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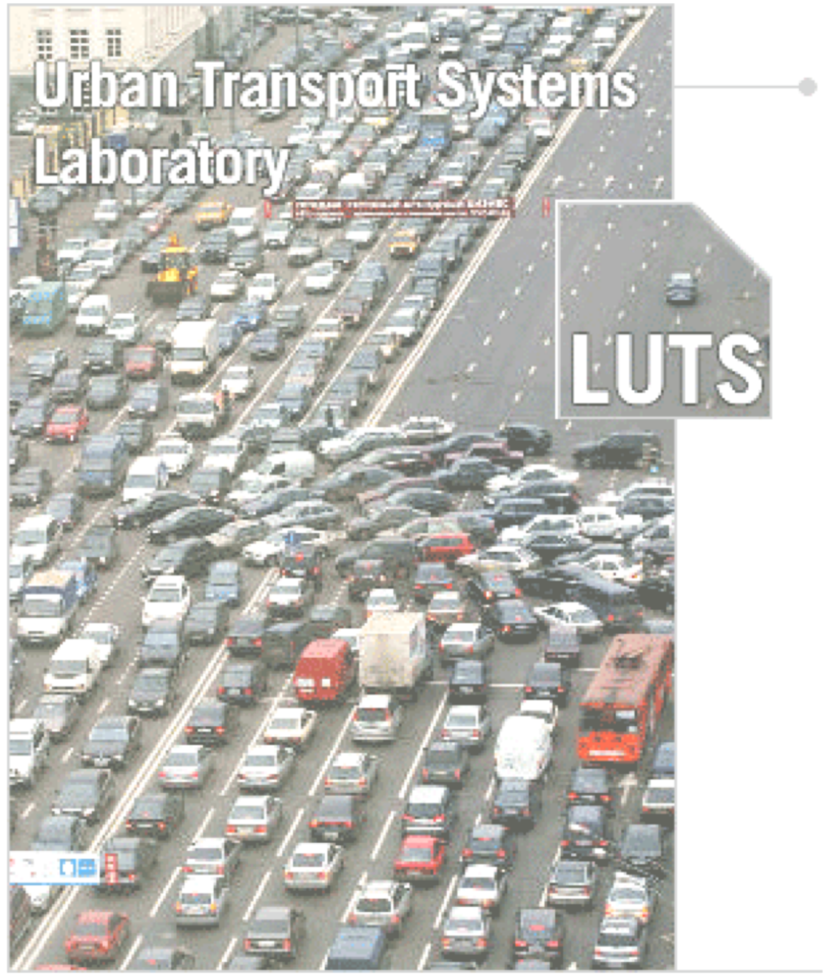
Macroscopic Fundamental Diagram:
Existence, Physical Properties and Dynamic Modeling



Intro to traffic flow modeling and ITS

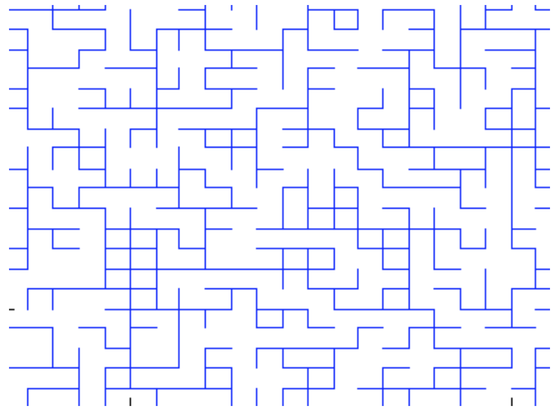
Prof. Nikolas Geroliminis

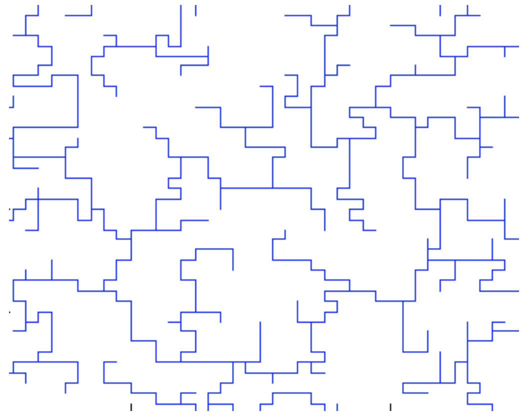
Regularity conditions for MFD

MFD **IS NOT** A UNIVERSAL LAW

Regularity conditions that possibly ensure an MFD

- A slow-varying and distributed demand
- Homogeneous spatial distribution of congestion
- A redundant network with many route choices
- Homogeneity in network topology





Regularity conditions for MFD

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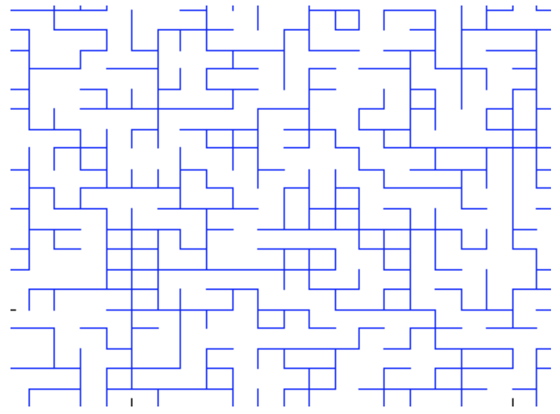
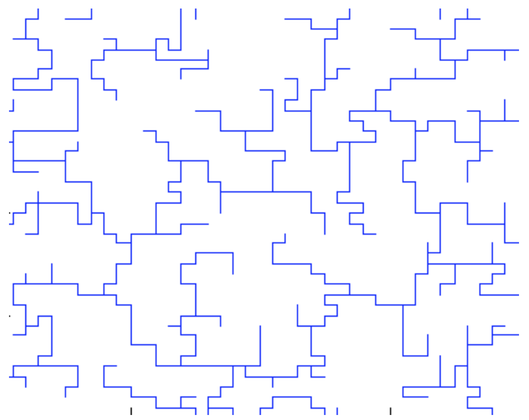
Regularity conditions that possibly ensure an MFD

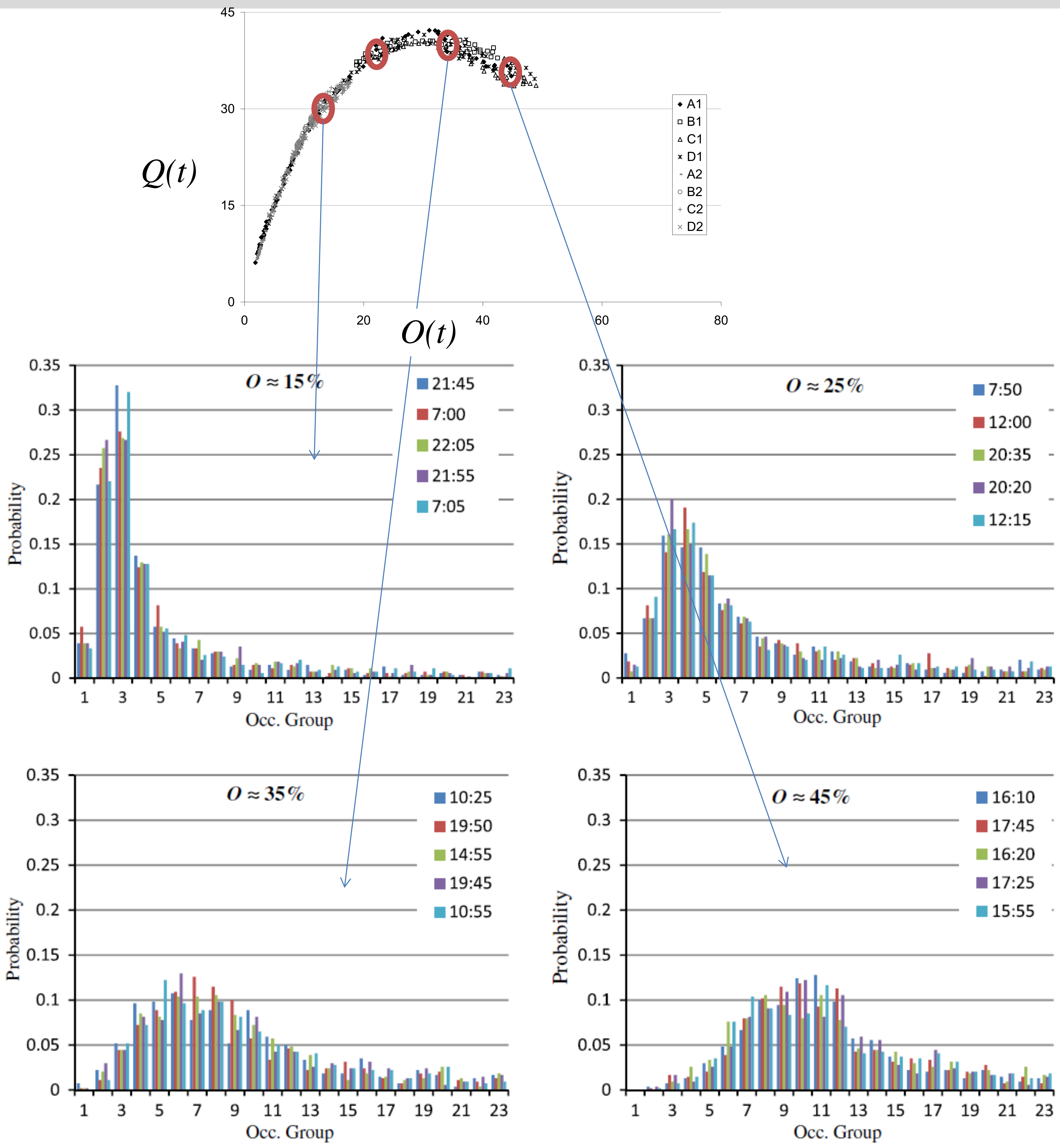




- A slow-varying and distributed demand
- Homogeneous spatial distribution of congestion
- A redundant network with many route choices
- Homogeneity in network topology

- An MFD with low scatter
  - locally heterogeneous but macroscopically regular networks (e.g. cities with multiple modes)
- An MFD with high scatter
  - Networks with uneven and inconsistent distribution of congestion (e.g. freeways)

