Modern Roundabouts: Design Workshop

Delaware
December 11-12, 2012

Hillary Isebrands, PE, PhD – FHWA Resource Center Safety and Design TST

Topics for Discussion

- Welcome
- Self Introductions
- Modern Roundabout Basics
- Safety Evaluation – Alternatives Analysis
- The Conceptual Design Footprint
- Geometry
- Capacity Analysis
- Beyond Geometry and Capacity
- Plan Reviews
- Delaware Roundabouts
- Delaware Roundabout Guidance Discussion
- Conceptual Design Case Study
- Wrap up
- Evaluations

Self Introductions

- Name
- What is your primary responsibility?
- What is one myth about roundabouts that within your agency/state?
- What do you want to learn about roundabouts today?
Modern Roundabout Basics

Physical Features of a Modern Roundabout

- Raised Central Island
- Raised Splitter Island
- Deflected Entry Path with Yield control
- Pedestrian Crossing
- Counter-clockwise Circulatory Roadway
Roundabouts FACTS

<table>
<thead>
<tr>
<th>Safety</th>
<th>Operations</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in Total</td>
<td>Single lane roundabouts (25,000 vehicles per day)</td>
<td>Access Management Technique</td>
</tr>
<tr>
<td>Crashes by ~35% to 60%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction in Injury</td>
<td>Two lane roundabouts (+/- 45,000 vehicles per day)</td>
<td>Environmental noise reduction, fuel consumption, wide nodes and narrow roads</td>
</tr>
<tr>
<td>Crashes by ~76% to 90%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slower speeds</td>
<td>Optimizes intersection efficiency 24 hours a day</td>
<td>Opportunities of Aesthetic Enhancements</td>
</tr>
<tr>
<td>15-25 mph</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Roundabouts are a type (or subset) of circular intersections

Bottom Line: Not all circular intersections are roundabouts!!!

Signalized traffic circles are NOT roundabouts !!!

Dupont Circle, Washington, DC
Is Not a Roundabout

Photo source: Google Earth
Traffic calming circles are NOT roundabouts!!

Photo source: FHWA

Roundabout Categories

• Mini-roundabouts
• Single-Lane Roundabouts
• Multilane Roundabout

2010 NCHRP 672

Mini (ICD 45 to 90 ft)
Single-lane (ICD 90 to 180 ft)
Multi-lane (ICD 150 to 300 ft)

Mini Roundabouts

Small roundabouts used in low-speed urban environments often characterized by having mountable (or painted only) center islands and splitter islands.

Source: FHWA Guide, 2000 & NCHRP 672
**Mini Roundabouts**

Dimondale, MI

Photo source: Isebrands

**Single Lane Roundabouts**

Characterized as having a single-lane entry at all legs and one circulatory lane. The geometric design includes raised splitter islands, a non-traversable central island, and may include an apron surrounding the non-traversable part of the central island to accommodate trucks.

Source: FHWA/NCHRP

**Single Lane Roundabouts**

Florence, KS

Kansas City, KS Suburb
Multilane Roundabouts

Multilane roundabouts have at least one approach leg with two or more entry lanes. They require wider circulatory roadways to accommodate more than one vehicle traveling side by side. They may include an apron surrounding the non-traversable part of the central island to accommodate long trucks.

Source: FHWA/NCHRP

Multilane Roundabouts

Duvall, WA

Coralville, IA

Roundabouts: An Informational Guide

This report was jointly funded by and written in cooperation with the Federal Highway Administration, and carries the FHWA logo on the cover. Although published as an NCHRP report, this document has been accepted by FHWA as the official update to, and hereby supersedes, the 2000 Guide.
Roundabouts are the preferred safety alternative for a wide range of intersections. Although they may not be appropriate in all circumstances, they should be considered as an alternative for all proposed new intersections on Federally-funded highway projects, particularly those with major road volumes less than 90 percent of the total entering volume. Roundabouts should also be considered for all existing intersections that have been identified as needing major safety or operational improvements. This would include freeway interchange ramp terminals and rural intersections.

**Why Roundabouts are Safer**

- They Reduce Fatal and Injury Crashes Significantly
- Crash Types are Changed
- Safety Improved in all Types of Environments (Urban, Suburban, Rural)
- Slower speeds & shorter crossings are safer for pedestrians
- It’s a FHWA Proven Safety Countermeasure
The safety research is DEFINITIVE!!!

