Traffic Congestion and Bottlenecks

*Identification, Diagnosis, Solutions*

U.S. Department of Transportation
FEDERAL HIGHWAY ADMINISTRATION
Workshop Overview

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:

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Principal Investigator Contact Information:
David Hale david.k.hale@leidos.com (202) 493-3296
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)
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 Below Below Good Very Good Excellent
Average Average Average Average

Please circle the numbers below which reflect your ratings.

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)
Traffic Congestion and Bottlenecks

Identification, Diagnosis, Solutions

U.S. Department of Transportation
FEDERAL HIGHWAY ADMINISTRATION
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”

Understanding Merging

“Why is recurring traffic like “cat herding”?”

What is stopping us from fixing bottlenecks?

ops.fhwa.dot.gov/bn/index.htm
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 **Duration**, **Intensity**, **Variability**, **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

HCM

STM

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

Performance Measures

Prioritize Locations
Spatiotemporal Traffic Matrix (STM)

Each cell is one analysis period of an analysis segment.

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

<table>
<thead>
<tr>
<th>Roadway Specific</th>
<th>Facility Specific</th>
<th>Specific to Interchanges</th>
<th>Intersections /TCD/ITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Design Speed</td>
<td>1. Bridges</td>
<td>1. Merge and diverge sections</td>
<td>1. Intersection sight distance</td>
</tr>
</tbody>
</table>

### Operational Challenges

<table>
<thead>
<tr>
<th>Agency Related</th>
<th>Driver Related</th>
<th>Non-motorist Related</th>
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</thead>
<tbody>
<tr>
<td>2. Intersection spacing</td>
<td>2. Roadside distraction/rubbernecing</td>
<td></td>
</tr>
<tr>
<td>3. Interchange spacing</td>
<td>3. Non-roadside distractions</td>
<td></td>
</tr>
<tr>
<td>4. Policy on entry/exit ramp placement</td>
<td>4. Unsafe vehicle condition for weather condition</td>
<td></td>
</tr>
<tr>
<td>5. Posted speed limit (static/dynamic)</td>
<td>5. Aggressive lane change/weaving</td>
<td></td>
</tr>
<tr>
<td>6. Signal timing administration</td>
<td>6. Driving unauthorized roadway section</td>
<td></td>
</tr>
<tr>
<td>7. Traffic composition</td>
<td>7. Driver performance in work zone</td>
<td></td>
</tr>
<tr>
<td>8. Work zone</td>
<td>8. Driver performance when involved in an incident</td>
<td></td>
</tr>
</tbody>
</table>
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.”
   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
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
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
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

Cut-off speed using Bayesian approach

Normalized cut-off speed vs. Visibility

- Clear
- Medium Rain
- Heavy Rain
- Freezing rain
- Snow
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

\[
d_i(t) = l_i \times q_i(t) \times \left( \frac{1}{u_i(t)} - \frac{1}{u_f} \right) \quad \text{Total Delay} = \sum_{\Omega} d_i(t)
\]

$d = \text{delay}$, $l = \text{length}$, $q = \text{flow}$, $u = \text{speed}$
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)
Spatiotemporal Traffic Matrix (STM)

Each cell is one analysis period of an analysis segment.

Source: HCM 2010
STM Versus ARM

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

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

Bottleneck #1

<table>
<thead>
<tr>
<th>Percentile</th>
<th>Worst Day</th>
<th>Intensity</th>
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<tbody>
<tr>
<td>0%</td>
<td>50%</td>
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<td>50%</td>
<td>100%</td>
</tr>
<tr>
<td>0%</td>
<td>50%</td>
<td>100%</td>
</tr>
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</table>

Bottleneck #2

<table>
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<th>Percentile</th>
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<th>Intensity</th>
</tr>
</thead>
<tbody>
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<td>50%</td>
<td>100%</td>
</tr>
<tr>
<td>0%</td>
<td>50%</td>
<td>100%</td>
</tr>
<tr>
<td>0%</td>
<td>50%</td>
<td>100%</td>
</tr>
</tbody>
</table>

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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

- Example problem
- 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)

