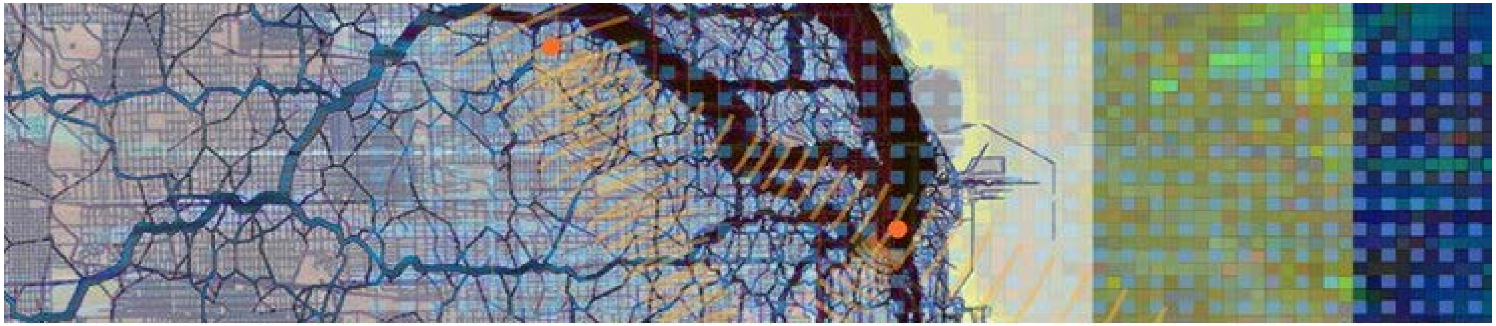
Leveraging Sensor Technologies for Smarter Mobility

Hani Mahmassani



Smarter Cities/Smarter Mobility

April 24, 2013 • Northwestern University Transportation Center

Outline

1. THE CONTEXT: MOBILITY AS PROCESS IN CONNECTED SYSTEMS
2. SYSTEM INTELLIGENCE THROUGH PREDICTIVE ANALYTICS
3. PREDICTION AND REAL-TIME TRAVELER INFORMATION
4. PREDICTIVE CONTROL: PRICING
5. WEATHER-RELATED TRAFFIC MANAGEMENT
6. LOGISTICS OPERATIONS IN CONGESTED URBAN ENVIRONMENTS
7. TAKEAWATS

I.

The Context:
Mobility as *Process* in Connected Systems

THE *USER* IS AT THE *CENTER* OF THIS WEB OF *CONNECTIVITY* AND “ALWAYS AWARE” SYSTEMS AND DEVICES


Source: Qualcomm

WHY IS THIS RELEVANT TO TRANSPORTATION?

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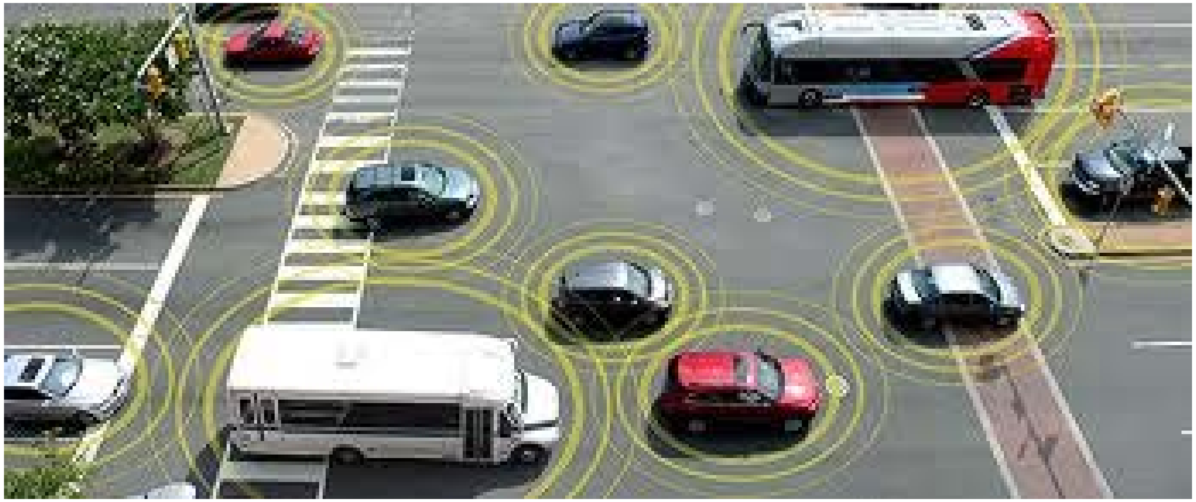
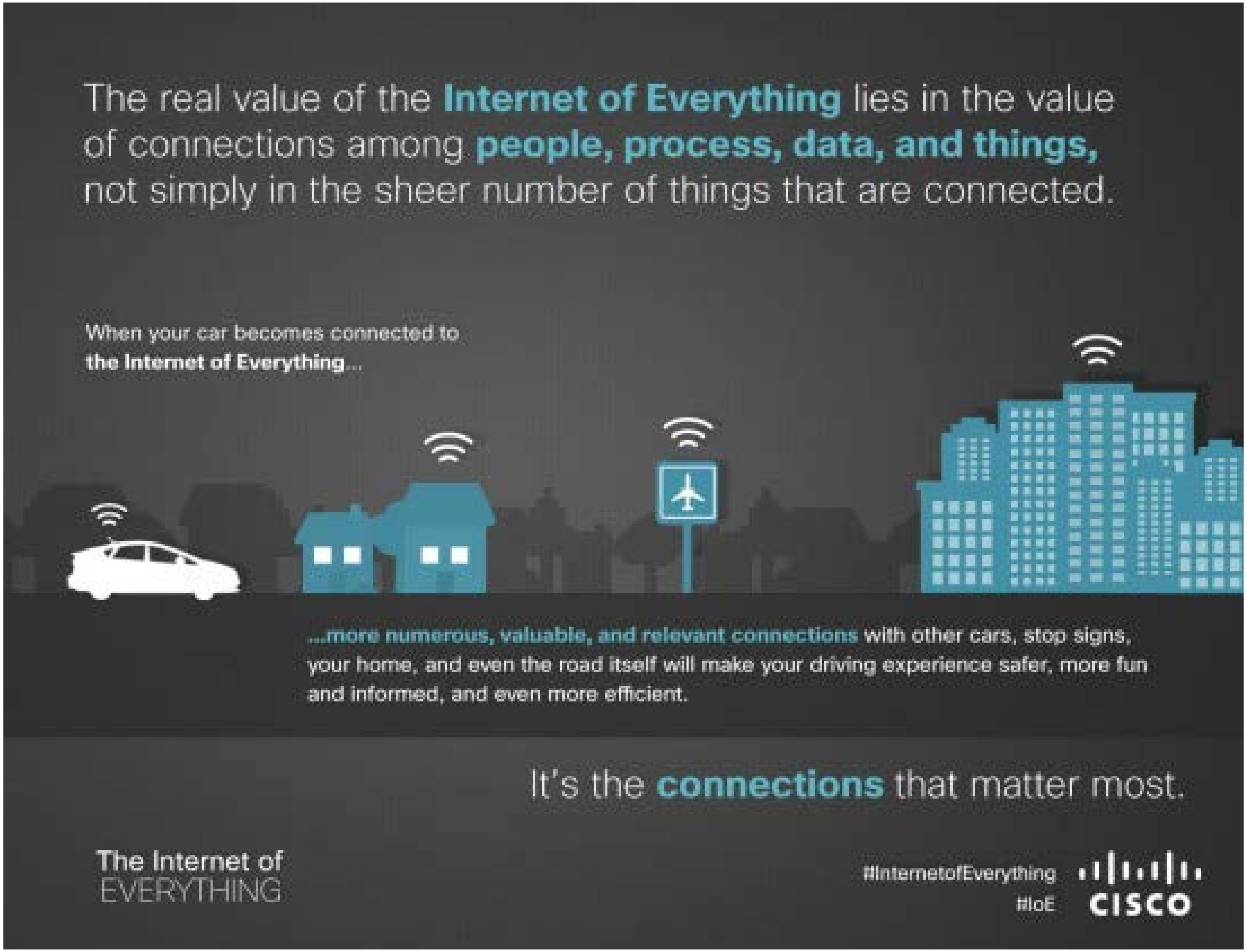
SEAMLESS CONNECTIVITY

TRANSPORTATION DELIVERS PHYSICAL MOBILITY IN A VIRTUALLY CONNECTED MOBILE ENVIRONMENT



Everybody is talking about it



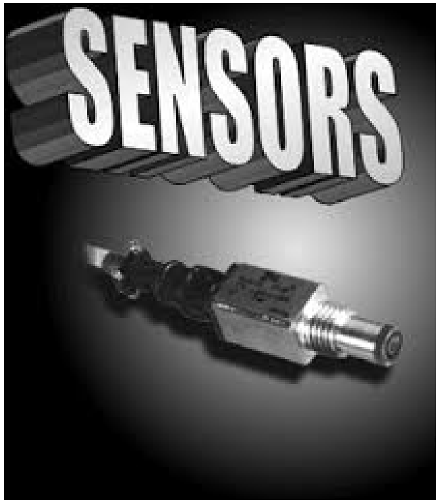
The real value of the **Internet of Everything** lies in the value of connections among **people, process, data, and things,** not simply in the sheer number of things that are connected.

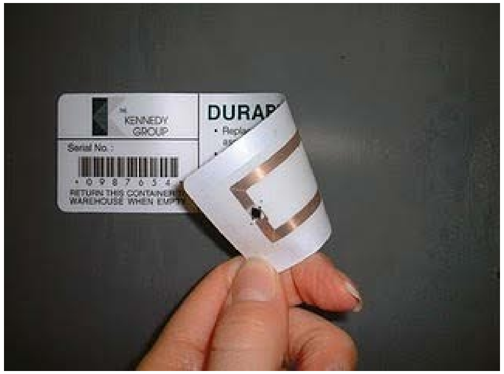
When your car becomes connected to **the Internet of Everything**...

...more numerous, valuable, and relevant connections with other cars, stop signs, your home, and even the road itself will make your driving experience safer, more fun and informed, and even more efficient.

It's the **connections** that matter most.

KEY TECHNOLOGY ENABLERS





Canon CMOS sensor, EOS 400D

Sony CCD sensor, Nikon D2X

Foveon X3 sensor, Sigma SD14

NETWORKS

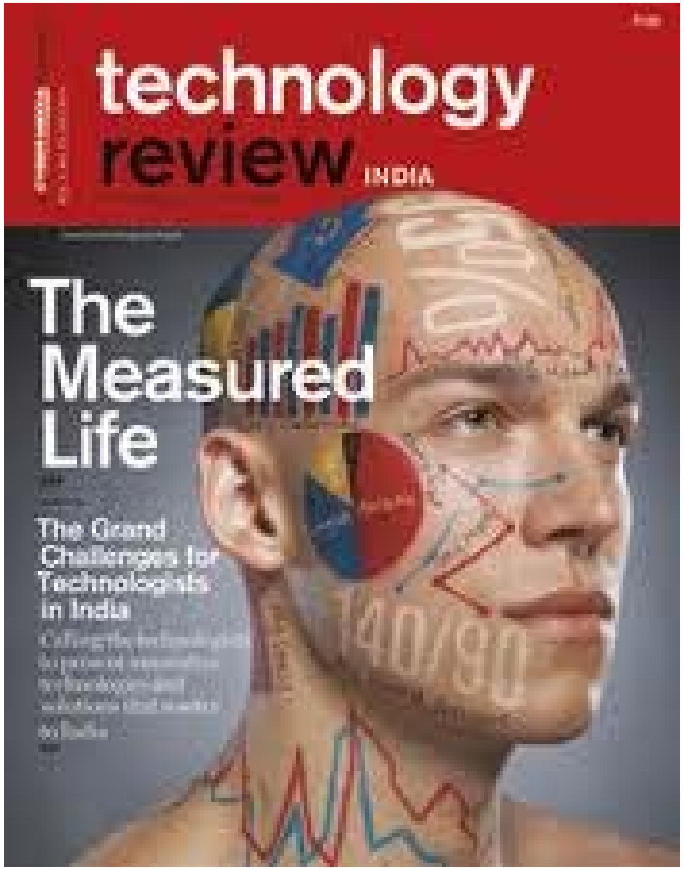
Peer to peer

Wide area wireless

Backbone

SERVERS AND DATA STORAGE

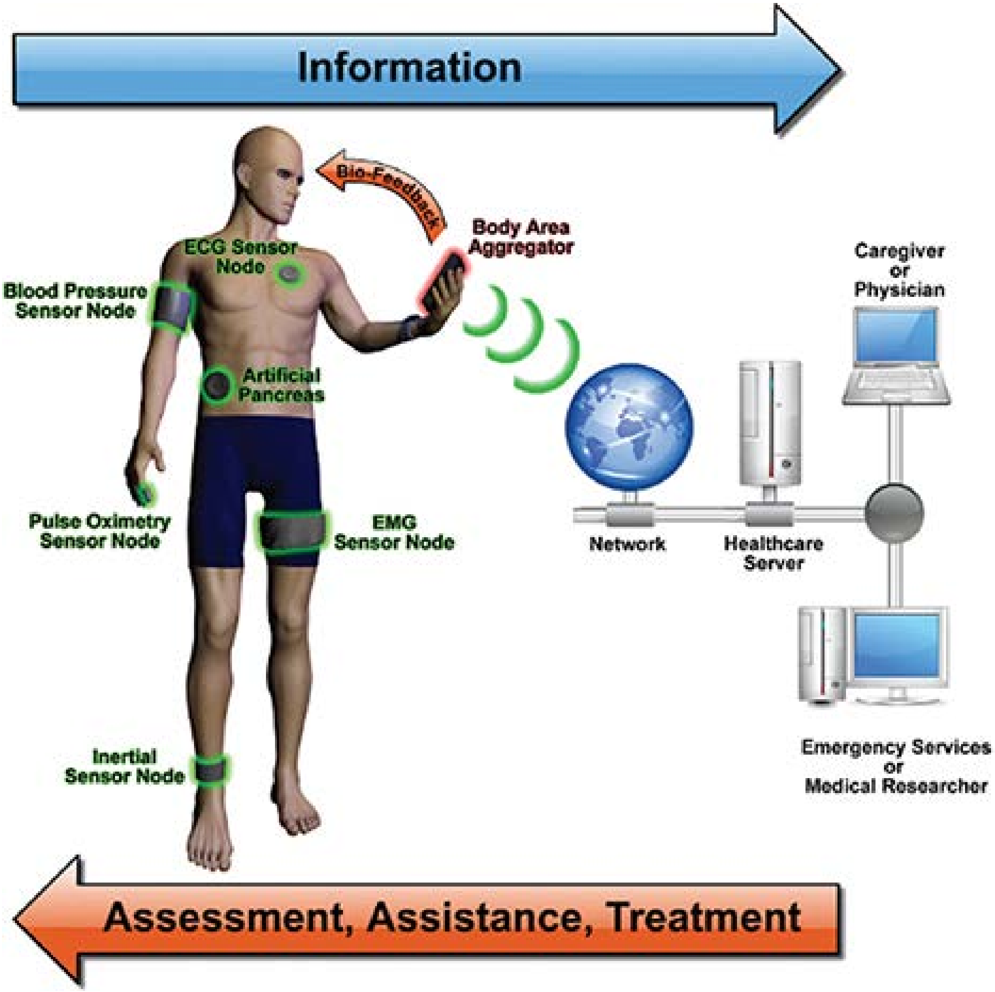
NOT LIMITED TO CARS AND OBJECTS



technology
review INDIA

The Measured Life

The Grand Challenges for Technologists in India



II.

System Intelligence through Predictive Analytics

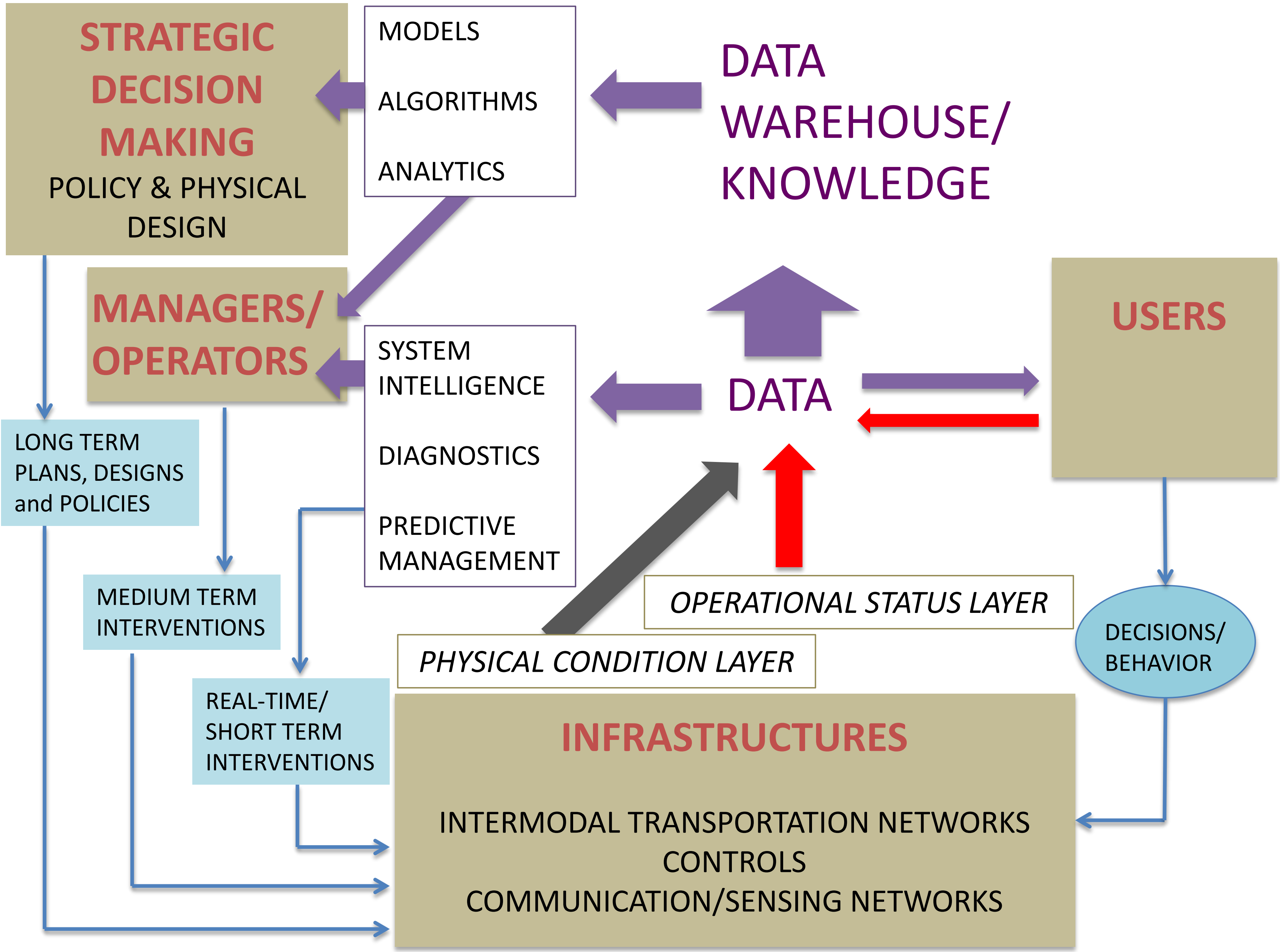
Mobile units +
wireless internet:

Provides particle
(user-centric)
views of system

Inexpensive
wireless sensors

Provides view from
perspective of
infrastructure or
fixed assets

REAL-TIME INFORMATION


STRATEGIC DECISION MAKING
POLICY & PHYSICAL DESIGN
MODELS
ALGORITHMS
ANALYTICS
DATA WAREHOUSE/ KNOWLEDGE
MANAGERS/ OPERATORS
SYSTEM INTELLIGENCE
DIAGNOSTICS
PREDICTIVE MANAGEMENT
DATA
USERS
LONG TERM PLANS, DESIGNS and POLICIES
MEDIUM TERM INTERVENTIONS
REAL-TIME/ SHORT TERM INTERVENTIONS
OPERATIONAL STATUS LAYER
PHYSICAL CONDITION LAYER
DECISIONS/ BEHAVIOR
INFRASTRUCTURES
INTERMODAL TRANSPORTATION NETWORKS
CONTROLS
COMMUNICATION/SENSING NETWORKS

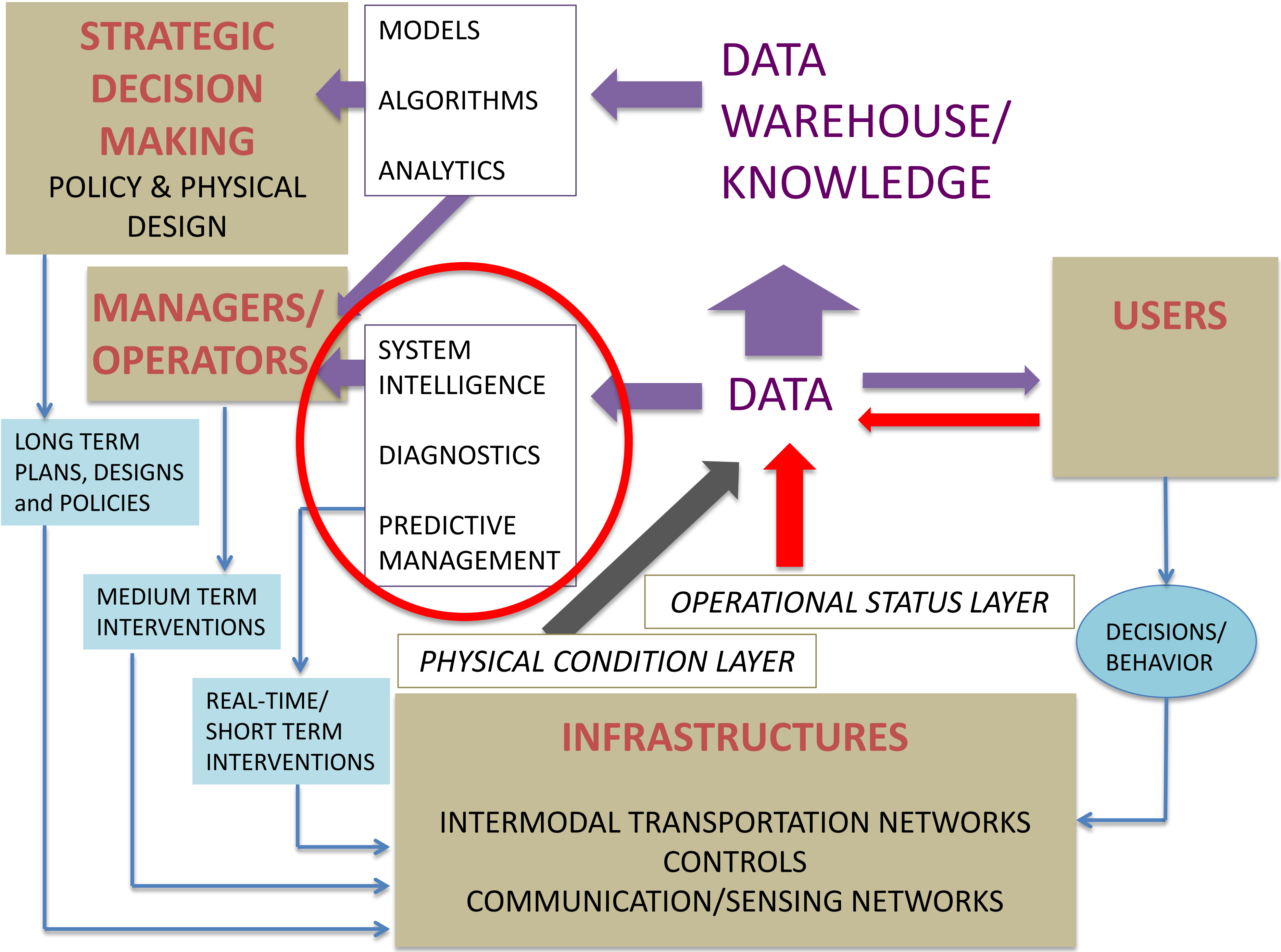
ACID TEST

How is more data allowing me to

Do things differently (better– faster, cheaper, safer, higher impact, customer-pleasing…)

Do different things (grow activities, revenue, improve image, employee retention…)

?



