City of Bend

Roundabout Evaluation and Design Guidelines

April 2010

Prepared For:
The City of Bend

Prepared By:
Kittelson & Associates, Inc.

Introduction

In the 2001 Transportation Implementation Plan for the *City of Bend Transportation System Plan*, the Bend City Council adopted a policy stating that roundabouts are the preferred option for intersection improvements. This policy formalized the City's practice of giving preference to roundabouts as a safe and efficient form of intersection control. The evolution of roundabout implementation in Bend has resulted in designs with varying details and attributes. Furthermore, the analysis tools used to evaluate the operational characteristics of roundabouts have often varied.

To achieve consistency in roundabout evaluation and design, the City of Bend has developed the following guidelines. These guidelines represent the City's preferred methodologies for roundabout evaluation and design.

Roundabout Operational Analysis Guidelines

The *City of Bend Roundabout Operational Analysis Guidelines* establish a consistent methodology for analyzing the operational characteristics of roundabouts within the City's jurisdiction. These guidelines apply to analyses conducted for development applications or to support the evaluation and selection of City-sponsored capital improvement projects. Methodologies for calculating capacity, delay, and queues are presented for single-lane and multilane roundabouts.

Roundabout Design Consistency Guidelines

The purpose of the *City of Bend Roundabout Design Consistency Guidelines* is to promote consistent roundabout design within the City by:

- reinforcing the design guidelines contained in the FHWA's *Roundabouts: An Informational Guide* (*FHWA Guide*, Reference 1) and subsequent national research, and
- supplementing the *FHWA Guide* by documenting criteria and considerations for certain design elements according to specific objectives of the City.

In addition to providing general design guidance, these guidelines present specific design elements the City of Bend expects in roundabout designs within the City's jurisdiction.

Intersection Form Evaluation Framework

While the City of Bend has adopted a "roundabouts first" policy, the City also recognizes that site-specific conditions or other factors may ultimately necessitate other intersection forms. The *City of Bend Intersection Form Evaluation Framework* provides a framework and criteria for comparing roundabouts and other intersection forms. A case study that applies the intersection comparison process is included.

City of Bend

Roundabout Operational Analysis Guidelines

April 2010

Prepared For:
The City of Bend

Prepared By:
Kittelson & Associates, Inc.

Introduction

The intent of these operational guidelines is to establish a consistent methodology for analyzing roundabouts within the City's jurisdiction. These guidelines apply to analyses conducted for development applications or to support the evaluation and selection of City-sponsored capital improvement projects.

Much of the guidance provided within this document is based on NCHRP Report 572, *Roundabouts in the United States* (Reference 1), which summarizes a comprehensive review of U.S. roundabouts. The operational findings and recommendations from NCHRP Report 572 form the basis of the procedures that are anticipated to be included in the 2010 update of the Highway Capacity Manual (2010 HCM). Once the 2010 HCM is released, these guidelines could be revisited and modified to be consistent with national practice. However, the local calibration factors presented in these guidelines will still be applicable to the anticipated HCM capacity models.

Measures of Effectiveness

VOLUME-TO-CAPACITY RATIO

Volume-to-capacity (V/C) ratios are the primary measure of effectiveness for evaluation against the City's performance standards. V/C ratios for roundabouts should be calculated based on the entry demand and capacity for the most critical approach (i.e. approach with the highest v/c ratio) for single-lane roundabouts and the most critical lane (i.e. individual lane with the highest v/c ratio) for multilane roundabouts.

QUEUING

Queuing estimates should be included with all near-term roundabout operational analyses (e.g., development applications, capital improvement projects). Depending on site-specific conditions and at the City's discretion, queuing analyses may be required for long-term operational analysis (e.g., transportation system plan, transportation planning rule (TPR)). Queues between roundabouts and adjacent intersections and/or driveways have the potential to impact the safety and efficiency of the roadway and intersection elements away from the intersection being analyzed.

DELAY

While the City's operational performance standard for roundabouts is measured against a V/C ratio, to ensure a balanced comparison of alternative intersection forms, delay estimates should be developed when comparing alternative intersection forms to the roundabout. As a general rule, under the same traffic conditions, roundabouts typically will result in lower overall delay than traffic signals and all-way stop control but may result in higher overall delays than two-way stop control. Delay estimates can also be used to estimate vehicle emissions that result from various forms of intersection control.

LEVEL OF SERVICE

Level of service should be defined by the delay values presented in Table 1. These values are consistent with NCHRP Report 572 and are the same as the delay thresholds for other unsignalized intersections, as defined in the 2000 HCM (Reference 2) and the proposed 2010 HCM.

Table 1 Level of Service Thresholds for Roundabouts

Level of Service	Average Control Delay (s/veh)
A	0 - 10
B	> 10 - 15
C	> 15 - 25
D	> 25 - 35
E	> 35 - 50
F	> 50

Roundabout Operational Analysis Models

The following models are the City's preferred roundabout operational analysis models for capacity, delay, and queuing. The models described in this section are calibrated to either local conditions (single-lane roundabouts) or general U.S. conditions (multilane roundabouts).

CAPACITY

The City's base entry capacity model is consistent with NCHRP Report 572 and is shown in Equation 1.

$$c_{pce} = A \cdot exp(-B \cdot v_{c,\,pce}) \qquad \textbf{(Equation 1)}$$

where,

c_{pce} = *lane capacity, adjusted for heavy vehicles, (pc/h)*

$A = 3600/t_f$

$B = (t_c - t_f/2)/3600$

t_c = *critical headway (s)*

t_f = *follow-up headway (s)*

$v_{c,\,pce}$ = *conflicting circulating flow rate, adjusted for heavy vehicles, (pc/h)*

If project specific values for critical headway (t_c) and follow-up headway (t_f) are identified, this generalized model should be used to develop a project specific capacity model. If the analyst intends to collect project specific values for t_c and t_f, City staff should first be consulted to ensure an appropriate data collection methodology.

Bend Calibrated Capacity Model for Single-Lane Roundabouts

The capacity model shown in Equation 2 should be used for all single-lane entry capacity analyses, unless project specific values for critical headway (t_c) and follow-up headway (t_f) have been developed.

$$c_{pce} = 1333 \cdot \exp(-0.0008 \cdot v_{c,\,pce}) \quad \textbf{(Equation 2)}$$

where,

c_{pce} = *capacity, adjusted for heavy vehicles, (pc/h)*
$v_{c,\,pce}$ = *conflicting circulating flow rate, adjusted for heavy vehicles, (pc/h)*

Equation 2 is based on Bend-specific values for critical headway (4.1s) and follow-up headway (2.7s) observed at single-lane roundabouts in 2009.

Capacity Model for Multilane Roundabouts

Recognizing the need to provide a variety of lane configurations to accommodate a range of traffic patterns and the lane use imbalances that may result, multilane capacity analysis should be conducted on a lane-by-lane basis and reported for the most critical lane (i.e. lane with the highest volume) on each approach.

For entry lanes conflicted by one circulating lane, the single-lane capacity model presented in Equation 2 should be applied to the most critical lane on each approach.

For entry lanes conflicted by two circulating lanes, Equation 3 should be applied to the most critical lane on each approach.

$$c_{pce} = 1130 \cdot \exp(-0.0007 \cdot v_{c,\,pce}) \quad \textbf{(Equation 3)}$$

where,

c_{pce} = *capacity, adjusted for heavy vehicles, (pc/h)*
$v_{c,\,pce}$ = *conflicting circulating flow rate, adjusted for heavy vehicles, (pc/h)*

Equation 3 reflects the multilane capacity model identified in NCHRP Report 572. Given that single-lane roundabouts in Bend perform at a higher capacity than the national average, it is possible that the capacities of multilane roundabouts in Bend will also exceed the national average. However, at the time these guidelines were prepared, no multilane roundabouts in Bend operated near or at capacity to enable accurate measurements. Care is recommended when assessing multilane roundabouts that are projected to operate near capacity.

(Note: If conditions permit future data collection at multilane roundabouts in Bend, Equation 3 could be calibrated to local conditions.)

DELAY AND LOS

Equation 4 provides a delay estimation model to be used in determining delay for each approach or critical lane. This model is based on the HCM unsignalized delay model and is consistent with recommendations from NCHRP Report 572. The delay estimates resulting from this model should be used to determine LOS according to the thresholds identified in Table 1.

$$D = \frac{3600}{c} + 900T \times \left[x - 1 + \sqrt{(x-1)^2 + \frac{\left(\frac{3600}{c}\right)x}{450T}} \right] + 5 \times \min[x,1] \qquad \textbf{(Equation 4)}$$

where,

D = average control delay (s/veh)
x = volume-to-capacity ratio of the subject lane
c = capacity of the subject lane (veh/h)
T = time period (h) = 0.25 for a 15-minute analysis

QUEUING

Queue lengths should be estimated using Equation 5 for each single-lane approach and for the critical lane on each multilane approach. As shown, Equation 5 will result in the 95th-percentile queue likely to occur during the peak fifteen minutes of the hour being analyzed. If an hourly queue evaluation is desired, the flow rate should not be adjusted by the PHF and T will equal 1.0.

$$Q_{95} = 900T \times \left[x - 1 + \sqrt{(1-x)^2 + \frac{\left(\frac{3600}{c}\right)x}{150T}} \right] \times \frac{c}{3600} \qquad \textbf{(Equation 5)}$$

where,

Q_{95} = queue length (veh)
x = volume-to-capacity ratio of the subject lane
c = capacity of the subject lane (veh/h)
T = time period (h) = 0.25 for a 15-minute analysis

Roundabout Analysis Process

The following diagram outlines the analysis process to be used for analyzing roundabouts within the City of Bend.

Step 1: Convert movement demand volumes (V, veh/h) to flow rates (v, veh/h).

Peak 15-minute analysis: $v = V/PHF$ Hourly analysis: $v = V$

Step 2: Adjust flow rates for heavy vehicles.

$v_{pce} = v/f_{HV}$, $f_{HV} = 1/[1 + P_T(E_T - 1)]$, P_T = Heavy Vehicle %, $E_T = 2.0$ for Heavy Vehicles

Step 3: Determine circulating and exiting flow rates.

Step 4: Determine entry flow rates by lane.

Step 5: Determine the capacity of each entry lane in passenger car equivalents.

(see Equations 2 and 3)

Step 6: Determine pedestrian impedance (f_{ped}) to vehicles.

(see *FHWA Roundabout Guide* (Reference 3) Exhibits 4-7 and 4-8)

Step 7: Convert lane flow rates and capacity into vehicles per hour.

$v = v_{pce} f_{HV}$ $c = c_{pce} f_{HV} f_{ped}$

Step 8: Compute the volume-to-capacity ratio for each lane.

$x = v/c$

Step 9: Compute the average control delay and corresponding LOS for each lane.

(see Equation 4)

Step 10: Compute 95th-percentile queues for each lane.