<table>
<thead>
<tr>
<th>I-695</th>
<th>I-495</th>
<th>I-895</th>
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</thead>
<tbody>
<tr>
<td>BII 52%</td>
<td>BII 46%</td>
<td>BII 23%</td>
</tr>
<tr>
<td>SD 33%</td>
<td>SD 17%</td>
<td>SD 11%</td>
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</table>
Ranking Arterial Bottlenecks

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

<table>
<thead>
<tr>
<th>Highway</th>
<th>BII</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>US-13</td>
<td>64%</td>
<td>21%</td>
</tr>
<tr>
<td>MD-147</td>
<td>24%</td>
<td>6%</td>
</tr>
<tr>
<td>US-50</td>
<td>19%</td>
<td>6%</td>
</tr>
</tbody>
</table>

--- Intensity ---

<---Percentile worst day--->

U.S. Department of Transportation
Federal Highway Administration
• 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
1. Congestion and bottleneck concepts
2. Congestion and bottleneck identification methods
3. Modernized causes of congestion pie chart
4. Featured bottleneck mitigation strategies
Congestion Pie Chart

Identification, Diagnosis, Solutions
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

- Poor Signal Timing (5%)
- Special Events/Others (5%)
- Work Zones (10%)
- Bad Weather (15%)
- Traffic Incidents (25%)
- Bottlenecks (40%)
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

<table>
<thead>
<tr>
<th></th>
<th>Speed Drop</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overburden</td>
<td>50%</td>
<td>66.7%</td>
</tr>
<tr>
<td>Workzone</td>
<td>25%</td>
<td>33.3%</td>
</tr>
</tbody>
</table>
Eastbound I-66 Pie Chart

- Updated, weighted pie chart with spatio-temporal effects
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)
## Arterial Data Analysis

### Incidents on Eastbound of Broward Blvd.

<table>
<thead>
<tr>
<th>Type</th>
<th>Date</th>
<th>Time</th>
<th>Road</th>
<th>Location</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congestion</td>
<td>9/7/2014</td>
<td>9:07:24</td>
<td>SR-842 EB</td>
<td>US-1</td>
<td>25</td>
</tr>
<tr>
<td>Congestion</td>
<td>9/7/2014</td>
<td>10:52:29</td>
<td>SR-842 EB</td>
<td>US-1</td>
<td>205</td>
</tr>
<tr>
<td>Congestion</td>
<td>9/11/2014</td>
<td>8:42:42</td>
<td>NW 7 Ave</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Vehicle Alert</td>
<td>9/12/2014</td>
<td>9:53:05</td>
<td>SR-842 EB</td>
<td>NW 7 Ave</td>
<td>5</td>
</tr>
<tr>
<td>Road Work - Scheduled</td>
<td>9/12/2014</td>
<td>10:18:28</td>
<td>SR-842 EB</td>
<td>Andrews Ave</td>
<td>117</td>
</tr>
<tr>
<td>Congestion</td>
<td>9/14/2014</td>
<td>7:52:09</td>
<td>SR-842 EB</td>
<td>US-1</td>
<td>124</td>
</tr>
<tr>
<td>Congestion</td>
<td>9/16/2014</td>
<td>7:55:51</td>
<td>SR-842 EB</td>
<td>I-95</td>
<td>10</td>
</tr>
<tr>
<td>Congestion</td>
<td>9/18/2014</td>
<td>8:41:23</td>
<td>SR-842 EB</td>
<td>Andrews Ave</td>
<td>60</td>
</tr>
<tr>
<td>Congestion</td>
<td>9/19/2014</td>
<td>8:52:22</td>
<td>SR-842 EB</td>
<td>US-1</td>
<td>116</td>
</tr>
<tr>
<td>Disabled Vehicle</td>
<td>9/20/2014</td>
<td>8:34:21</td>
<td>SR-842 EB</td>
<td>I-95</td>
<td>24</td>
</tr>
<tr>
<td>Congestion</td>
<td>9/20/2014</td>
<td>8:37:22</td>
<td>SR-842 EB</td>
<td>NW 7 Ave</td>
<td>21</td>
</tr>
<tr>
<td>Congestion</td>
<td>9/21/2014</td>
<td>9:07:09</td>
<td>SR-842 EB</td>
<td>NW 7 Ave</td>
<td>21</td>
</tr>
<tr>
<td>Road Work - Scheduled</td>
<td>9/21/2014</td>
<td>12:32:12</td>
<td>SR-842 EB</td>
<td>US-441</td>
<td>48</td>
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<tr>
<td>Road Work - Scheduled</td>
<td>9/21/2014</td>
<td>17:49:03</td>
<td>SR-842 EB</td>
<td>US-441</td>
<td>23</td>
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<td>Congestion</td>
<td>9/22/2014</td>
<td>7:35:44</td>
<td>SR-842 EB</td>
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<td>76</td>
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<tr>
<td>Congestion</td>
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<td>7:13:09</td>
<td>SR-842 EB</td>
<td>NW 7 Ave</td>
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<tr>
<td>Congestion</td>
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<td>15</td>
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<td>8:56:13</td>
<td>SR-842 EB</td>
<td>NW 21 Ave</td>
<td>262</td>
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### Incidents on Westbound of Broward Blvd.

