Speakers

- **John Beery, PE, PTOE**  
  City Engineer, City of Noblesville, IN
- **Jeromy Grenard, PE**  
  Traffic Services Manager, American Structurepoint
- **Mike McBride, PE**  
  City Engineer, City of Carmel, IN
- **Craig Parks, PE**  
  Project Development Director, American Structurepoint

Overview

- **Part I**  
  - Introduction to Roundabouts  
  - Roundabout Safety  
  - Pavement Markings and Signs  
  - Maintenance of Traffic During Construction  
  - Lighting  
  - Q & A

- **Part II**  
  - Capacity Study in Indiana  
  - Capacity Calculation Options  
  - Use of Simulation for Roundabout Evaluation  
  - Roundabout Design  
  - Q & A

Art, Engineering, or Both?

Merriam-Webster:

- **Art**: “The conscious use of skill and creative imagination especially in the production of aesthetic objects.”
- **Engineering**: “The application of science and mathematics by which the properties of matter and the sources of energy in nature are made useful to people.”
- Where does good roundabout design fit in?  
  - BOTH!

History of Roundabouts

1800s-1940s  
Traffic circles and rotaries used

1950s  
Circular intersections fall out of favor

1966  
UK institutes “yield on entry” – birth of the Modern Roundabout

1990  
First Modern Roundabouts built in US - Nevada

1997  
First Modern Roundabouts constructed in Indiana
**Definition – Modern Roundabout**

Yield at Entry
- Yield signs
- Yield line
- Circulating traffic has right-of-way

Deflection of entering vehicle path
- Accomplished using “splitter islands”

Entry flare
- Lane width is increased near yield line
- Not mandatory

**Indianapolis – Monument Circle**

Not a roundabout!

**Kingston, NY Rotary**
Converted to Roundabout

The roundabout is much smaller

**Benefits of a Roundabout**
- Keeps traffic moving (efficient)
  - Yield instead of stop
- Aesthetically pleasing
  - Central island provides opportunity for landscaping
- Less pollution
  - Air
  - Noise
- Safer than conventional intersections
  - Greater than 90% reduction in fatalities!!
- Studies performed by Insurance Institute of Highway Safety

**Roundabout Applications**
- High-crash locations
- Congested locations
- Freeway interchanges
- Corridor with multiple intersections
- Where widening is cost-prohibitive
- Access management
- Unusual geometry

**Where NOT to use a Roundabout**
- Wherever queues would back up into the roundabout
- Insufficient sight distance (can’t see the roundabout on the approach)
- In the middle of a traffic signal system with good progression
- On a steep (≥ 5%) grade
**ADA Issues**

- Access Board of Americans With Disabilities Act (ADA) has concerns for sight-impaired pedestrians at roundabouts
- What is the concern?
  - Safety – not primarily
  - Accessibility – yes
  - Access Board Research ongoing

**Roundabout Safety**

According to the IIHS, over 800 people die and over 200,000 are injured in the US each year in crashes involving red light running

- In 2000, the IIHS found roundabouts had 79% fewer accidents with injuries than ordinary intersections.
- Since 2001, IIHS has issued a total of five reports promoting the use of roundabouts

**Conflict Points**

- 32 Vehicle to vehicle conflicts
- 24 Vehicle to pedestrian conflicts

**Pedestrian Crossings**

- 25’ back from yield line at roundabouts
- Splitter island minimum 6’ wide for refuge
**Speed Reduction**

![Speed Reduction Diagram](image)

**Pedestrian Fatality in Pedestrian/Vehicle Crash**

<table>
<thead>
<tr>
<th>Vehicle Speed</th>
<th>Odds of Pedestrian Death, Source 1</th>
<th>Odds of Pedestrian Death, Source 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 mph</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>30 mph</td>
<td>45%</td>
<td>37%</td>
</tr>
<tr>
<td>40 mph</td>
<td>85%</td>
<td>83%</td>
</tr>
</tbody>
</table>


**Carmel Citywide Crash Data 2002-2006**

- % Accidents with Injury at All Intersections: 29%
- % Accidents with Injury at Roundabouts:
  - Single Lane: 4%
  - Multi-Lane: 7%

**Accident Damage Cost Savings**

Cost of accident damages is less at roundabouts than traditional signalized intersections.

