Insights from Macroscopic Models of Urban Transportation Systems

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www.its.berkeley.edu/volvocenter/

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Locarno, September 2010

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7. Gayah, V. and Daganzo, C.F. (2010b) “Hysteresis Loops in the MFD” ITS Working Paper VWP-2010-7 (submitted to Transportation Research Part B).
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10. Estrada, M., Roca-Riu, M. Badia, H., Robuste, F. and Daganzo, C.F. (2010) “Design and implementation of efficient transit networks: Procedure, case study and validity test” (draft, submitted for publication, ISTTT).

Approaches to City-Scale Modeling

- Disaggregate Model
  - Unavailable Inputs
  - Untestable Theories

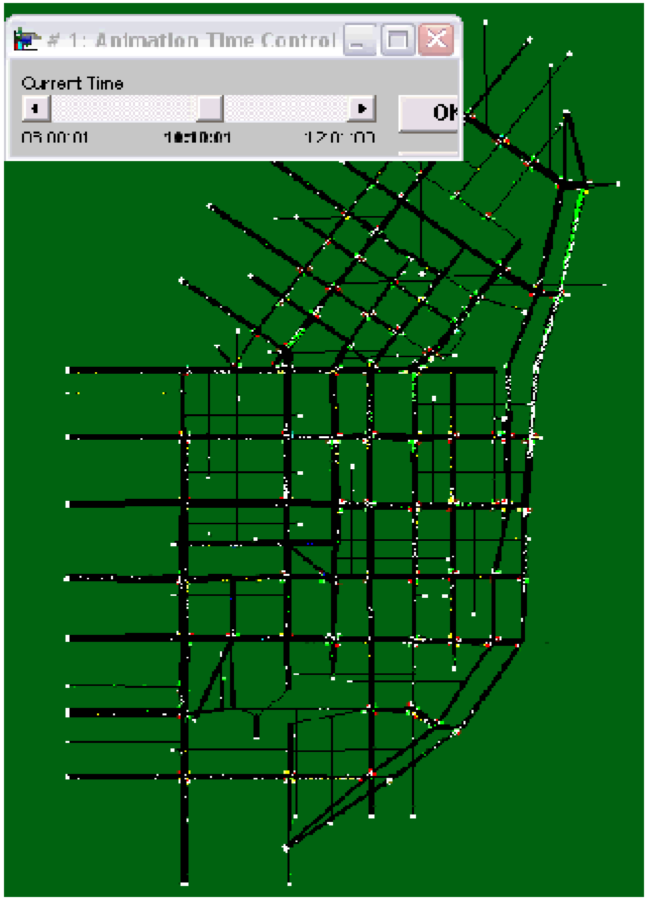
Mountains of Data

- Aggregate Model
  - Observable Inputs
  - Testable Theories

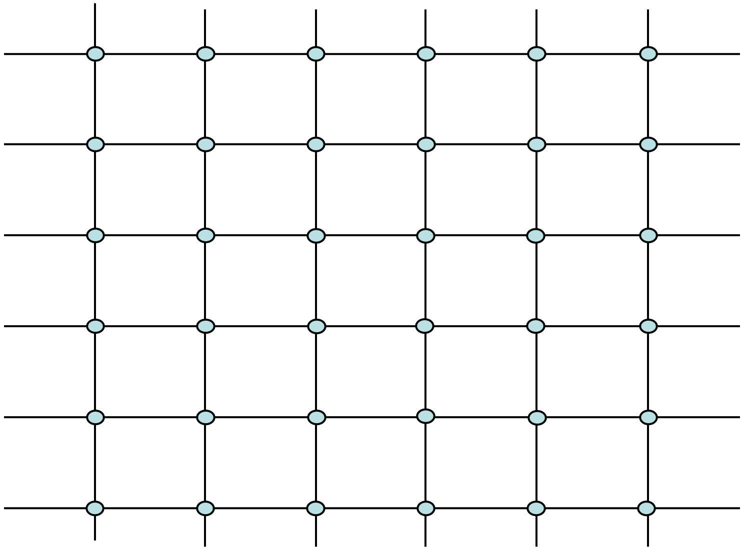
Measurable Data

At the aggregate level,
we can find testable laws of behavior.

Aggregate Models of Traffic & Transit



Traffic Network



Transit Network

URBAN TRAFFIC: Two Conjectures

Hypothesis

If vehicles (i.e., congestion) are uniformly distributed in space

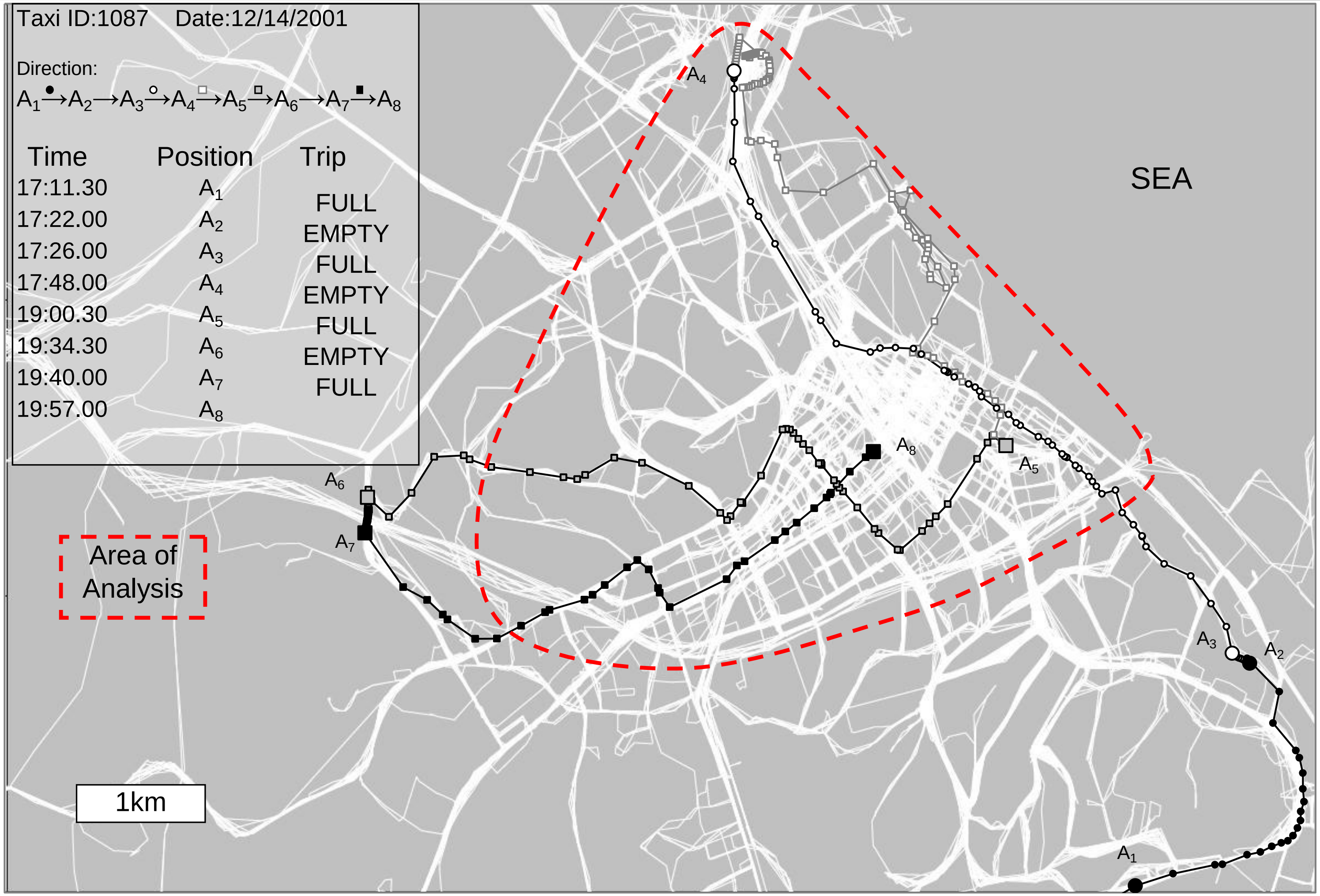
Then

(a) VKT (i.e., average network flow) and VHT (i.e., average number of vehicles in network, average density or average occupancy) are related by MFD.

