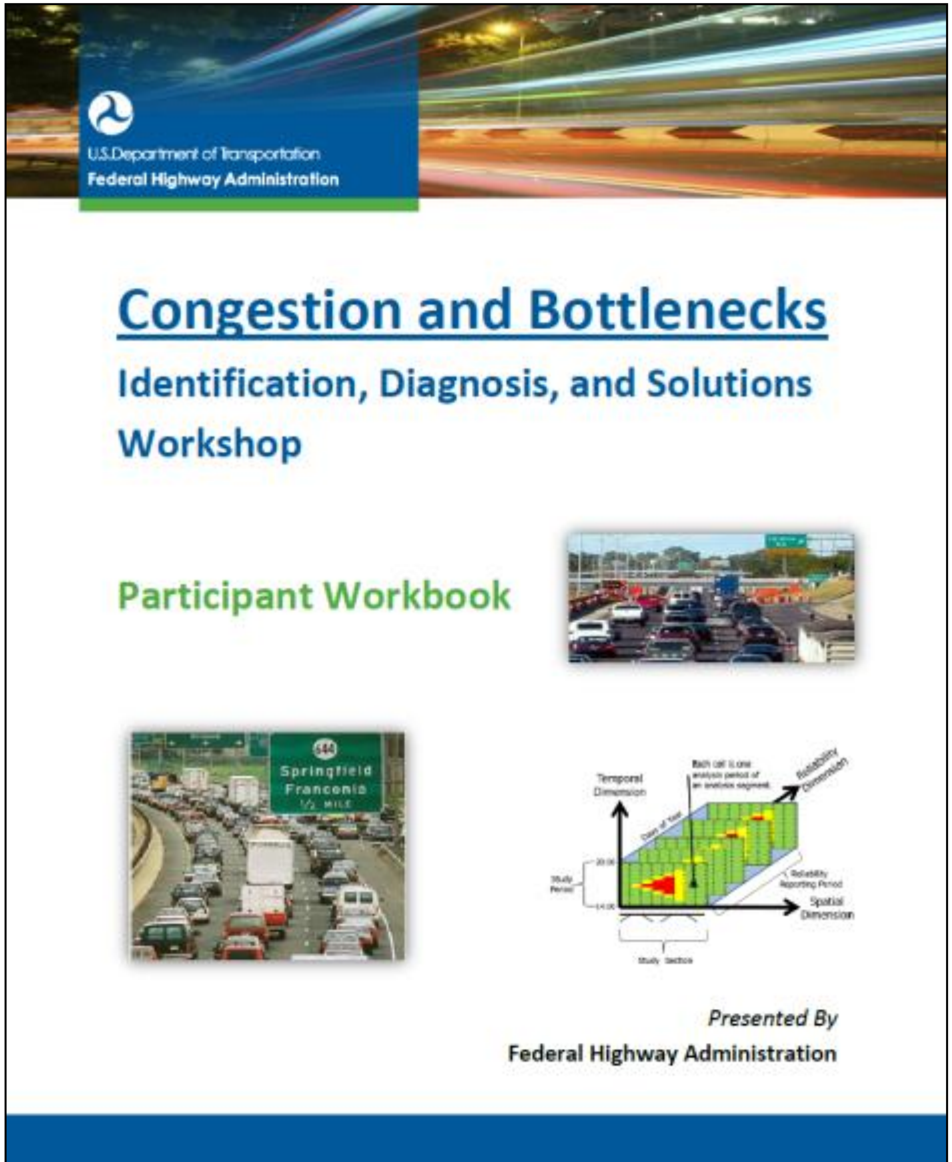
Traffic Congestion and Bottlenecks

Identification, Diagnosis, Solutions

U.S. Department of Transportation
FEDERAL HIGHWAY ADMINISTRATION

Workshop Overview



U.S. Department of Transportation
Federal Highway Administration

Congestion and Bottlenecks

Identification, Diagnosis, and Solutions Workshop

Participant Workbook

Presented By
Federal Highway Administration

ACKNOWLEDGMENTS

This workshop on congestion and bottlenecks is sponsored by the Federal Highway Administration. Thank you for your participation in the course. An evaluation form is included within this workbook, to obtain your feedback. Please forward any additional comments to:

Project Leader Contact Information:

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Workshop Overview

- Session One (70-90 min)
  - Workshop Overview (David Hale, Leidos)
  - Congestion and Bottleneck Concepts (Neil Spiller, FHWA)
  - Congestion and Bottleneck Identification (David Hale, Leidos)
- Break (15 min)
- Session Two (70-90 min)
  - Congestion Causal Pie Chart (Jiaqi Ma, Leidos)
  - Bottleneck Mitigation Strategies (Joe Bared, FHWA)

Workshop Overview

Evaluation

CONGESTION AND BOTTLENECK WORKSHOP

Location: ____________________ Date: ______________

Items will be rated on a scale ranging from 1 to 7 defined as follows:

1	2	3	4	5	6	7
Poor	Well Below Average	Below Average	Below Average	Good	Very Good	Excellent

Please circle the numbers below which reflect your ratings.

1. Do you feel that the objectives of this course were met? Yes ____ No ____

Comments: ____

2. Supervision and planning of the seminar or workshop was:

1	2	3	4	5	6	7
Poor			Average			Excellent

Comments: ____

3. Overall presentation was:

1	2	3	4	5	6	7
Poor			Average			Excellent

Comments: ____

4. Physical facilities were:

1	2	3	4	5	6	7
Poor			Average			Excellent

Comments: ____

5. Was the material generally presented at the correct level for this group?

Yes ___ No ___

Comments: ____

6. The course visual materials were:

1	2	3	4	5	6	7
Poor			Average			Excellent

Comments: ____

7. Overall value of the seminar or workshop to you, in your own words.

____

8. Suggestions for improvement.

____

9. What is your job title? ____________________

10. Employed by? Government __ University __ Private __

Traffic Congestion and Bottlenecks

- Self-introductions
  - Name
  - Company
  - Reason for interest in workshop (optional)

SAXTON LABORATORY
Driving Future Highways

U.S. Department of Transportation
Federal Highway Administration

Traffic Congestion and Bottlenecks

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FEDERAL HIGHWAY ADMINISTRATION

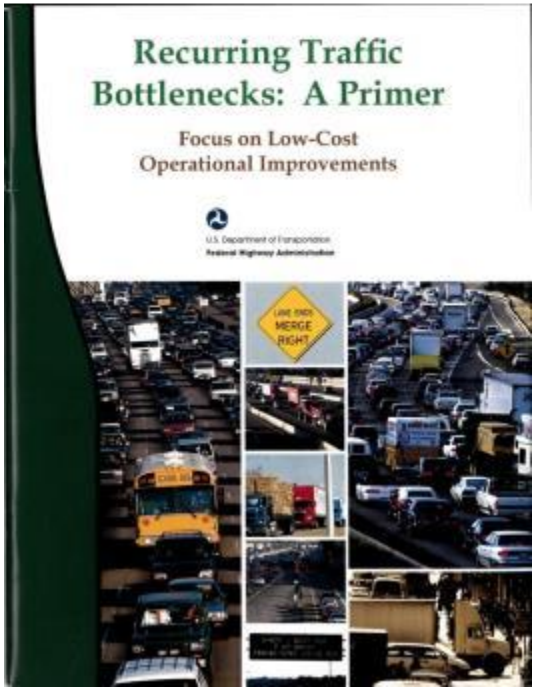
Workshop is Sponsored by

SAXTON LABORATORY
Driving Future Highways

The Saxton Laboratory is located at the
FHWA Turner-Fairbanks Research Center in McLean, VA.

- Comprised of three test beds:
  - Data Resources test bed (DRT),
  - Concepts and Analysis test bed, and
  - Cooperative Vehicle-Highway test bed (CVHT).

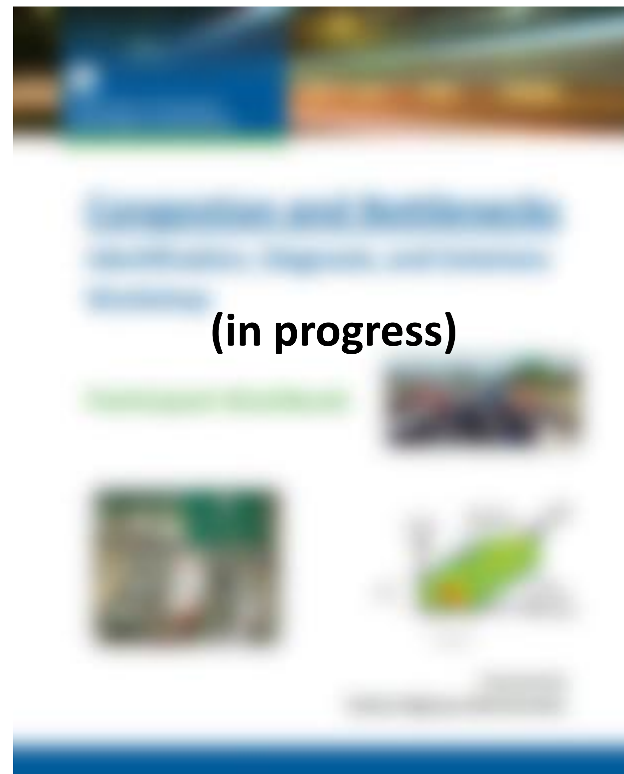
FHWA “Localized Bottleneck Reduction” Program



FHWA BN Program
2006-2012

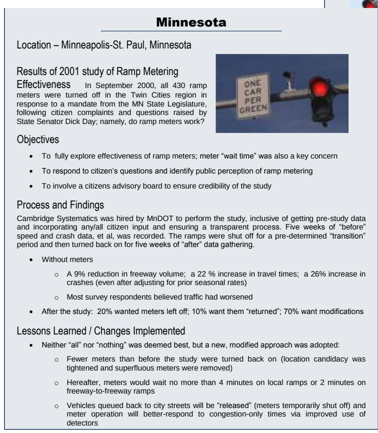
(Primer: c. 2012 Version 3)

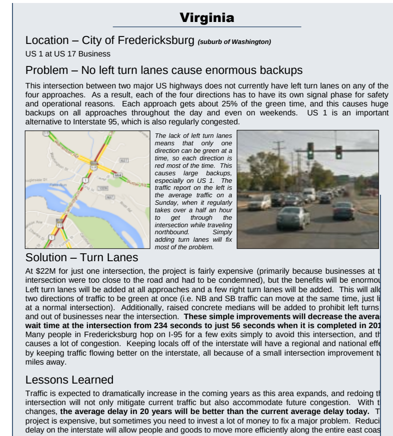
FHWA BN Analysis
2013-2015

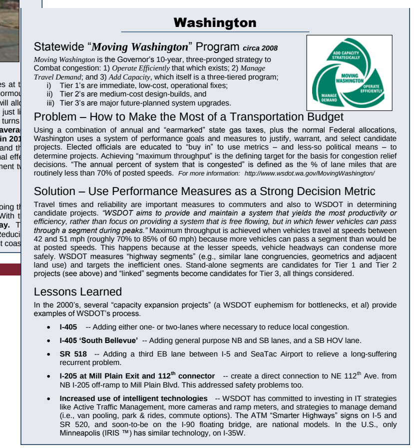


(in progress)

FHWA "Localized Bottleneck Reduction" Program







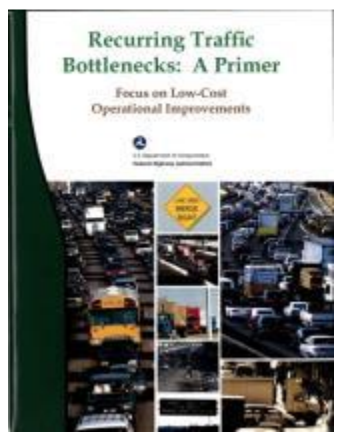
Case Studies

Real-World, Low-Cost!

Understanding Merging

"Why is recurring traffic like "cat herding?"

What is stopping us from fixing bottlenecks?



"(Combating) traffic is like combating ever-evolving weather fronts"

Are you a "profiteering" lane merger or an "altruistic" enabler?

ops.fhwa.dot.gov/bn/index.htm

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Problem Statement

- U.S. traffic congestion is worsening, and the resulting economic damages are increasing
- A TTI report suggests that vehicle emissions are accelerating economic damages by causing short-term and long-term health issues (asthma, lung cancer, climate change) on top of traditional mobility-based economic costs
- There is decreasing reliability of surface transportation because studies show it takes more time to ensure on-time arrival/delivery/reliability.

Problem Statement

- Tight budgets for transportation
- Autonomous vehicles are not yet ready
- Agencies must demonstrate return-on-investment
- Mitigation of bottlenecks is a top priority
- This workshop
  - describes new methods of precise congestion identification
  - updates the congestion causal pie chart
  - presents new research on bottleneck mitigation

Workshop Overview

We will cover:

1. Congestion and bottleneck concepts
2. Congestion and bottleneck identification methods
3. Modernized causes of congestion pie chart
4. Featured bottleneck mitigation strategies

This Session

1. **Congestion and bottleneck concepts**
2. Congestion and bottleneck identification methods
3. Modernized causes of congestion pie chart
4. Featured bottleneck mitigation strategies

Difference between . . .

- Nonrecurring
  - When an *event* occurs (*The delay dissipates when the event is removed)*
- Recurring
  - *"Bottleneck" -- When an operational influence is overwhelmed by traffic overburden (The delay dissipates when the overburden subsides)*
  - *"Systemic" -- overarching; urban density; pervasive (Can be reduced by reducing demand on automobile trips)*

---

event = weather, accident, incident, work zone

operational influences = on/off ramps, merges, lane drops, curves, traffic signals, junctions, narrow underpasses

“Congestion” vs “Bottlenecks”

A “bottleneck is congestion” but “congestion” is often-times more than just a bottleneck.

Speaking of “Recurring” congestion --

When too many vehicles compete along all segments of a facility, "congestion" will inevitably result, and is overarching. But when only determinant, subordinate segments of that facility are routinely over taxed, then "operationally recurring bottlenecks" within the facility are said to exist.

Speaking of “Nonrecurring” congestion – the event-based problem is temporary and therefore is usually termed “an incident” and not pervasive “congestion”

Defining Bottleneck Congestion

" Localized sections of highway where traffic experiences reduced speeds and delays due to recurring operational conditions or nonrecurring traffic-influencing events"

- Characterized by generally low speeds, high delays
- Measured differently by planners, engineers, academics
- All BN's have **D**uration, **I**ntensity, **V**ariability, Extent (DIVE)
- Congestion occurs pervasively along entire corridor
- *Recurring* bottlenecks repeat at specific locations
  - Cause 40-80%(?) of all congestion
  - Caused by "operational influence" + traffic overburden
  - Can often be mitigated with low-cost solutions

D. I. V. E.

- Duration
  - ❑ How long did the event last?
- Intensity
  - ❑ Computed as a 2-D percentage of congestion
- Variability
  - ❑ Percentile difference between that day and a “nominal” day
- Extent
  - ❑ Longest horizontal length of the BN

D. I. V. E. exists regardless of whether recurring or nonrecurring

Spatiotemporal Traffic Matrix (STM)

“Measurements” versus “Models”

INRIX → STM ← HCM

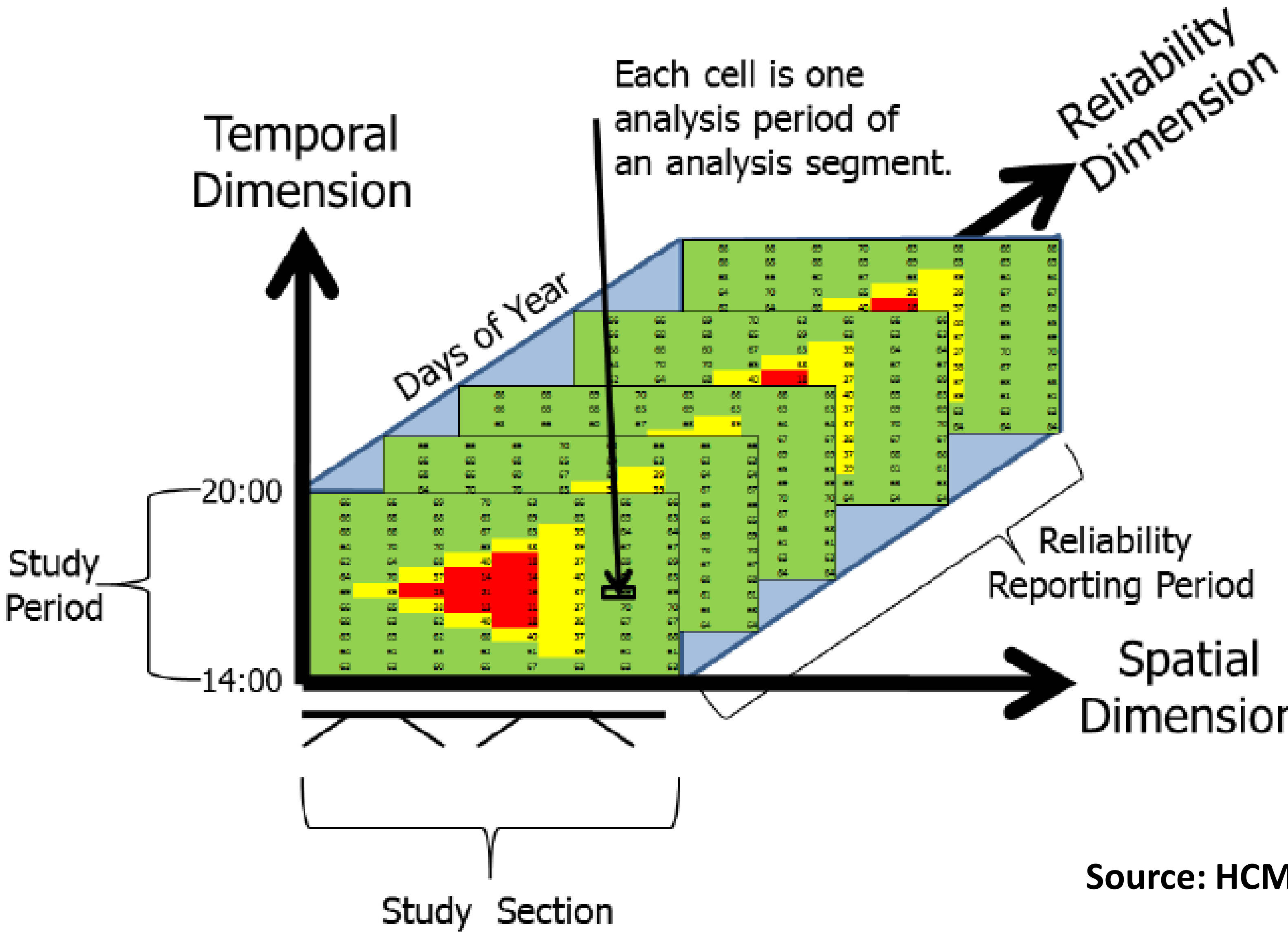
STM ↓

1. Duration
2. Intensity
3. Variability
4. Extent

Performance Measures

Prioritize Locations

Spatiotemporal Traffic Matrix (STM)



Source: HCM 2010

Bottleneck Solutions

- Solutions “playbook”
  - Developed by Texas A&M, Cambridge Systematics
  - Framework with 7 bottleneck categories
  - Each category has many proposed solutions
  - Report appendix (40 pages) details all 70 solutions
- Micro-simulation and benefit-cost analysis
  - 5 promising cost-effective solutions
- Alternative intersections/interchanges (DDI, RCUT, MUT, DLT)
- Additional innovative treatments (Spring 2015)

Bottleneck Solutions

Geometric Fixes

- widen
- lengthen
- grade-separate
- CF intersections
- roundabouts
- auxiliary lanes
- restripe

Operational Fixes

- reversible lanes
- signal modifications
- signal redesign
- frontage system
- close, combine or relocate a ramp(s)

Active Traffic Mgmt.

- ramp metering
- use hard shoulders
- speed harmonization
- managed lanes
- variable speed limits
- queue jumps
- signal priority

Overlap . . .

- access management
- redesign
- restore lane continuity

Active Bottleneck

Geometric Challenges				Operational Challenges		
Roadway Specific	**Facility Specific**	**Specific to Interchanges**	**Intersections /TCD/ITS**	**Agency Related**	**Driver Related**	**Non-motorist Related**
1. Design Speed 2. Number of Lanes 3. Lane Width 4. Presence and Type of shoulders 5. Lane drops 6. Lane reduction transition 7. Hz clearance 8. Vl clearance 9. Sun Glare Alignment 10. Hz alignment 11. Vl alignment 12. SSD 13.Pavement friction/surface 14. Cross Slope 15. Super-elevation 16. Access pts 17.Mid-block Crossing 18. Medians 19. Lighting/Glare	1. Bridges 2. Tunnels and underpass 3. Collector-distributor network	1. Merge and diverge sections 2. Auxiliary lanes 3. Weaving areas 4. On-ramp/off-ramp 5. Acceleration/ deceleration lanes	1. Intersection sight distance 2. Left-turn and Right-turn lane overflow 3. Parking 4. TCD (signal, stop sign, etc.)	1. Managing demand 2. Intersection spacing 3. Interchange spacing 4. Policy on entry/exit ramp placement 5. Posted speed limit (static/dynamic) 6. Signal timing administration 7. Traffic composition 8. Work zone 9. Roadway closure administration 10.Incident management and clearance 11.Ramp metering 12.Heavy vehicle lane restrictions	1. Bunching vehicle 2. Roadside distraction/rubbernecking 3. Non-roadside distractions 4. Unsafe vehicle condition for weather condition 5. Aggressive lane change/weaving 6. Driving unauthorized roadway section 7. Driver performance in work zone 8.Driver performance when involved in an incident	1. Sub-optimal peds and bicyclist performance

10. Sub-optimal Driver Performance with regard to emergency vehicles

a. **Description/Definition of the Element**

   i. Drivers may slow down and/or get distracted when they hear emergency vehicle sirens, but cannot locate the direction the vehicle is coming from.

   ii. Drivers may slow down *below* the design speed limit when they are traveling near a law enforcement vehicle, even if the vehicle is not responding to an emergency.

b. **Theoretical/Empirical Effects:** Drivers who do not move over or are slow to move over can slow emergency services.

c. **Existing Solutions**

   i. Emergency Vehicle Preemption (EVP) - uses "special control features in traffic signals to provide clear guidance on whether autos should stop (providing a red display) or go (providing a green display) at signalized intersections during the approach of Emergency Vehicles (EVs). In these systems, ITS systems attempt to reduce the "surprise" factor, which may cause drivers to make bad decisions or perform poorly. The benefit of the ITS is the change in the performance of the traffic flow as a result of improved driver behavior."[clxvii]

   ii. Larger Shoulders for vehicles to pull over.

   iii. Properly timed signals that coordinate with emergency vehicles

   i. Sirens that can be heard consistently rather than when the vehicle is right behind you.

   ii. Enforcement and stricter penalties for non-compliance

d. **New Solutions**

   i. Interaction with ITS and personal GPS devices as well as automated vehicle guidance systems to alert drivers ahead of time

Summary

- Traffic congestion is worsening
  - Economic damage, vehicle emissions, decreasing reliability
- Tight budgets for transportation
- Connected/autonomous vehicles not ready
- Agencies must show return on investment
- Need precise identification of bottlenecks
- Bottleneck mitigation strategies
  - Mobility analysis, benefit-cost analysis

Preview – Next Session

1. Congestion and bottleneck concepts
2. **Congestion and bottleneck identification methods**
3. Modernized causes of congestion pie chart
4. Featured bottleneck mitigation strategies

Congestion and Bottleneck Identification

Identification, Diagnosis, Solutions

U.S. Department of Transportation
FEDERAL HIGHWAY ADMINISTRATION

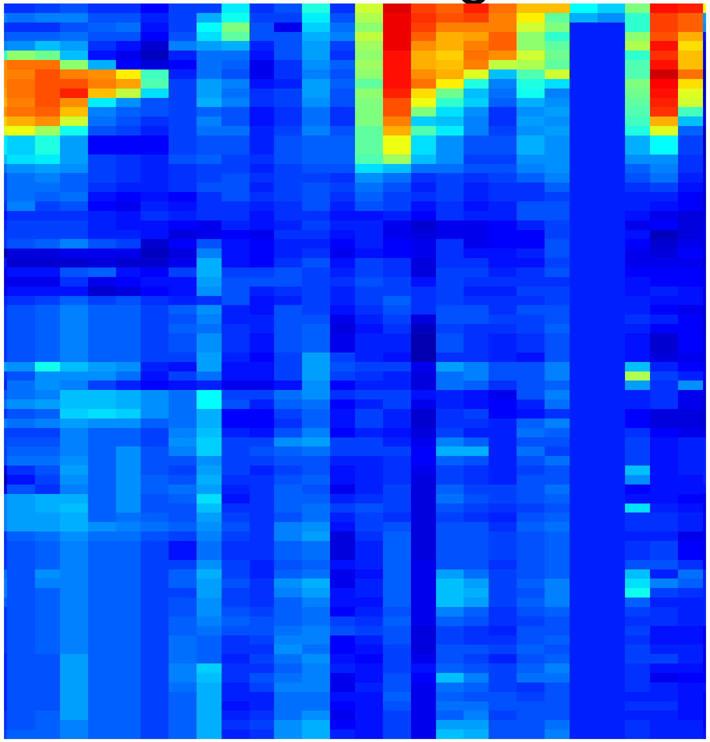
Workshop Overview

1. Congestion and bottleneck concepts
2. **Congestion and bottleneck identification methods**
3. Modernized causes of congestion pie chart
4. Featured bottleneck mitigation strategies

Introduction

- Space-time matrix (STM) helps identify congestion
- Several colors represent several speed levels
- A simpler (two-color) matrix could identify bottlenecks
  - Blue = uncongested, red = congested

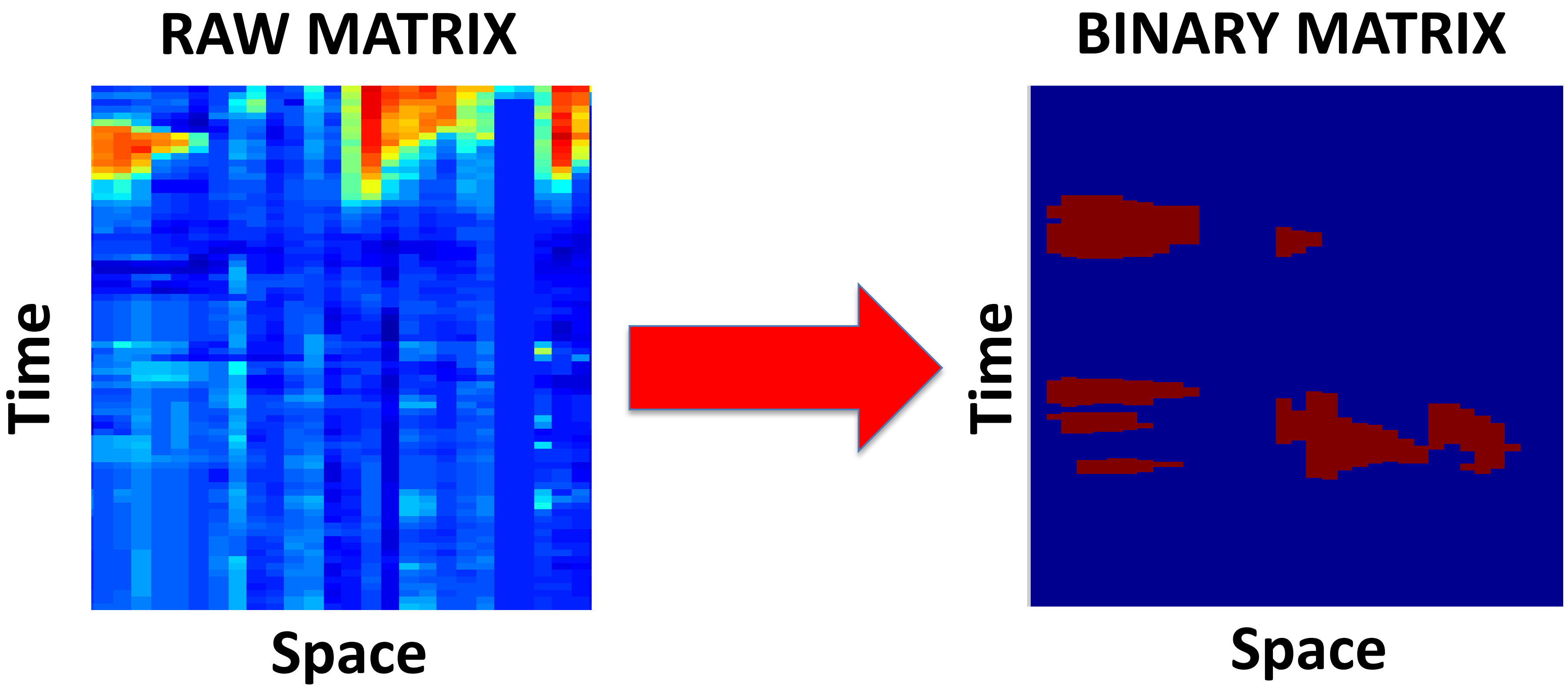
Time



Space

Introduction

- Cut-off speeds can convert raw matrix to binary matrix
  - Blue = uncongested, red = congested



