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Macroscopic traffic flow modeling and control of heterogeneous cities with multi-sensor data

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Outline

- **Motivation**
- Aggregated modeling with multi-sensor data
- Application to San Francisco
- Field implementation in Melbourne, Australia
- Aggregated Modeling for bi-modal networks

Motivation

Goal:

- Mitigate congestion in transport networks via appropriate control policies and by using multi-sensor data

Approach:

- Understand what causes congestion (+gridlocks)
- **Urban road networks:** Meter the input flow to the system and hold vehicles outside the system if necessary (to maintain maximum throughput, e.g. number of trip completion)
- **Motorways:** Meter the input flow to the on-ramp (merging area) and hold vehicles outside the motorway if necessary (to maintain maximum throughput in the mainline)

Walking experiment (TRAIL Conference, 2010)

No control
(nature)

Ramp metering
(control of the entrance point)

Funnel experiment

- Poor rice into a funnel using two different strategies:
  - Poor as much rice into the funnel as possible without spilling
  - Try to limit the inflow such that there is "**no queue of rice**"
- Which strategy is quicker or **maximises the output**?
- Funnel = **merging traffic infrastructure**
- Rice = **vehicles**
- Output = **number of trips completed**

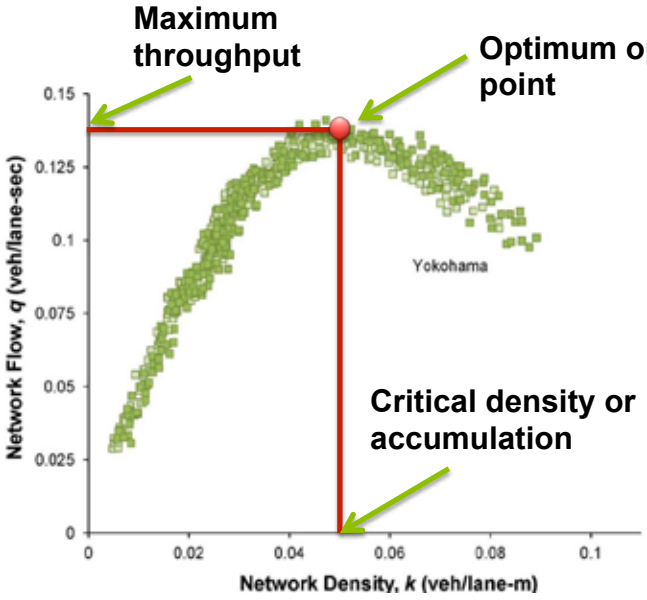
Dump all rice into the funnel on the left

slowly pour rice into the funnel on the right

The rice passes through the right funnel much faster.

Aggregated modeling with multi-sensor data

- Fixed sensors: 500 detectors (Occupancy and Counts per 5min)
- Mobile sensors: 140 taxis with GPS; Time and position (stops, hazard lights etc)
- Geometric data (detector locations, link lengths, control, etc.)



Geroliminis & Daganzo, 2008, TR Part B

Problem

Problem

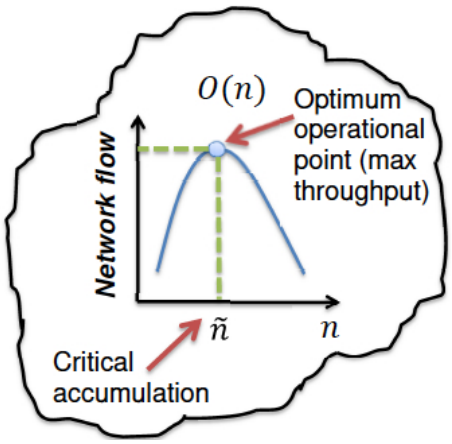
- A **single-region city** exhibits consistent aggregated traffic behavior (**Macroscopic or Network Fundamental Diagram**) if congestion is homogeneously distributed

- How the concept of aggregated traffic behavior be applied to:
  - **Multi-region cities with multiple centers of congestion**?
  - **Mixed bi-modal (cars and buses) multi-region networks?**

- Can we observe a similar aggregated traffic behavior if we collect heterogeneous multi-sensor data?

Modeling: City-wide, homogeneous, single-region

- A single-region city exhibits consistent aggregated traffic behavior: **Macroscopic Fundamental Diagram** (MFD)
- Network flow (q) vs. Accumulation (n) or Density (k): $q = O(n)$



Modeling: City-wide, heterogeneous, multi-region (1)

- A **heterogeneous large-scale city** can be partitioned in a small number of **homogeneous regions**

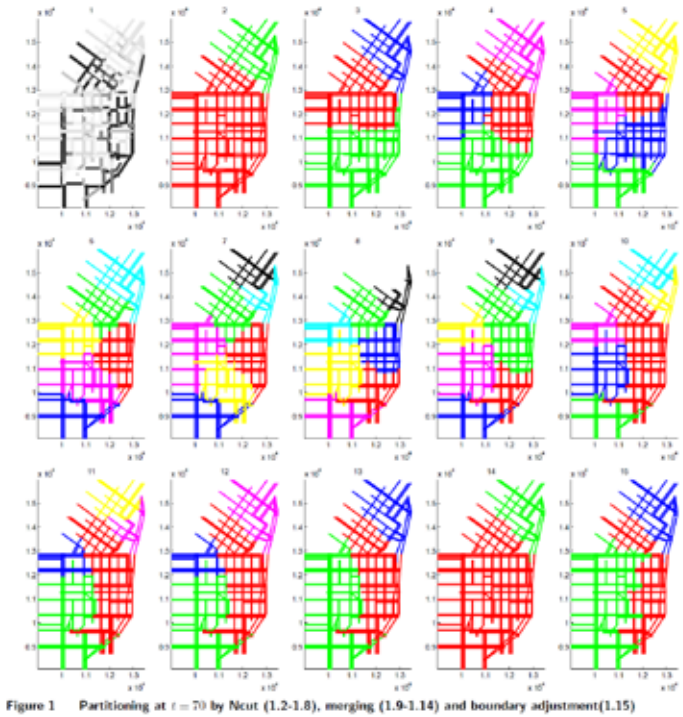
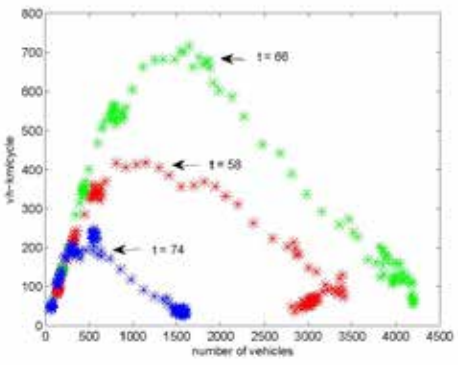