NCHRP Report 572 –
Roundabouts in the United States (2007)
Before-after studies at 55 US intersections
- 35% overall decrease in crashes
- 76% decrease in injury crashes
- 81% decrease in fatal/incapacitating crashes for single lane urban roundabouts
- 71% decrease in fatal/incapacitating crashes for single lane rural roundabouts

Roundabouts are SAFER !!!

FHWA Proven Safety Countermeasures

Roundabouts Eliminate the Vehicle-Vehicle Crossing Conflict Points
Vehicle-Pedestrian Conflicts at Intersections

16 Conflicts
8 Conflicts

Pedestrian Safety

- Slow speeds (15-25mph) for all vehicles at the intersection,
- Fewer pedestrian-vehicle conflict points,
- Shorter crossing distances for pedestrians,
- Pedestrians cross only one direction of conflicting traffic at a time – finding refuge in the splitter island.

Likelihood of a pedestrian fatality when hit at vehicle speed:

- 15% for US 50
- 45% for US 77
- 85% for US 77

US 50 – US 77 Roundabout

Photo Source: Kansas DOT
Intersection has long been a deadly site

Two teens die in U.S.-50/77 collision

Source: Marion County Record

Quantitative Safety Evaluations -
Highway Safety Manual (HSM)

- Nominal vs. Substantive Safety
- Predicted Safety – CMF's
CMF’s for Conversion of 2-Way Stop Intersection to Roundabout

<table>
<thead>
<tr>
<th>Setting (Intersection type)</th>
<th>Traffic Volume</th>
<th>Crash Type (Severity)</th>
<th>CMF</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>All settings (One or two lanes)</td>
<td>All types (All severities)</td>
<td>0.56</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Rural (One lane)</td>
<td>All types (All severities)</td>
<td>0.19</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td></td>
<td>All types (Injury)</td>
<td>0.29</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td></td>
<td>All types (Injury)</td>
<td>0.13</td>
<td>0.04</td>
<td></td>
</tr>
</tbody>
</table>

Safety Alternatives Analysis Example
California Route 12 and Route 113 (West of Rio Vista)
Crash History

Crashes by Year

<table>
<thead>
<tr>
<th>Year</th>
<th>Total</th>
<th>Fatal</th>
<th>Injury</th>
<th>PDO</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2002</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2003</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>2004</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2005</td>
<td>6</td>
<td>0</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>2006</td>
<td>6</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>0</td>
<td>12</td>
<td>15</td>
</tr>
</tbody>
</table>

4 to 5 Crashes per Year
Severity Index = 12/26 = 0.46

SR 12 and SR 113 Crash History
Safety Analysis - Highway Safety Manual Methodology

- Existing Crash History - 5 crashes/yr
  - Severity Index – 0.46
- Predict the Number of Crashes for the Existing Intersection Design
- Predict the Number of Crashes for Intersection Alternatives
  - Add Left Turn Lane
  - Roundabout
  - Signal

Traffic Volumes

<table>
<thead>
<tr>
<th>AADT</th>
<th>Peak Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR 12 – 14,100</td>
<td>SR 12 - 1,150</td>
</tr>
<tr>
<td>SR 113 – 3,900</td>
<td>SR 113 - 580</td>
</tr>
</tbody>
</table>
Existing Right Turn Lane

Table 10-14. Crash Modification Factors (CMF) for Right-Turn Lanes on Approaches to an Intersection on Rural Four-Lane, Two-Way Highways

<table>
<thead>
<tr>
<th>Intersection Typ.</th>
<th>Intersecting Traffic Control</th>
<th>Number of Approaches with Right Turn Lanes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three-Leg Intersection</td>
<td>Median strip closed?</td>
<td>One Approach</td>
</tr>
<tr>
<td>Four-Leg Intersection</td>
<td>Median strip closed?</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Significant factor for example is not complete in determining the number of approaches with right turn lanes. First column presents the number of approaches only.

Existing Lighting

CMF<sub>l</sub> = Lighting

![Diagram](image)

The CMF for lighting is the measure of intersection lighting. The CMF for lighted intersections is calculated from the work of ElSaka and Van Den (1979), as:

\[
CMF_{l} = 1 - 0.38 \times \rho_{a}
\]

Where:

- \(CMF_{l}\) = crash modification factor for the effect of lighting on crash rates,
- \(\rho_{a}\) = proportion of total crashes for unlighted intersections that occur at night.

This CMF applies to unlighted intersections. Table 10-13 presents initial values for the unlighted crash proportion \(\rho_{a}\) and discusses how to estimate the values as Table 10-13 with locally derived values.