Properties of well-defined MFDs



$d_r(t)$: pdf of individual detectors' density in region r

$Q(t)$ and $O(t)$: Space-Mean network flow and occupancy

$$\{Q(t_1) = Q(t_2) \quad \text{and} \quad O(t_1) = O(t_2)\}$$

$$\Longleftrightarrow d_r(t_1) \sim d_r(t_2).$$

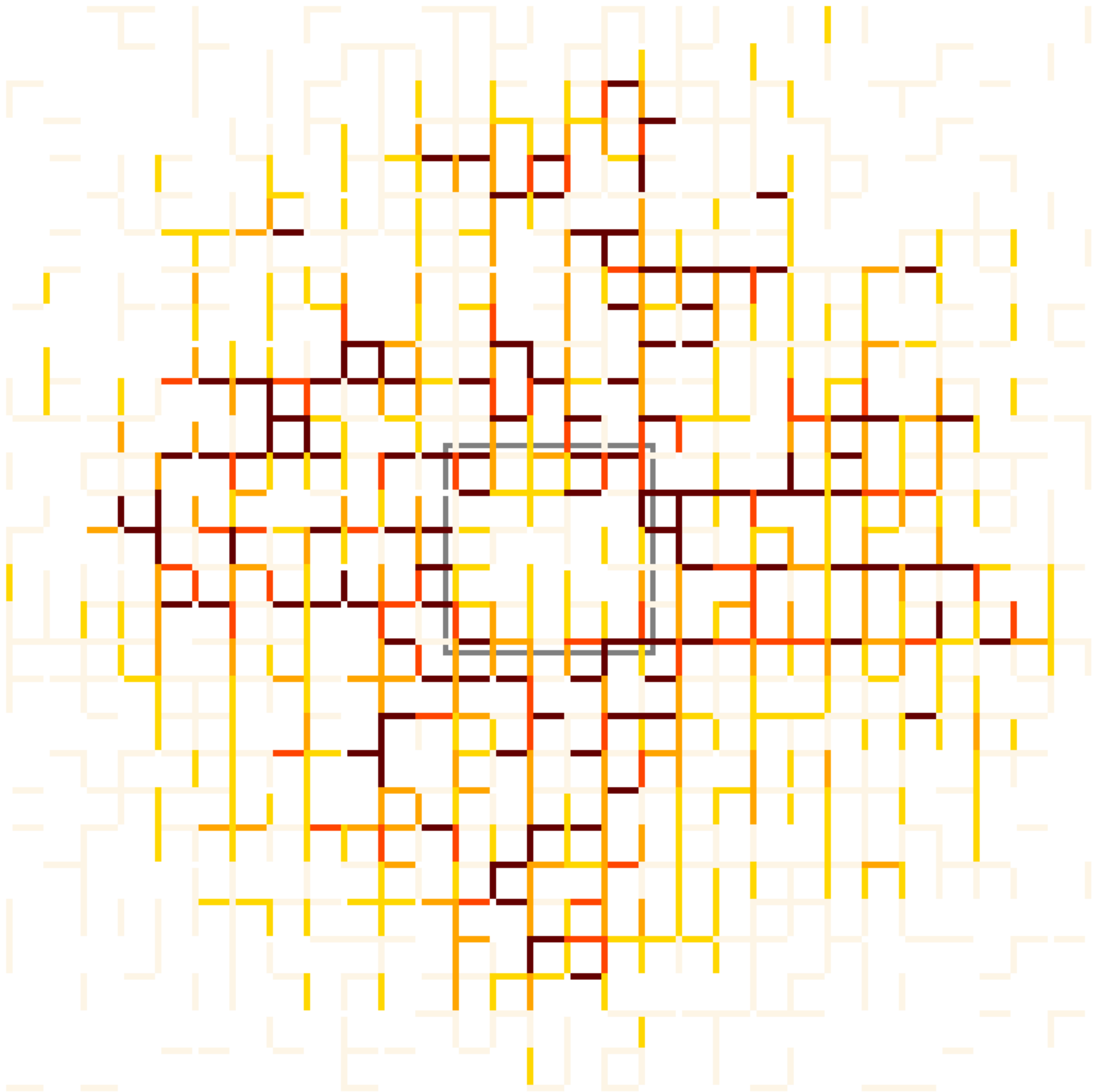
Variance much higher than binomial's

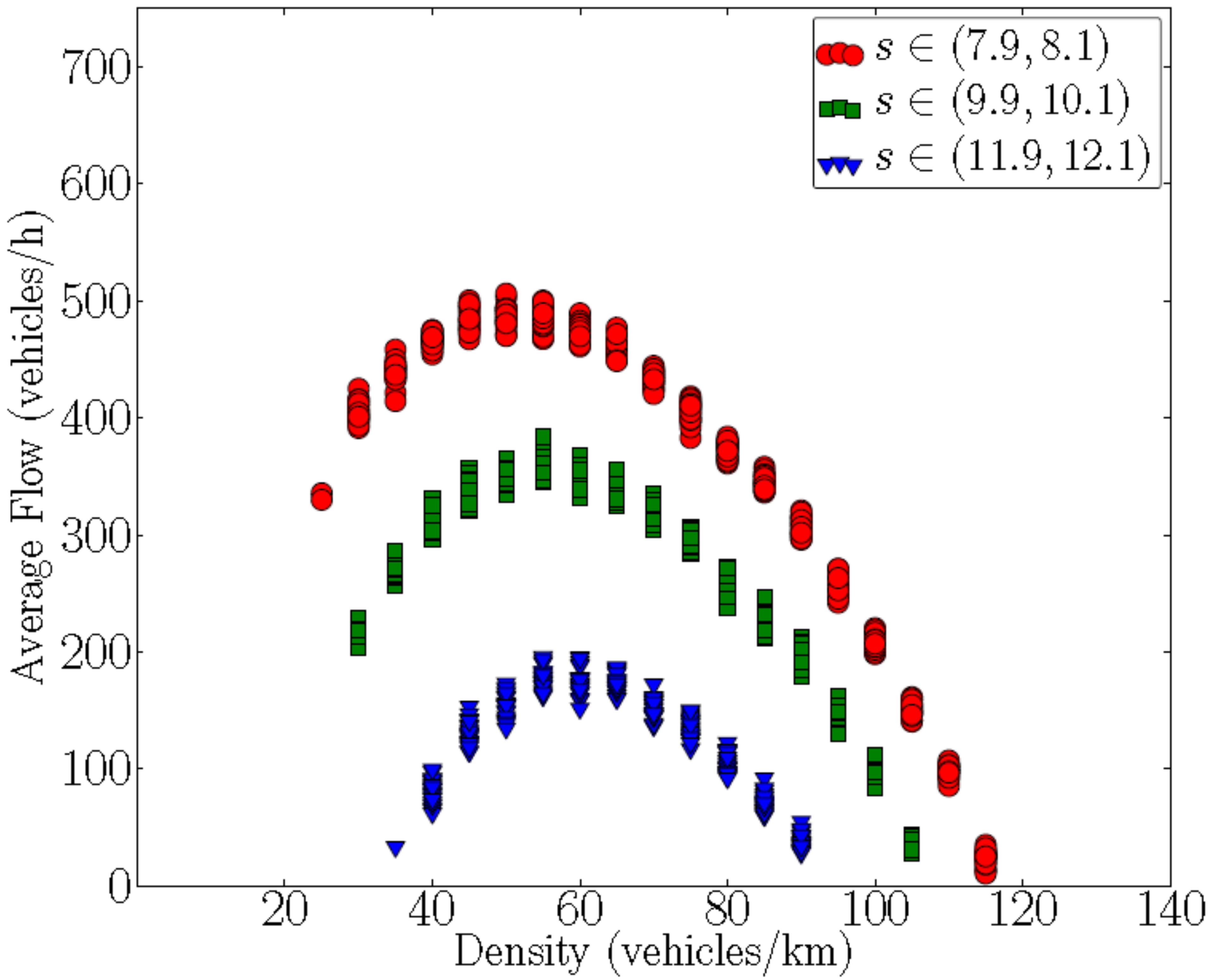
WHY?

Correlation of link density (propagation)