Figure 1 Partitioning at $t = 70$ by Ncut (1.2-1.8), merging (1.9-1.14) and boundary adjustment(1.15)

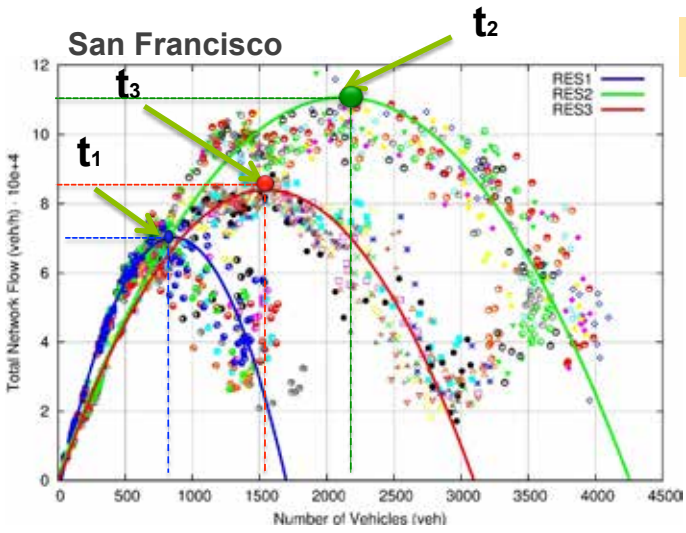
Congestion Spreading



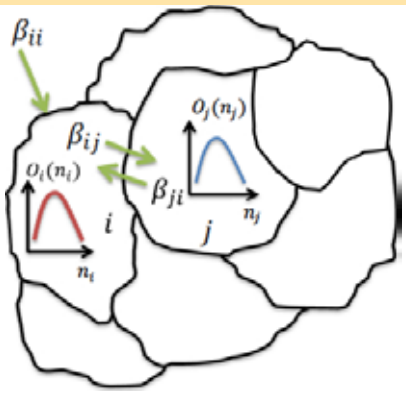
Ji & Geroliminis, 2012, TR Part B

Modeling: City-wide, heterogeneous, multi-region (2)

- A **heterogeneous large-scale city** can be partitioned in a small number of **homogeneous regions**
- **Finding:** Each reservoir *i* exhibits an MFD with moderate scatter
- **Heterogeneity:** Each reservoir reach the congested regime at different time



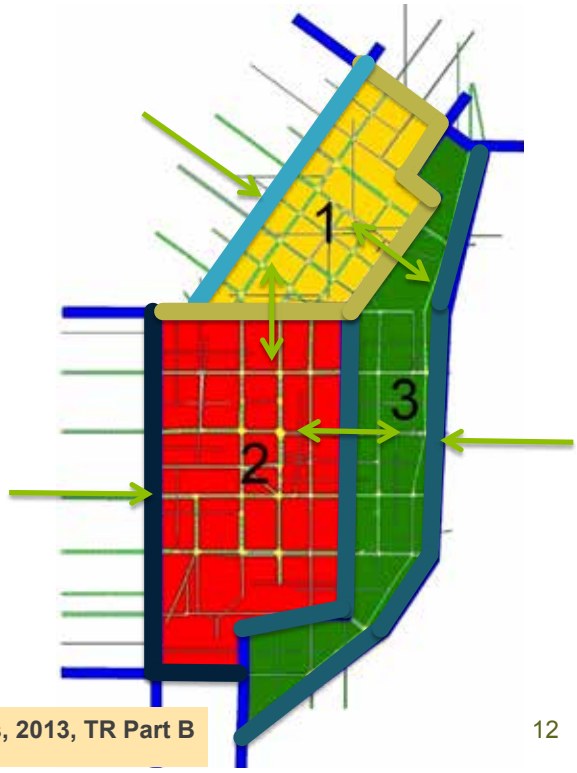
Aboudolas & Geroliminis, 2013, TR Part B



Application: Downtown of San Francisco, CA

Original network (single-region)

