McCormick

Northwestern Engineering

Northwestern University Transportation Center

# Development, Calibration and Application of Simulation-Based Dynamic Traffic Assignment to Greater Chicago Network Using DYNASMART-P


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March 7, 2012


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# Outline

- Introduction to Simulation-based DTA
- Greater Chicago Network
- Calibration and Validation of DYNASMART-P
  - Supply side
  - Demand side
- Applications
  - Weather-responsive traffic estimation and prediction
  - Congestion management

# Introduction to Simulation-based DTA

# DYNASMART-P

What is DYNASMART-P?

- **DY**namic **N**etwork **A**ssignment-**S**imulation **M**odel for **A**dvanced **R**oadway **T**elematics (**P**lanning version)
- It is an intelligent transportation network design, planning, evaluation, and traffic simulation tool.

# State of Practice in Network Modeling

- Most agencies use static assignment models, often lacking formal equilibration, with very limited behavioral sensitivity to congestion-related phenomena (incl. reliability)

- Some agencies use traffic micro-simulation models downstream from assignment model output, primarily for local impact assessment

- Time-dependent (dynamic) assignment models continuing to break out of University research into actual application– market growing, still fragmented, with competing claims and absence of standards:
  - existing static players adding dynamic simulation-based capabilities,
  - existing traffic micro-simulation tools adding assignment (route choice) capability, often in conjunction with meso-simulation
  - standalone simulation-based DTA tools

# State of Practice in Network Modeling

- Applications to date complementary, not substitutes, for static assignment; primary applications for operational planning purposes: work zones, evacuation, ITS deployment, HOT lanes, network resilience, etc…
- Existing commercial software differs widely in capabilities, reliability and features; not well tested.
- Equilibration for dynamic models not well understood, and often not performed
- Dominant features, first introduced by DYNASMART-P in mid 90's:
  - Micro-assignment of travelers; ability to apply disaggregate demand models
  - Meso-simulation for traffic flow propagation: move individual entities, but according to traffic flow relations among averages (macroscopic speed-density relations): faster execution, easier calibration
  - Ability to load trip chains (first tool with this capability, essential to integrate with activity-based models)

# Greater Chicago Network

# Data Overview

- Five categories of data required for DYNASMART-P
  - Network data
  - Control data
  - Demand data
  - Scenario data
  - System data

First three groups are critical for setting up the network

Last two group are critical for scenario analysis

# Sources of data

- Network:
  CMAP TransCAD network
  converted to DYNASMART-P using DYNASMART-P utility (DynaBuilder)

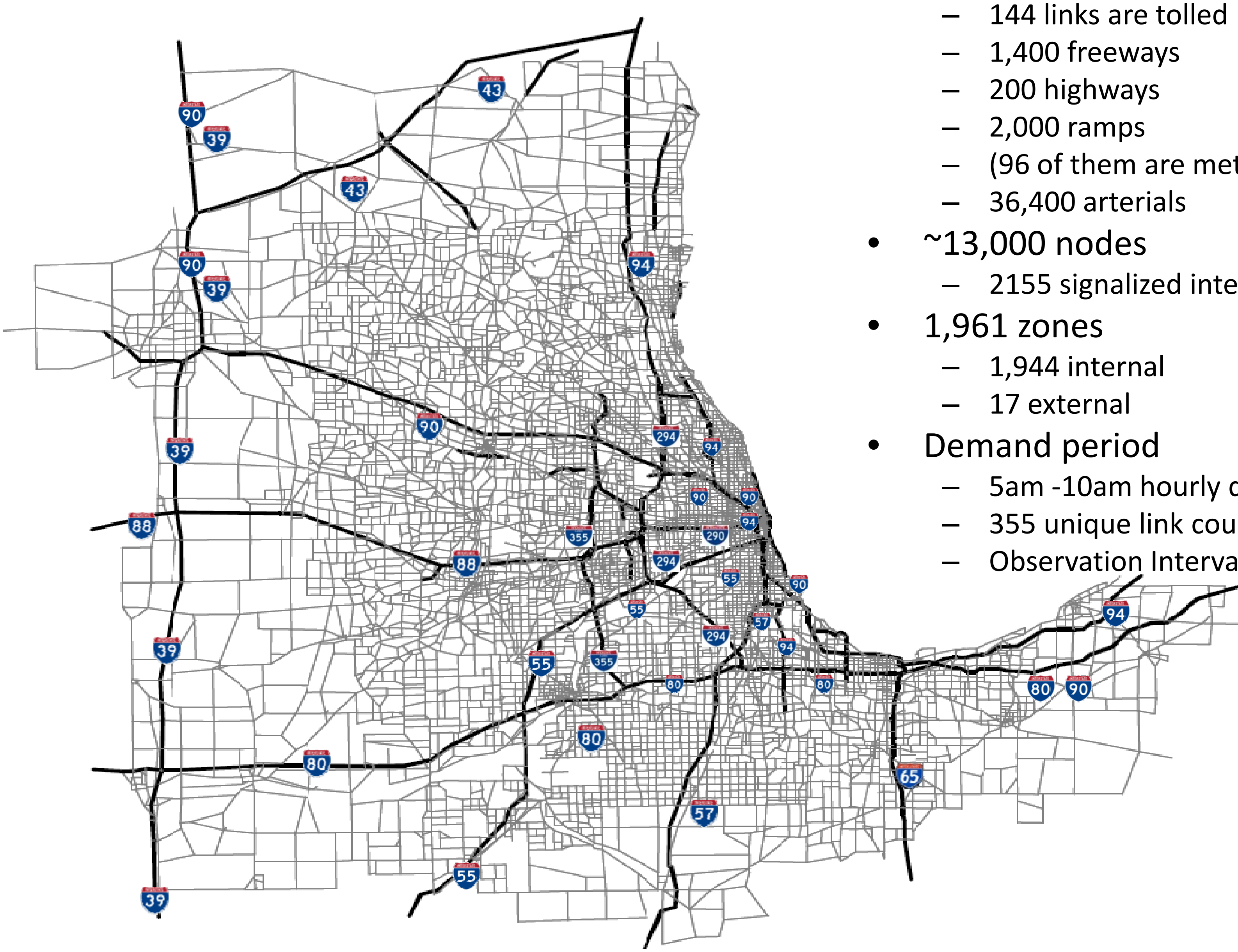
- Control:
  Signal locations based on TranCAD network
  Other control locations inferred by spatial reasoning logic, confirmed by Google Earth
  Timing plans have been coded in DSPEd
  - Actual timing plans not available
  - Actuated Control signal timing plans specified by default

- Transit:
  Bus routes and frequencies
  - Not implemented to this network, yet

- Demand:
  Static demand matrix provided on daily basis and hourly factors

  Link counts obtained from IDOT loop detectors (in 5 minutes intervals)

# Greater Chicago Network

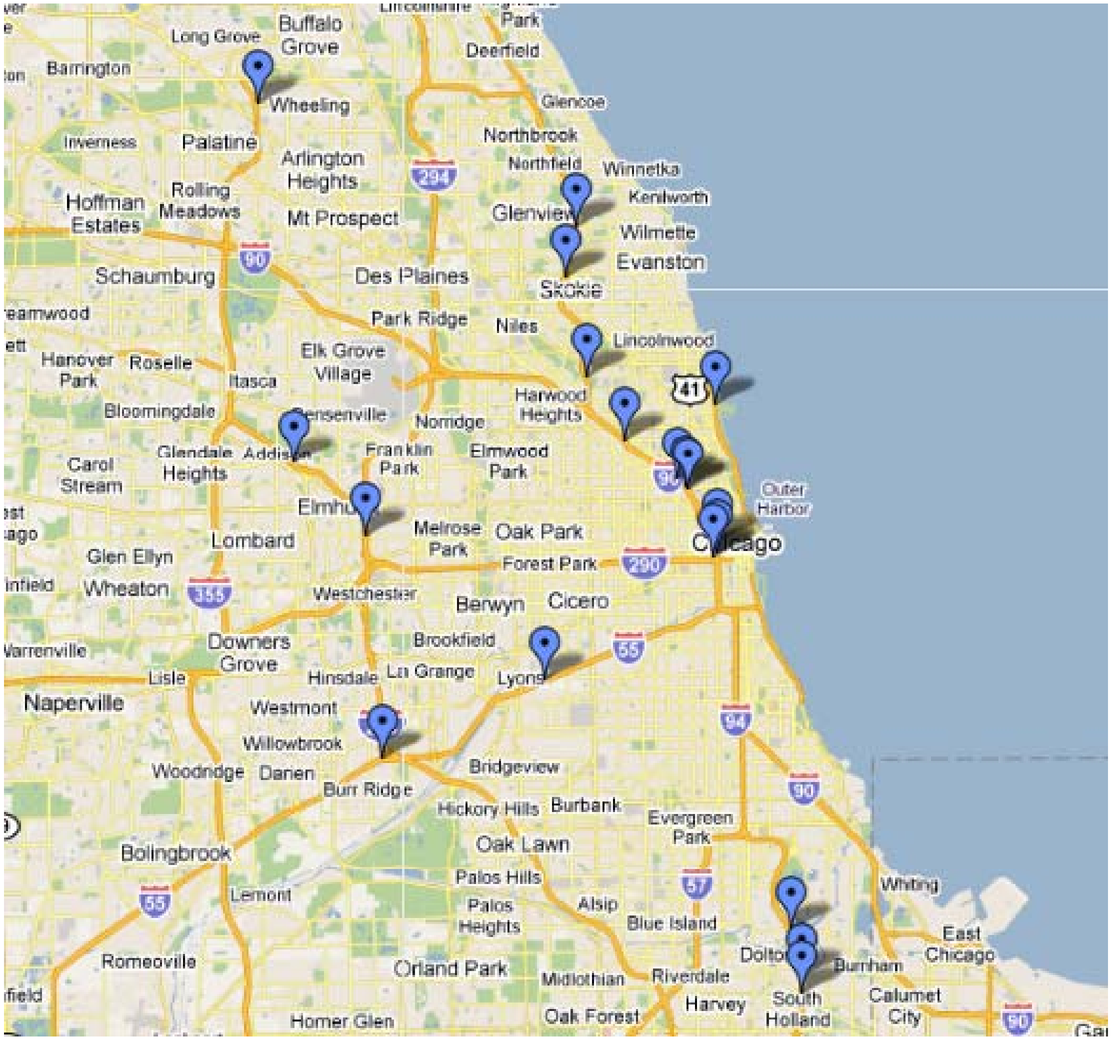



- ~40,000 links
  - 144 links are tolled
  - 1,400 freeways
  - 200 highways
  - 2,000 ramps
  - (96 of them are metered)
  - 36,400 arterials
- ~13,000 nodes
  - 2155 signalized intersections
- 1,961 zones
  - 1,944 internal
  - 17 external
- Demand period
  - 5am -10am hourly demand
  - 355 unique link counts
  - Observation Interval: 5 min

# Calibration and Validation of

# DYNASMART-P

# Location of traffic data for traffic flow calibration



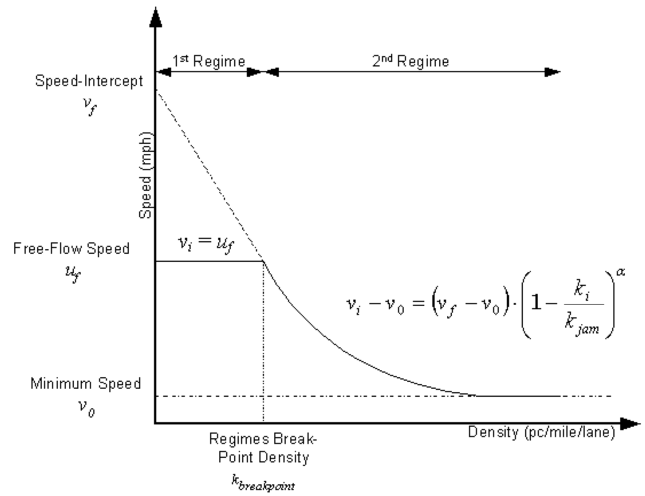
# Calibrating parameters in the traffic flow model / Procedure

**Step 1.** Plot the speed vs. density graph, and set initial values for all the parameters, i.e. breakpoint density ($k_{bp}$), speed-intercept ($v_f$), minimum speed ($v_0$), jam density ($k_{jam}$), and the shape parameter ($\alpha$), based on observations.

**Step 2.** For each observed density ($k_i$), calculate the predicted speed value and the parameters initialized in Step 1.

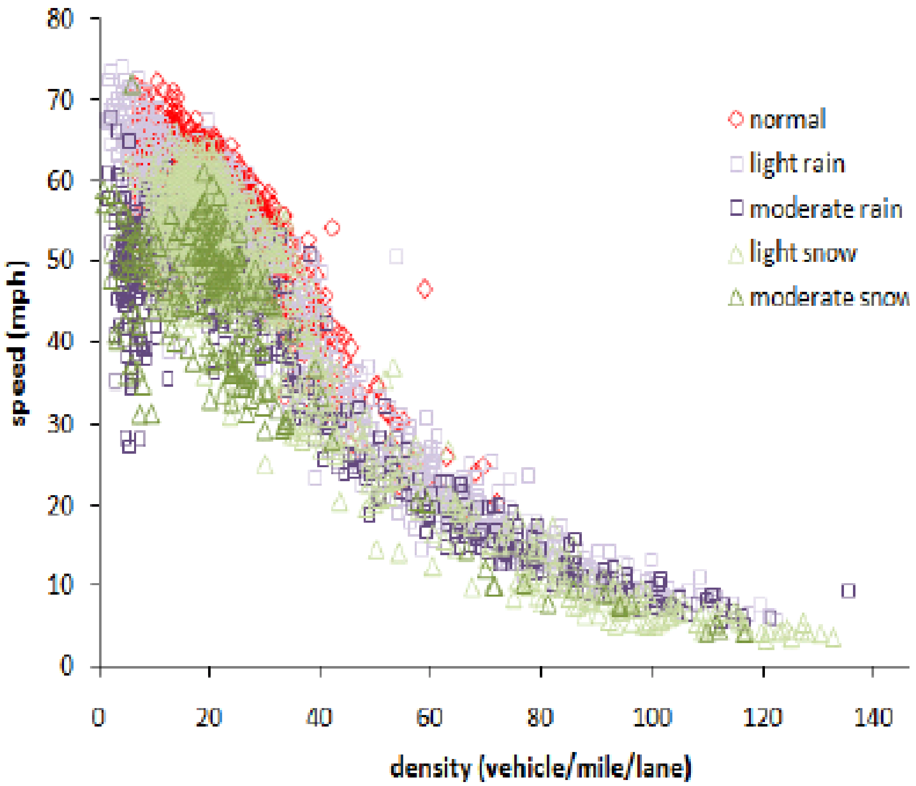
**Step 3.** Compute the squared difference between observed speed value ($v_i$) and predicted speed value, for each data point, and sum the squared error over the entire data set.

**Step 4.** Minimize the sum of squared error obtained in Step 3, by changing the values of model parameters.

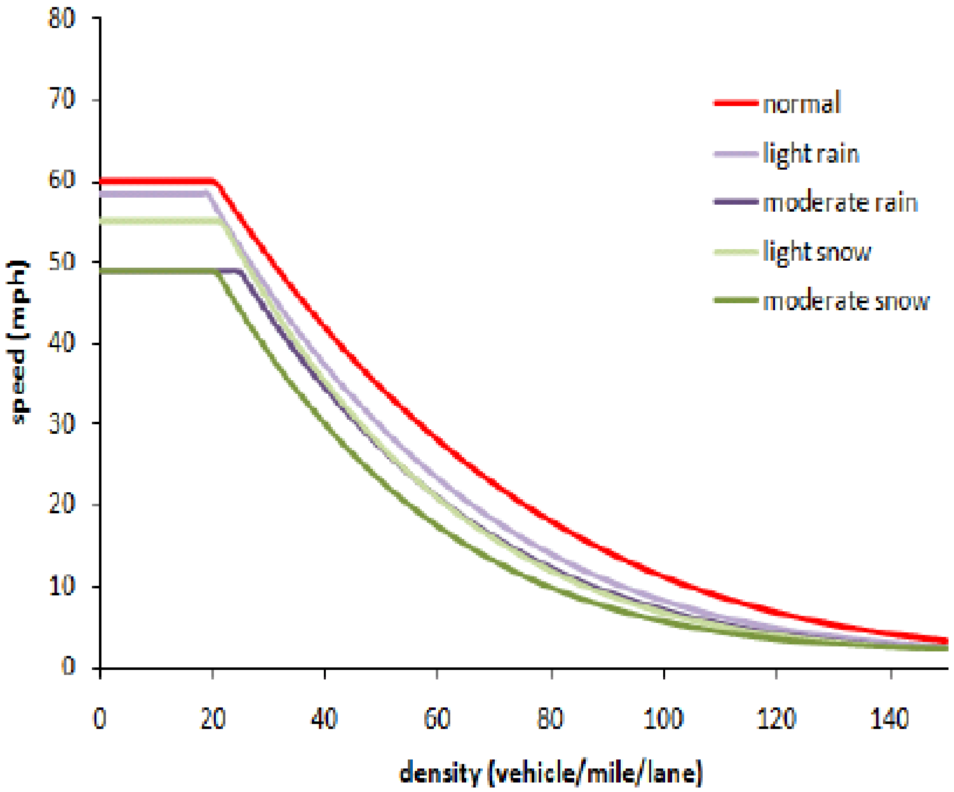



**Modified Greenshields**

# Calibrating parameters in the traffic flow model for different weather conditions

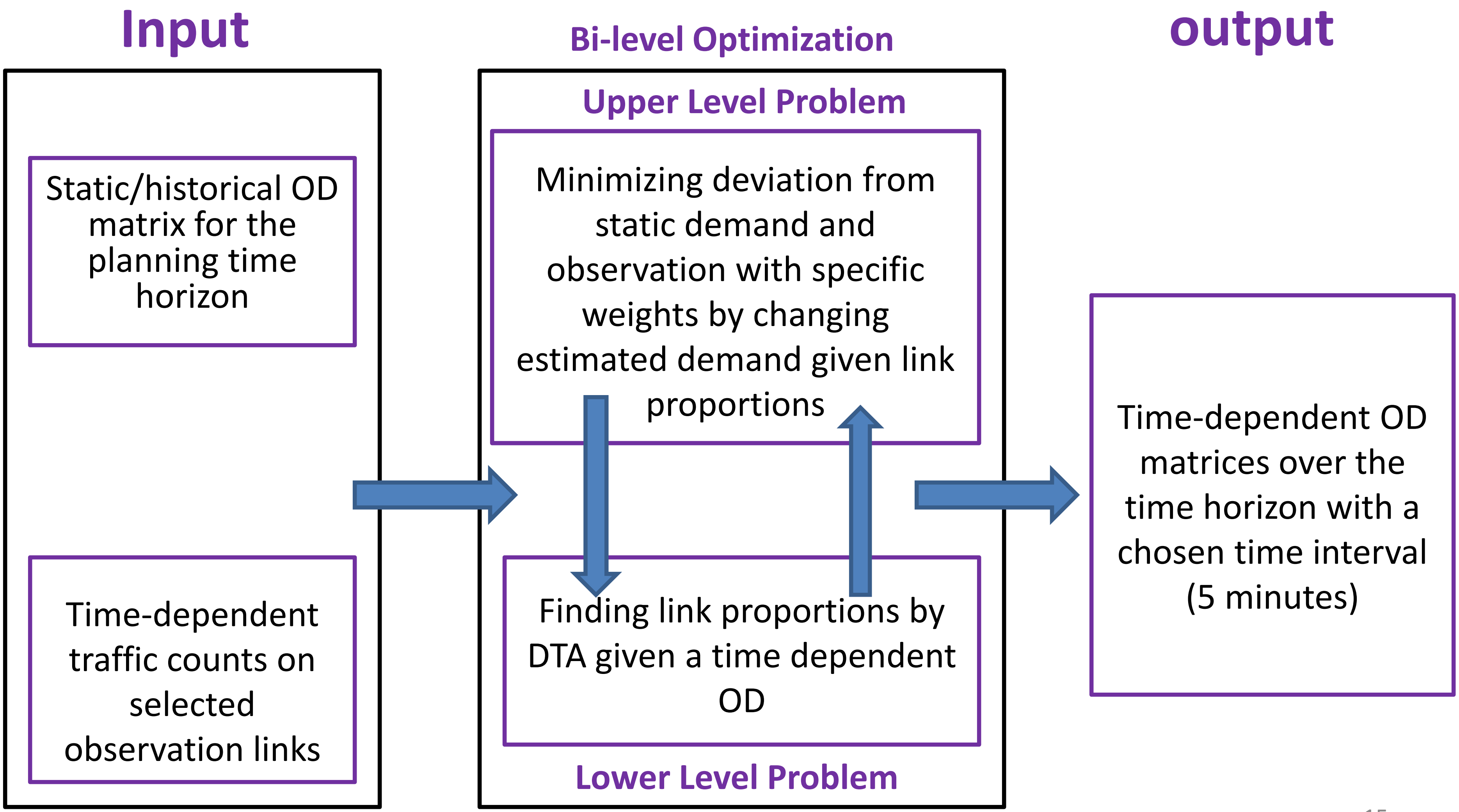



Speed-Density Data




Speed-Density Calibrated Relationship

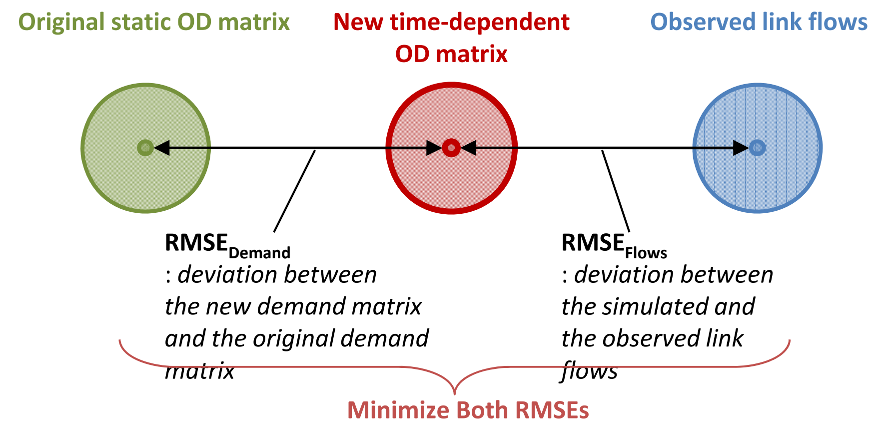
# Time-dependent OD Estimation / Methodology



# Time-dependent OD Estimation for large scale networks / Results

$$RMSE_{Demand} = \sqrt{\frac{\sum_{i=1}^{I}\sum_{j=1}^{J}\left[\left\{\sum_{h=1}^{H} d_{i,j,h}\right\} - \delta_{i,j}\right]^2}{IJH - 1}}$$

$$RMSE_{Flows} = \sqrt{\frac{\sum_{l=1}^{L}\sum_{t=1}^{T}[M_{l,t} - O_{l,t}]^2}{LT - 1}}$$