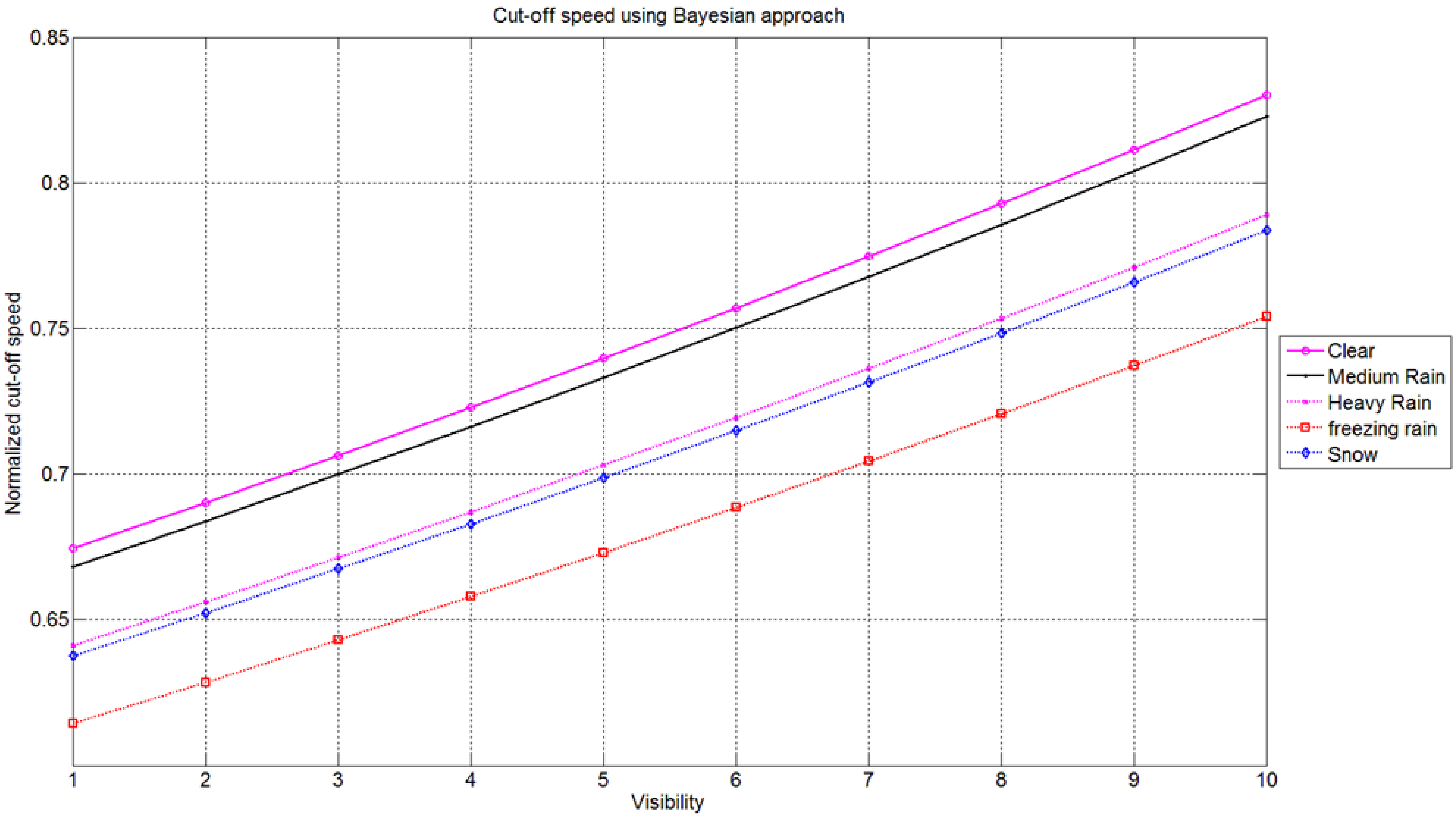
Factors Affecting Cutoff Speed

- Arterial vs. Freeway
  - Arterials have lower cut-off speeds
  - 45 mph considered slow on freeway?
  - 25 mph considered slow on arterial?
- Urban vs. suburban
- Free-flow speeds (or posted speed limits)
- Work zones
- Weather conditions, visibility levels
  - VTTI algorithm computes cut-off speeds
  - accounts for weather, visibility, and free-flow speed

Cutoff Speed Model Development

- Based on INRIX data from VA, CA, and TX
  1. 2011~2013 data along I-66 eastbound
  2. 2012 data along US-75 northbound
  3. 2012 data along I-15 southbound

Cutoff Speed Model



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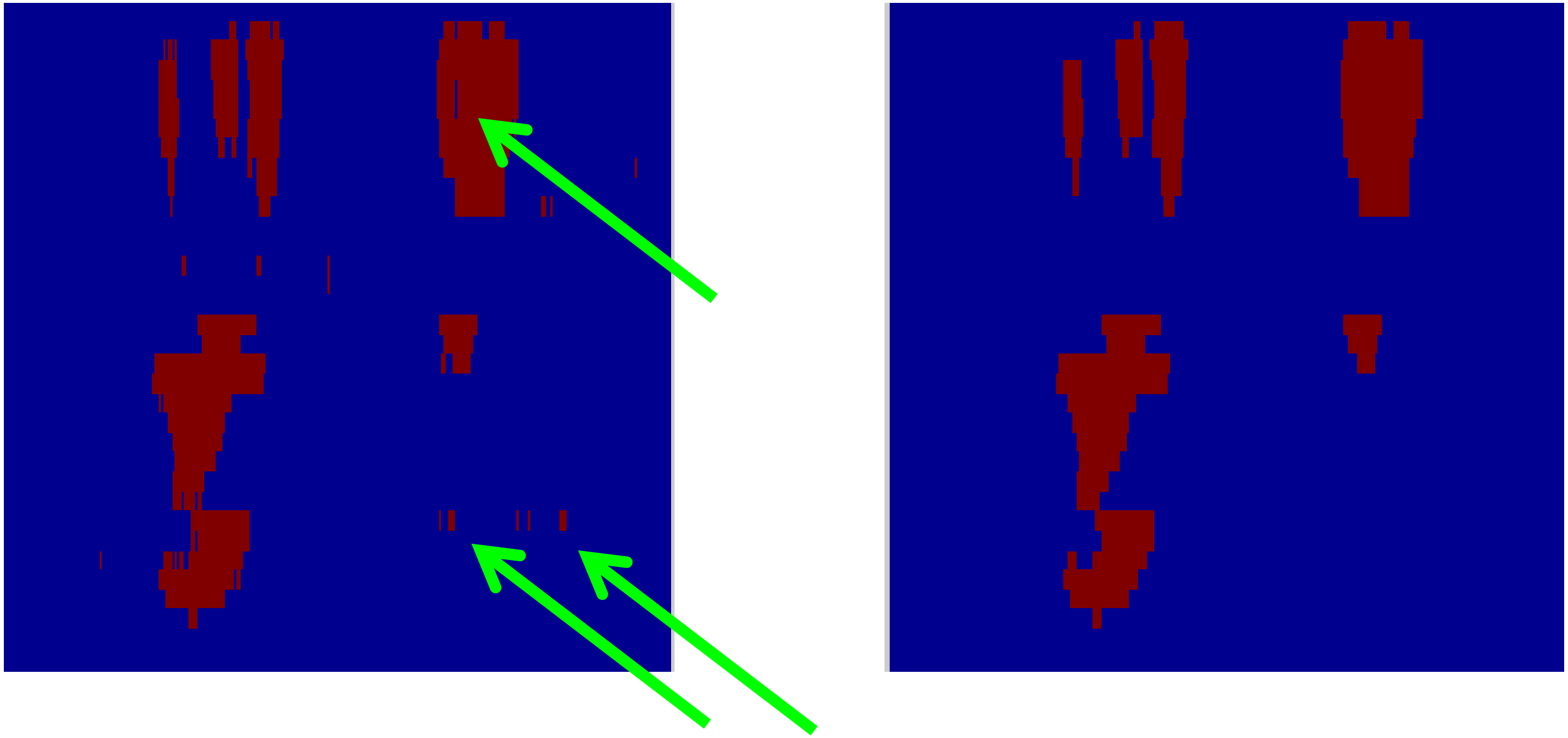
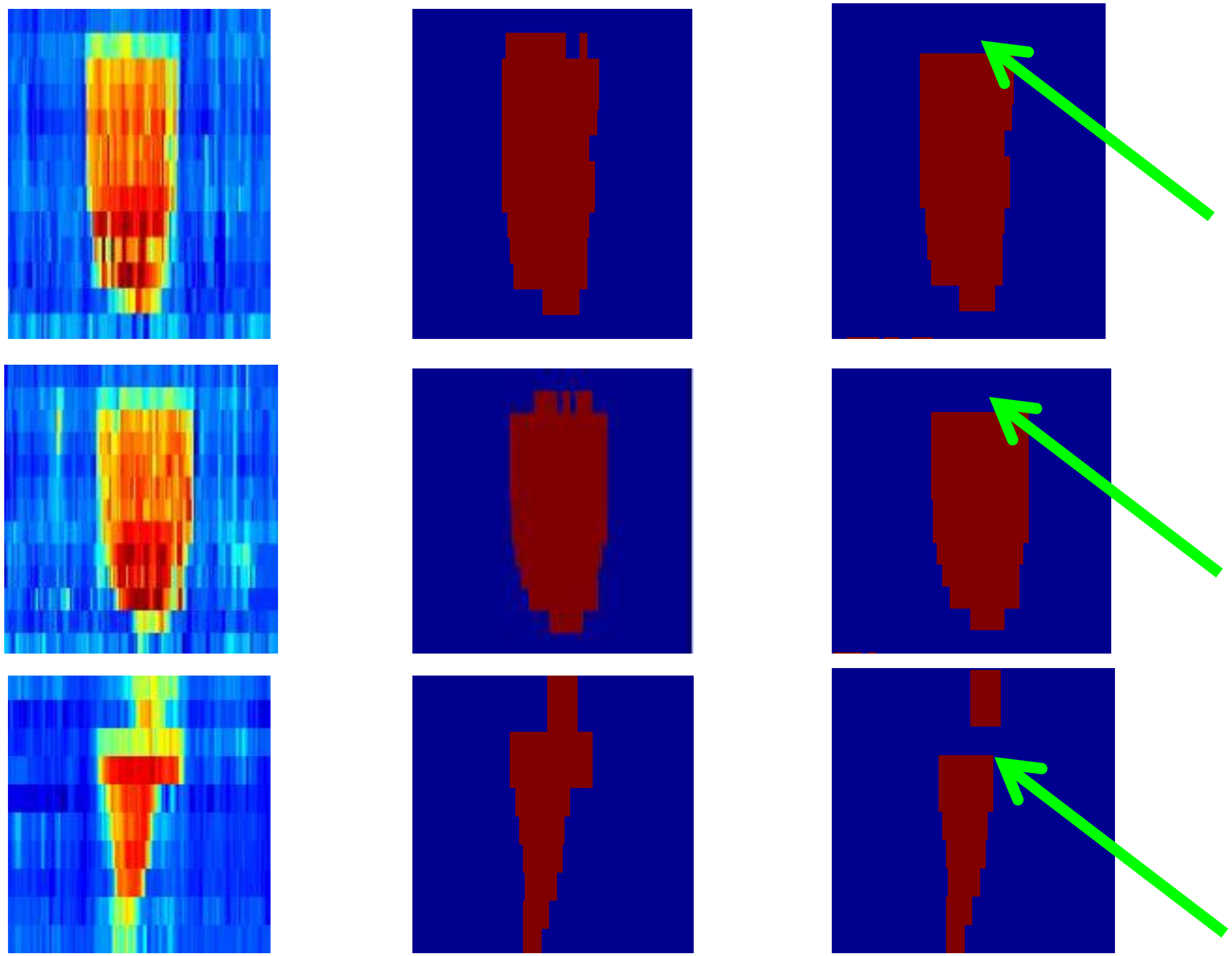
Bottleneck Matrix Processing

- Eliminate “noise”
- Fill in missing data



Bottleneck Matrix Processing



Speed matrix | before removing acceleration area | after removing acceleration area

Bottleneck Matrix Processing

- "Delay caused by bottleneck" calculation
  - For segment i at time interval t, need actual speed, and free-flow speed

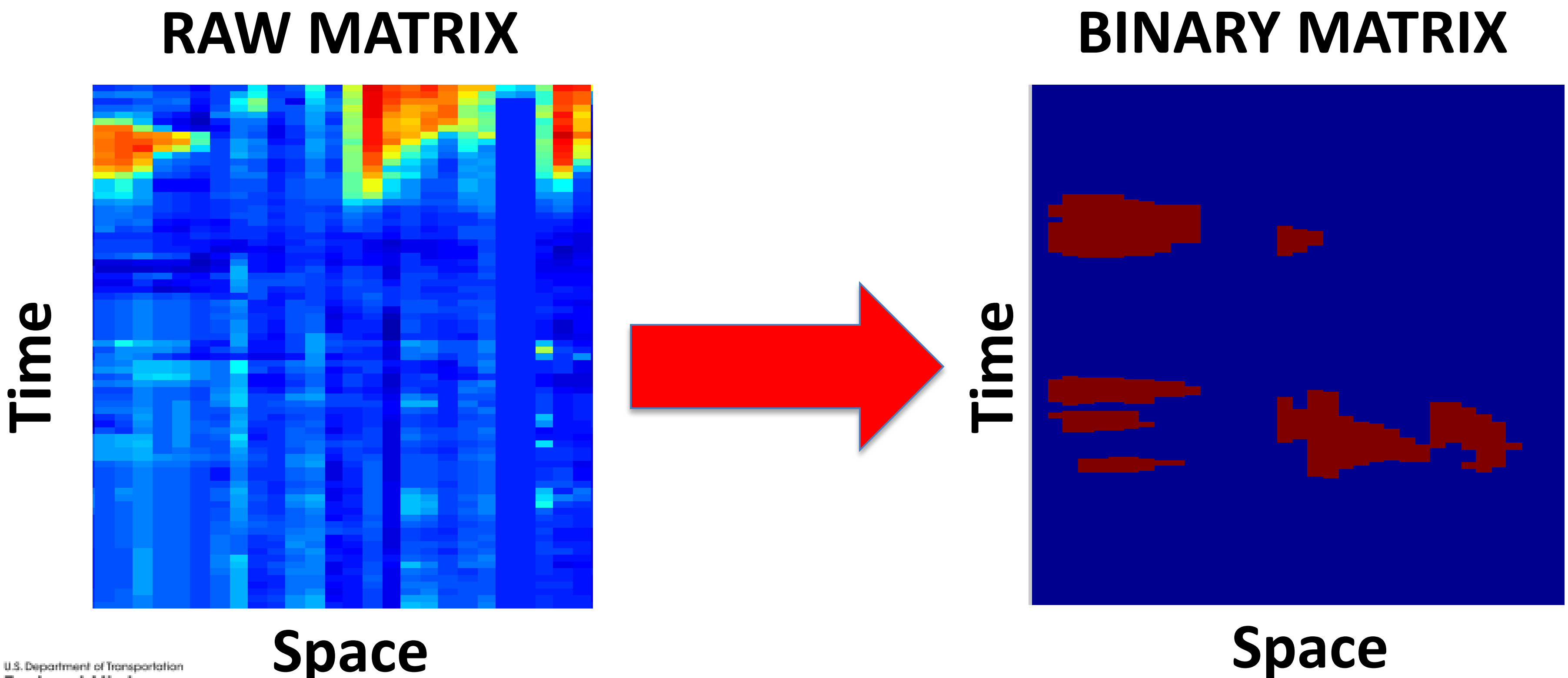
$$d_i(t) = l_i \times q_i(t) \times \left(\frac{1}{u_i(t)} - \frac{1}{u_f} \right)$$

$$Total\ Delay = \sum_{\Omega} d_i(t)$$

d = delay, l = length, q = flow, u = speed

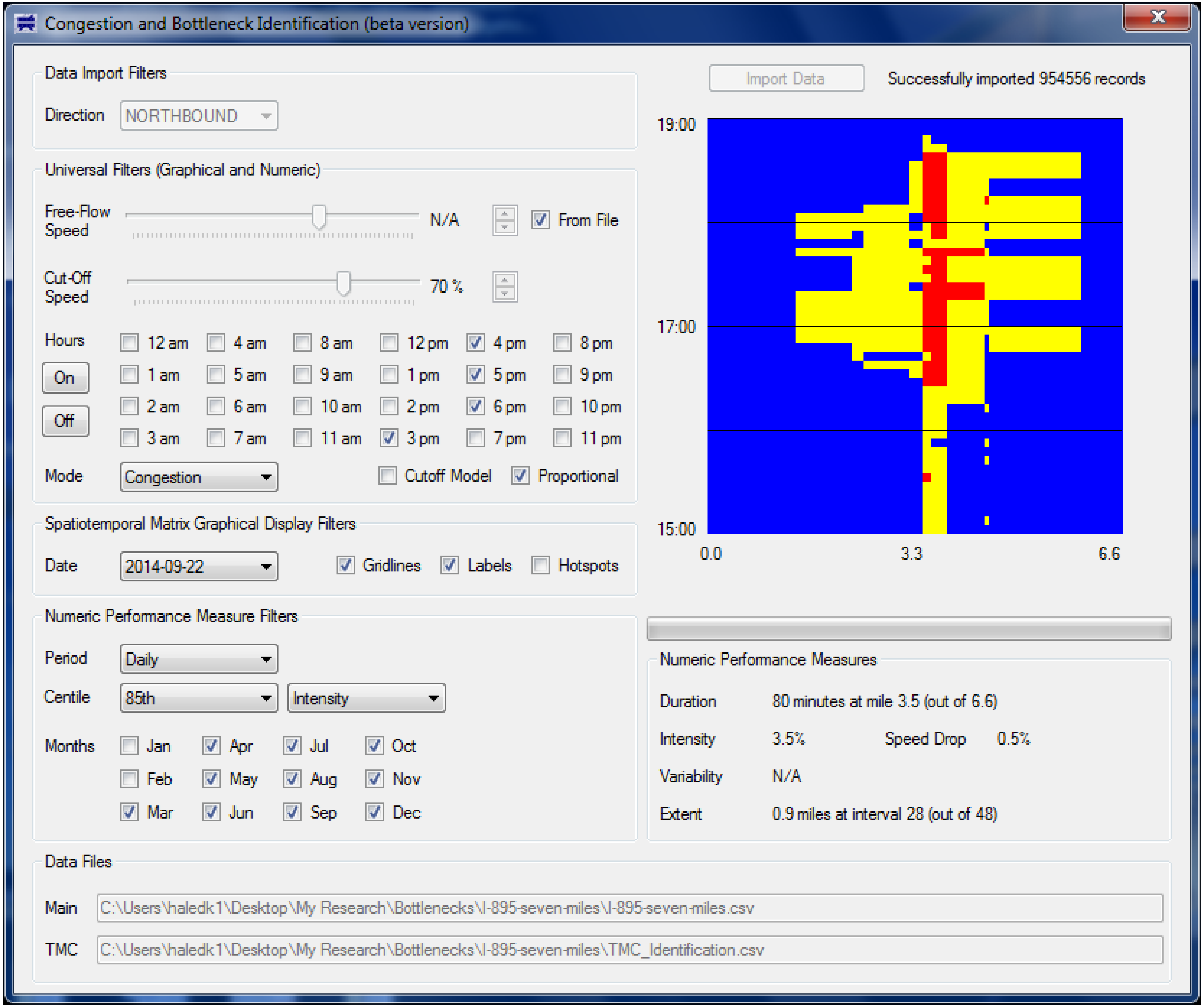
Arterial Congestion Identification

- Some delay caused by signals (not congestion)
- Lower accuracy of INRIX data on arterials
- Wavelet model might help

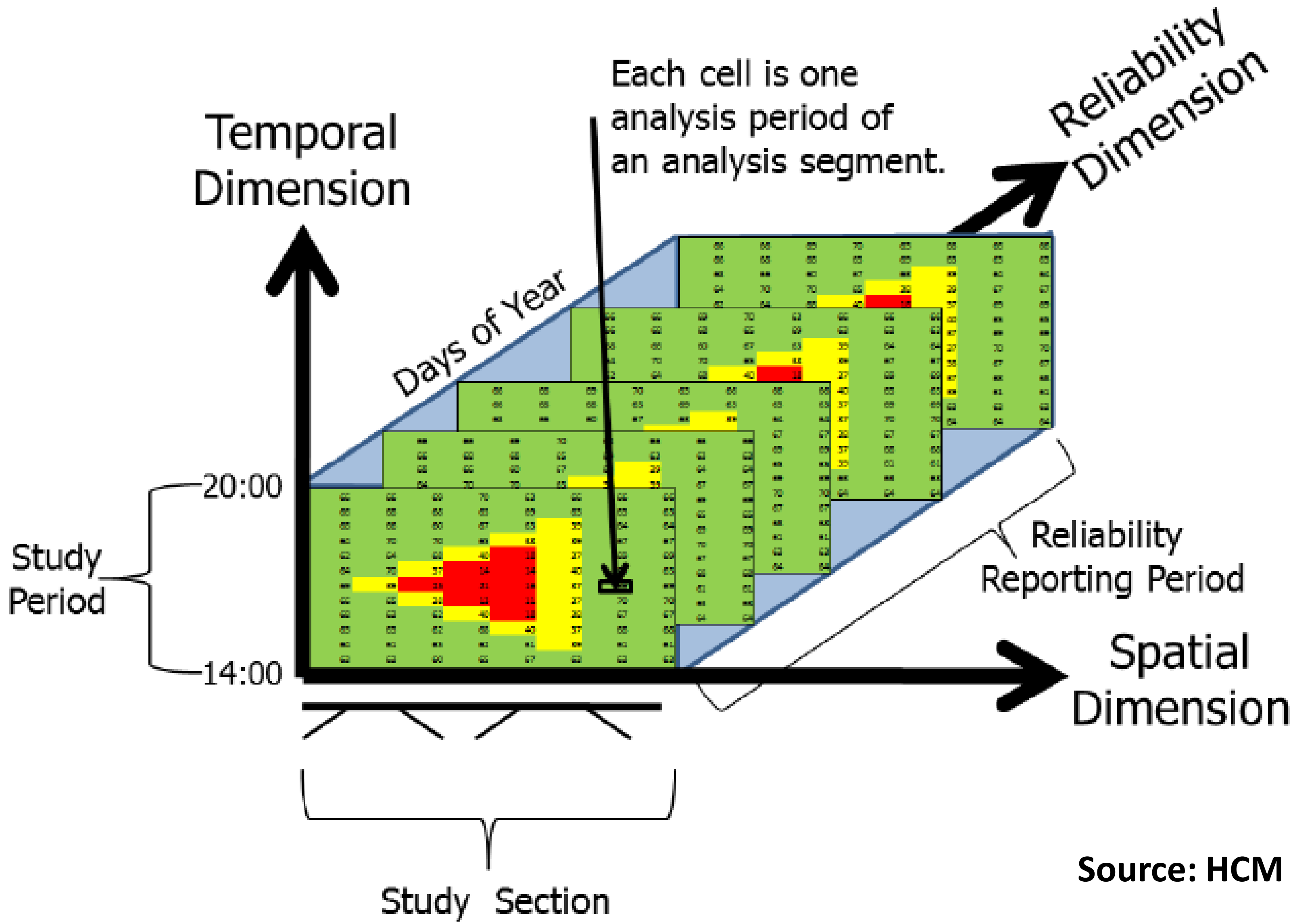


Software Tool Overview

- VTTI tool features
  - Algorithm to compute bottleneck cut-off speeds
  - Graphical spatiotemporal matrix (STM)
  - Weather and visibility modeling
  - Filters for acceleration areas and “noise”
  - Delay due to bottleneck, shockwave speed
- CBI tool features
  - User-defined bottleneck cut-off speeds
  - Graphical spatiotemporal matrix (STM)
  - Intensity and variability statistics, percentile results
  - Directly imports INRIX files
  - User-friendly GUI (graphical user interface)


Congestion and Bottleneck Identification (beta version)
Data Import Filters
Direction
NORTHBOUND
Import Data
Successfully imported 954556 records
Universal Filters (Graphical and Numeric)
Free-Flow Speed
N/A
From File
Cut-Off Speed
70 %
Hours
12 am
4 am
8 am
12 pm
4 pm
8 pm
1 am
5 am
9 am
1 pm
5 pm
9 pm
2 am
6 am
10 am
2 pm
6 pm
10 pm
3 am
7 am
11 am
3 pm
7 pm
11 pm
On
Off
Mode
Congestion
Cutoff Model
Proportional
19:00
17:00
15:00
0.0
3.3
6.6
Spatiotemporal Matrix Graphical Display Filters
Date
2014-09-22
Gridlines
Labels
Hotspots
Numeric Performance Measure Filters
Period
Daily
Centile
85th
Intensity
Months
Jan
Apr
Jul
Oct
Feb
May
Aug
Nov
Mar
Jun
Sep
Dec
Numeric Performance Measures
Duration
80 minutes at mile 3.5 (out of 6.6)
Intensity
3.5%
Speed Drop
0.5%
Variability
N/A
Extent
0.9 miles at interval 28 (out of 48)
Data Files
Main
C:\Users\haledk1\Desktop\My Research\Bottlenecks\I-895-seven-miles\I-895-seven-miles.csv
TMC
C:\Users\haledk1\Desktop\My Research\Bottlenecks\I-895-seven-miles\TMC_Identification.csv

Spatiotemporal Traffic Matrix (STM)