Clustering into 3-regions



Aboudolas & Geroliminis, 2013, TR Part B

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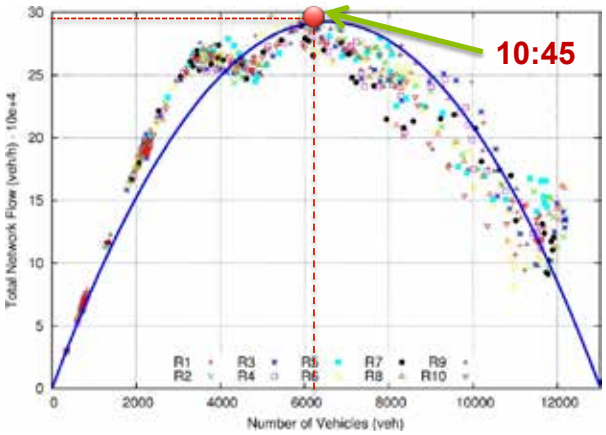
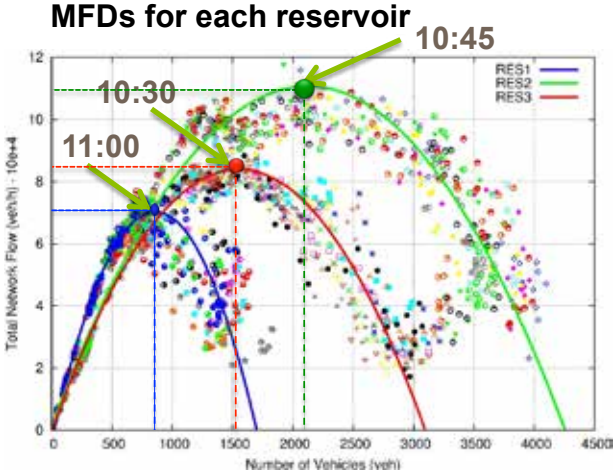
Results: MFDs and Heterogeneity

MFD for the original network



MFDs for each reservoir



Experiments:

- AIMSUN microscopic simulator
- 4-hours demand scenario
- 10 replications R1-R10

Findings:

- MFD: RES1-RES3 exhibit MFDs with quite moderate scatter
- Heterogeneity: RES1-RES3 reach the congested regime different time

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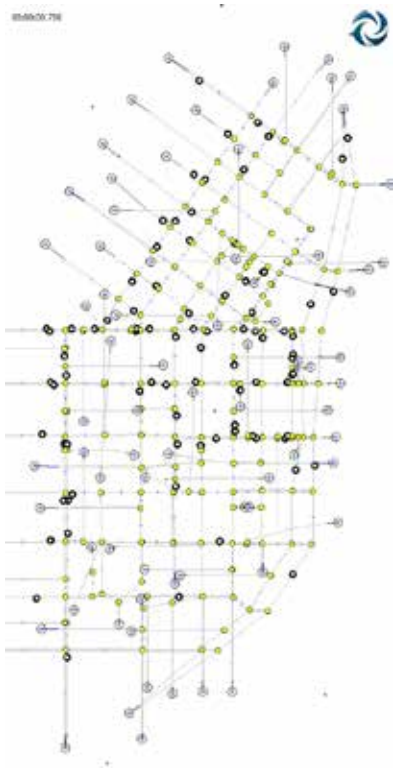
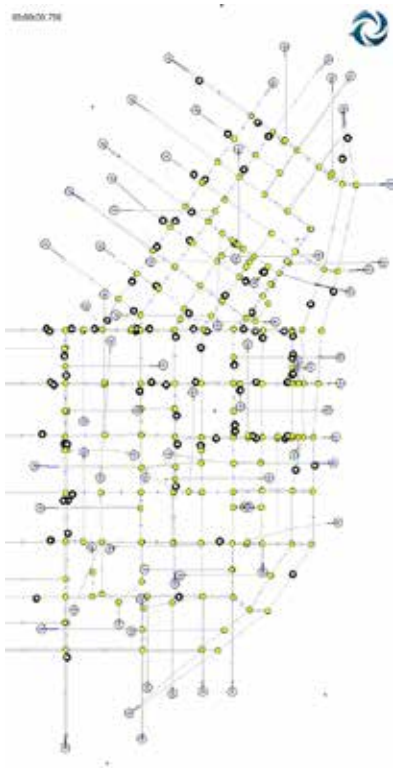
Perimeter control (non-adaptive drivers)

No control

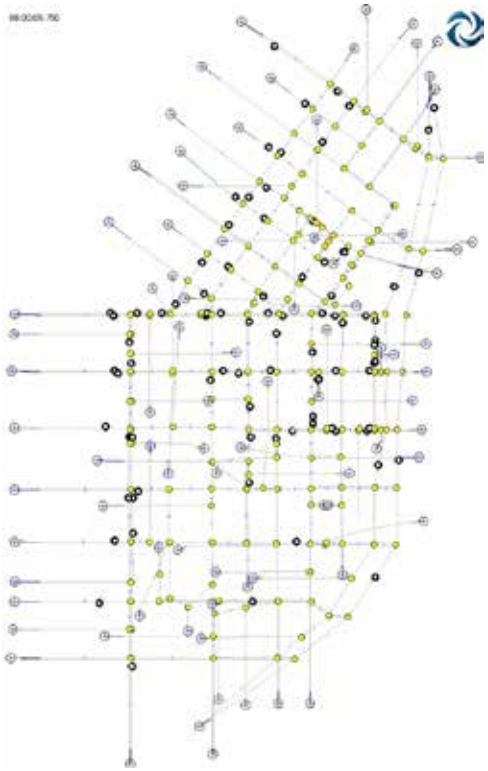


Feedback perimeter control

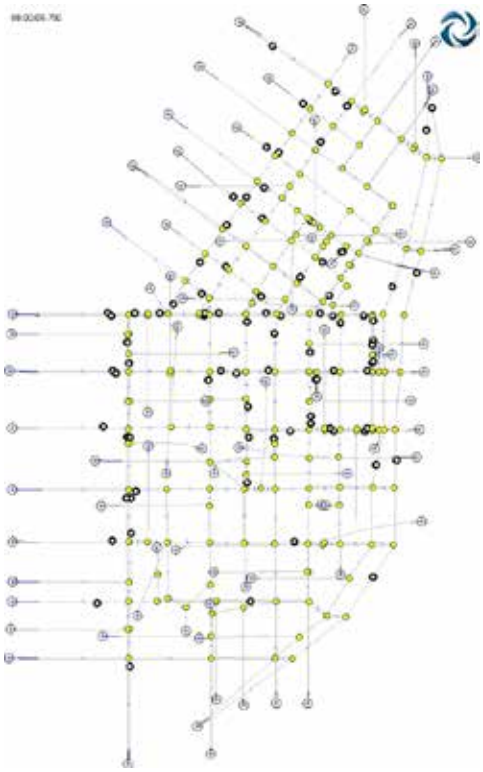


Perimeter control (somewhat adaptive drivers)

