Well designed roundabouts should minimize accidents, delay and costs for everyone using the intersection. This session covers the design process that leads to a well designed roundabout as well as challenging conditions where roundabouts may fail.
Presentation Outline – Part 1

• Identifying Candidate Intersections
• Evaluation Process
• Safety Performance
• Design Principles
• Balanced Design
• Design Composition
  – What can go wrong?
Presentation Outline – Part 2

• Geometry and Capacity
• Choosing a Capacity Analysis Method
  – Modeling differences
    • Capacity
    • Delay
    • Limitations
• Variation / Uncertainty in Prediction
• Examples
• Staging Construction to Match Volume Increase
Modern Roundabout Benefits

- Superior safety performance
- Very high capacity ... up to 6,000 VPH
- Great geometric flexibility – ROW
- Simple for traffic to use
- Simple for pedestrians to use
- Environmental benefits
- Aesthetic .. can look superb .. Civic Feature
Where to Consider Roundabouts

- Intersections with high crash rates/high severity rates
- Intersections with complex geometry, skewed approaches, >4 approaches
- Rural intersections with high-speed approaches
- Freeway interchange ramp terminals
- Closely spaced intersections
- Replacement of all-way stops
- Replacement of signalized intersections
- At intersections with high left turn volumes
- Replacement of 2-way stops with high side-street delay
- Intersections with high U-turn movements
- Transitions from higher-speed to lower-speed areas
- Where accommodating older drivers is an objective
Evaluate Alternatives

• Do Nothing
• Install Traffic Signals
• Install Roundabout
• Other options (DDI?)

• Primary MOE’s:
  – Cost
  – Safety
  – Capacity

• Secondary MOE’s:
  - Environmental factors of air, fuel and time
Signal vs. Roundabout
Intersection Control Study Contents

1. Project Background - describe site conditions
2. Safety Assessment (historical crash data)
3. Operational Analyses – Arcady, HCM
4. Cost Comparison – Construction, crash savings, life-cycle
5. Alternative Selection – screening criteria (capacity, safety, cost)
6. Conceptual Roundabout Design – nearly a 30% design
7. Conclusions and Recommendations

The Key Mindset:
- Be sure to solve a problem if a roundabout is to be used!
Substantial Design Effort for Intersection Control Studies (Concept Development)

- Traffic Flow Worksheet
- Lane Configuration
- Context Considerations & Problem Statement
- Initial Geometric Parameters
- Capacity Analysis

Milestone: Scoping And Feasibility Input

Multiple Design Iterations:
- Concept Sketch
- Design Vehicle
- Fastest Path
- Path Overlap
- Impact Assessment

Performance Checks and Context Sensitive Evaluation

- Concept Check
- Design Vehicle
- Fastest Path
- Path Overlap
- Impact Assessment

Context Considerations & Problem Statement

- Final Horizontal Layout
- Alignments/Profiles
- Drainage Cross Slope
- Staging
- Cross Sections

- Scoping And Feasibility Input

60%

- Final Horizontal Layout
- Alignments/Profiles
- Drainage Cross Slope
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- Cross Sections

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- Alignments/Profiles
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60%

- Signing
- Lighting
- Landscaping
- Sight Evaluation

90%

- Signing
- Lighting
- Landscaping
- Sight Evaluation

90%

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Design Inputs – Traffic Forecasts

“Model it first, draw it next”
### Existing and Future Operations

<table>
<thead>
<tr>
<th>Alternative</th>
<th>2013 LOS (AM/PM)</th>
<th>2033 LOS (AM/PM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing two way stop (CTH F LOS)</td>
<td>C (22.5)/F (86.0)</td>
<td>E (42.5)/F (425.5)</td>
</tr>
<tr>
<td>Traffic Signal</td>
<td>Not Evaluated</td>
<td>B (10.6)/B (12.3)</td>
</tr>
<tr>
<td>Roundabout</td>
<td>Not Evaluated</td>
<td>A (6.0)/A (6.9)</td>
</tr>
</tbody>
</table>

- Reduced delay = reduced vehicle emissions
## Collision Cost Assessment

<table>
<thead>
<tr>
<th>Crash Severity</th>
<th>Economic Cost per Crash (2008 dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatality</td>
<td>$4,200,000</td>
</tr>
<tr>
<td>Class A (incapacitating injury)</td>
<td>$214,200</td>
</tr>
<tr>
<td>Class B (non-incapacitating evident injury)</td>
<td>$54,700</td>
</tr>
<tr>
<td>Class C (possible injury)</td>
<td>$26,000</td>
</tr>
<tr>
<td>Property Damage Only (per crash)</td>
<td>$2,400</td>
</tr>
</tbody>
</table>