Geroliminis and Sun (2011) – Tr. Res. Part B

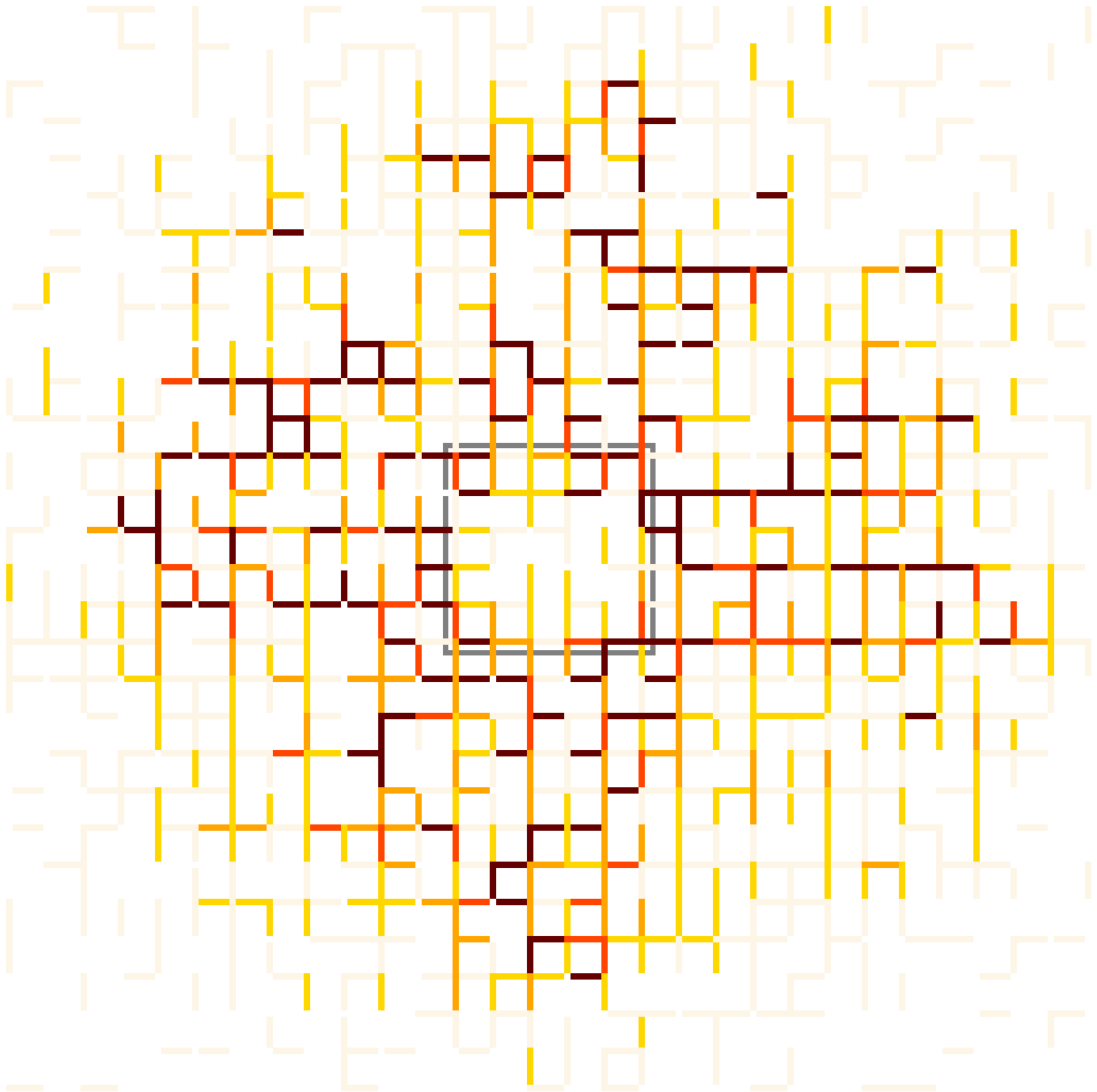
Spatial heterogeneity and MFD shape

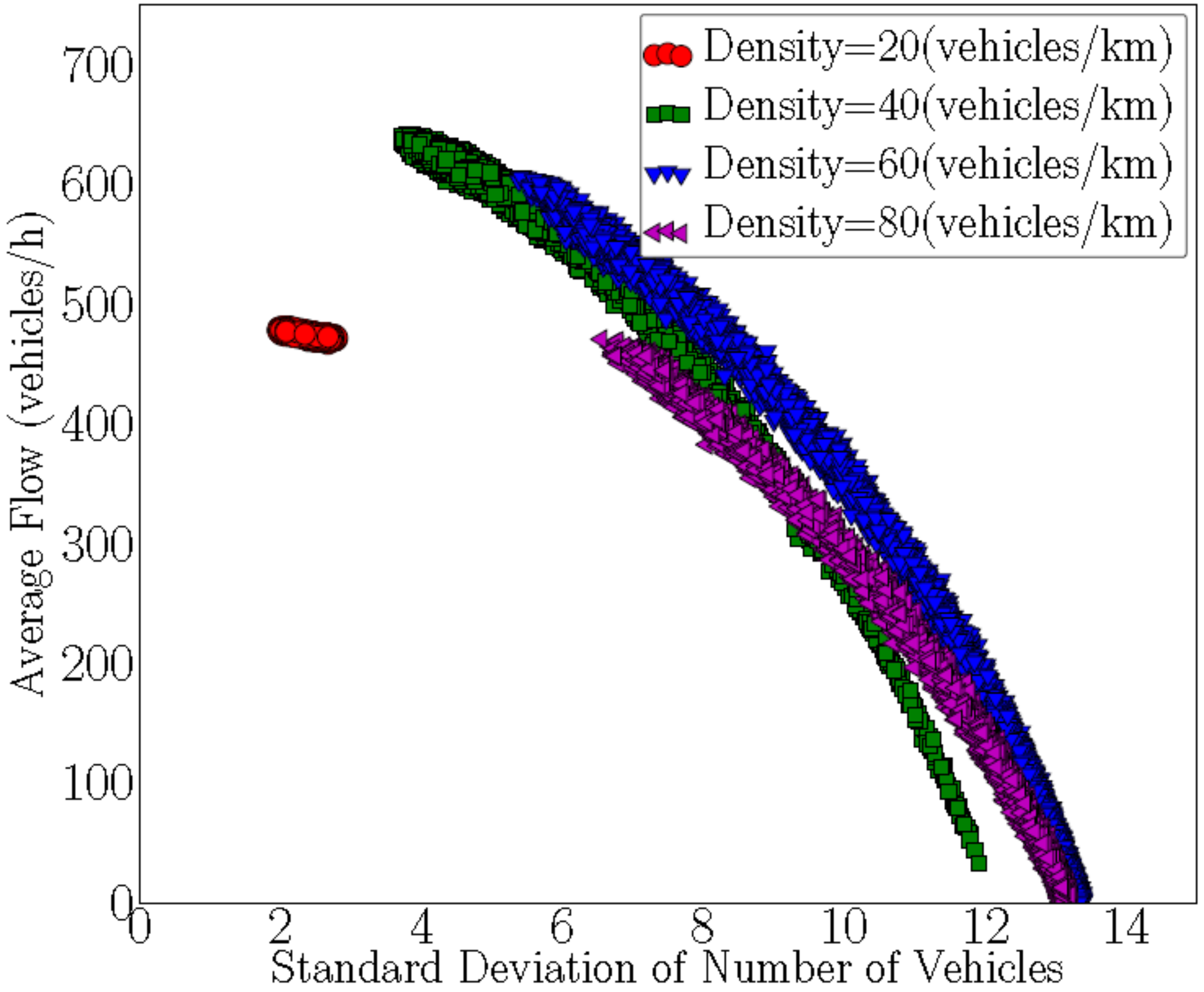




Mazloumian, Geroliminis and Helbing (2010) – Ph.Trans.Roy. Soc. A

Spatial heterogeneity and MFD shape

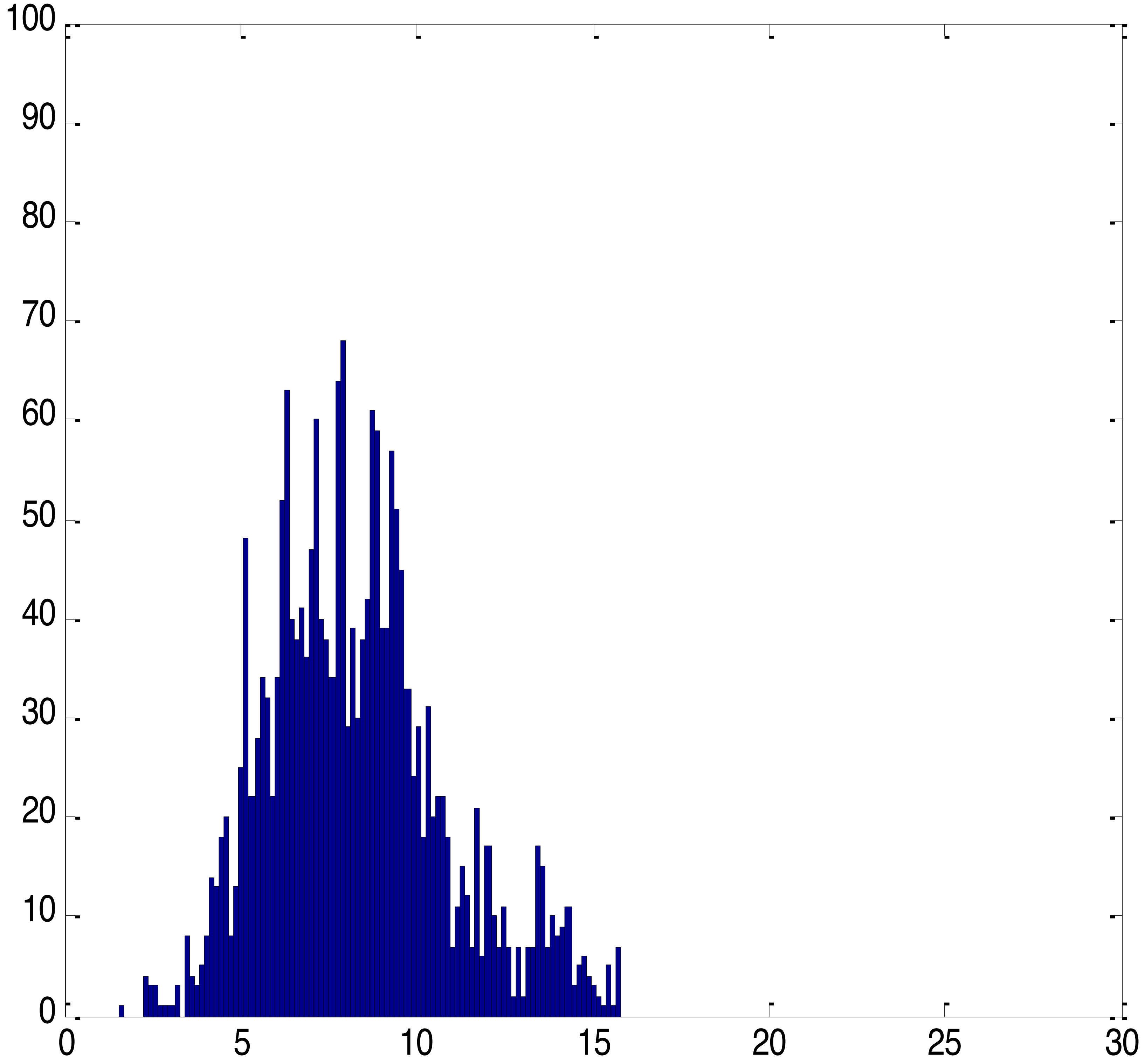




Mazloumian, Geroliminis and Helbing (2010) – Ph.Trans.Roy. Soc. A

Congestion propagation and MFD – Empirical analysis for a megacity

20000 taxis (25M points/day)	9000 links	12M population	Shenzhen, China

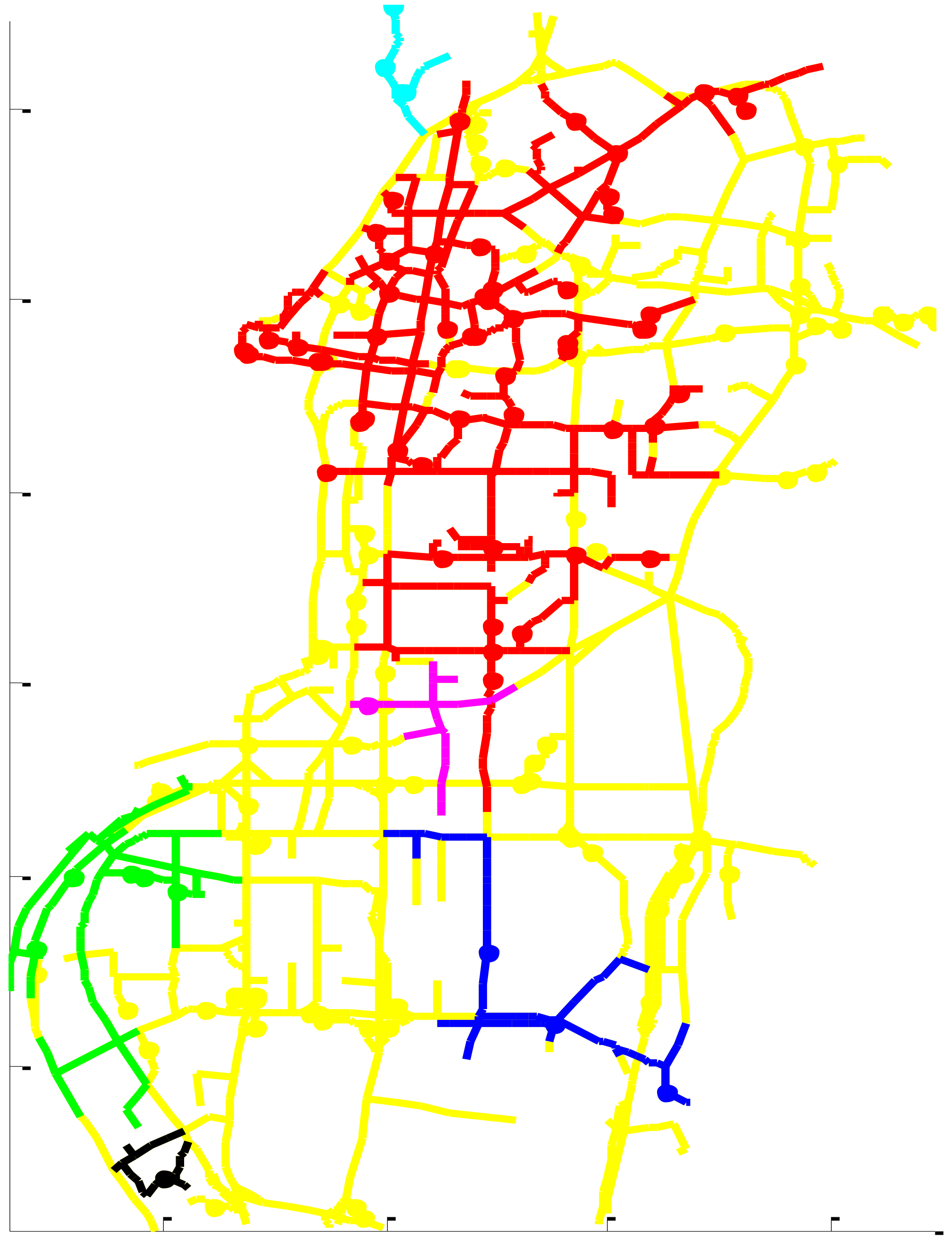


Link Speed Histogram (miles/hr)

Ji, Y., Luo, J., Geroliminis, N. (2014). Empirical Observations of Congestion Propagation and Dynamic Partitioning with Probe Data for Large-Scale Systems, in Transportation Research Record, 2422 (2), 1-11. ***(Greenshields' prize)***

