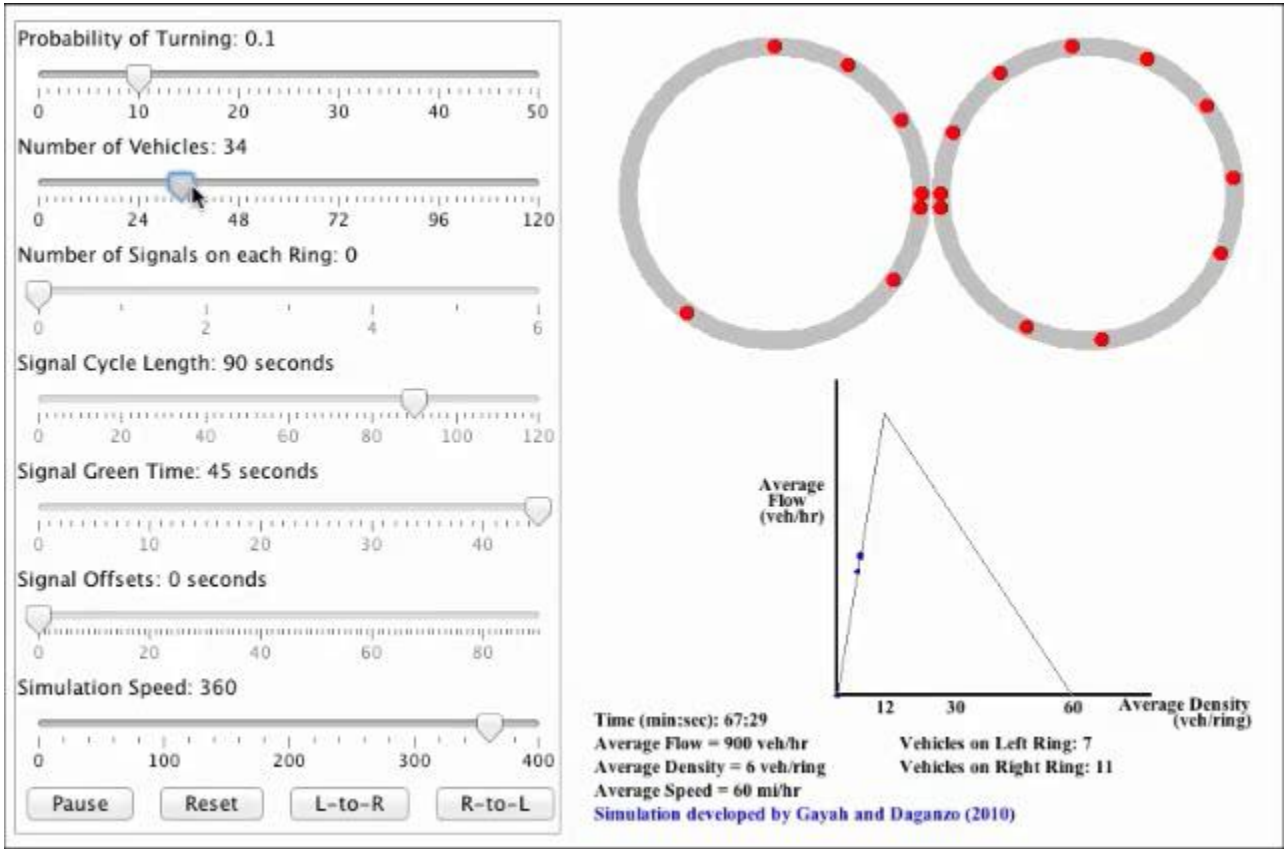

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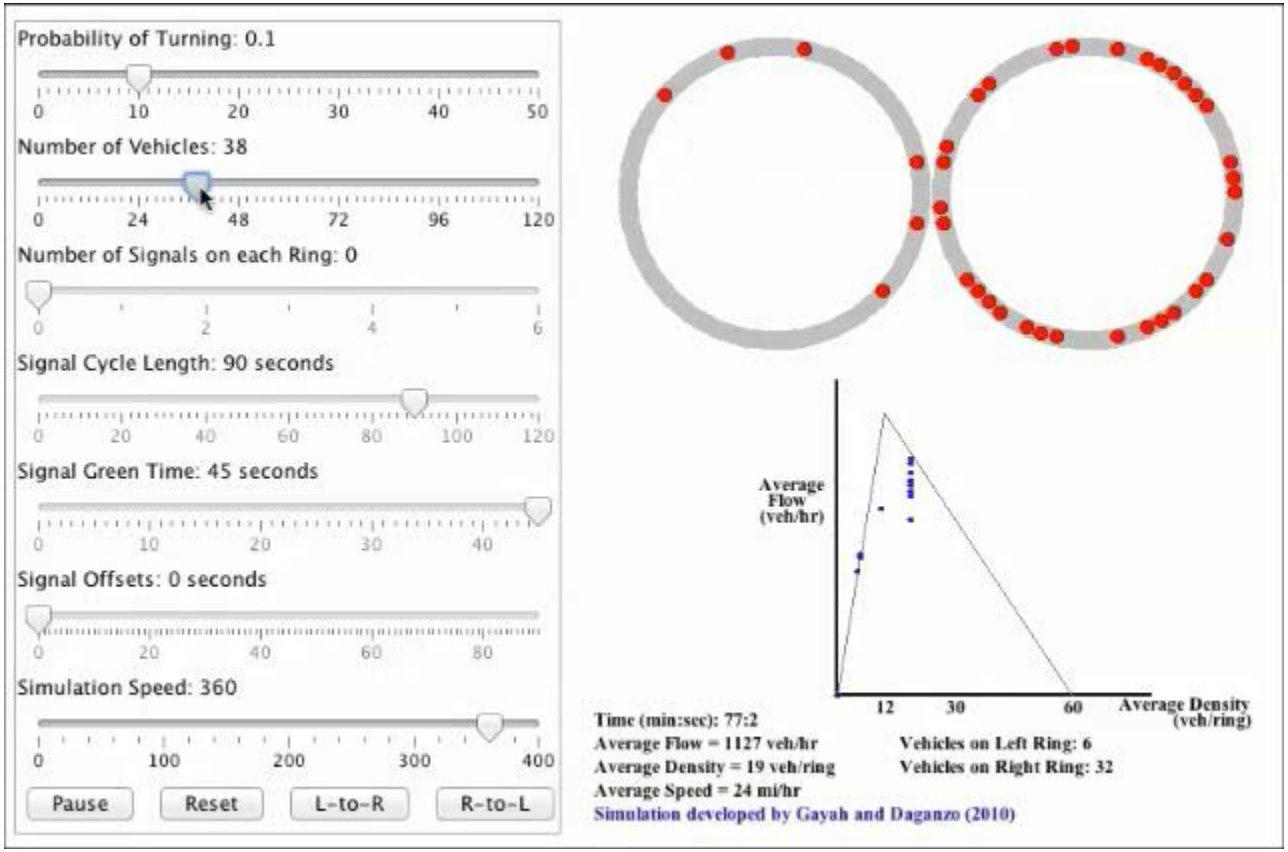