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Avg. Cost of Damages</th>
</tr>
</thead>
<tbody>
<tr>
<td>96th Street (signal)</td>
<td>$13,800</td>
</tr>
<tr>
<td>116th Street (signal)</td>
<td>$7,300</td>
</tr>
<tr>
<td>126th Street (RBT)</td>
<td>$2,500</td>
</tr>
<tr>
<td>131st Street (RBT)</td>
<td>$2,500</td>
</tr>
</tbody>
</table>

*(Statistics from Carmel Police Dept., 2006)*

**Signing/Striping**

Locals often complain about sign clutter

**FHWA Advanced Signage Guide**

![Advanced Signage Guide](image)
Carmel Standard Approach Signage

- Roundabout Ahead Sign Assembly
- Multi-Lane Usage Sign

- Pedestrian Crossing Sign
- Yield Sign

- Center Island Sign
- Exiting Street Name Sign
Standard Striping

Approved by NDOTCD

Zebra Crosswalk Striping
Lane Delineation Lines
Circulatory Roadway Edge Line
“Sharks Teeth” Yield Line

Standard Carmel Striping

Specialty Fishhook Lane Indication Arrows

Standard Striping

Spiral Pavement Markings

Standard Carmel Striping

Spiral Pavement Markings

Standard Carmel Striping

Spiral Pavement Markings
**Standard Carmel Striping**

**Early Education**

**Early Education**

**Roundabout Construction Maintenance-of-Traffic Options**

**Full Closure**

- Full intersection closure is quickest and least expensive
  - Must have a detour route available
  - Typical closure time is 45 days

**45-Day Closure**

141st & Towne Road
60-Day Closure

136th Street & Illinois Street

30-Day Closure

Spring Mill Road & Dorset

Roundabout Construction

- Full intersection closure is quickest and least expensive
  - Must have a detour route available
  - Typical closure time is 45 days

- Partial access can be maintained
  - Extends time of construction
  - Can be accomplished in many variations

Partial Access

Illinois Street & 131st Street

Partial Access

Illinois Street & 131st Street

Partial Access

Old Meridian Street & Guilford Road

Partial Access
Partial Access

Old Meridian Street & Guilford Road

Partial Access

Old Meridian Street & Grand Boulevard

Partial Access

Old Meridian Street & Grand Boulevard

Topics of Discussion

- Roundabout safety
- Available lighting resources
  - IESNA
  - AASHTO
  - State DOT
  - Others
- Developing illumination strategies
  - Location and placement
  - Luminaire selection
  - Spacing
  - Geometrics and signage
- Examples
- Results and conclusions

Available Resources

- “Roadway Lighting Design Guide” by AASHTO.
Why Provide Lighting?

- Reduce nighttime accidents
- Aid police protection and security
- Facilitate traffic flow
- Promote business and use in night hours
- Provide advance warning

Source: "Roadway Lighting" by IESNA

Lighting Methodology

- Present guidance and resources
  - AASHTO
  - IESNA
  - State and local standards
  - Proprietary methods and vendor assistance
- Limitations and applicability

Traditional Roadway Lighting Analysis and Methodology

- Linear roadway methodology
  - Select luminaire and mounting height
  - Analyze photometric contours
  - Manually or by computer model
  - Determine spacing and Placement
  - Analyze alternatives

AASHTO Guidance

"Roundabouts should be lit to a level that is 1.3 to 2 times the value used on the best lit approach. Uniformity should be 3:1 or better. The Illuminance method should be used."