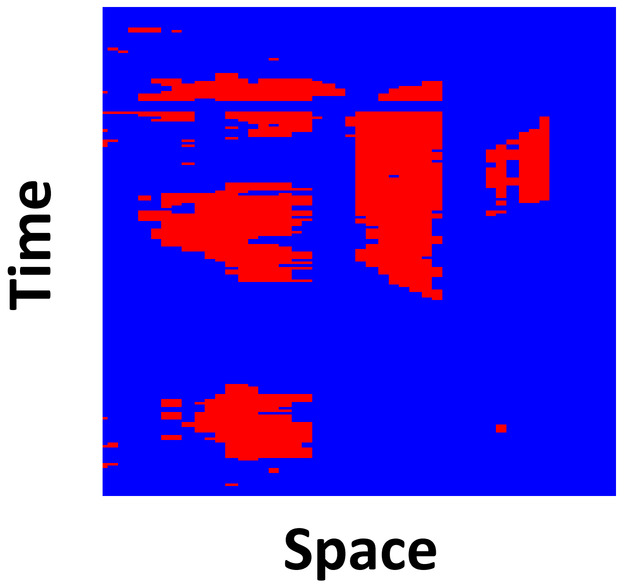


Source: HCM 2010

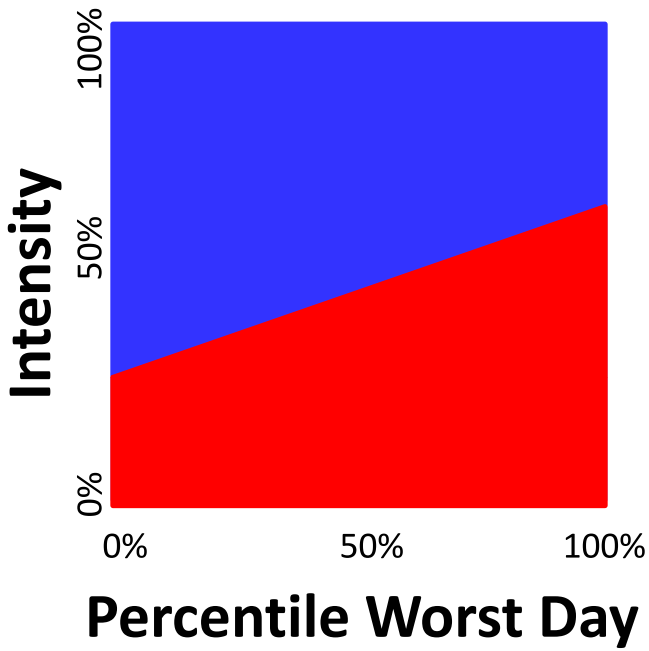
STM Versus ARM

- STM (Spatiotemporal Traffic State Matrix)
- ARM (Annual Reliability Matrix)

STM

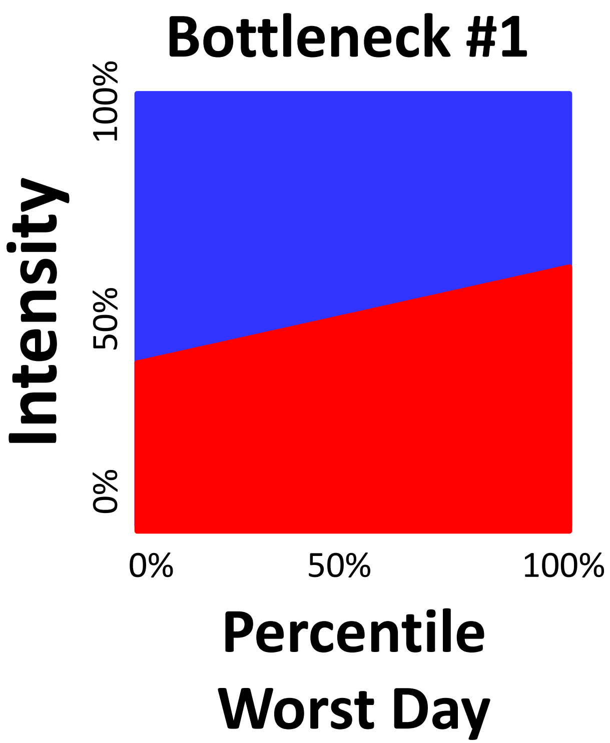


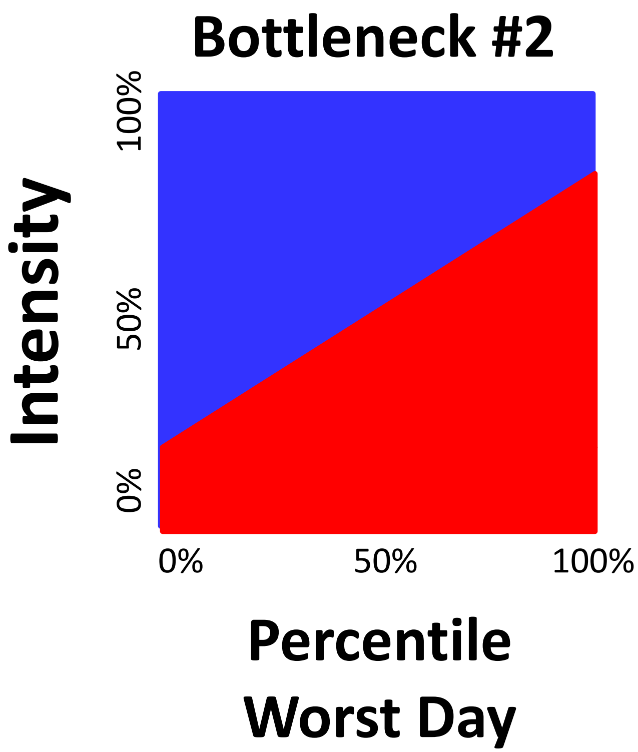
ARM



Comparing ARMs

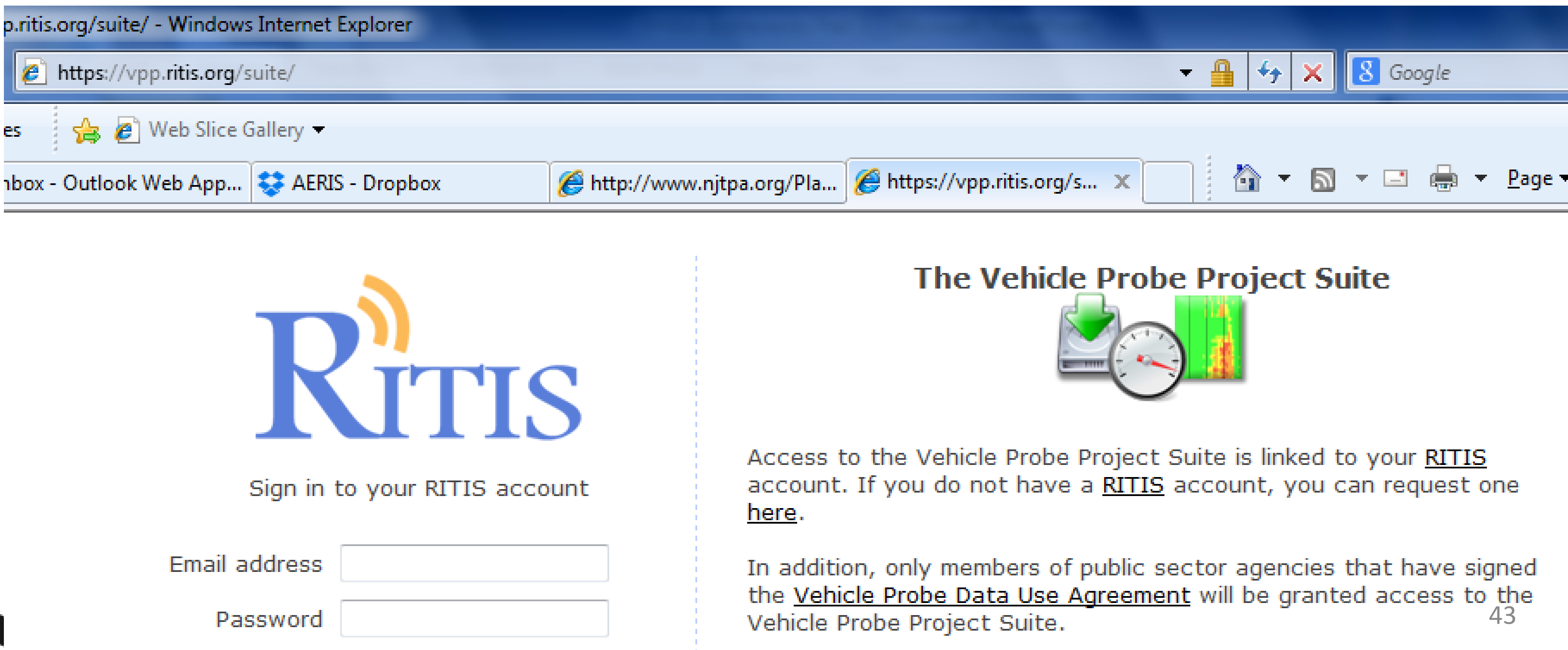
- STM (Spatiotemporal Traffic State Matrix)
- ARM (Annual Reliability Matrix)





Software Tool Overview

- Downloading INRIX files from RITIS
  - Readings.csv
  - TMC_Identification.csv
- https://vpp.ritis.org/suite/download/



Software Tool Overview

2. Date Range

01/01/2014 - 12/31/2014

Add another date range

3. Days of week

Sun ☐ | Mon ☑ | Tue ☑ | Wed ☑ | Thu ☑ | Fri ☑ | Sat ☐

4. Time of day

12 : 00 AM -to- 11 : 59 PM

Add another time of day

5. Fields

- ☑ Speed
- ☐ Historic average speed
- ☑ Reference speed
- ☐ Travel time
- ☐ Confidence score
- ☐ C-Value

6. Averaging

- ◯ Don't average
- ◉ 5 minutes
- ◯ 10 minutes
- ◯ 15 minutes
- ◯ 30 minutes
- ◯ 1 hour

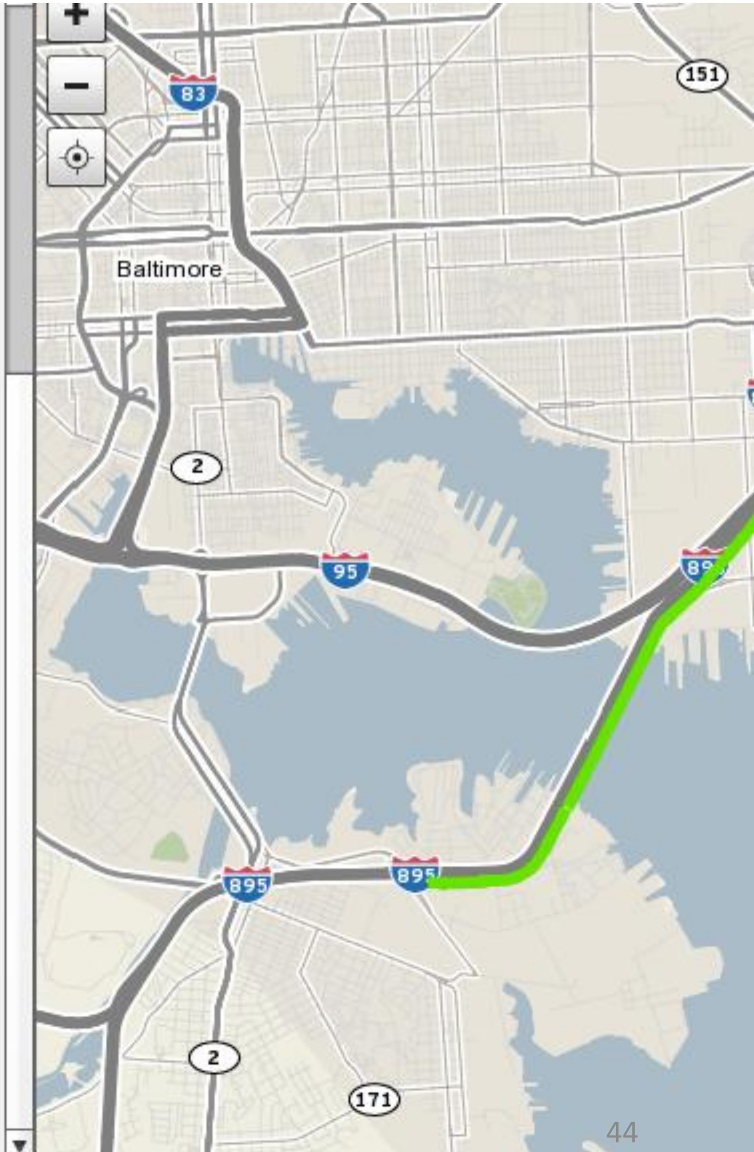
7. Description

Northbound I-895

8. Notification

☑ Send me an email when this export is ready

Submit download request



Software Tool Demo

Play demo

Example of Ranking Bottlenecks

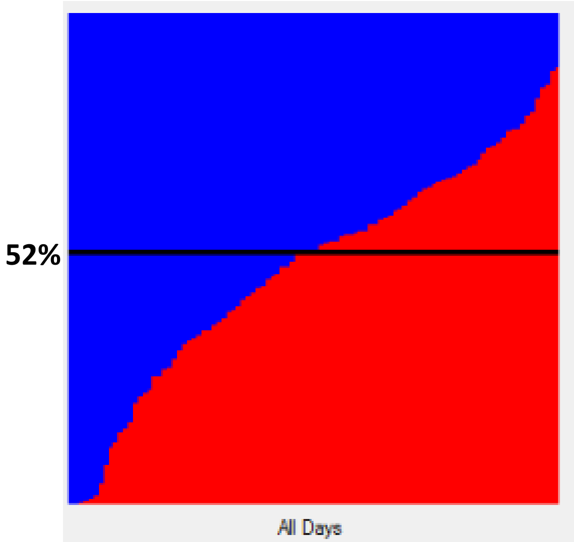
- In practice, probably better to compare bottlenecks
- However, our test datasets are full corridors

- <u>Example problem</u>
- PM peak hour analysis only (4-7 PM)
- One year of historical data (2014)
- Bottleneck mode only
- Proportional segments (length matters)
- 25 mph arterial cut-off speed
- 45 mph freeway cut-off speed
- 85th percentile intensity (speed drop tiebreaker)

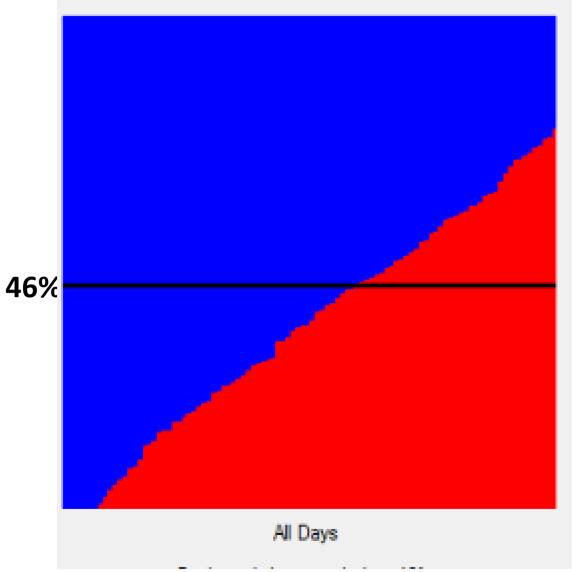
Ranking Freeway Bottlenecks

- Annual intensity and reliability
  - Bottleneck Intensity Index (BII), Speed Drop (SD)

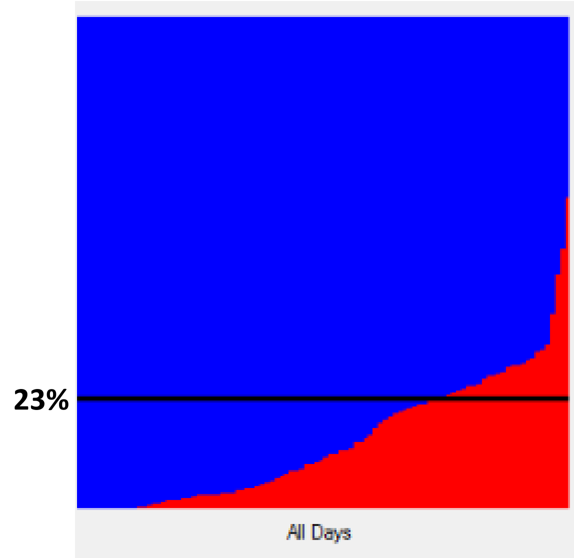
I-695
BII 52%
SD 33%



I-495
BII 46%
SD 17%



I-895
BII 23%
SD 11%



<---Intensity--->

<---Percentile worst day--->

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Ranking Arterial Bottlenecks

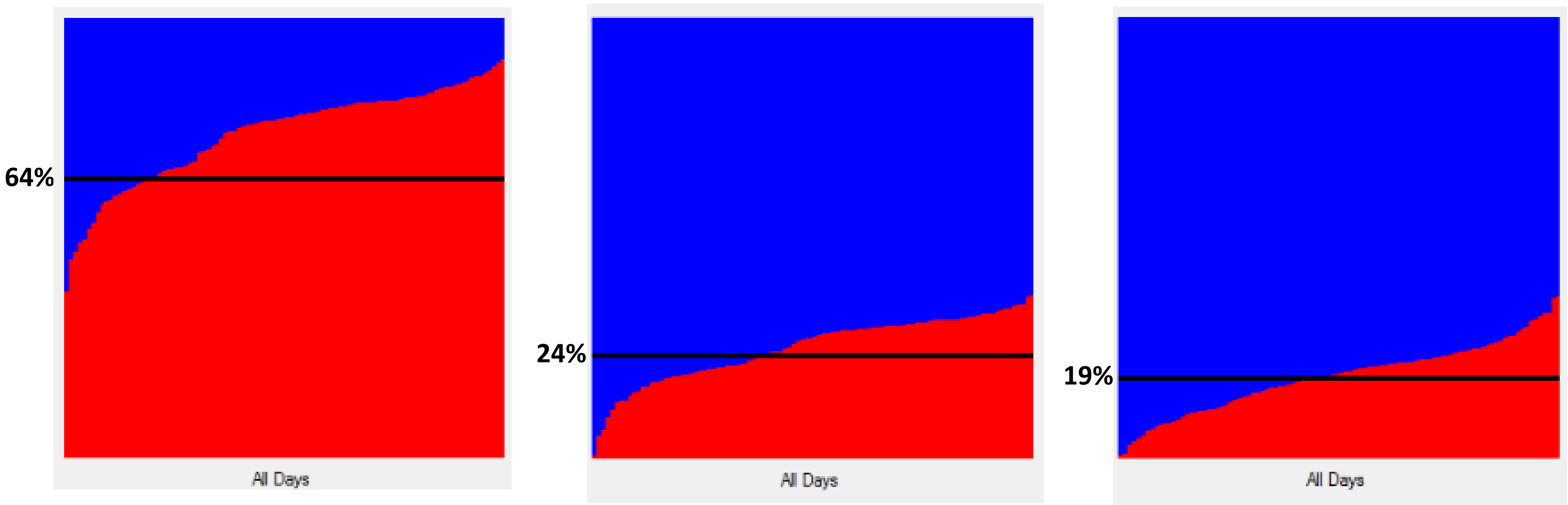
- Annual intensity and reliability
  - Bottleneck Intensity Index (BII), Speed Drop (SD)

US-13
BII 64%
SD 21%

MD-147
BII 24%
SD 6%

US-50
BII 19%
SD 6%

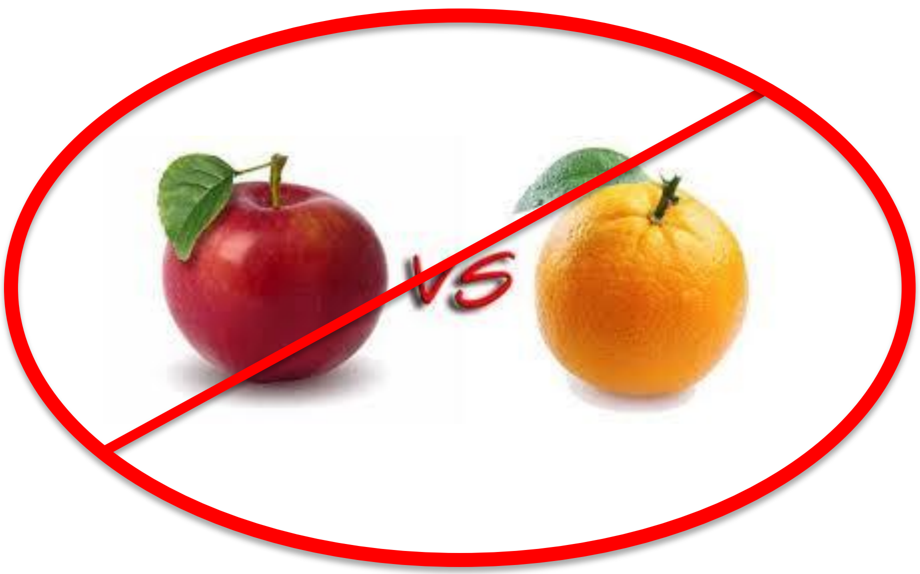
<---Intensity--->



<---Percentile worst day--->

Ranking Bottlenecks

- When comparing different INRIX datasets…
- They should have the same
  - Interval duration (e.g., 5-minute)
  - Corridor length (sum of all segments)
  - Hours of day, days of week, months of year



Possible Future Development

- VTTI models and processing methods
  - Import and analyze weather and visibility data
  - Eliminate noise and acceleration areas
  - Fill in missing data
  - Shockwave speed, delay due to bottleneck
- Wavelet model for surface arterials
  - Filter out mandatory signal delay
- Batch processing
  - Automatically load and rank numerous datasets
- New performance measures
  - Travel time index, variance, standard deviation, others?

Summary

- Precise assessment of bottlenecks
- Customize your analysis with software
  - Time period of analysis
  - Congestion cut-off speed
  - Percentile results
- Prioritize problem areas
- Justify transportation investments

Preview

1. Congestion and bottleneck concepts
2. Congestion and bottleneck identification methods
3. **Modernized causes of congestion pie chart**
4. Featured bottleneck mitigation strategies

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Congestion Pie Chart

Identification, Diagnosis, Solutions

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Workshop Overview

1. Congestion and bottleneck concepts
2. Congestion and bottleneck identification methods
3. **Modernized causes of congestion pie chart**
4. Featured bottleneck mitigation strategies

Introduction

FHWA Report, *"Traffic Congestion and Reliability: Linking Solutions to Problems"* July 2004

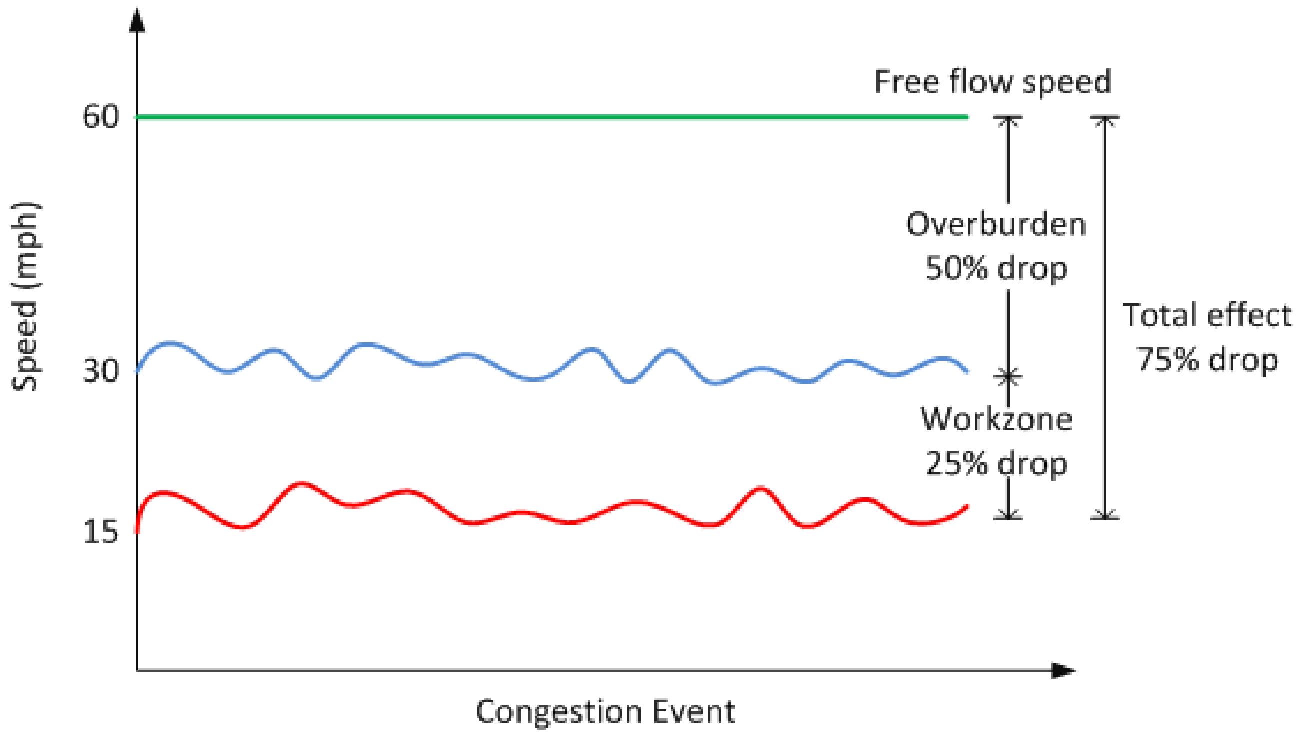
Data-Driven Analysis

- Data continuously collected in the field
  - Incident code (0 = no incident, 1 = incident)
  - Weather code (0 = good weather, 1 = bad weather)
  - Workzone code (0 = no active wz, 1 = active wz)
- Congestion identification (using VTTI method)
  - Congestion code (0 = uncongested, 1 = congested)
  - “Speed drop” percentage

Data-Driven Analysis

- Dilemma of “multiple factors”
- How to measure impact of “overburden”
  - v/c > 100%
- Example problem:
  - Free-flow speed = 60 mph, actual speed = 15 mph
  - 75% speed drop
  - Workzone code = 1 (weather & incident codes = 0)
- How much speed drop caused by v/c > 1 (Overburden)?
- How much speed drop caused by workzone?