<table>
<thead>
<tr>
<th>Type</th>
<th>Date</th>
<th>Time</th>
<th>Road</th>
<th>Location</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congestion</td>
<td>8/1/2014</td>
<td>14:11:29</td>
<td>SR-842 WB</td>
<td>I-95</td>
<td>254</td>
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<tr>
<td>Road Work - Scheduled</td>
<td>8/4/2014</td>
<td>11:32:25</td>
<td>SR-842 WB</td>
<td>I-95</td>
<td>429</td>
</tr>
<tr>
<td>Congestion</td>
<td>8/5/2014</td>
<td>15:32:32</td>
<td>SR-842 WB</td>
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<td>145</td>
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<tr>
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<td>8/7/2014</td>
<td>9:09:42</td>
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<tr>
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<td>8/7/2014</td>
<td>10:42:37</td>
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<tr>
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</tr>
<tr>
<td>Crash</td>
<td>8/11/2014</td>
<td>14:20:52</td>
<td>SR-842 WB</td>
<td>NW 7 Ave</td>
<td>263</td>
</tr>
<tr>
<td>Crash</td>
<td>8/12/2014</td>
<td>9:24:48</td>
<td>SR-842 WB</td>
<td>NW 7 Ave</td>
<td>23</td>
</tr>
<tr>
<td>Congestion</td>
<td>8/12/2014</td>
<td>11:44:00</td>
<td>SR-842 WB</td>
<td>I-95</td>
<td>274</td>
</tr>
<tr>
<td>Congestion</td>
<td>8/14/2014</td>
<td>15:40:14</td>
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<td>90</td>
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<tr>
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<td>17:15:24</td>
<td>SR-842 WB</td>
<td>I-95</td>
<td>24</td>
</tr>
<tr>
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<td>8/15/2014</td>
<td>14:09:18</td>
<td>SR-842 WB</td>
<td>I-95</td>
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<tr>
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<td>8/16/2014</td>
<td>15:06:11</td>
<td>SR-842 WB</td>
<td>I-95</td>
<td>202</td>
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<tr>
<td>Crash</td>
<td>8/18/2014</td>
<td>17:11:07</td>
<td>SR-842 WB</td>
<td>I-95</td>
<td>77</td>
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<tr>
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<td>8/19/2014</td>
<td>17:43:49</td>
<td>SR-842 WB</td>
<td>I-95</td>
<td>37</td>
</tr>
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<td>Congestion</td>
<td>8/20/2014</td>
<td>15:12:55</td>
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<td>I-95</td>
<td>152</td>
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<tr>
<td>Congestion</td>
<td>8/21/2014</td>
<td>15:39:45</td>
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<td>I-95</td>
<td>25</td>
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<td>Congestion</td>
<td>8/21/2014</td>
<td>9:01:10</td>
<td>SR-842 WB</td>
<td>I-95</td>
<td>43</td>
</tr>
<tr>
<td>Congestion</td>
<td>8/21/2014</td>
<td>15:25:42</td>
<td>SR-842 WB</td>
<td>I-95</td>
<td>72</td>
</tr>
<tr>
<td>Congestion</td>
<td>8/23/2014</td>
<td>17:09:40</td>
<td>SR-842 WB</td>
<td>I-95</td>
<td>52</td>
</tr>
<tr>
<td>Congestion</td>
<td>8/25/2014</td>
<td>15:25:44</td>
<td>SR-842 WB</td>
<td>I-95</td>
<td>176</td>
</tr>
<tr>
<td>Congestion</td>
<td>8/27/2014</td>
<td>15:29:19</td>
<td>SR-842 WB</td>
<td>I-95</td>
<td>151</td>
</tr>
<tr>
<td>Congestion</td>
<td>8/28/2014</td>
<td>15:45:20</td>
<td>SR-842 WB</td>
<td>I-95</td>
<td>160</td>
</tr>
<tr>
<td>Congestion</td>
<td>8/28/2014</td>
<td>10:44:22</td>
<td>SR-842 WB</td>
<td>NW 7 Ave</td>
<td>101</td>
</tr>
<tr>
<td>Crash</td>
<td>8/28/2014</td>
<td>15:29:02</td>
<td>SR-842 WB</td>
<td>I-95</td>
<td>147</td>
</tr>
</tbody>
</table>
## August 26 – Congestion (1)