No control

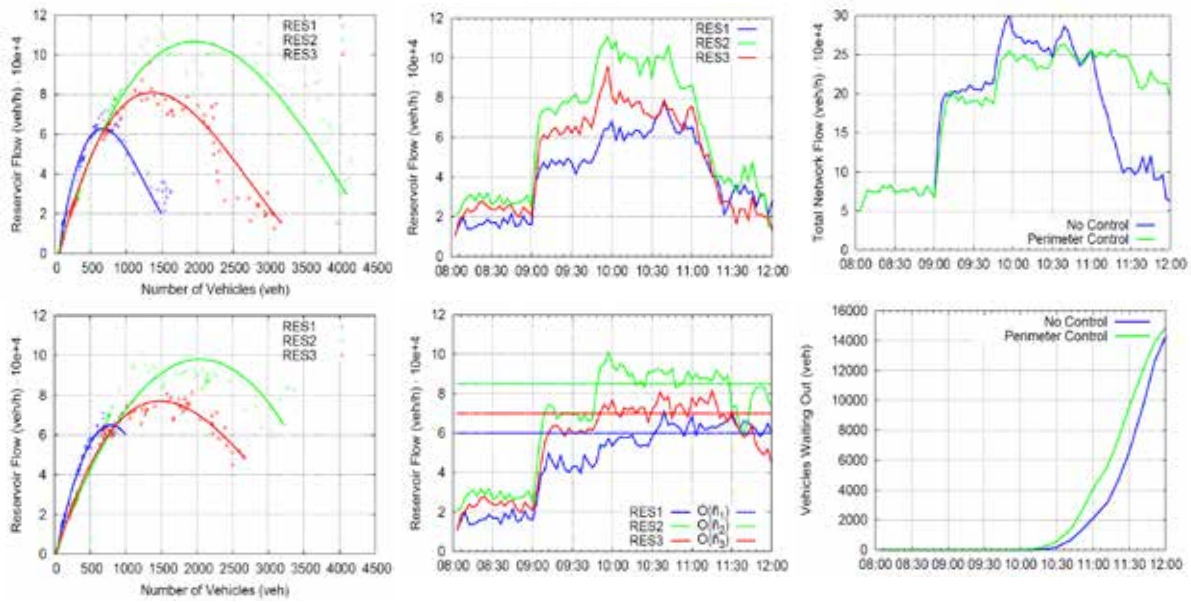


Feedback perimeter control



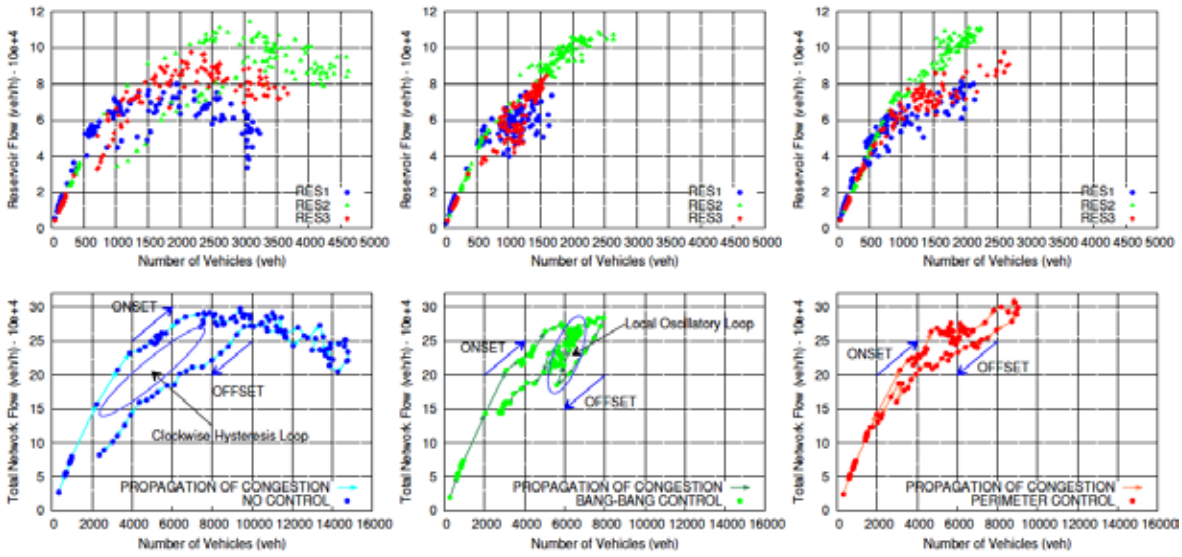
Results: Perimeter and boundary control effect

- TTS and space-mean speed are improved in average 11.7% and 15.4% respectively
- **FPC:** creates temporary queues at the perimeter of the network
- **FPC:** maintains the overall throughput to high values during rush