STRATEGIC DECISION MAKING

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INTERMODAL TRANSPORTATION NETWORKS

CONTROLS

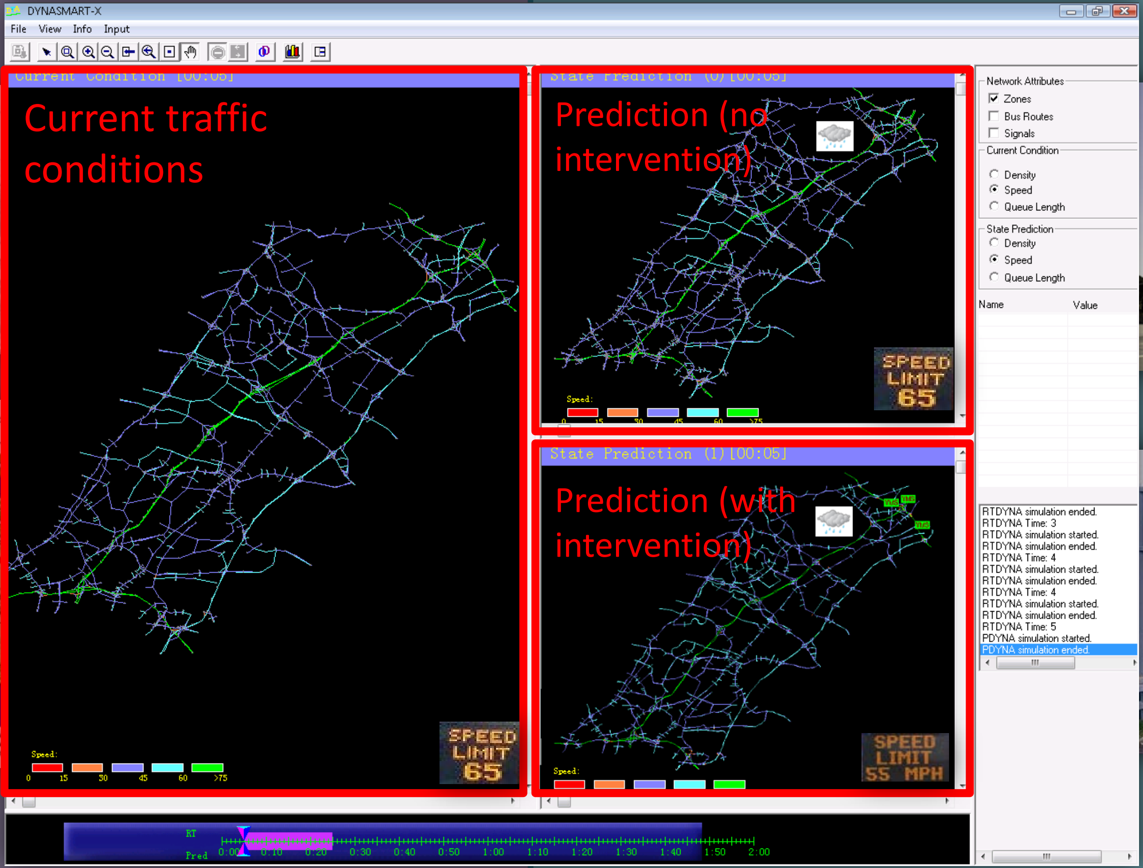
COMMUNICATION/SENSING NETWORKS

Traffic Estimation and Prediction System (TrEPS)

DYNASMART-X

ESTIMATION

PREDICTION



Current traffic conditions

Prediction (no intervention)

Prediction (with intervention)