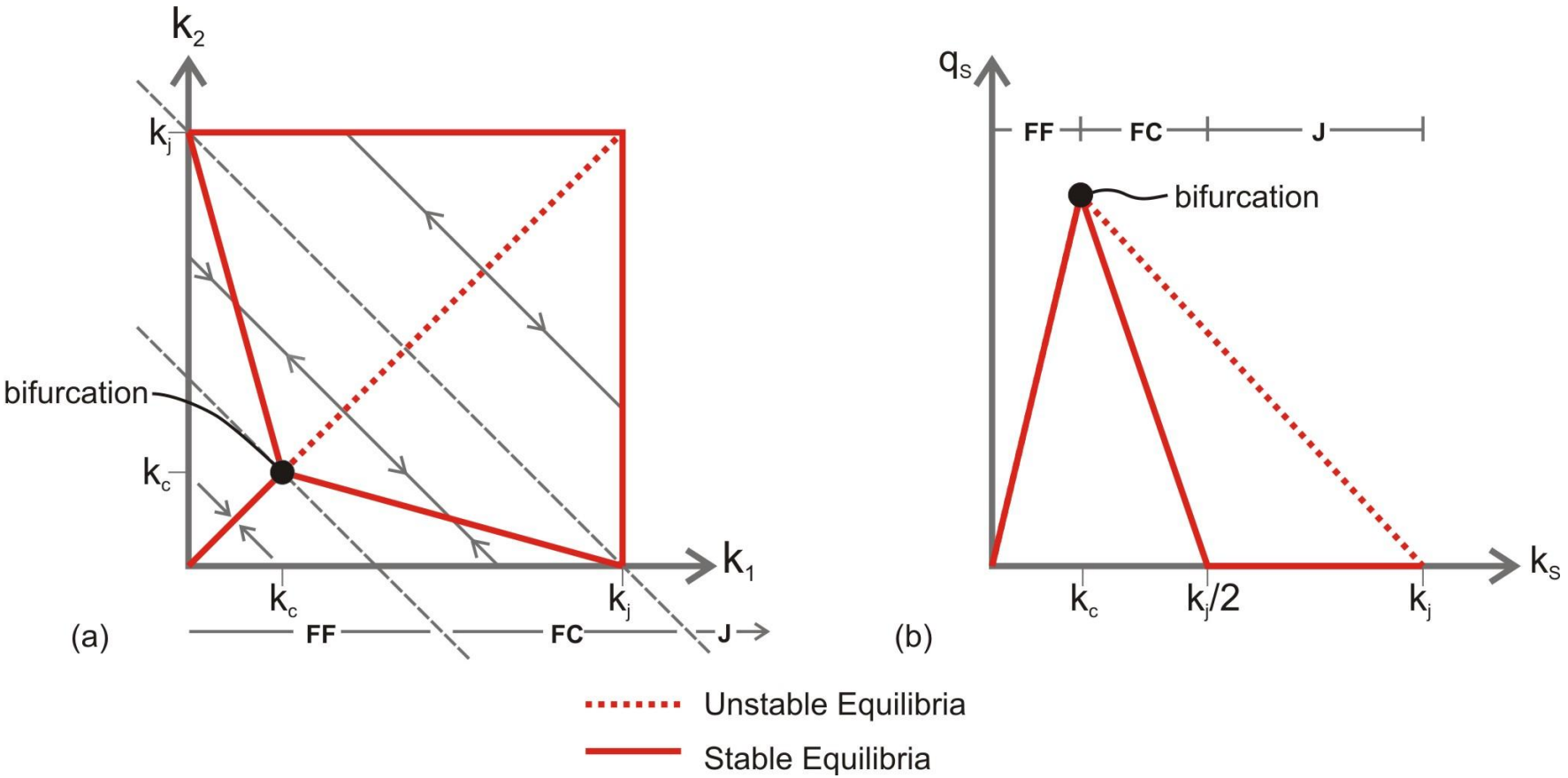


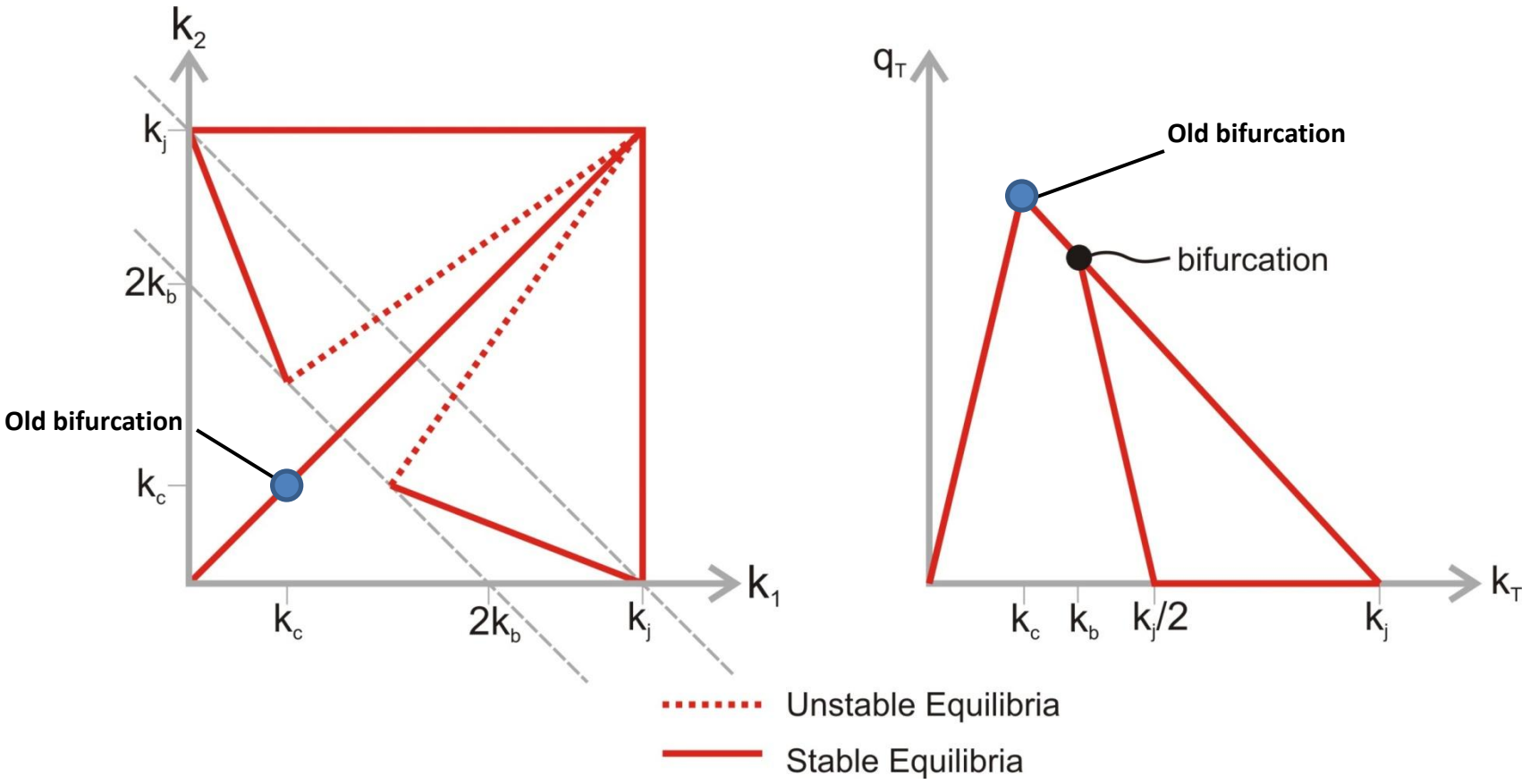
Source: Gayah and Daganzo (2011)