Data-Driven Analysis



	Speed Drop	Final
Overburden	50%	66.7%
Workzone	25%	33.3%

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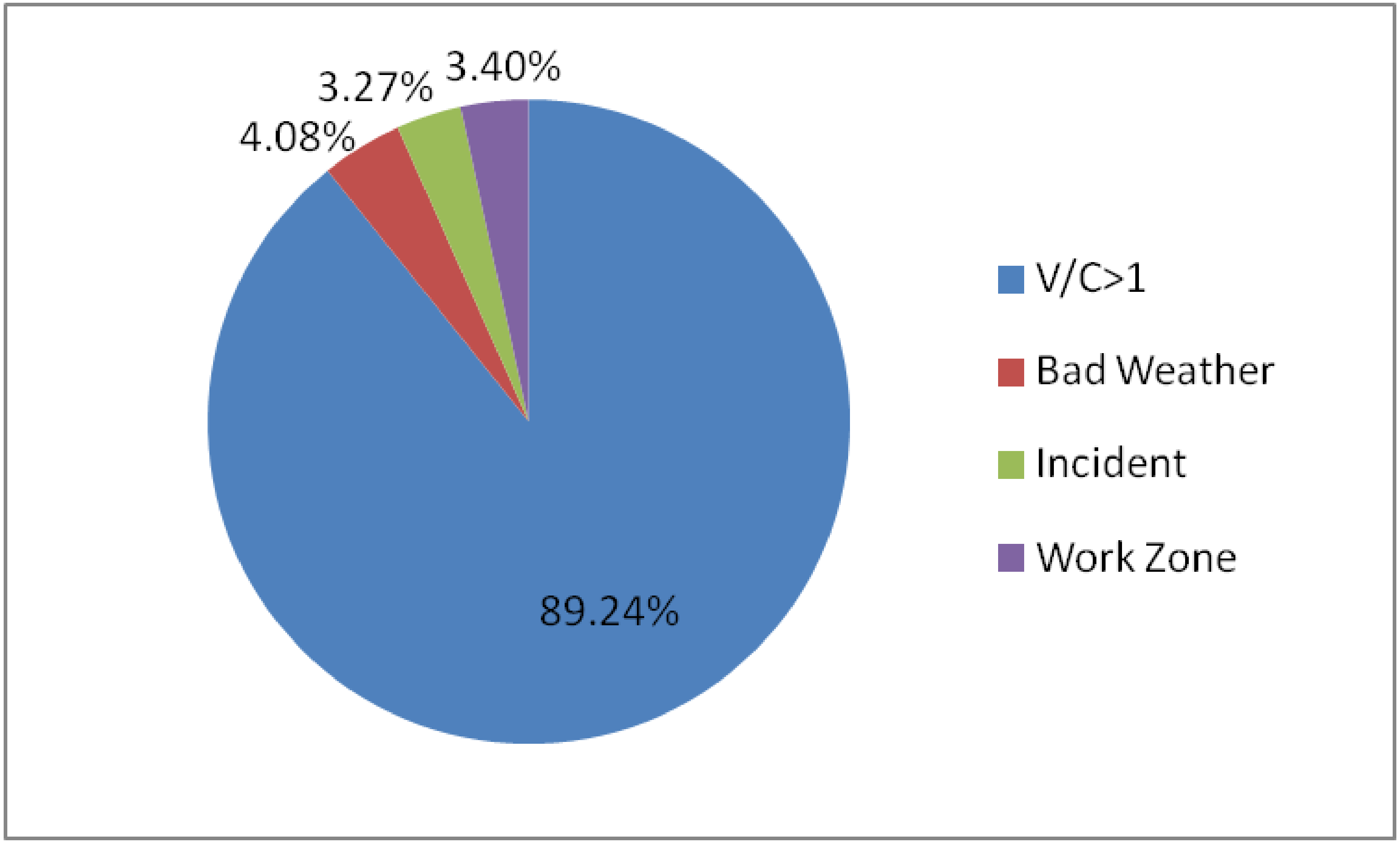
Eastbound I-66 Pie Chart

- Updated, weighted pie chart with spatio-temporal effects



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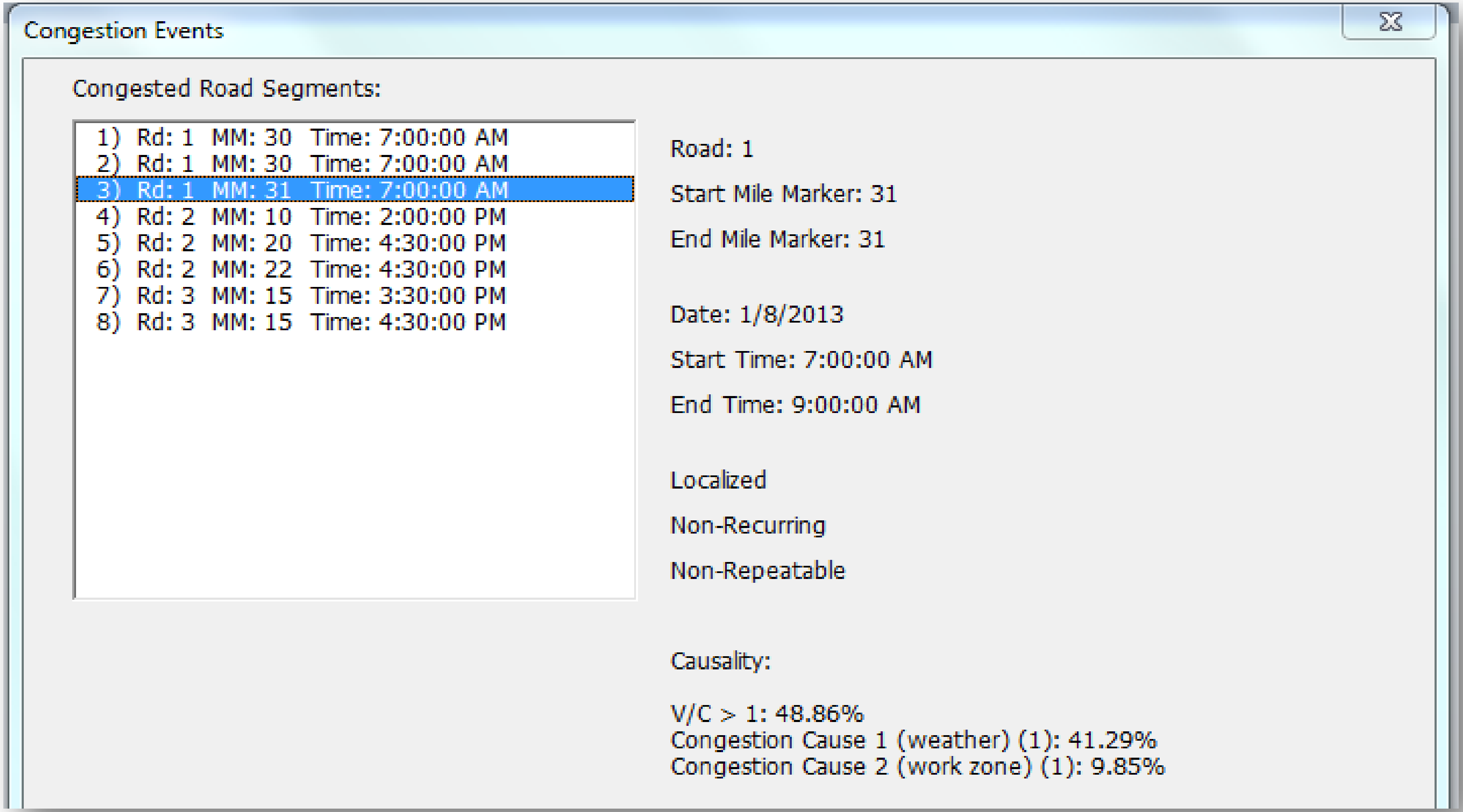
Pie Chart Software

- Open-source tool
- Compatible with Microsoft Access



Surface Arterial Pie Chart

- How difficult to find congestion causes?
  - Arterials much more difficult than freeways
- Complexity of field data sources
  - Not uniform, not standardized
  - Inductive loops, radar, video, ITS devices
- Possible arterial congestion causes
  - Poor signal timing
  - Inadequate geometry
  - Multimodal effects
  - Safety designs
  - Freeway congestion causes (weather, incidents, work zones, overburden)

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Arterial Data Analysis

Incidents on Eastbound of Broward Blvd.

Type	Date	Time	Road	Location	Duration
Congestion	8/5/2014	8:31:30	SR-842 EB	US-1	95
Congestion	8/7/2014	8:07:24	SR-842 EB	US-1	25
Congestion	8/7/2014	10:52:29	SR-842 EB	US-1	288
Congestion	8/8/2014	7:48:39	SR-842 EB	US-1	432
Congestion	8/12/2014	8:42:42	SR-842 EB	NW 7 Ave	80
Vehicle Alert	8/12/2014	9:55:05	SR-842 EB	NW 7 Ave	6
Road Work - Scheduled	8/12/2014	10:18:33	SR-842 EB	Andrews Ave	117
Congestion	8/14/2014	7:53:09	SR-842 EB	US-1	124
Congestion	8/18/2014	7:56:51	SR-842 EB	I-95	10
Congestion	8/18/2014	8:41:33	SR-842 EB	Andrews Ave	60
Congestion	8/19/2014	8:50:22	SR-842 EB	US-1	118
Disabled Vehicle	8/20/2014	8:24:32	SR-842 EB	I-95	24
Congestion	8/20/2014	9:12:22	SR-842 EB	NW 7 Ave	21
Congestion	8/21/2014	9:07:09	SR-842 EB	NW 7 Ave	21
Road Work - Scheduled	8/21/2014	13:33:12	SR-842 EB	US-441	46
Road Work - Scheduled	8/21/2014	17:49:03	SR-842 EB	US-441	33
Congestion	8/22/2014	8:36:44	SR-842 EB	I-95	76
Congestion	8/25/2014	7:48:36	SR-842 EB	Andrews Ave	170
Disabled Vehicle	8/25/2014	17:16:05	SR-842 EB	US-1	15
Congestion	8/26/2014	8:13:09	SR-842 EB	NW 7 Ave	72
Congestion	8/27/2014	7:41:33	SR-842 EB	I-95	15
Congestion	8/27/2014	8:21:10	SR-842 EB	NW 7 Ave	123
Congestion	8/28/2014	7:25:35	SR-842 EB	NW 7 Ave	127
Road Work - Scheduled	8/28/2014	10:18:05	SR-842 EB	US-441	302
Disabled Vehicle	8/28/2014	12:38:38	SR-842 EB	NW 7 Ave	7
Congestion	8/29/2014	7:54:19	SR-842 EB	I-95	13
Road Work - Scheduled	8/29/2014	8:56:13	SR-842 EB	NW 21 Ave	262

Incidents on Westbound of Broward Blvd.

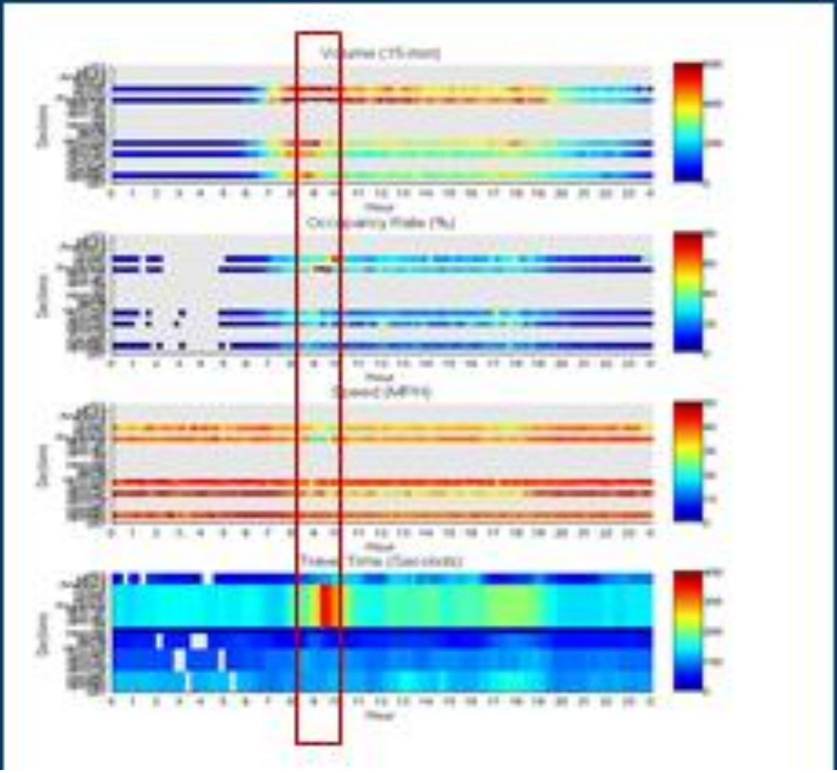
Type	Date	Time	Road	Location	Duration
Congestion	8/1/2014	14:11:39	SR-842 WB	I-95	254
Road Work - Scheduled	8/4/2014	11:33:35	SR-842 WB	I-95	439
Congestion	8/4/2014	15:33:53	SR-842 WB	I-95	145
Congestion	8/5/2014	12:31:53	SR-842 WB	NW 7 Ave	278
Congestion	8/7/2014	8:09:45	SR-842 WB	NW 7 Ave	22
Congestion	8/7/2014	10:42:53	SR-842 WB	NW 7 Ave	490
Congestion	8/8/2014	11:07:27	SR-842 WB	NW 7 Ave	246
Congestion	8/11/2014	14:20:53	SR-842 WB	NW 7 Ave	263
Crash	8/12/2014	9:24:44	SR-842 WB	NW 7 Ave	33
Congestion	8/12/2014	11:44:00	SR-842 WB	I-95	274
Congestion	8/14/2014	15:40:14	SR-842 WB	I-95	90
Congestion	8/14/2014	17:15:24	SR-842 WB	I-95	24
Congestion	8/15/2014	14:09:18	SR-842 WB	I-95	222
Congestion	8/18/2014	15:06:11	SR-842 WB	I-95	202
Crash	8/18/2014	17:11:07	SR-842 WB	I-95	77
Congestion	8/19/2014	17:45:49	SR-842 WB	I-95	37
Congestion	8/20/2014	15:13:55	SR-842 WB	I-95	152
Congestion	8/21/2014	15:39:45	SR-842 WB	I-95	85
Congestion	8/22/2014	9:01:19	SR-842 WB	I-95	43
Congestion	8/22/2014	15:39:42	SR-842 WB	I-95	72
Congestion	8/25/2014	17:09:43	SR-842 WB	I-95	53
Congestion	8/26/2014	15:25:34	SR-842 WB	I-95	176
Disabled Vehicle	8/26/2014	17:19:34	SR-842 WB	Andrews Ave	17
Congestion	8/27/2014	15:29:38	SR-842 WB	I-95	151
Congestion	8/28/2014	15:45:20	SR-842 WB	I-95	160
Congestion	8/28/2014	16:44:32	SR-842 WB	NW 7 Ave	101
Crash	8/28/2014	17:25:03	SR-842 WB	I-95	37
Congestion	8/29/2014	15:25:38	SR-842 WB	I-95	147

Arterial Incident Records

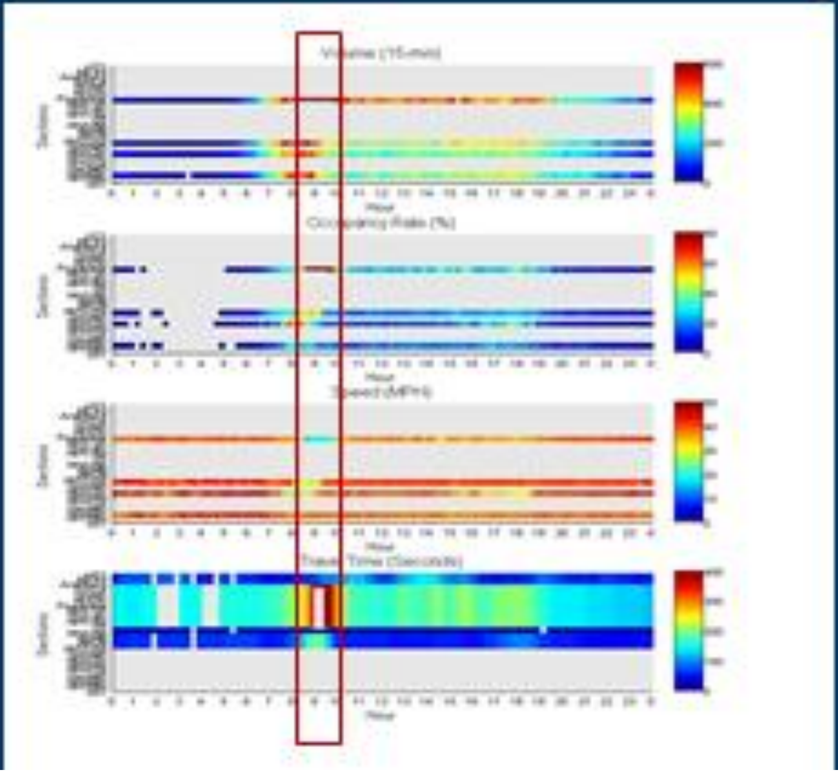
August 26 – Congestion (1)

Incident #	Incident Type	Date	Time	Major Rd	Minor Rd	Duration(min)
1025	Congestion	8/26/2014	8:13:09	SR-842 EB	NW 7 Ave	72

Normal-day Traffic on Eastbound of Broward Blvd.



Incident Traffic on Eastbound of Broward Blvd.



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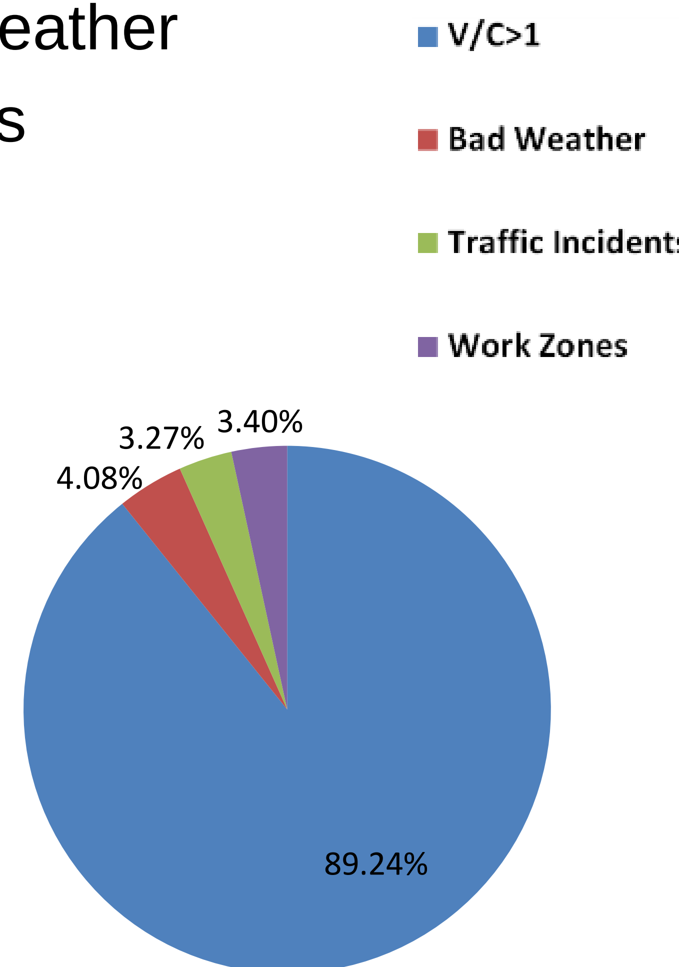
Summary

- Data-driven congestion causal pie chart
  - Bigger impact: road geometry, bad weather
  - Smaller impact: incidents, work zones
- Coming soon
  - Surface arterial pie chart
  - Analysis of more freeways



Preview

1. Congestion and bottleneck concepts
2. Congestion and bottleneck identification methods
3. Modernized causes of congestion pie chart
4. **Featured bottleneck mitigation strategies**

Bottleneck Mitigation Strategies

Identification, Diagnosis, Solutions

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Active Bottleneck

Geometric Challenges				Operational Challenges		
Roadway Specific	**Facility Specific**	**Specific to Interchanges**	**Intersections /TCD/ITS**	**Agency Related**	**Driver Related**	**Non-motorist Related**
1. Design Speed 2. Number of Lanes 3. Lane Width 4. Presence and Type of shoulders 5. Lane drops 6. Lane reduction transition 7. Hz clearance 8. Vl clearance 9. Sun Glare Alignment 10. Hz alignment 11. Vl alignment 12. SSD 13. Pavement friction/surface 14. Cross Slope 15. Super-elevation 16. Access pts 17. Mid-block Crossing 18. Medians 19. Lighting/Glare	1. Bridges 2. Tunnels and underpass 3. Collector-distributor network	1. Merge and diverge sections 2. Auxiliary lanes 3. Weaving areas 4. On-ramp/off-ramp 5. Acceleration/ deceleration lanes	1. Intersection sight distance 2. Left-turn and Right-turn lane overflow 3. Parking 4. TCD (signal, stop sign, etc.)	1. Managing demand 2. Intersection spacing 3. Interchange spacing 4. Policy on entry/exit ramp placement 5. Posted speed limit (static/dynamic) 6. Signal timing administration 7. Traffic composition 8. Work zone 9. Roadway closure administration 10. Incident management and clearance 11. Ramp metering 12. Heavy vehicle lane restrictions	1. Bunching vehicle 2. Roadside distraction/rubbernecking 3. Non-roadside distractions 4. Unsafe vehicle condition for weather condition 5. Aggressive lane change/weaving 6. Driving unauthorized roadway section 7. Driver performance in wz 8. Driver performance when involved in an incident	1. Sub-optimal peds and bicyclist performance

Featured Bottleneck Solutions

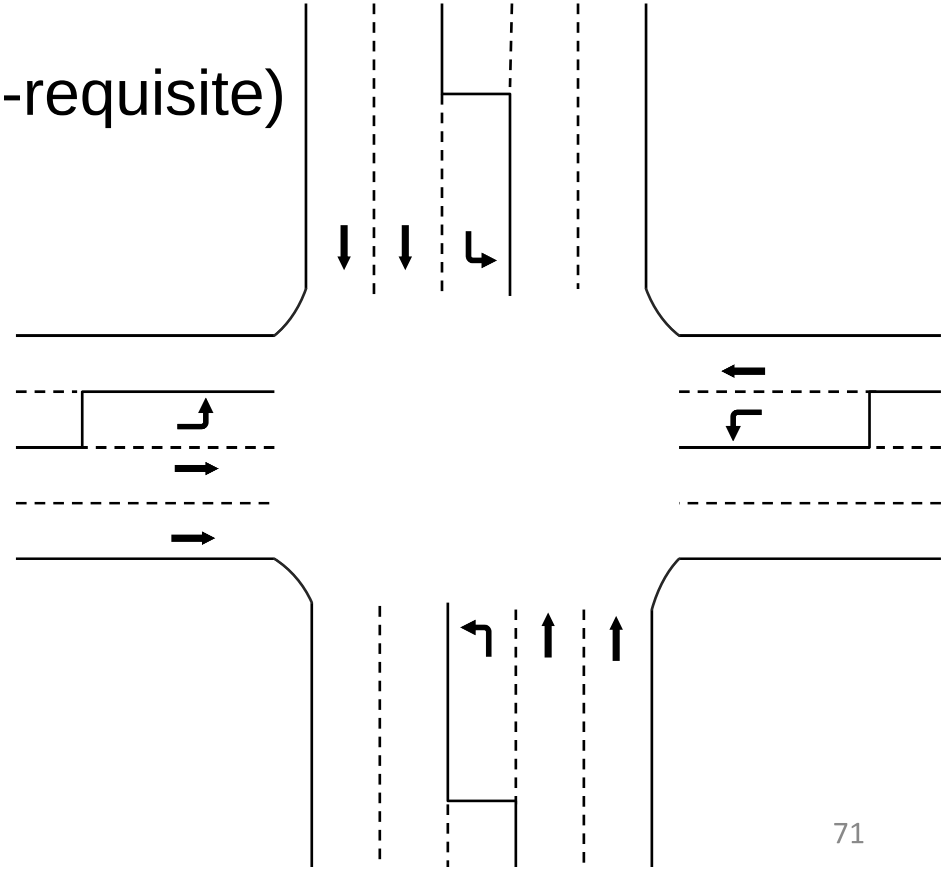
1. **Dynamic Lane Grouping**
2. Dynamic Merge Control
3. Acceleration Lane Extension
4. Hard Shoulder Running
5. Lane Narrowing to Add a Lane
6. Alternative Intersections and Interchanges

Innovative Solutions (coming soon)

1. Dynamic Hard Shoulder Running
2. Contraflow Left-Turn Lanes
3. Freeway Merge with Variable Speed Limits
4. Signal Optimization via SPSA

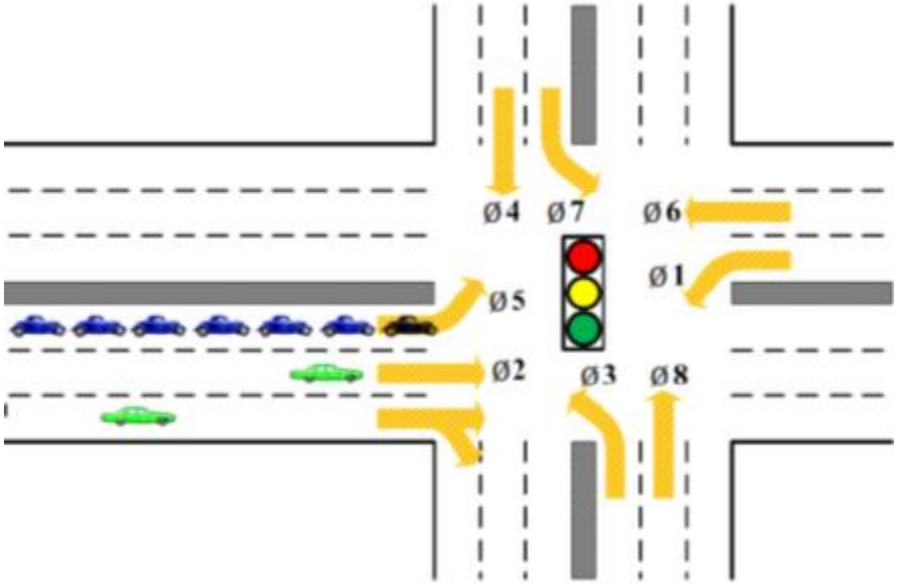
Dynamic Lane Grouping (DLG)

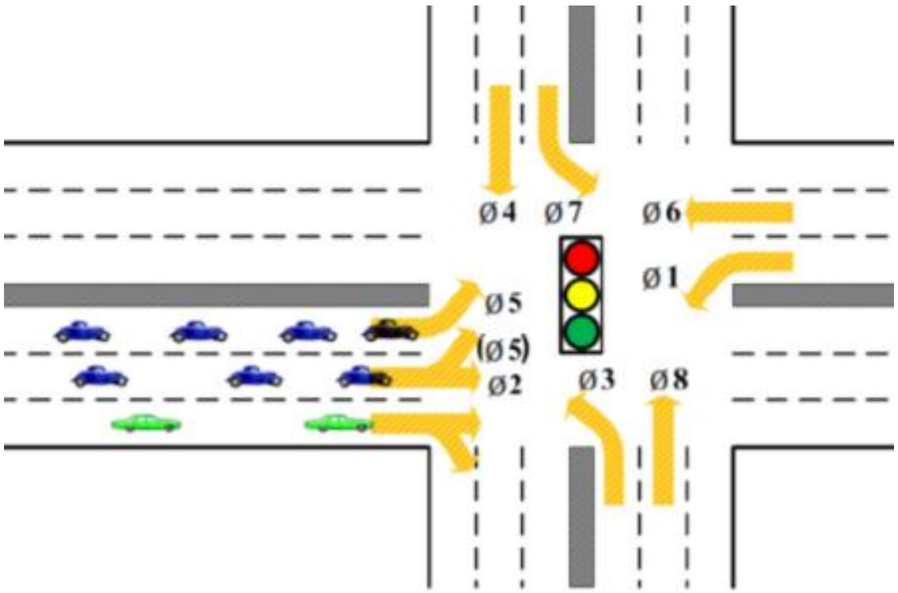
- Dynamically assigns lanes to turning movements
- Scan for good candidates among many intersections
- Four screening criteria
  - Safe turning geometry (pre-requisite)
  - Volume change
  - Volume per lane
  - Degree of saturation



Dynamic Lane Grouping (DLG)

