CITY OF REDMOND
Community Development Department

411 SW 9th Street
Redmond, OR 97756
541-923-7724
www.redmondoregon.gov

REDMOND URBAN AREA PLANNING COMMISSION

411 SW 9th Street-COUNCIL CHAMBERS Redmond, OR 97756
Wednesday, December 3, 2025 5:30 PM

Oral comments can be provided in-person or virtually. For those who plan to provide oral comments virtually during the meeting, pre-register at planredmond@redmondoregon.gov (must pre-register before 3:00 PM on December 3, 2025)

Stream the meeting live at: www.redmondoregon.gov/PlanningCommissionLive

Agenda

RUAPC Members

Tobias Colvin, Chair

Norman Schultz, Vice-Chair

Heather DeWolf

Mercedes Cook-Bostick

Michael Rogers

Tom Kuhn

Ben Schimmoller

Ex-Officio Vacant

I. CALL TO ORDER / INTRODUCTIONS

II. CITIZEN COMMENTS FOR ITEMS NOT ON THE AGENDA

III. PUBLIC HEARING
a. Horizon Pointe: Planned Unit Development, Tentative Subdivision, Conditional Use (File Nos.: 711-24-000216-PUD, 711-25-000086-SUB, 711-25-000087-CU)
-- Continued

IV. NEXT MEETING – December 10, 2025

V. COMMISSIONER COMMENTS

VI. ADJOURN

Please note that these documents are also available on the City's website www.redmondoregon.gov; click on City Government, hover on Commissions and Committees, click on Urban Area Planning Commission. You may also request a copy from City Recorders Office 541-923-7751 or email Kelly.morse@redmondoregon.gov

The City of Redmond encourages all citizens to participate in its programs and activities. This meeting location is accessible to people with disabilities. Requests for accommodation may include sign language interpreter service, assistive listening devices, materials in an alternate format or any other accommodation. If any accommodations are needed, please contact the ADA Coordinator at 541-504-3036 or access@redmondoregon.gov. Requests should be made as soon as possible, but at least 3 business days prior to the scheduled meeting. The City of Redmond does not discriminate on the basis of disability status in the admission or access to, or treatment, or employment in, its programs or activities.

HORIZON POINTE PLANNED UNIT DEVELOPMENT, TENTATIVE SUBDIVISION, AND CONDITIONAL USE

HEARING DATE:	November 12, 2025, (continued to December 3, 2025) at 5:30 PM in Redmond City Hall Council Chambers and via digital conference (GoTo Meeting)
HEARINGS BODY:	Redmond Urban Area Planning Commission
FILE NUMBERS:	711-24-000216-PUD, 711-25-000086-SUB, 711-25-000087-CU
FILE NAME:	Horizon Pointe
REQUEST:	Approval of a Planned Unit Development, 321-lot Tentative Subdivision, and Conditional Use
LOCATION:	2577 SW Helmholtz Way (taxlot: 1513190001101), 2897 SW Helmholtz Way (taxlot: 1513190001100), and 2571 SW Helmholtz (taxlot: 1513190001102) in Redmond, OR 97756
APPLICANT:	Redmond Land Group, LLC
PROPERTY OWNER:	Ronald Nelson, Richard & Meghan Holmes, Nathan & Jessica Hadfield
REVIEWING STAFF:	Megan Peninger, Associate Planner Kyle Roberts, AICP, Planning Director
RECOMMENDATION:	Deny

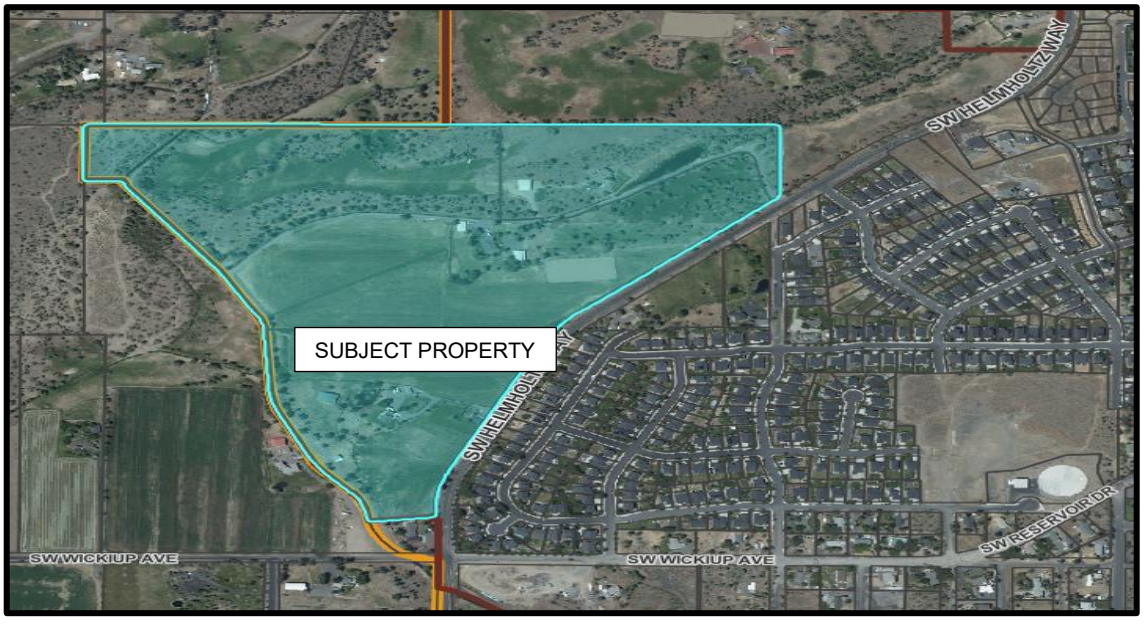


Figure 1 - Vicinity Map

I. BACKGROUND

Site Description:

The project site is comprised of three parcels totaling roughly 78.31 acres and is located in southwest Redmond. More specifically, the site abuts SW Helmholtz Way to the east/northeast, Little Texas Planned Unit Development to the north, and the Urban Growth Boundary and Urban Reserve Area to the west and northwest. The site has situs addresses of 2577 SW Helmholtz Way (Parcel 2, taxlot: 1513190001101), 2897 SW Helmholtz Way (Parcel 3, taxlot: 1513190001100), and 2571 SW Helmholtz Way (Parcel 1, taxlot: 1513190001102) and includes three zones: Limited Residential (R-3), General Residential (R-4), and High-density Residential (R-5). The site has three existing single-family dwellings with several outbuildings and has Central Oregon Irrigation District (COID) laterals running along the western boundary and east-west bisecting the site.

The current configuration of Parcels 1 and 2 are the result of a lot line adjustment, file number 12-02 (Deschutes County Official Record CS18402). The current configuration of Parcel 3 was created by Partition Plat No. 1991-23, file number MP-90-31. As a separate submittal, the applicant has submitted a lot line adjustment (File Number 711-25-000248-LLA) to move the common property line of Parcel 2 and Parcel 3 south.

Land Use History:

The subject properties were annexed in 2008 via Resolution No. 2008-41. At that time, the subject properties were rezoned to R-3 Limited Residential, R-4 General Residential, and R-5 High Density Residential designations, with the R-3 zone—representing the lowest residential density—strategically located adjacent to the Urban Reserve Area to ensure a compatible land use transition.

Proposal:

The applicant, Redmond Land Group, LLC, submitted applications for: 1) planned unit development; 2) tentative subdivision; and 3) conditional use. On approximately 67.32 acres, the applicant is proposing to create a 321-lot planned unit development residential subdivision. In keeping with the Comprehensive Plan and Zone Map's R-3, R-4, and R-5 zoning designations, the applicant will, in seven phases, construct 245 detached single-family dwellings and 76 townhouses, and create roughly 6.67 acres of open space.[1]

Adjacent Zoning & Land Uses:

	Zoning	Land Use
Northwest	Exclusive Farm Use – Tumalo/Redmond/Bend Subzone (EFUTRB)	Rural residential on large lots
Northeast	Limited Residential R-3, General Residential R-4, High Density Residential R-5	Future suburban residential subdivision development
East	Limited Residential R-2	Suburban residential subdivision development
South	Urban Holding UH-10	Single-family dwelling
West	Exclusive Farm Use – Tumalo/Redmond/Bend Subzone (EFUTRB)	Rural residential on a large lot Farmland

[1] Open space is defined as land retained as undeveloped land for use as passive or active recreational area; land that is developed with park, landscaping, or other non-structural amenities (Redmond Code Section 8.020: Definitions).

Comments:

Several public comments were submitted to the Community Development Department. These comments are included in Attachment D.

Attachments:

Attachment A – Project Plans, updated November 18, 2025
Attachment B – Applicant Burden of Proof, updated November 18, 2025
Attachment C – City Department and Related Agency Comments
Attachment D – Letters Received from the Public
Attachment E – Transportation System Analysis, approved July 29, 2024 (revised April 28, 2025)

Application Timeline:

The following items are included herein by reference in this land use decision and are located in the record for this matter and are on-file with the Community Development Department, Planning Division:

- Planned Unit Development, Tentative Subdivision, and Conditional Use applications and materials submitted by the applicant on April 14, 2025
- Application deemed incomplete for review on May 9, 2025
- Application deemed complete for review on September 12, 2025
- City department and related agency request for comments routed on September 17, 2025
- Adjacent property owner notices of public hearing mailed on October 22, 2025
- Public Hearing Notice published in the *Redmond Spokesman* on October 30, 2025
- Public hearing with Planning Commission continued on November 12, 2025, to December 3, 2025, as requested by the applicant
- Final action 120-day deadline (ORS 227.178) is January 10, 2026

Applicable Criteria:

The following are the applicable sections from the Oregon Revised Statues, Oregon Administrative Rules, the City of Redmond Urban Area Comprehensive Plan, and the Redmond Development Code:

- City of Redmond Comprehensive Plan 2040
- City of Redmond Framework Plan
- City of Redmond Transportation System Plan
- City of Redmond Public Facility Master Plans
- Oregon Revised Statutes (ORS), Chapters 92, 197, and 227
- City of Redmond Development Code (last amended by Ord. 2024-14)
  Article I – Zoning Standards
    - Section 8.065: Establishment of Zones and Districts
    - Section 8.080: Zone Boundaries
    - Section 8.135: Table A, Residential Zones, Uses Permitted
    - Section 8.140: Table B, Minimum Standards
    - Section 8.275: Planned Unit Development (PUD)
    - Section 8.385: Neighborhood Meeting
    - Section 8.600: Authorization to Grant or Deny Conditional Uses
    - Section 8.602: Neighborhood Meeting
    - Section 8.605: General Conditions

  Article II – Land Use Procedures
  Article III – Land Division Standards
    - Section 8.2000: Title
    - Section 8.2005: Purpose

- Section 8.2010: Interpretation
- Section 8.2100: Procedure
- Section 8.2200: Pre-Application Meeting
- Section 8.2202: Neighborhood Meeting
- Section 8.2215: Informational Requirements
- Section 8.2220: Phased Development Plan
- Section 8.2225: Approval of Phased Development Plan
- Section 8.2230: Development Following Approval
- Section 8.2235: Approval Criteria for Tentative Subdivision Plans
- Section 8.2240: Future Subdivision
- Section 8.2700: Compliance Required
- Section 8.2705: Blocks, Lots and Parcels
- Section 8.2710: Streets
- Section 8.2715: Fundamental Design Standards
- Section 8.2720: Grading of Building Sites
- Section 8.2800: Improvement Procedures
- Section 8.2815: Transportation System Analysis
- Section 8.2820: Access Management Standards
- Section 8.2825: Street Dedications

II. FINDINGS & CONCLUSIONS

Findings:
Chapter 8 of the Redmond Code (RC), known as the Redmond Development Code, used to evaluate these applications is the code in effect on the day the applications were submitted (April 14, 2025, which had been last amended by Ordinance 2024-14).[2] Article I – Zoning Standards: Sections 8.065, 8.080, 8.135, 8.140, 8.275, 8.385, 8.600-8.605; and Article III – Land Division Standards: Sections 8.2000-8.2010, 8.2100, 8.2200, 8.2202, 8.2215, 8.2220-8.2240, 8.2700-8.2720, 8.2800, and 8.2815-8.2825 set forth the procedure and standards for approval. Staff findings for all applicable standards are presented below.

ARTICLE I – ZONING STANDARDS > INTRODUCTORY PROVISIONS

RC Sections 8.065 and 8.080

Sec. 8.065. Establishment of Zones and Districts.

[…]

R-3 Limited Residential Zone. To provide medium density residential neighborhoods with a mix of single-family detached residences, middle housing, and a mix of other housing types.

FINDING: The applicant is proposing a residential planned unit development subdivision that includes approximately 47 acres zoned R-3. The proposal includes single-family detached dwelling lots and townhouse lots.

R-4 General Residential Zone. To provide medium density residential neighborhoods with a mix of single-family detached residences, middle housing, and a mix of other housing types including multi-family residential development. Limited commercial uses such as offices are also conditionally

[2] Per ORS 227.178(3)(a), an application must be reviewed using the adopted standards and criteria that were applicable at the time the application was submitted.

permitted where compatible with surrounding development.

FINDING: The applicant is proposing a residential planned unit development subdivision that includes approximately 17.37 acres zoned R-4. The proposal includes single-family detached dwelling lots and townhouse lots.

R-5 High Density Residential Zone. To provide high density residential neighborhoods with an emphasis on multi-family development, middle housing, and smaller lot single family developments. Limited commercial uses such as offices are also conditionally permitted where compatible with surrounding development.

FINDING: The applicant is proposing a residential planned unit development subdivision that includes approximately 2.95 acres of R-5 zoned land. The proposal includes single-family detached dwelling lots and townhouse lots.

Sec. 8.080. Zone Boundaries.

Unless otherwise specified, Zone Boundaries are section lines, subdivision lines, lot lines, center lines of streets, alleys, canal, or rights-of-way, water courses, ridges or rimrocks, other readily recognizable or identifiable natural features, or such lines extended. Whenever any uncertainty exists as to the boundary of a zone as shown on the Zoning Map or amendment thereto, the following regulations shall control:

1. Where a boundary line is indicated as following a street, alley, canal, or right-of-way, it shall be construed as following the center line of such right-of-way.
2. Where a boundary line follows or approximately coincides with a section, lot, or property ownership line, it shall be construed as following such line.
3. When a lot is divided by a zone boundary and the property owner disputes the location of the boundary, the owner may file a declaratory ruling to determine the exact location of the zone boundary. In this case, the determination shall be made by the Hearings Body, subject to appeal by the City Council.
4. Where a public street, alley, canal, or railroad right-of-way is officially vacated, the zoning regulations applicable to abutting property on each side of the center line of such right-of-way is officially vacated, the zoning regulations applicable to abutting property on each side of the center line of such right-of-way on each respective side thereof. If the right-of-way is vacated in total to one property owner, the zoning of that abutting property shall apply to the total vacated property.

FINDING: As mentioned previously, the project site is comprised of three different zoning districts. As shown on page P2.0 of the applicant's plan set, several proposed lots would be split-zoned if the zoning boundaries were to be implemented as established by the 2040 Redmond Urban Area Comprehensive Plan and Zone Map. However, the applicant's plan set proposes nominal shifting of zone boundaries in order to avoid creating split-zoned lots. Because the applicant's proposal is a planned unit development, staff finds that the proposed minor adjustment to the zone boundaries is consistent with the purposes of a PUD and therefore will comply with this section.

Sec. 8.135. Table A, Residential Zones, Uses Permitted.

The following uses are allowed outright or conditionally in each of the Residential zones as follows:

"O" means Permitted Outright "C" means Permitted Conditionally "N" means Not Allowed

Residential Uses:	**R-1**	**R-2**	**R-3**	**R-4**	**R-5**	**RESTRICTIONS AND REQUIREMENTS**
Accessory Building:						
Detached sheds, shops, and garages	O	O	O	O	O	Must be located within the property and not in the yard setback areas. Moveable shipping containers, or similar, are not allowed.
Guest House	O	O	O	O	O	No kitchen; uses main houses' sewer & water
Accessory Dwelling Unit / Accessory Suite	O	O	O	O	O	Uses main houses' sewer & water or individual City Services; may have kitchen
Accessory Use	O	O	O	O	O	Includes Home Occupations
Apartments						See Multi-Family Complex / Dwelling
Bed and Breakfast	C	C	C	C	C	
Boarding or Rooming House	N	N	C	O	O	
Duplex, Triplex, Quadplex, Townhouse, Cottage Cluster	O	O	O	O	O	
Manufactured Home	O	O	O	O	O	See Single Family Detached Dwelling
Manufactured Home Park	N	N	N	O	O	See Section 8.375
Manufactured Home Subdivision	N	N	O	O	O	Subject to compliance w/ applicable ORS
Multi Family Complex (five + units)	C	C	C	O	O	
Public-Owned Affordable Housing Developments	O	O	O	O	O	See Section 8.145
Nursing, Convalescent, and Assisted Living Facility	N	N	C	C	C	More than 15 people
Planned Unit Development	C	C	C	C	C	
Residential Care Facility	N	N	C	C	O	Defined in and regulated by ORS
Residential Care Home	O	O	O	O	O	Defined in and regulated by ORS
Single Family Detached Dwelling	O	O	O	O	O	
Single Room Occupancy Development	O	O	O	O	O	
Non Residential Uses:	**R-1**	**R-2**	**R-3**	**R-4**	**R-5**	**RESTRICTIONS AND REQUIREMENTS**
Child Care Facility:						
Child Care Center	C	C	C	C	C	

Child Care Home	O	O	O	O	O	
Church, Religious Institution	C	C	C	C	C	
Community Center (private)	C	C	C	C	C	
Community Pool (private)	C	C	C	C	C	
Emergency Shelter	O	O	O	O	O	Reviewed under ORS 197.782. Emergency shelters for natural disaster response are not subject to review.
Farm Use, Farming	O	O	O	O	O	
Mini Storage	N	N	N	N	N	
Mobile Food Pod	N	N	N	N	N	
Mobile Food Unit	N	N	N	N	N	
Mobile Food Vendor on private property	O	O	O	O	O	Permitted through Business Licensing provisions in City Code, Section 7.005 et seq. Can only operate between 8 AM and 9 PM for no more than two consecutive days within a 90-day period and must be located on real property in association with an event.
Mobile Food Vendor on public property	O	O	O	O	O	Permitted through Special Events provisions in City Code, Section 7.350 et seq. or Parks Reservation Permit.
Multi-Use Trail	O	O	O	O	O	
Park	O	O	O	O	O	
Livestock	O	O	O	O	O	Subject to livestock provisions, Section 8.365
Office	N	N	C	C	C	Conditional in conjunction with a master plan or PUD
Retail	N	N	C	C	C	Conditional in conjunction with a master plan or PUD
Residential Conversion of Existing Commercial Structure	O	O	O	O	O	See Section 8.144
School (private)	C	C	C	C	C	
Supportive Shelter	O	O	O	O	O	See Section 8.370, Supportive Shelter Standards.
Tennis Court (private)	O	O	O	O	O	Non-commercial use only
Public Facility or Emergency Management Services	C	C	C	C	C	
City Owned Utility Facility	O	O	O	O	O	
Private Utility Facilities	C	C	C	C	C	
All "R" zones are subject to density transfer provisions. See Section 8.020, "Definitions," Density Transfer, and 8.367, "OSPR / 'R' Zone Density Transfer Provision						

FINDING: The applicant is proposing a residential planned unit development subdivision comprised of R-3, R-4, and R-5 zoning and includes 245 single-family dwelling lots and 76 townhouse lots. These uses are outright permitted in the R-3, R-4, and R-5 zones. This standard is met.

Sec. 8.140. Table B, Minimum Standards.

The following minimum standards apply in each of the Residential zones:

Standard:	R-1	R-2	R-3, R-3A	R-4	R-5
Minimum Lot size - Square Feet					
Single Family, Duplex, Triplex, Single Room Occupancy Development	9,000	9,000	7,500	5,500	5,500
Quadplex, Cottage Clusters	9,000	9,000	7,500	7,000	7,000
Townhouse	1,500	1,500	1,500	1,500	1,500
Multi-family Complex: 5+ units	No Minimum Lot Size Must Meet Density Standards				
Density - Units/Net Acres					
Minimum Density: All	4	4	5	5	8
Maximum Density: Single Family, Single Room Occupancy Development	5	5	5.8	8	8
Maximum Density: Duplex, Triplex, Quadplex, Cottage Cluster	No Maximum Density Must Meet Minimum Lot Size				
Maximum Density: Townhouses	20	20	23.2	25	25
Maximum Density: Multi-family Complex 5+ units	N/A	N/A	N/A	14.5	17.4
Standard:	**R-1**	**R-2**	**R-3, R-3A**	**R-4**	**R-5**
Planned Unit Developments (PUDs) densities in Section 8.275.					
Minimum Setback Distance - Feet					
Front Façade, excluding garage	10	10	10	10	10
Interior Side	5/10	5/10	5	5	5
Interior side yards must be a minimum of 5 feet on one side and 10 feet on the other side for single family, duplex, triplex, and quadplex residences. Where alley access is provided, both interior side yards may be reduced to 5 feet. Exceptions to the 10-foot setback are allowed (1) when the residential lot was created prior to the adoption of this standard (November 9, 2006); (2) on cul-de-sac lots; or (3) on flag lots.					
Street Side	10	10	10	10	10
Rear	20	20	20	15	5
Attached Garage, access from alley or street	20	20	20	20	20
Setbacks:					
ADUs: Specified in Section 8.325					
Detached Accessory Structures: Specified in Section 8.323					
Cottage Clusters: Specified in Section 8.143					
Multi-family Complexes: Specified in Section 8.3035(4.E. Table A)					
Townhouses: Specified in Section 8.142					
Maximum Building Height - Feet					
Single Family, Plexes, ADU	32	32	32	45	45
Cottage Cluster	25	25	25	25	25
Townhouse	35	35	35	45	45
Minimum Street Frontage - Feet					
Standard Street	50	50	50	50	40

Cul-de-sac	30	30	30	30	30
Flag Lot	20	20	20	20	20
Townhouse	20	20	20	20	20

FINDING: This section presents minimum dimensional and siting specification standards for residential zoning districts. As the proposed project is a Planned Unit Development (PUD), the applicant is requesting exception from four standards from this section.

Specifically, the applicant is requesting exceptions from the:

- minimum lot size standard for 149 of the 245 single-family lots
- maximum density standard for single-family in the R-3 zone
- rear setback for proposed Lot 247
- minimum street frontage standards for four of the 76 townhouse lots and 60 of the 245 single-family lots

Minimum lot size: The applicant is proposing a mix of single-family dwelling lots and townhouse lots in the R-3, R-4, and R-5 zones.

The minimum lot size information is represented in the table below. The applicant is requesting the exception as part of the PUD application, which is addressed in Section 8.275 in this staff report.

Zone	Number of single-family lots requesting exception	Single-family minimum lot size standard (ft^2)	Mean average lot size of lots requesting exception (ft^2)	Deviation from the standard
R-3	112	7,500	6,146	18%
R-4 & R-5	37	5,500	5,095	7%

Density: The Redmond Code defines 'density' as "a measurement of the number of dwelling units in relationship to a specified unit of land; density calculations are based upon net acreage, which generally excludes land devoted to right-of-way. The net acreage is determined by subtracting from the total acreage of the lot or parcel that which [sic] is deemed necessary for street dedication and that area used for private streets and common driveways, if any."[3] The applicant's density exceeds the maximum density in R-3 for single-family. The maximum density for single-family in R-3 is 5.8 units per net acre. The applicant is proposing 6.18 units per net acre. The exception requested is discussed in greater detail as part of the PUD application, which is addressed in Section 8.275 in this staff report.

Minimum street frontage: The Redmond Code defines 'street frontage' as "That portion of a parcel of property which abuts a dedicated public street or highway or an approved private way (except an alley)"[3]. The applicant is requesting an exception to this standard for four of the townhouse lots and 60 of the single-family lots as part of the PUD application, which is addressed in Section 8.275 in this staff report.

[3] Redmond Code Section 8.020: Definitions.

Zone	Lot type	Proposed number of lots	Minimum street frontage standard	Number of lots requesting exception	Mean average street frontage of lots requesting exception
R-3	Single-family	167	50 feet	48	45.88 feet
R-4	Single-family	72	50 feet	11	48.17 feet
R-5	Single-family	6	40 feet	1	21.50 feet
R-4	Townhouse	10	20 feet	4	13.16 feet

Setbacks and building heights: All proposed lots are adequate in size to ensure compliance with applicable setbacks with the exception of the proposed lot 247 zoned R-3. Proposed lot 247 is the site of an existing single-family dwelling which the applicant wishes to retain. R-3 has a minimum rear setback standard of 20 feet. Due to the existing COID canal, as it relates to the existing dwelling, the applicant is requesting a 5-foot rear setback.

Evaluation of setback and building height standards will occur during zoning conformance review at time of building permit submittal. Staff finds, as proposed, the applicant's plans can meet these standards subject to approval of the PUD criteria addressed in the next section (i.e., Sec. 8.275) of this staff report.

ARTICLE I – ZONING STANDARDS > PLANNED UNIT DEVELOPMENTS

RC Sections 8.275

Sec. 8.275. Planned Unit Development (PUD).

1. Purpose *and Applicability.* The purpose of a PUD is to:
   - A. Permit greater flexibility in land use regulations in applicable zones (e.g., reduction of minimum lot size requirements).
   - B. Encourage creative developments.
   - C. Incentivize a variety of land uses and housing types, mixed use, the economy of shared services and facilities, public amenities, and developments compatible with the surrounding area and neighborhoods.
   - D. Promote and encourage infill development, flexibility in improvements on lots, and affordable and workforce housing.
   - E. Encourage preservation of natural features and enhancement of the area vegetation.
   - F. Facilitate sustainable design, energy efficiency, desirable aesthetics, and efficient use of open space.

   Density requirements, setbacks, land use regulations, and required improvements may be adjusted to allow for a more creative, functional, and desirable living environment. In return for greater flexibility in site design and development, the PUD process introduces special requirements and standards for approval.

2. *Approval.* PUD approval is subject to:
   - A. Land use review and approval as Conditional Use.
   - B. Zoning standards, except as modified by the PUD.
   - C. Subdivision and Partitions Standards, except as modified by the PUD.

D. Site and Design Review Standards, except as modified by the PUD.

E. PUD Standards and Requirements.

FINDING: The applicant has submitted a Conditional Use and Subdivision application as part of this application package. The Conditional Use and Subdivision review criteria is addressed later in this staff report. The applicant is requesting exceptions from zoning and land division standards as part of the PUD application and is addressed in detail below.

3. Exceptions. Exceptions of City standards may be allowed through the PUD approval process without a variance.

   A. Exceptions shall substantially result in improved design of the PUD. Improved design includes but is not limited to: alleys; public or private parks, trails, recreational areas, open spaces, common or natural areas; innovative housing design; public or private activity areas; a mixture of housing types, sizes, and projected prices; energy efficient design; a variety of trees and landscaping; art and other similar design features. A PUD need not include all of these design features in order to be approved.

   B. Exceptions to City standards include, but are not limited to:

      1. Minimum lot sizes.
      2. Setbacks.
      3. Permitted land uses.
      4. Grid street spacing standards.
      5. Connecting to public utilities, subject to acceptance by City Engineer.
      6. Street frontage, street and right-of-way width, sidewalk placement and standards, subject to acceptance by City Engineer.
      7. Landscaping.
      8. Fences and walls.

FINDING: As part of the PUD application, the applicant is requesting exceptions from the:

- minimum lot size standard for 149 of the 245 single-family lots
- maximum density standard for single-family in the R-3 zone
- rear setback for proposed Lot 247
- minimum street frontage standards for four of the 76 townhouse lots and 60 of the 245 single-family lots

Minimum lot size: The applicant is proposing a mix of single-family dwelling lots and townhouse lots in the R-3, R-4, and R-5 zones. The minimum lot size information is represented in the table below.

Zone	Number of single-family lots requesting exception	Single-family minimum lot size standard (ft^2)	Mean average lot size of lots requesting exception (ft^2)	Deviation from the standard
R-3	112	7,500	6,146	18%
R-4 & R-5	37	5,500	5,095	7%

Density: The Redmond Code defines 'density' as "a measurement of the number of dwelling units in relationship to a specified unit of land; density calculations are based upon net acreage, which generally excludes land devoted to right-of-way. The net acreage is determined by subtracting from the total acreage of the lot or parcel that which [sic] is deemed necessary for street dedication and that area used for private streets and common driveways, if any."[4] The applicant's density exceeds the maximum density in R-3 for single-family. The maximum density for single-family in R-3 is 5.8 units per net acre. The applicant is proposing 6.18 units per net acre.

Minimum street frontage: The Redmond Code defines 'street frontage' as "That portion of a parcel of property which abuts a dedicated public street or highway or an approved private way (except an alley)"[4]. The applicant is requesting an exception to this standard for four of the townhouse lots and 60 of the single-family lots.

Zone	Lot type	Proposed number of lots	Minimum street frontage standard	Number of lots requesting exception	Mean average street frontage of lots requesting exception
R-3	Single-family	167	50 feet	48	45.88 feet
R-4	Single-family	72	50 feet	11	48.17 feet
R-5	Single-family	6	40 feet	1	21.50 feet
R-4	Townhouse	10	20 feet	4	13.16 feet

Setbacks: Proposed lot 247 is the site of an existing single-family dwelling which the applicant wishes to retain. R-3 has a minimum rear setback standard of 20 feet. Due to the existing COID canal, as it relates to the existing dwelling, the applicant is requesting a 5-foot rear setback.

Street layout: The applicant is proposing a non-grid street system that is curvilinear in design. Although the City encourages curvilinear street design, it is intended to be a secondary feature to the City's grid street standard. That said, the applicant's proposed street layout is a significant departure from the standard and is not supported by staff. Additionally, as part of the curvilinear design, the applicant is requesting a deviation from the City's minimum horizontal curve radius standard along Celestial Ridge Way, Horizon Peak Road, Dawn Meadow Street, and Horizon Light Road. Staff does not support a deviation from the horizontal curve radius standard.

Intersection spacing: As part of this design there are segments of Horizon Peak Road that intersect with other proposed streets that do not meet the minimum 165-foot intersection spacing requirement. These include Horizon Peak Road between Horizon Peak Road and SW 45th Street (~160 feet), Horizon Peak Road between Horizon Light Road and Dusk Valley Road (~155 feet), and between Dusk Valley Road and Morning Vista Road (~130 feet). Intersection spacing is important for safety, efficiency, and network connectivity. Standards for intersection spacing help reduce crashes, traffic delays, congestion, and also ensure that drivers have sufficient sight distance. Staff is not in support of deviating from a standard intended to ensure traffic safety.

Block length: Due to the proposed curvilinear street design, several blocks exceed the maximum standard of 660 feet in length between street center lines.[5] These include Horizon Peak Road from Horizon Peak Road to Horizon Crest Lane (~1,035 feet); Horizon Peak Road from Horizon Crest Lane to Serenity Skyway (~2,525 feet); and Horizon Peak Road from Horizon Crest Lane to Horizon Peak Road (~1,255 feet) and from Dawn Meadow Street to Horizon Peak Road (~955 feet). The general

[4] Redmond Code Section 8.020: Definitions.

[5] Redmond Code Section 8.2020: Definitions, defines 'Block' as "An area of land bounded by streets or by a combination of streets and public parks, cemeteries, railroad rights-of-way or lines, shore lines or waterways, natural topographical barriers, or City limit."

purpose of block length standards is to balance street connectivity and pedestrian walkability. Given the length of the proposed blocks exceeding the City's maximum standard by two-to-three times, staff does not support the exception without, at a minimum, adding pedestrian connection points as outlined in conditions of approval #12 and #14.

Access clearance to corner: Although the specific location of lot driveways/access points are determined during zoning conformance review as part of the building permit application submittal, the applicant is requesting a deviation from the minimum access clearance to corners for driveway placements. Specifically, the request is to reduce driveway access clearance to corners from the minimum standard of 30 feet to 20 feet for proposed Lots 22, 139, 242, 269, 270, 290, 301, and 319; however, no reason for the request was provided.

4. *Standards and Requirements.* The following standards and requirements apply to a PUD application:

   A. PUDs must be a minimum of one acre in size. In the Downtown Urban Renewal District, a minimum of 0.5 acre in size.

   B. The applicant shall submit a written narrative that addresses the applicable standards, code, and regulations.

   C. A PUD approach may be utilized in the design and development of residential, mixed use, or commercial and industrial service areas.

   D. D*ensities.* Maximum densities are identified in Table 8.140. Additional density (i.e., bonus density) beyond the maximum density will be considered as follows:

      1. Up to 20 percent beyond maximum densities for qualified Affordable Housing and Workforce Housing units. A bonus density request beyond 10 percent shall be restricted to Affordable Housing. Affordable and Workforce Housing units should be designed to be intermixed throughout the development and similar design and quality to market rate units.

      2. Up to 10 percent beyond maximum densities for including amenities that provide a community benefit or helps realize specified public policy goals. Examples include: additional protection of green space, recreational areas, open space, natural resources or view corridors. environmental improvements, trail connectivity, higher quality building design, or other additional amenities.

      3. As identified in respective Area Plans.

FINDING: The proposed PUD is just over 67 acres in size, exceeding the minimum one-acre requirement. The PUD may afford the applicant additional density if certain elements are incorporated into the development. As mentioned above, the proposed development slightly exceeds the maximum density standard for single-family lots in the R-3 zone. Given the PUD is proposing just over two times the amount of required open space along with facilitating trail connectivity, staff can support a density bonus of up to 10%.

   E. A PUD must include usable open space, recreational area, common area or park designed for the use and benefit of all the units or lots in the development. The land area used shall be determined by the type of amenities added by the developer.

FINDING: The proposed PUD is located in the R-3, R-4, and R-5 zones, all of which are considered medium and high-density zones. As such, the applicant is proposing a grand total of 321 residential lots, which will require at least 36,000 square feet of pocket parks. The applicant's plans show Tracts

G, H, I, J, and R as areas eligible for meeting the pocket pock and open space requirements. Said tracts amount to a total of 66,857 square feet, exceeding the standard. The other tracts proposed do not count toward this standard as they are requirements outside of a PUD. In other words, Tracts S and T are provided for the required urban-rural interface buffer and Tracts B, C, and D are provided for the required multi-use pathways, identified in the Transportation System Plan.

F. Thoughtful design and architectural themes are required for all structures within any development. Design shall take into consideration themes continues on all elevations for each building, and onto the entire site including, but not limited to: lighting, fencing, accessory structures, signage, and trash enclosures.

FINDING: The applicant has stated *"Monte Vista Homes intends to build all the homes within this subdivision. Using Monte Vista Homes' standard footprints and three cohesive elevation styles the architectural themes will remain consistent through the entirety of the project."* Additionally, as part of their submittal, the applicant has provided illustrative examples of potential homes.

G. A separate application or rezoning may accompany the application for approval of the PUD in which case the two items shall be considered simultaneously.

FINDING: The applicant has submitted tentative subdivision and conditional use applications with the PUD application. The three applications are being reviewed concurrently as one land use package.

H. The City may recommend a performance bond or other surety to assure the proposed development will be completed as approved and within the time limits agreed to in the conditions of approval.

FINDING: This is entirely informational. No finding is needed.

5. *Review Procedure for PUD's.* The following procedure shall be followed in requesting approval of a PUD.

A. A pre-development meeting is required prior to submittal of an application.

FINDING: The applicant submitted a pre-development application (File No. 711-24-000029-PD), and a pre-development meeting was held on March 5, 2024. This standard is met.

B. Proof a neighborhood meeting was conducted for residential or mixed-used development proposals that generate 200 or more daily trip ends, or 20 or more PM peak hour trip ends, where a Transportation Impact Analysis (TIA) is required, See Section 8.385 for meeting requirements.

FINDING: As this land use proposal includes a development that will generate more than 200 daily trip ends, a neighborhood meeting is required. The applicant provided sufficient evidence that a neighborhood meeting was held on November 19, 2024, well within 180 days of the date they submitted their land use applications. This standard is met.

C. An applicant shall submit an electronic version of the complete application. The plan shall contain and show, at an engineer's scale of no less than 1" =10', the following information:

1. The relationship of the property to the surrounding area.
2. The preliminary plan of subdivision or re-subdivision, if any, which shall include the information required by the Subdivision Ordinance.
3. Land uses, building locations, density proposed, architectural style, efficiency measures, housing market served, and number of dwelling units.
4. The arrangement of streets and pedestrian ways.
5. Proposals that include reduced yards and lot size shall be designed to be served by private alleys or drives.
6. The location of off-street parking spaces, and a parking management plan if the total number of spaces required exceeds 75.
7. The location of service commercial areas, open space, recreational area, common areas, or park.
8. Plans for site grading and drainage.
9. Plans for water supply and sewage disposal.
10. Plans for transfer of ownership of the property, if any, and arrangements for maintenance of common areas and facilities.
11. Landscape plan including the list of species proposed and size/coverage at time of planting and at five years.
12. Proposed project timing schedule and surety, if required by City.

FINDING: Staff has examined the applicant's entire submittal and has found that plans for the programming of proposed open space and pocket parks tracts are not sufficient. Without detailed information, it is difficult to ascertain how the proposed PUD subdivision is different from a standard subdivision in terms of amenities offered for these spaces. Based on review of what was submitted, staff does not believe the proposed PUD offer amenities or elements that go beyond the minimum required.

D. In considering the PUD, the City shall determine:

1. There are special development objectives or physical conditions which justify a request for a PUD.

FINDING: The applicant has stated "*The Horizon Pointe property presents several physical conditions that justify the use of the Planned Unit Development (PUD) process. The site's unconventional shape, challenging terrain especially in the North Section and the fixed alignment of the COID canals create geometric constraints that make strict application of traditional grid-based development standards impractical and, in certain locations, counterproductive to safety and neighborhood function.*

The proposed curvilinear street layout is a direct response to these conditions and achieves a superior design outcome by improving neighborhood circulation, reducing the number of four-way intersections, enhancing walkability, and creating more intuitive and context-sensitive block and lot patterns. These benefits—supported by established transportation research demonstrating the safety advantages of T-intersections and curved residential streets—could not be accomplished under the conventional standards without compromising the site's functionality, safety, or livability."

Staff would like to better understand the applicant's concerns regarding the site's challenging physical conditions. Staff notes that a pre-development application (file number 711-23-000054-PD) was submitted for this site that had a plan with a grid street layout.

2. The PUD will contain buffers on sides of the development that abut neighboring properties.

FINDING: The applicant's plans do not show buffers on all sides of the development that abut neighboring properties. With exception of the need for an urban-rural interface buffer along the PUD's west and northwest boundaries as discussed in Section 8.2715(9) findings, staff believes that no buffer is needed at the development's northeastern and southern boundaries as these areas abut lands in that are in city limits and are planned for future urban development.

3. The PUD, through its design and function, will improve livability for planned residents.

FINDING: The applicant has stated "*The Horizon Pointe curvilinear street network was intentionally designed to enhance neighborhood livability through improved visibility, safer circulation, and a more open and attractive streetscape. The geometry of the curved layout naturally creates a pattern of throated-out lots along the outer radii—resulting in wider frontages and broader view corridors—paired with throated-in lots along the inner radii, where homes are positioned deeper on the lot than the typical 20-foot minimum setback. This alternating pattern expands line-of-sight distances at driveways and intersections and produces a rhythmic sequence of open view sheds that contribute to a park-like, visually spacious neighborhood character.*

This configuration stands in contrast to traditional grid developments, where uniform setbacks and long straight streets often compress the streetscape and limit visibility. The curvilinear design improves the resident experience by creating a more comfortable, varied, and visually appealing environment.

From a safety standpoint, the layout also eliminates four-way intersections, which are well-documented to have the highest crash rates and the greatest number of conflict points in residential areas. Replacing these with safer T-intersections and gentle curves enhances driver predictability, improves sightlines, and supports calmer vehicle speeds—all of which directly contribute to a more livable and pedestrian-friendly neighborhood.

This approach fulfills the intent of Redmond Development Code § 8.270 and § 8.275, which encourage creative, context-sensitive neighborhood design that elevates safety, livability, and compatibility with surrounding development. The result is a community that feels open, intuitive, and distinctly safe—establishing Horizon Pointe as a model for future neighborhoods in Redmond."

After reviewing the applicant's response to this standard as well as the information submitted with the application, staff does not agree with the applicant's response. Staff has concerns about sight distance/stopping sight distance, intersection spacing, block lengths, the design and placement of sewer mains with curvilinear streets, to name a few. Ultimately, the applicant has proposed a PUD that is designed in a way that deviates significantly from the City's standards, thus requiring exceptions to several standards. Given that the purpose of many street design standards are to ensure safety and efficient traffic flow, staff does not believe the design, function, and benefits offered by Horizon Pointe will improve livability for planned residents.

4. The PUD contains a mix of housing types, variety of uses or services.

FINDING: The applicant is proposing 245 single-family dwellings and 76 townhouse units over three different residential zoning districts. Although not an extensive mix of housing types, the proposed PUD generally includes the housing types needed in the R-3, R-4, and R-5 zones. This is substantiated by the breakdown of need by housing type and zone as presented in the City's Housing Needs Analysis.[6] The PUD does not provide for other uses aside from residential. A PUD does afford an opportunity to provide limited-scale commercial in the R-3, R-4, and R-5 zones.

5. The PUD can be completed within five years or phased for later development.

FINDING: The applicant has stated that the proposed PUD is planned to be constructed in seven phases over eight years.

6. The PUD will not overload adjacent streets, utilities, or infrastructure.

FINDING: City Engineering has reviewed the proposal and did not find that the development will exceed operational capacity of City infrastructure with regard to water and sewer. The applicant was required to submit a Transportation System Analysis (TSA) to the City for review and approval. Identified by the TSA are required mitigations and improvements to the transportation system as a result of the impacts the development will have on the transportation system. Therefore, complying with conditions of approval will ensure that the proposed PUD will not overload adjacent streets, utilities, or infrastructure. Lastly, programmed in the City's Capital Improvement Program are future transportation improvements to SW Helmholtz Way that will be needed as more vehicular trips are added to the corridor. These improvements include: future roundabouts along SW Helmholtz Way at the intersections of SW Wickiup Avenue, SW Obsidian Avenue, and Oregon Highway 126. Additionally, the Little Texas development will be required to construct a roundabout at the intersection of SW Helmholtz Way and SW 45th Street.

7. The PUD will be consistent with the objectives of Area Plans and the Redmond Comprehensive Plan.

FINDING: The Horizon Pointe PUD is not located in an area with an established area plan. Staff has concluded that the PUD is not consistent with the objectives of the Redmond Comprehensive Plan. The City's development code serves as the major implementation mechanism of the Comprehensive Plan. Because staff findings have found that the PUD does not comply with several development code standards, the PUD cannot be found to be consistent with the objectives of the Comprehensive Plan.

E. The City Shall notify the applicant whether in its judgment the foregoing provisions have been satisfied and, if not, whether they can be satisfied with other alternatives or revision to the PUD.

FINDING: The applicant's proposed PUD plan set has undergone revisions, albeit relatively minor revisions, since Horizon Pointe was first presented to the City at the pre-development meeting in March 2024. Revisions were made due to City staff feedback on the proposal, which occurred over several meetings since the pre-development meeting. It is important to note, however, that staff had consistently communicated, early and often, that Horizon Pointe's major departure from the City's grid street design standards would likely not be supported. Staff's final position on recommending not to approve the PUD is based on the comprehensive review of the applicant's plans and burden of proof,

[6] 2019 Redmond Housing Needs Analysis, Exhibit 70, page 71.

and findings for compliance with the City's development code.

6. *PUD Post Approval & Modifications.* Where a PUD has been authorized pursuant to applicable zoning regulations, the plan of the subdivision shall conform with the plan of the PUD as approved.

   Minor Modification. Minor modification to an approval PUD will be granted when the requested change is so minor that the CDD Director, or designee, determines that it would be appropriate for an administrative decision. Examples of minor changes include, but are not limited to: (1) a reduction in the overall number of lots, (2) minor architectural changes to approved buildings, (3) changes to phases that do no impact public facilities or change the number of approved phases, (4) changes that result in a reduction of impacts (i.e., reduced traffic flows), or (5) changes that are required to protect or increase public safety.

   Major Modification. Major modifications to an approved PUD are subject to Section 8.1400.

FINDING: This subsection is procedural. Any proposed post-approval modification will be subject to these standards.

ARTICLE I – ZONING STANDARDS > SUPPLEMENTARY PROVISIONS

RC Section 8.385

Sec. 8.385. Neighborhood Meeting.

1. *Purpose and Intent.* The purpose of the neighborhood meeting is to provide a forum for the applicant, surrounding neighbors, and interested members of the community to meet and consider a proposed land use application, and to discuss issues/concerns regarding the proposal prior to application submittal. Neighborhood meetings encourage citizen participation early in the development process, and an opportunity to revise the land use application to address the issues prior to application submittal.
2. *Applicability.* Neighborhood meetings are encouraged prior to submitting any land use application. The following application types or development proposals shall be subject to the neighborhood meeting requirements:
   A. Master Development Plans.
   B. Residential or mixed use development proposals that generate 200 or more daily trip ends, or 20 or more p.m. peak hour trip ends, where a Transportation Impact Analysis (TIA) is required.
   C. Wireless and Broadcast Communications Facilities.
3. *Requirements and Procedures.* The neighborhood meeting must be held after a pre-development meeting with City Staff, but before submittal of a land use application. The applicant shall be required to hold only one meeting prior to submitting an application for a specific site but may hold more if desired. If the development proposal is revised after the neighborhood meeting, and a major modification is requested, a second neighborhood meeting with a new notice shall be required before the revised application is submitted.
   A. *Location and Time.* Neighborhood meetings shall be held in person at a location in reasonable proximity to the subject site. The meeting shall be held at a location open to the public, City Staff, and at a facility that is ADA accessible. The meeting shall be held on a weekday evening, or weekends at any reasonable time. Applicants may provide a virtual component for participants to join in the meeting. The virtual component shall not

be done in lieu of the in-person requirements. ADA accommodations when requested by attendee must be provided.

B. *Notice - Mail.* Mailed notice of the meeting shall be provided by the applicant to the neighboring property owners (within 750 feet outside city limits and 250 feet within city limits) and the Community Development Department between ten and 30 calendar days prior to the meeting. Notices must be sent first class and shall include the date, time, and location of the meeting, as well as a brief description of the development proposal and property location. The description shall take into consideration information provided by City staff at the pre-development meeting, include project contact information, a copy of the tax map or a GIS map that clearly identifies the location of the proposed development, and a conceptual site plan.

C. *Notice - Signage.* The applicant shall also post notice of the neighborhood meeting on the subject site or on an access easement to the site within clear view of a public street at least seven days in advance of the meeting. The sign must display the meeting date, time, and address as well as project contact information.

D. *Meeting Requirements.* The developer must provide a sign-in sheet for attendees to provide their name, address, telephone number, and email address. At the meeting, the applicant shall provide a conceptual site plan and describe the major elements of the proposal. Depending on the type and scale of the particular application, the applicant should be prepared to discuss proposed land uses and densities; traffic impacts; proposed building size and height; proposed access and parking; and proposed landscaping, buffering and/or protection of natural resources as applicable. Attendees will have an opportunity to speak at the meeting and may identify any issues that they believe should be addressed. If no one arrives within 30 minutes of the scheduled start time for the meeting, the applicant may close the meeting and this requirement will be considered met upon the applicant's submittal of the documentation to that effect.

E. *Materials Submitted with Application.* The neighborhood meeting notes that identify the major points discussed about the development, list of parties notified, signed affidavits of mailing and posting notices, copies of all materials provided by the applicant, and a signature sheet of attendees shall be included with the development application upon submittal.

F. *Validity Period.* The land use application shall be submitted to the City within 180 days of the neighborhood meeting. If an application is not submitted in this timeframe, the applicant shall be required to hold a new neighborhood meeting.

G. *Denial.* Failure of the applicant to hold a neighborhood meeting in accordance with these provisions prior to submittal of a land use application shall result in an incomplete application and the application may be rejected.

FINDING: As this land use proposal includes a development that will generate more than 200 daily trip ends, a neighborhood meeting is required. The applicant provided sufficient evidence that a neighborhood meeting was held on November 19, 2024, well within 180 days of the date they submitted their land use applications. This standard is met.

ARTICLE I – ZONING STANDARDS > CONDITIONAL USES

RC Sections 8.600-8.605

Sec. 8.600. Authorization to Grant or Deny Conditional Uses.

Uses designated herein as conditional uses may be permitted upon authorization by the Hearings Body in accordance with the standards and procedures established in this Article. Before approving an application for a conditional use, the Hearings Body shall find the following criteria are either met, can be met by observance of conditions, or are not applicable:

1. The proposed use will be consistent with the Comprehensive Plan, the zoning ordinances and other applicable ordinances and standards of the City.

FINDING: The applicant is proposing a Planned Unit Development in the R-3, R-4, and R-5 zones. Applying for a PUD in these zones requires the applicant submit a Conditional Use application. As proposed, the applicant's proposed development will be consistent with the Comprehensive Plan and City ordinances, subject to an approval of the deviations requested through the PUD as well as complying with conditions of approval.

2. The location, size, design, and operating characteristics of the proposed use will have minimal adverse impact on the livability, value, or approximate development of abutting properties and the surrounding area.

FINDING: As proposed, staff has determined the location, size, design, and operating characteristics of the proposed development may have minimal adverse impacts on the livability, value, or approximate development of abutting properties and the surrounding area. Directly north of the proposed development is the planned Little Texas residential Planned Unit Development comprised of single-family and townhouses. The proposed development will connect SW 51st Street and C Street to Little Texas. To the east is existing residential located in a lower density residential zone and is separated from Horizon Pointe by SW Helmholtz Way, a minor arterial street. Directly south is a large lot with an existing single-family dwelling, owned by one of the project's property owners.[7] Finally, to the west and northwest is land zoned Exclusive Farm Use, which has a purpose of preserving and maintaining agricultural lands and to serve as a sanctuary for farm uses, and is located outside the urban growth boundary and urban area reserve.[8] The City has an urban-rural interface standard that is applied to residential development adjacent to areas outside of the urban area reserve and thus applies to the western and northwestern boundary of the proposed development. The applicant has designed the proposed development in such a way that generally larger single-family lots are located along the development's northwestern edge along with 20-foot-wide open space Tracts S and T. Additionally, along the western boundary is COID's B Lateral of the Pilot Butte Canal, which includes a total easement of 70 feet in width – 45 feet of which lies within the subject property and in part includes the applicant's proposed open space Tract D. Staff believes that the combination of the COID B Lateral and Tract D will provide adequate buffering between the existing rural farmland and the proposed urban development; however, Tracts S and T as presented do not demonstrate adequate buffering with the adjacent rural lands to the north.

Lastly, given the proposed development's sizable impacts (i.e., additional traffic generation) to the existing street network, the applicant was required to conduct a transportation impact analysis study that was reviewed and approved by the City and includes required mitigations and improvements to the existing transportation system as detailed in the proposed conditions of approval.

[7] On November 19, 2025, the applicant for Horizon Pointe submitted a Lot Line Adjustment application to propose moving the common property line of existing Parcel 2 and Parcel 3 south.
[8] Deschutes County Code, Chapter 18.16 Exclusive Farm Use Zone; EFU, Section 18.16.010 Purpose.

3. The proposed use will not exceed operational capacity of City infrastructure including sewage system, water system or the transportation system.

FINDING: City Engineering has reviewed the proposal and did not find that the development will exceed operational capacity of City infrastructure with regard to water and sewer. The applicant was required to submit a Transportation System Analysis (TSA) to the City for review and approval. Identified by the TSA are required mitigations and improvements to the transportation system as a result of the impacts the development will have on the transportation system. This standard can be met by complying with the conditions of approval. Lastly, programmed in the City's Capital Improvement Program are future transportation improvements to SW Helmholtz Way that will be needed as more vehicular trips are added to the corridor. These improvements include: future roundabouts along SW Helmholtz Way at the intersections of SW Wickiup Avenue, SW Obsidian Avenue, and Oregon Highway 126. Additionally, the Little Texas development will be required to construct a roundabout at the intersection of SW Helmholtz Way and SW 45th Street.

4. That the proposed use will not conflict with, diminish, or substantially adversely affect the character and nature of the established neighborhood in which it is located.

FINDING: The proposed development is on the edge of the city and will be creating an entirely new neighborhood, generally in compliance with the subject properties' designated zoning districts, subject to an approval of the zoning deviations requested through the PUD as well as complying with conditions of approval. Additionally, the proposed development will provide for an orderly transition from the planned residential Planned Unit Development to the north. This standard is met.

Sec. 8.602. Neighborhood Meeting.

Proof a neighborhood meeting was conducted for residential or mixed use development proposals that generate 200 or more daily trip ends, or 20 or more PM peak hour trip ends, where a Transportation Impact Analysis (TIA) is required, See Section 8.385 for meeting requirements.

FINDING: As this land use proposal includes a development that will generate more than 200 daily trip ends, a neighborhood meeting is required. The applicant provided sufficient evidence that a neighborhood meeting was held on November 19, 2024, well within 180 days of the date they submitted their land use applications. This standard is met.

Sec. 8.605. General Conditions.

In addition to the ordinances set forth in a specific zone, this Article, and other applicable standards and criteria used in addressing a new conditional use or the alteration of an existing conditional use, the Hearings Body may impose conditions which it finds necessary to avoid an unacceptable impact and to otherwise protect the best interests of the surrounding area or the City. These conditions may include the following:

1. Limiting the way the use is conducted including restricting the time an activity may take place and establish conditions or restraints that will minimize such environmental effects as noise, vibration, air pollution, glare, and odor. The City may require additional proof from the applicant that quantifies compliance with this requirement at the time of application submittal.
2. Establishing an open space or recreation area.
3. Limiting the height, size, or location of a building or other structure(s).
4. Designating the size, number, location, and nature of vehicle access points.

5. Increasing the amount of street dedication, roadway width or improvements within the street right-of-way, including (but not limited to) lighting and landscaping improvements. Any oversizing of public infrastructure that is required by the City that exceeds minimum City standards may be a candidate for SDC credits at the discretion of the City Engineer or designate.
6. Designating the size, location, screening, landscaping, drainage, surfacing, or other improvement within a parking area or loading zone.
7. Limiting or otherwise designating the number, size, location, height, and lighting of signs.
8. Limiting the location and intensity of outdoor lighting and requiring it's shielding from any adjacent properties, or public or private streets and roads.
9. Requiring diking, screening and/or landscaping of a facility to protect adjacent or nearby property and designating standards for its installation and maintenance.
10. Designating the size, height, location, and materials for a fence.
11. Protecting and preserving existing trees, vegetation, or other significant natural resources.

FINDING: This section is entirely informational.

ARTICLE III – LAND DIVISION STANDARDS > TENTATIVE SUBDIVISION PLAN

RC Sections 8.2200, 8.2202, and 8.2220-8.2240

Sec. 8.2200. Pre-Application Meeting.

Prior to submitting a tentative subdivision plan each applicant or their representative is required to meet with the Community Development Director or a designated staff member(s) to review the proposal.

FINDING: The applicant submitted a pre-development application (File No. 711-24-000029-PD), and a pre-development meeting was held on March 5, 2024. This standard is met.

Sec. 8.2202. Neighborhood Meeting.

The applicant or their representative shall conduct a neighborhood meeting that meets the requirements of Section 8.385 for residential or mixed use development proposals that generate 200 or more daily trip ends, or 20 or more p.m. peak hour trip ends, where a Transportation Impact Analysis (TIA) is required per Section 8.2815.

FINDING: As this land use proposal includes a development that will generate more than 200 daily trip ends, a neighborhood meeting is required. The applicant provided sufficient evidence that a neighborhood meeting was held on November 19, 2024, well within 180 days of the date they submitted their land use applications. This standard is met.

Sec. 8.2220. Phased Development Plan.

An applicant may propose phased development of a tentative subdivision plan by submitting a phased development plan that shall include but not be limited to, the following elements:

1. Overall development plan, including phase or unit sequence.
    A. For development that includes a commercial component, a surety may be required when the commercial component is not sequenced in the initial phases.

2. Show compliance with all applicable land division standards and policies as described in this Article.
3. Schedule of improvements initiation and completion.
4. Overall transportation and traffic pattern plan showing compliance with grid street standards, and for land within the North Redmond US 97 Interchange Area Management Plan (IAMP), compliance with the Local Street Connectivity Plan (Comprehensive Plan Addendum Chapter 9 Transportation Element figure 1).
5. General program for phasing timetable projection.
6. Development plans for any common elements or facilities.

FINDING: The applicant is proposing a seven-phased planned unit development residential subdivision and is entitling the entire project at this time. The applicant has stated that Horizon Pointe is planned to be constructed over eight years with the goal of finalizing phase 7 improvements by the end of 2033. The tentative phasing schedule includes: Phase 1 in Spring 2026; Phase 2 in Spring 2027; Phase 3 in Winter 2028; Phase 4 in Spring 2029; Phase 5 in Winter 2030; Phase 6 in Winter 2031; and Phase 7 in Winter 2032. It should be noted that any minor alteration to an approved tentative plan that includes minor amendments to phasing so as long as there would be no adverse effect on the phasing of public improvements will be subject to the Alteration to an Approved Plan provisions of the Redmond Code [i.e., Sec. 8.1400(2)].

Sec. 8.2225. Approval of Phased Development Plan.

The Review Authority shall review a phased development plan at the same time the tentative plan is reviewed. The Review Authority may approve, modify, or disapprove the phased development plan and shall set forth findings for such decision. The Review Authority may also attach conditions necessary to bring the plan into compliance with all applicable land use standards and policies.

FINDING: The applicant has submitted a tentative plan for a seven-phased subdivision. As stated in this standard, a phased development plan may be approved before the tentative plan for the first phase is submitted. Tentative plans submitted for each phase shall conform to the proposed tentative plan for the multiple-phased subdivision as included in this land use application package.

Sec. 8.2230. Development Following Approval.

1. Once a phased development plan is approved, the plan shall be binding, upon both the City and the applicant. The applicant shall submit a final plat for each phase per Section 8.2305.
2. The Review Authority may attach conditions to any changes proposed that are deemed necessary to ensure compliance with the Comprehensive Plan and implementing regulations.

FINDING: This is a procedural provision.

Sec. 8.2235. Approval Criteria for Tentative Subdivision Plans.

1. The Review Authority shall approve, approve with conditions, or deny a proposed tentative subdivision plan. Approval, or approval with conditions shall be based on compliance with the following criteria:
    A. Proposal is in compliance with ORS Chapter 92.

FINDING: The proposed tentative plan has been submitted in conjunction with a Planned Unit Development application for which the applicant has requested exceptions to various zoning and land division standards. Staff has determined that the tentative subdivision plan can comply with ORS Chapter 92 by complying with the proposed conditions of approval as substantiated by way of findings addressing said ORS, plans, standards, and criteria throughout this staff report.

B. Proposal complies with the standards of this Code, including but not limited to:

1. Section 8.2705, Blocks, Lots and Parcels.
2. Section 8.2710, Streets.
3. Section 8.2715, Fundamental Design Standards.
4. Section 8.2720, Grading of Building Sites.
5. Section 8.2815, Transportation System Analysis.
6. Section 8.2820, Access Management Standards.
7. Any other applicable standards.

FINDING: Findings related to these sections appear in a later section of this staff report.

C. Proposal complies with the standards of the zoning district in which the project is located.

FINDING: The proposed tentative plan does not comply with all standards of the zoning districts that the proposed development is located. Specifically, 149 of the 245 proposed single-family lots do not meet the minimum lot size standard; four of the 76 proposed townhouse lots and 60 of the 245 proposed single-family lots do not meet the minimum street frontage standard; and the density of the single-family lots is just over the maximum density standard for single-family dwellings in the R-3 zone. However, the applicant has requested exceptions from these standards as part of the Planned Unit Development submittal, which is addressed in Section 8.275 of this staff report.

D. The proposal is in conformance with any applicable approved area plan, master plan, and/or framework plan.

FINDING: The location of the proposed tentative subdivision is not within an approved area plan, master plan, or framework plan; therefore, this standard is not applicable. Instead, the proposal must comply with applicable zoning regulations for the property.

E. Proposal does not conflict with acquired public access easements within or adjacent to the subdivision.

FINDING: The applicant's tentative plan will not conflict with acquired public access easements within or adjacent to the subdivision.

F. The proposed subdivision will provide required transportation system infrastructure, water supply, sewage disposal, drainage, and other public utilities consistent with the Public Works Standards and Specifications.

FINDING: The tentative subdivision proposes 14 new local streets, all of which will be required to be built to City standards. Additionally, right-of-way dedication and improvements to the west side of SW Helmholtz Way and SW 45th Street along the development's frontages will be required in addition to installing a southbound right-turn lane and northbound left-turn lane at SW Helmholtz Way/Dusk Valley Road. An enhanced pedestrian crossing on SW Helmholtz Way and a proportionate share payment to help mitigate transportation impacts to key off-site intersections will be required as well as separated multiuse paths along the COID laterals (B and B-5) and along SW Helmholtz Way.

However, the proposed subdivision's internal street network does not meet City grid street standards. Specifically, the minimum horizonal curve radius standard identified in the City's Public Works Standards and Specifications is not met along Celestial Ridge Way, Dawn Meadow Street, Horizon Light Road, and Horizon Peak Road. Additionally, the intersection spacing on Horizon Peak Road between Horizon Peak Road and SW 45th Street, and the intersection spacing on Horizon Peak Road between Horizon Light Road and Dusk Valley Road and between Dusk Valley Road and Morning Vista Road do not meet minimum intersection spacing standards.

Water and wastewater mains are proposed to extend to and through the site to serve each lot. Extension of water and sewer mains will be required and specifications and standards that will require compliance are detailed in conditions of approval.

G. The subdivision will not exceed the operational capacity of public facilities and services as identified in the City's Water and Wastewater Master Plan and the Transportation System Plan, which are required to serve the development, or a determination that sufficient capacity can be provided.

FINDING: City Engineering has reviewed the proposal and did not find that the development will exceed operational capacity of the City infrastructure with regard to water and sewer. The applicant was required to submit a Transportation System Analysis (TSA) to City for review and approval. Identified by the TSA are required mitigations and improvements to the transportation system as a result of the impacts the development will have on the transportation system. This standard can be met by complying with the conditions of approval. Lastly, programmed in the City's Capital Improvement Program are future transportation improvements to SW Helmholtz Way that will be needed as more vehicular trips are added to the corridor. These improvements include: future roundabouts along SW Helmholtz Way at the intersections of SW Wickiup Avenue, SW Obsidian Avenue, and Oregon Highway 126. Additionally, the Little Texas development will be required to construct a roundabout at the intersection of SW Helmholtz Way and SW 45th Street.

H. A water rights division plan has been approved by the applicable irrigation district.

FINDING: The applicant will need to coordinate with COID on the removal of rights via quitclaim deed. Refer to COID comments in Attachment C for more details. This standard can be met by complying with the conditions of approval

Sec. 8.2240. Future Subdivision.

On any Residential zoned property, if the subdivision results in a lot greater than twice the minimum lot size in the underlying zone, the application shall indicate the location of lot lines and other details of layout that show future division of the lot may be made without violating the requirements of this code and without interfering with the orderly extension of adjacent streets, bicycle paths, and accessways.

FINDING: The proposed tentative plan includes a small number of lots that are greater than twice the minimum lot size in the underlying zone. While future partitioning of these lots is not anticipated, any such proposal would be subject to compliance with all applicable land division standards. Based on the current proposal, staff has determined that this standard does not apply.

ARTICLE III – LAND DIVISION STANDARDS > DESIGN STANDARDS AND IMPROVEMENTS

RC Sections 8.2700-8.2720

Sec. 8.2700. Compliance Required.

1. Any land division or development shall be in compliance with the design and improvement standards and requirements of this Section, and all other applicable provisions, as set forth in this Chapter.

FINDING: This section is provided for informational purposes only.

Sec. 8.2705. Blocks, Lots and Parcels.

1. *Blocks.* The resulting or proposed length, width and shape of blocks shall take into account the requirements for adequate building lot sizes, street widths, access needs and topographical limitations.

    A. No block shall be more than 660 feet in length between street center lines unless it is adjacent to an arterial street, or unless topography or the location of adjoining streets justifies an exception and is so approved by the reviewing authority. In MUN, MUE and MULW zones, block lengths shall be an average of 330 feet, except where required to meet grid street or access management requirements.

FINDING: The applicant has proposed a curvilinear street design with several blocks exceeding 660 feet in length between street center lines.[9] Horizon Peak Road from Horizon Peak Road to Horizon Crest Lane (~1,035 feet); Horizon Peak Road from Horizon Crest Lane to Serenity Skyway (~2,525 feet); and Horizon Peak Road from Horizon Crest Lane to Horizon Peak Road (~1,255 feet) and from Dawn Meadow Street to Horizon Peak Road (~955 feet). The applicant has requested an exception from this standard, which is addressed in Section 8.275.

    B. The recommended minimum length of a block along an arterial street is 1,320 feet, except that along such blocks, a public right-of-way for pedestrian and bicycle access shall be dedicated at or nearest the mid-point of the block length as is practical. The right-of-way shall be a minimum of ten feet wide, with an all weather surface a minimum of five feet wide, constructed and centered within the right-of-way.

FINDING: The proposed subdivision does not include any blocks that abut an arterial street. Although the proposed subdivision abuts SW Helmholtz Way, an arterial street, the proposed blocks are buffered by proposed landscaped tracts. This standard is not applicable.

[9] Redmond Code Section 8.2020: Definitions, defines 'Block' as "An area of land bounded by streets or by a combination of streets and public parks, cemeteries, railroad rights-of-way or lines, shore lines or waterways, natural topographical barriers, or City limit."

C. A block shall have sufficient width to provide for two tiers of lots unless topography, the location of adjoining streets, or adjacency to an arterial street justifies an exception.

FINDING: The proposed tentative plan shows blocks with two tiers of lots with exception of areas where it may not be feasible such as abutting urban reserve area boundaries, the lots along the southern boundary line, and lots which are confined by SW Helmholtz Way, an arterial street. The proposed development meets the intent and requirements of this standard.

D. Where appropriate at approved cul-de-sacs, dead-end streets, or along blocks approved at more than the maximum block length standard, pedestrian and bicycle access corridors shall be required to be constructed between lots to minimize travel distance between subdivisions, parks, school, and collector or arterial streets. Access corridors shall be located to provide a reasonably direct connection between likely pedestrian destinations and shall be consistent with the City of Redmond Bicycle Refinement Plan where applicable. A reasonably direct connection is a route which minimizes out of direction travel for people likely to use the connection considering terrain, safety, and likely destination. The Review Authority may determine based on evidence in the record that construction of a separate access corridor is inappropriate or impractical. Such evidence may include but is not limited to:

1. When the nature of abutting existing development makes construction of an access corridor impractical.
2. When the access corridor would cross a natural area with significant natural habitat and construction would be incompatible with protection of natural values.
3. When the access corridor would cross topography where slopes exceed 30 percent or where path grade would exceed 12 percent slope; or
4. When a cul-de-sac or dead-end street abuts rural resource land at the urban growth boundary. In industrial zones, this standard may be waived at the discretion of the Review Authority, when it is determined that the City's grid street standards should not be applied to the industrial development.