City-wide traffic:
Analytical model (non-adaptive)



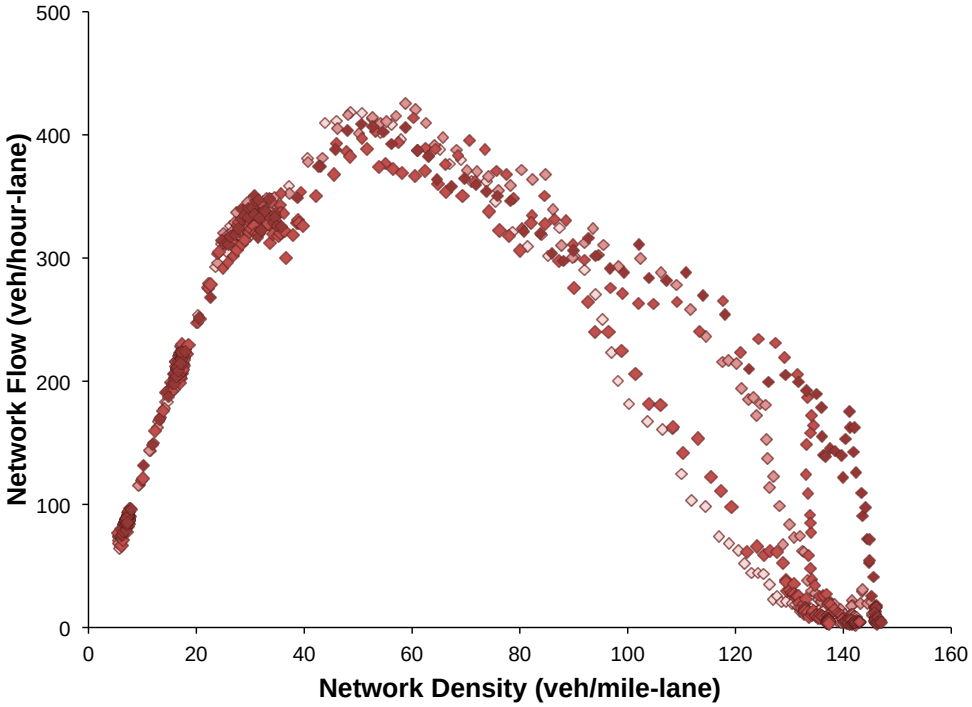
Source: Daganzo et al (2011a)

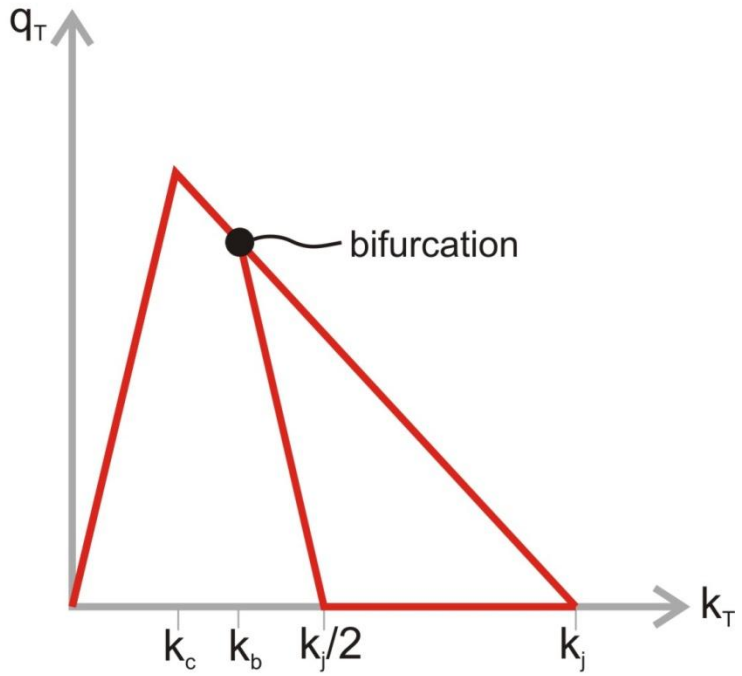
City-wide traffic:
Analytical model (adaptive)



Source: Daganzo et al (2011a)