<table>
<thead>
<tr>
<th>Incident #</th>
<th>Incident Type</th>
<th>Date</th>
<th>Time</th>
<th>Major Rd</th>
<th>Minor Rd</th>
<th>Duration(min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1025</td>
<td>Congestion</td>
<td>8/26/2014</td>
<td>8:13:09</td>
<td>SR-842 EB</td>
<td>NW 7 Ave</td>
<td>72</td>
</tr>
</tbody>
</table>

### Normal-day Traffic on Eastbound of Broward Blvd.

### Incident Traffic on Eastbound of Broward Blvd.
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
1. Congestion and bottleneck concepts
2. Congestion and bottleneck identification methods
3. Modernized causes of congestion pie chart
4. **Featured bottleneck mitigation strategies**
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
# Active Bottleneck

## Geometric Challenges

<table>
<thead>
<tr>
<th>Roadway Specific</th>
<th>Facility Specific</th>
<th>Specific to Interchanges</th>
<th>Intersections /TCD/ITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Design Speed</td>
<td>1. Bridges</td>
<td>1. Merge and diverge sections</td>
<td>1. Intersection sight distance</td>
</tr>
<tr>
<td>2. Number of Lanes</td>
<td>2. Tunnels and underpass</td>
<td>2. Left-turn and Right-turn lane overflow</td>
<td></td>
</tr>
<tr>
<td>3. Lane Width</td>
<td>3. Auxiliary lanes</td>
<td>3. Parking</td>
<td></td>
</tr>
<tr>
<td>4. Presence and Type of shoulders</td>
<td>4. Weaving areas</td>
<td>4. TCD (signal, stop sign, etc.)</td>
<td></td>
</tr>
<tr>
<td>5. Lane drops</td>
<td>5. On-ramp/off-ramp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Lane reduction transition</td>
<td>5. Acceleration/ deceleration lanes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Hz clearance</td>
<td>1. Design Speed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. VI clearance</td>
<td>2. Number of Lanes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Sun Glare Alignment</td>
<td>3. Lane Width</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Hz alignment</td>
<td>4. Presence and Type of shoulders</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. VI alignment</td>
<td>5. Lane drops</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. SSD</td>
<td>6. Lane reduction transition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. Pavement friction/surface</td>
<td>7. Hz clearance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. Cross Slope</td>
<td>8. VI clearance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17. Mid-block Crossing</td>
<td>11. VI alignment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18. Medians</td>
<td>12. SSD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19. Lighting/Clari #</td>
<td>13. Pavement friction/surface</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Operational Challenges

<table>
<thead>
<tr>
<th>Agency Related</th>
<th>Driver Related</th>
<th>Non-motorist Related</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Intersection spacing</td>
<td>2. Roadside distraction/rubbertaking</td>
<td></td>
</tr>
<tr>
<td>3. Interchange spacing</td>
<td>3. Non-roadside distractions</td>
<td></td>
</tr>
<tr>
<td>4. Policy on entry/exit ramp placement</td>
<td>4. Unsafe vehicle condition for weather condition</td>
<td></td>
</tr>
<tr>
<td>5. Posted speed limit (static/dynamic)</td>
<td>5. Aggressive lane change/weaving</td>
<td></td>
</tr>
<tr>
<td>6. Signal timing administration</td>
<td>6. Driving unauthorized roadway section</td>
<td></td>
</tr>
<tr>
<td>8. Work zone</td>
<td>8. Driver performance when involved in an incident</td>
<td></td>
</tr>
<tr>
<td>10. Incident management and clearance</td>
<td>10. Ramp metering</td>
<td></td>
</tr>
<tr>
<td>11. Ramp metering</td>
<td>11. Heavy vehicle lane restrictions</td>
<td></td>
</tr>
<tr>
<td>12. Heavy vehicle lane restrictions</td>
<td>12. Heavy vehicle lane restrictions</td>
<td></td>
</tr>
</tbody>
</table>
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
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