Network Attributes
- ☑ Zones
- ☐ Bus Routes
- ☐ Signals

Current Condition
- ○ Density
- ● Speed
- ○ Queue Length

State Prediction
- ○ Density
- ● Speed
- ○ Queue Length

Name	Value

```
RTDYNA simulation ended.
RTDYNA Time: 3
RTDYNA simulation started.
RTDYNA simulation ended.
RTDYNA Time: 4
RTDYNA simulation started.
RTDYNA simulation ended.
RTDYNA Time: 4
RTDYNA simulation started.
RTDYNA simulation ended.
RTDYNA Time: 5
PDYNA simulation started.
PDYNA simulation ended.
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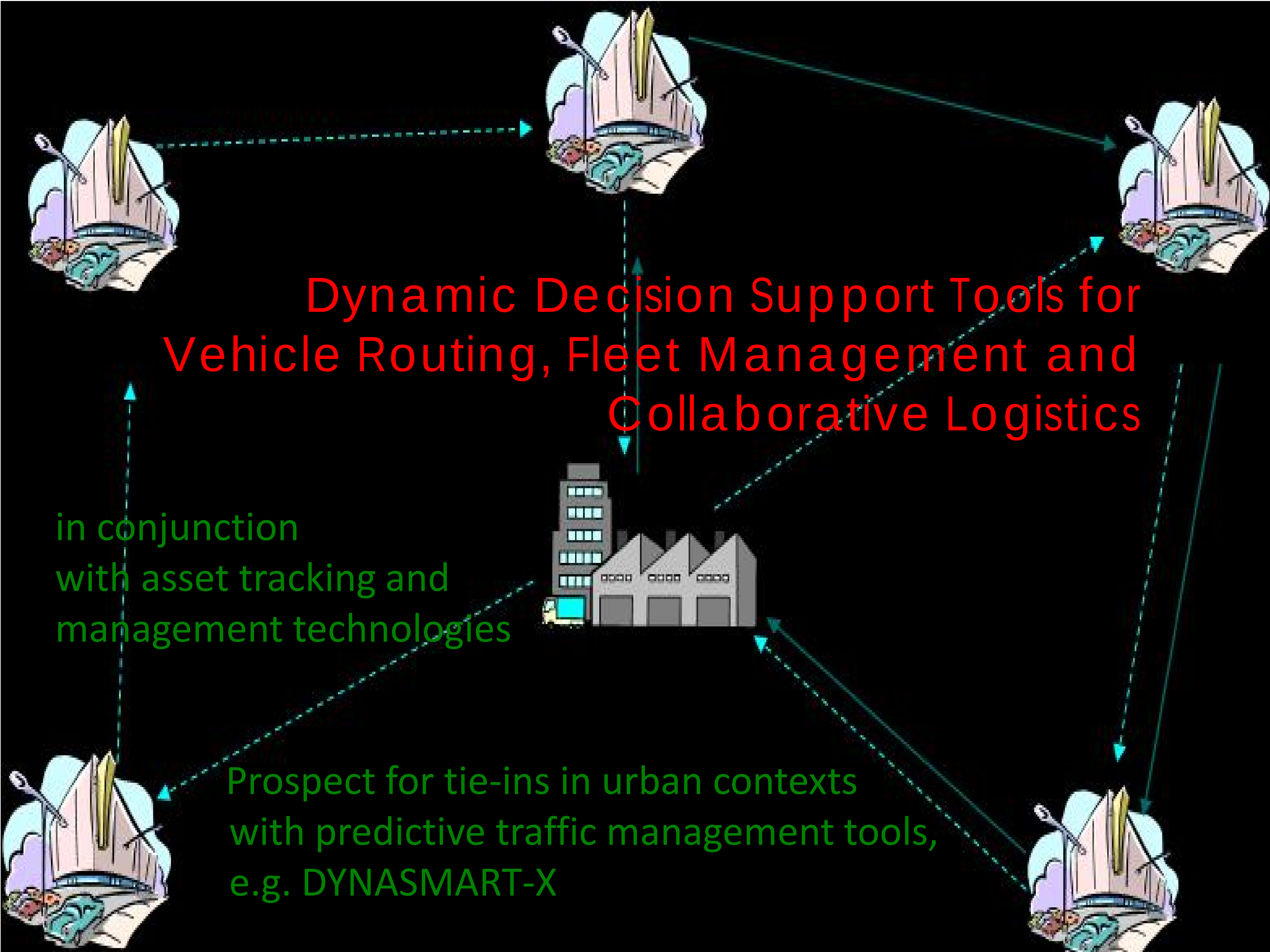
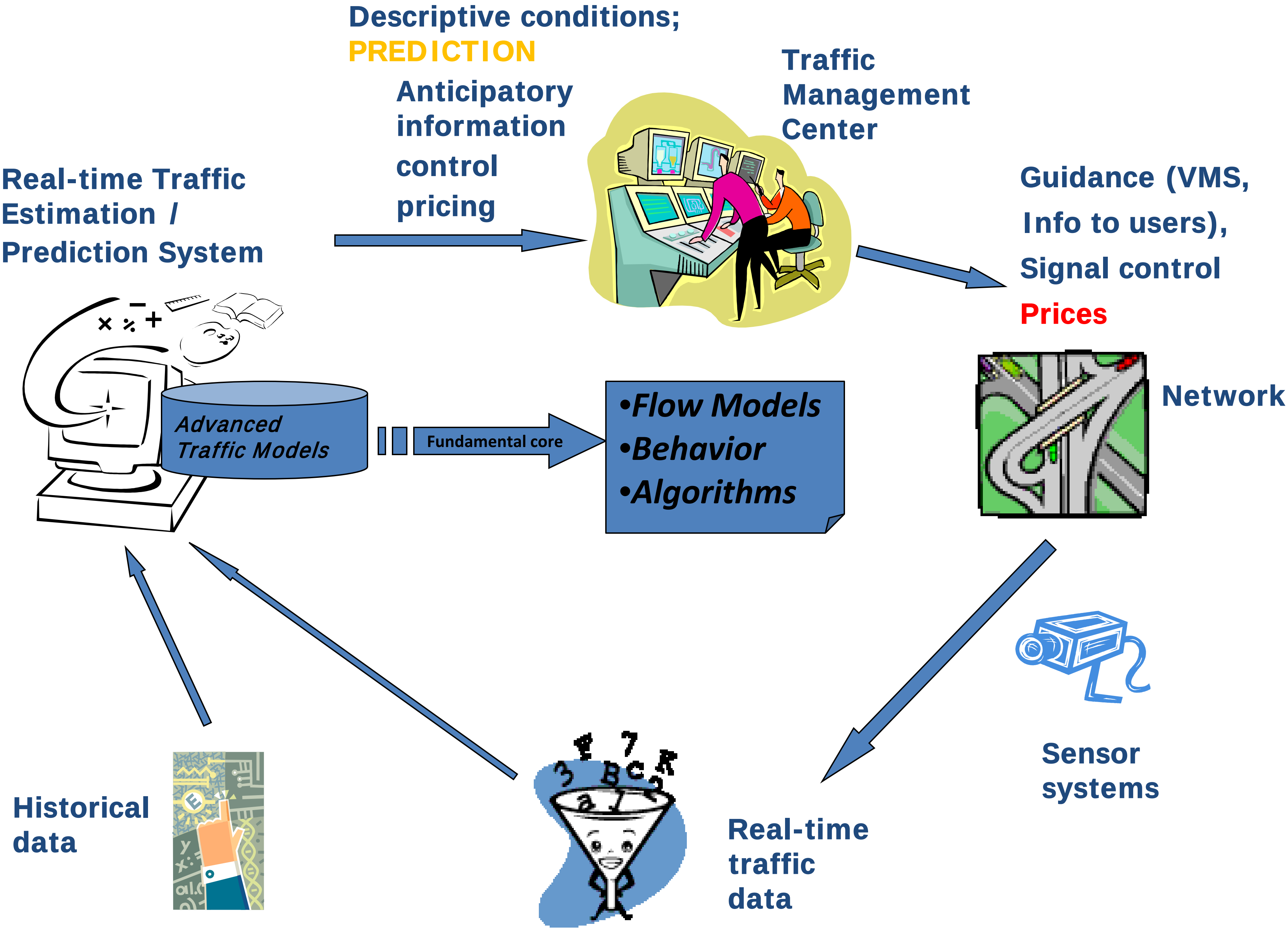


Dynamic Decision Support Tools for Vehicle Routing, Fleet Management and Collaborative Logistics

in conjunction
with asset tracking and
management technologies

Prospect for tie-ins in urban contexts
with predictive traffic management tools,
e.g. DYNASMART-X

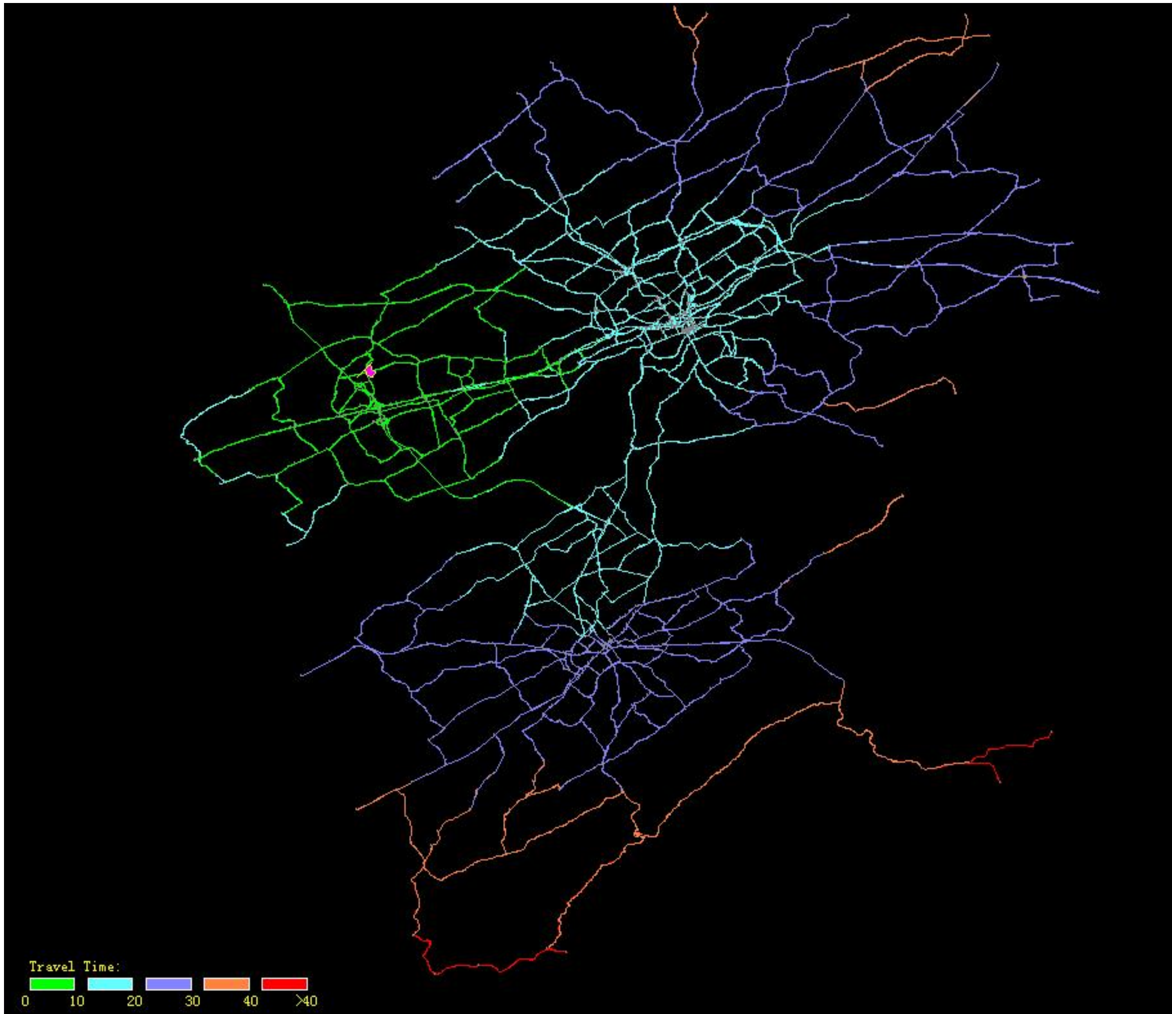


III.

Prediction and Real-time Traveler Information

Consistent Anticipatory Travel Time Information

(*Reference: Dong and Mahmassani, 2010*)



Consistent Anticipatory Travel Time Information

WHAT WE KNOW

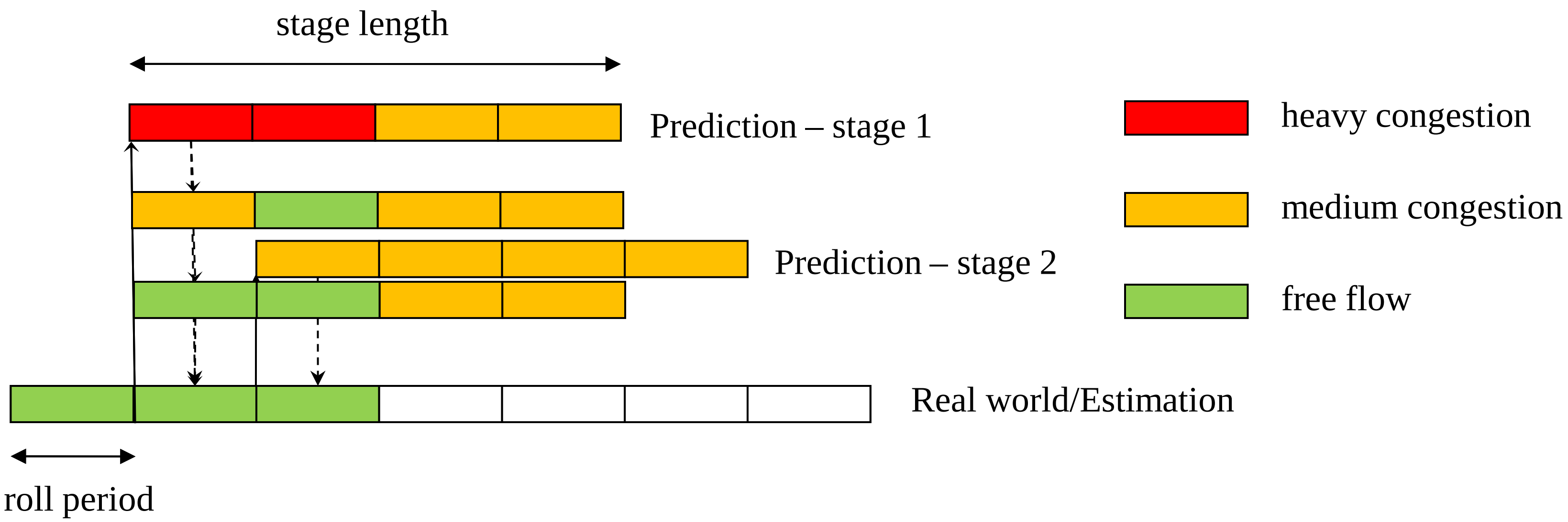
Information on currently prevailing conditions may not be effective: *overreaction, time lags, stochastic and dynamic variation*

Anticipatory information effective, but poses three challenges:

- capturing user responses to provided information:
  CONSISTENCY
- users care about reliability of information
- computation for large networks

Closed-loop Rolling Horizon Framework

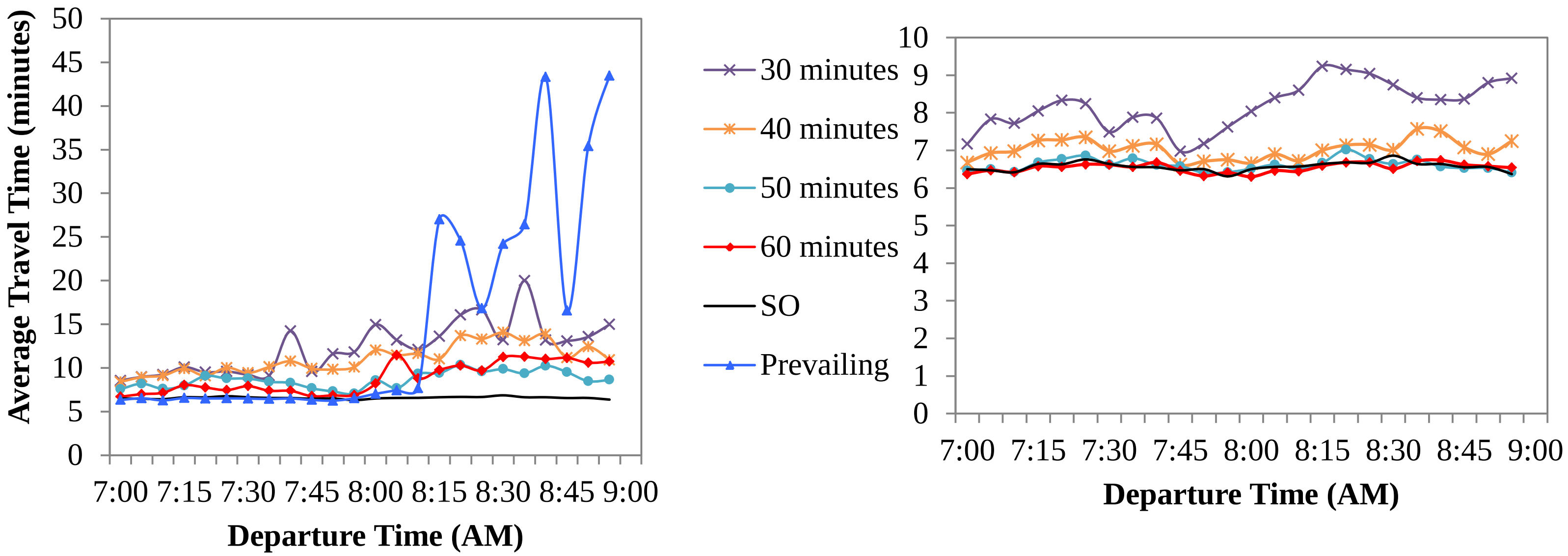
- RH approach is a practical method for generating and implementing solutions to dynamic programming problems.
- Closed-loop structure allows the control policies obtained in traffic prediction model to be implemented in real world and transferred to state estimation model.



The Test Bed Network : Irvine

- Network
  - Freeways I-405, I-5, state highway 133
  - 326 nodes
  - 626 links
  - 61 TAZs
  - 57 road detectors
- Demand
  - Two hours morning peak
  - 15min warm-up period + 45 min clearance time
- Parameters
  - Roll period: 5 minutes
  - Prediction horizon varying from 30 to 60 minutes

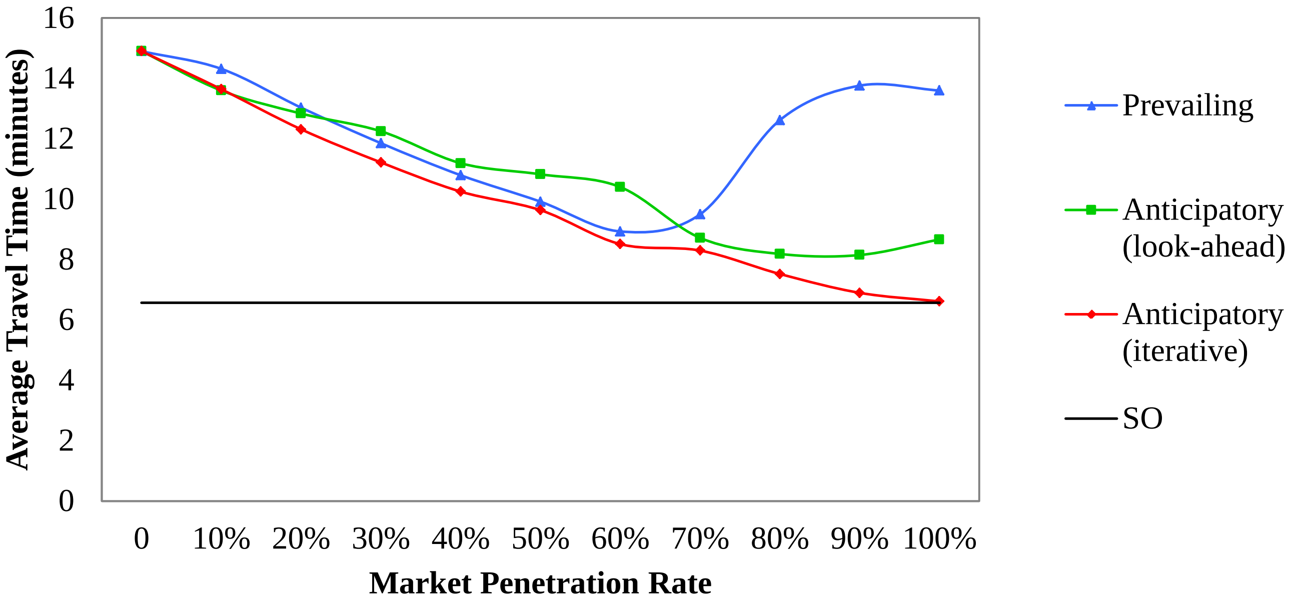
Sensitivity to *Prediction Horizon*


look-ahead algorithm

