Modern Roundabouts: Design Workshop

Delaware

December 11-12, 2012

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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

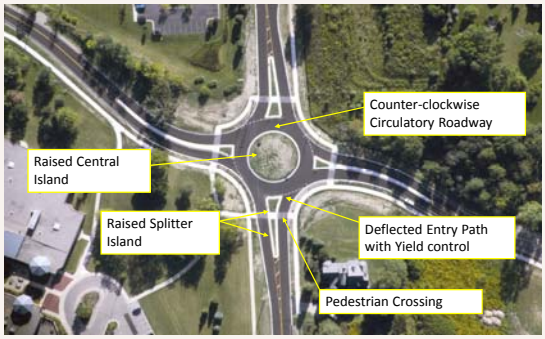
Self Introductions

- 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?

Delaware Roundabout Video

Modern Roundabout Basics

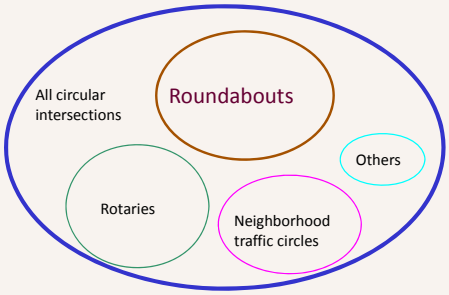
Physical Features of a Modern Roundabout



Roundabouts FACTS

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

Roundabouts are a type (or subset) of circular intersections



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

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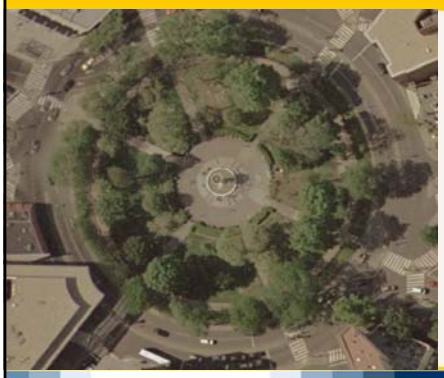
Signalized traffic circles are NOT roundabouts !!!



Dupont Circle, Washington, DC

Is Not a Roundabout

Photo source: Google Earth

Traffic calming circles are NOT roundabouts!!

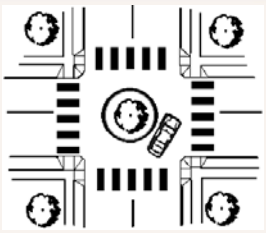


Photo source: FHWA

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Roundabout Categories

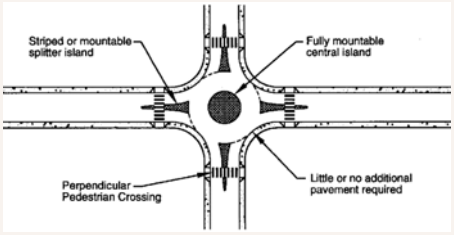
- Mini-roundabouts
- Single-Lane Roundabouts
- Multilane Roundabout

Caution regarding categorization: The planning and design for roundabouts should be based on compatibility with key principles rather than adherence to strict rules or one-size fits all standards. Design flexibility should be exercised depending upon various factors, especially for examples where there are no set categories (i.e. transitional areas).

2010 NCHRP 672
Mini (ICD 45 to 90 ft)
Single-lane (ICD 90 to 180 ft)
Multi-lane (ICD 150 to 300 ft)

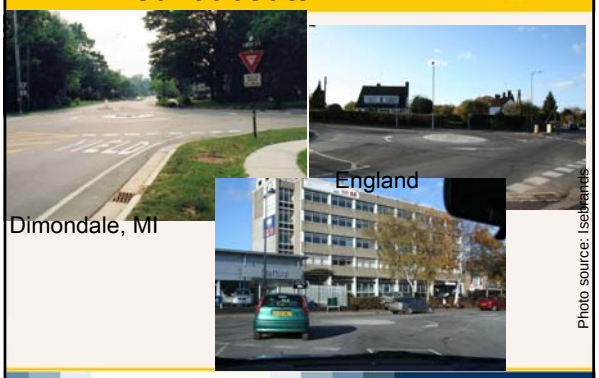
Mini Roundabouts

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



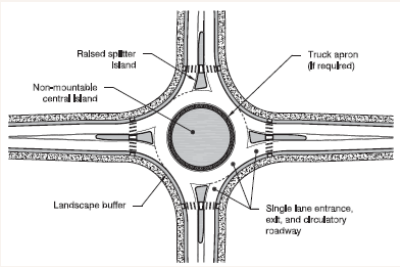
Source: FHWA Guide, 2000 & NCHRP 672

Mini Roundabouts



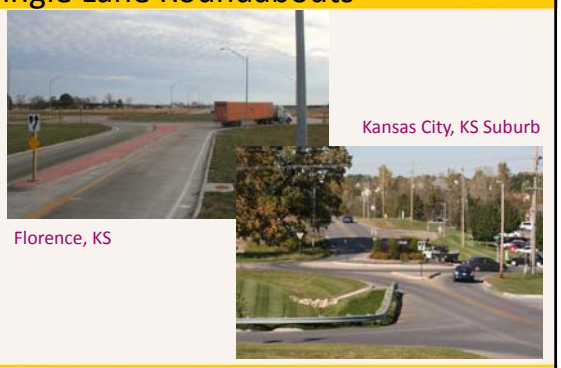
Single Lane Roundabouts

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.

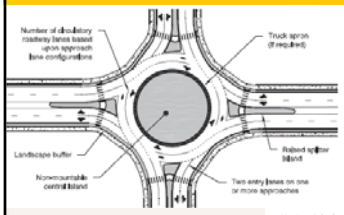


Source: FHWA/NCHRP

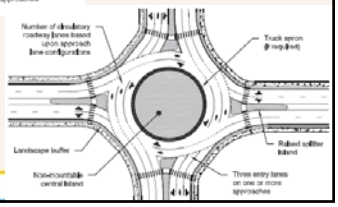
Single Lane Roundabouts



Multilane Roundabouts

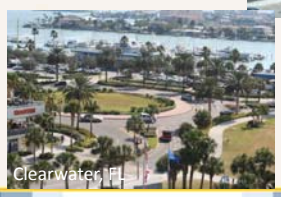


Multilane roundabouts have at least one approach leg with two or more entry lanes. They require wider circulatory roadways to accommodate more than one vehicle traveling side by side. They may include an apron surrounding the non-traversable part of the central island to accommodate long trucks.

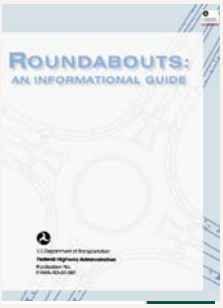


Source: FHWA/NCHRP

Multilane Roundabouts



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.

FHWA Roundabout Guidance

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 are Safer: There is No Denying It!!

- 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 !!!

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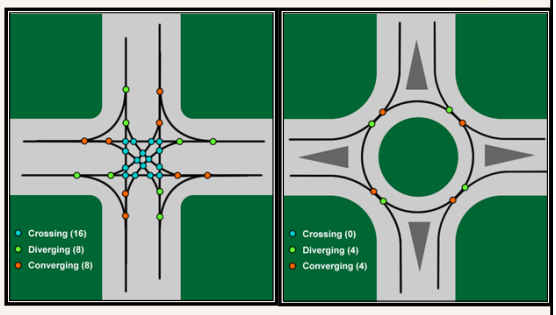
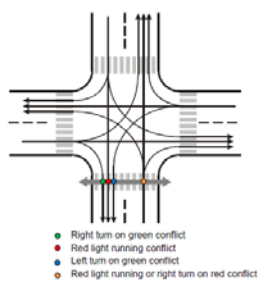
FHWA Proven Safety Countermeasures

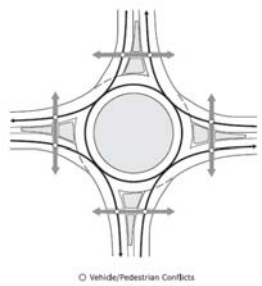
Roundabouts Eliminate the Vehicle-Vehicle Crossing Conflict Points



Vehicle-Pedestrian Conflicts at Intersections



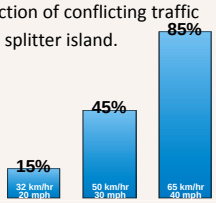
16 Conflicts



8 Conflicts

Pedestrian Safety

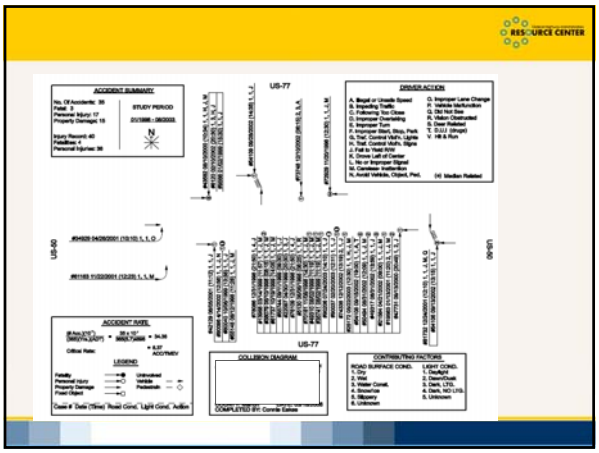
- Slow speeds (15-25mph) for all vehicles at the intersection,
- Fewer pedestrian-vehicle conflict points,
- Shorter crossing distances for pedestrians,
- Pedestrians cross only one direction of conflicting traffic at a time – finding refuse in the splitter island.