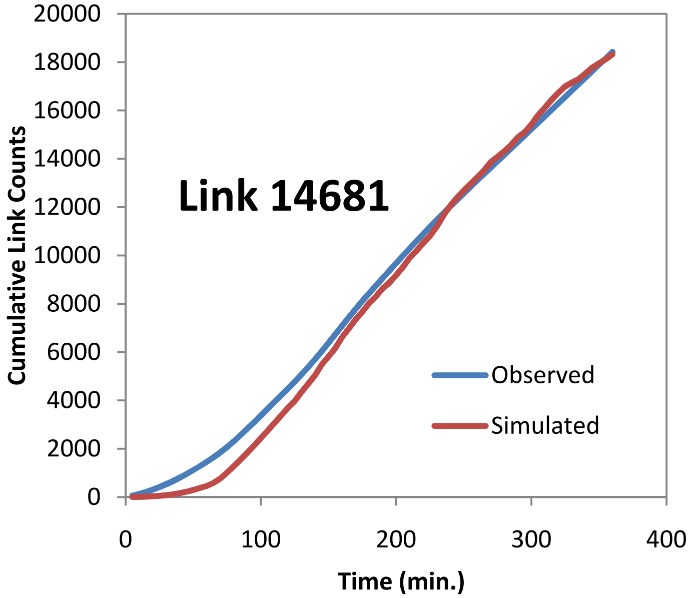


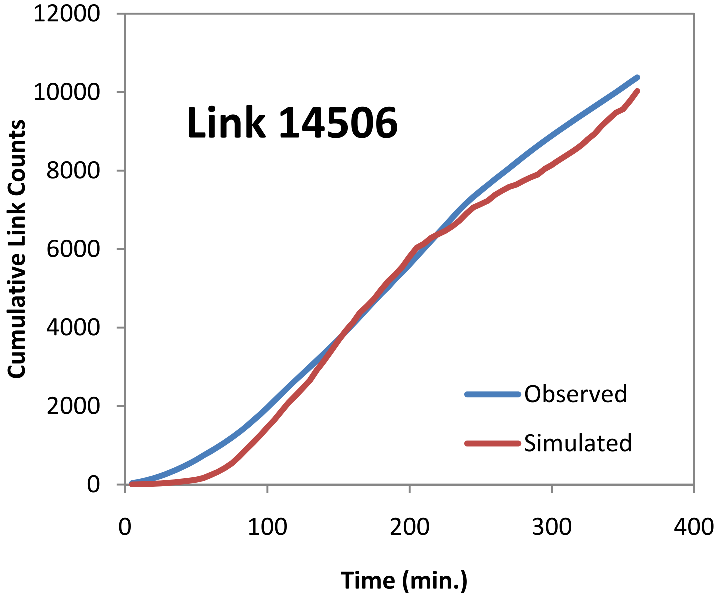

| | Number of Trips | RMSE Values | |
|---|---|---|---|
| | SOV* | $RMSE_{Demand}$ | $RMSE_{Flows}$ |
| Historical OD matrix | 4,145,413 | 0** | 228.759 |
| New time-dependent OD matrix after **Iteration 1** | 4,179,062 | 0.044 | 219.148 |
| New time-dependent OD matrix after **Iteration 2** | 4,157,199 | 0.049 | 217.739 |
| New time-dependent OD matrix after **Iteration 3** | 4,141,043 | 0.049 | 217.030 |

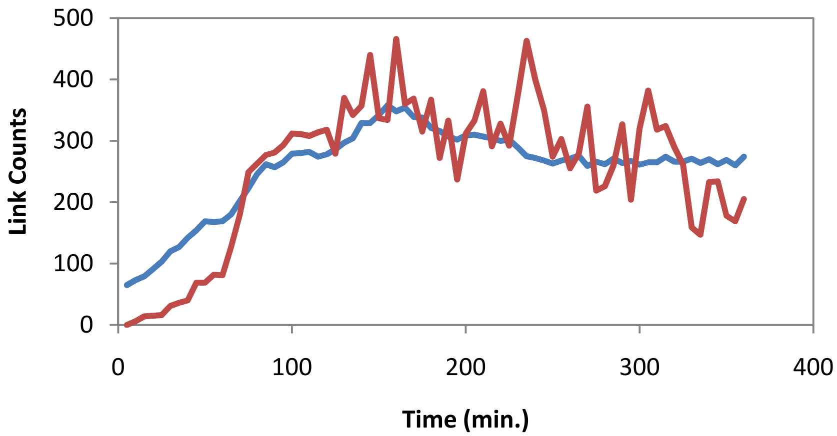
* *SOV: Single-occupancy vehicle*

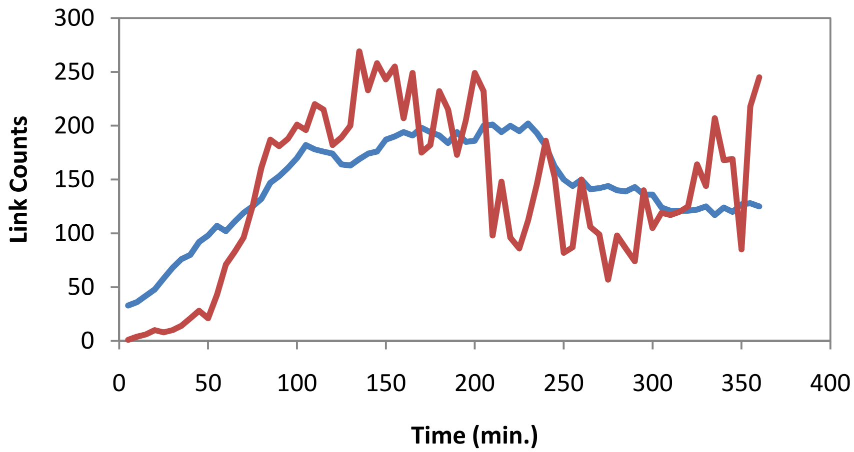
** *Deviation is zero because $RMSE_{Demand}$ in this case represents the deviation between the static OD matrix and itself.*

# Time-dependent OD Estimation / Results



# VALIDATION OF WEATHER SENSITIVE DYNASMART-P

$$RMSE_{Speeds} = \sqrt{\frac{\sum_{l=1}^{L}\sum_{t=1}^{T}[MS_{l,t} - OS_{l,t}]^2}{LT - 1}} \qquad RMSE_{Flows} = \sqrt{\frac{\sum_{l=1}^{L}\sum_{t=1}^{T}[M_{l,t} - O_{l,t}]^2}{LT - 1}}$$

| SNOW Scenario: 2010-01-07 (Chicago) | | | |
|---|---|---|---|
| **RMSE Speeds** | | **RMSE Flows** | |
| With Weather Features | Without Weather Features | With Weather Features | Without Weather Features |
| 26.2731 | 36.0101 | 181.5455 | 173.1032 |

Relative difference : 37%

Relative difference : -5%

# Applications

## I- Weather-responsive traffic estimation and prediction

# Objectives

- Reduce the impact of **inclement weather events** and mitigate **congestion**
- Determine weather-related advisory and controls based on predicted traffic conditions and anticipatory road weather information
- This calls for integrated real-time **Weather-Responsive Traffic Management** (WRTM) and a **Traffic Estimation and Prediction System** (TrEPS)

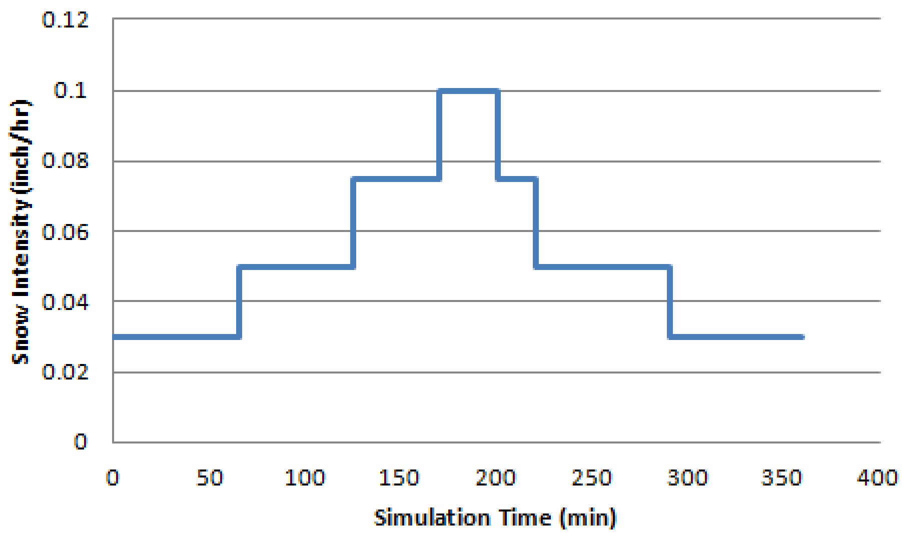
# Offline WRTM

- Historical weather and traffic count data from different days can be used to simulate **various real-world scenarios.**
- Many different **What-If scenarios** can be tested and evaluated.
- Successful scenarios can be added to the **WRTM strategy repository** to be used as an **initial input** for real-time implementation in DYNASMART-X via **Scenario Manager.**

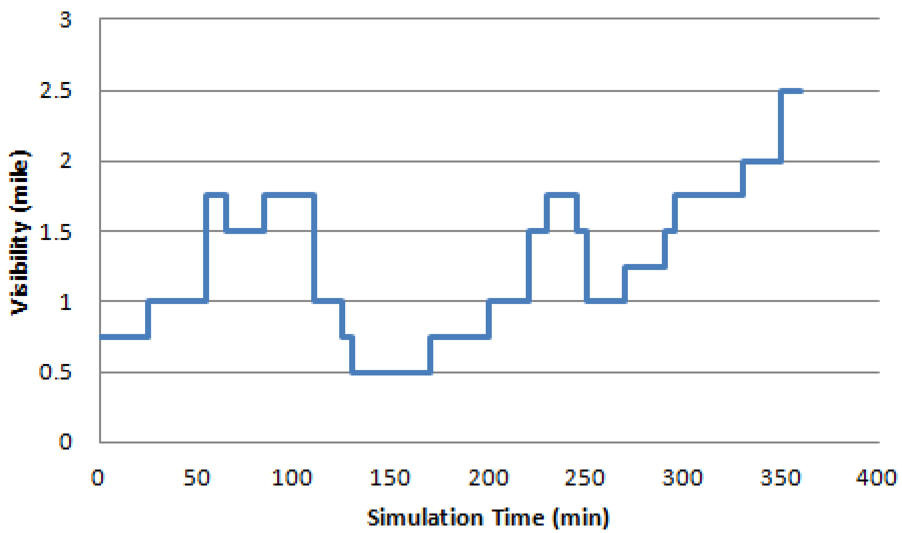
# Description of 5 Scenarios

1. **Clear Day:** Maximum visibility with zero precipitation.
2. **Snow:** Visibility ranges from 0.5 to 2.0 miles, snow intensity ranges from 0.03 to 0.10 inches per hour, network-wide.
3. **Snow with VMS – Variable Speed Limit:** Speed reduction strategies are implemented on freeway corridors.
4. **Snow with VMS – Detour:** Vehicles are detoured from some heavily impacted links to alternative routes.
5. **Snow with VMS – Detour plus Variable Speed Limit:** Vehicles are detoured from some heavily impacted links to alternative routes and Speed reduction strategies are implemented on freeway corridors.

# Weather data during simulation with snow

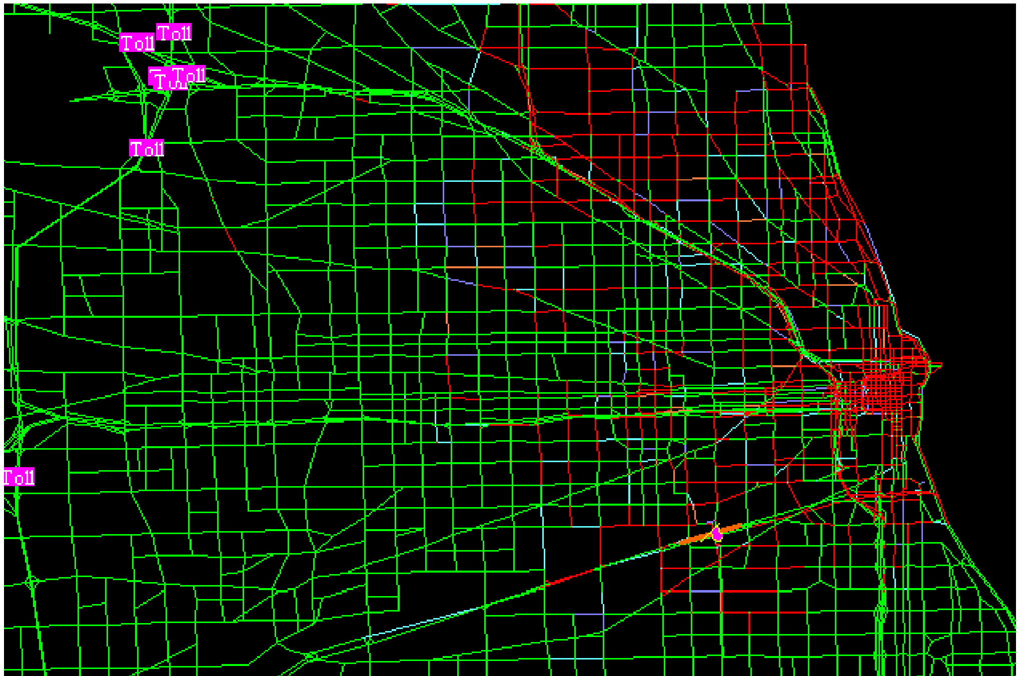



Snow Intensity



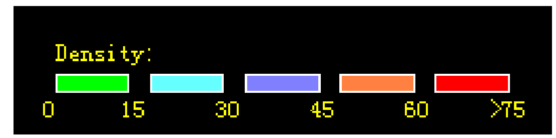

Visibility

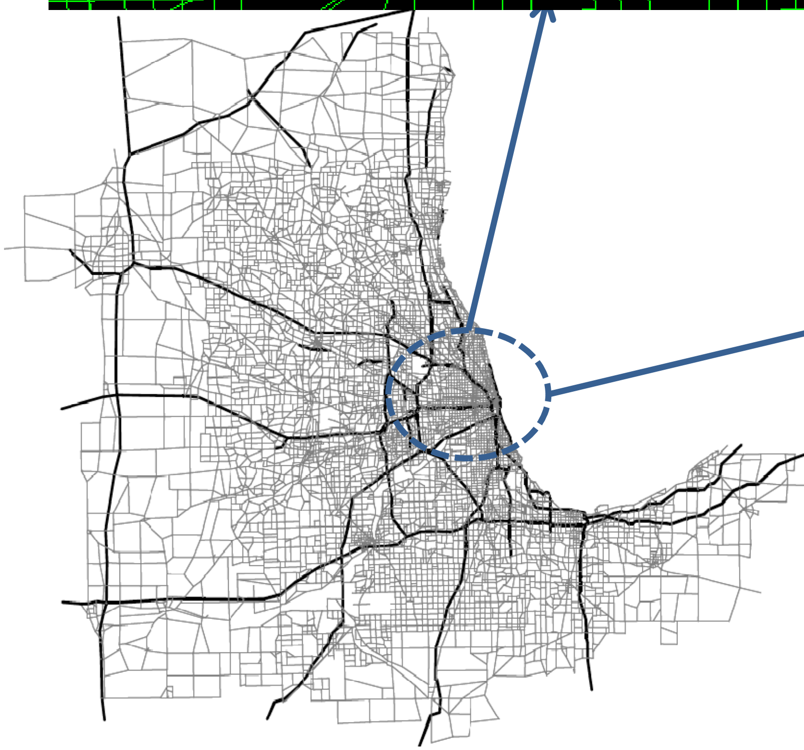
# Weather Impact on density

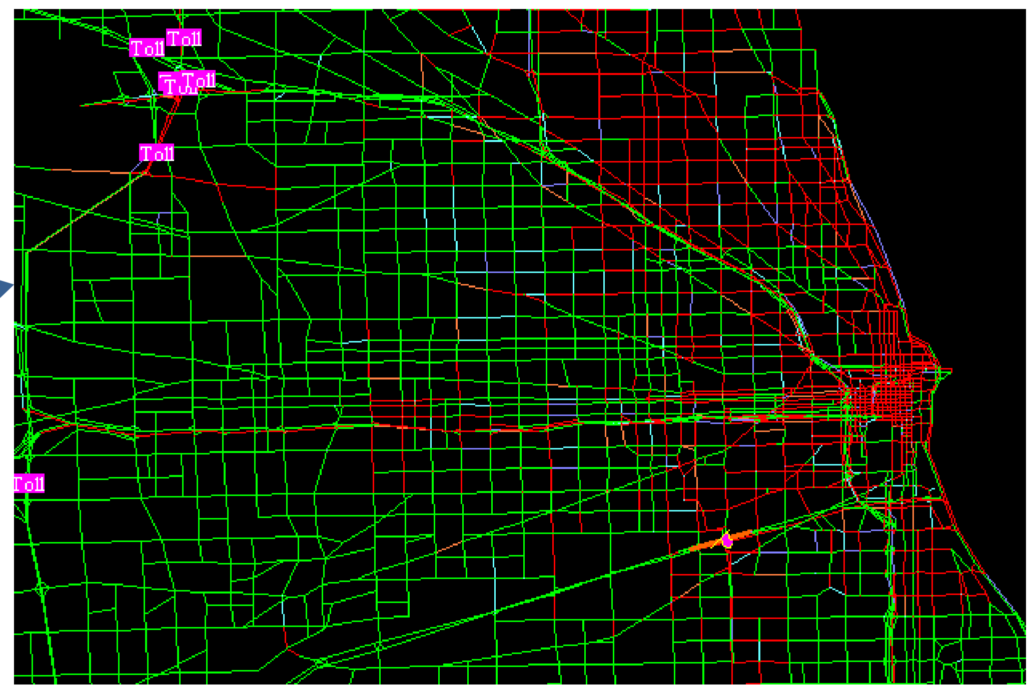



Clear Day

Snow



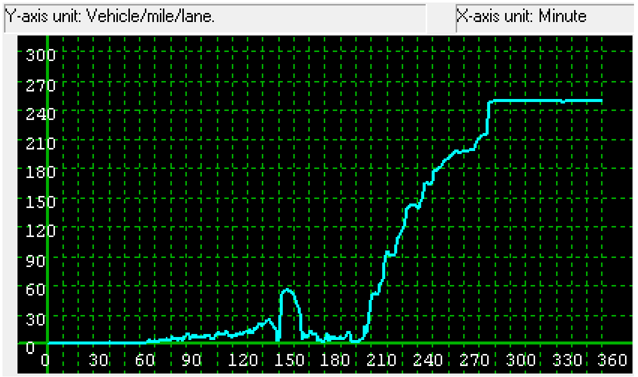


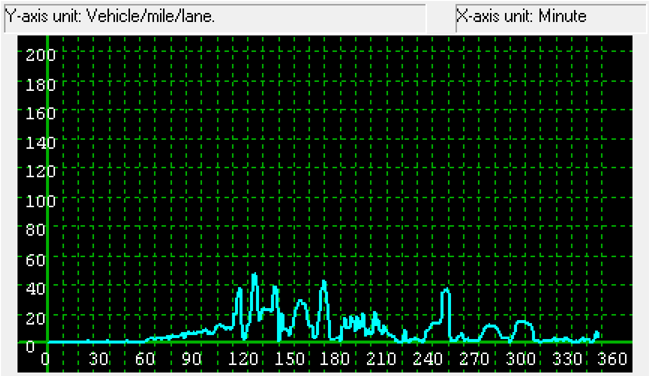
# Lake Shore Dr North bound between Belmont and Fullerton