recursive averaging algorithm

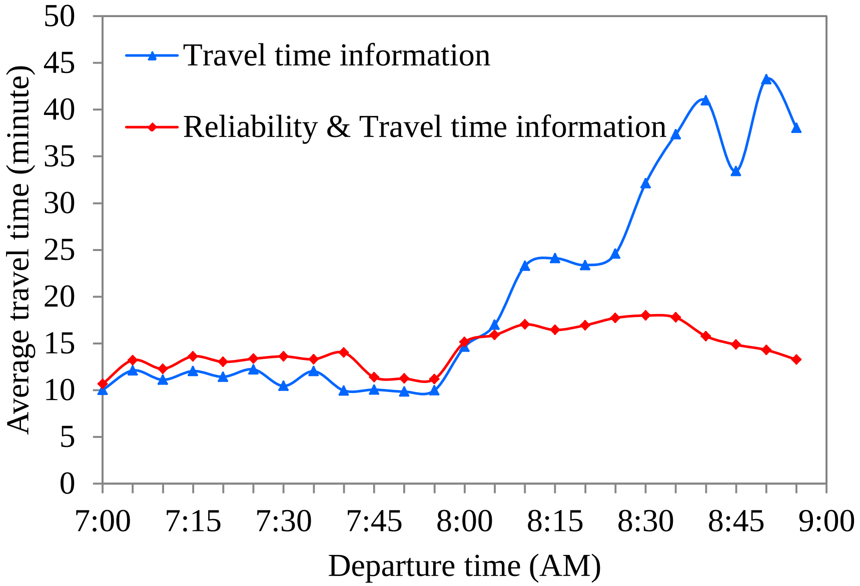
- Anticipatory information works better than prevailing information
- Longer prediction horizon provides better performance

Sensitivity to *Market Penetration Rate*

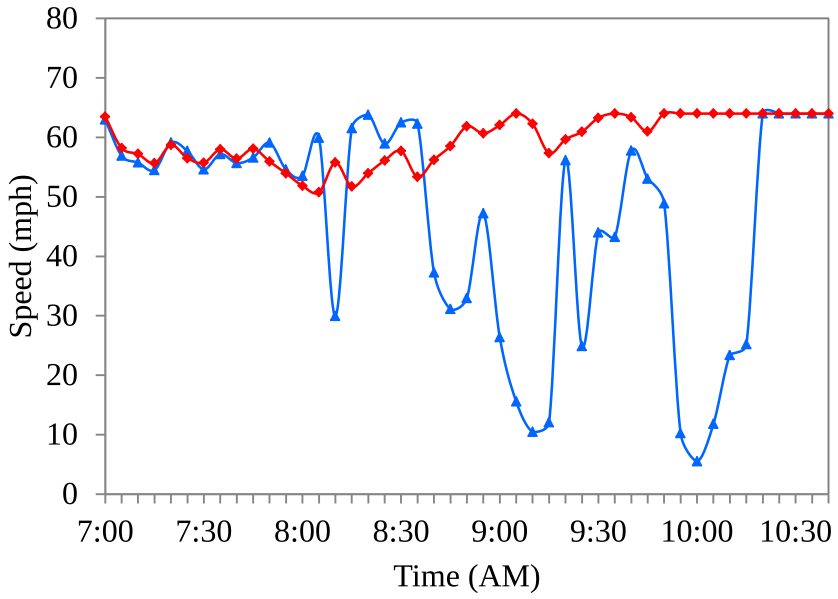


- Provision of anticipatory travel time information improve the overall network performance
- Solve the overreaction problem caused by providing prevailing (instantaneous) information

Average Travel Time



Freeway Speed



Scenarios:

- only anticipatory travel time information is provided
- both anticipatory travel time and reliability information provided

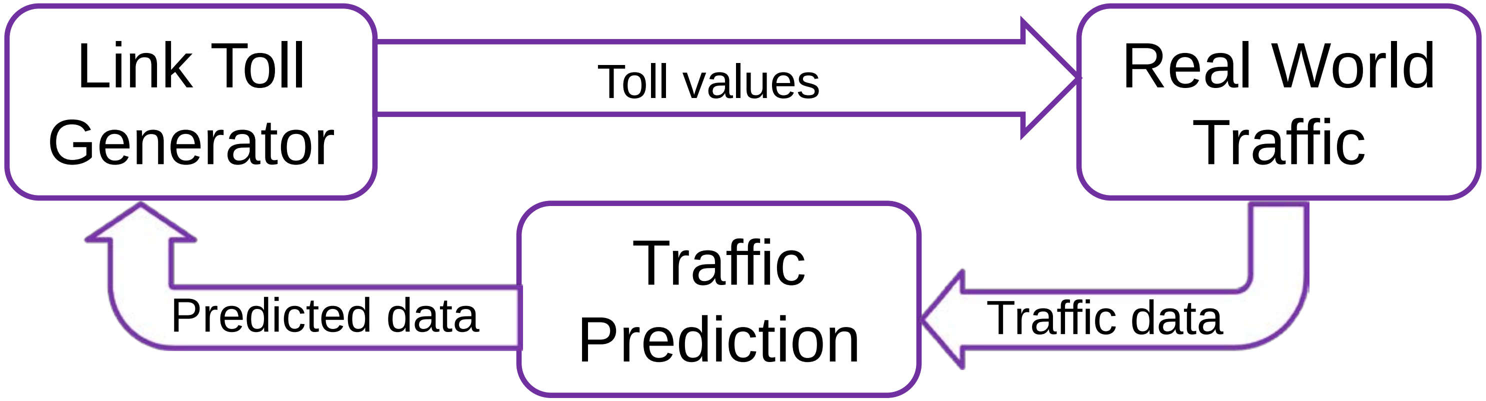
- Significant time savings are observed when travel reliability information is provided in addition to travel time information
- Providing travel reliability information contributes to *delaying the onset of breakdown* and alleviating its extent, with higher and more stable flow indicating an increase in freeway's utilization

IV.

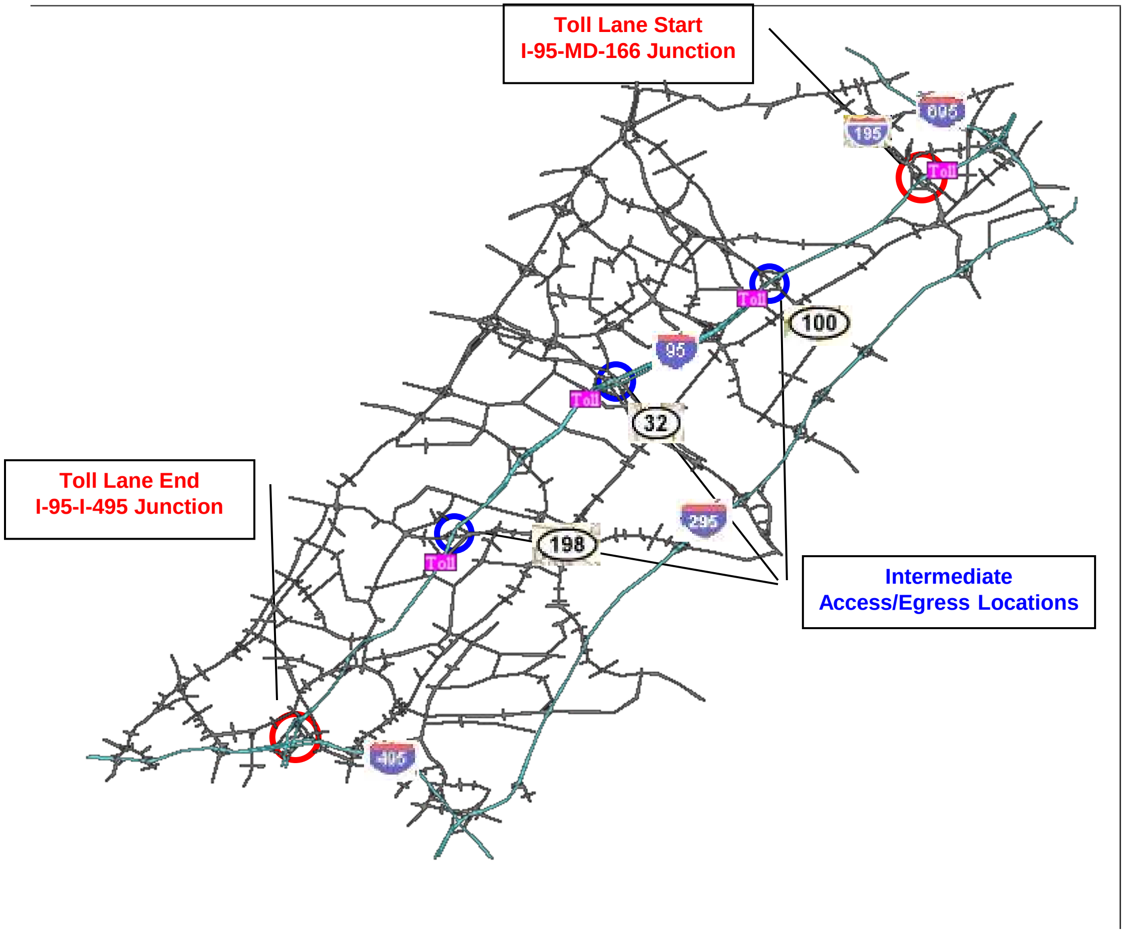
Predictive Control: Pricing

Anticipatory Pricing Strategy for Managed Lane Operation

- What differentiates anticipatory from reactive pricing?
  - Network state prediction
  - Use predicted traffic conditions
  - Calculate link toll within the prediction horizon and implement it in real time



The Test Bed Network: CHART



- I-95 corridor between Washington, DC and Baltimore, MD, US
- 2 toll lanes
- 2241 nodes
- 3459 links
- 111 TAZ zones
- 2 hours morning peak demand

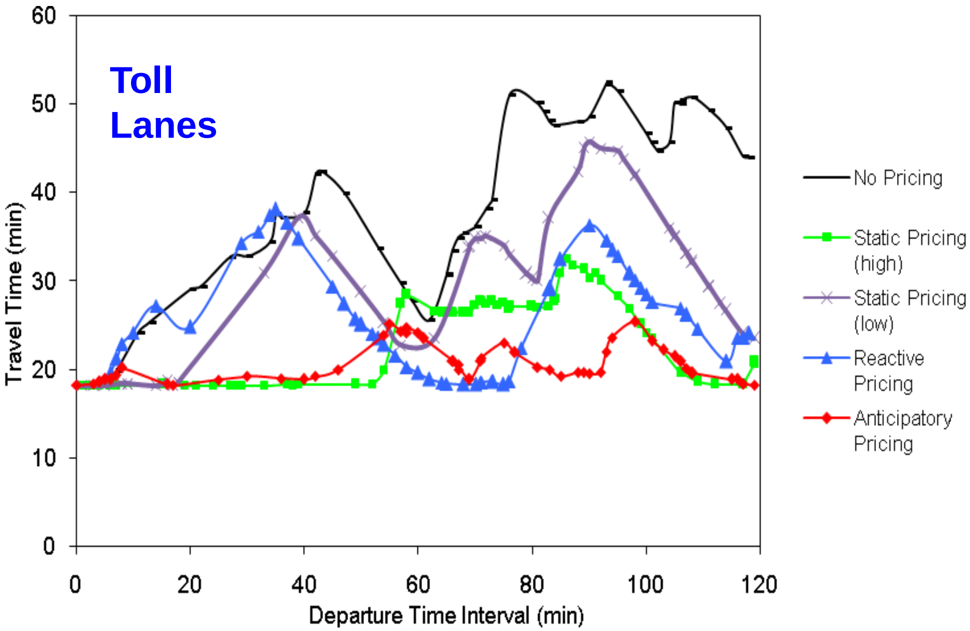
Pricing Strategies Compared

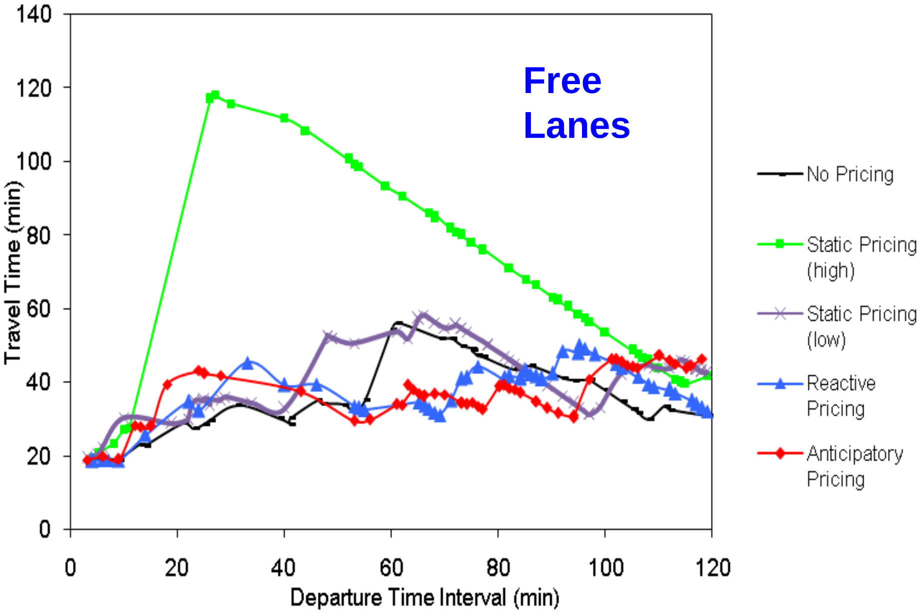
- No pricing (base case)
- Static pricing
  - Predetermine the time-varying link tolls based on the historical information
- Reactive pricing
  - Set time-varying link tolls based on prevailing traffic conditions
- Anticipatory pricing
  - Set time-dependent link tolls based on predicted traffic conditions

OBJECTIVE: AVOID BREAKDOWN– optimize throughput, reliability, under economically efficient allocation

Illustrative Results – Travel Time

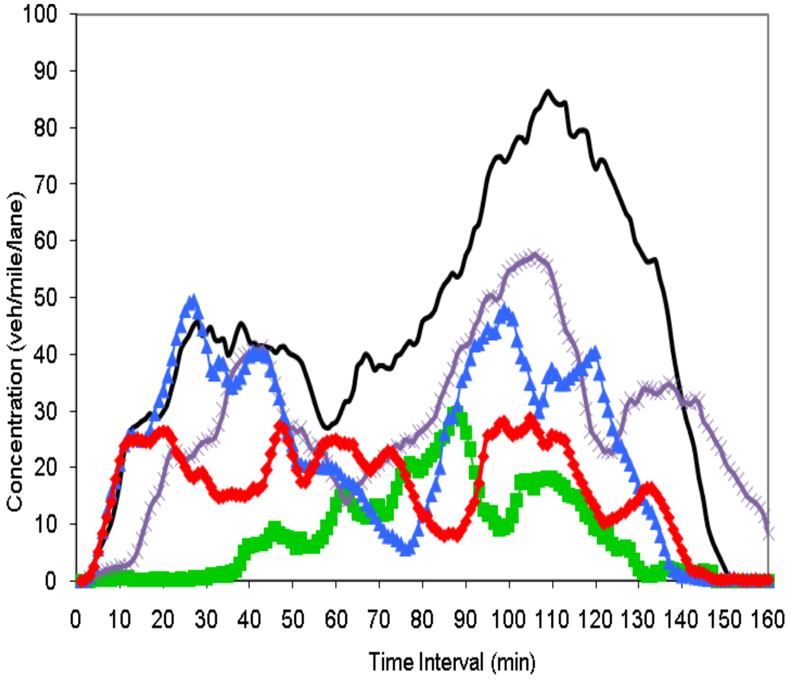
- Warm-up period: increase in travel time at the beginning
- With the anticipatory pricing strategy, the travel times become steady after 1 hour (free flow condition)