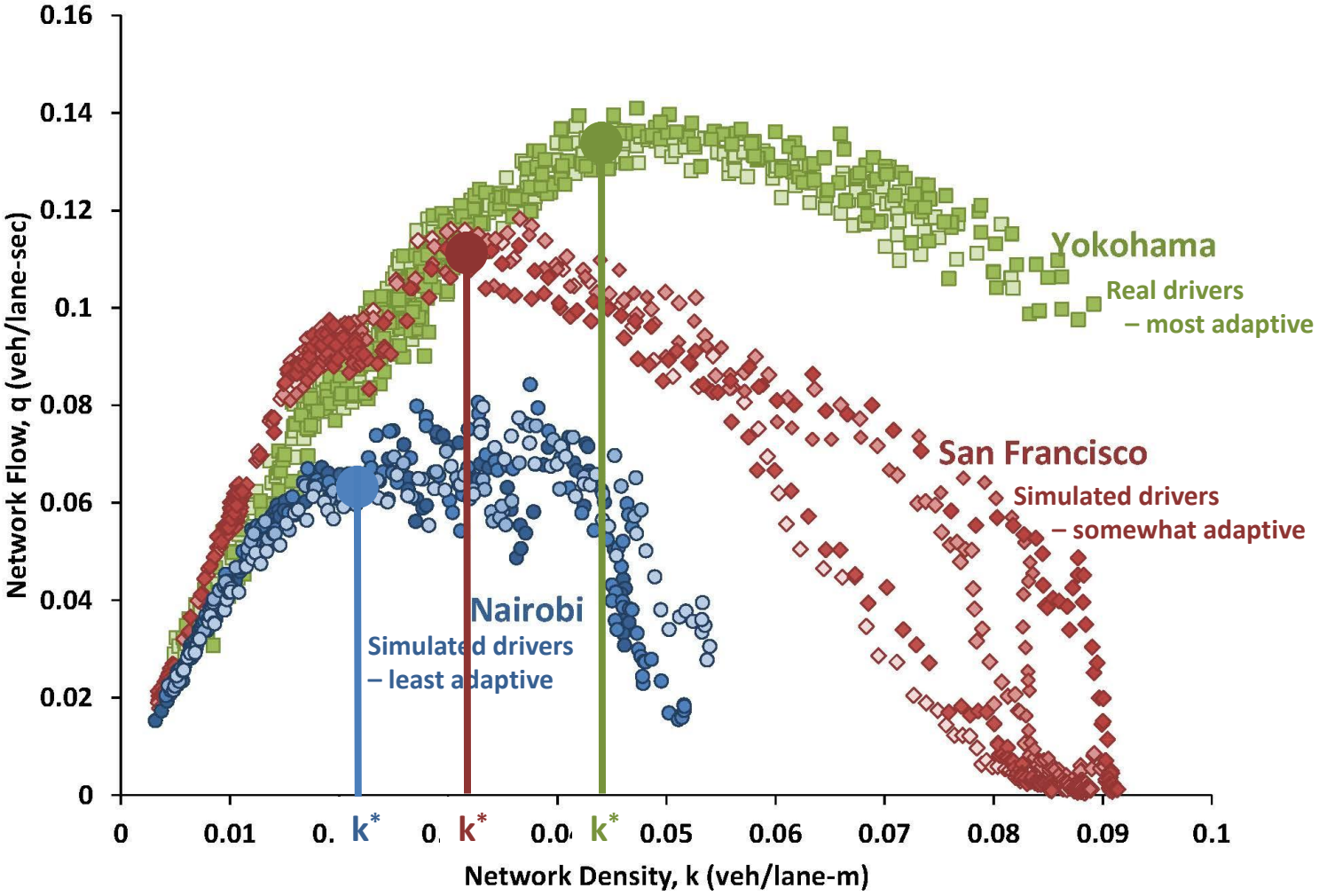
City-wide traffic:
Analytical model (adaptive)





Source: Daganzo et al (2011a)

City-wide traffic:
Adaptive and non-adaptive cases



Source: Gonzales et al (2009)

City-wide traffic:
Spatial considerations

- l_c – space-time consumed by one car trip
- L_c – required network length

$$l_c$$

space needed | time needed | exit rate

$$\left(\frac{1}{k}\right) \times \left(\frac{d}{v}\right) \times \mu$$

$$L_c$$

$$\longrightarrow \quad \boxed{L_c = l_c \mu}$$

Source: Daganzo et al (2011b)

City-wide traffic:
Summary

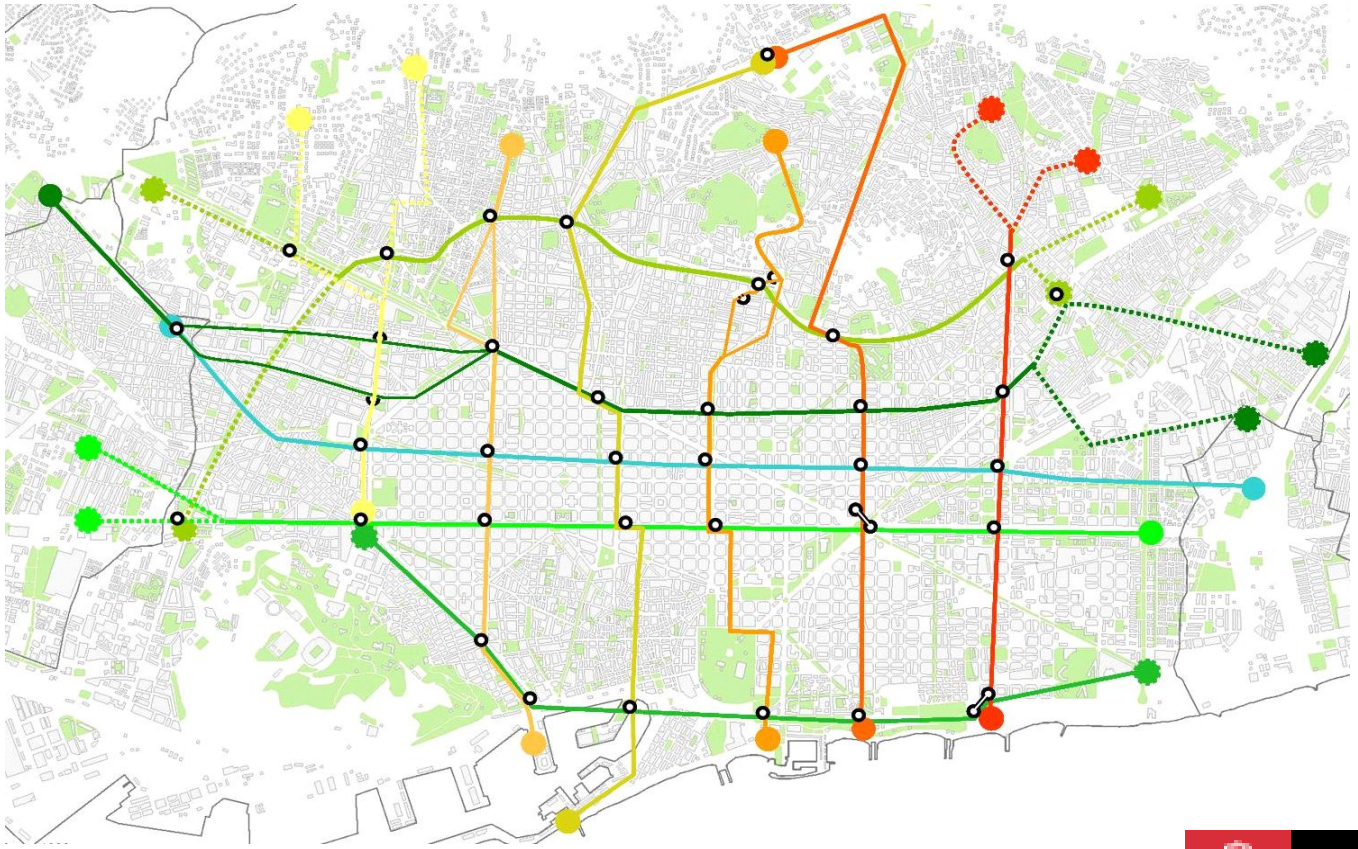
- Determinants of performance
  - N_c – number of daily car users
  - μ – exit rate