(see Equation 5)

Comparison with Alternative Intersection Forms

Roundabouts are often evaluated against a signalized intersection alternative. Phase splits at a signalized intersection can be adjusted to meet varying demand. Therefore, analysis for signalized intersections is conducted and reported for the intersection as a whole. When comparing a roundabout alternative to a signalized intersection or all-way stop control alternative, Equation 6 should be used to develop a weighted average of the delay estimate for the roundabout intersection as a whole. All movements, including those using bypass lanes, should be included in the weighted average.

$$D_{\text{intersection}} = \frac{\sum_i D_i V_i}{\sum_i V_i} \qquad \textbf{(Equation 6)}$$

where,

$D_{intersection}$ = *intersection control delay, s/veh*

D_i = *control delay on approach i, s/veh*

V_i = *volume on approach i, veh/hr*

Additional guidance on conducting comparative analyses for different intersection forms is provided in the *City of Bend Intersection Form Evaluation Framework* (Reference 3).

Alternative Tools for Operational Analysis

At the discretion of City staff, additional analysis tools, such as other deterministic tools or microsimulation, may be required to augment the methodologies described in this document. If alternative operational analysis tools will be used on a project, the analyst should consult with City staff early in the process to ensure appropriate calibration of the analysis method.

References

1. Rodegerdts, L., M. Blogg, E. Wemple, E. Myers, M. Kyte, M. Dixon, G. List, A. Flannery, R. Troutbeck, W. Brilon, N. Wu, B. Persaud, C. Lyon, D. Harkey, and D. Carter. *NCHRP Report 572: Roundabouts in the United States,* TRB, National Academy of Sciences, Washington, D.C., 2007. [online] http://www.trb.org/Main/Public/Blurbs/158299.aspx

2. Transportation Research Board. *Highway Capacity Manual*. TRB, National Research Council, Washington, DC, 2000.

3. Kittelson & Associates, Inc. *City of Bend Intersection Form Evaluation Framework*. City of Bend, November 2009.

City of Bend

Roundabout Design Consistency Guidelines

April 2010

Prepared For:
The City of Bend

Prepared By:
Kittelson & Associates, Inc.

Introduction

The City of Bend plans and implements transportation facilities that serve all vehicular and non-vehicular users. As conventional intersections have been applied extensively and their design, operations, and use are generally well understood and documented, this document focuses on roundabouts. This design guide has been prepared to promote consistent roundabout design within the City. The intent of this guide is to:

- reinforce the design guidelines contained in the FHWA's *Roundabouts: An Informational Guide* (*FHWA Guide*, Reference 1) and subsequent national research, and
- supplement the *FHWA Guide* by documenting criteria and considerations for certain design elements according to specific objectives of the City.

Roundabout design is an iterative process, and the roundabouts that the City of Bend has implemented over the years exhibit a variety of traits and features. Based on the City's experience with roundabouts, this guide provides information and approaches to roundabout implementation to promote consistency and uniformity for future roundabouts. The City recognizes roundabout designs must adapt to the context of their potential application and, therefore, is willing to explore and consider tradeoffs and possible deviations that allow the City the ability to continue to promote roundabout implementation. There are no explicit limitations or conditions under which roundabouts may be considered. While the City has adopted a "roundabouts first" policy, the City also recognizes that site-specific conditions or other factors may ultimately necessitate other intersection forms. Guidance on conducting comparative analyses for different intersection forms is provided in the *City of Bend Intersection Form Evaluation Framework* (Reference 2).

Intersection Context

Intersection context includes fundamental considerations such as whether the intersection is part of a new facility or a retrofit situation. New locations provide increased flexibility in locating and designing the intersection forms, while retrofit conditions often exhibit constrained right of way or secondary considerations, such as access to adjacent land uses. Intersection context also includes understanding user types and appropriately serving non-motorized users and design vehicle needs. Design vehicle choices have a significant effect on roundabout dimensions and configurations.

The context of the transportation system and land use scenario in which a roundabout is situated will often dictate fundamental design decisions. For instance, the roundabout at the Simpson Avenue/Century Drive intersection was constructed in a built environment with limited available right-of-way. The surrounding land uses have the potential to generate significant pedestrian and bicyclist activity through the intersection. These factors appear to make the selection of a compact urban design, as shown in Exhibit 1, appropriate.

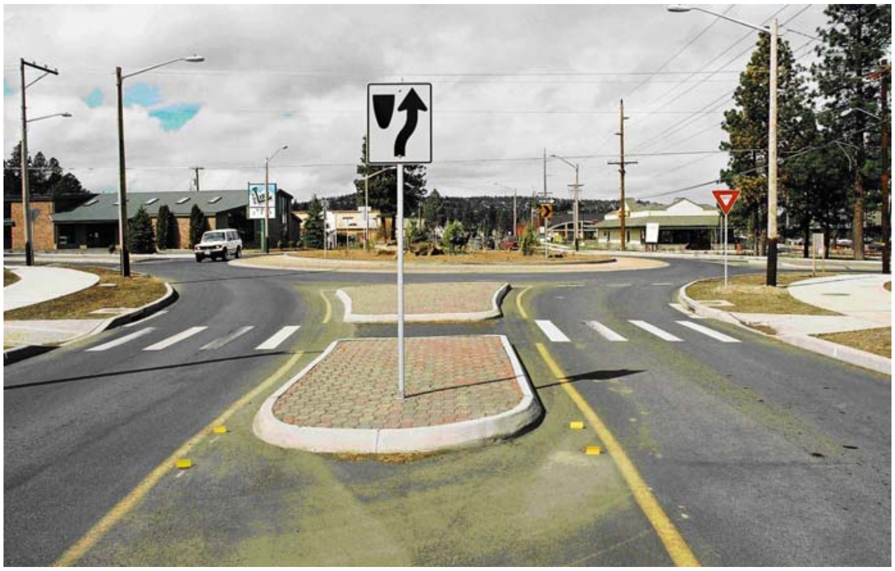


Photo: Lee Rodegerdts

Exhibit 1 **Compact urban design – Simpson Avenue / Century Drive**

However, if the greater context of this intersection is considered, a design with more generous geometry and higher capacity may have been selected. A rock extraction pit in the vicinity of the intersection results in a relatively high number of heavy vehicles through the intersection. These heavy vehicles have a difficult time negotiating the compact urban design of this roundabout and have caused damage to the splitter islands and curbs. The tight geometry also results in reduced capacity, which can result in queuing during peak periods. While this may be an acceptable condition in an urban environment, the queues have the potential to block a fire station driveway on the east approach to the intersection. Fortunately, there are opportunities to retrofit this roundabout to better accommodate heavy vehicles and increase capacity while maintaining slow speeds desirable in a built, urban environment.

Planning and Design Principles

The roundabout design process is more iterative than that of other intersection forms. Small changes to the roundabout geometry can have significant effects on the operational and safety characteristics of the roundabout. Designers should refer to Exhibit 6-2 of the *FHWA Guide* for guidance on the design process. At the initial layout of a roundabout, three fundamental elements of the roundabout design should be considered:

1. the location of the roundabout;
2. the size of the roundabout; and
3. the approach alignment.

Changes to any of these three fundamental elements during the design process may require a reassessment of the other two elements.

LOCATION

To minimize impact to adjacent properties and right-of-way acquisition, designers should begin by attempting to center a proposed roundabout at either the center of the existing intersection or the intersection of the centerlines of the intersection approaches. However, the designer should not be constrained to centering the roundabout on the center of the existing intersection. Reasons for shifting the roundabout include constraints in one or more quadrants of the intersection, providing more deflection on a particular approach to reduce speeds, and the ability to stage construction while maintaining traffic. Fundamentally, the location of the roundabout should be prioritized to a position that optimizes the desired operating and safety performance characteristics.

INSCRIBED CIRCLE DIAMETER

The City desires roundabouts that are as small as possible while still addressing fundamental capacity, emergency response, design vehicles, and other operational and safety needs. Diameter ranges and considerations are presented in the *FHWA Guide*. These values provide a starting point in determining the appropriate size that results in desired operations and safety performance. Site-specific conditions may require inscribed circle diameters that are outside the published ranges.

APPROACH ALIGNMENT AND DESIGN

To the extent possible, the City desires roundabout approaches that are as near 90 degrees as possible. These alignments facilitate desirable slow and consistent speeds and reduce the size of the roundabout's inscribed circle diameter. Regardless of the approach alignment, roundabout designs should promote slow operating speeds at the entry and relatively small speed differentials between successive geometric elements or conflicting movements.

As described in the *FHWA Guide*, entry curves should be curvilinearly tangential to the outside edge of the circulatory roadway and the central island. The primary considerations when selecting an entry curve radius are entry speed control and accommodating the design vehicle. Typical entry curve radii for a single-lane roundabout range from 50 to 100 feet. Considerations for entry design at multilane approaches are similar with the additional consideration of path alignment, as described in a later section.

Similar to entry design, exit curves should be designed curvilinearly tangential to the circulatory roadway and the central island. The exit radius should not result in a vehicle path radius that is smaller than the circulating vehicle path radius. Although tangential exit designs may be acceptable, careful consideration should be made to the resulting vehicle speed at the pedestrian crossing downstream from the exit.

Safety and Performance Evaluations

SPEED CHECKS

Speed checks are one of the key performance checks of a roundabout concept. The predicted speed values are used to assess a roundabout's safety performance and are used in the intersection and stopping sight distance computations.

The first priority in investigating a roundabout's predicted speed is attaining low entry speeds. Target maximum design entry speeds are 20 to 25 mph for single-lane roundabouts and 25 to 30 mph for multilane roundabouts (assuming drivers do not adhere to lane markings on the entry). While designers should strive to achieve these design speeds, site-specific constraints may require a trade-off between achieving these design speeds and accommodating other design elements (e.g., promoting good path alignment, accommodating the design vehicle). In these cases, the designer should coordinate with City staff early in the planning process to consider the context of the intersection and acceptable design tradeoffs.

In addition to appropriate entry speeds, the roundabout configuration should be evaluated for speed consistency between success geometric elements, such as the path of a through movement through a roundabout. In addition, speed checks should consider the speed differential between conflicting traffic movements, such as a through movement potentially overtaking a relatively slow left turning movement. As described previously, the exit geometry should not result in exiting speeds that are slower than circulating speeds. Exhibit 2 shows a small exit radius that can result in vehicles slowing within the circulatory roadway to navigate the exit.