(b) Trip completion rate/network flow(or VKT) ≈ constant

(Daganzo, 2007)

Real World Experiment: Yokohama, Japan



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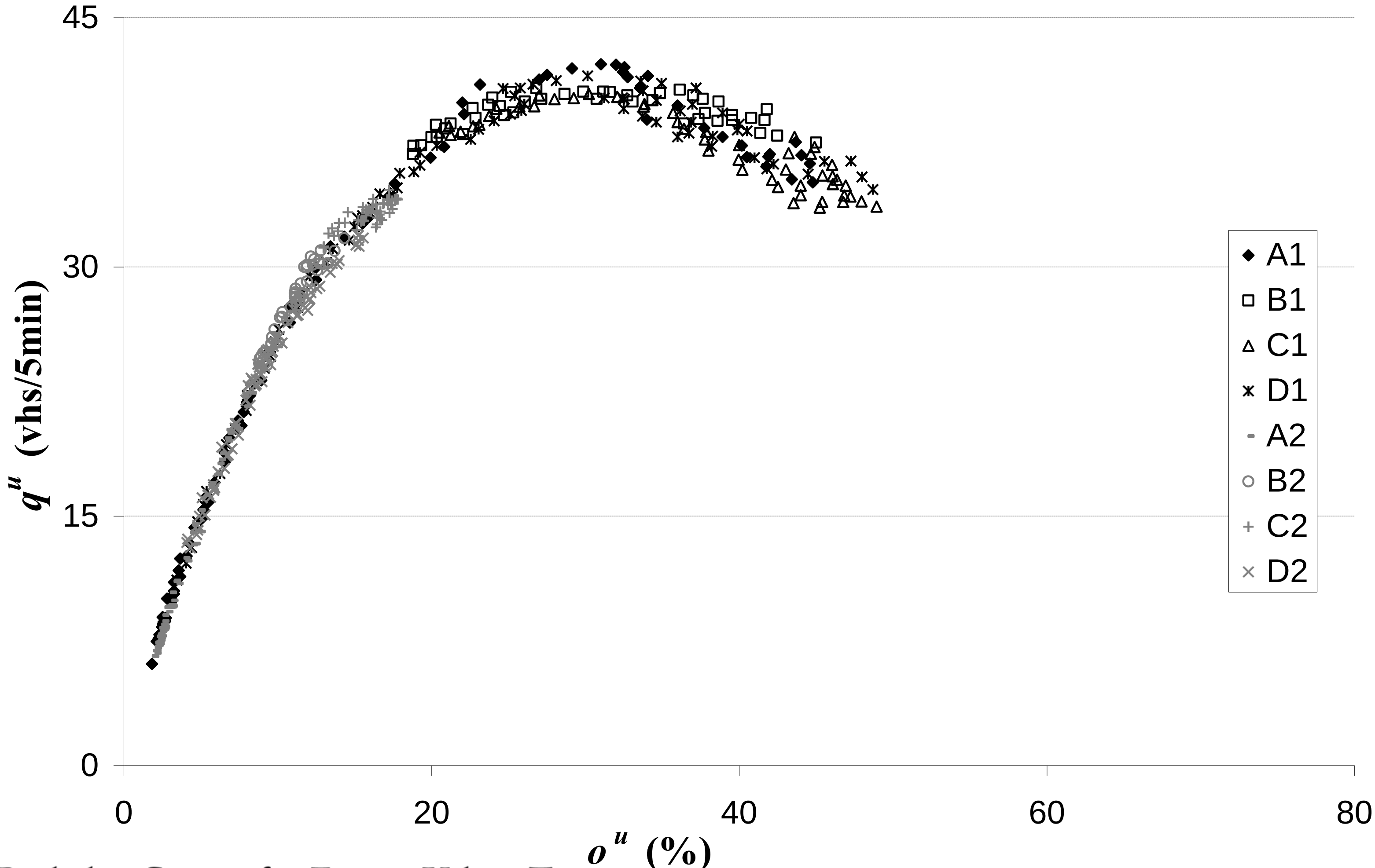
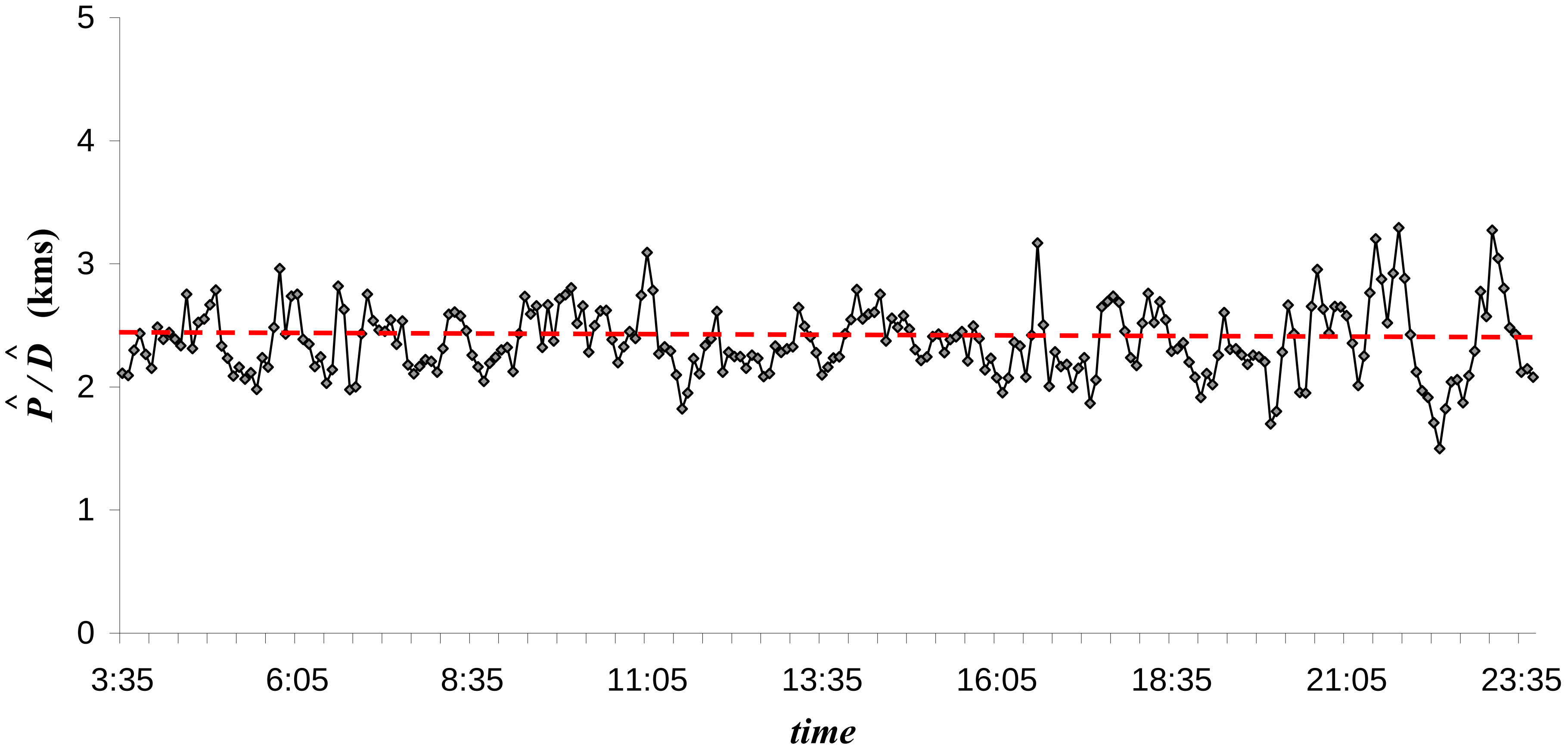
(Geroliminis & Daganzo, 2008)

Experiment Result: Conjecture (a) MFD



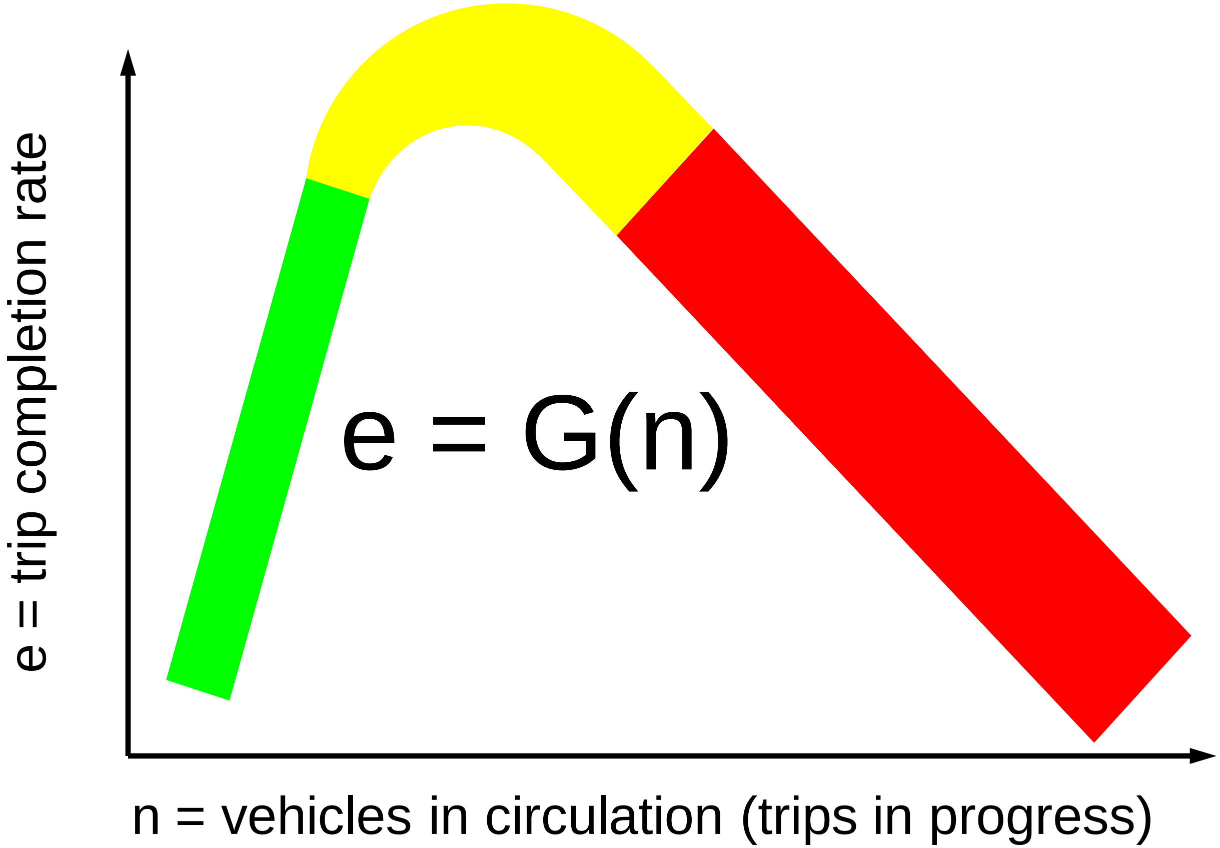
(Geroliminis & Daganzo, 2008)