**Clear Day**

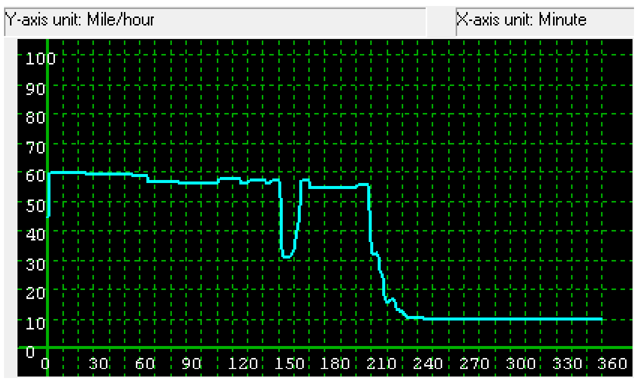
**Snow**

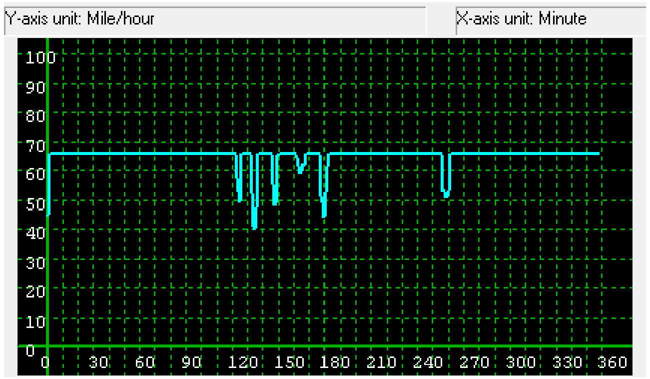
**Density**



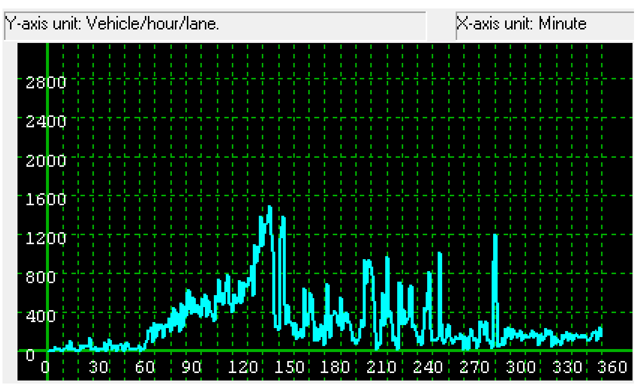



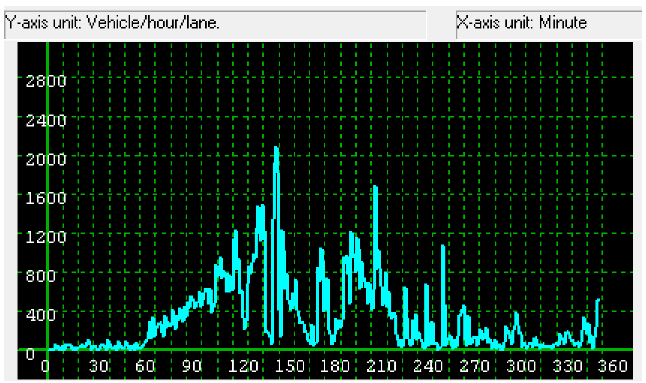

**Speed**




**Volume**

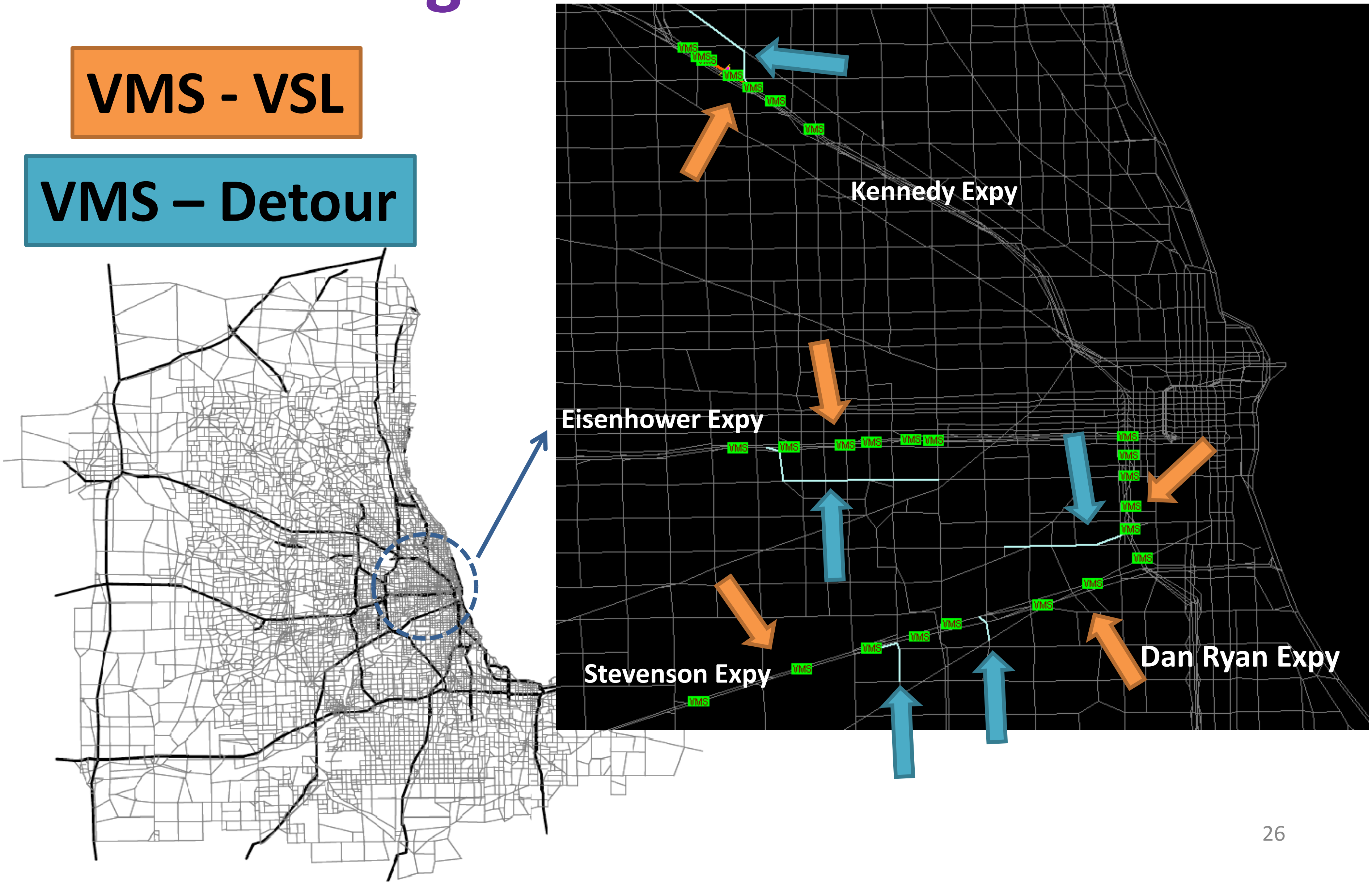


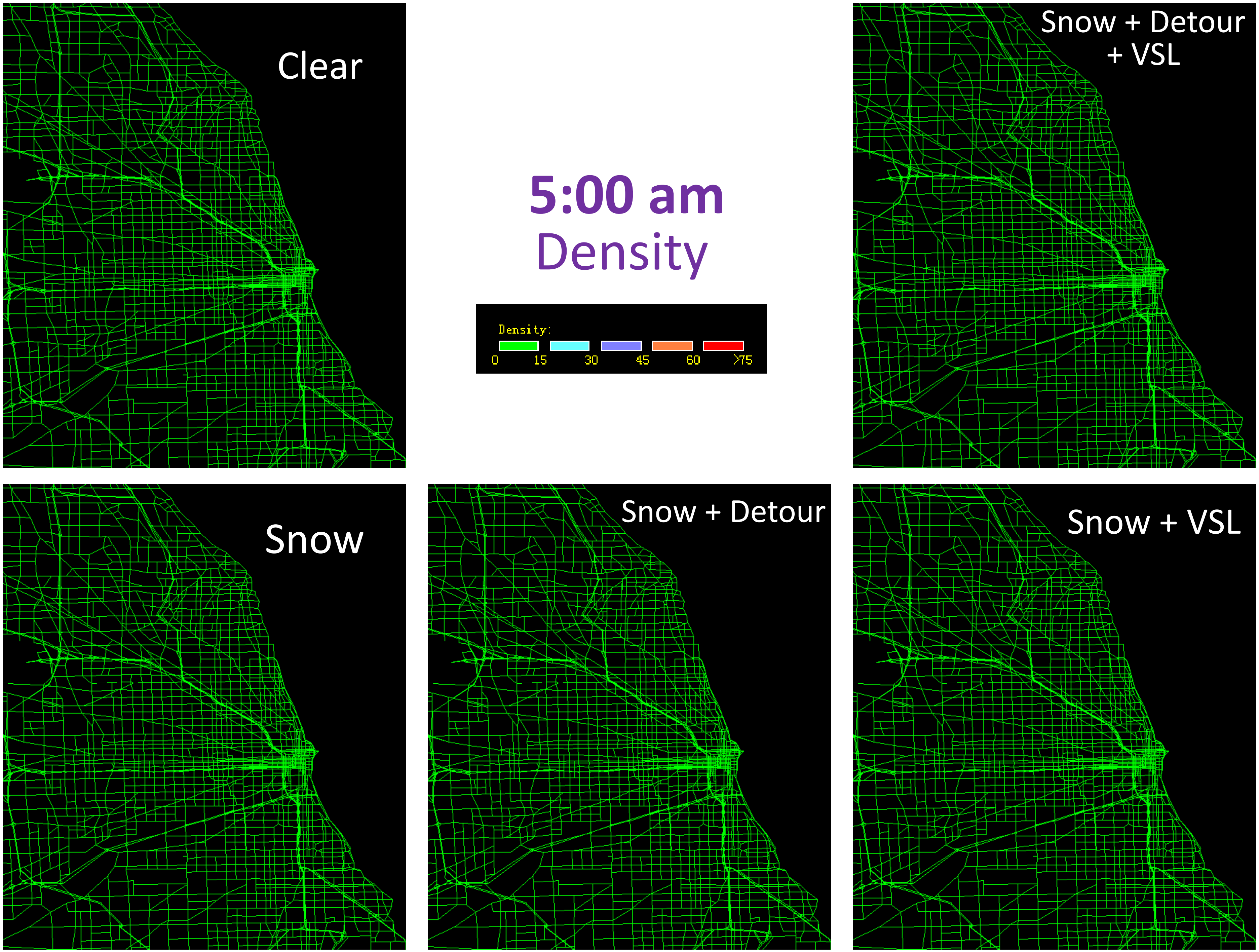



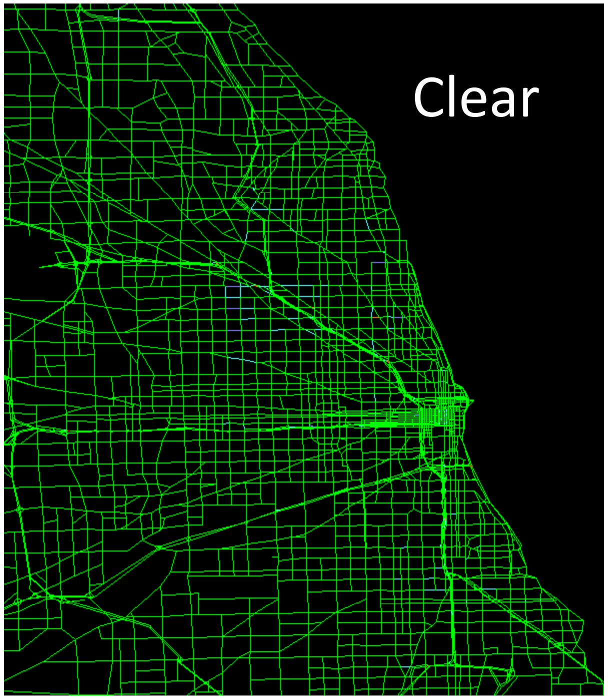
# WRTM Strategies

VMS - VSL

VMS – Detour




5:00 am
Density
Clear
Snow + Detour + VSL
Snow
Snow + Detour
Snow + VSL
Density:
0
15
30
45
60
>75

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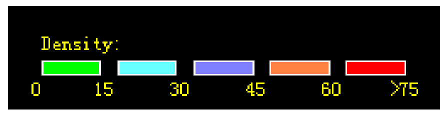


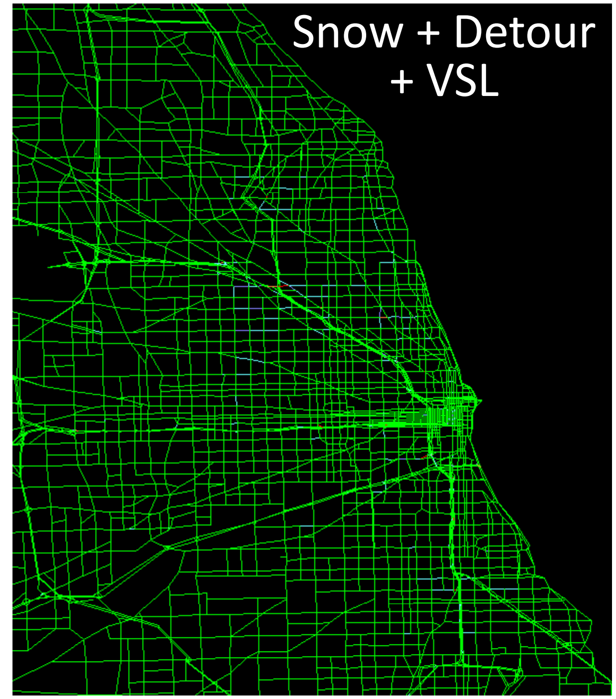



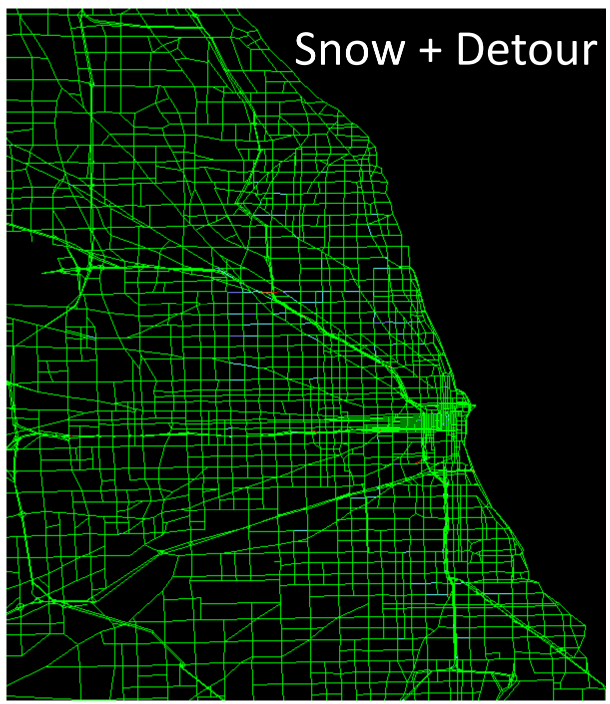


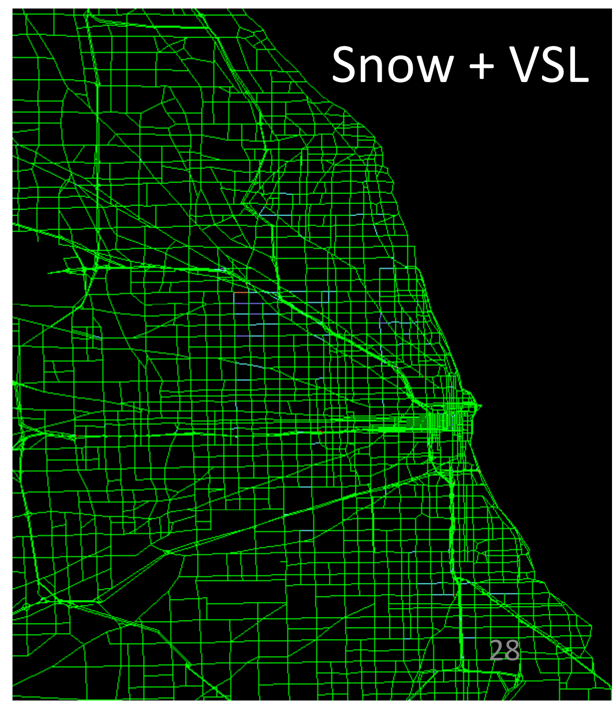

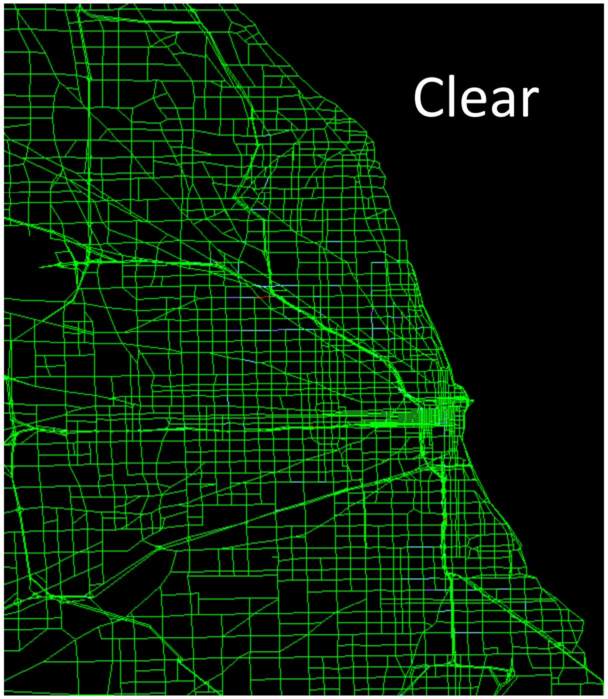


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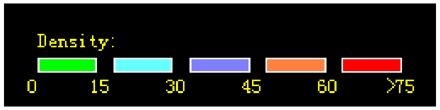


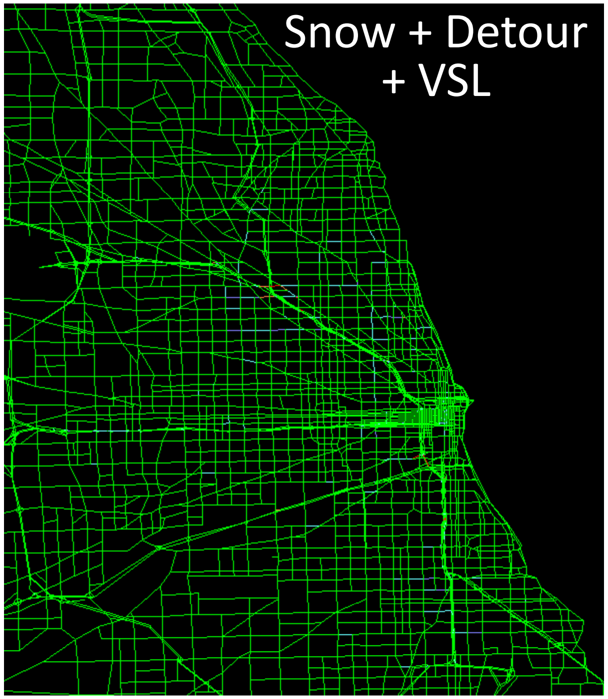



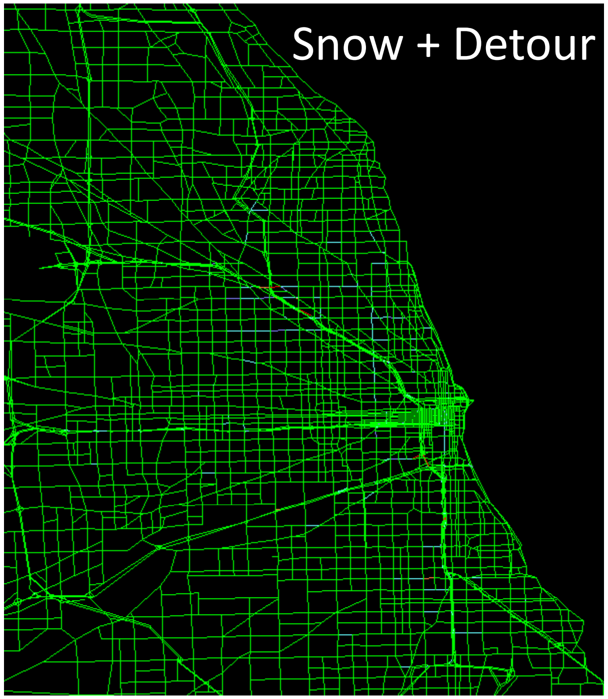


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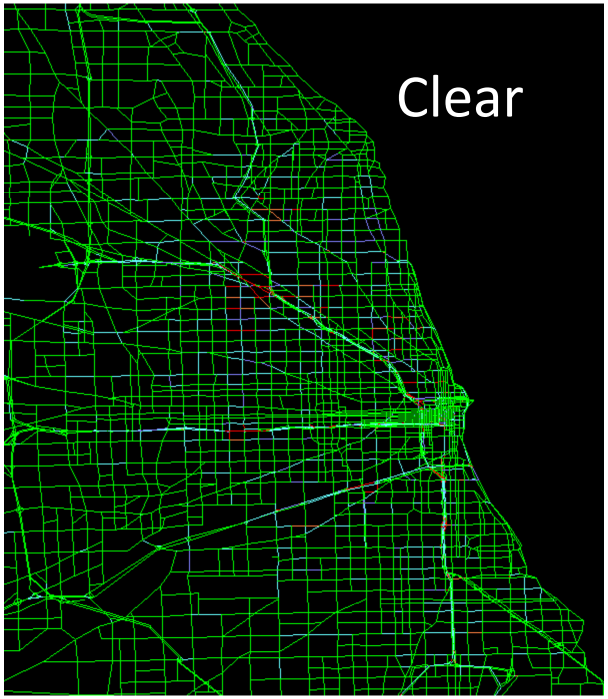


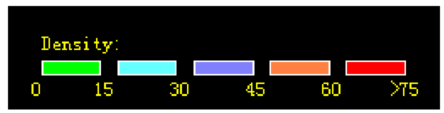


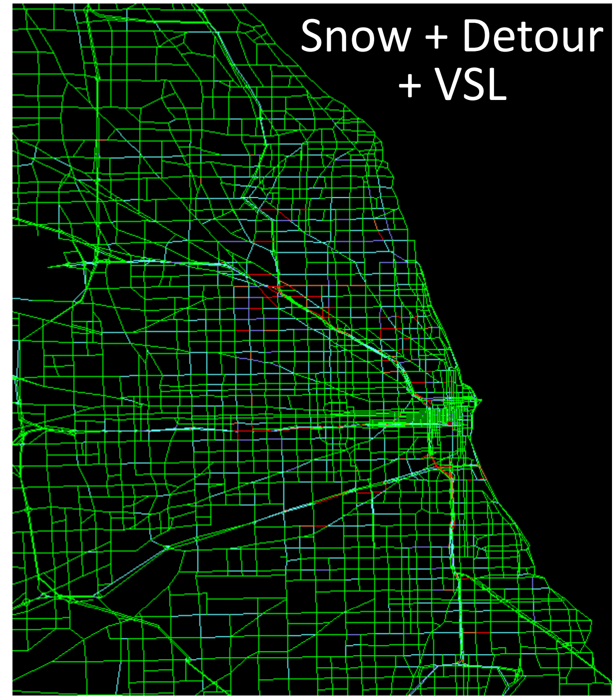


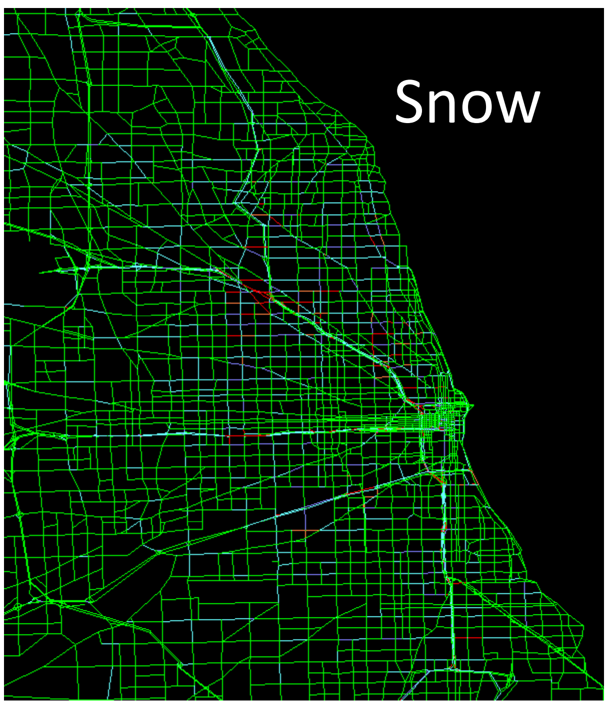


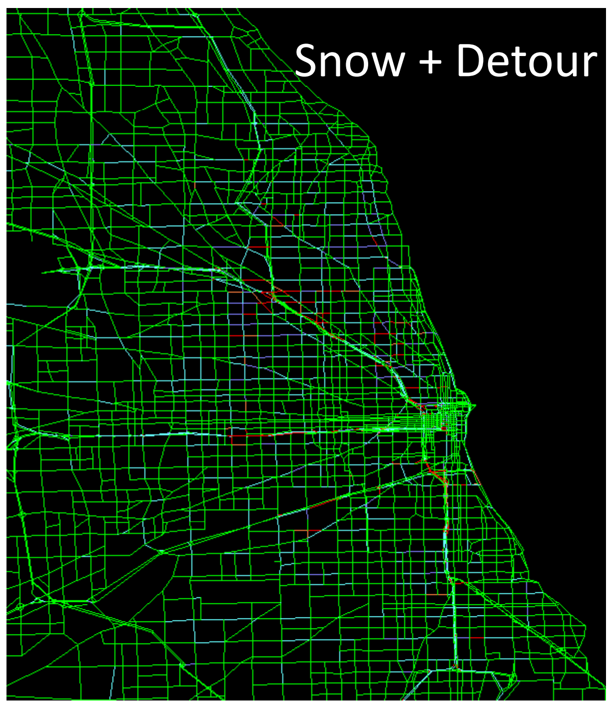


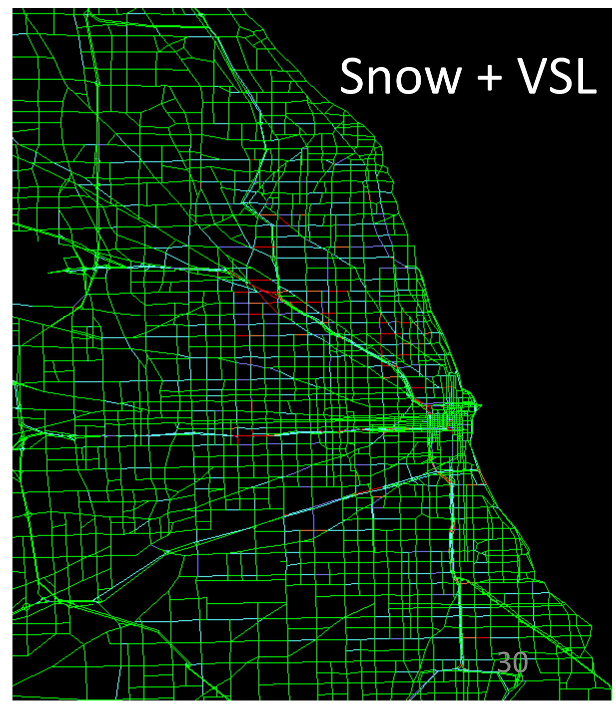

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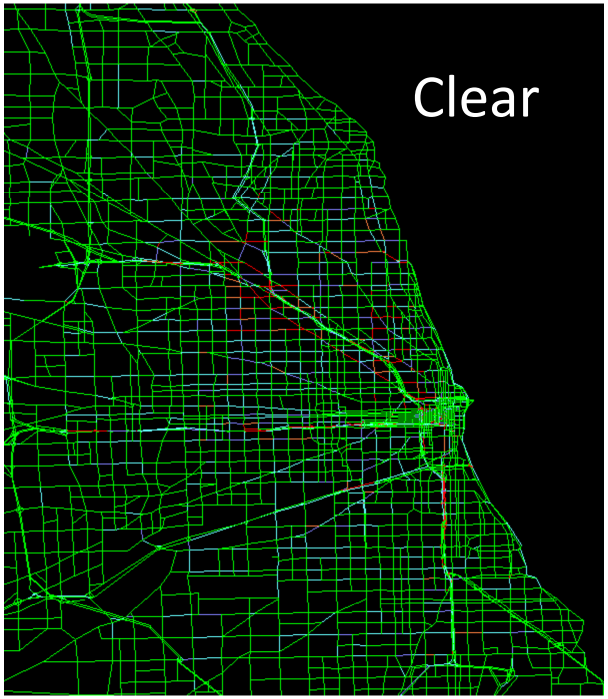