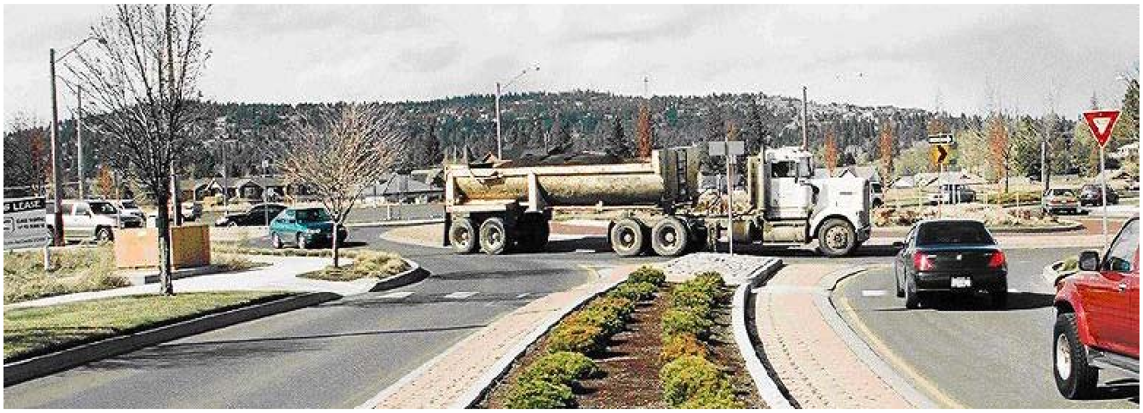


Photo: Lee Rodegerdts

Exhibit 2 Example of tight exit geometry

The City follows the guidance provided in the *FHWA Guide* for assessing vehicle fastest paths. *NCHRP Report 572, Roundabouts in the United States* (Reference 3) provides information that augments the *FHWA Guide* for exiting speed. *NCHRP Report 572* indicates exit speeds may be controlled by speed reduction at the entering and circulating radii and, therefore, the actual speeds for exiting vehicles ("V_3") may be lower than predicted by the FHWA methodology. Consequently, speed checks for the exit should be conducted using Equation 5-4a in *NCHRP Report 572*. Designers should generally target design speeds in the range of 25 mph at the exit.

DESIGN VEHICLE

The appropriate design vehicle is a fundamental consideration influencing the size of a roundabout and, therefore, should be considered in the earliest stages of intersection planning. In addition, the volumes, patterns, and frequency of the design vehicle should be considered early and the roundabout configuration customized for the anticipated movements. This means some roundabouts may be configured to serve different design vehicles on different movements, which results in a customized design at each location based on anticipated design vehicle needs.

A WB-50 design vehicle should be considered as the base condition for intersection design on City facilities. However, the specific context of the intersection and the frequency and sensitivity of the need for a larger design vehicle must be considered and documented. This might mean that a WB-67 vehicle be considered on specific movements within the roundabout and the roundabout sized accordingly and customized to anticipated uses and patterns. Similarly, a WB-40 design vehicle may be adequate for certain facilities. The designer should consult with City transportation staff early to identify the context of the intersection and document the appropriate design vehicle by approach as these evaluations could greatly influence the roundabout configuration.

Design vehicle checks (using a tool such as AutoTurn) should be conducted as part of concept development and included in the 30% design submittal. To increase operator comfort and minimize the possibility of overturning, the designer should strive to reserve use of the truck apron for only the trailer of the design vehicle. Generally, the cab of the design vehicle should be able to circulate without using the truck apron. While the tracking of the trailer of the design vehicle will define the inside edge of the truck apron, a bus (e.g., B-40) or emergency vehicle should be used to define the outside edge of the truck apron. Buses and emergency vehicles generally should not encroach upon the truck apron and, therefore, will define the edge between the circulatory roadway and the truck apron. Care should be taken to avoid excessively large circulatory roadway widths. Widths should generally not exceed 20 feet for a single-lane roundabout to avoid the possibility of drivers mistaking the roundabout for having two circulating lanes. Adjustments to the inscribed circle diameter may be required to balance the truck accommodations with the circulatory roadway width.

The choice of design vehicle affects a variety of design elements. Improperly designed roundabouts may result in long-term maintenance issues. These issues can include broken curbs, crushed landscaping, and impacted traffic furniture and signing. Operational issues include vehicles encroaching in pedestrian areas or generally decreasing traffic flow because of extra slow speeds by trucks navigating the roundabout.

PATH ALIGNMENT

The alignment of vehicle paths should be considered for any multilane entry or exit. Designers should take care to promote proper path alignment. Without proper path alignment, the phenomenon of path overlap, as demonstrated in Exhibit 3, can occur at multilane roundabouts. Path overlap results when the natural path of a vehicle in one lane encroaches on an adjacent lane in response to the geometry. Path overlap can occur on either the roundabout entry or exit. Exhibit 4 demonstrates an occurrence of path overlap at a roundabout exit and a retrofit of the same exit to eliminate path overlap. Exhibit 5 provides guidance to designers on how to avoid path overlap. The same treatments are applicable to the design of the roundabout exits. Exhibit 6 shows a roundabout entry design incorporating design features to promote proper path alignment.

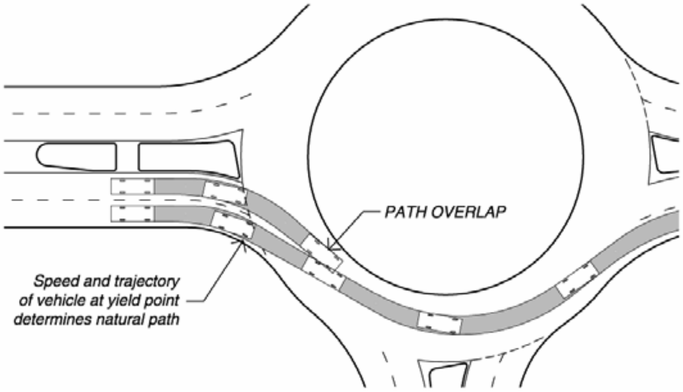

PATH OVERLAP
Speed and trajectory of vehicle at yield point determines natural path

Exhibit 3 Example of path overlap (KSDOT Exhibit 6-19, Reference 4)

Photo: Barry Crown

Photo: Lee Rodegerdts

Exhibit 4 Example of exit path overlap and retrofit

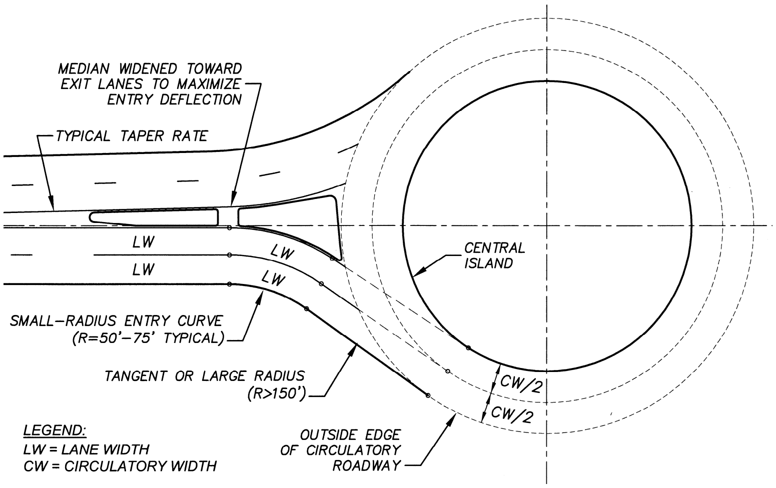

MEDIAN WIDENED TOWARD EXIT LANES TO MAXIMIZE ENTRY DEFLECTION
TYPICAL TAPER RATE
LW
LW
LW
LW
CENTRAL ISLAND
SMALL–RADIUS ENTRY CURVE (R=50'–75' TYPICAL)
TANGENT OR LARGE RADIUS (R>150')
CW/2
CW/2
LEGEND:
LW = LANE WIDTH
CW = CIRCULATORY WIDTH
OUTSIDE EDGE OF CIRCULATORY ROADWAY

Exhibit 5 Multilane design details (KSDOT Exhibit 6-20)

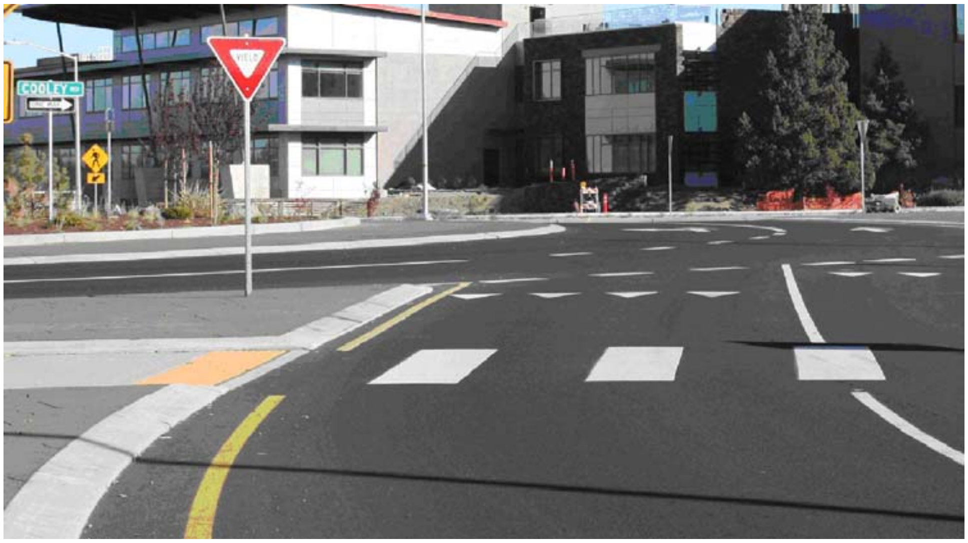


Photo: Lee Rodegerdts

Exhibit 6 **Appropriate entry design with proper path alignment (18th Street / Cooley Road)**

Roundabout Design Elements

PEDESTRIAN TREATMENTS

Roundabouts simplify pedestrian roadway crossings by providing a two-stage crossing. As such, roundabout splitter islands should serve the anticipated volume of pedestrians and have a raised refuge area of adequate width to accommodate the anticipated user types. The City prefers a pedestrian refuge area of at least 8 to 9 feet in width. In no case should the refuge area be less than 6 feet in width. The pedestrian crossing and refuge area should be located a minimum of 20 feet from the circulatory roadway and preferably not more than 25 feet.

At roundabouts, cyclists have the option to exit the roadway, which means pedestrians and bicycles must coexist at roundabouts. Therefore, in the areas around a roundabout and bound by the bicycle ramps, the pedestrian facilities should be designed as a multiuse path with a width of preferably no less than 10 feet and a minimum of 8 feet. In constrained areas, the multiuse path may need to be designed curb-tight to attain the minimum width; alternatively, cyclists may need to walk their bicycles if they choose not to ride through as a vehicle.

The City supports mobility for all users and takes care to provide appropriate facilities and designs for special user needs. Roundabouts must include grades, access ramps, and detectable warning surfaces at all pedestrian-roadway interfaces to make them accessible per the requirements of the *ADA Accessibility Guidelines* (ADAAG, Reference 5) and the best practices described in the draft *Rights-of-Way Accessibility Guidelines* (PROWAG, Reference 6). Pedestrian facilities should support wayfinding. For roadway crossings, the crossing should be designed perpendicular to the center line of the roadway and provide as linear a path as possible from one access ramp to the other via the refuge area. If a crosswalk must be oriented perpendicular to the traveled way due to site constraints, a defined angle point should be provided in the refuge island to help orient visually impaired pedestrians to the receiving access ramp.