IESNA Guidance

Recommended Illuminance for the Intersection of Continuously Lighted Urban Streets

<table>
<thead>
<tr>
<th>Functional Classification</th>
<th>Eavg/Emin</th>
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<th>Eavg/Emin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor/Major</td>
<td>14.0/1.0</td>
<td>16.0/1.6</td>
<td>18.0/2.2</td>
</tr>
<tr>
<td>Minor/Collector</td>
<td>20.0/2.0</td>
<td>24.0/2.8</td>
<td>30.0/3.6</td>
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<td>30.0/3.6</td>
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</tbody>
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Applying Traditional Strategies to Roundabouts

- Issues:
  - Roundabout is non-linear
  - Motorist unfamiliarity
  - Roundabout offers added flexibility over traditional intersection
  - Luminaire use
  - Pedestrian considerations
  - Other pros and cons
Luminaire Selection
- Know capabilities
- Avoid glare and trespass
  - Don’t over illuminate
  - Consider trespass stds
- Select based on functionality
- Consider stock and standard practice

Conflict Points and Luminaire Placement
- Initial Locations
  - Crosswalks
  - 45°, 135°, 225°, 315° quadrant points
- Accommodate luminaire capability, and illumination and uniformity requirements
- Consider clear zone
- Evaluate arm lengths

Illumination Strategy: Single-Lane Roundabout
- Single-lane roundabout up to 110’ in diameter
- Understand capability of luminaires considered
- Place luminaire and poles near conflict points
- Light from exterior of roundabout

Single Lane vs. Multiple Lanes
- Considerations
  - Pedestrians
  - Higher Traffic Levels
  - Larger Area to Light
  - Higher Speeds into Entry Lanes
Illumination Strategy:
Two-Lane Roundabout

- Two lanes from 120° to 180° in diameter
- Know capability of luminaires considered
- Place luminaire and poles near conflict points
- Light from interior of roundabout

Results and Conclusions

1. Identify and establish a standard luminaire and mounting height to provide consistent and cost-effective illumination. Attempt to accommodate both aesthetics and function.
2. Establish preliminary lighting locations adjacent to the conflict points of the roundabout, including crosswalks.
3. Single-lane roundabouts can typically be lit from the exterior of the intersection. Two-lane roundabouts typically require pole placement within the inner circle near the 45°, 135°, 225°, and 315° points for the inner circle conflict points.
4. Two-lane roundabouts may require closer pole spacing or more intense luminaires when lit from the inner circle to improve intensity and to reduce the number of lights.
5. Observe IES guidelines for illumination levels based on the type of intersection.
6. Adjust the type of pole, its location, and the base depending on clear zone requirements.

Questions?

- ADA
- Safety
- Pavement markings & signage
- Maintenance of traffic during construction
- Lighting
Assessing Roundabout Capacity and Project Selection

Roundabouts: Art, Engineering, or Both?

Why did the chicken cross the road?
Because the available time headway in opposing traffic met his parameters for gap acceptance.

Roundabout Capacity
- Where do I put them?
- What is the capacity of a roundabout?
- Why is the most common question regarding capacity related to ADT?
- What is true capacity of and entry lane?
- Can capacity be quantified?
- What methods can be used to determine operational characteristics?
- What values for capacity are correct?
- Can simulations be accurately utilized?
- On what premise do roundabouts operate?
- Can we recognize “Garbage In/Garbage Out”?