FINDING: The applicant is proposing a curvilinear street design with pedestrian connections via various tracts throughout the development. A 30-foot-wide corridor (Tract C) running generally west-east bisects the development. Additionally, proposed Tracts K and L provide mid-block pedestrian access corridors. Additionally, the proposed subdivision also includes a cul-de-sac, which shall provide for a pedestrian pathway constructed and right-of-way shall be dedicated between Morning Vista Road and Horizon Peak Road, located between Lots 222, 223, 234, and 235. The right-of-way shall be a minimum of ten feet wide, with an all-weather surface a minimum of five feet wide, constructed and centered within the right-of-way. Lastly, given the proposed block lengths, a pedestrian pathway shall be constructed, and right-of-way shall be dedicated between Horizon Peak Road and Horizon Peak Road, located between Lots 160, 161, 257, and 258. The right-of-way shall be a minimum of ten feet wide, with an all-weather surface a minimum of five feet wide, constructed and centered within the right-of-way.

2. *Lots and Parcels.* The size, width, and orientation of newly created lots and parcels shall be appropriate for the location of the land division and for the type of development and use contemplated. Lots and parcels shall be generally rectangular in shape and shall be consistent with the lot size provisions of the zoning standards and the density requirements as established in the City of Redmond Comprehensive Plan. Notwithstanding these requirements, the following exceptions may apply:

A. In areas beyond the City Limits where public sewer is not currently available, minimum lot and parcel sizes shall permit compliance with the requirements of the Department of Environmental Quality and shall be sufficient to permit adequate sewage disposal. Any problems posed by soil structure and water table as related to sewage disposal by septic tank shall be addressed and resolved in the applicant's initial plan.

B. Where property is zoned and planned for business or industrial use, other widths and areas may be permitted by the Review Authority. Depth and width of properties reserved or laid out for commercial and industrial purposes shall be adequate to provide for the off-street service and parking facilities required by the type of use and development contemplated.

C. In steep terrain, increased lot or parcel sizes may be required to avoid excessive cuts, fills, and steep driveways.

FINDING: The tentative subdivision includes 321 residential lots, which are generally rectangular in shape. The proposed 76 townhouse lots meet the density requirements and the lot size provisions of the zoning standards, with exception of four lots that do not meet the minimum street frontage standard. The majority of the 245 single-family lots do not meet the minimum lot size standard, and a significant amount do not meet the minimum street frontage standards. Additionally, the maximum density standard for single-family in the R-3 zone is exceeded. The applicant has applied for a PUD and is requesting exceptions from the single-family minimum lot size, single-family and townhouse lot minimum street frontage standards, and single-family maximum density for R-3, which is addressed in Section 8.275 of this staff report.

The proposed subdivision is located in city limits, does not include land zoned for business or industrial use, and the site does not contain any steep terrain; therefore, subsections A., B., and C. of this section do not apply.

3. *Frontage.* Each newly created lot and parcel shall abut upon a public street other than an alley for at least 50 feet (at least 25 feet in Mixed Use zones). Lots fronting on the bulb of a cul-de-sac the minimum frontage shall be 30 feet. Flag lots shall have no less than 20 feet of street frontage measured at the property line. Townhouse frontage shall be at least 20 feet. Vehicular access shall be provided as specified in Section 8.2820, Access Management Standards, of this Chapter, or as specified in Section 8.2705(6.) below, for residential lots and parcels abutting collector and arterial streets. All lot and parcels shall be addressed from the primary public street frontage, not including alleys.

FINDING: The applicant is proposing townhouse lots in the R-3, R-4, and R-5 zones, which meet the minimum street frontage standard of 20 feet with exception of proposed Lots 129-132. The applicant is proposing 245 single-family lots in the R-3, R-4, and R-5 zones in which 60 lots do not meet the minimum street frontage standard. The applicant is requesting an exception to the minimum street frontage standard for 60 single-family lots and four townhouse lots as part of the PUD application, which is addressed in Section 8.275 in this staff report.

4. *Side Lot or Parcel Lines.* All side lot lines shall be at right angles to street lines or radial to curved streets wherever practical except as provided for in Subsection (10.) of this Section.

FINDING: The tentative plan shows that all side lot lines are generally at right angles to street lines or radial to curves. The proposed development meets the intent of this standard.

5. *Through/Double Frontage Lots and Parcels.* Through lots or parcels, and lots or parcels with double frontage shall be avoided whenever possible, including lots or parcels created adjacent to Collector and Arterial Streets, but not including alley frontage as described in Section 8.2705(6.) below, except when they are necessary due to an irregular parent lot or parcel configuration, or are necessitated by topography or other unique circumstance.

FINDING: The proposed subdivision includes one double-frontage lot – proposed Lot 270 as it will have frontage on both Horizon Peak Road and SW 45th Street. Staff has deemed the proposed double-frontage lot as acceptable but will require vehicular access be taken off Horizon Peak Road.

6. *Residential Lots and Parcels Abutting Collector and Arterial Streets.* Lots and parcels created adjacent to Collector and Arterial streets shall be oriented so that the front elevation of the residential development faces the Collector or Arterial Street. Vehicular access shall be provided pursuant to Section 8.2820, Access Management Standards, of this Chapter. In instances where direct vehicular driveway access to lot or parcel from the Collector or Arterial Street is not permissible, alley access shall be provided to the rear of the lot or parcel in accordance with the design standards included in Section 8.2710(3.) of this Chapter.

FINDING: As shown on the tentative plan, no lots will abut SW Helmholtz Way, an arterial street, as lots will be separated from SW Helmholtz Way by Tracts O, P, and Q. This standard is met.

7. *Corner Lots and Parcels.* Corner lots and parcels shall be five feet more in width than other lots and parcels and also shall have sufficient extra width to meet the additional side yard requirements of the zoning district in which they are located.

FINDING: As shown on the tentative plan, the proposed subdivision includes several corner lots. While generally the corner lots are adequate in size to accommodate the additional side yard requirements, proposed single-family corner lots 139, 242, 301, and 319 do not meet the minimum frontage requirement and as part of the PUD request are requesting an exception to the minimum access clearance to the corner standard.

8. *Special Building Setback Lines.* If special building setback lines, in addition to those required by the applicable zoning, are to be established in a development, they shall be shown on the final plat of the development and included in the deed restrictions.

FINDING: For proposed townhouse lots 116-132, vehicular access is being proposed via a private easement alley on said lots. The rear setback for a townhouse with garage and alley access in the R-3 and R-4 zones is only five feet. Additionally, per the City's Access Management Standards [Sec. 8.2820(8)], a minimum of 24 feet of backing distance shall be provided. In order to comply with the aforementioned standards, a special setback line shall be designated and measured from the southern edge of the access easement, rather than from the northern property line, and included in the deed restrictions for lots 116-132.

9. *Large Building Lots; Re-division.* In the case where lots or parcels are of a size and shape that future redivision is possible, the Review Authority, may require that the blocks be of a size and shape so that they may be redivided into building sites, and the development approval and site restrictions may require provision for the extension and opening of streets at intervals which will permit a subsequent redivision of any tract of land into lots or parcels of smaller sizes than

originally platted, and in conformance with the density provisions established in the City of Redmond Comprehensive Plan for the existing or intended Zone. A plan indicating the ability for re-division according to these standards may be required as part of the initial land division process.

FINDING: The applicant is proposing 245 lots intended for single-family dwellings and 76 lots intended for townhouses. Given the general lot sizes proposed, staff has determined that no re-division plan is needed or required.

10. *Curvilinear Street and Block Design.* Although a basic grid street design with minimum and maximum block lengths are requirements of this Section, a curvilinear street/block design is encouraged for the purpose of adding interest to new subdivision development.

FINDING: As shown on the tentative plan, curvilinear street design has been proposed exclusively. As the standard states, a basic grid street design that complies with block length standards are required. As proposed, this standard is not met and the applicant has requested an exception to this standard as part of the PUD application, which is addressed in Section 8.275 in this staff report.

11. *Flag Lots.* A flag lot shall be considered as a "flag lot" if the pole of the flag lot is less than half the width of the average lot width. For flag lots, the following shall be required:

    A. Flag poles shall be no less than 20 feet wide. Flag lot frontage can be reduced by approval from Redmond Fire & Rescue and City Engineer.

    B. All zone regulations apply, including the minimum required lot size and setbacks unless setback reductions are allowed as described in (E).

    C. Each flag lot shall contain a minimum 12-foot-wide paved driveway.

    D. A flag lot is exempt from the 50-foot street frontage requirement; however, a minimum of 20 feet of street frontage is required.

    E. Front and/or rear yard setbacks may be reduced to no less than ten feet subject to review and approval by the Community Development Director. The orientation of any structure (determination of front) may be suggested by the property owner and is subject to the review and approval of the Community Development Director, or designee. The location(s) of all structures immediately adjacent to any flag lot shall be shown on a site plan (1) during planning review and during the act of creating any new flag lot, and (2) during a building permit review for any structure built on a flag lot.

    F. No flag lot shall be partitioned or further divided, except as provided for by middle housing.

    G. The "pole" of the flag lot shall be no longer than 150 feet measured from the street intersection to the beginning of the base of the flag.

    H. The "pole" of the flag shall not be included in the minimum lot size calculation.

    I. Flag lots shall be exempt from street tree requirements unless the street frontage portion of the flag lot is 30 feet or greater.

    J. Flag lots are prohibited along or abutting the Dry Canyon Rim.

    K. Two off-street parking spaces shall be provided for single family detached dwellings; and one space per unit for middle housing on a flag lot.

FINDING: The proposed subdivision does not include the creation of any flag lots; therefore, these standards do not apply.

Sec. 8.2710. Streets.

1. *General.* Streets shall be in conformance with the City of Redmond Transportation System Plan as specified herein.

   A. Except along Arterial Street, public streets shall be spaced a maximum of 660 feet between centerlines. The purpose is to provide a street grid pattern of through streets to facilitate traffic movement. Street designs shall conform to topography and other existing natural and man-made conditions. Illustrative examples of other conditions include the dry canyon, main COI canal, Highway 97, and the Burlington Northern Railroad tracks.

FINDING: The applicant has proposed a curvilinear street design with several blocks exceeding 660 feet in length between street center lines.[10] Horizon Peak Road from Horizon Peak Road to Horizon Crest Lane (~1,035 feet); Horizon Peak Road from Horizon Crest Lane to Serenity Skyway (~2,525 feet); and Horizon Peak Road from Horizon Crest Lane to Horizon Peak Road (~1,255 feet) and from Dawn Meadow Street to Horizon Peak Road (~955 feet). The applicant has requested an exception from this standard, which is addressed in Section 8.275.

   B. All proposed streets, sidewalks, bike lanes and pedestrian pathways shall connect to other streets, sidewalks bike lanes and pedestrian pathways within a development and to existing and planned streets, sidewalks, bike lanes and pedestrian pathways outside the development. Such facilities shall serve existing and planned parks, schools, or other public lands within a neighborhood.

FINDING: As shown on the applicant's plan set, the proposed subdivision includes streets, sidewalks, and pedestrian pathways that will connect to other streets, sidewalks, and pathways to existing and planned streets, sidewalks, and pathways outside of the development. Internal to the site the proposed streets, sidewalks, and pedestrian pathways provide connections internally in a non-grid designed network. No bike lanes are required or proposed.

   C. To the maximum extent possible, new local streets shall align and connect with existing local streets and collectors, and in certain special cases arterial streets. Cul-de-sac streets shall be permitted only where no feasible connection with an adjacent street exists, or if the local street connection would be to an arterial street and the function of the arterial street may be diminished as determined through the land use review process, or the block length would be less than that which is permitted by Section 8.2705(1.B.).

FINDING: As shown on the tentative plan, the proposed subdivision's local streets will align and connect with planned SW 51st Street, C Street, and SW 45th Street. Additionally, the subdivision proposes access via a new local street (Dusk Valley Road) to an adjacent minor arterial, SW Helmholtz Way. This connection point is permitted given that its location complies with the minimum intersection spacing standards for a minor arterial street. This standard is met.

[10] Redmond Code Section 8.2020: Definitions, defines 'Block' as "An area of land bounded by streets or by a combination of streets and public parks, cemeteries, railroad rights-of-way or lines, shore lines or waterways, natural topographical barriers, or City limit."

D. Consideration should be given to alternative street designs other than required herein in the City's non-residential land use zones to allow for more effective developments. Such designs may be considered and approved during the subdivision or partition process without need for variance.

FINDING: The proposed subdivision is in a residential zone; therefore, this standard is not applicable.

E. All proposed or required streets and alleys shall comply with Section 8.2820 Access Management Standards, the Transportation System Plan, and with Local Street Connectivity Plans adopted as part of the transportation element of the Comprehensive Plan.

FINDING: Compliance with the City's access management standards are discussed in Section 8.2820 below. As part of the PUD, the applicant is requesting exceptions to some of the access management standards. The proposed right-of-way dedication and improvements to SW Helmholtz Way comply with the City's Transportation System Plan.

2. *Existing Streets.* Whenever existing streets, adjacent to or within a tract, are of inadequate width per Public Works Standards and Specifications and the City's approved Transportation System Plan additional right-of-way shall be provided at the time of the land division by the applicant. During consideration of the tentative plat for the subdivision or partition, the Review Authority shall determine whether the improvements to existing streets, adjacent to or within the tract, are required. If so determined, such improvements shall be required as a condition of approval of the tentative plat. Improvements to adjacent streets shall be required where traffic on said streets shall be directly affected by the proposed subdivision. Notwithstanding these provisions, off-site improvements to streets not within or adjacent to the development may be required when impacts resulting from the development necessitate such improvements as demonstrated through a transportation impact analysis.

FINDING: The only existing street that is adjacent to the proposed subdivision is SW Helmholtz Way, a minor arterial street, as identified in the Transportation System Plan. As required and proposed, right-of-way dedication to achieve a full 50 feet from centerline will occur in addition to improving the western half of SW Helmholtz Way up to minor arterial standards along Horizon Pointe's frontage. This standard is met.

3. *Existing Access Easements.* Whenever existing unpaved access easements, adjacent to or within a tract, the Review Authority may require paving to City standards at the time of the land division by the applicant.

FINDING: The only unpaved access easements adjacent to or within a tract will include the COID easements. COID has full control over how their easements are improved; however, as required by the City's Transportation System, a paved multi-use path will be required within the COID easements.

4. Minimum Right-of-Way and Roadway Standards. The minimum street right-of-way widths shall be in conformance with Table 1 below. Additional right-of-way may be required at intersections to accommodate intersection widening and roundabouts

Table 1 - Minimum Right of Way Width Standards	
Functional Classification	**Minimum Right of Way Width**
Minor Arterial	100 feet
Major Collector	80 feet
Minor Collector	60 feet
Industrial Collector	80 feet
Industrial Local	60 feet
Local Residential	60 feet
Alley	20 feet
Cul-de-sacs	108 feet

Street surfacing, sidewalks or multi-use paths, travel lanes, medians, planter strips, curbs and bicycle lanes must be installed in conformance with the Public Works Standards and Specifications and the Transportation System Plan. Oregon Department of Transportation (ODOT) facilities must meet ODOT design standards.

FINDING: The proposed subdivision includes 14 local streets designed with 60 feet of right-of-way. Adjacent to the eastern portion of the subject property is SW Helmholtz Way, a minor arterial street as identified in the Transportation System Plan. The applicant is required to dedicate 50 feet of right-of-way from centerline along the property's frontage. Additionally, the applicant will be required to dedicate 30 feet of right-of-way for the western half of SW 45th Street. Lastly, alleys proposed will be required to have a minimum of 20 feet of right-of-way.

5. *Future Extension of Streets.* When necessary to give access to or permit a satisfactory future division of adjoining land, streets shall be extended to the boundary of the subdivision or partition and the resulting dead-end streets may be approved without a permanent turn around if they are 150 feet or less in length, although, an adequate temporary turn around to ensure emergency vehicle access must be provided if such streets are greater than 150 feet in length.

FINDING: As shown on the proposed tentative plan, seven proposed streets will extend to the boundary of the subdivision allowing for future connections when adjacent properties develop. Redmond Fire and Rescue may require an approved turnaround for dead-end streets in excess of 150 feet. This standard can be met by complying with conditions of approval. Staff notes that the proposed Horizon Peak Place and Cloudview Drive extensions to the property boundary is not required as the adjacent lands are outside of the urban reserve area, and as such, the City is not required to plan for urban infrastructure outside of the urban reserve area. This standard is met.

6. *Collector and Arterial Street Access.* Notwithstanding the provisions of Section 8.2705 of this Chapter, if a land division abuts or contains an existing or proposed collector or arterial street, the Review Authority, may require other treatments, including but not limited to frontage roads, necessary for adequate protection of residential properties and to afford separation of through and local traffic. Provision may be made for emergency access. All frontage roads shall comply with the City of Redmond Transportation System Plan.

FINDING: The proposed subdivision does not contain an existing or proposed collector or arterial street and does not directly abut a collector or arterial street (SW Helmholtz Way is will be separated by Tracts O, P, and Q); therefore, this standard does not apply.

7. *Streets Adjacent to Railroads, Freeways and Parkways.* When the area to be subdivided or partitioned is residentially zoned and abuts a railroad, freeway, or parkway, a provision may be required for a street approximately parallel to and on either side of such right-of-way at a distance suitable for use of the land between the required street and the abutting railroad, freeway, or parkway. In the case of a railroad, there shall be a land strip of not less than 25 feet in width between the railroad right-of-way and residential property. The land strip must be occupied by the fire-resistant materials, and may contain a fence, a trellis, a wall, or small decorative or artistic feature. If the intervening property between such parallel streets and a freeway or a parkway is less than 80 feet in width, such intervening property shall be dedicated to a passive-style park or thoroughfare use by bicycles and/or pedestrians. The intersections of such parallel streets, where they intersect with streets that cross a railroad, shall be determined with due consideration as cross streets of a minimum distance required for approach grades to a future grade separation and right-of-way widths of the cross street.

FINDING: Although the proposed subdivision is residentially zoned, it does not abut a railroad, freeway, or parkway; therefore, this standard is not applicable.

8. *Continuation of Streets.* Subdivision or partition streets which constitute the continuation of streets in contiguous territory shall be aligned so that their center lines coincide. Where straight line continuations are not possible, such center lines shall be continued as curves. These streets or the continuation of streets in contiguous territory may be required by the Review Authority, where such continuation is necessary to maintain the function of the street or desirable in the surrounding area.

FINDING: There are no existing street stubs abutting the proposed subdivision; however, the proposed subdivision layout includes, with proper alignment, the continuation of the future street extensions of SW 51st Street and C Street from the adjacent Little Texas development. Additionally, needed right-of-way will be dedicated along with frontage improvements for the future extension of SW 45th Street. This standard is met.

9. *Street Names.* Except for extensions of existing streets, no street names shall be used which will duplicate or be confused with the name of an existing street in a nearby city or in the County. Street names and numbers shall conform to the established pattern in the City, including the continuation of street names across intersecting streets, and shall be subject to the approval of the Redmond Fire and Rescue and Deschutes County.

FINDING: As shown on the tentative plan, the proposed subdivision does propose continuation of SW 51st Street, C Street, and SW 45th Street. As stated in this standard, continuation of street names and numbers is subject to the approval of the Redmond Fire and Rescue and Deschutes County.

10. *Sidewalks.* Sidewalks are required to be installed on both sides of a public street and in any special pedestrian way within the subdivision or partition that comply with the City of Redmond Transportation System Plan. In the case of collectors, arterials, special industrial districts or in steep terrain, the Review Authority may approve a subdivision or partition without sidewalk if alternative pedestrian routes are available or provided by the developer. Sidewalks shall be required along routes to existing or future school and park sites.

FINDING: As shown on the tentative plan, all proposed streets will have sidewalks installed on both sides. Additionally, installation of sidewalks will be required along the property frontages of SW 45th Street and SW Helmholtz Way.

11. *Bicycle Facilities and Multi-Use Pathways.* Bicycle facilities and multi-use pathways are required to be installed within the subdivision or partition that comply with the City of Redmond Transportation System Plan.

FINDING: As identified in the Transportation System Plan (project IDs B1 and B67), a multi-use pathway will be required, and is being proposed within the COID B and B-5 lateral easements. These pathways shall be designed according the City's Standards and Specifications.

12. *Intersection Angles.* Street intersections shall be as near right angles as possible except where topography or existing conditions requires a lesser angle, but in no case shall the acute angle be less than as permitted by the adopted Public Works Standards and Specifications.

FINDING: As shown on the tentative plan, the proposed subdivision will include numerous street intersections, all of which are shown at near right angles as possible. This standard is met.

13. *Alignment.* Staggered street alignment shall whenever possible, leave a minimum of 200 feet distance between the center line of the streets, but in no case be less than as permitted by Public Works Standards and Specifications.

FINDING: This standard applies to a traditional grid street system for which the applicant is not proposing; however, the close proximity of intersecting streets along Horizon Peak Road between Horizon Light Road and Serenity Skyway do not appear to meet a minimum of 200 feet distance from centerlines.

14. *Narrow Streets.* Local streets designed at widths less than 36 feet may be permitted subject to the following:

    A. The narrow street is internal to a Subdivision or Planned Unit Development with street connections on both ends.

    B. All lots adjoining the narrow streets are at least 5,000 square feet and have a minimum 50 feet of frontage.

    C. Sidewalks, curbs, and street trees conforming with Public Works Standards and Specifications shall be installed.

    D. Curb cuts along the narrow street shall not be less than the minimum width required within the adopted Public Works Standards and Specifications.

    E. Covenants, Conditions, and Restrictions (CC&Rs) and a Homeowners Association (HOA) are established for the development. The CC&Rs must effectuate the HOA as responsible for parking enforcement.

FINDING: The proposed subdivision does not propose narrow streets; therefore, this standard is not applicable.

15. *Private Steets.* Private streets must be approved by the City Engineer. The City Engineer may require private streets to meet public standards. Private streets must comply with fire code and access management standards and will only be permitted when accompanied by CC&Rs that designate an HOA as responsible for maintenance and repair.

FINDING: The proposed subdivision does not propose any private streets; therefore, this standard does not apply.

Sec. 8.2715. Fundamental Design Standards.

1. *Lighting.* The subdivider or partitioner shall provide underground wiring to the City standards and a base for any proposed ornamental streetlights at locations approved by the affected utility company.

FINDING: The applicant acknowledges this standard will be applied when proposing street lighting. Utility improvements will be reviewed by the City's Engineering Department as part of the public improvement review process.

2. *Multiple* Access *Points.* Whenever possible, a minimum of two points of access to the subdivision or partition shall be provided to provide assured access for emergency vehicles and ease resident evacuation.

FINDING: The applicant's plan set indicates that the proposed subdivision will have multiple points of access to the subdivision. Specifically, direct access onto SW Helmholtz Way will be constructed during phase 1; a second access point to SW Helmholtz Way, via SW 45th, will be constructed during phase 3; and phases 4 and 5 will provide direct connections to the future Little Texas development via C Street and SW 51st Street, respectively. Lastly, the applicant is proposing future connection points to the adjacent property to the south via Horizon Light Road and Horizon Echoes Road in phases 1 and 2, respectively. This standard is met.

3. *Water/Sewer.* All subdivisions and partitions shall provide water and sewer lines constructed to City standards and specifications approved by the City Engineer. All lots or parcels shall be served from the City of Redmond water and sewer systems or by water and sewer systems acceptable to the City. Water and sewer mains and service lines shall be installed prior to the curbing and paving of new streets in all new subdivisions or partitions.

FINDING: All proposed lots will be served by City water and sewer. Extension of water and sewer mains will be required and specifications and standards that will require compliance are detailed in conditions of approval.

4. *Underground Utilities.* All permanent utility service, cell service, and minor power transmission lines that are within or immediately adjacent to lots in a subdivision or parcels in a partition shall be provided from underground facilities unless otherwise approved by the Review Authority. The

subdivider, partitioner, or developer shall be responsible for complying with requirements of this Section and shall:

A. Obtain a permit from Public Works for placement for all underground utilities within the public right-of-way.

B. Make all necessary arrangements with the utility companies and other persons or corporations affected by the installation of such underground utilities and facilities in accordance with rules and regulations of the Public Utility Commission of the State of Oregon.

C. All underground utilities, water lines, sanitary sewer lines and storm drains installed in streets shall be constructed prior to the surfacing of such streets to the extent practicable, and water and sanitary sewer service lines shall be placed to such lengths as will negate the necessity for disturbing the street improvements when service connections are made.

FINDING: The applicant shall coordinate directly with the City's Engineering Department and utility companies during construction plan review. These standards can be met by complying with conditions of approval.

5. *Preservation of Natural Features.* Existing natural features (i.e., rock outcrops) add character to the development and shall be preserved to the greatest extent practicable.

FINDING: The applicant has stated that all effort has been made to design the site to mitigate the amount of demolition necessary for development and that the location of the rock outcroppings influenced the placement of the proposed piped COID canal and home and street placement. Staff determines that this standard is met.

6. *Preservation and Replacement Trees.* All deciduous or coniferous existing trees having a ten-inch trunk diameter 4.5 feet above grade or greater are considered significant and shall be preserved or replaced at a 'one-to-one' ratio. Replacement trees shall have a minimum 1-1/2-inch trunk diameter measured at 4.5 feet above grade. This criterion shall be met in the submitted landscape plan. Street trees are counted as replacement trees. Trees removed for installation of public infrastructure are not required to be replaced, however they should be preserved where possible. The Community Development Director, or designee, may prohibit removal of significant trees located within the setback along the perimeter of the parcel to be developed, located adjacent to water features, or that provide screening or buffering to existing development where not located within the proposed or potential building footprint. An alternate restoration plan may be approved by the Community Development Director, or designee.

FINDING: The applicant's plan set indicates that no trees are being considered for preservation. The applicant states that 369 trees with a diameter greater than 10" will be removed during development. Replacement with trees that have a minimum 1 ½-inch trunk diameter measured at 4.5 feet above ground at a one-to-one ratio will be required. This standard is met.

7. Easements.

A. *Utility Easements.* Easements shall be provided along property lines when necessary for the placement of underground utilities and to provide the subdivision or partition with electric

power, communication facilities, street lighting, sewer lines, water lines, gas lines, or drainage. Such easements shall be labeled "Public Utility Easement" on the tentative and final plat; they shall be at least 12 feet in width and centered on lot lines where possible, unless determined otherwise by the City Engineer or designate. Excepting utility pole guylines easements along the rear of lots adjacent to unsubdivided land may be reduced to ten feet in width, unless determined otherwise by the City Engineer or designate.

B. *Drainage.* If a tract is traversed by a water course, such as a drainage way, channel or stream, there shall be provided a stormwater easement or drainage right-of-way conforming substantially with the lines of the water course or in such further width as will be adequate for the purpose. Streets or parkways parallel to major water courses and drainage ways may be required.

FINDING: The applicant's plan set depicts Public Utility Easements (PUEs) along public street rights-of-way. There is an existing Central Oregon Irrigation District (COID) B-5 sub lateral that bisects the subject property east to west as well as two delivery ditches (B-5-1 and B-9) and the B lateral along the western edge of the property (plan set shows a 20-foot-wide ditch rider easement is proposed through the backside of several lots along the development's western edge as well as through open space Tract J). Each of these includes rights-of-way of varying widths. The applicant shall coordinate with COID for the piping and requirements of working within and around the easements as discussed in COID's comments presented in Attachment C.

8. Fully developed "pocket parks" or "tot lots" shall be incorporated into medium and high density zoned residential subdivisions and site plans. These areas shall be developed for every 25 lots/units, a minimum of 3,000 square feet and privately maintained. Park amenities shall, at a minimum, include: 1/2 of the park dedicated to turf areas, benches, trees, shrubs, ground cover, irrigation, other landscape or decorative features, and acceptable trash receptable(s) and lighting.

FINDING: The proposed PUD is located in the R-3, R-4, and R-5 zones, all of which are considered medium and high-density zones. As such, the applicant is proposing a total of 321 residential lots, which will require at least 36,000 square feet of pocket parks. The applicant's plans show Tracts G, H, I, J, and R as areas eligible for meeting the pocket pock requirement. Said tracts amount to a total of 66,857 square feet, exceeding the standard. All open space tracts must be privately maintained and will require City review and approval of landscaping and amenities prior to final platting. Note: staff did not include all other tracts as part of the pocket park calculation due to the fact the tracts are intended for the Transportation System Plan-required multi-use pathways, walkway connectors, and urban-rural interface buffering.

9. Urban-Rural Interface. Residential subdivisions adjacent to areas outside of the Urban Reserve Area (URA) shall provide buffering to manage the transition from urban to rural intensities by meeting at least one of the following standards:

A. Provide landscaped buffers at least 100 feet wide, exclusive of rights-of-way, for the entire length that the urban development is adjacent to lands outside of the URA. The buffers shall be landscaped with native vegetation characteristic of the local ecosystem; or

B. Locating lower density development at the urban-rural interface; or

C. Other appropriate and equivalent transitional elements as approved by the Review Authority.

FINDING: The proposed development abuts the urban reserve area (URA) boundary to the west and northwest. Specifically, to the west and northwest is land zoned Exclusive Farm Use, which has a purpose of preserving and maintaining agricultural lands and to serve as a sanctuary for farm uses, and is located outside the urban growth boundary and urban area reserve.[11] The applicant has designed the proposed development in such a way that generally larger single-family lots are located along the development's northwestern edge along with 20-foot-wide open space Tracts S and T. Additionally, along the western boundary is COID's B Lateral of the Pilot Butte Canal, which includes a total easement of 70 feet in width – 45 feet of which lies within the subject property and in part includes the applicant's proposed open space Tract D. Staff believes that the combination of the COID B Lateral and Tract D will provide adequate buffering between the existing rural farmland and the proposed urban development; however, Tracts S and T as presented do not demonstrate adequate buffering with the adjacent rural lands to the north.

Sec. 8.2720. Grading of Building Sites.

Grading of building sites shall conform to the City of Redmond Public Works Standards and Specifications.

FINDING: This standard will be applied after the applicant receives tentative plan approval. A subdivision site grading and drainage plan with erosion/sediment control plan and drainage report will be required upon development of each project phase per current City standards.

ARTICLE III – LAND DIVISION STANDARDS > SUPPLEMENTARY PROVISIONS

RC Sections 8.2800, and 8.2815-8.2825

Sec. 8.2800. Improvement Procedures.

In addition to other requirements, public or private improvements to be installed by the applicant either as a requirement of these standards or other applicable regulations or at his or her own option, shall conform to the requirements of this Article:

1. *Plan Review and Approval.* Improvement work shall not be commenced until plans thereof have been reviewed and approved by the Community Development Director, or Hearings Body, or a designated representative thereof. To the extent necessary for evaluation of a proposed development, such improvement plans may be required before approval of the tentative plat or preliminary map or drawing.
2. *Public Improvements as Platted.* Public improvements shall be designed, installed, and constructed as platted and approved by the City Engineering Division, and plans shall be filed with the final plat at the time of recordation or upon completion.
3. *Inspection.* Improvements shall be constructed under the inspection and approval of a city Inspector. Expenses incurred thereby shall be borne by the applicant/owner. The inspector may require changes in sections and details of the improvements if unusual conditions arise during construction to warrant such changes.
4. *As-Built Plans.* A map showing the completed public improvements shall be filed with the Community Development Department upon completion of the improvements.

[11] Deschutes County Code, Chapter 18.16 Exclusive Farm Use Zone; EFU, Section 18.16.010 Purpose.

FINDING: This section is procedural and must be complied with following tentative plan approval.

Sec. 8.2815. Transportation System Analysis.

It shall be the burden of the developer to evaluate transportation system impacts when a proposed development involves either a Subdivision, Site and Design Review, Planned Unit Development, Master Development Plan, Comprehensive Plan and Zone Map Amendment, a change or expansion of use, or any other development that the City Engineer deems necessary. Transportation System Analyses are not required for residential site plan review for up to four units or Partitions.

Transportation System Analyses are approved based on the information presented in the report and must not be older than 180 days from approval at the time the land use application is deemed complete. If the associated land use application is not deemed complete prior to the expiration, the City may require the approved report be updated.

[…]

FINDING: The applicant submitted a Transportation System Analysis Application (TSAA) and a Traffic Impact Analysis (TIA) conducted by Ferguson & Associates, Inc., dated May 2024. The TSAA and TIA have been reviewed and approved by City Engineering. Transportation mitigation requirements have been incorporated into the conditions of approval [see also, TSA approval memo, dated July 29, 2024 (revised April 28, 2025), in Attachment E].

Sec. 8.2820. Access Management Standards.

Access management standards apply to new developments, redevelopments, subdivisions, and partitions.

Location of Access Points.

1. Access shall be taken from the lower order street or alley unless otherwise approved by Public Works and/or ODOT. Access to higher order streets may be allowed for emergency vehicles when restricted with a locked fire gate, bollards or similar, when approved or required by Redmond Fire and Rescue.

FINDING: According to the tentative plan, all proposed lots will be accessed via local streets or alleys. No direct access will be provided via SW Helmholtz Way. This standard is met.

2. Every lot or parcel shall be limited to one point of access, subject to the following exceptions:
    A. *Single Family Dwellings, Accessory Dwelling Units, Plexes, Mixed-Use Developments.*
        1. Lots with multiple frontages on local roadways or alleys may be permitted one access per frontage, provided the driveways meet all other required standards.
        2. Lots with accessory structures requiring vehicular access, such as a shop or detached garage, may be permitted two access points, provided the lot frontage is on a local roadway, the driveways are separated by a minimum of 10 feet, and the driveways meet all other required standards.
    B. *All Other Uses.*
        1. Lots may be permitted a secondary access when it is demonstrated that the additional access improves on-site circulation, does not adversely impact the

operations of the transportation system, and when approved by the City Engineer or designee.

FINDING: The layout and design of the proposed subdivision's single-family and townhouse lots are such that only one access point to each lot will be permitted. This standard is met.

3. Lots with more than one existing access may be required to close an existing street access upon redevelopment. This standard may be waived when access to an existing, permanent garage structure would be removed, or removal of the access would result in increasing the nonconformity of the site.

FINDING: The proposed subdivision includes newly-created lots and it is anticipated that each lot will have its own (new) access. Proposed lot 247 is the site of an existing single-family dwelling to be retained. The applicant is proposing a singular new access point will be constructed for lot 247. This standard is considered met at this time.

4. In the event that the access management standards cannot be achieved on the subject property, shared access with adjacent property may be permitted. When a driveway serves more than one lot, the developer must record an access and maintenance easement/agreement to benefit each lot prior to building permit issuance. Shared access points should be centered on property boundaries when possible.

FINDING: The applicant acknowledges this standard. The specific location of the proposed lots' driveways will be determined during zoning conformance review as part of the building permit application submittal. This standard may be applicable at that time.

5. In all instances, access near an intersection shall be located beyond the influence of standing queues and opposing left turns sharing a continuous two-way left turn lane. This requirement may result in greater corner clearance or access spacing than the minimum distance indicated.

FINDING: The applicant acknowledges this standard. The specific location of the proposed lots' driveways will be determined during zoning conformance review as part of the building permit application submittal. This standard may be applicable at that time.

Design of Access Points.

6. The City Engineer or designee may require access locations to align with existing driveways on the opposite side of the roadway, be located as far from driveways on the same side of the street or intersections as possible, or to be right-in/right-out. Right-in/right-out may be required when the access is located within 300 feet of a signalized intersection or roundabout.

FINDING: The specific location of the proposed lots' driveways will be determined during zoning conformance review as part of the building permit application submittal. This standard may be applicable at that time.

7. Property-tight driveway aprons excluding the wings must be located a minimum of three feet from property lines, and curb-tight driveway aprons excluding the wings must be located a minimum of six feet from property lines, unless the access is approved to be shared.

FINDING: The specific location of the proposed lots' driveways will be determined during zoning conformance review as part of the building permit application submittal. This standard may be applicable at that time.

8. A minimum of 24 feet of backing distance shall be provided and shall be measured from the rear end of a perpendicular parking stall or garage door face to the opposite end of a paved alley or roadway. If the abutting alley or street is unpaved, the measurement shall be taken to the opposite end of the right-of-way. If the backing distance is demonstrated onsite, the measurement shall be taken to the nearest barrier, such as a property line, retaining wall, fence, or edge of driveway.

FINDING: The specific location of the proposed lots' driveways will be determined during zoning conformance review as part of the building permit application submittal. This standard may be applicable at that time. However, to ensure compliance with this standard for proposed townhouse lots 116-132, a special rear setback line is required as a condition of approval.

9. Corner clearance shall be provided and is measured from the edge of right-of-way to the nearest edge of the access. Spacing is measured from centerline of access/intersection to centerline of access/intersection. Driveway spacing and corner clearance is required as follows:

   All land use approvals shall be in compliance with the following standards.

Roadway Classification	Minimum Access Driveway Spacing	Minimum Access Clearance to Corner	Intersection Spacing (Min.)
Local Street	No Restrictions	30 ft	165 ft
Minor Collector	50 ft	80 ft	330 ft
Major Collector	165 ft	165 ft	330 ft
Minor Arterial	330 ft	330 ft	1/4 mile
Major Arterial	ODOT Stds	ODOT Stds	ODOT Stds

FINDING: The specific location of the proposed lots' driveways/access points will be determined during zoning conformance review as part of the building permit application submittal. However, all proposed lots will have access onto local streets, as such, there are no minimum access driveway spacing restrictions. A minimum access clearance to corners for driveway placements will require 30 feet. As part of the PUD exceptions in Section 8.275, the applicant is requesting that the driveway minimum access clearance to corner for proposed lots 22, 139, 242, 269, 270, 290, 301, and 319 be reduced to 20 feet. Additionally, as part of the PUD, the applicant is requesting an exception to the intersection spacing standard for the intersections that do not meet the minimum spacing requirement of 165 feet. These include Horizon Peak Road between Horizon Peak Road and SW 45th Street (~160 feet), Horizon Peak Road between Horizon Light Road and Dusk Valley Road (~155 feet), and between Dusk Valley Road and Morning Vista Road (~130 feet). All other local street intersections meet the minimum 165 feet spacing requirement. Lastly, the minimum standard for intersection spacing along SW Helmholtz Way, a minor arterial, is 1,320 feet, which is met between the intersections of SW 45th Street, Dusk Valley Road, and SW Wickiup Avenue.

Additional Standards.

10. Adequate intersection sight distance and clear zone shall be maintained at all access/driveway locations per AASHTO standards (American Association of State Highway and Transportation Officials).

FINDING: The specific location of the proposed lots' driveways/access points will be determined during zoning conformance review as part of the building permit application submittal. This standard may be applicable at that time.

11. Access within the North Redmond US 97 Interchange Area Management Plan (IAMP) shall also conform to the 2007 "North Redmond US 97 Interchange Area Management Plan (IAMP)," as amended.

FINDING: The proposed subdivision is not located within the geographic area of the North Redmond US 97 Interchange Area Management Plan (IAMP); therefore, this standard is not applicable.

12. Public Works may require supporting information, including but not limited to traffic count data, trip generation, trip distribution, truck and trailer turning/backing templates and/or onsite circulation diagram. Transportation Impact Analysis study, etc., in order to make a proper determination of access/driveway location.

FINDING: The specific location of the proposed lots' driveways/access points will be determined during zoning conformance review as part of the building permit application submittal. This standard may be applicable at that time.

Sec. 8.2825. Street Dedications.

Any person desiring to create a street not part of a subdivision or partition shall make written application to the Community Development Department.

1. *Application.* Said application shall be accompanied by the required information and appropriate filing fee. In cases where such dedication would have the effect of creating a land division, the dedication shall be treated as a new subdivision or partition as applicable.
2. *Minimum Design Standards.* The minimum standards of design and improvements for the dedication of a street shall be in compliance with the City of Redmond Public Works Standards and Specifications and all other applicable street standards and regulations as specified in Section 8.2710.
3. *Procedure.*
    A. Upon receipt of written application and appropriate filing fee for street dedication, the Community Development Director shall refer the proposal to the City Engineer, or designee, for review and recommendation.
    B. The City Engineer shall report his or her findings and recommendations regarding the proposed dedication to the Community Development Director.
    C. Upon receipt by the Community Development Director of written findings and recommendations from the City Engineer, the proposal shall be submitted to the City

Council for a public hearing, unless part of a proposed project undergoing Planning Commission review.

D. The only notice required for a hearing under this Section shall be by publication.

E. Following the hearing, the Council may accept or reject the proposed dedication.

FINDING: All proposed streets are part of the proposed Horizon Pointe planned unit development subdivision; therefore, this standard does not apply.

Conclusion:

Based upon the submitted plans, materials, and the proposed findings included herein, staff does not believe that all requirements have been fulfilled to support the Horizon Pointe Planned Unit Development, Tentative Subdivision Plan, and Conditional Use consistent with all applicable City policies, rules, and regulations.

III. RECOMMENDATION & CONDITIONS OF APPROVAL

Recommendation:

Based on the submitted plans, staff findings and conclusions, staff recommends the Planning Commission deny the Horizon Pointe Planned Unit Development, Tentative Subdivision, and Conditional Use applications (File Nos. 711-24-000216-PUD, 711-25-000086-SUB, and 711-25-000087-CU).

If the Planning Commission decides to approve the applications, staff recommends the conditions of approval presented below. It should be noted, however, that complying with the proposed conditions of approval would necessitate a significant redesign of the project, and thus likely require a new submittal.

Conditions of Approval:

The following conditions of approval shall be required:

1. Any substantial alteration to the approved plans, except as modified by the following conditions of approval, shall be subject to the standards and procedures in RC Sections 8.275(6), PUD Post Approval & Modifications, and 8.1400, Modifications of Approval.

2. The Hadfield and Nelson Lot Line Adjustment (File No. 711-25-000248-LLA) must be approved and executed prior to platting Phase 1.

3. The applicant shall revise Tracts S and T to demonstrate compliance with the urban-rural interface as required by Redmond Code Section 8.2715(9).

4. All open space tracts must be privately maintained and will require City review and approval of landscaping and amenities prior to final plat.

5. Lot 270 has frontage on both Horizon Peak Road and SW 45th Street. Vehicular access shall be taken from Horizon Peak Road.

6. To ensure adequate backing distance, a special setback line shall be designated and measured from the southern edge of the access easement, rather than from the northern property line, and included in the deed restrictions for Lots 116-132.

7. The applicant shall replace the identified 369 trees with a diameter greater than 10 inches to be removed with 369 replacement trees that have a minimum 1 ½-inch trunk diameter measured at 4.5 feet above ground.

8. Lot 247, site of an existing single-family dwelling, will be considered a pre-existing non-conforming structure due to its five-foot rear setback. The dwelling will be subject to the Non-Conforming Uses provisions of the Redmond Development Code if/when future development or alteration of the dwelling occurs.

9. Prior to final plat approval of all affected phases, suitable fire access must be maintained for all project phases. Temporary turn-arounds may be required at the termination of streets longer than 150' as required by Redmond Fire.

10. Prior to final plat approval of all affected phases, local streets and cul-de-sacs shall be dedicated as a 60 foot public right-of-way (30-feet from centerline) and 54 foot cul-de-sac radius public right-of-way and constructed as full width street section per CORSS Standard Drawing 2-1 and 2-4 where possible. A partial street section will be required where a full width street section is not feasible. Horizontal curves will not be permitted to be less than 198-ft radius per Standards and Specifications. Substandard centerline curve radii are identified (but may not be limited to) along Celestial Way, Horizon Peak Rd, Dawn Meadow St and Horizon Light Road. All intersection spacing and intersection sight distance/stopping sight distance must meet City of Redmond Development Code Section 8.2820 - Access Management Standards. Substandard intersection spacing are identified (but may not be limited to) along Horizon Peak Rd between Morning Vista Rd, Dusk Valley Rd and Horizon Light Road. Directional curb ramps shall be required at all intersections serving crossings in all directions. End of roadway signs shall be installed at each street/phase terminus per City standards, until streets are extended.

11. Prior to final plat approval of all affected phases, a separated multiuse path conforming to City of Redmond Standards and Specifications shall be required along the COID Canal Lateral B and B-5 (identified as B67) and along SW Helmholtz Way (identified as B1) per City Transportation System Plan (TSP). Accessible ramps, continental crosswalks, illumination and advanced warning signs are required where the path intersects with any roadway(s). The path will be required to connect and align with the path proposed along SW 45th St. within the Little Texas subdivision located to the north.

12. Prior to final plat of Phase 3, a pedestrian pathway shall be constructed and right of way or easement shall be dedicated between Horizon Peak Road and Helmholtz Way, located between Lot 284 and 285. The right of way or easement shall be a minimum of twenty feet wide, with a paved surface a minimum of ten feet wide per COR Std Dwg 2-6, constructed and centered within the right-of-way/easement.

13. Prior to final plat of Phase 1 and 2, a pedestrian pathway shall be constructed and right of way or easement shall be dedicated between Morning Vista Road and Horizon Peak Road, located between Lots 222, 223, 234, and 235. The right of way or easement shall be a minimum of twenty feet wide, with a paved surface a minimum of ten feet wide per COR Std Dwg 2-6, constructed and centered within the right-of-way/easement.

14. Prior to final plat of Phase 3 and 4, a pedestrian pathway shall be constructed and right of way or easement shall be dedicated between Horizon Peak Road and Horizon Peak Road, located between Lots 160, 161, 257 and 258. The right of way or easement shall be a minimum of twenty feet wide, with

a paved surface a minimum of ten feet wide per COR Std Dwg 2-6, constructed and centered within the right-of-way/easement.

15. Prior to final plat approval of all affected phases, alleys shall be identified as privately owned and maintained and shall meet City of Redmond Standards and Specification requirements. Backup distance minimum of 24 ft. from face of garage or edge of parking stall to opposite side of alley shall be required for turnaround purposes.

16. Prior to Phase 1 final plat approval, SW Helmholtz Way shall be dedicated to minor arterial street standards per CORSS Standard Drawing 2-1 to achieve a total public right-of-way width of 100 feet (minimum of 50-feet west from centerline) and 5-foot-wide minimum public utility easement along project/property frontage. No direct vehicular/truck access to SW Helmholtz Way shall be permitted unless required by Redmond Fire and Rescue (RFR) for emergency access only with approved locked, removable bollards.

17. Prior to Phase 1 final plat approval, SW 45th St. shall be dedicated to local street standards per CORSS Standard Drawing 2-1 and in coordination and alignment with Little Texas North Subdivision to achieve a total of 60-feet minimum width public right-of-way (or 30 feet west from centerline) and 5-foot-wide minimum public utility easement along project/property frontage. No direct vehicular/truck access to SW 45th St shall be permitted due to proximity to the future roundabout at SW 45th St. and Helmholtz Way.

18. Prior to Phase 1 final plat approval, SW Helmholtz Way shall be improved and constructed along Phase 1 frontage to minor arterial street standards (3-lane) per CORSS Standard Drawing 2-1 and Development Code requirements, to achieve 50-feet of pavement with travel lanes and center turn lane, striping, curb and curb ramps on both sides, sidewalks, and street trees on the west side.
Prior to Phase 1 final plat approval, a southbound right-turn lane and northbound left-turn lane shall be installed at SW Helmholtz Way/SW Dusk Valley Rd. A stop bar and stop sign shall be installed for eastbound traffic at the intersection

19. Prior to Phase 1 final plat approval, an enhanced pedestrian crossing shall be installed in SW Helmholtz Way at SW Dusk Valley Rd on the north side of the intersection. This crossing shall include continental crosswalk striping, a raised pedestrian refuge island, and a Rectangular Rapid Flashing Beacon to increase awareness of the crossing, signage, and overhead illumination.

20. Prior to Phase 1 final plat approval, a total proportionate share of $199,686 shall be required for development impacts to; OR 126/SW 27th Street, based on the cost of the parallel route improvements at OR 126/SW 35th Street; a northbound right turn lane at SW Helmholtz Way/SW Obsidian Avenue; a northbound right turn lane at SW Helmholtz Way/SW Quartz Avenue; and a northbound right turn lane at Helmholtz Way/Antler Ave. The proportionate share, or portions of the payment, will not be required if the City adopts a separate funding mechanism that addresses the impacts in their entirety prior to final plat of Phase 1. The total payment is either due prior to final plat approval of Phase 1 or $28,526.57 may be paid prior to final plat approval of each individual phase.

21. Prior to Phase 1 final plat approval, applicant shall coordinate with Cascades East Transit (CET) and City to site a location of bus stop and associated infrastructure, if required by CET. If required, construction shall occur prior to final plat of Phase 1.

22. Prior to Phase 3 final plat approval, SW Helmholtz Way shall be improved and constructed along Phase 3 frontage to minor arterial street standards (3-lane) per CORSS Standard Drawing 2-1 and Development Code requirements, to achieve 50-feet of pavement with travel lanes and center turn lane, striping, curb and curb ramps on both sides, sidewalks, and street trees on the west side.

23. Prior to Phase 3 final plat approval, SW 45th St. shall be improved and constructed along Phase 3 frontage to City local street standards per CORSS Standard Drawing 2-1 and Development Code requirements in coordination with the Little Texas Subdivision, if not constructed already.

24. Prior to final plat approval of all affected phases, all infrastructure connections, design, and construction shall be coordinated with the Little Texas subdivision located to the north.

25. Prior to final plat approval of all affected phases, the 12-inch minimum diameter water main identified as P4640 west of Helmholtz Way per City Water System Master Plan (WSMP) shall be extended and constructed in Horizon Peak Rd., Dusk Valley Rd., Horizon Crest Lane, Horizon Peak Rd., Celestial Ridge Way and SW 51st St. for a looping connection between Little Texas North Subdivision and SW Helmholtz Way.

26. Prior to final plat approval of all affected phases, 8-inch minimum diameter water mains shall otherwise be extended and constructed along public streets and project/lot frontages. One water service shall be provided to each proposed lot or tract. Abandonment of any existing water well, cistern or other private water facility located on subject properties shall be in accordance with City Municipal Code, Standards and Specifications, and any applicable Oregon requirements.

27. Prior to final plat of all affected phases, 8-inch minimum diameter gravity sewer mains shall be extended and constructed along all public streets and project frontages per City standards. One sewer service shall be provided to each proposed lot. Abandonment of any existing sewage drill hole, septic tank or other private sewer facility located on subject properties shall be in accordance with City Municipal Code, Standards and Specifications, and any applicable Oregon requirements.

28. Prior to engineering plan approval for all affected phases, the proposed location, alignment and depth of the Obsidian Interceptor (Interceptor) through the project/property shall be reviewed and approved by the City Engineer. A cash contribution will be required for the standard eight (8) inch pipe portion of the Interceptor at ten (10) foot average depth in lieu of constructing the Interceptor extension through the project/property frontage per current Redmond Collection System Master Plan (CSMP) due to the incontiguous nature for the Interceptor in relation to this development.

29. Prior to final plat of all affected phases, a combined gravity, pump station, and interim pressure system within the proposed development and sewer discharge to the existing 15-inch SW Helmholtz Way sewer main shall be reviewed and approved by the City Engineer. The interim pump station shall be located near the proposed location of Obsidian Interceptor and the low point of the development near the north project/property boundary. The interim pump station and force main must meet City of Redmond and DEQ standards. The plans must conceptually demonstrate how the development will connect to the Obsidian Interceptor once the Lift Station is decommissioned. Alternatively, the development may discharge to the Little Texas Subdivision pump station, provided capacity is available at the pump station and a proportionate payment is provided prior to connection and/or private cost sharing is established with Little Texas. The proportionate share will be determined based on actual design and construction costs of the pump station, relative to the sewer demand (gallons per minute) required by Horizon Pointe.

30. Prior to building permit issuance and after land use decision issuance, a separate set of construction drawings shall be submitted directly to the City Engineering Division along with a Site Development (SD) Review Application for design review and approval of all proposed and/or required public infrastructure improvements, water/sewer service connections, subdivision-site grading/drainage and utilities per City of Redmond Standards and Specifications.

// **END OF CONDITIONS** //

Prepared by:

Megan Peninger, Associate Planner
Kyle Roberts, AICP, Planning Director

Attachment A

HORIZON POINTE

PLANNED UNIT DEVELOPMENT AND SUBDIVISION APPLICATION

2577 SW HELMHOLTZ WAY
REDMOND, OR 97756
November, 2025

SITE INFORMATION

ADDRESS: 2577 SW HELMHOLTZ WAY, REDMOND, OR 97756
TAX ASSESSORS MAP: TAX LOT 1100, 1101, 1102, MAP 151319000
PROPERTY SIZE: 78.01
EXISTING USE: ACTIVE AGRICULTURAL LAND
ZONING: R3, R4, & R5 / SINGLE-FAMILY(SF), & TOWNHOMES(T)
PROPOSED R3 NET AREA: 31.63 ACRES
PROPOSED R4 NET AREA: 11.33 ACRES
PROPOSED R5 NET AREA: 1.99 ACRES
OPEN SPACE NET AREA: 6.67 ACRES

PROPOSED USE

PLANNED USE DEVELOPMENT (PUD) - 321 LOTS
245 SINGLE FAMILY
76 TOWNHOMES

OWNER'S

RONALD NELSON
2577 SW HELMHOLTZ WAY
REDMOND, OR 97756

RICHARD & MEGHAN HOLMES
2572 SW HELMHOLTZ WAY
REDMOND, OR 97756

NATHAN & JESSICA HADFIELD
2897 SW HELMHOLTZ WAY
REDMOND, OR 97756

VERTICAL DATUM

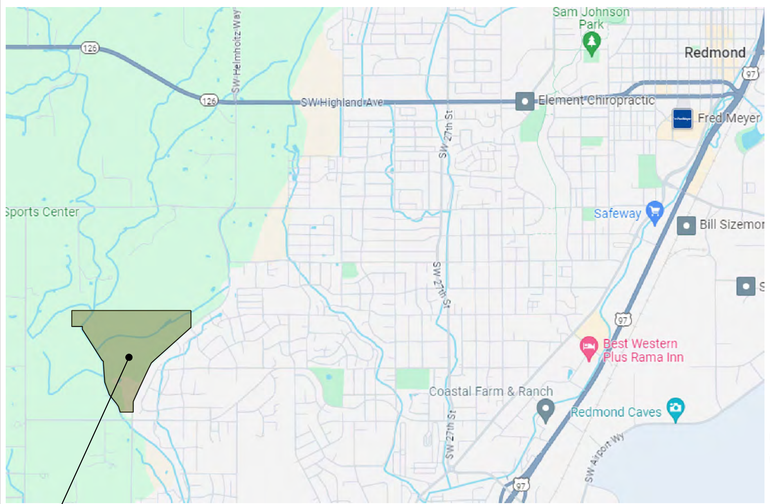
ELEVATIONS ARE BASED ON TIE TO CITY OF REDMOND BENCHMARK 8-M-2 BEING A 3" BRASS DISK SET IN CONCRETE ABUTMENT OF WING WALL AT THE SW CORNER OF CANAL BRIDGE AT THE INTERSECTION OF NW GREENWOOD AVE. AND NW CANAL BLVD. ELEVATION = 2,990.38'.

SHEET INDEX

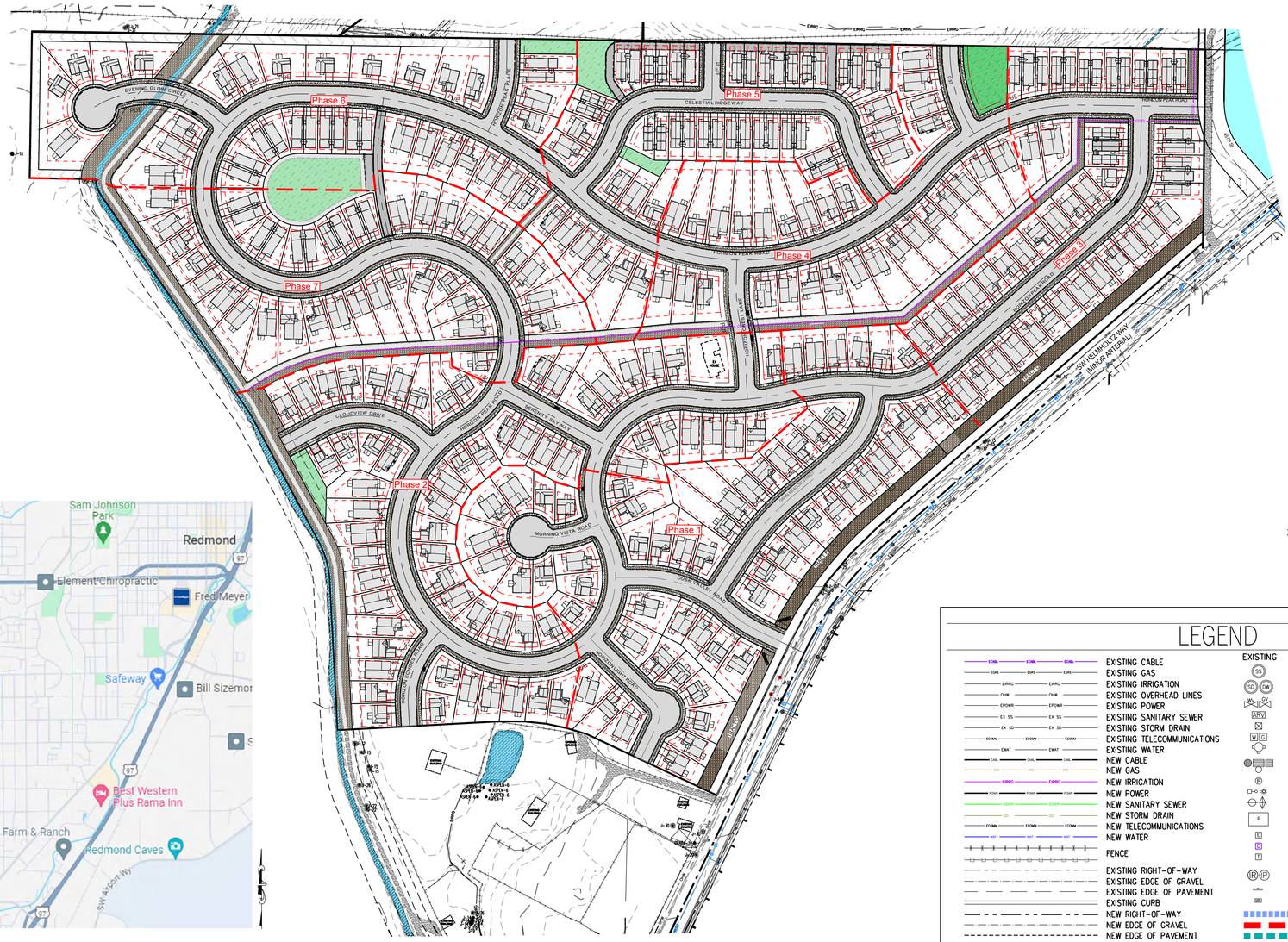
P1.0	COVER SHEET
P1.1	EXISTING CONDITIONS OVERVIEW
P1.2	EXISTING CONDITIONS NW
P1.3	EXISTING CONDITIONS NE
P1.4	EXISTING CONDITIONS S
P2.0	TENTATIVE PLAT OVERVIEW
P2.1	TENTATIVE PLAT NW
P2.2	TENTATIVE PLAT NE
P2.3	TENTATIVE PLAT S
P3.0	UNUSED
P4.0	TENTATIVE UTILITY PLAN OVERVIEW
P4.1	TENTATIVE UTILITY PLAN NW
P4.2	TENTATIVE UTILITY PLAN NE
P4.3	TENTATIVE UTILITY PLAN S
P5.1	ROAD CROSS-SECTIONS
P5.2	UNIT MIX
P5.3	SEWER BASINS
P5.4	STREET CONNECTIONS
P5.5	TAXLOT 1100 SHADOW PLAT

CIVIL ENGINEER

HICKMAN WILLIAMS & ASSOCIATES INC
CONTACT: BRANDON GRIP
brandong@hwa-inc.org
541-389-9351



VICINITY MAP
NTS



OVERALL SITE MAP

N

200' 0' 100' 200' 400'
GRAPHIC SCALE: 1" = 200'
FOR 22" X 34" PAPER

LEGEND

	EXISTING	PROPOSED
EXISTING CABLE		
EXISTING GAS		
EXISTING IRRIGATION		
EXISTING OVERHEAD LINES		
EXISTING POWER		
EXISTING SANITARY SEWER		
EXISTING STORM DRAIN		
EXISTING TELECOMMUNICATIONS		
EXISTING WATER		
NEW CABLE		
NEW GAS		
NEW IRRIGATION		
NEW POWER		
NEW SANITARY SEWER		
NEW STORM DRAIN		
NEW TELECOMMUNICATIONS		
NEW WATER		
FENCE		
EXISTING RIGHT-OF-WAY		
EXISTING EDGE OF GRAVEL		
EXISTING EDGE OF PAVEMENT		
EXISTING CURB		
NEW RIGHT-OF-WAY		
NEW EDGE OF GRAVEL		
NEW EDGE OF PAVEMENT		
NEW CURB		
		SANITARY SEWER MANHOLE
		STORM DRAIN MANHOLE, DRYWELL
		WATER VALVE, GAS VALVE
		AIR RELEASE VALVE
		BACKFLOW PREVENTER
		WATER METER, GAS METER
		FIRE HYDRANT
		CATCH BASIN/CURB INLET
		CLEAN OUT
		RAIN DRAIN
		STREET LIGHT, PARKING LOT LIGHT
		UTILITY POLE, GUY ANCHOR
		UTILITY VAULT
		ELECTRICAL PEDESTAL
		CABLE PEDESTAL
		TELECOMMUNICATIONS PEDESTAL
		IRON ROD, IRON PIPE
		SIGN
		MAILBOX
		EX OWNER PROPERTY LINE
		PHASES
		EX ZONE

MonteVista HOMES

DESIGNED BY: GWM/JH
DRAWN BY: GWM
CHECKED BY: JH
DATE: 11/18/2025

HORIZON POINTE
COVER SHEET

No. | REVISIONS: | DATE:

SHEET: P1.0

TM 151224
TL 200

TM 151224
TL 101

TM 151319
TL 504

TM 151319
TL 1102

TM 151319
TL 1101

TM 151319
TL 504

TM 151224
TL 1801

TM 151319
TL 1100

EX 20' ESMT
COID LATERAL B-9-2

EX 30' ESMT
COID LATERAL B5

EX COID POND EASEMENT

EX 20' ESMT
DITCH ROAD

EX 20' ESMT
COID LATERAL B-5
EX 20' ESMT
DITCH ROAD

EX 20' ESMT
DITCH ROAD

EX 75' ESMT
COID LATERAL B

EX 26'
STREET WIDTH

SW HELMHOLTZ WAY
(MINOR ARTERIAL)

EX 85' ROW

EX 80' ROW

EXISTING OWNER
PROPERTY LINE

PROJECT BOUNDARY

NW LINE
NW LINE
NE LINE
NE LINE
MATCH LINE
MATCH LINE
MATCH LINE

EXISTING BUILDING

ASPEN-8

ASPEN-6

1
2
3
4
5
6
7
8
9
10

Existing Demo Trees
- Aspen
- Elm
- Juniper
- Pine

TREE NOTE:
369 TREES ARE TO BE REMOVED AS PART OF THIS DEVELOPMENT.

HORIZON POINTE PLANS FOR THE INSTALLATION OF A MINIMUM 50 TREES TO BE LOCATED WITHIN NEIGHBORHOOD PARKS AND OPEN SPACE TRACTS IN ADDITION TO THE MINIMUM 321 STREET TREES THAT ARE TO BE INSTALLED WITHIN STREET-SIDE LANDSCAPING STRIPS. A MINIMUM OF 371 TREES CONFORMING TO CITY OF REDMOND TREE STANDARDS WILL BE INSTALLED AS PART OF THIS DEVELOPMENT. FINAL TREE SPECIES AND PLACEMENT WILL BE DECIDED DURING ENGINEERING OF EACH SPECIFIC PHASE.