Pedestrian Signals

The U.S. Access Board has developed guidance in the draft *Public Rights-of-Way Accessibility Guidelines* (PROWAG, Reference 6) that would require installing "some form of signalization" or other equivalently accessible features on the entries and exits of all multilane roundabout approaches. The pedestrian hybrid beacon identified in the 2009 MUTCD, would likely meet the intent of this PROWAG requirement. The rectangular rapid flashing beacon (RRFB), which has interim approval from FHWA, may also be an acceptable treatment. In anticipation of a final PROWAG decision that could include signalizing multilane roundabout approaches, designers should, at a minimum, include appropriately placed conduit and junction boxes to accommodate potential future installations of signals.

BICYCLE TREATMENTS

Designers should strive to provide cyclists the opportunity to either navigate the roundabout with vehicular traffic or to exit the vehicular travel way and use a multiuse path adjacent to the roundabout. To accommodate those cyclists that would prefer to exit the vehicular travel way, exit and entry ramps should be provided. Historically, roundabout design in Bend has resulted in a variety of bicycle ramp treatments. This variation in design reflects both an evolution of theory and, in some cases, the need to adapt designs to constrained situations (e.g., adjacent driveways).

Exhibit 7 demonstrates the City's preferred design for bicycle ramps. The designer should consider site-specific conditions when locating bike ramps. Generally, the ramps should be located approximately 50 to 100 feet from the entrance line and, in all cases, prior to the pedestrian crossing. As shown, the ramps are angular to the approach roadway and the multiuse path. This facilitates the exiting movement from the roadway without requiring cyclists to swing into the vehicular travel way to access the ramp. On the re-entry to the bike lane on the exit side of the approach, the angular ramp minimizes the probability of a visually impaired pedestrian mistaking the ramp for a sidewalk. In addition, detectable warning surfaces (e.g., truncated domes or stamped or textured concrete) should be installed across the full width of each ramp at the edge of the sidewalk. As shown in Exhibit 7, the transition between the bike lane and the bike ramp has been designed to accommodate street sweeping.

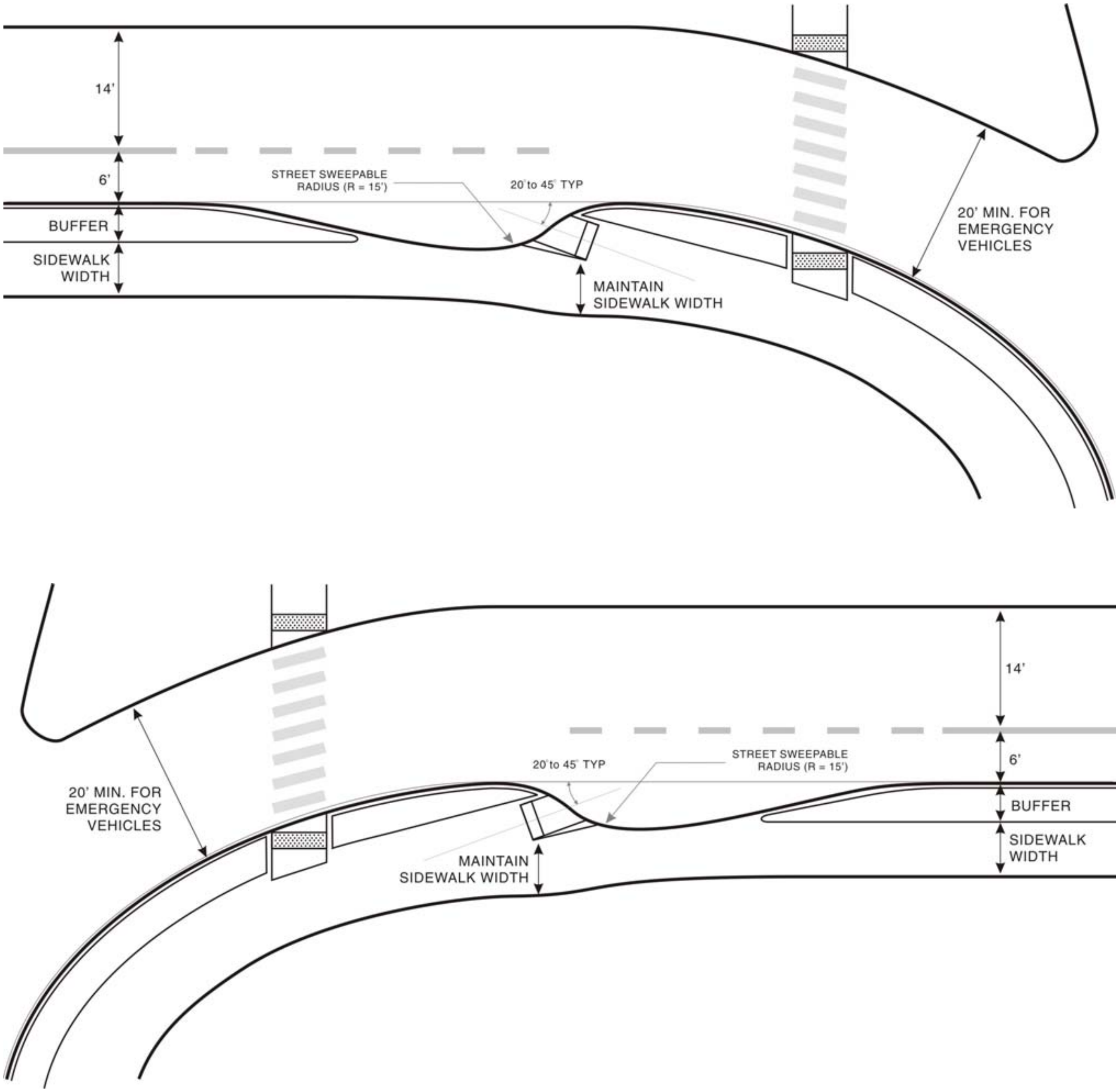

14'
6'
STREET SWEEPABLE RADIUS (R = 15')
20° to 45° TYP
BUFFER
SIDEWALK WIDTH
MAINTAIN SIDEWALK WIDTH
20' MIN. FOR EMERGENCY VEHICLES
20' MIN. FOR EMERGENCY VEHICLES
20° to 45° TYP
STREET SWEEPABLE RADIUS (R = 15')
14'
6'
BUFFER
SIDEWALK WIDTH
MAINTAIN SIDEWALK WIDTH

Exhibit 7 Bike Treatment Concept

These bike treatment concepts should be considered at all single-lane and multilane roundabouts, even where bike lanes are not present in advance of the roundabout. If possible, where bike lanes do not exist on an approach, a bike lane should be provided through the extent of the construction limits on both the entry and exit of each approach. This will accommodate the future addition of bike lanes. Under no circumstance should a striped bike lane or shoulder be provided on the roundabout circulatory roadway.

SPLITTER ISLAND

Splitter islands serve a variety of purposes from positive guidance to sign placement and should be included on all roundabouts. Splitter islands should be raised to optimize their effectiveness. Should a geometric or site-specific constraint appear to preclude a raised splitter island, extra care and consultation with City staff is required, and the constraints should be thoroughly documented. Fundamentally, there should be very few instances where a raised splitter island is not feasible and all efforts should be explored to refine a design to attain a raised splitter island. If a raised island cannot be attained, the splitter island should be a textured surface to distinguish it from the adjacent pavement. Only in rare cases, such as low-volume approaches, should painted splitter islands be considered.

While splitter islands should be at least 50 feet long, 100 feet is desirable and, generally, splitter islands should be as long as practical within the design environment. Longer islands are desirable to help manage speed on high speed approaches, to manage access and encourage right-in/right-out movements from adjacent access, or to help promote positive guidance on roadway approaches that have significant realignment from their former configurations.

The *FHWA Guide* and *NCHRP Report 279* (Reference 7) provide examples and applications of the principles of channelization. These documents encourage offsetting splitter islands from the approach traveled way and narrowing the offset on the departures to create a funneling effect. The *FHWA Guide* provides end treatment dimensions that reflect a philosophy of larger radii on island approaches and smaller radii on the departures. The City prefers that all median end treatments be nearly flush with the roadway, as shown in Exhibit 8, to accommodate snowplows. These principles and the intent of these configurations should be incorporated in all roundabout designs.

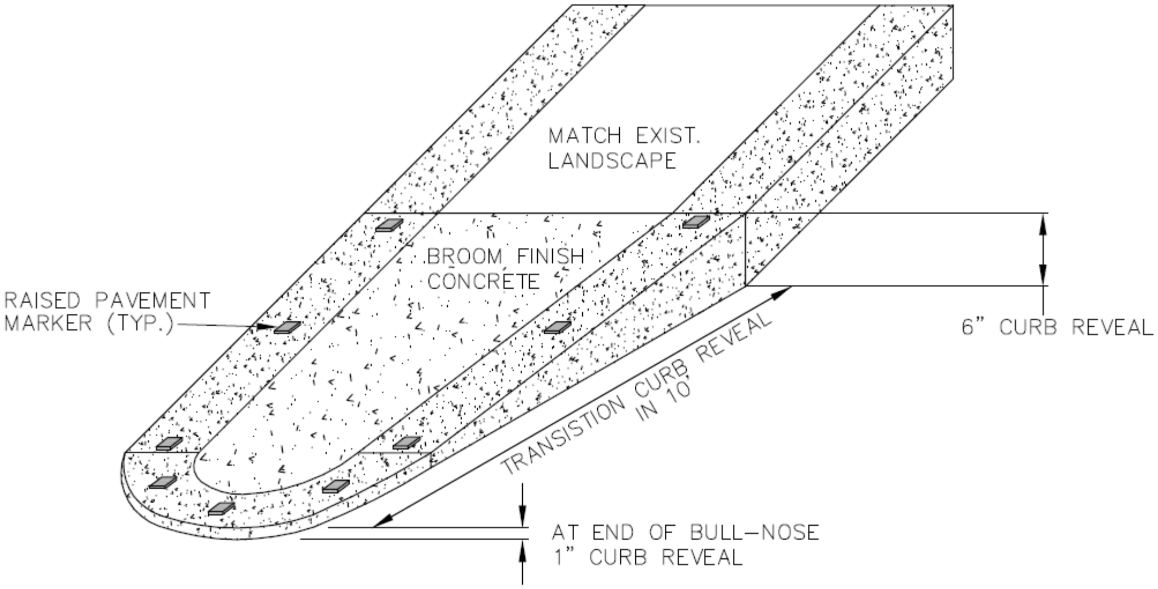


Exhibit 8 **Median End Treatment Concept**

APPROACH WIDTH

In general, roundabout approach widths should be as narrow as practical while serving the traffic volume needs (single-lane versus multilane) and the applicable design vehicle. This holds true for exit widths also. In most cases a tractor trailer design vehicle will control the immediate entry and exit widths; however, emergency vehicle needs may control roundabout approach, entry, and exit widths. As a minimum, 20 feet of clear width (curb face to curb face) should be provided on all approaches, entries, and exits to accommodate emergency vehicles. Designers and design reviewers should be especially alert that these approach widths could influence vehicular speeds and, therefore, fastest path evaluations must be conducted to ensure target speeds can be attained while serving emergency vehicle and other design vehicle needs. If appropriate design speeds cannot be achieved while still providing 20 feet of clear width, the designer should consider design modifications, such as a larger inscribed circle diameter or an offset-left approach alignment.