Table 10-13. Nighttime Crash Proportions for Unlighted Intersections

<table>
<thead>
<tr>
<th>Intersection Type</th>
<th>Proportion of Crashes that Occur at Night</th>
</tr>
</thead>
<tbody>
<tr>
<td>R2D</td>
<td>0.200</td>
</tr>
<tr>
<td>H2D</td>
<td>0.244</td>
</tr>
<tr>
<td>C2D</td>
<td>0.350</td>
</tr>
</tbody>
</table>

Safety Analysis - Highway Safety Manual Methodology

- Existing Crash History – 5 crashes/yr
  - Severity Index – 0.46
- Predict the Number of Crashes for Existing Intersection Design
  - \((8.5 \times 0.86 \times 0.907) = 6.63 \text{ crashes/yr}\)
- Predict the Number of Crashes for Intersection Improvements
  - Add Left Turn Lane
  - Roundabout
  - Signal

Add a Left Turn Lane

<table>
<thead>
<tr>
<th>Table 16-13: Crash Modification Factors (CMF) for Installation of Left-Turn Lanes on Intersection Approaches</th>
<th>(\text{CMF} \times \text{Traffic Flow} \times \text{Number of Approaches} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 Approach</td>
</tr>
<tr>
<td>Three Leg Intersection</td>
<td>0.70</td>
</tr>
<tr>
<td>Four Leg Intersection</td>
<td>0.70</td>
</tr>
<tr>
<td>Two leg Intersection</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Safety Analysis - Highway Safety Manual Methodology

- Existing Crash History – 5 crashes/yr
  - Severity Index – 0.46
- Predict the Number of Crashes for Existing Intersection Design
  - \((8.5 \times 0.86 \times 0.907) = 6.6 \text{ crashes/yr}\)
- Predict the Number of Crashes for Intersection Improvements
  - Add Left Turn Lane \((6.6 \times 0.72) = 4.75 \text{ crashes/year}\)
  - Roundabout
  - Signal
Replace with a Roundabout

<table>
<thead>
<tr>
<th>Intersection Type</th>
<th>Crash Type (Severity)</th>
<th>CMF</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>All settings</td>
<td>All types (All severities)</td>
<td>0.56</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>All types (Injury)</td>
<td>0.18</td>
<td>0.04</td>
</tr>
<tr>
<td>Rural</td>
<td>All types (All severities)</td>
<td>0.29</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>All types (Injury)</td>
<td>0.13</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Highway Safety Manual Methodology

- Existing Crash History – 5 crashes/yr
  - Severity Index – 0.46
- Predict the Number of Crashes for Existing Intersection Design
  - \((8.5 \times 0.86 \times 0.907) = 6.6\) crashes/yr
- Predict the Number of Crashes for Intersection Improvements
  - Add Left Turn Lane \((6.6 \times 0.72 = 4.75\) crashes/year)
  - Roundabout \((8.5 \times 0.29 = 2.5\) crashes/year)
  - Signal

Replace with a Signal

Figure 10-6: Graphical Representation of the SPF for PTV by Signalized (2G) Intersections (Equation: 10-30)
Add Turn Lanes

Table 10-13: Crash Modification Factors (CMFs) for installation of Left Turn Lanes on Intersection Approaches

<table>
<thead>
<tr>
<th>Intersection Type</th>
<th>Intersection Traffic Control</th>
<th>One Approach</th>
<th>Two Approaches</th>
<th>Three Approaches</th>
<th>Four Approaches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-way interaction</td>
<td>Traffic signal</td>
<td>0.97 0.12</td>
<td>0.93 0.14</td>
<td>0.95 0.12</td>
<td>0.97 0.15</td>
</tr>
</tbody>
</table>

CMFs are not considered in determining the number of approaches with left turn lanes. Data presented on other crash approaches only.

Table 10-14: Crash Modification Factors (CMFs) on Approaches to an Intersection on Rural Two-Lane, Two-Way Highways

<table>
<thead>
<tr>
<th>Intersection Type</th>
<th>Intersection Traffic Control</th>
<th>Number of Approaches with Right Turn Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-way interaction</td>
<td>Traffic signal</td>
<td>0.54 0.72</td>
</tr>
</tbody>
</table>

CMFs are not considered in determining the number of approaches with right turn lanes. Data presented on other crash approaches only.