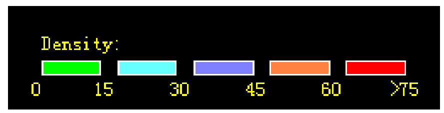


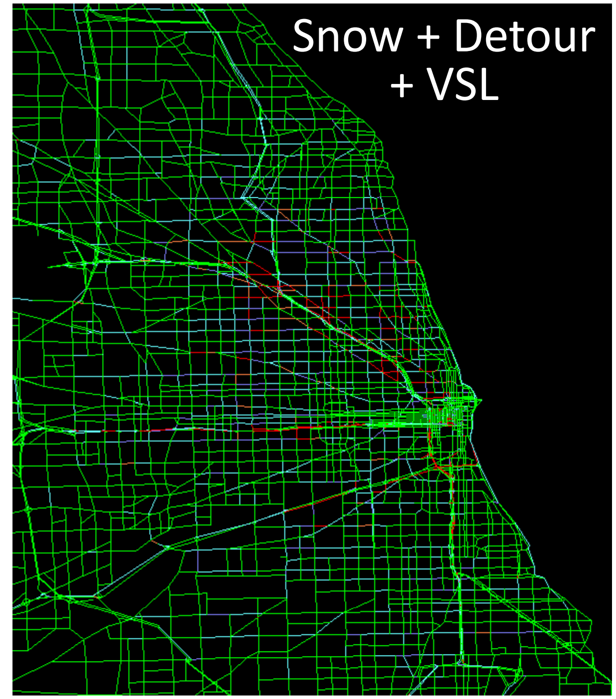



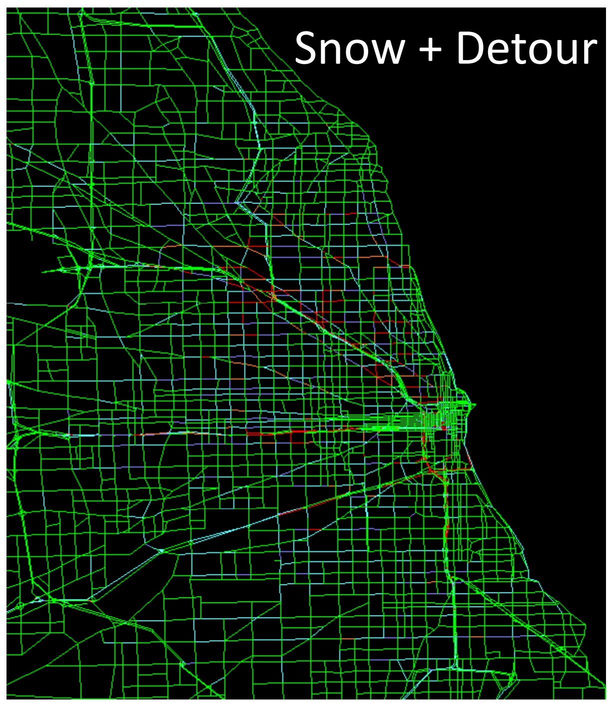


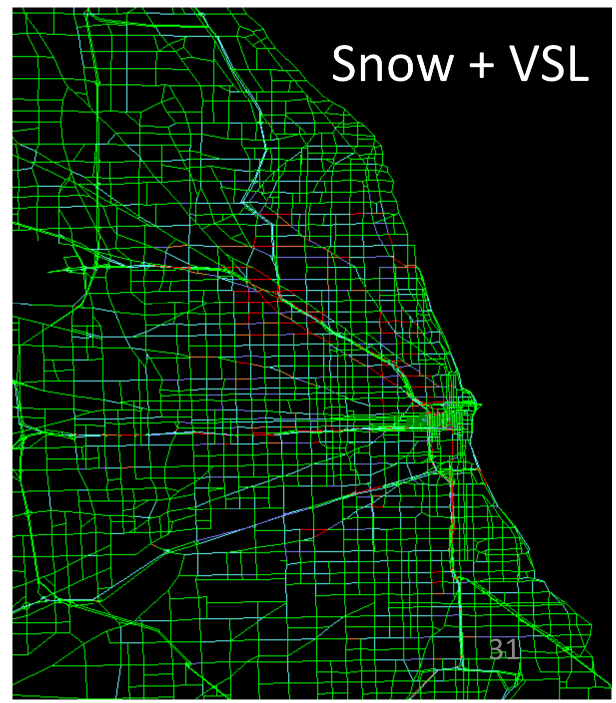

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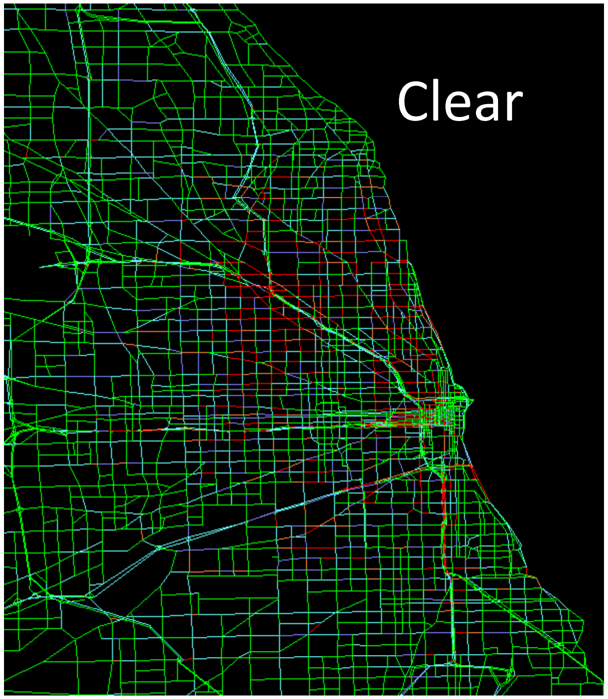


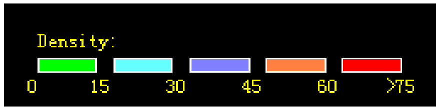


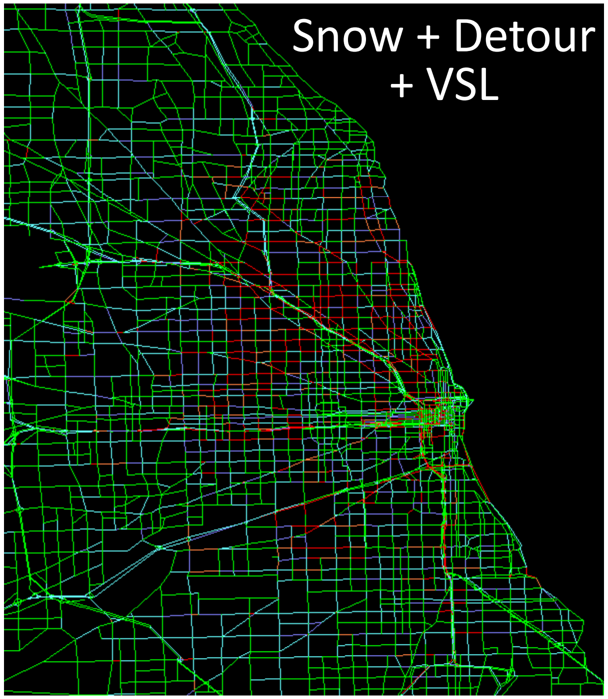


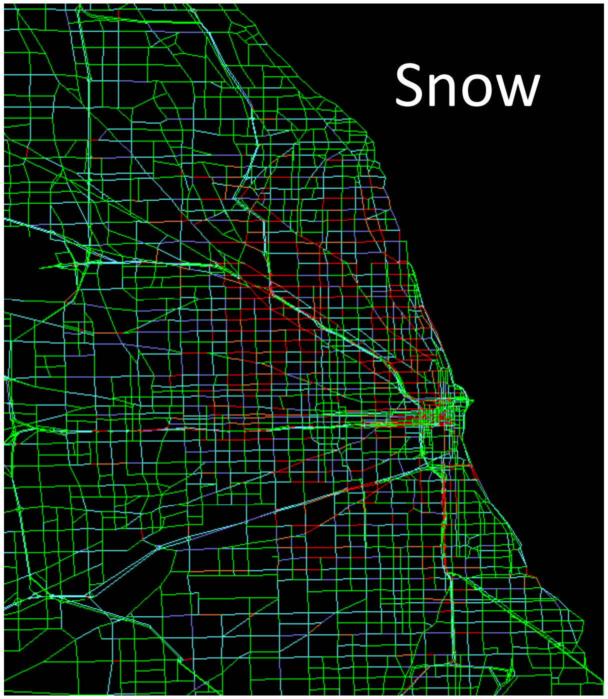


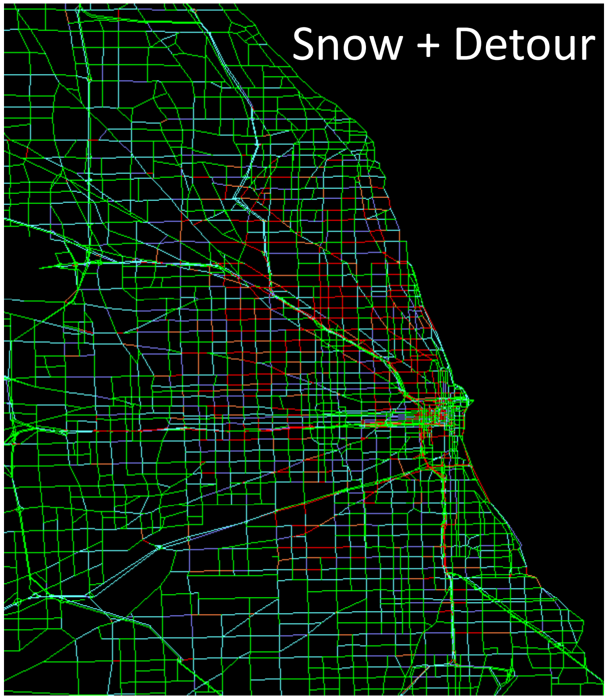


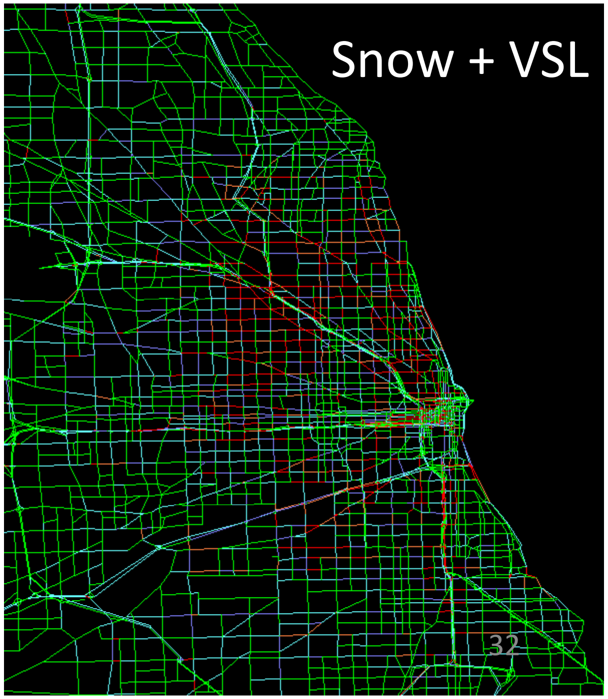

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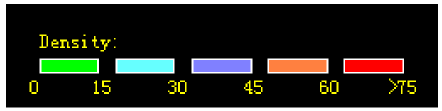


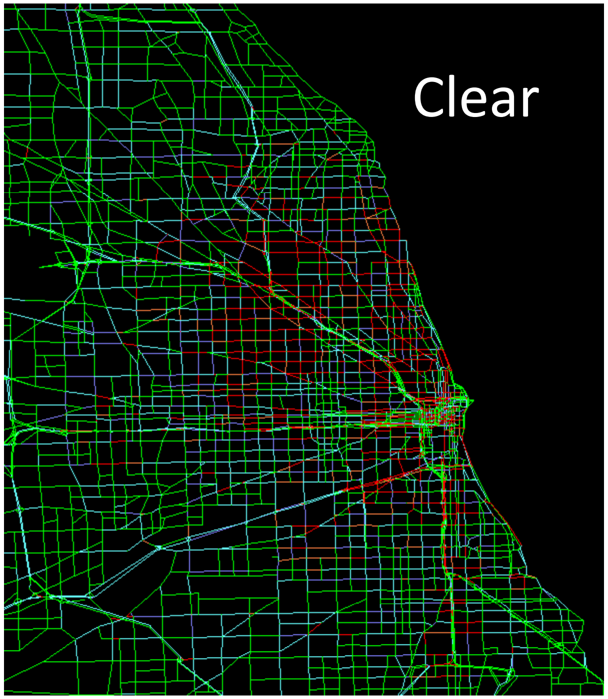


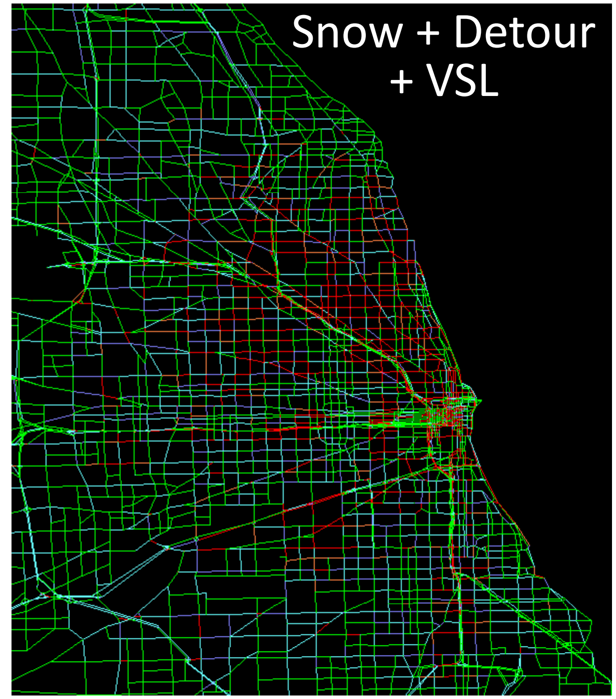


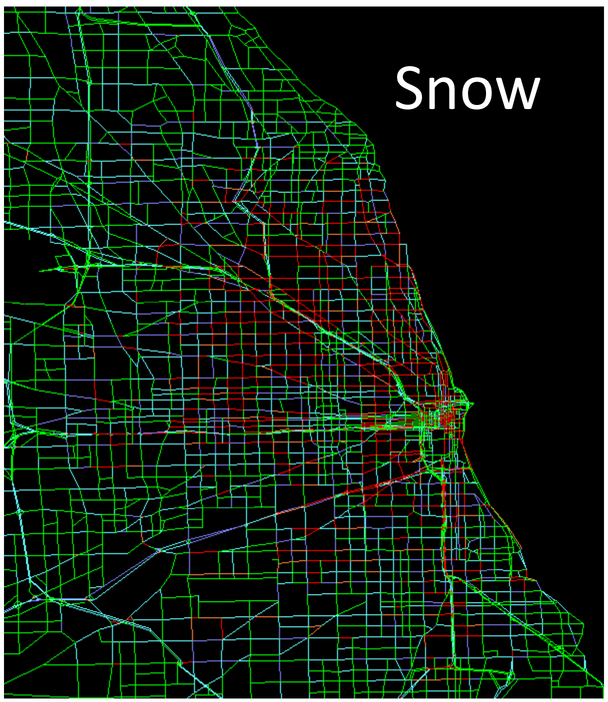


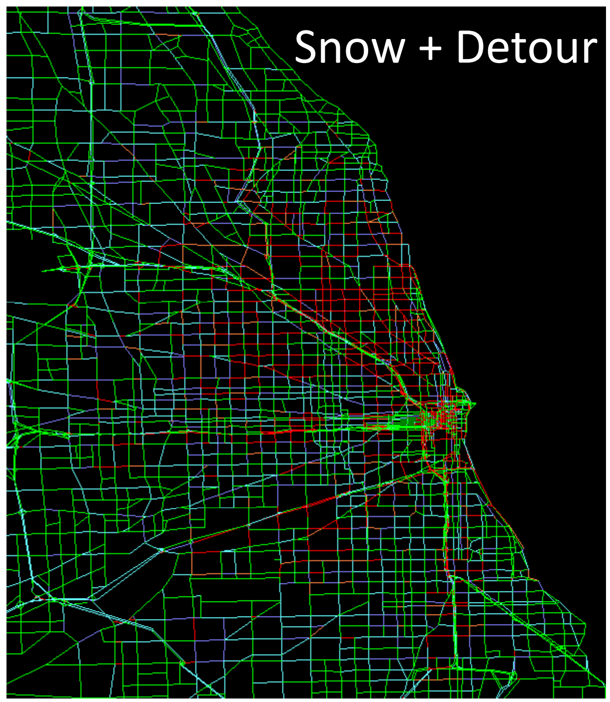


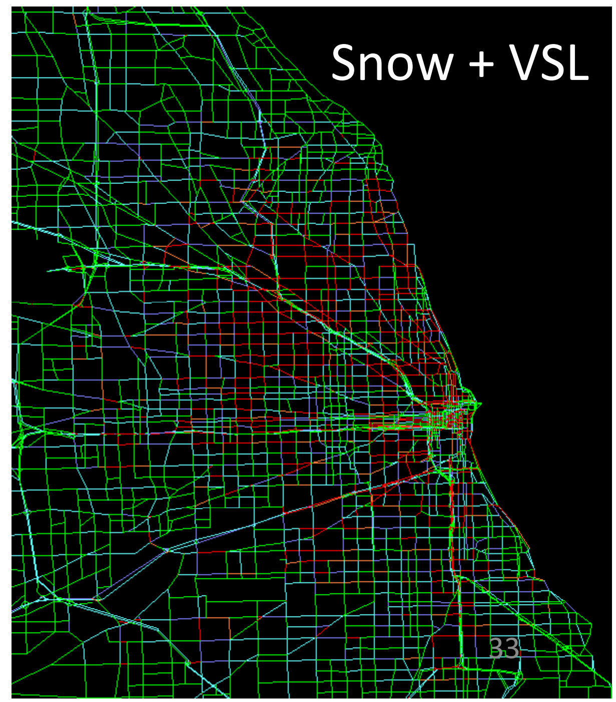

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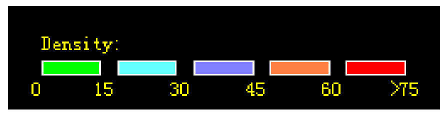