Source: National Safety Council (7)

Note: Different figures are used for HSIP applications
Roundabout collisions = low severity (failure to yield)
Roundabout collisions = low severity (failure to yield)
24 roundabouts built before 2008
3 years before/after crash data
Results based on Empirical Bayes adjustment
Mixed results for total crash frequency
9% decrease in total crashes
Significant 52% decrease in injury crashes
- Speed limit did not show significant impact on safety
- Multi-lanes seem to be safer than single lane roundabouts for injury crashes
- Single lanes saw the largest decrease in total crashes
Comprehensive Evaluation of Wisconsin Roundabouts

Simple Distribution (before EB adjustment) 3 yrs before / 3 yrs after crash data

| Collision Type | Before | | | | | | After | | | | |
|----------------|--------|---|---|---|---|---|--------|---|---|---|---|---|
|                | K      | A | B | C | PD | Total | K   | A | B | C | PD | Total |
| ANGL           | 1      | 4 | 16| 26| 72 | 119   | 2   | 3 | 49| 54|   |       |
| HEAD           | 2      | 2 | 2 | 2 | 4  | 4      | 1   |   |   |   |   |       |
| NO C           | 1      | 1 | 2 | 2 | 29 | 35    | 9   | 4 | 64| 77|   |       |
| REAR           | 5      | 13| 37| 65|    | 55    | 1   | 1 | 39| 54|   |       |
| SSOP           | 3      | 3 | 6 |   | 9  | 16    | 1   |   |   |   |   |       |
| SSS            | 1      | 1 | 8 | 10|    | 10    | 1   | 1 | 6 | 75|   |       |
| Total          | 2      | 5 | 26| 47| 149| 229   | 4   | 11| 26| 221| 262|       |

Crash Type = Significant Reduction in Economic Cost
### Typical Quantitative Comparison

<table>
<thead>
<tr>
<th>Item</th>
<th>Traffic Signals</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Construction Cost</td>
<td>$1,095,000</td>
<td>$1,262,000</td>
</tr>
<tr>
<td>Property Acquisition</td>
<td>$140,000</td>
<td>$320,000</td>
</tr>
<tr>
<td>Injury Crash Cost (PC)</td>
<td>$905,000</td>
<td>$316,000</td>
</tr>
<tr>
<td>Traffic Signal Annual Maintenance and Replacement (PC)</td>
<td>$184,000</td>
<td>-</td>
</tr>
<tr>
<td>Additional Street Lighting and Annual Maintenance (PC)</td>
<td>-</td>
<td>$33,000</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$2,324,000</td>
<td>$1,931,000</td>
</tr>
</tbody>
</table>

### Evaluation Criteria

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>Traffic Signals</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Injury Crashes by 2027</td>
<td>2.6</td>
<td>0.9</td>
</tr>
<tr>
<td>Traffic Operations by 2027</td>
<td>LOS ‘C’ to ‘D’</td>
<td>LOS ‘B’</td>
</tr>
<tr>
<td>Total Capital Costs</td>
<td>$1.1 million</td>
<td>$1.3 million</td>
</tr>
<tr>
<td>Capital plus Life Cycle Costs</td>
<td>$2.3 million</td>
<td>$1.9 million</td>
</tr>
</tbody>
</table>
## Typical Qualitative Comparison

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Traffic Signals</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Roundabouts</strong></td>
<td></td>
</tr>
<tr>
<td>Vehicle Noise, Fuel Consumption and Emissions</td>
<td>Status quo.</td>
</tr>
<tr>
<td></td>
<td>Reductions in proportion to reductions in average delay – about 60 percent in the AM and PM peak hours.</td>
</tr>
<tr>
<td>Speed Control</td>
<td>Traffic speeds controlled only during red phase. Higher operating speeds on minor road.</td>
</tr>
<tr>
<td></td>
<td>Potential to control speeds at all times.</td>
</tr>
<tr>
<td>Pedestrians and Persons with Disabilities</td>
<td>May require push-button actuation. Audible signals possible.</td>
</tr>
<tr>
<td></td>
<td>Shorter crossing distances, and splitter islands provide refuge. Audible signals possible on individual legs.</td>
</tr>
<tr>
<td>Bicyclists</td>
<td>Crossing and left turn movements not accommodated under actuated control.</td>
</tr>
<tr>
<td></td>
<td>Lower motor vehicle speeds good for bicyclists.</td>
</tr>
<tr>
<td>Emergency Services, Transit</td>
<td>Pre-emption equipment may be required.</td>
</tr>
<tr>
<td></td>
<td>Comparable to traffic signals having pre-emption.</td>
</tr>
<tr>
<td>Truck Movements</td>
<td>Provides optimal operations on green, but lower operating speeds otherwise.</td>
</tr>
<tr>
<td></td>
<td>Good operations for all turning movements.</td>
</tr>
</tbody>
</table>
Factors affecting the outcome of these studies:

• What is the year chosen for the life-cycle cost?
• Discount factors
• Collision costs
• Societal costs versus agency costs
• Accuracy of secondary factors (emissions, etc.)
• Decision Environments
Balanced Design Composition

• Good designs should minimize:
  ➢ Accidents (Safety)
  ➢ Delay
  ➢ Costs

• For all who use the intersection:
  ➢ Vehicles (cars, trucks, motorcycles…)
  ➢ Bicyclists
  ➢ Pedestrians
Balancing Competing Objectives
I-70 / Edwards, CO Interchange
1. Composition (Strategic):
   – Traffic and lane configuration
   – Space for trucks
   – Stopping sight distance
   – Entry and exit paths (overlap for multi-lane)

2. Details:
   1. Grading
   2. Intersection sight distance
   3. Lighting, signs, markings and cross walks

We generally spend more of our time on this.
Substantial Design Effort for Intersection Control Studies (Concept Development)

- Conceptual Design Planning
  - Traffic Flow Worksheet
  - Lane Configuration
  - Context Considerations & Problem Statement
  - Initial Geometric Parameters
  - Capacity Analysis

- Conceptual Design
  - Concept Sketch
  - Design Vehicle
  - Fastest Path
  - Path Overlap
  - Impact Assessment

- Performance Checks and Context Sensitive Evaluation
- Multiple Design Iterations
- Scoping And Feasibility Input
  - 30% & Feasibility Recommendation

- Detailed Design Project Development
  - Final Horizontal Layout
  - Alignments/Profiles
  - Drainage Cross Slope
  - Staging
  - Cross Sections

- Scoping And Feasibility Input
  - 60%

- Scoping And Feasibility Input
  - 90%

- Scoping And Feasibility Input
  - Signings
  - Lighting
  - Landscaping
  - Sight Evaluation

- Scoping And Feasibility Input
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- Scoping And Feasibility Input
  - 90%

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Performance Based Design
with context consideration

• Speed Reduction
  – Entry Path Curvature

• Vehicle Paths
  – Entry Path Overlap
  – Exit Path Overlap
  – Instinctive Paths

• Traffic Information System

• Sight Distance

• Truck Accommodation

• Design Details

Composition involves synthesizing all of these elements
Safety Issue #1
Inadequate Entry Path Deflection

RESULTS:

- Speed of entry too fast
- Impacts pedestrian safety
- Entry / circulating crashes
Speed Profile

The steepness of the entry speed profile indicates deceleration.
Inadequate Speed Control
What is the design entry speed?
Entry speed is not defined by markings
Ways to Achieve Deflection

1. Approaching lanes offset to left of circle’s center
2. Circle size
3. Compactness of entry curve combinations

Note: Too much deflection can lead to reduced safety, e.g. SMV crashes
Entry Deflection

Figure 30.3. Entry Deflection

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Problems with Guidance

A faster path than the main entry...
Safety Issue #2: Entry/Exit Path Overlap

Perpendicular entries

Entry Path Overlap

Tight exit radii

Exit Path Overlap

Source: FHWA Guide with Edits
Poor Deflection + Entry Path Overlap

• Avoid tight entry radii and reverse curvature on Multi-lane
Unnatural Entry Paths Owing to Geometry
Unnatural Entry Paths Owing to Geometry
Good Entry Path Design
Exit Path Overlap
Radial vs. Offset Left Design

Tight entry radius obtains speed control but coincides with path overlap.