Lighting

\[ CMF_{eq} = 1 - (0.38 \times 0.286) = 0.891 \]

Safety Analysis - Highway Safety Manual Methodology

- Existing Crash History – 5 crashes/yr
  - Severity Index – 0.46
- Predict the Number of Crashes for Existing Intersection Design
  - \( (8.5 \times 0.86 \times 0.907) = 6.6 \) crashes/yr
- Predict the Number of Crashes for Intersection Improvements
  - Add Left Turn Lane \( (6.6 \times 0.72 = 4.75 \) crashes/year)
  - Roundabout \( (8.5 \times 0.29 = 2.8 \) crashes/year)
  - Signal \( (9.5 \times 0.96 \times 0.82 \times 0.891 = 6.66 \) crashes/year)
Questions/ Discussion

The Conceptual Footprint

They are Diverse: Small, Big, Round, Ellipse, 5 legs, etc...

- Difficult Geometry (skews, closely spaced intersections, 5/6 legs)
- Doesn’t Necessarily Need to be Round
- Turn Lanes Not Required
- Wide Nodes and Narrow Roads
Range of Potential Applications

- Residential Subdivision
- Urban Center
- Small Town/Municipality
- Rural Settings
- Schools
- Interchanges
- Gateway Treatments
- Unusual Geometry
- Commercial Developments
- Closely spaced intersections

The Footprint

<table>
<thead>
<tr>
<th>Design Element</th>
<th>Mini-Roundabout</th>
<th>Single-Lane Roundabout</th>
<th>Multile Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum number of entries per approach</td>
<td>1</td>
<td>1</td>
<td>2+</td>
</tr>
<tr>
<td>Minimum required circle diameter</td>
<td>40 to 80 ft (12 to 24 m)</td>
<td>60 to 100 ft (18 to 30 m)</td>
<td>110 to 200 ft (34 to 61 m)</td>
</tr>
<tr>
<td>Central island overpass</td>
<td>Raised (may have traversable apron)</td>
<td>Raised (may have traversable apron)</td>
<td>Raised (may have traversable apron)</td>
</tr>
</tbody>
</table>
| Operational analysis needed to verify upper limit for specific applications or for roundabouts with more than two lanes of traffic.

Planning Level Capacity

- Double-lane roundabout may be sufficient (additional analysis needed).
- Single-lane roundabout likely to operate acceptably.
- Single-lane roundabout likely to operate acceptably.
- Double-lane roundabout likely to operate acceptably.

FHWA Roundabouts Design Workshop
Hillary Isebrands, FHWA Resource Center
Planning Level Capacity

<table>
<thead>
<tr>
<th>Volume Range (sum of entering and exiting volumes)</th>
<th>Number of Lanes Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 1,000 vph</td>
<td>Single-lane entry likely to be sufficient</td>
</tr>
<tr>
<td>1,000 to 1,500 vph</td>
<td>Two-lane entry may be needed</td>
</tr>
<tr>
<td>1,500 to 1,800 vph</td>
<td>Single-lane may be sufficient based on more detailed analysis</td>
</tr>
<tr>
<td>Above 1,800 vph</td>
<td>Two-lane entry likely to be sufficient</td>
</tr>
<tr>
<td></td>
<td>More than two entering lanes may be required</td>
</tr>
<tr>
<td></td>
<td>A more detailed capacity evaluation should be conducted to verify lane numbers and operations</td>
</tr>
</tbody>
</table>

Source: New York State Department of Transportation

Roundabouts: An International Guide

Exhibit 9.8

Estimated Number of Lanes Using Turning Movement Volume

Example: 2000 60 70

Single Lane Left: 1.5

Single Lane Right: 1.2

Dual Lane: 1.0

Dual Lane Left: 0.8

Two-lane entry using turning movement volume.

Use turning movement volume technique to evaluate lane capacity.

Note: These values are for design purposes only.

Roundabouts: An International Guide

Exhibit 2.1

Wreaths, Hampers Concept

Wreaths may be required for safety

Source: American Association of State Highway and Transportation Officials

Roundabouts: An International Guide

Exhibit 3.1

Small Round About Concept

Small roundabouts are typically designed for half-turn cut corners. While it is important to plan for future traffic volume and capacity needs, the immediate effects on pedestrian and bicycle users should also be considered. A roundabout connected with a weave
Circulatory Roadway Width

At least as wide as the maximum entry width (up to 120% of maximum entry width)

Single Lane Roundabout - Typical circulatory roadway widths range from 16 to 20 feet for single lane roundabouts. Care should be taken to avoid making the circulatory roadway width too wide within a single lane roundabout, as drivers may think that two vehicles are allowed to circulate side by side.

Two Lane Roundabout - Multilane circulatory roadway lane widths typically range from 14 to 16 ft. This results in a total circulating width of 28 to 32 ft for a two lane circulatory roadway.