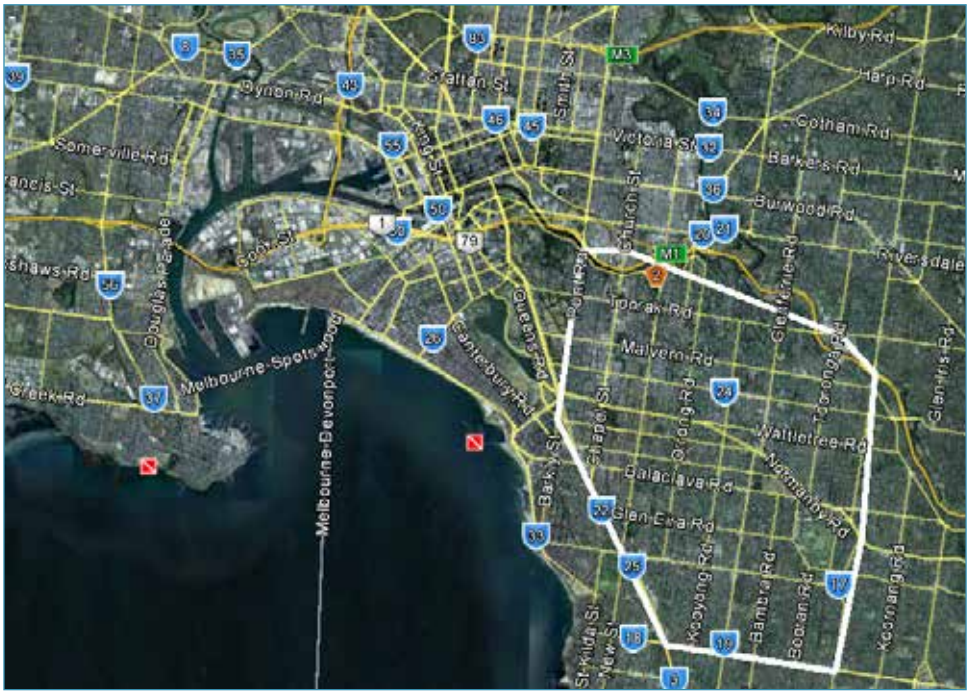
Results: Perimeter and boundary control effect

- Simulation with OD + DTA: **improvement in average 45%**
- Comparison with Bang-bang control: Improvement 10%
- **FPC: No temporal queues** at the perimeter of the network
- **FPC:** maintains throughput; respect reservoirs' homogeneity