TRUCK APRON

Truck aprons are typically provided around the central island to accommodate the design vehicle while still maintaining appropriate speed control through the roundabout. Truck aprons on the outer edge of entries and exits to the roundabout should generally be avoided as they could result in a potential conflict between non-motorized users and trucks. Given that the truck apron is intended to serve heavily loaded vehicles, all elements of the truck apron (edges and apron) should be constructed of high-strength concrete and include appropriate steel reinforcing to promote a long service life. The truck apron should have colors and textures that distinguish it from the traveled way and adjacent sidewalks.

Cross Slope

The cross slope of the truck apron should generally be 1 to 2% but can vary based on design and drainage needs. If larger cross slope values are applied, the design should specifically be checked to address low clearance tractor trailer design vehicles. In all cases the truck apron should slope out to the circulatory roadway.

Reveal

The reveal provides a clear distinction between the circulatory roadway and the truck apron. Too small of a reveal may result in drivers riding up on the apron resulting in undesirable speeds. Too much reveal can create an overly abrupt edge that could disrupt flow or be impacted by vehicles. The City prefers to use its Type “B” curb design for the outer edge of the truck apron.

Interior Curb

An interior curb or other fixed raised demarcation should be provided between the truck apron and the non-traversable central island. This curb distinguishes between the apron and planted area and discourages use of the landscaped central island.

ILLUMINATION

Illumination should be provided at all roundabouts with special care taken to light conflict areas at the proper level. The primary conflict areas for consideration are fixed objects (e.g., splitter islands, central island), pedestrian crossings, bike transitions, and the entering and exiting conflict areas on each approach. Luminaire type may vary to serve vehicular and pedestrian traffic together or with separate lighting systems employed to separately serve user needs. Current guidance from the Illuminating Engineering Society (IES) suggests that illumination at pedestrian crossings be placed in front of the crossing (i.e. as the driver approaches the crossing) to provide sufficient positive contrast.

Exhibit 9 depicts areas of the roundabout where lighting is susceptible to vehicular impact. To the extent possible, these conflict areas should be avoided. If the location cannot be avoided, other design treatments, such as larger offsets from the traveled way and longer luminaire arms, should be considered.

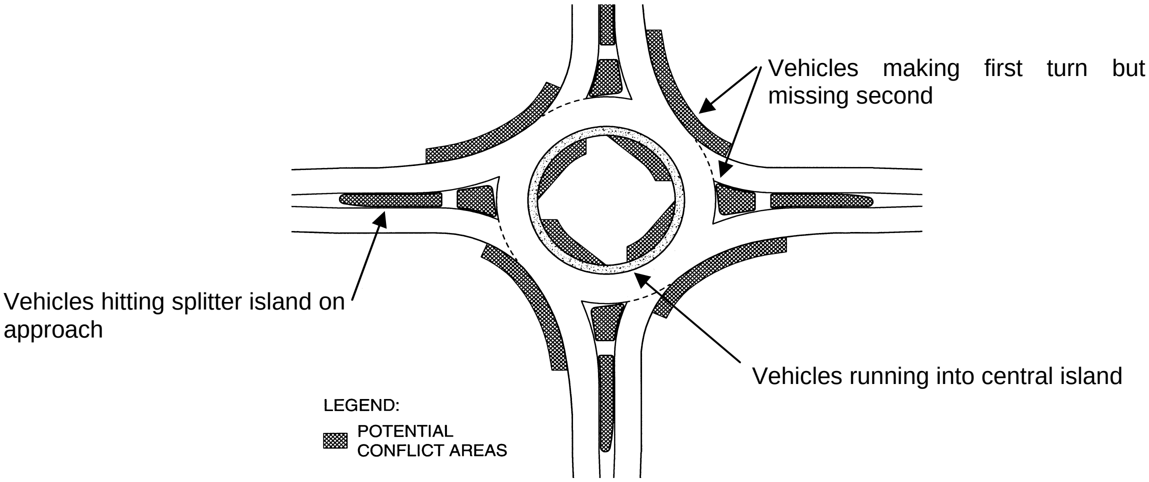

Vehicles making first turn but missing second
Vehicles hitting splitter island on approach
Vehicles running into central island
LEGEND:
▨ POTENTIAL CONFLICT AREAS

Exhibit 9 **Areas to avoid for pole placement**

Generally, the designer should start by placing luminaries along the perimeter of the roundabout in advance of each pedestrian crossing. Depending on pole placement and the size of the roundabout, it may be necessary to light the circulatory roadway from both the exterior and the interior (i.e. the central island) of the roundabout. In all cases, a photometric analysis should be conducted to ensure appropriate lighting levels and uniformity.

The current City standard for horizontal illumination at roundabouts is a minimum illumination level of 1.0 foot-candles and a uniformity of 3:1 or better. Recent studies and guidance suggest that vertical illuminance, which helps drivers identify pedestrians in crosswalks, should also be considered. Vertical illuminance provides illumination of objects in the vertical plane. IES suggests that vertical illuminance should be measured at a height of 5 feet along the centerline of each crossing. The average vertical illuminance along this line should meet the same standard as the minimum horizontal illuminance and uniformity and the measurement should be made at least one safe stopping distance from the crossing. Additional design guidance can be found in the *Design Guide for Roundabout Lighting* (Reference 8) prepared by IES.

Application of Traffic Control Devices

An update to the *Manual on Uniform Traffic Control Devices* (MUTCD) was released by FHWA in late 2009. The updated MUTCD includes revised information for roundabout signing and striping. The following is not intended to replace the MUTCD but instead provide guidance to designers on the optional pavement markings and signs in the 2009 MUTCD (Reference 9).

PAVEMENT MARKINGS

Yield Line and Yield Legend

The MUTCD identifies the use of yield lines and yield legends as optional at roundabouts. The City's preference is to not use the yield line or legend to reduce ongoing maintenance.

Lane-Use Arrows

Lane-use arrows should be used on all multilane approaches and within the circulatory roadway of multilane roundabouts. Lane-use arrows should not be used at single-lane roundabouts. Where used, the City prefers to use the traditional (i.e. not fish-hook) lane-use arrows without a dot symbolizing the central island, as described in the 2009 MUTCD.

SIGNING

Lane-Use Signs

The City prefers to use lane-use signs depicting traditional (i.e. not fish-hook) lane-use arrows and without a dot symbolizing the central island. Lane-use signs should only be used on multilane approaches.

Yield Sign

Yield signs (R1-2) shall be placed on the outside edge of all single-lane approaches. Depending on the approach geometry and sign visibility, a yield sign may also be necessary in the splitter island on single-lane approaches. Yield signs shall be placed on both the outside edge and in the splitter island on all multilane approaches.

Circular Intersection Sign

The Circular Intersection sign (W2-6) should be used in advance of all roundabout intersections. A plaque should be included with each W2-6 sign indicating the name of the upcoming cross-street.

Pedestrian Crossing Sign

The pedestrian crossing sign (W11-2) and associated downward arrow plaque should not be used at crossings of single-lane approaches except at single-lane approaches within a school zone. At crossings of multilane approaches, a W11-2 and associated downward arrow plaque should be placed on both the outside edge and in the splitter island.

Directional Arrow and Street Name Sign Assembly

Consistent with the R6-4 sign series in the 2009 MUTCD, a horizontal, rectangular sign with black chevrons on a white background should be placed in the central island opposite each roundabout entry. A street sign indicating the name of the cross-street should be mounted above the directional arrow sign.

Exhibits 10 and 11 demonstrate the typical pavement markings and signing described above for single-lane and multilane roundabouts, respectively.

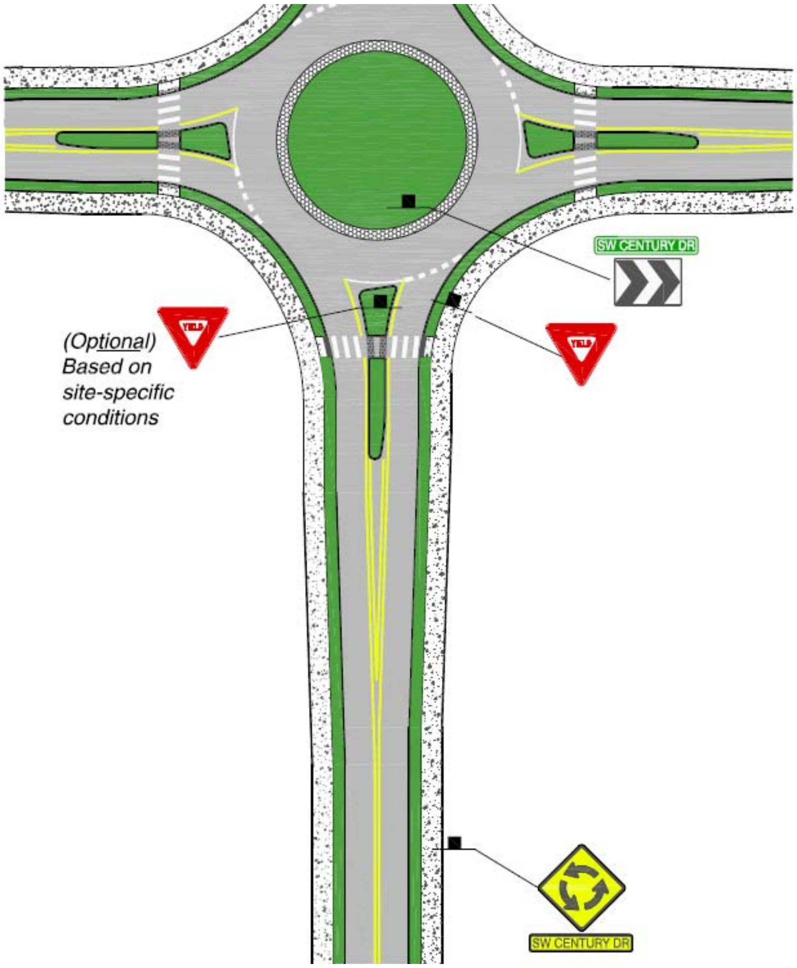
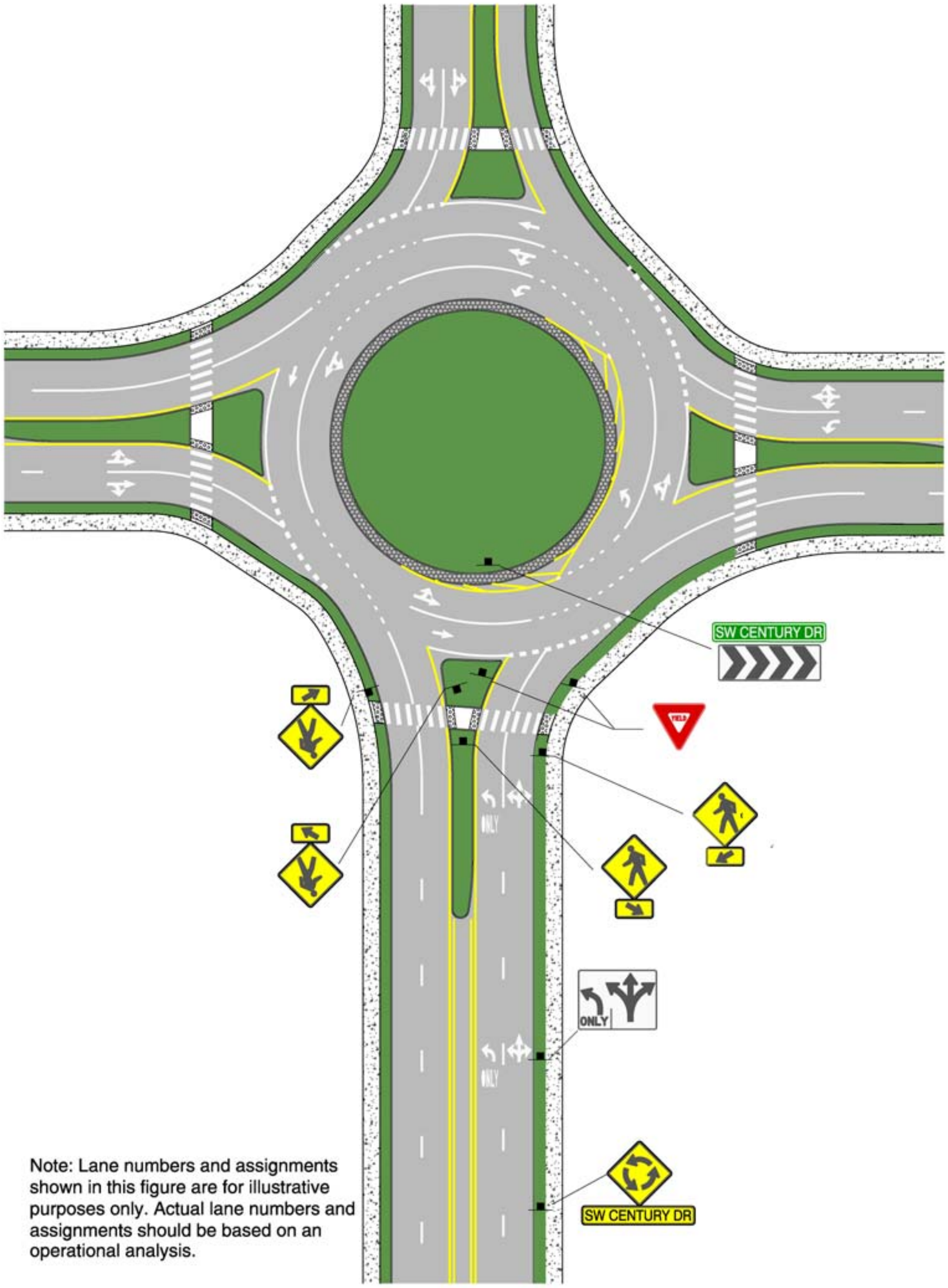