N

100' 0' 50' 100' 200'

GRAPHIC SCALE: 1" = 100'
FOR 22" X 34" PAPER

MonteVista HOMES

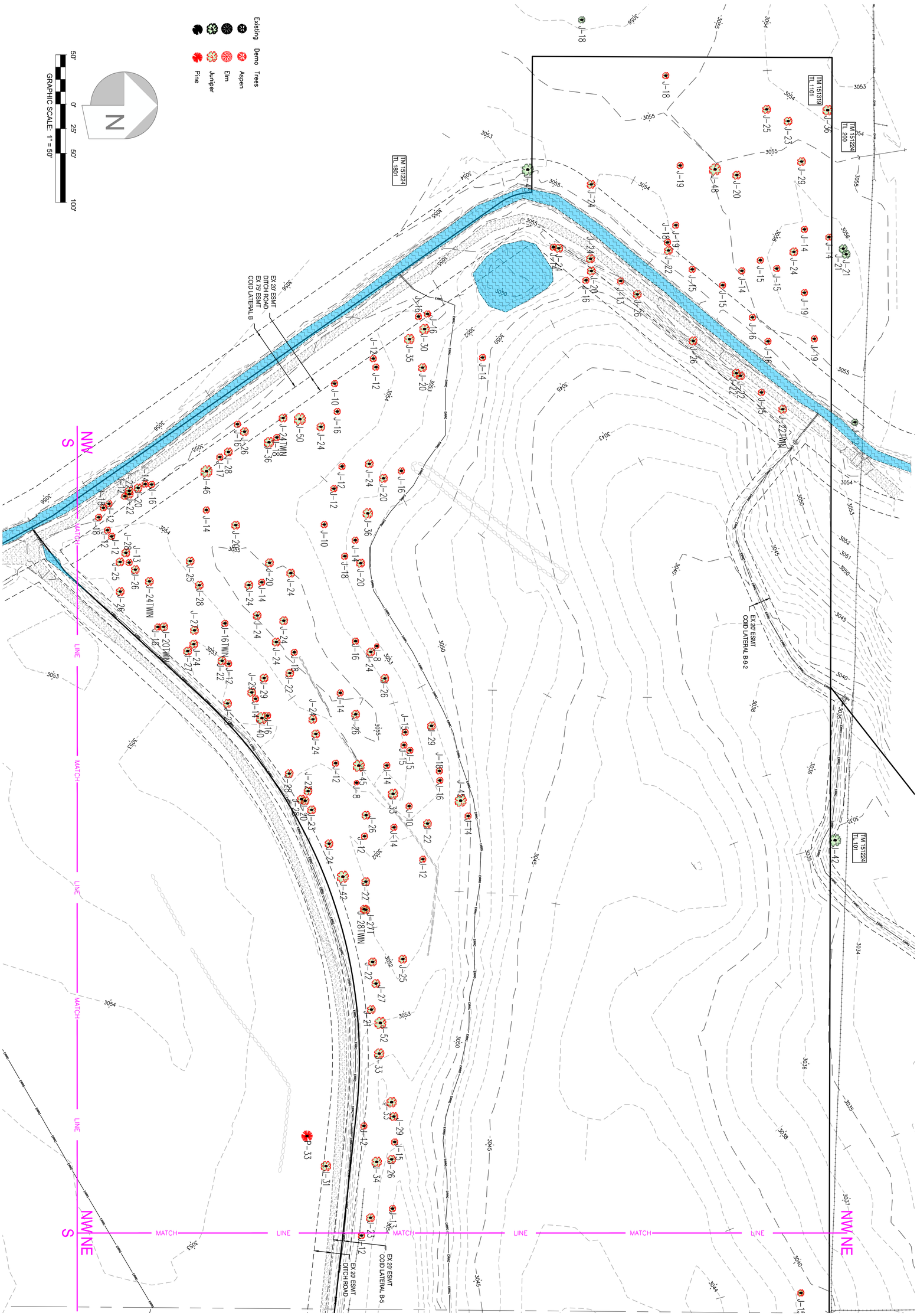
DESIGNED BY: GWM/JH
DRAWN BY: GWM
CHECKED BY: JH
DATE: 11/18/2025

HORIZON POINTE

EXISTING CONDITIONS OVERVIEW

No.	REVISIONS:	DATE:

SHEET:
P1.1



SHEET: P1.2

No.	REVISIONS:	DATE:

HORIZON POINTE

EXISTING CONDITIONS NW

DESIGNED BY: GWM/JH
DRAWN BY: GWM
CHECKED BY: JH

DATE: 11/18/2025

MonteVista HOMES

TM 151319
TL 1102

NW NE

TM 151319
TL 1101

TM 151224
TL 101

TM 151319
TL 504

EX 30' ESMT
LATERAL B-5

EXISTING OWNER
PROPERTY LINE

EX ESMT COID POND

EXISTING
BUILDING

EX 20' ESMT
DITCH ROAD

EX 20' ESMT
LATERAL B-5

EX 20' ESMT
DITCH ROAD

TM 151319
TL 1100

EX 26' STREET WIDTH

EX 85' ROW

SW HELMHOLTZ WAY
(MINOR ARTERIAL)

NW NE
S

MATCH LINE

NE
S

Existing Demo Trees
Aspen
Elm
Juniper
Pine

N

50' 0' 25' 50' 100'
GRAPHIC SCALE: 1" = 50'

MonteVista
HOMES

DESIGNED BY: GWM/JH
DRAWN BY: GWM
CHECKED BY: JH

DATE: 11/18/2025

HORIZON POINTE

EXISTING CONDITIONS
NE

No.	REVISIONS:	DATE:

SHEET:
P1.3

MATCH LINE MATCH LINE MATCH LINE NW NE S MATCH LINE MATCH LINE MATCH LINE

EX 20' ESMT DITCH ROAD
EX 20' ESMT COID LATERAL B5
TM 151319 TL 1101
EX 75' ESMT COID LATERAL B
EX 20' ESMT DITCH ROAD
TM 151319 TL 1100
TM 151224 TL 1801
EXISTING OWNER PROPERTY LINE
PROJECT BOUNDARY
EXISTING BUILDING
EX 85' ROW
EX ~39' STREET WIDTH
EX 80' ROW
EX ~40' STREET WIDTH
SW HELLMHOLTZ WAY (MINOR ARTERIAL)
GRADE-10
ASPEN-8
ASPEN-6
ELM-42

Existing Demo Trees
Aspen
Elm
Juniper
Pine

N

60' 0' 30' 60' 120'
GRAPHIC SCALE: 1" = 60'
FOR 22" X 34" PAPER

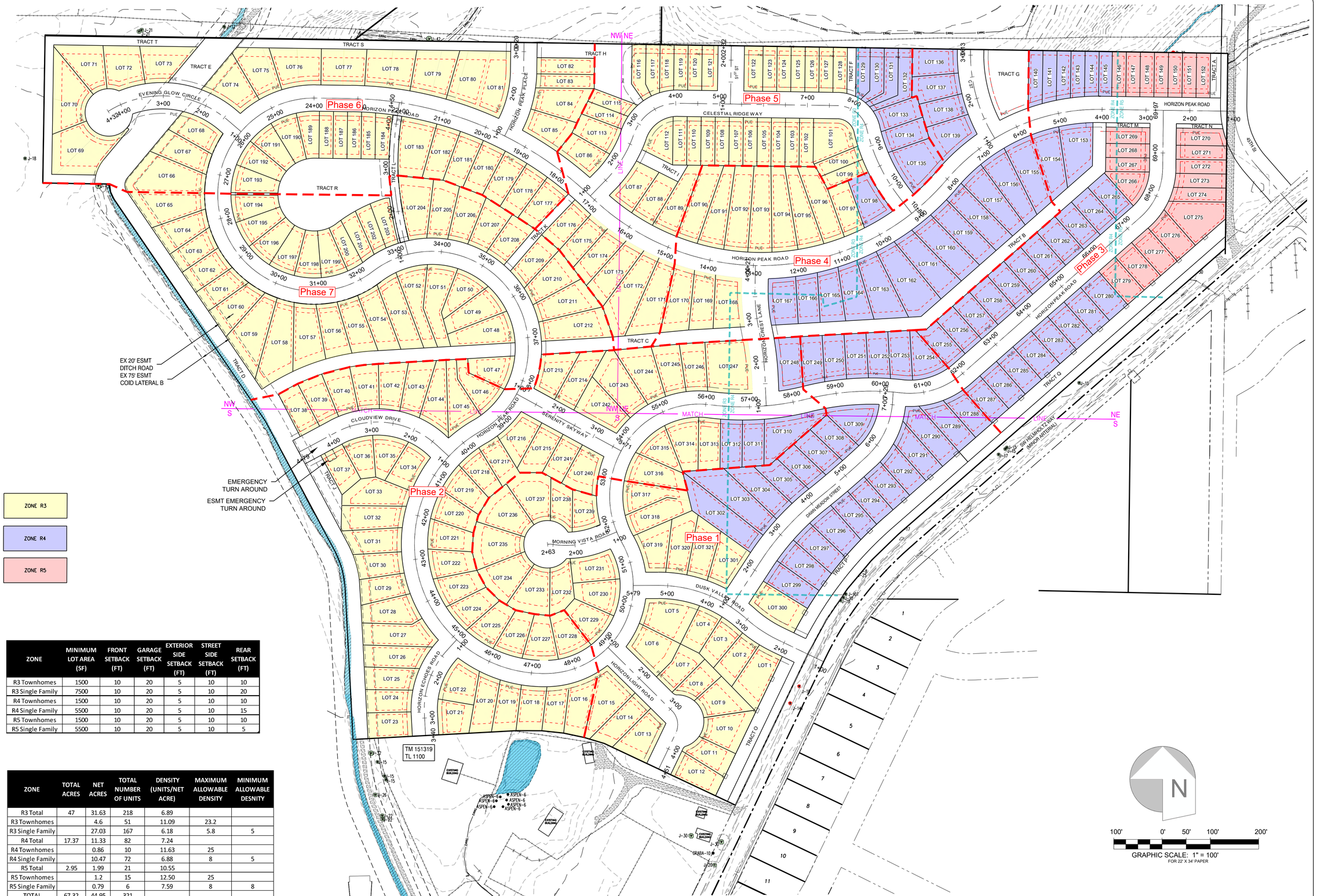
MonteVista HOMES

DESIGNED BY: GWM/JH
DRAWN BY: GWM
CHECKED BY: JH
DATE: 11/18/2025

HORIZON POINTE
EXISTING CONDITIONS
S

No.	REVISIONS:	DATE:

SHEET:
P1.4



ZONE	MINIMUM LOT AREA (SF)	FRONT SETBACK (FT)	GARAGE SETBACK (FT)	EXTERIOR SIDE SETBACK (FT)	STREET SIDE SETBACK (FT)	REAR SETBACK (FT)
R3 Townhomes	1500	10	20	5	10	10
R3 Single Family	7500	10	20	5	10	20
R4 Townhomes	1500	10	20	5	10	10
R4 Single Family	5500	10	20	5	10	15
R5 Townhomes	1500	10	20	5	10	10
R5 Single Family	5500	10	20	5	10	5

ZONE	TOTAL ACRES	NET ACRES	TOTAL NUMBER OF UNITS	DENSITY (UNITS/NET ACRE)	MAXIMUM ALLOWABLE DENSITY	MINIMUM ALLOWABLE DESNITY
R3 Total	47	31.63	218	6.89		
R3 Townhomes		4.6	51	11.09	23.2	
R3 Single Family		27.03	167	6.18	5.8	5
R4 Total	17.37	11.33	82	7.24		
R4 Townhomes		0.86	10	11.63	25	
R4 Single Family		10.47	72	6.88	8	5
R5 Total	2.95	1.99	21	10.55		
R5 Townhomes		1.2	15	12.50	25	
R5 Single Family		0.79	6	7.59	8	8
TOTAL	67.32	44.95	321			

100' 0' 50' 100' 200'

GRAPHIC SCALE: 1" = 100'
FOR 22" X 34" PAPER

MonteVista HOMES

DESIGNED BY: GWM/JH
DRAWN BY: GWM
CHECKED BY: JH

DATE: 11/18/2025

HORIZON POINTE

TENTATIVE PLAT OVERVIEW

No.	REVISIONS:	DATE:

SHEET: P2.0

Phase 6

Phase 7

ZONE R3

ZONE R4

ZONE R5

N

50' 0' 25' 50' 100'

GRAPHIC SCALE: 1" = 50'

MonteVista HOMES

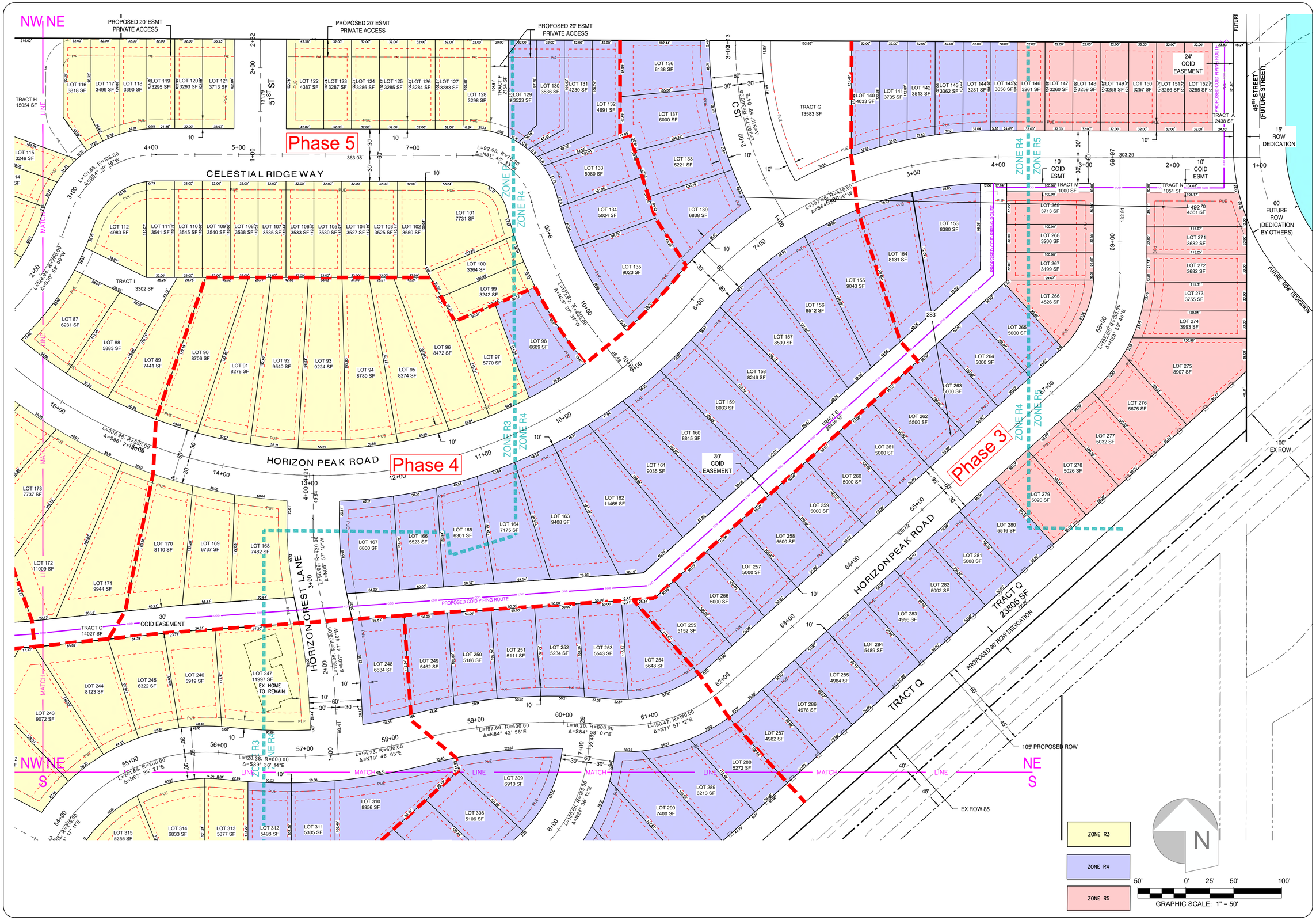
DESIGNED BY: GWM/JH
DRAWN BY: GWM
CHECKED BY: JH
DATE: 11/18/2025

HORIZON POINTE

TENTATIVE PLAT NW

No.	REVISIONS:	DATE:

SHEET: P2.1



MonteVista HOMES

DESIGNED BY:	GWM/JH
DRAWN BY:	GWM
CHECKED BY:	JH
DATE:	11/18/2025

HORIZON POINTE

TENTATIVE PLAT NE

No.	REVISIONS:	DATE:

SHEET: P2.2

CLOUDVIEW DRIVE
SERENITY SKYWAY
HORIZON PEAK ROAD
MORNING VISTA ROAD
DUSK VALLEY ROAD
HORIZON ECHOES ROAD
HORIZON LIGHT ROAD
SW HELMHOLTZ WAY (MINOR ARTERIAL)
DAWN MEADOW STREET
20' ROW DEDICATION
PROPOSED 105' ROW
PROPOSED 100' ROW
EX 80' ROW
TRACT P 16998 SF
TRACT O 10554 SF
TRACT D 83023 SF
TRACT J 5582 SF
EMERGENCY TURN AROUND
EMERGENCY TURN AROUND ESMT
EX 75' ESMT COID LATERAL B
EX 20' ESMT DITCH ROAD
Phase 1
Phase 2
EXISTING BUILDING
ASPEN-6
GRABA-10
J-10
J-15
J-17
J-19
J-20
J-22
J-26
J-30
J-32
ZONE R3
ZONE R4
ZONE R5
GRAPHIC SCALE: 1" = 60'
FOR 22" X 34" PAPER

MonteVista HOMES

DESIGNED BY: GWM/JH
DRAWN BY: GWM
CHECKED BY: JH
DATE: 11/18/2025

HORIZON POINTE
TENTATIVE PLAT
S

No.	REVISIONS:	DATE:

SHEET: P2.3



SHEET: P4.0

No.	REVISIONS:	DATE:

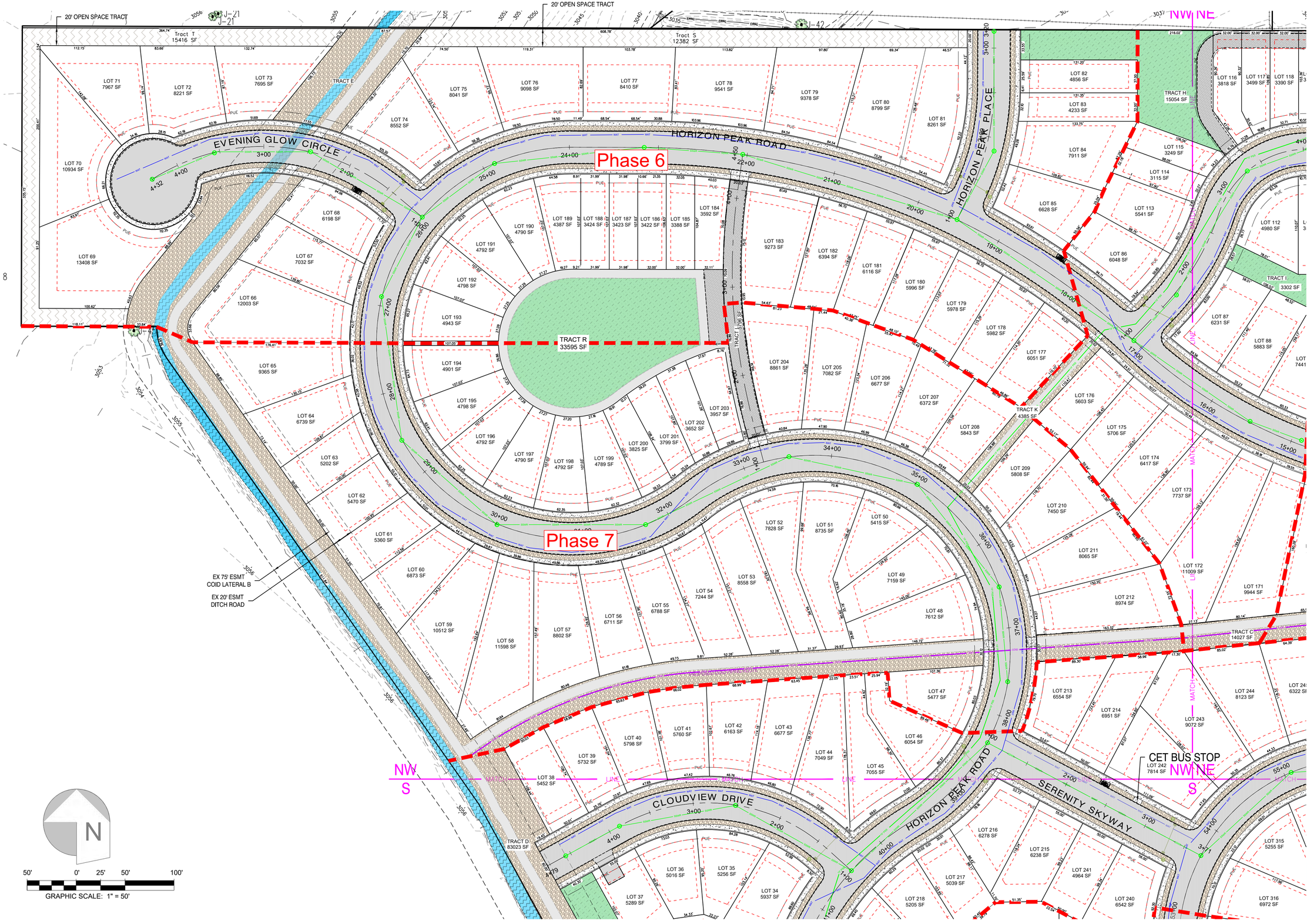
HORIZON POINTE

TENTATIVE UTILITY PLAN OVERVIEW

DESIGNED BY: GWM/JH
DRAWN BY: GWM
CHECKED BY: JH

DATE: 11/18/2025

MonteVista HOMES



MonteVista HOMES

DESIGNED BY: GWM/JH
DRAWN BY: GWM
CHECKED BY: JH

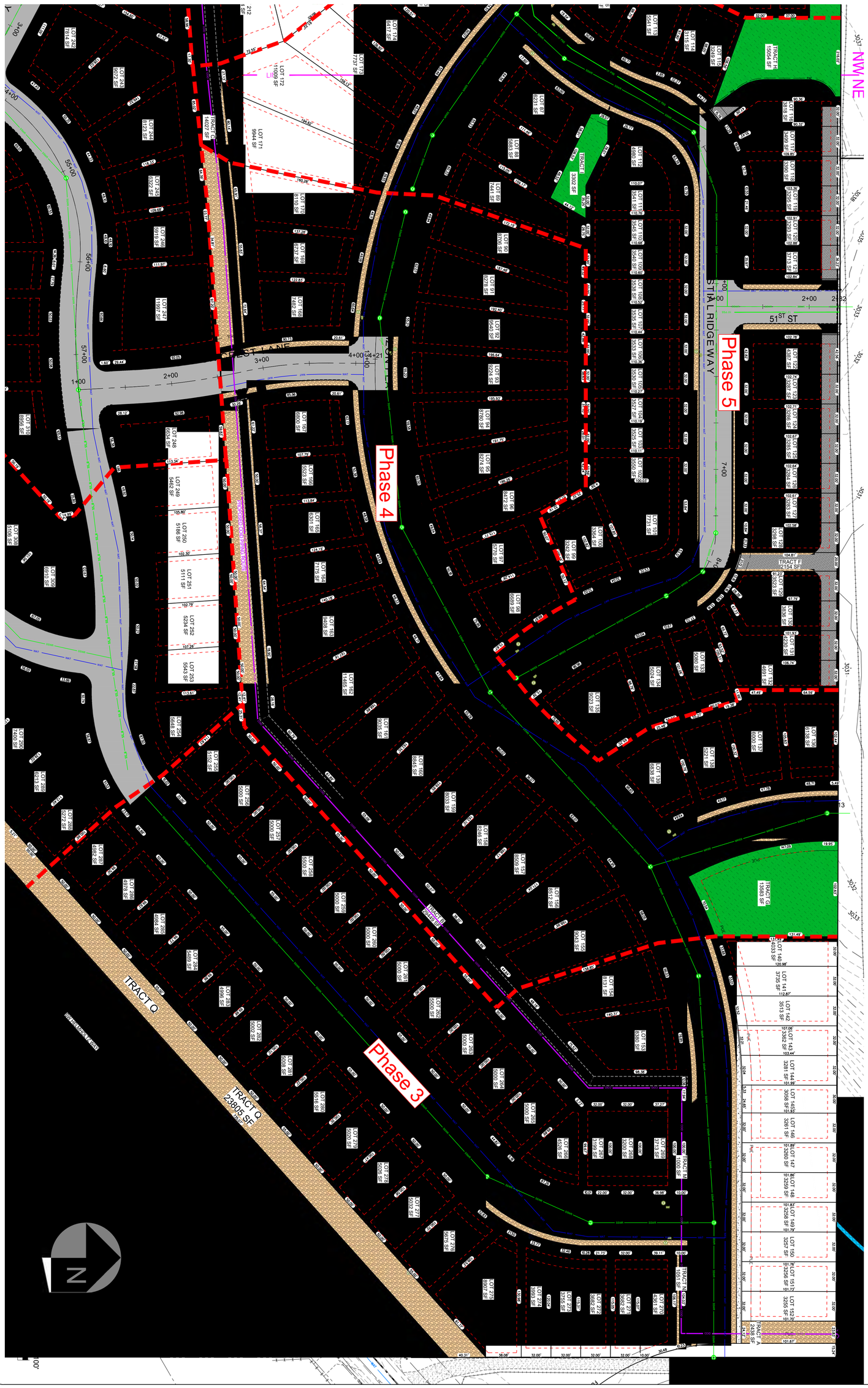
DATE: 11/18/2025

HORIZON POINTE

TENTATIVE UTILITY PLAN NW

No.	REVISIONS:	DATE:

SHEET: P4.1



SHEET:
P4.2

No.	REVISIONS:	DATE:

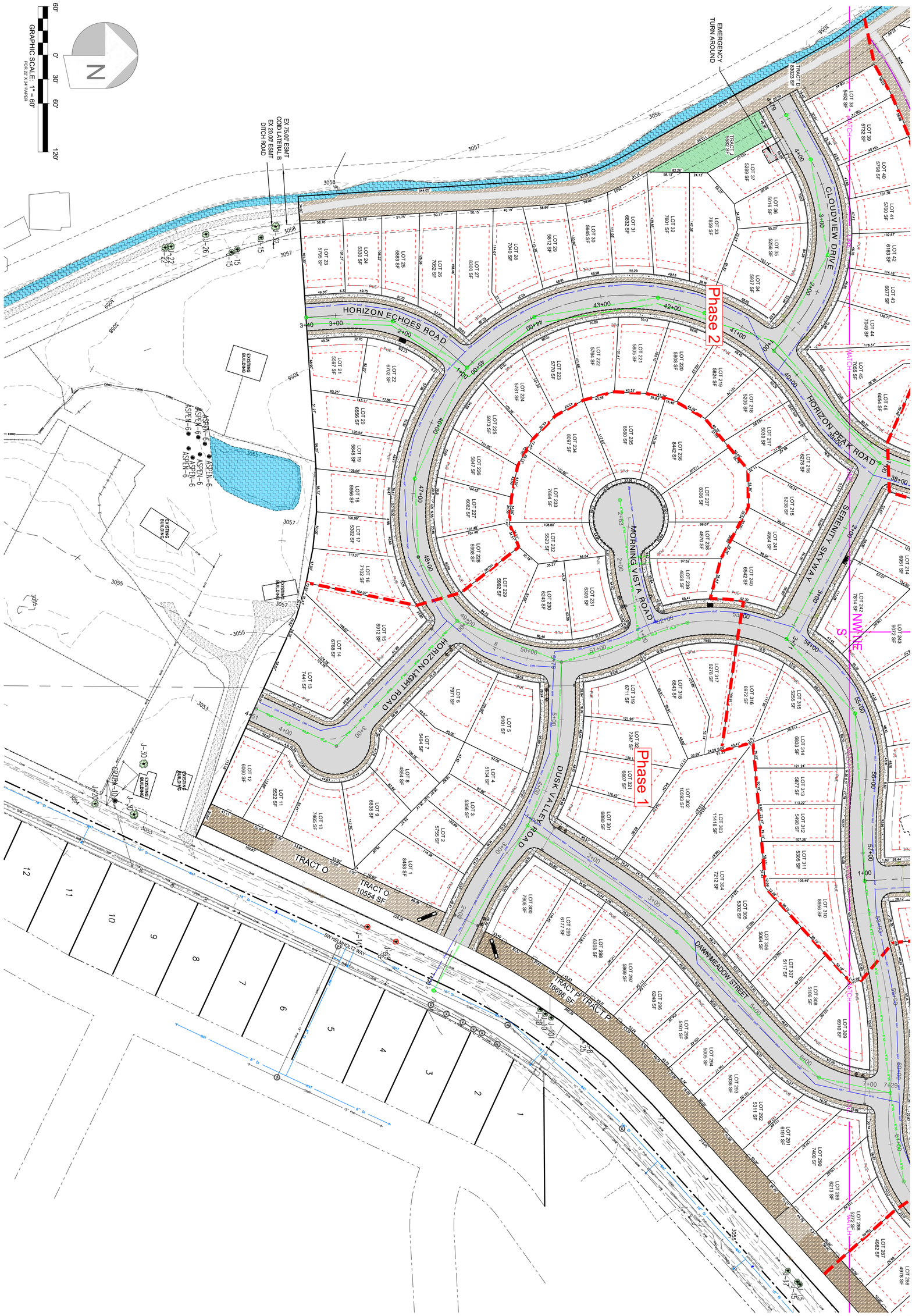
HORIZON POINTE

TENTATIVE UTILITY PLAN NE

DESIGNED BY: GWM/JH
DRAWN BY: GWM
CHECKED BY: JH

DATE: 11/18/2025

MonteVista HOMES



SHEET: P4.3

No.	REVISIONS:	DATE:

HORIZON POINTE

TENTATIVE UTILITY PLAN S

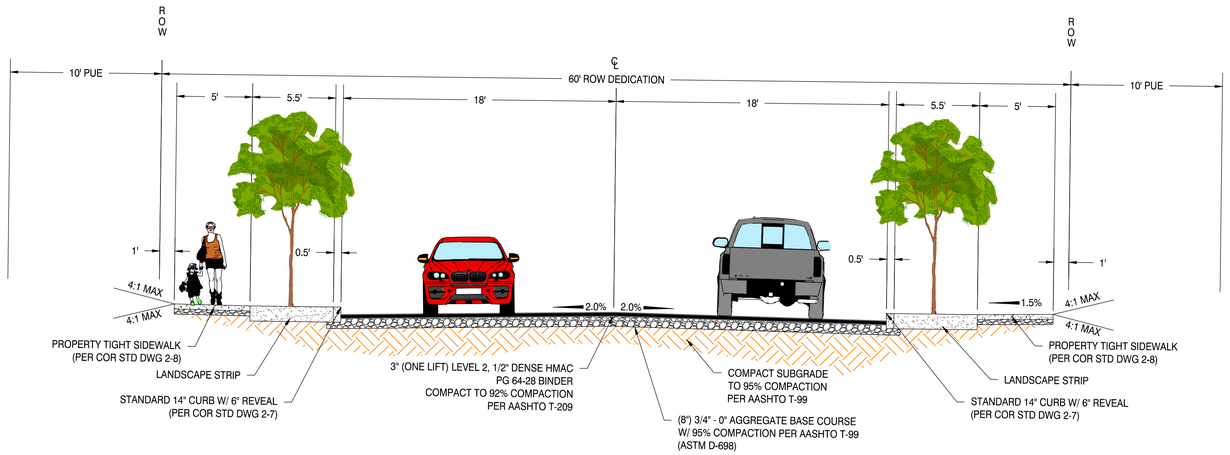
DESIGNED BY: GWM/JH

DRAWN BY: GWM

CHECKED BY: JH

DATE: 11/18/2025

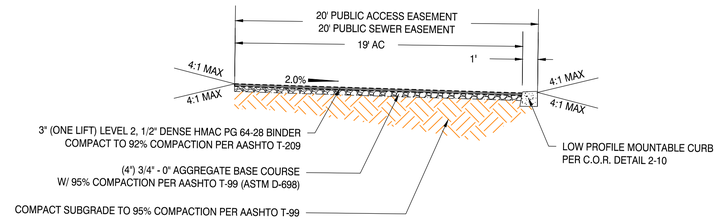
MonteVista HOMES



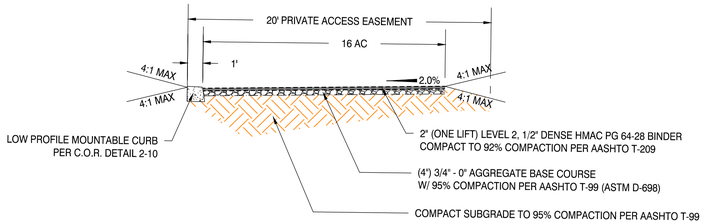
1 / P4.1 LOCAL STREET SECTION
NTS (PER COR STD DWG 2-1)

HORIZON PEAK ROAD
CELESTIAL RIDGE WAY
EVENING GLOW CIRCLE
SERENITY SKYWAY
HORIZON ECHOES ROAD
DUSK VALLEY ROAD

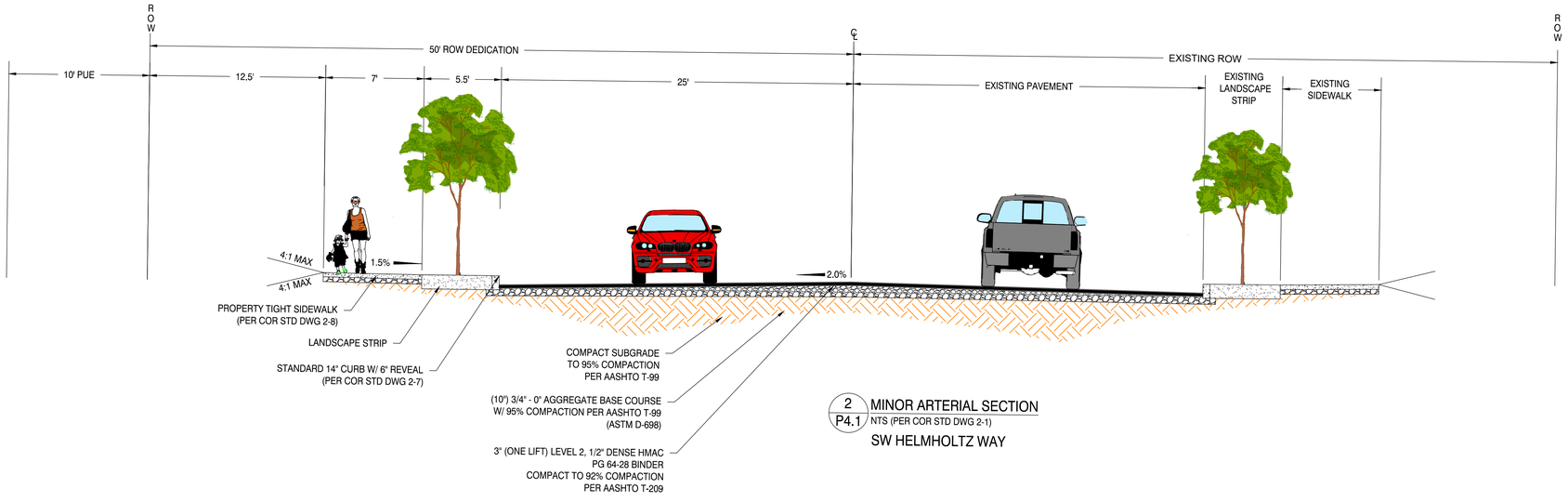
DAWN MEADOW STREET
HORIZON CREST LANE
HORIZON LIGHT AVENUE
MORNING VISTA ROAD
CLOUDVIEW DRIVE
C STREET
51ST STREET



3 / P4.1 ALLEY TRACT L
NTS (PER COR STD DWG 2-1)



4 / P4.1 TYPICAL ALLEY
NTS (PER COR STD DWG 2-1)



2 / P4.1 MINOR ARTERIAL SECTION
NTS (PER COR STD DWG 2-1)
SW HELMHOLTZ WAY

MonteVista HOMES

DESIGNED BY: GWM/JH
DRAWN BY: GWM
CHECKED BY: JH
DATE: 11/18/2025

HORIZON POINTE
ROAD CROSS-SECTIONS

No.	REVISIONS:	DATE:

SHEET:
P5.1







SINGLE FAMILY – 2 STORIES





SINGLE FAMILY – 1 STORIES

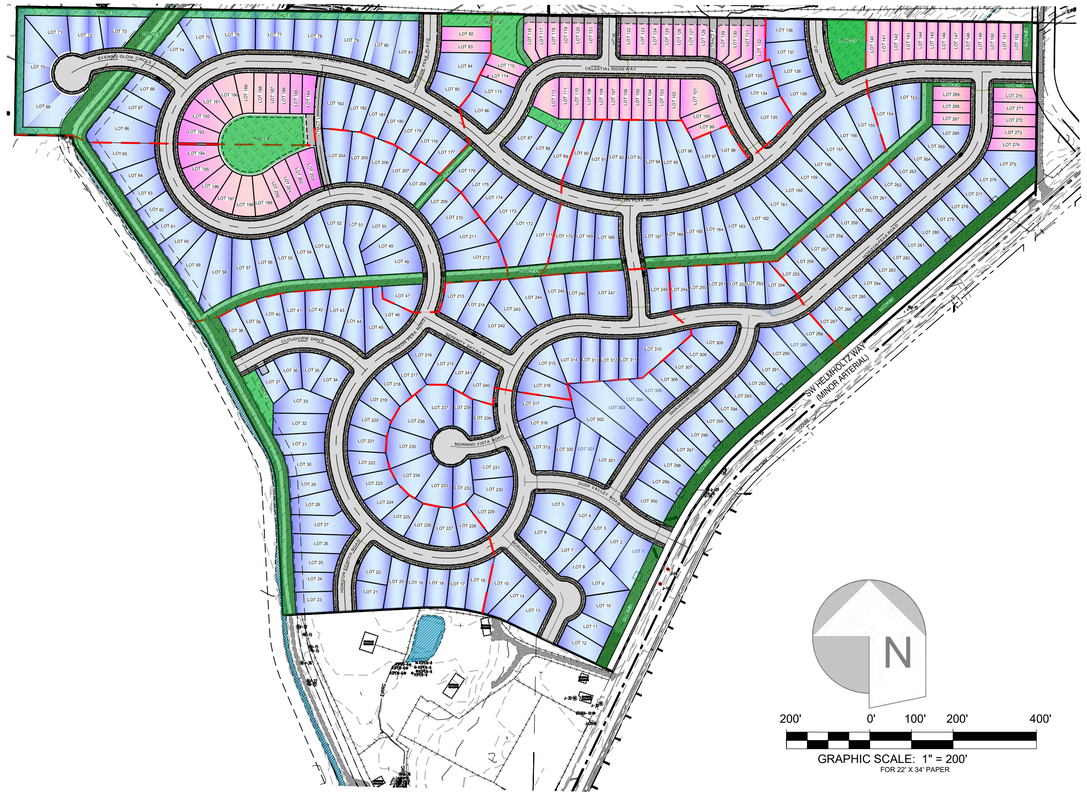


TOWNHOMES

LEGEND

	SINGLE FAMILY LOTS
	TOWNHOME LOTS
	OPEN SPACE

TYPE	QTY	%
SINGLE FAMILY	245	76%
TOWNHOME	76	24%
TOTAL:	321	



MonteVista HOMES

DESIGNED BY: GWM/JH
DRAWN BY: GWM
CHECKED BY: JH
DATE: 11/18/2025

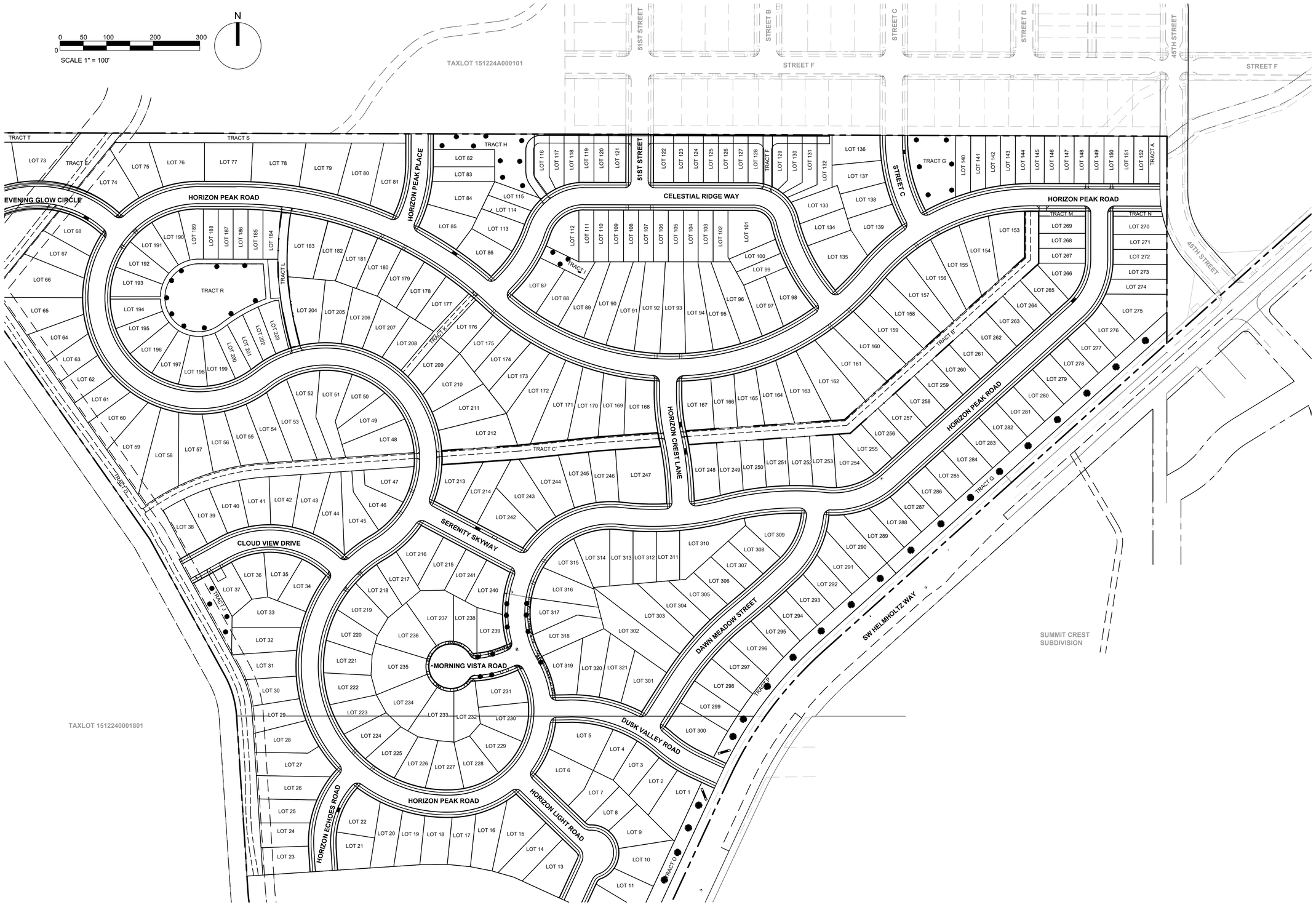
HORIZON POINTE

UNIT MIX

No.	REVISIONS:	DATE:

SHEET: P5.2

Phase 1
Phase 2
Phase 3
Phase 4
Phase 5
Phase 6
Phase 7
HORIZON PEAK ROAD
HORIZON PEAK PLACE
EVENING GLOW CIRCLE
CELESTIAL RIDGEWAY
HORIZON CREST LANE
CLOUDVIEW DRIVE
SERENITY SKYWAY
MORNING VISTA ROAD
DUSK VALLEY ROAD
HORIZON LIGHT ROAD
DAWN MEADOW STREET
SW HELMHOLTZ WAY (MINOR ARTERIAL)
TRACT A
TRACT B
TRACT C
TRACT D
TRACT E
TRACT F
TRACT G
TRACT H
TRACT I
TRACT J
TRACT K
TRACT L
TRACT M
TRACT N
TRACT O
TRACT P
TRACT R
TRACT S
TRACT T
LOT 1
LOT 2
LOT 3
LOT 4
LOT 5
LOT 6
LOT 7
LOT 8
LOT 9
LOT 10
LOT 11
LOT 12
LOT 13
LOT 14
LOT 15
LOT 16
LOT 17
LOT 18
LOT 19
LOT 20
LOT 21
LOT 22
LOT 23
LOT 24
LOT 25
LOT 26
LOT 27
LOT 28
LOT 29
LOT 30
LOT 31
LOT 32
LOT 33
LOT 34
LOT 35
LOT 36
LOT 37
LOT 38
LOT 39
LOT 40
LOT 41
LOT 42
LOT 43
LOT 44
LOT 45
LOT 46
LOT 47
LOT 48
LOT 49
LOT 50
LOT 51
LOT 52
LOT 53
LOT 54
LOT 55
LOT 56
LOT 57
LOT 58
LOT 59
LOT 60
LOT 61
LOT 62
LOT 63
LOT 64
LOT 65
LOT 66
LOT 67
LOT 68
LOT 69
LOT 70
LOT 71
LOT 72
LOT 73
LOT 74
LOT 75
LOT 76
LOT 77
LOT 78
LOT 79
LOT 80
LOT 81
LOT 82
LOT 83
LOT 84
LOT 85
LOT 86
LOT 87
LOT 88
LOT 89
LOT 90
LOT 91
LOT 92
LOT 93
LOT 94
LOT 95
LOT 96
LOT 97
LOT 98
LOT 99
LOT 100
LOT 101
LOT 102
LOT 103
LOT 104
LOT 105
LOT 106
LOT 107
LOT 108
LOT 109
LOT 110
LOT 111
LOT 112
LOT 113
LOT 114
LOT 115
LOT 116
LOT 117
LOT 118
LOT 119
LOT 120
LOT 121
LOT 122
LOT 123
LOT 124
LOT 125
LOT 126
LOT 127
LOT 128
LOT 129
LOT 130
LOT 131
LOT 132
LOT 133
LOT 134
LOT 135
LOT 136
LOT 137
LOT 138
LOT 139
LOT 140
LOT 141
LOT 142
LOT 143
LOT 144
LOT 145
LOT 146
LOT 147
LOT 148
LOT 149
LOT 150
LOT 151
LOT 152
LOT 153
LOT 154
LOT 155
LOT 156
LOT 157
LOT 158
LOT 159
LOT 160
LOT 161
LOT 162
LOT 163
LOT 164
LOT 165
LOT 166
LOT 167
LOT 168
LOT 169
LOT 170
LOT 171
LOT 172
LOT 173
LOT 174
LOT 175
LOT 176
LOT 177
LOT 178
LOT 179
LOT 180
LOT 181
LOT 182
LOT 183
LOT 184
LOT 185
LOT 186
LOT 187
LOT 188
LOT 189
LOT 190
LOT 191
LOT 192
LOT 193
LOT 194
LOT 195
LOT 196
LOT 197
LOT 198
LOT 199
LOT 200
LOT 201
LOT 202
LOT 203
LOT 204
LOT 205
LOT 206
LOT 207
LOT 208
LOT 209
LOT 210
LOT 211
LOT 212
LOT 213
LOT 214
LOT 215
LOT 216
LOT 217
LOT 218
LOT 219
LOT 220
LOT 221
LOT 222
LOT 223
LOT 224
LOT 225
LOT 226
LOT 227
LOT 228
LOT 229
LOT 230
LOT 231
LOT 232
LOT 233
LOT 234
LOT 235
LOT 236
LOT 237
LOT 238
LOT 239
LOT 240
LOT 241
LOT 242
LOT 243
LOT 244
LOT 245
LOT 246
LOT 247
LOT 248
LOT 249
LOT 250
LOT 251
LOT 252
LOT 253
LOT 254
LOT 255
LOT 256
LOT 257
LOT 258
LOT 259
LOT 260
LOT 261
LOT 262
LOT 263
LOT 264
LOT 265
LOT 266
LOT 267
LOT 268
LOT 269
LOT 270
LOT 271
LOT 272
LOT 273
LOT 274
LOT 275
LOT 276
LOT 277
LOT 278
LOT 279
LOT 280
LOT 281
LOT 282
LOT 283
LOT 284
LOT 285
LOT 286
LOT 287
LOT 288
LOT 289
LOT 290
LOT 291
LOT 292
LOT 293
LOT 294
LOT 295
LOT 296
LOT 297
LOT 298
LOT 299
LOT 300
LOT 301
LOT 302
LOT 303
LOT 304
LOT 305
LOT 306
LOT 307
LOT 308
LOT 309
LOT 310
LOT 311
LOT 312
LOT 313
LOT 314
LOT 315
LOT 316
LOT 317
LOT 318
LOT 319
LOT 320
LOT 321
J-1
J-2
J-3
J-4
J-5
J-6
J-7
J-8
J-9
J-10
J-11
J-12
J-13
J-14
J-15
J-16
J-17
J-18
J-19
J-20
J-21
J-22
J-23
J-24
J-25
J-26
J-27
J-28
J-29
J-30
J-31
ASPEN-6
ASPEN-10
EXISTING BUILDING
3035
3036
3037
3038
3039
3040
3041
3042
3043
3044
3045
3046
3047
3048
3049
3050
3051
3052
3053
3054
3055
3056
3057
3058
3059
3060
3061
3062
3063
3064
3065
3066
3067
3068
3069
3070
3071
3072
3073
3074



NOT FOR CONSTRUCTION

HORIZON POINT P.U.D.
STREET CONNECTION EXHIBIT

REDMOND, OREGON

REVISIONS:

HWA
CIVIL ENGINEERING | SURVEYING | PLANNING
62930 O.B. RILEY ROAD, STE. 100, BEND, OR 97703
PH: (541)388-3003 | FAX: (541)388-5416
WEB: WWW.HWA-INC.COM

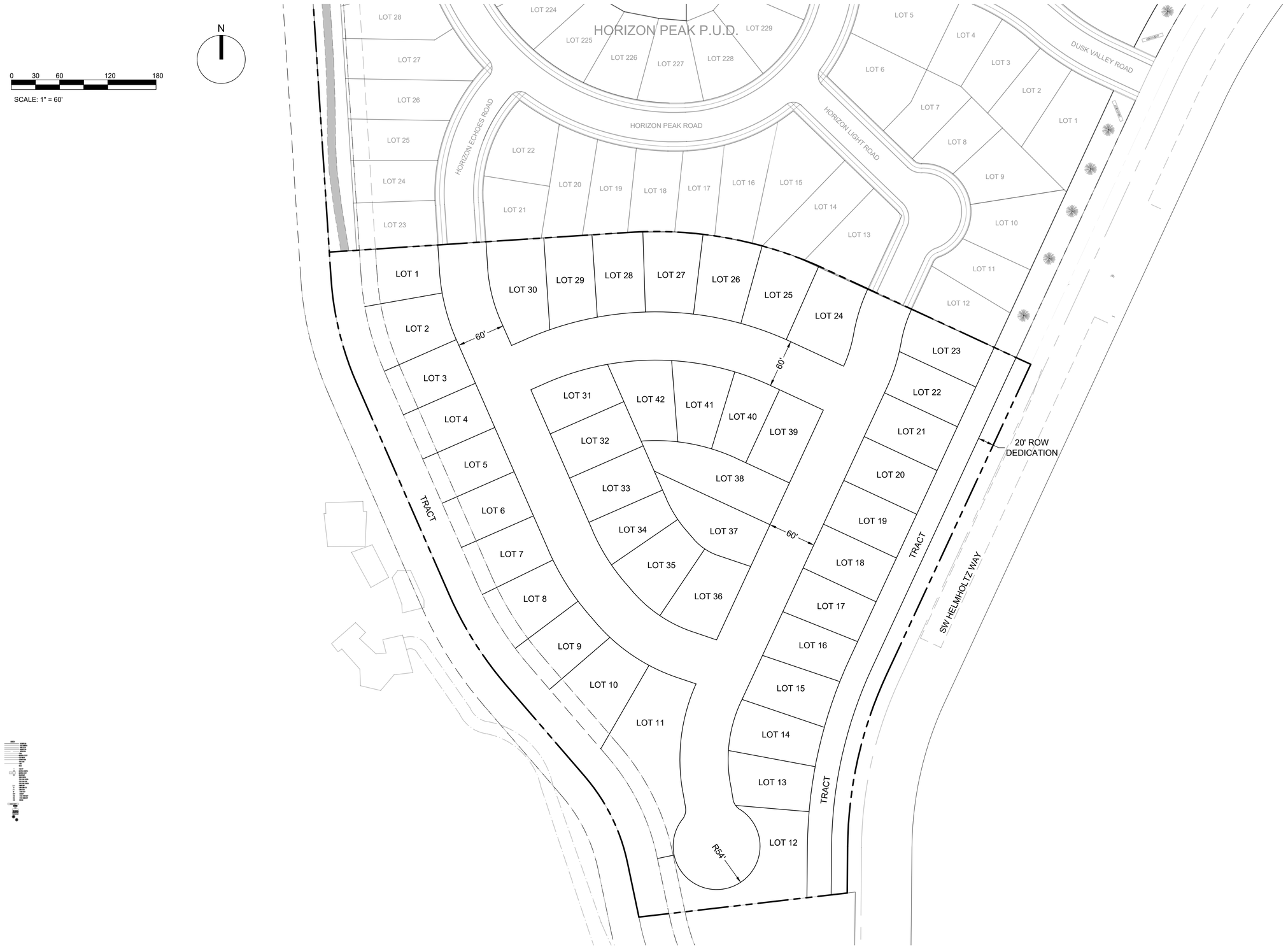
DESIGNED BY: BRG
DRAWN BY: BRG
CHECKED BY: GMH
SCALE: AS NOTED
FILE: 250101_CD.dwg
DATE: 11/18/2025

VERIFY SCALES
0 1"
BAR EQUALS ONE INCH ON ORIGINAL DRAWING

SHEET:
P5.4

HWA # 250101

BrandonG S:\Land Projects\250101-Horizon Pointe Subd, Phase 1\dwg\CIVIL\CD\SHEETS\250101_CD.dwg Tue Nov 18, 2025 - 11:23am



NOT FOR CONSTRUCTION

HADFIELD PROPERTY SHADOW PLAT

REDMOND, OREGON

REVISIONS:

HWA
CIVIL ENGINEERING | SURVEYING | PLANNING
62920 O.B. RILEY ROAD, STE. 100, BEND, OR 97703
PH: (541) 388-9351 | FAX: (541) 388-8416
WEB: WWW.HWAGEO.COM

DESIGNED BY: BRG
DRAWN BY: BRG
CHECKED BY: GMH
SCALE: AS NOTED
FILE: 250101_CD.dwg
DATE: 11/18/2025

VERIFY SCALES
0 1"
BAR EQUALS ONE INCH ON ORIGINAL DRAWING

SHEET:
P5.5

HWA # 250101

BrandonG S:\Land Projects\250101-Horizon Pointe Subd, Phase 1\dwg\CIVIL\CD\SHEETS\250101_CD.dwg Tue Nov 18, 2025 - 11:24am

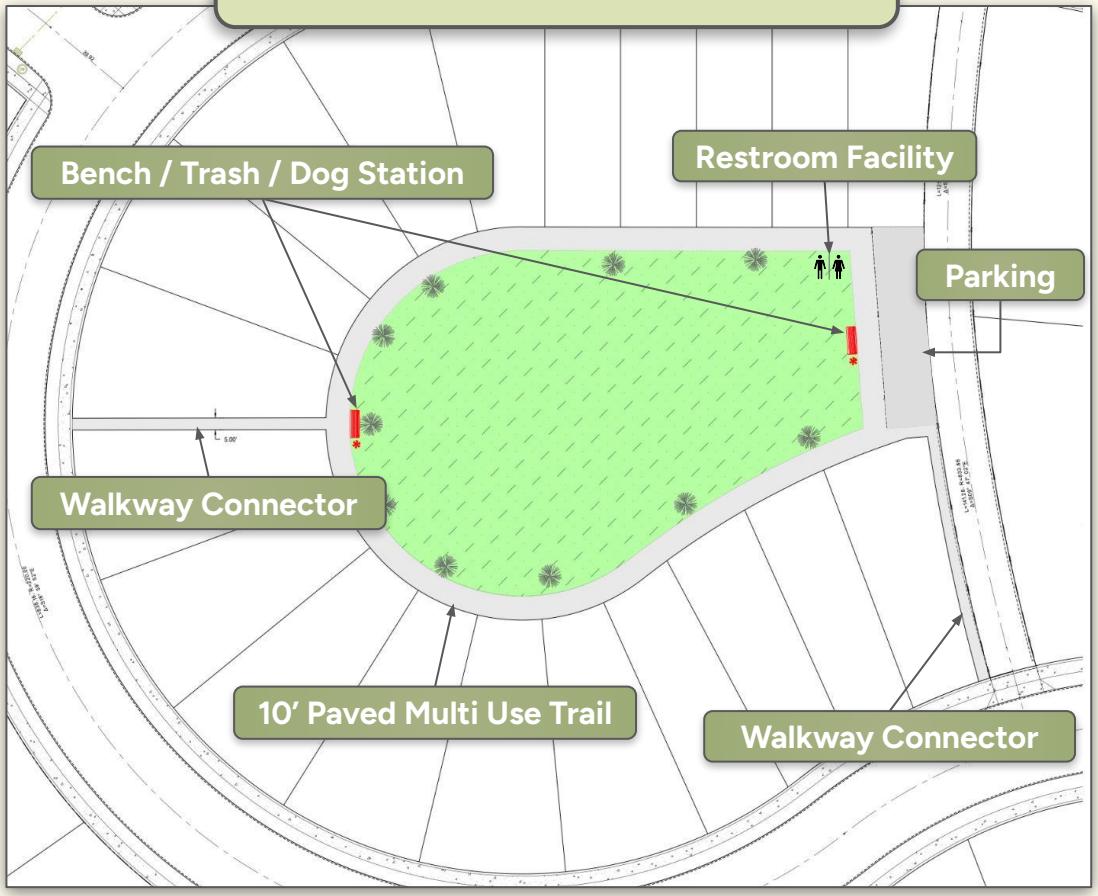
HORIZON POINTE

PARKS & TRAILS CONCEPTUAL PLANNING

MonteVista HOMES

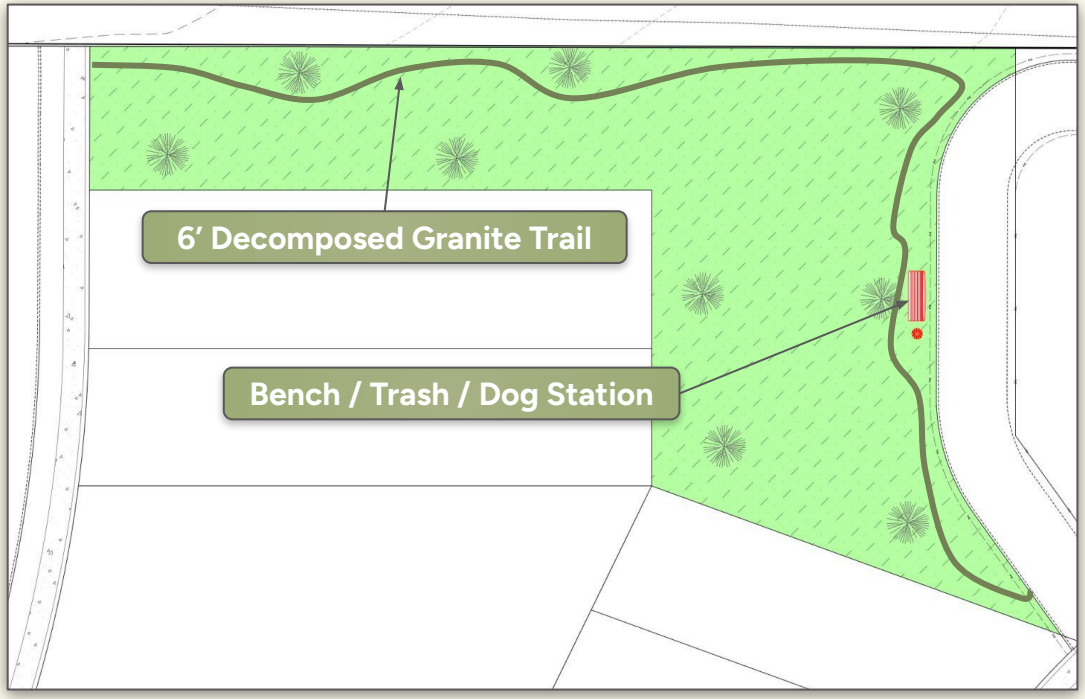
11/17/2025

TRACT R


Bench / Trash / Dog Station
Restroom Facility
Parking
Walkway Connector
10’ Paved Multi Use Trail
Walkway Connector



TRACT H


6’ Decomposed Granite Trail
Bench / Trash / Dog Station

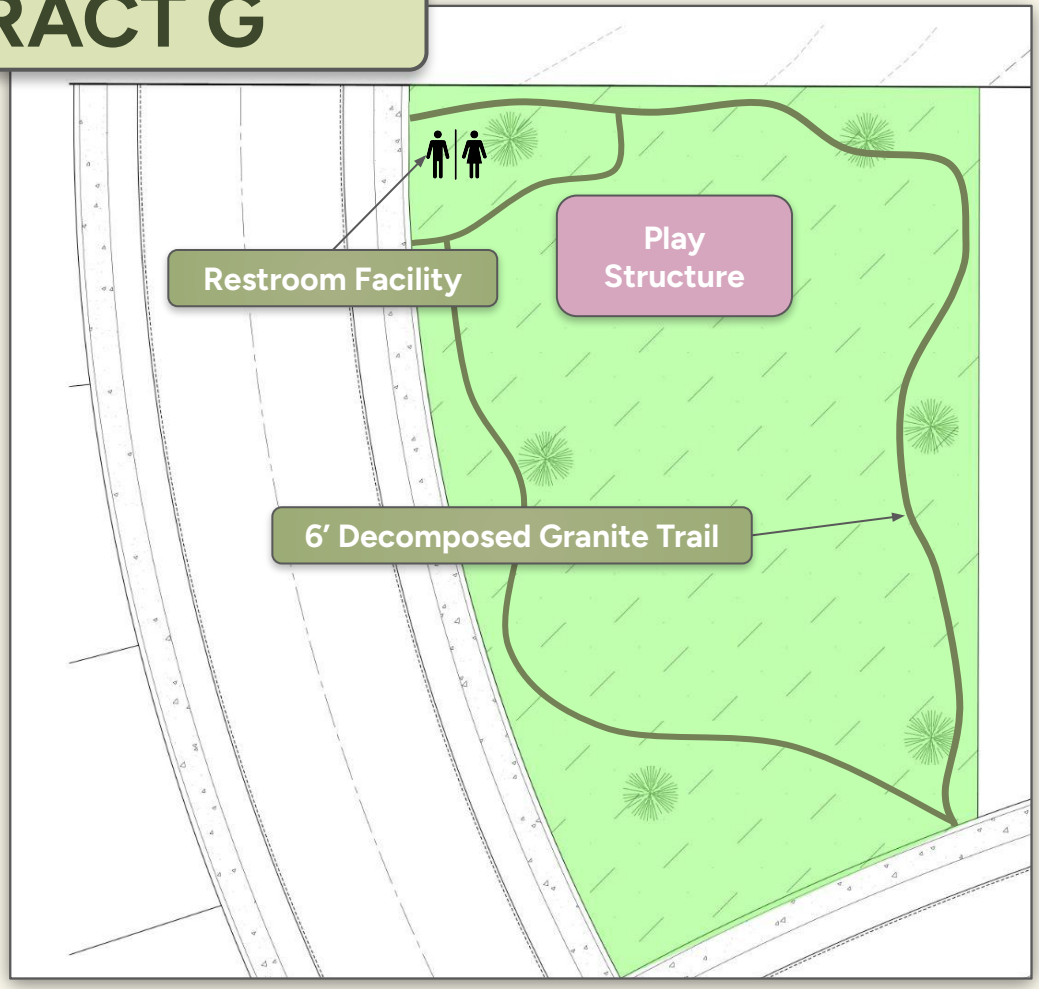

HORIZON POINTE
TRAILHEAD ENTRANCE



TRACT G

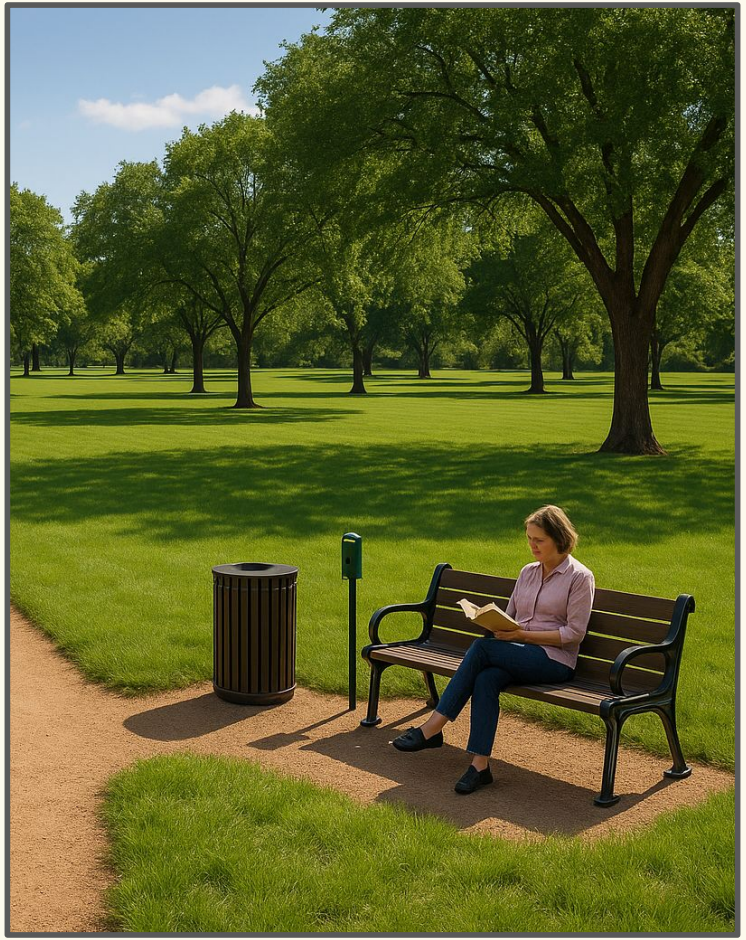




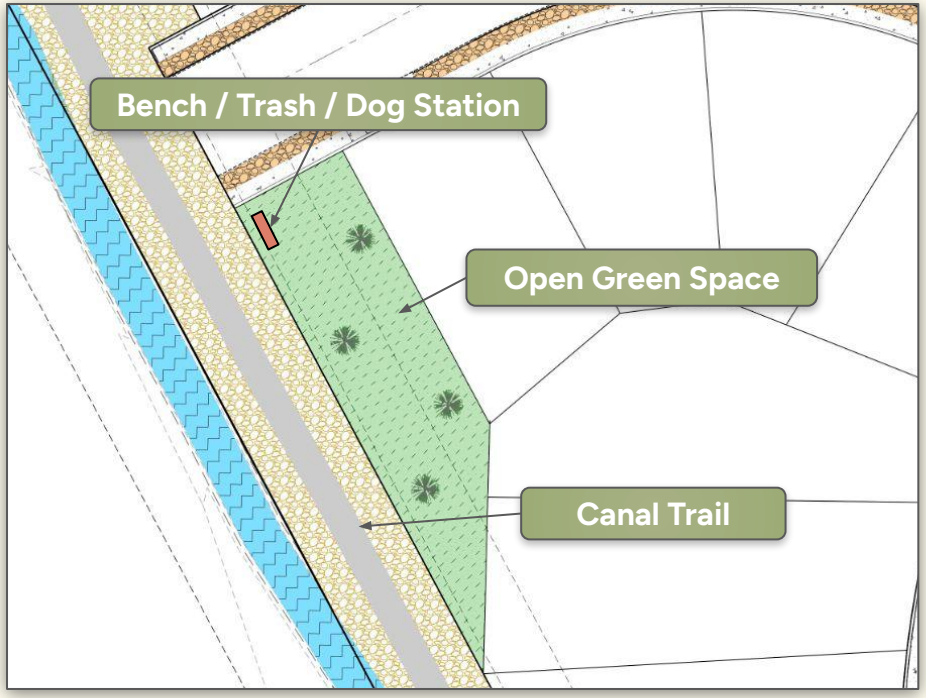

Restroom Facility
Play Structure
6’ Decomposed Granite Trail

TRACT I





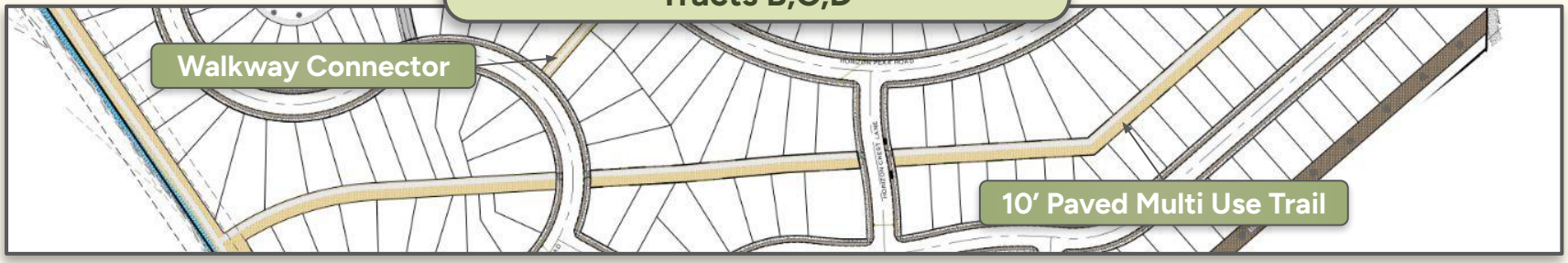
TRACT J





CANAL TRAIL 1

Tracts B,C,D

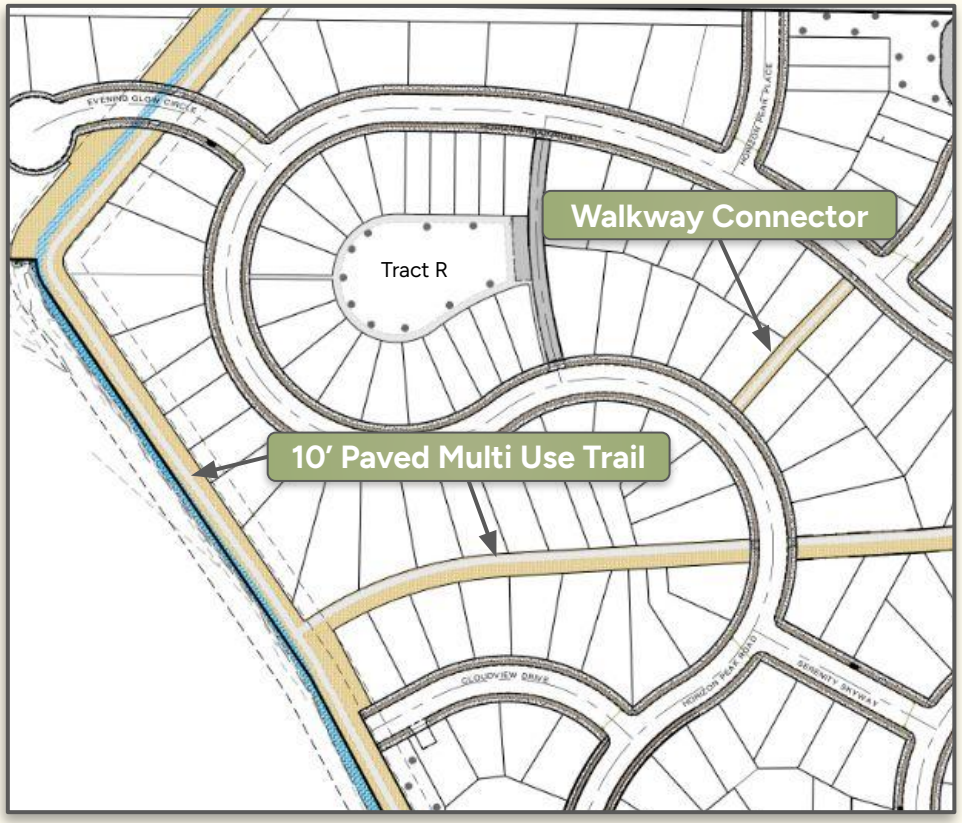






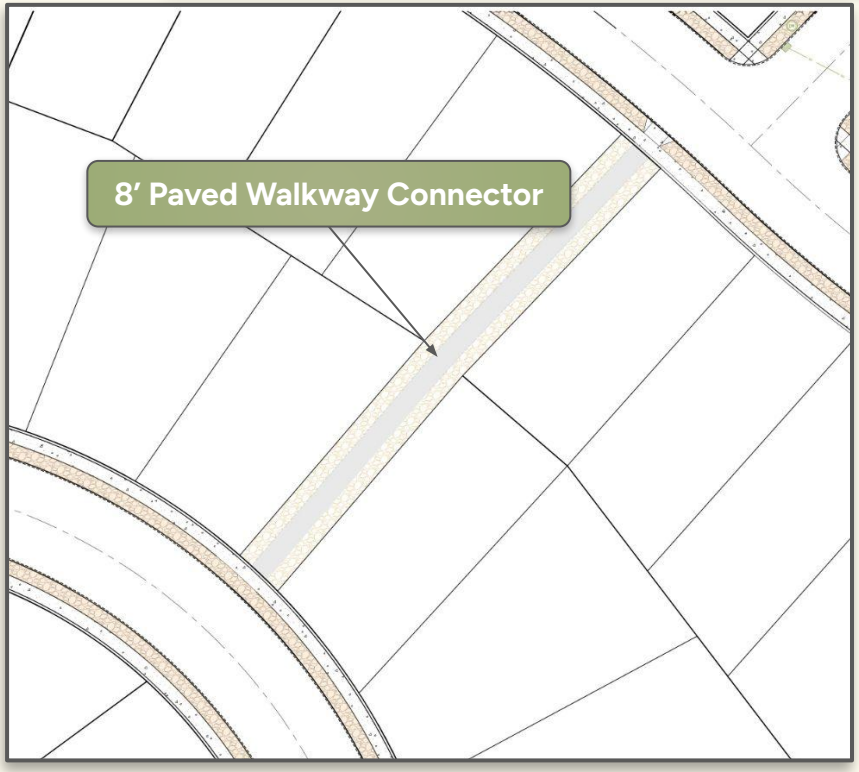
CANAL TRAIL 2

Tracts D,E





TRACT K (WALKWAY CONNECTOR)





URBAN RURAL INTERFACE

Tracts S,T





PROGRAMMING TABLES

Programmed Parks & Trails	Description	Open Space Sq.Ft.	Paved Trails Lineal Feet	Paved Trails Sq.Ft	Natural Trails Lineal Feet
Tract G	Parks	13,597	-	-	420
Tract H	Parks	12,622	-	-	345
Tract I	Parks	3,301	-	-	-
Tract J	Parks	5,581	-	-	-
Tract R	Parks	31,756	854	7,465	-
Tract B, C, D, E	Trails (Canal Trails)	135,987	3,925	38,155	-
Tract M, N, A	Trails (Canal Trails Open Space)	4,489	-	-	-
Tract S	Urban Rural Interface	12,382	-	-	636
Tract T	Urban Rural Interface	15,416	-	-	995
Tract K	Walkway Connector	4,385	221	1768	-
	Totals	**239,516**	**5,000**	**47,388**	**2,396**

Open Frontage	Description	Open Space Sq.Ft.
Tract	O	10,554
Tract	P	16,698
Tract	Q	23,805
	Total	**51,057**

Open Space Grand Total	
Square Feet	290,573
Acres	6.67







HORIZON POINTE







MonteVista HOMES

Horizon Pointe Subdivision
Burden of Proof for City of Redmond
Application for Planned Unit Development (PUD), Conditional Use Permit (CUP), and Subdivision (SUB)

APPLICANT:
Redmond Land Group LLC
389 Scalehouse Ct. Suite 110
Bend, OR 97702

OWNER(s):
Ronald Nelson
2577 SW Helmholtz Way
Redmond, OR 97756

Richard & Meghan Holmes
2572 SW Helmholtz Way
Redmond, OR 97756

Nathan & Jessica Hadfield
2897 SW Helmholtz Way
Redmond, OR 97756

SURVEYOR/ ENGINEER:
Hickman Williams & Associates Inc
62930 O.B. Riley Rd.
Suite 100
Bend, OR 97703
(541) 389-9351

LOCATION:
The property is located at 2577 SW Helmholtz Way and is further identified as Tax Lot 1100, 1101, & 1102 on Deschutes County Tax Assessors Map 151319000.