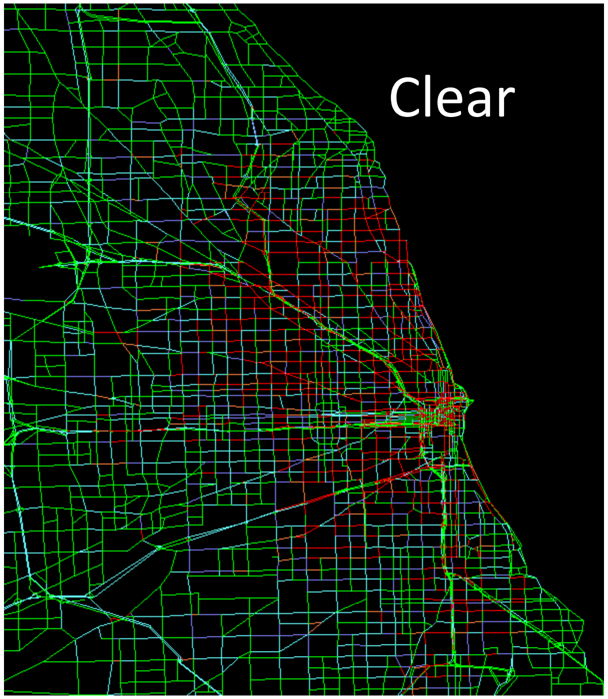


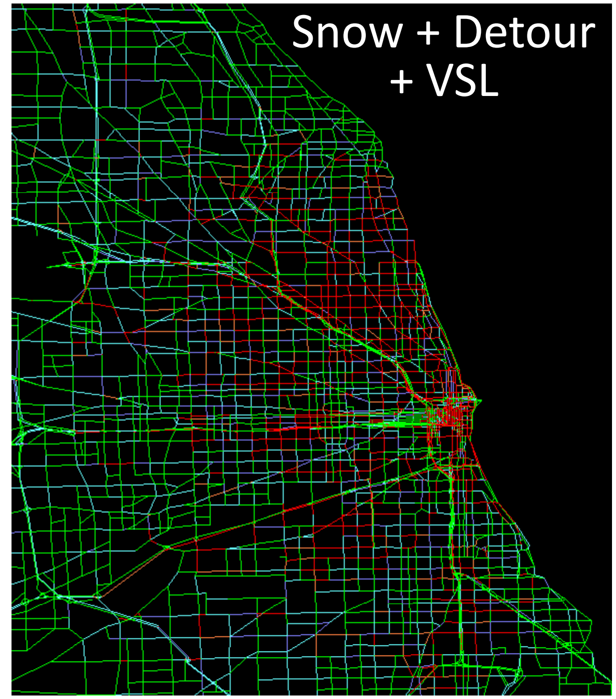


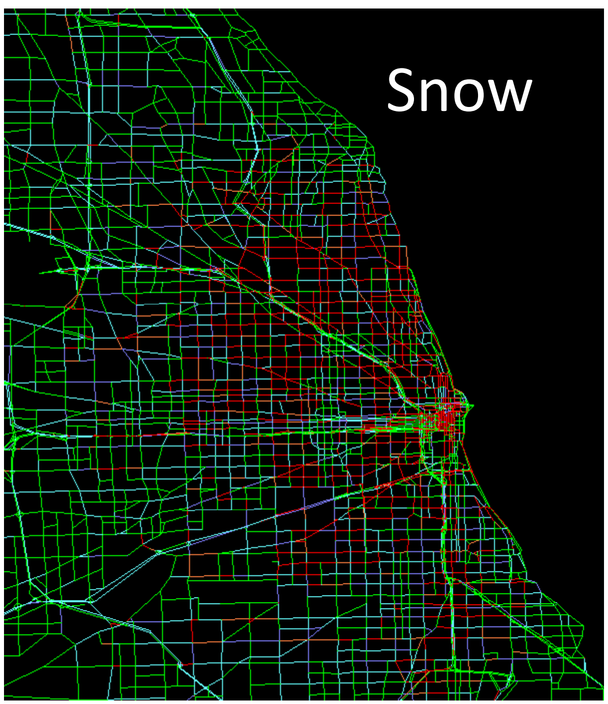


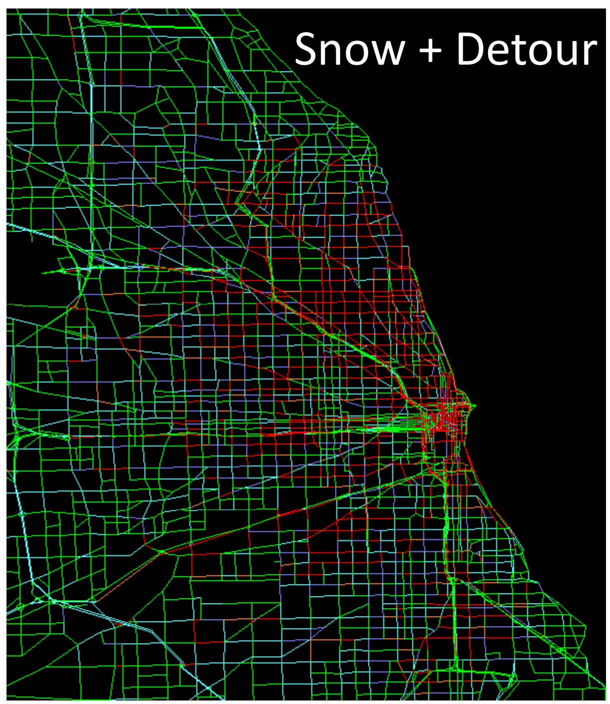


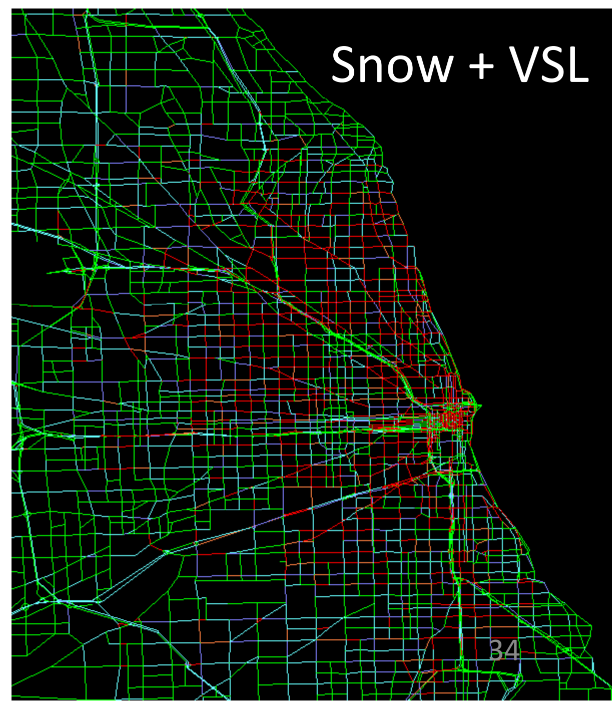

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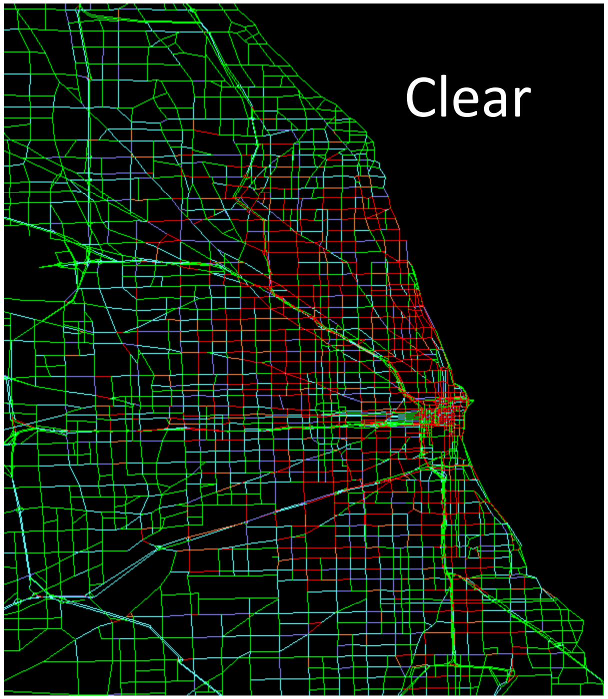


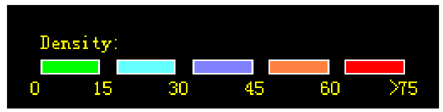


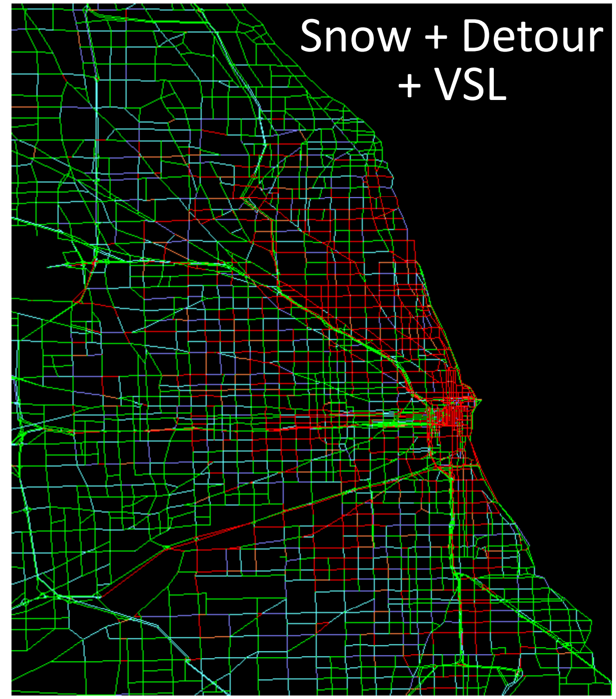


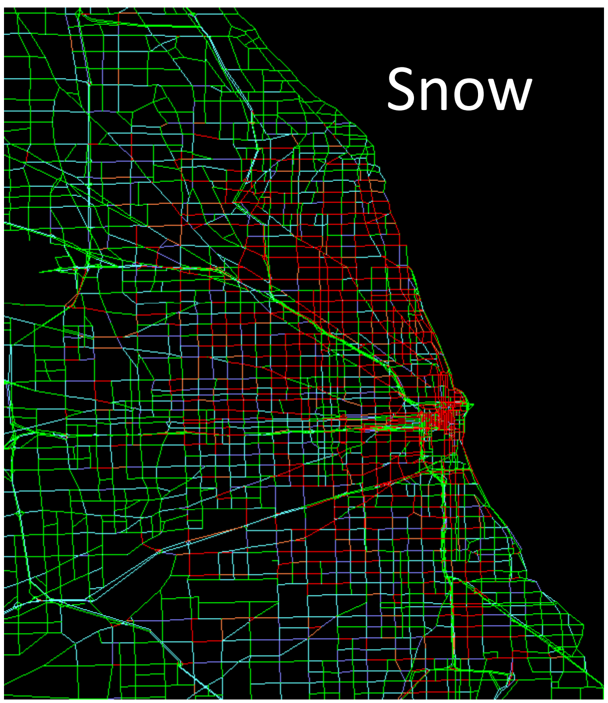


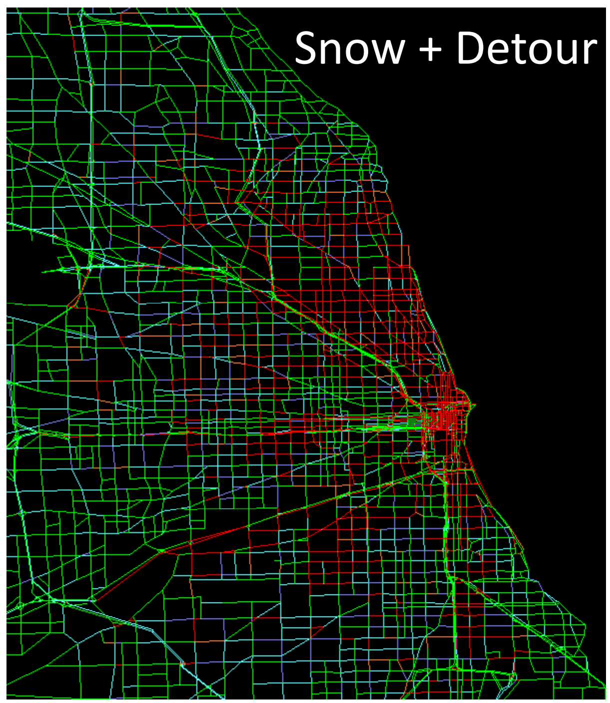


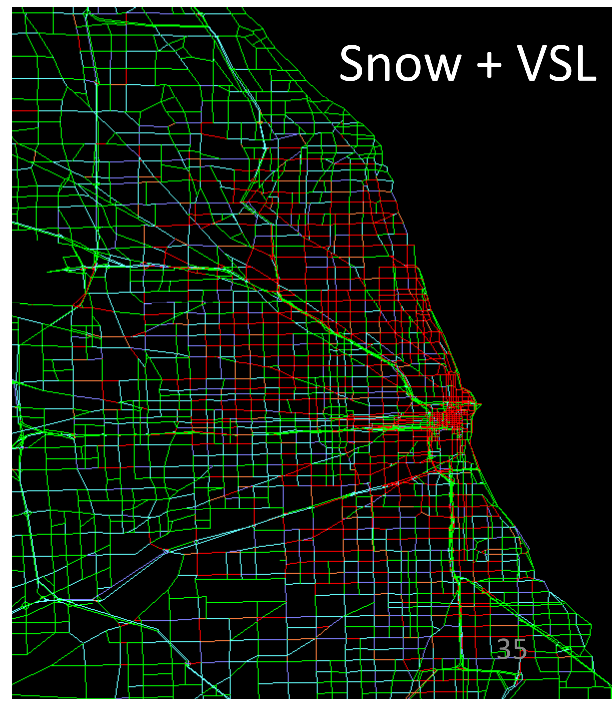

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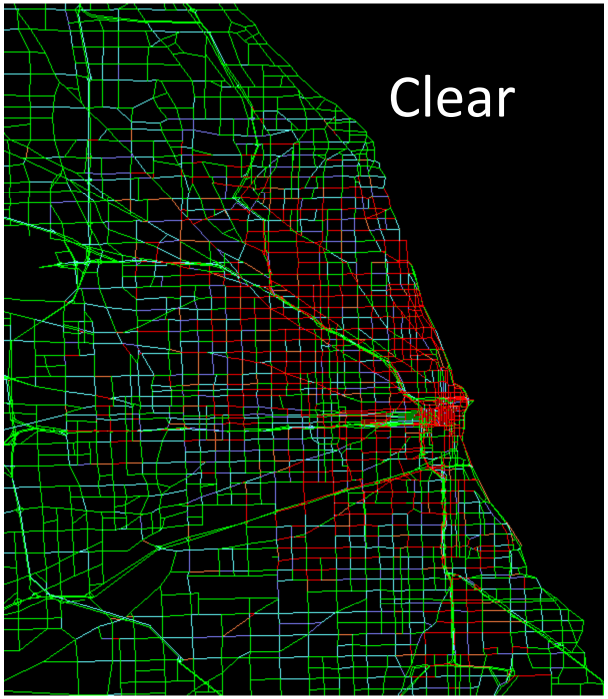


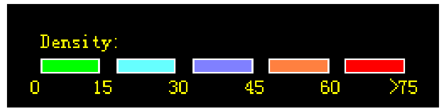


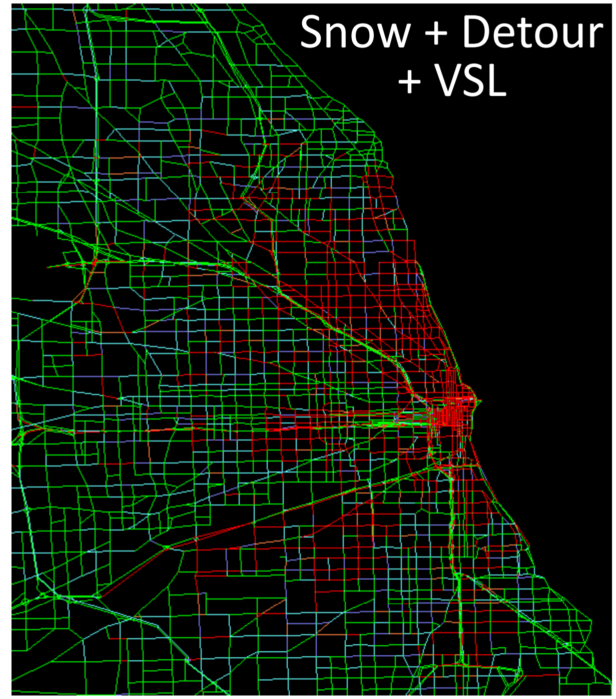


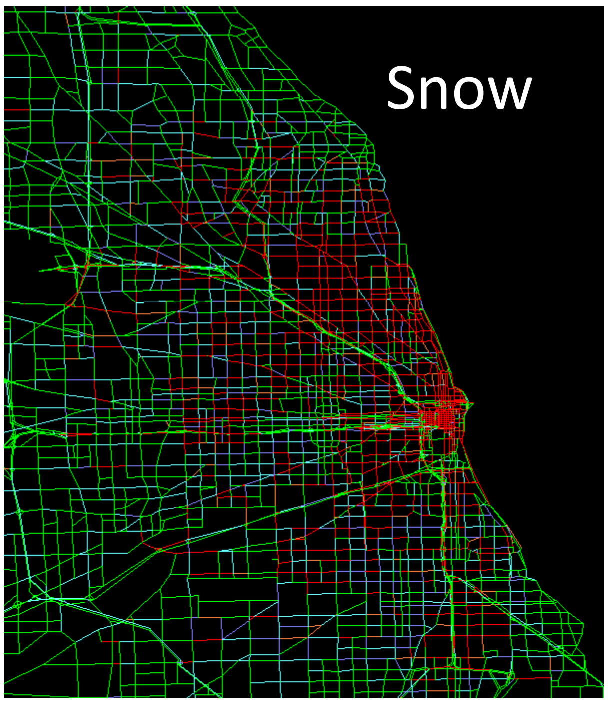


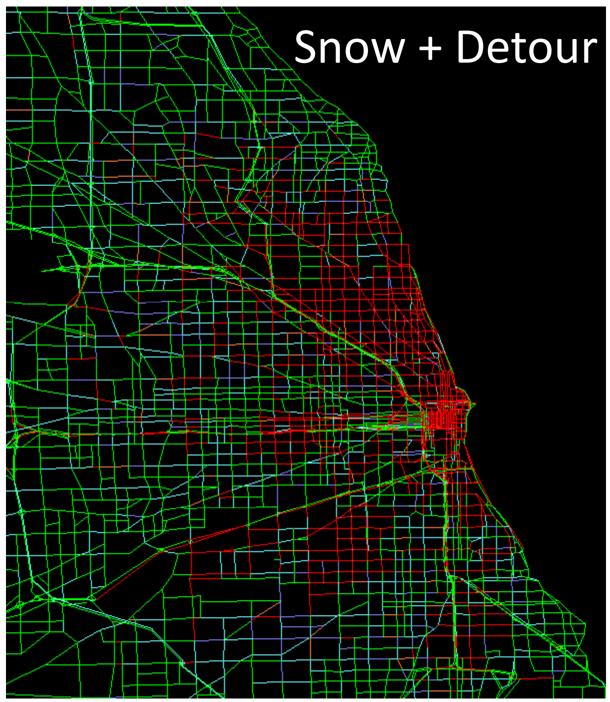


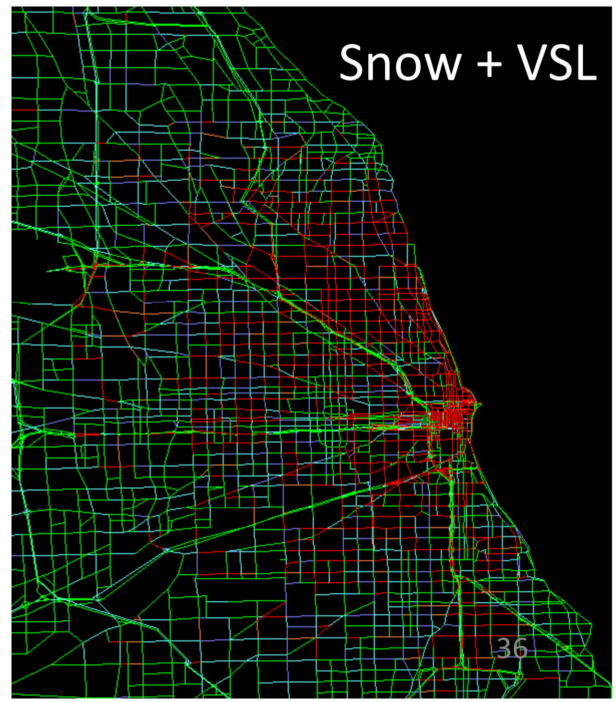

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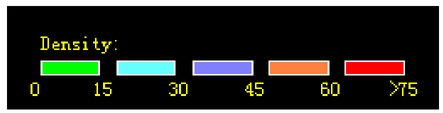


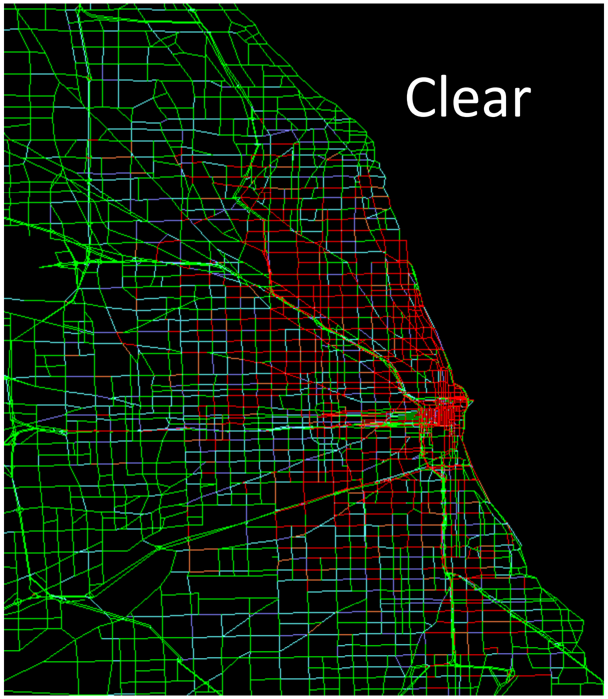


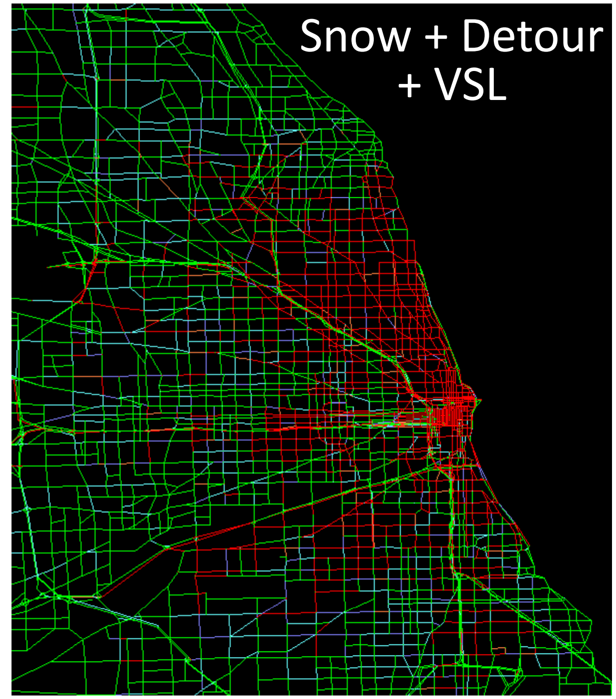


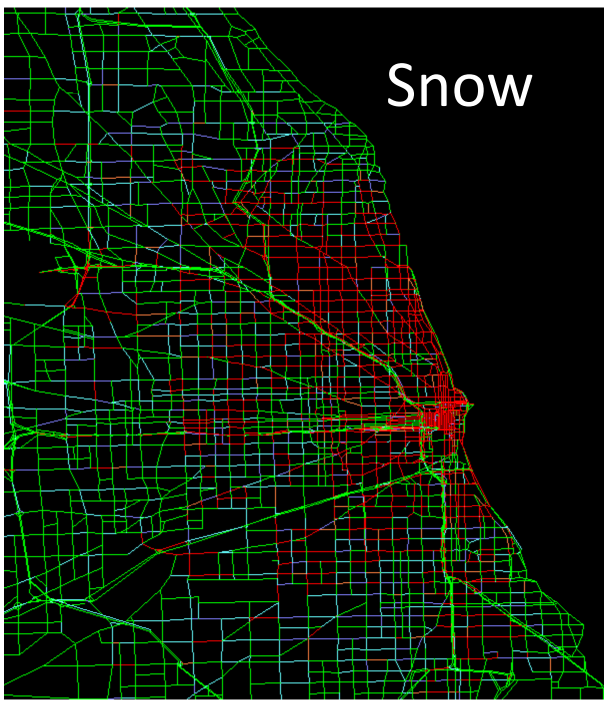


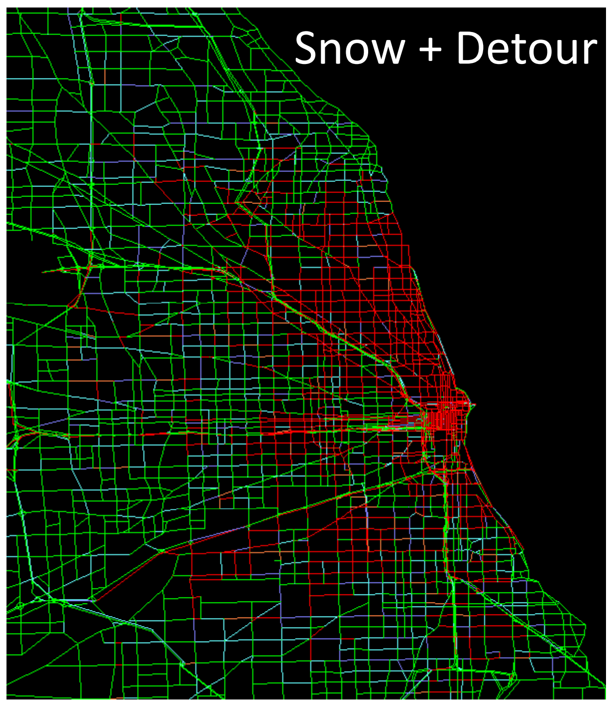


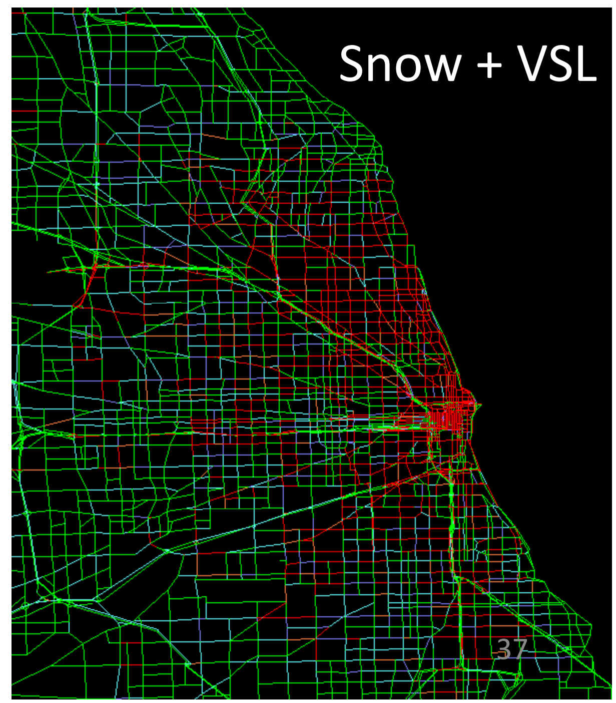

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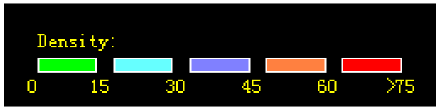