Exhibit 10 Pavement markings and signing for single-lane roundabouts


SW CENTURY DR
YIELD
ONLY
ONLY
ONLY
SW CENTURY DR

Note: Lane numbers and assignments shown in this figure are for illustrative purposes only. Actual lane numbers and assignments should be based on an operational analysis.

Exhibit 11 **Pavement markings and signing for multilane roundabouts**

Access Management

The City recognizes access management as a valuable tool to enhance the flow of traffic, reduce user conflicts, and improve safety. Access management is a means of optimizing the available capacity of a roadway and perhaps eliminating or postponing expensive or impacting roadway widening. Roundabouts provide opportunities to support access management objectives and should be considered explicitly for this purpose. Roundabouts may also support flexibility in access management. For instance, right-in/right-out driveways that would not be permitted within the influence area of a conventional intersection may be permitted near a roundabout as the roundabout will facilitate U-turn movements. Furthermore, the low speed environment in the influence area of a roundabout may permit driveways that would not be permitted at a conventional intersection to operate safely. The context of each location should be reviewed on a case-by-case basis when considering access management near a roundabout.

References

1. Robinson, B. W., L. Rodegerdts, W. Scarbrough, W. Kittelson, R. Troutbeck, W. Brilon, L. Bondzio, K. Courage, M. Kyte, J. Mason, A. Flannery, E. Myers, J. Bunker, and G. Jacquemart. *Roundabouts: An Informational Guide*. Report FHWA-RD-00-067. FHWA, U.S. Department of Transportation, June 2000. [online] http://www.tfhrc.gov/safety/00068.htm.

2. Kittelson & Associates, Inc. *City of Bend Intersection Form Evaluation Framework*. City of Bend, November 2009.

3. Rodegerdts, L., M. Blogg, E. Wemple, E. Myers, M. Kyte, M. Dixon, G. List, A. Flannery, R. Troutbeck, W. Brilon, N. Wu, B. Persaud, C. Lyon, D. Harkey, and D. Carter. *NCHRP Report 572: Roundabouts in the United States*, TRB, National Academy of Sciences, Washington, D.C., 2007. [online] http://www.trb.org/Main/Public/Blurbs/158299.aspx

4. Kittelson & Associates, Inc. and TranSystems Corporation. *Kansas Roundabout Guide: A Supplement to FHWA's Roundabouts: An Informational Guide*. Kansas Department of Transportation, Topeka, Kansas, October 2003. [online] http://www.ksdot.org/burTrafficEng/Roundabouts/Roundabout_Guide/RoundaboutGuide.asp

5. United States Access Board. *Americans with Disabilities Act Accessibility Guidelines.* Federal Register, July 2004 and amended August 2005. [online] http://www.access-board.gov/ada-aba/adaag.cfm

6. United States Access Board. *Draft Guidelines for Accessible Public Rights-of-Way.* U.S. Architectural and Transportation Barriers Compliance Board, Washington, D.C., 2005. [online] http://www.access-board.gov/prowac/draft.htm#206

7. Neumann,T.R. *NCHRP Report 279: Intersection Channelization Design Guide*, TRB, National Research Council, Washington, D.C., 1985.

8. Illuminating Engineering Society (IES). *Design Guide for Roundabout Lighting*. IES DG-19-08. 2008. Available for purchase at http://www.ies.org/store/product/design-guide-for-roundabout-lighting-1037.cfm.

9. Federal Highway Administration (FHWA). *Manual on Uniform Traffic Control Devices*. FHWA, Washington, D.C., December 2009. [online] http://mutcd.fhwa.dot.gov/pdfs/2009/pdf_index.htm

City of Bend

Intersection Form Evaluation Framework

April 2010

Prepared For:
The City of Bend

Prepared By:
Kittelson & Associates, Inc.

Overview

The City of Bend maintains a "roundabouts first" approach to intersection treatments but is flexible in considering other forms should there be the need to evaluate various intersection options. This document provides a framework and criteria for evaluating roundabouts against other intersection forms. The body of this document outlines quantitative and qualitative criteria that can be used to compare intersection forms; the appendix contains a case study that applies the intersection comparison process.

This section describes basic steps to evaluate intersection forms with the intent that completing the basic steps will provide the input needed to conduct the evaluation. The evaluation criteria include:

- Safety Assessment (crash data, known deficiencies, sight distance, etc.)
- Traffic Operations (forecast volumes, performance measures)
- Anticipated Users
- System Context
- Context at Intersection (e.g., ROW impacts, design vehicle)
- Benefit/Cost Ratios

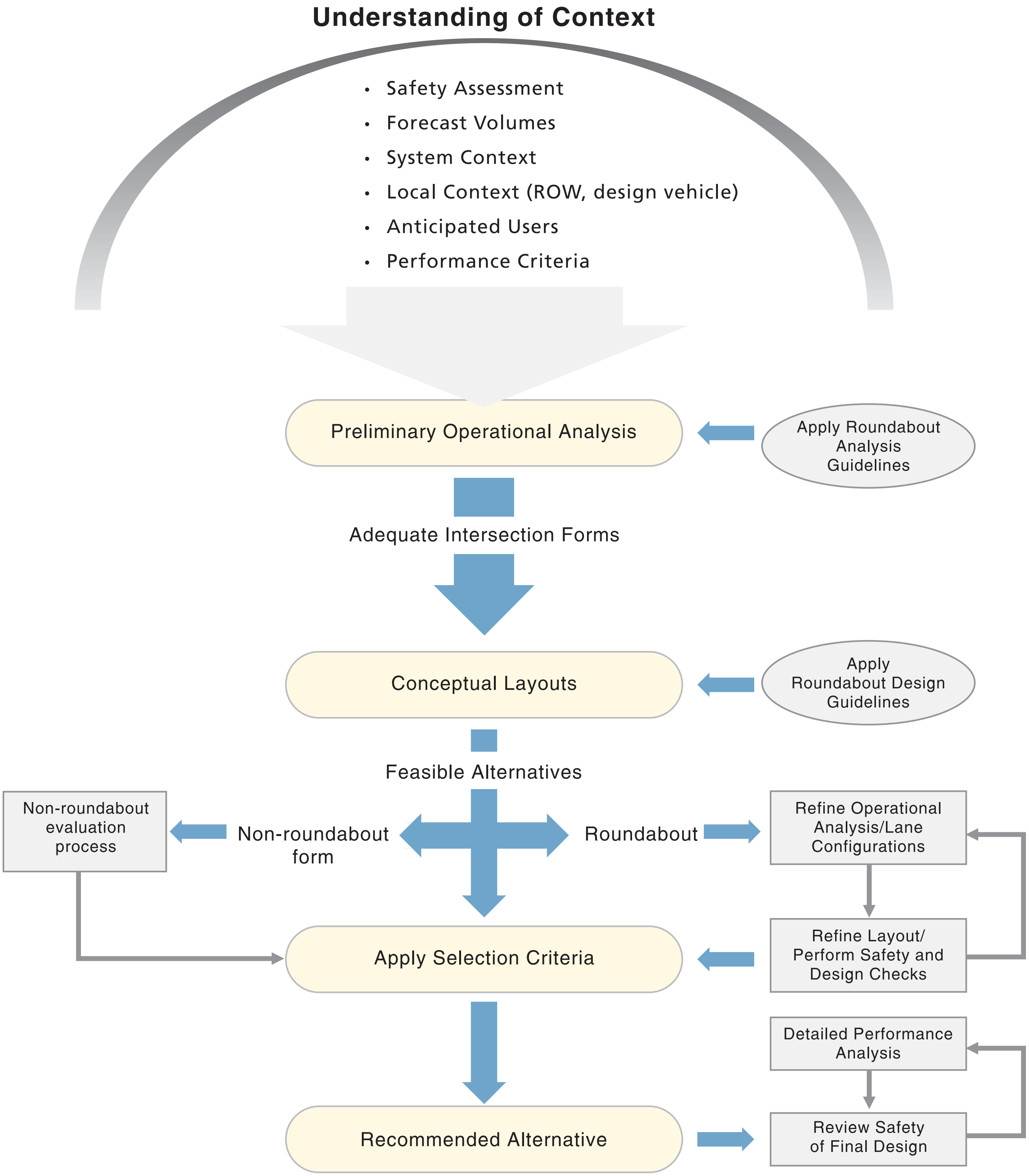
Each intersection form evaluation will be unique in the breadth of the evaluation and the availability of data. To streamline evaluations, criterion has been prioritized based on relative importance. These priorities are designated as Tier 1 and Tier 2. Tier 1 criteria are identified as the most important and should be considered each time an evaluation is conducted. Tier 2 criteria may be considered, if needed, should Tier 1 criteria not be sufficient to provide a clear differentiation between alternatives. If applicable to a project's needs, some criteria may be shifted from one tier to the next. Evaluation criteria should be considered and discussed with city staff at the earliest stages of an intersection evaluation process.