Three Lane Roundabout - Multilane circulatory roadway lane widths typically range from 14 to 16 ft and 42 to 48 ft total width for a three lane circulatory roadway. Wider lane widths may be necessary to accommodate side by side semi trailer vehicles.

Size, Position and Alignment

Exhibit 6-8

(a) Centered on Existing Intersection
(b) Centered Shifted to the South
(c) Centered Shifted to the East
Questions/ Discussion

Geometric Design

Before

After

Photo: KS

Photo: WisDOT
**Speed Prediction Based on Vehicle Path Radii**

Five critical path radii

Note: Vehicular path radii ≠ Curb radii

**Fastest Vehicle Path through a Single Lane Roundabout**

Source: FHWA/NCHRP

**Fastest Vehicle Path through a Two Lane Roundabout**

Source: FHWA/NCHRP
Example of Good Speed Consistency

Approach Angles
Perpendicular Preferred Over Obtuse

Source: Kansas Roundabout Guide

Approach Offset to Increase Entry Deflection
Entry Width
Typical 14-16 ft for single-lane entrance

Measured from point where yield line intersects left edge of travel way to right edge of travel way

Entry Width based on Capacity Requirements and Design Vehicle Requirements

Outside Entry Curve
Postedge to Outside Edge of Circulatory Roadway

Continuation of Inside Entry Curve Design Requirements

Arrows indicate

Entry Width

Measured from point where yield line intersects left edge of travel way to right edge of travel way

Entry Width based on Capacity Requirements and Design Vehicle Requirements

Outside Entry Curve
Postedge to Outside Edge of Circulatory Roadway

Continuation of Inside Entry Curve Design Requirements

Arrows indicate
Natural Path – Vehicle Path Overlap

Poor entry deflection can lead to vehicle path overlap on multi-lane roundabouts

Note that vehicle entry paths are not properly “aligned” at the Yield Bar

Before

Photo: Bruce Robinson

Source: FHWA/NCHRP
Truck Aprons

<table>
<thead>
<tr>
<th>NCHRP 672</th>
<th>Width</th>
<th>3 to 15 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cross slope</td>
<td>1% to 2% (away)</td>
</tr>
<tr>
<td></td>
<td>Curb height</td>
<td>2 to 3 in</td>
</tr>
</tbody>
</table>

Truck Aprons Width 3 to 15 ft
Cross slope 1% to 2% (away)
Curb height 2 to 3 in

[Diagram of Truck Aprons]

[Diagram of Roundabouts, an International Guide]

[Diagram of Roundabouts, an International Guide]

[Diagram of Roundabouts, an International Guide]

[Diagram of Roundabouts, an International Guide]

[Diagram of Roundabouts, an International Guide]

[Diagram of Roundabouts, an International Guide]
**Outside Curb is Needed to Achieve Proper Lane Use, Position and Speeds**

Source: FHWA/NCHRP

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**Exclusive Right-Turn Lanes**

Source: FHWA

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**Required Stopping Sight Distance at Entries**

Source: FHWA, 2000
**Mini Roundabouts**

- Diameter - 50 to 80 ft
- Traversable Center Island
- Up to ~15,000 AADT
- Urban/Suburban
- 20 – 35mph Roadways
- Low Truck Volume
Option B: Use of Successive Curves on High Speed Approaches

Intersection Spacing

Intersection Spacing
Access Management

- Capacity “at the intersections” – wide node
- Increased roadway capacity and safety, with less roadway ‘road diet’ – narrow road
- Less conflicts, easier decision making for ingress and egress
- Access even with right-in, right-out restrictions
Capacity Analysis

Effect of Geometry on Capacity

Geometry plays a significant role in operational performance:
• Geometry affects the speed of vehicles through the intersection, thus influencing their travel time (geometric delay).
• Geometry dictates the number of lanes over which entering and circulating vehicles travel and therefore governs the rate at which vehicles may enter the circulating roadway.
• Geometry can affect the degree to which flow in a given lane is facilitated or constrained.
  – For example, the angle at which a vehicle enters affects the speed of that vehicle, with entries that are more perpendicular requiring slower speeds and thus longer headways.