REQUEST:
A Planned Unit Development Subdivision Plat for a 321 unit subdivision. This includes 245 detached single family lots and 76 townhome lots. The subject properties currently total to 78.31 acres of undeveloped farmland. The existing zoning is R-3, R-4, & R-5 and the property is currently within city limits.

Table of Contents

I. APPLICABLE CRITERIA 3

II. UGB and Special Area Plans 4

III. SITE DESCRIPTION 5

IV. PROPOSAL 6

V. PROPOSED FINDINGS 7

Sec. 8.135. – Table A, Residential Zones, Uses Permitted 7

Sec. 8.140. - Table B, Minimum Standards. 7

Sec. 8.141. – Single Family Detached Dwellings and Plexes Development and Design Standards. 9

Sec. 8.142. – Townhouse Development and Design Standards. 12

Sec. 8.275. – Planned Unit Development (PUD). 14

Sec. 8.385. – Neighborhood Meeting 36

Sec. 8.600. – Authorization to Grant or Deny Condition Uses 37

Sec. 8.2200. Tentative Subdivision Plan et. Seq. (SUB). 38

Sec. 8.2700. et. Seq.– Design Standards and Improvements 43

Sec. 8.2800. - Improvement Procedures. 61

I. APPLICABLE CRITERIA

The following are the applicable sections from The City of Redmond Development Code:

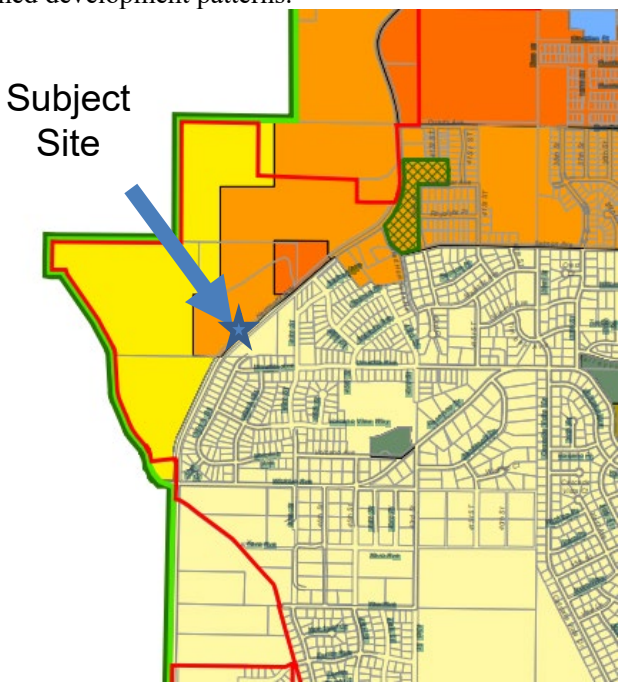
- The City of Redmond Urban Area 2040 Comprehensive Plan.
- The City of Redmond Framework Plan
- City of Redmond Transportation System Plan
- City of Redmond Public Facility Master Plans (Water, Wastewater)
- City of Redmond Park Master Plan
- Oregon Revised Statutes (ORS) – ORS 197.250
- The City of Redmond Development Code, Chapter 8;
  - Section 8.135 Table A, Residential Zones, Uses Permitted
  - Section 8.140 Table B, Minimum Standards
  - Section 8.141 Single Family Detached Dwellings and Plexes Development and Design Standards
  - Section 8.142 Townhouse Development and Design Standards.
  - Section 8.275 Planned Unit Development (PUD)
  - Section 8.385 Neighborhood Meeting
  - Section 8.600 Authorization to Grant or Deny Condition Uses
  - Section 8.2200 Tentative Subdivision Plan et. Seq. (SUB)
  - Section 8.2700 et. Seq.-Design Standards and Improvements
  - Section 8.2800 Improvement Procedures
- This application also aligns with Redmond's and Oregon's broader housing objectives, including the State's directive to increase the supply of attainable housing for Oregon families. Horizon Pointe's efficient land design and reduced infrastructure burden directly support these priorities.

II. UGB and Special Area Plans

Horizon Pointe is located within the Redmond Urban Growth Boundary and is fully consistent with the City's long-range planning direction. The project's curvilinear street design, efficient land design pattern, and integrated open space network advance the objectives of the UGB by promoting orderly, efficient, and coordinated urban development.

The site's unconventional shape, terrain and the alignment of the COID canals create unique design constraints that make traditional grid layouts inefficient and inconsistent with the intent of Redmond's UGB planning. The proposed curvilinear street network responds directly to these conditions and results in less infrastructure, improved safety, and larger, more functional homesites.

The proposal supports Redmond's Great Neighborhood Principles by improving connectivity, enhancing pedestrian experience, reducing unnecessary pavement, and delivering a housing community that is compatible with surrounding planned development patterns.



III. SITE DESCRIPTION

The subject property is 78.31 acres with significant elevation change across the property. The subject property has been and is currently used for agriculture. An existing house, along with several outbuildings, exists on each Lot (1100, 1101, 1102). COID B lateral canal runs north south along the west of Lots 1100 and 1101 and COID B-9 canal runs east west through the center of the properties.

The surrounding area is a mix of new residential development with Little Texas to the north and Summit Crest to the east. Large tracts of pastureland remain throughout the area. SW Helmholtz, a Minor Arterial, abuts the property to the east. The west side of Lots 1100 and 1101 is the new Urban Growth Boundary.

The subject property has an unconventional shape, terrain constrains especially on the North side of the sire and is bisected by a COID canal. These fixed physical constraints significantly influence the site's development potential and make a traditional grid street system inefficient and inconsistent with Redmond's planning goals

The canal, combined with the irregular geometry of the parcel, creates natural limitations on block orientation, intersection placement, and lot depth. Rather than force a rigid grid onto these constraints—which would result in land waste, awkward lots, and excessive infrastructure—the proposed layout works with the land's natural form.

The canal along the western edge also serves as a natural buffer and fire break, improving public safety and reducing wildfire risk for homes located along the western boundary. This aligns with local and state wildfire resilience objectives



Vicinity Map

IV. PROPOSAL

The Horizon Pointe Planned Unit Development and Tentative Subdivision Plat submitted by the applicant proposes to provide a variety of houses in the R-3, R-4, & R-5 zones. The tentative plan includes 321 units in total, 245 single family lots, and 76 townhome lots.

The proposed design uses a curvilinear street network that responds directly to the site's shape, terrain and the COID canal alignment. This approach creates a more efficient lot structure, reduces unnecessary pavement, sidewalk and utility main lengths, and enhances neighborhood safety by minimizing four-way intersections.

The street system produces fewer conflict points and reduces vehicle speeds, consistent with research from the Federal Highway Administration (FHWA) and Oregon Department of Transportation (ODOT), which both identify T-intersections as safer than traditional four-way intersections.

By reducing total street length and utility mains, the proposal significantly lowers long-term City maintenance obligations while allowing larger lots, which increases assessed tax value and enhances fiscal sustainability for the City of Redmond.

The design also improves pedestrian connectivity by orienting more homes toward the street and avoiding long stretches of side-yard fences typical in grid systems, which advances the City's Great Neighborhood Principles.

This proposal directly supports Redmond's and Oregon's housing priorities by lowering the cost of infrastructure and delivering more attainable homes for families who work in Redmond but increasingly cannot afford to live here.

V. PROPOSED FINDINGS

The findings proposed herein are intended to provide the City Planning Staff with an adequate response to the requirements of The City of Redmond development code.

Sec. 8.135. – Table A, Residential Zones, Uses Permitted

Residential Uses:	R-1	R-2	R-3	R-4	R-5	RESTRICTIONS AND REQUIREMENTS
Accessory Building:						
Detached sheds, shops, and garages	O	O	O	O	O	Must be located within the property and not in the yard setback areas. Moveable shipping containers, or similar, are not allowed.
Guest House	O	O	O	O	O	No kitchen; uses main houses' sewer & water
Accessory Dwelling Unit / Accessory Suite	O	O	O	O	O	Uses main houses' sewer & water or individual City Services; may have kitchen
Accessory Use	O	O	O	O	O	Includes Home Occupations
Duplex, Triplex, Quadplex, Townhouse, Cottage Cluster	O	O	O	O	O	
Planned Unit Development	C	C	C	C	C	
Single Family Detached Dwelling	O	O	O	O	O	

Response: Single Family Detached Units and Townhomes are permitted outright in all the zones on the subject properties. A Planned Unit Development is conditionally permitted in all the zones on the subject properties. The curvilinear street layout enhances the functionality of the permitted residential uses by improving safety, reducing speeding, and creating a calmer, more livable residential environment. This directly supports the intended use of the site for single-family and townhouse residential development as contemplated under Table A

Sec. 8.140. - Table B, Minimum Standards.

The following minimum standards apply in each of the Residential zones as follows:

Standard:	R-1	R-2	R-3, R-3A	R-4	R-5
Minimum Lot size - Square Feet					
Single Family, Duplex, Triplex, Single Room Occupancy Development	9,000	9,000	7,500	5,500	5,500

Quadplex, Cottage Clusters	9,000	9,000	7,500	7,000	7,000
Townhouse	1,500	1,500	1,500	1,500	1,500
Multi-family Complex: 5+ units	No Minimum Lot Size Must Meet Density Standards				
Density – Units/Net Acres					
Minimum Density: All	4	4	5	5	8
Maximum Density: Single Family, Single Room Occupancy Development	5	5	5.8	8	8
Maximum Density: Duplex, Triplex, Quadplex, Cottage Cluster	No Maximum Density Must Meet Minimum Lot Size				
Maximum Density: Townhouses	20	20	23.2	25	25
Maximum Density: Multi-Family Complex 5+ units	N/A	N/A	N/A	14.5	17.4
Standard:	R-1	R-2	R-3, R-3A	R-4	R-5
Planned Unit Developments (PUDs) densities in Section 8.275.					
Minimum Setback Distance – Feet					
Front Façade, excluding garage	10	10	10	10	10
Interior Side	5/10	5/10	5	5	5
Interior side yards must be a minimum of 5 feet on one side and 10 feet on the other side for single family, duplex, triplex, and quadplex residences. Where alley access is provided, both interior side yards may be reduced to 5 feet. Exceptions to the 10-foot setback are allowed (1) when the residential lot was created prior to the adoption of this standard (November 9, 2006); (2) on cul-de-sac lots; or (3) on flag lots.					
Street Side	10	10	10	10	10
Rear	20	20	20	15	5
Attached Garage, access from alley or street	20	20	20	20	20
Setbacks:					
ADUs: Specified in Section 8.325					
Detached Accessory Structures: Specified in Section 8.323					
Cottage Clusters: Specified in Section 8.143					
Multi-family Complexes: Specified in Section 8.3035(4.E. Table A.)					
Townhouses: Specified in Section 8.142					
Maximum Building Height - Feet					
Single Family, Plexes, ADU	32	32	32	45	45

Cottage Cluster	25	25	25	25	25
Townhouse	35	35	35	45	45
Minimum Street Frontage - Feet					
Standard Street	50	50	50	50	40
Cul-de-sac	30	30	30	30	30
Flag Lot	20	20	20	20	20
Townhouse	20	20	20	20	20

Response: All instances in which these criteria are not met by the proposed layout the exceptions have been requested as a part of the PUD narrative within this document.

Although the curvilinear design produces variable lot frontage widths, the layout results in larger and more functional lots overall. This is achieved by reducing unnecessary roadway length, which preserves more land for homesites while still meeting applicable dimensional standards.

The street network enhances compliance with minimum standards by producing lots with improved building envelopes and more efficient placement of homes, reducing constraints and maximizing usability.

In addition, the reduced total street length lowers the extent of required utilities and public improvements, leading to long-term cost efficiencies for the City while maintaining full compliance with all dimensional standards of Table B

Sec. 8.141. – Single Family Detached Dwellings and Plexes Development and Design Standards.

1. *Purpose.* The purpose of these Development and Design Standards is to promote and sustain:
   A. Quality development throughout a variety of housing choices;
   B. Architectural design that:
      1. Enhances the visual environment and character of the community;
      2. Preserves and protects property values, as well as public and private infrastructure investment;
      3. Conveys a sense of balance and character among all neighborhoods throughout Redmond; and
      4. Elevates the attractiveness and quality of life in Redmond.
2. *Intent.* The intent of the Development and Design Standards is to:
   A. Maintain flexibility for a variety of architectural style to be developed;
   B. Continue to allow innovations in design that recognize newer technologies such as solar and wind power, telecommunications, and environmentally conscious construction methods; and,

C. Promote quality design characteristics that will enhance the long-term desirability of the dwelling, neighborhood, and community.

3. *Procedure.* New single-family detached dwellings and plexes, shall be reviewed for conformance with the requirements listed in this Section, subject to the procedures outlined below:

A. If applicable, pursuant to Section 8.2135, for proposed development on a lot created by a subdivision that received tentative subdivision approval no more than ten years ago, the applicant shall elect in writing that: a) development and design standards in effect at time of tentative subdivision approval be applied; or b) development and design standards herein be applied. The standards chosen shall apply to all subsequent development in the subdivision.

B. Track 1. Clear and Objective Process. Conformance with Section 8.141(5.), below. An application demonstrating conformance with this Section shall be shown on the architectural plans submitted with the building permit application and administered as part of the plan review process. These applications are reviewed administratively.

C. Track 2. Discretionary Process. As an alternative to the Track 1 procedure, an application may be submitted which demonstrates conformance with the Purpose and Intent of this Section as listed above. These applications are reviewed administratively unless it is determined that a public hearing is necessary, in which case the application will be reviewed by the appropriate Hearings Body. The City may also approve other architectural designs or design elements not listed in this Section, approve exceptions or uniquely identifiable house styles provided they comply with the intent of this Section.

D. Design Review for Manufactured and Mobile Homes not within approved mobile home parks: Some manufactured homes and mobile homes may not be able to fully comply with the requirements below. In those cases, the following features are required as part of a Track 2 process.

1. At least one covered porch;

2. One exterior types of wall siding material on four sides;

3. Band courses; and

4. *Application and Approval Process.* The applications for either a Track 1 or 2 review as specified in Sections 8.141(3.)(A.) and (B.) above, shall be submitted prior to or in conjunction with an application for a building permit.

5. *Architectural Design Standards.* Although specific architectural styles are not mandated, single family detached dwellings and plexes, shall conform with the following standards:

A. Screening of Mechanical Equipment. All exterior ground mounted mechanical equipment located forward from the line of the front façade (living space and garage) of the building shall be screened from the street at the ground/eye level line of sight. Solar power, wind power, and satellite dishes necessitating placement on walls or roofs for normal operation are exempt from this provision.

B. Building Design. The standards of this Section apply per residential structure, rather than per dwelling unit contained in the residential structure.

1. Architectural Design. Duplicate or repetitive exterior home designs must be separated by at least one lot/attached building of non-repetitive exterior design on either side of the home and not be directly across the street from one another. Home designs will not be considered repetitious if three differentiating criteria are used as listed below:

a. Process. Builders of dwelling units or residential structures on the same street, with the exception of multiple dwelling units that are part of a single plex development, shall submit a plat showing the house plan names, elevation designations, or pictures for adjacent homes.

b. Attached plexes are exempt.

2. Roof Design. Required Roof Design Elements:
    a. Pitched or sloping roof elements;
    b. Eave of at least 12 inches.
3. Front Façade Wall Design. Ten façade elements listed below shall be used on the front elevation. Use of T-111 exceeding 20 percent of all facades, combined, is not allowed.
    a. Twenty five percent fenestration of the first story front façade.
    b. Window trim at least 3.5 inches wide that completely surrounds the window;
    c. Band course, band molding, bellyband, belt course that runs the entire width of the front façade of relatively slight projection; or at the break of the second floor (if one exists) or at the line made by the lower roofline at the gable end;
    d. Variation in wall siding, wall surface pattern or decorative materials. If an area above the highest band course exists, it must contain a different siding material than the area below the band;
    e. Recessed or covered front entry at least 20 square feet, with a minimum four foot depth measured from the front door. If columns are used, they must not be exposed dimensional lumber less than 6" x 6";
    f. Windows with multi-paned sashes, operable sashes, or windows that are elliptical, round, arched, bay, semi-circular or similar design;
    g. Shutters;
    h. Balconies;
    i. Garage doors, including patterning relief over the door surface;
    j. Optional enhancements and substitutions:
        i. Enclosed soffits;
        ii. One- and one-half inches caliper tree, in addition to required street trees;
        iii. Covered rear patio or porch;
        iv. Eave greater than 12 inches in depth, including extended soffit details;
        v. Where gable ends are proposed, at least three gable end elements;
        vi. Masonry accents;
        vii. Paint color schemes, with a minimum of two colors used; and
        viii. Other elements or substitutions as approved by the Community Development Director, or designee.
4. Side Elevations Facing Public Streets. Side elevations facing streets must include either window trim at least 3.5" in width, or full-lap siding. Façade facing streets are required to have at least ten square feet of windows or doors.
5. Front Door. A front door that is visible from the public street frontage (front yard) and pedestrian connection between the front door and the public sidewalk is required.
6. Driveways and Garages.
    a. A garage is required for each newly constructed residential structure and shall be of adequate size to accommodate a minimum of one vehicle, and shall at a minimum, meet the design requirements in Sections 8.505 through 8.515 (Off Street Parking and Loading Requirements) and Section 8.2820 (Access Management Standards).
        i. Manufactured homes may meet this standard by substituting a garage with covered parking or carport.
        ii. Triplexes and quadplexes may meet this standard by substituting garage or covered parking with uncovered, paved parking spot(s) per the design requirements in Sections 8.505 through 8.515.
    b. Driveways shall be of adequate size to accommodate a minimum of one vehicle, and shall at a minimum, meet the design requirements in Section 8.515 Parking Table and Diagram.
    c. A single-family detached home that adds an ADU shall continue to meet the minimum parking spaces requirement for the primary home.

d. Notwithstanding the applicable provisions of Sections 8.505 through 8.515 (Off-Street Parking and Loading Requirements) and Section 8.2820 (Access Management Standards), all required off-street parking areas and driveways constructed in conjunction with single family detached dwellings or plexes may have alternative surfaces to concrete or asphalt and may include permeable surfaces to the extent they provide an all-weather surface sufficient for vehicular travel. Loose gravel, aggregate and similar surface treatments are not permitted for required parking spaces.

7. Off-street Parking. The minimum number of required off-street parking spaces for single-family detached dwellings and plexes are specified in Section 8.500.
8. Landscaping. See Sections 8.520 through 8.540 for applicable landscaping standards.
9. Fences. See Section 8.340.
10. Conversion. Conversions of an existing single-family detached dwelling to a duplex, triplex, or quadplex is allowed, provided that the conversion does not increase non-conformance with applicable standards of the underlying zone and this Section.

RESPONSE: Compliance with design standards for Single Family Detached Dwellings will be reviewed with building permit application. No buildings are proposed at this time.

Sec. 8.142. – Townhouse Development and Design Standards.

1. *Procedure.* New townhouses shall be reviewed for conformance with the requirements listed in this Section.
2. *Table A: Minimum Standards.*

Standard:	**R-1**	**R-2**	**R-3, R-3A**	**R-4**	**R-5**
Maximum Density (Units/Net Acre)	20	20	23.2	25	25
Minimum Lot Size (Square Feet)	1,500	1,500	1,500	1,500	1,500
Maximum Building Height (Feet)	35	35	35	45	45
Minimum Street Frontage (Feet)	20	20	20	20	20
Minimum Setback Distance (Feet)					
Front with alley or other rear access	10	10	10	10	5
Front without alley or other rear access	10	10	10	10	10
Front garage setback from street	20	20	20	20	20
Non-street side: Common wall lot line where units are attached	0	0	0	0	0

Exterior wall at end of a townhouse structure	5	5	5	5	5
Street Side	10	10	10	10	10
Rear with garage and alley access	5	5	5	5	5
Rear without garage	10	10	10	10	10

3. *Off-Street Parking.* Townhouses shall meet the off-street parking requirements of Section 8.500.
4. *Areas Owned in Common.* For townhouse projects, common areas must be maintained by a homeowners association or other legal entity. A homeowners association may also be responsible for exterior building maintenance. A copy of any applicable covenants, restrictions and conditions must be recorded and provided to the City prior to issuance of a building permit.
5. *Design Standards.* New townhouses shall meet the design standards in Subsections (A.) through (G.) of this Section.

A. *Entry Orientation.* The main entrance of each townhouse must:

1. Be within 8 feet of the longest street-facing wall of the dwelling unit, if the lot has public street frontage; and
2. Either:
    a. Face the street (see Figure 1);
    b. Be at an angle of up to 45 degrees from the street (see Figure 2);
    c. Face a common open space or private access or driveway that is abutted by dwellings on at least two sides; or
    d. Open onto a porch (see Figure 3). The porch must:
        i. Be at least 25 square feet in area; and
        ii. Have at least one entrance facing the street or have a roof.

B. *Unit Definition.* Each townhouse must include at least one of the following on at least one street-facing façade (see Figure 4):

1. A roof dormer a minimum of four feet in width, or
2. A balcony a minimum of two feet in depth and four feet in width and accessible from an interior room, or
3. A bay window that extends from the facade a minimum of two feet, or
4. An offset of the facade of a minimum of two feet in depth, either from the neighboring townhouse or within the façade of a single townhouse, or
5. An entryway that is recessed a minimum of three feet, or
6. A covered entryway with a minimum depth of four feet, or
7. A porch meeting the standards of Subsection (A.2.d.) of this Section. Balconies and bay windows may encroach into a required setback area.

C. *Windows.* A minimum of 15 percent of the area of all street-facing facades on each individual unit must include windows or entrance doors. Half of the window area in the door of an attached garage may count toward meeting this standard. See Figure 5.

D. *Driveway Access and Parking.* Townhouses with frontage on a public street shall meet the following standards:

1. Garages on the front façade of a townhouse, off-street parking areas in the front yard, and driveways in front of a townhouse are allowed if they meet the following standards (see Figure 6).
    a. Each townhouse lot has a street frontage of at least 15 feet on a local street.
    b. A maximum of one driveway approach is allowed for every townhouse. Driveway approaches and/or driveways may be shared.

c. Outdoor on-site parking and maneuvering areas do not exceed 12 feet wide on any lot.

d. The garage width does not exceed 12 feet, as measured from the inside of the garage door frame.

2. The following standards apply to driveways and parking areas for townhouse projects that do not meet all of the standards in Subsection (1.).

a. Off-street parking areas shall be accessed on the back façade or located in the rear yard. No off-street parking shall be allowed in the front yard or side yard of a townhouse.

b. A townhouse project that includes a corner lot shall take access from a single driveway approach on the side of the corner lot. See Figure 7.

c. Townhouse projects that do not include a corner lot shall consolidate access for all lots into a single driveway. The driveway and approach are not allowed in the area directly between the front façade and front lot line of any of the townhouses. See Figure 8.

d. A townhouse project that includes consolidated access or shared driveways shall grant access easements to allow normal vehicular access and emergency access.

3. Townhouse projects in which all units take exclusive access from a rear alley are exempt from compliance with Subsection (2.).

4. All driveway accesses for townhouses must comply with Section 8.2820 (Access Management Standards).

E. *Screen of Mechanical Equipment.* All exterior ground mounted mechanical equipment located forward from the line of the front façade (living space and garage) of the building shall be screened from the street at the ground/eye level line of sight. Solar power, wind power, and satellite dishes necessitating placement on walls or roofs for normal operation are exempt from this provision.

F. Landscaping. See Sections 8.520 through 8.540 for applicable landscaping requirements.

G. Fences. See Section 8.340.

RESPONSE: Compliance with design standards for Townhomes will be reviewed with building permit application. No buildings are proposed at this time.

Townhome blocks benefit from the curvilinear alignment by receiving enhanced frontage conditions, improved sightlines, and reduced intersection density. These design benefits support safer access, calmer vehicle speeds, and a more enjoyable pedestrian environment consistent with Section 8.142.

The reduced infrastructure footprint also contributes to improved affordability, which supports the intent of townhouse development to deliver diverse and attainable housing types within Redmond.

Sec. 8.275. – Planned Unit Development (PUD).

1. *Purpose and Applicability.* The purpose of a PUD is to:

A. Permit greater flexibility in land use regulations in applicable zones (e.g., reduction of minimum lot size requirements).

B. Encourage creative developments.

C. Incentivize a variety of land uses and housing types, mixed use, the economy of shared services and facilities, public amenities, and developments compatible with the surrounding area and

neighborhoods.

D. Promote and encourage infill development, flexibility in improvements on lots, and affordable and workforce housing.

E. Encourage preservation of natural features and enhancement of the area vegetation.

F. Facilitate sustainable design, energy efficiency, desirable aesthetics, and efficient use of open space.

Density requirements, setbacks, land use regulations, and required improvements may be adjusted to allow for a more creative, functional, and desirable living environment. In return for greater flexibility in site design and development, the PUD process introduces special requirements and standards for approval.

The Horizon Pointe PUD proposes a modern, context-responsive neighborhood design that introduces 321 homes into the City of Redmond while delivering over 66,000 square feet of programmed neighborhood parks and more than 5,000 linear feet of paved multi-use trails. This land plan represents a thoughtful evolution from the traditional grid pattern historically used in Redmond subdivisions.

While the grid has long served as a utilitarian framework, it frequently produces excessive street mileage, repetitive streetscapes, and limited ability to respond to topography or existing infrastructure. In contrast, the curvilinear street system at Horizon Pointe is designed around the site's defining features—most notably the unconventional parcel shape and the alignment of the COID canal, which runs along the western boundary. This pattern follows the land's form, preserves natural features, and maintains full internal and external connectivity.

The proposed design directly advances the City of Redmond's Great Neighborhood Principles, which encourage varied block structures, integration of natural systems, pedestrian-friendly design, and creative street networks. Curved streets produce broader view corridors, calmer travel speeds, and a more intuitive progression through the neighborhood. These characteristics enhance safety and walkability by reducing the number of four-way intersections—replacing them with safer T-intersections—and by orienting more homes toward the street rather than creating long walls of side yards.

In addition to design benefits, the layout yields measurable community outcomes—referred to as "The Big Three":

1. ***Less Infrastructure:***
   The curved pattern results in substantially less total infrastructure—streets, sidewalks, curbs, gutters, and utilities—than an equivalent grid. This reduction lowers long-term maintenance obligations for the City and reduces lifecycle replacement costs.
2. ***More Usable Space, Larger Lots, Greater Assessed Value:***
   Land saved by reducing excessive right-of-way is reallocated to individual homesites and meaningful community amenities (parks, trails). This results in larger, more functional lots and a stronger long-term tax base through increased assessed property value.
3. ***Lower Housing Costs:***
   By constructing fewer linear feet of road and utilities, overall development costs are reduced. These efficiencies translate directly into more attainable home prices for Redmond families.

These combined outcomes create a true win-win-win:
a win for residents through safer streets and more attainable homes;
a win for the City through reduced maintenance burden and increased tax revenue; and
a win for Redmond's future through efficient, sustainable land use.

The Horizon Pointe design meets and exceeds the intent of Redmond Development Code § 8.270 and § 8.275, which permit and encourage flexible, innovative neighborhood design where such flexibility yields demonstrably superior results for the City and the community.



2. *Approval.* PUD approval is subject to:

A. Land use review and approval as Conditional Use.

B. Zoning standards, except as modified by the PUD.

C. Subdivision and Partitions Standards, except as modified by the PUD.

D. Site and Design Review Standards, except as modified by the PUD.

E. PUD Standards and Requirements.

Response: This document evaluates the requirements for the Conditional Use, Zoning Standards, Subdivision Standards, Site and Design Review Standards, and PUD standards. Applicant wishes to modify these requirements through the PUD to allow for exceptions of minimum lot sizes, frontage requirements, setback requirements, as well as block length & grid spacing standards.

3. *Exceptions.* Exceptions of City standards may be allowed through the PUD approval process without a variance.

A. Exceptions shall substantially result in improved design of the PUD. Improved design includes but is not limited to: alleys; public or private parks, trails, recreational areas, open spaces, common or natural areas; innovative housing design; public or private activity areas; a mixture of housing types, sizes, and projected prices; energy efficient design; a variety of trees and landscaping; art and other similar design features. A PUD need not include all of these design features in order to be approved.

Response: Horizon Pointe's open-space framework is designed as an intentional system of connected green corridors rather than isolated or leftover land. The plan emphasizes open green space with integrated trail connections, creating a continuous network of pedestrian pathways, landscaped buffers, and visual relief areas that enhance both the function and the character of the neighborhood.

The primary objective is to provide residents with meaningful outdoor spaces for walking,

recreation, and informal community gathering. The trail system, which extends throughout the project, links multiple open-space tracts & neighborhood parks to the street network and the COID canal trails, forming a cohesive network that supports safe and enjoyable non-vehicular movement.

Horizon Pointe is designed with flexibility to allow the Homeowners Association (HOA) to thoughtfully plan and implement park programming over time. However, a conceptual programming plan has been included with this application. As the neighborhood matures and community needs evolve, the HOA will elect to add features such as play areas, gathering spaces, or other passive amenities to complement the existing trail and open-space network.

This phased and adaptive approach ensures that the open spaces & programmed parks remain attractive and functional from the earliest stages of development, while preserving the opportunity for future enhancements under private ownership. The design fulfills the intent of Redmond Development Code § 8.275(4)(E) and the Great Neighborhood Principles, which encourage accessible, connected, and adaptable open spaces that evolve with the neighborhood.

Parks programing as provided is conceptual and parks programming will be finalized and constructed with each phase of construction. All programmed spaces (tracts) will be owned and maintained by the HOA to ensure consistent quality, design cohesion, and long-term stewardship of these community assets. The Link below includes a conceptual plan for programming of the neighborhood parks and trails:

Horizon Pointe Parks and Trails Conceptual Plan 11-17-25:
https://drive.google.com/file/d/1UuIFyUyRyNtM6ruxpbp0mEckSdX2dxYR/view

B. Exceptions to City standards include, but are not limited to:

1. Minimum lot sizes.

Response:

The Horizon Pointe PUD includes 149 lots that are smaller than the minimum lot size standards of the underlying zoning districts. This is an intentional and appropriate use of the flexibility allowed under Redmond Development Code § 8.275, which expressly permits modified dimensional standards where the overall PUD design provides a superior community outcome.

The slight reductions in lot size are a direct result of two site-specific conditions:

1. ***The property's unconventional shape and terrain, prevents efficient use of a traditional grid pattern; and***
2. ***The fixed alignment of the COID canals, which limits block orientation and available depth.***

To respond to these constraints while maintaining full internal and external connectivity, the PUD uses a curvilinear street system. Curvilinear streets produce non-orthogonal block structures and therefore create nontraditional lot shapes, particularly at curves and transitions. These lots often have reduced widths at the frontage, but are functionally equivalent—or superior—to conventional lots because they:

- ***Provide more usable private yard area behind the building footprint;***
- ***Reduce the amount of land consumed by right-of-way; and***

- ***Improve pedestrian connections to the 5,000+ linear feet of internal trails.***

Importantly:

• All density requirements are fully met,

• No increase in unit count is requested beyond what the zones permit,

• The reductions do NOT create crowding or diminish livability,

• And overall neighborhood quality is improved.

The use of smaller lots in select locations produces several measurable community benefits, including:

- ***Greater housing attainability, consistent with the City's and State's housing priorities;***
- ***Reduced infrastructure, because less overall street length is needed—supporting the Big Three (less infrastructure, more assessed value, lower housing cost);***
- ***A safer neighborhood due to fewer four-way intersections and improved sightlines created by the curvilinear design; and***
- ***Better alignment with Redmond's Great Neighborhood Principles, which encourage diverse lot sizes, active streetscapes, and improved walkability.***

A table provided on the following page identifies each lot for which a minimum-size exception is requested, including proposed square footage, underlying zone, housing type, and the percentage deviation from the standard.

Minimum Lot Size Exception Requests															
Lot Number	Prop. Sq Ft	Zone	Classification	% Reduction From Standard	Lot Number	Prop. Sq. Ft.	Zone	Classification	% Reduction From Standard	Lot Number	Prop. Sq. Ft.	Zone	Classification	% Reduction From Standard
LOT 2	5755	R3	Single Family	23%	LOT 168	7482	R3	Single Family	0%	LOT 283	4996	R4	Single Family	9%
LOT 3	5356	R3	Single Family	29%	LOT 169	6737	R3	Single Family	10%	LOT 284	5489	R4	Single Family	0%
LOT 4	5134	R3	Single Family	32%	LOT 174	6417	R3	Single Family	14%	LOT 285	4984	R4	Single Family	9%
LOT 7	5494	R3	Single Family	27%	LOT 175	5706	R3	Single Family	24%	LOT 286	4978	R4	Single Family	9%
LOT 8	4854	R3	Single Family	35%	LOT 176	5603	R3	Single Family	25%	LOT 287	4982	R4	Single Family	9%
LOT 9	6838	R3	Single Family	9%	LOT 177	6051	R3	Single Family	19%	LOT 288	5272	R4	Single Family	4%
LOT 10	7465	R3	Single Family	0%	LOT 178	5982	R3	Single Family	20%	LOT 292	5311	R4	Single Family	3%
LOT 11	5522	R3	Single Family	26%	LOT 179	5978	R3	Single Family	20%	LOT 293	5036	R4	Single Family	8%
LOT 12	6060	R3	Single Family	19%	LOT 180	5996	R3	Single Family	20%	LOT 294	5005	R4	Single Family	9%
LOT 13	7441	R3	Single Family	1%	LOT 181	6116	R3	Single Family	18%	LOT 301	6880	R3	Single Family	8%
LOT 14	6768	R3	Single Family	10%	LOT 182	6394	R3	Single Family	15%	LOT 305	5302	R4	Single Family	4%
LOT 16	7102	R3	Single Family	5%	LOT 205	7082	R3	Single Family	6%	LOT 306	5064	R4	Single Family	8%
LOT 17	5302	R3	Single Family	29%	LOT 206	6677	R3	Single Family	11%	LOT 307	5117	R4	Single Family	7%
LOT 18	5956	R3	Single Family	21%	LOT 207	6372	R3	Single Family	15%	LOT 308	5106	R4	Single Family	7%
LOT 19	5848	R3	Single Family	22%	LOT 208	5843	R3	Single Family	22%	LOT 311	5305	R4	Single Family	4%
LOT 20	6556	R3	Single Family	13%	LOT 209	5808	R3	Single Family	23%	LOT 312	5498	R4	Single Family	0%
LOT 21	5597	R3	Single Family	25%	LOT 210	7450	R3	Single Family	1%	LOT 313	5877	R3	Single Family	22%
LOT 22	6702	R3	Single Family	11%	LOT 213	6554	R3	Single Family	13%	LOT 314	6833	R3	Single Family	9%
LOT 23	5795	R3	Single Family	23%	LOT 214	6951	R3	Single Family	7%	LOT 315	5255	R3	Single Family	30%
LOT 24	5330	R3	Single Family	29%	LOT 215	6238	R3	Single Family	17%	LOT 316	6972	R3	Single Family	7%
LOT 25	5883	R3	Single Family	22%	LOT 216	6278	R3	Single Family	16%	LOT 317	6278	R3	Single Family	16%
LOT 26	7052	R3	Single Family	6%	LOT 217	5039	R3	Single Family	33%	LOT 318	6843	R3	Single Family	9%
LOT 28	7040	R3	Single Family	6%	LOT 218	5205	R3	Single Family	31%	LOT 319	6711	R3	Single Family	11%
LOT 29	5812	R3	Single Family	23%	LOT 219	5824	R3	Single Family	22%	LOT 320	7247	R3	Single Family	3%
LOT 30	5645	R3	Single Family	25%	LOT 220	5808	R3	Single Family	23%	LOT 321	6807	R3	Single Family	9%
LOT 31	6832	R3	Single Family	9%	LOT 221	5805	R3	Single Family	23%					
LOT 34	5937	R3	Single Family	21%	LOT 222	5764	R3	Single Family	23%					
LOT 35	5256	R3	Single Family	30%	LOT 223	5770	R3	Single Family	23%					
LOT 36	5016	R3	Single Family	33%	LOT 224	5781	R3	Single Family	23%					
LOT 37	5289	R3	Single Family	29%	LOT 225	5973	R3	Single Family	20%					
LOT 38	5452	R3	Single Family	27%	LOT 226	5847	R3	Single Family	22%					
LOT 39	5732	R3	Single Family	24%	LOT 227	6082	R3	Single Family	19%					
LOT 40	5798	R3	Single Family	23%	LOT 228	5998	R3	Single Family	20%					
LOT 41	5760	R3	Single Family	23%	LOT 229	5992	R3	Single Family	20%					
LOT 42	6163	R3	Single Family	18%	LOT 230	6243	R3	Single Family	17%					
LOT 43	6677	R3	Single Family	11%	LOT 231	6309	R3	Single Family	16%					
LOT 44	7049	R3	Single Family	6%	LOT 232	5523	R3	Single Family	26%					
LOT 45	7055	R3	Single Family	6%	LOT 238	4870	R3	Single Family	35%					
LOT 46	6054	R3	Single Family	19%	LOT 239	4828	R3	Single Family	36%					
LOT 47	5477	R3	Single Family	27%	LOT 240	6542	R3	Single Family	13%					
LOT 49	7149	R3	Single Family	5%	LOT 241	4964	R3	Single Family	34%					
LOT 50	5415	R3	Single Family	28%	LOT 245	6322	R3	Single Family	16%					
LOT 54	7244	R3	Single Family	3%	LOT 246	5919	R3	Single Family	21%					
LOT 55	6788	R3	Single Family	9%	LOT 249	5462	R4	Single Family	1%					
LOT 56	6711	R3	Single Family	11%	LOT 250	5186	R4	Single Family	6%					
LOT 60	6873	R3	Single Family	8%	LOT 251	5111	R4	Single Family	7%					
LOT 61	5360	R3	Single Family	29%	LOT 252	5234	R4	Single Family	5%					
LOT 62	5470	R3	Single Family	27%	LOT 255	5152	R4	Single Family	6%					
LOT 63	5202	R3	Single Family	31%	LOT 256	5000	R4	Single Family	9%					
LOT 64	6739	R3	Single Family	10%	LOT 257	5000	R4	Single Family	9%					
LOT 67	7932	R3	Single Family	-6%	LOT 259	5000	R4	Single Family	9%					
LOT 68	6198	R3	Single Family	17%	LOT 260	5000	R4	Single Family	9%					
LOT 85	6628	R3	Single Family	12%	LOT 261	5000	R4	Single Family	9%					
LOT 86	6048	R3	Single Family	19%	LOT 263	5000	R4	Single Family	9%					
LOT 87	6231	R3	Single Family	17%	LOT 264	5000	R4	Single Family	9%					
LOT 88	5883	R3	Single Family	22%	LOT 265	5000	R4	Single Family	9%					
LOT 89	7441	R3	Single Family	1%	LOT 266	4526	R5	Single Family	18%					
LOT 97	5770	R3	Single Family	23%	LOT 277	5032	R5	Single Family	9%					
LOT 113	5541	R3	Single Family	26%	LOT 278	5026	R5	Single Family	9%					
LOT 133	5080	R4	Single Family	8%	LOT 279	5020	R5	Single Family	9%					
LOT 134	5024	R4	Single Family	9%	LOT 281	5008	R4	Single Family	9%					
LOT 138	5221	R4	Single Family	5%	LOT 282	5002	R4	Single Family	9%					

2. Setbacks.

Response: On Lot 247, applicant wishes to keep the existing Nelson Family home. Because of the proximity of the Nelson home to the existing COID canal, applicant is requesting a 5' rear setback on Lot 247 to allow for the home to remain without rerouting the COID lateral pathway more than necessary.

3. Permitted land uses.

Response: The project only proposes outright permitted uses.

4. Grid street spacing standards.

Response: The Horizon Pointe street network provides strong internal and external connectivity while appropriately responding to fixed site constraints which make a rigid grid both impractical and inconsistent with achieving the functional goals of Redmond's street-spacing standards.

Multiple north–south and east–west connections tie directly into SW Helmholtz Way, Horizon Peak Road, and the future SW 45th Street. This results in a highly connected transportation network that supports efficient movement by vehicles, pedestrians, and emergency services.

While the layout does not follow a traditional grid pattern, it meets or exceeds the intent of Redmond's block-length and spacing requirements by:

- ***Creating a logical and intuitive hierarchy of neighborhood streets;***
- ***Providing direct pedestrian connections through more than 5,000 linear feet of paved multi-use trails;***
- ***Ensuring that pedestrians experience shorter walking distances than in a comparable grid; and***
- ***Maintaining full connectivity despite the natural curvature of the system.***

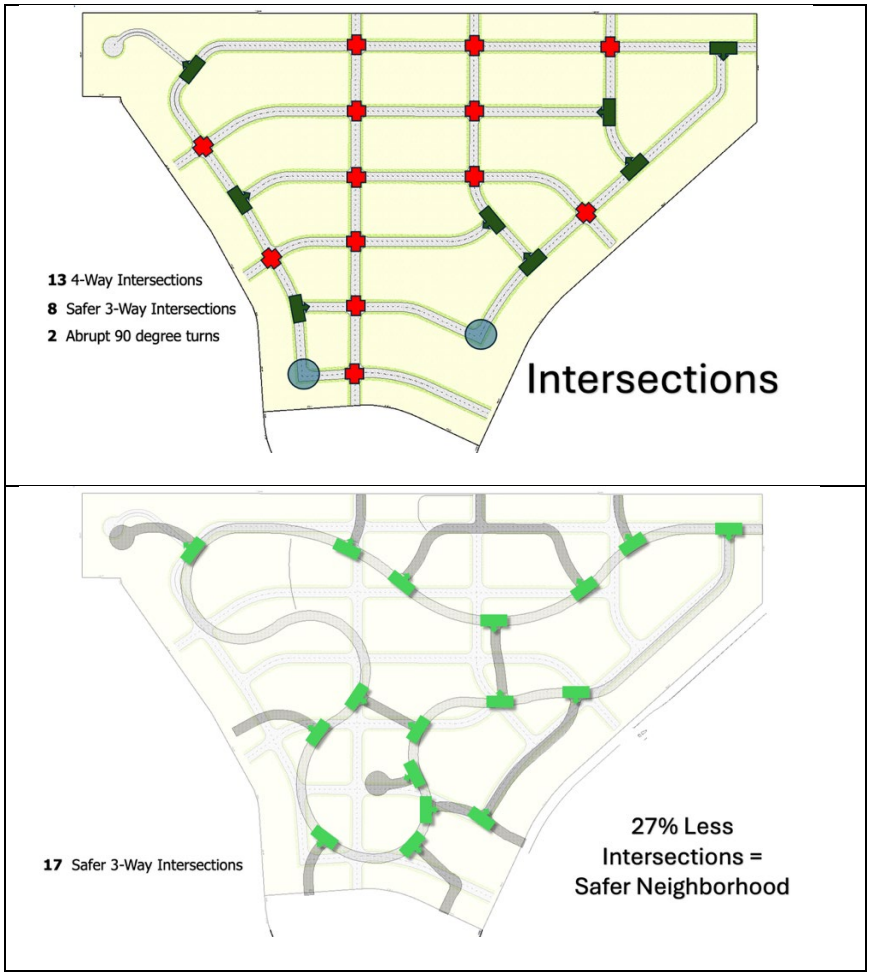
In locations where block lengths approach or exceed numerical thresholds, the design provides equivalent connectivity through trail corridors, mid-block pedestrian linkages, and open-space pathways. This achieves the same planning intent as a grid without imposing an artificial street alignment onto a constrained site.

A central advantage of the curvilinear layout is its documented safety performance. The design intentionally eliminates traditional four-way intersections and replaces them with T-intersections and gentle curves, a configuration widely recognized as safer in residential neighborhoods. Technical findings from the Oregon Department of Transportation (ODOT) and the Federal Highway Administration (FHWA) confirm:

- ***Crash rates are lower at T-intersections than at cross intersections in all cases (ODOT).***
- ***Paired T-intersections are 1.5 to 2.0 times as safe as four-way intersections for the same traffic volumes (ODOT).***
- ***Replacing cross intersections with staggered T-intersections results in a 47% reduction in crashes (cited by ODOT).***
- ***Four-way intersections contain 32 conflict points, compared to 22 for paired T-intersections (ODOT Fig. 1).***

- ***FHWA intersection crash-prediction models consistently show higher crash frequency for four-way intersections versus T-intersections across almost all studied ADT volumes.***

These improvements directly further the intent of RMC § 8.275(4)(D), which prioritizes safe and convenient movement for all travel modes.



Additionally, the curved alignments reduce sightline obstructions and prevent the creation of long, uninterrupted straight road segments that often encourage higher vehicle speeds in grid layouts. This produces a calmer, more predictable neighborhood travel environment—without relying on artificial traffic-calming devices.

Taken together, the Horizon Pointe street network:

- ***Achieves full vehicular and pedestrian connectivity,***
- ***Provides shorter pedestrian travel distances,***
- ***Minimizes conflict points and improves intersection safety,***
- ***Supports better walkability with front-facing home orientation, and***

- ***Meets or exceeds the intent of Redmond's street-spacing standards, even where numerical block-lengths vary due to site constraints.***

Federal Highway Administration (FHWA) Study:
Harkey , D., Srinivasan, R., Kumfer, W., Carter, D., & Nujjetty, A. (2021, January). Impact of intersection angle on Highway Safety. FHWA.
https://www.fhwa.dot.gov/publications/research/safety/20067/

ODOT Study:
Monsere, C. (2001, October 30). Safety comparison of 4-way cross and offset T intersections. ODOT. https://www.oregon.gov/odot/Engineering/TRSDocs/Safety_Research/safety_of_4-leg_vs_t.pdf

The resulting street network is safer, more intuitive, and more comfortable to use—supporting walkability, strengthening neighborhood cohesion, and creating a calmer and more predictable travel environment for residents. By reducing conflict points, improving sightlines, reinforcing logical routing, and integrating continuous pedestrian pathways, the Horizon Pointe design enhances the daily experience of neighborhood life. The street system fully meets the purpose and intent of Redmond Development Code § 8.275 by providing a creative, context-responsive design solution that delivers superior safety performance, improved connectivity, and a more livable community for all users.

The requested exceptions to block length are as follows:

Applicant requests an exception to minimum intersection spacing of 129 ft along Horizon Peak Road between the intersections with Morning Vista Road and Horizon Light Road. Exception is requested due to the required placement of the Dusk Valley Road/Helmholtz Intersection as well as required secondary street connection to the property to the south.

Applicant requests an exception to minimum intersection spacing of 161 ft along Horizon Peak Road (STA 1+00 to STA 2+61) between the intersections of 45th St and Horizon Peake Road. Exception is requested due to the required placement of the COID Canal and existing topography of the site.

Applicant requests an exception for maximum block length of 967ft along Horizon Peak Rd (STA 60+30 to STA 69+97) between the intersections with Dawn Meadow Street and Horizon Peak Rd. Exception is requested due to required placement of the piped COID Canal & existing topography of the site.

Applicant requests an exception for maximum block length of 1245 ft along Horizon Peak Road, between the intersections with Serenety Skyway and Evening Glow. It should be noted this block length is split in half by the proposed alley access through Tract L. There is also proposed pedestrian/bike access through Tract K.

Although several block lengths exceed the numerical standards of the Redmond Development Code, the overall subdivision provides greater functional connectivity than a traditional grid through its system of pedestrian pathways, mid-block access points, and open-space corridors. These elements create direct, convenient, and safe routes for people walking or biking—often shortening travel distances compared to what would occur under a strict grid applied to this uniquely shaped site.

The design incorporates compensating pedestrian or bicycle connections—such as Tracts L and K—which effectively divides the long block for non-vehicular travel and preserves the permeability that the block-length standard is intended to achieve. These mid-block connections ensure that residents can move efficiently through the neighborhood without relying solely on street intersections, resulting in a finer-grained pedestrian network than would be possible with a rigid block grid constrained by the COID canal and site topography.

Redmond Development Code § 8.275 allows block-length flexibility within a Planned Unit Development when the resulting design produces a superior outcome. Here, that superior outcome is achieved by pairing vehicular block-length variations with enhanced pedestrian access, safer T-intersections, and a circulation system tailored to the land's physical form. The result is a neighborhood that is more connected, more walkable, and safer than would be possible through strict application of the block-length standards.

Block Length & Intersection Spacing – Summary Table

Standard / Requirement	Redmond Development Code	Horizon Pointe Proposed Condition	Exception Requested
Along Horizon Peak Road between the intersections with Morning Vista Road and Horizon Light Road.	Min 165ft	129 ft	Exception Requested
Minimum Intersection Spacing (Horizon Peak Rd STA 1+00–2+61)	Min 165ft	161 ft	Exception Requested
Along Horizon Peak Rd (STA 60+30 to STA 69+97) between the intersections with Dawn Meadow Street and Horizon Peak Rd.	≤ 660 ft max block length	967 ft	Exception Requested
Along Horizon Peak Road, between the intersections with Serenety Skyway and Evening Glow	≤ 660 ft max block length	1245 ft (functionally split by Tract L alley + Tract K)	Exception Requested

5. Connecting to public utilities, subject to acceptance by City Engineer.

Response: The proposed layout does not require any exceptions to how the project connects to public utilities.

6. Street frontage, street and right-of-way width, sidewalk placement and standards, subject to acceptance by City Engineer.

Response: The proposed layout does not require any exceptions to street right-of-way width or sidewalk placement.

Applicant does request exceptions to the driveway minimum access clearance to corner on local streets for lots 22, 139, 242, 269, 270, 290, 301, & 319. Applicant requests an access clearance of 20' for these lots.

Applicant additionally requests exception to minimum lot frontage requirements for 64 lots. These lots have slightly reduced street frontages compared to the standard minimum; however, the design fully satisfies the intent of the Redmond Development Code by ensuring safe access, functional utility placement, and an attractive streetscape appearance.

Each lot provides a full-width driveway apron and direct pedestrian access from the public sidewalk to the front entry. Driveways are aligned to provide clear sight lines to the street, and curb spacing between adjacent driveways is sufficient to accommodate utility laterals, landscaping, and on-street drainage.

This design approach allows Horizon Pointe to offer a more attainable housing product within the PUD while maintaining high standards of safety and visual quality. It aligns with the flexibility permitted under Redmond Development Code § 8.275(3)(B)(6), which allows exceptions to dimensional standards when the result is a superior overall design. In this case, the Horizon Point's proposed single family homes & townhomes advance the City's housing diversity goals and demonstrate efficient use of land consistent with the Great Neighborhood Principles of variety, compact design, and housing choice. Please refer to table below for lot number & requested allowable lot frontage.

Frontage Exception Requests								
Lot #	Requested Frontage (LF)		Lot #	Requested Frontage (LF)		Lot #	Requested Frontage (LF)
2	47.41		163	48.33			
13	48.64		164	45.69			
19	49.47		165	48.58			
24	49.75		169	49.08			
29	48.91		170	46.11			
30	48.98		171	39.55			
32	49.53		172	38.18			
33	36.19		173	46.07			
39	48.73		176	49.32			
40	47.69		204	40.84			
41	47.42		205	47.9			
42	46.76		206	46.99			
43	46.8		207	46.38			
55	49.22		208	49.46			
56	48.55		210	42.52			
57	49.86		211	41.46			
58	39.86		212	44.07			
59	29.87		242	47.45			
60	44.11		244	44.33			
64	42.58		245	48.1			
65	36.02		246	48.1			
66	42.17		249	48.92			
67	48.52		275	21.5			
84	49.28		301	48.48			
90	49.94		302	49.03			
96	49.04		303	48.03			
129	13.16		319	45.93			
130	13.16		320	48.49			
131	13.16		321	48.1			
132	13.16						
137	47.78						
138	49.17						
139	49.64						
161	47.94						
162	46.71						

An additional exception is requested for street geometry and minimum curve radii. The curvature of Celestial Ridge Way and portions of Horizon Peake Road (specifically between STA 60+31 & STA 69+97) were designed intentionally to reinforce the curvilinear character of the Horizon Pointe neighborhood and to serve as a natural traffic-calming measure. While some horizontal curves may not meet the standard 198-foot minimum radius, the design achieves the same—or greater—level of safety and functionality intended by the City's standard.

The reduced curvature in these locations contributes to slower vehicle speeds, improved driver attentiveness, and enhanced pedestrian safety—key outcomes supported by the Oregon Department of Transportation (ODOT) and Federal Highway Administration (FHWA) in residential street design guidance. These curves are fully accessible to emergency vehicles and provide adequate sight distance for both drivers and pedestrians.

Within a Planned Unit Development, Redmond Development Code § 8.275 allows for flexibility in street design when it results in a superior neighborhood layout. The slight reduction in curve radius supports the visual rhythm, topographic response, and

neighborhood identity of Horizon Pointe, consistent with the City's Great Neighborhood Principles of safety, livability, and character.

In this context, the existing curvature represents a deliberate design choice that achieves the underlying purpose of the standard—safe, comfortable, and context-sensitive neighborhood streets—without the need for modification.

7. Landscaping.

Response: The Horizon Pointe open-space and landscaping framework builds upon the previously described system of parks, green corridors, and landscaped open areas. Rather than treating open space as isolated or leftover parcels, these areas are intentionally arranged to provide visual relief, pedestrian access, and a strong sense of neighborhood identity.

The landscaping approach emphasizes green corridors, comfortable walking routes, and open lawn areas suitable for informal recreation. Each open-space tract is positioned to relate directly to nearby streets and pathways, ensuring residents can conveniently and safely access outdoor spaces throughout the neighborhood. These elements support the walkability and neighborhood design principles outlined in earlier sections of this Burden of Proof.

Consistent with Redmond Development Code § 8.275(4)(E) and the City's Great Neighborhood Principles, the design also allows for flexibility over time. While a conceptual parks and open-space plan accompanies this application, final programming for each tract will occur as development progresses. The Homeowners Association (HOA) will guide long-term planning, enhancements, and maintenance, enabling the spaces to evolve with community needs while maintaining consistent quality.

This approach ensures a cohesive landscape system from the earliest phases of development, while preserving the opportunity for thoughtful future improvements. All programmed open-space tracts will remain privately owned and maintained by the HOA, ensuring unified design standards, long-term stewardship, and high-quality landscaping throughout Horizon Pointe.

Horizon Pointe Parks and Trails Conceptual Plan 11-17-25:
https://drive.google.com/file/d/1UuIFyUyRyNtM6ruxpbp0mEckSdX2dxYR/view

Horizon Pointe

Parks, Trails and Open Space Table

Programmed Parks & Trails	Description	Open Space Sq.Ft.	Paved Trails Lineal Feet	Paved Trails Sq.Ft	Natural Trails Lineal Feet
Tract G	Parks	13,597	-	-	420
Tract H	Parks	12,622	-	-	345
Tract I	Parks	3,301	-	-	-
Tract J	Parks	5,581	-	-	-
Tract R	Parks	31,756	854 [1]	7,465	-
Tract B, C, D, E	Trails (Canal Trails)	135,987	3,925	38,155	-
Tract M, N, A	Trails (Canal Trails Open Space)	4,489	-	-	-
Tract S	Urban Rural Interface	12,382	-	-	636
Tract T	Urban Rural Interface	15,416	-	-	995
Tract K	Walkway Connector	4,385	221	1768	-
	Totals	**239,516**	**5,000**	**47,388**	**2,396**

Open Space Community Frontage Buffer

Open Frontage	Description	Open Space Sq.Ft.
Tract	O	10,554
Tract	P	16,698
Tract	Q	23,805
	Total	**51,057**

Open Space Grand Total

Square Feet	290,573
Acres	6.67

Each neighborhood park will incorporate landscaping and core amenities—such as trees, benches, and trash receptacles—with final design elements completed during engineering submission for the applicable phase. These spaces will be privately owned and maintained by the HOA, ensuring unified design standards and long-term stewardship.

8. Fences and walls

Response: No exceptions to fencing are requested.

4. Standards and Requirements. The following standards and requirements apply to a PUD application:

A. PUDs must be a minimum of one acre in size. In the Downtown Urban Renewal District, a minimum of 0.5 acre in size.

Response: The proposed project is a total of 67.33 acres which far exceeds the 1 acre minimum.

B. The applicant shall submit a written narrative that addresses the applicable standards, code, and regulations.

Response: The written narrative is herein.

C. A PUD approach may be utilized in the design and development of residential, mixed use, or commercial and industrial service areas.

Response: This planned unit development is being utilized for residential development.

D. D*ensities.* Maximum densities are identified in Table B Sec. 8.140. Additional density (i.e., bonus density) beyond the maximum density will be considered as follows:

1. Up to 20 percent beyond maximum densities for qualified Affordable Housing and Workforce Housing units. A bonus density request beyond 10 percent shall be restricted to Affordable Housing. Affordable and Workforce Housing units should be designed to be intermixed throughout the development and similar design and quality to market rate units.

2. Up to 10 percent beyond maximum densities for including amenities that provide a community benefit or helps realize specified public policy goals. Examples include: additional protection of green space, recreational areas, open space, natural resources or view corridors. environmental improvements, trail connectivity, higher quality building design, or other additional amenities.

3. As identified in respective Area Plans.

Response: Below is the table of densities based on underlaying zone and use for the proposed layout. The maximum density requirements are met in all but one area of the code: R3 Single Family. For the R3 Single Family Home density, the proposal exceeds the maximum density by 6.5% of the standard which is within the allowed density exception range per 8.275.4.D.2 listed above. Applicant requests to be granted this density exception. Allowing for greater density enables the applicant to provide more options for more affordable housing types, such as townhomes, as well as provide the proposed 5000 linear feet of interconnected trails & over 66,000 sf of programmed neighborhood parks.

ZONE	TOTAL ACRES	NET ACRES	TOTAL NUMBER OF UNITS	DENSITY (UNITS/NET ACRE)	MAXIMUM ALLOWABLE DENSITY	MINIMUM ALLOWABLE DESNITY
R3 Total	47	31.63	218	6.89		
R3 Townhomes		4.6	51	11.09	23.2	
R3 Single Family		27.03	167	6.18	5.8	5
R4 Total	17.37	11.33	82	7.24		
R4 Townhomes		0.86	10	11.63	25	
R4 Single Family		10.47	72	6.88	8	5
R5 Total	2.95	1.99	21	10.55		
R5 Townhomes		1.2	15	12.50	25	
R5 Single Family		0.79	6	7.59	8	8
TOTAL	67.32	44.95	321			

E. A PUD must include usable open space, recreational area, common area or park designed for the use and benefit of all the units or lots in the development. The land area used shall be determined by the type of amenities added by the developer.

Response: This project provides several neighborhood parks, totaling over 66,000 square feet of programmed parks via Tracts G,H,I,J & R including a large park in the northwest portion of the project. All proposed community parks are accessible by the interconnected trail system that is proposed with this project, totaling over 5000 linear feet of paved trails.

Horizon Pointe Parks and Trails Conceptual Plan 11-17-25
https://drive.google.com/file/d/1UuIFyUyRyNtM6ruxpbp0mEckSdX2dxYR/view

F. Thoughtful design and architectural themes are required for all structures within any development. Design shall take into consideration themes, continues all elevations for each building, and onto the entire site including, but not limited to: lighting, fencing, accessory structures, signage, and trash enclosures.

Response: Monte Vista Homes intends to build all the homes within this subdivision. Using MonteVista Homes' standard footprints and three cohesive elevation styles the architectural themes will remain consistent through the entirety of the project. Examples of MonteVista architecture are provided below.



G. A separate application or rezoning may accompany the application for approval of the PUD in which case the two items shall be considered simultaneously.

Response: A rezoning application does not accompany this application.

H. The City may recommend a performance bond or other surety to assure the proposed development will be completed as approved and within the time limits agreed to in the conditions of approval.

Response: This is understood.

5.Review Procedure for PUD's. The following procedure shall be followed in requesting approval of a PUD.

A. A pre-development meeting is required prior to submittal of an application.

Response: A Pre-application meeting was held for this project in February of 2024

B. Proof a neighborhood meeting was conducted for residential or mixed-used development proposals that generate 200 or more daily trip ends, or 20 or more PM peak hour trip ends, where a Transportation Impact Analysis (TIA) is required, See Section 8.385 for meeting requirements.

Response: A neighborhood meeting was held for this project on November 18th, 2024. The Materials required by Section 8.385 have been included with this application.

C. An applicant shall submit an electronic version of the complete application. The plan shall contain and show, at an engineer's scale of no less than 1" =10', the following information:

1. The relationship of the property to the surrounding area.

Response: This information is included in the Land Use Application Plan Set

2.The preliminary plan of subdivision or re-subdivision, if any, which shall include the information required by the Subdivision Ordinance.

Response: The required information is included in the Land Use Application Plan Set

3.Land uses, building locations, density proposed, architectural style, efficiency measures, housing market served, and number of dwelling units.

Response: This information is included in the Land Use Application Plan Set

4. The arrangement of streets and pedestrian ways.

Response: This information is included in the Land Use Application Plan Set

5.Proposals that include reduced yards and lot size shall be designed to be served by private alleys or drives.

Response: Proposed private alleys and drives are being utilized to service rear-loaded townhome products. All other home types are to be serviced by typical driveway locations at street frontage.

6.The location of off-street parking spaces, and a parking management plan if the total number of spaces required exceeds 75.

Response: Project proposes a total of 9 off-street parking spaces for the proposed neighborhood park, "Tract R", in the northwest corner of the site.

7. The location of service commercial areas, open space, recreational area, common areas, or park.

Response: There are no commercial areas proposed with this development. Proposed open space tracts & parks have been included in the Land Use Application Plan Set.

8. Plans for site grading and drainage.

Response: Preliminary drainage infrastructure locations have been included in the Land Use Application Plan Set.

9. Plans for water supply and sewage disposal.

Response: Preliminary utility locations for sewer & water mains have been included in the Land Use Application Plan set.

10. Plans for transfer of ownership of the property, if any, and arrangements for maintenance of common areas and facilities.

Response: MonteVista Homes has optioned the land that is to become Horizon Pointe. The Memo Of Option has been included in this application submittal. The existing property owners are listed on the Land Use Application. Transfer of properties from MonteVista Homes to new homebuyers will occur at time of lot purchase following final plat approval. Common Areas are to be maintained by the to-be-established Horizon Pointe HOA.

11. Landscape plan including the list of species proposed and size/coverage at time of planting and at five years.

Response: A preliminary landscaping plan has been included with this application submittal, as well as a preliminary programming schedule for the neighborhood parks included in this document above.