\[
< \frac{\# \text{Through Lanes} - 1}{\# \text{Through Lanes}}
\]
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
- $17 \times 8 \times 8 = 1,088$ candidates
Dynamic Lane Grouping (DLG)

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

<table>
<thead>
<tr>
<th>Network Name</th>
<th>OBN</th>
<th>TCN</th>
<th>ID Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td># of candidates</td>
<td>448</td>
<td>640</td>
<td></td>
</tr>
<tr>
<td>Volume/Capacity</td>
<td>6(5)</td>
<td>2(2)</td>
<td>87.5%</td>
</tr>
<tr>
<td>Volume/Lane</td>
<td>4(1)</td>
<td>42(7)</td>
<td></td>
</tr>
<tr>
<td>Volume Change</td>
<td>4(2)</td>
<td>12(1)</td>
<td>18.8%</td>
</tr>
</tbody>
</table>
Dynamic Lane Grouping (DLG)

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

<table>
<thead>
<tr>
<th></th>
<th>Volume/Capacity</th>
<th>Volume/Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left-Turn</td>
<td>0.99</td>
<td>452</td>
</tr>
<tr>
<td>Through</td>
<td>0.31</td>
<td>223</td>
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Sunday Peak

Weekday PM Peak
Dynamic Lane Grouping (DLG)

Play before video

<table>
<thead>
<tr>
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<th>EBL</th>
<th>EBT</th>
<th>EBR</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>452</td>
<td>446</td>
<td>188</td>
<td></td>
</tr>
<tr>
<td>Base Delay/Veh (s)</td>
<td>147</td>
<td>25</td>
<td>9</td>
<td>60</td>
</tr>
<tr>
<td>DLG Delay/Veh (s)</td>
<td>78</td>
<td>27</td>
<td>9</td>
<td>47</td>
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</table>
Dynamic Lane Grouping (DLG)

Play after video

<table>
<thead>
<tr>
<th></th>
<th>EBL</th>
<th>EBT</th>
<th>EBR</th>
<th>Total</th>
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<tbody>
<tr>
<td>Volume</td>
<td>452</td>
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<tr>
<td>DLG Delay/Veh (s)</td>
<td>78</td>
<td>27</td>
<td>9</td>
<td>47</td>
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Dynamic Lane Grouping (DLG)
### Dynamic Lane Grouping (DLG)

<table>
<thead>
<tr>
<th>Hour</th>
<th>Shady Grove Road From West</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>L</td>
</tr>
<tr>
<td>Begin</td>
<td>6:00</td>
</tr>
<tr>
<td></td>
<td>7:00</td>
</tr>
<tr>
<td>8:00</td>
<td>445</td>
</tr>
<tr>
<td></td>
<td>9:00</td>
</tr>
<tr>
<td></td>
<td>10:00</td>
</tr>
<tr>
<td></td>
<td>11:00</td>
</tr>
<tr>
<td></td>
<td>12:00</td>
</tr>
<tr>
<td></td>
<td>13:00</td>
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<tr>
<td></td>
<td>14:00</td>
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<tr>
<td></td>
<td>15:00</td>
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<tr>
<td></td>
<td>16:00</td>
</tr>
<tr>
<td>17:00</td>
<td>950</td>
</tr>
<tr>
<td></td>
<td>18:00</td>
</tr>
</tbody>
</table>

- **Morning Peak**: 8:00 AM - 17:00 PM
- **Evening Peak**: 17:00 PM - 18:00 PM
Dynamic Lane Grouping (DLG)
Dynamic Lane Grouping (DLG)
Play DLG in the field
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