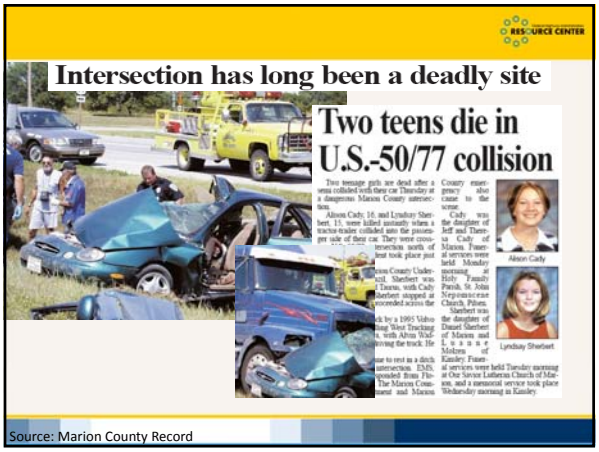


Likelihood of a pedestrian fatality when hit at vehicle speed

US 50 – US 77 Roundabout

Photo Source: Kansas DOT

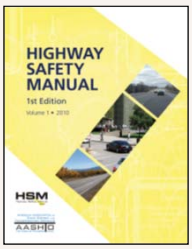




Source: Marion County Record

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 14-4. Potential Crash Effects of Converting a Stop-Controlled Intersections into a Modern Roundabout (29)

Setting (Intersection Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
All settings (One or two lanes)		All types (All severities)	0.56	0.05
		All types (Injury)	0.18	0.04
Rural (One lane)		All types (All severities)	0.29	0.04
		All types (Injury)	0.13	0.04

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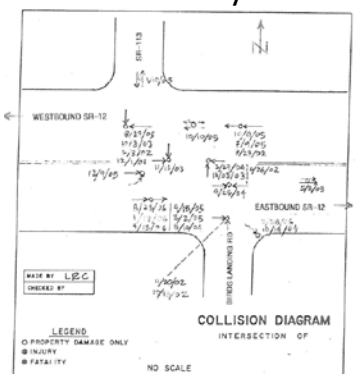
Safety Alternatives Analysis Example California Route 12 and Route 113 (West of Rio Vista)

Crash History

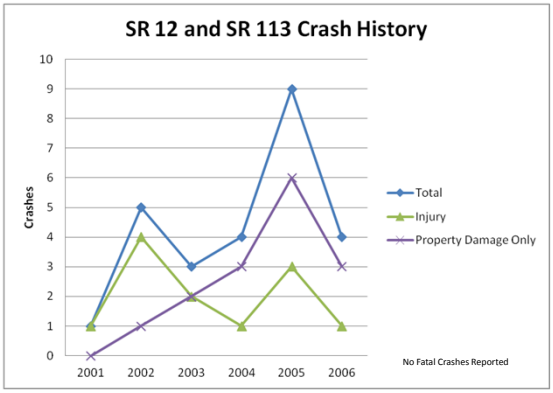


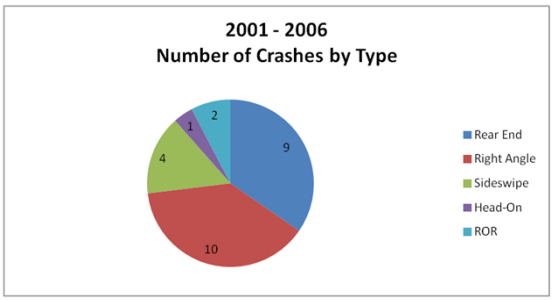
Crashes by Year

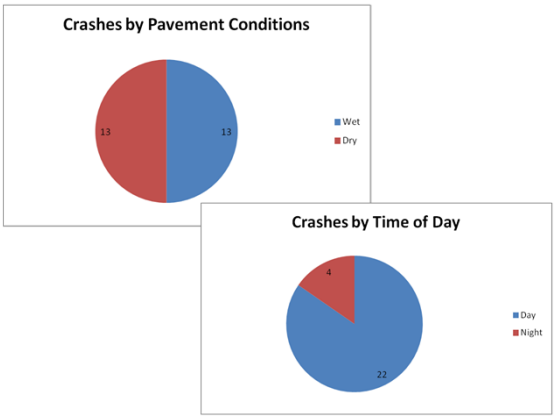
Year	Total	Fatal	Injury	PDO
2001	1	0	1	0
2002	5	0	4	1
2003	3	0	2	2
2004	4	0	1	3
2005	9	0	3	6
2006	4	0	1	3
	26	0	12	15

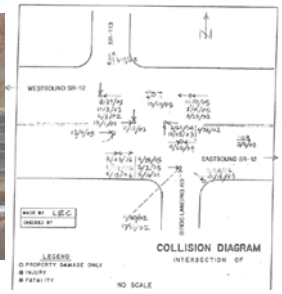
4 to 5 Crashes per Year

Severity Index = 12/26 = 0.46




2001 - 2006
Number of Crashes by Type
9
10
4
1
2
Rear End
Right Angle
Sideswipe
Head-On
ROR


Crashes by Pavement Conditions
13
13
Wet
Dry
Crashes by Time of Day
4
22
Day
Night


COLLISION DIAGRAM
NO SCALE

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

AADT
- SR 12 – 14,100
- SR 113 – 3,900

Peak Hour
- SR 12 - 1,150
- SR 113 - 580

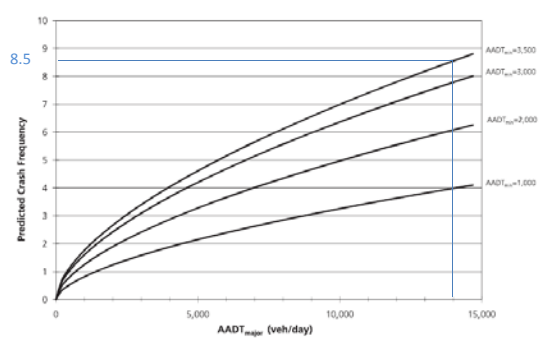


Figure 10-5. Graphical Representation of the SPF for Four-leg, Stop-controlled (4ST) Intersections (Equation 10-9)

Existing Right Turn Lane

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

Intersection Type	Intersection Traffic Control	Number of Approaches with Right-Turn Lanes[a]			
		One Approach	Two Approaches	Three Approaches	Four Approaches
Three-Leg Intersection	Minor road stop control[b]	0.86	—	—	—
Four-Leg Intersection	Minor road stop control[b]	0.86	0.74	—	—
	Traffic signal	0.96	0.92	0.88	0.85

[a] Stop-controlled approaches are not considered in determining the number of approaches with right-turn lanes.
[b] Stop signs present on minor road approaches only.

Existing Lighting

CMF_{ni}—Lighting

The base condition for lighting is the absence of intersection lighting. The CMF for lighted intersections is adapted from the work of Elvik and Vaa (2), as:

$$CMF_{ni} = 1 - 0.38 \times p_{ni} \quad (10\text{-}24)$$

Where:

CMF_{ni} = crash modification factor for the effect of lighting on total crashes; and

p_{ni} = proportion of total crashes for unlighted intersections that occur at night.

This CMF applies to total intersection crashes. Table 10-15 presents default values for the nighttime crash proportion p_{ni}. HSM users are encouraged to replace the estimates in Table 10-15 with locally derived values.

Table 10-15. Nighttime Crash Proportions for Unlighted Intersections

Intersection Type	Proportion of Crashes that Occur at Night p_{ni}
3ST	0.260
4ST	0.244
4SG	0.286

Note: Based on HSIS data for California (2002–2006)

CMF_{4st} = 1- (0.38 x 0.244) = 0.907

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 x 0.86 x 0.907 = 6.63 crashes/yr)
- Predict the Number of Crashes for Intersection Improvements
  - Add Left Turn Lane
  - Roundabout
  - Signal

Add a Left Turn Lane

Table 10-13. Crash Modification Factors (CMF_{2i}) for Installation of Left-Turn Lanes on Intersection Approaches

		Number of Approaches with Left-Turn Lanes[a]			
Intersection Type	Intersection Traffic Control	One Approach	Two Approaches	Three Approaches	Four Approaches
Three-leg Intersection	Minor road stop control[b]	0.56	—	—	—
Four-leg Intersection	Minor road stop control[b]	0.72	0.52	—	—
	Traffic signal	0.82	0.67	0.55	0.45

[a] Stop-controlled approaches are not considered in determining the number of approaches with left-turn lanes
[b] Stop signs present on minor road approaches only.

