Morning Session

Welcome to the
Diverging Diamond Interchange Session

Presenters:
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Larry Sutherland
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Topics covered in this session will include:

• Introduction
• Planning and Operations
• Freeway Operations
• Signal Timing
• Geometric Design
• Costs and Construction
• Lessons Learned
What are DDIs?
What are DDIs?

Innovative Interchange Design
Planning and Operations

- Provides for two-phase signals with short cycle lengths, significantly reducing delay
- Increases the capacity of turning movements to and from the ramps
- Reduces the number of lanes on the crossroad, minimizing impacts to existing right-of-way
- Substantially reduces the number of conflict points. Theoretically improving safety
- Public perception: “Easy to Drive”, “Intuitive”, “No Delay”
## Planning and Operations

<table>
<thead>
<tr>
<th>Type</th>
<th>Diamond</th>
<th>SPUI</th>
<th>DDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diverging Diamond</td>
<td>10</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Merging</td>
<td>10</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Crossing</td>
<td>10</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>30</strong></td>
<td><strong>24</strong></td>
<td><strong>18</strong></td>
</tr>
</tbody>
</table>

Diamond = 30  
SPUI = 24  
DDI = 18
Planning and Operations

• Compare DDI to other Popular Interchange Types
  ▪ Diamond
  ▪ Tight Diamond
  ▪ SPUI

• All Interchange Types Can Accommodate Volumes
• DDI and SPUI can Handle Left Turns Better
• Number of Lanes
  ▪ Examples: I-85/Poplar Tent: 8 lanes with Diamond, 6 lanes with DDI
  ▪ Example: I-44/MO 13: 6 lanes with Diamond, 4 lanes with DDI

• DDI Advantage: Left-turns Do Not Conflict with Oncoming Traffic:
  ▪ No Turning Phases
  ▪ 2-Phase Signal
  ▪ Less Loss and All-Red Time
Planning and Operations

• In General: DDI increase capacity 15%-25%
• Reducing Delay by up to 60%
• Specific Example: Ashland, OR
• I-5/OR 66

<table>
<thead>
<tr>
<th></th>
<th>Standard Diamond</th>
<th>DDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intersection Capacity Utilization %</td>
<td>65.2%</td>
<td>39.7%</td>
</tr>
<tr>
<td>Average Delay per Vehicle (seconds)</td>
<td>21.1</td>
<td>5.0</td>
</tr>
<tr>
<td>Number of Signals</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Signal Phasing</td>
<td>4+ phase</td>
<td>2 phase</td>
</tr>
</tbody>
</table>
## Planning and Operations

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Volume Scenario</th>
<th>Delay (seconds)</th>
<th>Latent Delay (seconds)</th>
<th>Total Delay (seconds)</th>
<th>Latent Demand (vehicles)</th>
<th>Total Demand (vehicles)</th>
<th>% Unserved</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDI</td>
<td>Base + 30%</td>
<td>97</td>
<td>284</td>
<td>381</td>
<td>726</td>
<td>19515</td>
<td>3.7%</td>
</tr>
<tr>
<td>SPUI</td>
<td>Base + 20%</td>
<td>143</td>
<td>728</td>
<td>871</td>
<td>1708</td>
<td>18013</td>
<td>9.5%</td>
</tr>
</tbody>
</table>

**Diverging Diamond**

**Single Point Interchange**
Planning and Operations

- DDI requires fewer lanes than SPUIs or diamonds for most situations.
- Fewer lanes does not always mean less right-of-way.
- DDI effectiveness increases as turning movements increase.
- DDIs show significantly decreased impacts for merging operations on freeway.
<table>
<thead>
<tr>
<th>Location/Lane</th>
<th>Tight Diamond</th>
<th>SPUI</th>
<th>Tight DDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>¼ Mile Upstream – Right Lane</td>
<td>53.9</td>
<td>53.3</td>
<td>54.9</td>
</tr>
<tr>
<td>¼ Mile Upstream – Left Lane</td>
<td>55.2</td>
<td>54.3</td>
<td>55.7</td>
</tr>
<tr>
<td>Approaching Gore – Right Lane</td>
<td>49.9</td>
<td>52.8</td>
<td>55.2</td>
</tr>
<tr>
<td>Approaching Gore – Left Lane</td>
<td>56.9</td>
<td>56.6</td>
<td>57.8</td>
</tr>
<tr>
<td>Merging Section – Aux Lane</td>
<td>36.5</td>
<td>46.8</td>
<td>49.0</td>
</tr>
<tr>
<td>Merging Section – Right Lane</td>
<td>36.5</td>
<td>47.0</td>
<td>50.4</td>
</tr>
<tr>
<td>Merging Section – Left Lane</td>
<td>54.1</td>
<td>56.9</td>
<td>58.1</td>
</tr>
<tr>
<td>Downstream – Right Lane</td>
<td>40.4</td>
<td>46.5</td>
<td>48.5</td>
</tr>
<tr>
<td>Downstream – Left Lane</td>
<td>52.2</td>
<td>57.4</td>
<td>58.5</td>
</tr>
</tbody>
</table>
Signal Timing and Phasing

- Queuing is Major Factor
- Adjacent Signal Timings
- 2-Phase Signals
- Allows for Coordination
- Can be run through one signal cabinet (although two cabinets are typical)
DDI Phasing: Option 1 (Favor Cross-Street)
Phase 1

Phase 2

DDI Phasing: Option 2 (Favor Off-Ramps)
## Emissions

Example From Athens, Ohio  
(US 33/State Street)