Effect of Geometry on Capacity

• Geometry may affect the driver’s perception of how to navigate the roundabout and their corresponding lane choice approaching the entry.
• Imbalanced lane flows on an entry can increase the delay and queuing on an entry despite the entry operating below its theoretical capacity.
Suggested Operational Analysis Steps

- Establish the design volumes for the AM and PM peak periods
  - Turning volumes for each movement on all approaches
  - Adjust to Passenger Car Equivalents
- Calculate the circulating volumes for each leg (AM and PM peak)
- Determine the approach capacity for each leg
- Compare the entering volume (v) to the approach capacity (c) for each approach
- If v/c exceeds 0.85, evaluate the need for multi-lane entry or right-turn bypass for that approach
- Determine the quantity and configuration of lanes for the roundabout (examine flows for exclusive turn lanes)
- Sketch a preliminary configuration

Roundabout Traffic Flow Terminology

Source: FHWA 2000

Roundabouts: An International Guide

Delaware
December 11-12, 2012
Operational Performance Measures for Roundabouts

- Degree of saturation (v/c)
- Delay (sec/veh)
- Queue length (ft)
- LOS (based on control delay and per individual approach)

Volume to Capacity Ratio

- The volume-to-capacity ratio is a comparison of the demand at the roundabout entry to the capacity of the entry and provides a direct assessment of the sufficiency of a given design.
- For a given lane, the v/c ratio is calculated by dividing the lane’s calculated capacity into its demand flow rate where both input values are in vehicles per hour.
- While there are no absolute standards for the v/c ratio, international and domestic experience suggests that ratios in the range of 0.85 to 0.90 represent an approximate threshold for satisfactory operation.

Example - Circulating Volume – EB

\[ V_{EB\,circ} = V_{EB\,in} + V_{EB\,out} + V_{EB\,left} + V_{EB\,right} + V_{EB\,through} \]

\[ V_{EB\,circ} = 300 + 100 + 226 + 0 + 0 = 626 \]
**Example Exercise – EB Entry Capacity**

Entry Lane Capacity

\[ V_{EB,CI}=626 \]

**Example - Entering Flow – EB**

\[ V_{EB,Ent\,Flow}=V_{EB,LT}+V_{EB,TH}+V_{EB,RT} \]

\[ = 140 + 211 + 20 \]

\[ = 371 \]

\[ V/C = \frac{V_{EB,Ent\,Flow}}{EB\,Entry\,Capacity} \]

\[ = \frac{371}{600} \]

\[ = 0.62 \]

0.62 < 0.85 OK

**Average Control Delay**

Control delay is the time spent queuing and then waiting for an acceptable gap in the circulating flow while at the front of the queue.

\[ d = \frac{3.600}{c} \times 900 \left[ x - 1 + \left( x - 1 \right)^{2} + \left( \frac{3.600}{c} \times 450 \right) \right] + 5 \times \text{min}[x,1] \]

where:

- \( d \) = average control delay, s/veh
- \( x \) = volume-to-capacity ratio of the subject lane
- \( c \) = capacity of subject lane, veh/h, and
- \( T \) = time period, h (1 for a 1-hour analysis, 0.25 for a 15-minute analysis)
**Level Of Service**

Level of Service (LOS) is a qualitative performance measure based upon the estimated control delay. The LOS for the critical lane on each approach is determined using the computed or measured values of control delay. The HCM does not define LOS for non-critical lanes or the intersection as a whole.

<table>
<thead>
<tr>
<th>Control Delay (s/veh)</th>
<th>Level of Service for Lane In Service Ratio (v/s ≤ 1.0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5</td>
<td>A</td>
</tr>
<tr>
<td>&gt;5–10</td>
<td>B</td>
</tr>
<tr>
<td>&gt;10–15</td>
<td>C</td>
</tr>
<tr>
<td>&gt;15–20</td>
<td>D</td>
</tr>
<tr>
<td>&gt;20–25</td>
<td>E</td>
</tr>
<tr>
<td>&gt;25–30</td>
<td>F</td>
</tr>
<tr>
<td>&gt;30–50</td>
<td>G</td>
</tr>
<tr>
<td>&gt;50</td>
<td>H</td>
</tr>
</tbody>
</table>

* For approaches and intersections where assessment, LOS is defined solely by control delay.

**Queue Length**

The estimated length of queue on each roundabout approach is important for assessing the design and operational characteristics of a roundabout and can also serve as a basis for comparison to other intersection types. Queue interaction with adjacent intersections or driveways is another important consideration.