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 x 0.86 x 0.907 = 6.6 crashes/yr)
- Predict the Number of Crashes for Intersection Improvements
  - Add Left Turn Lane (6.6 x 0.72 = 4.75 crashes/year)
  - Roundabout
  - Signal

Replace with a Roundabout

Table 14-4. Potential Crash Effects of Converting a Stop-Controlled Intersections into a Modern Roundabout (29)

Setting (Intersection Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
All settings (One or two lanes)		All types (All severities)	0.56	0.05
		All types (Injury)	0.18	0.04
Rural (One lane)		All types (All severities)	0.29	0.04
		All types (Injury)	0.13	0.04

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 x 0.86 x 0.907 = 6.6 crashes/yr)
- Predict the Number of Crashes for Intersection Improvements
  - Add Left Turn Lane (6.6 x 0.72 = 4.75 crashes/year)
  - Roundabout (8.5 x 0.29 = 2.5 crashes/year)
  - Signal

Replace with a Signal

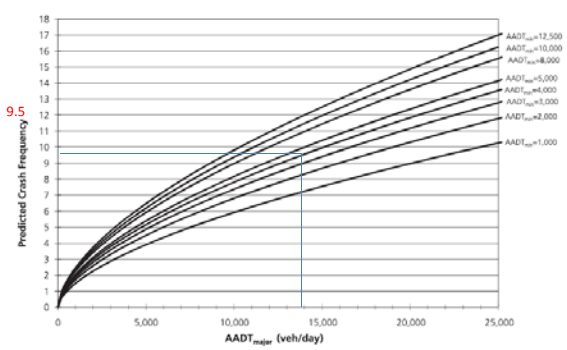


Figure 10-6. Graphical Representation of the SPF for Four-leg Signalized (4SG) Intersections (Equation 10-10)

Add Turn Lanes

Table 10-13. Crash Modification Factors (CMF_{2L}) for Installation of Left-Turn Lanes on Intersection Approaches

Intersection Type	Intersection Traffic Control	Number of Approaches with Left-Turn Lanes[a]			
		One Approach	Two Approaches	Three Approaches	Four Approaches
Three-leg Intersection	Minor road stop control[b]	0.56	—	—	—
Four-leg Intersection	Minor road stop control[b]	0.72	0.52	—	—
	Traffic signal	0.82	0.67	0.55	0.45

[a] Stop-controlled approaches are not considered in determining the number of approaches with left-turn lanes
[b] Stop signs present on minor road approaches only.

Table 10-14. Crash Modification Factors (CMF_{3R}) for Right-Turn Lanes on Approaches to an Intersection on Rural Two-Lane, Two-Way Highways

Intersection Type	Intersection Traffic Control	Number of Approaches with Right-Turn Lanes[a]			
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	Traffic signal	0.96	0.92	0.88	0.85

[a] Stop-controlled approaches are not considered in determining the number of approaches with right-turn lanes.
[b] Stop signs present on minor road approaches only.

Lighting

CMF_{4L}—Lighting

The base condition for lighting is the absence of intersection lighting. The CMF for lighted intersections is adapted from the work of Elvik and Vaa (2), as:

$$CMF_{4L} = 1 - 0.38 \times p_{nl} \quad (10\text{-}24)$$

Where:

CMF_{4L} = crash modification factor for the effect of lighting on total crashes; and

p_{nl} = proportion of total crashes for unlighted intersections that occur at night.

This CMF applies to total intersection crashes. Table 10-15 presents default values for the nighttime crash proportion p_{nl}. HSM users are encouraged to replace the estimates in Table 10-15 with locally derived values.

Table 10-15. Nighttime Crash Proportions for Unlighted Intersections

Intersection Type	Proportion of Crashes that Occur at Night
	p_{nl}
3ST	0.260
4ST	0.244
4SG	0.286

Note: Based on HSIS data for California (2002–2006)

CMF_{4sg} = 1- (0.38 x 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 x 0.86 x 0.907 = 6.6 crashes/yr)
- Predict the Number of Crashes for Intersection Improvements
  - Add Left Turn Lane (6.6 x 0.72 = 4.75 crashes/year)
  - Roundabout (8.5 x 0.29 = 2.5 crashes/year)
  - Signal (9.5 x 0.96 x 0.82 x 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 Developmer
- Closely spaced intersections

Clearwater, Florida

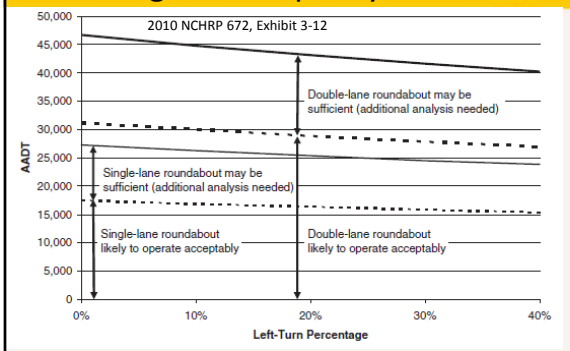
Benefits	Considerations
• Lower vehicle speeds in and around intersection • Improved pedestrian and vehicle safety • Landscaping and gateway treatment	• Design vehicle (school bus, emergency vehicles) • Right-of-way • User education and outreach • If crossing guards are used, the distance between crosswalks may require two crossing guards instead of one.

The Footprint

Design Element	Mini-Roundabout	Single-Lane Roundabout	Multilane Roundabout
Desirable maximum entry design speed	15 to 20 mph (25 to 30 km/h)	20 to 25 mph (30 to 40 km/h)	25 to 30 mph (40 to 50 km/h)
Maximum number of entering lanes per approach	1	1	2+
Typical inscribed circle diameter	45 to 90 ft (13 to 27 m)	90 to 180 ft (27 to 55 m)	150 to 300 ft (46 to 91 m)
Central island treatment	Fully traversable	Raised (may have traversable apron)	Raised (may have traversable apron)
Typical daily service volumes on 4-leg roundabout below which may be expected to operate without requiring a detailed capacity analysis (veh/day)*	Up to approximately 15,000	Up to approximately 25,000	Up to approximately 45,000 for two-lane roundabout

*Operational analysis needed to verify upper limit for specific applications or for roundabouts with more than two lanes or four legs.

Planning Level Capacity



Planning Level Capacity

Volume Range (sum of entering and conflicting volumes)	Number of Lanes Required
0 to 1,000 veh/h	▪ Single-lane entry likely to be sufficient
1,000 to 1,300 veh/h	▪ Two-lane entry may be needed ▪ Single-lane may be sufficient based upon more detailed analysis.
1,300 to 1,800 veh/h	▪ Two-lane entry likely to be sufficient
Above 1,800 veh/h	▪ More than two entering lanes may be required ▪ A more detailed capacity evaluation should be conducted to verify lane numbers and arrangements.

Source: New York State Department of Transportation

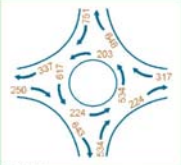
Roundabouts: An Informational Guide

Exhibit 3-15
Example Planning-Level Exercise for Determining Required Numbers of Lanes Using Turning-Movement Data

Example: Estimating Number of Lanes Using Turning-Movement Volumes

Question

How many lanes are required to serve these design-year traffic volumes:



Calculations

Entering volume + Circulating volume = X Compare to Exhibit 3-14

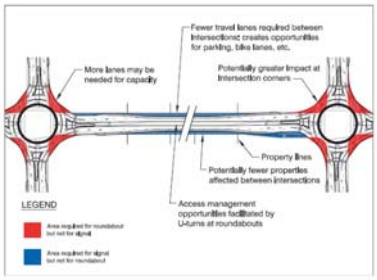
250 + 617 = 867	<1,000	Single Lane OK
534 + 224 = 758	<1,000	Single Lane OK
317 + 534 = 851	<1,000	Single Lane OK
751 + 203 = 954	<1,000	Single Lane OK

Conclusions

Using the traffic data identified above and the volume ranges in Exhibit 3-14, a single-lane roundabout would be estimated to adequately handle the design-year traffic volumes for each individual approach. Therefore, a single-lane roundabout could be advanced forward for the rest of the planning-level evaluations, including estimates of the intersection footprint (right-of-way needs) and impacts.

Roundabouts: An Informational Guide

Exhibit 2-1
Wide Nodes, Narrow Roads Concept



Most roundabouts on arterial streets are designed to accommodate traffic volume estimated for a future horizon year, which can extend 20 years or more from the construction date. Collector and local-street roundabouts are typically designed for full build-out conditions. 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 constructed with a wide

Circulatory Roadway Width

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

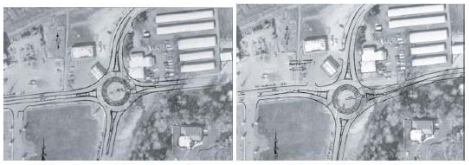
Single Lane Roundabout - Typical *circulatory roadway widths* range from 16 to 20 feet for single lane roundabouts. Care should be taken to avoid making the circulatory roadway width too wide within a single lane roundabout, as drivers may think that two vehicles are allowed to circulate side by side.

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.