12. Proposed project timing schedule and surety, if required by City.

Response: Horizon Pointe is to be constructed over 7 phases over the next 8 years, with the phase 7 improvements tentatively expected to finish construction by the end of 2033. All necessary bonding will be completed at the appropriate time with respect to each phase. The tentative phasing construction start schedule is as follows:

Phase 1 - Spring 2026

Phase 2 - Spring 2027

Phase 3 - Winter 2028

Phase 4 - Spring 2029

Phase 5 - Winter 2030

Phase 6 - Winter 2031

Phase 7 - Winter 2032

D. In considering the PUD, the City shall determine:

1. There are special development objectives or physical conditions which justify a request for a PUD.

Response: The Horizon Pointe property presents several physical conditions that justify the use of the Planned Unit Development (PUD) process. The site's unconventional shape, challenging terrain especially in the North Section and the fixed alignment of the COID canals create geometric constraints that make strict application of traditional grid-based development standards impractical and, in certain locations, counterproductive to safety and neighborhood function.

The proposed curvilinear street layout is a direct response to these conditions and achieves a superior design outcome by improving neighborhood circulation, reducing the number of four-way intersections, enhancing walkability, and creating more intuitive and context-sensitive block and lot patterns. These benefits—supported by established transportation research demonstrating the safety advantages of T-intersections and curved residential streets—could not be accomplished under the conventional standards without compromising the site's functionality, safety, or livability.

For these reasons, the PUD is the appropriate mechanism to allow flexibility in specific dimensional and spacing standards while delivering a design that better fulfills the intent of Redmond Development Code § 8.275 and the City's Great Neighborhood Principles.

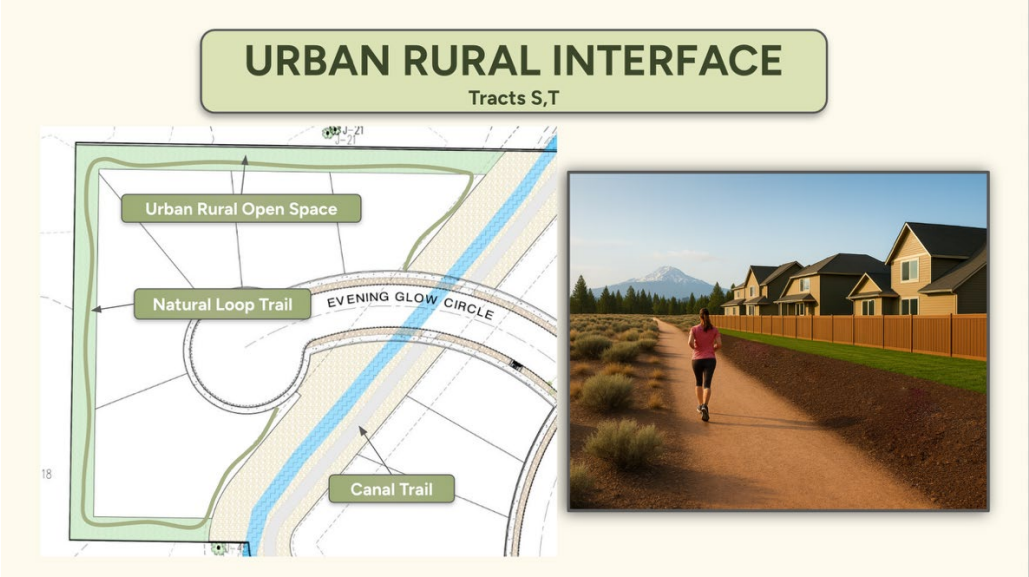
2. The PUD will contain buffers on sides of the development that abut neighboring properties.

Response: There is a large COID canal (Lateral B) with a significant easement on the western boundary of this project. This easement is 95' in total width that will exist in perpetuity, and serves as a natural buffer to neighboring properties to the west.

Along the northwest boundary, Horizon Pointe adjoins the Little Texas North subdivision, which the City of Redmond previously approved with a defined open-space buffer along the Urban Reserve Area. Horizon Pointe continues this same approach to maintain a consistent and compatible edge condition between the two communities.

The proposed buffer (Tracts S & T) within Horizon Pointe mirrors the same open-space width and placement established in Little Texas North, ensuring that the visual and functional transition along the City's Urban Growth Boundary remains cohesive. This open-space tract fulfills the intent of Redmond Development Code § 8.270 and § 8.275, which require that new neighborhoods provide compatibility and thoughtful transitions with adjacent developments and the Urban Reserve interface.

By continuing the established open-space treatment and incorporating accessible trail connections within this tract, Horizon Pointe advances the City's Great Neighborhood Principles of connectivity, integration of natural features, and preservation of neighborhood identity. Together, these elements create a manicured edge that gives the neighborhood a defined and intentional boundary—one that feels open, well-maintained, and visually inviting. This edge not only softens the transition to the Urban Reserve Area but also establishes a lasting sense of place that reflects the quality and character the City of Redmond seeks to encourage along its growing western boundary. Below is a reference from the conceptual parks and trails plan: **https://drive.google.com/file/d/1UuIFyUyRyNtM6ruxpbp0mEckSdX2dxYR/view**



3. The PUD, through its design and function, will improve livability for planned residents.

Response: The Horizon Pointe curvilinear street network was intentionally designed to enhance neighborhood livability through improved visibility, safer circulation, and a more open and attractive streetscape. The geometry of the curved layout naturally creates a pattern of throated-out lots along the outer radii—resulting in wider frontages and broader view corridors—paired with throated-in lots along the inner radii, where homes are positioned deeper on the lot than the typical 20-foot minimum setback. This alternating pattern expands line-of-sight distances at driveways and intersections and produces a rhythmic sequence of open view sheds that contribute to a park-like, visually spacious neighborhood character.

This configuration stands in contrast to traditional grid developments, where uniform setbacks and long straight streets often compress the streetscape and limit visibility. The curvilinear design improves the resident experience by creating a more comfortable, varied, and visually appealing environment.

From a safety standpoint, the layout also eliminates four-way intersections, which are well-documented to have the highest crash rates and the greatest number of conflict points in residential areas. Replacing these with safer T-intersections and gentle curves enhances driver predictability, improves sightlines, and supports calmer vehicle speeds—all of which directly contribute to a more livable and pedestrian-friendly neighborhood.

This approach fulfills the intent of Redmond Development Code § 8.270 and § 8.275, which encourage creative, context-sensitive neighborhood design that elevates safety, livability, and compatibility with surrounding development. The result is a community that feels open, intuitive, and distinctly safe—establishing Horizon Pointe as a model for future neighborhoods in Redmond.

Below are two renders from the 3d model which are visually in the correct size and scale





4. The PUD contains a mix of housing types, variety of uses or services.

Response: Horizon Pointe proposes a mix of Single Family Units & Townhome units. The Townhome units will be split between two types, rear-loaded & front-loaded.

5. The PUD can be completed within five years or phased for later development.

Response: Horizon Pointe is to be constructed over 7 phases over the next 8 years, with the phase 7 improvements tentatively expected to finish construction by the end of 2033. All necessary bonding will be completed at the appropriate time with respect to each phase. The tentative phasing construction start schedule is as follows:

Phase 1 - Spring 2026

Phase 2 - Spring 2027

Phase 3 - Winter 2028

Phase 4 - Spring 2029

Phase 5 - Winter 2030

Phase 6 - Winter 2031

Phase 7 - Winter 2032

6. The PUD will not overload adjacent streets, utilities, or infrastructure.

Response: All infrastructure will be improved as needed to provide necessary operational capacity determined as part of the relative infrastructure studies completed prior to submittal of this Land Use Application. Per the project's approved TIA, and in conformance with the City of Redmond 2020 Transportation System Plan, SW Helmholtz Way along property frontage will be improved to Minor Arterial Roadway Standards per City of Redmond Standards and Specifications and Development Code Requirements. Adequate water capacity from SW Helmholtz way is available to service the subdivision. Adequate sewer capacity is available in SW Helmholtz Way, however due to site topography and relatively shallow sewer connection at Helmholtz, sanitary sewer for much of the northwest area of the proposed development will drain to the to-be-constructed lift station as part of the neighboring Little Texas North Subdivision. Per coordination with Little Texas North's developer, this lift station is to be constructed in Little Texas North Phase 1, which is to begin construction over the next year. Horizon Pointe will not need to utilize this lift station until phase 4, which is tentatively expected to begin construction in 2029. This area is denoted on the submitted Land Use Plans. Should the Little Texas North subdivision project not proceed, a lift station will be constructed during phase 4, and shall be located on Tract H.

7. The PUD will be consistent with the objectives of Area Plans and the Redmond Comprehensive Plan.

Response: Proposal is in conformance with 2040 Greater Redmond Area Comprehensive Plan adopted December 8th, 2020. Subject properties' tax lots have been zoned for R3, R4, and R5 zoning, with expectation for these lots to become residential housing. Subject properties are currently within the City of Redmond Urban Growth Boundary and have been previously annexed into the City.

E. The City Shall notify the applicant whether in its judgment the foregoing provisions have been satisfied and, if not, whether they can be satisfied with other alternatives or revision to the PUD.

Response: This is understood.

6. PUD Post Approval & Modifications. Where a PUD has been authorized pursuant to applicable zoning regulations, the plan of the subdivision shall conform with the plan of the PUD as approved.

Minor Modification. Minor modification to an approval PUD will be granted when the requested change is so minor that the CDD Director, or designee, determines that it would be appropriate for an administrative decision. Examples of minor changes include, but are not limited to: (1) a reduction in the overall number of lots, (2) minor architectural changes to approved buildings, (3) changes to phases that do no impact public facilities or change the number of approved phases, (4) changes that result in a reduction of impacts (i.e., reduced traffic flows), or (5) changes that are required to protect or increase public safety.

Response: This is understood.

Sec. 8.385. – Neighborhood Meeting

1. Purpose and Intent. The purpose of the neighborhood meeting is to provide a forum for the applicant, surrounding neighbors, and interested members of the community to meet and consider a proposed land use application, and to discuss issues/concerns regarding the proposal prior to application submittal. Neighborhood meetings encourage citizen participation early in the development process, and an opportunity to revise the land use application to address the issues prior to application submittal.

2. Applicability. Neighborhood meetings are encouraged prior to submitting any land use application. The following application types or development proposals shall be subject to the neighborhood meeting requirements:

    A. Master Development Plans.

    B. Residential or mixed use development proposals that generate 200 or more daily trip ends, or 20 or more PM peak hour trip ends, where a Transportation Impact Analysis (TIA) is required.

    C. Wireless and Broadcast Communications Facilities.

3. *Requirements and Procedures.* The neighborhood meeting must be held after a pre-development meeting with City Staff, but before submittal of a land use application. The applicant shall be required to hold only one meeting prior to submitting an application for a specific site but may hold more if desired. If the development proposal is revised after the neighborhood meeting, and a major modification is requested, a second neighborhood meeting with a new notice shall be required before the revised application is submitted.

    A. *Lo*cation and Time. Neighborhood meetings shall be held in person at a location in reasonable proximity to the subject site. The meeting shall be held at a location open to the public., City Staff, and at a facility that is ADA accessible. The meeting shall be held on a weekday evening, or weekends at any reasonable time. Applicants may provide a virtual component for participants to join in the meeting. The virtual component shall not be done in lieu of the in-person requirements. ADA accommodations when requested by attendee must be provided.

    B. Notice - Mail. Mailed notice of the meeting shall be provided by the applicant to the neighboring property owners (within 750 feet outside city limits and 250 feet within city limits) and the Community Development Department between ten and 30 calendar days prior to the meeting. Notices must be sent first class and shall include the date, time, and location of the meeting, as well as a brief description of the development proposal and property location. The description shall take into consideration information provided by City staff at the pre-development meeting, include project contact information, a copy of the tax map or a GIS map that clearly identifies the location of the proposed development, and a conceptual site plan.

    C. Notice - Signage. The applicant shall also post notice of the neighborhood meeting on the subject site or on an access easement to the site within clear view of a public street at least seven days in advance of the meeting. The sign must display the meeting date, time, and address as well as project contact information.

    D. Meeting Requirements. The developer must provide a sign-in sheet for attendees to provide their name, address, telephone number, and email address. At the meeting, the applicant shall provide a conceptual site plan and describe the major elements of the proposal. Depending on the type and scale of the particular application, the applicant should be prepared to discuss proposed land uses and densities; traffic impacts; proposed building size and height; proposed access and parking; and proposed landscaping, buffering

and/or protection of natural resources as applicable. Attendees will have an opportunity to speak at the meeting and may identify any issues that they believe should be addressed. If no one arrives within 30 minutes of the scheduled start time for the meeting, the applicant may close the meeting and this requirement will be considered met upon the applicant's submittal of the documentation to that effect.

E. Materials Submitted with Application. The neighborhood meeting notes that identify the major points discussed about the development, list of parties notified, signed affidavits of mailing and posting notices, copies of all materials provided by the applicant, and a signature sheet of attendees shall be included with the development application upon submittal.

F. Validity Period. The land use application shall be submitted to the City within 180 days of the neighborhood meeting. If an application is not submitted in this timeframe, the applicant shall be required to hold a new neighborhood meeting.

G. Denial. Failure of the applicant to hold a neighborhood meeting in accordance with these provisions prior to submittal of a land use application shall result in an incomplete application and the application may be rejected.

Response: A neighborhood meeting adhering to the requirements of Sec. 8.385 was held for this project on November 18th, 2024. The materials required by Section 8.385 have been included in this application.

Sec. 8.600. – Authorization to Grant or Deny Condition Uses

Uses designated herein as conditional uses may be permitted upon authorization by the Hearings Body in accordance with the standards and procedures established in this Article. Before approving an application for a conditional use, the Hearings Body shall find the following criteria are either met, can be met by observance of conditions, or are not applicable:

1. The proposed use will be consistent with the Comprehensive Plan, the zoning ordinances and other applicable ordinances and standards of the City.

   Response: The proposed use is still residential that is consistent with the underlying zoning of the property.

2. The location, size, design, and operating characteristics of the proposed use will have minimal adverse impact on the livability, value, or approximate development of abutting properties and the surrounding area.

   Response: The proposed use will have the same impact as the outright permitted uses of the underlying zoning.

3. The proposed use will not exceed operational capacity of City infrastructure including sewage system, water system or the transportation system.

Response: All city infrastructure will be improved as needed to provide the needed operational capacity determined as part of the relative infrastructure studies completed prior to submittal of land use application. Please see relevant PUD section of this document above.

4. That the proposed use will not conflict with, diminish, or substantially adversely affect the character and nature of the established neighborhood in which it is located.

   Response: The proposed use will not conflict with, diminish, or substantially adversely affect the character or nature of established neighborhoods. The proposed development of this project is residential use similar to that of the surrounding neighborhoods.

Sec. 8.2200. Tentative Subdivision Plan et. Seq. (SUB).

Sec. 8.2200. - Pre-Application Meeting.

Prior to submitting a tentative subdivision plan each applicant or their representative is required to meet with the Community Development Director or a designated staff member(s) to review the proposal.

Response: A pre-application meeting was held for this project in February of 2024.

Sec. 8.2202. - Neighborhood Meeting.

The applicant or their representative shall conduct a neighborhood meeting that meets the requirements of Section 8.385 for residential or mixed use development proposals that generate 200 or more daily trip ends, or 20 or more p.m. peak hour trip ends, where a Transportation Impact Analysis (TIA) is required per Section 8.2815.

Response: A neighborhood meeting was held for this project on November 18th, 2024. The materials required by Section 8.385 have been included with this application.

Sec. 8.2205. - Application Submission.

Any person, authorized agent, or representatives, proposing a subdivision, shall include with an application and filing fee for a subdivision, a tentative plan together with improvement plans and other supplementary material as may be required.

Response: All of the required application materials have been supplied with this submittal.

Sec. 8.2210. - Scale of Tentative Subdivision Plan.

The tentative plan of a proposed subdivision shall be drawn on a sheet at an engineer's scale not greater than one inch per 100 feet, or as approved by the Community Development Director, or designee.

Response: The proposed subdivision has been drawn at a scale of one inch per 50 feet.

Sec. 8.2215. - Informational Requirements.

The following information shall be shown on the tentative plan or provided in accompanying materials. A tentative plan must be prepared by a professional land surveyor, a registered professional engineer, or a registered landscape architect. No tentative plan shall be considered complete unless all such information is provided:

1.General Information Required.

A. Proposed name of the subdivision.

B. Names, address, and phone numbers of the owner of record, authorized agents or representatives, engineer or surveyor, and any assumed business names filed or to be filed with the Oregon Secretary of State Corporation Division by the applicant. If the application is filed by anyone other than the owner of record, a letter or other evidence of the owner's permission to file the application.

C. Date of plan preparation, north and magnetic north and south, scale and gross area of the proposed subdivision.

D. Appropriate identification of the drawing as a tentative plan for a subdivision. Location and tract designation sufficient to define its location and boundaries, and a legal description of the tract boundaries in relation to existing plats and streets.

E. Certified copy of the recorded instrument under which the applicant claims an ownership interest, or copy of a land sales contract, which binds the applicant in the event of tentative approval.

F. Title report or subdivision guarantee, issued within the last 90 days, and supporting documentation of all easements identified on the property.

Response: The proposed name for the subdivision is Horizon Pointe. All contact information for the authorized agents and representatives has been included and the memo of option allowing Redmond Land Group, LLC to submit applications on behalf of the owners. All plan standards have been met.

2.Information Concerning Existing Conditions.

A. Location, names, and widths of existing improved and unimproved public or private streets and roads within and adjacent to the proposed subdivision.

B. Location of any existing features such as section lines, section corners, City and special district boundary lines, and survey monuments.

C. Location of existing structures, irrigation canals and ditches, pipelines, waterways, railroads, and any natural features such as rock outcroppings, designated wetlands, wooded areas, and natural hazards.

D. Location and direction of water courses, and the location of areas subject to flooding and high water tables.

E. Location, width and use or purpose of any existing easement or right-of-way within and adjacent to the proposed subdivision.

F. Existing sewer lines or septic tanks and drain fields, water mains, wells, fire hydrants, culverts, and other underground and overhead utilities within and adjacent to the proposed subdivision together with pipe sizes, grades, and locations.

G. Contour lines related to some established benchmark or other engineering acceptable datum and having minimum intervals of two feet for slopes of less than five percent, five feet for slopes of five to 15 percent, ten feet for slopes of 15 to 20 percent, and 20 feet for slopes greater than 20 percent.

H. Zoning classification of land within and adjacent to the proposed subdivision.

I. Names and addresses of all adjoining property owners.

J. Existing covenants, conditions, and restrictions.

K. Conditions specified on the approved Transportation System Analysis prepared in accordance with Section 8.2815.

Response: All existing conditions have been illustrated on the existing conditions sheets of the application plan set.

3.Information Concerning Proposed Subdivision.

A. Location, names, width, typical improvements, cross sections, bridges, culverts, approximate grades, curve radii and centerline lengths and reserve strips of all proposed streets, and the relationship to all existing and projected streets.

B. Location, width, and purpose of all propose easements or rights-of-way and relationship to all existing easements and rights-of-way.

C. Location of at least one temporary benchmark within the proposed subdivision boundary.

D. Location, approximate area and dimensions of each proposed lot, and proposed lot and block numbers.

E. Location, approximate area and dimensions of any lot or area proposed for public use, the use proposed, and plans for improvements or development thereof.

F. Proposed use, location, approximate area, and dimensions of any lot intended for non-residential use.

G. An outline of the area proposed for partial recording, if contemplated or proposed.

H. Source, method, and preliminary plans, prepared by a licensed civil engineer, for domestic and other water supplies, sewage disposal, solid waste disposal, and all utilities.

I. Description and location of any proposed community facility.

J. Storm water, drainage facility and grading plans.

K. Proposed deed restrictions including access restrictions or protective covenants if such are proposed to be utilized for the proposed subdivision.

L. Statement from each utility company proposed to serve the proposed subdivision stating that each company is able and willing to serve the proposed subdivision as set forth in the tentative plan, and the conditions and estimated costs of such service.

M. Proposed fire protection or fire hydrant system for the proposed subdivision and written approval thereof by the appropriate serving fire protection agency.

Response: All information concerning the proposed subdivision has been included in the application plan set.

4.Narrative. Letter or narrative report documenting compliance with the applicable approval criteria contained in Section 8.2235.

Response: This document is the narrative report document for compliance with the applicable approval criteria.

5.Tree Survey. A survey indicating location of all trees having ten-inch trunk diameter 4.5 feet above grade or greater, their diameter, and whether they are coniferous or deciduous on private property and in the right-of-way adjacent to the property. The plan shall show which trees are proposed for removal and the location of replacement trees. The plan shall show the Tree Protection Zone (TPZ) for trees to be preserved, conforming with the Public Works Standards and Specifications. The tree survey shall show the proposed improvements or potential improvements, indicated by the buildable area of a lot consistent with the maximum lot coverage area of the zone.

Response: A topographic survey was conducted for the subject properties and all trees have been documented on the topographic survey as well as the existing conditions pages of the land use plan.

Sec. 8.2220. - Phased Development Plan.

An applicant may propose phased development of a tentative subdivision plan by submitting a phased development plan that shall include but not be limited to, the following elements:

1.Overall development plan, including phase or unit sequence.

A. For development that includes a commercial component, a surety may be required when the commercial component is not sequenced in the initial phases.

2.Show compliance with all applicable land division standards and policies as described in this Article.

3.Schedule of improvements initiation and completion.

4.Overall transportation and traffic pattern plan showing compliance with grid street standards, and for land within the North Redmond US 97 Interchange Area Management Plan (IAMP), compliance with the Local Street Connectivity Plan (Comprehensive Plan Addendum Chapter 9 Transportation Element figure 1).

5.General program for phasing timetable projection.

6.Development plans for any common elements or facilities.

Response: The phase sequencing for this project has been included in the application plan set. Response: Horizon Pointe is to be constructed over 7 phases over the next 8 years, with the phase 7 improvements tentatively expected to finish construction by the end of 2033. All necessary bonding will be completed at the appropriate time with respect to each phase. The tentative phasing construction start schedule is as follows:

Phase 1 - Spring 2026

Phase 2 - Spring 2027

Phase 3 - Winter 2028

Phase 4 - Spring 2029

Phase 5 - Winter 2030

Phase 6 - Winter 2031

Phase 7 - Winter 2032

Documentation of any common elements or facilities has been provided with this application. The proposed subdivision layout includes street extensions at logical locations to connect to future subdivisions when the properties to the north and south are ultimately developed. Coordination has been had with developers of Little Texas Subdivision (the northern neighbor) to ensure that proposed street extensions are in alignment.

Sec. 8.2225. - Approval of Phased Development Plan.

The Review Authority shall review a phased development plan at the same time the tentative plan is reviewed. The Review Authority may approve, modify, or disapprove the phased development plan and shall set forth findings for such decision. The Review Authority may also attach conditions necessary to bring the plan into compliance with all applicable land use standards and policies.

Response: This is understood.

Sec. 8.2230. - Development Following Approval.

1.Once a phased development plan is approved, the plan shall be binding, upon both the City and the applicant. The applicant shall submit a final plat for each phase per Section 8.2305.

2.The Review Authority may attach conditions to any changes proposed that are deemed necessary to ensure compliance with the Comprehensive Plan and implementing regulations.

Response: This is understood.

Sec. 8.2235. - Approval Criteria for Tentative Subdivision Plans.

1.The Review Authority shall approve, approve with conditions, or deny a proposed tentative subdivision plan. Approval, or approval with conditions shall be based on compliance with the following criteria:

A. Proposal is in compliance with ORS Chapter 92.

B. Proposal complies with the standards of this Code, including but not limited to:

1.Section 8.2705, Blocks, Lots and Parcels.

2.Section 8.2710, Streets.

3.Section 8.2715, Fundamental Design Standards.

4.Section 8.2720, Grading of Building Sites.

5.Section 8.2815, Transportation System Analysis.

6.Section 8.2820, Access Management Standards.

7.Any other applicable standards.

Response: Proposal complies with standards set forth in these sections unless otherwise noted in this document, with exceptions requested as necessary within the PUD narrative section of this document.

C. Proposal complies with the standards of the zoning district in which the project is located.

Response: Proposal complies with standards of the underlying zoning district unless otherwise noted in this document, with exceptions requested as necessary within the PUD section of this document.

D. The proposal is in conformance with any applicable approved area plan, master plan, and/or framework plan.

Response: Proposal is in conformance with 2040 Greater Redmond Area Comprehensive Plan adopted December 8th, 2020. These tax lots have been zoned for R3, R4, & R5 zoning, with expectation for these lots to become residential housing.

E. Proposal does not conflict with acquired public access easements within or adjacent to the subdivision.

Response: There are no existing public access easements located on the property. This criterion does not apply.

F. The proposed subdivision will provide required transportation system infrastructure, water supply, sewage disposal, drainage, and other public utilities consistent with the Public Works Standards and Specifications.

Response: Each lot is adequately sized for utility service for residential uses as allowed in the code. Each lot can be served by public utilities consistent with the Public Works Standards and Specifications. The proposed street layout allows driveway access to all lots in conformance with the Public Works Standards.

G. The subdivision will not exceed the operational capacity of public facilities and services as identified in the City's Water and Wastewater Master Plan and the Transportation System Plan, which are required to serve the development, or a determination that sufficient capacity can be provided.

Response: Per the project's approved TIA, and in conformance to the City of Redmond 2020 Transportation System Plan, SW Helmholtz Way along project frontage will be improved to Minor Arterial roadway standards per City of Redmond Standards and Specifications and Development Code Requirements. Adequate water services are available in SW Helmholtz Way to serve the subdivision. Adequate Sewer Capacity is available in SW Helmholtz Way, however due to site topography and relatively shallow sewer connection at Helmholtz, sanitary sewer for much of the northwest area of the proposed development will drain to the to-be-constructed lift station as part of the neighboring Little Texas North Subdivision. Per coordination with Little Texas North's developer, this lift station is to be constructed in Little Texas North Phase 1, which is expected to begin construction over the next year. Horizon Pointe will not need to utilize this lift station until phase 5, which is expected to begin construction in 2029. This area is denoted on the submitted Land Use Plans. Should the Little Texas North subdivision project not proceed, a lift-station will be constructed during phase 5, and shall be located on Tract H.

H. A water rights division plan has been approved by the applicable irrigation district.

Response: All water rights will be addressed with the irrigation district to ensure compliance with the requirements for the division of water rights to the greatest extent possible. Therefore, it has been demonstrated that this criterion can be met.

Sec. 8.2700. et. Seq.– Design Standards and Improvements

Sec. 8.2700. - Compliance Required.

1.Any land division or development shall be in compliance with the design and improvement standards and requirements of this Section, and all other applicable provisions, as set forth in this Chapter.

Response: This is understood

Sec. 8.2705. - Blocks, Lots and Parcels.

1.Blocks. The resulting or proposed length, width and shape of blocks shall take into account the requirements for adequate building lot sizes, street widths, access needs and topographical limitations.

A. No block shall be more than 660 feet in length between street center lines unless it is adjacent to an arterial street, or unless topography or the location of adjoining streets justifies an exception and is so approved by the reviewing authority. In MUN, MUE and MULW zones, block lengths shall be an average of 330 feet, except where required to meet grid street or access management requirements.

Response: The curvilinear design of Horizon Pointe necessarily results in block lengths that differ from a traditional grid. These variations are a direct response to the site's unconventional shape and the fixed alignment of the COID canal, which limit the ability to create uniform rectangular blocks without compromising functionality or safety.

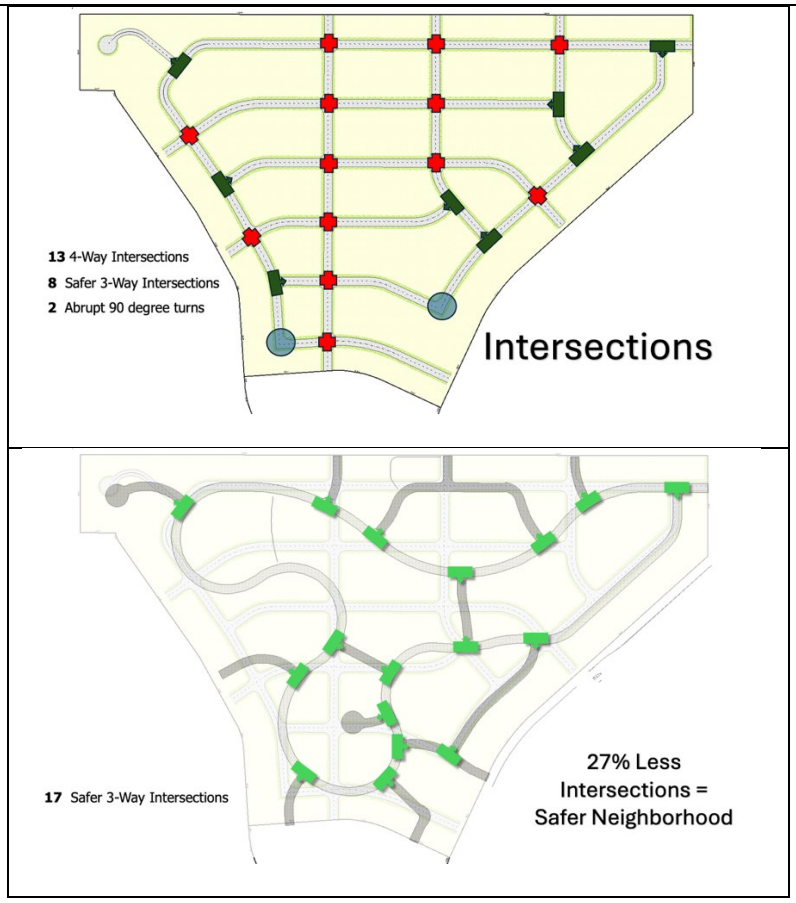
While some block lengths exceed the numerical 660-foot standard, the proposed layout meets or exceeds the intent of Redmond's block-length requirements. The purpose of these standards is to ensure appropriate access, pedestrian permeability, safe circulation, and efficient emergency response. Horizon Pointe achieves these objectives in the following ways:

1. Equivalent or Superior Connectivity
Block-length variations are offset by a system of pedestrian pathways, open-space corridors, and strategically placed connections that ensure residents can move through the neighborhood efficiently on foot or bicycle. As detailed earlier in the PUD findings, these corridors create direct, intuitive routes that often result in shorter walking distances than a traditional grid on the same site.

2. Safer Intersection Patterns
The curvilinear design significantly reduces the number of four-way intersections, which have the highest crash rates and the greatest number of conflict points. Consistent with both ODOT (2001) and FHWA research:

- ***Crash rates are lower at T-intersections in all cases***
- ***Paired T-intersections are 1.5–2.0 times as safe as cross intersections***
- ***Replacing a 4-way intersection with staggered T-intersections results in a 47% reduction in crashes***

This improved intersection pattern better fulfills the safety intent of the block-length standard than a rigid grid would allow on this constrained site.



3. Emergency Access Performance
Emergency response relies heavily on clear routing, predictable traffic behavior, and reduced conflict points. Because the curvilinear system eliminates 4-way intersections and uses gentle curves and T-intersections instead, it supports more consistent vehicle flow and reduces potential collision points during high-demand evacuation or response scenarios. These characteristics align with the underlying intent of RMC block-length requirements related to access and emergency circulation.

4. Compliance with PUD Flexibility Criteria
Redmond Development Code § 8.275 expressly allows block-length flexibility within a Planned Unit Development when the resulting design provides a superior land-use outcome. Horizon Pointe accomplishes this by improving safety, providing better pedestrian circulation, responding to site constraints, and creating an orderly, legible neighborhood form not achievable under conventional block-spacing standards.

For these reasons, the block-length exceptions requested through the PUD process appropriately fulfill the intent of RMC § 8.2700 et seq., and the overall street and block layout provides safe, connected, and efficient access for all modes of travel.

The requested exceptions to block length are as follows:

Applicant requests an exception to minimum intersection spacing of 129 ft along Horizon Peak

Road between the intersections with Morning Vista Road and Horizon Light Road. Exception is requested due to the required placement of the Dusk Valley Road/Helmholtz Intersection as well as required secondary street connection to the property to the south.

Applicant requests an exception to minimum intersection spacing of 161 ft along Horizon Peak Road (STA 1+00 to STA 2+61) between the intersections of 45th St and Horizon Peake Road. Exception is requested due to the required placement of the COID Canal and existing topography of the site.

Applicant requests an exception for maximum block length of 967ft along Horizon Peak Rd (STA 60+30 to STA 69+97) between the intersections with Dawn Meadow Street and Horizon Peak Rd. Exception is requested due to required placement of the piped COID Canal & existing topography of the site.

Applicant requests an exception for maximum block length of 1245 ft along Horizon Peak Road, between the intersections with Serenety Skyway and Evening Glow. It should be noted this block length is split in half by the proposed alley access through Tract L. There is also proposed pedestrian/bike access through Tract K.

Block Length & Intersection Spacing – Summary Table

Standard / Requirement	Redmond Development Code	Horizon Pointe Proposed Condition	Exception Requested
Along Horizon Peak Road between the intersections with Morning Vista Road and Horizon Light Road.	Min 165ft	129 ft	Exception Requested
Minimum Intersection Spacing (Horizon Peak Rd STA 1+00–2+61)	Min 165ft	161 ft	Exception Requested
Along Horizon Peak Rd (STA 60+30 to STA 69+97) between the intersections with Dawn Meadow Street and Horizon Peak Rd.	≤ 660 ft max block length	967 ft	Exception Requested
Along Horizon Peak Road, between the intersections with Serenety Skyway and Evening Glow	≤ 660 ft max block length	1245 ft (functionally split by Tract L alley + Tract K)	Exception Requested

B. The recommended minimum length of a block along an arterial street is 1,320 feet, except that along such blocks, a public right-of-way for pedestrian and bicycle access shall be dedicated at or nearest the mid-point of the block length as is practical. The right-of-way shall be a minimum of ten feet wide, with an all weather surface a minimum of five feet wide, constructed and centered within the right-of-way.

Response: Applicant does not request any deviations to block length along arterial roadways. Applicant proposes a distance of 1321 linear feet between the centerline-centerline intersection of the Quartz x Helmholtz intersection and the proposed Dusk Valley Road x Helmholtz intersection.

Applicant proposes a distance of 1495 linear feet between the centerline-centerline intersection of the proposed Dusk Valley Road x Helmholtz intersection and the 45th St x Helmholtz intersection that is to be constructed as part of the Little Texas North Phase 1 project.

This criterion is satisfied.

C.A block shall have sufficient width to provide for two tiers of lots unless topography, the location of adjoining streets, or adjacency to an arterial street justifies an exception.

Response: Proposed blocks have sufficient width to facilitate two tiers of lots where practical.

D. Where appropriate at approved cul-de-sacs, dead-end streets, or along blocks approved at more than the maximum block length standard, pedestrian and bicycle access corridors shall be required to be

constructed between lots to minimize travel distance between subdivisions, parks, school, and collector or arterial streets. Access corridors shall be located to provide a reasonably direct connection between likely pedestrian destinations and shall be consistent with the City of Redmond Bicycle Refinement Plan where applicable. A reasonably direct connection is a route which minimizes out of direction travel for people likely to use the connection considering terrain, safety, and likely destination. The Review Authority may determine based on evidence in the record that construction of a separate access corridor is inappropriate or impractical. Such evidence may include but is not limited to:

1.When the nature of abutting existing development makes construction of an access corridor impractical.

2.When the access corridor would cross a natural area with significant natural habitat and construction would be incompatible with protection of natural values.

3.When the access corridor would cross topography where slopes exceed 30 percent or where path grade would exceed 12 percent slope; or

4.When a cul-de-sac or dead-end street abuts rural resource land at the urban growth boundary. In industrial zones, this standard may be waived at the discretion of the Review Authority, when it is determined that the City's grid street standards should not be applied to the industrial development.

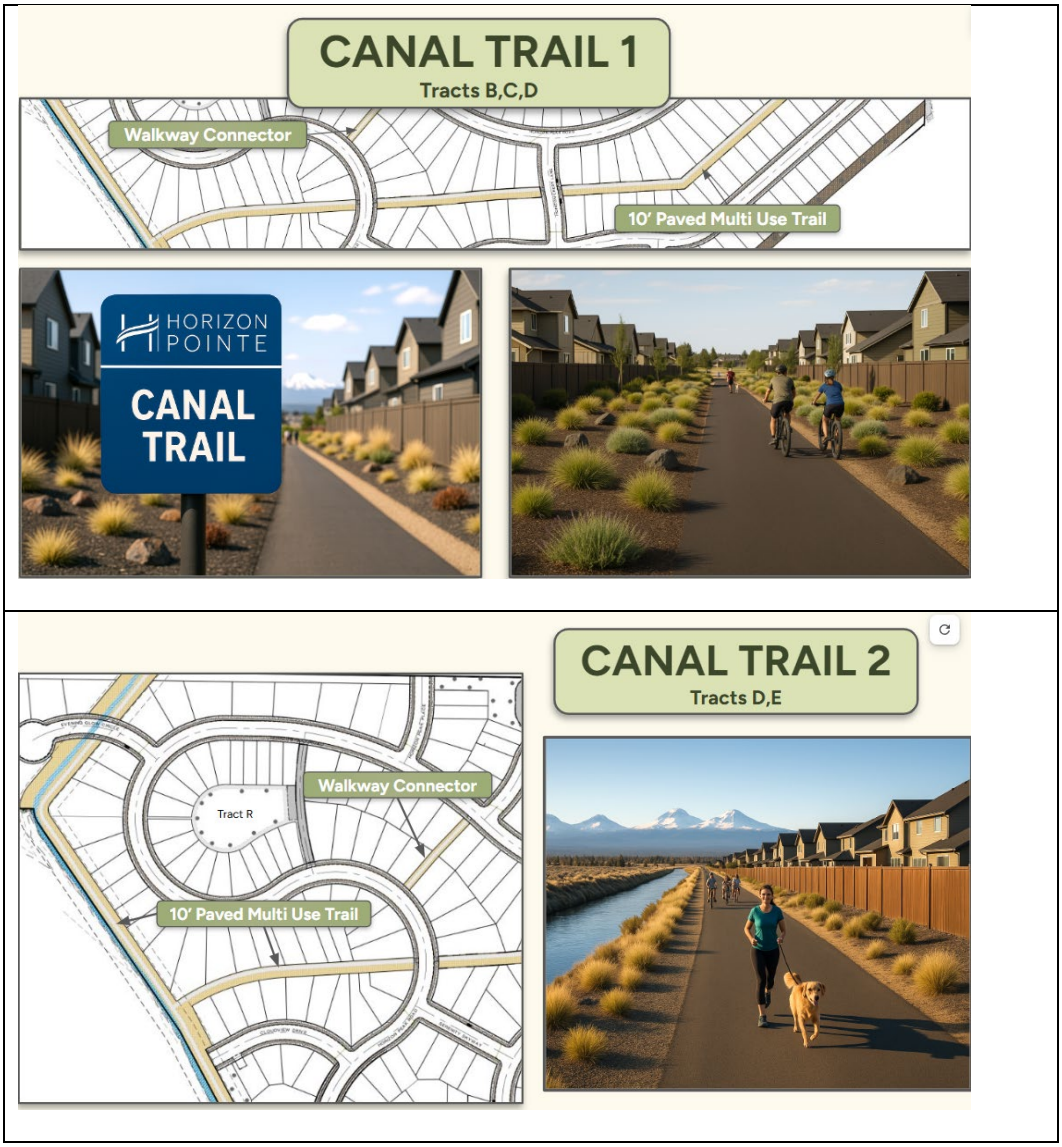
Response: Horizon Pointe's curvilinear street system was carefully designed to balance vehicular efficiency with pedestrian comfort and safety. While some block lengths within the project exceed the standard dimensions established in the Redmond Development Code, the overall layout enhances connectivity and accessibility throughout the neighborhood. The design minimizes the number of four-way intersections—traditionally the highest-conflict points for both vehicles and pedestrians—while maintaining continuous pedestrian linkages.

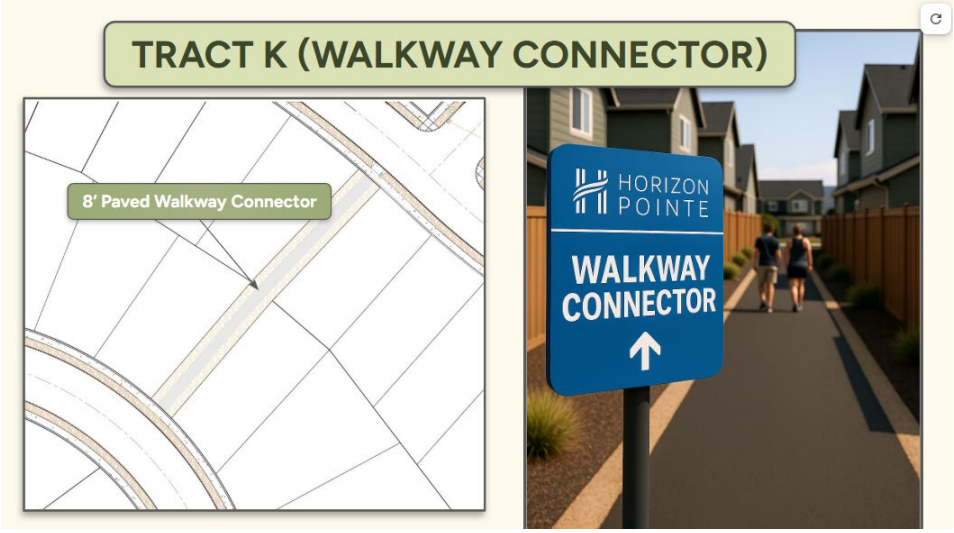
The subdivision integrates an internal network of trails, pathways, and open-space corridors that allow residents to move easily between parks, schools, and neighborhood streets without relying exclusively on the public roadway system. These connections provide direct, convenient pedestrian routes and often shorten walking distances compared to traditional grid layouts, where pedestrians must follow right-angled street paths and cross multiple intersections.

This system not only improves walkability but also enhances overall neighborhood safety by reducing exposure to traffic and encouraging slower vehicle speeds. Each pathway is designed to feel comfortable, visible, and integrated into the surrounding landscape, creating a cohesive environment that aligns with Redmond's Great Neighborhood Principles of walkability, connectivity, and safety.

This design approach is consistent with the flexibility provided in Redmond Development Code § 8.275(3)(B)(4) and § 8.270, which allow alternative street configurations when they achieve equal or better outcomes for connectivity and livability. In this case, Horizon Pointe provides a pedestrian network that fulfills—and, in many ways, exceeds—the intent of the City's standards by offering a safer, more direct, and more enjoyable walking experience.

Below includes a visual overview of Horizon Pointe's proposed pedestrian & bicycle trails:


CANAL TRAIL 1
Tracts B,C,D
Walkway Connector
10' Paved Multi Use Trail
HORIZON POINTE
CANAL TRAIL
CANAL TRAIL 2
Tracts D,E
Tract R
Walkway Connector
10' Paved Multi Use Trail



2.Lots and Parcels. The size, width, and orientation of newly created lots and parcels shall be appropriate for the location of the land division and for the type of development and use contemplated. Lots and parcels shall be generally rectangular in shape and shall be consistent with the lot size provisions of the zoning standards and the density requirements as established in the City of Redmond Comprehensive Plan. Notwithstanding these requirements, the following exceptions may apply:

A.In areas beyond the City Limits where public sewer is not currently available, minimum lot and parcel sizes shall permit compliance with the requirements of the Department of Environmental Quality and shall be sufficient to permit adequate sewage disposal. Any problems posed by soil structure and water table as related to sewage disposal by septic tank shall be addressed and resolved in the applicant's initial plan.

B.Where property is zoned and planned for business or industrial use, other widths and areas may be permitted by the Review Authority. Depth and width of properties reserved or laid out for commercial and industrial purposes shall be adequate to provide for the off-street service and parking facilities required by the type of use and development contemplated.

C.In steep terrain, increased lot or parcel sizes may be required to avoid excessive cuts, fills, and steep driveways.

Response: All lot sizes, widths, and orientations have been curated to fit the unique shape of the property and overall project layout. Lots are generally rectangular and generally in alignment with the underlying zoning criteria. All cases where the underlying zoning criteria are not met, exceptions have been requested in the Planned Unit Development section of this narrative.

3.Frontage. Each newly created lot and parcel shall abut upon a public street other than an alley for at least 50 feet (at least 25 feet in Mixed Use zones). Lots fronting on the bulb of a cul-de-sac the minimum frontage shall be 30 feet. Flag lots shall have no less than 20 feet of street frontage measured at the property line. Townhouse frontage shall be at least 20 feet. Vehicular access shall be provided as specified in Section 8.2820, Access Management Standards, of this Chapter, or as specified in Section 8.2705(6.) below, for residential lots and parcels abutting collector and arterial streets. All lot and parcels shall be addressed from the primary public street frontage, not including alleys.

Response: The proposed curvilinear layout of this project results in variability in proposed frontage. All cases in which frontage requirements have not been met have been addressed in the Planned Unit Development section of this narrative.

4.Side Lot or Parcel Lines. All side lot lines shall be at right angles to street lines or radial to curved streets wherever practical except as provided for in Subsection (10.) of this Section.

Response: Per the submittal plans, this criterion is satisfied.

5.Through/Double Frontage Lots and Parcels. Through lots or parcels, and lots or parcels with double frontage shall be avoided whenever possible, including lots or parcels created adjacent to Collector and Arterial Streets, but not including alley frontage as described in Section 8.2705(6.) below, except when they are necessary due to an irregular parent lot or parcel configuration, or are necessitated by topography or other unique circumstance.

Response: There is a single double frontage lot proposed with this design, lot 270, located in the northeast section of the property. This lot is to front the proposed Horizon Peak Rd & the future 45th St. The unique shape of the parent parcel as well as the required location of the future 45th St that will service the Little Texas North project, requires the lot to have double frontage. Both the proposed Horizon Peak Rd & future 45th Streets are to be local streets. There are no double frontage lots proposed along any collectors or arterials. A series of 30' wide open space tracts (Tracts O,P,&Q) separate the lots located on the east/southeast of the project from SW Helmholtz Way. This criterion is satisfied.

6.Residential Lots and Parcels Abutting Collector and Arterial Streets. Lots and parcels created adjacent to Collector and Arterial streets shall be oriented so that the front elevation of the residential development faces the Collector or Arterial Street. Vehicular access shall be provided pursuant to Section 8.2820, Access Management Standards, of this Chapter. In instances where direct vehicular driveway access to lot or parcel from the Collector or Arterial Street is not permissible, alley access shall be provided to the rear of the lot or parcel in accordance with the design standards included in Section 8.2710(3.) of this Chapter.

Response: There are no lots abutting collector or arterial streets proposed with this design. A series of 30' wide open space tracts (Tracts O,P,&Q) separate the lots located on the east/southeast of the project from SW Helmholtz Way. This criterion is satisfied.

7.Corner Lots and Parcels. Corner lots and parcels shall be five feet more in width than other lots and parcels and also shall have sufficient extra width to meet the additional side yard requirements of the zoning district in which they are located.

Response: All of the corner lots have been drawn on the plans to demonstrate the intended residential home fit for the respective lot and all corner lots are able to meet the additional side yard requirements.

8.Special Building Setback Lines. If special building setback lines, in addition to those required by the applicable zoning, are to be established in a development, they shall be shown on the final plat of the development and included in the deed restrictions.

Response: No special building setbacks are to be established in this development.

9.Large Building Lots; Re-division. In the case where lots or parcels are of a size and shape that future redivision is possible, the Review Authority, may require that the blocks be of a size and shape so that they may be redivided into building sites, and the development approval and site restrictions may require provision for the extension and opening of streets at intervals which will permit a subsequent redivision of any tract of land into lots or parcels of smaller sizes than originally platted, and in conformance with the density provisions established in the City of Redmond Comprehensive Plan for the existing or intended Zone. A plan indicating the ability for re-division according to these standards may be required as part of the initial land division process.

Response: No large building lots are included as a part of this project.

10.Curvilinear Street and Block Design. Although a basic grid street design with minimum and maximum block lengths are requirements of this Section, a curvilinear street/block design is encouraged for the purpose of adding interest to new subdivision development.

Response: Horizon Pointe represents a thoughtful departure from the traditional grid street pattern historically used in Redmond subdivisions. While the grid has long served as a utilitarian framework for subdivision design, it often produces excessive roadway, repetitive streetscapes, and limited opportunities to respond to site topography or natural features

In contrast, the curvilinear design of Horizon Pointe is a modern neighborhood pattern that follows the land's natural contours and existing infrastructure constraints—most notably the COID canal corridors—while maintaining full connectivity. This approach aligns directly with the City of Redmond's Great Neighborhood Principles, which encourage creative street design, integration of natural features, and neighborhood identity through varied block and lot configurations.

From a community-design standpoint, curvilinear streets provide broader, more dynamic view corridors, reduce intersection conflicts, and create an intuitive flow of movement throughout the neighborhood. The resulting environment feels more walkable, calm, and visually open, enhancing both safety and livability for resident. Less linear feet of street = less land in Street Right of Way = less land dedicated to the Public and more land available to those living within the development = less paved surface = more pervious organic surface = less environmental impacts.

The layout also yields measurable community benefits—what we refer to as "The Big Three":

1. ***Less Infrastructure: The curvilinear design results in substantially less total infrastructure—including streets, sidewalks, curbs, gutters, and utilities—than a comparable grid layout. This directly reduces long-term maintenance costs for the City and improves long-term service efficiency.***

2. ***More Usable Space, Larger Lots, Greater Assessed Value: The land saved from reduced infrastructure is reallocated to amenities such as parks and paved trails, as well as individual homesites, increasing lot sizes and thereby generating higher assessed property values and ongoing tax revenue for the City.***

3. ***Lower Home Costs: By constructing fewer linear feet of roadway and utility improvements, overall development costs are reduced, enabling homes to be delivered to Redmond residents at a lower total price point.***

These combined outcomes create a win-win-win—less maintenance burden for the City, greater tax revenue from the same acreage, and more attainable homes for Redmond families. This design fulfills the intent of Redmond Development Code § 8.270 and § 8.275, which allow for flexible, innovative neighborhood design when such flexibility produces a demonstrably superior outcome for both the community and the City.



11.Flag Lots. A flag lot shall be considered as a "flag lot" if the pole of the flag lot is less than half the width of the average lot width. For flag lots, the following shall be required:

A. Flag poles shall be no less than 20 feet wide. Flag lot frontage can be reduced by approval from Redmond Fire & Rescue and City Engineer.

B. All zone regulations apply, including the minimum required lot size and setbacks unless setback reductions are allowed as described in (E).

C. Each flag lot shall contain a minimum 12-foot-wide paved driveway.

D. A flag lot is exempt from the 50-foot street frontage requirement; however, a minimum of 20 feet of street frontage is required.

E. Front and/or rear yard setbacks may be reduced to no less than ten feet subject to review and approval by the Community Development Director. The orientation of any structure (determination of front) may be suggested by the property owner and is subject to the review and approval of the Community Development Director, or designee. The location(s) of all structures immediately adjacent to any flag lot shall be shown on a site plan

(1) during planning review and during the act of creating any new flag lot, and

(2) during a building permit review for any structure built on a flag lot.

F. No flag lot shall be partitioned or further divided, except as provided for by middle housing.

G. The "pole" of the flag lot shall be no longer than 150 feet measured from the street intersection to the beginning of the base of the flag.

H. The "pole" of the flag shall not be included in the minimum lot size calculation.

I. Flag lots shall be exempt from street tree requirements unless the street frontage portion of the flag lot is 30 feet or greater.

J. Flag lots are prohibited along or abutting the Dry Canyon Rim.

K. Two off-street parking spaces shall be provided for single family detached dwellings; and one space per unit for middle housing on a flag lot.

Response: Lots 129-132 do not meet the criteria to be considered a "flag lot" as they do not take driveway access through the pole. These lots are to be rear-loaded townhomes. There are no proposed flag lots. This criterion does not apply.

Sec. 8.2710. - Streets.

1.General. Streets shall be in conformance with the City of Redmond Transportation System Plan as specified herein.

A. Except along Arterial Street, public streets shall be spaced a maximum of 660 feet between centerlines. The purpose is to provide a street grid pattern of through streets to facilitate traffic movement. Street designs shall conform to topography and other existing natural and man-made conditions. Illustrative examples of other conditions include the dry canyon, main COI canal, Highway 97, and the Burlington Northern Railroad tracks.

Response: This proposed project does not use a traditional grid plan. Because of this, please refer to the PUD section of this narrative for code exception requests.

The intent of this code section is to provide quick evacuation routes for the residents of the subdivision. Wildfire safety and evacuation efficiency were central considerations in the design of Horizon Pointe. Along the western boundary, the Central Oregon Irrigation District (COID) canal corridor provides a naturally irrigated, non-combustible buffer that forms the backbone of the subdivision's fire-defensible edge. This corridor is complemented by a paved multi-use trail and an open-space tract, creating a continuous area free from structures or dense vegetation. Together, these elements establish a layered fire-protection zone that separates homes from adjacent rural lands while maintaining public access and connectivity.

Horizon Pointe's street network further strengthens public-safety outcomes by distributing traffic through multiple ingress and egress points, avoiding the single-entry congestion common in older neighborhoods. In an evacuation scenario, residents can disperse toward SW Helmholtz Way via Dusk Valley Road or the future SW 45th Street, providing redundant routes consistent with Redmond Development Code § 8.275(4)(D), which requires that Planned Unit Developments be designed to enhance public safety and community resilience.

Collectively, these measures demonstrate a proactive approach to wildfire readiness: natural fuel breaks, clear evacuation pathways, and a subdivision layout that supports safe, orderly movement during an emergency. Horizon Pointe's design not only aligns with City standards but also reflects the broader regional commitment to wildfire-resilient community planning in Central Oregon.

Additionally, the parent parcel for this project is a unique shape that also presents topographic challenges. There is a rock knob central to the north boundary of the project and the proposed piped COID canal must be located to the south and east of this rock knob to achieve the desired fall and

discharge connections as well as prevent prohibitively deep bury of the COID Pipe, something that COID would like to avoid. This required COID alignment is driving the need for street spacing exception requests.

B. All proposed streets, sidewalks, bike lanes and pedestrian pathways shall connect to other streets, sidewalks bike lanes and pedestrian pathways within a development and to existing and planned streets, sidewalks, bike lanes and pedestrian pathways outside the development. Such facilities shall serve existing and planned parks, schools, or other public lands within a neighborhood.

Response: The existing street system (Helmholtz) will be improved to minor arterial street standards at property frontage per the Approved TIA for the project. Internal streets will be constructed to City standards. The street improvements proposed will connect to the existing street system (Helmholtz) as well as provide a protected refuge for pedestrians crossing Helmholtz at the intersection with Dusk Valley Rd per the approved TIA. The proposed streets of 51st St, and C St, have been coordinated with the developer of the Little Texas North subdivision (the northern neighbor) to ensure connectivity with the future subdivision.

Horizon Pointe's curvilinear street system was carefully designed to balance vehicular efficiency with pedestrian comfort and safety. While some block lengths within the project exceed the standard dimensions established in the Redmond Development Code, the overall layout enhances connectivity and accessibility throughout the neighborhood. The design minimizes the number of four-way intersections—traditionally the highest-conflict points for both vehicles and pedestrians—while maintaining continuous pedestrian linkages.

The subdivision integrates an internal network of trails, pathways, and open-space corridors that allow residents to move easily between parks, schools, and neighborhood streets without relying exclusively on the public roadway system. These connections provide direct, convenient pedestrian routes and often shorten walking distances compared to traditional grid layouts, where pedestrians must follow right-angled street paths and cross multiple intersections.

This system not only improves walkability but also enhances overall neighborhood safety by reducing exposure to traffic and encouraging slower vehicle speeds. Each pathway is designed to feel comfortable, visible, and integrated into the surrounding landscape, creating a cohesive environment that aligns with Redmond's Great Neighborhood Principles of walkability, connectivity, and safety.

This design approach is consistent with the flexibility provided in Redmond Development Code § 8.275(3)(B)(4) and § 8.270, which allow alternative street configurations when they achieve equal or better outcomes for connectivity and livability. In this case, Horizon Pointe provides a pedestrian network that fulfills—and, in many ways, exceeds—the intent of the City's standards by offering a safer, more direct, and more enjoyable walking experience.

C. To the maximum extent possible, new local streets shall align and connect with existing local streets and collectors, and in certain special cases arterial streets. Cul-de-sac streets shall be permitted only where no feasible connection with an adjacent street exists, or if the local street connection would be to an arterial street and the function of the arterial street may be diminished as determined through the land use review process, or the block length would be less than that which is permitted by Section 8.2705(1.B.).

Response: The submitted plans demonstrate compliance with the above criteria by proposing street extensions that have been coordinated with the developer of the Little Texas North Subdivision (the northern neighbor). Based on the included plans, the applicant finds that the requirement has been

satisfied.

D. Consideration should be given to alternative street designs other than required herein in the City's non-residential land use zones to allow for more effective developments. Such designs may be considered and approved during the subdivision or partition process without need for variance.

Response: There are no non-residential zoned areas, therefore, this criterion does not apply.

E. All proposed or required streets and alleys shall comply with Section 8.2820 Access Management Standards, the Transportation System Plan, and with Local Street Connectivity Plans adopted as part of the transportation element of the Comprehensive Plan.

Response: The submitted plans demonstrate compliance with all above criteria by providing improvements that meet the standards listed in the appropriate City plans unless otherwise requested as part of the PUD application. The applicant is aware that engineered plans for all infrastructure will be required to be submitted to the City of Redmond Engineering Department for review and approval prior to any construction and platting.

2.Existing Streets. Whenever existing streets, adjacent to or within a tract, are of inadequate width per Public Works Standards and Specifications and the City's approved Transportation System Plan additional right-of-way shall be provided at the time of the land division by the applicant. During consideration of the tentative plat for the subdivision or partition, the Review Authority shall determine whether the improvements to existing streets, adjacent to or within the tract, are required. If so determined, such improvements shall be required as a condition of approval of the tentative plat. Improvements to adjacent streets shall be required where traffic on said streets shall be directly affected by the proposed subdivision. Notwithstanding these provisions, off-site improvements to streets not within or adjacent to the development may be required when impacts resulting from the development necessitate such improvements as demonstrated through a transportation impact analysis.

Response: Per the project's approved TIA, the applicant proposes to dedicate a minimum of 20' of ROW along property frontage on SW Helmholtz Way to ensure a minimum of 100' of ROW will be provided. Helmholtz along property frontage will be improved to minor arterial roadway standards per City of Redmond Standards and Specifications and Development Code requirements. The applicant will also dedicate the necessary ROW along the future 45th St to provide a minimum of 60' of ROW.

3.Existing Access Easements. Whenever existing unpaved access easements, adjacent to or within a tract, the Review Authority may require paving to City standards at the time of the land division by the applicant.

Response: There exist no unpaved public access easements on the subject properties. This criterion does not apply.

4.Minimum Right-of-Way and Roadway Standards. The minimum street right-of-way widths shall be in conformance with Table 1 below. Additional right-of-way may be required at intersections to accommodate intersection widening and roundabouts. Street surfacing, sidewalks or multi-use paths, travel lanes, medians, planter strips, curbs and bicycle lanes must be installed in conformance with the Public Works Standards and Specifications and the Transportation System Plan. Oregon Department of Transportation (ODOT) facilities must meet ODOT design standards.

Response: All Proposed streets are designed according to current City of Redmond Public Works Standards. No exceptions for right-of-way widths are proposed.

5.Future Extension of Streets. When necessary to give access to or permit a satisfactory future division of adjoining land, streets shall be extended to the boundary of the subdivision or partition and the resulting dead-end streets may be approved without a permanent turn around if they are 150 feet or less in length, although, an

adequate temporary turn around to ensure emergency vehicle access must be provided if such streets are greater than 150 feet in length.

Response: As discussed above, the subdivision provides street extensions where necessary to facilitate a logical extension of streets, while considering connection with the to-be-developed property to the north. Additionally, please see correspondence from Redmond Fire and Rescue concerning required fire turn arounds. The applicant finds this criterion is satisfied.

6.Collector and Arterial Street Access. Notwithstanding the provisions of Section 8.2705 of this Chapter, if a land division abuts or contains an existing or proposed collector or arterial street, the Review Authority, may require other treatments, including but not limited to frontage roads, necessary for adequate protection of residential properties and to afford separation of through and local traffic. Provision may be made for emergency access. All frontage roads shall comply with the City of Redmond Transportation System Plan.

Response: The project does not propose any direct lot access to any collector or arterial streets. All lots will take driveway access from either proposed local streets or private alleys. The design as proposed meets the above criterion.

7.Streets Adjacent to Railroads, Freeways and Parkways. When the area to be subdivided or partitioned is residentially zoned and abuts a railroad, freeway, or parkway, a provision may be required for a street approximately parallel to and on either side of such right-of-way at a distance suitable for use of the land between the required street and the abutting railroad, freeway, or parkway. In the case of a railroad, there shall be a land strip of not less than 25 feet in width between the railroad right-of-way and residential property. The land strip must be occupied by the fire-resistant materials, and may contain a fence, a trellis, a wall, or small decorative or artistic feature. If the intervening property between such parallel streets and a freeway or a parkway is less than 80 feet in width, such intervening property shall be dedicated to a passive-style park or thoroughfare use by bicycles and/or pedestrians. The intersections of such parallel streets, where they intersect with streets that cross a railroad, shall be determined with due consideration as cross streets of a minimum distance required for approach grades to a future grade separation and right-of-way widths of the cross street.

Response: The subject property does not abut any railroad alignments; therefore, this criterion is not applicable.

8.Continuation of Streets. Subdivision or partition streets which constitute the continuation of streets in contiguous territory shall be aligned so that their center lines coincide. Where straight line continuations are not possible, such center lines shall be continued as curves. These streets or the continuation of streets in contiguous territory may be required by the Review Authority, where such continuation is necessary to maintain the function of the street or desirable in the surrounding area.

Response: There are no existing street stubs abutting the subject properties. As discussed above, the proposed layout includes future street extensions to connect into the northerly Little Texas subdivision, as well as dedicating right-of-way for construction of the future 45th St at the eastern boundary of the project. This criterion is satisfied.

9.Street Names. Except for extensions of existing streets, no street names shall be used which will duplicate or be confused with the name of an existing street in a nearby city or in the County. Street names and numbers shall conform to the established pattern in the City, including the continuation of street names across intersecting streets, and shall be subject to the approval of the Redmond Fire and Rescue and Deschutes County.

Response: All street names shown on the submitted plan set are preliminary. Street names will be submitted and reviewed by Redmond Fire and Rescue & Deschutes County and receive approval prior to platting.

10.Sidewalks. Sidewalks are required to be installed on both sides of a public street and in any special pedestrian way within the subdivision or partition that comply with the City of Redmond Transportation System Plan. In the case of collectors, arterials, special industrial districts or in steep terrain, the Review Authority may approve a subdivision or partition without sidewalk if alternative pedestrian routes are available or provided by the developer. Sidewalks shall be required along routes to existing or future school and park sites.

Response: Sidewalks will be constructed on both sides of all new internal streets, as well as the west side of Helmholtz. A paved pathway running north-south & adjacent to the existing COID Lateral on the west side of the project as well as a pathway running East-West & adjacent to the proposed COID piped-canal will be constructed per COID requirements and City of Redmond Standards and Specifications. Applicant is aware that engineered plans for all infrastructure will be required to be submitted to the City of Redmond Engineering Department for review and approval prior to any construction, as well as platting, for each phase of the development.

11.Bicycle Facilities and Multi-Use Pathways. Bicycle facilities and multi-use pathways are required to be installed within the subdivision or partition that comply with the City of Redmond Transportation System Plan.

Response: The construction of Helmholtz to arterial standards shall include bike lanes. As discussed above, the project proposes an interconnected trail system, allowing easy bicycle & pedestrian access to all proposed community parks. Applicant is aware that engineered plans for all infrastructure will be required to be submitted to the City of Redmond Engineering Department for review and approval prior to any construction, as well as platting, for each phase of the development.

12.Intersection Angles. Street intersections shall be as near right angles as possible except where topography or existing conditions requires a lesser angle, but in no case shall the acute angle be less than as permitted by the adopted Public Works Standards and Specifications.

Response: The submitted plans demonstrate conformance with this criterion. Applicant is aware that engineered plans for all infrastructure will be required to be submitted to the City of Redmond Engineering Department for review and approval prior to any construction, as well as platting, for each phase of the development.

13.Alignment. Staggered street alignment shall whenever possible, leave a minimum of 200 feet distance between the center line of the streets, but in no case be less than as permitted by Public Works Standards and Specifications.

Response: Wherever possible, a minimum of 200' of distance has been provided between the centerline of staggered streets. Please refer to the PUD section of this narrative for exception requests concerning intersection separations. Based on the included plans, the applicant believes this criterion is satisfied.

14.Narrow Streets. Local streets designed at widths less than 36 feet may be permitted subject to the following:

A. The narrow street is internal to a Subdivision or Planned Unit Development with street connections on both ends.

B. All lots adjoining the narrow streets are at least 5,000 square feet and have a minimum 50 feet of frontage.

C. Sidewalks, curbs, and street trees conforming with Public Works Standards and Specifications shall be installed.

D. Curb cuts along the narrow street shall not be less than the minimum width required within the adopted Public Works Standards and Specifications.

E. Covenants, Conditions, and Restrictions (CC&Rs) and a Homeowners Association (HOA) are established for the development. The CC&Rs must effectuate the HOA as responsible for parking enforcement

Response: No narrow streets are proposed as part of this project; therefore, this standard does not apply.

15.Private Steets. Private streets must be approved by the City Engineer. The City Engineer may require private streets to meet public standards. Private streets must comply with fire code and access management standards and will only be permitted when accompanied by CC&Rs that designate an HOA as responsible for maintenance and repair.

Response: Proposed private alleys are designed per City of Redmond Standards and Specifications for Construction, and will be the responsibility of the HOA to maintain. Applicant is aware that engineered plans for all infrastructure will be required to be submitted to the City of Redmond Engineering Department for review and approval prior to any construction, as well as platting, for each phase of the development. This criterion is satisfied.

Sec. 8.2715. - Fundamental Design Standards.

1.Lighting. The subdivider or partitioner shall provide underground wiring to the City standards and a base for any proposed ornamental streetlights at locations approved by the affected utility company.

Response: This is understood. Applicant will propose street lighting according to City of Redmond standards during the engineering design of the affected phase.

2.Multiple Access Points. Whenever possible, a minimum of two points of access to the subdivision or partition shall be provided to provide assured access for emergency vehicles and ease resident evacuation.

Response: Two immediate access points have been proposed with this project, access from the future 45th streety (to be constructed with Little Texas North Phase 1) as well as the proposed Dusk Valley Rd. Based on the proposal, this criterion is satisfied.

3.Water/Sewer. All subdivisions and partitions shall provide water and sewer lines constructed to City standards and specifications approved by the City Engineer. All lots or parcels shall be served from the City of Redmond water and sewer systems or by water and sewer systems acceptable to the City. Water and sewer mains and service lines shall be installed prior to the curbing and paving of new streets in all new subdivisions or partitions.

Response: All lots will be provided with water and sewer service from the utility lines shown on the supplied land use plan set. Applicant is aware that engineered plans for all infrastructure will be required to be submitted to the City of Redmond Engineering Department for review and approval prior to any construction, as well as platting, for each phase of the development. This criterion is satisfied.

4.Underground Utilities. All permanent utility service, cell service, and minor power transmission lines that are within or immediately adjacent to lots in a subdivision or parcels in a partition shall be provided from underground facilities unless otherwise approved by the Review Authority. The subdivider, partitioner, or developer shall be responsible for complying with requirements of this Section and shall:

A. Obtain a permit from Public Works for placement for all underground utilities within the public right-of-way.

B. Make all necessary arrangements with the utility companies and other persons or corporations affected by the installation of such underground utilities and facilities in accordance with rules and regulations of the Public Utility Commission of the State of Oregon.