The following information provides a framework for conducting an intersection planning, operations, and design evaluation with a special emphasis on roundabout-specific considerations.

Intersection Evaluation Process

Exhibit 1 provides a process framework for considering intersection treatment forms. Since conventional intersection planning, operations, and design evaluations are well established and documented (and are a relatively common practice for most professionals), this framework emphasizes the special needs of appropriately considering and evaluating roundabout forms. This emphasis is intended to guide transportation professionals in conducting appropriate analyses and conceptually evaluating and developing roundabout concepts that are consistent with City-desired qualities and attributes.

Exhibit 1 Intersection Evaluation Process Framework


Understanding of Context
Safety Assessment
Forecast Volumes
System Context
Local Context (ROW, design vehicle)
Anticipated Users
Performance Criteria
Preliminary Operational Analysis
Apply Roundabout Analysis Guidelines
Adequate Intersection Forms
Conceptual Layouts
Apply Roundabout Design Guidelines
Feasible Alternatives
Non-roundabout evaluation process
Non-roundabout form
Roundabout
Refine Operational Analysis/Lane Configurations
Refine Layout/ Perform Safety and Design Checks
Apply Selection Criteria
Detailed Performance Analysis
Review Safety of Final Design
Recommended Alternative

INTERSECTION CONTEXT

Intersection context includes fundamental considerations such as whether the intersection is part of a new facility or a retrofit situation. New locations provide increased flexibility in locating and designing the intersection forms, while retrofit conditions often exhibit constrained right of way or secondary considerations, such as access to adjacent land uses. Context also includes understanding user types including appropriately serving non-motorized users and design vehicle needs. Design vehicle choices have a significant effect on roundabout dimensions and configurations. If the intersection is a retrofit, the project may be based on improving capacity or addressing a documented safety need. A well documented summary of existing conditions and future demands helps form the basis for evaluating alternative intersection treatments.

PRELIMINARY OPERATIONAL ANALYSIS

A preliminary operational analysis evaluates future traffic needs compared to applicable mobility criteria to screen candidate intersection forms. This preliminary analysis also establishes the intersection lane numbers and arrangements, which defines the basic size of the intersection. Operational analyses should be conducted in accordance with the methodologies outlined in the *City of Bend Roundabout Operational Analysis Guidelines* (Reference 1) for roundabouts and the *Highway Capacity Manual* (Reference 2) for all other intersection forms. Traffic signal warrants as defined in the *Manual on Uniform Traffic Control Devices* (MUTCD) (Reference 3) may be used at this stage to determine whether traffic signals are a viable alternative for further consideration.

CONCEPTUAL LAYOUTS

The lane numbers and arrangements, roadway approach geometry, design vehicle, and safety performance checks influence the intersection conceptual layouts. Roundabout intersection qualities should conform to the guidelines and principles outlined in the FHWA publication, *Roundabouts: An Informational Guide* (Reference 4), in general and specifically reflect design qualities and attributes outlined in the *City of Bend Roundabout Design Consistency Guidelines* (Reference 5). Conceptual layouts should consider fundamental objectives for safety performance and design vehicle types. These early conceptual layouts can be used to begin assessing basic right of way and access management needs.

FEASIBLE ALTERNATIVES

As intersection forms and configurations are evaluated and the associated trade-offs indentified, the promising alternatives can be advanced. As these alternatives are advanced, the roundabout concept designs should be refined and evaluated based on design vehicle needs, fastest paths and, for multilane configurations, natural path evaluations to consider path alignment. Refining concept designs is an iterative process to optimize the intersection safety performance balanced with the site specific constraints of that location. Should the design be modified in such a way as to change the lane numbers or arrangements, additional operational analyses should be performed to assess anticipated operational performance.

SELECTION CRITERIA AND RECOMMENDED ALTERNATIVE

If conventional and roundabout forms are being compared, the tiered selection criteria should be applied. Tier 1 and 2 criteria are outlined in Tables 1 and 2, respectively. To provide a reasonable comparison, each intersection form should be developed at a consistent and comparable level of detail.

Tier 1 criteria represent those considerations that typically are the highest priority. Capacity, safety, footprint, and secondary impacts (access management or driveway closures), often guide project decisions. Tier 2 criteria are also important considerations and represent an increased level of detail (such as predicting crashes or defining costs) or subject area that may not vary greatly enough to be a Tier 1 consideration. For example, pedestrian crossing distances may not vary significantly between alternative intersection forms on a lower order roadway. The City, with an understanding of project context has the opportunity to adjust the criteria and the tiered priorities in the earliest stages of a project. For example, if pedestrian safety is a project driver or if high volumes necessitate a relatively large intersection (roundabout or signalized), it may be appropriate at the onset to make pedestrian crossing distances a Tier 1 consideration.

Appendix A provides an example application of the intersection form selection criteria using a case study for the Murphy Road/Parrell Road intersection.

Table 1 Tier 1 Intersection Form Selection Criteria

Category	Criteria	Resources
Safety		
Motor Vehicle Safety	Conflict points (exposure) Severity (speed)	• *Roundabouts: An Informational Guide (Reference 4)* o Chapter 2, Exhibit 2-3
Non-Motorized Vehicle Safety	Conflict points (exposure) Severity (speed)	• *Roundabouts: An Informational Guide (Reference 4)* o Chapter 2, Exhibit 2-2
Traffic Operations		
Peak-Hour Traffic Operations	Volume-to-capacity ratio Average delay LOS Queue lengths	• Roundabouts: *Bend Roundabout Operational Analysis Guidelines (Reference 1)* • Non-roundabout intersection forms*: Highway Capacity Manual (Reference 2)*
Anticipated Users		
Design Vehicle	Appropriate heavy vehicle Buses Emergency vehicles	• *Bend Roundabout Design Consistency Guidelines (Reference 5)*
Special User Needs	School children Elderly Visually impaired ADA compliance	• *Bend Roundabout Design Consistency Guidelines (Reference 5)*
System Context		
System Effects	Adjacent traffic control Railroad crossing	• *Highway Capacity Manual (Reference 2)* o Upstream impacts and vehicle arrival patterns
Environmental Impact	Land use context	• Review of existing adjacent land use and planned land use
Emergency Response	Response time/control delay	• Roundabouts: *Bend Roundabout Operational Analysis Guidelines (Reference 1)* • Non-roundabout intersection forms*: Highway Capacity Manual (Reference 2)*
Context at Intersection		
Intersection Footprint	Intersection proper (physical & operational influence area) Roadway approach geometry	• *Roundabouts: An Informational Guide (Reference 4)* o *Chapter 3, Section 3.6* • Review of conceptual geometric design
Intersection Influence Area	Driveway closures or impacts	• Review of conceptual geometric design

Table 2 Tier 2 Intersection Form Selection Criteria

Category	Criteria	Resources
Safety		
Motor Vehicle Safety	Crash Prediction	- *AASHTO Highway Safety Manual (Reference 6)*
Traffic Operations		
Peak Hour Traffic Operations	Sensitivity to changes in volumes/ travel patterns	- Roundabouts: *Bend Roundabout Operational Analysis Guidelines (Reference 1)* - Non-roundabout intersection forms: *Highway Capacity Manual (Reference 2)*
24-Hour Traffic Operations	Average Delay	
Anticipated Users		
Pedestrians	Crossing distances	- *Bend Roundabout Design Consistency Guidelines (Reference 5)*
Bicyclists	Adjacent bike facilities Intersection specific considerations	
System Context		
Environmental Impact	Estimated emissions output	
Access Management	Facilitates access management Median and U-turn opportunities Driveway connections	- Review of conceptual geometric design
Emergency Response	Evaluating likely emergency response routes	
Context at Intersection		
Environmental Impact	Impervious surface area Aesthetics	- Review of conceptual geometric design
Intersection Influence Area	Approach and segment cross-section	
Benefit/Cost Ratio		
Benefits	Crash reduction Reduced fuel consumption Reduced delay (15-min delay, 24-hour delay)	- *AASHTO Highway Safety Manual (Reference 6)* - Roundabouts: *Bend Roundabout Operational Analysis Guidelines (Reference 1)* - Non-roundabout intersection forms: *Highway Capacity Manual (Reference 2)*
Costs	Design/Engineering Costs Construction costs including ROW acquisition Operations/maintenance costs (includes energy costs for signals)	

References

1. Kittelson & Associates, Inc. *City of Bend Roundabout Operational Analysis Guidelines*. City of Bend, November 2009.

2. Transportation Research Board. *Highway Capacity Manual*. TRB, National Research Council, Washington, DC, 2000.

3. Federal Highway Administration (FHWA). *Manual on Uniform Traffic Control Devices*. FHWA, Washington, D.C., December 2009. [online] http://mutcd.fhwa.dot.gov/pdfs/2009/pdf_index.htm

4. Robinson, B. W., L. Rodegerdts, W. Scarbrough, W. Kittelson, R. Troutbeck, W. Brilon, L. Bondzio, K. Courage, M. Kyte, J. Mason, A. Flannery, E. Myers, J. Bunker, and G. Jacquemart. *Roundabouts: An Informational Guide*. Report FHWA-RD-00-067. FHWA, U.S. Department of Transportation, June 2000. [online] http://www.tfhrc.gov/safety/00068.htm.

5. Kittelson & Associates, Inc. *City of Bend Roundabout Design Consistency Guidelines*. City of Bend, November 2009.

6. American Association of State Highway and Transportation Officials. *Draft Highway Safety Manual*. AASHTO, 2009

Appendix A

CASE STUDY: MURPHY ROAD AND PARRELL ROAD

Intersection Context

Murphy Road is a key east-west corridor in southeast Bend. Parrell Road is a north-south roadway that parallels 3rd Street and provides a secondary north-south roadway while serving local access. Much of the access is residential, but urban renewal plans in the southern areas of Bend near the Parkway will likely include mixed uses. Presently the intersection is a two-way stop controlled intersection with priority to Murphy Road. The current posted speed on Murphy Road is 35 mph and 30 mph on Parrell Road. The land around the intersection is developed with relatively closely-spaced driveways. In the future, Murphy Road will be extended to the east and west. West of Parrell Road, Murphy Road will be realigned and a new crossing over the Parkway will be constructed. These enhancements further solidify the importance of Murphy Road as a key long-range network linkage and, as a result, traffic is anticipated to grow at this location.

There are presently a limited number of pedestrians, but pedestrian volumes are likely to increase as mixed-use land develops. Parrell Road may serve as access to properties that front 3rd Street, and therefore, the intersection will likely serve WB-50 trucks.