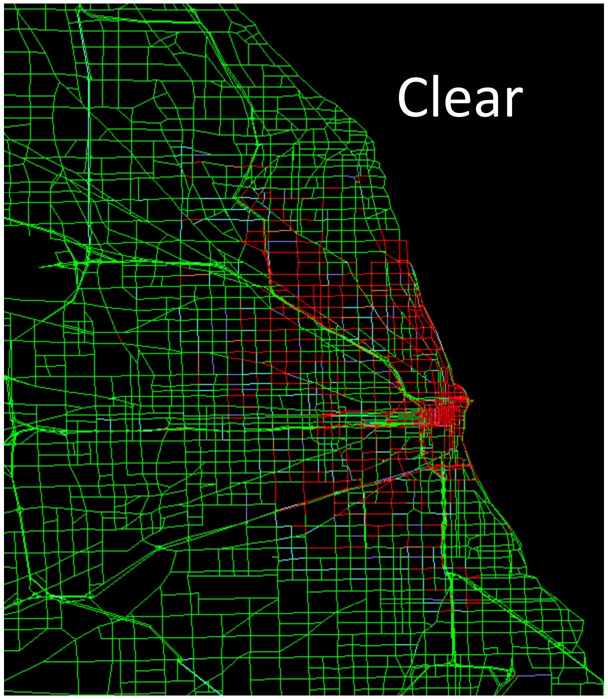


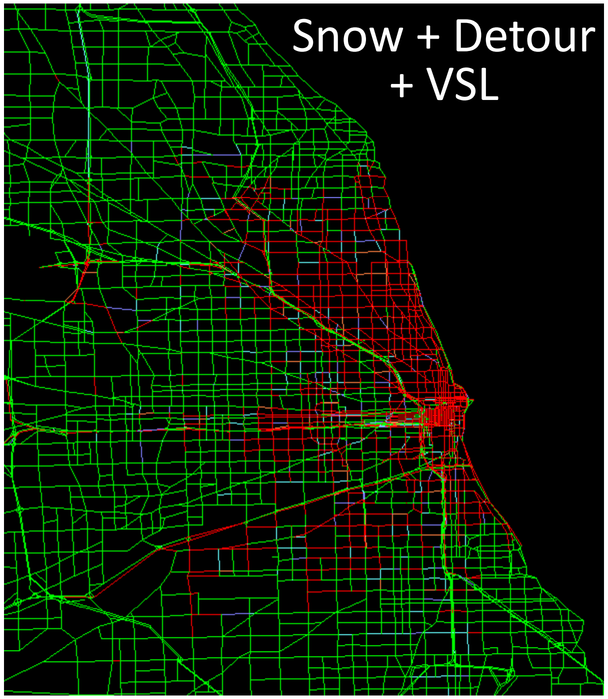


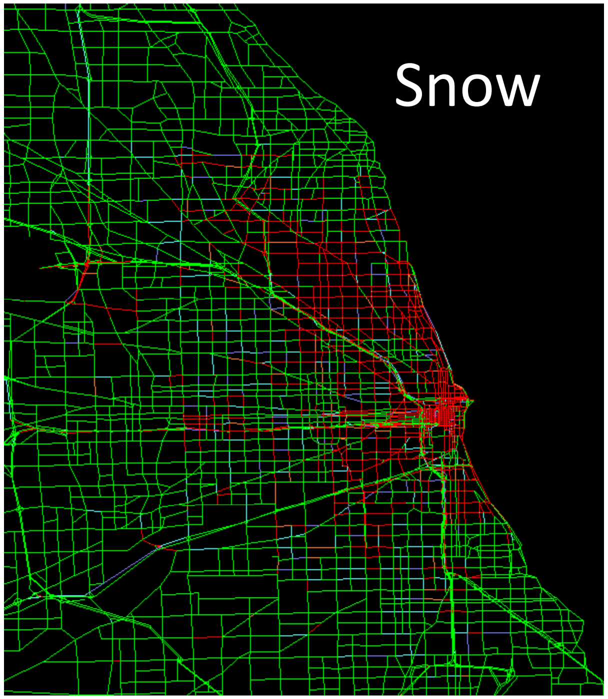


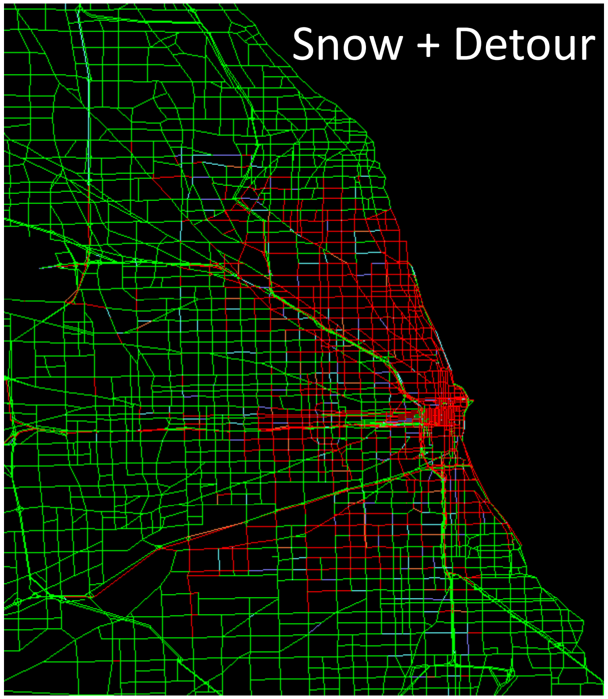


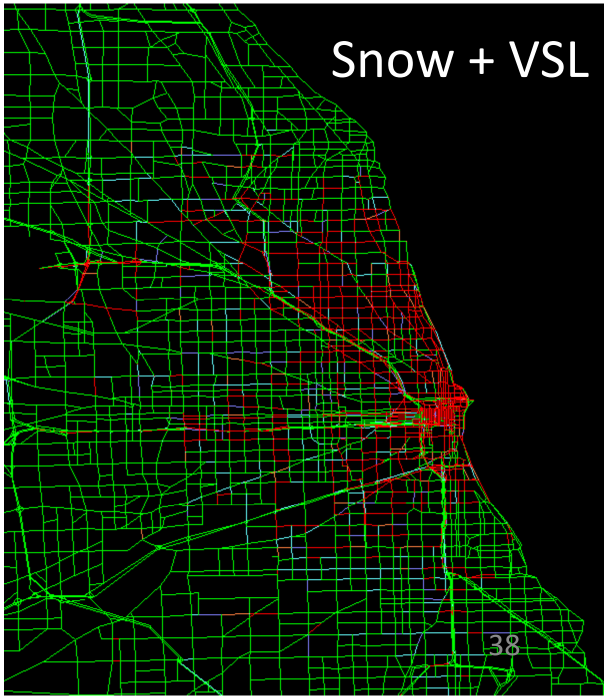

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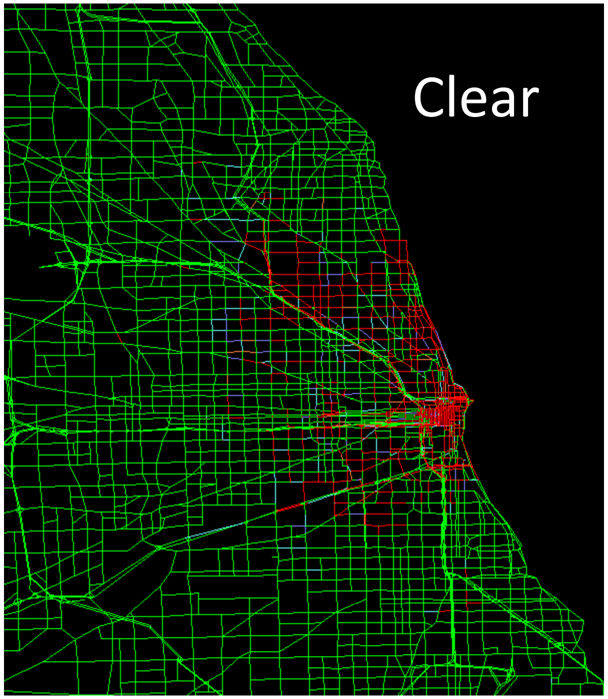
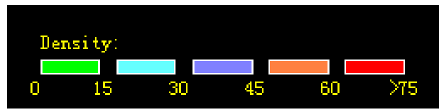
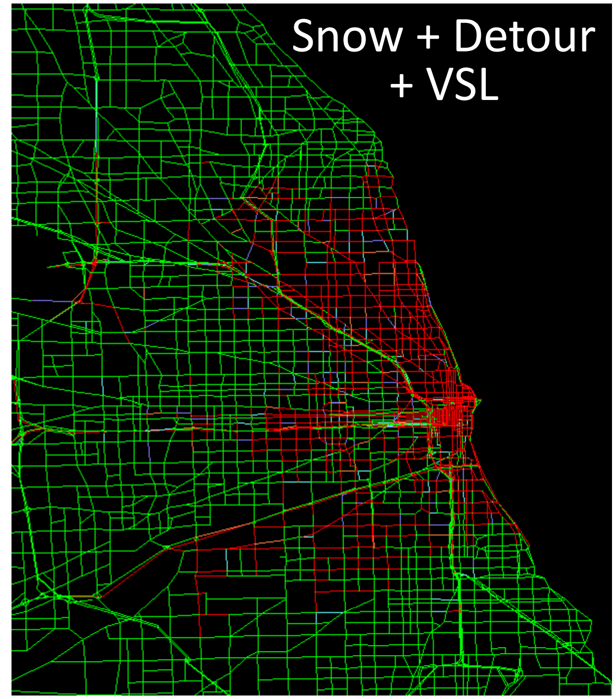
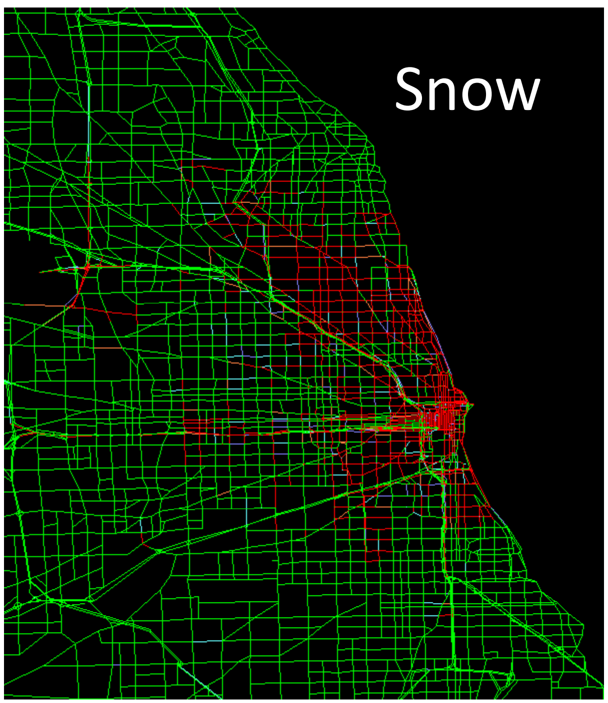
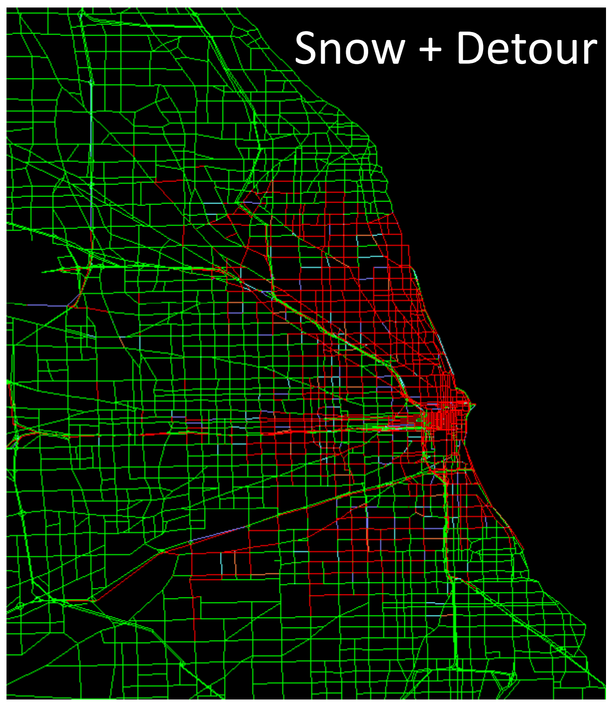
# Density

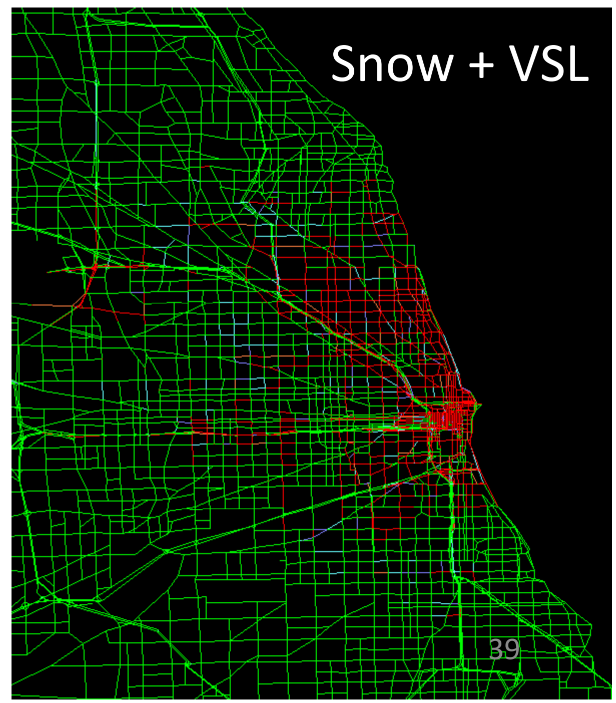


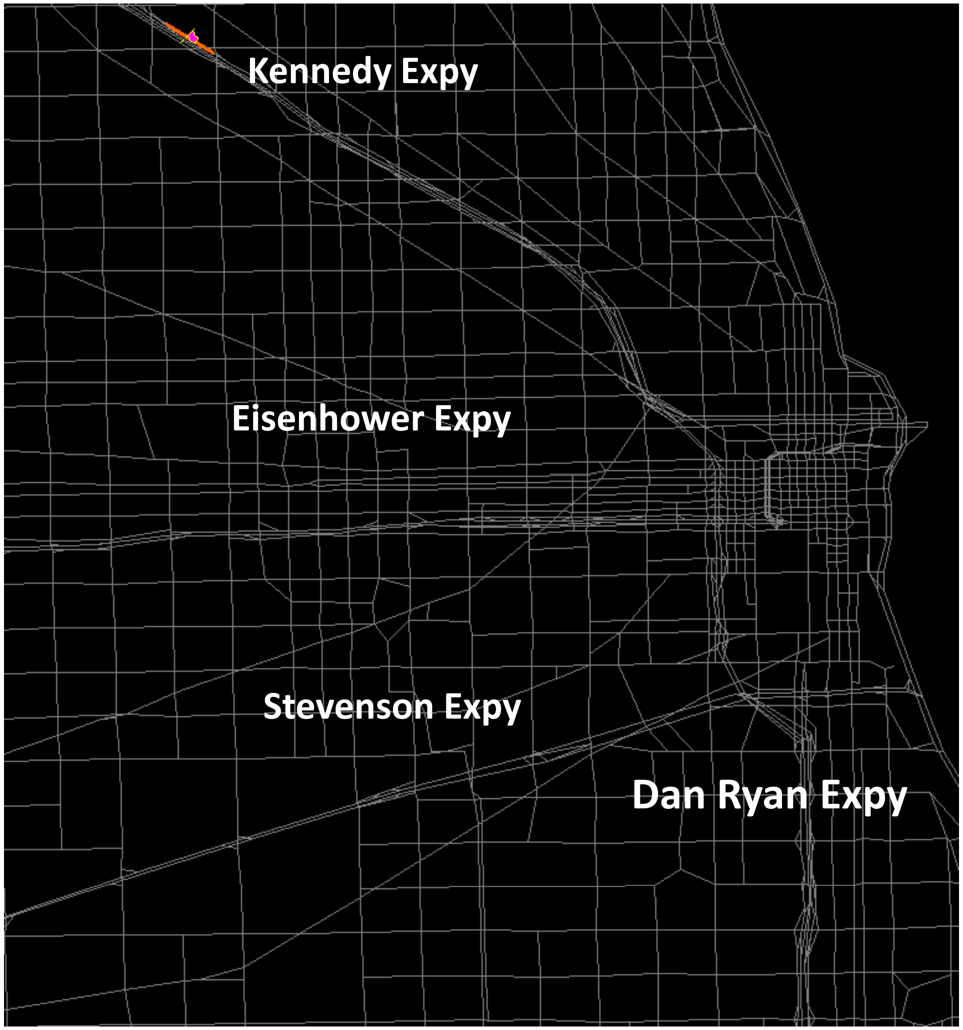



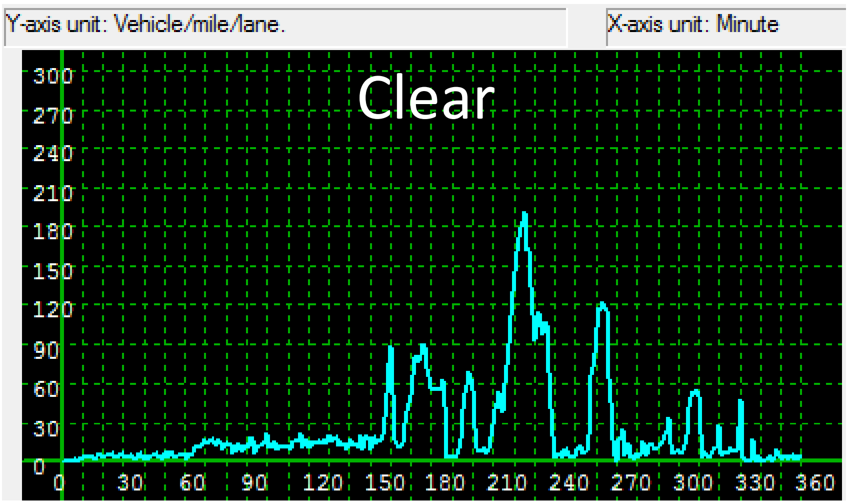



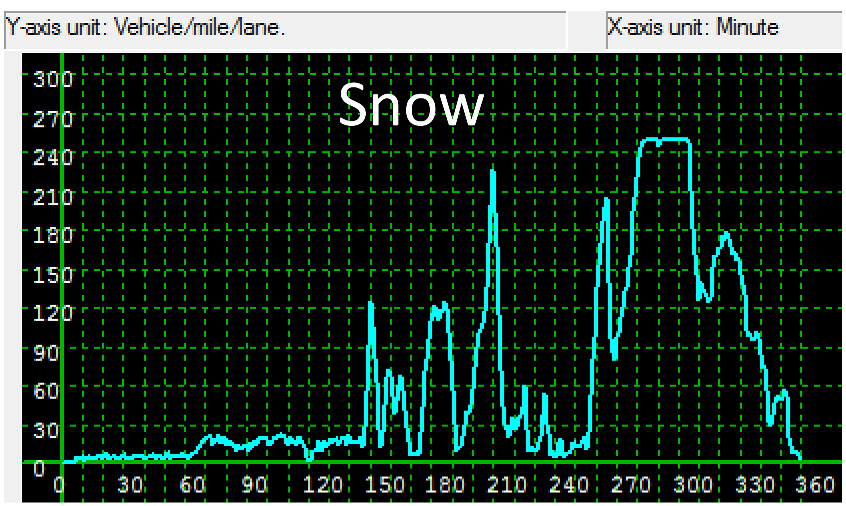



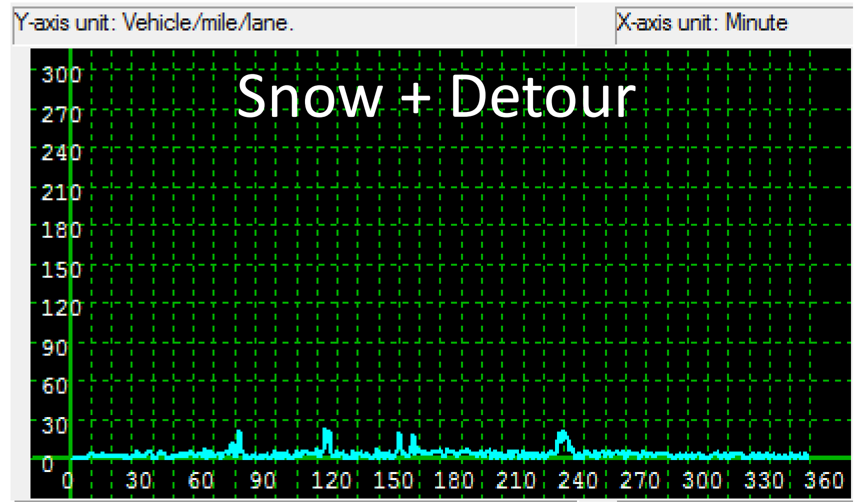
# A Closer Look: Link Densities and Speeds

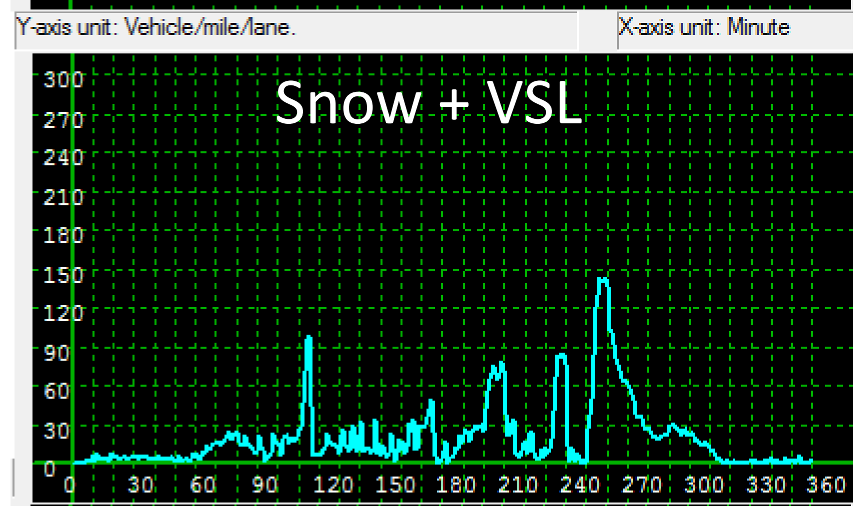


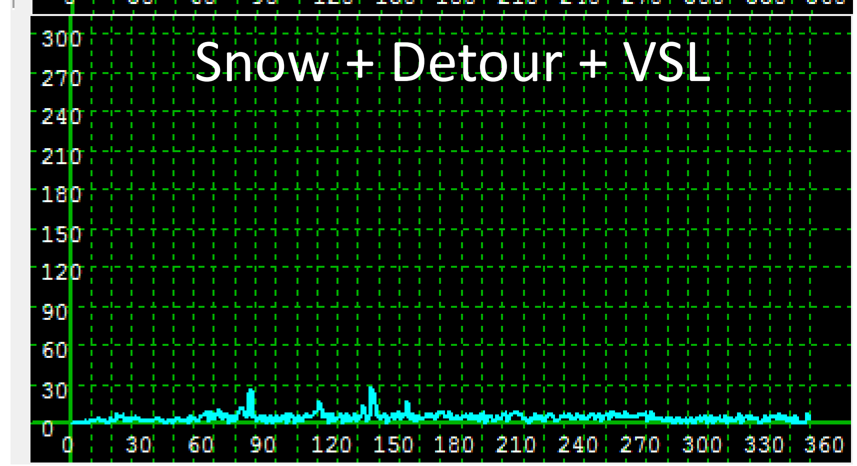
# Kennedy Expy between Pulaski Rd and N Cicero Ave (west bound) (Density)