Guidelines for Use

Typical Peak Flow Ranges for Various ADTs

<table>
<thead>
<tr>
<th>AADT</th>
<th>Est. Range Peak Flow for Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000</td>
<td>300 to 700</td>
</tr>
<tr>
<td>15,000</td>
<td>520 to 1,420</td>
</tr>
<tr>
<td>20,000</td>
<td>770 to 2,480</td>
</tr>
<tr>
<td>25,000</td>
<td>910 to 1,480</td>
</tr>
<tr>
<td>30,000</td>
<td>1,150 to 2,480</td>
</tr>
<tr>
<td>40,000</td>
<td>1,150 to 2,880</td>
</tr>
</tbody>
</table>

For Single Lane, Urban Route

FHWA Roundabout Capacity

ACCURATE?
Summary of Capacity Resources

Entry Lane Capacity vs. Rate of Flow in Inner Circle

Entry Lane Capacity vs. Time Headway in Inner Circle

Parameters Affecting Flow and Capacity

- Classification of Facility
- Upstream Free-Flow Speed
- Geometrics
  - Deflection causes reduction in speed
  - Control Delay is inherent from geometrics
- Geometrics of Inner Circle
- Lane Widths
- Driver Familiarity and Behavior
- Peak Hour Flow and ADT
- Upstream Flow in Inner Circle
- Turning movements within intersection

Understanding Capacity

- Understand Differences
  - Conventional Intersection
    - All traffic yields to through movements to the right if no other
    - Through movements typically take precedent over other
    - Entry movements yield to inner circle, regardless of its movement.
    - Therefore, a combinations or all movements in a certain direction
  - Roundabouts
    - Entry movements yield to inner circle, regardless of its movement.
    - Therefore, a combinations or all movements in a certain direction
    - Control

Flow Parameters

Delay Study

- Completed a series of delay studies in September of 2007 for
  - Intent of study – To determine the point at which demand
  - Parameters:
    - Data collected in 10 second intervals
    - Counted number of vehicles in queue on entry lane approach
    - Counted vehicles travelling in inner circle upstream of entry lane
    - Time headways for 10 second vehicle counts were analyzed
    - Data was extrapolated to evaluate the effects of sustained flow
    - Conditions over longer periods of time.
Study Results

Figure 2: Entry Flow Rate and Inner Circle Time Headway vs. Inner Circle Flow Rate in Roundabout

Comparison to MUTCD Signal Warrant #1

<table>
<thead>
<tr>
<th>Condition for Determining Continuation Traffic</th>
<th>Flow (vph)</th>
<th>Average Headway (sec/veh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of lanes for opposing traffic on each approach</td>
<td>750</td>
<td>4.8</td>
</tr>
<tr>
<td>1</td>
<td>750</td>
<td>4.8</td>
</tr>
<tr>
<td>2 or more lanes</td>
<td>750</td>
<td>4.8</td>
</tr>
<tr>
<td>3 or more lanes</td>
<td>750</td>
<td>4.8</td>
</tr>
</tbody>
</table>

ADT Evaluation

<table>
<thead>
<tr>
<th>ADT Major Road</th>
<th>ADT Single Road</th>
<th>Roundabout Usage</th>
<th>Comment</th>
</tr>
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<tbody>
<tr>
<td>5,500</td>
<td>1,590</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>10,000</td>
<td>3,000</td>
<td>Medium</td>
<td></td>
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Roundabout Usage

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Conclusions on Capacity

- The flow in the entry lane is directly related to available gaps in flow within the inner circle and the acceptance of those gaps.
- Flow in the inner circle is not a direct function of flow-through ADT.
- Entry lane flow is reduced when the time headway of opposing flow in the inner circle is approximately 5 sec/veh.
- Entry lane flow is shut down at flow rate of approximately 1,100 vph in the inner circle upstream of the subject entry lane.
- Don’t believe recommendations from Urban Planners when dealing with the selection of the appropriate traffic control.
- Future consideration of warrants for roundabouts should range from and overlap the warrants for two-way stops, through four-way stops, to at least the minimum warrants for traffic signals (depending on the volume and classification of facility).
- Hierarchy of Flow Parameters that Affect Capacity
  - Movements in Inner Circle
  - Flow Through ADT
  - Geometrics
- Each entry lane approach acts as a TWSC governed by HCM 2000.