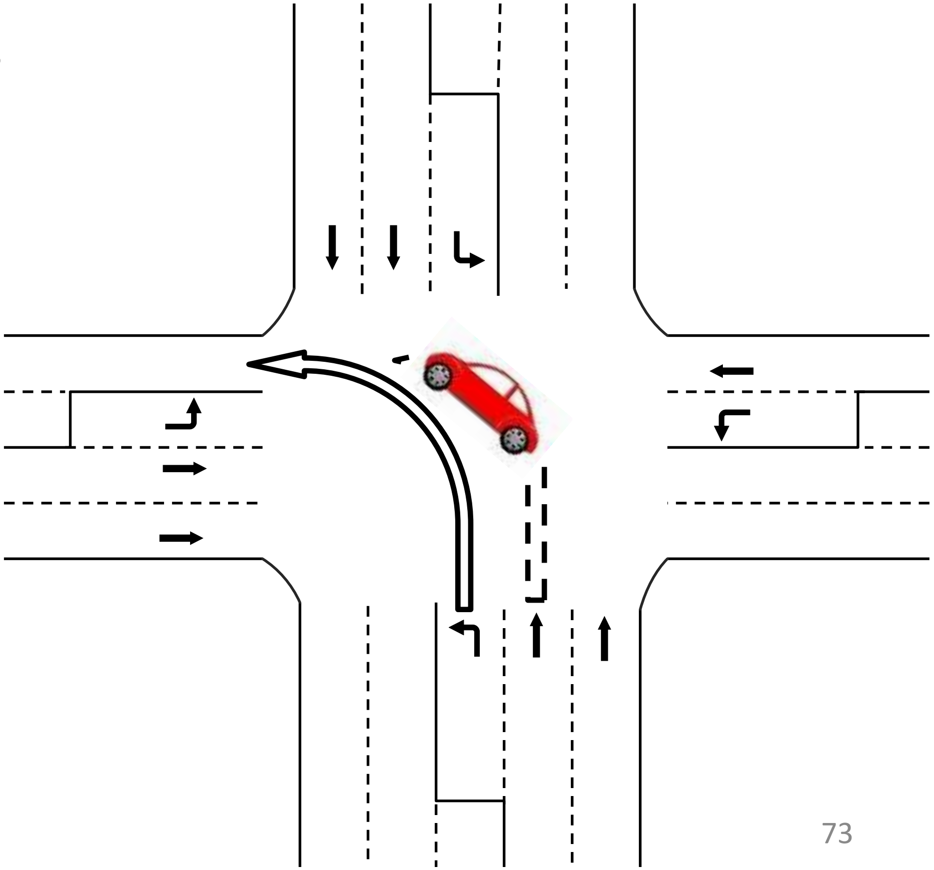
- Visual example: convert middle lane to a left-turn lane, during certain times of the day





Dynamic Lane Grouping (DLG)

- Screening criteria #1: Safe Turning Geometry
- Pre-requisite
- Adequate number of receiving lanes
- At least two through lanes



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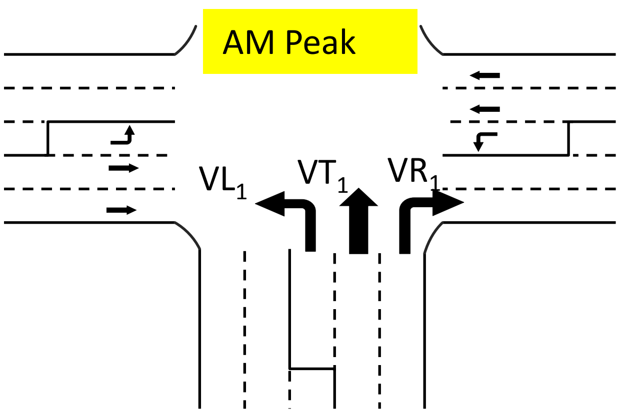
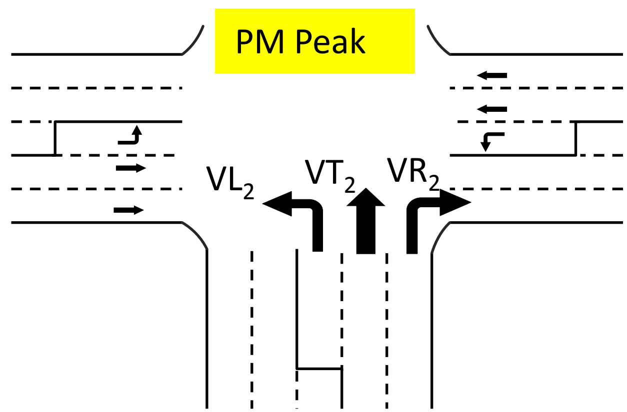
Dynamic Lane Grouping (DLG)

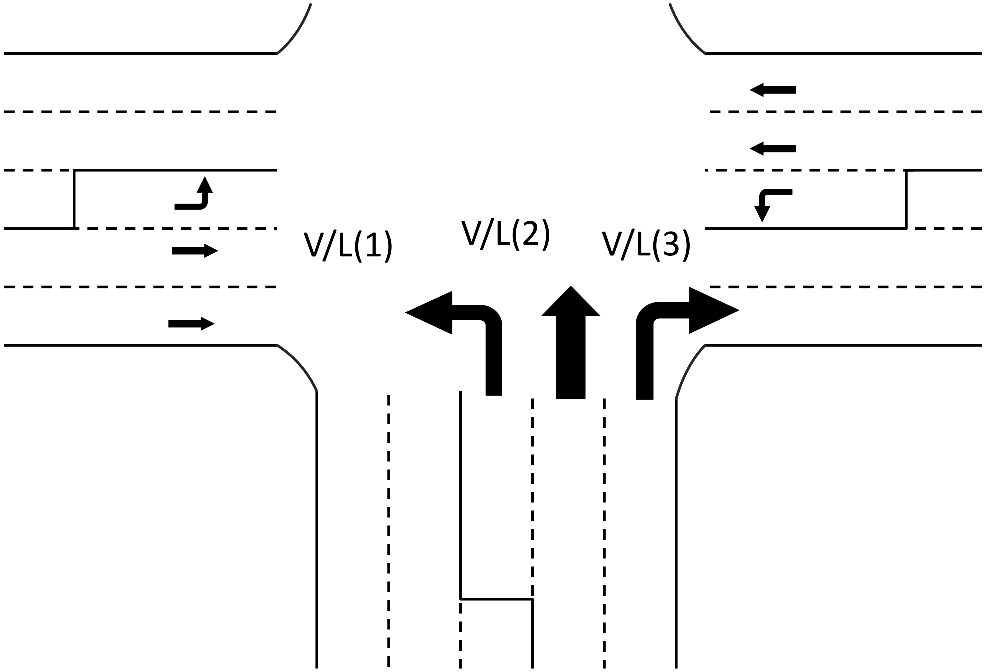
- Screening criteria #2: Volume Change
- Compare AM and PM peak volumes
- LT or RT volumes increase by at least 20%
- TH volumes decrease by at least 20%





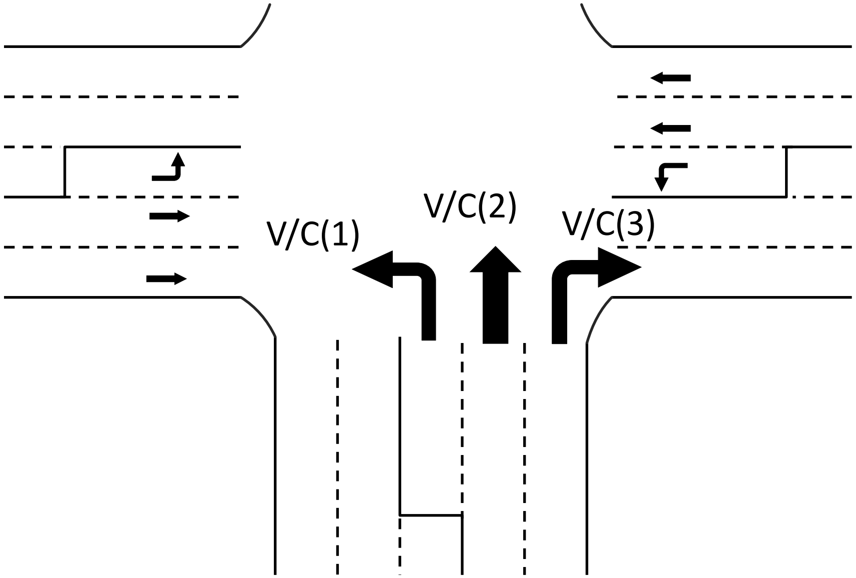
Dynamic Lane Grouping (DLG)

- Screening criteria #3: Volume per Lane
- Left-turn or right-turn volume per lane exceeds through volume per lane by at least 50%



Dynamic Lane Grouping (DLG)

- Screening criteria #4: V/C Ratio
- High left-turn or right-turn V/C (> 70%)
- Low through V/C $(< \frac{\#\, Through\ Lanes - 1}{\#\, Through\ Lanes})$



Dynamic Lane Grouping (DLG)

- Case study of 17 intersections (along 2 networks in Virginia)
  - TCN network
  - OBN network
- 8 candidate movements (LT and RT) per intersection
- 8 candidate time periods
- 17*8*8 = 1,088 candidates

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Dynamic Lane Grouping (DLG)

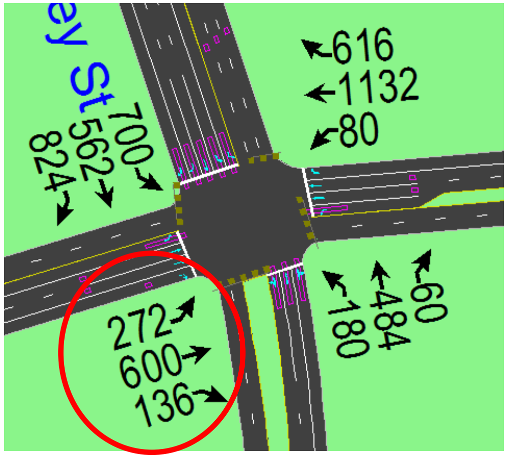
- Degree of saturation criterion
  - Best identification rate
  - Fewest number of false positives

Network Name	OBN	TCN	ID Rate
# of candidates	448	640	
Volume/Capacity	6(5)	2(2)	**87.5%**
Volume/Lane	4(1)	42(7)	**17.4%**
Volume Change	4(2)	12(1)	**18.8%**

Dynamic Lane Grouping (DLG)

- DLG improvements at Lee Highway @ Nutley Street
- Sunday peak period: switch to dual left turns

Sunday Peak



Weekday PM Peak

	Volume/Capacity	Volume/Lane
Left-Turn	0.99	452
Through	0.31	223

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Dynamic Lane Grouping (DLG)

Play before video

	EBL	EBT	EBR	Total
Volume	452	446	188	
Base Delay/Veh (s)	147	25	9	60
DLG Delay/Veh (s)	78	27	9	47

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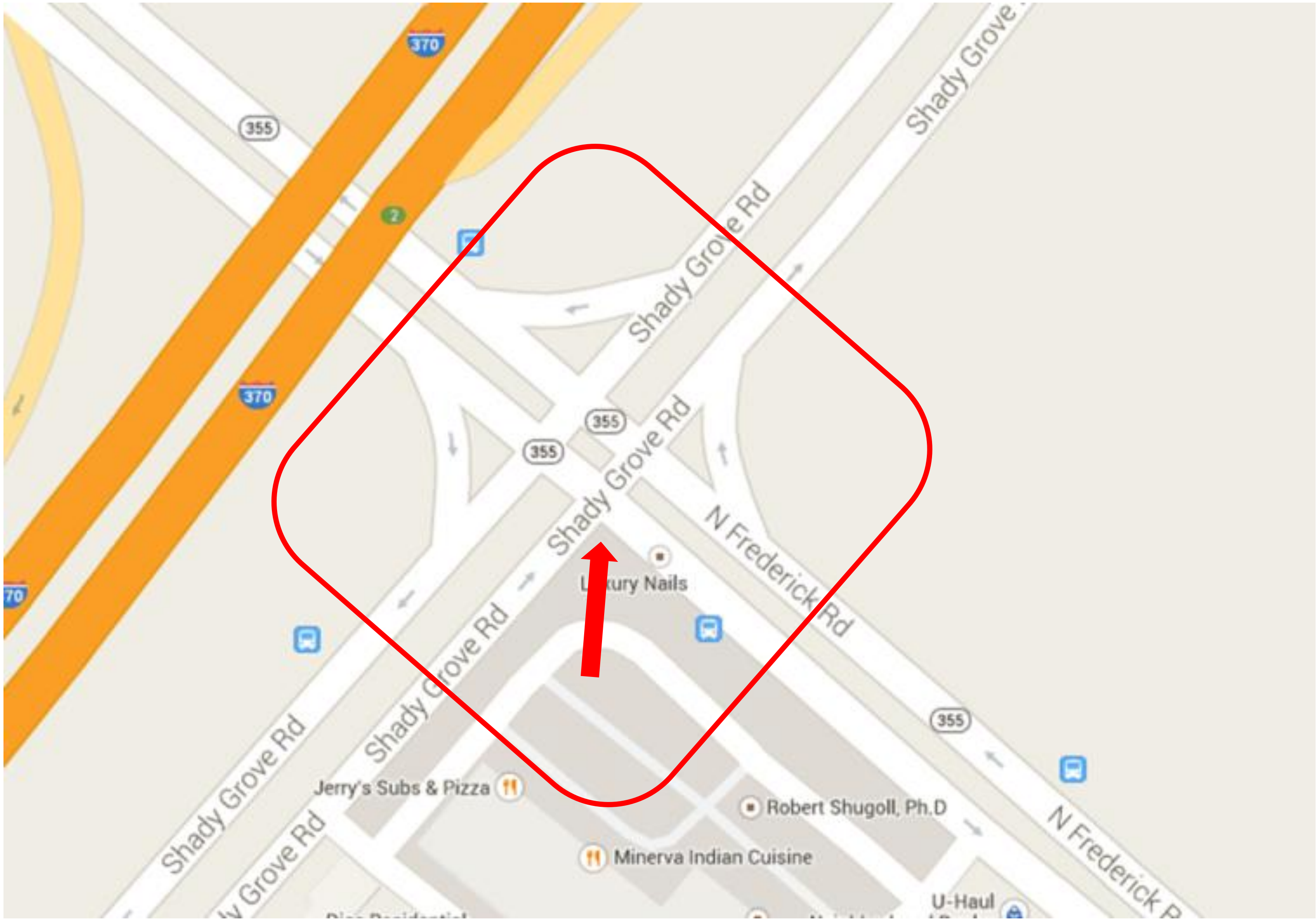
Dynamic Lane Grouping (DLG)

Play after video

	EBL	EBT	EBR	Total
Volume	452	446	188	
Base Delay/Veh (s)	147	25	9	60
DLG Delay/Veh (s)	78	27	9	47

Dynamic Lane Grouping (DLG)



Dynamic Lane Grouping (DLG)

Hour Begin	Shady Grove Road From West			
	L	T	R	TOT
6:00	119	428	404	951
7:00	370	477	926	1773
8:00	**445**	**569**	**1087**	**2101**
9:00	350	831	1395	2576
10:00	478	748	691	1917
11:00	488	933	743	2164
12:00	562	963	689	2214
13:00	567	1096	820	2483
14:00	701	1236	844	2781
15:00	660	1070	568	2298
16:00	1092	1757	495	3344
17:00	**950**	**1865**	**678**	**3493**
18:00	1030	1862	629	3521

Morning Peak (7:00–9:00)

Evening Peak (16:00–18:00)

Dynamic Lane Grouping (DLG)

Dynamic Lane Grouping (DLG)

Dynamic Lane Grouping (DLG)

[Play DLG in the field]

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Dynamic Lane Grouping (DLG)

- Benefit-cost analysis based on SHRP2 report
  - Commuter travel time valued at 50% of prevailing wage rate
  - National wage rate of $21 per hour in the year 2009
- Simplifying assumptions
  - 250 commuting days per year
  - No life-saving benefits or GDP benefits
  - No safety costs or environmental costs

$$\frac{\$21}{hr} \times \frac{1\ wage\ rate}{2} \times \frac{1.6\ persons}{veh} = \frac{\$17}{veh \cdot hr}$$

Benefit-Cost Analysis

- Annual benefits between $68K and $295K
- Greatest benefits at high-volume intersections
- Benefit-cost ratios between 5:1 and 22:1
- This analysis assumed
  - 15-year lifespan for DMS signs, capital cost of $125K, O&M costs of $2K per year, 250 commuting days per year

	Capital Cost	Operating Cost
Dynamic Message Sign	$47-117K	$2.4-6K
Dynamic Message Sign Tower	$25-120K	
Dynamic Message Sign – Portable	$18-25K	$1.2-2K

Summary

- DLG reduces the gap between supply and demand
- Screening criteria quickly identify candidate locations
- Volume/Capacity was the top screening criterion
  - Few false positives
  - Candidates showed noticeable delay reductions
- Volume Change and Volume/Lane do not require signal data
- Case study results
  - DLG reduced overall intersection delay 15-30% in some cases

Featured Bottleneck Solutions

1. Dynamic Lane Grouping
2. **Dynamic Merge Control**
3. Acceleration Lane Extension
4. Hard Shoulder Running
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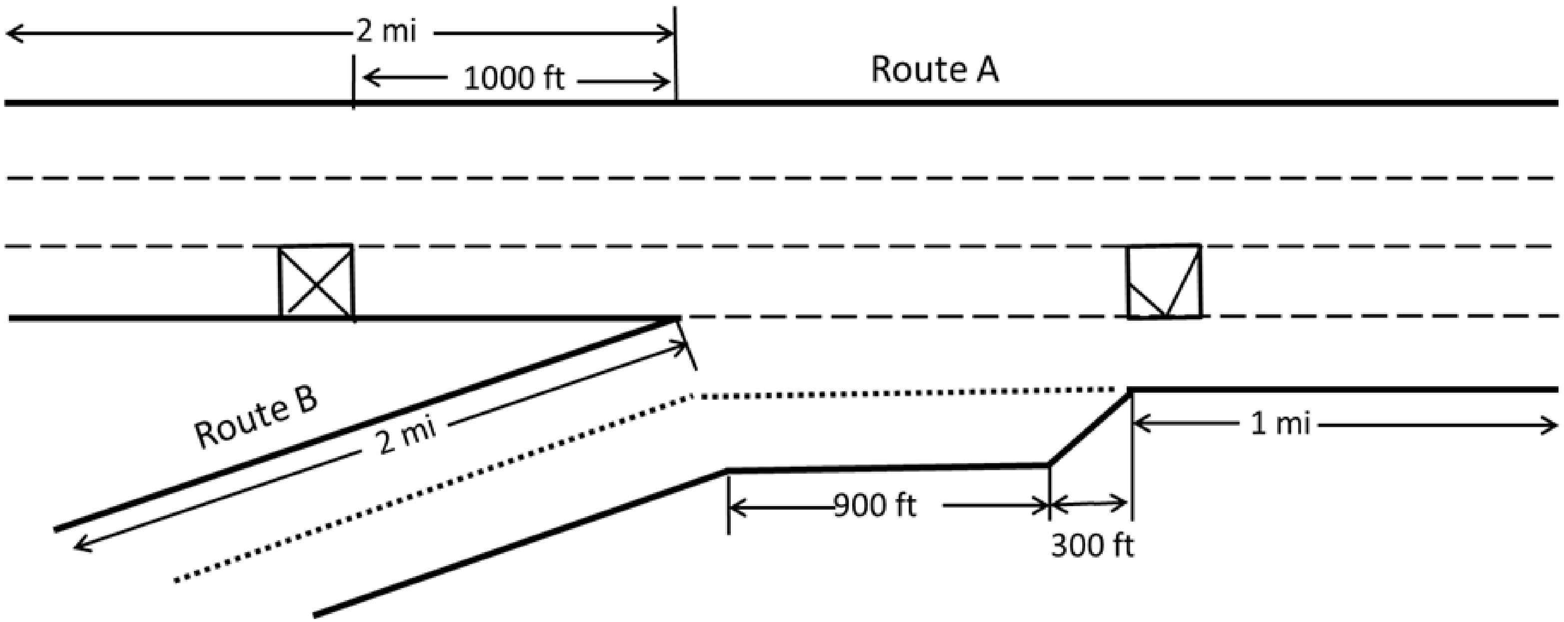
Dynamic Merge Control (DMC)

- Dynamic lane closing (mainline or on-ramp)
- Goal is to reduce friction in the merging area



Florida – Lane reconfiguration

Before: FDOT tried a faux work zone to change 3 lanes to 2

After: the plan worked so well they made it permanent

Dynamic Merge Control (DMC)

- Source: “Managed Lanes in the Netherlands” by Bert Helleman

Dynamic Merge Control (DMC)

- Source: “Managed Lanes in the Netherlands” by Bert Helleman

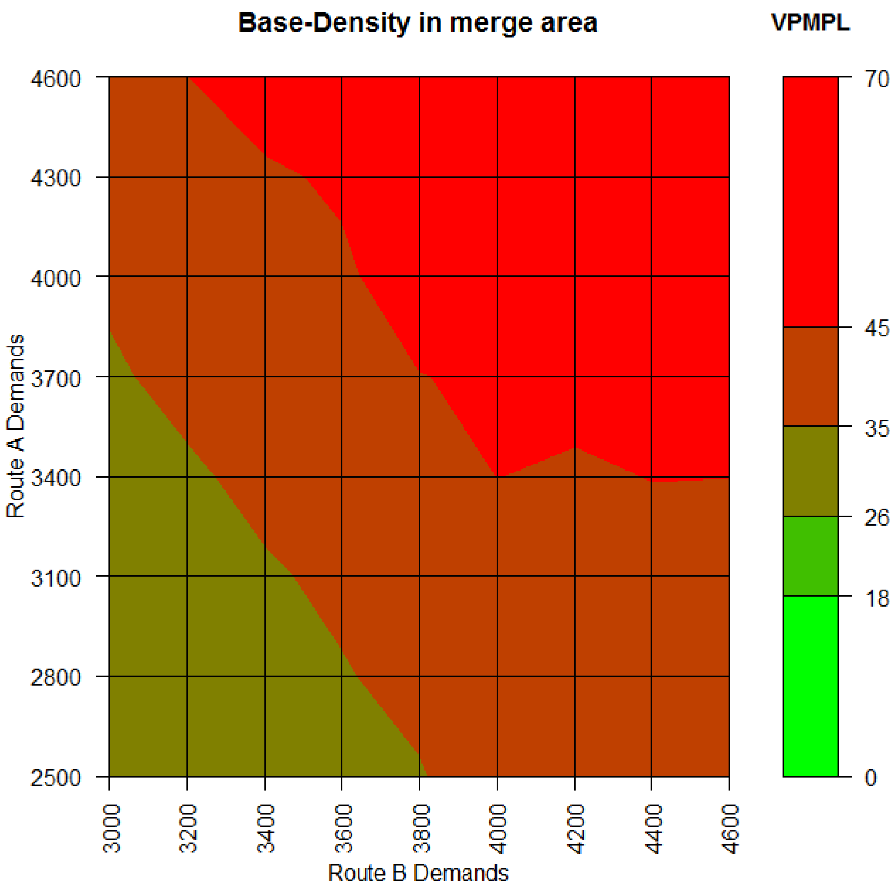
Evaluation results

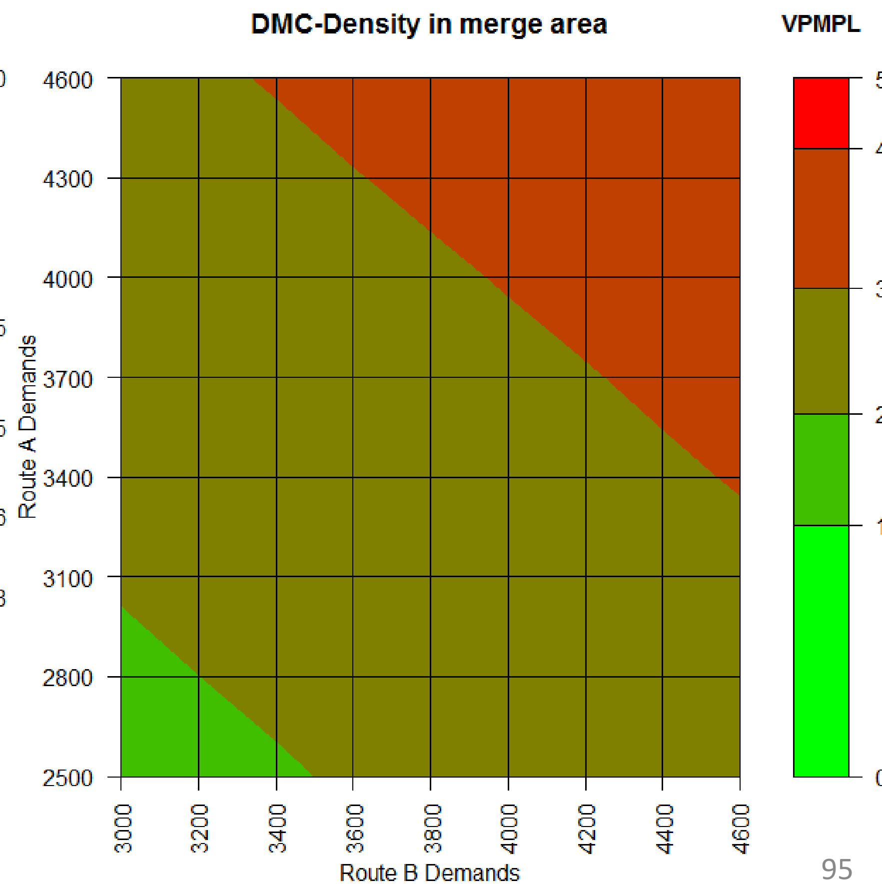
Red route	Free flow	Without IMC	With IMC	Change %
mean travel time	4.76	11.03	10.42	- 8%
mean travel speed	98	41	45	+ 8%
Vehicle hours of delay	-	1558	1361	- 13%

Blue route	Free flow	Without IMC	With IMC	Change %
mean travel time	2.78	7,07	6.56	- 7%
mean travel speed	106	42	45	+ 7%
Vehicle hours of delay	-	1455	1398	- 4%

Dynamic Merge Control (DMC)

- Hypothetical network study (3-lane merge with 2-lane)
- DMC substantially improved flows for all demand combinations

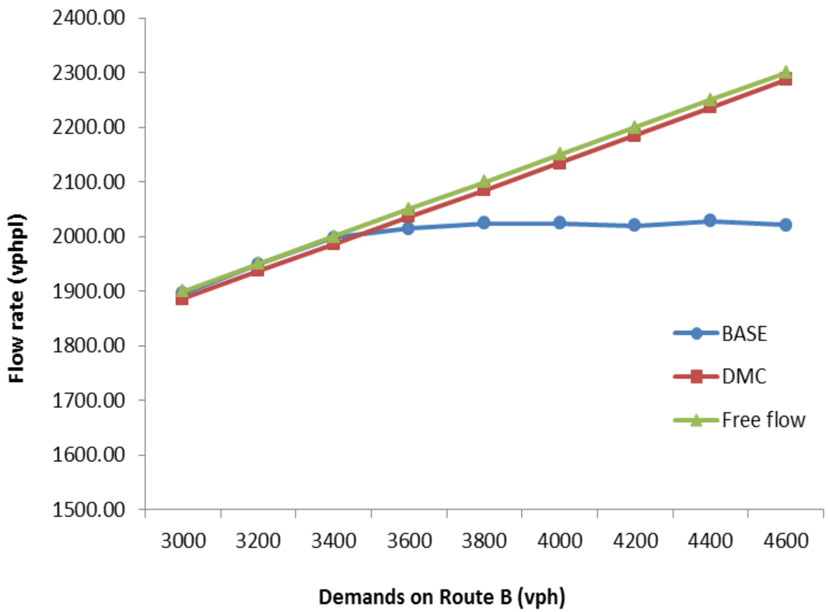




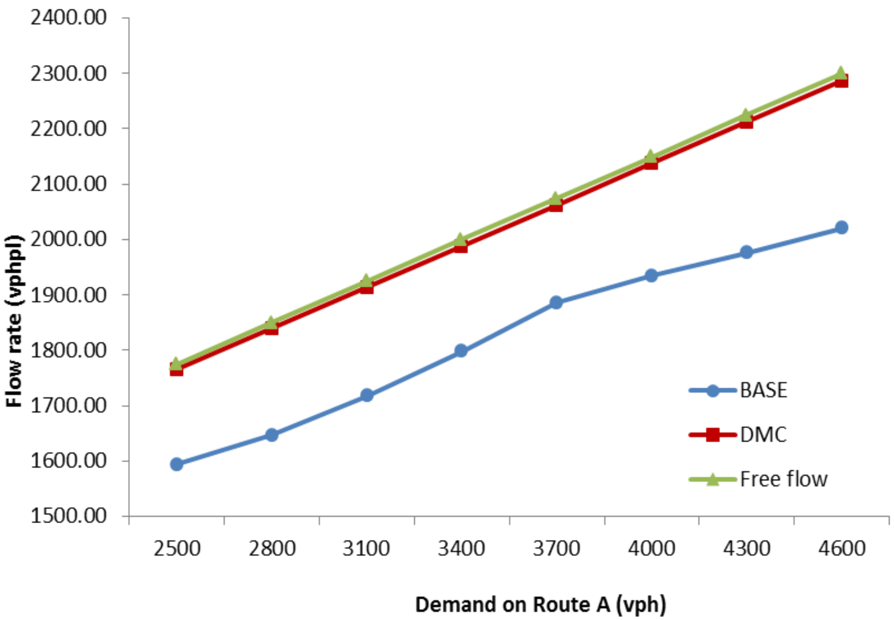
Dynamic Merge Control (DMC)