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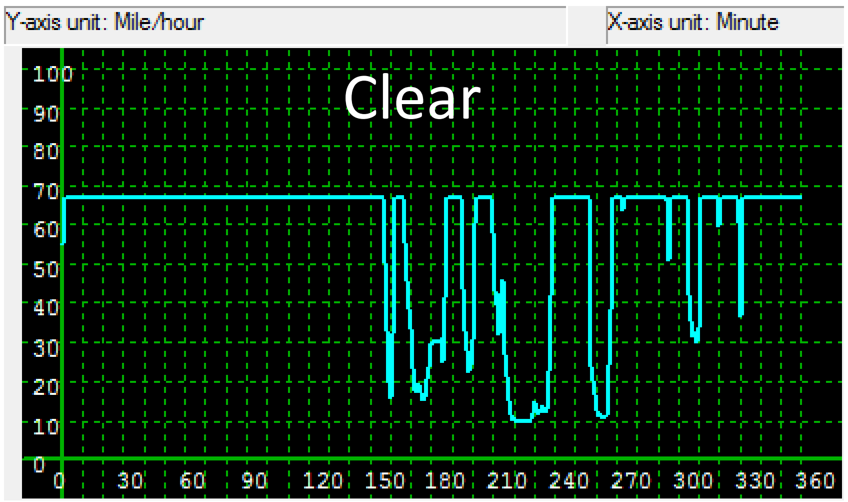
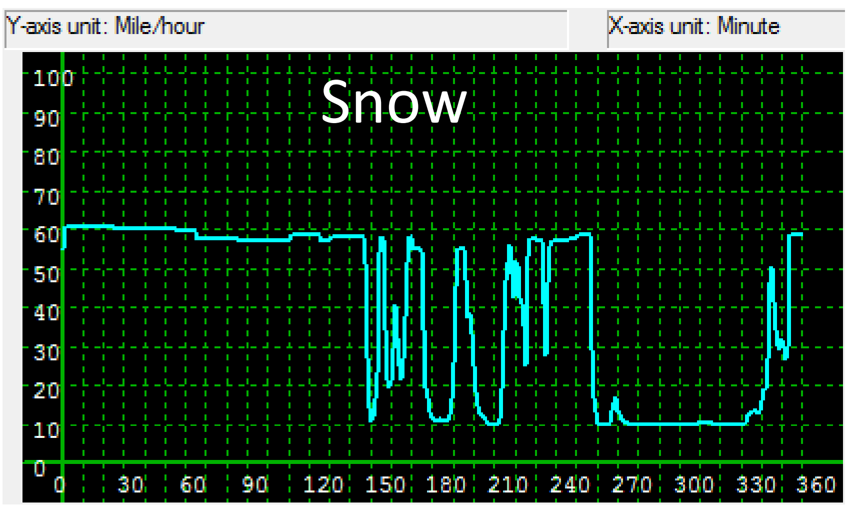
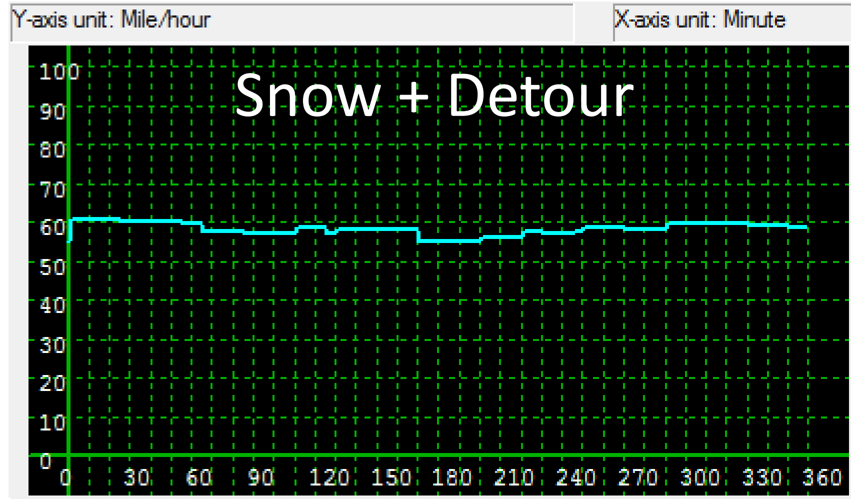
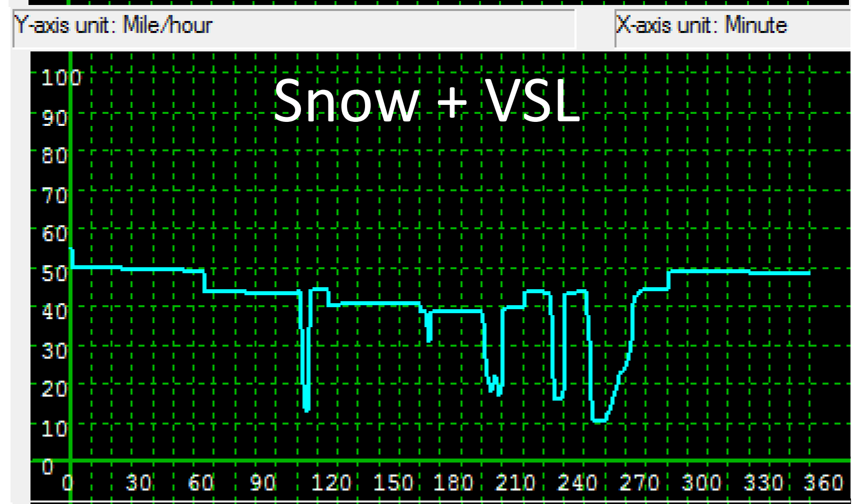
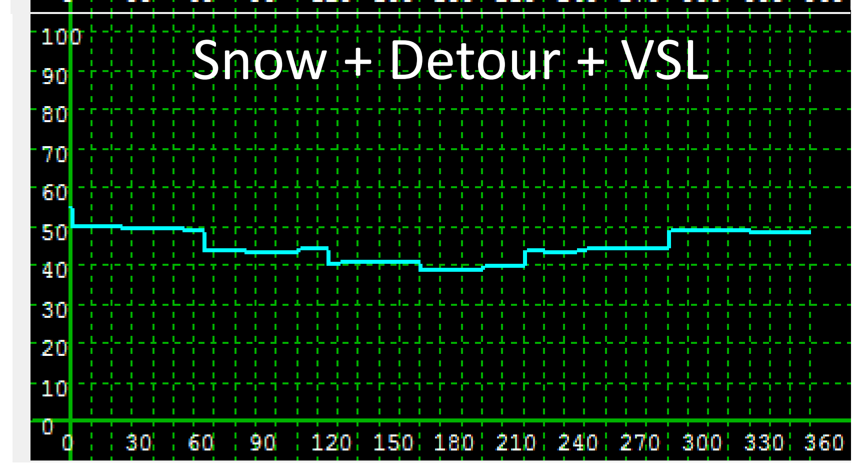


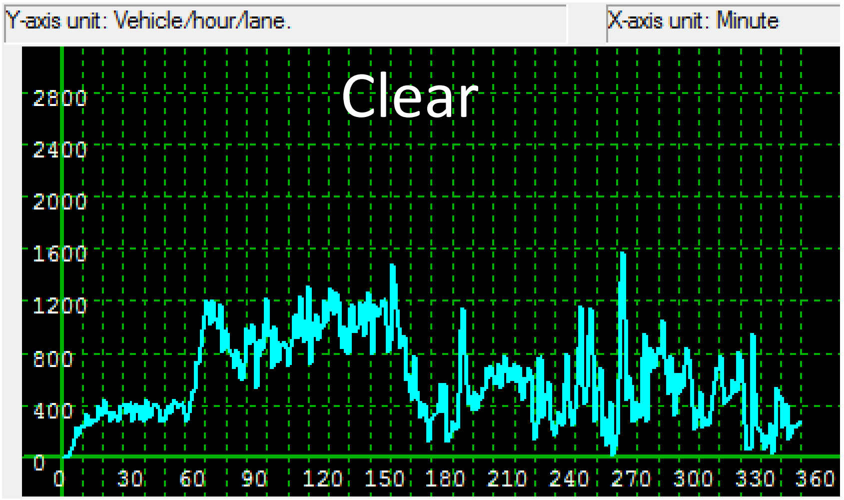



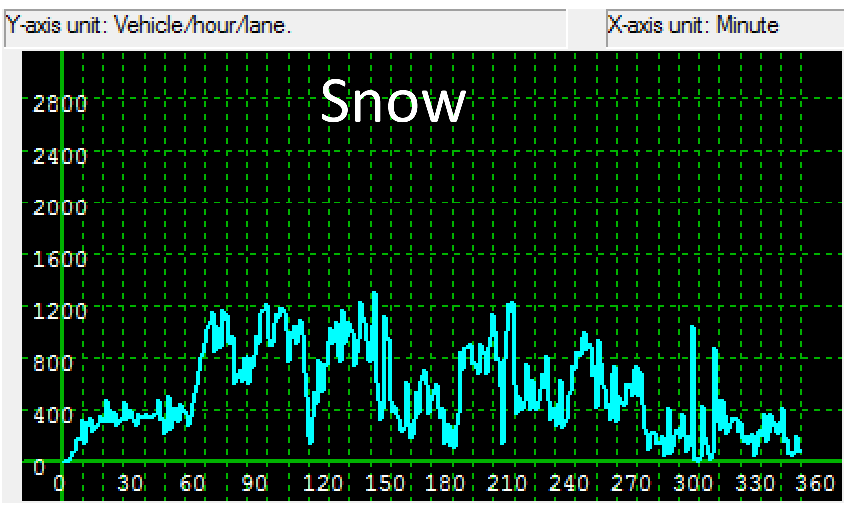



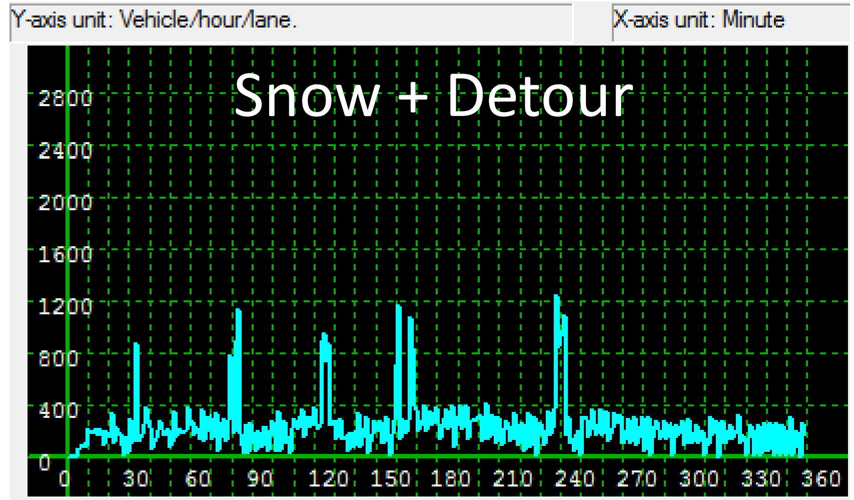



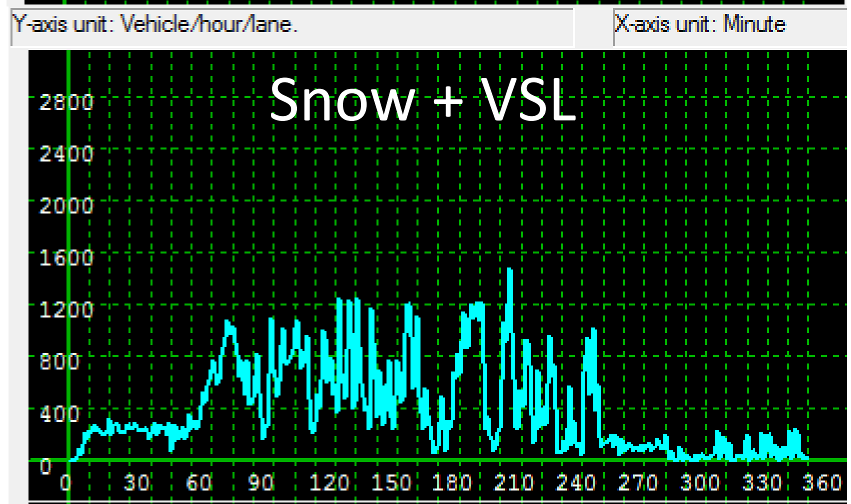



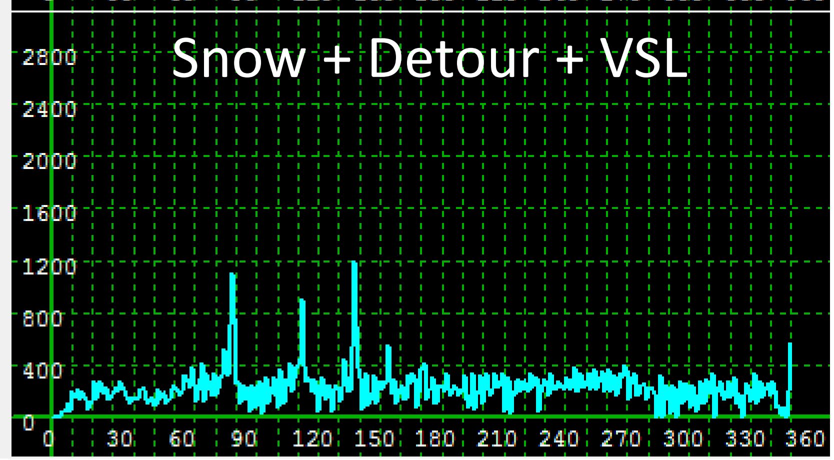
# Kennedy Expy between Pulaski Rd and N Cicero Ave (west bound) (Volume)



## Application I- Weather-responsive traffic estimation and prediction

- A **validated offline WRTM** strategy can provide a predefined input to be used for **online WRTM.**

- **Variable Speed Limit (VSL)** is a more general strategy which can be implemented for an entire corridor and can be **evaluated offline.**

- **Detour (VMS2)** is a strategy that should always be considered. However, its effectiveness should not be tested offline as it is more **case-dependent.**

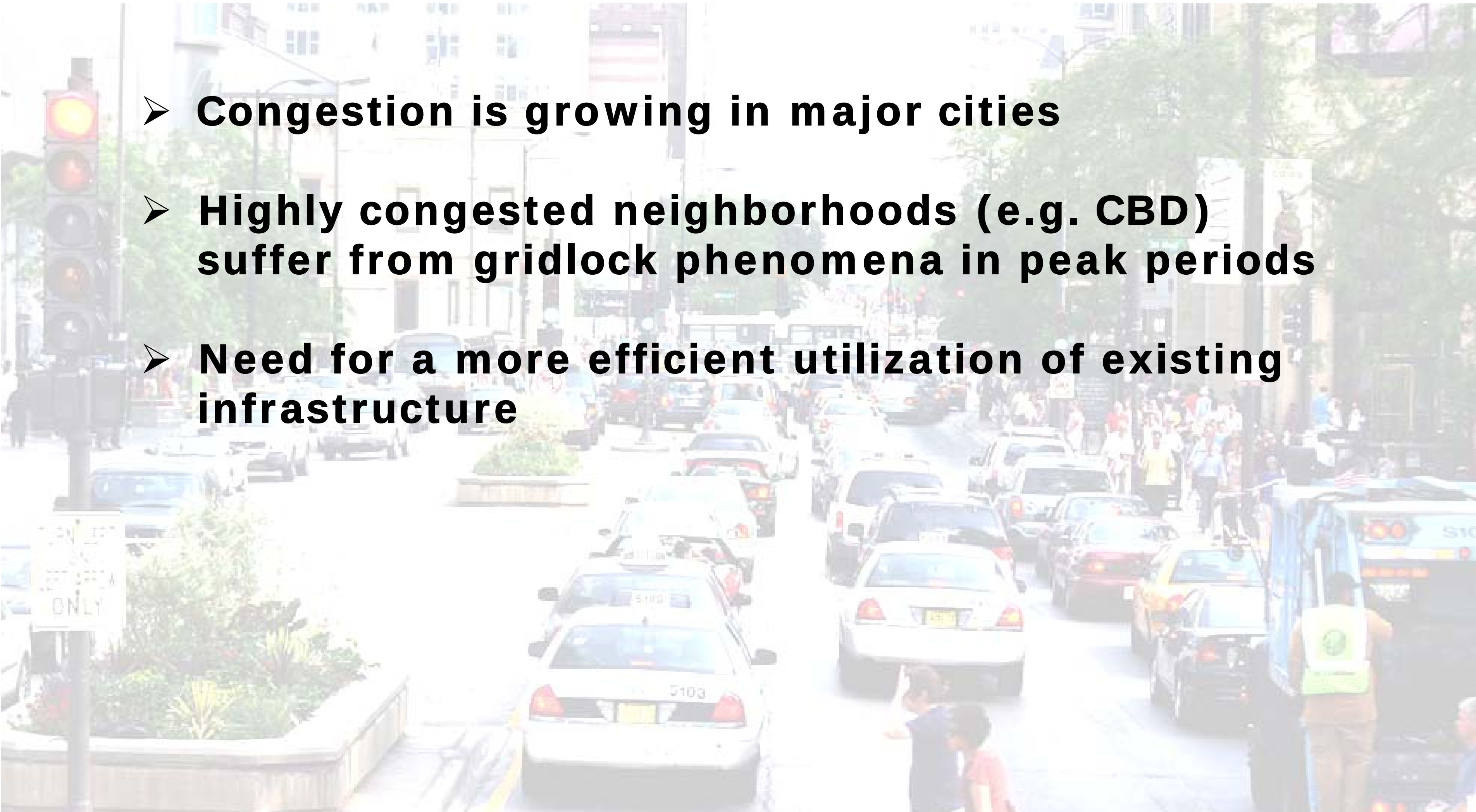
- This calls the **need** for an **online implementation** with **Detector Measurement data** and **Weather Prediction** in order to predict near-future events based on prevailing real-world conditions and make **proper interventions** using **online WRTM** strategies.

# Applications

## II- Congestion management

# What is the Problem?

# What is the Problem?

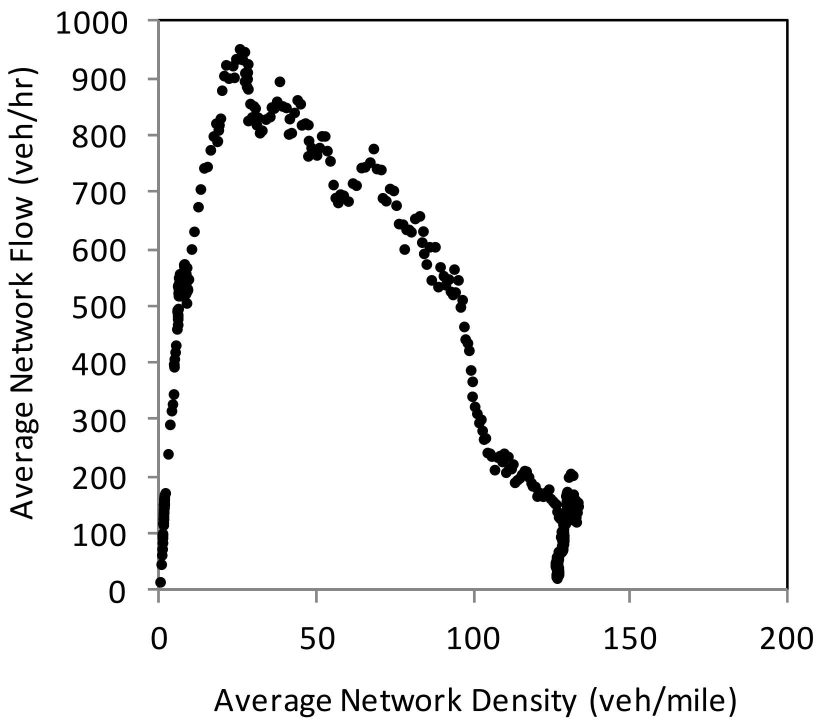


- Congestion is growing in major cities
- Highly congested neighborhoods (e.g. CBD) suffer from gridlock phenomena in peak periods
- Need for a more efficient utilization of existing infrastructure

# Objectives

- Improve mobility and accessibility
- Congestion mitigation
- Finding an effective and practical solution