Cost: $Z_C(N_C) = z_C N_C$

Space Used: $L_C(\mu) = l_C \mu$

Source: Daganzo et al (2011b)

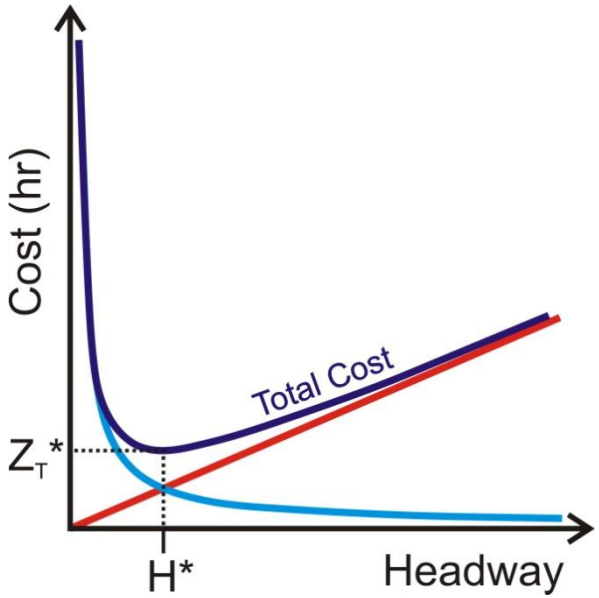
City-wide transit:
Overview



Barcelona (2012)

Source: Estrada et al (2011)

City-wide transit:
Analytical Model



β – value of time

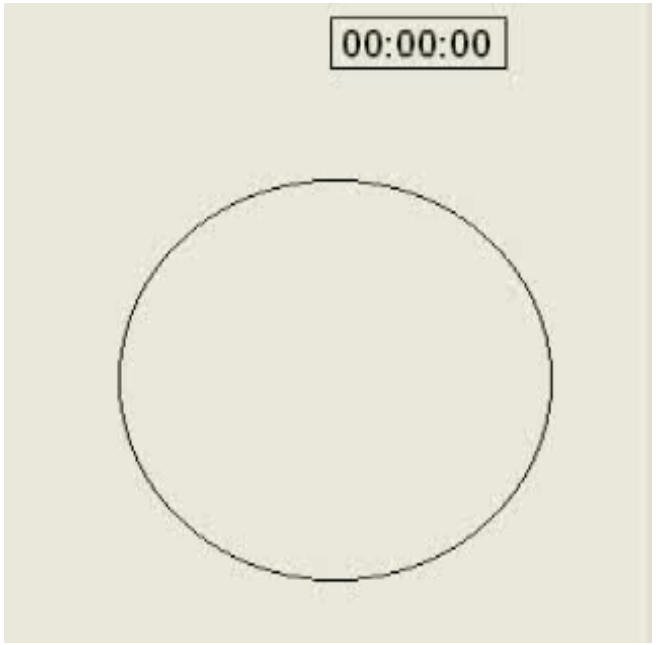
Model

- Cost: $Z_T(N_T) = z_1 + z_2\sqrt{N_T} + z_3 N_T$
- Space Used: $L_T(N_T) = (1-\alpha)L$

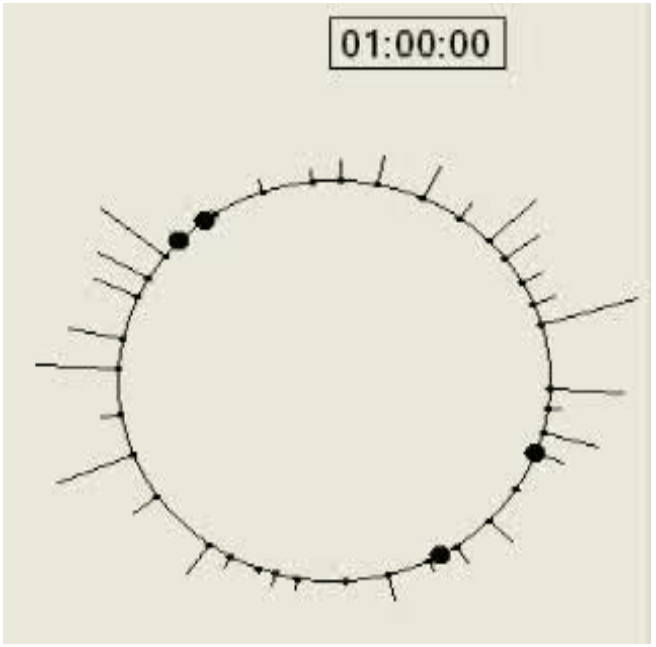
Source: Daganzo et al (2011b)

City-wide transit:
Spatial distribution of buses

4 Buses Uncontrolled



4 Buses Controlled



Source: Daganzo and Pilachowski (2011)

City-wide transit:
Model verification

- Simulation of Barcelona with real network
- Discrepancies between model and simulation
    - User cost (5%)
    - Agency cost (7.5%)
- Most subcomponent discrepancies (10%)
- All discrepancies due to differences between the real and idealized networks