(Left offset gets speed control without path overlap)
Compliance but Poor Composition
Compliance but Poor Composition
Angles of Visibility

* ISD = Intersection Sight Distance

Source: California Department of Transportation (7)

FHWA Roundabout Guide

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Safety Issue #3: Traffic Information System

Incorrect Design Consequences:

• Incorrect lane choice – exit crashes (sideswipe)
• Sudden lane changes
• Weaving in the circle
• Improper left turns
• Navigational and way-finding errors
Coordination of Geometry and Lane Designation

The diagram illustrates the layout of a roundabout with various roads and lanes. The text explains that the offset is critical, particularly for ensuring safe entry and exit from the roundabout. The offset, typically 0.75 feet from the tangents, is crucial for maintaining safety and allowing enough space for entering drivers.
Lane Choice Before Entry
Lane Choice is Essential
Overhead Lane Designation Signs
Balanced designs require consideration for trucks

A WB-65 may require an 20 to 23 foot wide entry path
Each Site has a Different User Mix

- Freeways have more and larger trucks
  - Sometimes 30% trucks, rare pedestrians.
- Arterials mix fewer trucks
  - 3-15% and more frequent pedestrians
- Collectors: few trucks
  - ~ 1% or less depending on land use classification
- Local streets: cars, peds, school buses
- Isolated sites can have special user classes
A Trend Toward Wider Entries

Source: New York State Department of Transportation (11)
Design Vehicle = WB-65?

Apron 10ft.-16ft
Load Envelope Diagram
Grades

• Relatively flat circle desired (minor grade for drainage)
• Desirable profile through the circle is $\leq 4\%$

Photo source: Mark Doctor  Brighton, CO
Visualize and extract the profiles before you build...
What do these all have in common?

- A poor understanding of the principles of safe roundabout operation
- The basic elements exist, but composition was overlooked
- Changes would not be costly
- Each will require a holistic approach to integrate the geometry with the project context
Balanced Design

• Roundabout operation is holistic – design should reflect this

• Balance competing needs of:
  ➢ Achieving capacity
  ➢ Providing space for trucks
  ➢ Slowing speeds
  ➢ Accommodating pedestrians

✓ ITERATIVE PROCESS!
Balanced Design

• Design is a top down process
  ➢ General first ➔ specifics second

• Two parts to design
  1. Problem solving – *Strategic* – What to do
  2. Details – *Tactical* – Doing it

> Complexity = > Strategy
Safety Issue #1
Inadequate Entry Path Curvature (EPC)

SOLUTIONS:

• Adjust ICD size

• Adjust entry radius

• Offset entry alignment

• Apply EPC based on traffic flows – (ACCIDENT CHANGE IS A NET EFFECT)
Safety Issue #2: Entry / Exit Path Overlap

RESULTS:

• Unnatural vehicle paths

• Sideswipe or rear-end entry-entry or exiting crashes (lane change)
Safety Issue #2: Entry/Exit Path Overlap

SOLUTIONS:

• Increasing exit radii

• Realigning entry

• Modify entry angle (compound radii and tangential entry/exit)

• Road markings (exit striping)
Geometric Parameters Affecting Safety:

- Entry Path Curvature
- Entry Width
- Approach lane(s) width
- Angle between arms
- Inscribed Circle Diameter/Central Island Diameter

-(U.K. Research TRL Report LR 1120)
Performance Based Design

• We tend to try to create templates based on right-of-way or road classification
• Retrofits are not addressed in most standards
• Standard drawings don’t address anomalies and unusual conditions – only principles can
• Producing an optimized design, requires effective application of operating principals (prior to designing)
Sign Clutter
(information overload)
Spot the flaws...
Exhibit 6-33
Exit–Circulating Conflict
Caused by Large Separation between Legs

Note: Separation between entry and exit results in circulating-entering path conflict.

Paths merge rather than cross

Source: California Department of Transportation

Exhibit 6-35
Realignment to Resolve Exit–Circulating Conflicts

Paths cross rather than merge

Realignment approach

Previous alignment

Source: California Department of Transportation (†)
Sample Policy for Roundabout Consideration

Specifically, a roundabout should be considered as an alternative in the following instances:

1. For any intersection that is being designed as new or is being reconstructed;
2. For all existing intersections that have been identified as needing major safety or operational improvements; and
3. For all intersections where a request for a traffic signal has been made.
Standard Roundabouts: Effect of Entry Path Curvature

INCREASING entry path curvature...

- DECREASES entering-circulating accidents
- INCREASES approaching accidents
- INCREASES single vehicle accidents
Traffic affects markings/affects geometry

- Spiral markings set up for exclusive lanes and correct lane choice for exiting traffic
Spot the Strategic Flaws