The 95th-percentile queue for a given lane on an approach is calculated as:

\[
Q_{95} = \frac{d}{c} \left[ 1 - \left( \frac{d}{c} \right)^{0.586} \right] \left( \frac{c \cdot n}{3600} \right)
\]

where:

- \(Q_{95}\) = 95th-percentile queue length (ft)
- \(d\) = 95th-percentile queue length (ft)
- \(c\) = capacity of subject lane (veh/h/ln)
- \(n\) = time period, h (1 for a 4-hour analysis, 1.5 for a 9-hour analysis)

**Queue Length – Consider “spill-over” effects from adjacent intersections**

Photo shows queue “spill-over” from adjacent signalized intersection blocking roundabout exit.
Example of 2 x 2 Roundabout
This roundabout is not suggested as specific lane groups are over capacity

Georgia DOT Analysis Tool
Questions/ Discussion

Best Practices for Vulnerable Road Users at Roundabouts

Who are Vulnerable Road Users?
• Pedestrians
• Bicyclists
• Older persons
• Younger persons

Photo credits: Isebrands
Why are they SAFER for Vulnerable Users?

- Slower speeds for all motorists
- Shorter crossing distances
- Only crossing one direction of travel at a time
- Refuge island
- Fewer Conflict Points

Pedestrian and Bicycle Accommodations

- Sidewalks should be set back from the edge of the circulatory roadway (assists with wayfinding)
- Recommended sidewalk width of 6ft (10ft if shared with bicyclists)
- A typical and minimum crosswalk setback is 20 ft from the yield line
- Raised crosswalks can encourage slow vehicle speeds where pedestrians cross
Bicycle Operations

Pedestrian and Bicycle Accommodations

- Bicycle lanes and shoulders should be terminated in advance of roundabouts
- Full-width bicycle lanes should normally end at least 100 ft before the edge of the circulatory roadway
- Bicycle ramps should be placed entirely within the planting strip between the sidewalk and the roadway at a 35° to 45° angle to the roadway and the sidewalk to enable cyclists to use the ramp even if pulling a trailer, but to discourage them from entering the sidewalk at high speeds

Bicycle Accommodations: Exhibit 6-67

Photo credits: Isebrands
Roundabouts and sight impaired pedestrians:
Circulating traffic masks the sound cues that sight impaired pedestrians use to identify gaps and masks the sound of yielding vehicles.

PROWAG – US Access Board

- Public comment period from July 26, 2011 to November 23, 2011

R306.3 Roundabouts

R306.3.1 Separation. Where sidewalks are flush against the curb and pedestrian street crossing is not intended, a continuous and detectable edge treatment shall be provided along the street side of the sidewalk. Detectable warning surfaces shall not be used for edge treatment. Where chains, fencing, or railings are used for edge treatment, they shall have a bottom edge 380 mm (15 in) maximum above the sidewalk.
R306.3 Roundabouts

R306.3.2 Pedestrian Activated Signals. At roundabouts with multi-lane pedestrian street crossings, a pedestrian activated signal complying with R209 shall be provided for each multi-lane segment of each pedestrian street crossing, including the splitter island. Signals shall clearly identify which pedestrian street crossing segment the signal serves.

R209 Accessible Pedestrian Signals and Pedestrian Pushbuttons

R209.1 General. Where pedestrian signals are provided at pedestrian street crossings, they shall include accessible pedestrian signals and pedestrian pushbuttons complying with sections 4E.08 through 4E.13 of the MUTCD (incorporated by reference, see R104.2). Operable parts shall comply with R403.
R306.3 Roundabouts

R306.4 Channelized Turn Lanes at Roundabouts. At roundabouts with pedestrian street crossings, pedestrian activated signals complying with R209 shall be provided at pedestrian street crossings at multi-lane channelized turn lanes.

Raised Crosswalk at Two-lane Roundabout

NCHRP 3-78A/NCHRP 674 Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities

Golden CO

Golden CO
Possible Mitigation for 2-lane Roundabout w/ Heavy Pedestrian and Vehicle Volumes

Spring Break Statistics (2000)
• 8,000 peds/day
• 58,000 vehicles/day

Questions/Discussion

Beyond Geometry and Capacity
Traffic Control Matters: Signing and Marking

What is Wrong Here?

Signing and Marking Key Messages

- **Signing and Markings** should complement the geometrics ... not “compensate” for bad geometry

- **Signing and Markings are integral and necessary** for a modern multi-lane roundabout

- We are still “evolving” in knowledge for best practices in signing and marking multi-lane roundabouts in the US
Signing and Marking Key Messages

- Drivers rely on pavement marking and signing
- Signing and marking layout should be considered early during design
- There is no “cook book” for roundabout signing and markings
- Design engineer should consider being on site when marking is being placed to assure accurate placement
- Make sure your law enforcement know how to enforce the rules of the road

Richfield, MN Video

Lane Assignment

Traditional Intersection

Roundabout
### Striping

- White line on the shoulder
- Red lines on the shoulder
- Yellow lines on the shoulder

### Lighting Options

**Exhibit 8-4**

<table>
<thead>
<tr>
<th>Description</th>
<th>Type</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approach Mounted Lighting</td>
<td>B-250W HPS</td>
<td>25 Lux</td>
</tr>
<tr>
<td>Center Mounted Lighting</td>
<td>B-400W HPS</td>
<td>25 Lux</td>
</tr>
</tbody>
</table>

### Example Lighting Plan – Rural High Speed Approaches
Roundabouts can be constructed under three types of traffic conditions:

• With all traffic diverted away from the work area,
• With some traffic diverted, or
• Under full traffic conditions.