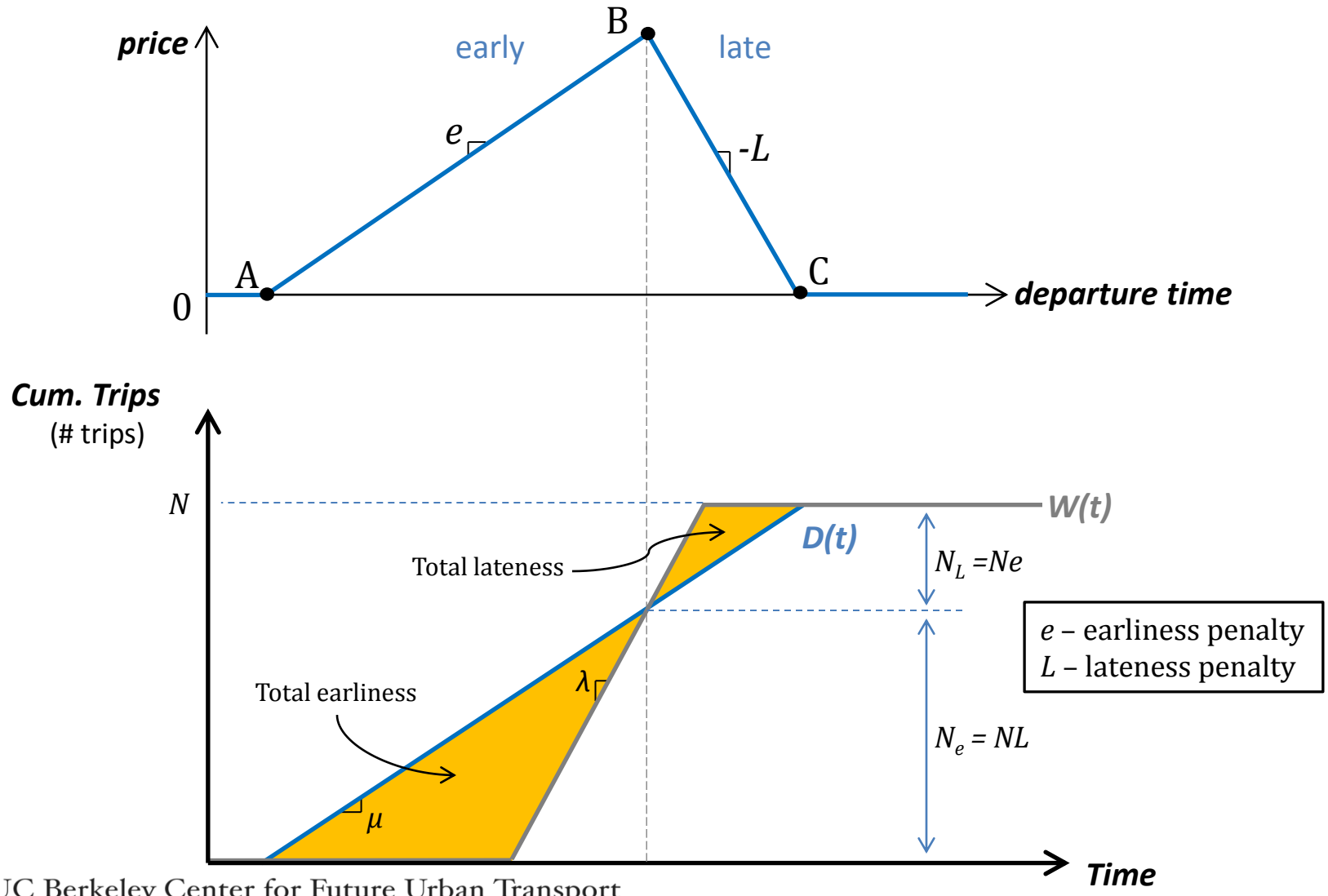
Source: Estrada et al (2011)

Sharing space:
Overview

- Wish to optimally segregate the two modes

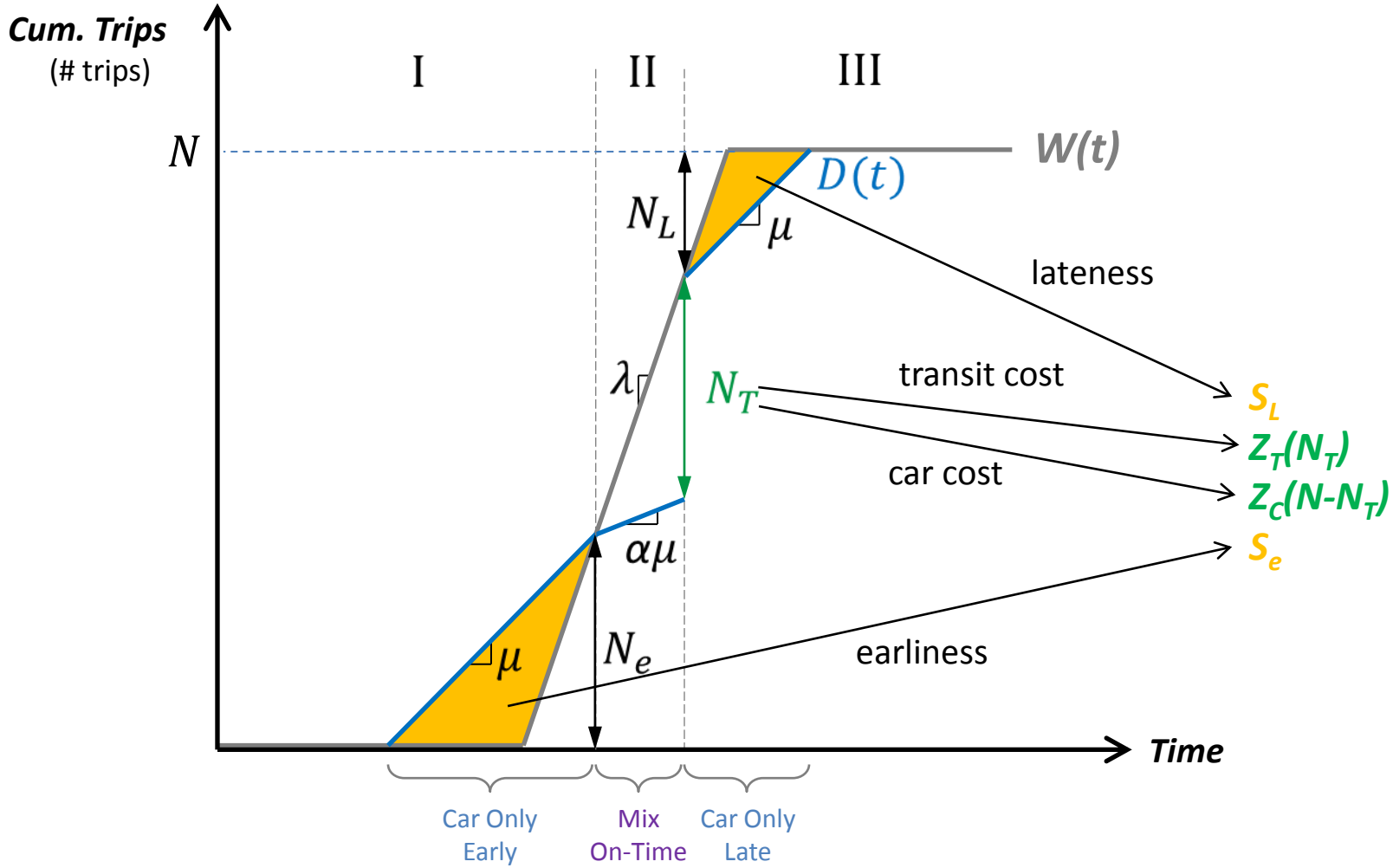
Sharing space:

System optimum allocation for single mode and prices to achieve it



Sharing space:

System optimum allocation for two modes



Source: Gonzales and Daganzo (2011)

Sharing space:
System optimal solution

Schedule Penalty:

$$S(N_T) = \left(t_p - \frac{N_T}{\lambda - \alpha\mu} \right)^2 \frac{\lambda e L (\lambda - \mu)}{2\mu(e + L)}$$

Transit Cost and Car Cost:

$$Z_T(N_T) = z_1 + z_2\sqrt{N_T} + z_3 N_T$$

$$Z_C(N - N_T) = z_C \times (N - N_T)$$

Total Cost:

$$Z(N_T) = S(N_T) + Z_T(N_T) + z_C \times (N - N_T)$$

System Optimum:

$$N_T^* = \arg\min_{N_T} Z(N_T) \qquad Z^* = \min_{N_T} Z(N_T)$$

Source: Gonzales and Daganzo (2011)

Sharing Space:
System optimum properties

- Solution depends on properties of the city
  $(z_1, z_2, z_3, z_C) \rightarrow (N, L, l_C \text{ and } \beta)$

  and design variables

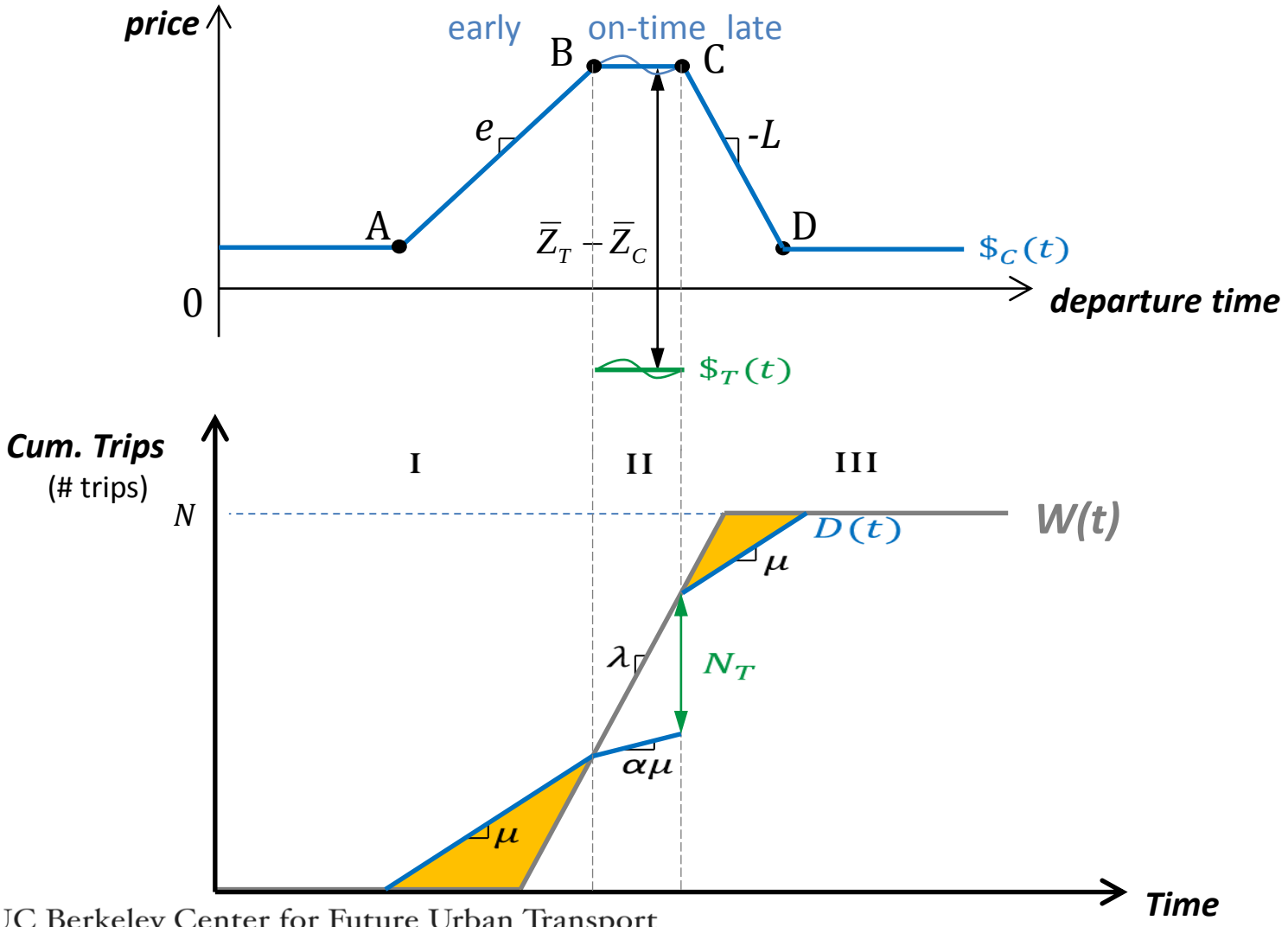
  (μ and α)

- N_T* can be:
  - 0 All car
  - (0,N) Mixed
  - N All transit

Source: Gonzales and Daganzo (2011)