Computer Applications for Capacity Analysis and Simulation

- HCM 2000

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VISSIM

- Many transportation applications:
  - Signalized intersections
  - Roundabouts
  - Freeway corridors
  - Transit facilities
  - ITS
  - Etc.

VISSIM Advantages for Roundabouts

- Ability to model actual geometry
  - Links and connectors can be configured to any geometry – from simple to complex
  - Ability to model traffic interactions between adjacent approaches or intersections
  - Seeing is Believing
  - Public Education
  - Good estimate of US roundabout capacity

VISSIM Advantages for Roundabouts

Quoted directly from the paper:

- “(VISSIM) simulated capacities of single-lane roundabouts are noticeably lower than RODEL and aaSIDRA; however, they are comparable to fitted US field capacity data.”

- “Similarly, capacities of dual-lane roundabouts as simulated by VISSIM are significantly lower than RODEL and aaSIDRA, and are comparable to US field capacity data for a certain fitted regression.”

VISSIM Advantages for Roundabouts

Simulation Limitations

Limitations of Simulation

- Model parameters can be changed by the user that affect results
- Steep learning curve
- Extensive inputs required to build a model
Links and Connectors

Priority Rule (Yielding Behavior)

Typically determined by engineering judgment and driving behavior in that region.

Reduced Speed Area

Speed Decisions

Route Decisions

Project Experience:
Roundabout vs. Signal
**Project Experience:**
Roundabout/Signal Intersection

**Project Experience:**
Vehicle/Pedestrian Interaction

**Project Experience:**
Roundabout Interchanges

**Roundabout Design**

**Design Considerations**
- Vehicle speeds
  - Entry and exit radii
  - Circulatory roadway diameter
- Design vehicle negotiation of roundabout
- Vehicle path overlap (multi-lane roundabouts)
- Capacity (RODEL, aaSIDRA, or simulation)
- Lighting
- Signs and pavement markings
- Vehicle sight distances
- Pedestrian crossing locations and refuges
- Bicycle facilities

**Single-Lane Geometric Layout**
Basic Definitions using photo
- Inscribed Diameter
- Truck Apron
- Roundabout Bypass Lane
- Circulatory Roadway Width
Single-Lane Geometric Layout

**Geometric Basics**

- Inscribed diameter
  - Can range from 100’-150’
  - Typically start with 110’ and adjust based on existing conditions
  - Dependent on your design vehicle
- Circulatory roadway width
  - Dependent on your design vehicle
  - Typically start with 25’-40’ for a single lane roundabout
- Truck apron width
  - Dependent on your design vehicle tracking
  - Typically start with a minimum of 5’

**Roundabouts: Art, Engineering, or Both?**

**Single-Lane Geometric Layout**

- Entry width
  - 15’ practical maximum
- Approach Radius
  - Can range from 80’-120’
  - Typically start with 100’
  - Affects your roundabout capacity and speeds
- Exit Radius
  - Can range from 400’-800’
  - Typically start with 600’
  - Affects your roundabout capacity and speeds

**Roundabouts: Art, Engineering, or Both?**

**Our Recommendations**

- Desired deflection is easier to achieve
- Can utilize a smaller circle without reducing deflection
- Results in slower entry speeds

**Roundabouts: Art, Engineering, or Both?**
Roundabout Speeds – Circulating vs. Entering

- Conflicting speeds are optimally separated by no more than 6 mph
- 6 mph is rarely achievable
- A maximum speed difference of 12 mph is suggested

Roundabout Speeds – Fastest Path

- FHWA Guide provides this illustration to create these paths and graphs to measure the resulting speeds
- HOWEVER, these paths do not necessarily predict your speeds.
- Proper deflection in advance of roundabout will negate the ability to reach R1 speed based on radius/speed tables
- Actual speed should be measured by acceleration calculations based on speeds where entry is the limiting factor

Getting Started

- Easy 5-step process with a foundation of designing pavement marking alignments
- Multiple iterations of these five steps will need to be completed to achieve the best geometric design
- Curbs and edges of pavement are derived by the pavement markings in accordance with the FHWA Roundabout Guide.