Experiment Result: Conjecture (b) Completion Rate Ratio



(Geroliminis & Daganzo, 2008)

Application:
Trips in progress vs. trips leaving



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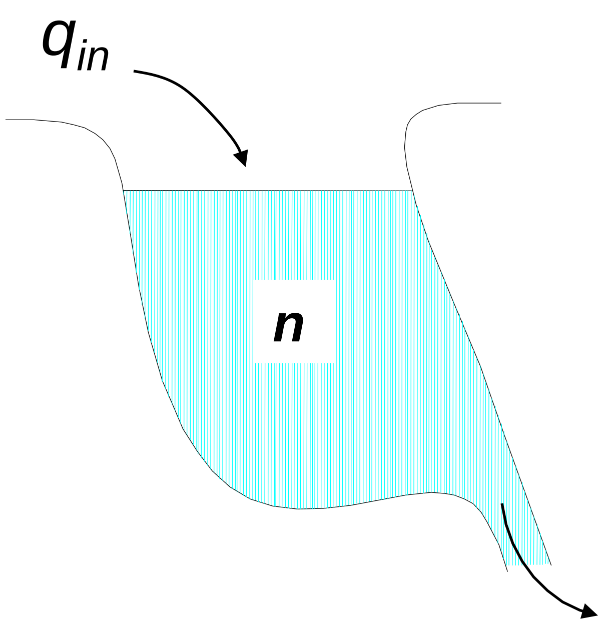
(Daganzo, 2007)

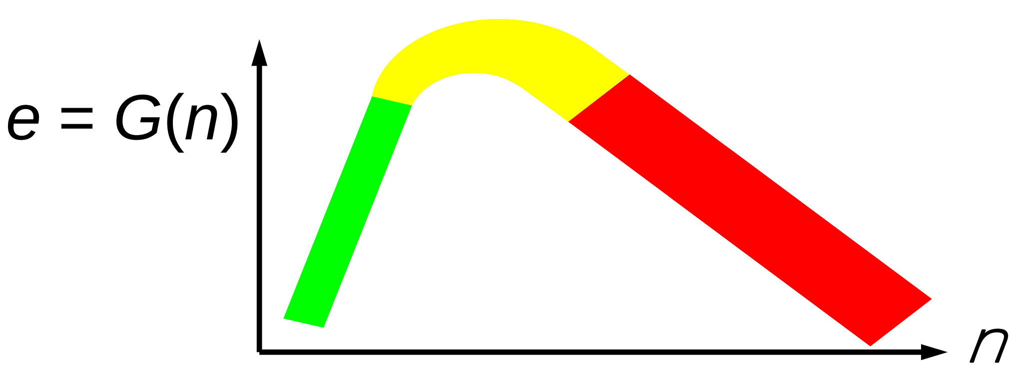
1-Bin Model: Aggregate Dynamics



Given : inflow q_{in}

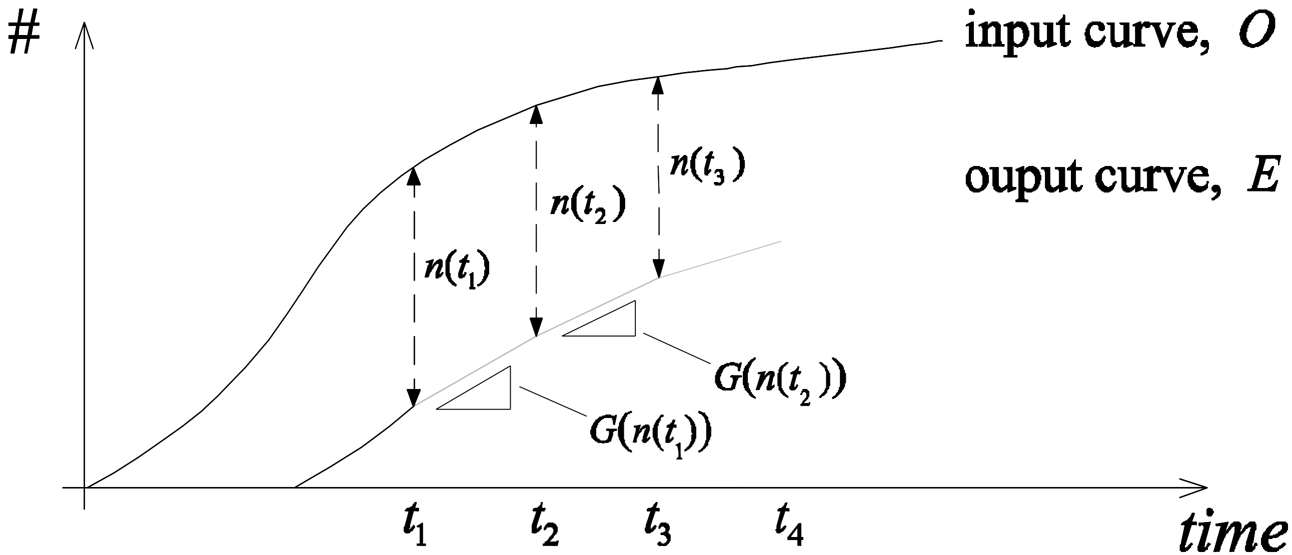
Output: $e = G(n)$

$$\frac{dn(t)}{dt} = q_{in}(t) - G(n(t))$$



(Daganzo, 2007)

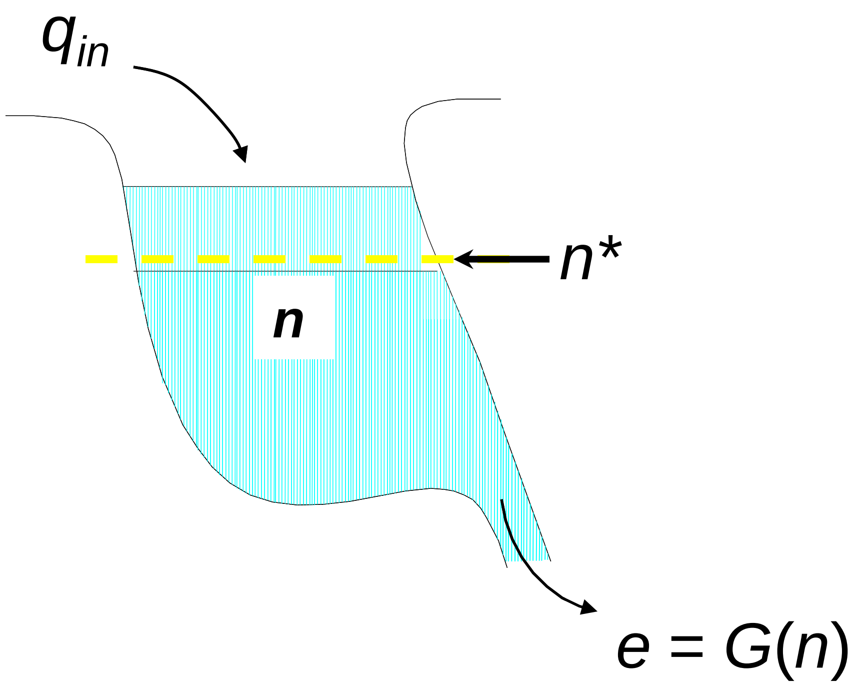
1-Bin Solution: Graphical Interpretation

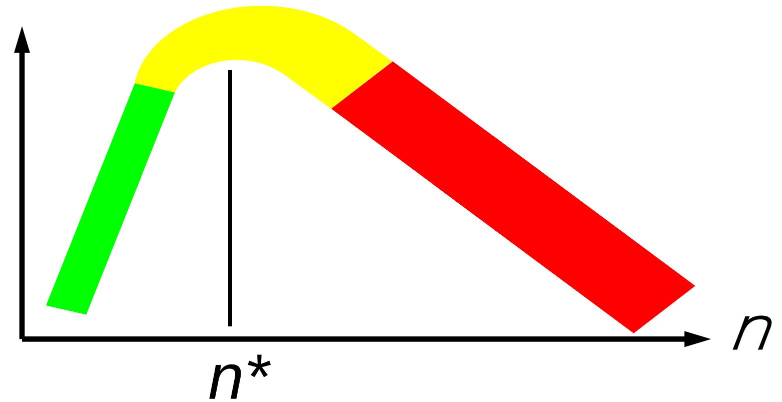


$$\frac{dn(t)}{dt} = O(t) - G(n(t))$$

(Daganzo, 2007)