Taxi data processing

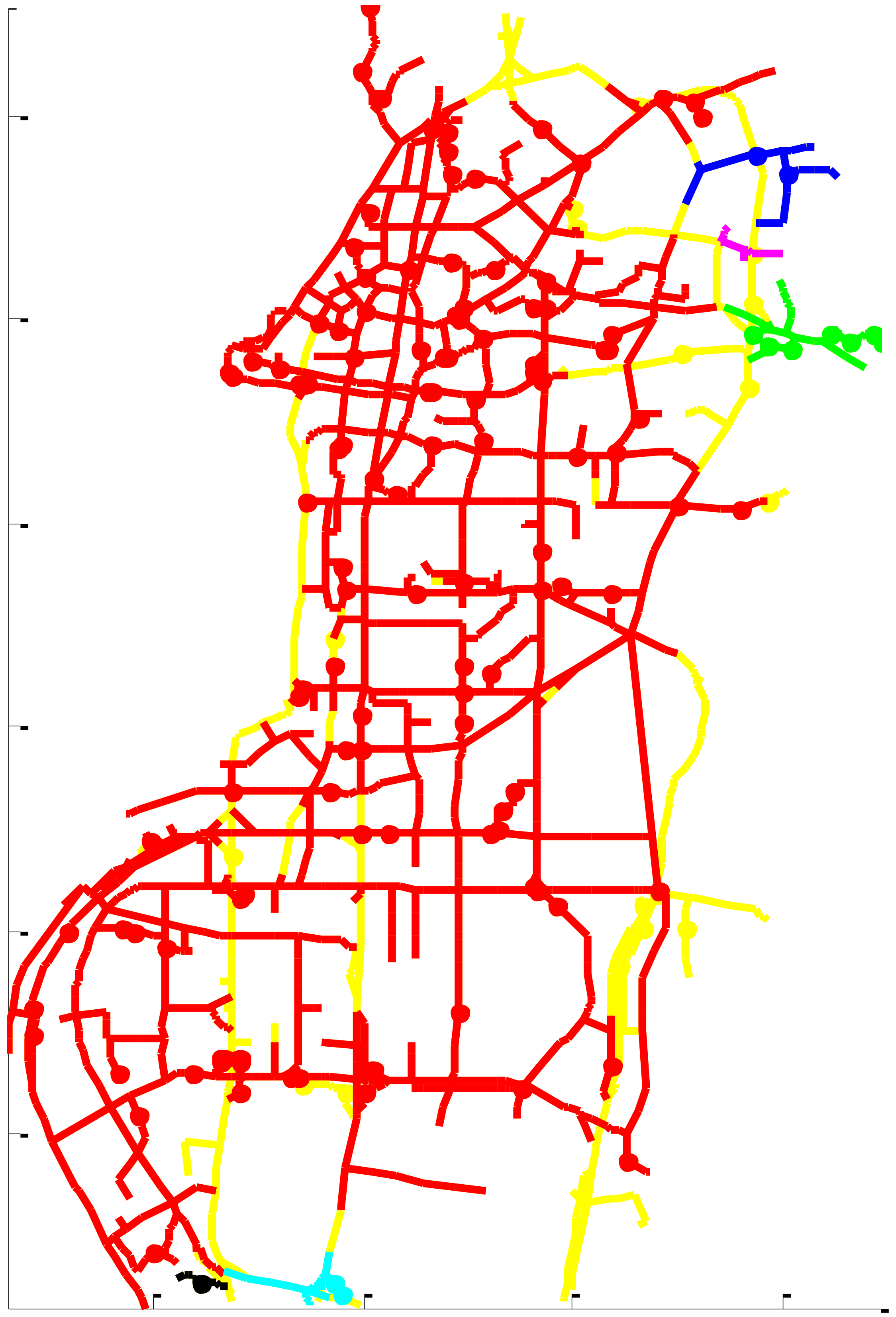
- Location and speed of taxis every ~20sec
- Estimate link speeds from taxi data
  - 6am - 8am, 15-min interval every 5 min
- Identify congested links
  - Congested link speed <= 1/3 of max speed
- Estimate the largest connected components
  - breadth-first search algorithm