Disclaimer: There are many approaches to achieve a sound geometric roundabout design. Our approach is just one simple method we have found to work.

Situation

- Simple 90-degree intersection
- Both roadways are 2-lane roads

Step 1

- Draw center circle
- Offset for circulatory roadway width
- Draw exits
Step 2
- Fillet centerline to inside of circulatory roadway for exits

Step 3
- Fillet inside of exit lane with inside circle to create inside approach lane

Step 4
- Offset inside of exit lane to match approaching lane width

Step 5
- Fillet with outside edge of circulatory roadway

Step 6
- Trim and review your geometrics

Deflection Check
- Tangent to outside edge of approach should line up close to point where inside edge of approach intersects circulatory roadway
Situation 2
- Offset intersection
- Higher speed on east-west road

Step 1
- Draw center circle to maximize deflection on higher speed approach
- Offset for circulatory roadway width
- Draw exits

Step 2
- Fillet centerline to inside of circulatory roadway for exits

Step 3
- Fillet inside of exit lane with inside circle to create inside approach lane

Step 4
- Offset inside of exit lane to match approaching lane width

Step 5
- Fillet with outside edge of circulatory roadway
**Single-Lane Geometric Layout**

*Step 6*
- Trim and review your geometrics

**Splitter Islands**
- Once you are happy with the geometrics of your roundabout, create splitter islands as illustrated Exhibit 6-7 of the FHWA Guide

**Single-Lane Geometric Layout**

**Splitter Islands**
- Where pedestrian facilities exist, the splitter island should be at least 50'
- Additional modifications to your geometrics may be necessary to develop required splitter island length

**Single-Lane Geometric Layout**

**Multi-Lane Geometric Layout**

**Geometric Basics**
- Inscribed diameter
  - Can range from 150'-200'
  - Typically start with 160' and adjust based on existing conditions
  - Dependent on your design vehicle
- Circulatory roadway width
  - Dependent on your design vehicle
  - Typically start with 30'-31' for a 2 lane roundabout
- Truck apron width
  - Dependent on your design vehicle tracking
  - Typically start with a minimum of 5'
Multi-Lane Geometric Layout

**Situation**
- Skewed intersection
- East-west roadway is a 4-lane facility
- North-south roadway is a 2-lane facility

**Roundabouts: Art, Engineering, or Both?**

**Multi-Lane Geometric Layout**

**Step 1**
- Draw center circle
- Offset for circulatory roadway width
- Draw exits

**Roundabouts: Art, Engineering, or Both?**

**Multi-Lane Geometric Layout**

**Step 2**
- Fillet inside of exit lanes to inside of circulatory roadway

**Roundabouts: Art, Engineering, or Both?**

**Multi-Lane Geometric Layout**

**Step 3**
- Fillet inside of exit lane with inside circle to create inside approach lane.
- ONLY DO THIS FOR SINGLE LANE ENTRIES!

**Roundabouts: Art, Engineering, or Both?**

**Multi-Lane Geometric Layout**

**Step 4**
- Offset inside of exit lane to match approaching lane width
- Only do this for the single lane entries!

**Roundabouts: Art, Engineering, or Both?**

**Multi-Lane Geometric Layout**

**Step 5**
- Fillet with outside edge of circulatory roadway
- Only do this for the single lane entries!
Striping and proper geometric design is crucial to achieve proper lane use!

Multi-Lane Geometric Layout

Step 6
- Create tangents on two-lane approaches to prevent entry path overlap.

Multi-Lane Geometric Layout

Step 7
- Trim and review geometrics

Questions?
- Capacity Study in Indiana
- Capacity Calculation Options
- Use of Simulation for Roundabout Evaluation
- Roundabout Design