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

Pedestrian Crossings

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

Figure from FHWA Design Guide

**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**
Carmel Standard Approach Signage

Roundabout Ahead Sign Assembly

Carmel Standard Approach Signage

Multi-Lane Usage Sign

Carmel Standard Approach Signage

Pedestrian Crossing Sign

Carmel Standard Approach Signage

Yield Sign

Carmel Standard Approach Signage

Center Island Sign

Carmel Standard Approach Signage

Center Island Sign

Carmel Standard Approach Signage

Exiting Street Name Sign
Standard Striping

Approved by NDOT/CDD

Roundabouts: Art, Engineering, or Both?

Standard Carmel Striping

Zebra Crosswalk Stripping

“Sharks Teeth” Yield Line

Roundabouts: Art, Engineering, or Both?

Standard Carmel Striping

Specialty Fishhook Lane Indication Arrows

Roundabouts: Art, Engineering, or Both?

Standard Striping

Circulatory Roadway Edge Line

Roundabouts: Art, Engineering, or Both?

Standard Carmel Striping

Spiral Pavement Markings

Roundabouts: Art, Engineering, or Both?

Standard Carmel Striping

Spiral Pavement Markings

Roundabouts: Art, Engineering, or Both?
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
- Old Meridian Street & Guilford Road
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."[1]

IESNA Guidance

Recommended Illuminance for the Intersection of Continuously Lighted Urban Streets:

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

Summary of Methodology

- Evaluate geometrics
- Light conflict points
- Use familiar luminaires
- Provide consistent lighting to comply with IESNA requirements

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 its base depending on clear zone requirements

Questions?

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

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

FHWA Roundabout Capacity
Summary of Capacity Resources

Entry Lane Capacity vs. Rate of Flow in Inner Circle

<table>
<thead>
<tr>
<th>Flow Rate in Inner Circle (veh/hr)</th>
<th>Entry Lane Capacity (vph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>1400</td>
<td>1400</td>
</tr>
<tr>
<td>1600</td>
<td>1600</td>
</tr>
<tr>
<td>1800</td>
<td>1800</td>
</tr>
<tr>
<td>2000</td>
<td>2000</td>
</tr>
</tbody>
</table>

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 controls, such as signals are present.
    - Through movements typically take precedent over other movements, unless movement is protected.
  - Roundabouts
    - Entry movements yield to inner circle, regardless of its movement.
    - Therefore, a combinations or all movements in a certain direction can control through our entry movements.

Flow Parameters

Delay Study

- Completed a series of delay studies in September of 2007 for same existing roundabout approach during peak hour
- Intent of study – To determine the point at which demand meets capacity for an entry lane approach
- 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
  - 10 second vehicle counts were computed to hourly flow rates
  - Time headways for 10 second vehicle counts were analyzed individually
  - Data was extrapolated to evaluate the effects of sustained flow conditions over longer periods of time.
Study Results

Figure 2-1
Entry Flow Rate and Inner Circle Time Headway vs.
Inner Circle Flow Rate in Roundabout

Comparison to MUTCD Signal Warrant #1

Comparison to MUTCD Signal Warrant #2

ADT Evaluation

Roundabout Usage

Study Results

Roundabouts: Art, Engineering, or Both?
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

- Microscopic Simulation Models
  - Analyze each individual vehicle
  - Can give delay, number of stops, queue lengths, etc.
  - Based on gap acceptance theory
  - VISSIM, PARAMICS, Etc.

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).
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  - Movements in Inner Circle
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  - Geometrics
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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

- Microscopic Simulation Models
  - Analyze each individual vehicle
  - Can give delay, number of stops, queue lengths, etc.
  - Based on gap acceptance theory
  - VISSIM, PARAMICS, Etc.
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

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."

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
- Roundabout Bypass Lane
- Circulatory Roadway Width
- Truck Apron
Single-Lane Geometric Layout

Geometric Basics
- Inscribed diameter
  - Can range from 100'-150'
  - Typically start with 130' and adjust based on existing conditions
- Circulatory roadway width
  - Dependent on your design vehicle
  - Typically start with 15'-16' 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

Geometric Basics
- Entry width
  - 16' 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?

Single-Lane Geometric Layout

Our Recommendations

Roundabouts: Art, Engineering, or Both?

Single-Lane Geometric Layout

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

Roundabouts: Art, Engineering, or Both?
Single-Lane Geometric Layout

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.
**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
**Single-Lane Geometric Layout**

**Situation 2**
- Offset intersection
- Higher speed on east-west road

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

**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
Step 6
• Trim and review your geometrics

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

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

Can decrease exit radii to avoid R/W impacts or slow exiting traffic due to crosswalk.
• Be careful not to reduce exit radii too much

Typically start with 160’ and adjust based on existing conditions
• Dependent on your design vehicle

Dependent on your design vehicle
• Typically start with 30’-31’ for a 2 lane roundabout

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!

Roundabouts: Art, Engineering, or Both?
Desired Path of Vehicles

Entry Path Overlap

Speed & Trajectory of vehicle at yield point determines natural path.

Striping and proper geometric design is crucial to achieve proper lane use!

Multi-Lane Geometric Layout

Unacceptable Vehicle/Path Overlap

No Vehicle Path Overlap

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