C. All underground utilities, water lines, sanitary sewer lines and storm drains installed in streets shall be constructed prior to the surfacing of such streets to the extent practicable, and water and sanitary sewer service lines shall be placed to such lengths as will negate the necessity for disturbing the street improvements when service connections are made.

Response: Applicant will utilize rights of way and PUE's to provide new underground utility services to each lot. The utility installation as proposed will meet this criterion.

5.Preservation of Natural Features. Existing natural features (i.e., rock outcrops) add character to the development and shall be preserved to the greatest extent practicable.

Response: Preservation of the natural features on this site is not practicable. The topography of the site would not be developable without the removal of some of the natural rock outcroppings. All effort has been made to design the site to mitigate the amount of demolition necessary for development. The location of the rock outcroppings are driving the placement of the proposed piped COID canal, and subsequently, home and street placement.

6.Preservation and Replacement Trees. All deciduous or coniferous existing trees having a ten-inch trunk diameter 4.5 feet above grade or greater are considered significant and shall be preserved or replaced at a 'one-to-one' ratio. Replacement trees shall have a minimum 1-1/2-inch trunk diameter measured at 4.5 feet above grade. This criterion shall be met in the submitted landscape plan. Street trees are counted as replacement trees. Trees removed for installation of public infrastructure are not required to be replaced, however they should be preserved where possible. The Community Development Director, or designee, may prohibit removal of significant trees located within the setback along the perimeter of the parcel to be developed, located adjacent to water features, or that provide screening or buffering to existing development where not located within the proposed or potential building footprint. An alternate restoration plan may be approved by the Community Development Director, or designee.

Response: No trees are being considered for preservation. The vast majority of the trees on site are Juniper trees which are considered invasive to this area. As part of this project, 369 trees with a diameter greater than 10" will be removed during development. Applicant intends to install 50 trees within the various neighborhood parks and tracts proposed with this development. In addition, applicant will install a minimum of 321 lot frontage street trees as required by Redmond Development Code. Placement of street trees will be determined during the engineering design for the respective phase, and will be reviewed and approved by the City of Redmond Engineering Department prior to construction.

7.Easements.

A. Utility Easements. Easements shall be provided along property lines when necessary for the placement of underground utilities and to provide the subdivision or partition with electric power, communication facilities, street lighting, sewer lines, water lines, gas lines, or drainage. Such easements shall be labeled "Public Utility Easement" on the tentative and final plat; they shall be at least 12 feet in width and centered on lot lines where possible, unless determined otherwise by the City Engineer or designate. Excepting utility pole guylines easements along the rear of lots adjacent to unsubdivided land may be reduced to ten0 feet in width, unless determined otherwise by the City Engineer or designate.

B. Drainage. If a tract is traversed by a water course, such as a drainage way, channel or stream, there shall be provided a stormwater easement or drainage right-of-way conforming substantially with the lines of the water course or in such further width as will be adequate for the purpose. Streets or parkways parallel to major water courses and drainage ways may be required.

Response: All public streets have public utility easements granted along proposed right-of-way lines as required by the City of Redmond. The western boundary of the property abuts the existing COID Irrigation Lateral B, which has an existing total 95' width easement centered on the lateral. This easement is more than wide enough to protect COID's interests. All adjacent lots to this lateral will have their storm drainage maintained on the lot via the use of berms & swales, per typical City of Redmond Development Codes. There are no significant natural drainage/water courses on site. Storm drainage of public facilities will be handled via construction of drywells. Location & sizing of these drywells will be reviewed and approved by The City of Redmond Engineering Department during the engineering design of the respective phase. The applicant finds that this criterion is satisfied.

8.Fully developed "pocket parks" or "tot lots" shall be incorporated into medium and high density zoned residential subdivisions and site plans. These areas shall be developed for every 25 lots/units, a minimum of 3,000 square feet and privately maintained. Park amenities shall, at a minimum, include: 1/2 of the park dedicated to turf areas, benches, trees, shrubs, ground cover, irrigation, other landscape or decorative features, and acceptable trash receptable(s) and lighting.

Response: Several pocket parks and trails are proposed with this project. Programming of these parks is desired to be reviewed following the approval of the land use application. Per this criterion, with 321 lots proposed, a total of 38,520 square feet of "pocket park" space is required. Project proposes 66,857 square feet of programmed neighborhood parks via tracts G, H, I, J & R. These neighborhood parks will be landscaped & irrigated, with trees, grass, benches, trashcans, and other programming to be reviewed and approved by the City. Maintenance of these parks will be the responsibility of the Horizon Pointe HOA. Please see earlier in this document for conceptual park programming. In total, this project proposes over 6.67 acres of open space tracts, including over 5,000 linear feet of paved trails, offering pedestrian access to any of the "pocket parks" from any home within the community. The applicant finds that this requirement has been satisfied.

9.Urban-Rural Interface. Residential subdivisions adjacent to areas outside of the Urban Reserve Area (URA) shall provide buffering to manage the transition from urban to rural intensities by meeting at least one of the following standards:

A. Provide landscaped buffers at least 100 feet wide, exclusive of rights-of-way, for the entire length that the urban development is adjacent to lands outside of the URA. The buffers shall be landscaped with native vegetation characteristic of the local ecosystem; or

B. Locating lower density development at the urban-rural interface; or

C. Other appropriate and equivalent transitional elements as approved by the Review Authority.

Response: There is a large COID canal (Lateral B) with a significant easement on the western boundary of this project that offers a natural barrier between the project and adjacent farmland. This easement is 95 feet in width that will exist into perpetuity. Along the northwest boundary, Horizon Pointe adjoins the Little Texas North subdivision, which the City of Redmond previously approved with a defined open-space buffer along the Urban Reserve Area. Horizon Pointe continues this same approach to maintain a consistent and compatible edge condition between the two communities.

The proposed buffer within Horizon Pointe mirrors the same open-space width and placement established in Little Texas North, ensuring that the visual and functional transition along the City's Urban Growth Boundary remains cohesive. This open-space tract fulfills the intent of Redmond Development Code § 8.270 and § 8.275, which require that new neighborhoods provide compatibility and thoughtful transitions with adjacent developments and the Urban Reserve interface.

By continuing the established open-space treatment and incorporating accessible trail connections within

this tract, Horizon Pointe advances the City's Great Neighborhood Principles of connectivity, integration of natural features, and preservation of neighborhood identity. Together, these elements create a manicured edge that gives the neighborhood a defined and intentional boundary—one that feels open, well-maintained, and visually inviting. This edge not only softens the transition to the Urban Reserve Area but also establishes a lasting sense of place that reflects the quality and character the City of Redmond seeks to encourage along its growing western boundary.

It is the applicant's belief that this criterion is satisfied.

Sec. 8.2800. - Improvement Procedures.

In addition to other requirements, public or private improvements to be installed by the applicant either as a requirement of these standards or other applicable regulations or at his or her own option, shall conform to the requirements of this Article:

1. Plan Review and Approval. Improvement work shall not be commenced until plans thereof have been reviewed and approved by the Community Development Director, or Hearings Body, or a designated representative thereof. To the extent necessary for evaluation of a proposed development, such improvement plans may be required before approval of the tentative plan or preliminary map or drawing.

   Response: This is understood

2. Public Improvements as Platted. Public improvements shall be designed, installed, and constructed as platted and approved by the City Engineering Division, and plans shall be filed with the final plat at the time of recordation or upon completion.

   Response: This is understood

3. Inspection. Improvements shall be constructed under the inspection and approval of a city Inspector. Expenses incurred thereby shall be borne by the applicant/owner. The inspector may require changes in sections and details of the improvements if unusual conditions arise during construction to warrant such changes.

   Response: This is understood

4. As-Built Plans. A map showing the completed public improvements shall be filed with the Community Development Department upon completion of the improvements.

   Response: This is understood

Sec. 8.2805 -Improvements in Partitions

Improvements shall be considered for acceptance after final inspection, after the improvements have been completed.
Response: This is understood

Sec. 8.2815 – Transportation System Analysis

It shall be the burden of the developer to evaluate transportation system impacts when a proposed development involves either a Subdivision, Site and Design Review, Planned Unit Development, Master Development Plan, Comprehensive Plan and Zone Map Amendment, a change or expansion of use, or any other development that the City Engineer deems necessary. Transportation System Analyses are not required for residential site plan review for up to four units or Partitions.

Transportation System Analyses are approved based on the information presented in the report and must not be older

than 180 days from approval at the time the land use application is deemed complete. If the associated land use application is not deemed complete prior to the expiration, the City may require the approved report be updated.

Response: The City of Redmond Engineering Department Approved Transportation System Analysis for this project is included with the submittal of this document. Project proposal complies with all requirements as outlined in the approved Transportation System Analysis.

Sec. 8.2820 -Access Management Standards

Access management standards apply to new developments, redevelopments, subdivisions, and partitions.

Location of Access Points.

1. Access shall be taken from the lower order street or alley unless otherwise approved by Public Works and/or ODOT. Access to higher order streets may be allowed for emergency vehicles when restricted with a locked fire gate, bollards or similar, when approved or required by Redmond Fire and Rescue.
   Response: All lots have access from lowest order street. Criterion is met.

2. Every lot or parcel shall be limited to one point of access, subject to the following exceptions:

   A. *Single Family Dwellings, Accessory Dwelling Units, Plexes, Mixed-Use Developments.*

      1. Lots with multiple frontages on local roadways or alleys may be permitted one access per frontage, provided the driveways meet all other required standards.
      Response: All lots have a single driveway access.

      2. Lots with accessory structures requiring vehicular access, such as a shop or detached garage, may be permitted two access points, provided the lot frontage is on a local roadway, the driveways are separated by a minimum of 10 feet, and the driveways meet all other required standards.
      Response: No lots proposed with accessory structures. Criterion does not apply.

   B. *All Other Uses.*

      1. Lots may be permitted a secondary access when it is demonstrated that the additional access improves on-site circulation, does not adversely impact the operations of the transportation system, and when approved by the City Engineer or designee.
      Response: No lots proposed with accessory structures. Criterion does not apply.

3. Lots with more than one existing access may be required to close an existing street access upon redevelopment. This standard may be waived when access to an existing, permanent garage structure would be removed, or removal of the access would result in increasing the nonconformity of the site.
   Response: No lots with existing access to proposed streets are proposed. A singular new access will be constructed for the existing home on lot 247.

4. In the event that the access management standards cannot be achieved on the subject property, shared access with adjacent property may be permitted. When a driveway serves more than one lot, the developer must record an access and maintenance easement/agreement to benefit each lot prior to building permit issuance. Shared access points should be centered on property boundaries when possible.
   Response: This is understood.

5. In all instances, access near an intersection shall be located beyond the influence of standing queues and opposing left turns sharing a continuous two-way left turn lane. This requirement may result in greater corner clearance or access spacing than the minimum distance indicated.
Response: This is understood. Request for exception to access spacing noted in PUD section of this narrative.

Design of Access Points.

6. The City Engineer or designee may require access locations to align with existing driveways on the opposite side of the roadway, be located as far from driveways on the same side of the street or intersections as possible, or to be right-in/right-out. Right-in/right-out may be required when the access is located within 300 feet of a signalized intersection or roundabout.
Response: There are no existing driveways on opposite side of Helmholtz, nor is there a signalized intersection or roundabout within 300 feet. This criterion does not apply.

7. Property-tight driveway aprons excluding the wings must be located a minimum of three feet from property lines, and curb-tight driveway aprons excluding the wings must be located a minimum of six feet from property lines, unless the access is approved to be shared.
Response: Proposed project meets the requirements of this criterion.

8. A minimum of 24 feet of backing distance shall be provided and shall be measured from the rear end of a perpendicular parking stall or garage door face to the opposite end of a paved alley or roadway. If the abutting alley or street is unpaved, the measurement shall be taken to the opposite end of the right-of-way. If the backing distance is demonstrated onsite, the measurement shall be taken to the nearest barrier, such as a property line, retaining wall, fence, or edge of driveway.
Response: Proposed project meets the requirements of this criterion.

9. Corner clearance shall be provided and is measured from the edge of right-of-way to the nearest edge of the access. Spacing is measured from centerline of access/intersection to centerline of access/intersection. Driveway spacing and corner clearance is required as follows:

   All land use approvals shall be in compliance with the following standards.

Roadway Classification	Minimum Access Driveway Spacing	Minimum Access Clearance to Corner	Intersection Spacing (Min.)
Local Street	No Restrictions	30 ft	165 ft
Minor Collector	50 ft	80 ft	330 ft
Major Collector	165 ft	165 ft	330 ft
Minor Arterial	330 ft	330 ft	1/4 mile
Major Arterial	ODOT Stds	ODOT Stds	ODOT Stds

Response: Project meets requirements of this criterion unless otherwise noted in PUD section of this narrative. Please see PUD section for requested exceptions to these standards.

Additional Standards.

10. Adequate intersection sight distance and clear zone shall be maintained at all access/driveway locations per AASHTO standards (American Association of State Highway and Transportation Officials).
Response: The curvilinear street network within Horizon Pointe was intentionally designed to

improve sight distances, visual openness, and overall neighborhood safety. Because of the natural geometry of curved streets, homes on the outer radius of each curve are set on wider frontages, offering more expansive view corridors from within the homes across the street. Conversely, homes on the inner radius are set back beyond the standard 20-foot minimum, creating deeper setbacks that increase visibility at driveways and intersections.

Park-like Setting: This alternating pattern of throated-out and throated-in lots produces a rhythmic sequence of open view sheds that significantly enhance line-of-sight distances for both drivers and pedestrians. The result is a neighborhood that feels more spacious and visually connected than traditional grid developments, where straight corridors and uniform setbacks compress the streetscape and limit visibility.

From a safety standpoint, the absence of Four-Way intersections increases the ability to see on-coming traffic and contributes to a safer neighborhood.

This design approach fulfills the intent of Redmond Development Code § 8.270 and § 8.275, which encourage creative and context-sensitive neighborhood design that enhances safety, livability, and compatibility with the surrounding built environment. The result is a community that feels open, orderly, and intuitively safe—a distinctive streetscape character that will set Horizon Pointe apart as one of Redmond's model neighborhoods.

11. Access within the North Redmond US 97 Interchange Area Management Plan (IAMP) shall also conform to the 2007 "North Redmond US 97 Interchange Area Management Plan (IAMP)," as amended.
Response: Proposed project is not located within the North Redmond US 97 Interchange Area. This Criterion does not apply.

12. Public Works may require supporting information, including but not limited to traffic count data, trip generation, trip distribution, truck and trailer turning/backing templates and/or onsite circulation diagram. Transportation Impact Analysis study, etc., in order to make a proper determination of access/driveway location.
Response: This is understood.

Sec. 8.2825 -Street Dedications

Any person desiring to create a street not part of a subdivision or partition shall make written application to the Community Development Department.
Response: No streets are proposed that are not part of this subdivision. This criterion does not apply.

1. *Major Variance.* Upon application, the Community Development Director, or Hearings Body, may authorize variances from the standards of this Chapter pursuant to the criteria listed below if the applicant can establish:

A. That special conditions exist which are peculiar to the subject property, and which are not applicable to other properties in the same zone which make conformance to these standards impractical.
B. That the variance is the minimal deviance from these standards needed to accomplish the objective.
C. That the varied requirement(s) will conform to the purpose and objectives of the Comprehensive Plan and of these standards and will have no adverse impact on surrounding properties or on the provision of general urban services in the area.
D. That strict interpretation of these standards would deprive the applicant of rights commonly enjoyed by other properties in the same zone under the terms of these standards.
E.That the special conditions and circumstances do not result from actions of the applicant and such conditions and circumstances do not merely constitute pecuniary hardship or inconvenience.

2. *Minor Variance.* A minor variance under this Chapter shall be no greater than 25 percent of the requirements from which the variance is sought. Upon application, the Community Development Director, or Hearings Body, may authorize variances from the standards of this Chapter pursuant to the criteria listed below if the applicant can establish:

A. More efficient use of the site.
B. Preservation of natural features where appropriate.
C. Adequate provision of light, air, and privacy to adjoining properties.
D. Adequate access.
E. That the variance will have minimal adverse impact on the livability, value or development potential of abutting properties and the surrounding area.
F. Consistency with the overall objectives of the Comprehensive Plan.

3. The Community Development Director, or Hearings Body, may attach such conditions to any variance granted that will ensure the variance meets the objectives of the Comprehensive Plan and of these standards and does not have an adverse impact on surrounding properties or on the provision of general urban services in the area.

Response: No variances are being applied for with this project. All exceptions to code requirements are requested as part of the PUD application & narrative herein. This criterion does not apply.

Sec 8.2835 -City as Beneficiary to Covenants, Conditions and Restrictions

When Covenants, Conditions and Restrictions (CCR's), or other similar documents, are required by either the provisions of this Code or through the land use review process, the City of Redmond may require the CCR's (or other documents) include a provision or provisions that allow the City to come onto the property(s) that are subject to the CCR's for the purpose of removing, repairing or maintaining improvements and other common areas in the event such improvements or common areas are not property maintained or otherwise kept in good order. The provision(s) shall state that the City has sole and exclusive discretion to determine the need for and timing of any such removal, repair, or maintenance. The provision shall authorize the City to recover the cost of such removal, repair, or maintenance by directly billing the record owner of the property(s) subject to the CCR's or the property(s) directly benefited by the removal, repair, or maintenance. In the event a bill is not paid, the City may impose a lien on the property(s), which shall be recorded and may be enforced in the manner of an assessment lien. The inclusion of a provision or provisions described in this Section does not affect the obligations of an association, group and/or other persons or property owner(s) designated in the CCR's from any responsibilities or obligations respecting such improvements or common areas, nor shall it obligate the City to such undertake such removal, repair, or maintenance.

Response: This is understood. No CC&R's are proposed at this time. CC&R's will be recorded prior to any building occupancy.

Sec. 8.2840 -CC&Rs Middle Housing

CC&Rs developed on or after January 1, 2021, shall no restrict middle housing per ORS 93.277 as amended.

Response: This is understood. No CC&R's are proposed at this time. CC&R's will be recorded prior to any building occupancy.

Conclusion: Based upon the submitted tentative subdivision plan, Transportation Impact Analysis, Landscaping Plan, and the proposed responses included herein, the applicant believes that all requirements have been fulfilled. The applicant respectfully requests approval of the project.

Impact of Intersection Angle on Highway Safety

PUBLICATION NO. FHWA-HRT-20-067

JANUARY 2021







U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

FOREWORD

Intersection crashes account for approximately 22 percent of fatal crashes and 40 percent of all crashes in the United States. When designing new roadways or retrofitting existing roadways, careful consideration should be given to mitigation measures for skewed intersections. This research sought to obtain quantitative relationships between intersection angle and safety, where intersection crashes define safety. The relationships were used to determine appropriate crash modification factors for reducing or eliminating the skew angle of an intersection.

The study was conducted with data from Minnesota and Ohio. Models were derived separately for rural and urban three- and four-leg intersections. The relationships between intersection angle and safety in the Minnesota and Ohio data were used to determine the critical minimum angle at which safety is substantially diminished (75 degrees, 60 degrees, or other). The study developed new crash modification functions for intersection angles and new considerations for critical minimum angles commonly applied by roadway designers. The results and insights will be useful for highway engineers, safety engineers, and associations and nongovernmental organizations that develop nationally recognized guidelines.

Brian P. Cronin, P.E.
Director, Office of Safety and Operations
Research and Development

Notice

This document is disseminated under the sponsorship of the U.S. Department of Transportation (USDOT) in the interest of information exchange. The U.S. Government assumes no liability for the use of the information contained in this document.

The U.S. Government does not endorse products or manufacturers. Trademarks or manufacturers' names appear in this report only because they are considered essential to the objective of the document.

Quality Assurance Statement

The Federal Highway Administration (FHWA) provides high-quality information to serve Government, industry, and the public in a manner that promotes public understanding. Standards and policies are used to ensure and maximize the quality, objectivity, utility, and integrity of its information. FHWA periodically reviews quality issues and adjusts its programs and processes to ensure continuous quality improvement.

Cover photos source: FHWA.

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. FHWA-HRT-20-067	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Impact of Intersection Angle on Highway Safety		5. Report Date January 2021
		6. Performing Organization Code
7. Author(s) David Harkey, Bo Lan (ORCID: 0000-0002-7998-7252), Raghavan Srinivasan (ORCID: 0000-0002-3097-5154), Wesley Kumfer (ORCID:0000-0002-6705-5298), Daniel Carter (ORCID: 0000-0001-6572-6548), and Anusha Patel Nujjetty (ORCID: 0000-0002-1148-718X)		8. Performing Organization Report No.
9. Performing Organization Name and Address Highway Safety Research Center University of North Carolina Chapel Hill, NC 27599		10. Work Unit No.
		11. Contract or Grant No. DTFH61-11-C-00050
12. Sponsoring Agency Name and Address Office of Safety Research and Development Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101		13. Type of Report and Period Covered Final Report; January 2011–April 2014; June 2017–September 2020
		14. Sponsoring Agency Code HRDS-20

15. Supplementary Notes
This report was produced as a research product of the Highway Safety Information System (HSIS) under the direction of HSIS Program Managers Carol Tan, Ph.D. (HRDS-20; ORCID 0000-0002-0549-9782) and Ana Maria Eigen, Ph.D. (HRDS-20; ORCID 0000-0003-4056-361X).

16. Abstract
The preferred design for conventional intersections includes adjacent legs that intersect at 90 degrees. However, there are occasions when physical constraints result in intersection angles less than 90 degrees and thus produce skewed intersections. Skewed intersections may create potential safety and operational problems for both motorists and nonmotorists. To date, the research on problems related to skewed intersections has been limited, which may explain the lack of consensus among the policies and guidance that now exists in practice.
The objective of this study was to derive quantitative relationships between intersection angle and safety for which intersection crashes define safety. The relationships were used to determine appropriate crash modification functions (CMFunction) for reducing or eliminating the skew angle of an intersection, determine if there is a critical minimum angle at which safety is substantially diminished, and assess the need for revising current geometric design policies and practices.
Data-mining and -regression techniques were used to identify the most important predictor variables from many independent variables. Data from minor road stop-controlled intersections in Minnesota and Ohio were used to estimate negative binomial regression models using the identified variables. These models were used to derive CMFunctions for rural and urban three- and four-leg intersections. The relationship between the crash modification factor and intersection angle (represented by the CMFunctions) differs from previous studies. Agencies should consider modifying the minimum critical angle for intersections in roadway design policies to be revised to reflect the results of this research.

17. Key Words	18. Distribution Statement
Intersection angle, intersection safety, crash modification factor, crash modification function, skew angle, negative binomial regression, stop controlled	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161. http://www.ntis.gov

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	207	N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1,000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$candela/m^2$	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION 1
Background 1
Magnitude of the Problem 2
Objectives and Scope 5
Organization of the Report 6

CHAPTER 2. LITERATURE REVIEW 7
Current Design Guidance 7
Safety Research 9
Crash Research 9
Visibility Research 12
Physiology Research 13
Summary 14

CHAPTER 3. METHODOLOGY AND APPROACH 17
Analysis Approach 17
Variable Selection 17
Safety-Prediction Model Development and CMFunction Derivation 18
Summary 20

CHAPTER 4. DATA ACQUISITION AND PREPARATION 21
Data Source and Assessment 21
MN Data 21
OH Data 23
Data Acquisition 23
Supplemental Geometric Data Collection 26
Data Preparation 30
Data Description 31
MN Data 31
OH Data 40
Data Comparison 50

CHAPTER 5. ANALYSIS AND INTERPRETATION OF RESULTS 53
Data Mining 54
Safety-Prediction Models 59
Total Crashes for Four-Leg Intersections 62
Total Crashes for Three-Leg Intersections 68
Development of CMFs and Functions 72
All Rural Four-Leg CMFunctions 74
Rural Four-Leg Two-Lane CMFunctions 74
Rural Four-Leg Multilane CMFunctions 76
All Rural Three-Leg CMFunctions 76
Rural Three-Leg Two-Lane CMFunctions 77
Total Urban Four-Leg CMFunctions 78
Urban Four-Leg Two-Lane CMFunctions 79
All Urban Three-Leg CMFunctions 80

Urban Three-Leg Two-Lane CMFunctions 81
Critical Angle Assessment 82
Comparison of Results to Prior CMFs 85

CHAPTER 6. SUMMARY AND CONCLUSIONS 93
Summary 93
Research Conclusions 95
Methodology Conclusions 98

CHAPTER 7. FUTURE RESEARCH 99

APPENDIX A. HSIS DATA VARIABLES 101

APPENDIX B. SUPPLEMENTAL DATA-COLLECTION PROCEDURE AND ISSUES 107
MN Data-Collection Procedure 107
Issue 1—Corrected Skewed Intersection 109
Issue 2—Missing Approach Legs 110
Issue 3—Misclassification 111
Issue 4—Grade Separation 112
Issue 5—Incorrect Classification 113

APPENDIX C. DATA TABLES 115

APPENDIX D. DATA DESCRIPTORS AND DATA-MINING RESULTS 125
Data Mining: Background and Application 125
Data Mining: Procedure and Analysis 126
Data Descriptors for Minnesota 129
Data Descriptors for Ohio 145

APPENDIX E. SUPPLEMENTAL SAFETY-PREDICTION MODELS 149
MN Supplemental Safety-Prediction Models 150
All Four-Leg Intersections—Base Models for Total Crashes 150
All Four-Leg Intersections—Interaction Model for Total Crashes 153
Three-Leg Intersections—Base Models for Total Crashes 155
Three-Leg Intersections—Interaction Model for Total Crashes 159
Four-Leg Intersections—Additional Models 160
OH Supplemental Safety-Prediction Models 169

APPENDIX F. CMFUNCTION DEVELOPMENT AND ADDITIONAL MODELS 173
MN CMFunctions 173
Four-Leg Intersections—Total Crashes at All Intersections 173
Four-Leg Intersections—Total Crashes at Rural Intersections 175
Four-Leg Intersections—Total Crashes at Two-Lane Rural Intersections 177
Four-Leg Intersections—Total Crashes at Multilane Rural Intersections 179

ACKNOWLEDGMENTS 183

REFERENCES 185

LIST OF FIGURES

Figure 1. Chart. Percentage of fatal crashes in the United States by location (data from NHTSA).[7] 2
Figure 2. Chart. Percentage of total crashes in the United States by location (data from NHTSA).[7] 3
Figure 3. Chart. Percentage of MN intersections by number of legs and angle classification (2008 data). 4
Figure 4. Chart. Percentage of MN intersection crashes by number of legs and angle classification (2008 data).[1] 4
Figure 5. Equation. CMF for skew angle at a three-leg intersection of rural two-lane two-way roads.[24] 9
Figure 6. Equation. CMF for skew angle at a four-leg intersection of rural two-lane two-way roads.[24] 10
Figure 7. Equation. Number of predicted crashes at a three-leg intersection.[25] 10
Figure 8. Equation. Number of predicted crashes at a four-leg intersection.[25] 10
Figure 9. Equation. Total crash CMF for skew angle at a three-leg intersection of rural multilane and minor-leg stop-controlled roads.[24] 11
Figure 10. Equation. Total crash CMF for skew angle at a four-leg intersection of rural multilane and minor-leg stop-controlled roads.[24] 11
Figure 11. Equation. Fatal and injury crash CMF for skew angle at a three-leg intersection of rural multilane and minor-leg stop-controlled roads.[24] 11
Figure 12. Equation. Fatal and injury crash CMF for skew angle at a four-leg intersection of rural multilane and minor-leg stop-controlled roads.[24] 11
Figure 13. Equation. Number of predicted crashes for three- and four-leg rural two-lane intersections.[28] 12
Figure 14. Map. Skewed and nonskewed four-leg intersections in MN. 29
Figure 15. Map. Density of skewed and nonskewed three-leg intersections in MN. 29
Figure 16. Graph. Annual average total crash rate by intersection angle category, number of legs, and rural/urban classification in MN. 39
Figure 17. Graph. Annual average total crash rate for rural four-leg intersections by intersection angle category and number of approach lanes on the major road in MN. 40
Figure 18. Graph. Annual average total crash rate by intersection angle category, number of legs, and rural/urban classification in OH. 49
Figure 19. Graph. Annual average total crash rate for rural four-leg intersections by intersection angle category and number of approach lanes on the major road in OH. 49
Figure 20. Plot. Results of regression tree (ctree) analysis for total crashes at four-leg intersections. 58
Figure 21. Equation. AIC. 60
Figure 22. Equation. BIC. 60
Figure 23. Graph. Average total crashes per intersection for all four-leg intersections in MN and functional form of [(1 + cos(angle)) × *intersection AADT*] as distributed across the range of intersection angles. 63
Figure 24. Graph. Average total crashes per intersection for all four-leg intersections in MN and functional form of [(1 + cos(angle)) × *minor road AADT*] as distributed across the range of intersection angles. 64

Figure 25. Equation. Derived variable that incorporates intersection AADT and cosine of the intersection angle. 64
Figure 26. Equation. Derived variable that incorporates minor road AADT and cosine of the intersection angle. 64
Figure 27. Equation. Derivation of partial crash prediction term using intersection AADT, minor road AADT, and cosine of the intersection angle. 65
Figure 28. Graph. Average total crashes per intersection for all three-leg intersections in MN and functional form of [(1 + cos(angle)) × *intersection AADT*] as distributed across the range of intersection angles. 69
Figure 29. Graph. Average total crashes per intersection for all three-leg intersections in MN and functional form of [(1 + cos(angle)) × *minor road AADT*] as distributed across the range of intersection angles. 69
Figure 30. Equation. CMFunction calculation. 72
Figure 31. Equation. CMFunction flexible form model 1 calculation for total crashes at all four-leg intersections. 73
Figure 32. Equation. General form of Hoerl Curve. 73
Figure 33. Graph. CMF for all rural four-leg intersections. 74
Figure 34. Graph. CMFunctions for rural four-leg two-lane intersections. 75
Figure 35. Graph. CMFunctions for rural four-leg two-lane intersections with NC data. 75
Figure 36. Graph. CMFunctions for rural four-leg multilane intersections. 76
Figure 37. Graph. CMFunctions for rural three-leg total intersections. 77
Figure 38. Graph. CMFunction for rural three-leg two-lane intersections. 78
Figure 39. Graph. CMFunction for urban four-leg total intersections. 79
Figure 40. Graph. CMFunction for urban four-leg two-lane intersections. 80
Figure 41. Graph. CMFunction for urban three-leg total intersections. 81
Figure 42. Graph. CMFunction for urban three-leg two-lane intersections. 82
Figure 43. Graph. MN CMFs derived from the flexible form models for four-leg intersections, considering different severities. 84
Figure 44. Graph. CMFunctions derived from the MN flexible form models for rural four-leg intersections with different severities. 85
Figure 45. Graph. CMFs from the HSM for total crashes at rural two-lane roadway intersections.[(24)] 86
Figure 46. Graph. CMFs from the HSM for total crashes at rural multilane roadway intersections.[(24)] 87
Figure 47. Graph. CMFs from the current study and the HSM for total crashes at rural four-leg two-lane intersections. 89
Figure 48. Graph. CMFs from the current study and the HSM for total crashes at rural three-leg two-lane intersections. 89
Figure 49. Graph. CMFs from the current study and the HSM for total crashes at rural four-leg multilane intersections. 90
Figure 50. Graph. Crash-reduction potential based on CMFs for rural two-lane and multilane intersections. 91
Figure 51. Equation. Recommended CMFunction for all four-leg intersections, fatal-and-injury crashes. 96
Figure 52. Equation. Recommended CMFunction for all four-leg intersections, PDO crashes. 96

Figure 53. Equation. Recommended CMFunction for rural four-leg intersections, total crashes. 96
Figure 54. Equation. Recommended CMFunction for rural four-leg intersections, injury-and-fatal crashes. 96
Figure 55. Equation. Recommended CMFunction for rural four-leg intersections, PDO crashes. 96
Figure 56. Equation. Recommended CMFunction for rural four-leg two-lane intersections, total crashes. 96
Figure 57. Equation. Recommended CMFunction for rural four-leg two-lane intersections, fatal-and-injury crashes. 96
Figure 58. Equation. Recommended CMFunction for rural four-leg two-lane intersections, PDO crashes. 96
Figure 59. Equation. Recommended CMFunction for rural four-leg multilane intersections, total crashes. 97
Figure 60. Equation. Recommended CMFunction for rural four-leg multilane intersections, fatal-and-injury crashes. 97
Figure 61. Equation. Recommended CMFunction for rural four-leg multilane intersections, PDO crashes. 97
Figure 62. Equation. Recommended CMFunction for urban four-leg intersections total crashes. 97
Figure 63. Equation. Recommended CMFunction for urban four-leg two-lane intersections, total crashes. 97
Figure 64. Equation. Recommended CMFunction for rural three-leg intersections, total crashes. 97
Figure 65. Equation. Recommended CMFunction for rural three-leg two-lane intersections, total crashes. 97
Figure 66. Equation. Recommended CMFunction for urban three-leg intersections, total crashes. 97
Figure 67. Equation. Recommended CMFunction for urban three-leg two-lane intersections, total crashes. 97
Figure 68. Illustration. Measured intersection angle with the ArcGIS COGO tool and a 50-foot radius (67 degrees).[59] 108
Figure 69. Illustration. Measured intersection angle with the ArcGIS™ COGO tool and a 100-foot radius (62 degrees).[59] 108
Figure 70. Illustration. Intersection shown as skewed four-leg location in the GIS roadway network and as two three-leg intersections in the aerial image.[75] 110
Figure 71. Illustration. Intersection shown with a single minor leg approach in the GIS roadway network but with two minor leg approaches and a median connector in the aerial image.[76] 111
Figure 72. Illustration. Intersection shown as a full access four-leg location in the GIS roadway network but as two three-leg intersections (no median connector) in the aerial image.[77] 112
Figure 73. Illustration. Grade-separated intersection that should not have been included in the original HSIS data received.[78] 113

Figure 74. Illustration. Intersection that was classified as skewed in the HSIS database but is a right-angle intersection in both the GIS roadway network and the aerial imagery.[79] 114
Figure 75. Plot. Results of conditional RF (cforest) analysis for total crashes at four-leg intersections. 128
Figure 76. Plot. Conditional RF (cforest) results for total crashes at four-leg intersections. 133
Figure 77. Plot. Conditional RF (cforest) results for fatal-and-injury crashes at four-leg intersections. 134
Figure 78. Plot. Conditional RF (cforest) results for PDO crashes at four-leg intersections. 135
Figure 79. Plot. Conditional RF (cforest) results for total crashes at three-leg intersections. 136
Figure 80. Plot. Conditional RF (cforest) results for fatal-and-injury crashes at three-leg intersections. 137
Figure 81. Plot. Conditional RF (cforest) results for PDO crashes at three-leg intersections. 138
Figure 82. Plot. Regression tree for total crashes at four-leg intersections (results from ctree analysis). 139
Figure 83. Plot. Regression tree for fatal-and-injury crashes at four-leg intersections (results from ctree analysis). 140
Figure 84. Plot. Regression tree for PDO crashes at four-leg intersections (results from ctree analysis). 141
Figure 85. Plot. Regression tree for total crashes at three-leg intersections (results from ctree analysis). 142
Figure 86. Plot. Regression tree for injury crashes at three-leg intersections (results from ctree analysis). 143
Figure 87. Plot. Regression tree for PDO crashes at three-leg intersections (results from ctree analysis). 144
Figure 88. Graph. Scatterplot of intersection AADT versus major road AADT for all four-leg intersections in MN. 151
Figure 89. Graph. Scatterplot of intersection AADT versus minor road AADT for all four-leg intersections in MN. 151
Figure 90. Equation. Interaction term of intersection AADT and cosine of the intersection angle. 153
Figure 91. Equation. Interaction term of minor road to intersection AADT ratio and cosine of the intersection angle. 154
Figure 92. Equation. Interaction term of intersection AADT and skew angle expressed in radians. 154
Figure 93. Graph. Scatterplot of intersection AADT versus major road AADT for all three-leg intersections in MN. 156
Figure 94. Graph. Scatterplot of intersection AADT versus minor road AADT for all three-leg intersections in MN. 156
Figure 95. Equation. CMF base model calculation for total crashes at all four-leg intersections. 173
Figure 96. Graph. CMFs derived from the flexible form model 1 and alternative base model for total crashes at all four-leg intersections in MN. 173
Figure 97. Equation. CMF flexible form model 2 calculation for total crashes at all four-leg intersections. 174

Figure 98. Graph. CMFs derived from the flexible form models 1 and 2 and alternative base model for total crashes at all four-leg intersections in MN. 174
Figure 99. Graph. CMF derived from the alternative base model for total crashes at all four-leg intersections in MN. 175
Figure 100. Equation. CMF base model calculation for total crashes at rural four-leg intersections. 175
Figure 101. Graph. CMF derived from the alternative base model for total crashes at rural four-leg intersections in MN. 176
Figure 102. Graph. CMFs derived from the flexible form model 1 and alternative base model for total crashes at rural four-leg intersections in MN. 177
Figure 103. Equation. CMF base-model calculation for total crashes at rural four-leg two-lane intersections. 177
Figure 104. Graph. CMF derived from the alternative base model for total crashes at rural four-leg two-lane intersections in MN. 178
Figure 105. Graph. CMFs derived from the flexible form model 1 and alternative base model for total crashes at rural four-leg two-lane intersections in MN. 179
Figure 106. Equation. CMF base model calculation for total crashes at rural four-leg multilane intersections. 179
Figure 107. Graph. CMFs derived from the alternative base model for total crashes at rural four-leg multilane intersections in MN. 180
Figure 108. Graph. CMFs derived from the flexible form model 1 and alternative base model for total crashes at rural four-leg multilane intersections. 181

LIST OF TABLES

Table 1. Number of MN intersections by traffic control type and skew classification (2008 data). 22
Table 2. Number of crashes by intersection type for the first and last years (1999 and 2008) of the potential analysis period.[2] 22
Table 3. Number of crashes per intersection by intersection type for the first and last years (1999 and 2008) of the potential analysis period. 23
Table 4. Number of minor leg stop-controlled intersections without changes in the skew/nonskew attributes over time (1999–2008).[3] 23
Table 5. Distribution of four-leg intersections by angle classification and area type in MN. 31
Table 6. Distribution of three-leg intersections by angle classification and area type in MN. 32
Table 7. Distribution of four-leg intersections by intersection angle category and area type in MN.[6] 32
Table 8. Distribution of three-leg intersections by intersection angle category and area type in MN. 33
Table 9. Distribution of rural four-leg intersections by intersection angle category and number of lanes on the major road in MN. 34
Table 10. Distribution of skewed intersections by intersection angle for four-leg and three-leg intersections in MN. 34
Table 11. Distribution of total crashes and total crashes/intersection at four-leg intersections by intersection angle category and area type in MN. 35
Table 12. Distribution of total crashes and total crashes/intersection at three-leg intersections by intersection angle category and area type in MN.[10] 35
Table 13. Range of intersection AADT for four-leg intersections by intersection angle and area type in MN. 36
Table 14. Range of intersection AADT for three-leg intersections by intersection angle and area type in MN.[11] 37
Table 15. Range of intersection AADT for four-leg intersections by intersection angle category and the number of lanes on the major road in MN. 38
Table 16. Distribution of four-leg intersections by angle classification and area type in OH. 40
Table 17. Distribution of three-leg intersections by angle classification and area type in OH. 41
Table 18. Distribution of four-leg intersections by intersection angle category and area type in OH. 41
Table 19. Distribution of three-leg intersections by intersection angle category and area type in OH. 42
Table 20. Distribution of rural four-leg intersections by intersection-angle category and number of lanes on the major road in OH. 43
Table 21. Distribution of skewed intersections by intersection angle for four-leg and three-leg intersections in OH. 43
Table 22. Distribution of total crashes and total crashes per intersection at four-leg intersections by intersection-angle category and area type in OH. 44
Table 23. Distribution of total crashes and total crashes per intersection at three-leg intersections by intersection-angle category and area type in OH. 45

Table 24. Distribution of total crashes and total crashes per intersection at rural four-leg intersections by intersection angle category and the number of lanes on the major road in OH. 45
Table 25. Range of intersection AADT for four-leg intersections by intersection angle and area type in OH. 46
Table 26. Range of intersection AADT for three-leg intersections by intersection angle and area type in OH. 47
Table 27. Range of intersection AADT for four-leg intersections by intersection angle category and the number of lanes on the major road in OH. 48
Table 28. Quantity of total intersections by number of legs in each dataset. 50
Table 29. Quantity of skewed intersections by number of legs in each dataset. 50
Table 30. Weighted intersection volumes by roadway type, number of legs, and number of lanes in each State's dataset. 51
Table 31. Total crashes by number of legs in each dataset. 51
Table 32. Analysis framework for MN—summary of crashes by collision severity and intersection classification in the final database. 53
Table 33. Analysis framework for OH—summary of crashes by collision severity and intersection classification in the final database. 54
Table 34. Most important predictor variables for MN four-leg intersections (results from cforest analysis). 56
Table 35. Most important predictor variables for MN three-leg intersections (results from cforest analysis). 57
Table 36. General guidance for interpretation of models using AIC and BIC criteria. 60
Table 37. Different roadways with sufficient data for total crash CMFunction development. 62
Table 38. Flexible form model 1 results for total crashes at all four-leg intersections for MN. 66
Table 39. Model fit statistics for OH for total rural four-leg intersections. 67
Table 40. Model fit statistics for OH for urban four-leg total intersections. 67
Table 41. Flexible form model 1 results for total crashes at all three-leg intersections for MN. 70
Table 42. Model fit statistics for OH for rural three-leg all intersections. 71
Table 43. Model fit statistics for OH for urban three-leg, all intersections. 71
Table 44. Peak CMFunction values and corresponding angles for total crashes for all intersection types. 83
Table 45. CMFunction values derived from all models for total crashes at all intersections. 84
Table 46. List of variables available from the HSIS MN crash file. 101
Table 47. List of variables available from the HSIS MN roadlog file. 102
Table 48. List of variables available from the HSIS MN intersection file. 103
Table 49. Four-leg intersections by angle classification and area type in MN. 115
Table 50. Total crashes (2003–2009) at four-leg intersections by angle classification and area type in MN. 115
Table 51. Four-leg intersections by intersection angle and area type in MN. 115
Table 52. Total crashes (2003–2009) at four-leg intersections by intersection angle and area type in MN. 116
Table 53. Fatal-and-injury crashes (2003–2009) at four-leg intersections by intersection angle and area type in MN. 116

Table 54. PDO crashes (2003–2009) at four-leg intersections by intersection angle and area type in MN. 117
Table 55. Intersection AADT for four-leg intersections by intersection angle and area type in MN. 117
Table 56. Minor road AADT for four-leg intersections by intersection angle and area type in MN. 118
Table 57. Major road AADT for four-leg intersections by intersection angle and area type in MN. 118
Table 58. Total crash rates (per 100 M entering vehicles) for four-leg intersections by intersection angle and area type in MN. 119
Table 59. Fatal-and-Injury crash rates (per 100 M entering vehicles) for four-leg intersections by intersection angle and area type in MN. 119
Table 60. PDO crash rates (per 100 M entering vehicles) for four-leg intersections by intersection angle and area type in MN. 120
Table 61. Three-leg intersections by angle classification and area type in MN. 120
Table 62. Total crashes (2003–2009) at three-leg intersections by angle classification and area type in MN. 120
Table 63. Three-leg intersections by intersection angle and area type in MN. 120
Table 64. Total crashes (2003–2009) at three-leg intersections by intersection angle and area type in MN. 121
Table 65. Fatal-and-injury crashes (2003–2009) at three-leg intersections by intersection angle and area type in MN. 121
Table 66. PDO crashes (2003–2009) at three-leg intersections by intersection angle and area type in MN. 121
Table 67. Intersection AADT for three-leg intersections by intersection angle and area type in MN. 122
Table 68. Minor road AADT for three-leg intersections by intersection angle and area type in MN. 122
Table 69. Major road AADT for three-leg intersections by intersection angle and area type in MN. 123
Table 70. Total crash rates (per 100 M entering vehicles) for three-leg intersections by intersection angle and area type in MN. 123
Table 71. Fatal-and-injury crash rates (per 100 M entering vehicles) for three-leg intersections by intersection angle and area type in MN. 123
Table 72. PDO crash rates (per 100 M entering vehicles) for three-leg intersections by intersection angle and area type in MN. 124
Table 73. Variable names, descriptors, definitions, and attributes for MN. 130
Table 74. Variable names, descriptors, definitions, and attributes for OH. 145
Table 75. Number of sites in each angle bin for all rural, four-leg intersections in OH. 145
Table 76. Number of sites in each angle bin for rural four-leg two-lane intersections in OH. .. 146
Table 77. Number of sites in each angle bin for rural four-leg multilane intersections in OH. 146
Table 78. Number of sites in each angle bin for rural three-leg total intersections in OH. 146
Table 79. Number of sites in each angle bin for rural three-leg two-lane intersections in OH. 146
Table 80. Number of sites in each angle bin for urban four-leg total intersections in OH. 147

Table 81. Number of sites in each angle bin for urban four-leg two-lane intersections in OH. 147
Table 82. Number of sites in each angle bin for urban three-leg total intersections in OH. 147
Table 83. Number of sites in each angle bin for urban three-leg two-lane intersections in OH. 147
Table 84. Summary of severity models included in appendix E. 149
Table 85. Initial base model results for total crashes at all four-leg intersections in MN. 152
Table 86. Alternative base model results for total crashes at all four-leg intersections in MN. 153
Table 87. Interaction model results for total crashes at all four-leg intersections in MN..... 155
Table 88. Initial base model results for total crashes at all three-leg intersections in MN. 157
Table 89. Alternative base model results for total crashes at all three-leg intersections in MN. 158
Table 90. Flexible form model 2 results for total crashes at all three-leg intersections in MN. 158
Table 91. Interaction model results for total crashes at all three-leg intersections in MN. 159
Table 92. Flexible form model 1 results for fatal-and-injury crashes at all four-leg intersections in MN. 160
Table 93. Alternative base model results for PDO crashes at all four-leg intersections in MN. 161
Table 94. Flexible form model 1 results for PDO crashes at all four-leg intersections in MN. 161
Table 95. Alternative base model results for total crashes at all rural four-leg intersections in MN. 162
Table 96. Flexible form model 1 results for total crashes at all rural four-leg intersections in MN. 162
Table 97. Alternative base model results for fatal-and-injury crashes at all rural four-leg intersections in MN. 163
Table 98. Flexible form model 1 results for fatal-and-injury crashes at all rural four-leg intersections in MN. 163
Table 99. Alternative base model results for PDO crashes at all rural four-leg intersections in MN. 164
Table 100. Flexible form 1 model results for PDO crashes at all rural four-leg intersections in MN. 164
Table 101. Alternative base model results for total crashes at rural two-lane, four-leg intersections in MN. 165
Table 102. Flexible form model 1 results for total crashes at rural two-lane, four-leg intersections in MN. 165
Table 103. Flexible form model 1 results for fatal-and-injury crashes at rural two-lane, four-leg intersections in MN. 166
Table 104. Alternative base model results for PDO crashes at rural two-lane, four-leg intersections in MN. 166
Table 105. Flexible form model 1 results for PDO crashes at rural two-lane, four-leg intersections in MN. 167
Table 106. Alternative base model results for total crashes at rural multilane four-leg intersections in MN. 167

Table 107. Flexible form model 1 results for total crashes at rural multilane four-leg intersections in MN. 167
Table 108. Flexible form model 2 results for fatal-and-injury crashes at rural multilane four-leg intersections in MN. 168
Table 109. Alternative base model results for PDO crashes at rural multilane four-leg intersections in MN. 168
Table 110. Model fit statistics for OH for rural four-leg two-lane intersections in OH. 169
Table 111. Model fit statistics for OH for rural four-leg multilane intersections in OH. 170
Table 112. Model fit statistics for OH for rural three-leg two-lane intersections in OH. 170
Table 113. Model fit statistics for OH for urban four-leg two-lane intersections in OH. 171
Table 114. Model fit statistics for OH for urban three-leg two-lane intersections in OH. 171
Table 115. CMFunctions derived by NB model form for MN. 182
Table 116. CMF values derived from the flexible form models for four-leg rural intersections. 182

LIST OF ACRONYMS AND ABBREVIATIONS

AADT	annual average daily traffic
AASHTO	American Association of State Highway and Transportation Officials
AIC	Akaike information criterion
APS	accessible pedestrian signal
BIC	Bayesian information criterion
CA	California
CART	classification and regression tree
CMFunction	crash modification function
CMF	crash modification factor
CRF	conditional random forest
DOT	department of transportation
F&I	fatal and injury
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
GA	Georgia
GIS	geographic information system
HSIS	Highway Safety Information System
HSM	*Highway Safety Manual*
IHSDM	Interactive Highway Safety Design Model
ITE	Institute of Transportation Engineers
MARS	multivariate adaptive regression splines
MDT	Montana Department of Transportation
MI	Michigan
MN	Minnesota
MNDOT	Minnesota Department of Transportation
NB	negative binomial
NC	North Carolina
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NM	negative multinomial
ODOT	Ohio Department of Transportation
OH	Ohio
PDO	property damage only
RAM	random access memory
RF	random forest
ROW	right-of-way
SPF	safety performance function
vpd	vehicles per day

CHAPTER 1. INTRODUCTION

BACKGROUND

The preferred design for conventional intersections in which all movements are accommodated includes adjacent legs that intersect at 90 degrees. However, there are occasions where physical constraints result in intersection angles less than 90 degrees, which produce skewed intersections. Such intersections may create potential safety and operational problems for both motorists and nonmotorists.

Skewed intersections generally result in larger intersections. The additional space needed for skewed intersections introduces a couple of potential problems for drivers. First, drivers have a longer distance to travel when crossing the intersection or making certain turning maneuvers, which results in increased exposure within the intersection. Second, the increased surface area may result in driver confusion regarding alignment on the approach to the intersection or while turning or crossing. Both potential problems may also apply to bicyclists on the roadway.

The angles introduced at skewed intersections create additional problems. First, the orientation of crossing traffic to the waiting driver, bicyclist, or pedestrian may make it more difficult to detect and judge the speed of approaching vehicles on conflicting paths. Second, intersecting legs with acute angles between them can adversely affect the turning radius of the intersection, making it more difficult to accommodate large trucks. Third, acute angles may introduce additional sight obstructions, including possible obstructions from the body of the driver's vehicle. For older drivers, acute angles introduce the problem of not being able to physically turn their heads, necks, or upper bodies to create the necessary sight lines for seeing crossing traffic.

Skewed intersections present several problems to pedestrians. First, the distances that must be crossed by a pedestrian are greater at skewed intersections than at right-angle intersections. This problem increases the exposure time for a crossing pedestrian and is exacerbated for pedestrians, such as older persons, who may be traveling at a slower pace. Second, the sight lines between the pedestrian and driver are altered from a typical right-angle intersection, which creates an environment in which the two parties may not be looking at the correct places for potential conflicts. Third, skewed intersections are problematic for visually impaired pedestrians. Skewed intersections create an environment in which it is difficult for visually impaired pedestrians to align themselves for the crossing, ascertain the direction of traffic from sounds, and maintain alignment when crossing the street.

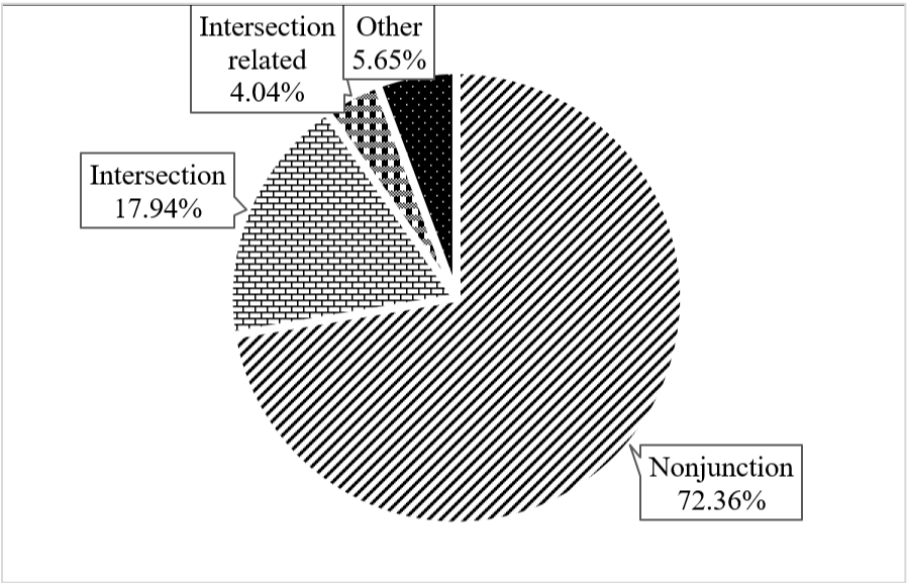
Properly addressing the operational and safety problems that result from skewed intersections requires sound design policies and practices. In *A Policy on Geometric Design of Highways and Streets*, the American Association of State Highway and Transportation Officials (AASHTO) recommends that "intersecting roads should generally meet at or nearly at right angles."[(1)] The Green Book also indicates that some deviation from a 90-degree angle is permissible but that an angle of at least 60 degrees provides most of the same benefits.[(1)] The Institute of Transportation Engineers' (ITE's) *Traffic Engineering Handbook* provides similar guidance.[(2)] However, prior ITE guidance recommended a minimum intersection angle of 70–75 degrees.[(3–5)]

The Federal Highway Administration's (FHWA's) *Highway Design Handbook for Older Drivers and Pedestrians* also recommends right-angle intersections where right-of-way (ROW) is not restricted and a minimum intersection angle of 75 degrees where ROW is restricted.[6] There are also differences among State departments of transportation (DOTs) regarding the desired minimum intersection angle.

To date, crash-based research on safety and operational implications of intersection angles has been limited. The limited research might explain the lack of consensus among existing policies and guidance. Researchers, practitioners, and agencies need to better understand the effects of intersection angles on crashes and enhance the current design guidance.

MAGNITUDE OF THE PROBLEM

Intersections account for a large portion of road-safety problems in the United States. Per data from the National Highway Traffic Safety Administration (NHTSA), almost 22 percent of fatal crashes (figure 1) and more than 40 percent of total crashes (figure 2) occur at or are related to intersections.[7] These facts are not unexpected because intersections are the locations on the Nation's roadway system that have the most conflicts. The number of potential conflicts is also a function of traffic volume; therefore, urban intersections are likely to have more collisions than rural intersections. Kuciemba and Cirillo found that intersections account for more than 50 percent of total crashes in urban areas while intersections account for just over 30 percent of total crashes in rural areas.[8] A study of California (CA) crashes found similar results. The CA study showed that, on average, 1.5 crashes per year occur at rural unsignalized intersections and 2.5 crashes per year occur at urban unsignalized intersections.[9]

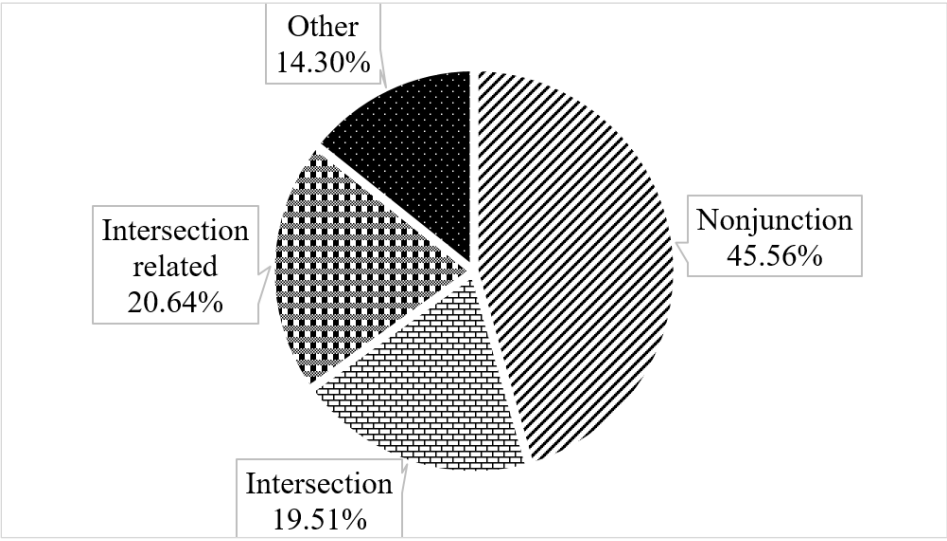


Source: FHWA.

Figure 1. Chart. Percentage of fatal crashes in the United States by location (data from NHTSA).[7]

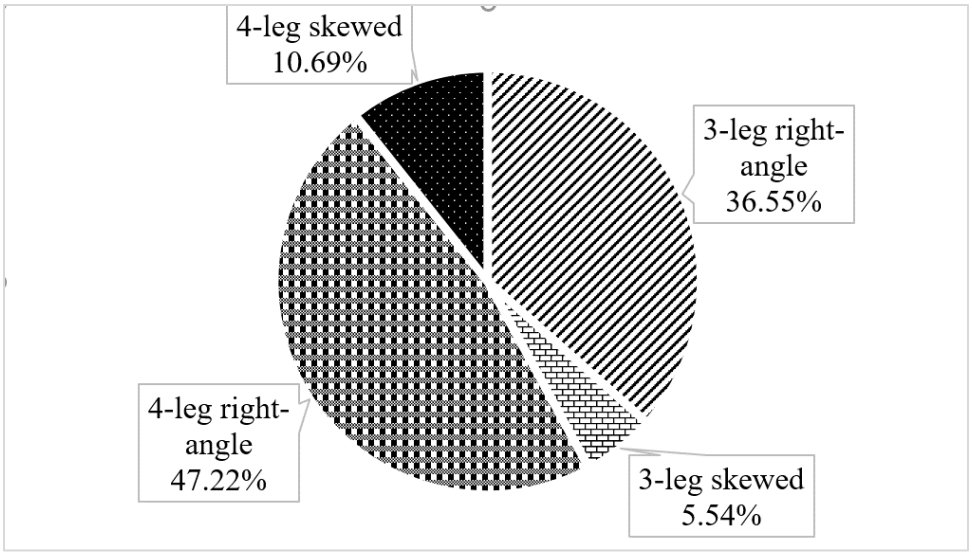
The number of these fatal crashes that occur at skewed intersections is more difficult to determine. There is no national database that includes geometric data on intersections.

Similarly, there are few States that have this information readily available. The Minnesota (MN) Department of Transportation (MNDOT) has this information available for most of its State-maintained intersections, as does the Ohio Department of Transportation (ODOT). An analysis of MNDOT's 2008 intersection inventory data revealed that more than 16 percent of the intersections are skewed (figure 3). This percentage includes signalized and unsignalized locations. A review of MNDOT crash data indicates that almost 18 percent of intersection crashes occurred at these skewed locations (figure 4), which indicates that such locations may be slightly overrepresented.[10] However, these statistics do not account for traffic volume, area type, or other factors that may contribute to the crash problem.



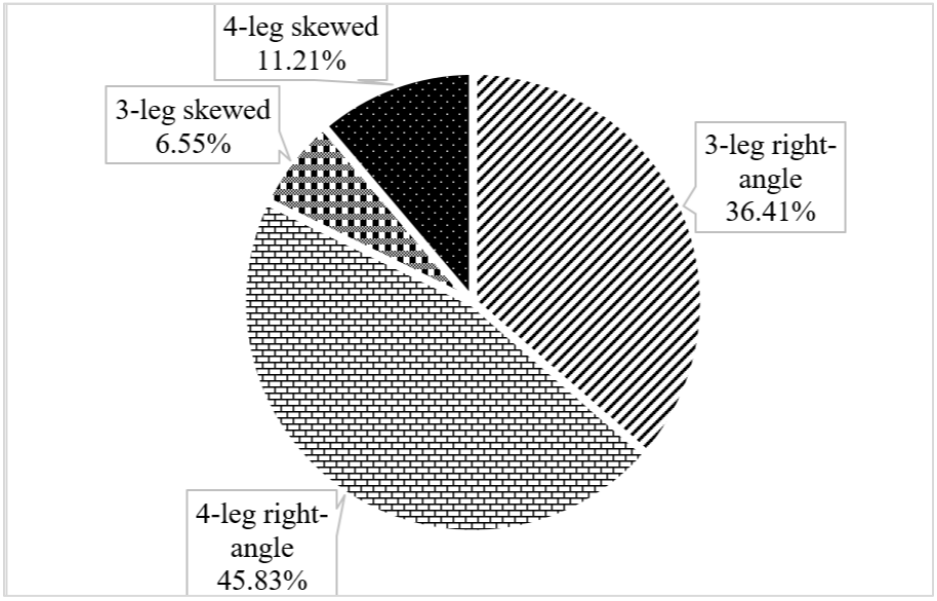
Source: FHWA.

Figure 2. Chart. Percentage of total crashes in the United States by location (data from NHTSA).[7]



Source: FHWA.

Figure 3. Chart. Percentage of MN intersections by number of legs and angle classification (2008 data).[1]



Source: FHWA.

Figure 4. Chart. Percentage of MN intersection crashes by number of legs and angle classification (2008 data).[1]

Intersections account for approximately 40 percent of the locations of crashes on U.S. roads. From the limited data available from MN, more than 16 percent of intersections in the State may be classified as skewed, and these locations may be overrepresented in terms of total crash occurrence.(10)

[1]Data available from HSIS.

This conclusion was supported by Fatality Analysis Reporting System (FARS) data for Ohio from 2016, which showed that roughly 26 percent of fatal crashes occurred at intersections in Ohio (OH).[12]

Given the facts obtained from MN and OH data, careful consideration should be given to mitigate skewed intersections when designing new roadways or retrofitting existing roadways. Guidance from the Green Book, State highway design manuals, and other resources range in terms of complexity.[1] Examples of mitigations include realignment of an intersection to generate a right-angle location, addition of traffic signals or signs to prohibit or more closely control certain movements, addition of auxiliary turning and acceleration lanes to lessen the severity of the angles and allow drivers to use their mirrors to detect conflicting traffic, addition of channelization to provide better guidance through the intersection and accommodate pedestrians, and installation of accessible pedestrian signals to meet the needs of visually impaired pedestrians.[1,13–16]

OBJECTIVES AND SCOPE

The objective of this study was to derive quantitative relationships between intersection angles and safety where intersection crashes define safety. The relationships were used as follows:

- Determine appropriate crash modification factors (CMFs) for reducing or eliminating the skew angle of an intersection.
- Determine if there is a critical minimum angle at which safety is substantially diminished (75 degrees, 60 degrees, or other).
- Assess the need for revision of current geometric design policies and practices.

This study was restricted to the analysis and interpretation of intersection crash data. Other observational studies examined specific aspects of skewed intersections, such as sight distance or pedestrian-crossing behaviors, which are described in chapter 2. Resources are available that discuss other aspects of the problem of skewed intersections and subsequent countermeasure possibilities and costs.[13,15] The greatest need related to the topic of intersection angles and safety at this time is a sound crash-based evaluation.

The statistics in the section that examines the magnitude of the problem did not fully differentiate among characteristics—such as type of area (rural versus urban), number of legs, type of traffic control present, and other features—used to further define and scope the problem. Many of these characteristics were used to limit the scope of this study for both practical reasons related to supplemental data-collection efforts and methodological reasons related to adequate sample size. Chapter 4 of this report examines the scope of this research effort in more detail.

One of the anticipated outcomes of this study is possible new guidance for design policies and practices. This new guidance may include recommended changes to the Green Book.[1] The current policy, which includes the critical minimum angle of 60 degrees, has been in place for decades. The 1965 AASHTO policy on geometric design notes that angles greater than 60 degrees produce only a small reduction in visibility; therefore, realignment may not be warranted.[17]

Other agencies and organizations, including FHWA and ITE, have recommended critical minimum angles of 70–75 degrees in recent years based on behavioral and observational research. AASHTO policymakers have reviewed these recommendations but have not yet revised the contents of the Green Book,[1] which may partly be a function of desiring definitive safety results on this issue. This study aims to fill this void.

ORGANIZATION OF THE REPORT

Chapter 1 presented an overview of intersection angles and skewed intersections. Chapter 2 reviews literature related to the topic of intersection angles. This chapter includes studies that have attempted to quantify the crash effects of intersection angles as well as studies that have addressed visibility (sight distance) and physiological issues of drivers and pedestrians. Chapter 3 describes the methodology and analysis approach. Chapter 4 discusses the data acquired for this project. Chapter 5 includes the results of the MN data analysis, and chapter 6 presents the OH analysis results. Chapter 7 includes a summary of the study and conclusions. Chapter 8 presents ideas for additional research related to intersection angles. There are also six appendices that include additional information related to the data and analysis results.

CHAPTER 2. LITERATURE REVIEW

As noted in the introduction, addressing the potential safety and operational problems of skewed intersections requires sound design policies and practices. The first part of this chapter describes the design policies and guidance that currently exist in the United States. These policies should be informed by or based on research that has been conducted on the topic. The second part of this chapter discusses the limited research that has addressed intersection angles and their effect on safety.

CURRENT DESIGN GUIDANCE

The Green Book addresses the issue of intersection alignment and skew angle in several chapters. In chapter 9, which focuses on intersections, the recommendation is that "intersecting roads should generally meet at or nearly at right angles" (p. 9-25).[1] This chapter also includes recommendations related to the realignment of a skewed intersection, noting that "the angle of the realigned intersection should be as close to 90 degrees as practical."[1] However, the policy includes a section indicating that some deviation from a right angle is permissible and that providing "an angle of at least 60 degrees provides most of the benefits of a 90-degree intersection angle while reducing the right-of-way takings and construction costs often associated with providing a right-angle intersection" (p. 9-27).[1] The foundation for the statement on deviations and their benefits is unclear.