- Static pricing strategy provides free flow condition on the toll lanes, but reduces the LOS on the alternative freeway lanes

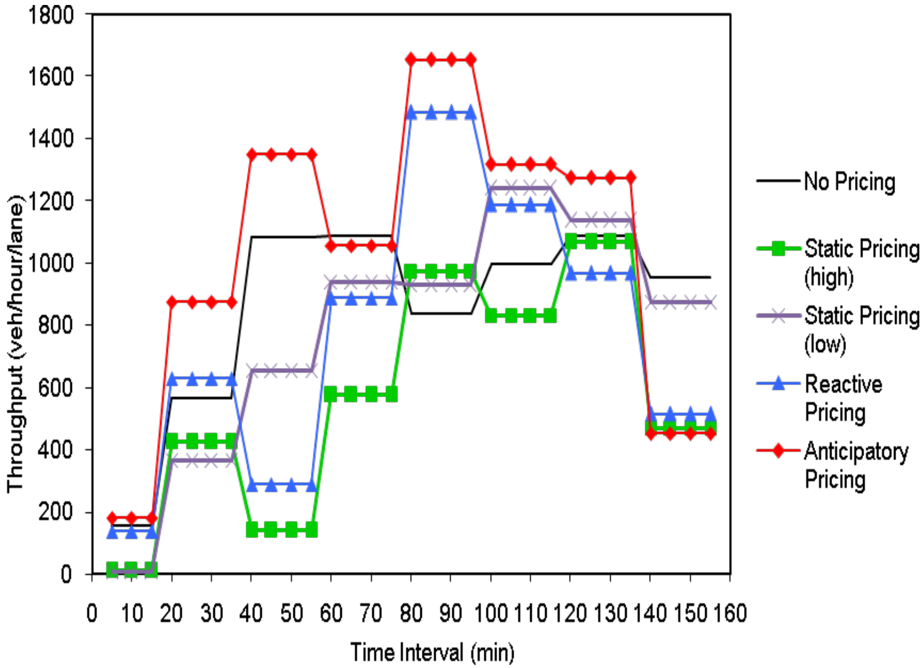




Illustrative Results – Traffic Measures

- Concentrations averaged over links along the congested portion of toll road, weighted by the link length
- Throughputs measured at downstream of where traffic breaks down in base case (no pricing)
- Anticipatory pricing strategy can provide higher throughput while maintaining lower concentration (steady traffic flow)

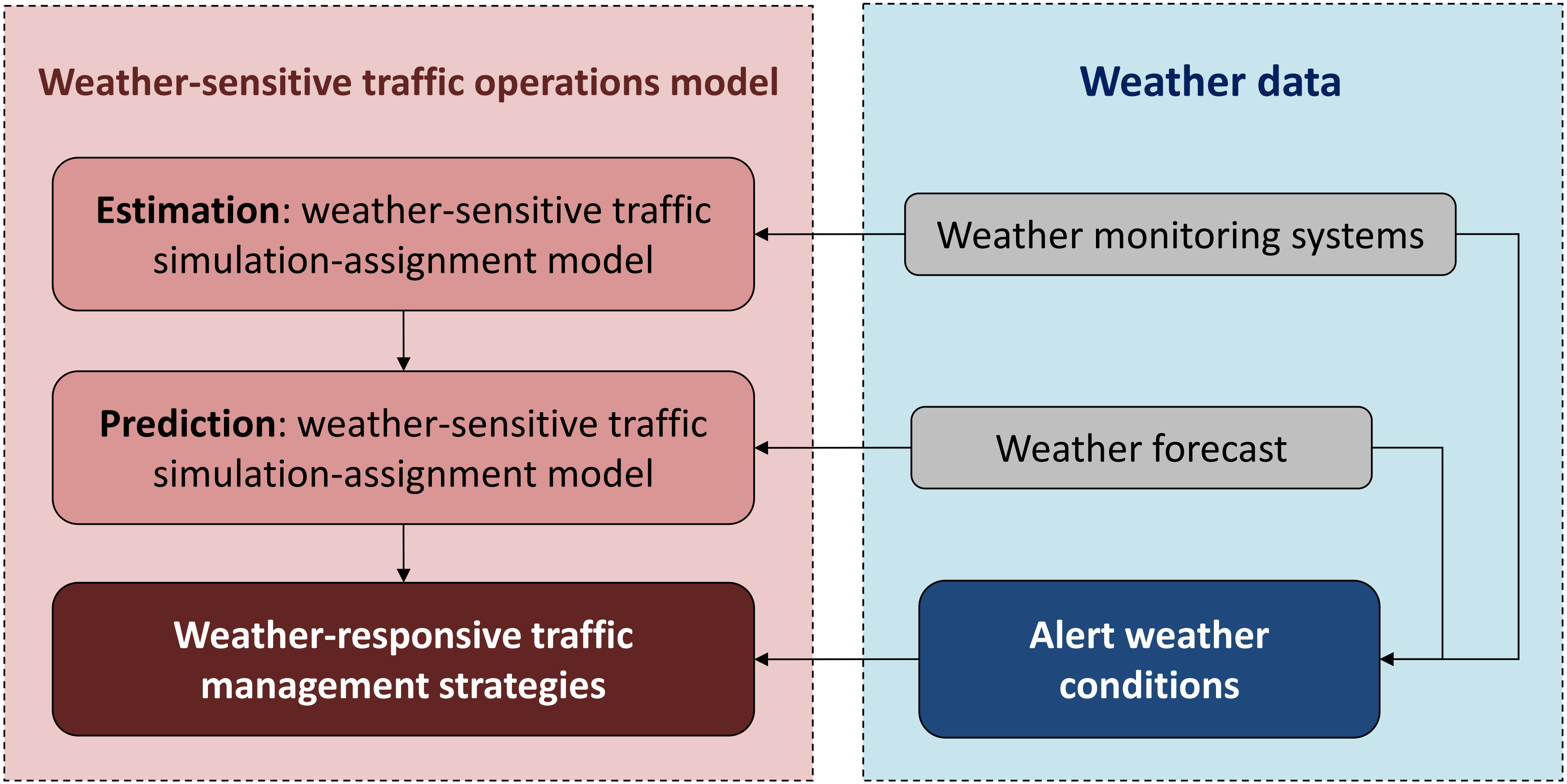




V.

Weather-Related Traffic Management (WRTM)

Weather-sensitive Traffic Estimation and Prediction System (TrEPS)



Weather-sensitive traffic operations model

Estimation: weather-sensitive traffic simulation-assignment model

Prediction: weather-sensitive traffic simulation-assignment model

Weather-responsive traffic management strategies

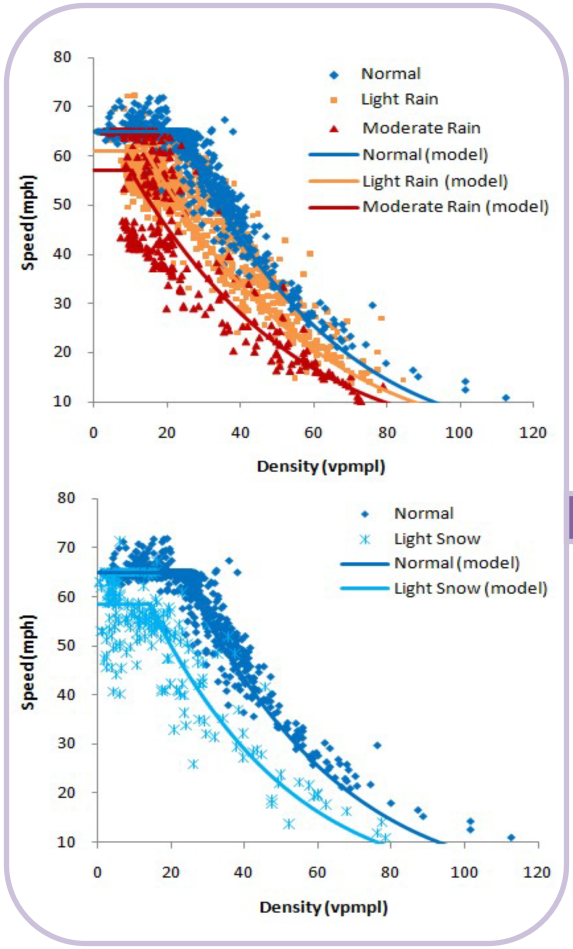
Weather data

Weather monitoring systems

Weather forecast

Alert weather conditions

Model impacts of adverse weather on transportation networks



TrEPS

DYNASMART

Weather Scenario Specification

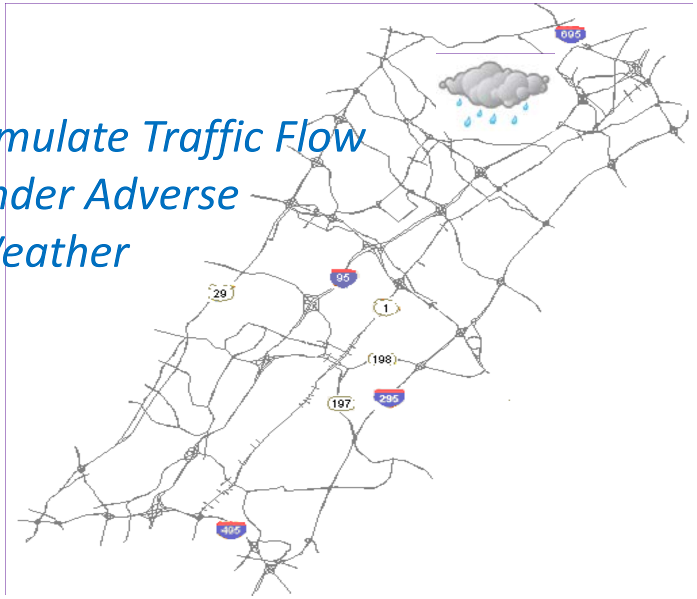
- Rain intensity (*r*)
- Snow intensity (*s*)
- Visibility (*v*)

Supply-side Parameter Calibration

Weather Adjustment Factor **(WAF)**

- Free-flow speed,
- Saturation flow rate,
- Section capacity,
- etc.

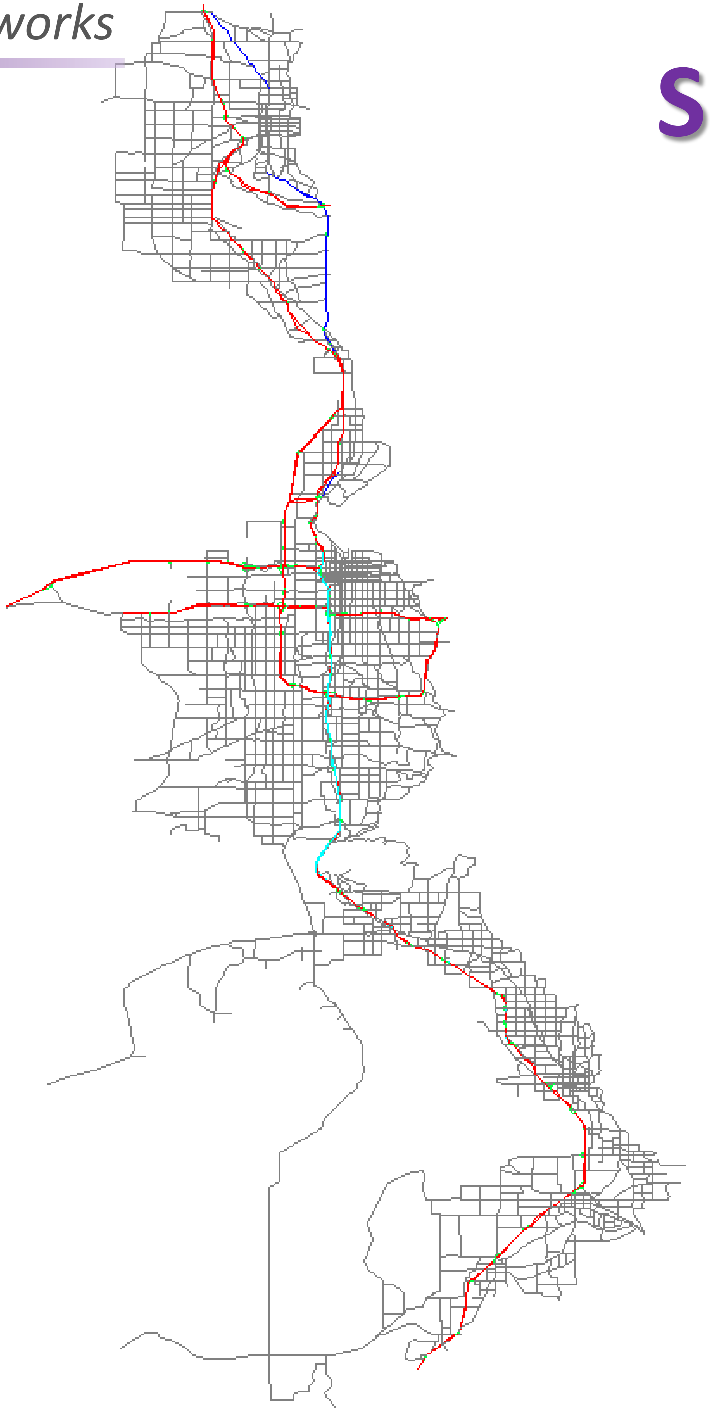
Simulate Traffic Flow under Adverse Weather



Chicago

- 40443 links
  - 144 links are tolled
  - 1400 freeways
  - 201 highways
  - 2120 ramps
  - (96 of them are metered)
  - 36722 arterials
- 13093 nodes
  - 2155 signalized intersections
- 1961 zones
  - 1944 internal
  - 17 external
- Demand period
  - 5am -10am hourly demand
  - 355 unique link counts
  - Observation Interval: 5 min

Salt Lake City



- 2,250 zones
- 17,947 links
  - 16,293 arterials
  - 576 ramps
  - 136 highways
  - 791 freeways
  - 151 HOV lanes
- 8,309 nodes
  - 1,134 signalized intersections
- Demand horizon
  - 6am – 9am
- Simulation horizon
  - 6am – 10am

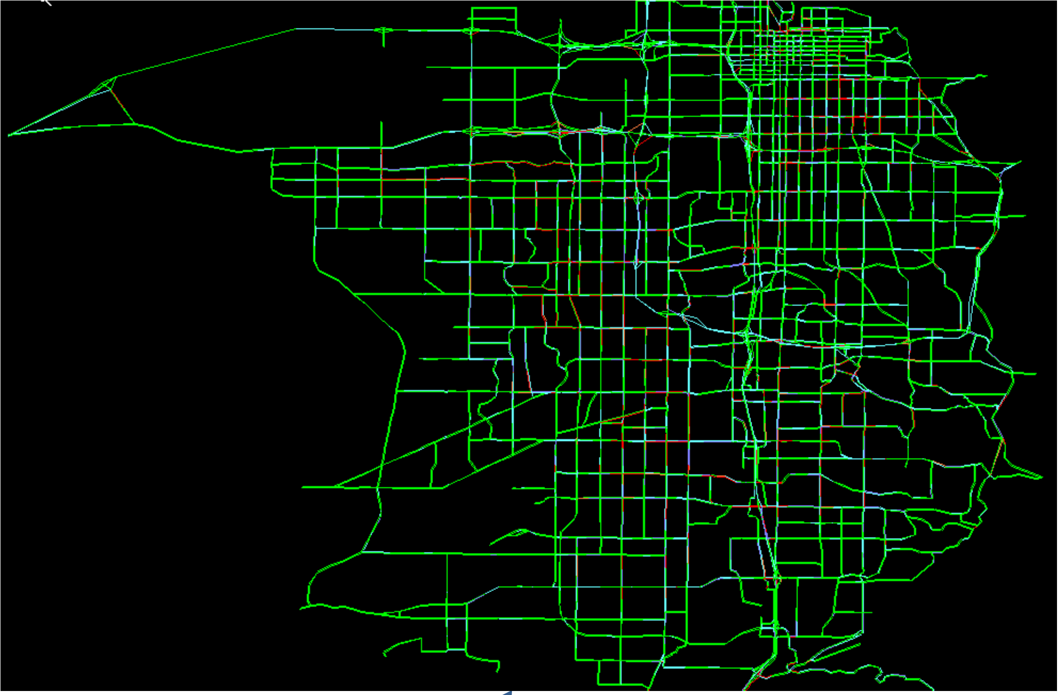
Long Island

- 1,431 zones
- 21,790 links
  - 17,942 arterials
  - 2,059 ramps
  - 31 highways
  - 1,588 freeways
  - 170 HOV lanes
- 9,402 nodes