# City-wide Traffic Flow Relations




**Traffic Control**

Network Flow

Network Speed

Network Density

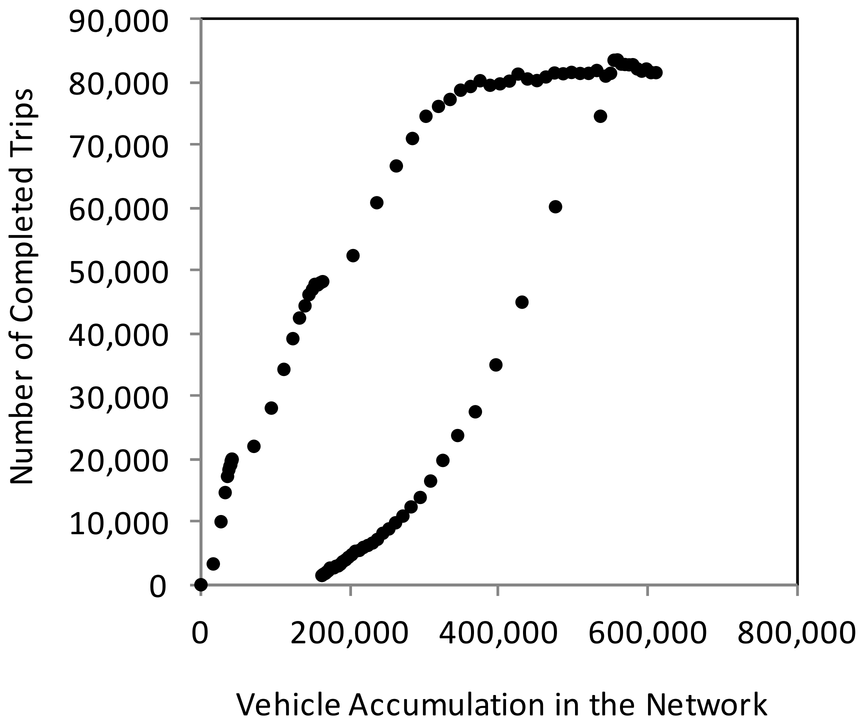
# City-wide Traffic Flow Relations

**Transportation Planning**

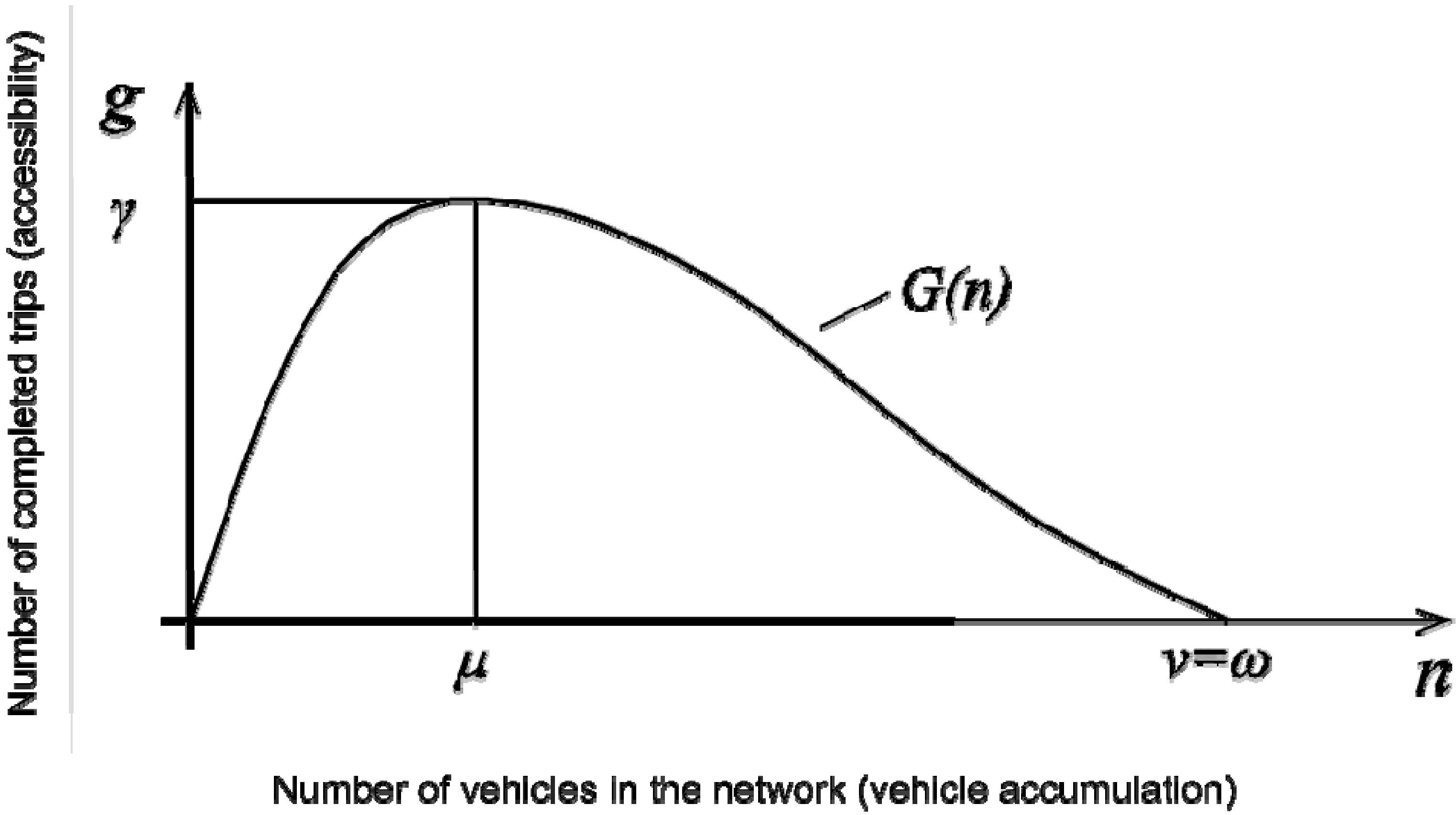
Mobility

Accessibility

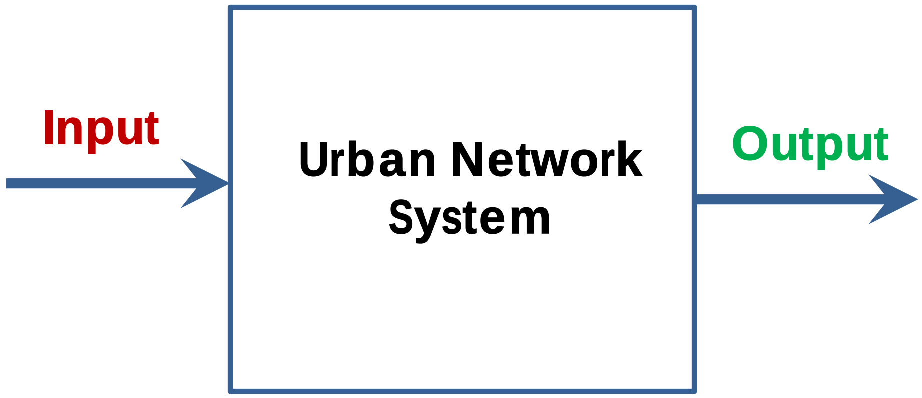
Vehicle Accumulation



# City-wide Traffic Flow Relations



# What is the idea?




**The idea is to monitor and control aggregate vehicle accumulation in the network in order to maximize the accessibility and mobility.**

# How can we do it?

**London, UK**

# How can we do it?

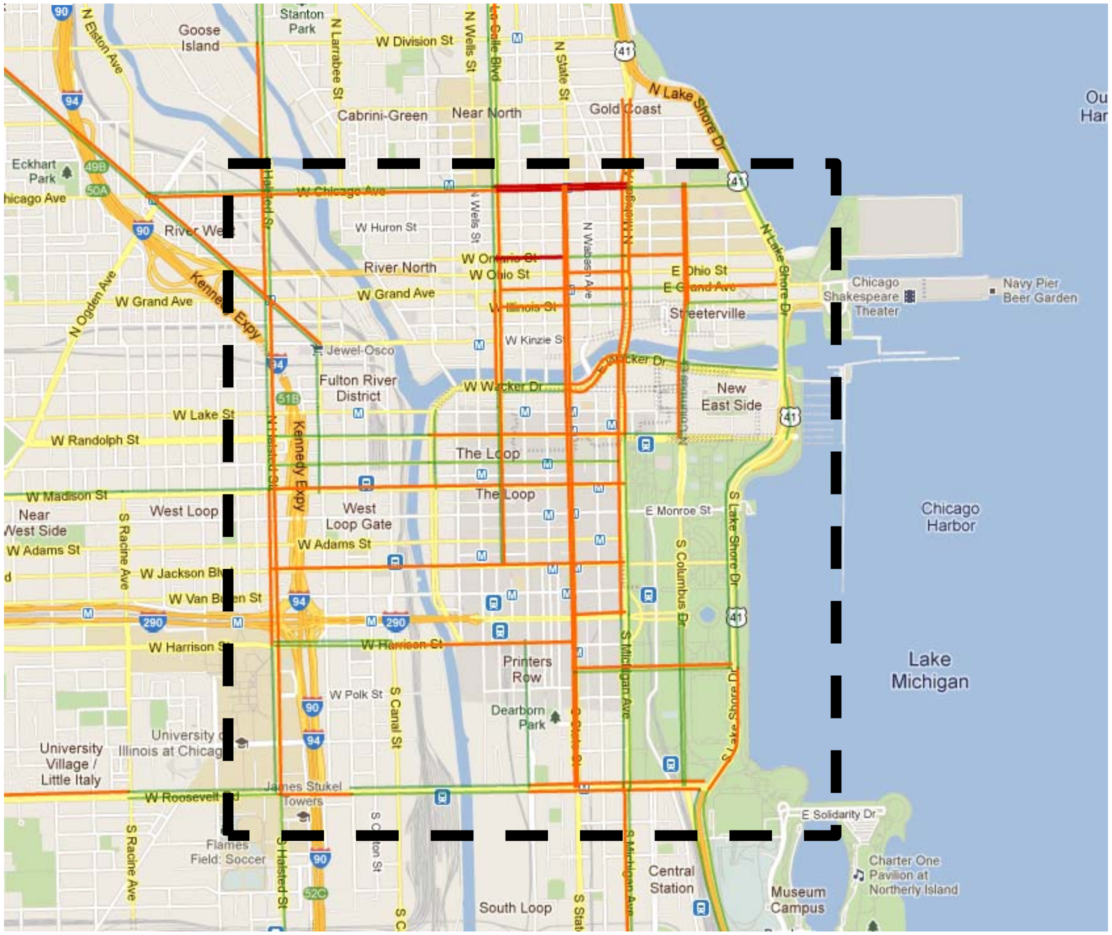
**Zurich, Switzerland**

## Application II- Congestion management

# How can we do it?

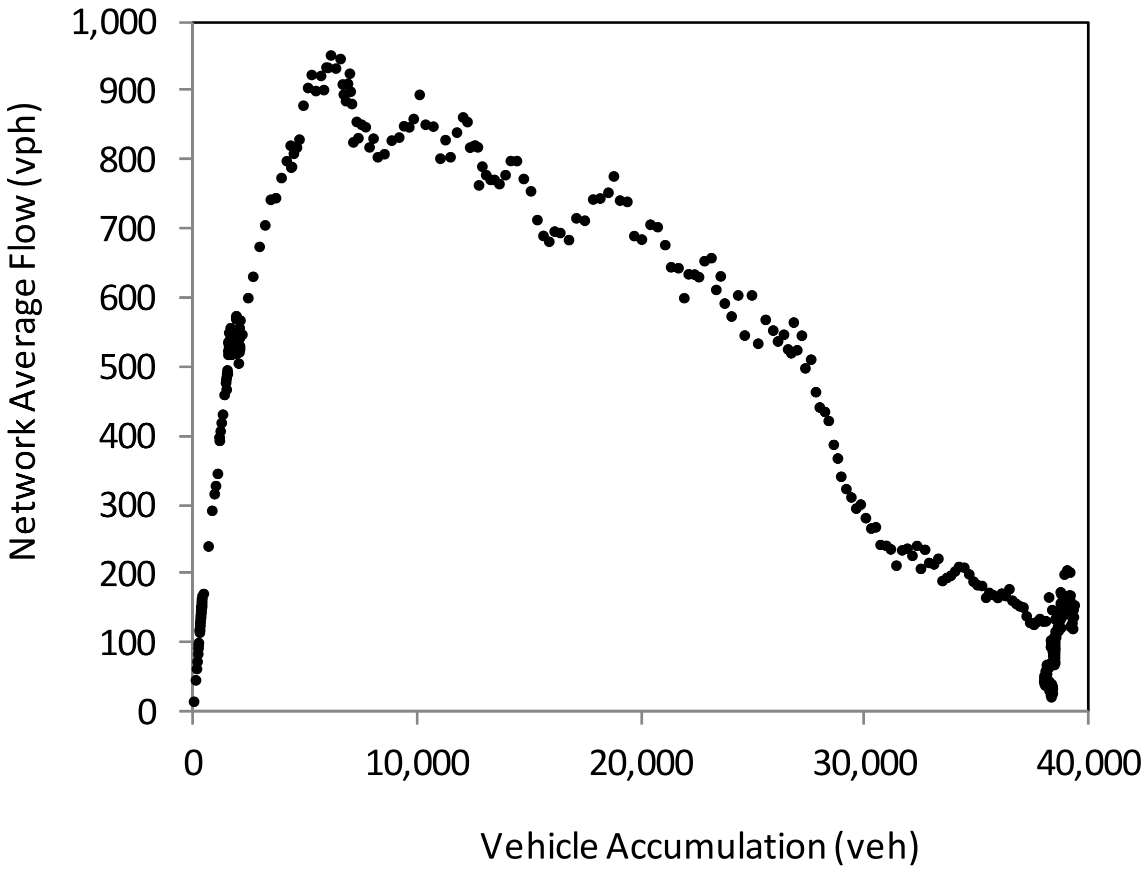
**Chicago, USA**

# Downtown Chicago

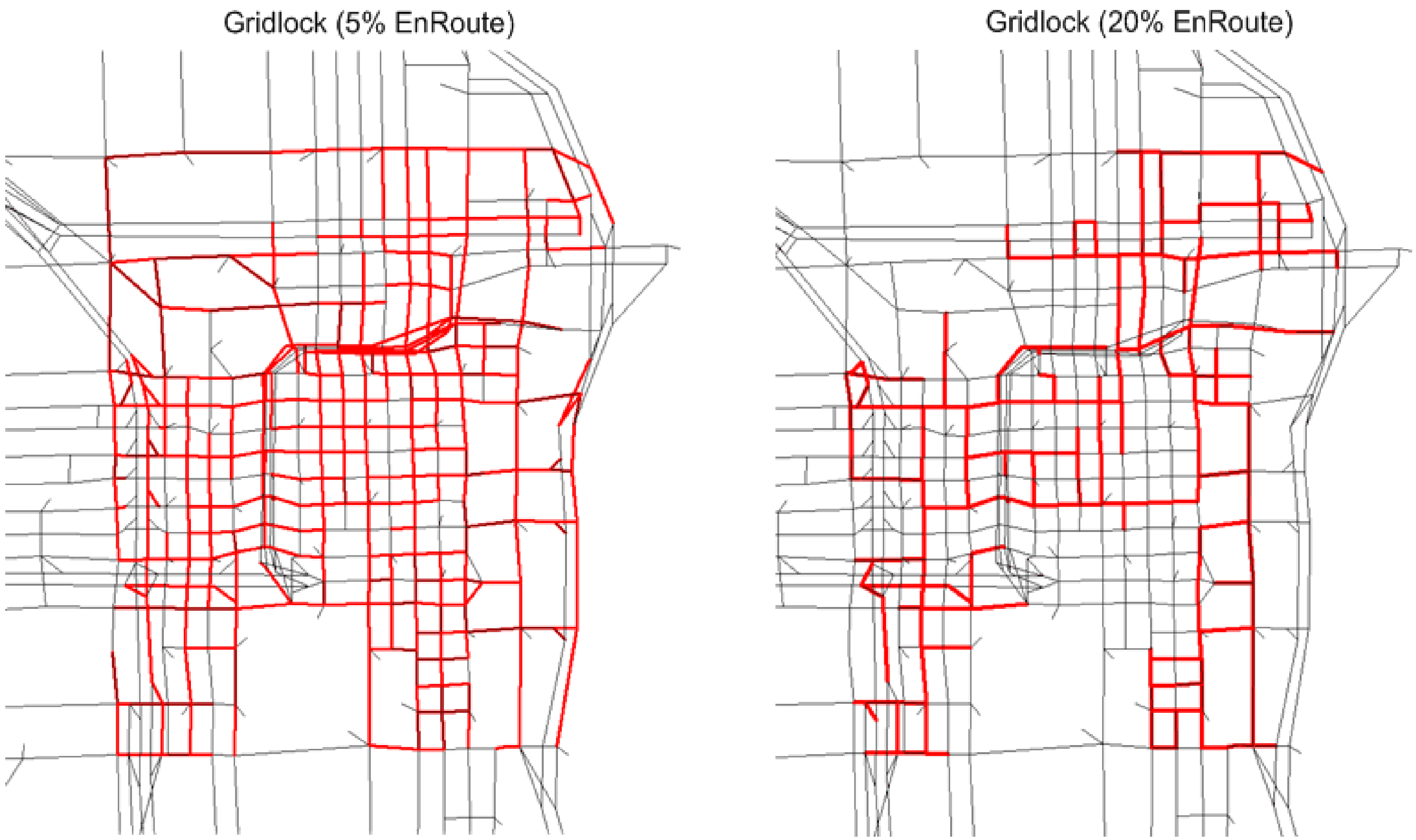


# Vehicle Accumulation vs. Network Flow

## Chicago CBD

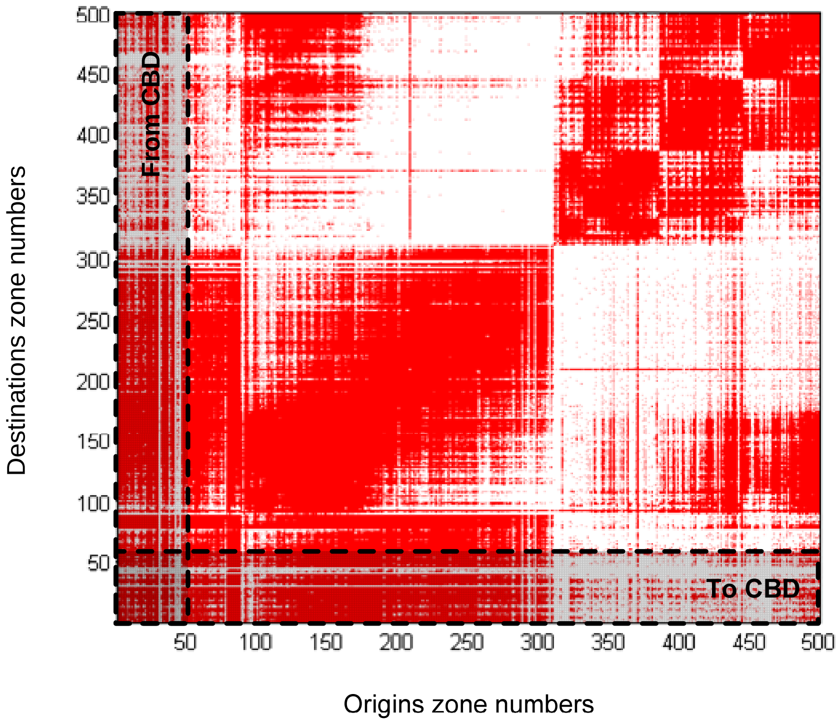


# Gridlock formation

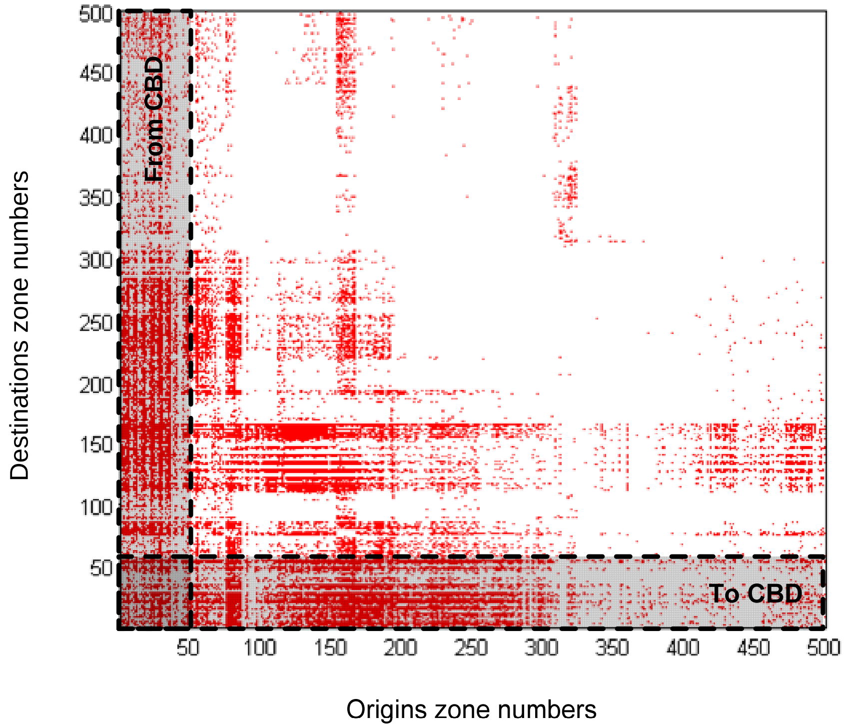


# Where they came from?

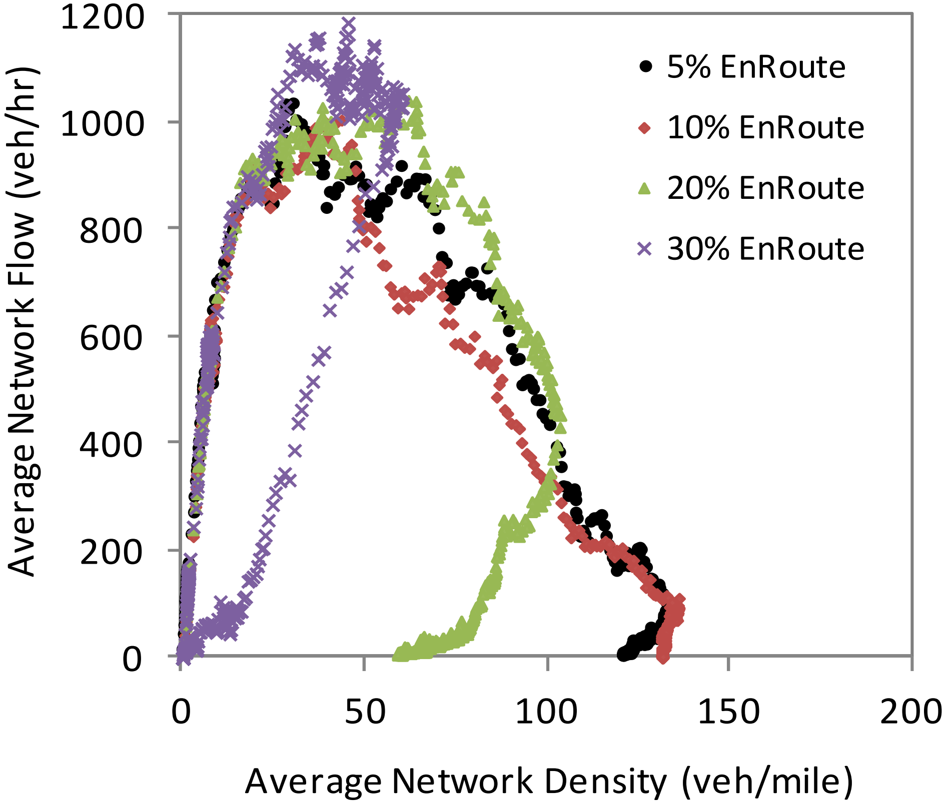
Spatial distribution of Origin-Destination demand in the network



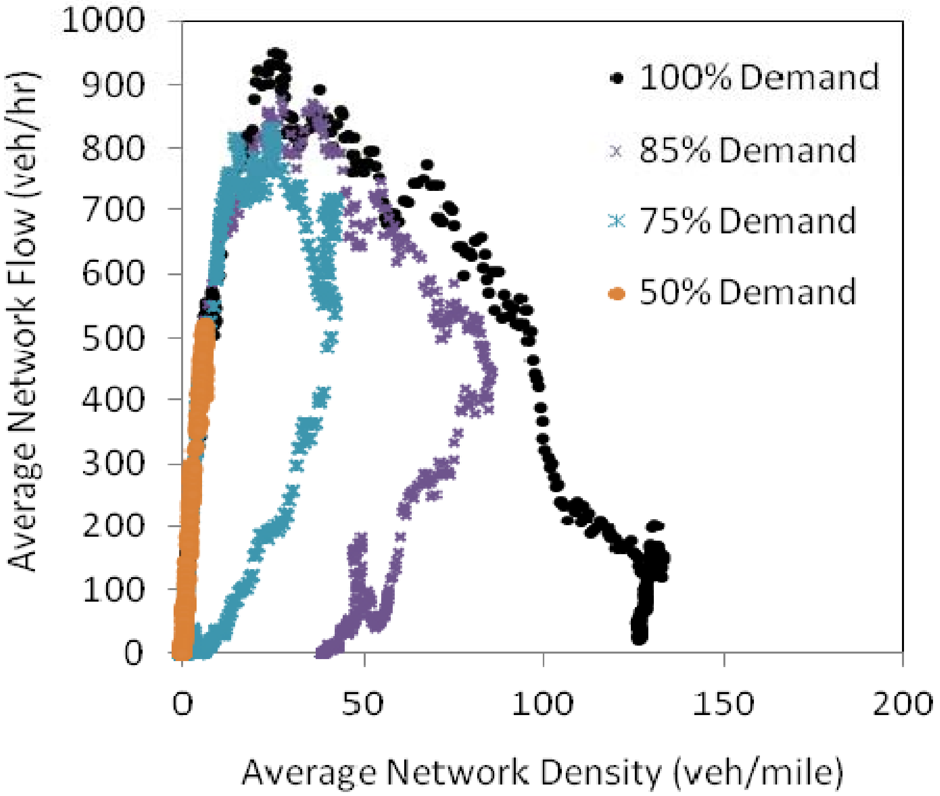

Spatial distribution of Origin-Destination demand associated with vehicles trapped in the gridlock



# Effect of traveler information



# Effect of demand management



# Work in progress

- We have identified 41 signals in the periphery of downtown Chicago.
- Restricting the accumulation of vehicles in downtown via modifying the **signal timings on the periphery** of downtown and/or pricing.
- Similar analysis will be performed in a **multi-modal network** to understand the impact of modes interaction and its effect on the network-wide mobility and accessibility.

# Summary

## Summary

- **Simulation-based DTA** tools overcome many of the known limitations of static assignment tools used in current practice.
- DYNASMART-P provides a platform for integrating **activity-based models** with network assignment and **performance simulation**.
- A Calibrated greater Chicago network is prepared in DYNASMART. Calibration includes both demand and supply side.
- Two Applications of DYNASMART-P were reviewed including :
  - **Weather-responsive** traffic estimation and prediction
  - Congestion management.

# Thank You

# Questions ?