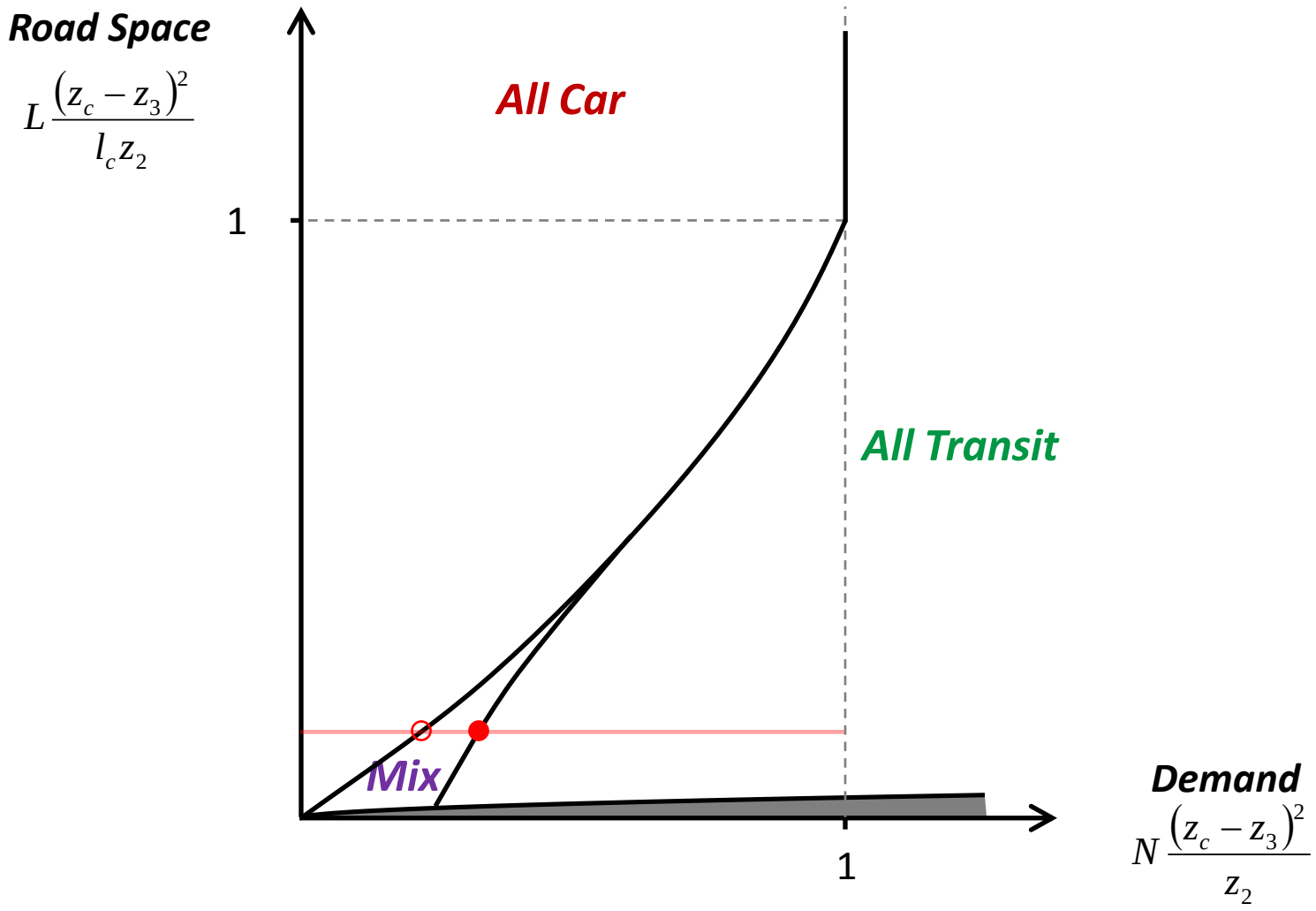
Sharing space:

Pricing to achieve system optimum



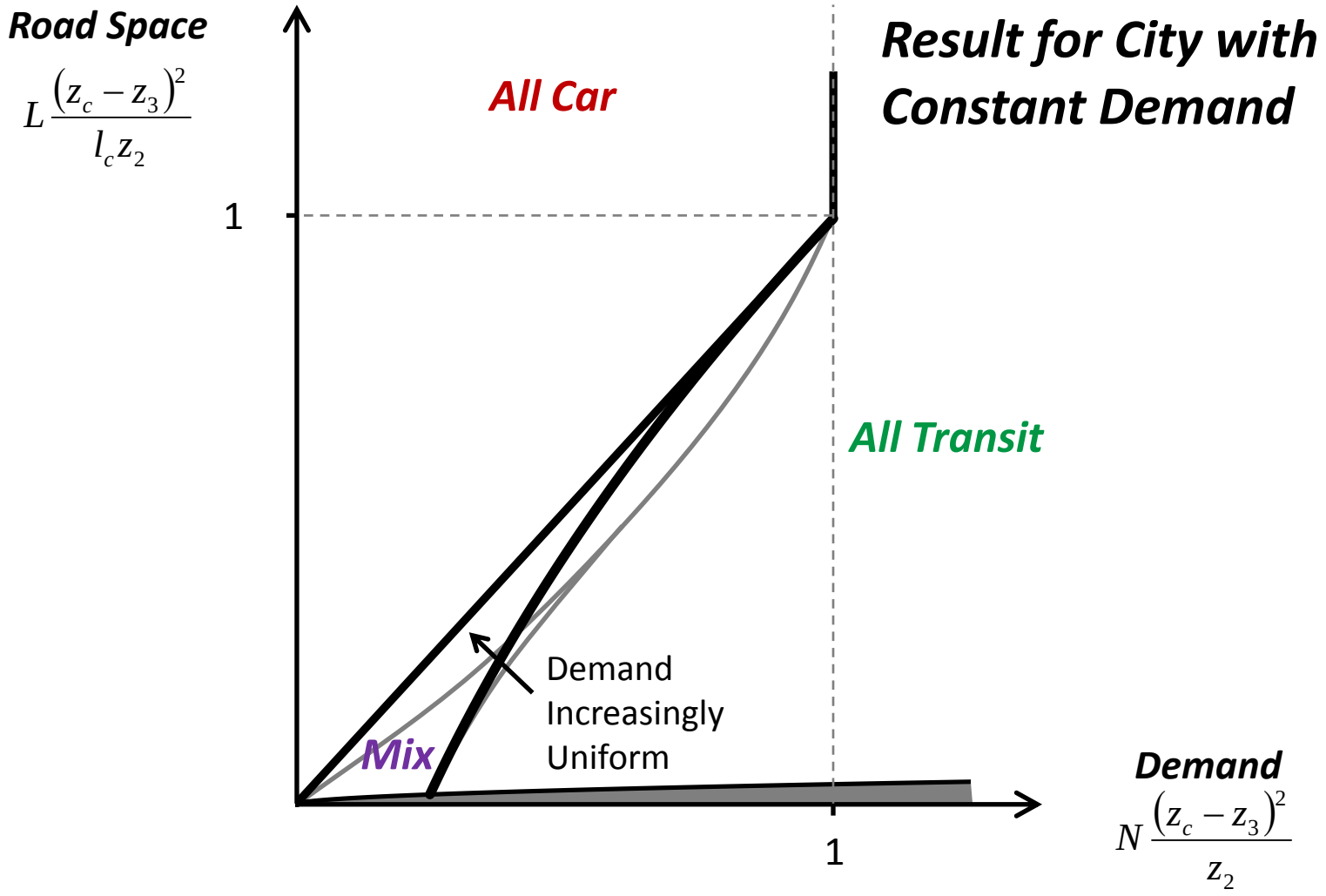
Source: Gonzales and Daganzo (2011)

City scale analysis:
Optimum deployment for peaked demand



Source: Gonzales and Daganzo (2012)

City scale analysis:
Optimum deployment for uniform demand



Source: Gonzales and Daganzo (2012)

Where do we go from here?

- Captive users
- Role of underground metro
- Day-long commute
- Pricing
- Experiments