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

<table>
<thead>
<tr>
<th></th>
<th>Capital Cost</th>
<th>Operating Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic Message Sign</td>
<td>$47-117K</td>
<td>$2.4-6K</td>
</tr>
<tr>
<td>Dynamic Message Sign Tower</td>
<td>$25-120K</td>
<td></td>
</tr>
<tr>
<td>Dynamic Message Sign – Portable</td>
<td>$18-25K</td>
<td>$1.2-2K</td>
</tr>
</tbody>
</table>
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
5. Lane Narrowing to Add a Lane
6. Alternative Intersections and Interchanges
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

1-lane off ramp tested as 2-lane ramp

2-lane merge is now 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**

<table>
<thead>
<tr>
<th></th>
<th>Free flow</th>
<th>Without IMC</th>
<th>With IMC</th>
<th>Change %</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean travel time</td>
<td>4.76</td>
<td>11.03</td>
<td>10.42</td>
<td>- 8%</td>
</tr>
<tr>
<td>mean travel speed</td>
<td>98</td>
<td>41</td>
<td>45</td>
<td>+ 8%</td>
</tr>
<tr>
<td>Vehicle hours of delay</td>
<td>-</td>
<td>1558</td>
<td>1361</td>
<td>- 13%</td>
</tr>
</tbody>
</table>

**Blue route**

<table>
<thead>
<tr>
<th></th>
<th>Free flow</th>
<th>Without IMC</th>
<th>With IMC</th>
<th>Change %</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean travel time</td>
<td>2.78</td>
<td>7.07</td>
<td>6.56</td>
<td>- 7%</td>
</tr>
<tr>
<td>mean travel speed</td>
<td>106</td>
<td>42</td>
<td>45</td>
<td>+ 7%</td>
</tr>
<tr>
<td>Vehicle hours of delay</td>
<td>-</td>
<td>1455</td>
<td>1398</td>
<td>- 4%</td>
</tr>
</tbody>
</table>
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
Dynamic Merge Control (DMC)

- Real-world network study (Virginia’s I-66)
Dynamic Merge Control (DMC)

- Real-world network study (Virginia’s I-66)
**Dynamic Merge Control (DMC)**

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

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<td>$1.2-2K</td>
</tr>
</tbody>
</table>
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
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
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

<table>
<thead>
<tr>
<th>No.</th>
<th>Through Lanes (Number)</th>
<th>Ramp Speed (Mph)</th>
<th>Acceleration Length (Feet)</th>
<th>AASHTO Guideline (Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>40</td>
<td>500</td>
<td>780+300 taper</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>40</td>
<td>1000</td>
<td>780+300 taper</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>40</td>
<td>1500</td>
<td>780+300 taper</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>30</td>
<td>500</td>
<td>1160+300 taper</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>30</td>
<td>1000</td>
<td>1160+300 taper</td>
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<tr>
<td>6</td>
<td>3</td>
<td>30</td>
<td>1500</td>
<td>1160+300 taper</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>40</td>
<td>500</td>
<td>780+300 taper</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>40</td>
<td>1000</td>
<td>780+300 taper</td>
</tr>
<tr>
<td>9</td>
<td>4</td>
<td>40</td>
<td>1500</td>
<td>780+300 taper</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>30</td>
<td>500</td>
<td>1160+300 taper</td>
</tr>
<tr>
<td>11</td>
<td>4</td>
<td>30</td>
<td>1000</td>
<td>1160+300 taper</td>
</tr>
<tr>
<td>12</td>
<td>4</td>
<td>30</td>
<td>1500</td>
<td>1160+300 taper</td>
</tr>
</tbody>
</table>
## Extending Acceleration Lanes

<table>
<thead>
<tr>
<th>Scenario No.</th>
<th>Through Demand (Vehicles)</th>
<th>ON Ramp Demand (Vehicles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4847</td>
<td>1278</td>
</tr>
<tr>
<td>2</td>
<td>5047</td>
<td>1278</td>
</tr>
<tr>
<td>3</td>
<td>5547</td>
<td>778</td>
</tr>
<tr>
<td>4</td>
<td>4147</td>
<td>1578</td>
</tr>
<tr>
<td>5</td>
<td>3547</td>
<td>1978</td>
</tr>
<tr>
<td>6</td>
<td>5797</td>
<td>578</td>
</tr>
<tr>
<td>7</td>
<td>5347</td>
<td>1078</td>
</tr>
<tr>
<td>8</td>
<td>4547</td>
<td>1428</td>
</tr>
<tr>
<td>9</td>
<td>4047</td>
<td>1678</td>
</tr>
</tbody>
</table>
Extending Acceleration Lanes