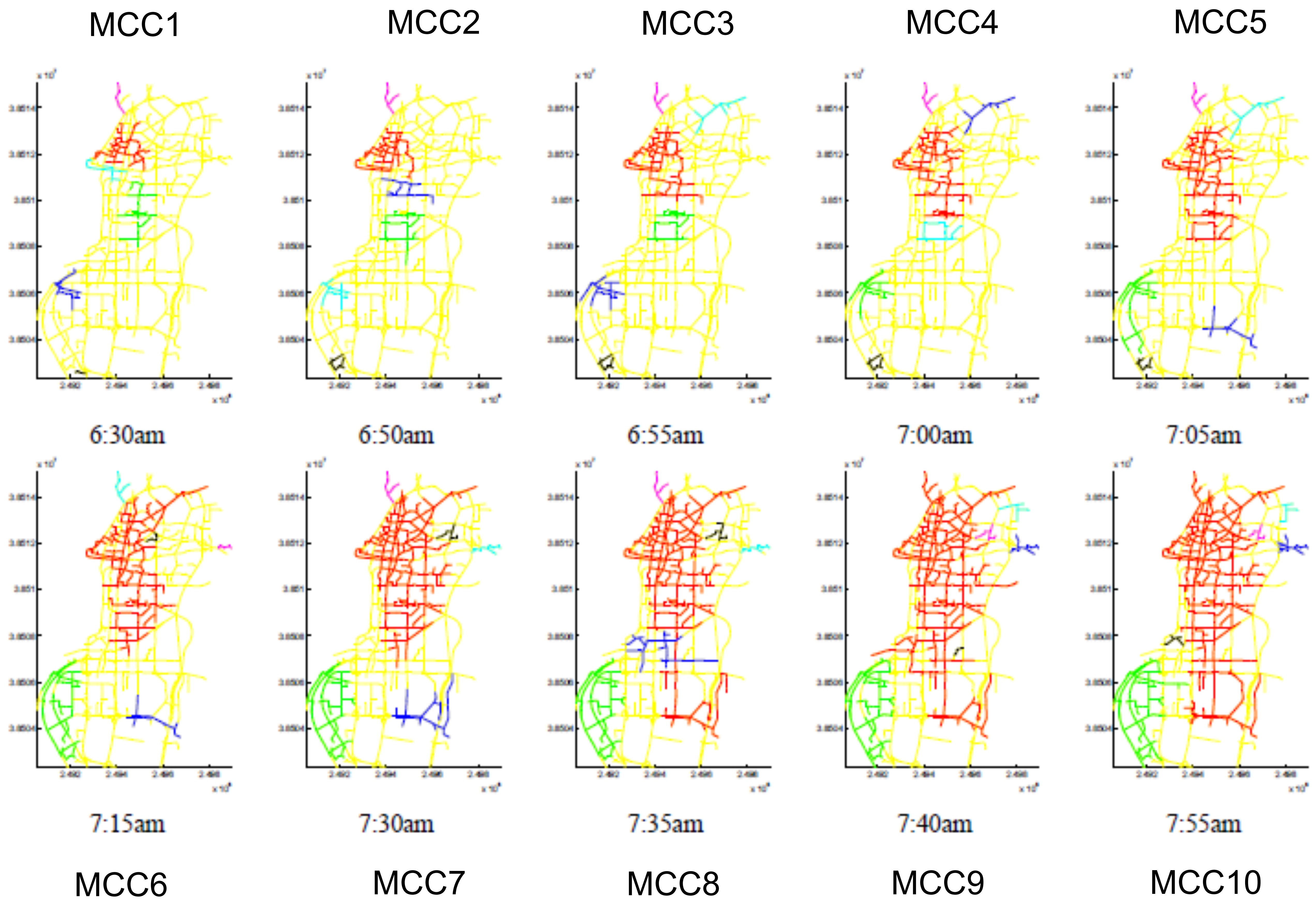
Evolution of congested regions

Small number of critical pockets of congestion

Dynamic partitioning is feasible with CC

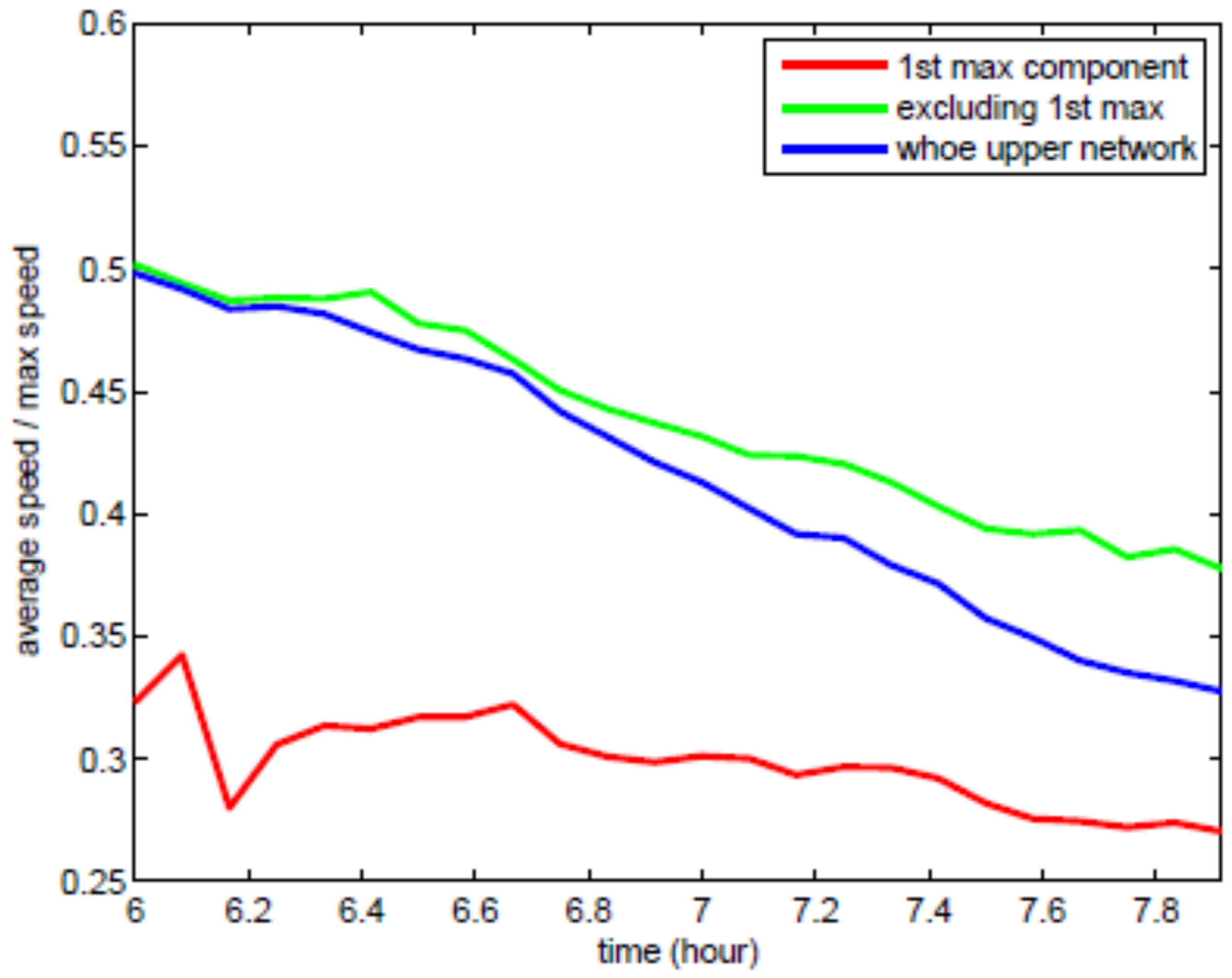


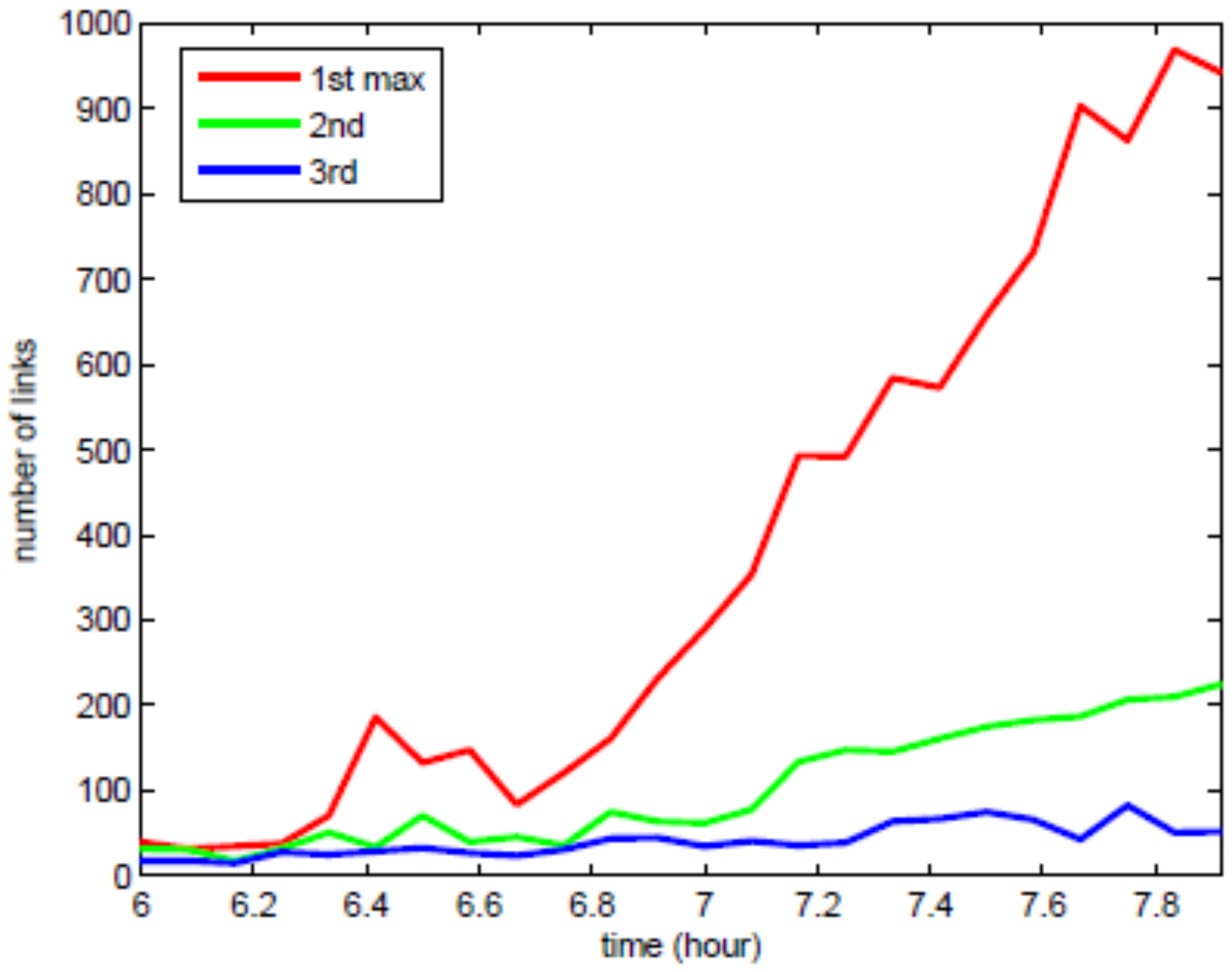
Snapshots for different time periods

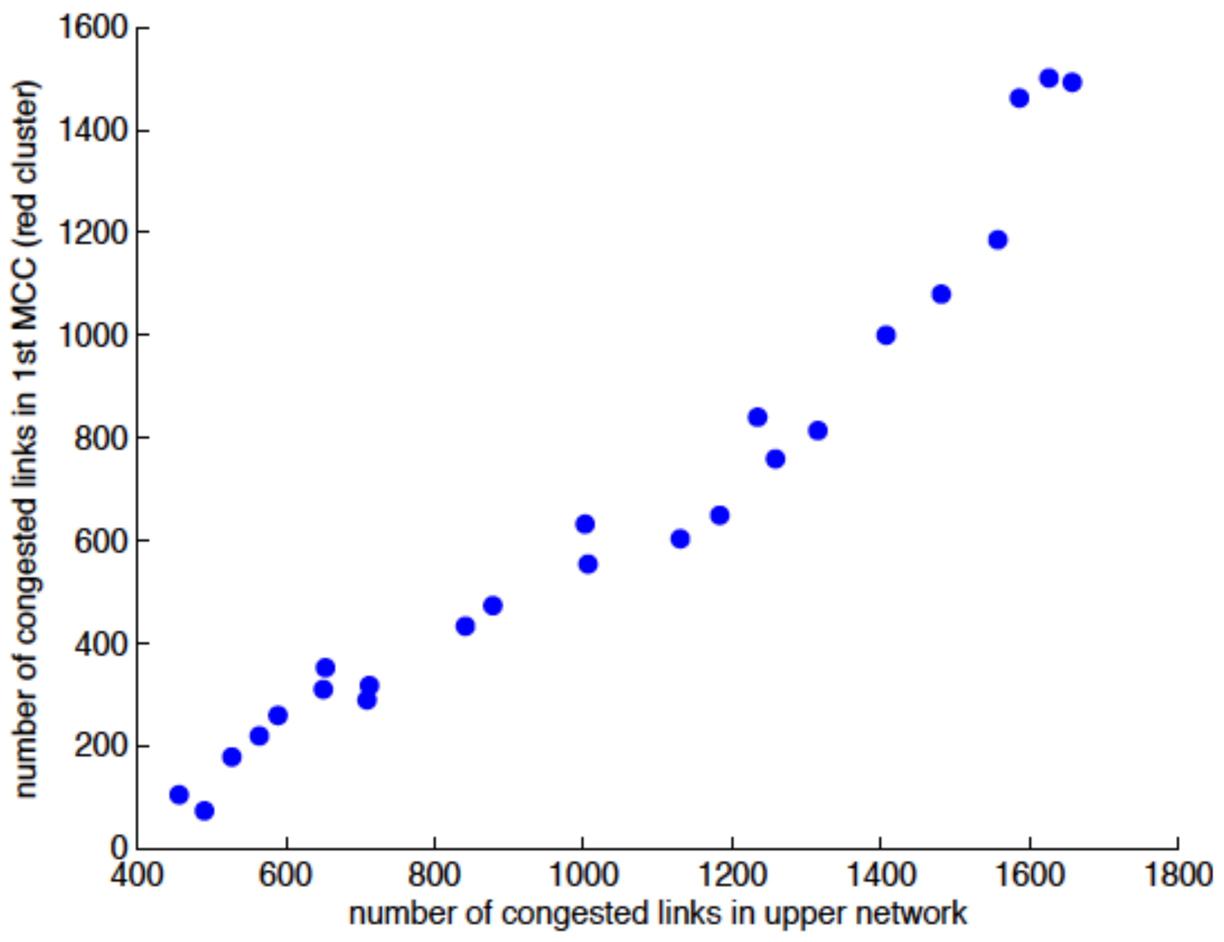


MCC: Maximum Connected Component (Red regions)

Congestion evolution of MCC







MFDs for MCCs

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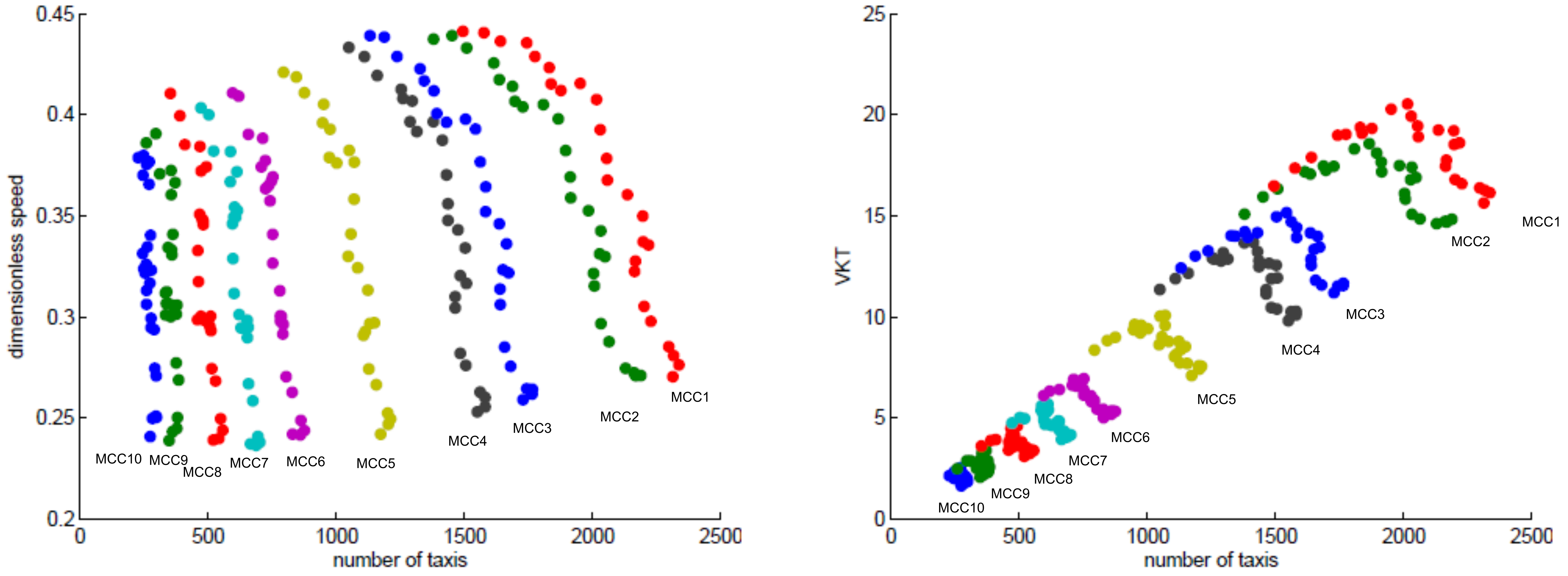
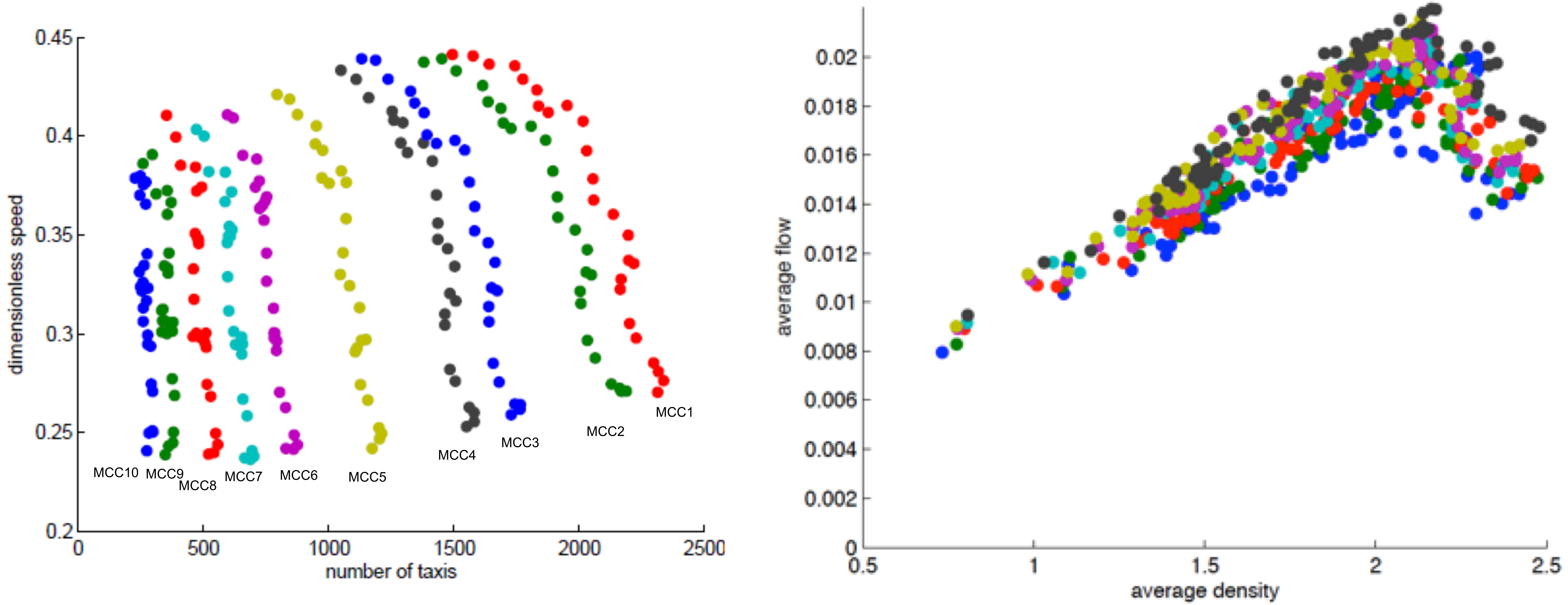