1-Bin Model:
Control Strategy

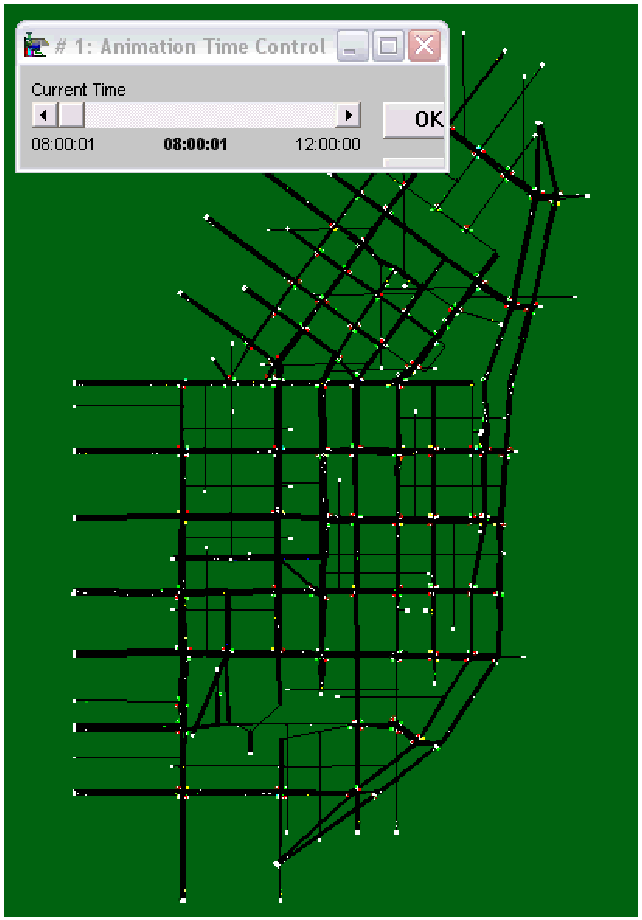


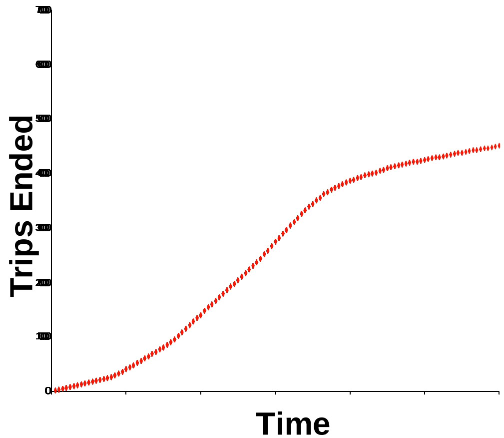


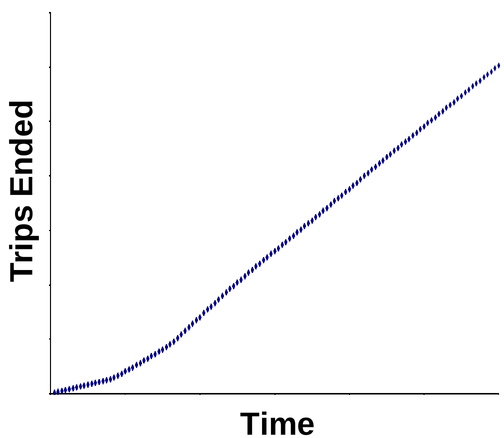
(Daganzo, 2007)

Application: Perimeter Control

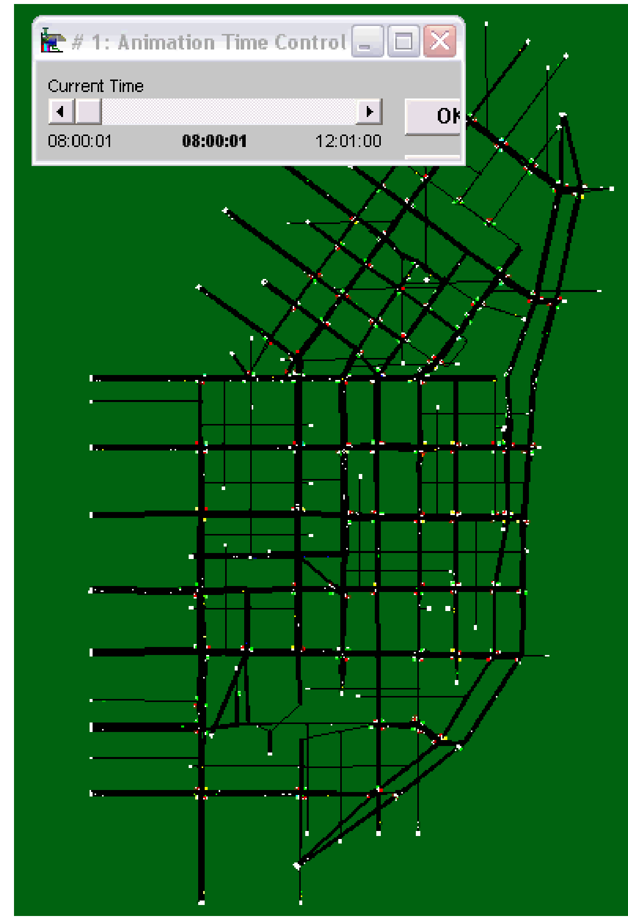
No Control







With Control



Restrict vehicles from entering

(Geroliminis & Daganzo, 2007)

1-Bin Model: Caveats

- Conditions favoring an even distribution of traffic
  - Uniform demand
  - Homogeneous networks
  - Adaptive drivers
  - Redundant networks
  - Neighborhoods big but not too big

- Are there forces working against an even distribution?
  - Yes: congestion attracts congestion
    But: Driver adaptation mitigates this effect

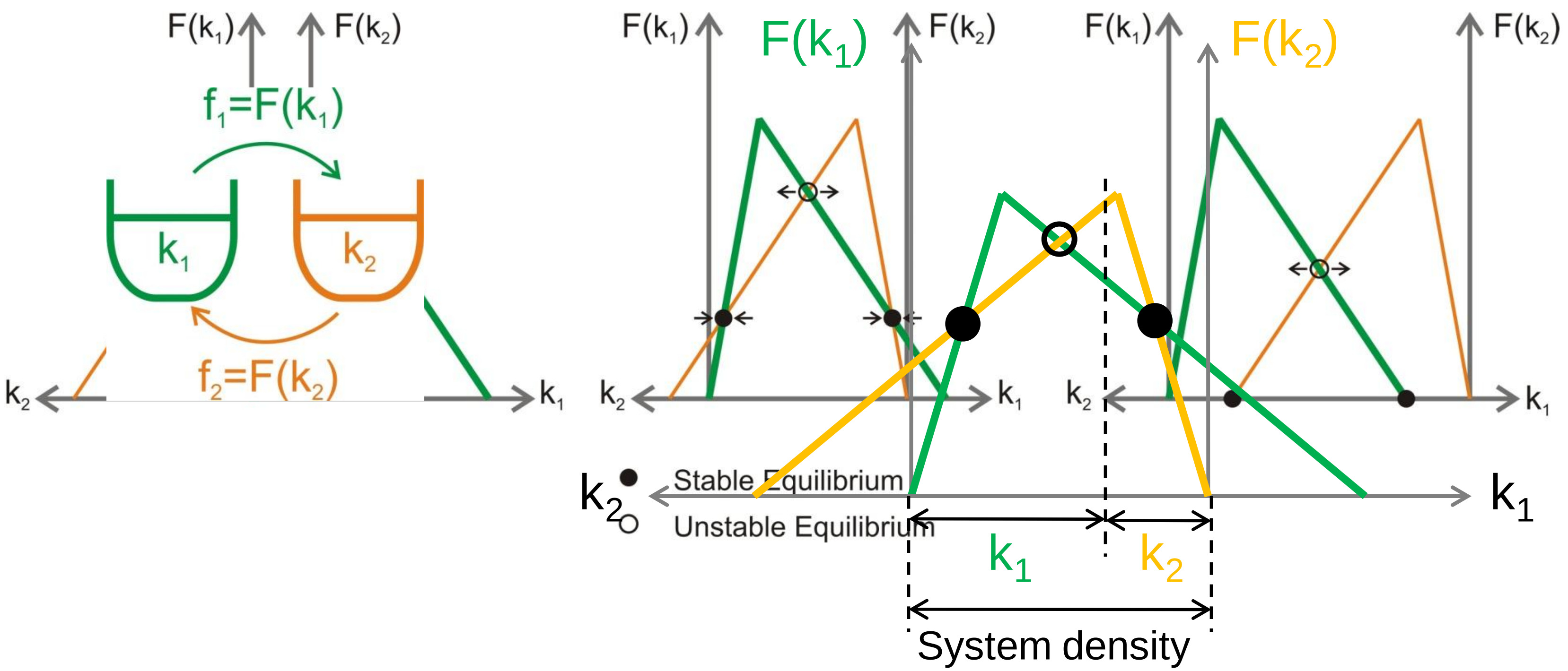
(Daganzo, 2007, Daganzo et al, 2010)

