Results from NCHRP 3-65: Applying Roundabouts in the United States

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AASHTO Subcommittee on Design
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NCHRP 3-65: Applying Roundabouts in the United States

- Project objective, panel, and team
- Findings and recommendations
  - Characteristics
  - Safety
  - Operational analysis
  - Design
- Closing thoughts
Overall Summary

- Roundabouts safety performance is generally outstanding, even with wide variation in design styles.
- Design elements appear to address many of the key potential safety challenges, particularly for multilane roundabouts.
- No observed safety problems for pedestrians and cyclists, although lack of motorist yielding is potential concern.
- Operational performance is currently more tentative than other countries.
NCHRP 3-65 Project Objective

- Produce a set of operational, safety, and design tools, calibrated to U.S. roundabout field data.

Photo: Lee Rodegdts

Port Orchard, WA
NCHRP 3-65 Project Panel

- Beatriz Caicedo-Maddison, Florida DOT (chair)
- Maria Burke, Texas DOT
- Jerry Champa, California DOT
- Leonard Evans, Science Serving Society
- Steve King, Kansas DOT
- Robert Limoges, New York State DOT
- Richard Long, Western Michigan University
- Ron Pfefer, HSM liaison
- Brian Walsh, Washington State DOT
- Mohsin Zaidi, City of Kansas City, MO
- Joe Bared, FHWA
- Hari Kalla, FHWA
- Rich Cunard, TRB
- Ray Derr, NCHRP
NCHRP 3-65 Project Team

- **P.I.:** Lee Rodegerdts (KAI)
  - *(Bruce Robinson, Co-P.I. Emeritus)*

- **USA**
  - Kittelson & Associates, Inc.
  - University of Idaho
  - Rensselaer Polytechnic Institute
  - George Mason University
  - David Harkey
  - John Mason

- **Australia**
  - Rod Troutbeck

- **Canada**
  - Bhagwant Persaud

- **Germany**
  - Werner Brilon

- **United Kingdom**
  - Richard Hall

- 94% urban or suburban
- 68% have 4 legs (7% > 4 legs)
- 73% are single-lane

Clearwater, FL

- 51% previously OWSC or TWSC
- 10% previously AWSC
- 9% previously signals
- 30% are new

Kennewick, WA

Before

After

Photos: Lee Rodegerdts
Sample of Safety Findings

- Overall safety experience: VERY GOOD
- Specific products from NCHRP 3-65:
  - Intersection-level accident models
  - Approach-level accident models
  - Before-after study of intersections converted to roundabouts
Intersection-Level Crash Prediction

- Used for comparing performance to other intersection types
- Baseline prediction on which approach-level AMFs could be applied
- Factors affecting coefficients:
  - Number of lanes
  - Number of approaches
- Example: Roundabout with 4 legs, 2 lanes
  - Crashes = 0.0038(AADT)^{0.7490}
  - Valid AADT range: 2,000 to 35,000
Approach-Level Crash Data (139 approaches)

- Total Number of Approach Crashes
  - Entering Circulating
  - Exiting/Circulating
  - Rear End on Approach
  - Loss of Control
  - Pedestrian
  - Bicycle

- Crash Type

- Single Lane
- Multi-Lane
### AMFs Implied from Design-Level Crash Prediction Models (to be considered by HSM)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Entering/ Circulating</th>
<th>Exiting/ Circulating</th>
<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry Radius (ft.)</td>
<td>0.9901 to 0.9896</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Entry Width (ft.)</td>
<td>1.0524</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Approach Half Width (ft.)</td>
<td>-</td>
<td>-</td>
<td>1.0306</td>
</tr>
<tr>
<td>Inscribed Circle Diameter (ft.)</td>
<td>-</td>
<td>1.0224</td>
<td>-</td>
</tr>
<tr>
<td>Central Island Diameter (ft.)</td>
<td>0.9924 to 0.9954</td>
<td>1.0138</td>
<td>-</td>
</tr>
<tr>
<td>Circulating Width (ft.)</td>
<td>-</td>
<td>1.1171</td>
<td>-</td>
</tr>
<tr>
<td>Angle To Next Leg (deg.)</td>
<td>0.9728</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
### Before-After Results – All Sites (55)

<table>
<thead>
<tr>
<th></th>
<th>All</th>
<th>Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crashes recorded in after period</td>
<td>726</td>
<td>72</td>
</tr>
<tr>
<td>EB estimate of accidents expected after without roundabouts</td>
<td>1122</td>
<td>296</td>
</tr>
<tr>
<td>Reduction (Standard error)</td>
<td>35.4 % (3.4)</td>
<td>75.8 % (3.2)</td>
</tr>
</tbody>
</table>