- Hypothetical network study
- Without DMC, merge-area capacity constrained by weaving friction

RAMP



MAINLINE



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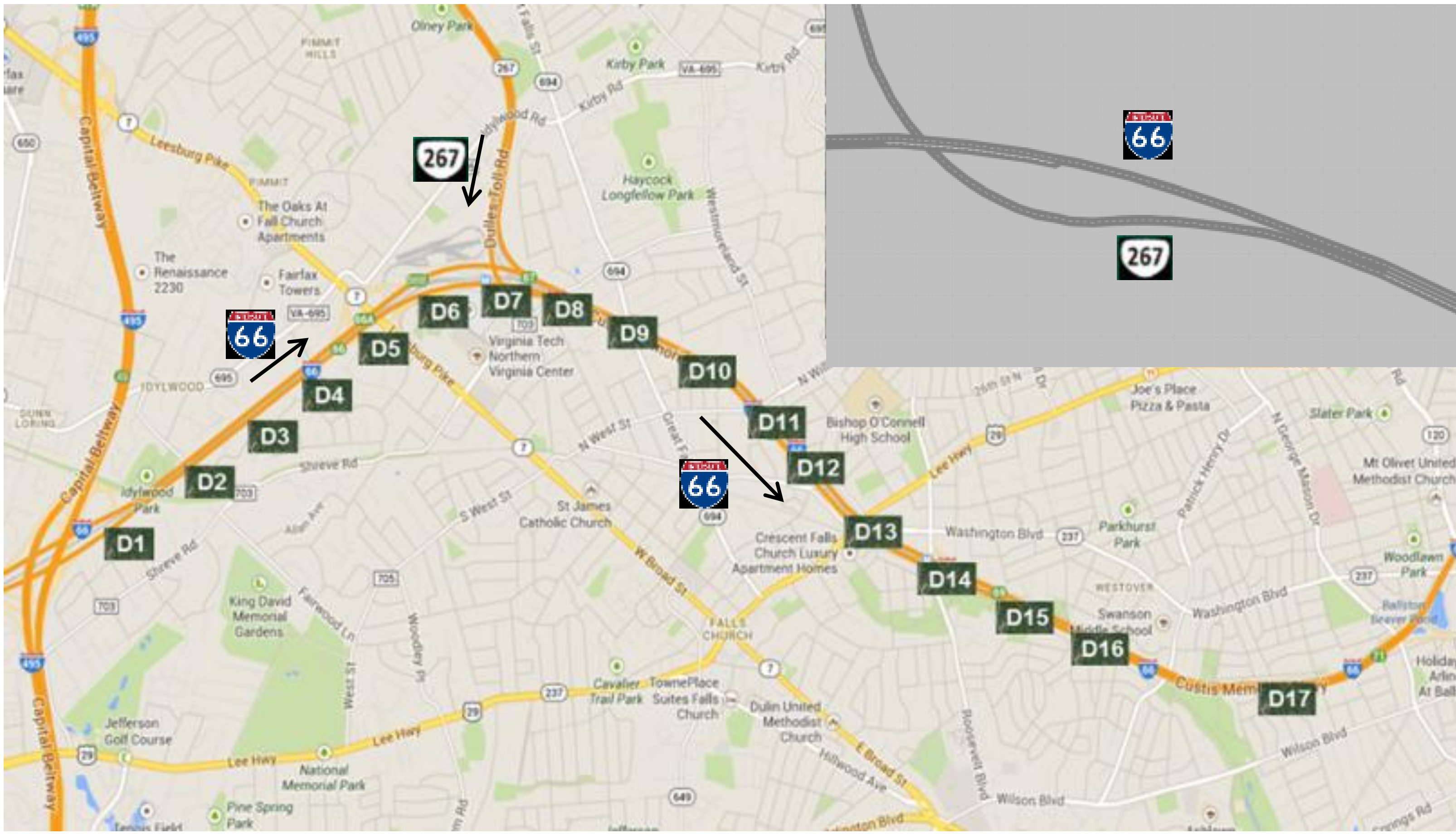
Dynamic Merge Control (DMC)

- Real-world network study (Virginia's I-66)



Dynamic Merge Control (DMC)

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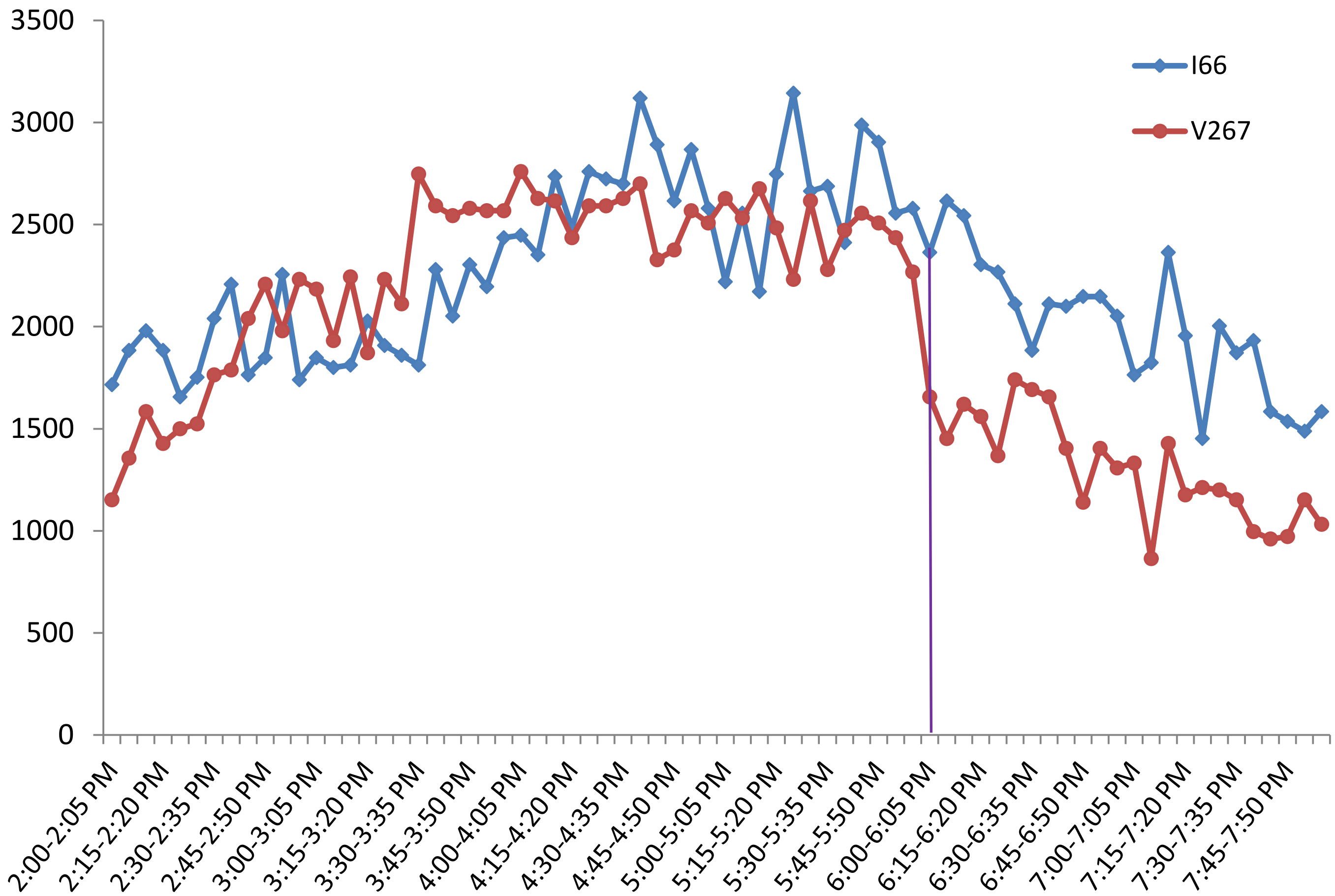

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Dynamic Merge Control (DMC)

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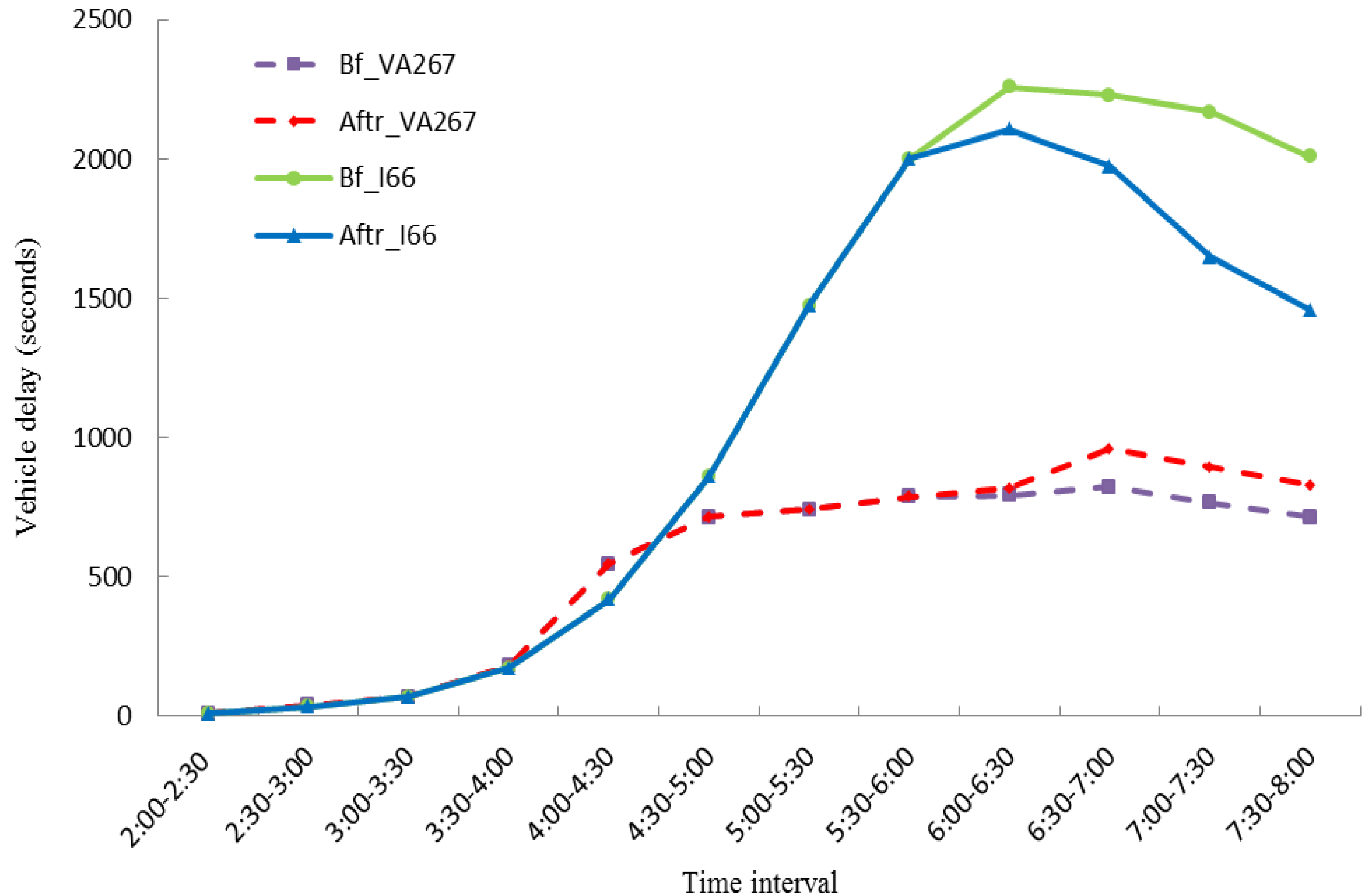

Before DMC

Play video

After DMC

[Play video]

Benefit-Cost Analysis

- Annual benefits between $236K and $1.02M
- Greatest benefits at high-volume on-ramps
- Benefit-cost ratio between 8:1 and 36:1
- This analysis assumed
  - 15-year lifespan for DMS signs, capital cost of $250K, O&M costs of $6K per year, 250 commuting days per year

	Capital Cost	Operating Cost
Dynamic Message Sign	$47-117K	$2.4-6K
Dynamic Message Sign Tower	$25-120K	
Dynamic Message Sign – Portable	$18-25K	$1.2-2K

Summary

- DMC strategy produced benefits at all demand combinations
- Strongest benefits when on-ramp demand reaches 1900 vphpl
- Less weaving friction in the merge area
  - increases capacity
  - delays formation of bottlenecks

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Featured Bottleneck Solutions

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Extending Acceleration Lanes

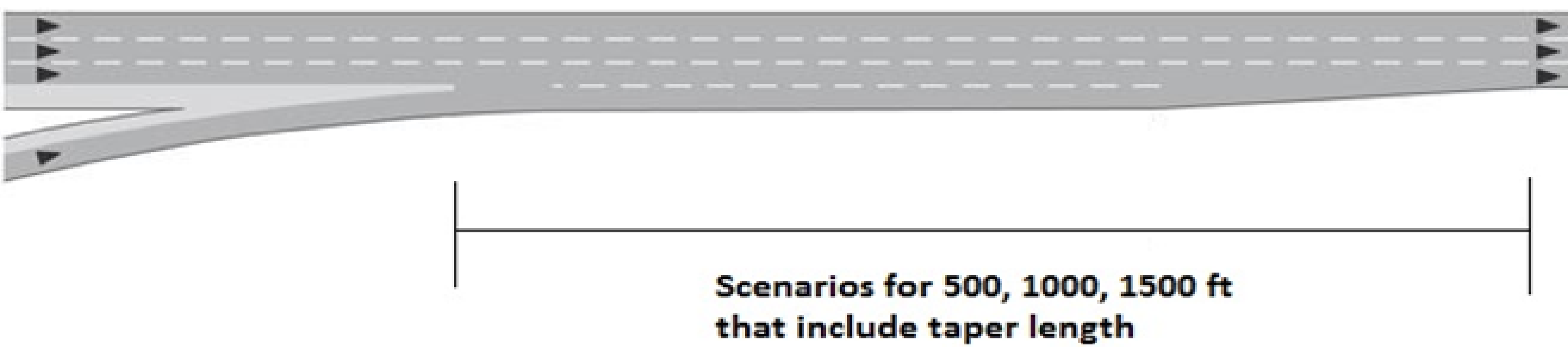
- Acceleration lane merging causes severe bottlenecks
- AASHTO guidelines: some acceleration lanes too short
- Paramics simulations: 3-lane and 4-lane corridors
  - increasing from 500 to 1000 feet
  - increasing from 500 to 1500 feet

Extending Acceleration Lanes

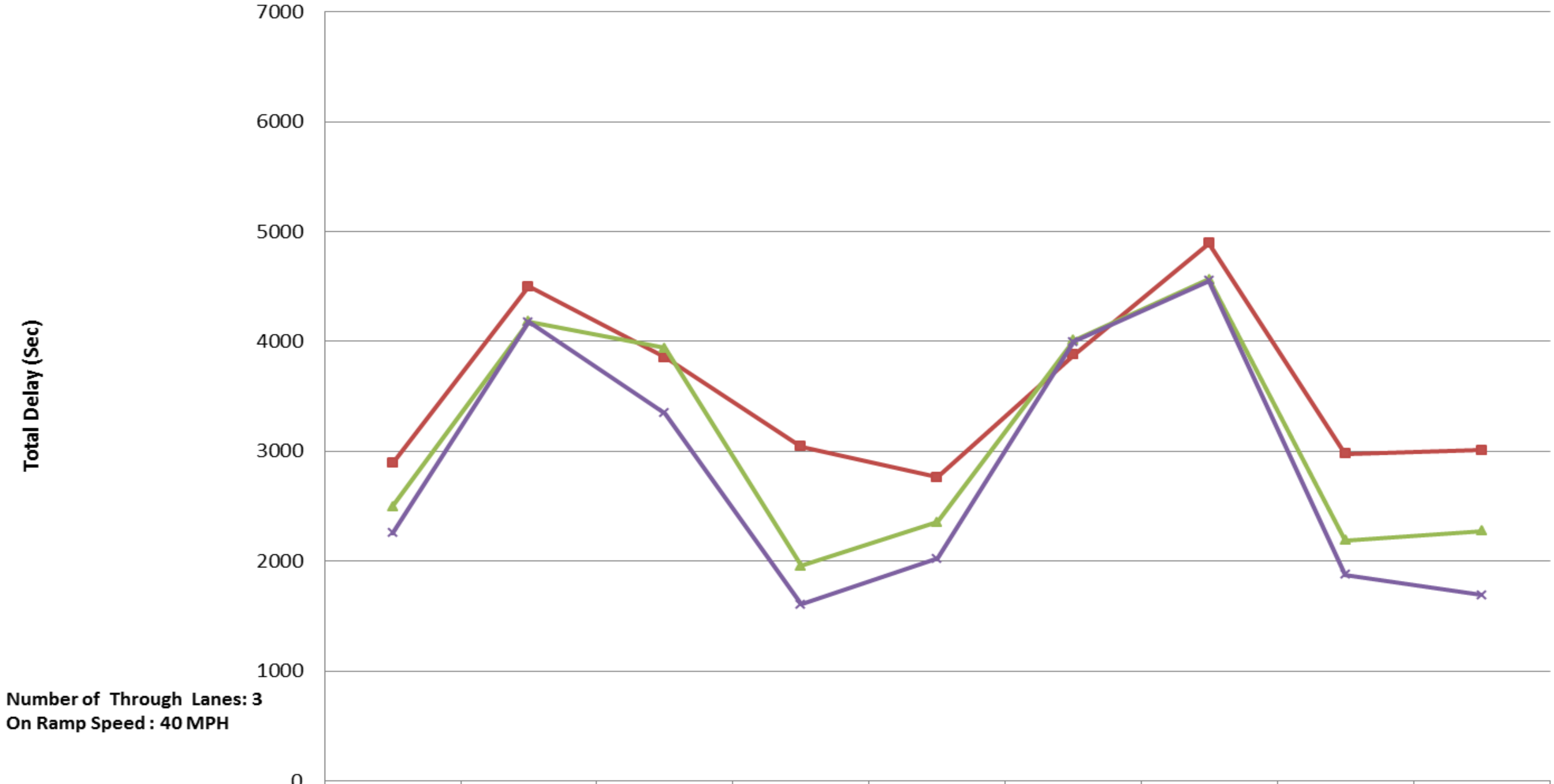
	Through Lanes	Ramp Speed	Acceleration Length	AASHTO Guideline
No.	(Number)	(Mph)	(Feet)	(Feet)
1	3	40	500	780+300 taper
2	3	40	1000	780+300 taper
3	3	40	1500	780+300 taper
4	3	30	500	1160+300 taper
5	3	30	1000	1160+300 taper
6	3	30	1500	1160+300 taper
7	4	40	500	780+300 taper
8	4	40	1000	780+300 taper
9	4	40	1500	780+300 taper
10	4	30	500	1160+300 taper
11	4	30	1000	1160+300 taper
12	4	30	1500	1160+300 taper

Extending Acceleration Lanes

Scenario No.	Through Demand (Vehicles)	ON Ramp Demand (Vehicles)
1	4847	1278
2	5047	1278
3	5547	778
4	4147	1578
5	3547	1978
6	5797	578
7	5347	1078
8	4547	1428
9	4047	1678



Total Delay (Minutes)



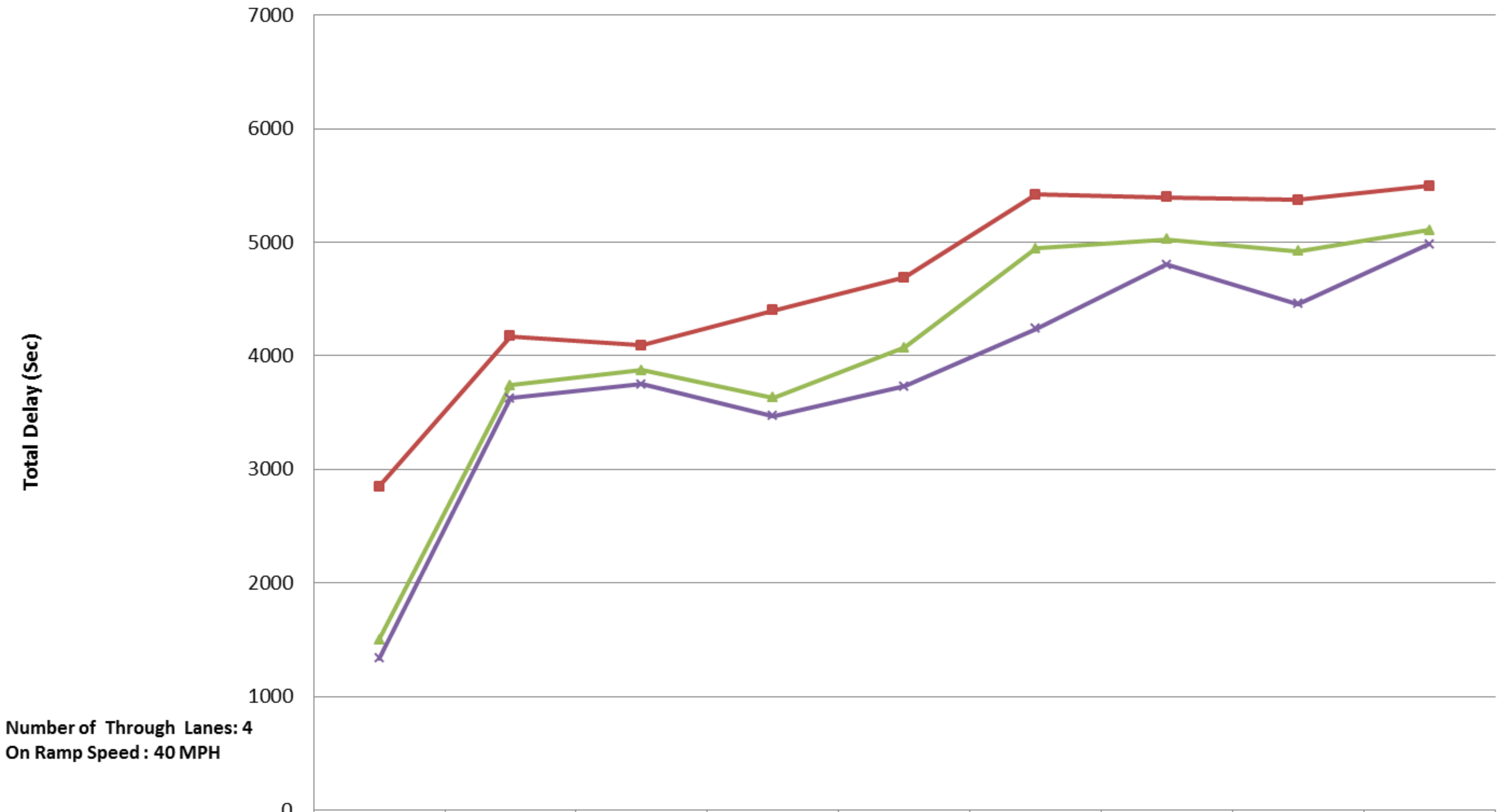
	1	2	3	4	5	6	7	8	9
500 Feet	2890	4497	3855	3044	2764	3880	4892	2976	3011
1000 feet	2495	4182	3939	1958	2354	4011	4564	2189	2272
1500 feet	2255	4176	3344	1603	2025	3998	4552	1876	1691
Through Demand (Veh.)	4847	5047	5547	4147	3547	5797	5347	4547	4047
On Ramp Demand (Veh.)	1278	1278	778	1578	1978	578	1078	1428	1678

Extending Acceleration Lanes

Volume demands (4-lane configuration)

Scenario No.	Through Demand (Vehicles)	ON Ramp Demand (Vehicles)
10	5347	1278
11	5647	1278
12	6147	1278
13	5347	1478
14	5347	1678
15	5647	1478
16	5647	1678
17	6147	1478
18	6147	1678

Total Delay (Minutes)



	10	11	12	13	14	15	16	17	18
500 Feet	2850	4171	4092	4400	4687	5421	5394	5374	5496
1000 feet	1500	3742	3875	3630	4072	4945	5028	4920	5106
1500 feet	1335	3624	3751	3472	3731	4236	4801	4458	4982
Through Demand (Veh.)	5347	5647	6147	5347	5347	5647	5647	6147	6147
On Ramp Demand (Veh.)	1278	1278	1278	1478	1678	1478	1678	1478	1678

Benefit-Cost Analysis

- Annual benefits between $45K and $79K
- Greatest benefits when on-ramp flow > 1400 veh/hr/ln
- No benefits when on-ramp flow < 800 veh/hr/ln
- Benefit-cost ratios between 1:1.4 and 20:1
- TTI research on acceleration lanes
  - simple shoulder conversion cost between $50K and $100K
  - complex retrofits can cost over $1M
  - Arlington TX spent $640K to extend ramp/accel lane (2014)

	1000 feet	1500 feet
3-lane, 40 mph	$ 27,965	$ 44,965
3-lane, 30 mph	$ 34,354	$ 61,058
4-lane, 40 mph	$ 43,562	$ 67,717
4-lane, 30 mph	$ 42,712	$ 78,838