67

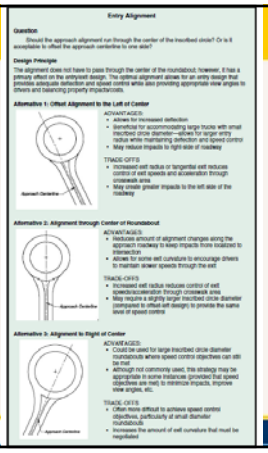
Size, Position and Alignment



(a) Centered on Existing Intersection (b) Center Shifted to the South

(c) Center Shifted to the East

Exhibit 6-8



Entry Alignment

Question

Design Principle

Alternative 1: Offset Alignment to the Left of Center

Alternative 2: Alignment through Center of Roundabout

Alternative 3: Alignment to Right of Center

Urban Compact Designs – ROW Impacts

Main St. and Center St.
Hamburg, NY

Source: NYSDOT

70

Photo Courtesy: Wisconsin Department of Transportation

Questions/ Discussion

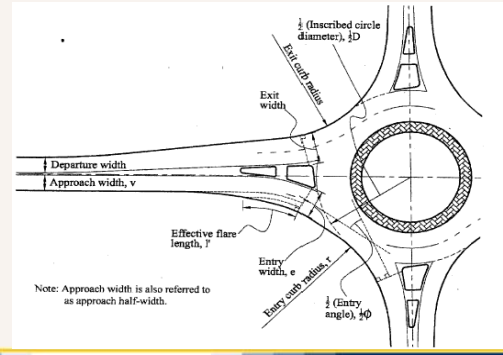
Geometric Design

Before

After

Photo Source: WisDOT

Roundabout Geometric Design Terminology



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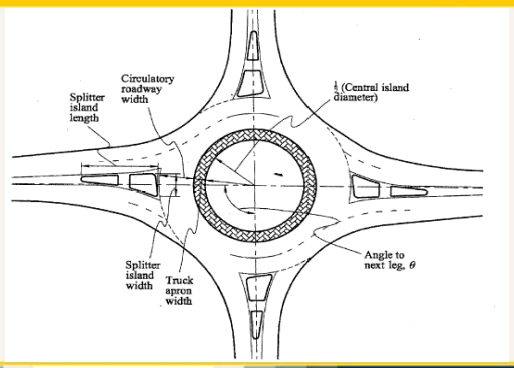
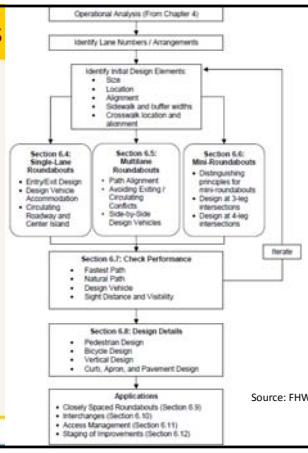
Roundabout Geometric Design Terminology



79

Design Process

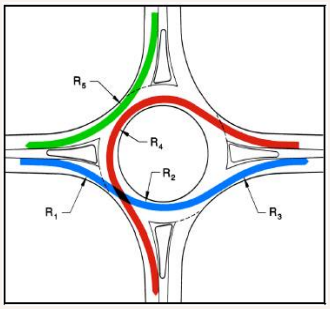


Source: FHWA/NCHRP

80

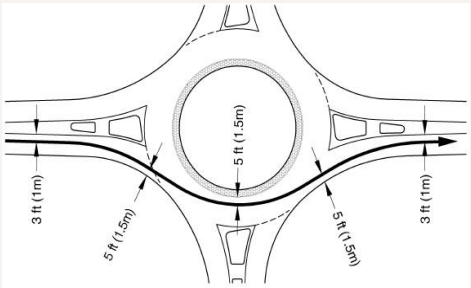
Speed Prediction Based on Vehicle Path Radii

Five critical path radii



Note: Vehicular path radii ≠ Curb radii

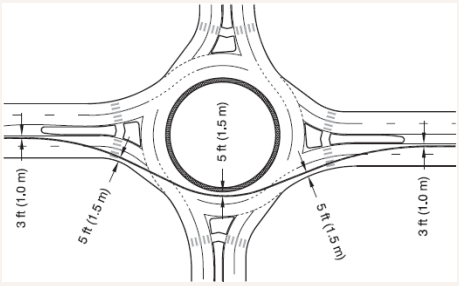
Fastest Vehicle Path through a Single Lane Roundabout



Source: FHWA/NCHRP

82

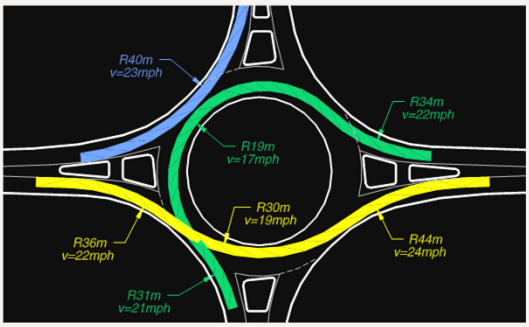
Fastest Vehicle Path through a Two Lane Roundabout



Source: FHWA/NCHRP

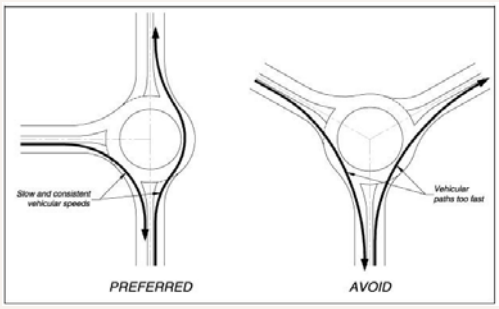
83

Example of Good Speed Consistency



84

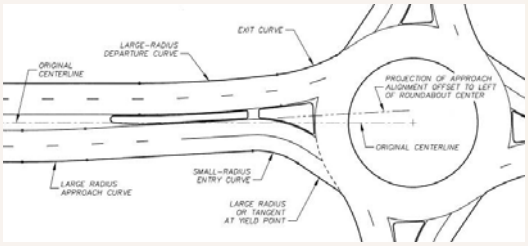
Approach Angles
Perpendicular Preferred Over Obtuse



Source: Kansas Roundabout Guide

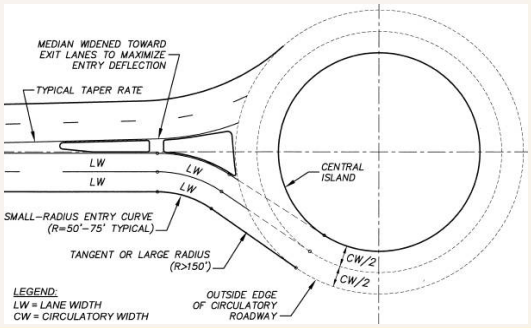
85

Approach Offset to Increase Entry Deflection



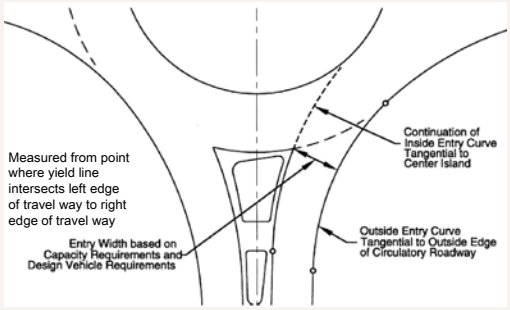
86

Multilane Entry Design Details

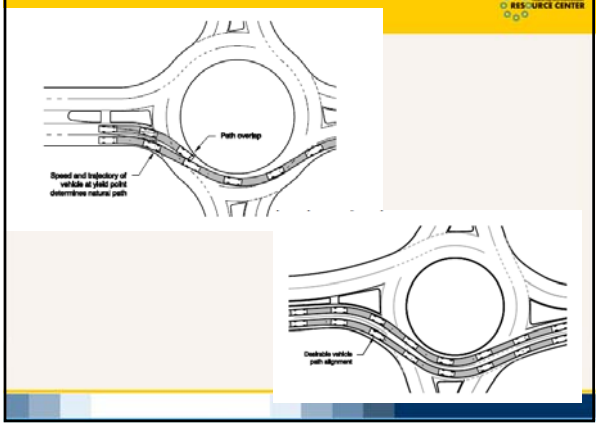


87

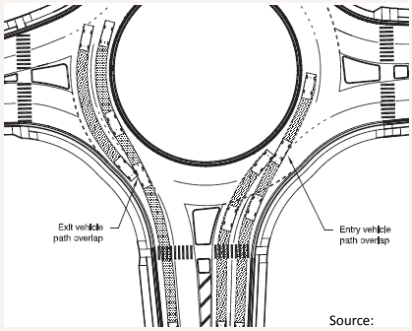
Entry Width
Typical 14-16 ft for single-lane entrance



88



Natural Path – Vehicle Path Overlap



Source: FHWA/NCHRP

90

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

91

Before

Photo: Bruce Robinson

After

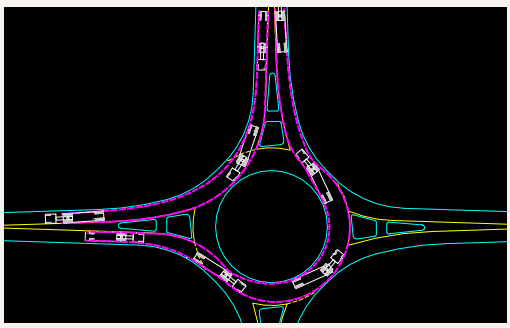
Photo: Lee Rodegerdts

93

Design Vehicles (and Users to Check for)