  - 4,691 signalized intersections
- Demand horizon
  - 5am – 10am
- Simulation horizon
  - 5am – 11am

Off-line Implementation : Effectiveness of VSL/VMS Strategies

- Test Scenarios
  - **Clear Day**: Maximum visibility with zero precipitation.
  - **Snow**: Visibility ranges from 10 to 1.75 miles, snow intensity ranges from 0.01 to 0.15 inches per hour network-wide.
  - **Snow with VMS – Variable Speed Limit**: Speed reduction strategies are implemented on freeway corridors.
  - **Snow with VMS – Mandatory Detour**: Vehicles are detoured from some heavily impacted links to alternative routes.

Weather Impact



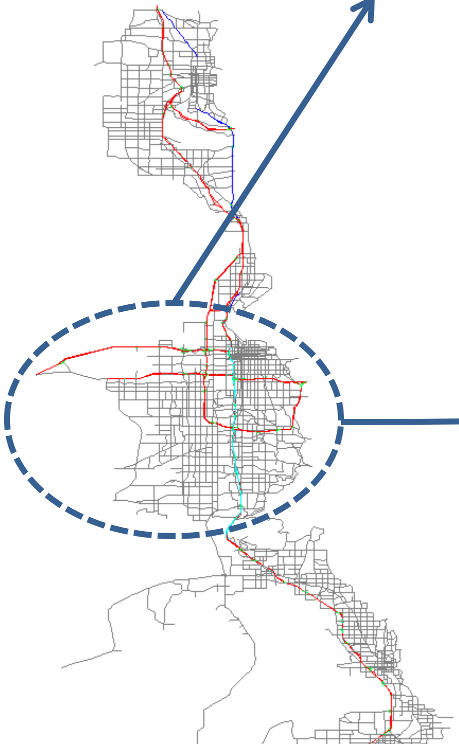
Clear Day

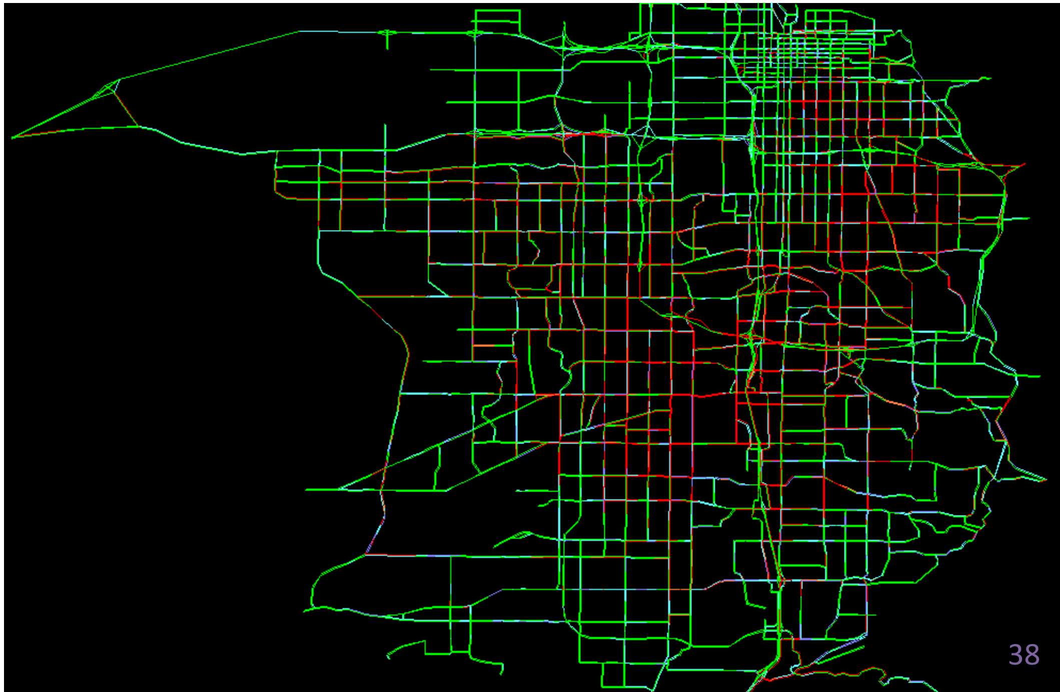
Snow

Density:

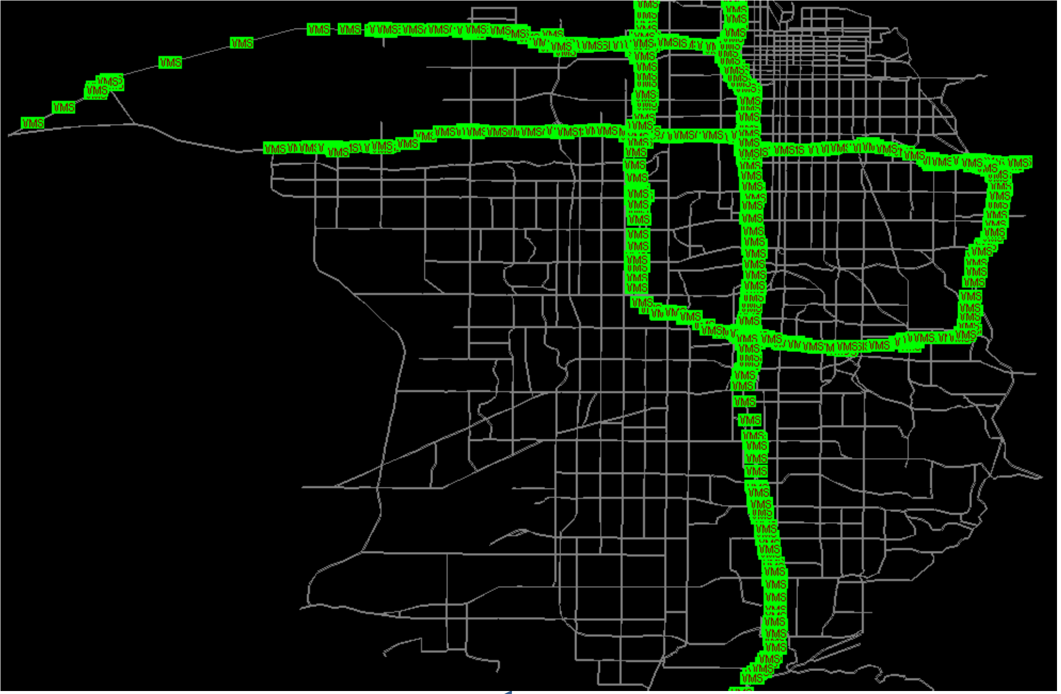
🟩 🟦 🟪 🟧 🟥

0 15 30 45 60 >75



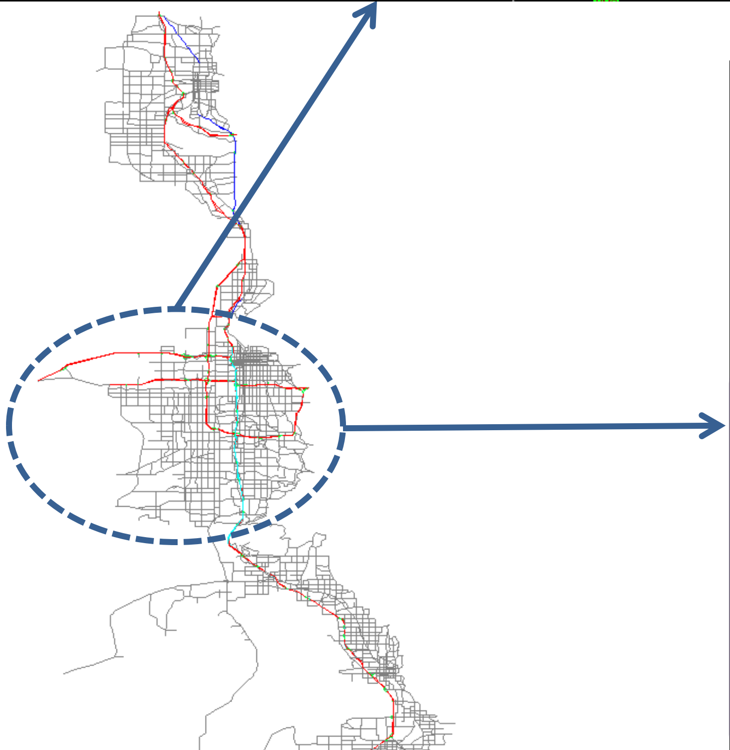


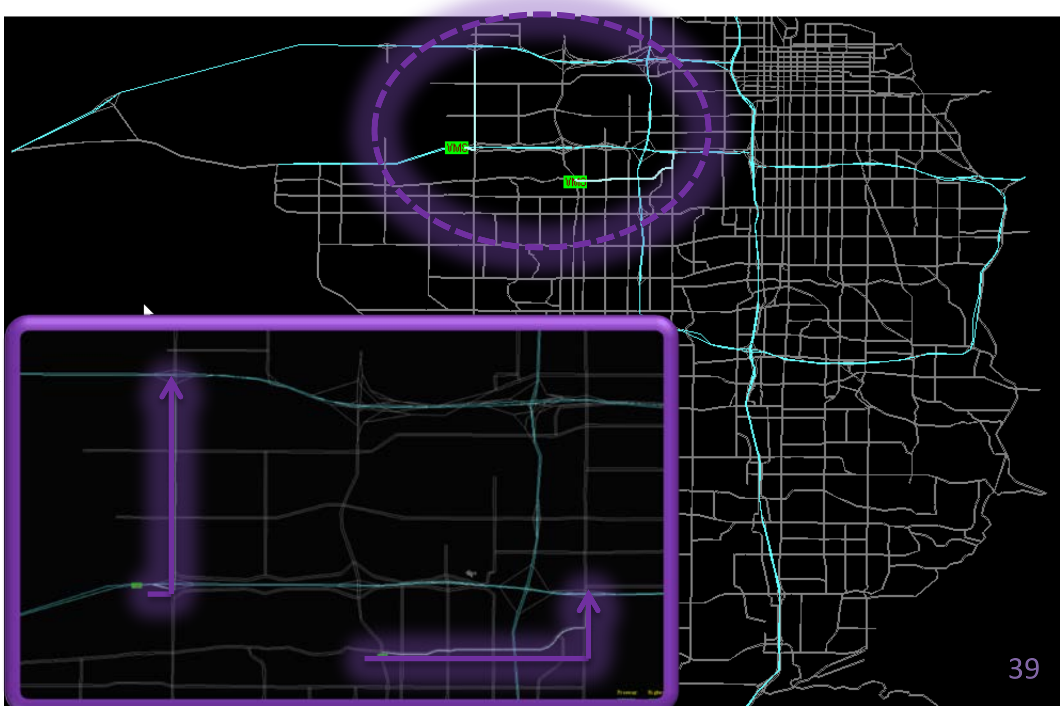
WRTM Strategies



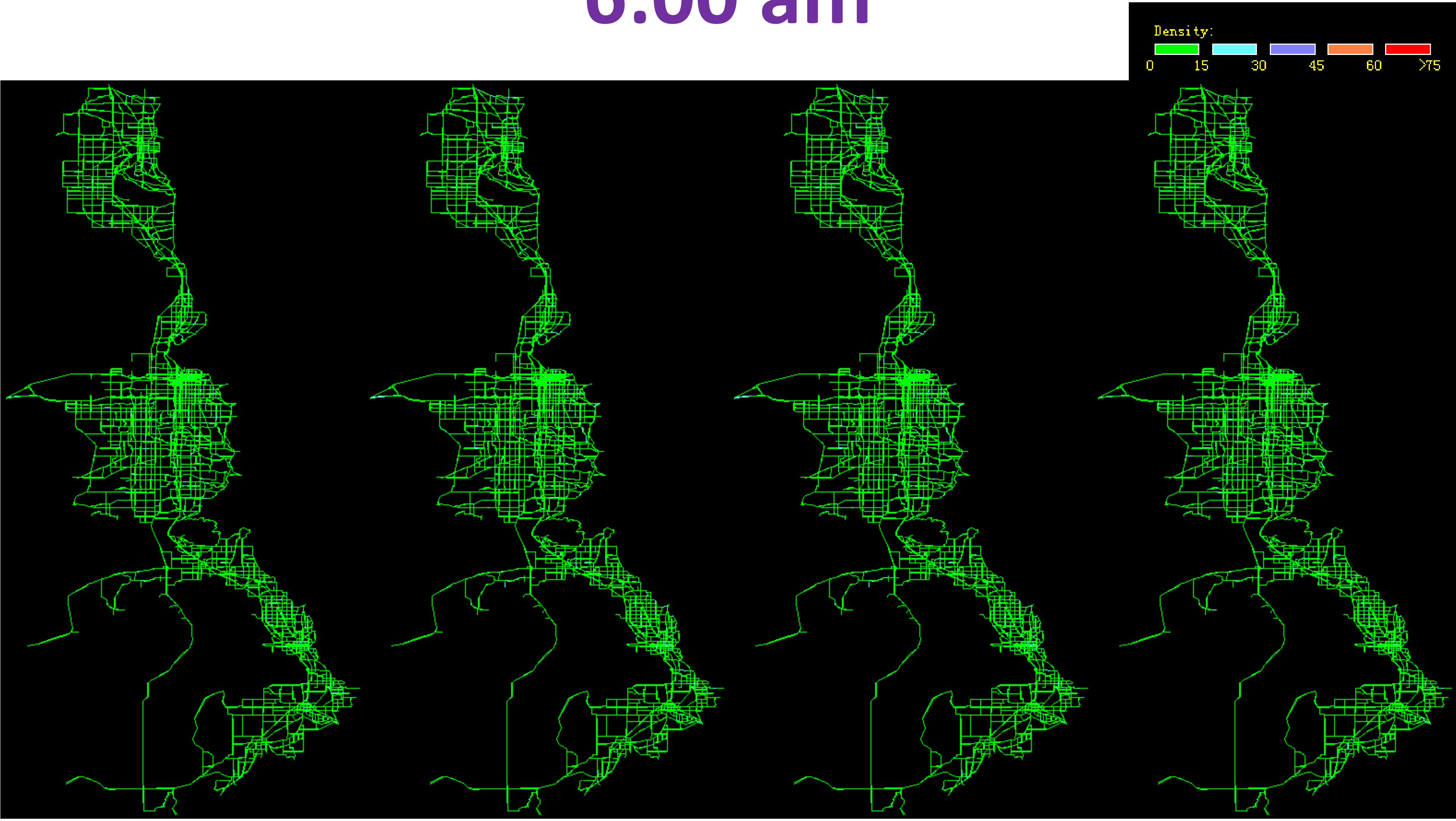
VMS - VSL

VMS – Detour





6:00 am



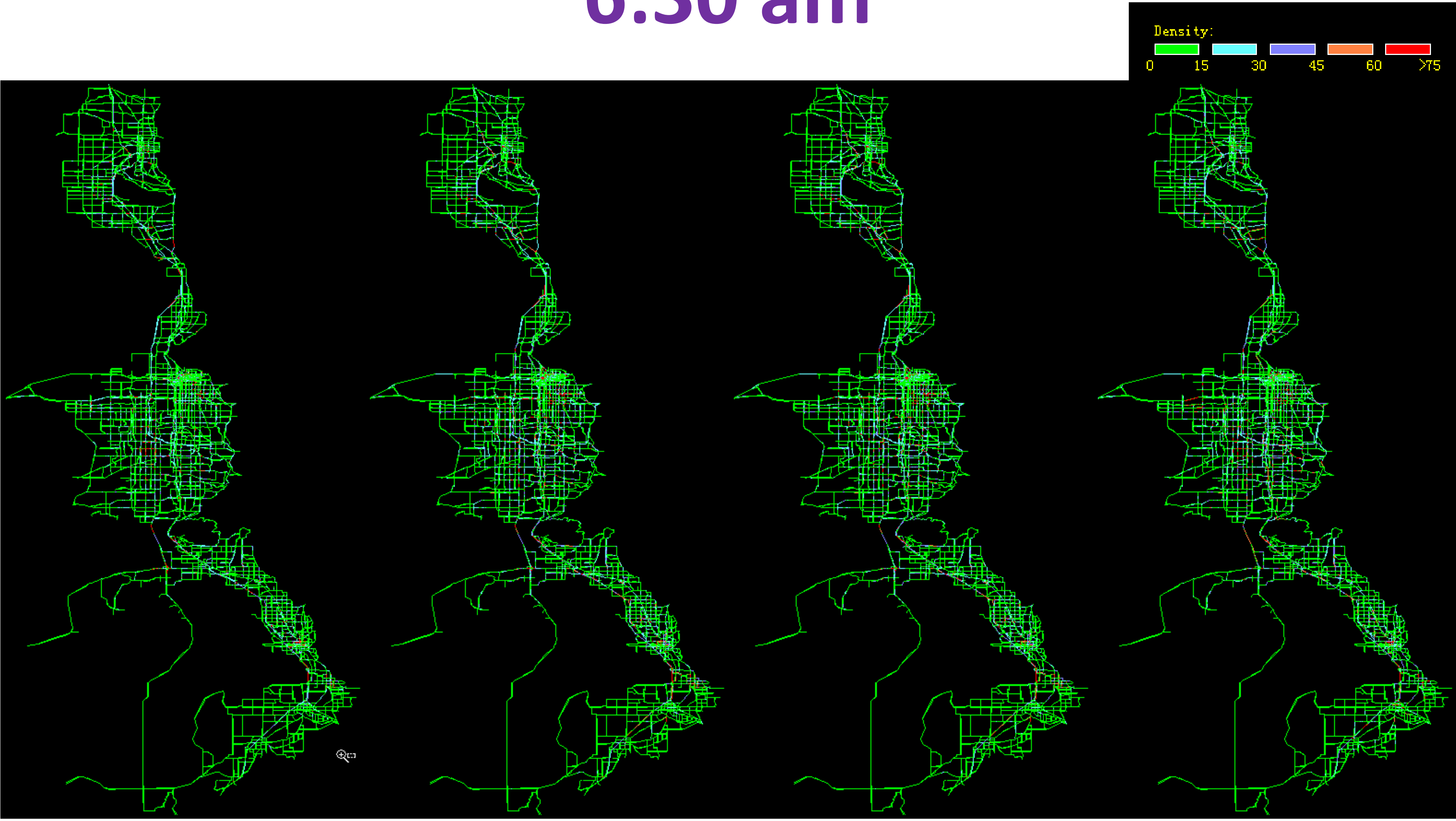
01-00.Regular

01-01.NoWRTM

01-02.VSL7

01-03.VMS2

6:30 am



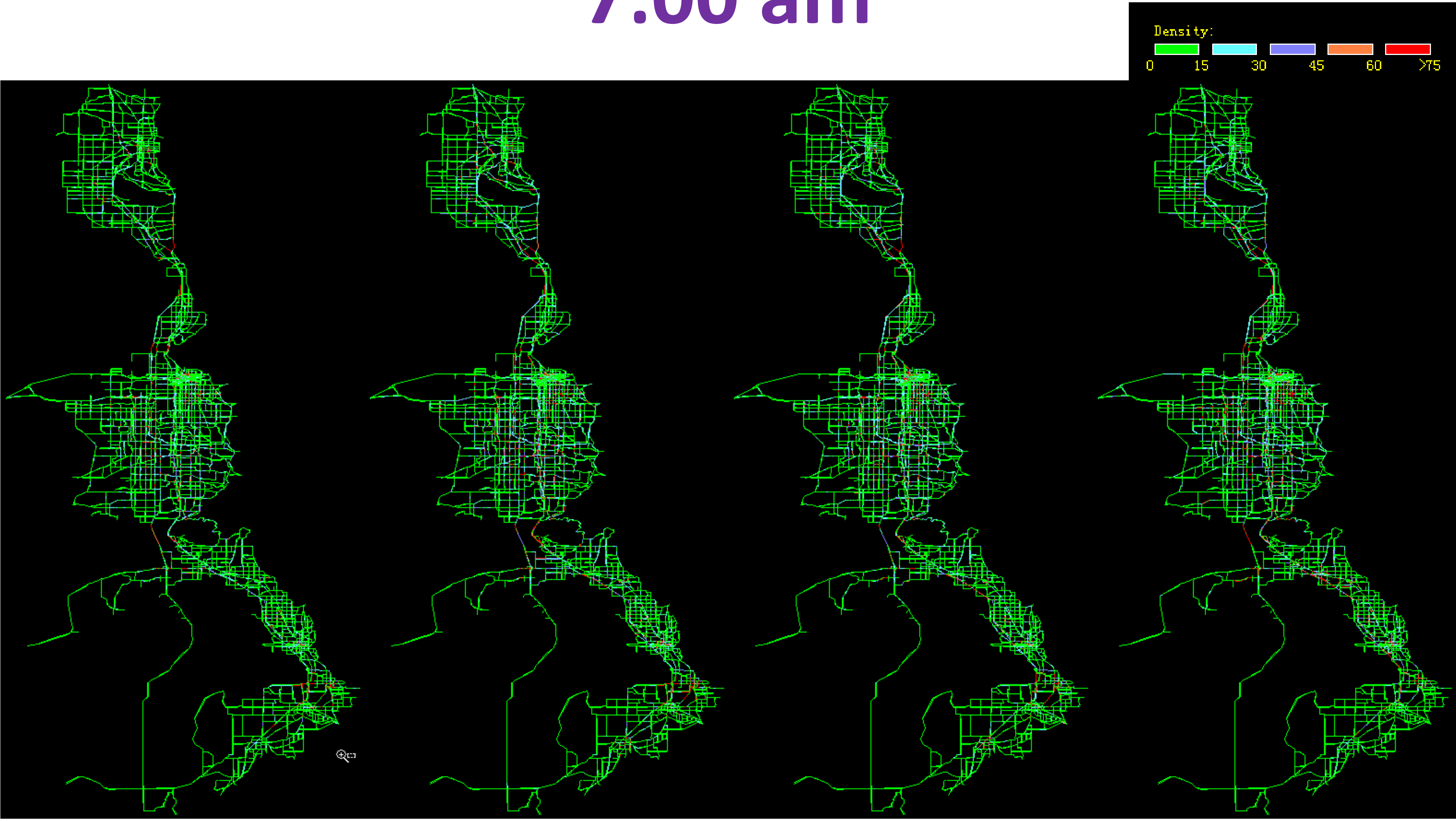
07-00.Regular

07-01.NoWRTM

07-02.VSL7

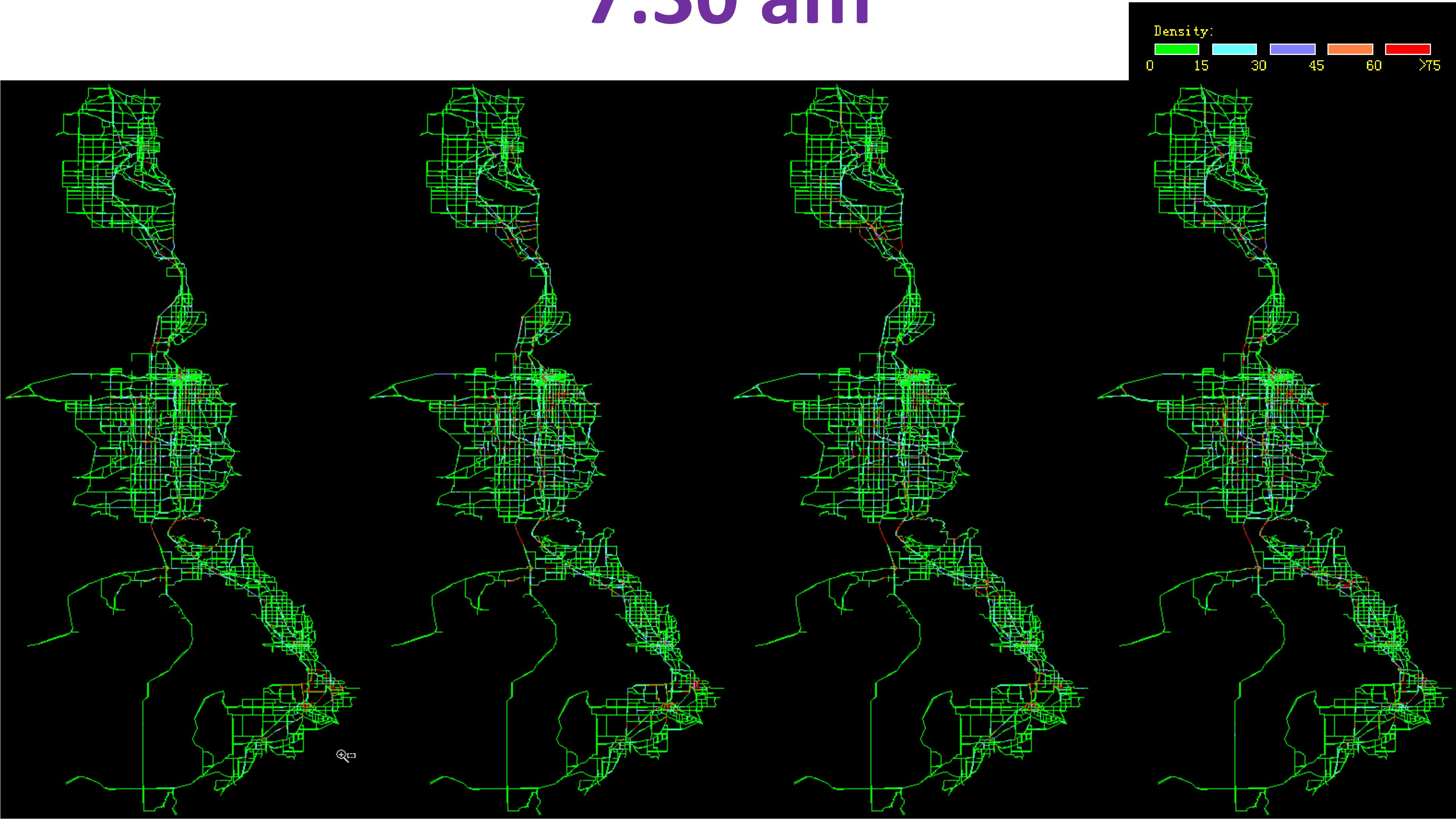
07-03.VMS2

7:00 am



13-00.Regular   13-01.NoWRTM   13-02.VSL7   13-03.VMS2

7:30 am



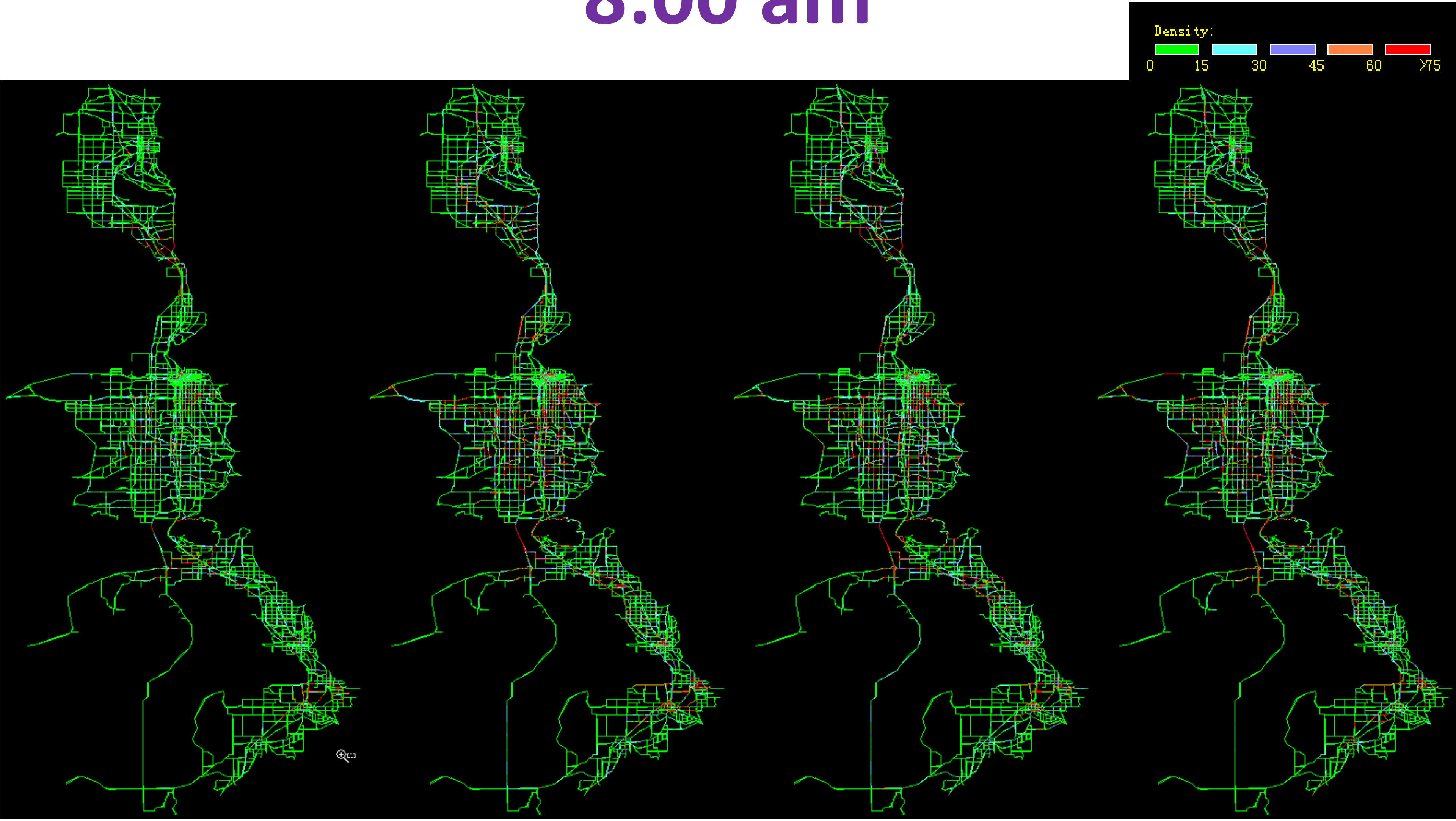
19-00.Regular

19-01.NoWRTM

19-02.VSL7

19-03.VMS2

8:00 am



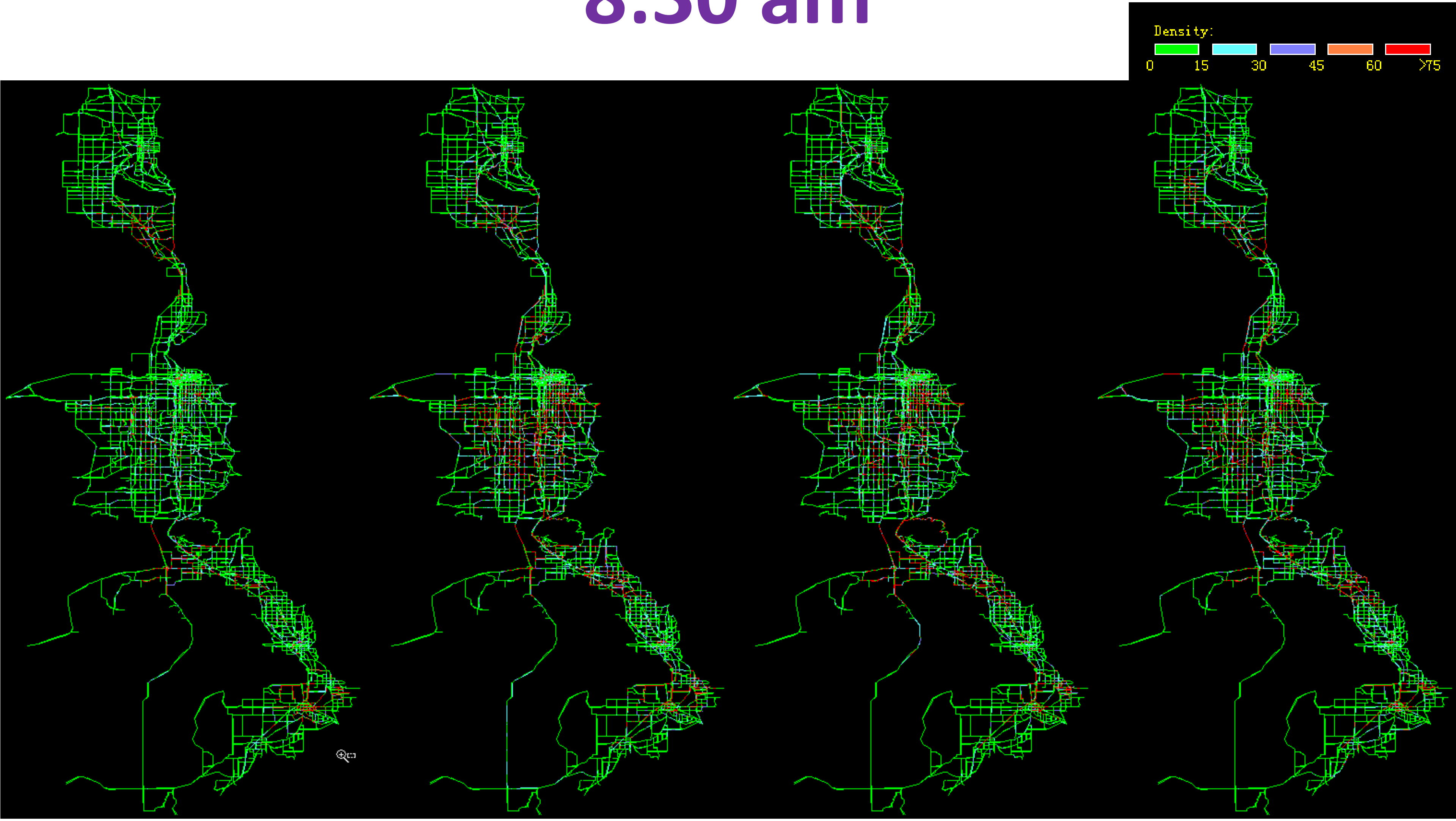
25-00.Regular

25-01.NoWRTM

25-02.VSL7

25-03.VMS2

8:30 am



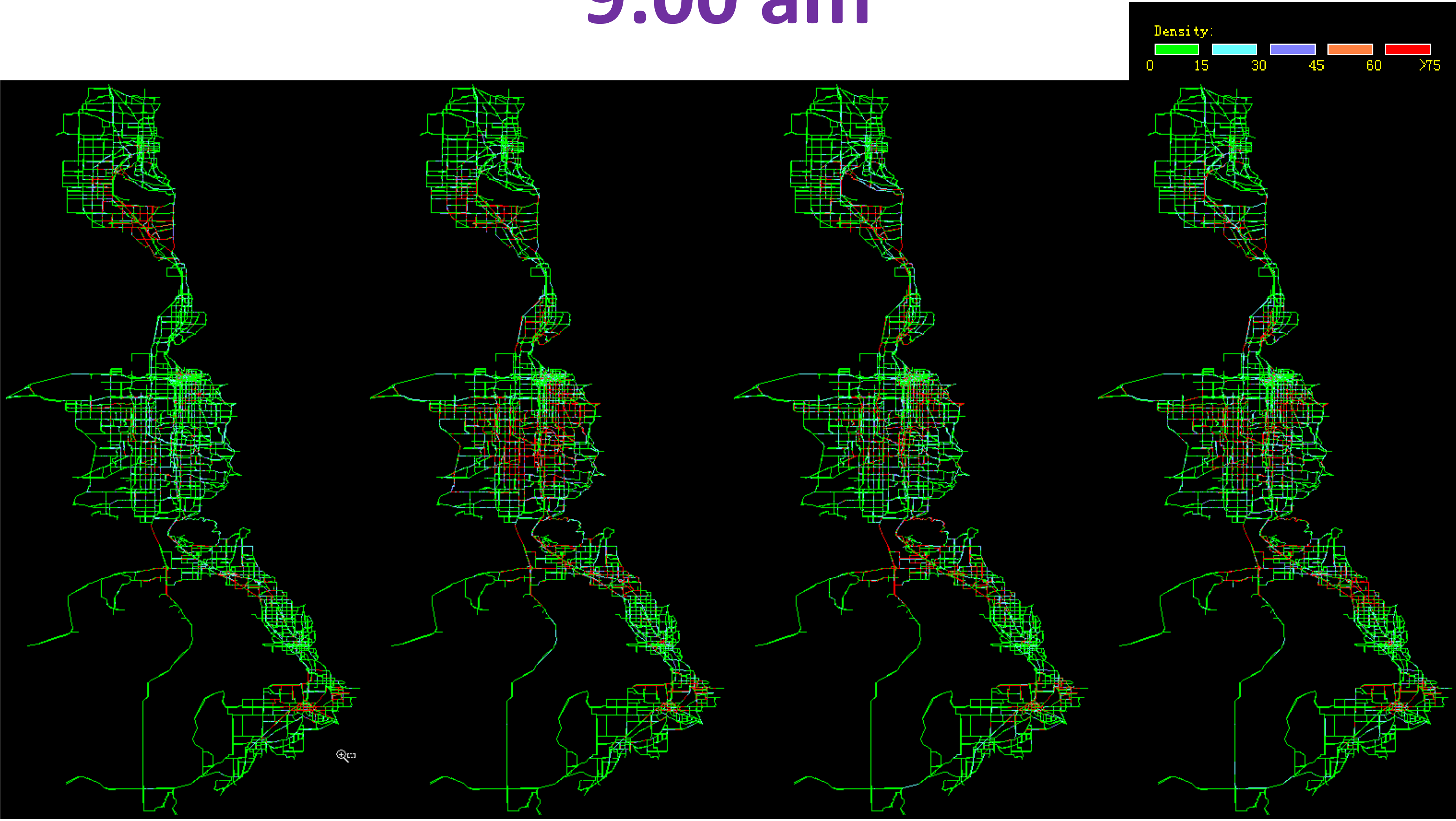
31-00.Regular

31-01.NoWRTM

31-02.VSL7

31-03.VMS2

9:00 am



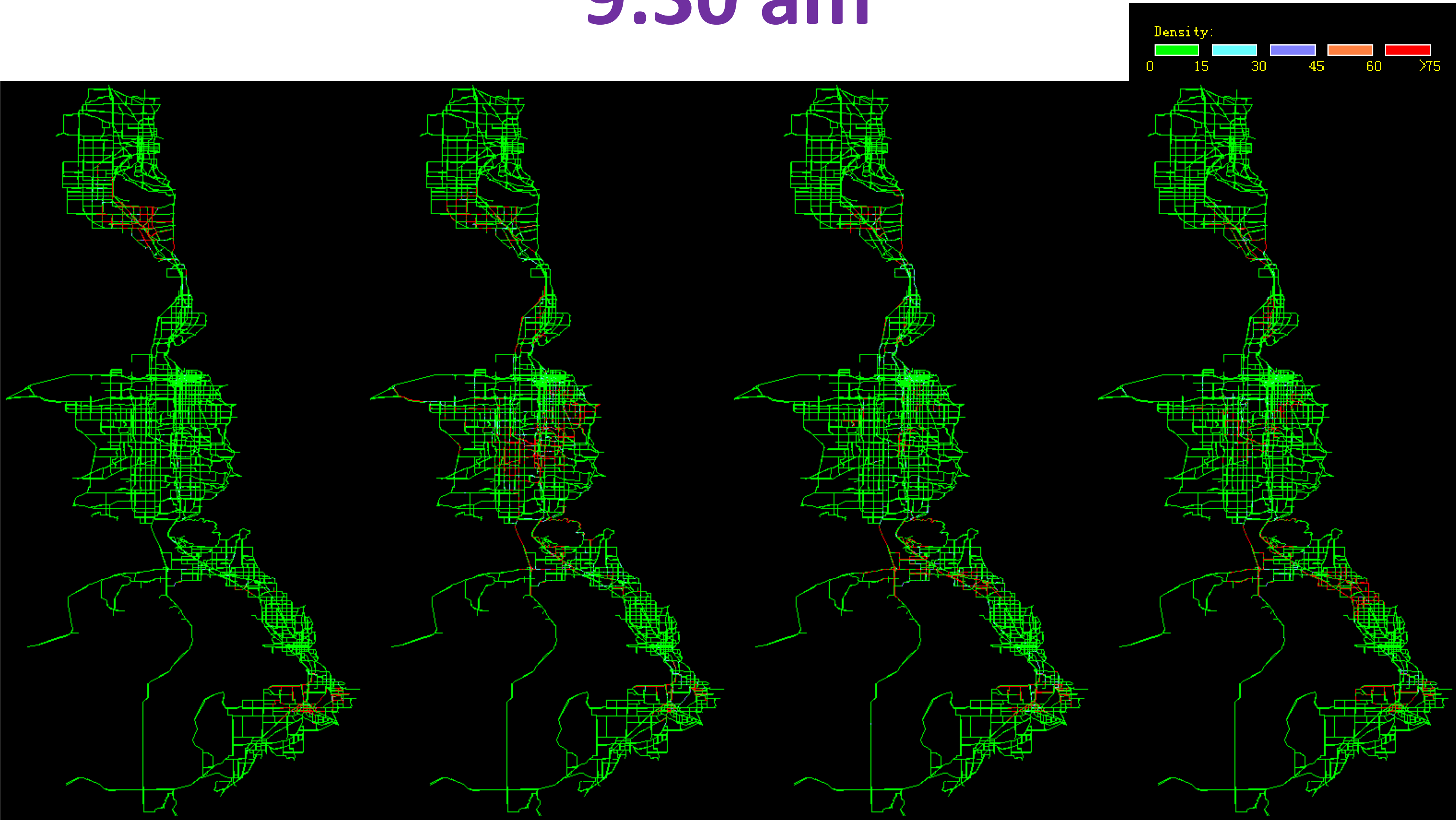
37-00.Regular

37-01.NoWRTM

37-02.VSL7

37-03.VMS2

9:30 am



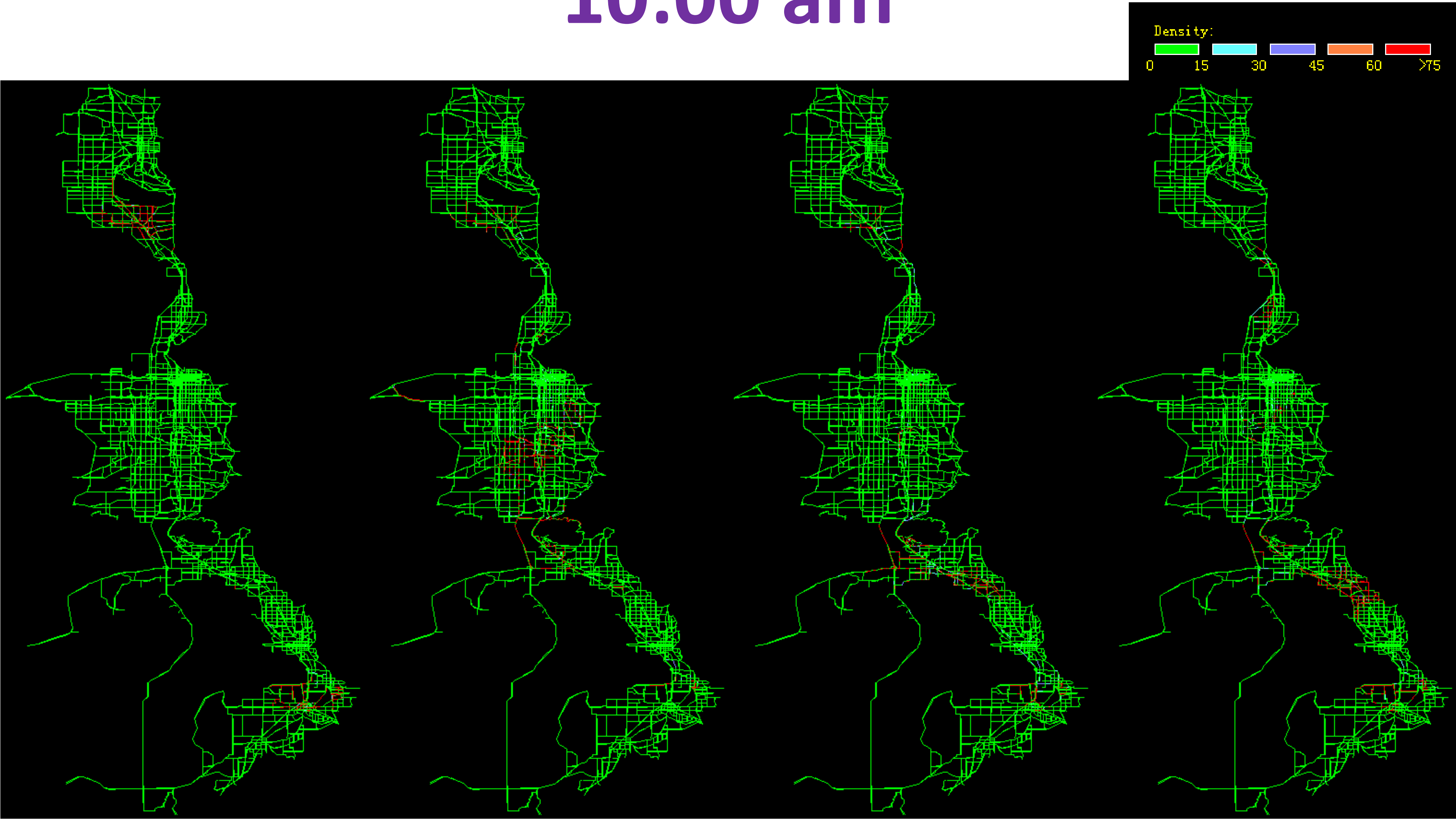
43-00.Regular

43-01.NoWRTM

43-02.VSL7

43-03.VMS2

10:00 am



49-00.Regular

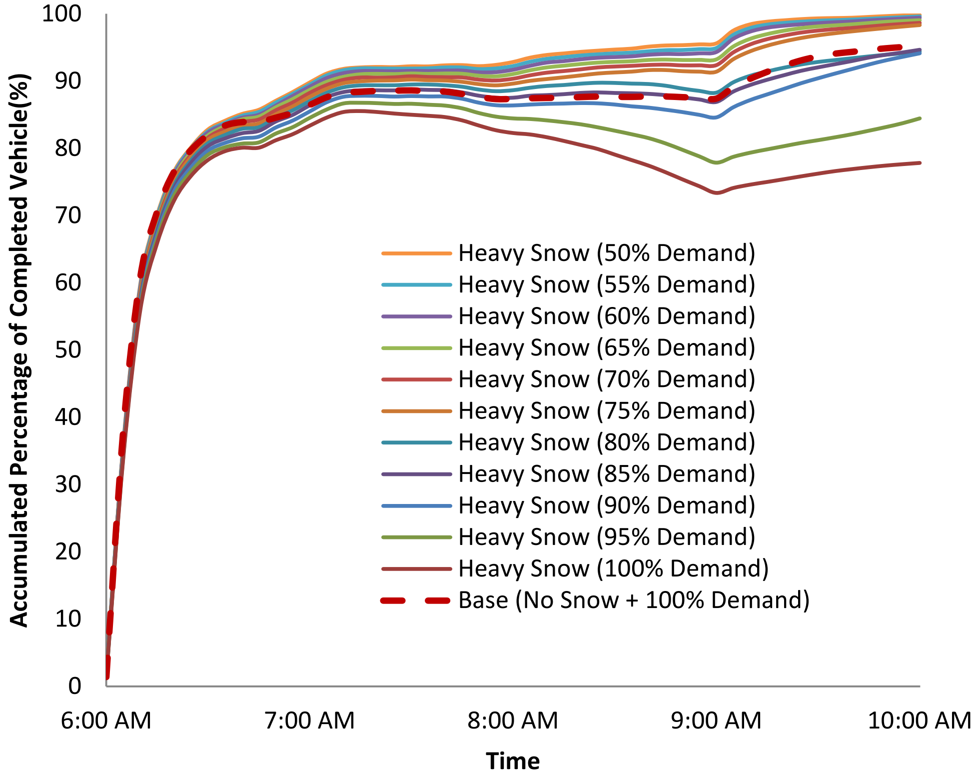
49-01.NoWRTM

49-02.VSL7

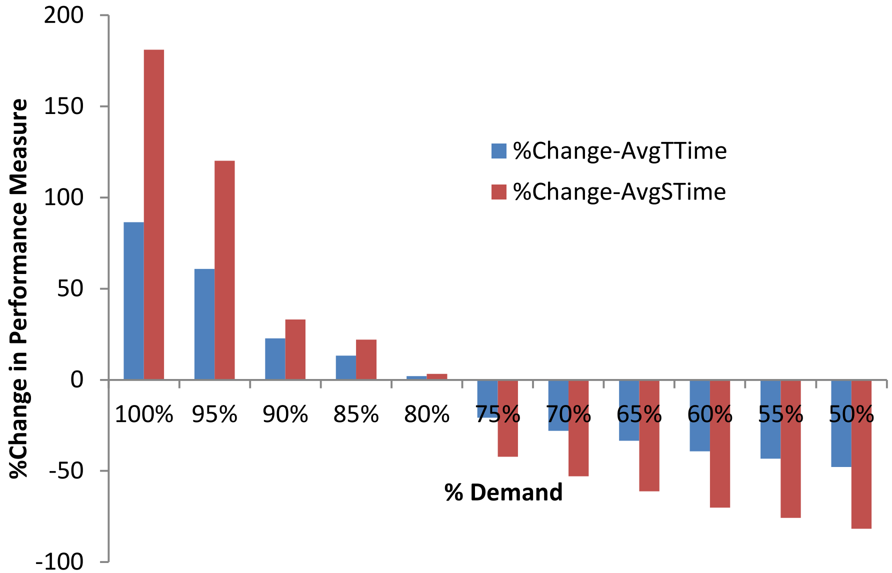
49-03.VMS2

Off-line Implementation (Salt Lake City)

- ## Demand Management
  - **Analysis Results**



(a) Time-dependent network throughput measure



(b) %Change in performance measures for different demand levels relative to base-case

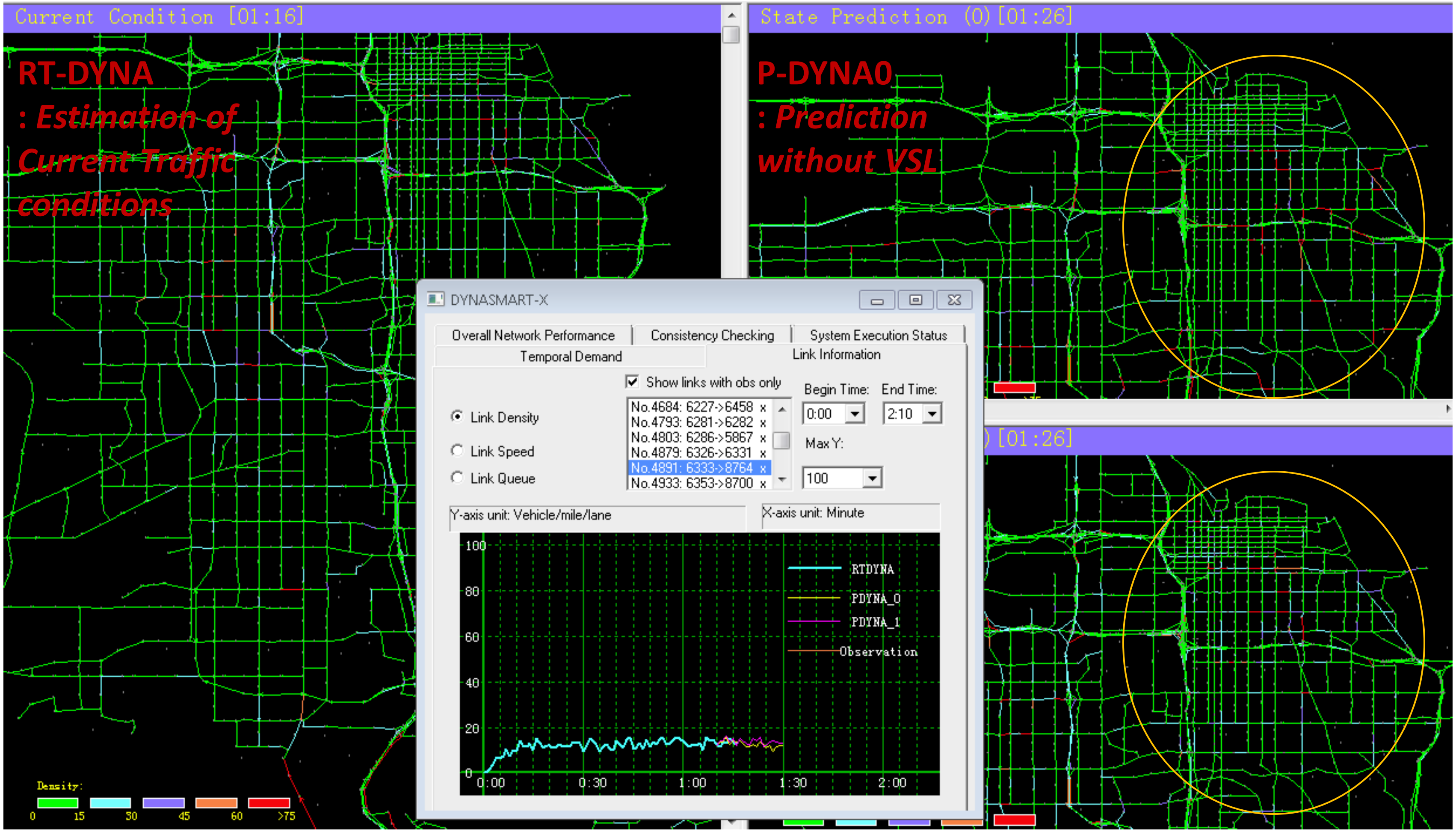
On-line Implementation (Salt Lake City)

- Target weather event :