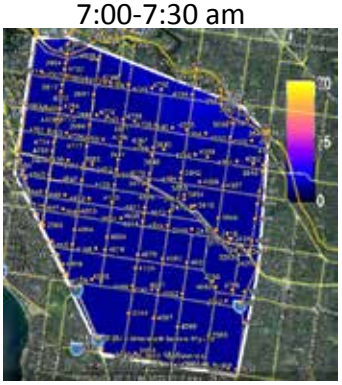
Field Implementation in Melbourne, AU

Stonnington area, around 120 intersections

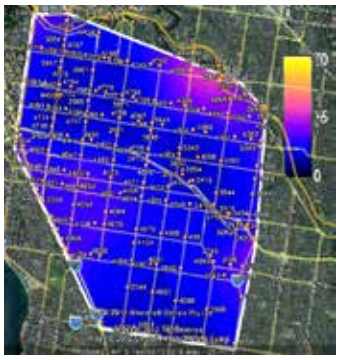


Field Implementation in Melbourne, AU

7:00-7:30 am

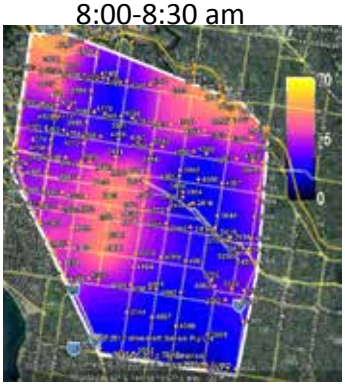


7:30-8:00 am

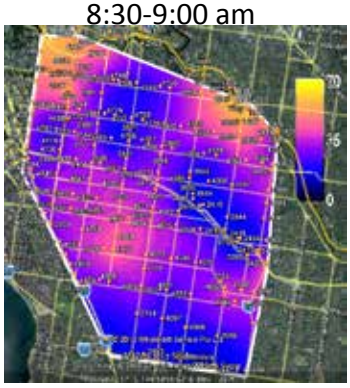


- Progression of congestion from 7:00 am to 9:00 am

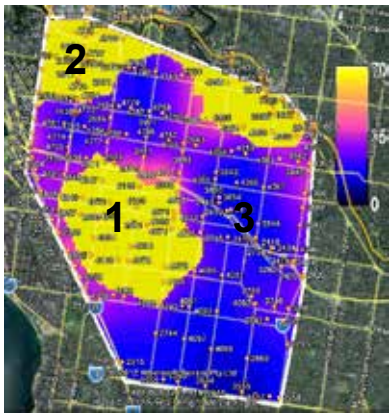
8:00-8:30 am



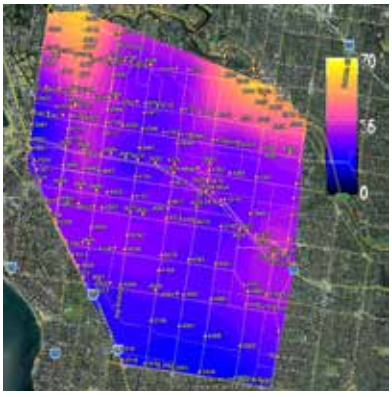
8:30-9:00 am

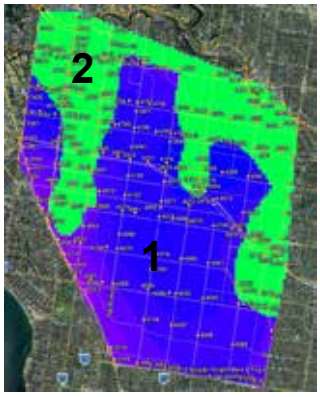


Field Implementation in Melbourne, AU



Morning peak and Partition





Evening peak and Partition

Outline

- Motivation
- Aggregated modeling with multi-sensor data
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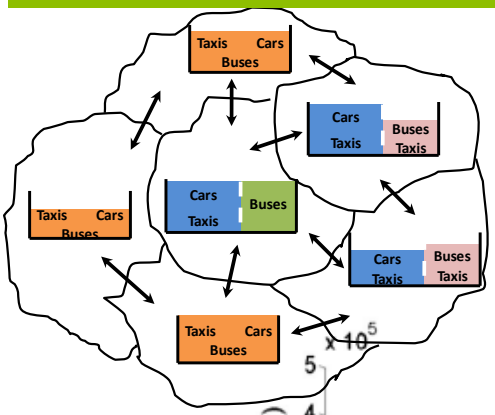
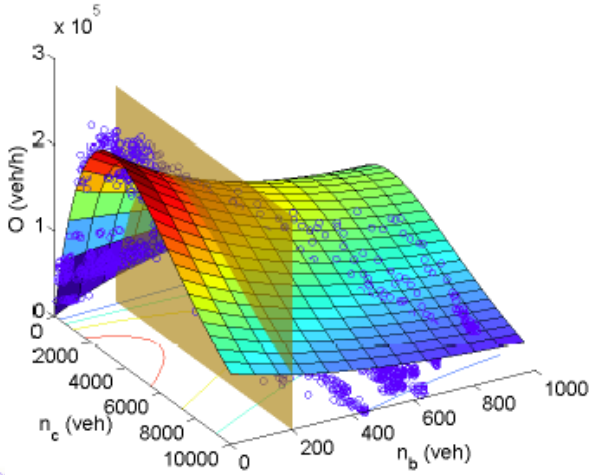
- Field implementation in Melbourne, Australia
- **Aggregated Modeling for bi-modal networks**

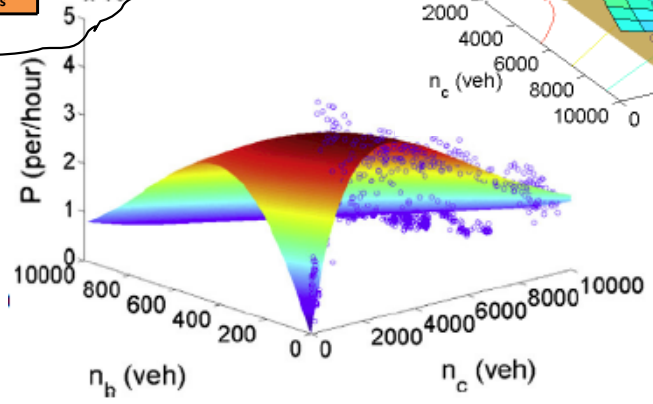
Existence of 3D MFD for bi-modal traffic (cars, buses)

Multi-reservoir multi-modal network



Three-Dimensional vehicle MFD





Three-Dimensional passenger MFD

Geroliminis, Zheng, Ampountolas (2014) TR Part C

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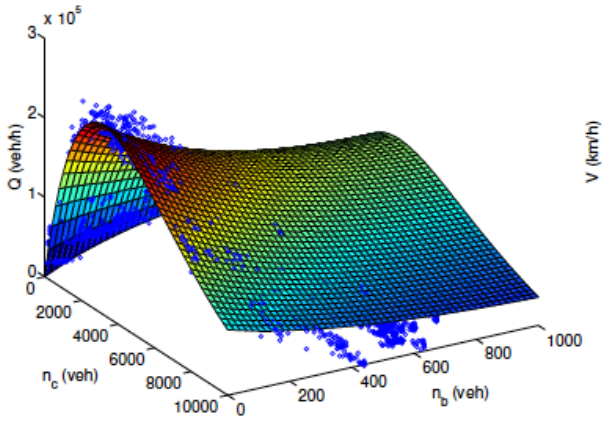
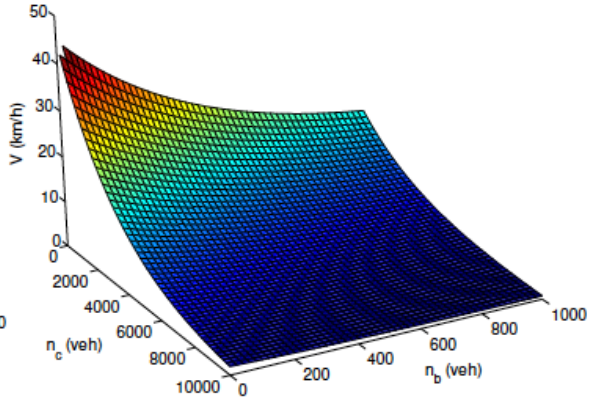
A 3D-vMFD for bi-modal mixed traffic