2-Ring Simulation

- http://www.ce.berkeley.edu/~daganzo/Simulations/two_ring_sim.html

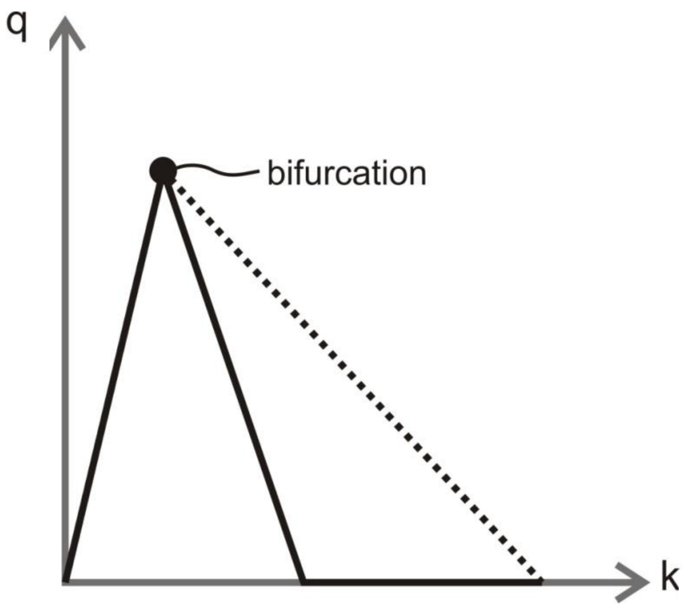
(Gayah and Daganzo 2010a)

Explanation: 2-Bin Model

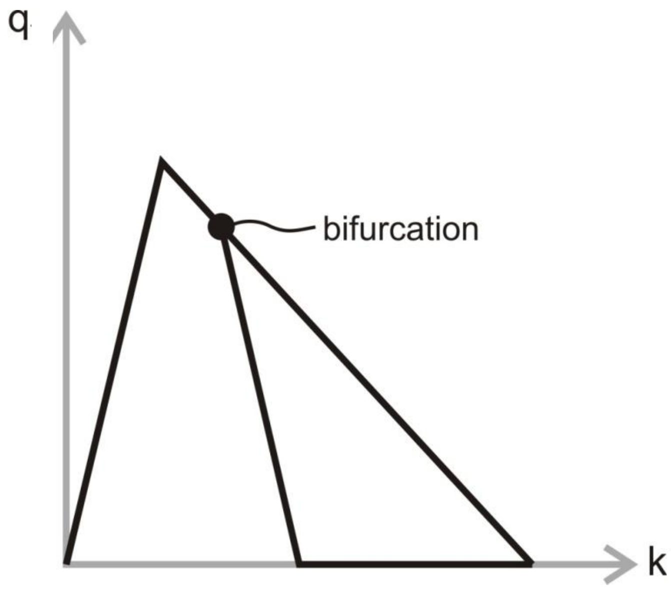


MFDs of 2-Bin Model

Non-adaptive drivers



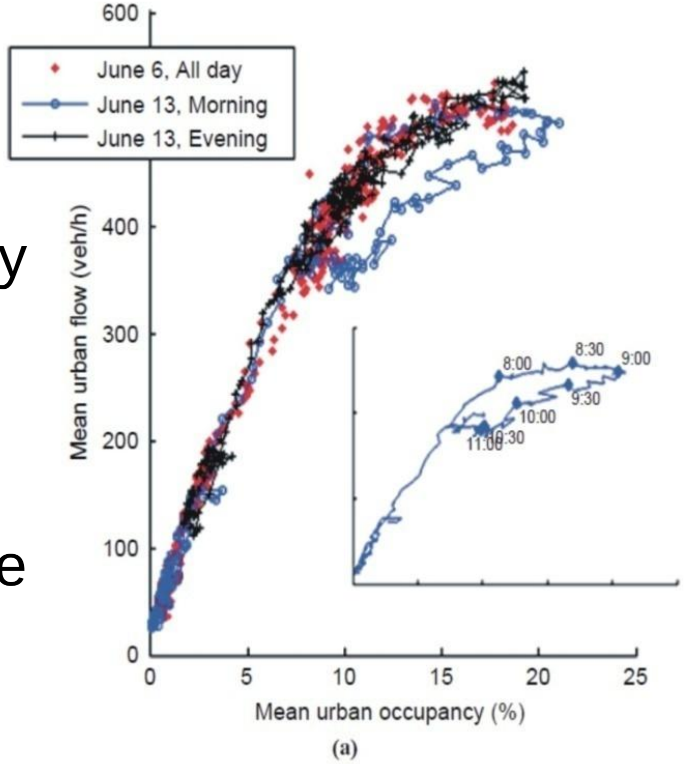
Adaptive drivers



Recent Findings

- Endogenous trip completion rates exacerbate effect and produce hysteresis loops beneath MFD.
- Hysteresis has been observed in reality

  (Buisson and Ladier, *JTRB* **2124**, 127-136, 2009)
- Yokohama's empirical evidence suggests that adaptation can overcome these problems for moderate congestion.



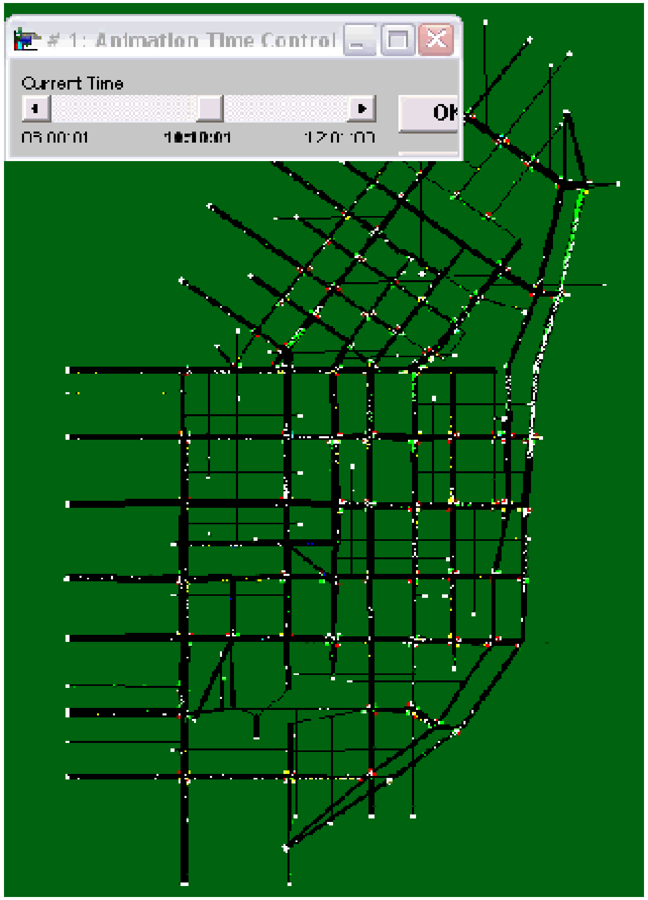
(Source: Buisson & Ladier, 2009)

(Gayah and Daganzo 2010b)

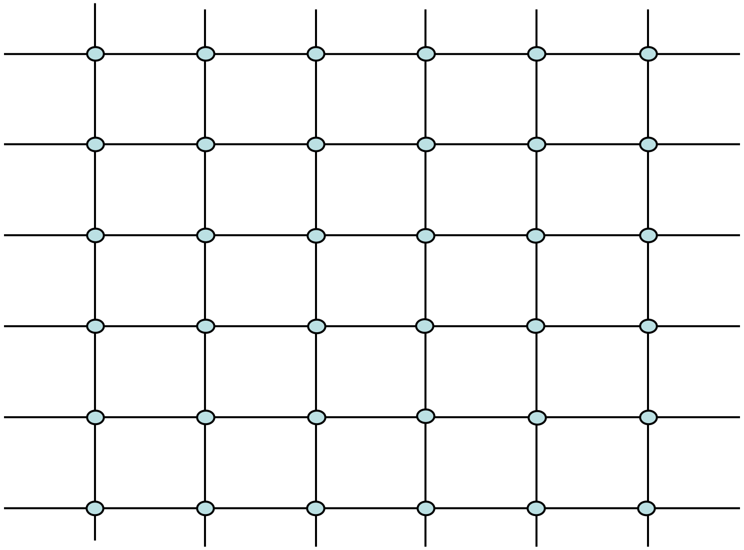
URBAN TRAFFIC: Summary

- Macroscopic models possible if vehicles distribute themselves evenly.
- Robust traffic management strategies are then possible.
- Homogeneous demand and driver adaptation even out the vehicular distribution
- Too much congestion can destroy evenness, reducing flow.
- Control strategies to redistribute traffic favorably should be considered.