The Green Book chapter on intersections also addresses the effect of skew angle on intersection sight distance. The chapter notes that the sight triangles at a skewed intersection will be larger or smaller, depending on the quadrant, than what is present at a right-angle intersection.[1] The policy examines the issues associated with longer crossing distances within the intersection and the effect longer crossing distances might have on sight-distance computations. Line-of-sight issues for the approaching driver are also discussed, and recommendations are provided for adjusting the sight-distance computation. The effect of skew angles on turning radius is addressed later in the chapter on intersections, with recommendations for defining the control radius and point of tangency that should be used when developing design alternatives for channelization at skewed intersections.[1]

In chapter 5 of the Green Book, which focuses on designing intersections of local roads and streets, the recommended policy is for intersecting streets to "meet at approximately a 90-degree angle" and for the alignment design to "avoid an angle of intersection of less than 60 degrees."[1] For collector roads and streets, the recommendation specifically addresses stop-controlled intersections. The policy indicates that the intersecting legs "should intersect at right angles, wherever practical, and should not intersect at an angle less than 60 degrees."[1]

The Green Book is a product of State transportation engineers, designers, and policymakers.[1] State DOTs, therefore, use the Green Book as the starting point for their own internal design policies.[1] The policies of several States were examined regarding intersection design and skew angle. Iowa's design manual addresses the intersection of crossroads with rural two-lane or multilane primary highways. The policy establishes an intersecting angle of 90 degrees as "ideal," between 90 and 75 degrees as "desirable," and between 75 and 60 degrees as

"acceptable." Any intersections with angles less than 60 degrees "will be realigned to provide a desirable intersection angle."[18]

The Montana Department of Transportation (MDT) policy indicates that "roadways should intersect at or as close to 90 degrees as practical" and provides several reasons why skewed intersections are undesirable. The policy notes that the intersection angle should not exceed 30 degrees from perpendicular. Regarding realignment, the MDT policy notes that it will rarely be warranted to realign "the intersection so that its skew is within 30 degrees of perpendicular." If the skew angle is greater than 30 degrees, the policy notes that "the intersection may require geometric improvements (realignment, auxiliary lanes, greater corner sight distance)."[19]

The policy for the Illinois Department of Transportation states that "highways should intersect at right angles" (p. 34-1(1)) and provides several reasons why acute angles are undesirable. However, the policy also notes that the angle should be within 15 degrees of perpendicular and "this amount of skew can often be tolerated because the impact on sight lines and turning movements is not significant" (p. 34-1(2)). The policy further notes that an intersection angle up to 30 degrees from perpendicular may be used under restricted conditions. For a skew angle greater than 30 degrees, geometric improvements or more positive traffic control (e.g., all stop, traffic signals) may be warranted.[20]

The California Department of Transportation (Caltrans) also recommends intersection angles of 90 degrees, and when a 90-degree angle cannot be achieved, it recommends a minimum angle of 75 degrees. The justification includes the following statement: "A 75 degree angle does not unreasonably increase the crossing distance or generally decrease visibility" (p. 400-5). For intersection angles less than 75 degrees, Caltrans recommends that a series of retrofit improvement strategies be considered, including realignment, provision of acceleration lanes, and turning movement restrictions.[21]

The Iowa DOT design manual cites the *Intersection Channelization Design Guide*. This National Cooperative Highway Research Program (NCHRP) publication includes recommended guidance regarding intersection angles for both new construction and reconstruction/rehabilitation. The recommendation for new construction is to maintain angles between 75 and 90 degrees unless there are "costly or severe constraints." If such constraints exist, angles as low as 60 degrees are acceptable. For reconstruction/rehabilitation projects, the *Intersection Channelization Design Guide* recommends examining crash rates and patterns that may be attributable to the skew of the intersection.[16]

The *Traffic Engineering Handbook* provides similar guidance to the guidance in the Green Book and other resources regarding the desire for right-angle intersections.[1,2] This handbook also acknowledges the safety and operational problems that exist at intersecting angles less than 60 degrees. The document does not recommend a minimum desirable angle, but prior ITE guidance documents have recommended minimum intersection angles. The 1999 edition of the *Traffic Engineering Handbook* recommends a minimum angle of 75 degrees.[4] The *Neighborhood Street Design Guidelines* recommends a minimum angle of 70 degrees.[3] A recommended practice for subdivision streets indicates that "in no case should the angle be less than 75 degrees."[5]

FHWA has published two guidance documents that include recommendations related to skewed intersections. The *Highway Design Handbook for Older Drivers and Pedestrians* recommends right-angle intersections in which ROW is not constrained.[6] For intersections in which ROW is restricted, the recommendation is for a minimum intersection angle of 75 degrees.[6] This handbook also recommends the prohibition of right turns on red in approach legs where the intersecting angle to the driver's left is less than 75 degrees. In *Signalized Intersections: Informational Guide*, the authors discuss several operational and safety issues associated with skewed intersections. A brief synopsis is provided of the range of minimum intersection angles from 60 to 75 degrees recommended in different sources.[22] This guide does not make a recommendation on a minimum angle value.

AASHTO's *Guide for the Planning, Design, and Operation of Pedestrian Facilities* discusses the implications of skewed intersections on pedestrians.[23] Concerns include longer crossing distances, increased exposure to traffic and possible conflicts, and proper location of the crosswalks. The authors also discuss navigational issues for the visually impaired pedestrian, including the pedestrian's ability to properly align themselves for crossing the intersection and maintaining alignment while crossing. This guide, however, does not make any recommendations regarding desirable or minimum intersection angles. The difficulties that visually impaired pedestrians have at skewed intersections are addressed in a best practices guide on accessible pedestrian signals (APS).[14] This APS best practices guide includes a prioritization tool for rating intersections regarding the need for APS to help pedestrians cross the street. A skewed crossing received the second highest number of points (more points equates to greater crossing difficulty) of any operational or geometric characteristic at a crosswalk.

SAFETY RESEARCH

The research available on the safety effects of intersection angles is limited and not definitive. The work that has been conducted can be divided into three types of studies: crash, visibility, and physiology. The crash-based research explored the relationships between the intersection skew angle and crash frequencies or rates. The visibility-based research focused on the sight lines and sight-distance requirements using observational inputs from drivers. The physiology-based research primarily addressed the diminished physical skills of older persons and how these diminished skills impacted the drivers' abilities to negotiate skewed intersections. A summary of the studies discovered in each of these areas follows.

Crash Research

The *Highway Safety Manual* (HSM) includes CMFs for skew angles at three- (figure 5) and four-leg (figure 6) intersections as part of the predictive method for rural two-lane two-way roads.[24]

$$CMF\ (\text{3-leg intersection}) = \text{EXP}(0.0040 \times skew)$$

Figure 5. Equation. CMF for skew angle at a three-leg intersection of rural two-lane two-way roads.[24]

$$CMF\ (\text{4-leg intersection}) = \text{EXP}\ (0.0054\ \times skew)$$

Figure 6. Equation. CMF for skew angle at a four-leg intersection of rural two-lane two-way roads.[24]

Where:

CMF = crash modification factor for total crashes.
skew = intersection skew angle in degrees; the absolute value of the difference between 90 degrees and the actual intersection angle.

For example, consider an intersection (either a three- or four-leg intersection) in which the smallest angle between any two legs is 70 degrees. The skew angle is 20 degrees, calculated as the difference between 90 and 70 degrees. Inserting 20 degrees into the equations shown in figure 5 and figure 6, the CMFs would be calculated as 1.08 and 1.11 for three- and four-leg intersections, respectively. Thus, a three-leg rural stop-controlled intersection with a 70-degree intersection angle is expected to have 8 percent more total crashes than a right-angle intersection. Similarly, a four-leg rural stop-controlled intersection is expected to experience 11 percent more total crashes.

These CMFs were developed as part of an FHWA study to develop an algorithm for predicting the safety performance of a rural two-lane highway.[25] This algorithm became the initial crash prediction module within FHWA's Interactive Highway Safety Design Model (IHSDM). The CMFs were derived from negative binomial (NB) regression models, which were developed using data from 382 three-leg and 324 four-leg stop-controlled intersections in MN. The distribution of these locations by the angle of intersection at each site was not provided. The models took the forms shown in figure 7 and figure 8.

$$N_{3\text{-}leg} = \text{EXP}(-12.82 + 1.01\ln ADT_{maj} + 0.406\ln ADT_{min} + RHRI + 0.33RT + 0.0040SKEW_3)$$

Figure 7. Equation. Number of predicted crashes at a three-leg intersection.[25]

$$N_{4\text{-}leg} = \text{EXP}(-9.34 + 0.60\ln ADT_{maj} + 0.61\ln ADT_{min} + 0.13ND_{maj} + 0.0054SKEW_4)$$

Figure 8. Equation. Number of predicted crashes at a four-leg intersection.[25]

Where:

$N_{3\text{-}leg}$ = predicted number of total crashes per year at a particular three-leg intersection and within 250 ft in either direction along the major road.
$N_{4\text{-}leg}$ = predicted number of total crashes per year at a particular four-leg intersection and within 250 ft in either direction along the major road.
ADT_{maj} = average daily traffic volume vehicles per day (vpd) on the major road.
ADT_{min} = average daily traffic volume (vpd) on the minor road.
ND_{maj} = number of driveways on the major road within 250 ft of the intersection.
RHRI = roadside hazard rating within 250 ft of the intersection on the major road.
RT = presence of right-turn lane on the major road (0 = no turn lane present; 1 = turn lane present).

$SKEW_3$ = intersection angle (degrees) minus 90 for the angle between the major-road leg in the direction of increasing stations and a leg to the right; 90 minus intersection angle (degrees) for the angle between the major-road leg in the direction of increasing stations and a leg to the left.

$SKEW_4$ = intersection angle (degrees) expressed as one-half of the angle to the right minus one-half of the angle to the left for the angles between the major-road leg in the direction of increasing stations and the right and left legs, respectively.

The four-leg model included all crash types and only variables that were significant at a significance level of 0.15 or less; skew angle was significant at a significance level (*p*-value) equal to 0.108. The three-leg model included only those crash types generally related to intersection operations; the *p*-value for skew angle in this model was 0.17. As part of this same study, a panel of road-safety research experts evaluated these models and determined that the coefficients for skew angles were appropriate to use for CMFs to ascertain the safety effect of intersection angles. However, the panel also recommended further research on this geometric characteristic.

The HSM also includes CMFs shown in figure 9 through figure 12 for intersection angles in which rural multilane highways intersect with minor roads under stop-control.[24] In figure 9 through figure 12, *CMF*(X) is the crash modification factor for the specified number of legs and crash type.

$$CMF(\text{3-leg, total crashes}) = [(0.016 \times skew)/(0.98 + 0.016 \times skew)] + 1$$

Figure 9. Equation. Total crash CMF for skew angle at a three-leg intersection of rural multilane and minor-leg stop-controlled roads.[24]

$$CMF(\text{4-leg, total crashes}) = [(0.053 \times skew)/(1.43 + 0.053 \times skew)] + 1$$

Figure 10. Equation. Total crash CMF for skew angle at a four-leg intersection of rural multilane and minor-leg stop-controlled roads.[24]

$$CMF(\text{3-leg, injury crashes}) = [(0.017 \times skew)/(0.52 + 0.017 \times skew)] + 1$$

Figure 11. Equation. Fatal and injury crash CMF for skew angle at a three-leg intersection of rural multilane and minor-leg stop-controlled roads.[24]

$$CMF(\text{4-leg, injury crashes}) = [(0.048 \times skew)/(0.72 + 0.048 \times skew)] + 1$$

Figure 12. Equation. Fatal and injury crash CMF for skew angle at a four-leg intersection of rural multilane and minor-leg stop-controlled roads.[24]

These CMFs were developed as part of an FHWA study to validate and calibrate the crash prediction statistical models for rural intersections within IHSDM.[26] The original models were developed using 3 yr of crash data (1993–1995) for a set of intersections in CA and Michigan (MI).[27] The validation study added 2 yr of crash data (1996–1997) for the same set of intersections and 2 yr of data (1996–1997) for a set of intersections in Georgia (GA). The CMFs were derived from the recalibrated NB regression models for three- and four-leg stop-controlled

intersections. The intersections included in the analysis had two lanes on the minor road and four lanes on the major road. The three-leg analysis included data from 218, 24, and 52 intersections in CA, MI, and GA, respectively. The four-leg analysis included data from 152, 18, and 52 intersections in CA, MI, and GA, respectively. As with the two-lane study previously noted, the distribution of these locations by the angle of intersection at each site was not provided.

A study designed to develop guidelines for the realignment of intersections in Nebraska used crash data from three- and four-leg rural two-lane roadway intersections.[28] Three years of crash data for 29 skewed intersections and 39 comparable nonskewed intersections were used to develop the Poisson regression model shown in figure 13.

$$N = 0.050\left(\frac{ADT_{maj}}{100}\right)^{0.545}\left(\frac{ADT_{min}}{100}\right)^{\beta} e^{0.011\alpha}$$

Figure 13. Equation. Number of predicted crashes for three- and four-leg rural two-lane intersections.[28]

Where:

N = number of crashes per year.
ADT_{maj} = annual average daily traffic (vpd) on major roadway.
ADT_{min} = annual average daily traffic (vpd) on minor roadway.
β = intersection-type factor = 0.129 + 0.260F.
F = 0 for three-leg intersection; 1 for four-leg intersection.
α = skew angle (degrees).
e = natural exponent.

The model produces an increase in crashes as the traffic volume and skew angle increases, with four-leg intersections having more crashes than three-leg intersections for the same volumes and skew angle.

Another study of three-leg intersections found that wye (skewed) intersections had crash rates approximately 50 percent higher than tee (right-angle) intersections, suggesting an effect of intersection angle.[29] A study of intersections in Finland found that acute and obtuse skew angles affected safety differently.[30] This phenomenon was discussed by the expert panel convened for the FHWA study on rural two-lane roads, but it was decided that this study alone "did not provide a sufficient basis for challenging the widely accepted view that any intersection skew that departs from a 90-degree angle, whether positive or negative, is detrimental to safety."[25]

Visibility Research

Gattis and Low conducted a field study and measured the angles at which drivers' lines of sight were obstructed by the body of their vehicles when looking to the right.[31,32] Two driver positions (sit back and lean forward) were used. A 13.5-degree vision angle (with respect to a line perpendicular to the vehicle path) was selected to represent an intermediate posture, between the sit-back and the lean-forward positions. The authors concluded that a 60-degree left-skewed intersection may result in an obstructed line of sight to the right for a driver for certain types of vehicles. Thus, the minimum angle present in the Green Book may not be appropriate.[1] Instead,

a minimum intersection angle of 70 to 75 degrees is recommended to offer an improved line of sight.

Son, Kim, and Lee also analyzed the right lateral visibility of drivers in both passenger cars and heavy trucks at left-skewed intersections.[33] Available sight distances were calculated using driver positions similar to what Gattis and Low used.[31] Son, Kim, and Lee concluded that intersection angles less than 70 degrees should not be used when the design vehicle is a large vehicle or semitrailer.

Two studies from Spain examined visibility at skewed intersections and merging areas.[34,35] Driver behaviors were observed in the field and through microsimulation. The authors concluded that an intersection angle of no less than 70 degrees should be used at intersections and no less than 7 degrees for merging areas.

Physiology Research

Angles between the legs of an intersection can impact one's ability to make decisions at and maneuver through intersections. These impacts are most negative for those who have diminished physical capabilities. Older persons are a demographic that might experience problems at skewed intersections. The following section examines a synthesis from an FHWA report that discusses the reasons for some of the problems older persons might experience as well as the supporting evidence from observations.[36]

Older persons often experience reduced head and neck mobility. One study showed that joint flexibility was estimated to decline as much as 25 percent due to a variety of age-related factors.[37] Other research showed older persons (age 70 and older) have approximately one-third the range of movement when turning their heads compared to younger counterparts (age 30 and younger).[38] Loss of flexibility can lead to a restricted range of motion that affects a driver's ability to turn and scan for conflicting vehicles and pedestrians at intersections.[39] One survey showed that many older drivers were aware of this problem: 21 percent reported difficulties turning their heads to scan behind them while driving.[40] Skewed intersections exacerbated this problem when older persons had to turn their heads farther than would be required at right-angle intersections.

A 1997 study was conducted to specifically explore the problems that older drivers may experience at skewed or channelized intersections where an exaggerated turn of the head was required to scan for oncoming traffic.[41] The comments received from participants indicated that they more often relied on their external mirrors when negotiating highly skewed intersections.

At the same time, they reported the most difficulty with the middle range of angles (40 to 55 degrees). In the middle range, drivers had difficulty turning their heads to scan for traffic and mirrors were of marginal benefit.

A 2007 observational field study was conducted to explore performance differences in younger and older drivers at skewed and right-angle intersections.[42] More than 70 participants, accompanied by a front-seat evaluator, drove an instrumented vehicle through five right-angle intersections and five skewed intersections (75 degrees or less). The results showed no significant differences in the performance of the two age groups (25 to 45 and 65 to 85).

However, results showed that right-angle intersections were associated with fewer behavioral errors (e.g., vehicle positioning, signaling, visual scanning, and gap acceptance) when compared to skewed intersections. The right-angle intersections also resulted in better driver performance as measured by the kinematics of lateral and longitudinal acceleration and yaw.

Diminished capabilities related to age may also impact the ability of older pedestrians to safely cross intersections. Research has shown that older pedestrians are more likely to delay before crossing, spend more time at the curb, take longer to cross the road, and make more head movements before and during crossing.[43] Skewed intersections typically require pedestrians to walk a longer distance to cross the intersection. The pace of crossing, therefore, becomes critical to minimize the exposure time in the vehicular travel lanes.

Older pedestrian Walking speeds of older pedestrians have been studied by numerous researchers. Most recently, ITE and the American Automobile Association's Foundation for Traffic Safety published *Pedestrian Signal Safety for Older Persons*, a study on pedestrian-walking rates of older persons and the effects of slower rates on signal timing operations.[44] The study included a review of past studies and the collection of additional observational data in six cities throughout the United States. The results showed the 15th percentile walking rates of older pedestrians range between 3.4 and 3.8 feet per second (ft/s). The ITE and American Automobile's Foundation for Traffic Safety study recommended a walking speed of 3.5 ft/s. However, additional guidance used a walking speed of 3.0 ft/s at locations where pedestrians are routinely crossing at a slower pace. Under those conditions, it is also recommended that the crossing distance used in the calculation of the walk and pedestrian clearance interval be measured from 6 ft back from the edge of the curb (starting location assumption) to the far side of the travel way being crossed.

The ITE/AAA study formed the basis of the recommendation in the FHWA *Handbook for Designing Roadways for the Older Population* to use a walking speed of 3.0 ft/s.[36] This recommendation is less than the 3.5 ft/s currently recommended in the *Manual on Uniform Traffic Control Devices*.[45]

SUMMARY

A consensus exists among the policy and design guidance in the highway-design field that intersecting roadways should be aligned to meet at 90 degrees. There is also a common recognition of the safety and operational problems introduced for different modes of travel once an intersection becomes skewed. However, differences exist among these documents regarding the critical minimum angle, which currently ranges from 60 to 75 degrees depending on the reference. Consideration should be given to realigning the intersection or implementing additional traffic-control measures.

Few studies have attempted to define the safety implications of intersection angles using crash data. An expert panel of road-safety researchers reviewed several of these studies as part of an effort for FHWA to quantify crash effects of specific design elements that could be used in the IHSDM. The panel decided that the results from the Harwood et al. analysis were the most credible at the time.[25] However, the panel also noted that more work was needed to better quantify the effects of intersection angles.

There is evidence that intersection angles can impact drivers and pedestrians whose physical capabilities have diminished. Older persons who have reduced flexibility may have difficulty turning their heads and necks to judge gaps in traffic at skewed intersections. Older or disabled pedestrians who walk at slower speeds will be exposed to traffic for a longer time at crossings that are lengthened because of the intersection angle. These research findings led to the 75-degree critical-minimum-angle recommendation in the FHWA *Handbook for Designing Roadways for the Older Population* to accommodate age-related performance deficits.[36]

The lack of consistency among current design policies and practices regarding critical minimum intersection angles, the potential negative safety implications of skew angles on drivers and pedestrians with diminished capabilities, and the limited crash-based research to date justify the need for the research conducted in this study.

CHAPTER 3. METHODOLOGY AND APPROACH

ANALYSIS APPROACH

The analytical approach for this evaluation was twofold. First, variables were selected for each of Ohio's and Minnesota's models using slightly different methods for each State. These methods are briefly introduced in this chapter, and the data are further explored in chapter 4. Prior to model development, random forest (RF) and classification and regression tree analyses were used on the MN data to help identify the most appropriate variables for the models.[46–50] This data-mining approach offers some unique advantages over the traditional iterative approach to variable selection when building predictive models. OH data were less detailed but contained more samples; therefore, this data-mining procedure was not used for that State. Instead, a backward regression procedure was used to eliminate nonsignificant variables from the models.

Second, the analytical approach included developing a series of cross-sectional models using the latest state-of-the-practice statistical method for developing crash-prediction models in the road-safety field. Currently, the favored modeling choice is NB regression, and models from both States were developed using this method. Finally, crash modification functions (CMFunctions) for intersection angle were derived from the NB models. The CMFunctions developed were then used to make recommendations for policy and design guidance documents, such as the Green Book.[1]

This analytical approach required a large sample of intersections that are skewed and not skewed. To determine if there was a minimum critical safety angle, it was desirable that the sample of intersections range in terms of skew severity. The next chapter on data acquisition and preparation discusses the data collected, including key data elements acquired through a supplemental data-collection effort.

The remainder of this chapter discusses of CMFunction development and the different safety performance function (SPF) functional forms attempted. The Safety Prediction Model Development and CMFunction Derivation section provide the justification for and discussion of the NB regression models chosen for this research and the derivation of CMFunctions for intersection angles.

VARIABLE SELECTION

Traditionally, selecting variables for inclusion in a regression model is accomplished through an iterative process in which variables are added or deleted in a sequential, one-at-a-time manner. Backward elimination is the process of including all independent variables under consideration in the model and deleting those not significant. Forward selection uses the opposite approach, adding one variable at a time and testing for a significant contribution to the predictive ability. Stepwise regression is a modification of forward selection in which nonsignificant variables are removed as new variables are added. This regression can be a time-consuming process with many variables. Selecting the order of entry or removing variables in the model can also affect the final set of independent variables, and the analyst must define the interactions among the independent variables. Alternatively, other approaches to variable selection focus on the relationships among the variables available for the model. One approach promoted by Hauer

explores the functional form of the possible explanatory variables and requires careful consideration of how the variables are introduced. This approach involves the methodical examination of the relationships among all independent variables before choosing those for inclusion in the model and the appropriate functional form for each.[50,51] Both approaches offer advantages over the traditional techniques previously noted for variable selection and more deliberate model development. However, both techniques require a substantial investment of time, particularly if the number of variables under consideration is large, as is the case in the current study.

As part of this effort, researchers used a data-mining approach for variable selection of MN data because this approach is believed to be a more efficient method for identifying the most relevant variables from a large list. A data-mining approach also allowed for the identification of interactions between variables in a systematic way prior to the development of the NB regression models. Both RFs and regression trees were used in the analysis to identify the independent variables believed to be the best predictors for the NB regression models. Tree analysis was also used to determine the interactions that exist among these variables. These techniques and past applications are further described in appendix D.

This data-mining process was not used for the OH data because this dataset did not include the same level of site characteristics detail as the MN dataset, and the project team felt that the data-mining approach would not provide any value. Instead, a more traditional NB regression process was used. Specifically, a backward elimination procedure was used to systematically eliminate variables with nonsignificant p-variables one at a time. Periodically, alternative models with different sets of eliminated variables were tested to ensure potentially significant explanatory variables were not being removed.

Data and variables are further explained in chapter 4. As described in that chapter, the final MN dataset consisted of 2,778 stop-controlled intersections with a range of variables, including traffic volumes for each approach, lane configurations, shoulder characteristics, speed limits, roadway classification, curb design, area type, access points, and more. By comparison, the OH dataset included 12,888 stop-controlled intersections with variables for traffic volume for each approach, lighting, roadway classification, number of lanes, trafficway description, and minimum angle.

SAFETY-PREDICTION MODEL DEVELOPMENT AND CMFUNCTION DERIVATION

Much of the research exploring relationships between crashes and roadway characteristics has relied on the development and interpretation of cross-sectional or regression models. The current state of the practice for road-safety models attempting to define relationships between crashes and geometric/roadside characteristics is using NB regression. Thus, NB regression was selected as the modeling approach for this research. This approach has been used to develop many of the predictive models included in the *Highway Safety Manual*.[24]

NB models were developed using the most important predictor variables identified from the data-mining analysis. The models were estimated using maximum likelihood methods. While NB modeling is the current state of the practice, the models have the following limitations:

- Requires a large sample size of data, which can sometimes be costly or otherwise impractical for certain crash types and categories.
- Assumes that crashes fit the NB regression distribution. Recent studies have argued for the use of other distributions (e.g., Lord and Mannering).[52]
- Involves difficult to handle multivariate correlation distributions, which can be problematic when crash data with different levels of severity and/or different types are available for safety evaluation. Intuitively, there should be some correlation between crashes of different severity levels, and disregarding this correlation may lead to biased results.

The range of models produced in the current study was highly dependent upon each State's available data due to differences in the range and depth of each final dataset. The goal at the start of the analysis was to produce separate total crash-prediction models for three- and four-leg intersections. Further model development based on factors, such as injury severity and rural/urban designation, was a function of sample size and range of data for some of the variables (e.g., intersection angle) in the final database.

Another outcome from the developed models was the identification of other potential contributing factors, other than intersection angles, that impact safety at intersections. These results provide insight into the geometric and operational characteristics of intersections as well as nonroadway factors that might contribute to safety problems at both skewed and nonskewed intersections.

The regression coefficients of the independent variable—the intersection angle—in the NB safety-prediction models were used to derive CMFunctions. The approach to this derivation of CMFunctions was similar to what was described in the literature review for the Harwood et al. study.[25] This same approach to CMFunction development has been applied to numerous studies in recent years. Many of the CMFunctions contained in the CMF Clearinghouse, an online repository of CMFs, were derived in this manner from cross-sectional models.[53] The number of models developed during the analysis dictated the number of CMFunctions produced.

The methodology used in this study for CMFunction development is not without limitations. There is some concern about whether cross-sectional analyses, such as those used for this study, can truly account for crash causality and mitigation as can be done with a well-designed before–after study. For an effective before–after study, researchers needed to collect a large sample size of entities with similar properties aside from that treatment/improvement under investigation.[54] If the treatment/improvement is very expensive (e.g., change in intersection or skew angle), there are often insufficient numbers of cases for an effective before–after analysis. The cross-sectional analysis approach was used in this study because of a lack of sound before–after data. As shown in the next chapter, skewed, stop-controlled intersections comprise a small proportion of total intersections, so a before–after evaluation would have been practically impossible. To compensate for the limitations of cross-sectional analysis when developing CMFs, the researchers paid careful attention to the functional forms of the variables in the model. Multiple functional forms were investigated for annual average daily traffic (AADT) and intersection angle. Cumulative residual plots were checked (as discussed in appendix D) as the predictive models were developed to ensure some consistency of data between intersection sites. In addition to paying careful attention to the functional form of the variables, researchers used data from two

States—MN and OH. If the resulting CMFunctions for intersections from the two States are similar, then this result provides further credence to the reliability of the CMFunctions that have been developed in this study.

SUMMARY

The approach chosen to evaluate the effect of intersection angles on safety consisted of data-mining tools, such as RF and classification and regression techniques, used to identify the most important predictors of intersection crashes from the relatively long list of independent variables. These techniques were also used to identify potential interactions among these same variables. NB regression models were developed separately for three- and four-leg intersections. The most important predictors identified with data-mining techniques served as the initial set of variables for the MN models, and only statistically significant variables that fit the desired functional forms were retained for the OH models. The regression coefficients for the variables associated with intersection angles were used to develop CMFunctions. An assessment of the critical minimum angle was made based on the derived CMFunction values.

CHAPTER 4. DATA ACQUISITION AND PREPARATION

DATA SOURCE AND ASSESSMENT

Data required for this study included crash data, intersection geometric data, and traffic volume data that can be linked by location. The Highway Safety Information System (HSIS) is a roadway-based system that was developed in 1990 and provides quality data from seven States and one urban center on several crash, roadway, and traffic variables.[10] Data are acquired annually, processed into a common format, documented, and prepared for analysis. Data from HSIS can be used to analyze many safety problems, including the development of models that attempt to predict future crashes from roadway characteristics and traffic factors. HSIS data were used for MN, but HSIS intersection inventory data were not yet available for OH. The research team subsequently acquired data directly from ODOT, including intersection, roadway, and crash data, and was able to use these data to validate the findings from MN.

MN Data

A review of the HSIS Guidebooks revealed that the MN intersection data include a unique data element to indicate if an intersection is skewed. Specifically, the element "TYPEDESC," or intersection description, includes the following attributes:

- 31 = Tee Intersection (tee).
- 32 = Wye Intersection (wye).
- 33 = Crossing at Right Angles Intersection (CROSS).
- 34 = Crossing Skewed Intersection (SKEW).

These attributes were used to distinguish skewed and nonskewed intersections. The first two attributes were used to separate skewed and nonskewed three-leg intersections. The last two attributes were used to make this separation for four-leg intersections. This variable allowed for a quick assessment of the number of intersections in each of these four categories.

The researchers used the HSIS website to request the last 10 yr of MN data, including crash, roadway, and intersection data.[55] At the time of the request, this period was 1999 to 2008.

Upon receipt of the data, the research team determined the number of intersections with the Intersection Description attributes. Using data from 2008, skew category and traffic control type determined the number of three- and four-leg intersections available for analysis. As shown in table 1, the majority of intersections are locations with minor-leg stop controls. The number and diversity of intersections available for the analysis within the other categories of intersection traffic control are limited. Thus, the scope of this research was limited to minor-leg stop-controlled intersections.

Table 1. Number of MN intersections by traffic control type and skew classification (2008 data).[2]

Traffic Control	Three-Leg Right-Angle Intersection	Three-Leg Skewed Intersection	Four-Leg Right-Angle Intersection	Four-Leg Skewed Intersection	Total
Yield control intersection	12	4	0	0	16
Minor-leg stop-control intersection	2,573	387	2,642	599	6,201
All-way stop-control intersection	4	0	39	4	47
Amber/red flashers	3	2	32	14	51
Red/red flashers	0	0	19	6	25
Signalized intersection	72	9	709	156	946
Other	3	2	4	1	10
Total	2,667	404	3,445	780	7,296

The research team then made sure that the primary characteristic of interest (i.e., skew) had not changed over the analysis period of interest. At the time of this assessment, the analysis period had not been determined. Based on experience with similar studies, it was likely to require between 5 and 10 yr of data to accumulate enough crashes for the analysis. Table 2 shows a count of crashes across the four classes of intersections for the first and last year of the 10-yr period (1999 to 2008). The number of crashes per intersection during these 2 yr for each of the intersection classifications is shown in table 3. The researchers realized that the sample of sites may be further reduced for a variety of reasons once the analysis was conducted, so they chose a 10-yr period (1998 to 2008) to check for consistency across all possible years.

Table 2. Number of crashes by intersection type for the first and last years (1999 and 2008) of the potential analysis period.[2]

Year	Three-Leg Right-Angle Intersection	Three-Leg Skewed Intersection	Four-Leg Right-Angle Intersection	Four-Leg Skewed Intersection	Total
1999	4,349	724	5,509	1,230	11,812
2008	4,073	733	5,128	1,254	11,188

Researchers conducted the consistency check by examining the classification indication each year for each site over the 10-yr period. If the indication remained consistent through the entire period (e.g., "CROSS" for all 10 yr), the site was retained as a "consistent" intersection. If the indication changed at all (e.g., wye to tee), researchers understood this as an indication that something about the intersection geometry may have changed during the 10-yr period, and the site was deemed "inconsistent." The results of this analysis are shown in table 4. Between 75 and 80 percent of the intersections in each of the four classification categories remained consistent in terms of traffic control (minor-leg stop-control) and skewed or nonskewed. This set of

[2]This table was produced by the authors using data from HSIS.

4,780 consistent intersections served as the starting point for the supplemental data-collection effort discussed later in this chapter.

Table 3. Number of crashes per intersection by intersection type for the first and last years (1999 and 2008) of the potential analysis period.[3]

Year	Three-Leg Right-Angle Intersection	Three-Leg Skewed Intersection	Four-Leg Right-Angle Intersection	Four-Leg Skewed Intersection	Total
1999	1.69	1.87	2.09	2.05	1.90
2008	1.58	1.89	1.94	2.09	1.80

Table 4. Number of minor leg stop-controlled intersections without changes in the skew/nonskew attributes over time (1999–2008).[3]

Traffic Control	Three-Leg Right-Angle Intersection	Three-Leg Skewed Intersection	Four-Leg Right-Angle Intersection	Four-Leg Skewed Intersection	Total
Minor-leg stop-control	1,930	305	2,095	450	4,780
% of original total*	75	80	80	76	78

*As shown in table 1.

OH Data

MN data were limited to only stop-controlled intersections, so only intersections with this type of traffic control were needed for the OH analysis to provide an accurate comparison for validation of the MN results. HSIS did not contain intersection inventory files for OH, so intersection data were acquired directly from ODOT. The intersection inventory provided from OH contained approximately 39,000 intersections stored as spatial data with attributes specific to the intersection in addition to the individual intersection approaches. One attribute of particular benefit to this study was that the approach-level information contained the angle between each approach leg. The research team examined this angle information as part of the initial investigation of the data. Intersections that had minimum angles of 5 degrees or less were deemed inaccurate and eliminated from the data (this was observed to be an artifact of the structure of the spatial linework). Data were further split by urban/rural distinction, number of legs (three or four), and number of lanes on the major approach (two or more). After these filters were applied, 12,981 intersections remained. Crash data were then requested directly from ODOT.

DATA ACQUISITION

The data available within HSIS are documented in guidebooks and are available on the HSIS website.(55) The Minnesota Guidebook was used to determine which data elements to request for the proposed analysis.(56) The available data of interest to the MN study were are in three separate files: crash, roadlog, and intersection/interchange. The list of possible elements from these files is included in appendix A of this report. Crash data elements were selected to allow

[3]This table was produced by the authors using data from HSIS.

models to be developed for total crashes, injury crashes, and specific collision-type crashes (e.g., rear-end crashes). Additional data elements needed for further model disaggregation or that could be important safety predictors within the models were selected from all files. The final variables selected are highlighted in the appendix tables. The tables include those variables required to link information from the various files for each intersection. HSIS data elements acquired for analysis consideration, excluding the linkage variables, are included in the following lists:

- HSIS MN crash file:
  - Date, year, hour, and day of week.
  - Collision type (e.g., rear end, sideswipe).
  - Roadway type.
  - Location type.
  - First-harmful-event location.
  - Light conditions.
  - Number of vehicles involved.
  - Urban/rural designation.
  - Alignment characteristics (e.g., curve and grade).
  - Road-surface conditions.
  - Roadway classification.
  - Road-work characteristics (e.g., work zones).
  - Route-system classification.
  - Severity.
  - Posted speed limit.
  - Traffic control devices.
  - Travel direction.
  - Weather conditions.
- HSIS MN roadlog file:
  - AADT.
  - Commercial AADT.
  - AADT year.
  - Curb presence.
  - Functional classification.
  - Number of lanes.
  - Lane width.
  - Shoulder type and width.
  - Median type and width.
  - Parking presence and type.
  - Number of vehicles involved.
  - Urban/municipal code.
- HSIS MN intersection file:
  - Intersection type.
  - Intersection description (used for skew indication).
  - Number of legs.
  - Leg direction (e.g., north, northeast, south).
  - Type of traffic control.

    - Lighting.
    - Number of through lanes.
    - Travel description (one way versus two way).
    - Surrounding land use.
    - Intersection AADT.
    - Major road AADT.
    - Minor road AADT.
    - AADT year.

Data were requested from HSIS for years 2003 to 2009 to gather more recent crash history for these entities encompassed by the 10 yr of data used to validate no change in intersection geometry. Based on experience with prior cross-sectional studies and the large sample of intersections noted in table 4, researchers concluded that 7 yr of data were enough to produce reliable and meaningful results without introducing concerns about the age of the data (e.g., effects of an older vehicle fleet on crash experience at intersections). The requested HSIS data were received in four Microsoft Excel™ files: four-leg skew, two-leg cross, three-leg wye, and three-leg tee. The number of intersections in each file matched the numbers shown in table 4. Each file included a separate record for each leg of each intersection and the attributes for all data elements previously listed. The roadlog data elements were appended to each intersection leg using the appropriate linkage variables in each file. Similarly, the number of crashes on each leg (within 250 ft of the intersection) for each of the 7 yr requested (2003–2009) were added to each intersection. Crash totals were provided for fatal, injury, and property-damage-only (PDO) crashes.

Crash and intersection data for OH were unavailable within the HSIS system at the time of analysis. However, the research team acquired data from ODOT in three separate files: crash, roadlog, and intersection. The data are detailed in the following list:

- ODOT OH crash file:
    - Date, year, hour, and day of week.
    - Roadway type.
    - Urban/rural designation.
    - Alignment characteristics (e.g., curve and grade).
    - Roadway classification.
    - Route system classification.
    - Severity.
    - Traffic control devices.
- ODOT OH roadlog file:
    - AADT.
    - AADT year.
    - Functional classification.
    - Number of lanes.
    - Lane width.
    - Roadway division.

- ODOT OH intersection file:
  - Number of legs.
  - Leg direction (e.g., north, northeast, south).
  - Type of traffic control.
  - Stop control.
  - Lighting.
  - Number of through lanes.
  - Travel description (one way versus two way).
  - Intersection AADT.
  - Major road AADT.
  - Minor road AADT.
  - AADT year.
  - Minimum angle.

Data were requested from ODOT for years 2011 through 2015. Although fewer years were available for analysis than for the MN dataset, data were sufficiently recent to ensure no major changes in vehicle fleet type or intersection control. Using only 5 yr of data also ensured no significant but unknown changes were made to intersection design. Unlike the MN data, the OH data contained sufficient information to determine minimum angle, so classifications such as wye or tee and manual measurement of angles were not needed. Crashes were carefully linked to specific intersections rather than individual legs by ODOT staff. Crash totals were provided for fatal, injury, and PDO crashes.

SUPPLEMENTAL GEOMETRIC DATA COLLECTION

For the MN data, the critical missing element from the list of MN variables is the actual intersection angle. Without this piece of information, it is not feasible to determine if there is a critical minimum angle at which safety is compromised nor is it possible to develop a CMF for a change in the angle of the intersection. Both needs are key objectives of the research. Thus, a supplemental data-collection effort was required to obtain this particular data element.

The full supplemental data-collection process for the MN data is beyond the scope of this report, but the process is described in detail in appendix B. While the intersecting angle between legs was deemed the most critical element to be collected in the supplemental data-acquisition effort, it was not the only element believed to be important for this analysis. Additional data elements were acquired for each approach leg of each intersection as part of this supplemental effort (some for confirmation of the HSIS data). The additional data elements are provided in the following list:

- Number of intersections within 250 ft.
- Sight obstructions on corner clockwise from approach leg (e.g., yes, no, maybe, not applicable).
- Curve on approach within 250 ft of intersection (e.g., none, slight, sharp).
- Terrain on approach (e.g., level, crest, sag).
- Number of through lanes.
- Number of exclusive left-turn lanes.
- Number of exclusive right-turn lanes.

- Type of channelized right-turn lanes (e.g., none, raised, painted, depressed, present but unknown type).
- Median presence/type (e.g., none, two-way left-turn lane, raised, painted, depressed, present but unknown type).
- Right-turning traffic from this leg has acceleration lane (e.g., yes/no).
- Ramp or street.
- Traffic flow (e.g., two way, one-way in, one-way out).
- Crosswalk on approach? (e.g., yes/no)
- Sidewalk along approach (e.g., yes, no, unknown).
- Number of major commercial/industrial driveway(s) on approach within 250 ft of intersection.
- Number of minor commercial/industrial driveway(s) on approach within 250 ft of intersection.
- Number of multifamily residential driveways on approach within 250 ft of intersection.
- Number of single-family residential driveways on approach within 250 ft of intersection.
- Onstreet parking presence (painted spaces visible or parked cars) (e.g., yes/no).

The approach selected to acquire these data made use of two sources of information—geographic information system (GIS) data and aerial images. Two GIS data components were required. The necessary base layer was the roadway network for MN. The GIS basemap is available for download from the MNDOT website for each county.[57] The research team downloaded the individual county files and then merged the files into a single shapefile that included the State roadway network. The second layer required was a point file of the intersections. This information was also acquired from MNDOT; it is part of their GIS point file that includes intersections, interchanges, bridges, and ramps. The aerial images were acquired from Google® Maps™.[58]

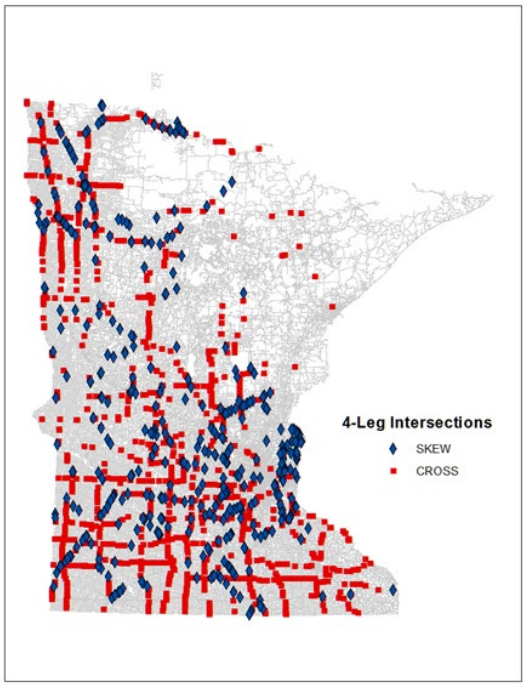
A Microsoft Excel workbook was developed for recording the supplemental data elements. The workbook was initially populated with the intersection identification numbers and approach leg cardinal directions from the HSIS data received. Fields were then added for the supplemental data elements. The data-collection protocol included the following steps for all skewed intersections:

1. Copy the intersection ID number from the Excel file and locate the intersection in the MN GIS layer. Use the info tool in ArcGIS™ to find the intersection coordinates (latitude and longitude).[59] Record the coordinates in the Excel file.
2. Copy the intersection coordinates from Excel to Google Maps.
3. Check to make sure the visual information between the spatial file and the aerial image match in terms of the number and direction of the intersecting legs. If they do not match, flag the intersection, make a note in the Excel file about the inconsistency, and continue to the next intersection.
4. Determine which legs in the Excel file correlate to legs in ArcGIS. Use the cardinal attribute within the “Direction” data element in the Excel file to match the intersecting legs.

5. Access the COGO (name derived from coordinate geometry) tool for measuring angles. The following discussion examines how this tool was applied.[71] Beginning with the leg with the cardinal direction of north or to the right of north, measure each angle between adjacent legs. Record the values in the Excel workbook.
6. Collect the information about nearby intersections using the 250-foot buffer in ArcGIS. Record the information in the Excel workbook.
7. Collect the remaining supplemental data using Google Maps.[58] As necessary, use StreetView™ to ensure that the information is accurate. Record the information in the Excel workbook.

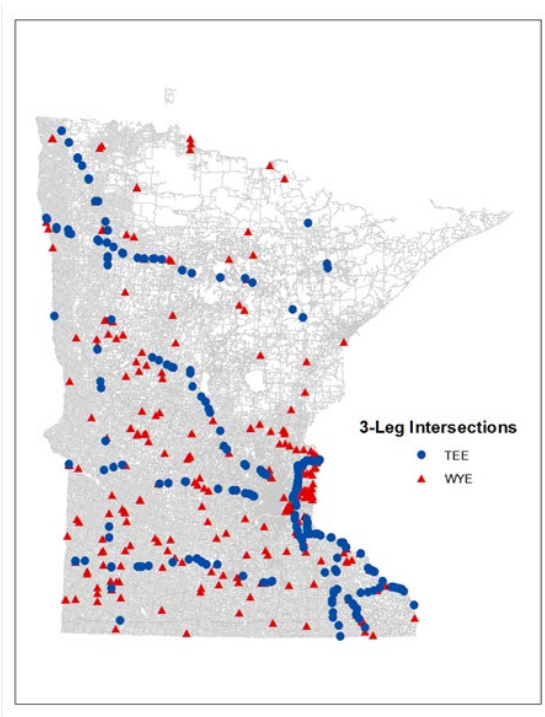
At the conclusion of the data-collection effort, data were acquired for 2,960 intersections: 1,185 three-leg and 1,775 four-leg locations. While the supplemental data intersections were randomly selected from the original pool of locations, care was taken to ensure that the skewed and nonskewed intersections had similar geographic distributions across MN. As shown in figure 14 and figure 15, the goal of similar distributions for skewed and nonskewed locations was obtained for both three- and four-leg intersections. The MN data within HSIS only include the roadways and intersections that are part of the State-owned highway network. Thus, the intersections included in the analysis are typically more rural and located along routes classified as collector and higher in the roadway functional classification scheme.

The primary reason for the supplemental data-collection effort was acquisiton of the measured intersection angle. The analysis would otherwise have been limited to an assessment of safety based only on the attributes of skewed or nonskewed in the HSIS MN database. The collection of the measured angles provided additional insight into the value of data verification. The reliability and accuracy of the skewed versus nonskewed attributes were unknown to MNDOT and HSIS staff because they had not been verfied for an extended period of time. The results of the supplemental data-collection effort clarified that approximately 24 percent of the four-leg intersections and 30 percent of the the three-leg intersections classified as right-angle intersections in the HSIS database had measured angles of 85 degrees or less. Misclassification in the other direction was also present. Approximately 3 percent of four-leg intersections and 15 percent of three-leg intersections classified as skewed in the HSIS database had measured angles of 86 to 94 degrees. The reasons for these misclassifications are not known but have been sent to HSIS database administrators and MNDOT staff for further investigation. The analysis conducted in this study relied only on the measured results.



Source: FHWA.

Figure 14. Map. Skewed and nonskewed four-leg intersections in MN.



Source: FHWA.

Figure 15. Map. Density of skewed and nonskewed three-leg intersections in MN.

A stringent supplemental data-collection process was unnecessary for the OH dataset. The data from OH contained the measurement of angles between any two approach legs, which eliminated the need for manual measurement. This made it feasible to include a much larger dataset in OH. More skewed intersections were included in the OH dataset than in the MN dataset.

DATA PREPARATION

The supplemental data collected for MN were merged with the HSIS data acquired for the 2,960 intersections. A series of quality-control checks were then used to produce a clean quality dataset for the analysis. The series of quality-control checks included the following steps:

1. Check the sum of the measured angles at each intersection, which should be 360 degrees. Intersections with summations less than 350 degrees or greater than 370 degrees were dropped. (Seven intersections were deleted.)
2. Check to make sure the number of stop-controlled legs is correct: one at three-leg intersections and two at four-leg intersections. (Sixty-nine intersections were deleted.)
3. Eliminate intersections where the traffic control includes anything other than minor street stop-control. (Ten intersections were deleted.)
4. Check the comments field in the supplemental data-collection Excel workbook for any issues that may warrant deletion of the intersection. (Nineteen intersections were deleted.)
5. Eliminate intersections that are on a ramp. (One intersection was deleted.)
6. Eliminate intersections that have one-way traffic flow. (Six intersections were deleted.)
7. Eliminate intersections with a right-turn acceleration lane. (Fifteen intersections were deleted.)
8. Check to make sure there were no changes in the intersection description data element from 2008 to 2009; years 1999–2008 were used to initially categorize the intersections with respect to being skewed. (One intersection was deleted.)
9. Eliminate three-leg intersections with multiple acute-adjacent angles and intersections in which the minimum angle exceeded 95 degrees. (Seven intersections were deleted.)
10. Check for missing values for key variables known to be significant safety predictors (e.g., AADT). (Forty-five intersections were deleted.)
11. Eliminate intersections with outlier crash frequencies across the 7-yr period and intersections with abnormally high frequencies in any of the 7 yr. (Two sites were deleted.)

At the conclusion of this series of quality-control checks, the final MN dataset included 2,778 intersections. The quality-control checks resulted in 6 percent of the initial locations being eliminated. The Data Description section provides a more complete description of this final set of intersections.

Similarly, OH data were prepared to produce a clean dataset for development of prediction models and CMFunctions. The data preparation steps include:

1. Stop-controlled intersections in the State System intersections database[4] were identified, totaling approximately 39,000 intersections.
2. Approach leg files were joined to the intersection file to eliminate any legs that may not have met the stop-controlled intersection criteria.
3. Intersections with double leg lines in GIS that resulted in very small in-between angles (5 degrees or less) were eliminated from the dataset.
4. Lanes were then added to the intersection file using the roadway inventory.
5. Intersections without a clean set of lanes consistent through the intersection area (either two, four, or six) on each leg were removed.

The result for the OH dataset was a file with 12,981 intersections. These sites were additionally narrowed to 12,888 because sites without the required data characteristics were removed. Crash data were linked to these intersections, and the intersections were further grouped based on area type (rural/urban) and number of legs. This sorting process removed over half the possible starting intersections, but the final sample is of significant size and far larger than the MN dataset.

DATA DESCRIPTION

MN Data

The data files produced for the MN analysis included 1,109 three-leg intersections and 1,669 four-leg intersections. Provided in this section of the report is a limited number of tables intended to provide an overview of the data characteristics for the final database for MN. Additional tables are provided in appendix C. Table 5 and table 6 show the distribution of the study intersections by angle classification (skewed versus right angle measured through the supplemental data-collection effort) and area type (rural versus urban) for four-leg and three-leg intersections, respectively. The protocol for the supplemental data-collection effort classified any intersection with an angle of 85 degrees or greater as a right-angle intersection. The descriptive tables that follow reflect this fact. Approximately 39 percent of the four-leg intersections in rural areas are skewed compared to 38 percent of the intersections in urban areas. For three-leg intersections, 39 percent of the rural intersections are skewed compared to 54 percent of the urban sites. For three-leg intersections, almost 20 percent of the sites are in urban environments compared to only 12 percent of the four-leg intersections.

Table 5. Distribution of four-leg intersections by angle classification and area type in MN.[5]

Area Type	Number of Rural Intersections	Rural (%)	Number of Urban Intersections	Urban (%)	Total
Right angle	892	60.6	123	62.4	1,015
Skewed	580	39.4	74	37.6	654
Total	1,472	100.0	197	100.0	1,669

[4]This database contains locations of intersections in OH. Ohio DOT provided the information to the authors for this report.

[5]This table was produced by the authors using data from HSIS.

Table 6. Distribution of three-leg intersections by angle classification and area type in MN.[6]

Area Type	Number of Rural Intersections	Rural (%)	Number of Urban Intersections	Urban (%)	Total
Right angle	538	60.6	101	45.7	639
Skewed	350	39.4	120	54.3	470
Total	888	100.0	221	100.0	1,109

Table 7 and table 8 show the distributions of the study intersections among 10 categories of intersection angle for four-leg and three-leg intersections, respectively. As shown in table 7, the skewed rural intersections are fairly evenly distributed across the angle categories, ranging from a low of 2.9 percent of the intersections in the less-than-40-degree category to 5.4 percent in the 70-to-74-degree category. In the urban area, the skewed intersections tend to be less concentrated in the smaller-angle categories. Of the 74 urban skewed intersections in the database, only 23 of those intersections had angles less than 60 degrees.

For three-leg intersections (table 8), the distribution of the skewed rural intersections is evenly distributed among the angle categories, ranging from 2.7 percent in the 40-to-49-degree category to 6.0 percent in the 80-to-84-degree category. The range is wider for the skewed urban sites, from 2.3 percent in the 55-to-59-degree category to 9.0 percent in the 70-to-74-degree category.

Table 7. Distribution of four-leg intersections by intersection angle category and area type in MN.[6]

Intersection Angle (Degrees)	Number of Rural Intersections	Rural (%)	Number of Urban Intersections	Urban (%)	Total
<40	42	2.9	2	1.0	44
40–49	67	4.6	10	5.1	77
50–54	50	3.4	6	3.0	56
55–59	67	4.6	5	2.5	72
60–64	63	4.3	6	3.0	69
65–69	75	5.1	10	5.1	85
70–74	79	5.4	13	6.6	92
75–79	70	4.8	12	6.1	82
80–84	67	4.6	10	5.1	77
≥85 (right angle)	892	60.6	123	62.4	1,015
Total	1,472	100.0	197	100.0	1,669

[6]This table was produced by the authors using data from HSIS.

Table 8. Distribution of three-leg intersections by intersection angle category and area type in MN.[7]

Intersection Angle (Degrees)	Number of Rural Intersections	Rural (%)	Number of Urban Intersections	Urban (%)	Total
<40	53	5.9	17	7.7	70
40–49	24	2.7	9	4.1	33
50–54	30	3.4	10	4.5	40
55–59	32	3.6	5	2.3	37
60–64	30	3.4	9	4.1	39
65–69	39	4.4	17	7.7	56
70–74	41	4.6	16	7.2	57
75–79	48	5.4	20	9.0	68
80–84	53	6.0	17	7.7	70
≥85 (right angle)	538	60.6	101	45.7	645
Total	888	100.0	221	100.0	1,109

Further breakdown of the rural four-leg intersections is provided in table 9, which shows the distributions of the study intersections among 10 categories of intersection angles by the number of lanes present on the major road approaches to the intersection. A two-lane intersection is defined as having two lanes (both travel directions) on the minor road and two lanes (both travel directions) on the major road. A multilane intersection is defined as having two lanes (both travel directions) on the minor road and four lanes (both travel directions) on the major road. For the 1,348 two-lane locations, more than 62 percent are categorized as right-angle intersections. The remaining skewed two-lane sites are fairly evenly distributed across the other angle categories. For the 103 multilane locations, less than half are right-angle intersections, and there is only one intersection with an angle less than 40 degrees.

Table 10 provides a more detailed breakdown of the skewed intersections in the database for each 5-degree category of intersection angle between 5 and 84 degrees. There are no intersections in the database with angles less than 20 degrees for four-leg intersections. Only 9 intersections (1.38 percent of the total number of skewed four-leg intersections) have angles between 20 and 29 degrees, while 35 intersections (5.36 percent) have angles between 30 and 39 degrees. More than 93 percent of the four-leg skewed intersections have angles between 40 and 84 degrees. The three-leg intersections have a different distribution. There are sites with extremely acute angles, including 10 intersections (2.13 percent of the total number of skewed three-leg intersections) with angles less than 15 degrees. An additional 25 sites (5.32 percent) have angles between 15 and 29 degrees. More than 85 percent of the three-leg skewed intersections have angles between 40 and 84 degrees.

[7]This table was produced by the authors using data from HSIS.

Table 9. Distribution of rural four-leg intersections by intersection angle category and number of lanes on the major road in MN.[8]

Intersection Angle (Degrees)	Number of Two-Lane Intersections	Two-Lane (%)	Number of Multilane Intersections	Multilane (%)
<40	41	3.0	1	1.0
40–49	57	4.2	9	8.7
50–54	44	3.3	5	4.9
55–59	64	4.7	3	2.9
60–64	59	4.4	3	2.9
65–69	63	4.7	8	7.8
70–74	65	4.8	10	9.7
75–79	62	4.6	7	6.8
80–84	56	4.2	9	8.7
≥85 (right angle)	837	62.1	48	46.6
Total	1,348	100.0	103	100.0

Table 10. Distribution of skewed intersections by intersection angle for four-leg and three-leg intersections in MN.[9]

Intersection Angle (Degrees)	Number of Four-Leg Intersections	Four-Leg (%)	Number of Three-Leg Intersections	Three-Leg (%)
>10	—	—	4	0.85
10–14	—	—	6	1.28
15–19	—	—	11	2.34
20–24	2	0.31	4	0.85
25–29	7	1.07	10	2.13
30–34	16	2.45	15	3.19
35–39	19	2.91	20	4.26
40–44	29	4.43	18	3.83
45–49	48	7.34	15	3.19
50–54	56	8.56	40	8.51
55–59	72	11.01	37	7.87
60–64	69	10.55	39	8.30
65–69	85	13.00	56	11.91
70–74	92	14.07	57	12.13
75–79	82	12.54	68	14.47
80–84	77	11.77	70	14.89
Total	654	100.00	470	100.00

—No data available.

The number of total crashes and crashes per intersection for the 7-yr study period (2003 through 2009) are provided in table 11 and table 12, respectively, as distributed across the intersection-angle categories. Rural right-angle four-leg intersections experienced 3.28 crashes per intersection. The number of crashes per intersection at rural skewed four-leg intersections ranged from 2.71 crashes for intersections in the less-than-40-degree category to 7.76 crashes for intersections in the 65-to-69-degree category. Urban four-leg intersections experienced a much greater rate of crashes per site when compared to their comparable rural intersections.

[8]This table was produced by the authors using data from HSIS.
[9]This table was produced by the authors using data from HSIS.

Urban right-angle four-leg intersections experienced 13.9 crashes per intersection. The rates varied between 9.30 and 17.50 crashes for urban skewed four-leg intersections.

Rural right-angle three-leg intersections experienced 3.24 crashes per intersection. The number of crashes per intersection at rural skewed three-leg intersections ranged from 2.07 crashes for intersections in the 60-to-64-degree category to 3.73 crashes for intersections in the 70-to-74-degree category. Urban three-leg intersections, like four-leg urban intersections, experienced a much higher rate of crashes per site when compared to their comparable rural intersections. Urban right-angle three-leg intersections experienced 10.06 crashes per intersection. The rates varied between 2.40 and 12.00 crashes for urban skewed three-leg intersections.

Table 11. Distribution of total crashes and total crashes/intersection at four-leg intersections by intersection angle category and area type in MN.[10]

Intersection Angle (Degrees)	Rural Crashes	Rural Crashes per Intersection	Urban Crashes	Urban Crashes per Intersection
—	114	2.71	35	17.50
40–49	259	3.87	93	9.30
50–54	328	6.56	82	13.67
55–59	250	3.73	79	15.80
60–64	330	5.24	57	9.50
65–69	582	7.76	122	12.20
70–74	378	4.78	186	14.31
75–79	404	5.77	123	10.25
80–84	295	4.40	129	12.90
≥85 (right angle)	2,928	3.28	1,708	13.89
Total	5,868	3.99	2,614	13.27

—No data available.

Table 12. Distribution of total crashes and total crashes/intersection at three-leg intersections by intersection angle category and area type in MN.[10]

Intersection Angle (Degrees)	Rural Crashes	Rural Crashes per Intersection	Urban Crashes	Urban Crashes per Intersection
—	191	3.60	129	7.59
40–49	51	2.13	108	12.00
50–54	81	2.70	24	2.40
55–59	90	2.81	53	10.60
60–64	62	2.07	63	7.00
65–69	123	3.15	95	5.59
70–74	153	3.73	113	7.06
75–79	156	3.25	158	7.90
80–84	180	3.39	141	8.29
≥85 (right angle)	1,742	3.24	1,017	10.06
Total	2,829	3.19	1,901	8.60

—No data available.

A further breakdown of the crashes at rural four-leg intersections is provided in table 12, which shows the distributions of crashes and crashes per intersection among 10 categories of

[10]This table was produced by the authors using data from HSIS.

intersection angle by the number of lanes present on the major road. Two-lane right-angle intersections experienced 2.98 crashes per intersection. The number of crashes per intersection at two-lane skewed intersections ranged from 2.61 crashes for intersections in the less-than-40-degree category to 5.34 crashes for intersections in the 50-to-54-degree category. Multilane intersections experienced a much greater rate of crashes per site when compared to their comparable two-lane intersections. Multilane right-angle intersections experienced 7.83 crashes per intersection. The rates varied between 6.90 and 24.38 crashes for multilane skewed four-leg intersections. Note that the number of multilane intersections in each of the skew-angle categories in table 9 is relatively small.

The traffic volume characteristics at the study intersections are shown in table 13 and table 14. Intersection AADTs for four-leg intersections ranged from a low of 163 vpd to 53,108 vpd (table 13). Average AADT for rural and urban right-angle intersections was 3,847 and 15,022 vpd, respectively. Average AADT values for skewed rural intersections ranged from 3,875 vpd for the less-than-40-degree category to 6,221 vpd for the 65-to-69-degree category. For skewed urban intersections, average AADT values ranged from 9,395 vpd for the 40-to-49-degree category to 22,943 vpd for the less-than-40-degree category.

Table 13. Range of intersection AADT for four-leg intersections by intersection angle and area type in MN.[11]

Intersection Angle (Degrees)	Rural Min	Rural Avg	Rural Max	Urban Min	Urban Avg	Urban Max
<40	622	3,875	26,514	18,772	22,943	27,114
40–49	163	4,911	25,985	5,113	9,395	19,839
50–54	640	5,678	26,462	4,586	13,737	36,710
55–59	805	4,258	25,467	6,369	11,369	21,563
60–64	787	4,675	22,204	4,642	13,903	37,000
65–69	643	6,221	30,172	5,821	13,225	29,631
70–74	995	4,984	28,146	10,632	21,785	52,827
75–79	527	4,987	19,683	5,491	11,753	32,625
80–84	767	4,812	17,869	2,474	18,215	36,781
≥85 (right angle)	178	3,847	31,056	3,440	15,022	53,108
Weighted average	—	4,293	—	—	14,969	—

—No data available.
Min = minimum; Avg = average; Max = maximum.

[11]This table was produced by the authors using data from HSIS.

Table 14. Range of intersection AADT for three-leg intersections by intersection angle and area type in MN.[11]

Intersection Angle (Degrees)	Rural Min	Rural Avg	Rural Max	Urban Min	Urban Avg	Urban Max
<40	531	4,606	22,026	1,735	12,903	27,057
40–49	658	4,999	25,755	4,817	14,772	40,475
50–54	549	5,193	25,849	6,210	10,854	20,770
55–59	1,055	4,042	20,593	8,179	19,052	35,955
60–64	710	4,399	19,196	5,689	10,736	27,724
65–69	674	3,937	17,110	5,821	15,232	36,971
70–74	380	6,200	24,998	4,066	14,268	43,288
75–79	400	6,547	31,433	4,836	17,418	40,718
80–84	1,005	5,591	25,643	6,228	16,352	36,857
≥85 (right angle)	322	5,393	31,520	3,480	20,255	57,975
Weighted average	—	5,275	—	—	18,274	—

—No data available.
Min = minimum; Avg = average; Max = maximum.

For the three-leg intersections, intersection AADTs ranged from 322 to 57,975 vpd. The average AADTs for rural and urban right-angle intersections were 5,393 and 20,255 vpd, respectively. The average AADT for rural skewed intersections ranged from 3,937 vpd for the 65-to-69-degree category to 6,547 vpd for the 75-to-79-degree category. For urban skewed intersections, the average AADT ranged from 10,736 vpd for the 60-to-64-degree category to 19,052 vpd for the 55-to-59-degree category.

A further breakdown of the AADTs at rural four-leg intersections is provided in table 15, which the distributions of traffic volumes among 10 categories of intersection angle by the number of lanes present on the major road. The two-lane intersections in the study averaged 3,570 vpd, while the multilane intersections averaged almost three times that volume at 12,677 vpd. The distribution of AADTs for the right-angle intersections and the skewed intersections were comparable for both two-lane and multilane intersections.

Table 15. Range of intersection AADT for four-leg intersections by intersection angle category and the number of lanes on the major road in MN.[12]

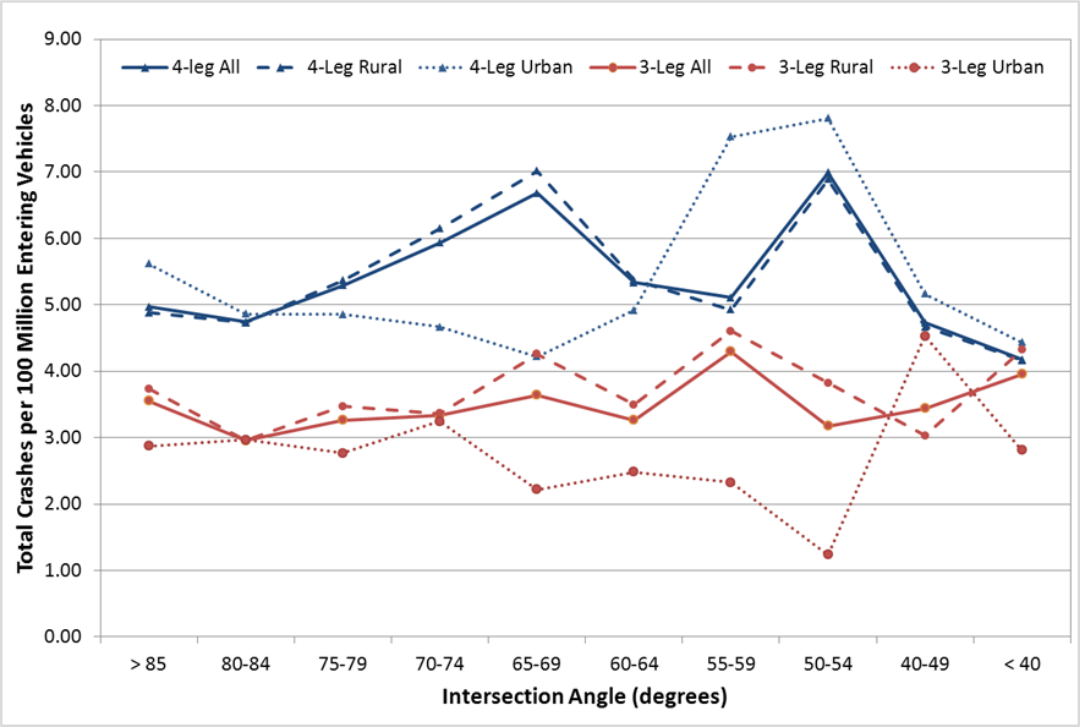
Intersection Angle (Degrees)	Two-Lane Min	Two-Lane Avg	Two-Lane Max	Multilane Min	Multilane Avg	Multilane Max
<40	622	3,324	10,589	26,514	26,514	26,514
40–49	163	3,317	16,965	3,978	14,974	25,985
50–54	640	4,531	16,048	3,567	16,220	26,462
55–59	805	3,954	25,467	4,690	10,748	20,308
60–64	787	4,244	19,951	7,358	12,596	22,204
65–69	643	3,863	11,832	7,569	20,120	30,172
70–74	995	3,637	11,429	6,013	11,846	28,146
75–79	527	4,399	19,683	4,512	10,089	19,306
80–84	767	4,163	13,607	4,752	8,548	17,869
≥85 (right angle)	178	3,330	15,922	2,812	12,245	31,056
Weighted average	—	3,570	—	—	12,677	—

—No data available.
Min = minimum; Avg = average; Max = maximum.

Crash frequencies and traffic volumes were combined to develop intersection crash rates. Figure 16 shows the annual average total crash rates per 100 million entering vehicles for each intersection-angle category. Separate crash rates were included for three-leg rural and urban intersections and four-leg rural and urban intersections. The four-leg intersections consistently exhibited higher crash rates than the three-leg intersections. The rural crash-rate patterns followed total crash patterns very closely because the sample of intersections in the database was predominately rural (88 percent for four-leg intersections and 80 percent for three-leg intersections). The highest crash rates for four-leg all and rural four-leg locations were present in the 50-to-54-degrees and 65-to-69-degrees categories. Urban four-leg intersections had the highest rates in the 50-to-54-degrees and 55-to-59-degrees categories. The highest crash rates for all and rural three-leg intersections occurred in the 55-to-59-degrees category and the less-than-40-degree category. Urban three-leg intersections experienced the highest rate in the 40-to-49-degree category.

Figure 16 depicts six plotted lines showing the number of crashes per 100 million entering vehicles (y-axis) at different intersection angles (x-axis) for six different intersection types. The line for all four-leg intersections peaks at approximately 6.9 and 7.0 million vehicles at 65–69 degrees and 50–54 degrees, respectively. The line for four-leg rural intersections depicts the same two peaks, except the rate is 7.0 million. The line for four-leg urban intersection shows is mostly below four-leg all intersections line and the four-leg rural intersections line until approximately 60–64 degrees. The rate then rises rapidly until peaking at almost 8.00 at 50–54 degrees. The line for all three-leg intersections oscillates until peaking at about 4.5 million vehicles at 55–59 degrees. The line for rural three-leg roadways follows roughly the same trend as the line for all three-leg intersections, except its peak at 55–59 degrees is almost 4.75 million vehicles. Another line plots the rate for urban three-leg intersections; this line stays below the three-leg all intersections line and the three-leg rural intersections line except at 40–49 degrees, where it peaks at approximately 4.75. These crash rates are for Minnesota.