Summary

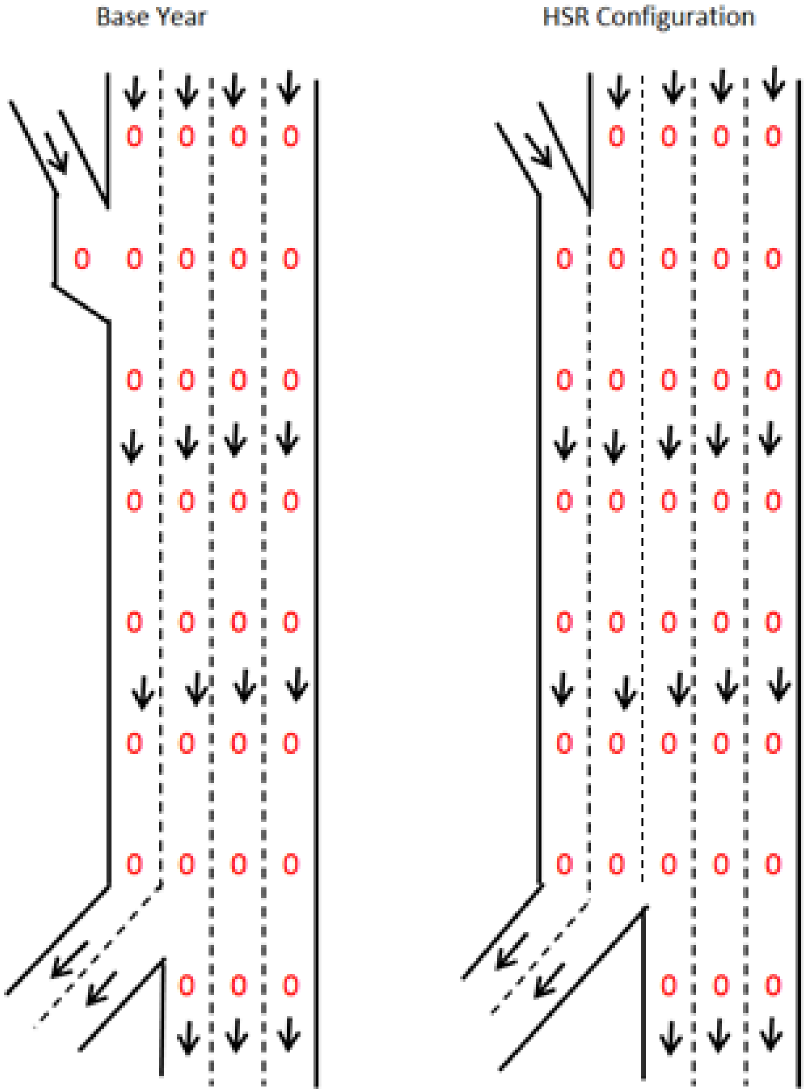
- Increasing from 500 to 1000 feet
  - reduced delay by 14% (average)
- Increasing from 500 to 1500 feet
  - reduced delay by 23% (average)
- Reduced delay up to 36% when on-ramp flow > 1400 veh/hr/ln
- No delay reduction when on-ramp flow < 800 veh/hr/ln

Featured Bottleneck Solutions

1. Dynamic Lane Grouping
2. Dynamic Merge Control
3. Acceleration Lane Extension
4. **Hard Shoulder Running**
5. Lane Narrowing to Add a Lane
6. Alternative Intersections and Interchanges

Hard Shoulder Running (HSR)

- Use of limited hard shoulder running for better merge control



Hard Shoulder Running (HSR)

- Simulation scenarios
  - Demand level (*3)
  - Speed limit and likelihood of use (*3)

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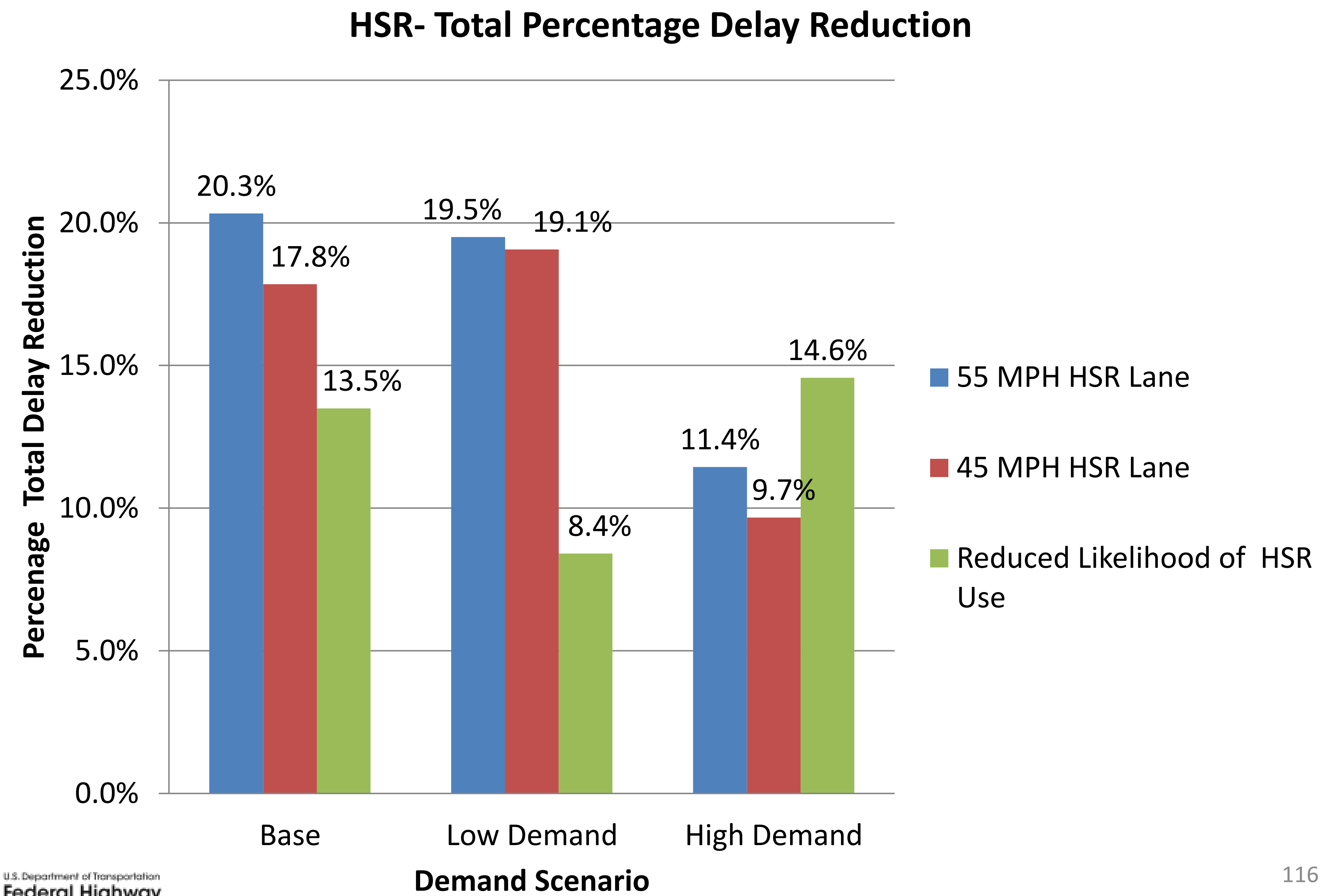
Federal Highway Administration

Hard Shoulder Running (HSR)



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Federal Highway Administration

Benefit-Cost Analysis

- Benefit-cost ratios between 1:1 and 21:1
- Assumptions
  – 30-year life, annual O&M $6-12K, start-up costs $0.25-1.5M

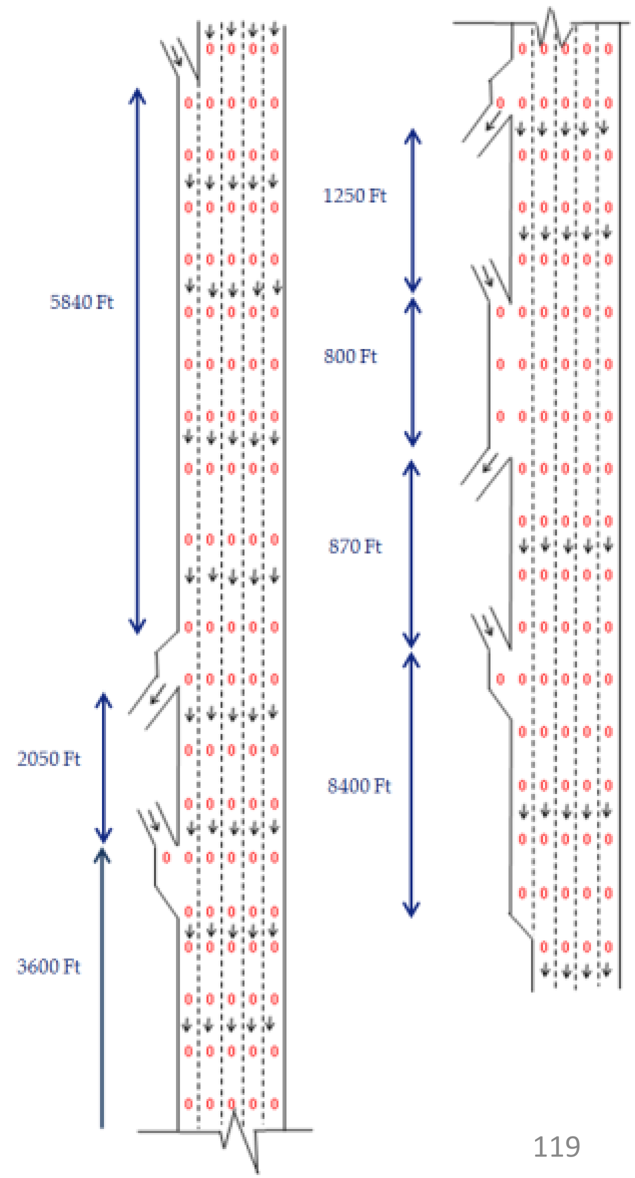
Simulation No.	Demand	HSR Type	Total Delays (Hours)	Annual Savings ($)
1	Base	No HSR	136.4	--
2	Base	55 MPH HSR Lane	108.7	$353,100
3	Base	45 MPH HSR Lane	112.1	$309,900
4	Base	Reduced HSR Use	118.0	$234,600
5	Low	No HSR	96.3	--
6	Low	55 MPH HSR Lane	77.5	$239,700
7	Low	45 MPH HSR Lane	78.0	$233,400
8	Low	Reduced HSR Use	88.2	$103,200
9	High	No HSR	224.9	--
10	High	55 MPH HSR Lane	199.1	$329,100
11	High	45 MPH HSR Lane	203.1	$278,100
12	High	Reduced HSR Use	192.1	$418,200

Featured Bottleneck Solutions

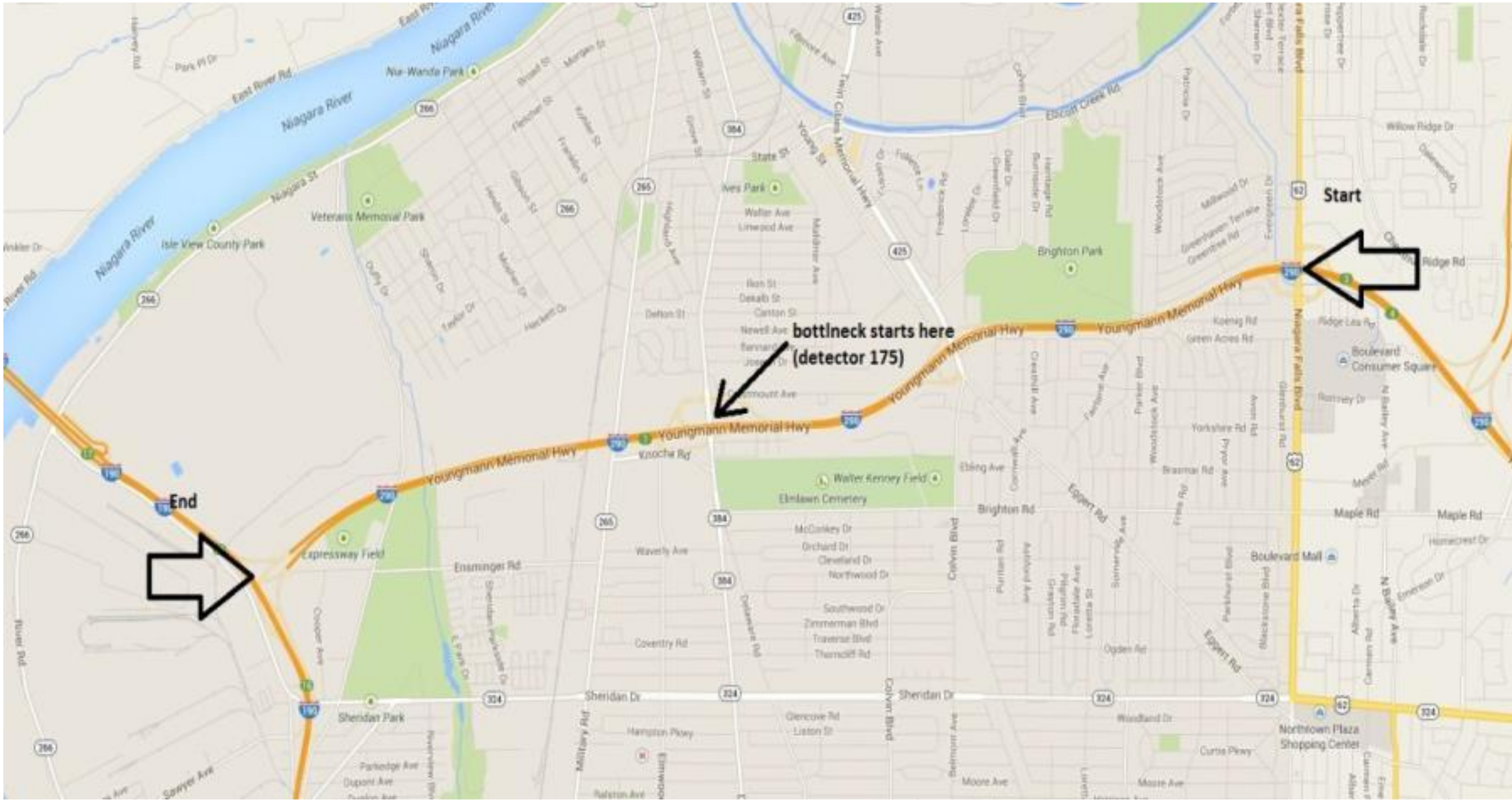
1. Dynamic Lane Grouping
2. Dynamic Merge Control
3. Acceleration Lane Extension
4. Hard Shoulder Running
5. **Lane Narrowing to Add a Lane**
6. Alternative Intersections and Interchanges

Lane Narrowing to Add a Lane

- Reducing lane width to 10’
  - often without construction,
  - or requisition of additional space
- Compared vs. five 12-foot lanes
  - impact of additional roadway
  - vs. redistributing the existing one

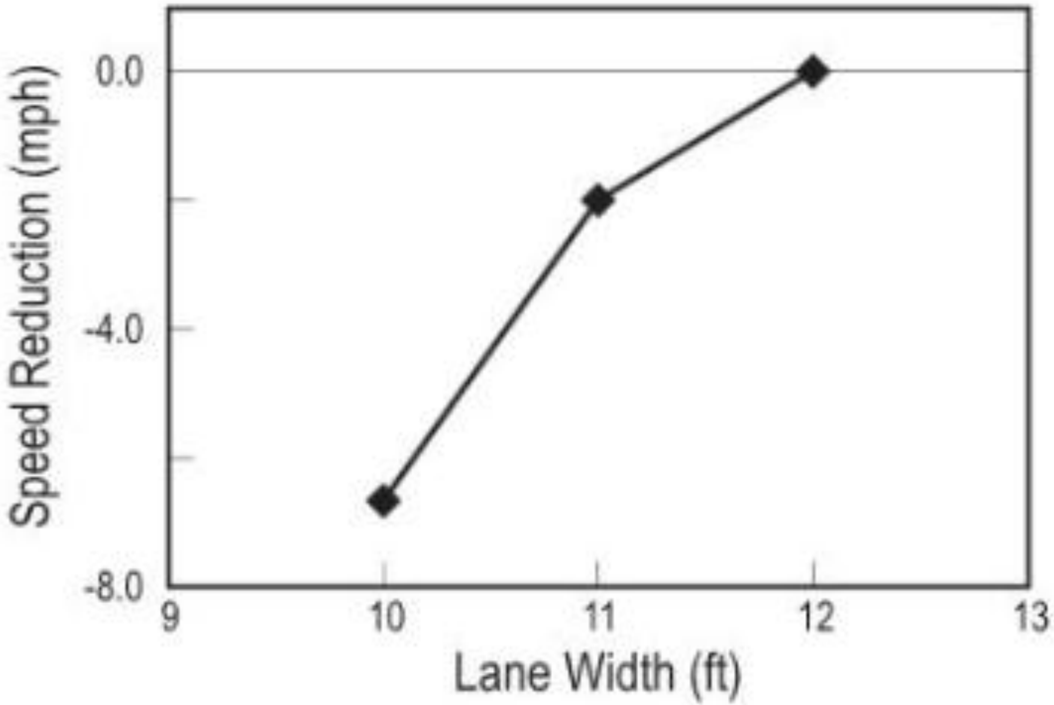


Lane Narrowing to Add a Lane



Lane Narrowing to Add a Lane

- Drivers reduce speed on lanes narrower than 12 feet
  - HCM, TransModeler



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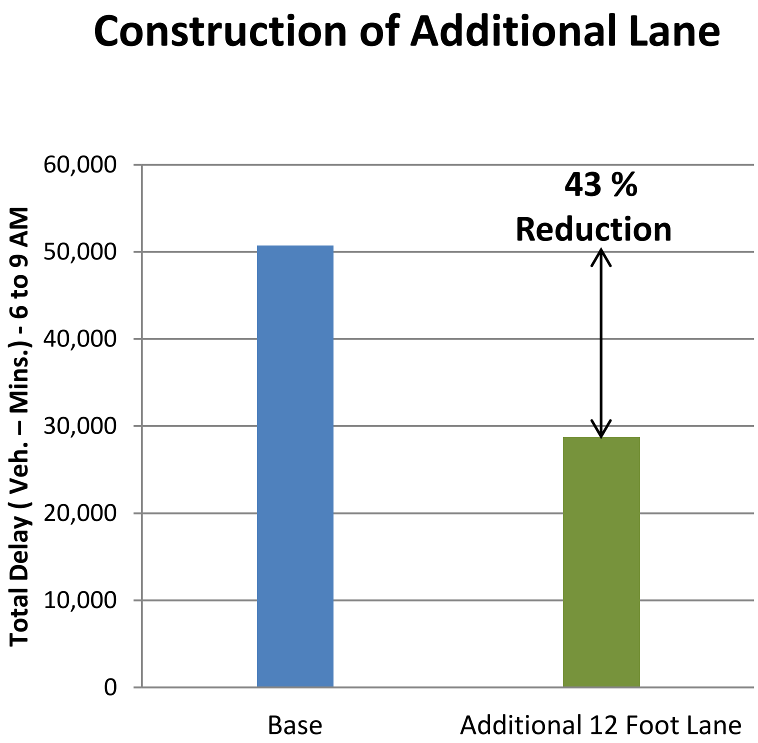
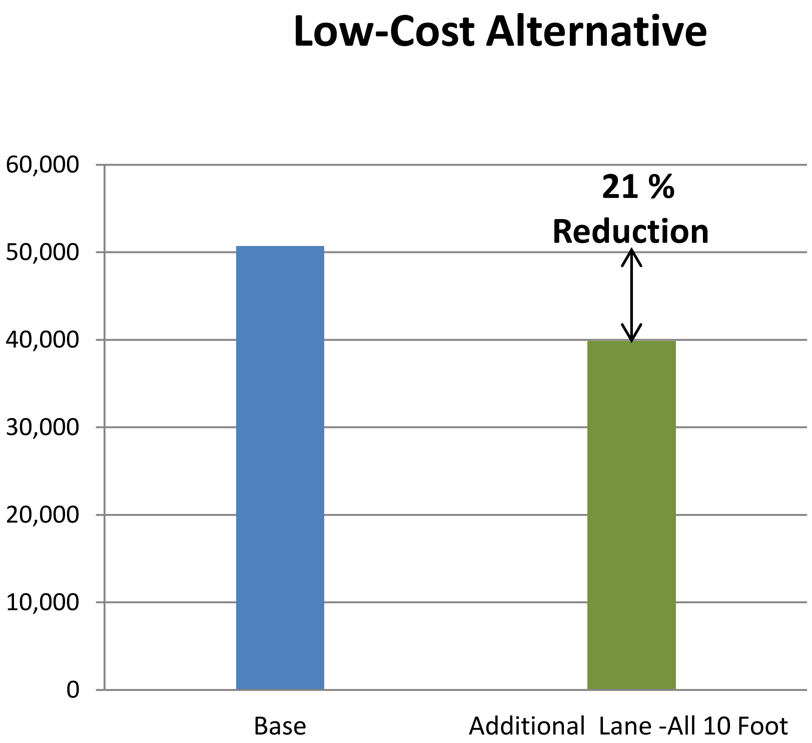
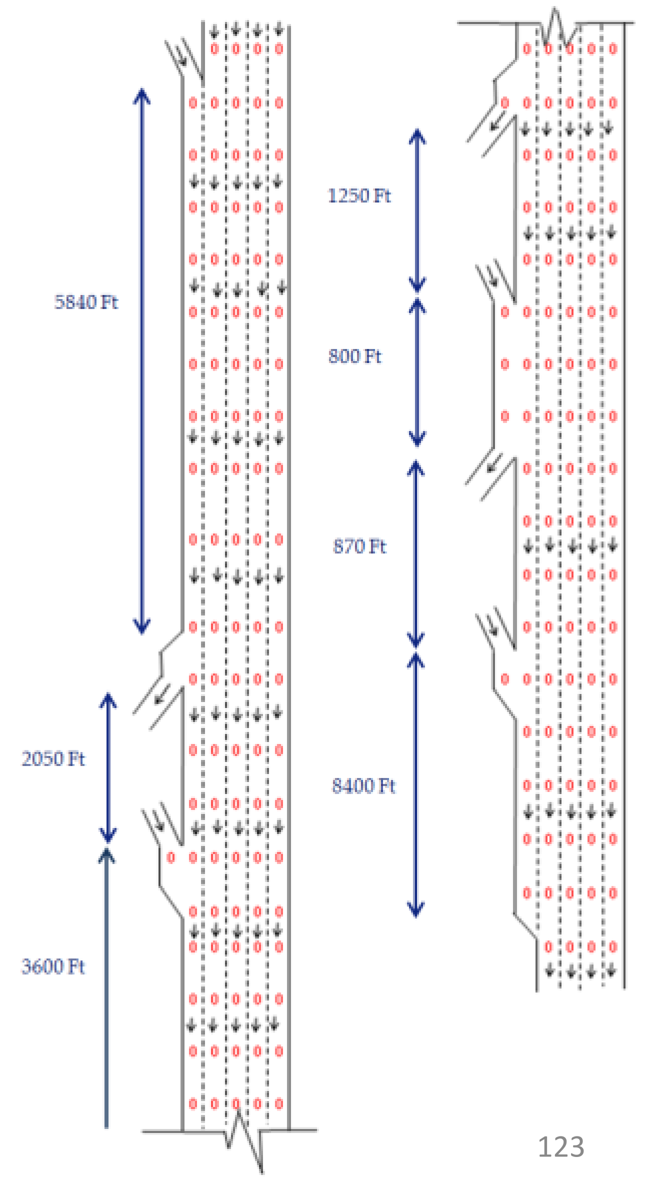
Lane Narrowing to Add a Lane





Lane Narrowing to Add a Lane

- Benefit-cost ratio of roughly 20:1
- Assumptions
  - 30-year life
  - annual O&M of $26K per mile
  - start-up cost of $2M



Featured Bottleneck Solutions

1. Dynamic Lane Grouping
2. Dynamic Merge Control
3. Acceleration Lane Extension
4. Hard Shoulder Running
5. Lane Narrowing to Add a Lane
6. **Alternative Intersections and Interchanges**

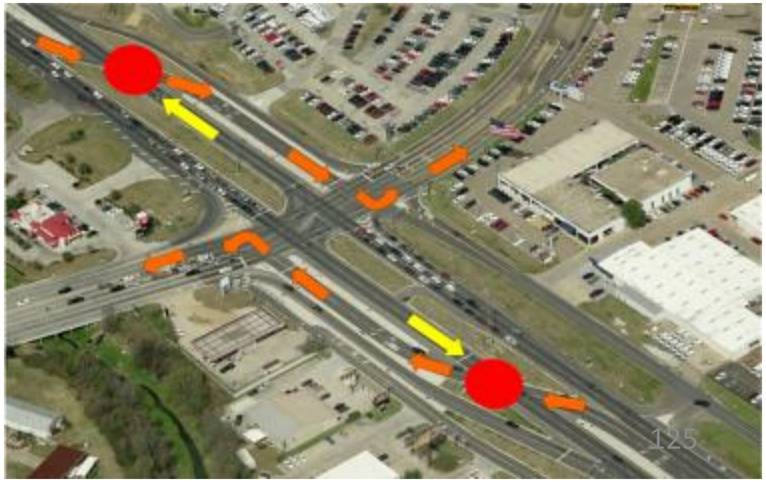
Alternative Intersection Design

Diverging Diamond Interchange

Median U-Turn

Restricted Crossing U-Turn

Displaced Left-Turn Lane



Double Crossover Diamond Interchange aka Diverging Diamond Interchange (DDI)

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Diverging Diamond Interchange (DDI)

Play video

Median U-Turn Intersection (MUT)

20% to 50% increase in throughput

15% to 30% reduction in network travel time

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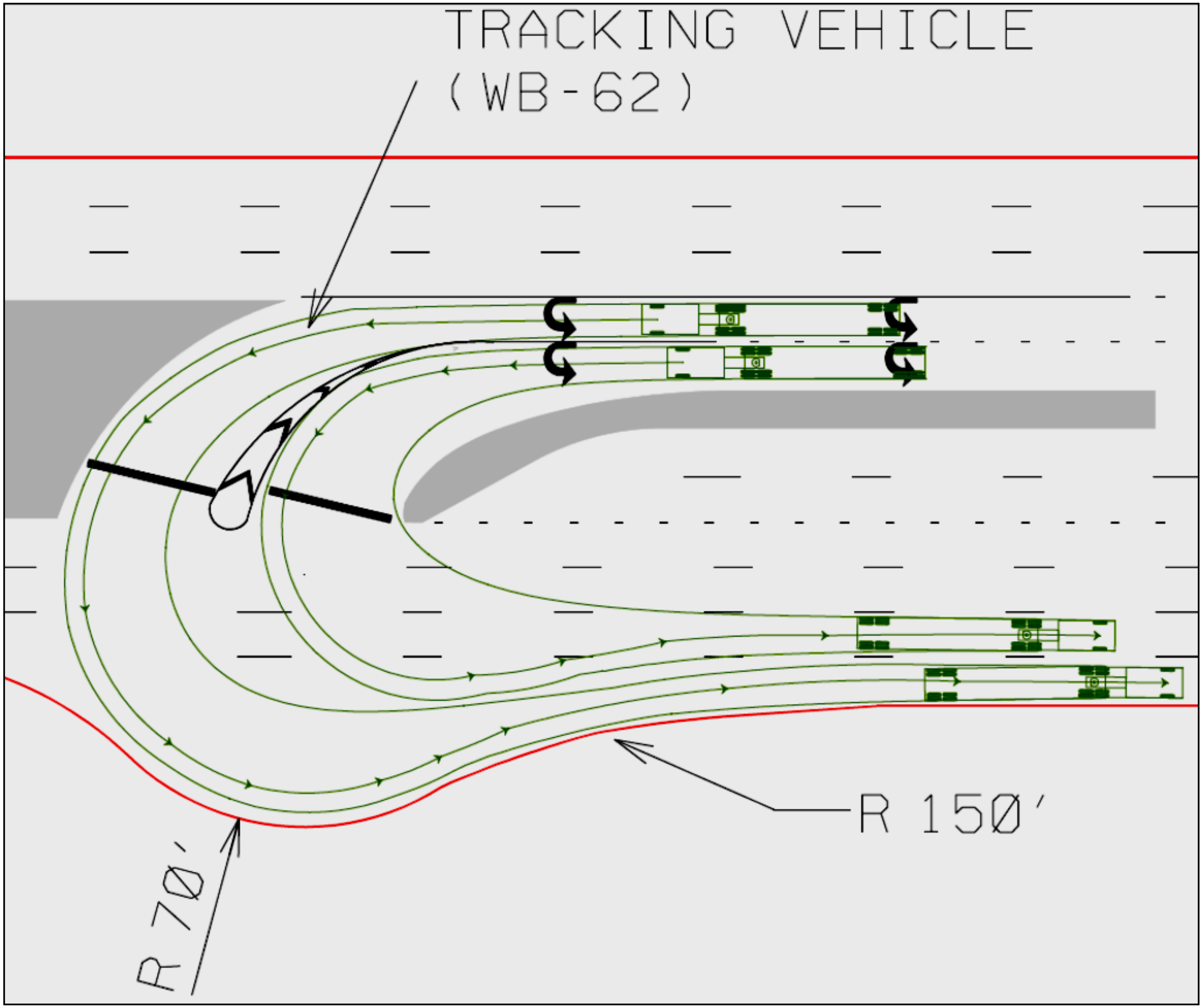
Median U-Turn Intersection (MUT)