$$n_j = n_u \times (l_j / l_u) \times \left(\left(n_j^f / n_j^e \right) / \left(n_u^f / n_u^e \right) \right)$$

number of taxis is proportional

- to the size of the region
- to the ratio of full over empty taxis

MFDs for MCCs



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number of taxis is proportional

- to the size of the region
- to the ratio of full over empty taxis

An example of a “bad” MFD

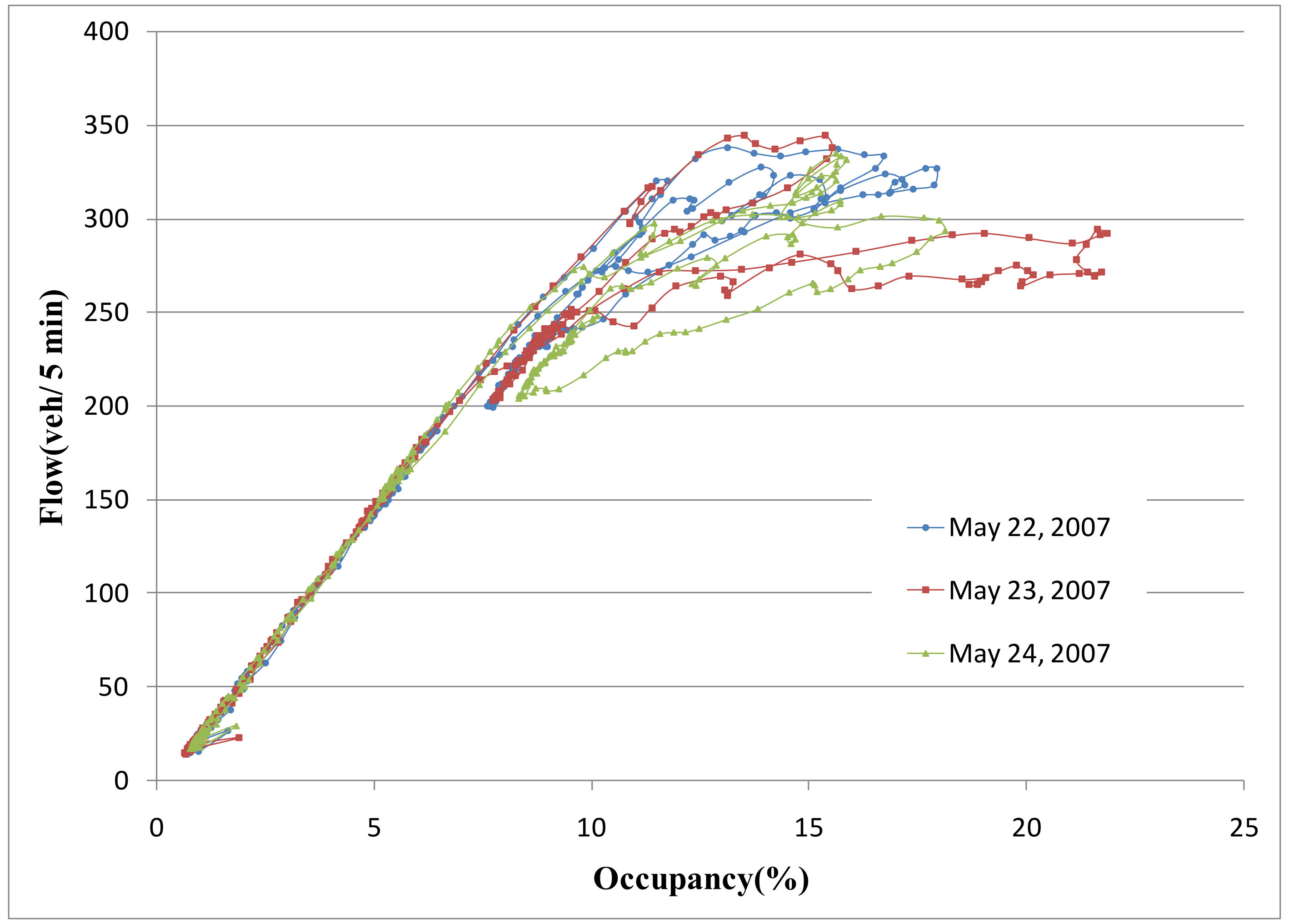
- **Strong hysteresis phenomena in freeway MFDs**

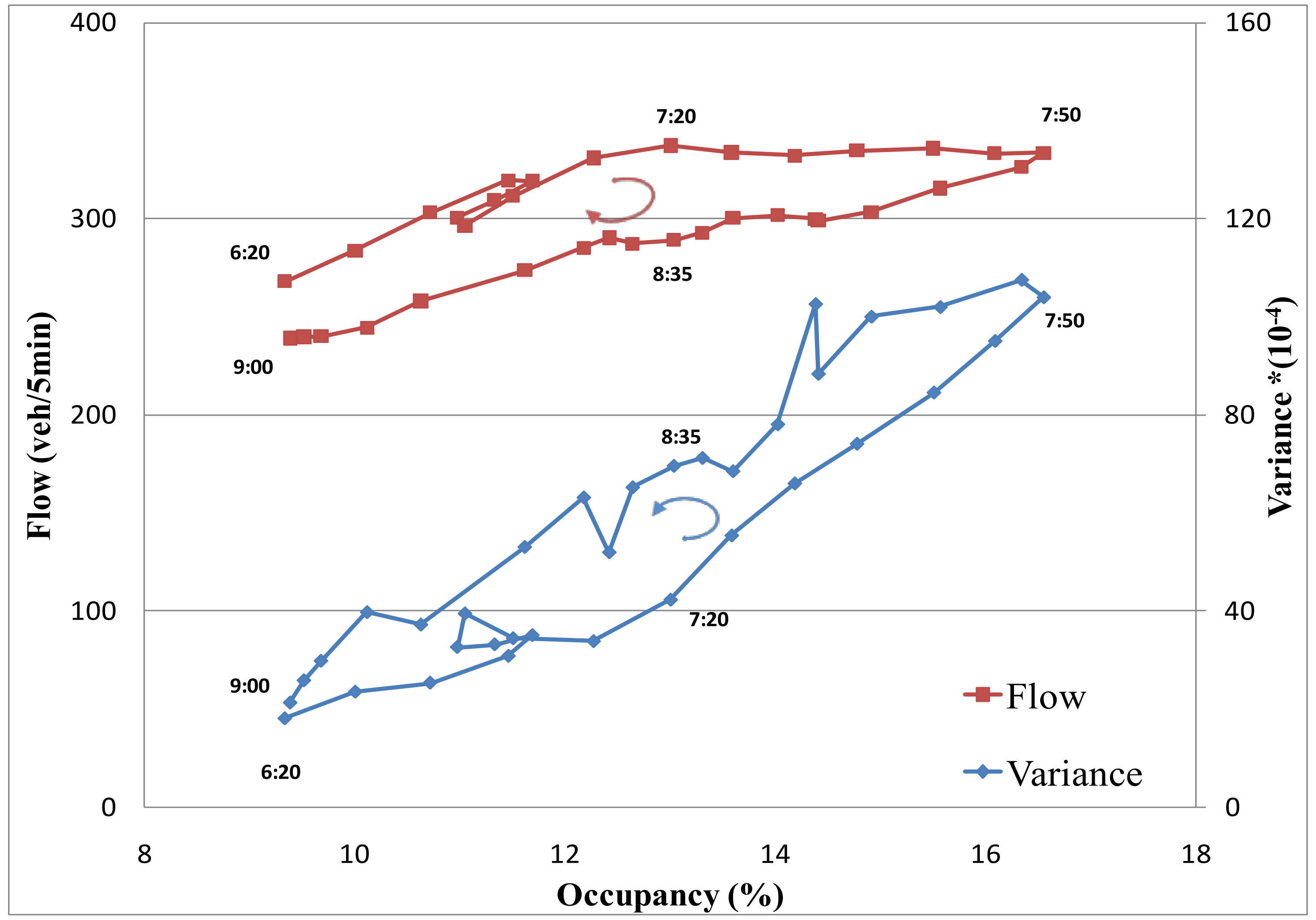
EXPLANATION

- Different distribution of congestion (onset vs. offset)
- Synchronized hysteresis of individual locations (due to capacity drop)

Freeway network of Minneapolis (USA)