95

Swept Paths of WB-50 Vehicles



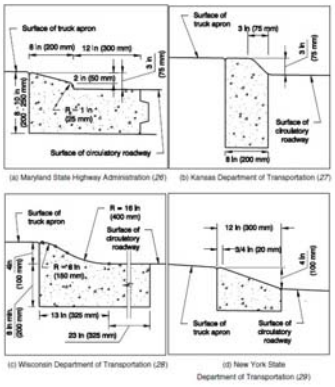
96

Truck Aprons

	NCHRP 672
Width	3 to 15 ft
Cross slope	1% to 2% (away)
Curb height	2 to 3 in

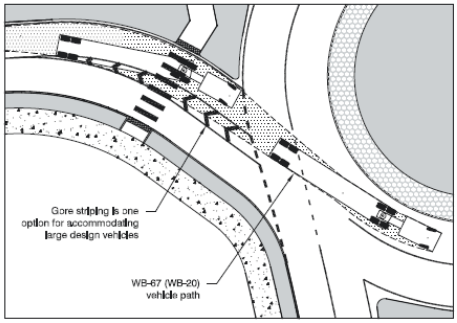
Roundabouts: An Informational Guide

Exhibit 6-78
Examples of Sloping Truck Apron Curb Shapes Used in the United States



(a) Maryland State Highway Administration (26) (b) Kansas Department of Transportation (27)

(c) Wisconsin Department of Transportation (28) (d) New York State Department of Transportation (29)



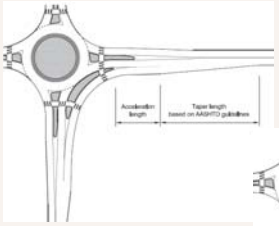
Source: New York State Department of Transportation (11)

Outside Truck Aprons

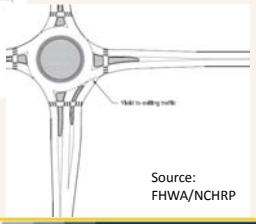
Photo source: ????

100

Right-Turn Bypass Lane



Configuration of Right-turn Bypass Lane with Acceleration Lane

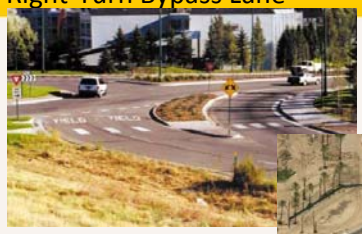


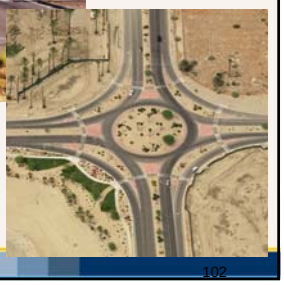
Configuration of Right-turn Bypass Lane with Yield at Exit Leg

Source: FHWA/NCHRP

101

Right-Turn Bypass Lane



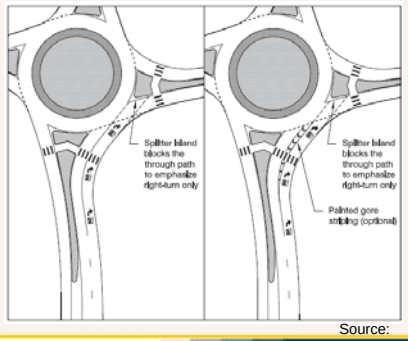


102

Outside Curb is Needed to Achieve Proper Lane Use, Position and Speeds

103

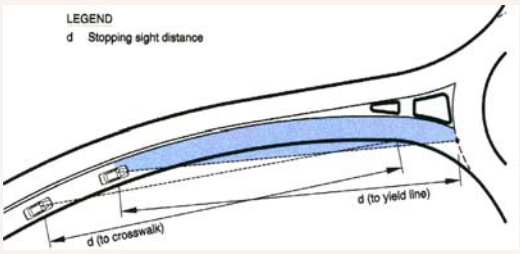
Exclusive Right-Turn Lanes



Source: FHWA/NCHRP

104

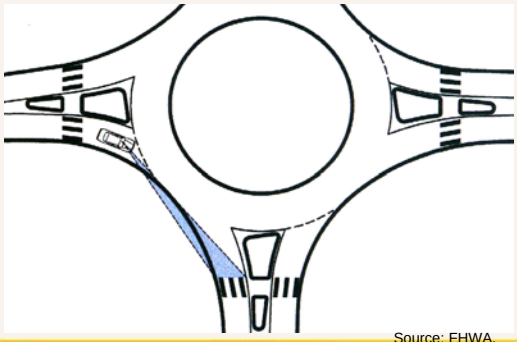
Required Stopping Sight Distance at Entries



Source: FHWA, 2000

105

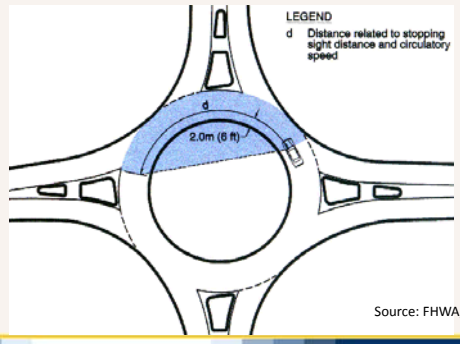
Stopping Sight Distance to Pedestrian Crosswalk



Source: FHWA, 2000

106

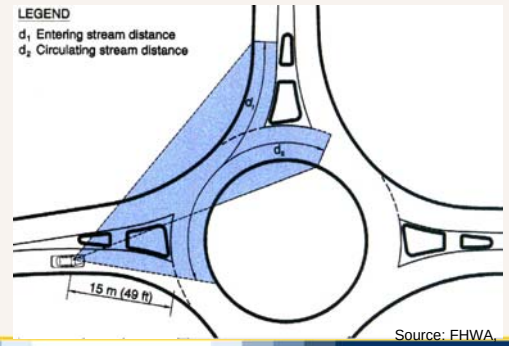
Stopping Sight Distance in the Circulatory Roadway



Source: FHWA, 2000

107

Intersection Sight Distance



Source: FHWA, 2000

108

Stopping Sight Distance

Speed (mph)	Computed Distance* (ft)
10	46.4
15	77.0
20	112.4
25	152.7
30	197.8
35	247.8
40	302.7
45	362.5
50	427.2
55	496.7

(11.2 ft/s^2) driver deceleration

Intersection Sight Distance

Conflicting Approach Speed (mph)	Computed Distance (ft)	Conflicting Approach Speed (km/h)	Computed Distance (m)
10	73.4	20	27.8
15	110.1	25	34.8
20	146.8	30	41.7
25	183.5	35	48.7
30	220.2	40	55.6

Note: Computed distances are based on a critical headway of 5.0 s.

Source: FHWA/NCHRP 109

Example Sight Distance Diagram

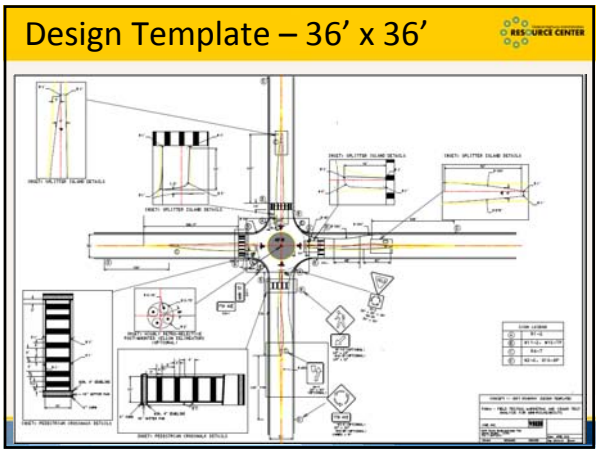
Source: FHWA/NCHRP 110

Mini Roundabouts

- Diameter - 50 to 80 ft
- Traversable Center Island
- Up to ~ 15,000 AADT
- Urban/Suburban
- 20 – 35mph Roadways
- Low Truck Volume

Waco, TX

Design Template – 36’ x 36’



Rural Roundabouts with High-Speed Approaches

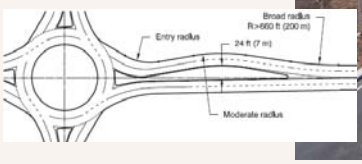
Photo source: WSDOT

Option A: Extended Splitter Island on Tangent Approaches

Source: FHWA/NCHRP

Photo Source: Isebrands

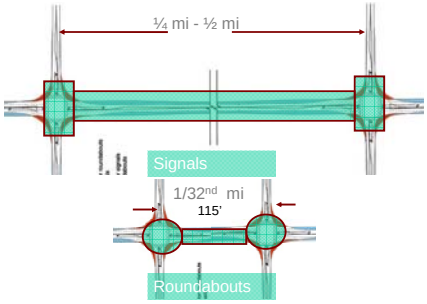
Option B: Use of Successive Curves on High Speed Approaches



115

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

Photo: City of Golden, CO

Photo: Hillary Isebrands

South Golden Road - Golden, Colorado

After

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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.