<table>
<thead>
<tr>
<th></th>
<th>Diverging Diamond</th>
<th>Convention Diamond</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>101.1 Seconds</td>
<td>231.9 Seconds</td>
<td>43 %</td>
</tr>
<tr>
<td>Travel Time</td>
<td>531.1 Seconds</td>
<td>807.6 Seconds</td>
<td>65 %</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>4639.1 MMt</td>
<td>5742.65 MMt</td>
<td>80 %</td>
</tr>
<tr>
<td>Nitric Oxide</td>
<td>902.6 MMt</td>
<td>1117.31 MMt</td>
<td>80 %</td>
</tr>
<tr>
<td>VOC</td>
<td>1075.16 MMt</td>
<td>1330.91 MMt</td>
<td>80%</td>
</tr>
<tr>
<td>Fuel Consumed</td>
<td>66.37 Gallons</td>
<td>82.16 Gallons</td>
<td>80%</td>
</tr>
</tbody>
</table>
Geometry

Horizontal and Vertical Design

- Flat as possible
- Increase sight distance
  - Help drivers unfamiliar with DDI
  - Critical at any interchange
- Grade separate the crossing?
Geometry

Crossing Intersection Angle
• Initially: 45-degree angle of intersection
• Recent designs have shown that 40 degrees may be optimal
• In places where ROW is an issue, 25 degrees have been used
• All intersection should be closer to 90 degrees to:
  ▪ Reduce likelihood of wrong way travel
  ▪ Minimize crossing time for better clearance time and signalization
• Best Range: 35-50 degrees
Geometry

Crossroad to Freeway Angle
• Other interchange types, such as SPUI and standard diamond, operate best at 90 degrees
• DDIs do not have to be at a 90 degree angle to freeway
• Depending on the conditions, ramps may take up more ROW
• Reverse curvature makes DDI unique
Geometry

Ramp Terminal Separation
• Distance between the ramp terminal governed by geometry
• Minimum distance should allow for good horizontal design
• Determine the largest radius that works with normal crown
• Tighter ramp terminals make offset signal timing more difficult
Geometry

Design Speed/Reverse Curvature of Interchange

- Design speed should not be less than posted speed limit
- Ideally, speed reduction should be in the 15 mph range
- May depend on truck percentage (higher % - lower DS)
- Most have used a design speed of 25 mph
- May consist of three curves
- Turning movement speeds: 10 mph and up (governed by traffic operations)
Design Vehicle and Lane Widths

- Typically design for WB-67
- Lane Width:
  - At least 12 feet
  - Some may be higher, using 15 feet in some locations at reverse curvature
  - Use truck turning template to ensure safe operation
• The design curvature determines if glare screens needed
• Shield blinding glare, but allow recognition light
• May use vegetation or other obstructions
Cost and Constructability

Costs

• Status of interchange:
  ▪ Retrofit/new
  ▪ Existing conditions

• Bridges:
  ▪ Number (one or two)
  ▪ Lane width

• Traffic control: phasing of construction

• Islands: directly on pavement?
Cost and Constructability

Costs

• Retrofits:
  ▪ Range from $1.5 million to $2.5 million
  ▪ Could be lower/higher depending on existing conditions

• New:
  ▪ All about the bridge costs!!

• Lifetime of a DDI
Cost and Constructability

- American Fork, UT – I-15/Pioneer Crossing ($22M)
- Springfield, MO – I-44/MO13 ($3.2M) {R}
- Springfield, MO – National Avenue/MO 60 James River Freeway ($8.2M) {R}
- Lehi, UT – I-15/Timpanogos Highway ($8.5M) {R}
- Rochester, NY – I-590/Winton Road ($4.5M) {R}
- St. Cloud, MN – Hwy 15/CR 120 ($17.5M)
- St. Peters, MO – I-70 / Mid Rivers ($14M)
- Alcoa, TN – US 129/Bessemer Street ($2.9M) {R}
Cost and Constructability

ROW Costs/Benefits to Surrounding Community
Cost and Constructability

Materials and Staging

- Open to all types of materials: low speeds and pedestrian movements
- Staging is similar to other interchanges
Maintenance of Traffic
Conversion to DDI
Conversion to DDI
Lessons Learned

Safety

• Fewer conflict points (18 for DDI, 30 for conventional)
• Better sight distance at turns
• Wrong way entry to ramps is extremely difficult
• Less horizontal curvature reduces risks of off-road crashes
• Virtually no driver confusion (FHWA study)

Operations

• Simple left and right turn from all directions
• Increases left turn lane capacity without adding lanes
• Two phase signals with shorter cycle lengths reduces delay
• Better storage between the ramps terminals
Lessons Learned

Right Turn From Freeway

- Qualitative observation
- MoDOT, NCSU, and others
- Right-turning drivers off the freeway look at the wrong direction along the cross street
- MO-13 added a signal
  - Need to prohibit RTOR as well?
- Other treatments?
Lessons Learned

I-44/MO 13 Operations

- Significant decrease in left turn delay
- Slight increase in through movement travel time
- Significant excess capacity
- Over-dimensional loads
Lessons Learned

Public perception

• Over 80% said traffic operations improved
• 87% said DDI is safer than standard diamond
• Over 80% said pedestrian/bike and large vehicle movements are easier
• 91% have a good understanding of how it works
Lessons Learned

NCSU Study for FHWA

- 6 DDIs (3 in MO, TN, UT, NY)
- Conflicts and other field observations
- Six-month camera monitoring for unusual maneuvers
- Collision data
  - At least two years of after period data
  - Comparison and reference sites to account for potential biases
- Operational results due end 2012
- Collision results due end 2014
Summary

Key Points:
• What is a DDI?
• Planning and Operations
• Freeway Operations
• Signal Timing
• Geometric Design
• Costs and Construction
• Lessons Learned

Autoroute de Normandie (Highway A13) avec Boulevard de Jardy, Versailles, France
What are DDIs?