### CONTROL BEFORE

<table>
<thead>
<tr>
<th>Control</th>
<th>All</th>
<th>Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIGNALS (9)</td>
<td>48%</td>
<td>78%</td>
</tr>
<tr>
<td>TWO WAY STOP (34)</td>
<td>44%</td>
<td>82%</td>
</tr>
<tr>
<td>ALL-WAY STOP (10)</td>
<td>Insignificant increase</td>
<td></td>
</tr>
</tbody>
</table>
Sample of Operations Findings

- **Overall findings:** Lower capacities relative to other countries
- **Specific NCHRP 3-65 findings:**
  - Analysis of existing models
  - Driver behavior and effect of geometry
  - Recommended operational models
Analysis of Existing Models

- All international models (including SIDRA and RODEL) predict capacities higher than observed.
Effect of Geometry on Operational Performance

- Capacity clearly sensitive to geometry IN THE AGGREGATE (first-order effects)
  - Number of lanes
  - Lane utilization

- Second-order effects masked by variations in driver behavior
  - Lane width, diameter, entry angle, etc.

- Capacity data is limited at this stage; future data may reveal more significant secondary effects
Example: Entry Lane Width versus Gap Acceptance Observations

- Entry lane width = entry width / # lanes

![Graph showing the relationship between entry lane width and gap parameters]

- For all tf:
y = -0.079x + 4.8345
R² = 0.0003

- For all tc:
y = -0.047x + 3.408
R² = 0.0336
**Other Operational Observations**

- **Several multilane sites exhibit strong queuing in only one lane**
  - *Proposed multilane model estimates performance of critical lane*
  - *Can account for turning movement effects, lane utilization, field-observed geometric effects*

- **Local calibration can improve estimates**
  - *Proposed models include parameters for calibration*
  - *Can allow adjustments for capacity improvement over time*
Proposed HCM Capacity Models: Empirical, Lane-Based Regression Models

- Critical Lane Regression
- Single Lane Regression
- Extrapolated Regression

Conflicting Flow (pcu/hr)
Max Entry Flow (pcu/hr)

\( y = 1130e^{-0.001x} \)
Sample of Design Findings

- **Overall findings:**
  - *Current techniques appear to be generally solid*
  - *Attention needed on roundabout exits for peds*

- **Specific NCHRP 3-65 findings:**
  - *Design speed modeling*
  - *Other design findings for motor vehicles*
  - *Pedestrian and bicycle observations*
Current Methods Predict 85th-percentile Circulating Speed Reasonably Well

\[ y = 1.1041x - 1.8409 \]

\[ R^2 = 0.6483 \]

Data Match Line 85th %ile (15+ obs.) Linear (85th %ile (15+ obs.))
Current Methods Overpredict Exit Speeds

\[ y = 0.2513x + 13.834 \]

\[ R^2 = 0.2933 \]
Exit Speed Prediction Improves after Including Acceleration Effects

\[ V_3 = \min \left\{ \frac{1}{1.47} \sqrt{(1.47V_2)^2 + 2a_{23}d_{23}} \right\} \]

\[ y = 0.6694x + 5.9115 \]

\[ R^2 = 0.5156 \]
Multilane roundabout issues

- Higher crash frequencies and crash rates than single-lane roundabouts
- Contributors that can be corrected:
  - Vehicle path overlap
  - Poor or improper striping
  - Separation between entries and exits
Anecdotal Evidence Suggests Ability for Design to Correct Potential Multilane Safety Problems

**Clearwater Beach, FL**

*Before (2001)*

*After (2005)*
### Pedestrian and Bicycle Observational Analysis

- Generally no observed safety problems for either pedestrians or bicyclists
- Some problems with motorists failing to yield to pedestrians
  - All sites: 30 percent
  - Entry leg: 23 percent
  - Exit leg: 38 percent
  - 1-lane approaches: 17 percent
  - 2-lane approaches: 43 percent
Yielding rates are better than uncontrolled, worse than stop- or signal-controlled

<table>
<thead>
<tr>
<th>Crossing control</th>
<th>Percent of “normal” crossings</th>
<th>Percent of non-yielding vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncontrolled</td>
<td>70%</td>
<td>48%</td>
</tr>
<tr>
<td>Roundabout</td>
<td>85%</td>
<td>32%</td>
</tr>
<tr>
<td>Signal-controlled</td>
<td>90%</td>
<td>15%</td>
</tr>
<tr>
<td>Stop-controlled</td>
<td>100%</td>
<td>4%</td>
</tr>
</tbody>
</table>
Two suggestions when faced with difficult intersection problems:

1. *Roundabouts should be considered as one of the alternatives*

2. *Roundabouts should be evaluated objectively; they can stand up on their own merits*

Results from NCHRP 3-65 confirm the need for #1 and provide the tools for #2

Ongoing and future research will continue to refine our understanding of roundabouts
Thank you!

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