Geroliminis and Sun (2011) – ISTTT 19

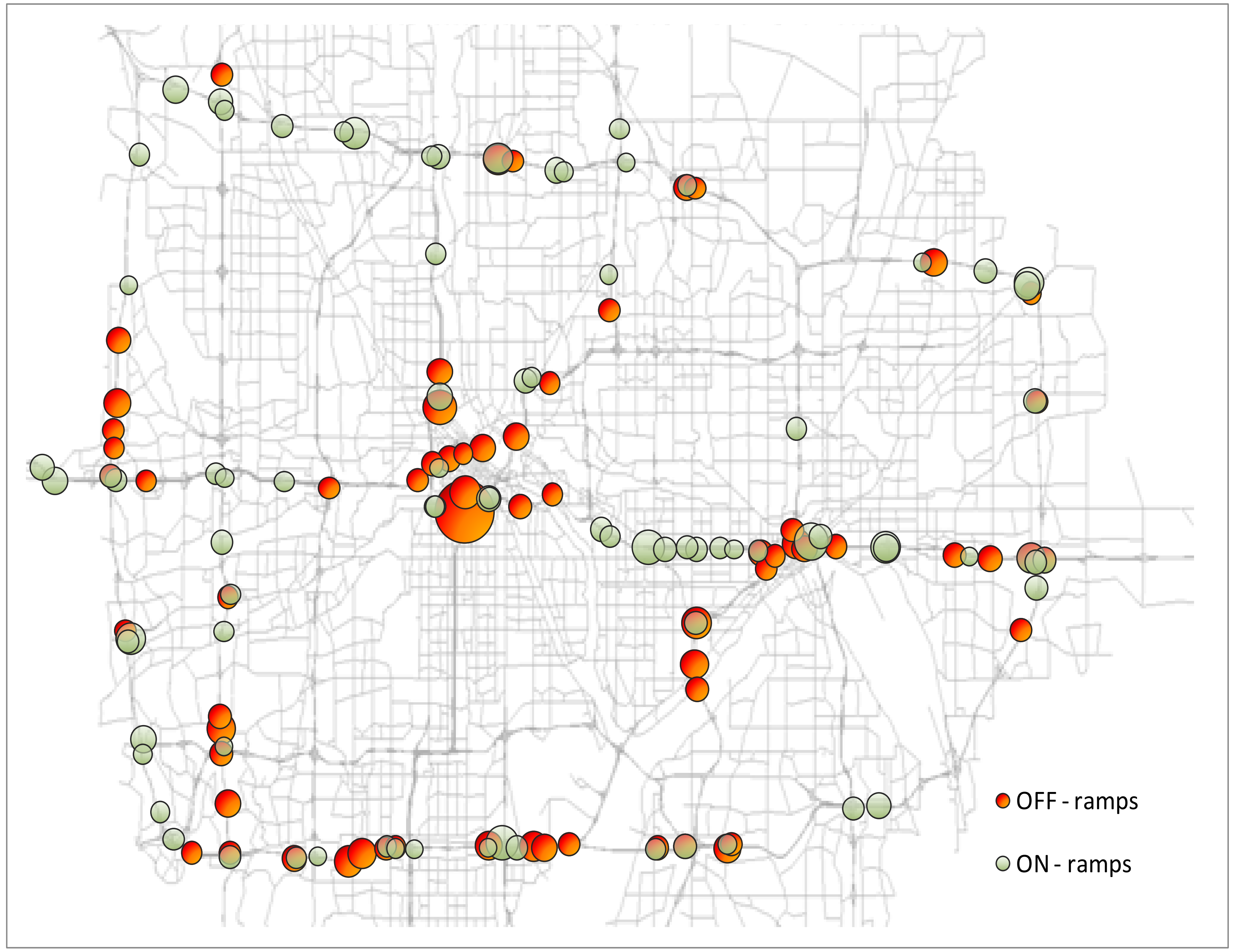


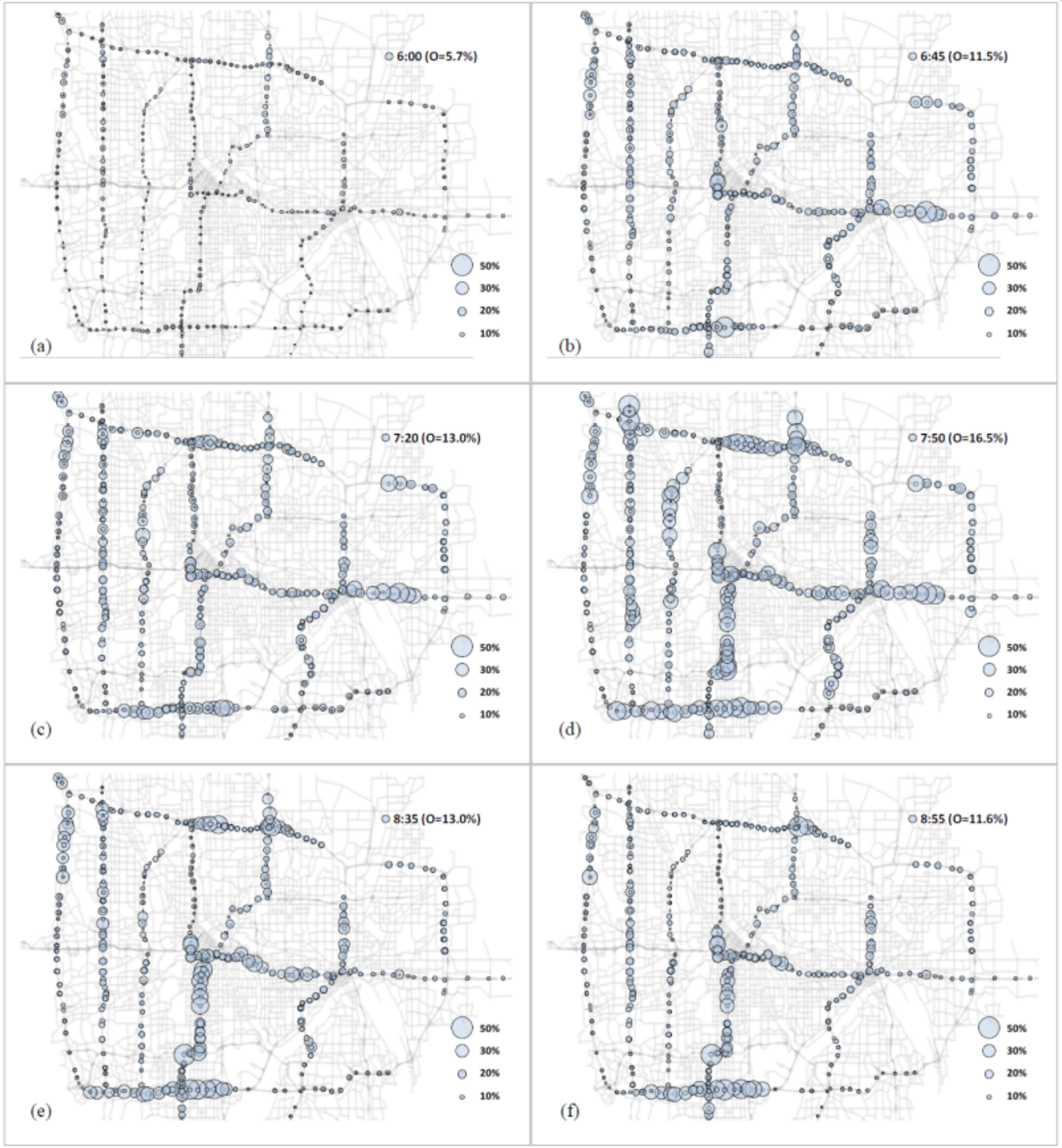


An example of a “bad” MFD

EXPLANATION 1

- Different distribution of congestion (onset vs. offset)

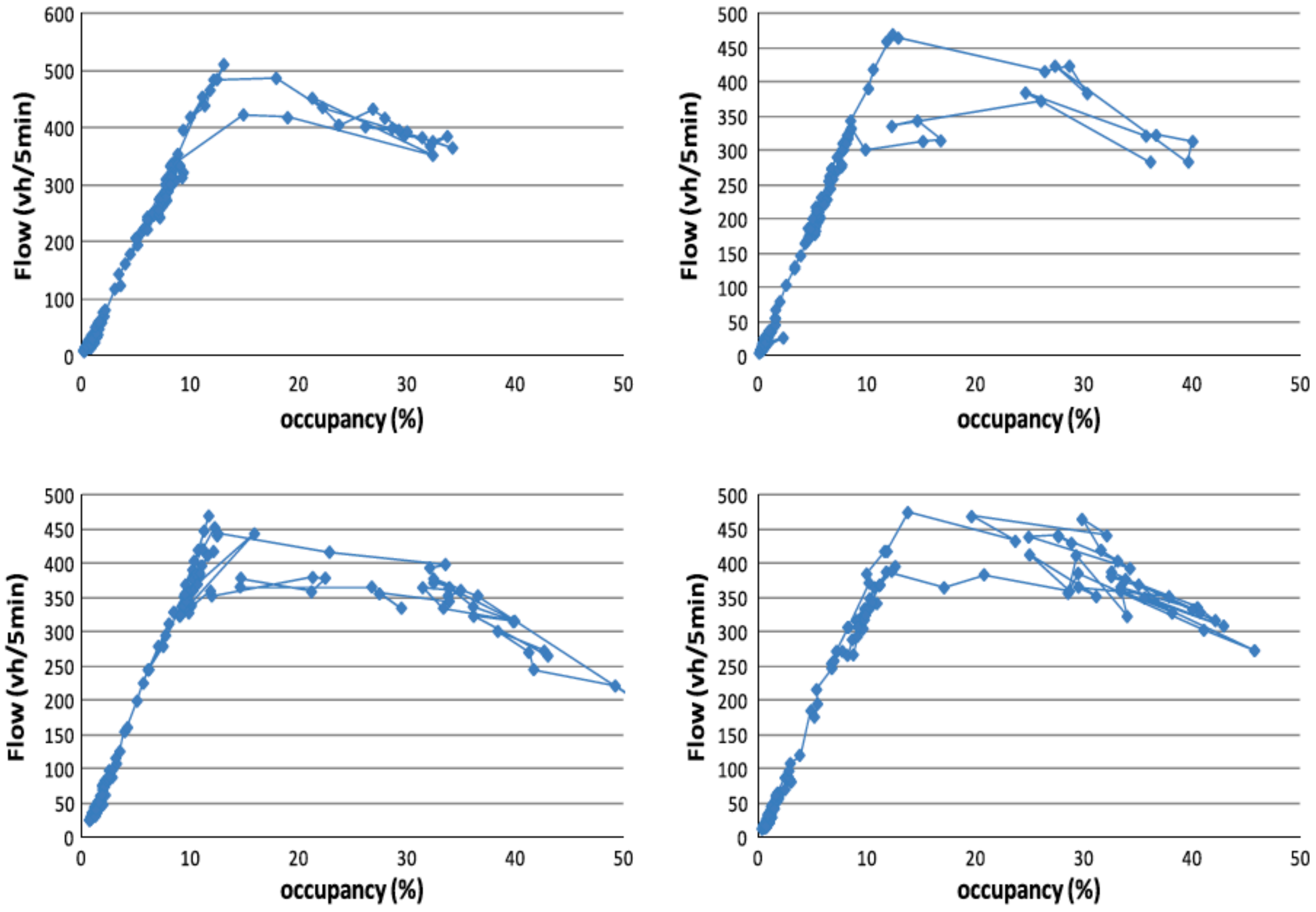




An example of a “bad” MFD

EXPLANATION 2

- Different distribution of congestion (onset vs. offset)
- Synchronized hysteresis of individual locations (due to capacity drop)



FDs for 4 individual detectors (5min data)