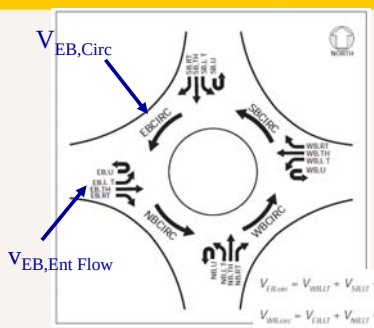
Effect of Geometry on Capacity

- 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



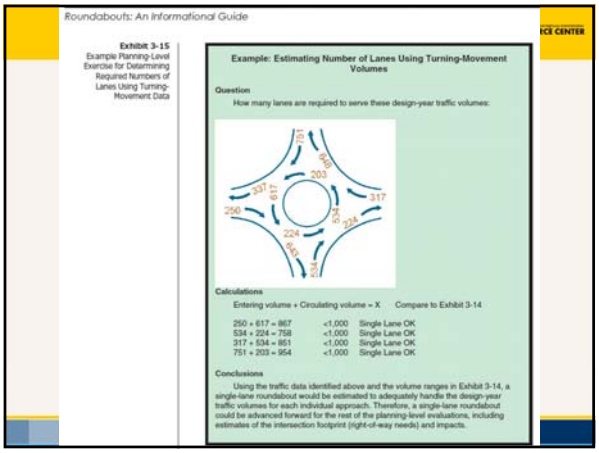
$$V_{EB,circ} = V_{WBLT} + V_{SBLT} + V_{SBTH} + V_{NBLU\text{-}turn} + V_{WBLU\text{-}turn} + V_{SBLU\text{-}turn}$$

$$V_{WB,circ} = V_{EBLT} + V_{NBLT} + V_{NBTH} + V_{SBLU\text{-}turn} + V_{EBLU\text{-}turn} + V_{NBLU\text{-}turn}$$

$$V_{NB,circ} = V_{EBLT} + V_{EBTH} + V_{SBLT} + V_{WBLU\text{-}turn} + V_{SBLU\text{-}turn} + V_{EBLU\text{-}turn}$$

$$V_{SB,circ} = V_{WBLT} + V_{WBTH} + V_{NBLT} + V_{EBLU\text{-}turn} + V_{NBLU\text{-}turn} + V_{WBLU\text{-}turn}$$

Source: FHWA 2000



Roundabouts: An Informational Guide

Exhibit 3-15
Example Planning-Level Exercise for Determining Required Numbers of Lanes Using Turning-Movement Data

Example: Estimating Number of Lanes Using Turning-Movement Volumes

Question

How many lanes are required to serve these design-year traffic volumes:

Calculations

Entering volume + Circulating volume = X Compare to Exhibit 3-14

250 + 617 = 867	<1,000	Single Lane OK
534 + 224 = 758	<1,000	Single Lane OK
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Conclusions

Using the traffic data identified above and the volume ranges in Exhibit 3-14, a single-lane roundabout would be estimated to adequately handle the design-year traffic volumes for each individual approach. Therefore, a single-lane roundabout could be advanced forward for the rest of the planning-level evaluations, including estimates of the intersection footprint (right-of-way needs) and impacts.

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)

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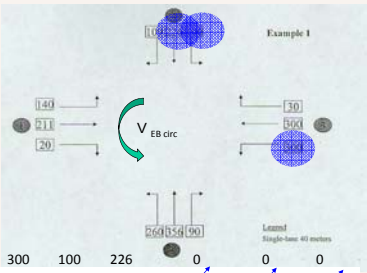
Volume to Capacity Ratio

- 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

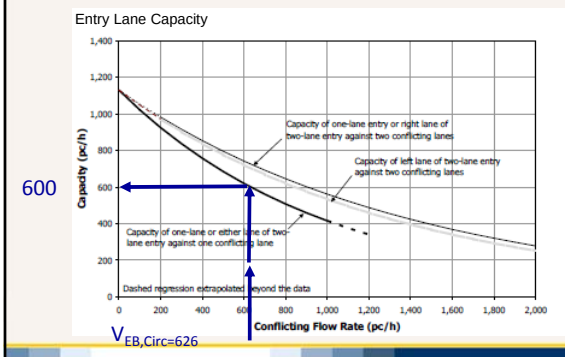


300 100 226 0 0 0

$$V_{EB\,circ} = V_{WB\,LT} + V_{SB\,LT} + V_{SB\,TH} + V_{NB\,U\text{-}turn} + V_{WB\,U\text{-}turn} + V_{SB\,U\text{-}turn} = 626$$

130

Example Exercise – EB Entry Capacity



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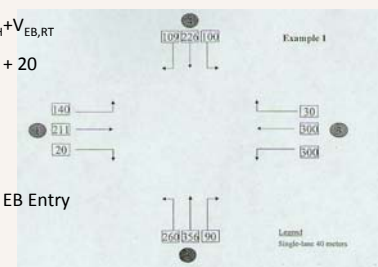
Example - Entering Flow – EB

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

= 140 + 211 + 20

= 371



V/C $= V_{EB,Entering\ Flow}$ / EB Entry Capacity

= 371 / 600

= 0.62 0.62 < 0.85 OK

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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.

$$d = \frac{3{,}600}{c} + 900T\left[x - 1 + \sqrt{(x-1)^2 + \frac{\left(\frac{3{,}600}{c}\right)x}{450T}}\right] + 5 \cdot \min[x,1]$$

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 (T = 1 for a 1-hour analysis, T = 0.25 for a 15-minute analysis).

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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.

Control Delay (s/veh)	Level of Service by Volume-to-Capacity Ratio* v/c ≤ 1.0	v/c >1.0
0 – 10	A	F
>10 – 15	B	F
>15 – 25	C	F
>25 – 35	D	F
>35 – 50	E	F
>50	F	F

* For approaches and intersection-wide 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:

$$Q_{95} = 900T\left[x - 1 + \sqrt{(1-x)^2 + \frac{\left(\frac{3{,}600}{c}\right)x}{150T}}\right]\left(\frac{c}{3{,}600}\right)$$

where:

Q_{95} = 95th-percentile queue, veh;

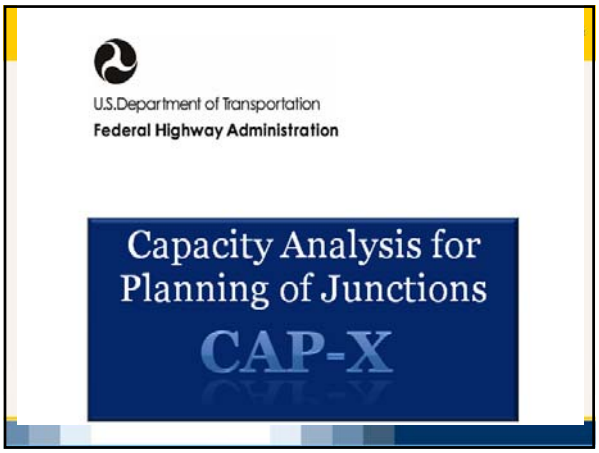
x = volume-to-capacity ratio of the subject lane;

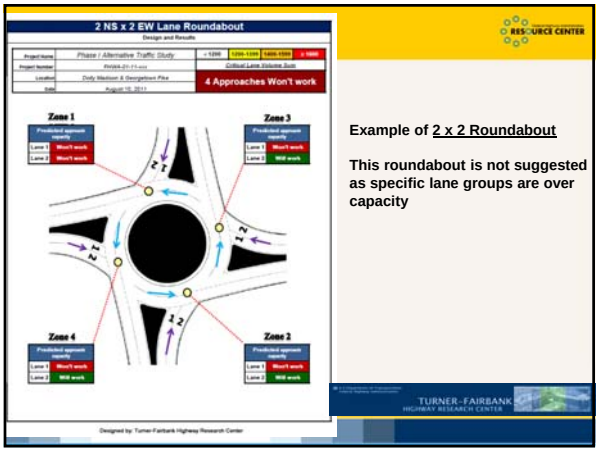
c = capacity of subject lane, veh/h; and

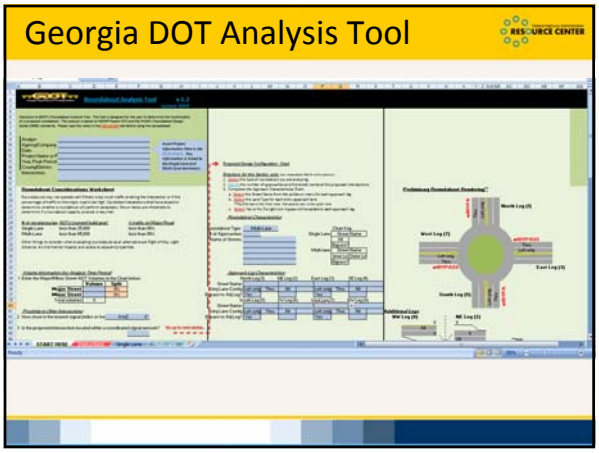
T = time period, h (T = 1 for a 1-hour analysis, T = 0.25 for a 15-minute analysis).

Queue Length – Consider "spill-over" effects from adjacent intersections

Photo shows queue "spill-over" from adjacent signalized intersection blocking roundabout exit


U.S.Department of Transportation
Federal Highway Administration
Capacity Analysis for Planning of Junctions
CAP-X


2 NS x 2 EW Lane Roundabout
4 Approaches Won't work
Zone 1
Zone 3
Zone 4
Zone 2
Example of 2 x 2 Roundabout
This roundabout is not suggested as specific lane groups are over capacity
TURNER-FAIRBANK HIGHWAY RESEARCH CENTER


Georgia DOT Analysis Tool

Questions/ Discussion

Best Practices for Vulnerable Road Users at Roundabouts

Photo credits: Isebrands

Who are Vulnerable Road Users?