Aggregate Models of Transit



Traffic Network



Transit Network

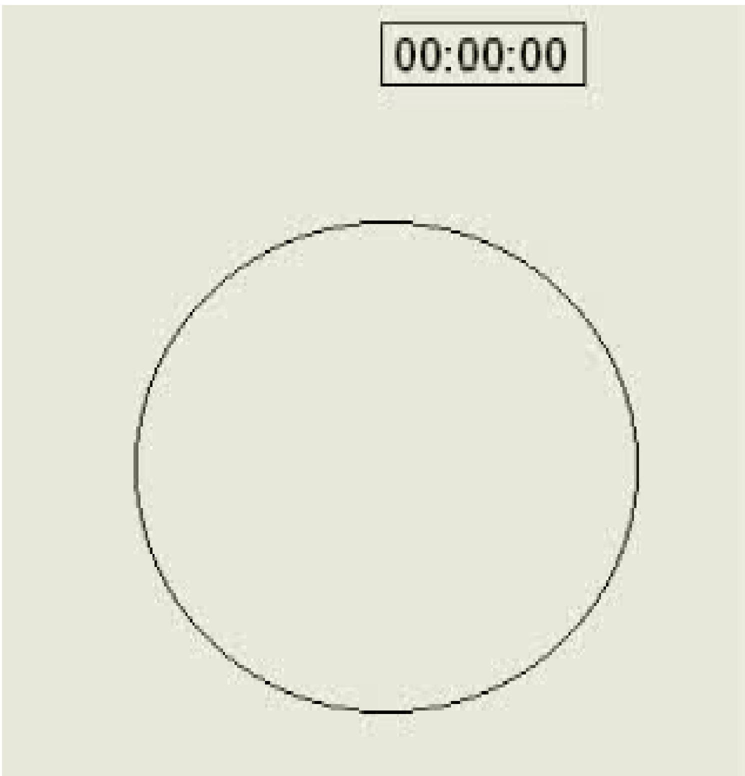
URBAN TRANSIT:
Goal of Design Method

	When you want it?	Where you want it?	Quick?
STATUS QUO			
Individual Transportation (Auto)	YES	YES	YES
Public Transportation (Metro)	YES	NO	YES
Public Transportation (Bus)	NO	YES	NO

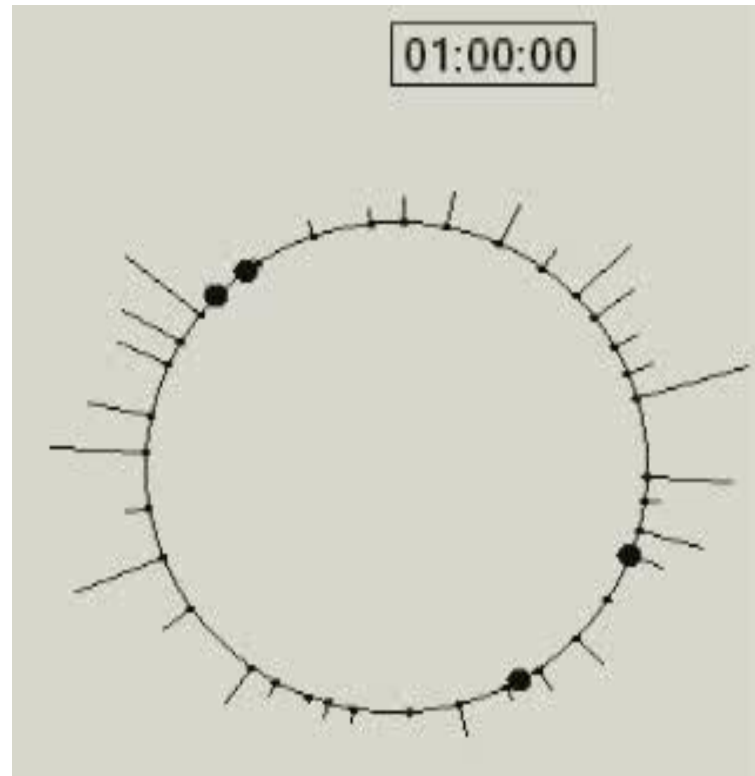
VISION			
Public Transportation (Next-gen Bus)	YES	YES	YES

The Spatial Distribution of Buses

4 Buses Uncontrolled



4 Buses Controlled



(Daganzo and Pilachowski, 2010)

1-Bin Design Method

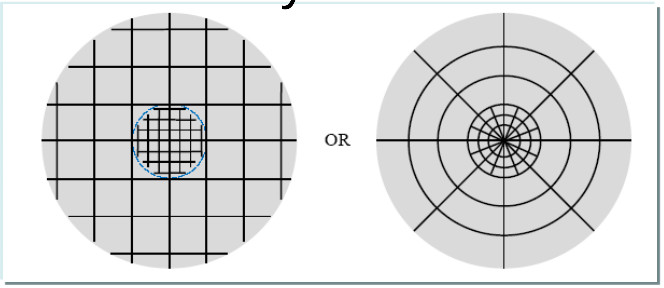
1. Define 2 decision variables for the network shape and the network density (i.e., the vehicular distribution inside the bin)

2. Define 1 decision variable for the headway or equivalently the fleet size (i.e., the number of buses in the bin)

3. Express society's welfare (combining passenger travel times and the agency costs) in terms of the 3 decision variables; and optimize.

4. Adapt the macroscopic 1-bin solution to the microscopic city details.

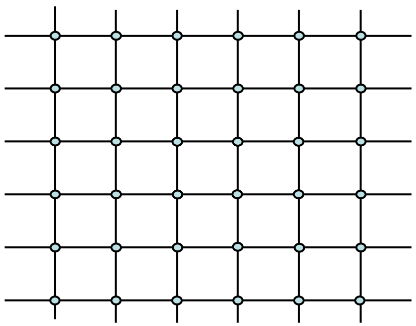
Analytic Model



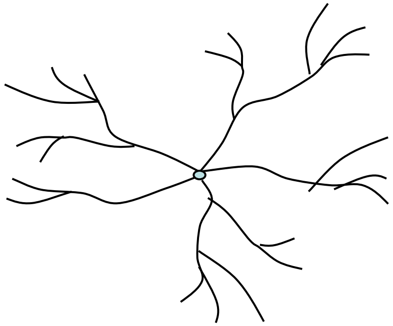
Real Solution

(Daganzo, 2010)

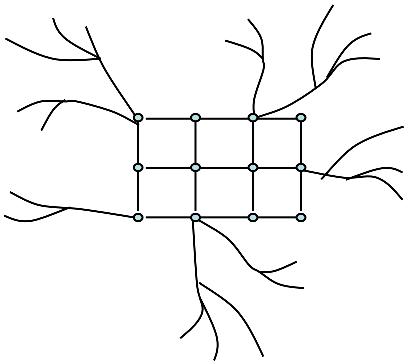
Network Shapes



Grid
(Holroyd, 1965)



Radial
(Air Transport 1980's)



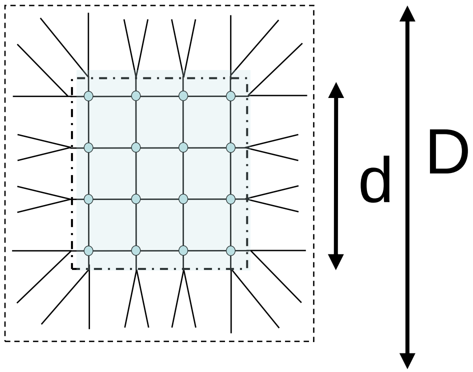
Hybrid
(Daganzo, 2010)

Decision Variable Definitions: Basic Concept

Headway (H)

Stop separation (s) = Line separation

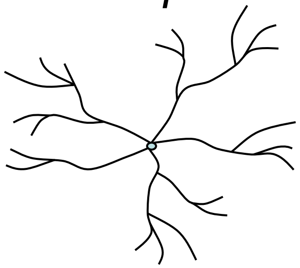
Ratio of central area, $\alpha=(d/D)$



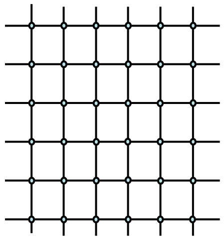
Basic Hybrid Structure

The hybrid concept can represent varied public transportation structures:

$\alpha=0$, radial



$\alpha=1$, grid

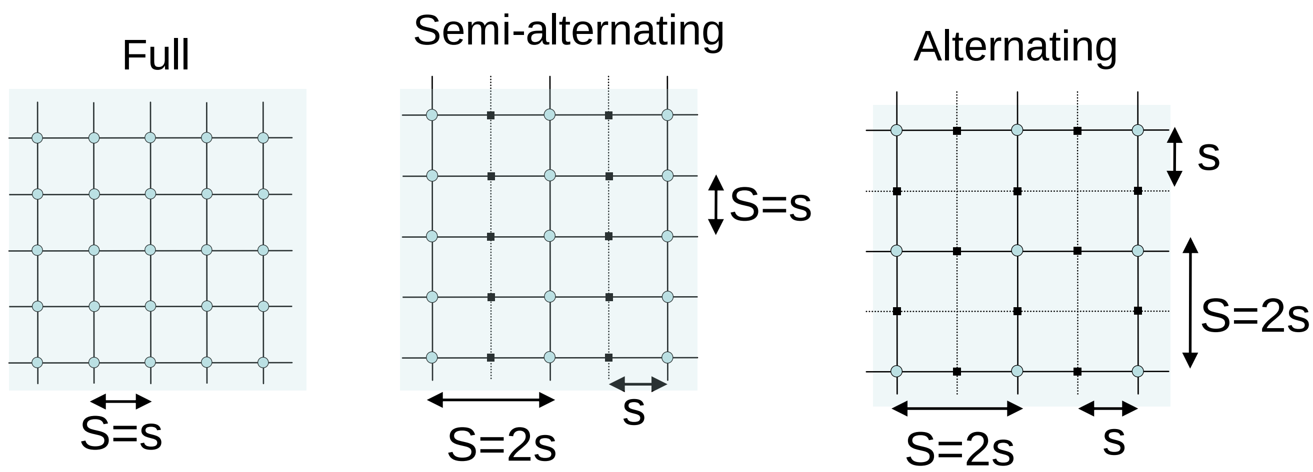


Generalized Concept

<u>Additional variable</u>

Line separation (S)