Total Delay (Minutes)

Number of Through Lanes: 3
On Ramp Speed: 40 MPH

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

<table>
<thead>
<tr>
<th>Scenario No.</th>
<th>Through Demand (Vehicles)</th>
<th>ON Ramp Demand (Vehicles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>5347</td>
<td>1278</td>
</tr>
<tr>
<td>11</td>
<td>5647</td>
<td>1278</td>
</tr>
<tr>
<td>12</td>
<td>6147</td>
<td>1278</td>
</tr>
<tr>
<td>13</td>
<td>5347</td>
<td>1478</td>
</tr>
<tr>
<td>14</td>
<td>5347</td>
<td>1678</td>
</tr>
<tr>
<td>15</td>
<td>5647</td>
<td>1478</td>
</tr>
<tr>
<td>16</td>
<td>5647</td>
<td>1678</td>
</tr>
<tr>
<td>17</td>
<td>6147</td>
<td>1478</td>
</tr>
<tr>
<td>18</td>
<td>6147</td>
<td>1678</td>
</tr>
</tbody>
</table>
Extending Acceleration Lanes

Total Delay (Minutes)

<table>
<thead>
<tr>
<th>Number of Through Lanes: 4</th>
<th>On Ramp Speed: 40 MPH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>500 Feet</td>
<td>2850</td>
</tr>
<tr>
<td>1000 feet</td>
<td>1500</td>
</tr>
<tr>
<td>1500 feet</td>
<td>1335</td>
</tr>
<tr>
<td>Through Demand (Veh.)</td>
<td>5347</td>
</tr>
<tr>
<td>On Ramp Demand (Veh.)</td>
<td>1278</td>
</tr>
</tbody>
</table>
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)

<table>
<thead>
<tr>
<th></th>
<th>1000 feet</th>
<th>1500 feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-lane, 40 mph</td>
<td>$27,965</td>
<td>$44,965</td>
</tr>
<tr>
<td>3-lane, 30 mph</td>
<td>$34,354</td>
<td>$61,058</td>
</tr>
<tr>
<td>4-lane, 40 mph</td>
<td>$43,562</td>
<td>$67,717</td>
</tr>
<tr>
<td>4-lane, 30 mph</td>
<td>$42,712</td>
<td>$78,838</td>
</tr>
</tbody>
</table>
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)
Hard Shoulder Running (HSR)

HSR- Total Percentage Delay Reduction

<table>
<thead>
<tr>
<th>Demand Scenario</th>
<th>55 MPH HSR Lane</th>
<th>45 MPH HSR Lane</th>
<th>Reduced Likelihood of HSR Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>20.3%</td>
<td>17.8%</td>
<td>13.5%</td>
</tr>
<tr>
<td>Low Demand</td>
<td>19.5%</td>
<td>19.1%</td>
<td>8.4%</td>
</tr>
<tr>
<td>High Demand</td>
<td>11.4%</td>
<td>9.7%</td>
<td>14.6%</td>
</tr>
</tbody>
</table>
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

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

Construction of Additional Lane

Low-Cost Alternative

<table>
<thead>
<tr>
<th>Total Delay (Veh. – Mins.)</th>
<th>6 to 9 AM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>50,000</td>
</tr>
<tr>
<td>Additional 12 Foot Lane</td>
<td>30,000</td>
</tr>
</tbody>
</table>

43% Reduction

<table>
<thead>
<tr>
<th>Total Delay (Veh. – Mins.)</th>
<th>6 to 9 AM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>50,000</td>
</tr>
<tr>
<td>Additional Lane – All 10 Foot</td>
<td>21% Reduction</td>
</tr>
<tr>
<td></td>
<td>21,000</td>
</tr>
</tbody>
</table>
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)
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
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

- 53.7% reduction in injury and fatal crashes.
- 34.8% reduction in all crashes
RCUT Intersection – Implementations
Restricted Crossing U-Turn (RCUT)
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)
Proposed NC Double Quadrants

From Presentation by VHB, Nov. 2013
Quadrant Roadway Intersection

Play video
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**

**Time**

**Space**
Featured Bottleneck Mitigation Strategies

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