- Pedestrians
- Bicyclists
- Older persons
- Younger persons

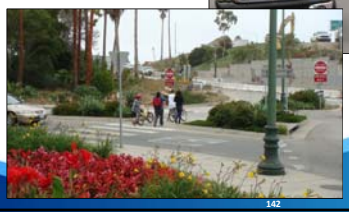


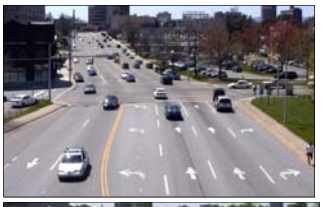
Photo credits: Isebrands

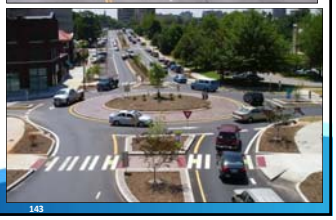
142

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

Photo credits: Butzek





143

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

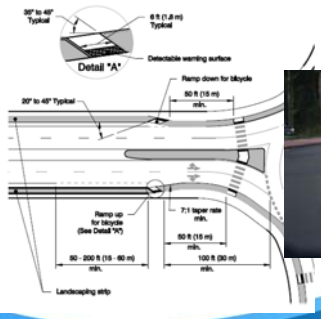


Photo credits: Isebrands

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

Towson MD

PROWAG – US Access Board

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

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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.

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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.

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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.

Advisory R209 Accessible Pedestrian Signals and Pedestrian Pushbuttons. An accessible pedestrian signal and pedestrian pushbutton is an integrated device that communicates information about the WALK and DON'T WALK intervals at signalized intersections in non-visual formats (i.e., audible tones and vibrotactile surfaces) to pedestrians who are blind or have low vision.

153

Advisory R306.3.2 Pedestrian Activated Signals. Roundabouts with single-lane approach and exit legs are not required to provide pedestrian activated signals. Pedestrian activated signals must comply with the requirements for accessible pedestrian signals and pedestrian pushbuttons (see R209). Pedestrian activated signals installed at splitter islands should be carefully located and separated so that signal spillover does not give conflicting information about which pedestrian street crossing has the WALK indication displayed. Pedestrian Hybrid Beacons can be used at roundabouts (see MUTCD sections 4F.01 through 4F.03). Pedestrian Hybrid Beacons are traffic signals that consist of a yellow signal centered below two horizontally aligned red signals. The signals are normally not illuminated. The signals are initiated only upon pedestrian activation and can be timed to minimize the interruption of traffic. The signals cease operation after the pedestrian clears the crosswalk. When activated by a pedestrian, the following signals are displayed to drivers: a flashing yellow signal, then a steady yellow signal, then two steady red signals during the pedestrian walk interval, and then alternating flashing red signals during the pedestrian clearance interval. The following signals are displayed to pedestrians: a steady upraised hand (symbolizing DON'T WALK) when the flashing or steady yellow signal is operating, then a walking person (symbolizing WALK) when the steady red signals are operating, and then a flashing upraised hand (symbolizing DON'T WALK) when the alternating flashing red signals are operating.

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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.

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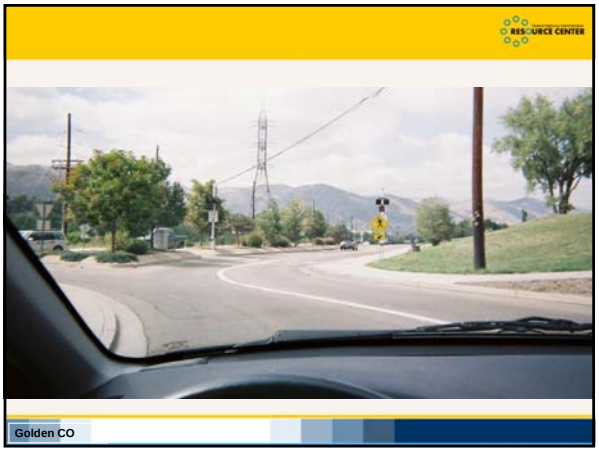
Raised Crosswalk at Two-lane Roundabout

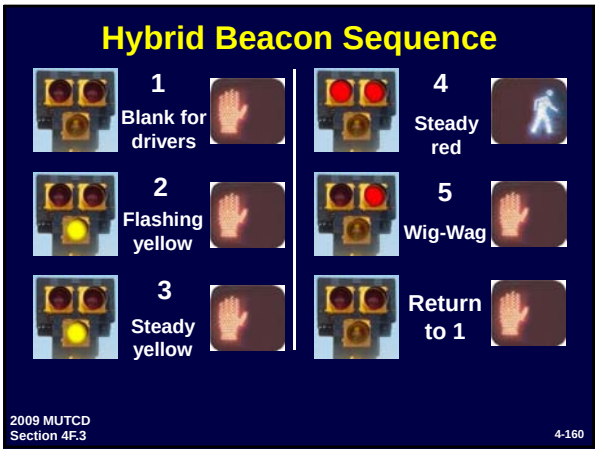
NCHRP 3-78A/NCHRP 674 Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities

Golden CO

Golden CO

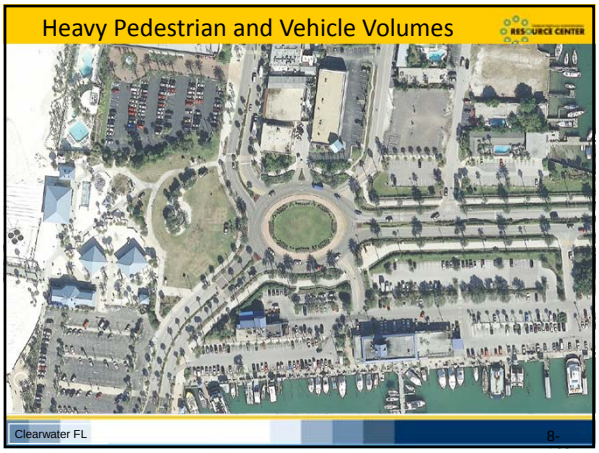

Pedestrian Hybrid Beacon at
Two-lane Roundabout
NCHRP 3-78A/NCHRP 674 Crossing Solutions at Roundabouts and Channelized
Turn Lanes for Pedestrians with Vision Disabilities
Golden CO


Golden CO


Hybrid Beacon Sequence
1
Blank for drivers
2
Flashing yellow
3
Steady yellow
4
Steady red
5
Wig-Wag
Return to 1
2009 MUTCD
Section 4F.3
4-160


RRFB at Multi-lane Roundabout
Springfield, OR


Springfield, OR


Heavy Pedestrian and Vehicle Volumes
Clearwater FL
8-

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

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

Signalized Pedestrian Crossing

Clearwater FL

Questions/ Discussion

Beyond Geometry and Capacity

166

Traffic Control Matters: Signing and Marking

167

What is Wrong Here?

168

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

169

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

170

Richfield, MN Video

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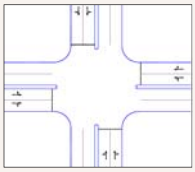
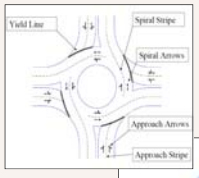
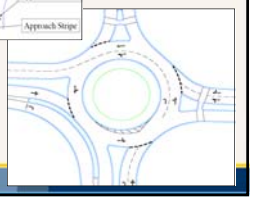
Lane Assignment

Traditional Intersection



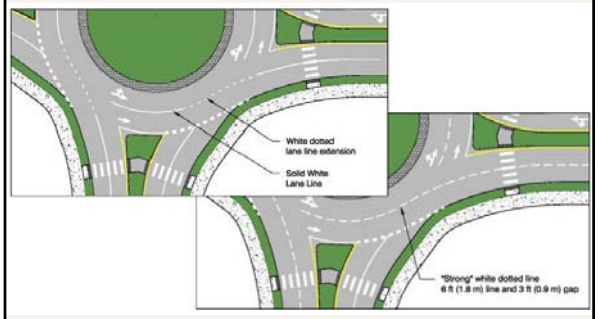
Roundabout





Source: Barry Crown

Striping

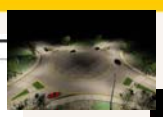


Lighting Options

Exhibit 8-4

Illumination Type	Advantages	Disadvantages
Perimeter Illumination	• Illumination can be strongest around critical bicycle and pedestrian areas. • Continuity of poles and luminaires is maintained for the illumination of the lanes, as well as good visual guidance on the circulatory roadway. • Approach signs typically appear in positive contrast and thus are clearly visible. • Maintenance of luminaires is easier due to curbside location.	• Illumination is weakest in central island, which may limit visibility of roundabout from a distance. • More poles are required to achieve the same illumination level. • Poles may need to be located in critical conflict areas to achieve illumination levels and uniformity.
Central Illumination	• Perception of the roundabout is assisted at a distance by illuminating the central island. • Fewer poles are required to achieve the same illumination. • Pole in central island is clear of critical conflict areas for all but the smallest of roundabouts. • Exit guide signs on the periphery appear in positive contrast (front lit) and thus are clearly visible.	• Cannot achieve adequate vertical lighting levels without additional approach lighting. • Illumination is weakest in critical pedestrian and bicycle areas. • Signs on the approach are in negative contrast (back lit). • A path is needed to the base of the central pole for maintenance. • There is a greater risk of glare. • The central pole affects central island landscaping plan. • High mast lighting may be inappropriate in urban areas, especially residential areas.