Source: Washington State Department of Transportation 30
Public Involvement Strategies

- Brochures
- Third party facilitator
- Practice run
  - Model scale
  - Parking lot demo

Photo source: FHWA

Educational Material

Current Research and Publications

- NCHRP 674 - Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities
- NCHRP 03-100 (Current) Evaluating the Performance of Corridors with Roundabouts
- FHWA - Accelerating Roundabout Implementation in the United States: Evaluations to Address Key Issues
- FHWA - Mini Roundabout Safety and Operational Study

Photo source: NYSDOT

Photo source: Isebrands

Source: Bend, OR
Roundabouts P2P Program

- Accelerate the rate of roundabouts implementation across the U.S.
- Facilitate timely access to key, peer-based expertise
- Create and foster relationships within the roundabouts community

Example P2P Expertise Areas

- Pedestrians and Accessibility
- Geometric Design
- Lighting and Landscaping
- Work Zones (construction/maintenance)
- Marketing and Outreach
- Working with Elected Officials
- Operational Analysis
- Bicycles and Transit
- Traffic Control Devices
- Selecting/Sizing a Roundabout
- Gaining Public Support
Possible Forms of P2P Assistance

- Phone/Conference Calls
- E-mail Exchanges/Support
- Virtual Dialogues (video/web conferencing)
- Specific Presentations
- Workshops and Training
- Design Review Assistance
- Peer Exchanges
- Site Visits (scans or reverse-scans)

Program Access & Contacts

- Program Email and Phone
  RoundaboutsP2P@dot.gov or (866) P2P-FHWA [727-3492]
- Program Website
  http://safety.fhwa.dot.gov/intersection/roundabouts/P2P

Other Resources

- Wisconsin DOT – Facilities Development Manual
- Kansas DOT
- Iowa DOT Planning Level Guidelines
- Washington DOT
- New York State DOT
- 2009 MUTCD – Manual on Uniform Traffic Control Devices
- 2010 Highway Capacity Manual
Questions/ Discussion

Plan Review

Plan Review Checklist

- Is the diameter appropriate for context? (too big, too small?)
- R1, R2, R3, R4 - Design Speeds
- Relationship between radiiuses (max 12mph difference)
- Deflection – Is there enough deflection?
- Potential for vehicle path overlap?
- Over-design? (Should it really be constructed as a SLR?)
- Is lighting provided?
- What is the design vehicle?
- Is there curb and gutter on the outside?
- Are the splitter island lengths appropriate?
- Are there pedestrian accommodations (landscaping buffer for wayfinding, width of crosswalk sufficient)?
Plan Review Checklist (con’t)

- Is there a truck apron? (check height, width)
- Is there signing and pavement marking? (Guide signs, lane assignment, warning signs)
- Were any tools used for analysis? (HCM/HCS, RODEL, aaSIDRA, VISSIM, Paramix, Synchro, etc)

Peer Reviews

- Why are they important?
  - Roundabouts are still fairly “new”
  - Roundabout design not in academic curriculum
  - A second set of third party eyes almost always adds value
  - Not every agency has a roundabout expert on board (and that is okay)
  - You can learn a lot from a peer review – it makes you a better designer
  - On-call contract until in-house expertise are developed (Iowa DOT, Kansas DOT)

I’m Not a Roundabout Expert Nor do I want to be…..BUT Be Able to Ask the Right Questions

- Be Able to Identify Fatal Flaws
- NO or Little Deflection
- Vehicle Path Overlap
- Inconsistent Speeds (Between circulating and approach drivers)
- If you were a truck driver would you want to traverse a 6 inch Vertical Curb?
- What Analysis Tools are Available?
Delaware MUTCD

http://deldot.gov/information/pubs_forms/manuals/de_mutcd/index.shtml

Design Case Study
SR 10 and SR 15
Camden, DE
Wrap-Up

Source: WisDOT

Evaluations

Final Thoughts...

Thank You

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FHWA Resource Center Safety and Design TST
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