- ▪ Ordinary stop (no transfer)
- ○ Transfer stop



(Estrada et al, 2010)

1-Bin Model Formulation: Objective function and decision variables

$$\min\left\{Z=\left[\pi_V V+\pi_M M+\pi_L L\right]+\left[A+W+T+\left(\delta/v_w\right)e_T\right]: s\geq 0, H\geq 0, 0\leq\alpha\leq 1, O\leq C\right\}$$

Agency time cost — User time cost

Agency costs (depend on α, s, H)

V	[veh-km/h]	Bus distance traveled per hour
M	[veh-h/h]	Fleet size
L	[km]	Length of two-way infrastructure
O	[pax/veh]	Maximum vehicle occupancy

User costs (depend on α, s, H)

A	[h]	Mean walking time
W	[h]	Mean waiting time
T	[h]	Mean riding time
e_T	[-]	Mean number of transfers
δ / v_w	[h]	Transfer Time

(Daganzo 2010)

Optimal Design: Large City Results

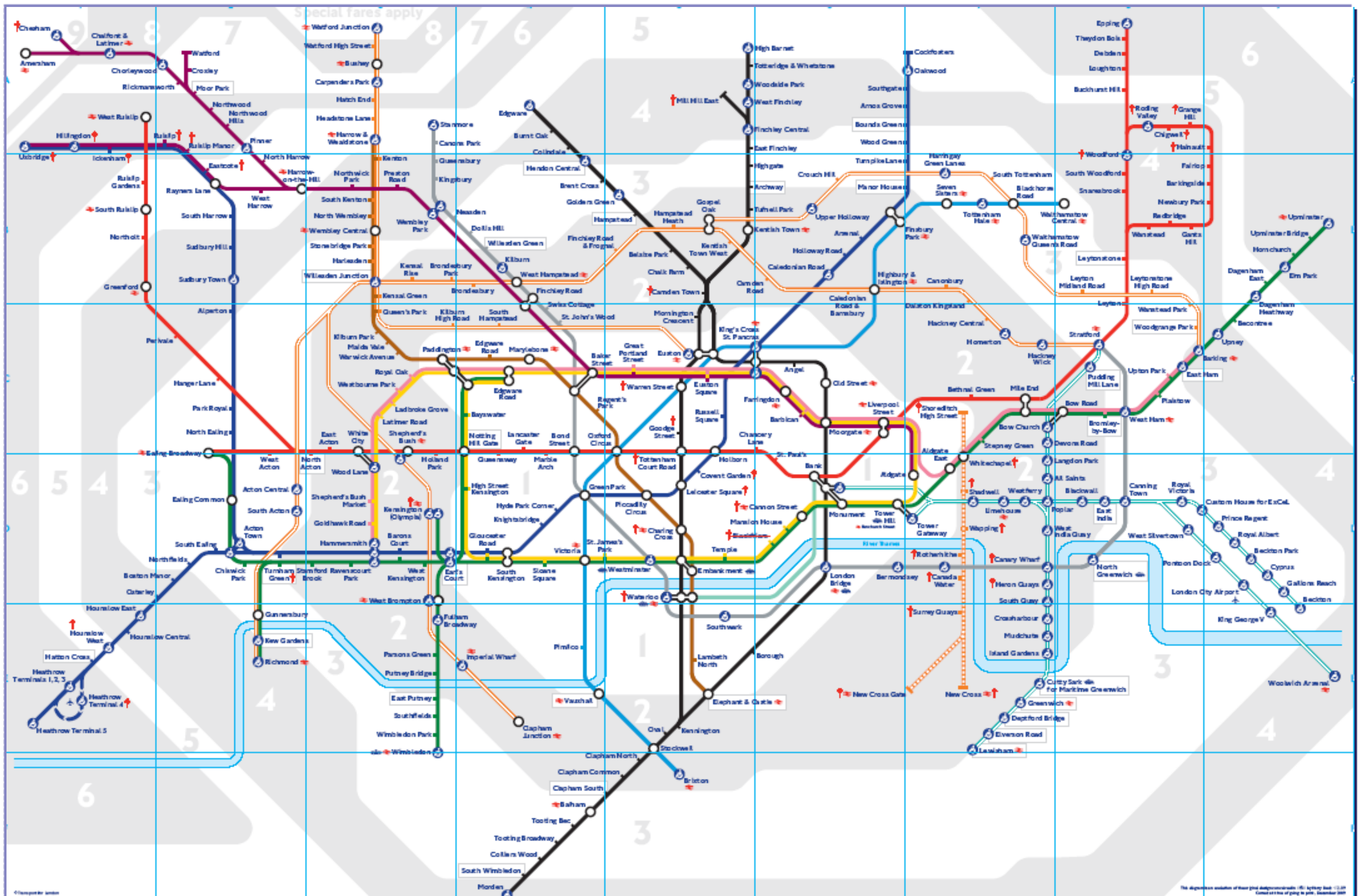
Typical parameter values for: Bus, BRT and Metro.

	C (p)	v (km/h)	$\$_L$ (\$/km-h)	$\$_V$ (\$/veh-km)	$\$_M$ (\$/veh-h)
Bus	120	25	9	1	30
BRT	150	40	90	1	30
Metro	1000	60	900	3	40

Application to a large city (e.g., London, I=80,000 pax/h; D=20 km)

	α	s (km)	*H* (min)	*O* (pax)	*M* (veh)	*v*c (km/h)	Z (min)
Bus	**0.92**	0.56	3.5	110	2627	17.8	**71**
BRT	**0.83**	0.61	3	150*	1882	25.1	**62**
Metro	**0.57**	1.05	2.5	396	724	35	**88**

London Metro



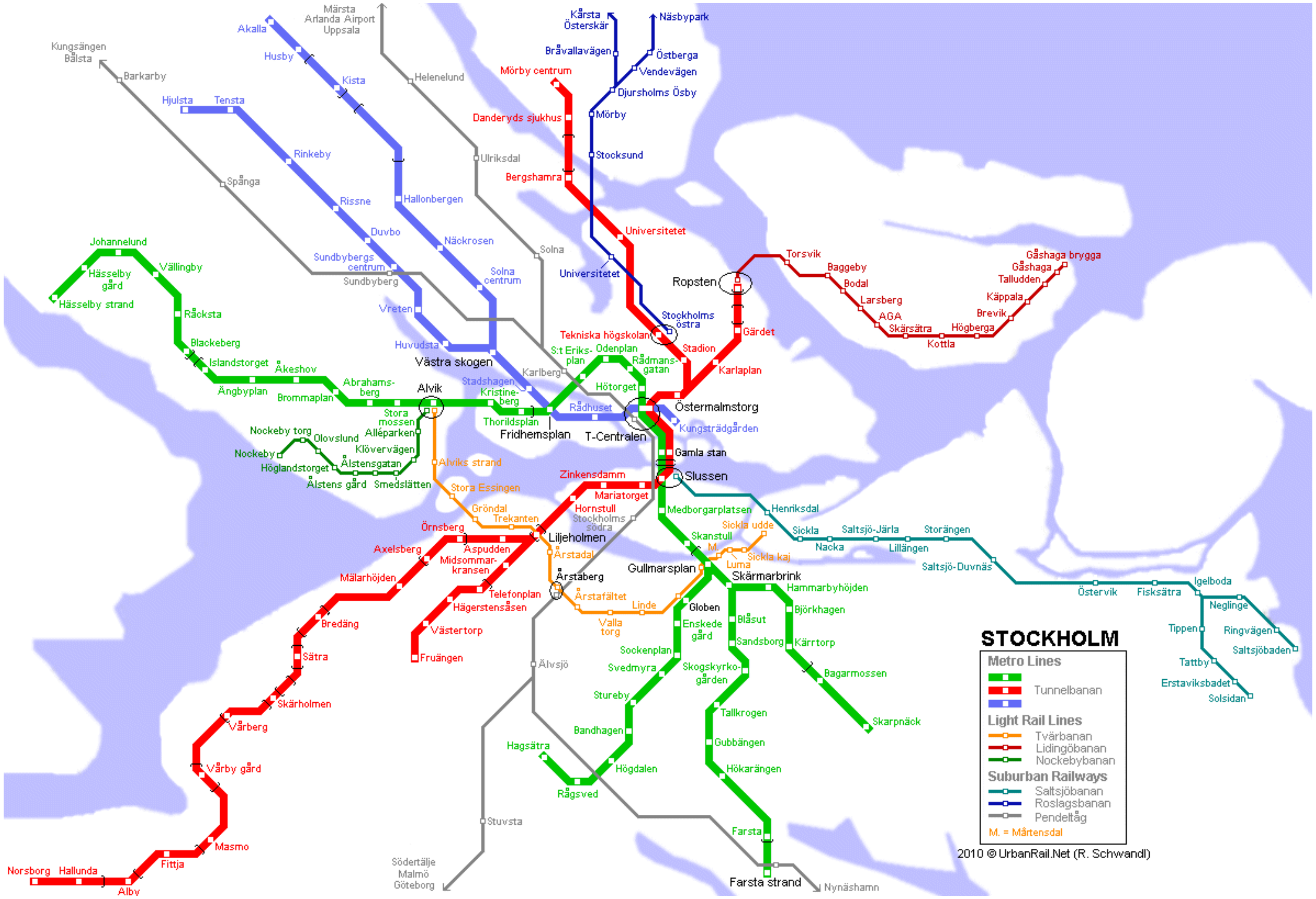
Optimal Design: Medium City Results

Application to a medium city
(e.g., Philadelphia l=20,000 pax/h; D=10 km)