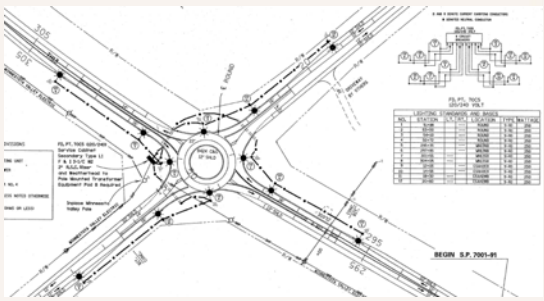
Source: Adapted from Kansas Roundabout Guide (2)



Approach Mounted Lighting
- 8-250W HPS
- 25 Lux

Center Mounted Lighting
- 8-400W HPS
- 28 Lux

Example Lighting Plan – Rural High Speed Approaches



Center Island Landscaping

Photo Source: Isebrands

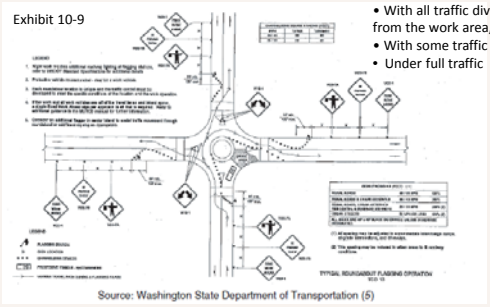
Photo Source: FHWA/NCHRP

Construction Staging

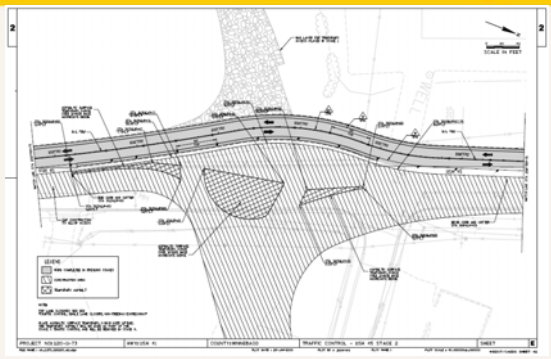
Roundabouts can be constructed under three types of traffic conditions:

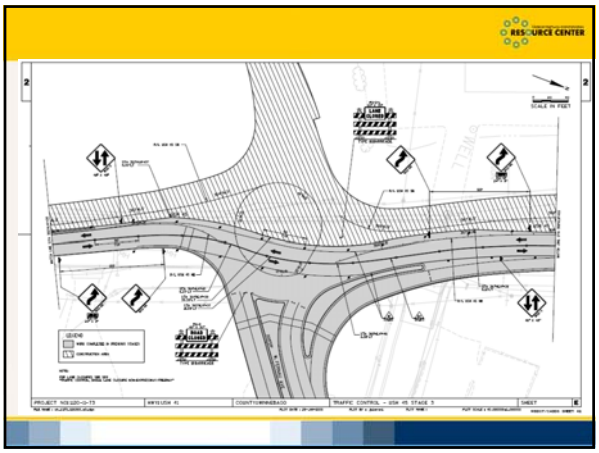
- With all traffic diverted away from the work area,
- With some traffic diverted, or
- Under full traffic

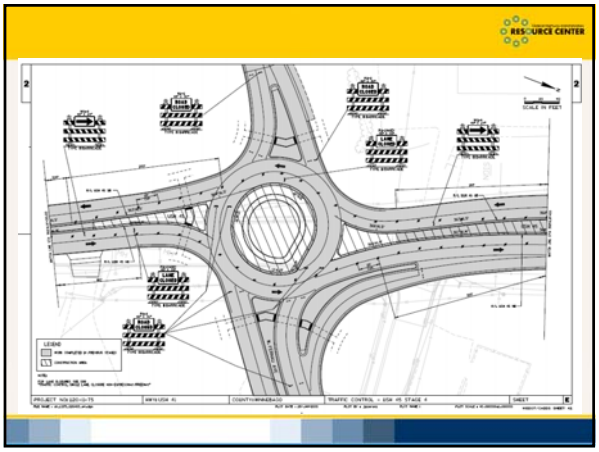
Exhibit 10-9



Source: Washington State Department of Transportation (5)







Opening to Traffic

Photo source: Isebrands

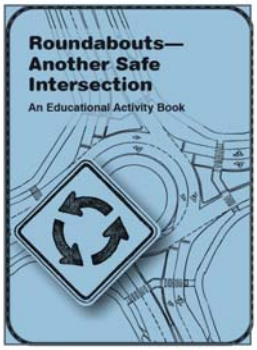
Public Involvement Strategies

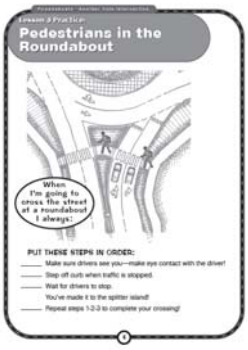
- Brochures
- Third party facilitator
- Practice run
  - Model scale
  - Parking lot demo

Photo source: NYSDOT

Photo source: Isebrands

Educational Material

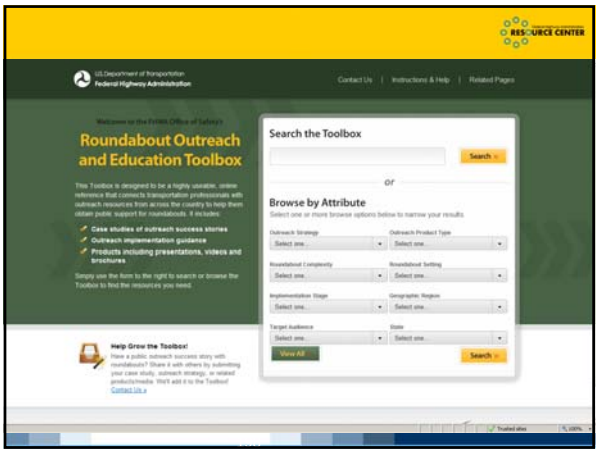




Source: Bend, OR

Current Research and Publications

- NCHRP 672 – Roundabouts: An Informational Report, Second Edition
- 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



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

Roundabouts Peer Assistance

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?
- R_1, R_2, R_3, R_4, R_5 - Design Speeds
- Relationship between radiuses (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

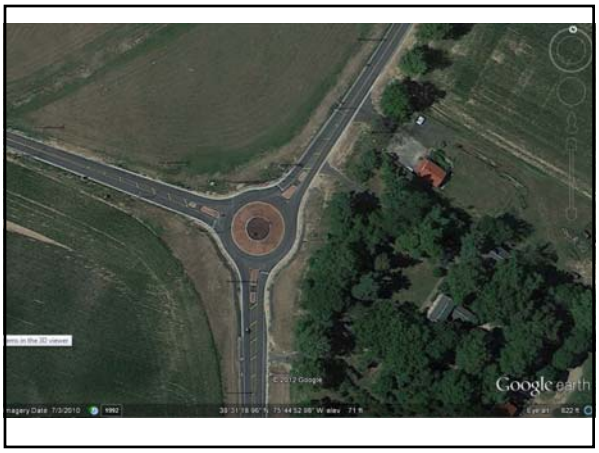
- Be Able to Indentify Fatal Flaws
- NO or Little Deflection
- Vehicle Path Overlap
- Inconsistent Speeds (Between circulating and approach drivers)
- If you were a truck driver would you want to traverse a 6 inch Vertical Curb?
- What Analysis Tools are Available?

Questions/ Discussion

Delaware Roundabouts


W Park Dr
E Park Dr
Google earth


Bunker Hill Rd
Griffiths Rd
Google earth


Google earth

Delaware Design Guidance

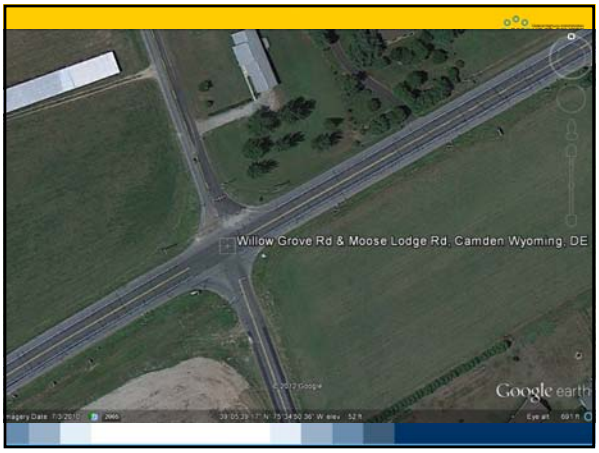
http://www.deldot.gov/information/pubs_forms/manuals/dgm/pdf/1-26_Roundabouts.pdf

Delaware MUTCD

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

Design Case Study

SR 10 and SR 15
Camden, DE



Design Exercise

Wrap-Up

Source: WisDOT

Evaluations

Final Thoughts…

Thank You

Hillary Isebrands, PE , PhD
Highway Safety Engineer
FHWA Resource Center Safety and Design TST
720-963-3222
hillary.isebrands@dot.gov