PM peak future roadway volumes were estimated by the Oregon Department of Transportation through the Bend MPO EMME/2 travel demand model for the future 2030 scenario assuming improvements to the intersection. Table A-1 provides a summary of 2030 volumes at the Murphy Road/Parrell Road intersection.

Table A-1 2030 Weekday PM Peak Forecast Volume at Murphy Road/Parrell Road

Movement	North Leg	East Leg	South Leg	West Leg
Left	45	65	50	15
Through	35	340	25	540
Right	35	45	70	60

Preliminary Operational Analysis

Traffic operational analyses were conducted for the intersection based on a 2030 future traffic volume forecast for a roundabout and a signalized intersection form. The results of the roundabout and signal analyses are provided in Tables A-2 and A-3, respectively. To provide an equivalent comparison between the signalized and roundabout alternatives, the weighted average of the roundabout approach control delay was computed, using Equation 1.

$$D_{\text{intersection}} = \frac{\sum_i D_i V_i}{\sum_i V_i} \qquad \textbf{(Equation 1)}$$

where,

$D_{intersection}$ = *intersection control delay, s/veh*

D_i = *control delay on approach i, s/veh*

V_i = *volume on approach i, veh/hr*

Table A-2 provides a summary of future intersection lane configurations and operational analysis results for the signalized alternative.

Table A-2 Signalized Intersection Analysis at Murphy Road/Parrell Road

Geometry Information	**North Leg**	**East Leg**		**South Leg**	**West Leg**	
Entry Lanes	L/T/R	L	T/R	L/T/R	L	T/R
Performance Measure	**2030 Operations**					
Volume/Capacity	0.56					
Intersection Control Delay (sec)	12.7					
Intersection LOS	B					
95% Queue Length (ft)	50	50	125	50	25	225

Table A-3 provides a summary of future intersection lane configurations and operational analysis results for the roundabout alternative.

Table A-3 Roundabout Intersection Analysis at Murphy Road/Parrell Road

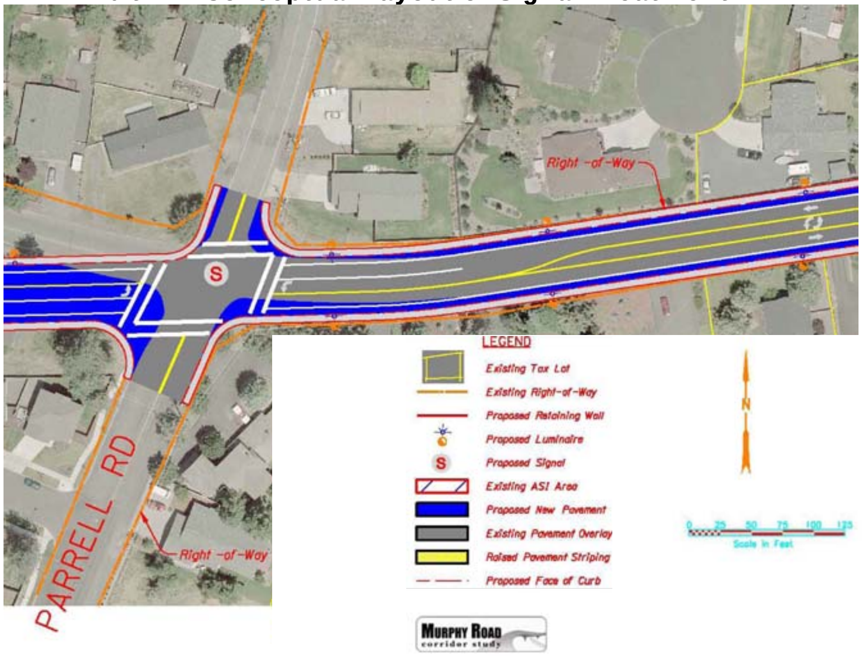
Geometry Information	**North Leg**	**East Leg**	**South Leg**	**West Leg**
Number of Entry/ Exit Lanes	1/1	1/1	1/1	1/1
Right Turn By-Pass	N	N	N	N
Circulating Lanes	1	1	1	1
Performance Measure	**2030 Operations**			
Approach Volume/Capacity	0.14	0.41	0.21	0.58
Critical Lane Average Delay (sec)	5.5	7.0	6.9	10.3
Intersection Control Delay (sec)	8.4			
Intersection LOS	A			
95% Queue Length (ft)	25	50	25	100

As shown in Tables A-2 and A-3, the signalized and roundabout alternatives are expected to provide acceptable operations in 2030. The roundabout results in similar capacity and delay while maintaining the east and west approaches as a single lane. The roundabout is expected to reduce queues on all approaches compared to the signal.

Conceptual Layouts

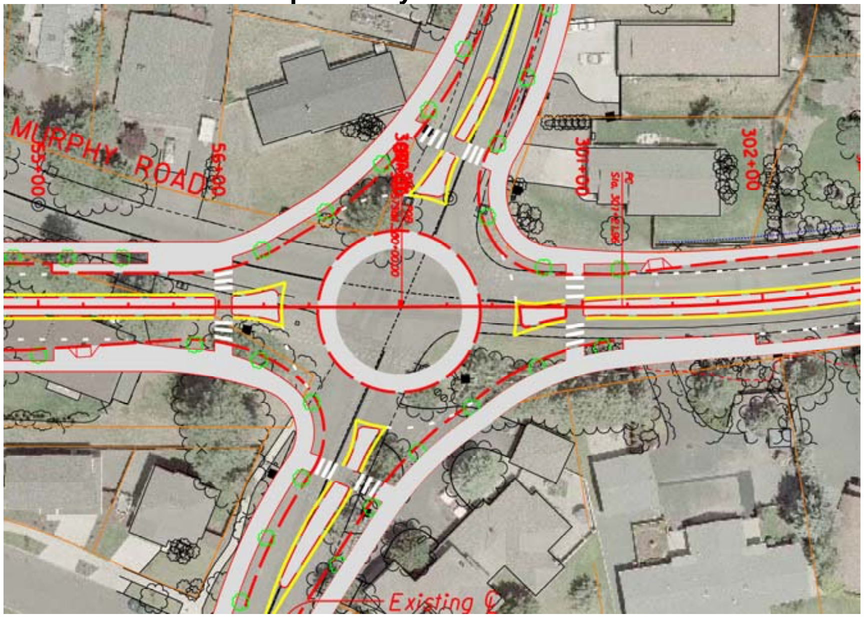
Exhibit A-1 shows the conceptual layout of the signalized intersection. Exhibit A-2 shows the layout of the roundabout form. The concepts were configured to serve WB-50 design vehicles and these early conceptual layouts were used to assess the planning level right-of-way impacts and the various access management needs.

Exhibit A-1 Conceptual Layout of Signal Treatment


Right -of-Way
S
PARRELL RD
Right -of-Way
LEGEND
Existing Tax Lot
Existing Right-of-Way
Proposed Retaining Wall
Proposed Luminaire
S Proposed Signal
Existing ASI Area
Proposed New Pavement
Existing Pavement Overlay
Raised Pavement Striping
Proposed Face of Curb
N
0 25 50 75 100 125
Scale in Feet
MURPHY ROAD corridor study

Concept drawing by CH2M HILL

Exhibit A-2 Conceptual Layout of Roundabout Treatment


MURPHY ROAD
55+00
56+00
301+00
302+00
Existing ℄

Concept drawing by CH2M HILL

Application of Selection Criteria

The Tier 1 Criteria presented in Table 1 were applied to evaluate the two intersection treatments. A summary of the criteria and evaluation comments for the Murphy Road/Parrell Road intersection evaluation is presented in Table A-4.

Table A-4 Summary of Tier 1 Criteria Evaluation

Category	Criteria	Evaluation Comments	Conclusion
Safety			
Motor Vehicle Safety	Conflict points (exposure) Severity (speed)	Signal:32 conflict points Roundabout: 8 conflict points Signal:85th percentile speed on Murphy Road = 35 mph Roundabout: Geometry on entry reduces speeds to 15-20 mph Highest crash rates along Murphy Road corridor occurred at Parrell Road	**Roundabout** reduces conflicts and severity
Non-Motorized Vehicle Safety	Conflict points (exposure) Severity (speed)	Signal:18 Roundabout: 8 conflict points Signal:85th percentile speed on Murphy Road = 35 mph Roundabout: Geometry on entry reduces speeds to 15-20 mph	**Roundabout** reduces conflicts and severity
Traffic Operations			
Peak-Hour Traffic Operations	Volume-to-capacity ratio Average delay LOS Queue lengths	See discussion above and results presented in Tables A-2 and A-3	**Roundabout** is forecast to operate with shorter queue lengths
Anticipated Users			
Design Vehicle	Appropriate heavy vehicle Buses Emergency vehicles	Both were designed appropriately to accommodate anticipated users	Neutral
Special User Needs	School children Elderly Visually impaired ADA compliance	Roundabout simplifies roadway crossings with two-stage crossing.	**Roundabout** reduces number of lanes required to cross and provides for two-stage crossing.
System Context			
System Effects	Adjacent traffic control Railroad crossing	Roundabouts are being considered along entire Murphy Road Corridor. Signal to west at 3rd Street may send platoons of vehicles to roundabout. No railroad crossing conflicts in vicinity	Neutral

Category	Criteria	Evaluation Comments	Conclusion
Environmental Impact	Land use context	Land along Murphy Road is primarily residential. Roundabouts can serve as a gateway feature to neighborhoods. Roundabouts will result in less stop-and-go traffic and, thereby, reduced noise.	**Roundabout** fits within the context of a residential environment
Emergency Response	Response time/control delay	Neither are expected to cause significant increase in response time as delay is relatively low on all approaches	Neutral
Context at Intersection			
Intersection Footprint	Intersection proper (physical & operational influence area) Roadway approach geometry	Roundabout requires larger footprint to accommodate inscribed circle diameter, which impacts properties in SW and NW quadrant more so than signal alternative. Roundabout and signal require similar area on approach due to need for splitter island with roundabout and left-turn for signal	**Signal** has smaller footprint for the site-specific conditions given.
Intersection Influence Area	Driveway closures or impacts	Both will require right-in-right-out at driveways within 200 feet. Roundabout includes raised splitter islands to enforce movement restriction and provides for u-turns for movements that are restricted.	**Roundabout** facilitates u-turn for restricted driveways

Recommended Alternative

A roundabout is recommended as the preferred intersection control at the Murphy Road/Parrell Road intersection. As shown in Table A-4, a roundabout will satisfy Tier 1 criteria better than a traffic signal alternative. A roundabout would reduce the severity of crashes for vehicular and non-vehicular users. Operationally, the two alternatives are forecast to operate at similar levels of capacity and delay, but the roundabout alternative is forecast to result in shorter queues. During off-peak periods, the roundabout will reduce side-street delay as drivers will not be required to wait to receive a green indication. A signalized intersection has a smaller footprint and may reduce impacts on adjacent properties, but a roundabout is expected to fit within the residential surroundings more so than a signal.