  - Snow on April 6, 2012
- Before the event
  - Retrieved a set of VSL strategies from the WRTM strategy repository.
  - Performed the off-line simulation analysis to select the best strategy given the predicted weather scenario.
  - Selected VSL strategy
    - ➢ **Deploy VSL on Veterans Memorial Highway (Southbound)**

Selected VSL strategy under the given snow scenario

On-line Implementation (Salt Lake City)

At 7:16AM, predicted traffic states for 7:26AM



Current Condition [01:16]

RT-DYNA
: Estimation of Current Traffic conditions

State Prediction (0) [01:26]

P-DYNA0
: Prediction without VSL

) [01:26]

DYNASMART-X

☑ Show links with obs only

● Link Density
○ Link Speed
○ Link Queue

No.4684: 6227->6458 x
No.4793: 6281->6282 x
No.4803: 6286->5867 x
No.4879: 6326->6331 x
No.4891: 6333->8764 x
No.4933: 6353->8700 x

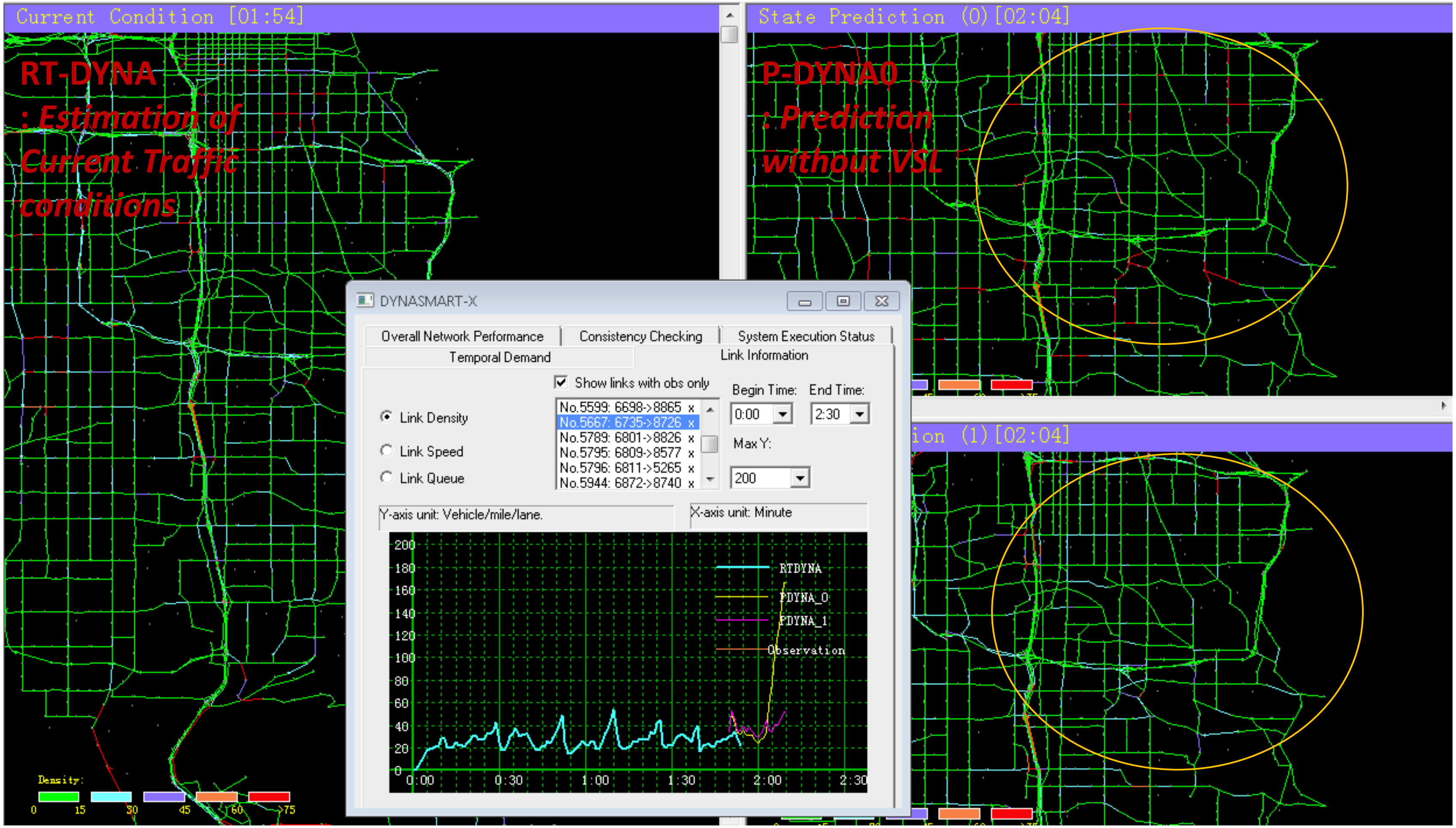
Begin Time: 0:00
End Time: 2:10
Max Y: 100

Y-axis unit: Vehicle/mile/lane
X-axis unit: Minute

P-DYNA1
: Prediction with VSL

On-line Implementation (Salt Lake City)

At 7:54AM, predicted traffic states for 8:04AM



Current Condition [01:54]

RT-DYNA
: Estimation of Current Traffic conditions

State Prediction (0) [02:04]

P-DYNA0
: Prediction without VSL

ion (1) [02:04]

DYNASMART-X

☑ Show links with obs only

● Link Density
○ Link Speed
○ Link Queue

No.5599: 6698->8865 x
No.5667: 6735->8726 x
No.5789: 6801->8826 x
No.5795: 6809->8577 x
No.5796: 6811->5265 x
No.5944: 6872->8740 x

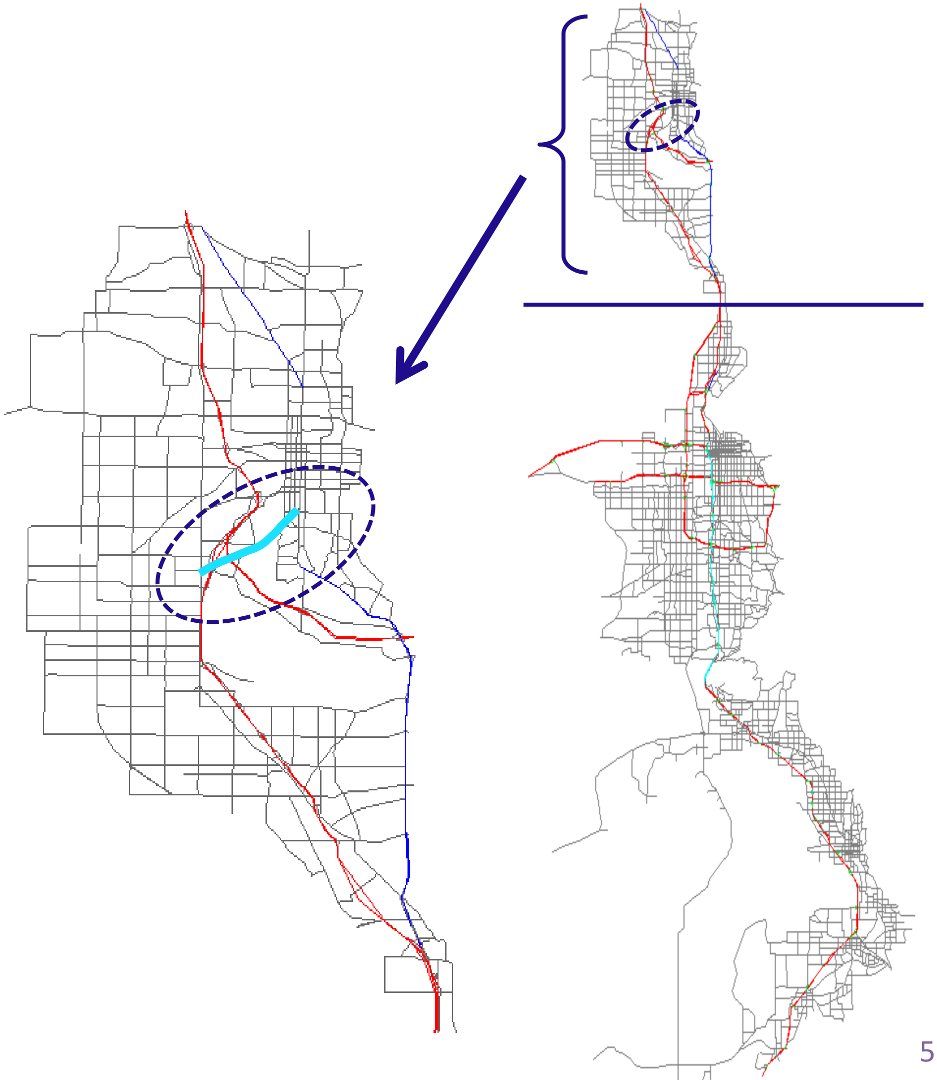
Begin Time: 0:00
End Time: 2:30
Max Y: 200

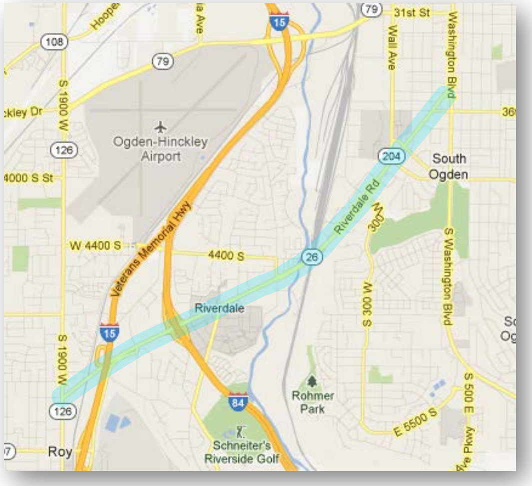
Y-axis unit: Vehicle/mile/lane.
X-axis unit: Minute

P-DYNA1
: Prediction with VSL

ONGOING PROJECT WITH FHWA and UDOT in Salt Lake City

Deploy and evaluate calibrated TrEPS for an arterial corridor(RIVERDALE) to support WRTM interventions, especially signal control strategies





VI.

Logistics Operations in Congested Urban Environments

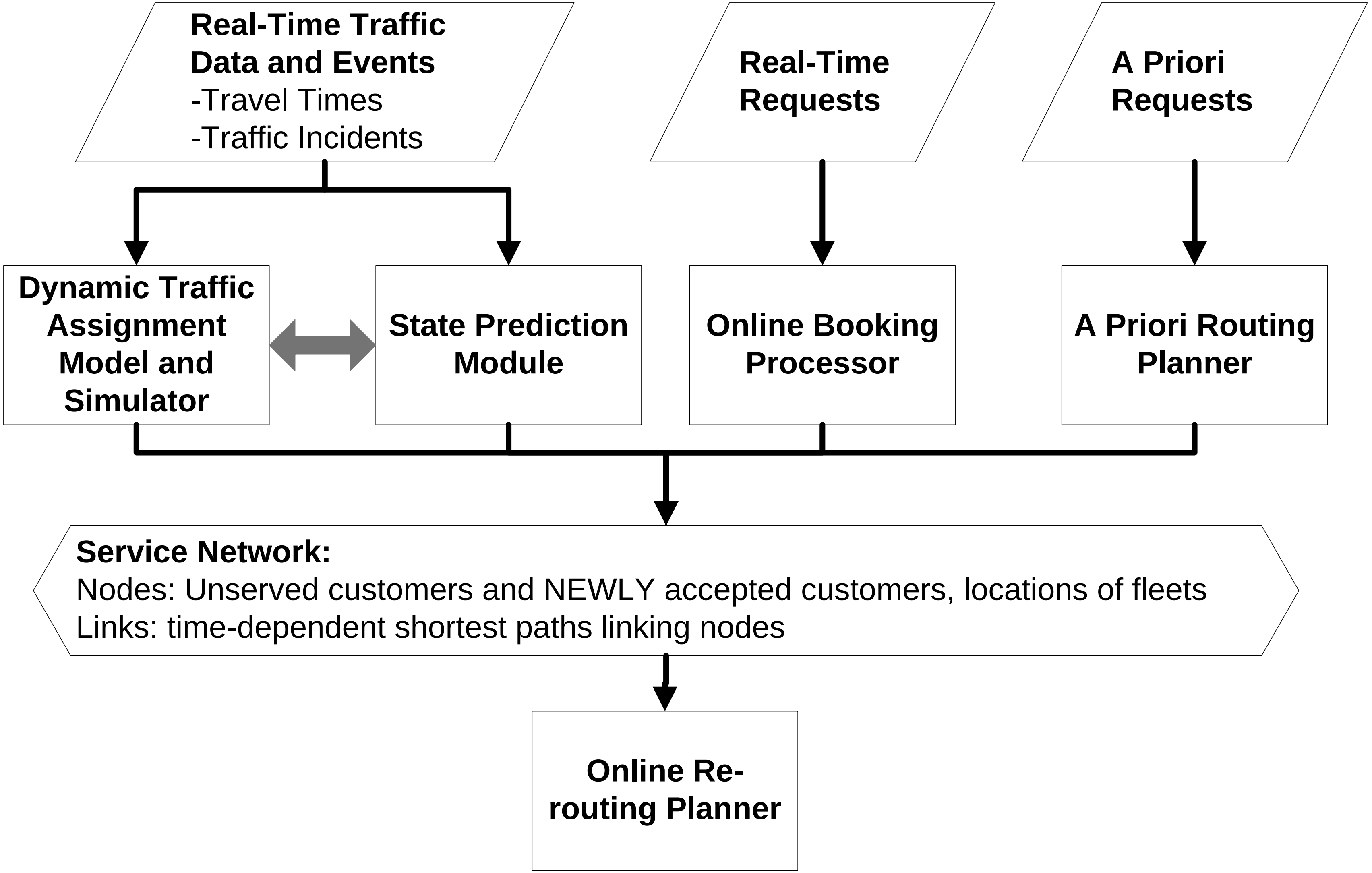
Challenges for City Logistics Carriers

- Deliveries in urban areas suffer from time-varying congestion, and various traffic events, such as lane-closure, accidents, construction, weather etc.
- Real time customer requests.
- Customers expect on-time deliveries within service time windows.

Research Objective