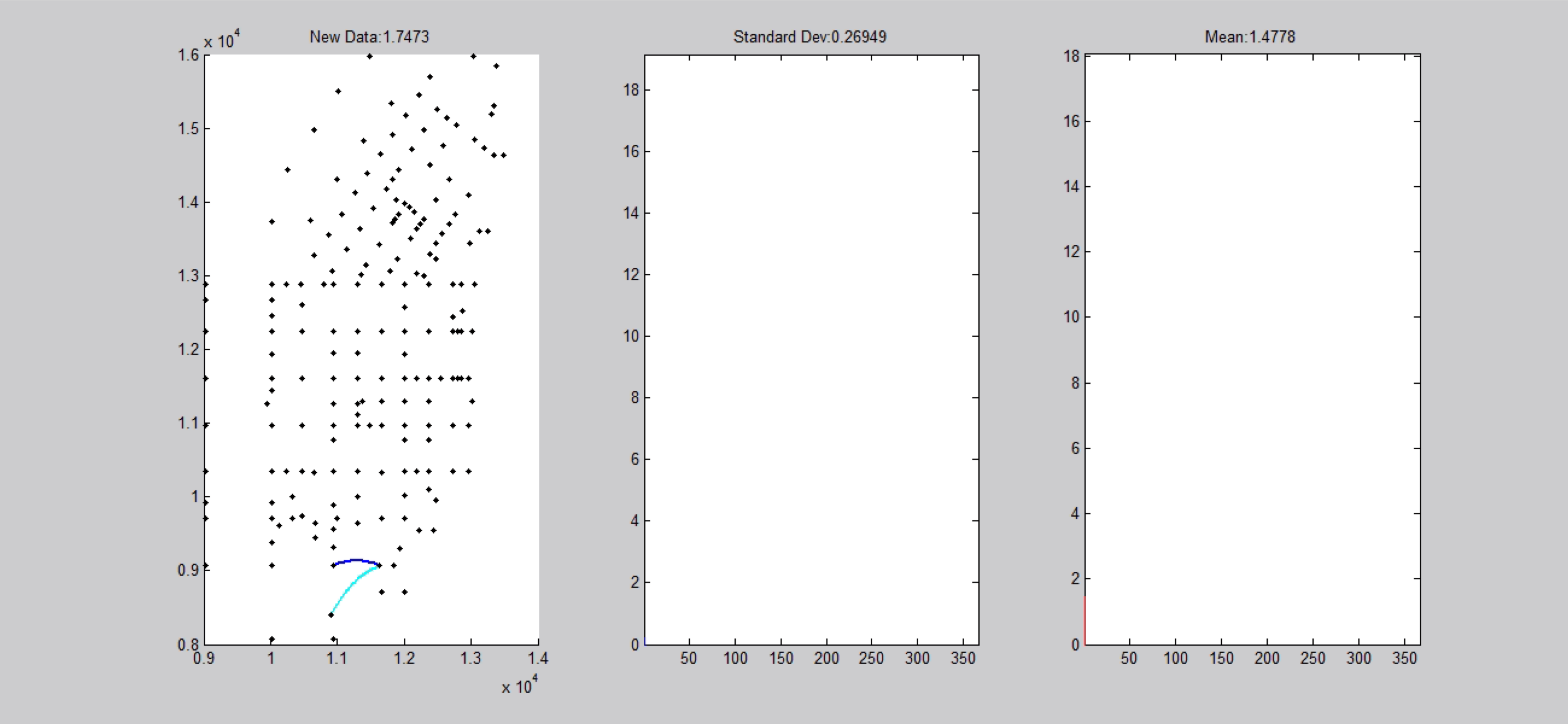
An intro to MFD clustering

- Objectives Detection of directional congestion
  - Static/Dynamic
  - Minimize Spatial regional heterogeneity
  - Deal with missing data

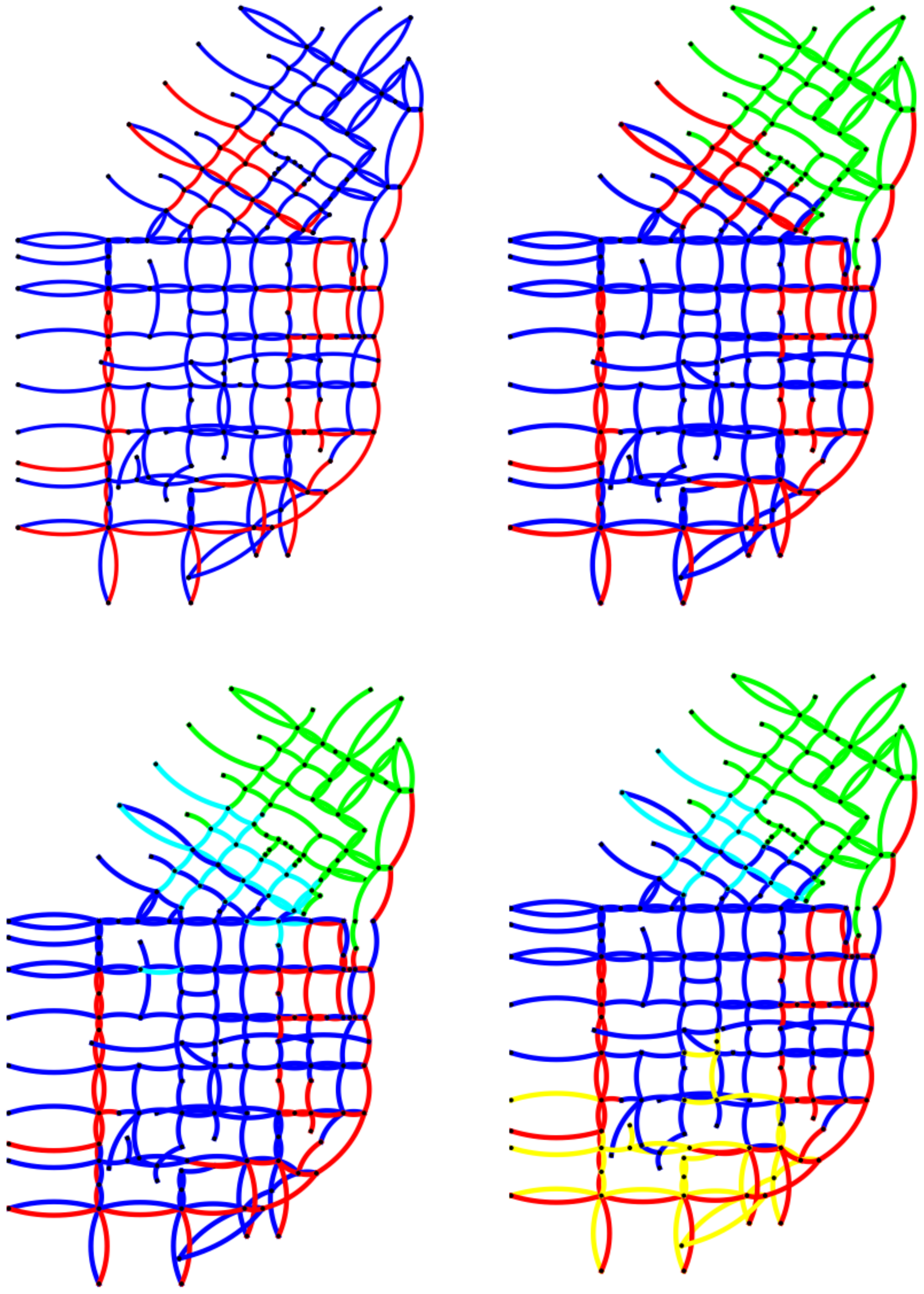
- Three-step algorithm
  - Find distinct local components (Snake)
    - Running snakes
    - Defining similarities
    - Reduce search-space
  - Snake segmentation (optimization approach)
  - Fine-tuning

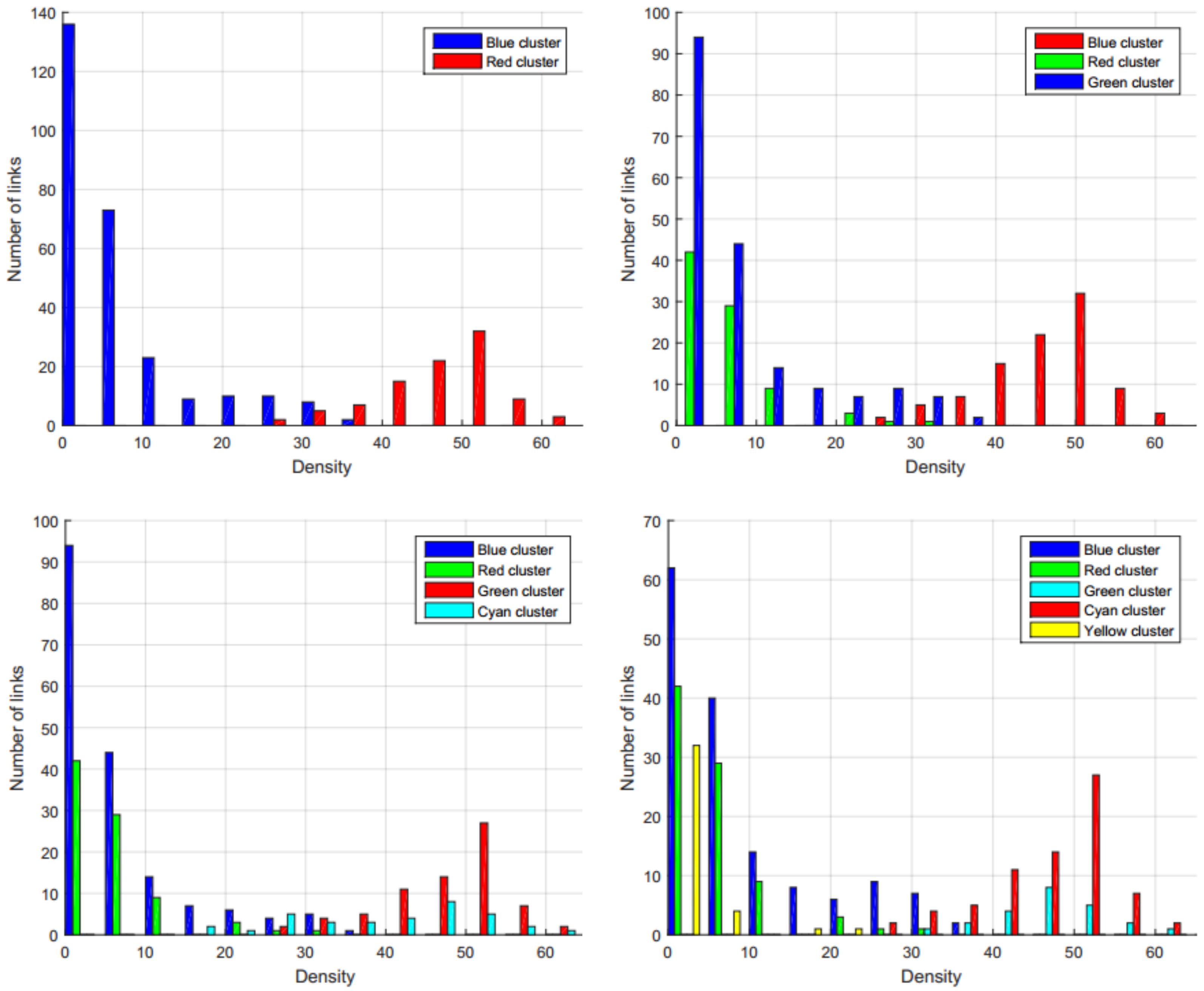
M. Saeedmanesh and N. Geroliminis. Clustering of heterogeneous networks with directional flows based on "Snake" similarities, in Transportation Research Part B Methodological, vol. 91, p. 250-269, 2016.

Illustration of Snake Algorithm



Partitioning results – Static case





(μ/σ)	Blue	Red	Green	Cyan	Yellow	TV_n
2	7.73/8.28	47.43/7.22	-	-	-	0.175
3	8.30/9.16	47.43/7.22	6.48/5.71	-	-	0.174
4	7.11/7.94	47.32/7.38	6.48/5.71	41.15/11.56	-	0.166
5	9.57/9.64	47.32/7.38	6.48/5.71	47.80/6.68	3.36/4.33	0.165

$$\text{TV}_\text{n} = \frac{\sum_{i=1}^{N_s} N_{A_i} \times var(A_i)}{N \times var(A)}$$