Flow-bi-Accumulation MFD = 3D-vMFD



Speed-bi-Accumulation 3D-vMFD



Composition of traffic AFFECTS the shape of the 3D-vMFD

Geroliminis, Zheng, Ampountolas (2014) TR Part C

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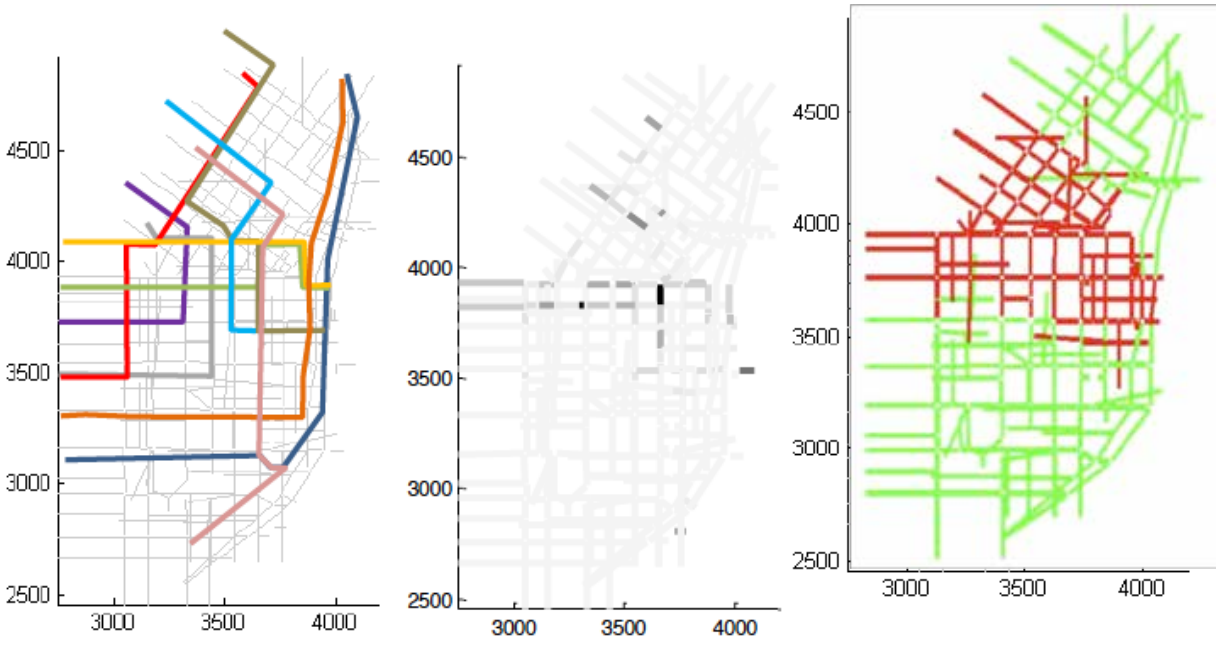
Two-region control of mixed bi-modal traffic

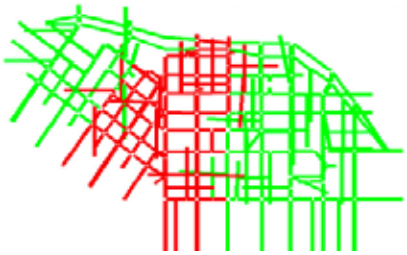
Ampountolas, Zheng, Geroliminis, 2016; TR Part B (under review)