- To develop an integrated system which has the following features:
    - Capable of mapping real-life operational components into analytical VRP models.
    - Respond to real-time customer requests.
    - Consider traffic variations on road networks (including effect of weather, incidents, special events, etc...)
    - Applicable to problems of practical sizes.

Overall Architecture



Real-Time Traffic Data and Events
-Travel Times
-Traffic Incidents

Real-Time Requests

A Priori Requests

Dynamic Traffic Assignment Model and Simulator

State Prediction Module

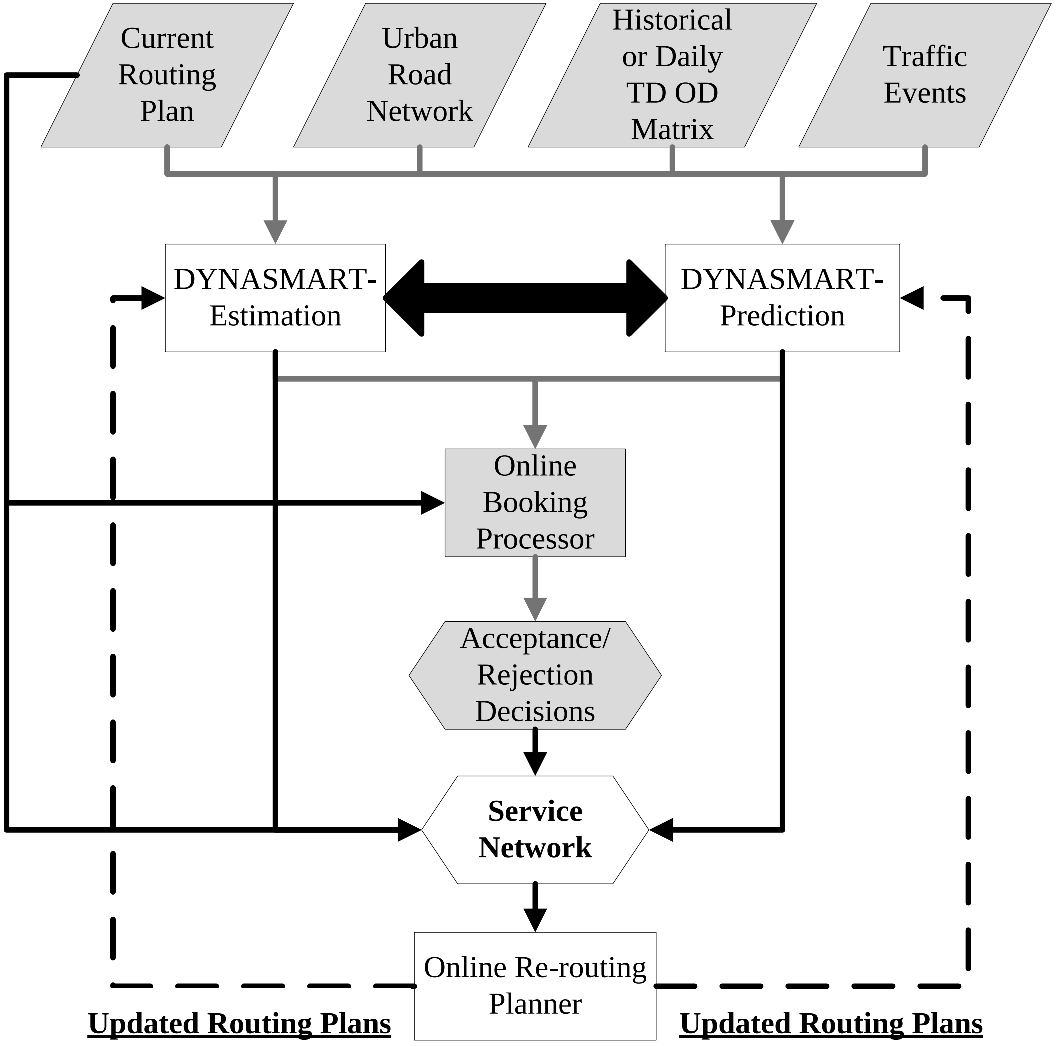
Online Booking Processor

A Priori Routing Planner

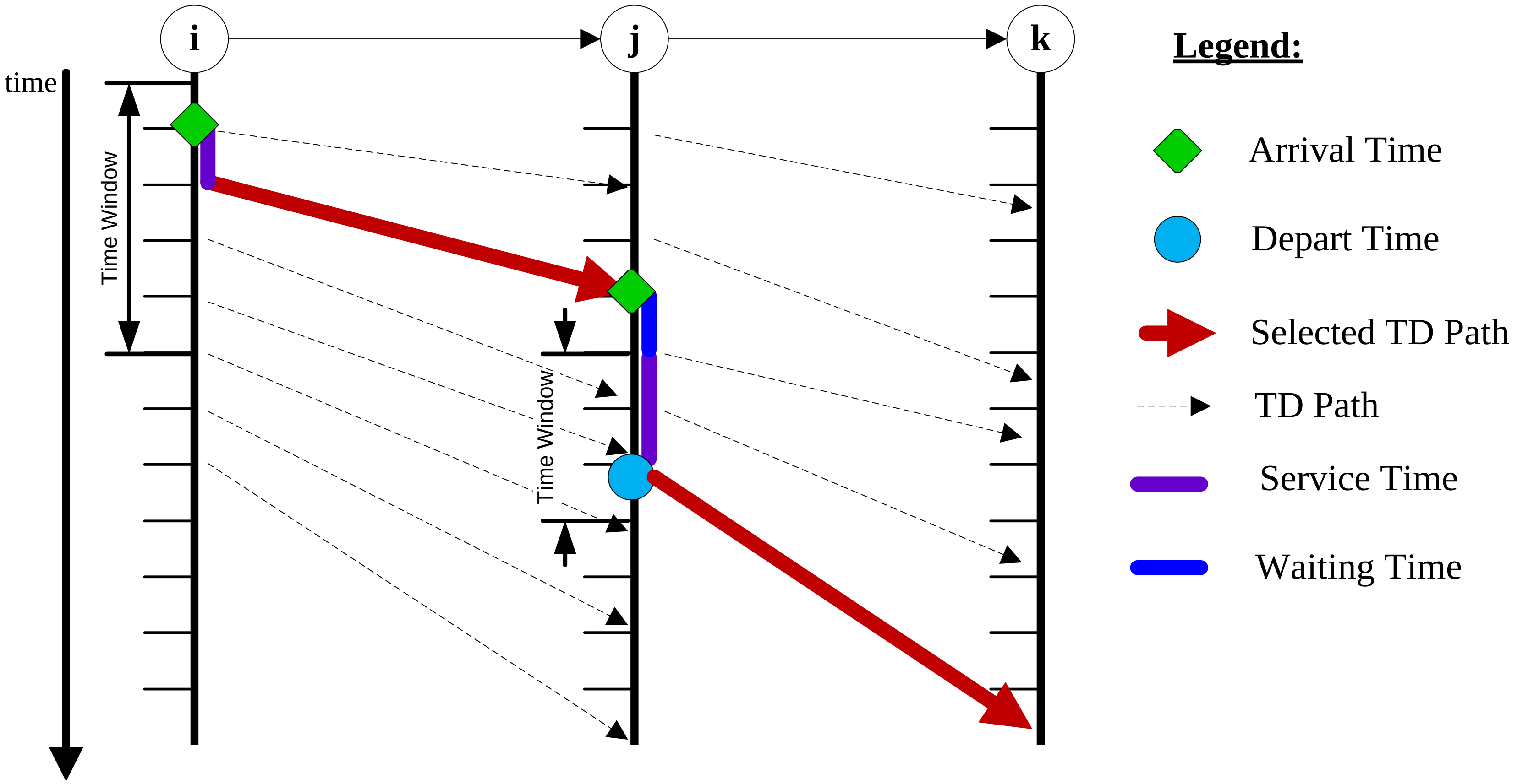
Service Network:
Nodes: Unserved customers and NEWLY accepted customers, locations of fleets
Links: time-dependent shortest paths linking nodes

Online Re-routing Planner

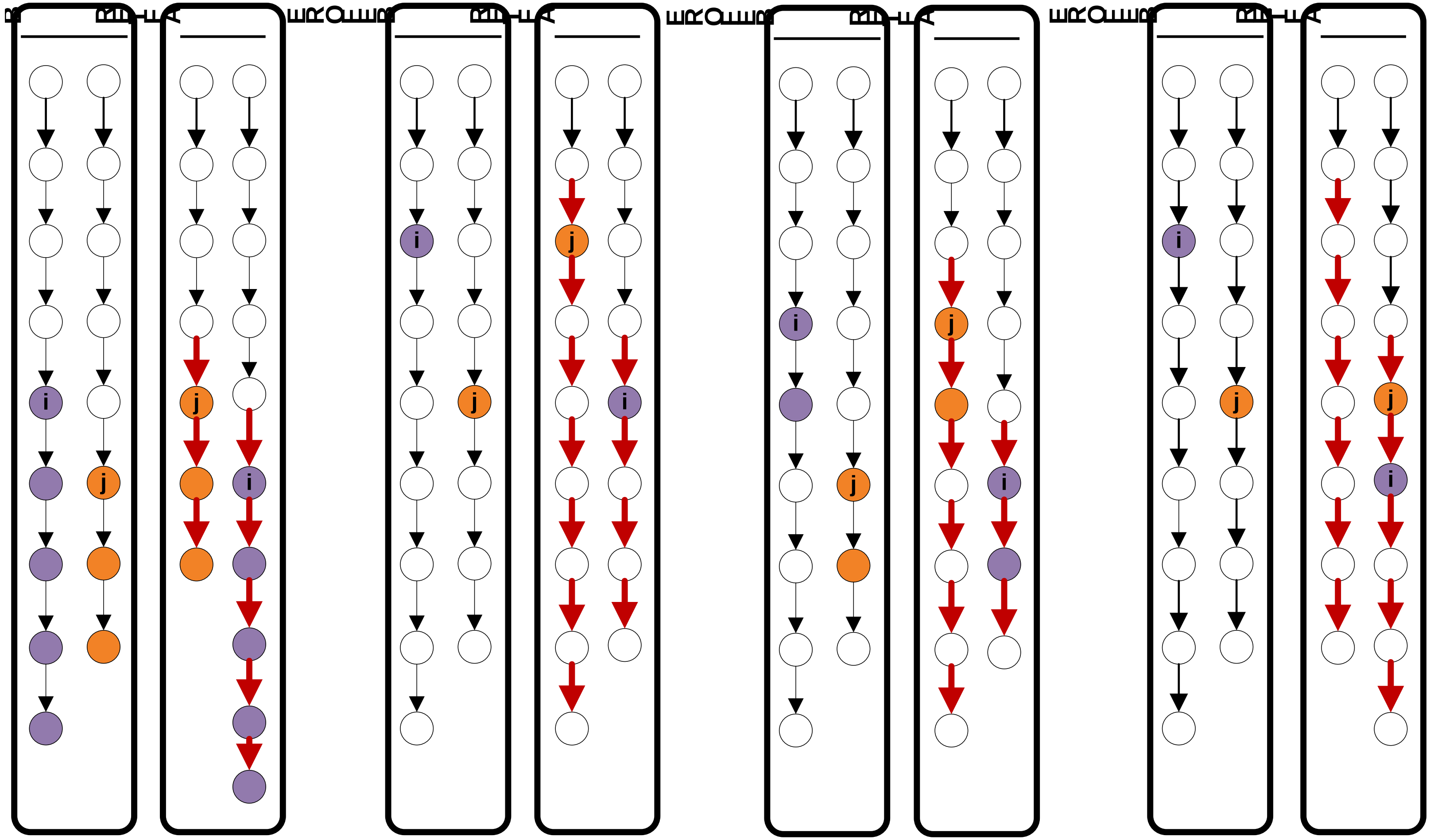
Online Booking Processor & Re-routing Planner



An Illustration of VRP with TDTT

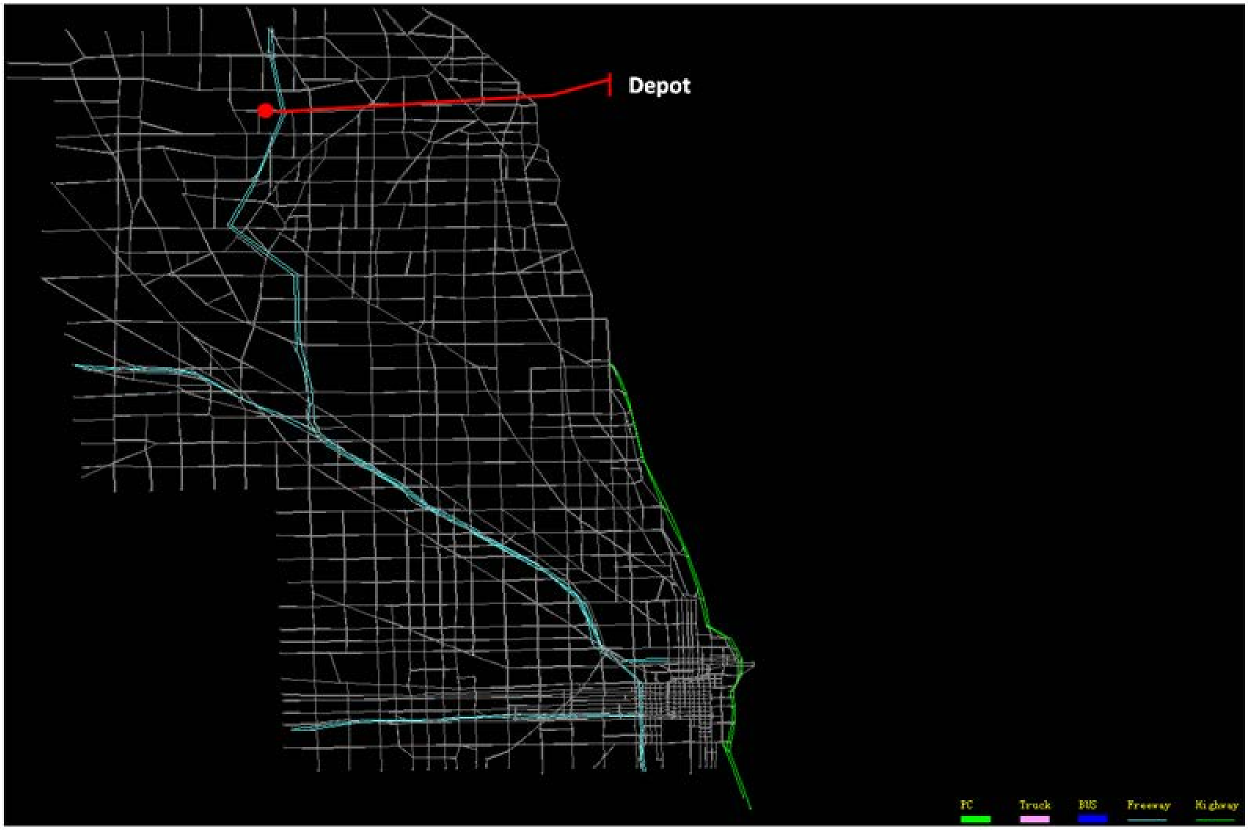


Heuristic Algorithm: Local Search Operators



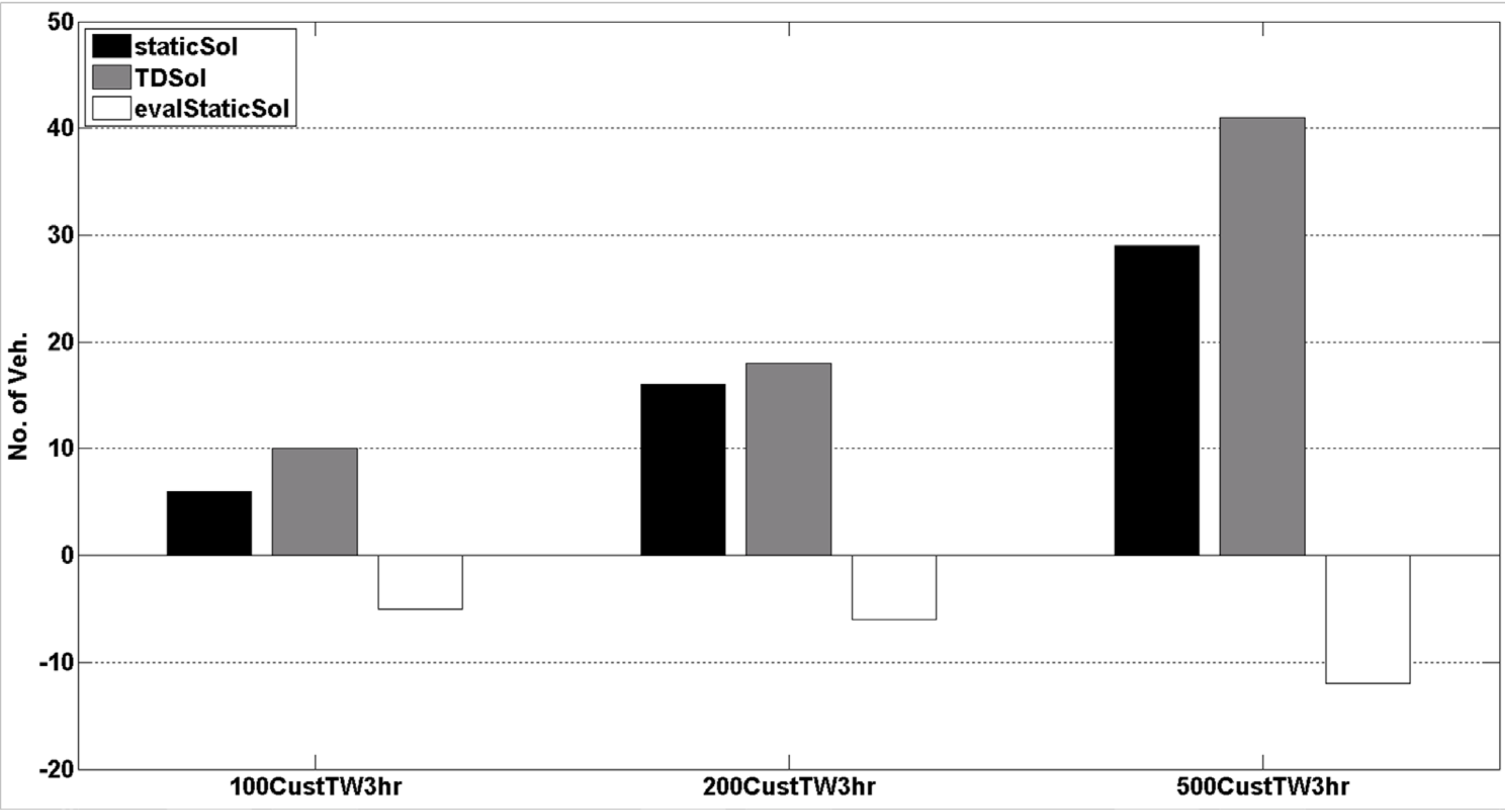
a) 2-opt*　b) Exchange　c) Segment Exchange　d) Insertion

Case Study: Chicago Network



- Nodes: 1,578
- Links: 4,805
- TAZ: 218
- TD OD: 16hr (5am-9pm), ~1.6mil vehicles

Numerical Results: Feasibility



VII.

Takeaways

PREDICTION essential in real-time traffic management and urban logistics

Considerable opportunities: new sources of personal information, emerging technologies

Computational challenges remain

User behavior: will remain moving target, because users will adapt hence need for adaptive schemes

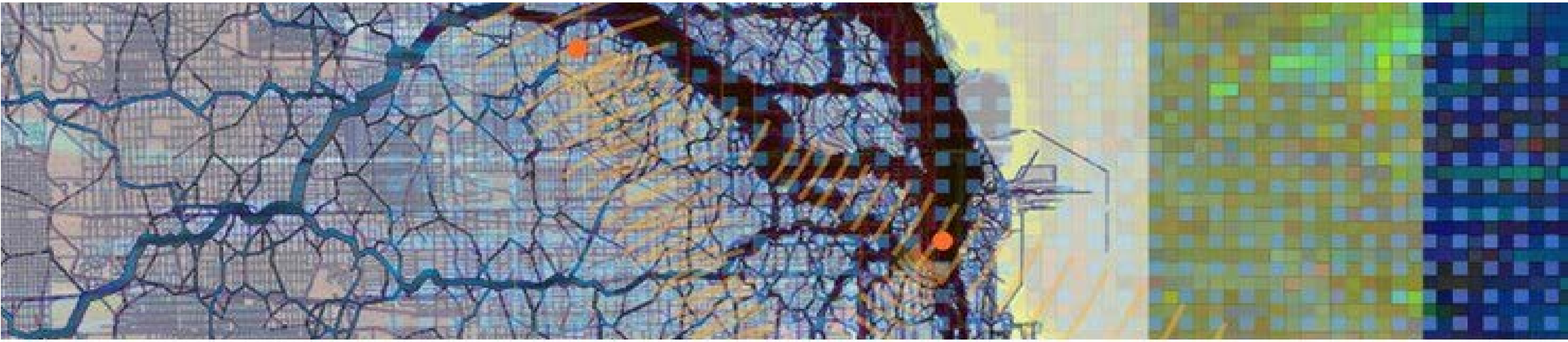
Growing role of private sector as business models become more compelling

THE SWEET SPOT FOR SYSTEM MANAGEMENT

Leverage system state information and individual characteristics (and preferences) in generating interventions that are

- dynamic (timely)
- localized (consider network and non-network factors)
- anticipatory (consider predicted events and system evolution)
- adaptive (learn about individual responses and system impacts)
- distributive (across modes, times of day, user groups)
- economically efficient (e.g. consider value of time distribution)

Thank you



Smarter Cities/Smarter Mobility