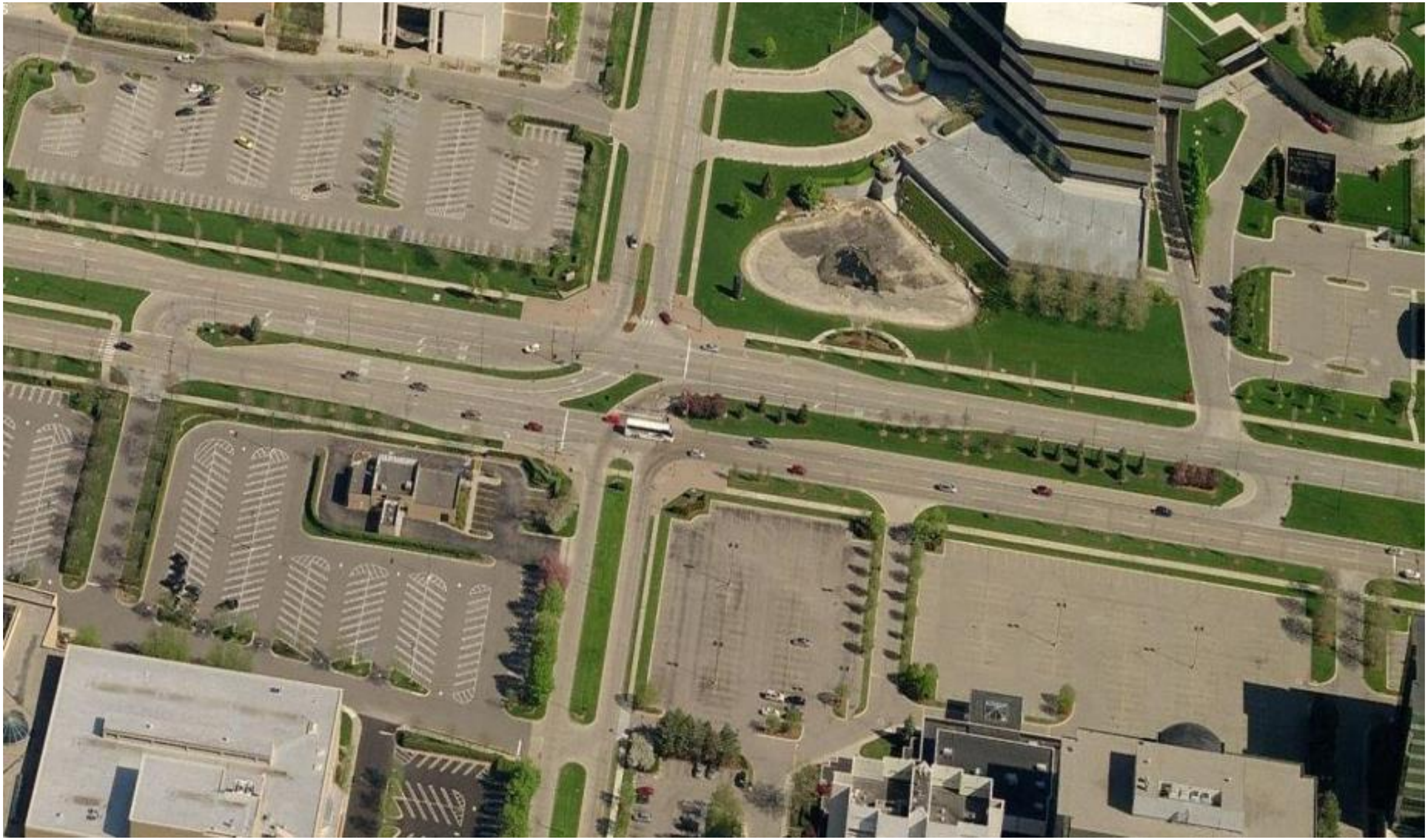
Wide median is not necessary



Median U-Turn Intersection (MUT)

Play video

Restricted Crossing U-Turn (RCUT)



RCUT Intersection – Implementations

U.S. Rt. 301 and Del Rhodes Ave Unsignalized RCUT in Maryland

RCUT Intersection – Implementations

Restricted Crossing U-Turn (RCUT)

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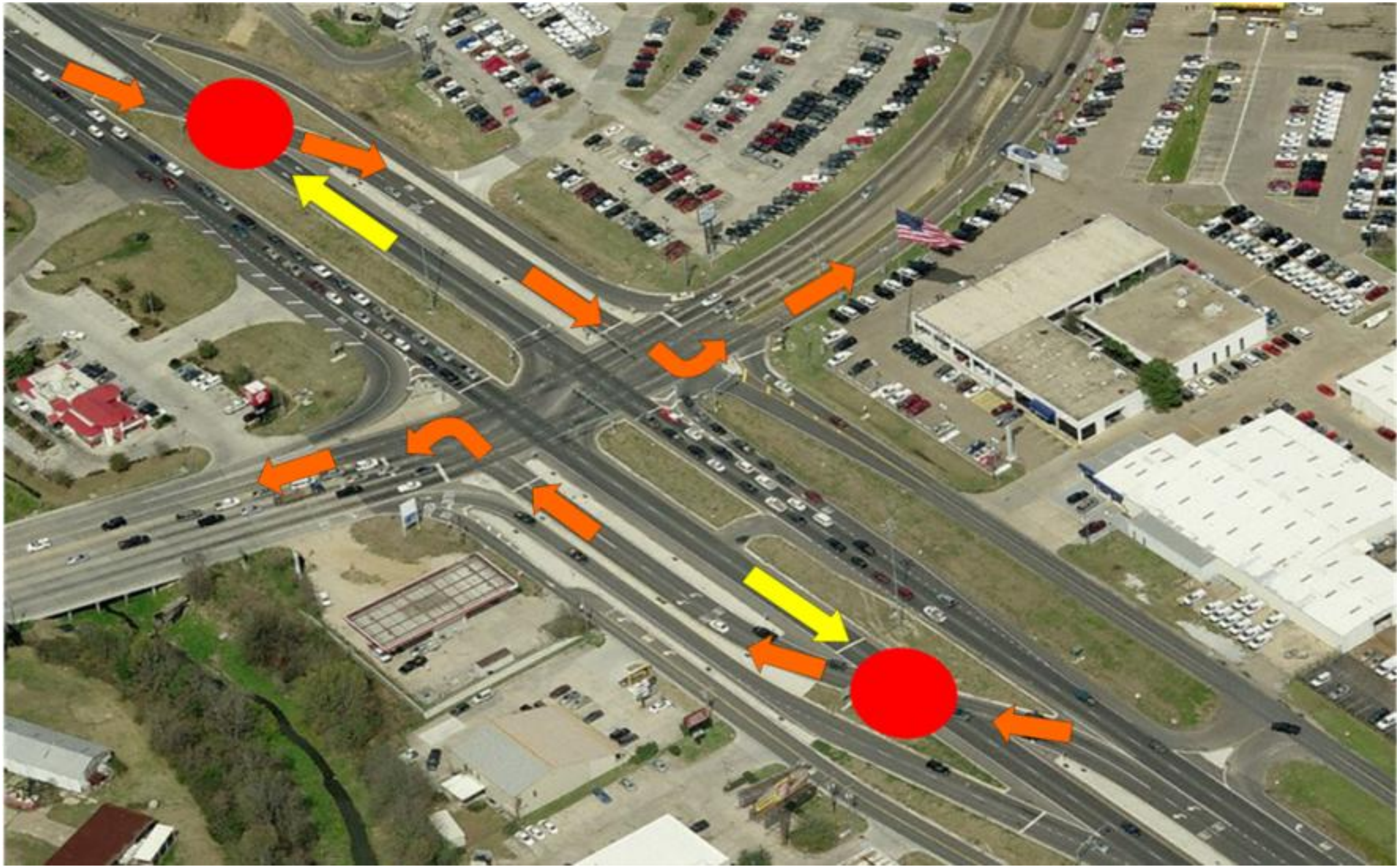
Displaced Left-Turn Intersection (DLT)
aka Continuous Flow Intersection

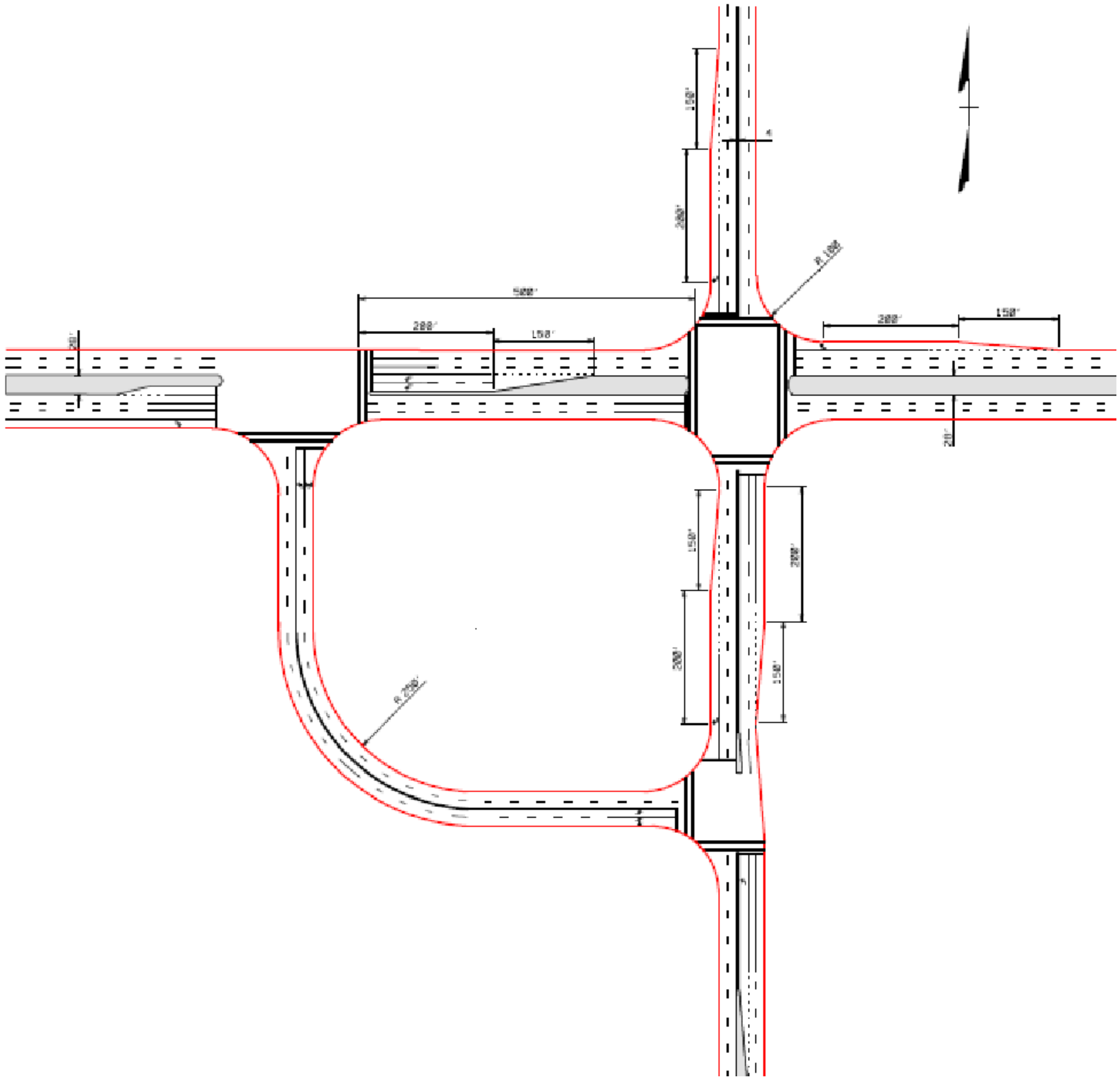


DLT Intersection in Utah (without bypass right-merge lane)

Displaced Left-Turn Intersection (DLT)
aka Continuous Flow Intersection

Play video

Quadrant Roadway Intersection Design



Fairfield, OH

(Google map image)

Quadrant Roadway Intersection

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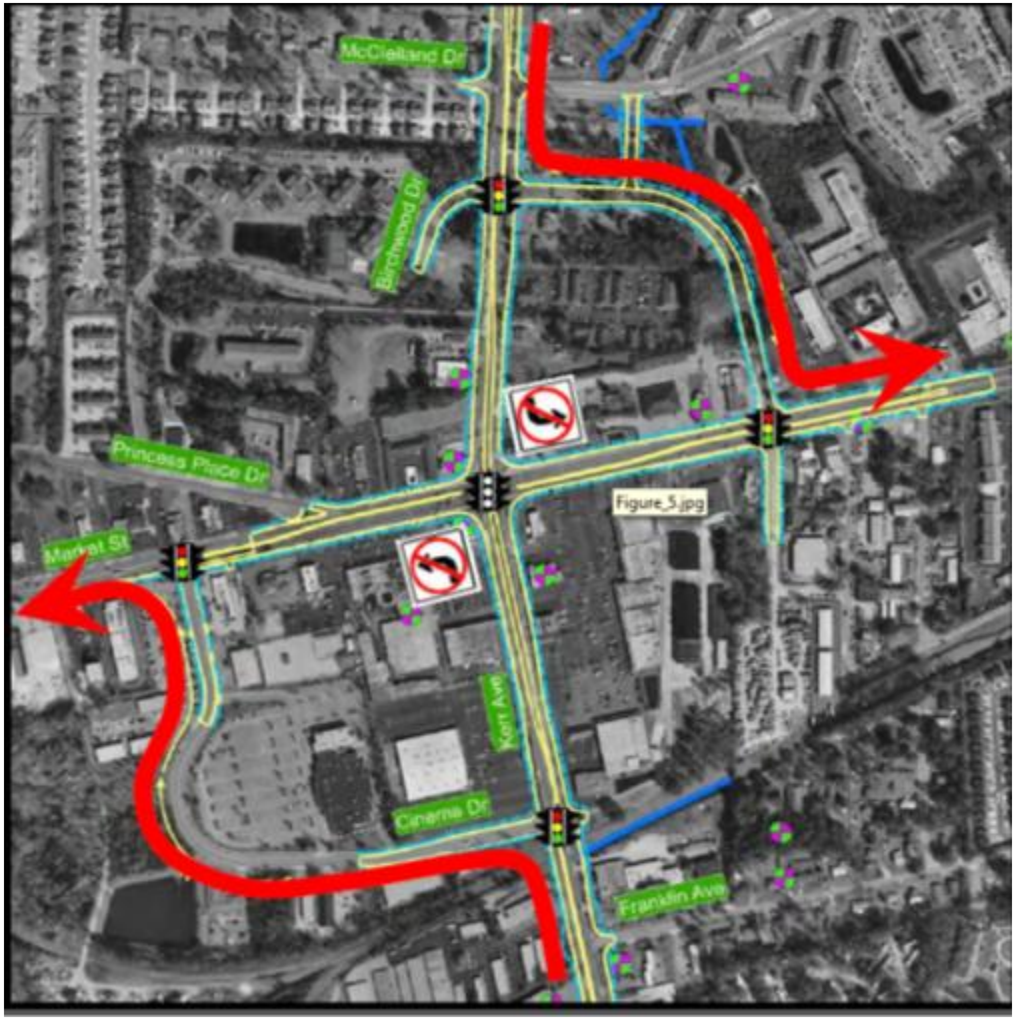
Proposed NC Double Quadrants

From Presentation by VHB, Nov. 2013



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Quadrant Roadway Intersection

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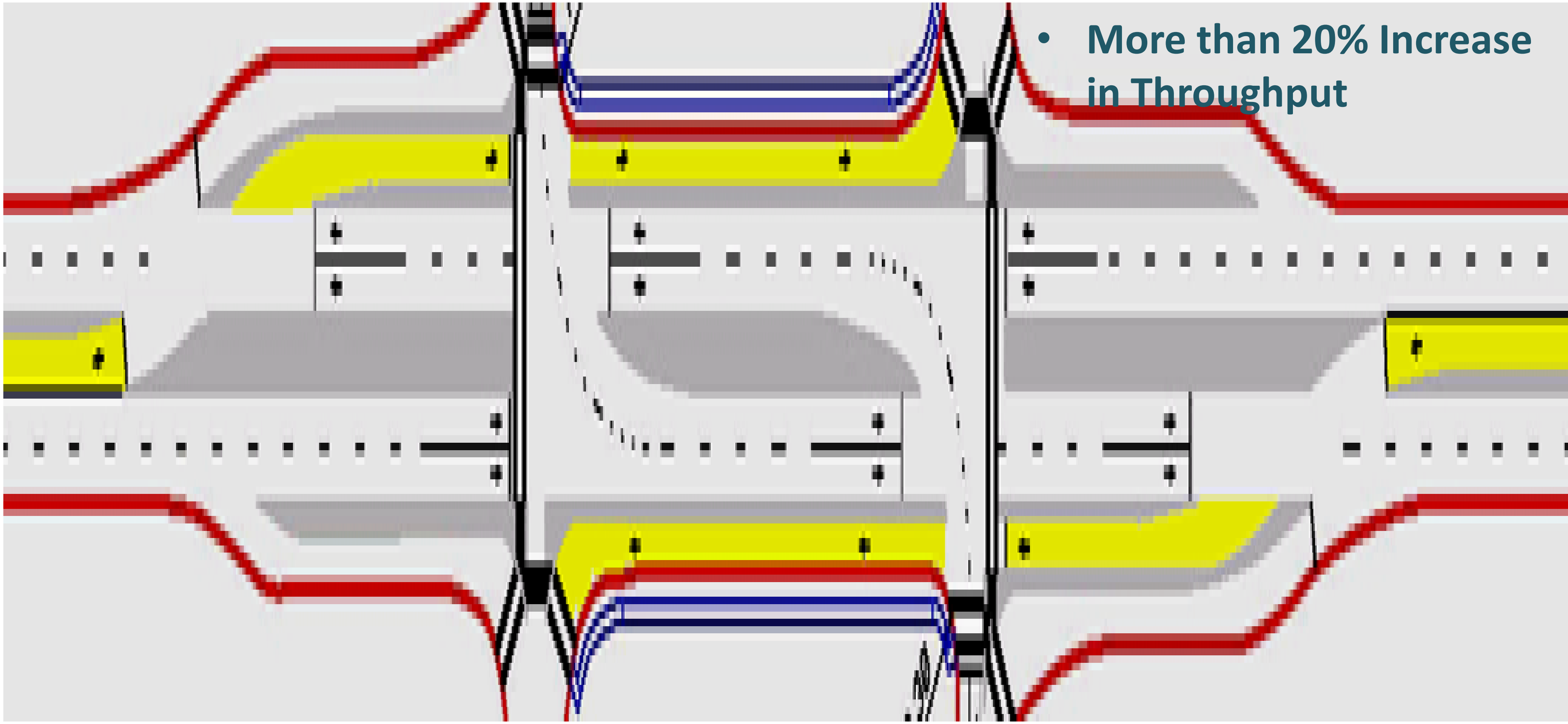
Displaced Left-Turn Interchange Concept



- More than 20% Increase in Throughput

Displaced Left-Turn Interchange

Play video

DLT Interchange with Peds

Play video

Displaced Left-Turn Interchange First Implementation in San Marcos, TX

https://www.youtube.com/watch?v=ULyjDcEeHG0&feature=youtu.be

Displaced Left-Turn Interchange First Implementation in San Marcos, TX

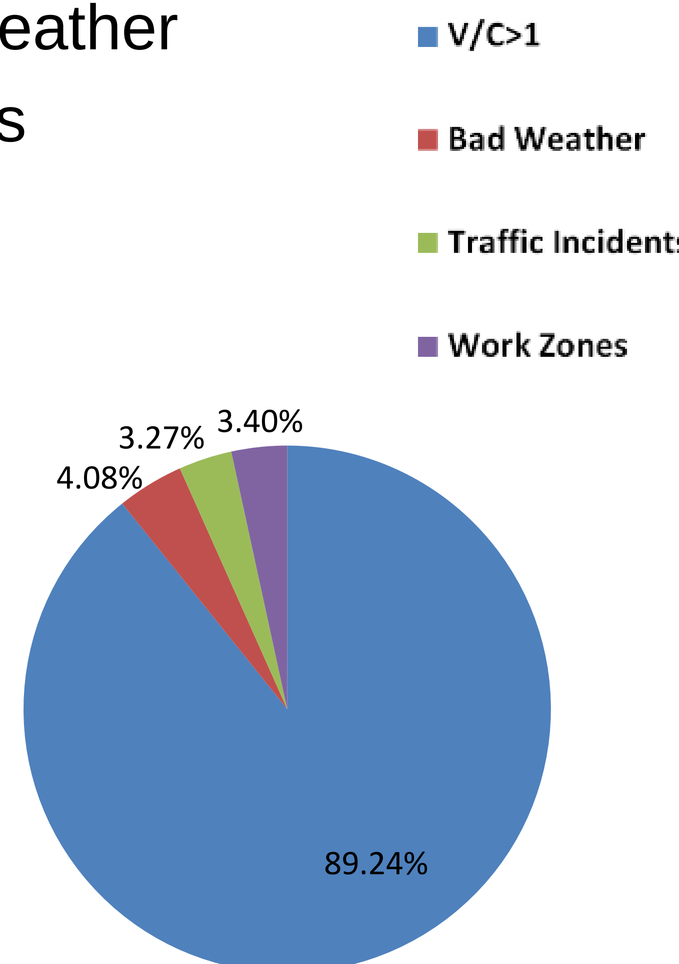
Play video

Workshop Summary

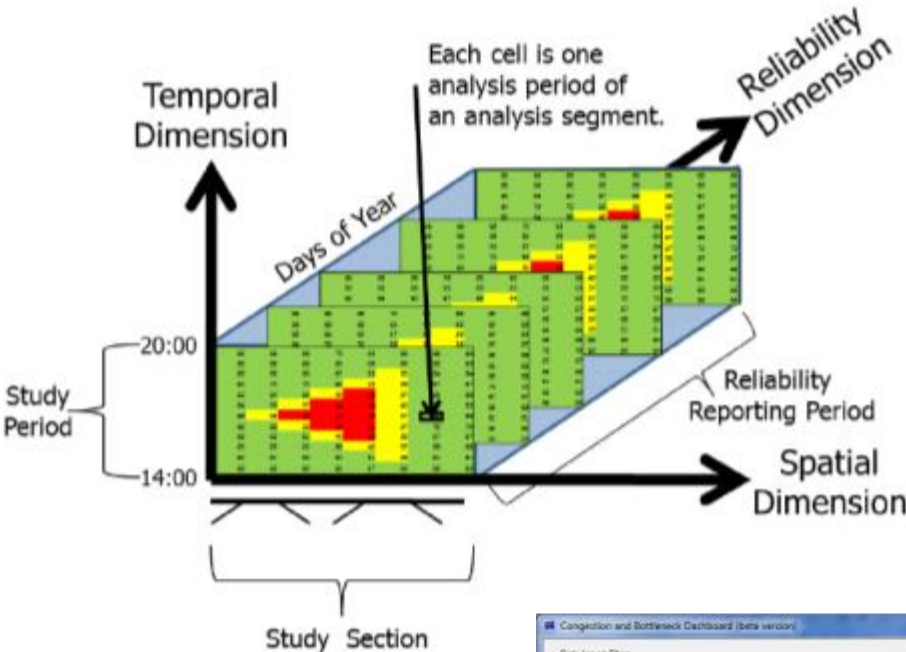
1. Congestion and bottleneck concepts
2. Congestion and bottleneck identification methods
3. Modernized causes of congestion pie chart
4. Featured bottleneck mitigation strategies

Workshop Summary

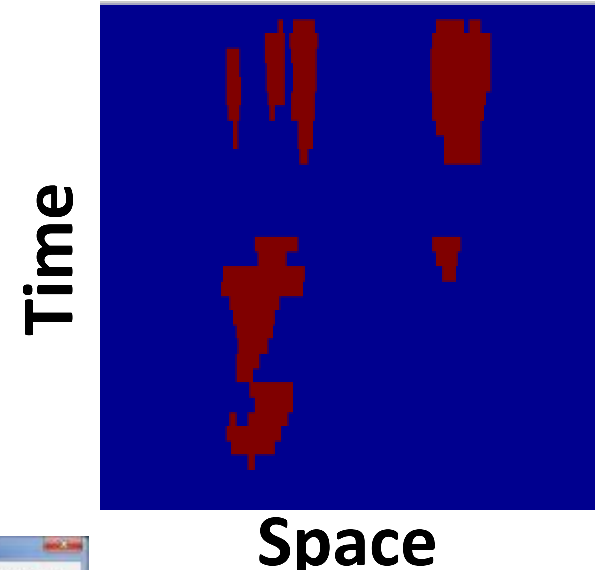
- Data-driven congestion causal pie chart
  - Bigger impact: road geometry, bad weather
  - Smaller impact: incidents, work zones
- Coming soon
  - Surface arterial pie chart
  - Analysis of more freeways

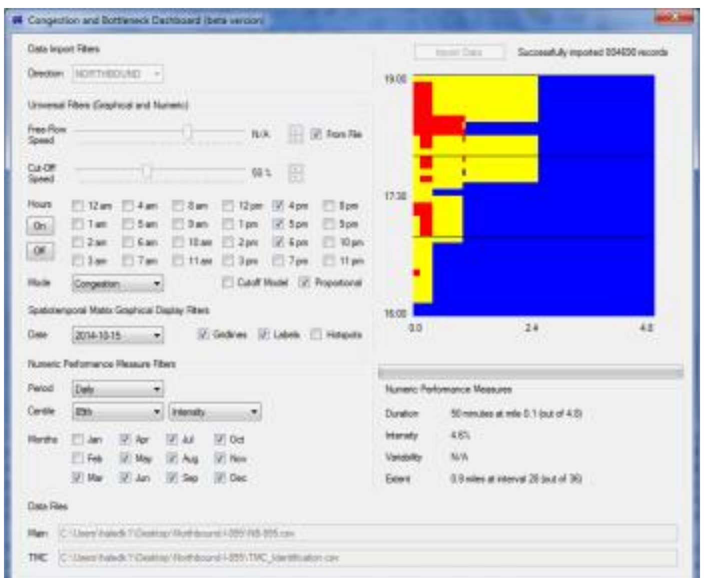


Workshop Summary



BINARY MATRIX





Workshop Summary

<u>Featured Bottleneck Mitigation Strategies</u>

1. Dynamic Lane Grouping
2. Dynamic Merge Control
3. Acceleration Lane Extension
4. Hard Shoulder Running
5. Lane Narrowing to Add a Lane
6. Alternative Intersections and Interchanges

Bottleneck Mitigation Strategies

SAXTON LABORATORY

Driving Future Highways