	α	s (km)	*H* (min)	*O* (pax)	*M* (veh)	*Vc* (km/h)	z (min)
Bus	**0.94**	0.47	5.0	65	599	16.5	**51**
BRT	**0.81**	0.53	4.0	95	437	23.0	**49**
Metro	**0.38**	0.97	3.0	314	121	33.8	**75**

Philadelphia

Stockholm



Märsta
Arlanda Airport
Uppsala
Kungsängen
Bålsta
Barkarby
Akalla
Husby
Kista
Helenelund
Hjulsta
Tensta
Rinkeby
Spånga
Ulriksdal
Rissne
Hallonbergen
Duvbo
Näckrosen
Solna
Sundbybergs centrum
Sundbyberg
Solna centrum
Vreten
Huvudsta
Västra skogen
Johannelund
Vällingby
Hässelby gård
Hässelby strand
Råcksta
Blackeberg
Islandstorget
Åkeshov
Ängbyplan
Brommaplan
Abrahamsberg
Alvik
Stora mossen
Alléparken
Nockeby torg
Olovslund
Klöververvägen
Nockeby
Höglandstorget
Ålstensgatan
Ålstens gård
Smedslätten
Alviks strand
Stora Essingen
Gröndal
Trekanten
Stadshagen
Kristineberg
Thorildsplan
Fridhemsplan
Karlberg
Rådhuset
T-Centralen
Kårsta
Österskär
Näsbypark
Bråvallavägen
Östberga
Vendevägen
Mörby centrum
Djursholms Ösby
Mörby
Danderyds sjukhus
Stocksund
Bergshamra
Universitetet
Universitetet
Ropsten
Stockholms östra
Tekniska högskolan
S:t Eriks-plan
Odenplan
Rådmansgatan
Stadion
Gärdet
Karlaplan
Hötorget
Östermalmstorg
Kungsträdgården
Gamla stan
Slussen
Torsvik
Baggeby
Bodal
Larsberg
AGA
Skärsätra
Kottla
Högberga
Brevik
Käppala
Talludden
Gåshaga
Gåshaga brygga
Zinkensdamm
Mariatorget
Hornstull
Stockholms södra
Liljeholmen
Medborgarplatsen
Henriksdal
Sickla udde
Skanstull
Sickla
Saltsjö-Järla
Storängen
Nacka
Lillängen
Saltsjö-Duvnäs
Sickla kaj
Luma
M
Gullmarsplan
Skärmarbrink
Hammarbyhöjden
Björkhagen
Kärrtorp
Bagarmossen
Skarpnäck
Östervik
Fisksätra
Igelboda
Neglinge
Tippen
Ringvägen
Saltsjöbaden
Tattby
Erstaviksbadet
Solsidan
Örnsberg
Aspudden
Axelsberg
Midsommarkransen
Mälarhöjden
Telefonplan
Hägerstensåsen
Västertorp
Fruängen
Årstadal
Årstaberg
Årstafältet
Linde
Valla torg
Globen
Enskede gård
Sockenplan
Svedmyra
Stureby
Bandhagen
Högdalen
Rågsved
Hagsätra
Blåsut
Sandsborg
Skogskyrkogården
Tallkrogen
Gubbängen
Hökarängen
Farsta
Farsta strand
Nynäshamn
Älvsjö
Stuvsta
Södertälje
Malmö
Göteborg
Bredäng
Sätra
Skärholmen
Vårberg
Vårby gård
Masmo
Fittja
Norsborg
Hallunda
Alby
STOCKHOLM
Metro Lines
Tunnelbanan
Light Rail Lines
Tvärbanan
Lidingöbanan
Nockebybanan
Suburban Railways
Saltsjöbanan
Roslagsbanan
Pendeltåg
M. = Mårtensdal
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Tokyo


Tokyo
Toei lines
Asakusa Line
Mita Line
Shinjuku Line
Ōedo Line
Tokyo Metro lines
Ginza Line
Marunouchi Line
Hibiya Line
Tōzai Line
Chiyoda Line
Yūrakuchō Line
Hanzōmon Line
Namboku Line
Fukutoshin Line
JR Rail East lines
Yamanote Loop Line
Chūō Line
Sōbu Line / Rapid Airport Narita
Sōbu Chūō Line
Keiyo Line
Shinkansen
Other lines
Yurikamome Line
Tōkyō Monorail to Haneda Airport
Keisei Line / Sky Liner to Narita Airport
Keisei Oshiage Line Local
Keikyū Line Express to Haneda Airport
Rinkai Line
Ikebukuro
Shinjuku
Shibuya
Ueno
Tōkyō
Ōtemachi
Shimbashi
Shinagawa
Meguro
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Optimal Design:
Medium City Results

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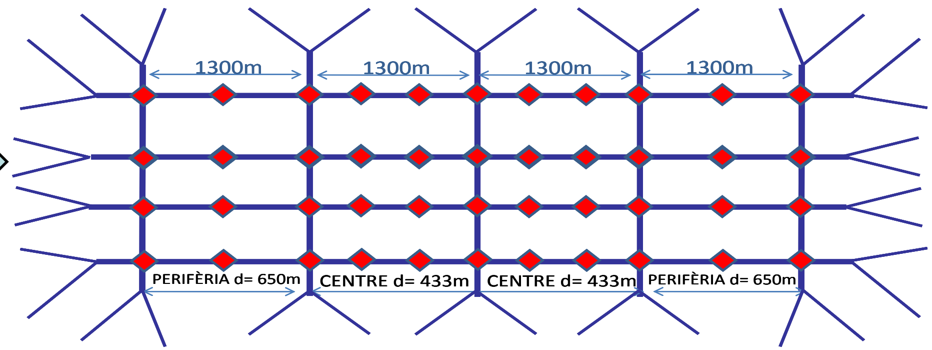
South Chicago: Buses and Metro

Numerical Results for Barcelona: a 10x5 km rectangle

	Current bus system	Semi-alternating (no BRT, v = 21 km/h)
Door-to-door travel time (min)	57,9	50,3
Commercial speed (km/h)	11,9	15,1
Number of Buses	890	272
Stop separations (m)	300	650 (430 in the center)
Network shape α = a/A = b/B	N.A.	0,80
Headway (min)	13	3



(Estrada et al, 2010)

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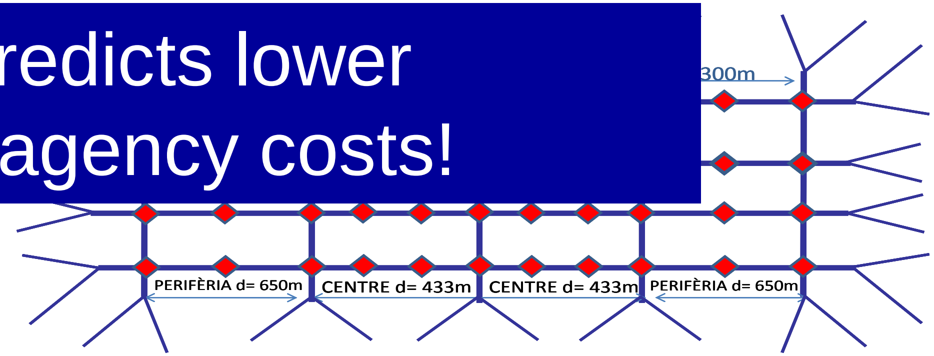
Commercial speed (km/h)	11,9	15,1
Number of Buses	**890**	**272**
Stop separations (m)	300	650 (430 in the center)
Network shape α = a/A = b/B	N.A.	0,80
Headway (min)	13	3

Model predicts lower
user and agency costs!



(Estrada et al, 2010)

Final Design Step:
From Macro to Micro

Simulations
- confirm the predicted savings
- match predictions to within 5%

Barcelona (2010-2011)

CENIT TMB Ajuntament de Barcelona

(Estrada et al, 2010)

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