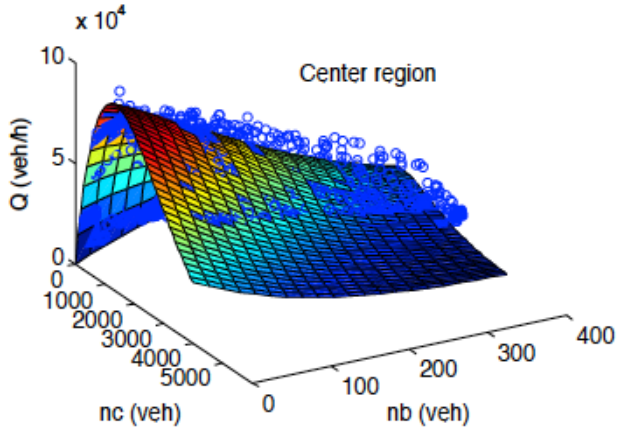
Spatial variation of bus/car ratio

Two-region control of mixed bi-modal traffic

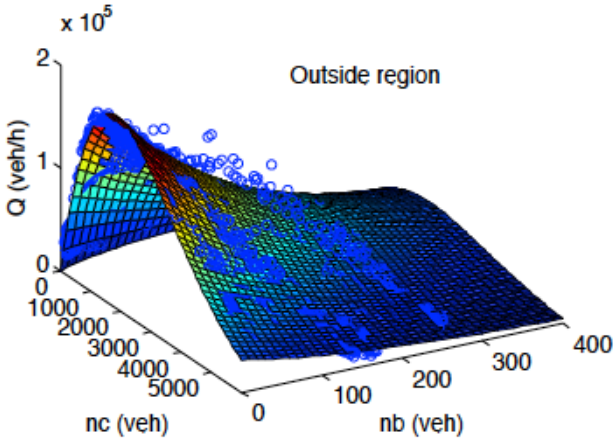
Network clustering



3D-vMFD Center



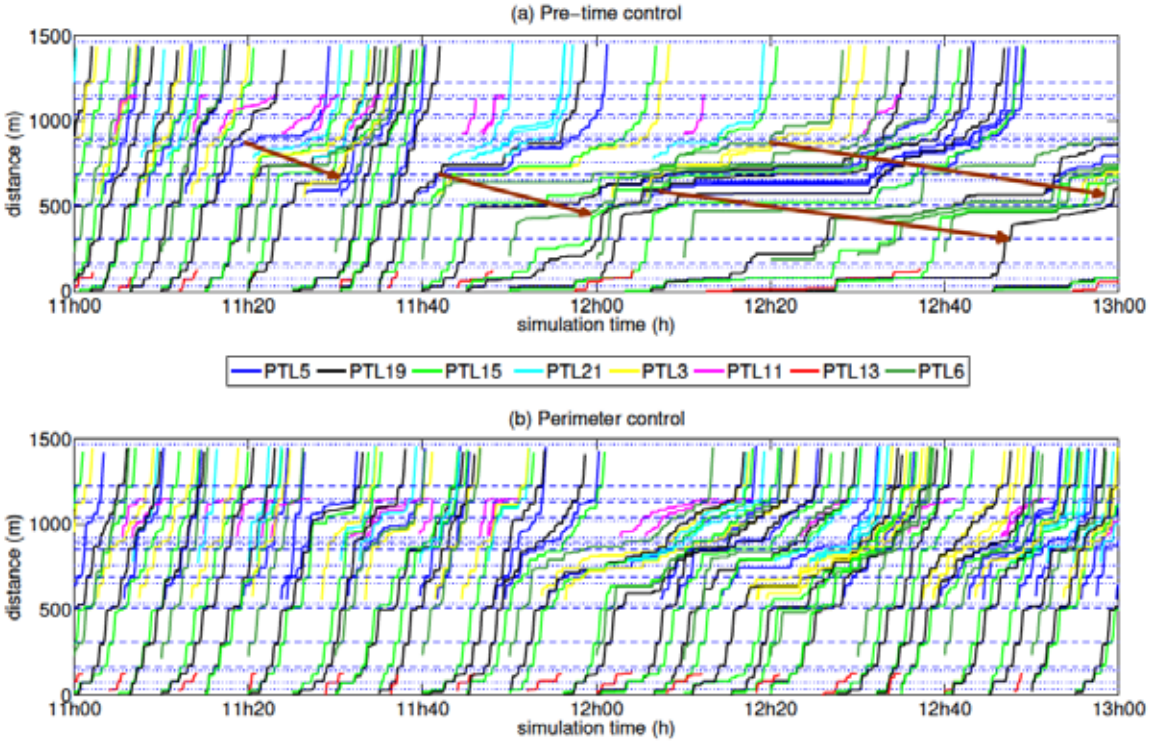
3D-vMFD Outside



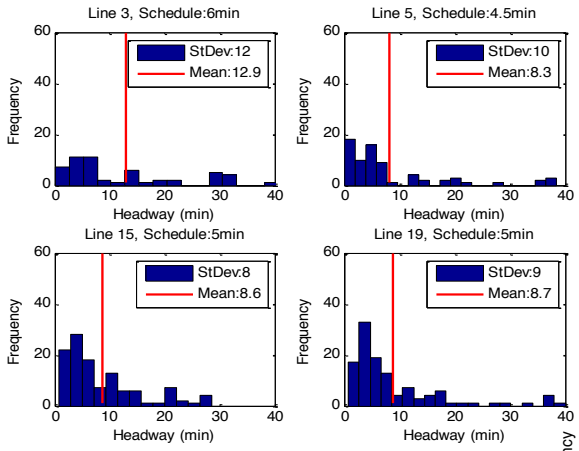
Ampountolas, Zheng, Geroliminis, 2016; TR Part B (under review)

Results: Bus bunching and congestion

- Time-space diagram for bus trajectories in several public

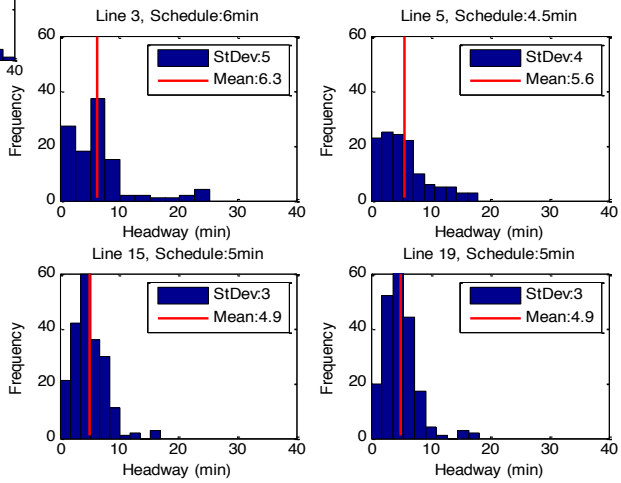


Bus bunching phenomena



PRE-TIMED TRAFFIC LIGHTS

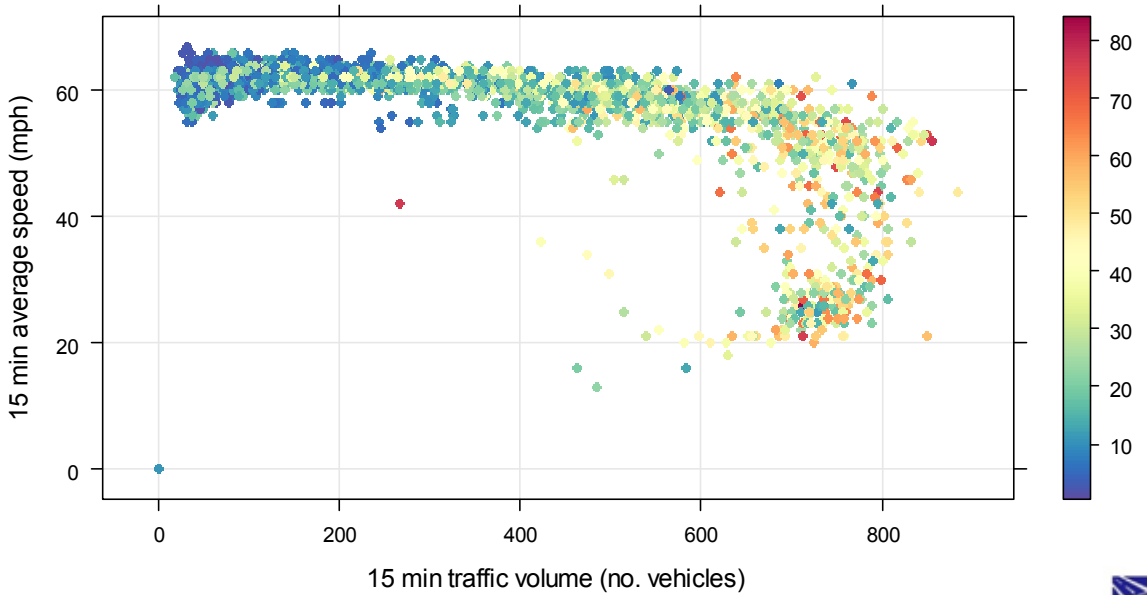
SMART TRAFFIC LIGHTS FOR 2 REGIONS



Histograms of headways for 4 bus lines

Other sensor data: Speed-flow relationship by NO_2

Traffic flow / speed curve by NO_2



Source of image Transport Scotland

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