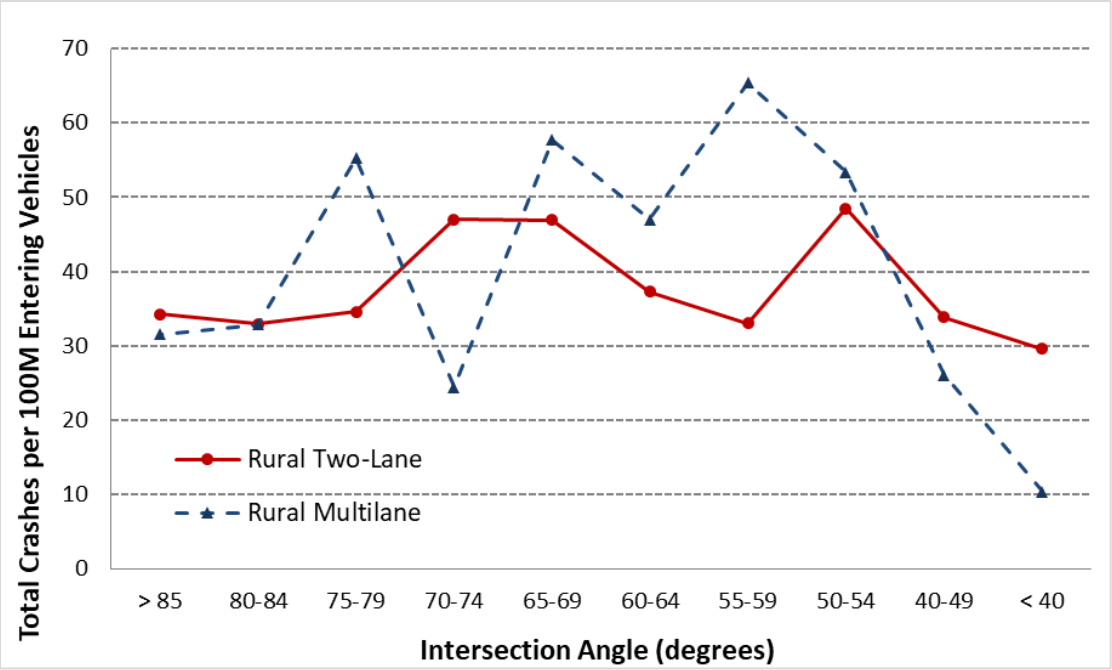
[12]This table was produced by the authors using data from HSIS.



Source: FHWA.

Figure 16. Graph. Annual average total crash rate by intersection angle category, number of legs, and rural/urban classification in MN.

Additional crash rates for the four-leg rural intersections are shown in figure 17. The crash rates for the intersections with two-lanes on major approach legs followed a similar pattern to the four-leg rural crash rates shown in figure 16. This was not unexpected because 93 percent of the four-leg rural intersections included two-lanes on the major approaches. The highest crash rates for these two-lane intersections occurred at locations with intersection angles of 50–54 degrees and 65–74 degrees. For the rural four-leg multilane intersections, the highest crash rates were present in the 55-to-59-, 65-to-69-, and 75-to-79-degrees categories.



Source: FHWA.

Figure 17. Graph. Annual average total crash rate for rural four-leg intersections by intersection angle category and number of approach lanes on the major road in MN.

OH Data

A key difference between the OH and MN datasets is the wider range of available sites for analysis within the OH set. Although there were only 5 yr of crash data available (2011–2015), there were 3,766 four-leg intersections in this set compared to the 1,669 four-leg intersection sites in the MN dataset. Additionally, there were 9,122 three-leg intersections in the OH dataset compared to 1,109 three-leg intersection sites in the MN dataset. This wider scope of available intersections allowed for more crash models to be developed, but there were tradeoffs for the available variables, which are addressed in chapter 5.

Table 16 shows there were significantly more rural four-leg intersections than urban four-leg intersections. Of 3,338 rural four-leg intersections, over half were skewed; this is true also for urban four-leg intersections, although the percent skewed was even higher at 62.1 percent. These distributions are a key difference from the MN dataset where the majority of four-leg intersections were right-angle intersections. The smaller proportion of urban intersections potentially explains the lack of urban models developed in the analysis of these data.

Table 16. Distribution of four-leg intersections by angle classification and area type in OH.

Angle Classification	Number of Rural	Rural (%)	Number of Urban	Urban (%)	Total
Right angle	1,569	47.0	162	37.9	1,731
Skewed	1,769	53.0	266	62.1	2,035
Total	3,338	100.0	428	100.0	3,766

This discrepancy between right-angle sites and skewed sites in the OH dataset remains true for three-leg intersections. More than half (62.4 percent) of the rural three-leg intersections and 51.4 percent of the urban three-leg intersections were skewed. Only urban three-leg intersections in MN had more sites skewed than right-angle intersections. Table 17 shows that there were still more rural three-leg intersections than urban three-leg intersections, although the number of sites in the three-leg categories was significantly higher than in the four-leg categories.

Table 17. Distribution of three-leg intersections by angle classification and area type in OH.

Angle Classification	Number of Rural	Rural (%)	Number of Urban	Urban (%)	Total
Right angle	2,760	37.6	863	48.6	3,623
Skewed	4,587	62.4	912	51.4	5,499
Total	7,347	100.0	1,775	100.0	9,122

Table 18 presents a closer examination of the angle categories for OH four-leg intersections for both rural and urban intersections. Table 18 shows that for both rural and urban four-leg intersections, 97 percent of the sites in the dataset had intersection angles greater than 40 degrees. The angle category with the largest percentage of the total number of intersections for both rural and urban sites was ≥85 degrees. For rural four-leg intersections, the angle category with the second largest number of sites was 80–84 degrees and for urban four-leg intersections, the angle category was 75–79 degrees. For both area types, the number of sites skewed toward larger intersection angles.

Table 18. Distribution of four-leg intersections by intersection angle category and area type in OH.

Intersection Angle (Degrees)	Number of Rural	Rural (%)	Number of Urban	Urban (%)	Total
<40	89	2.67	13	3.04	102
40–49	154	4.61	23	5.37	177
50–54	134	4.01	22	5.14	156
55–59	153	4.58	18	4.21	171
60–64	148	4.43	21	4.91	169
65–69	236	7.07	34	7.94	270
70–74	224	6.71	32	7.48	256
75–79	305	9.14	58	13.55	363
80–84	326	9.77	45	10.51	371
≥85 (right angle)	1,569	47.00	162	37.85	1,731
Total	3,338	100.00	428	100.00	3,766

The distribution of sites in different angle categories for three-leg intersections in OH is shown in table 19. Compared to four-leg intersections, there are more three-leg intersections with intersection angles less than 40 degrees in both rural and urban areas. As with four-leg intersections, the highest number of sites are within the right-angle categories for both rural and urban intersections. However, three-leg intersections differ from four-leg intersections in that three-leg intersections have a higher concentration of right-angle sites in urban areas than in rural areas.

Table 19. Distribution of three-leg intersections by intersection angle category and area type in OH.

Intersection Angle (Degrees)	Number of Rural	Rural (%)	Number of Urban	Urban (%)	Total
<40	519	7.06	75	4.23	594
40–49	402	5.47	39	2.20	441
50–54	237	3.23	37	2.08	274
55–59	295	4.02	56	3.15	351
60–64	371	5.05	82	4.62	453
65–69	480	6.53	112	6.31	592
70–74	633	8.62	122	6.87	755
75–79	749	10.19	172	9.69	921
80–84	901	12.26	217	12.23	1,118
≥85 (right angle)	2,760	37.57	863	48.62	3,623
Total	7,347	100.00	1,775	100.00	9,122

The four-leg intersections are further broken down in table 20. The majority of rural four-leg intersections (3,230) were on roadways with two lanes on the major approach. A much smaller number, 108, were on multilane roadways. Due to the low number of four-leg multilane sites, there were few intersections in several angle categories. This distribution informed the model development and results discussed in the next sections because such low numbers may provide unreliable results.

Table 21 presents a more-detailed distribution of OH sites in both leg categories. There were no sites in the category of 5–10 degree in either leg division. This may be because the sites with very small skew angles were initially eliminated from the dataset. Only three-leg intersections had any sites in the range of 10–14 degrees. The highest concentration of both four-leg intersections and three-leg intersections were for sites with an intersection angle greater than 65 degrees.

Table 20. Distribution of rural four-leg intersections by intersection-angle category and number of lanes on the major road in OH.

Intersection Angle (Degrees)	Number of Two-Lane	Two-Lane (%)	Number of Multilane	Multilane (%)
<40	88	2.72	1	0.93
40–49	150	4.64	4	3.70
50–54	133	4.12	1	0.93
55–59	150	4.64	3	2.78
60–64	144	4.46	4	3.70
65–69	214	6.63	22	20.37
70–74	214	6.63	10	9.26
75–79	295	9.13	10	9.26
80–84	315	9.75	11	10.19
≥85 (right angle)	1,527	47.28	42	38.89
Total	3,230	100.00	108	100.00

Table 21. Distribution of skewed intersections by intersection angle for four-leg and three-leg intersections in OH.

Intersection Angle (Degrees)	Number of Four-Leg	Four-Leg (%)	Number of Three-Leg	Three-Leg (%)
5–10	—	—	—	—
10–14	—	—	18	0.33
15–19	3	0.15	57	1.04
20–24	9	0.44	119	2.16
25–29	12	0.59	117	2.13
30–34	32	1.57	129	2.35
35–39	46	2.26	154	2.80
40–44	78	3.83	192	3.49
45–49	99	4.86	249	4.53
50–54	156	7.67	274	4.98
55–59	171	8.40	351	6.38
60–64	169	8.30	453	8.24
65–69	270	13.27	592	10.77
70–74	256	12.58	755	13.73
75–79	363	17.84	921	16.75
80–84	371	18.23	1,118	20.33
Total	2,035	100.00	5,499	100.00

—No data available.

Crash rates per intersection were also calculated for four-leg and three-leg intersections for the OH dataset. Table 22 shows the four-leg rural and urban intersection total crash counts and crashes per intersection. These were not annualized rates but represent all crashes in the 5-yr dataset. The intersection angle category with the largest number of total crashes in the four-leg rural category was the right-angle set, but the crash per intersection rate for this angle category was the lowest of any angle category. The highest crash per intersection rate for four-leg rural intersections in OH was 4.89 for intersections in the 60-to-64-degree category. In contrast, the intersection-angle category with the highest crash rate per intersection for urban four-leg sites were the range of 50–54 degrees. This rate was 11.27 crashes per intersection, and every rate per angle category was higher for four-leg urban intersections than for four-leg rural intersections.

Table 22. Distribution of total crashes and total crashes per intersection at four-leg intersections by intersection-angle category and area type in OH.

Intersection Angle (Degrees)	Rural Crashes	Rural Crashes per Intersection	Urban Crashes	Urban Crashes per Intersection
<40	292	3.28	100	7.69
40–49	612	3.97	184	8.00
50–54	590	4.40	248	11.27
55–59	615	4.02	107	5.94
60–64	724	4.89	207	9.86
65–69	1,092	4.63	263	7.74
70–74	1,023	4.57	263	8.22
75–79	1,309	4.29	482	8.31
80–84	1,349	4.14	408	9.07
≥85 (right angle)	4,735	3.02	1,448	8.94
Total	12,341	3.70	3,710	8.67

A similar, albeit less pronounced relationship, can be seen for the three-leg intersections in the OH dataset. The crashes per intersection were greater for every angle category for urban intersections than for rural intersections, though the difference was smaller. The rural three-leg intersection-angle category with the highest sum of total crashes was right-angle sites (4,873 total crashes), and the highest rate corresponded to the range of 65–69 degrees (2.03 crashes per intersection). For urban three-leg intersections, the highest total sum of crashes was for right-angle intersections, but the highest crash per intersection rate corresponded to the range of 55–59 degrees.

The four-leg and three-leg intersections in OH showed crash rates per intersection peaked in the angle range between 50 and 70 degrees. This finding questions the general guidance regarding critical angle suggestions discussed in chapters 1 and 2. If crashes per intersection do peak in the range of 50–70-degrees, a 60-degree minimum angle may be insufficient.[(1)]

Table 23. Distribution of total crashes and total crashes per intersection at three-leg intersections by intersection-angle category and area type in OH.

Intersection Angle (Degrees)	Rural Crashes	Rural Crashes per Intersection	Urban Crashes	Urban Crashes per Intersection
<40	1,004	1.93	411	5.48
40–49	764	1.90	221	5.67
50–54	420	1.77	201	5.43
55–59	516	1.75	387	6.91
60–64	681	1.84	359	4.38
65–69	972	2.03	561	5.01
70–74	1,254	1.98	611	5.01
75–79	1,306	1.74	752	4.37
80–84	1,749	1.94	1,109	5.11
≥85 (right angle)	4,873	1.77	4,744	5.50
Total	13,539	1.84	9,356	5.27

This high crash-per-intersection rate in the range of 50–70 degrees can also be observed for the more specific breakdown of rural four-leg two-lane intersections, as shown in table 24. For the four-leg two-lane intersection facility type, the crash rate per intersection peaks at 60–64 degrees with 4.74 crashes per intersection, and the lowest crash per intersection rate, 2.97, corresponds to right-angle intersections. This behavior, however, does not pertain to rural four-leg multilane intersections. For the rural four-leg multilane intersection facility type, the highest crash per intersection rate corresponds to the range of 80–84 degrees with 11.09 crashes per intersection; the second largest rate corresponds to the range of 60–64 degrees with 9.00 crashes per intersection.

For each facility type, three-leg or four-leg, the right-angle category has the highest number of total crashes. This finding indicates that there are more of these facilities in the dataset so more crashes in total occur at these intersections. The higher rates that occur at skewed intersections concern researchers most.

Table 24. Distribution of total crashes and total crashes per intersection at rural four-leg intersections by intersection angle category and the number of lanes on the major road in OH.

Intersection Angle (Degrees)	Two-Lane Crashes	Two-Lane Crashes per Intersection	Multilane Crashes	Multilane Crashes per Intersection
<40	291	3.31	0	0.00
40–49	596	3.97	0	0.00
50–54	576	4.33	7	7.00
55–59	605	4.03	8	2.67
60–64	683	4.74	36	9.00
65–69	957	4.47	36	1.64
70–74	969	4.53	85	8.50
75–79	1,253	4.25	82	8.20
80–84	1,266	4.02	122	11.09
≥85 (right angle)	4,534	2.97	319	7.60
Total	11,730	3.63	695	6.44

Table 25 through table 27 presents the AADT ranges for four-leg, three-leg, and rural four-leg intersections, respectively. For the four-leg intersections, shown in table 25, there was no clear trend regarding minimum and maximum AADT ranges as the intersection angle increases. For rural four-leg intersections, the lowest AADT count was observed at a right-angle intersection, and the highest count was observed at an intersection in the range of 65–69 degrees. The weighted average AADT (i.e., the average AADT weighted by the number of sites in each angle category for all four-leg rural intersections) is 3,627 vehicles per day, which is expectedly lower than the weighted average of 8,868 vpd at urban four-leg intersections. The highest maximum AADT occurred at right-angle intersections for urban four-leg sites, and the lowest AADT count occurred at intersections in the range of 50–54 degrees. The lack of uniformity in minima and maxima made it difficult to determine to what degree traffic volume interacts with intersection angle across the different angle categories.

Table 25. Range of intersection AADT for four-leg intersections by intersection angle and area type in OH.

Intersection Angle (Degrees)	Rural Min	Rural Avg	Rural Max	Urban Min	Urban Avg	Urban Max
<40	348	3,600	10,487	1,414	7,480	12,906
40–49	494	3,927	19,852	1,819	8,262	17,807
50–54	618	3,476	15,082	544	7,672	28,397
55–59	307	3,883	11,555	1,203	6,978	22,999
60–64	151	3,963	23,928	1,536	7,364	13,658
65–69	393	4,416	26,120	2,231	8,484	32,052
70–74	413	3,914	22,830	2,486	8,150	23,664
75–79	217	3,917	24,441	2,123	8,840	31,764
80–84	287	3,777	22,837	792	9,246	42,705
≥85 (right angle)	205	3,309	25,751	734	9,761	63,541
Weighted average	—	3,627	—	—	8,868	—

—No data available.
Min = minimum; Avg = average; Max = maximum.

Similar patterns were also observable for three-leg intersections in the OH dataset. The lowest AADT for rural three-leg intersections was observed at both 75-to-79-degree intersections and intersections with an angle less than 40 degrees, and the highest AADT count was observed at intersections in the range of 70–74 degrees. The weighted average for rural three-leg intersections is 3,356 vpd, and the weighted average for urban three-leg intersections is 9,369 vpd. A similar lack of scaling traffic volumes can be observed for the three-leg urban intersections as for the rural intersections because the lowest AADT count is observed at a right-angle intersection while the highest AADT count is observed at intersections in the range of 70–74 degrees. For these reasons, the relationship between traffic volume and intersection angle bears consideration in the cross-sectional models. In fact, the research team accounted for traffic volume's interaction with minimum angle through the functional form of the predictive models developed, which is discussed in chapter 5.

Table 26. Range of intersection AADT for three-leg intersections by intersection angle and area type in OH.

Intersection Angle (Degrees)	Rural Min	Rural Avg	Rural Max	Urban Min	Urban Avg	Urban Max
<40	172	2,905	13,704	1,346	7,852	37,238
40–49	300	2,958	15,204	991	8,192	20,827
50–54	295	3,078	11,928	1,261	8,030	22,154
55–59	248	3,050	10,898	1,954	8,161	19,898
60–64	208	3,279	18,421	1,947	7,717	30,859
65–69	191	3,333	22,842	2,122	9,161	32,052
70–74	309	3,601	22,830	1,220	8,925	43,419
75–79	172	3,324	16,527	1,042	8,701	34,140
80–84	309	3,423	22,755	1,015	9,085	32,647
≥85 (right angle)	183	3,524	28,638	826	10,235	34,976
Weighted average	—	3,356	—	—	9,369	—

—No data available.
Min = minimum; Avg = average; Max = maximum.

The four-leg rural intersection set was further broken into intersections with two lanes or multiple lanes on the major approach to identify whether rural intersections have some unique volume characteristics. For rural four-leg intersections with major two-lane roads, the lowest observed AADT is in the range of 60–64 degrees. The highest observed AADT is in the right-angle range. For rural four-leg intersections with multilane major approaches, the lowest observed AADT is in the range of 40–49 degrees and the highest observed AADT is in the range of 60–64 degrees. The weighted average AADT for rural four-leg intersections with two-lane major roads was 3,386 vpd, and the weighted average AADT for rural four-leg intersections with multilane major roads is 10,858 vpd. This difference is understandable given that multilane roadways are designed to carry more traffic. Of interest, though, is that in the OH dataset, the highest minimum volume for rural four-leg intersections with multilane major roads is in the range of 60–64 degrees, and this minimum AADT is larger than many of the maximum AADT values observed for intersections with two-lane roads. However, the largest maximum AADT observed for intersections with two-lane roads, 25,751 vehicles per day, is greater than any observed AADT for rural four-leg intersections with major multilane approaches. These results may simply be outliers, but they certainly warrant a consideration of the interaction between traffic volume and intersection angle in the predictive model development.

Table 27. Range of intersection AADT for four-leg intersections by intersection angle category and the number of lanes on the major road in OH.

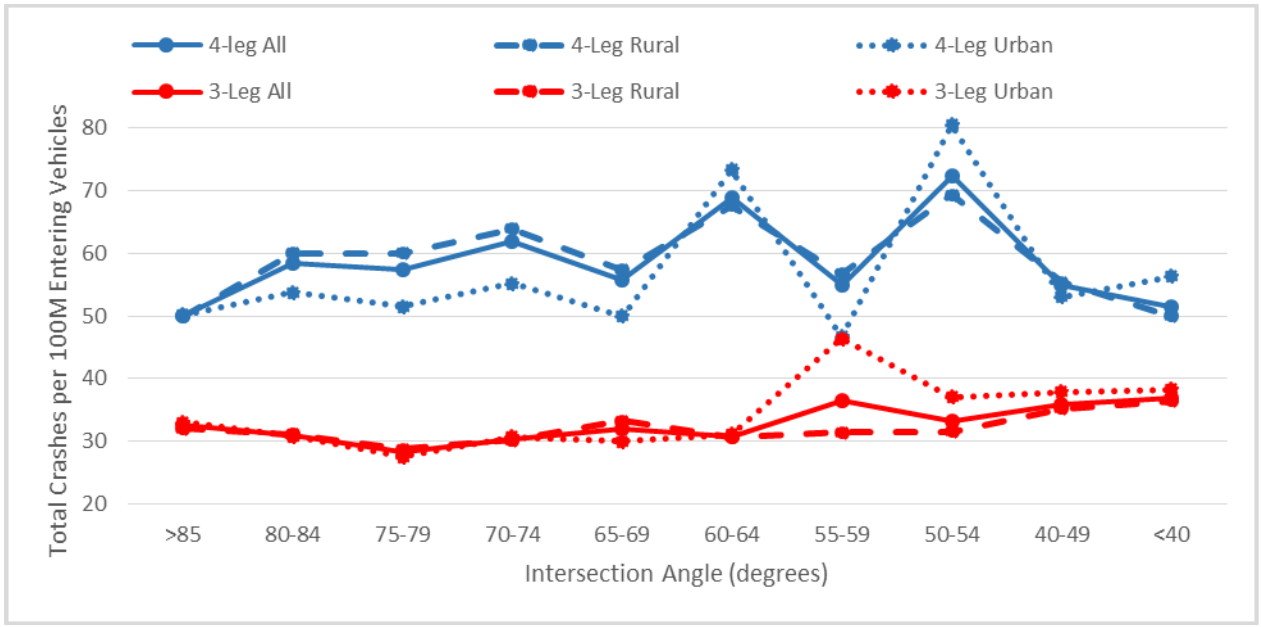
Intersection Angle (Degrees)	Two-Lane Min	Two-Lane Avg	Two-Lane Max	Multilane Min	Multilane Avg	Multilane Max
<40	348	3,599	10,487	3,712	3,712	3,712
40–49	494	3,805	13,686	2,686	8,476	19,852
50–54	618	3,468	15,082	4,527	4,527	4,527
55–59	307	3,785	11,555	3,904	8,766	11,285
60–64	151	3,667	15,400	11,031	14,620	23,928
65–69	393	3,527	14,274	4,462	13,058	26,120
70–74	413	3,568	18,409	3,659	11,334	22,830
75–79	217	3,722	24,441	4,124	9,684	18,305
80–84	287	3,543	14,721	3,840	10,494	22,837
≥85 (right angle)	205	3,117	25,751	4,193	10,307	19,769
Weighted average	—	3,386	—	—	10,858	—

—No data available.
Min = minimum; Avg = average; Max = maximum.

Figure 18 and figure 19 compare crashes per 100-million-entering vehicles for the major intersection types in the OH database. Figure 18 shows the crash rates for all four-leg intersections, four-leg rural intersections, four-leg urban intersections, all three-leg intersections, three-leg rural intersections, and three-leg urban intersections, respectively. As shown in figure 18, the crash rates for four-leg intersections were higher than the crash rates for three-leg intersections. For four-leg intersections, crashes peaked in two ranges: 60–64 degrees and 50–54 degrees. For the larger angle measures (65 degrees to greater than or equal to 85 degrees), the rural crash rate was higher than the other two, but the urban crash rate becomes higher for most angle categories at lower angle measures. For three-leg intersections, the three roadway types show consistent trends of crash rates peaking in the range of 55–59 degrees. The three-leg urban-intersection type emerged with the highest trends for three-leg intersections with angles 60 degrees or less.

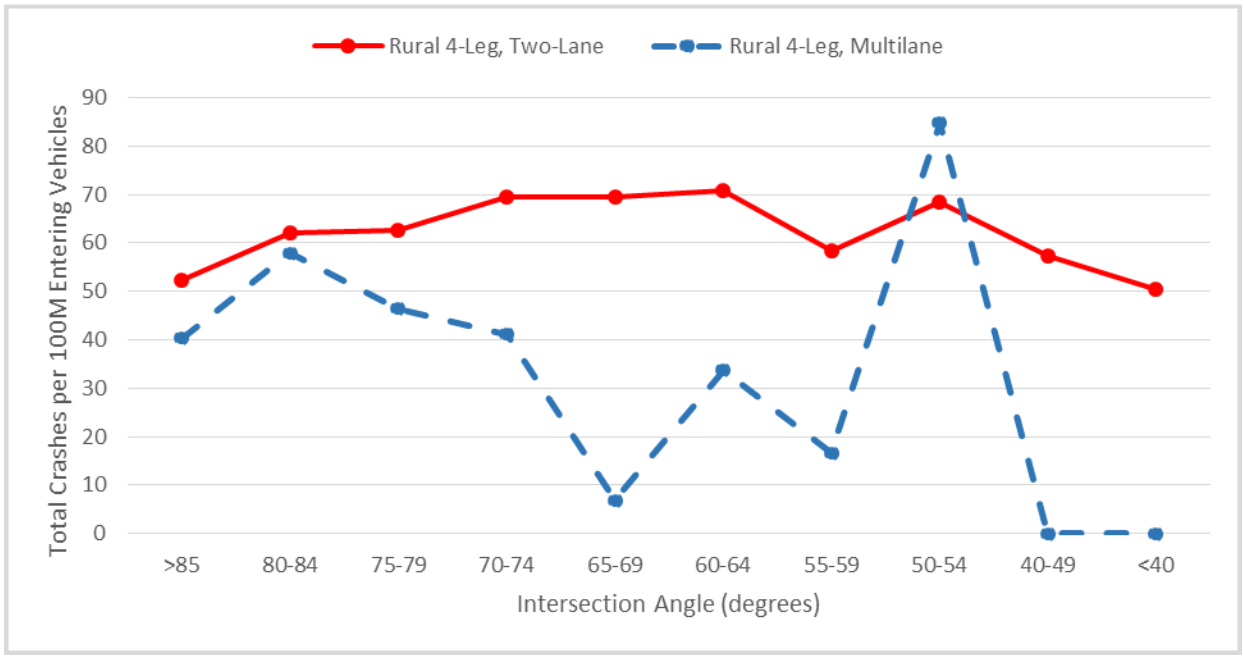
Figure 19 explores the crash trends for rural four-leg intersections more specifically. Rural four-leg two-lane intersections are compared to rural four-leg multilane intersections. Aside from the category of 50–54 degree, the rural four-leg two-lane roadways displayed higher crashes per 100-million-entering vehicles. This result is unexpected given the lower volumes but similar crash counts on this facility type, but researchers found it interesting that crashes on these facilities spike in the lower-angle categories: 60–64 degrees for rural two-lane intersections, and 50–54 degrees for rural intersections with multilane major approaches.

None of the crash trends peak below 40 degrees. While this could be because of a low sample of sites or lower traffic volumes at these uncommon intersections, these curves could also be indicative of problems with the general guidance for minimum angles.[(1)] Crash rates for four-leg intersections reached one of their peaks in the range of 60–64 degrees and rates were their highest between 70 and 50 degrees for all intersection types. These crash rates suggested that the guidance of 60-degree-minimum angles affording most of the safety benefits of right angles should be challenged, although more specific model development and verification is needed.



Source: FHWA.

Figure 18. Graph. Annual average total crash rate by intersection angle category, number of legs, and rural/urban classification in OH.



Source: FHWA.

Figure 19. Graph. Annual average total crash rate for rural four-leg intersections by intersection angle category and number of approach lanes on the major road in OH.

DATA COMPARISON

Although the results from MN and OH suggested a need for a more careful analysis of the CMFs and treatment guidance for intersection angles, there are key differences between the data available for the two States. The major discrepancy between the two States is the scope and breadth of the intersection data. MN data were retrieved from the HSIS and supplemented through further data collection; therefore, several additional variables existed for building models for MN than for OH. Including the full list of available site characteristics was beyond the scope of this section because these variables were tested and analyzed in a process described in chapter 5 in this report, but the difference in available data indicate that the MN dataset contained more specific information regarding the roadways in the dataset, intersection treatments, speed, and other design characteristics. The OH dataset contained only those variables necessary to divide the data into the requisite categories plus a few extra site descriptors, such as division of roadway, functional classification, and lighting.

The difference in data breadth was also characterized by the number of sites in each sample. These differences are summarized in table 28. The table shows that there were almost five times as many available intersections in the OH dataset as in the MN dataset despite fewer years of crash data gathered for OH. The OH dataset included more three-leg intersections than four-leg intersections; the opposite was true for the MN dataset. For MN, crash data were gathered from 2003 to 2009. For OH, crash data were gathered from 2011 to 2015. The number of skewed intersections per intersection type per State are shown in table 29.

Table 28. Quantity of total intersections by number of legs in each dataset.

Intersection Type	MN	OH
Three leg	1,109	9,122
Four leg	1,669	3,766
Total	2,778	12,981

The table shows that there were more skewed intersections in the OH dataset than in the MN dataset. These results enabled a wider range of models to be developed for the OH dataset.

Table 29. Quantity of skewed intersections by number of legs in each dataset.

Intersection Type	MN Rural	MN Urban	MN Total	OH Rural	OH Urban	OH Total
Three leg	350	120	470	4,587	912	5,499
Four leg	580	74	654	1,769	266	2,035
Total	930	194	1,124	6,356	1,178	7,534

Average AADT values were higher for every intersection type for MN than for OH. Despite the higher traffic volumes on the sample sites in MN, observed crashes in OH were larger for every facility type. This is likely explained by the sheer number of sites in the OH datasets. Comparing table 13 through table 16 reveals no bias toward high-crash intersections for OH, although the rate per million entering vehicles considered in addition to the crash sums and AADT values might explain why the rates in figure 18 are higher than the companion frequencies for MN.

As seen in the CMF Clearinghouse's guidance on calibration and on documentation of crash rates for MN and OH, MN's crash rates are lower than many other States in the Nation.[60–63] The weighted intersection AADTs also differed for MN and OH (table 30).

Table 30. Weighted intersection volumes by roadway type, number of legs, and number of lanes in each State's dataset.

Roadway Type Intersection Type	MN AADT Average	OH AADT Average
Rural two-lane four-leg	3,570	3,386
Multilane rural four-leg	12,677	10,858
Total rural four-leg	4,293	3,627
Total urban four-leg	14,969	8,868
Total rural three-leg	5,275	3,356
Total urban three-leg	18,274	9,369

Table 31. Total crashes by number of legs in each dataset.

Intersection Type	MN Rural	MN Urban	MN Total	OH Rural	OH Urban	OH Total
Three-leg	2,829	1,901	4,730	13,539	9,356	22,895
Four-leg	5,868	2,614	8,482	12,341	3,710	16,051
Total	8,697	4,515	13,212	25,880	13,066	38,946

CHAPTER 5. ANALYSIS AND INTERPRETATION OF RESULTS

The application of the methodology and the results of the analysis of both State datasets are presented in this chapter. The chapter starts with a brief discussion of data-mining efforts for MN that identified the most important independent variables and interactions among the variables The Development of CMFs and Functions discusses the NB regression models developed for both States and presents the two finalized model forms tested for both MN and OH. The development of CMFs or CMFunctions for intersection angles in both States is described in Critical Angle Assessment and Comparison of Results to Prior CMFs includes the interpretation of results related to critical minimum intersection angles. The framework for the analysis is shown in table 32 and table 33. The objective of the analysis was to produce results for three- and four-leg intersections separately for total crashes. Additional efforts were explored to further separate the data based on area type (rural versus urban) and collision severity. Collision-severity levels for the analysis are defined as follows:

- Total includes all crashes.
- Fatal and Injury (F&I) includes only those crashes in which a vehicle occupant, pedestrian, or bicyclist was killed or injured.
- PDO includes only those crashes in which there were no injuries or fatalities.

The primary focus of this analysis is total crashes. The main reason for this focus is the inherent need to establish clear guidelines for intersection minimum angle, which will help agencies design intersections to meet a specific guideline rather than accounting for the potential variations in CMFunctions that may result from developing different models for different severities. Another reason for this focus is that identifying the true crash type is difficult without delineating the specific leg of the intersection to which the crash belongs, and assigning crashes to specific legs is a time-consuming process beyond the scope of this report. Further disaggregating results by severity may only dilute the sample sizes for analysis. The focus of this study, therefore, is on total crashes. Findings for other crash severities were included when necessary to verify the main conclusions drawn from total crash CMFunctions.

Table 32. Analysis framework for MN—summary of crashes by collision severity and intersection classification in the final database.

Collision Severity	Four Legs All (1,669 sites)	Four Legs Rural (1,472 sites)	Four Legs Urban (197 sites)	Three Legs All (1,109 sites)	Three Legs Rural (888 sites)	Three Legs Urban (221 sites)
Total 7-yr total	8,482	5,868	2,614	4,730	2,829	1,901
Total 7-yr avg	5.08	3.99	13.27	4.27	3.19	8.60
Total ann avg	0.73	0.57	1.90	0.61	0.46	1.23
F&I 7-yr total	3,202	2,335	867	1,682	1,029	653
F&I 7-yr avg	1.92	1.59	4.40	1.52	1.16	2.95
F&I ann avg	0.27	0.23	0.63	0.22	0.17	0.42
PDO 7-yr total	5,204	3,484	1,720	3,007	1,784	1,223
PDO 7-yr avg	3.12	2.37	8.73	2.71	2.01	5.53
PDO ann avg	0.45	0.34	1.25	0.39	0.29	0.79

Ann = annual; Avg = average; F&I = fatal and injury; PDO = property damage only.

Table 33. Analysis framework for OH—summary of crashes by collision severity and intersection classification in the final database.

Total Crashes	Four Legs All (3,766 sites)	Four Legs Rural (3,338 sites)	Four Legs Urban (428 sites)	Three Legs All (9,122 sites)	Three Legs Rural (7,347 sites)	Three Legs Urban (1,775 sites)
5-yr total	16,051	12,341	3,710	22,895	13,539	9,356
5-yr avg	4.26	3.70	8.67	2.51	1.84	5.27
Ann avg	0.85	0.74	1.73	0.50	0.37	1.05

Ann = annual; Avg = average.

DATA MINING

The data-mining efforts for the MN dataset were used for two purposes: to determine the most important predictor variables from the large number of available independent variables in the final database and determine the interactions among the important predictor variables. The results of the data-mining analysis were then used to develop the safety prediction models.

The final raw database for MN included more than 60 possible predictor variables from HSIS and the supplemental data-collection effort. Each variable was examined to determine if it should be included in the analysis as a continuous or categorical variable or eliminated from further consideration. For some variables, such as intersection angle, the continuous data variable was retained. Categorical variables were obtained for further exploration in the data-mining analysis. Some variables were very unbalanced, where attributes in a variable are disproportionate and almost all of observations have only one of the attributed (i.e., more than 90 percent of the intersections were associated with one attribute of the data element). For example, the number of intersections in the database with sight obstructions was 43 out of 2,778, indicating 97 percent of the intersection do not have sign obstructions These unbalanced variables would not likely contribute to safety-prediction models and were eliminated from the analysis database. Other variables were eliminated because they had missing values, which cannot be supported in the development of the NB regression models. The final modified database used in the data-mining analysis included 39 and 34 potential predictor variables for four-leg and three-leg intersections, respectively. Table 74 in appendix D includes the complete list of variable names, descriptors, definitions, and attributes. The variable names are included in the tabular and graphical results from the data-mining analysis and the NB regression models in the remainder of this report.

RF methods were applied for determining the most important predictor variables. Two different statistical packages were explored for this analysis: Package randomForest, version 4.6-7 and cforest within Package party in R, version 1.0-6.[46,64–68] The two packages are similar because they both use random subsets of the input data to do recursive partitioning of the data and develop multiple classification or regression trees. The aggregated result of these multiple trees is then used to estimate the importance of each predictor variable in modeling the dependent variable. There are, however, key differences in these packages that relate to determining predictor variable importance. First, randomForest is best suited to predictor variables of the same type (e.g., continuous or categorical). When variables of different types are included, the randomForest algorithm tends to be biased toward the continuous variables and variables with many categories.[67] Second, randomForest does not accurately account for correlation among predictor variables. The result is an overestimation of the importance of highly correlated predictors.[68] The cforest algorithm overcomes these shortcomings by using a conditional

permutation-importance measure.[49] Third, randomForest requires that the continuous dependent variables be normally distributed. Crashes are commonly known to have an NB distribution. In brief, the cforest algorithm can better handle predictor variables of different types and does not tend to introduce the biases previously described. The algorithm also considers the marginal measure of importance of each predictor variable based on the intercorrelation with other predictors.

Given that the database for this study includes both continuous and categorical variables, the fact that some of the variables are likely correlated, and the fact that the dependent variable (number of crashes) is not normally distributed, cforest within Package party in R was selected for the RF analysis to determine the most important predictor variables. Using the analysis framework previously described, conditional random forest (CRF) results were produced separately for the following six conditions:

- Four-leg total crashes.
- Four-leg fatal-and-injury crashes.
- Four-leg PDO crashes.
- Three-leg total crashes.
- Three-leg fatal-and-injury crashes.
- Three-leg PDO crashes.

All cforest plots for the six scenarios (three leg and four leg; total, injury and fatal, and PDO crashes) are provided in appendix D. Each plot shows the chosen cutoff point. Table 34 and table 35 provide lists of the top predictor variables selected for each of these six scenarios. A total of 16, 15, and 15 predictor variables (table 36) were selected for total, injury and fatal, and PDO crashes, respectively, for four-leg intersections. For three-leg intersections, a total of 10, 12, and 10 predictor variables were selected for total, injury and fatal, and PDO crashes, respectively.

Table 34. Most important predictor variables for MN four-leg intersections (results from cforest analysis).

Total Crashes	Fatal-and-Injury Crashes	PDO Crashes
Intersection AADT	Intersection AADT	Intersection AADT
Major road AADT	Minor road AADT	Major road AADT
Minor road AADT	Major road AADT	Minor road AADT
Roadway class (major road)	Intersection angle (categorical)	Roadway class (major road)
Intersection angle (categorical)	Speed limit (minor road)	Area type (urban/rural)
Land use	Roadway class (major road)	Speed limit (major road)
Area type (urban/rural)	Land use	Commercial driveways (major road)
Speed limit (major road)	Speed limit (major road)	Crosswalk presence (major road)
Commercial driveways (major road)	Curb presence (major road)	Land use
Number of thru lanes (intersection)	Right-turn lane presence (major road)	Right-shoulder width (major road)
Left-turn lane presence (major road)	Number of thru lanes (intersection)	Number of thru lanes (intersection)
Crosswalk presence (major road)	Sidewalk presence (major road)	Crosswalk presence (major road)
Right-shoulder width (major road)	Left-turn lane presence (major road)	Commercial driveways (major/minor)
Left-shoulder width (major road)	Area type (urban/rural)	Adjacent intersections (major road)
Speed limit (minor road)	Onstreet parking (minor road)	Intersection angle (categorical)
Right-turn lane presence (major road)	—	—

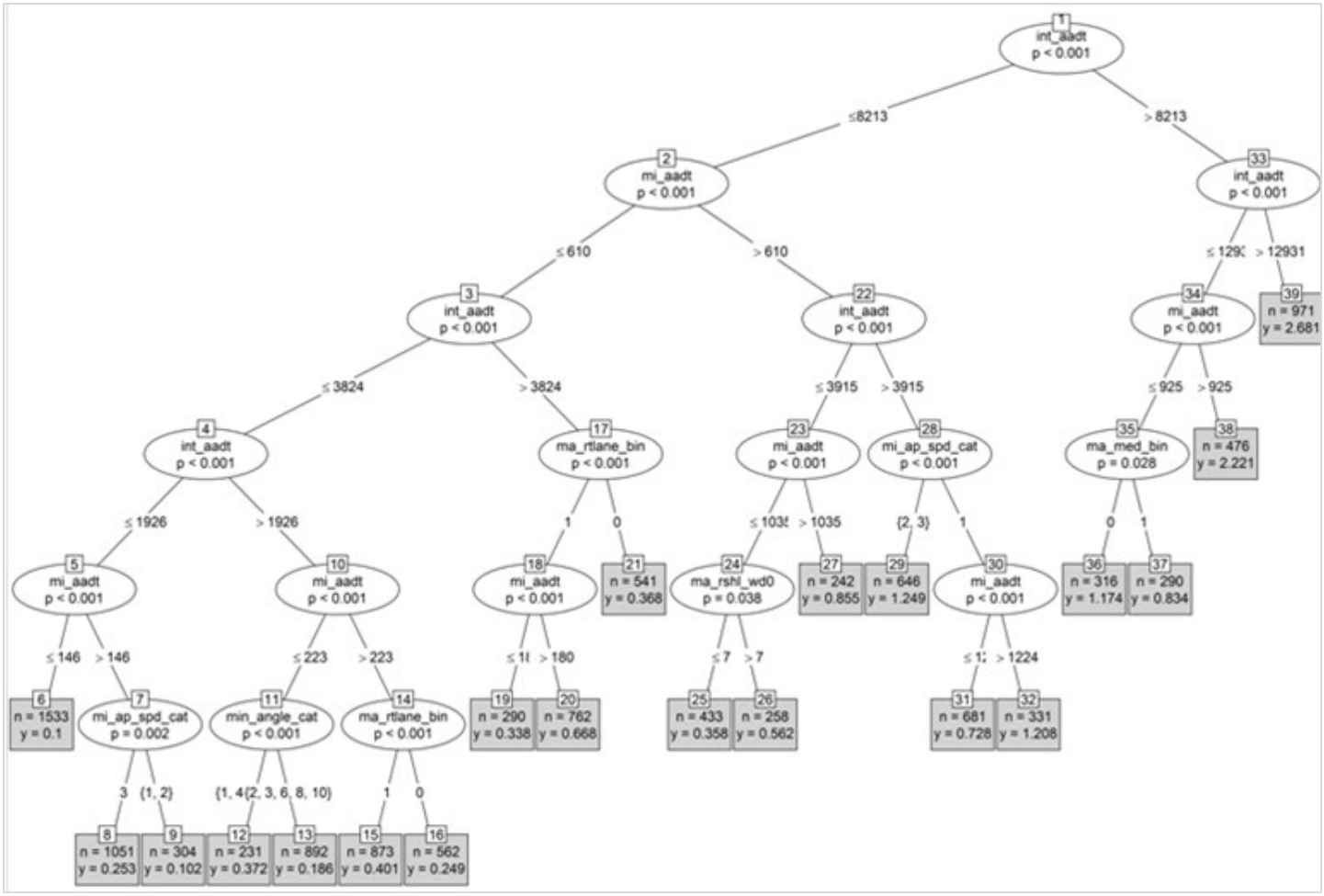
—No data available.

The proceeding results are from the ctree output for total crashes at four-leg intersections. Figure 20 shows the tree produced for this scenario. The first node in the tree is intersection AADT, which shows that it is the most important predictor for total crashes at four-leg intersections. The tree splits at an intersection AADT value of 8,213 vpd. For those intersections with an AADT greater than 8,213, intersection AADT enters the tree again as the most important predictor for this subset of intersections and branches at a value of 12,391 vpd. For those locations with an intersection AADT greater than 12,391, the tree then terminates. Termination of a branch occurs when any of the previously described stopping criteria are met. For those intersections with an intersection AADT less than or equal to 12,391 vpd, the tree splits again based on minor road AADT. This is followed by a split for intersections with a minor road AADT equal to or less than 925 vpd on the variable indicating presence of a median on the major road. That side of the tree terminates at that branch. The other side of the tree can be traced with a similar interpretation of the results.

Table 35. Most important predictor variables for MN three-leg intersections (results from cforest analysis).

Total Crashes	Fatal-and-Injury Crashes	PDO Crashes
Intersection AADT	Intersection AADT	Intersection AADT
Minor road AADT	Minor road AADT	Minor road AADT
Major road AADT	Major road AADT	Major road AADT
Speed limit (major road)	Roadway class (major road)	Speed limit (major road)
Roadway class (major road)	Land use	Roadway class (major road)
Intersection angle (categorical)	Speed limit (minor road)	Lane width (major road)
Land use	Speed limit (major road)	Land use
Curb presence (major road)	Left-turn lane presence (major road)	Intersection angle (categorical)
Lane width (major road)	Intersection angle (categorical)	Curb presence (major road)
Speed limit (minor road)	Residential single-family driveways (minor road)	Right-shoulder width (major road)
—	Curb presence (major road)	—
—	Driveways (major road)	—

—No data available.



Source: FHWA.

Figure 20. Plot. Results of regression tree (ctree) analysis for total crashes at four-leg intersections.

There are three reasons for the value from this analysis. First, the results confirm what was previously found from the CRF analysis: the AADT values are the most important predictor variables. The first three levels of the tree split on intersection AADT or minor road AADT. Six of the 10 nodes in the next two levels are the intersection AADT or minor road AADT variables. Second, a strong association exists between these two variables within the tree. Five branches within the trees that extend between levels are between intersection AADT and minor road AADT, which might indicate the need for an interaction variable within the negative binomial model that will be subsequently developed. Finally, the intersection-angle variable enters the tree as a significant variable for total crashes and fatal-and-injury crashes for both four-leg and three-leg intersections and for PDO crashes for three-leg intersections. The variable does not enter the PDO tree for four-leg intersections. These results confirm what was previously found from the CRF analysis regarding this last result: intersection angle for PDO crashes at four-leg intersections was the last variable selected before the cutoff point. Less-significant variables entering a single tree at the lower levels can be sensitive to small changes in the input variables. For this reason, CRF results, which combine the predictions of many different trees to produce an aggregated prediction, are more stable and robust and provide better indicators of variable importance.

Additional regression trees were produced for fatal-and-injury crashes and PDO crashes at four-leg intersections and total, fatal-and-injury, and PDO crashes at three-leg intersections. The results for all regression trees are provided in appendix D. All trees replicate the key findings previously noted, which are that AADT variables are important and there is a strong association between intersection AADT and minor road AADT.

SAFETY-PREDICTION MODELS

The NB regression models were developed using the GENMOD procedure (Release 9.3) developed by SAS.[69] The goal of the analysis was to develop models for each of the cells in the analysis framework presented in table 35 and table 36. Small sample sizes and limited data ranges for some variables prevented the development of models for some of the scenarios. The most important predictor variables from the MN data-mining analysis, as previously shown in table 35 and table 36, provided the candidate variables considered for each developed model for the MN dataset. Data mining was not conducted for OH data to identify potential explanatory variables within the dataset because of the limited number of descriptive parameters available. Instead, SPF models were tested in a backward regression format where all available parameters, including derived model parameters, were tested in an NB model using the GENMOD procedure. Statistically nonsignificant variables (at the $p < 0.05$ level), or variables not entered into the model, were removed until only a set of statistically significant explanatory variables that provided the best fit remained. The remainder of this section of the report describes the models developed for each scenario. The models developed for four-leg intersections are presented first, followed by the three-leg intersection models.

The focus of the discussion is on the models developed for predicting total crashes; however, the CMFunctions described later in this chapter are also for total crashes. Models were also developed for fatal-and-injury and PDO crashes when sample sizes permitted their development. Additional tables describing these supplemental models are provided in appendix E. All models were independently derived and the results from models for PDO crashes cannot be combined

with results from fatal-and-injury models to produce an estimate that would be equivalent to the estimate produced from the model for total crashes.

Two criteria were used to assess the goodness of fit for each model developed: Akaike information criterion (AIC) and Bayesian information criterion (BIC) or the Schwarz criterion.[70,71] The criteria are expressed as shown in figure 21 and figure 22.

$$AIC = 2k - 2\ln(L)$$

Figure 21. Equation. AIC.

$$BIC = k\ln(n) - 2\ln(L)$$

Figure 22. Equation. BIC.

Where:

k = number of free parameters in the model.
n = sample size.
L = maximized value of the likelihood function.

A smaller value for either criterion indicates a better model fit to the data. A larger L produced a smaller value for both metrics. Likewise, fewer k also produced a smaller value for both criteria. The difference in the two criteria is the magnitude of the penalty assigned for the number of parameters in the model. The AIC used a multiplier of 2.0 and did not account for sample size. The BIC accounted for the size of the sample with the multiplier $\ln(n)$. For example, a sample size of 10,000 had a $\log_e$ value of 9.2. In this example, the BIC added 9.2 to the value for each additional parameter, while the *AIC* added 2.0. The goal was to select the model with the best fit and the fewest parameters. Thus, the BIC was chosen as the preferred criterion for comparison of models. However, the AIC was also used when there was no or little change in the BIC. The magnitude of the change in these criteria when choosing among models was also considered. The values in table 36 provide general guidance on interpreting the change in value for the two criteria.

Table 36. General guidance for interpretation of models using AIC and BIC criteria.

Change in AIC	Model Difference Interpretation[72]	Change in BIC	Model Difference Interpretation[73]
0–2	Indistinguishable	0–2	Negligible
4–7	Substantial	2–6	Positive
>10	Very strong	6–10	Strong
—	—	>10	Very strong

—No data available.

For the OH dataset, regression models were developed in SAS twice for each intersection type to test two slightly different variable sets related to two potential functional forms used for CMFunction predictions. The first form, flexible form model 1, was initially developed using the MN data and is described in the next section. The second form, the Hoerl Curve suggested by Ezra Hauer, was suitable for capturing data with a parabolic shape.[74] Although the roadway variables were consistent in both the flexible form model 1 and Hoerl Curve models, the angle

and volume parameters were slightly different; therefore, two separate models were prepared for each intersection type to find the best fit, and the model that retained its fundamental variables for CMFunction development and had the lower AIC and BIC values was selected.

The variable set for the OH SPF development includes the following:

- *Minimum Angle.*
- *Lighting.*
- *Roadway Division of Major Approach.*
- *Functional Classification of Major Approach.*
- *AADT of Major Approach.*
- *AADT of Minor Approach*.
- *Total Intersection AADT* (derived variable).
- *Minor Road/Intersection AADT Ratio* (derived variable).
- *Natural Log of Major Approach AADT* (derived variable).
- *Natural Log of Minor Approach AADT* (derived variable).
- *Natural Log of Total Intersection AADT* (derived variable).
- *Natural Log of Minor Road/Intersection AADT Ratio* (derived variable).
- *Log Cos(intersection AADT)* (derived for flexible form model 1).
- *Log Cos(minor road AADT)* (derived for flexible form model 1).
- *Natural Log of Minimum Angle* (derived for Hoerl curve).

A full variable list, as well as their abbreviations, is included in appendix D.

The scope of the OH dataset allowed for even more SPFs to be developed than for the MN dataset (table 37). However, models were only tested for total crashes. Separate models were not developed for different crash severities using OH data.

Table 37. Different roadways with sufficient data for total crash CMFunction development.

Roadway Type	MN Dataset	OH Dataset
Rural four-leg two-lane	X	X
Rural four-leg multilane	X	X
Rural three-leg two-lane	—	X
Rural three-leg multilane	—	X
Urban four-leg all roads	—	X
Urban three-leg all roads	—	X
Urban four-leg two-lane	—	X
Urban four-leg multilane	—	X
Urban two lane	—	X
Urban three-leg multilane	—	X
Rural three-leg all roads	X	X
Rural four-leg all roads	X	X
Rural and urban three-leg	X	X

—Sufficient data not present.
X = sufficient data present.

Although data were available for each of the roadway types listed in table 38, the final list of prediction models was narrowed down to a smaller set because of unreliable results. The results were considered unreliable if the functional form provided poor fit (i.e., if the shape of the CMFunction produced by the prediction model was irregular and did not corroborate the observed shape of the other model curves) or if the variables necessary for either functional form were not statistically significant (i.e., if neither *lgcos_int* or *lgcos_mi* were significant for flexible form model 1 or if the log minimum angle term was not significant for the Hoerl Curve). After narrowing down the models, the following prediction results remained for total crashes:

- Rural four-leg all roads.
- Rural four-leg two-lane.
- Rural four-leg multilane.
- Rural three-leg all roads.
- Rural three-leg two-lane.
- Urban four-leg total.
- Urban four-leg two-lane.
- Urban three-leg all roads.
- Urban three-leg two-lane.

The next sections show the model parameters and fit statistics for total predicted crashes on each of three- and four-leg facilities. The specific model fit statistics for the further disaggregated facility types are included in appendix E.

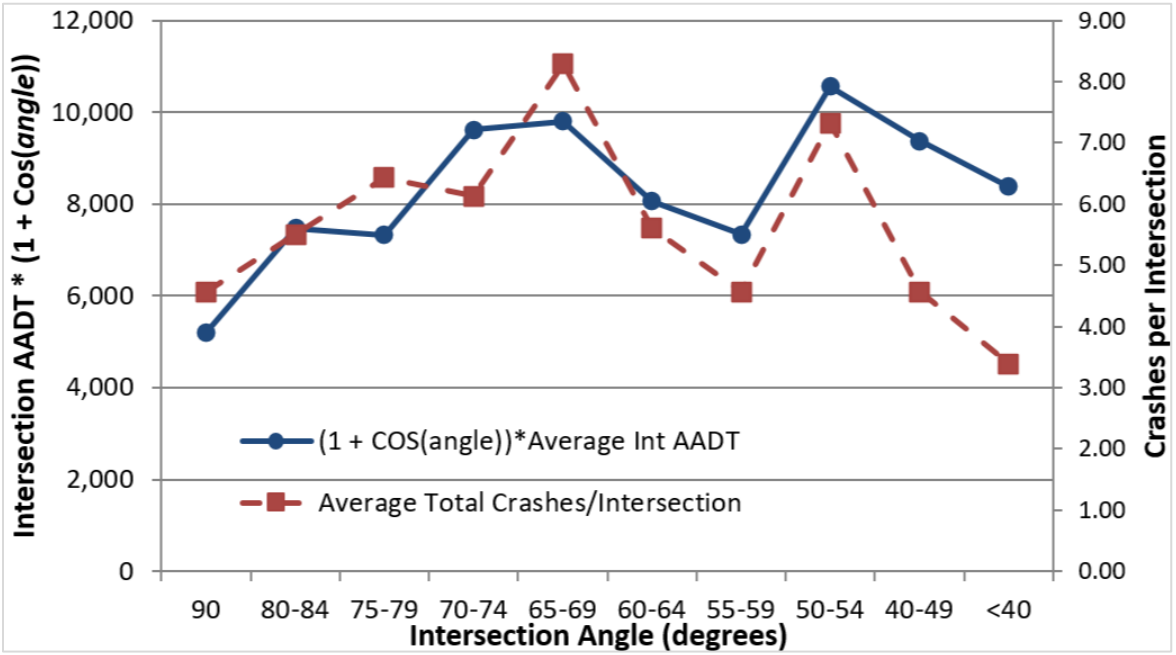
Total Crashes for Four-Leg Intersections

Multiple models were developed and tested to find the best-fitting functional form. Initially, a standard NB model was developed to predict total crashes using MN data; this model was referred to as the base model and is shown in appendix E. The model assumed a monotonic relationship between crashes and intersection angles. From the plot of crash rate (per 100 million entering vehicles) versus the intersection-angle category in figure 16 and figure 18, it is apparent

that this is not a monotonic relationship. For all four-leg intersections (rural and urban combined), the highest crash rates occurred in the categories of 65–69 degrees and 50–54 degrees. Crash rates for intersections with angles lower than 40 degrees are less than the crash rates for right-angle intersections. Given this nonmonotonic relationship, the researchers desired a more flexible form model 1 that better replicated the raw data. The alternating peaks and valleys in the data as one moves from a right angle to angles less than 40 degrees required a functional form that accounts for these changes in the data. Several variations of the angle parameter were tried to determine which form most closely matches the shape of the raw data.

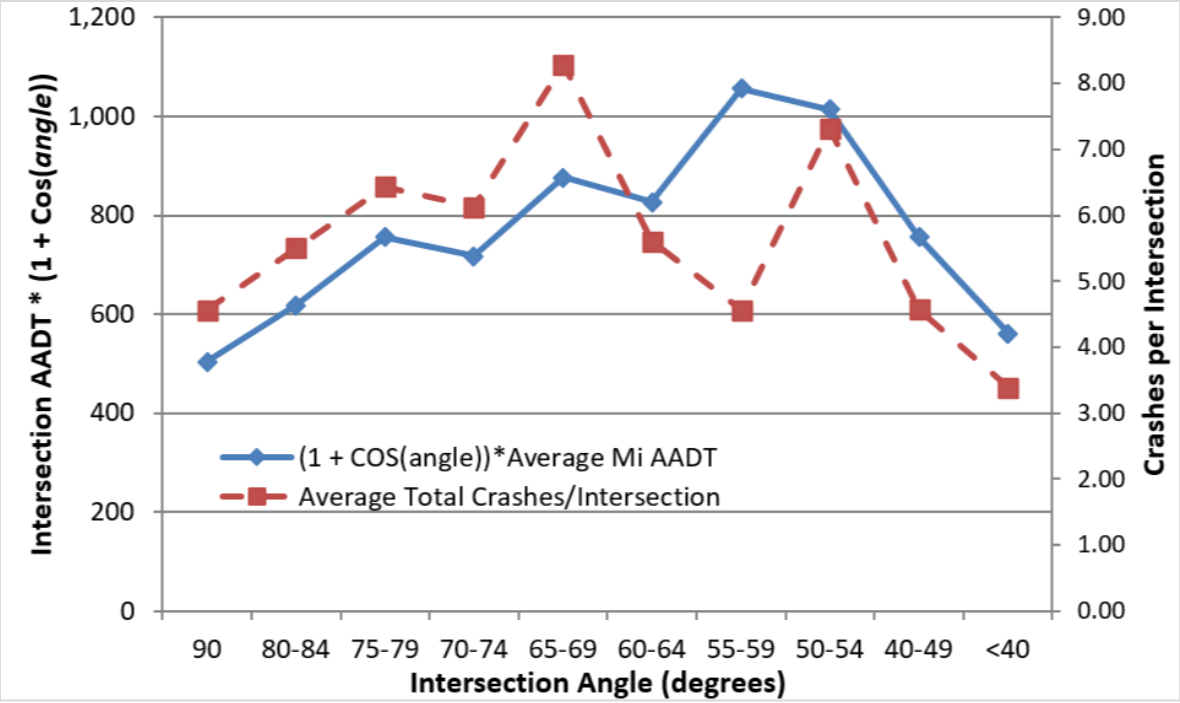
The final form chosen was 1 + cos(*angle*). For right-angle intersections, the value of the function becomes 1.0 as the cos(90 degrees) equals 0.0. As the intersection angle decreased, the value of the function increased. Figure 23 shows the plot of this functional form when multiplied by the average intersection AADT values from the angle categories and the plot of the average number of total crashes per intersection for four-leg intersections in these same categories. The patterns of peaks and valleys in the two lines across the range of intersection angles were very similar. The correlation coefficient ($r = 0.519$) indicated a strong association.

Figure 24 shows the plot of 1 + cos(*angle*) multiplied by the average minor road AADT values from the angle categories and the plot of the average number of total crashes per intersection for four-leg intersections in these same categories. Again, the patterns exhibited for the two lines across the range of intersection angles were very similar. The strength of association between these two variables was also strong ($r = 0.476$). Based on these strong associations, the variable 1 + cos(*angle*) was included in the flexible form model 1.



Source: FHWA.

Figure 23. Graph. Average total crashes per intersection for all four-leg intersections in MN and functional form of [(1 + cos(*angle*)) × *intersection AADT*] as distributed across the range of intersection angles.



Source: FHWA.

Figure 24. Graph. Average total crashes per intersection for all four-leg intersections in MN and functional form of [(1 + cos(*angle*)) × *minor road AADT*] as distributed across the range of intersection angles.

Two models were developed using the 1 + cos(*angle*) term. The first model, referred to hereafter as flexible form model 1, incorporated the term as shown in figure 23 and figure 24 because this was the association drawn with the raw data. The term was added to the AADT variables previously used in the base model. The new variables were structured as shown in figure 25 and figure 26.

$$lgcos_int = \ln\left[(\text{intersection_aadt}) \times (1 + \cos(angle))\right]$$

Figure 25. Equation. Derived variable that incorporates intersection AADT and cosine of the intersection angle.

$$lgcos_mi = \ln\left[(\text{minor road_aadt}) \times (1 + \cos(angle))\right]$$

Figure 26. Equation. Derived variable that incorporates minor road AADT and cosine of the intersection angle.

The form of the variable structure allows the parameter estimates for these two variables to be summed and applied to the angle term 1 + cos(*angle*). Figure 27 shows the derivation that allows for the separation of the terms within the variables in figure 25 and figure 26 and the application of the sum of the parameter estimates to produce the estimated crash predictive effect of this component within the model.

$$
\begin{aligned}
N_p &= \text{EXP}\{\ln[int_aadt) \times (1 + \cos(\alpha))]]\beta_1\} \times \text{EXP}\{[\ln[(mi_aadt) \times (1 + \cos(\alpha))]]\beta_2\} \\
&= [(int_aadt) \times (1 + \cos(\alpha))]^{\beta_1} \times [(mi_aadt) \times (1 + \cos(\alpha))]^{\beta_2} \\
&= (int_aadt)^{\beta_1} \times [1 + \cos(\alpha))]^{\beta_1} \times (mi_aadt)^{\beta_2} \times [(1 + \cos(\alpha))]^{\beta_2} \\
&= (int_aadt)^{\beta_1} \times (mi_aadt)^{\beta_2} \times [1 + cos(\alpha)]^{(\beta_1+\beta_2)} \\
&= (int_aadt)^{\beta_1} \times (mi_aadt)^{\beta_2} \times [1 + cos(\alpha)]^{\beta_3}
\end{aligned}
$$

Figure 27. Equation. Derivation of partial crash prediction term using intersection AADT, minor road AADT, and cosine of the intersection angle.

Where:

N_p = partial crash prediction using the parameters shown.
int_aadt = intersection AADT (vpd).
mi_aadt = minor road AADT (vpd).
α = intersection angle, degrees.
β_1, β_2, β_3 = parameter estimates from the regression model.
$\beta_3 = \beta_1 + \beta_2$.

A second model, hereafter referred to as flexible form model 2, incorporated the term 1 + cos(*angle*) as a unique variable (*lgcos_1* = ln[1 + cos(*angle*)]). The original AADT variables (*lgint_aadt* and *lgmi_aadt*) used in the base models were retained.

The results from flexible form model 1 for the MN data are shown in table 38. The same variables that were significant in the base models remained significant in this model. Intersection angle (*min_angle*) was included in the model as before and is significant with a *p*-value of <0.0001. The estimate for this variable was 0.0124. The additional variables incorporating the 1 + cos(*angle*) terms and AADT were both significant with *p*-values of <0.0001. The sum of the estimates for these two parameters was 1.1816.

The BIC and AIC for flexible form model 1 are 23,073 and 22,963, respectively. For flexible form model 2, the BIC and AIC are 23,078 and 22,960, respectively. The goodness-of-fit parameters were in opposing directions. The BIC showed a positive improvement in model 1 over model 2, while the AIC showed the two models to be close to indistinguishable. Considering both criteria, flexible form model 1 was the better of the two. The BIC and AIC values for the alternative base model, shown in appendix E, were 23,087 and 22,977, respectively. The fit metrics for the flexible form model 1 were much lower, indicating a very strong improvement in the model fit.

Table 38. Flexible form model 1 results for total crashes at all four-leg intersections for MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−10.6485	0.2614	−11.1607	−10.1363	1660.09	<0.0001
lgcos_int	0.8454	0.0325	0.7818	0.909	678.11	<0.0001
lgcos_mi	0.3362	0.0282	0.281	0.3915	142.44	<0.0001
min_angle	0.0124	0.001	0.0104	0.0143	158.92	<0.0001
mi_int	0.7427	0.2284	0.295	1.1904	10.57	0.0011
ma_rodwycls_cat (1)	0.2258	0.0576	0.1129	0.3386	15.38	<0.0001
ma_rodwycls_cat (2)	0.1068	0.0617	−0.0142	0.2278	2.99	0.0836
ma_rodwycls_cat (3)	−0.0403	0.0476	−0.1336	0.053	0.72	0.397
ma_rodwycls_cat (4)	0	0	0	0	—	—
spec_env_cat (0)	−0.1225	0.0549	−0.2301	−0.0149	4.98	0.0257
spec_env_cat (1)	−0.1233	0.0539	−0.229	−0.0177	5.24	0.0221
spec_env_cat (2)	−0.4814	0.0575	−0.5941	−0.3687	70.11	<0.0001
spec_env_cat (3)	0	0	0	0	—	—
ma_ap_spd_cat (1)	−0.2349	0.0583	−0.3492	−0.1207	16.23	<0.0001
ma_ap_spd_cat (2)	−0.0899	0.0526	−0.193	0.0133	2.92	0.0877
ma_ap_spd_cat (3)	0	0	0	0	—	—
ma_rshl_wd0	–0.0218	0.0049	–0.0313	–0.0123	20.13	<0.0001
Dispersion	0.4294	0.0245	0.3839	0.4802	—	—
Goodness-of-fit parameters: AIC (smaller is better)	—	22,963	—	—	—	—
Goodness-of-fit parameters: BIC (smaller is better)	—	23,073	—	—	—	—

—No data available.

Table 38 is a representative example of a four-leg intersection SPF developed using data from MN. SPFs were also developed for each entity in the OH database, and two model fit statistics tables are included here (table 39 and table 42) to demonstrate the disaggregation of four-leg sites in OH.

For the rural four-leg intersection model for all roads, flexible form model 1 provided a better fit than the Hoerl Curve (discussed in greater detail in the Crash-Prediction Model section) based on the AIC and BIC values. In addition to the *lgcos_int* and *lgcos_mi* variables, this model included logarithmic variables for both major approach AADT and total intersection AADT. Minimum angle was critical for prediction, and roadway characteristics like major road division and major road functional classification were statistically significant. Minimum-angle categories were further discretized down to 20 degrees because of the wider range of intersections available in the dataset. The highest concentrations of intersections were in the upper three brackets.

Table 39. Model fit statistics for OH for total rural four-leg intersections.

Parameter Description	Category	Estimate	Standard Error	Statistical Significance
Intercept	N/A	–40.3087	6.1746	<0.0001
lgcos_int	N/A	3.8250	0.5997	<0.0001
lgcos_mi	N/A	0.2055	0.0385	<0.0001
min_angle	N/A	0.0432	0.0072	<0.0001
lgma_aadt	N/A	–0.7958	0.1902	<0.0001
lgint_aadt	N/A	–2.2125	0.6325	0.0005
ma_division	Divided	–0.3448	0.0988	0.0005
ma_division	Undivided	Base category	—	—
ma_rodwycls_cat	Local	0.2030	0.1354	0.1338
ma_rodwycls_cat	Major collector	0.2071	0.0598	0.0005
ma_rodwycls_cat	Minor arterial	0.1336	0.0594	0.0245
ma_rodwycls_cat	Minor collector	0.3290	0.0998	0.0010
ma_rodwycls_cat	Principal arterial	Base category	—	—
Dispersion	N/A	0.4584	0.0202	—
Goodness-of-fit parameters: AIC (smaller is better)	14,799.8243	—	—	—
Goodness-of-fit parameters: BIC (smaller is better)	14,873.1711	—	—	—

—No data available.
N/A = not applicable.

Unlike the MN dataset, the OH dataset was sufficiently robust to allow multiple prediction models to be developed for urban intersections. The first of these presented is the urban four-leg total intersection-prediction model. Flexible form model 1 provided the best fit for this intersection type based on the AIC and BIC and statistically significant variables. However, this fit was provided by a partial flexible form model 1 that excluded the *lgcos_mi* variable. The statistically significant predictor variables included *lgcos_int*, *lgma_aadt*, and *min_angle*.

Unlike several of the other models, the total urban four-leg model had a truncated angle set because of a low quantity of sample counts less than 30 degrees.

Table 40. Model fit statistics for OH for urban four-leg total intersections.

Parameter Description	Category	Estimate	Standard Error	Statistical Significance
Intercept	N/A	−12.9443	2.6861	<0.0001
lgcos_int	N/A	1.3249	0.2551	<0.0001
lgma_aadt	N/A	−0.6556	0.2288	0.0042
lin_Angle	N/A	0.0133	0.0041	0.0014
Dispersion	N/A	0.5150	0.0457	—
Goodness-of-fit parameters: AIC (smaller is better)	2,614.5293	—	—	—
Goodness-of-fit parameters: BIC (smaller is better)	2,634.7780	—	—	—

—No data available.
N/A = not applicable.

Additional crash-prediction models were developed for four-leg intersections using the OH dataset. The model fit statistics for these models are included in appendix E. In total, five different four-leg models were developed using the OH data.

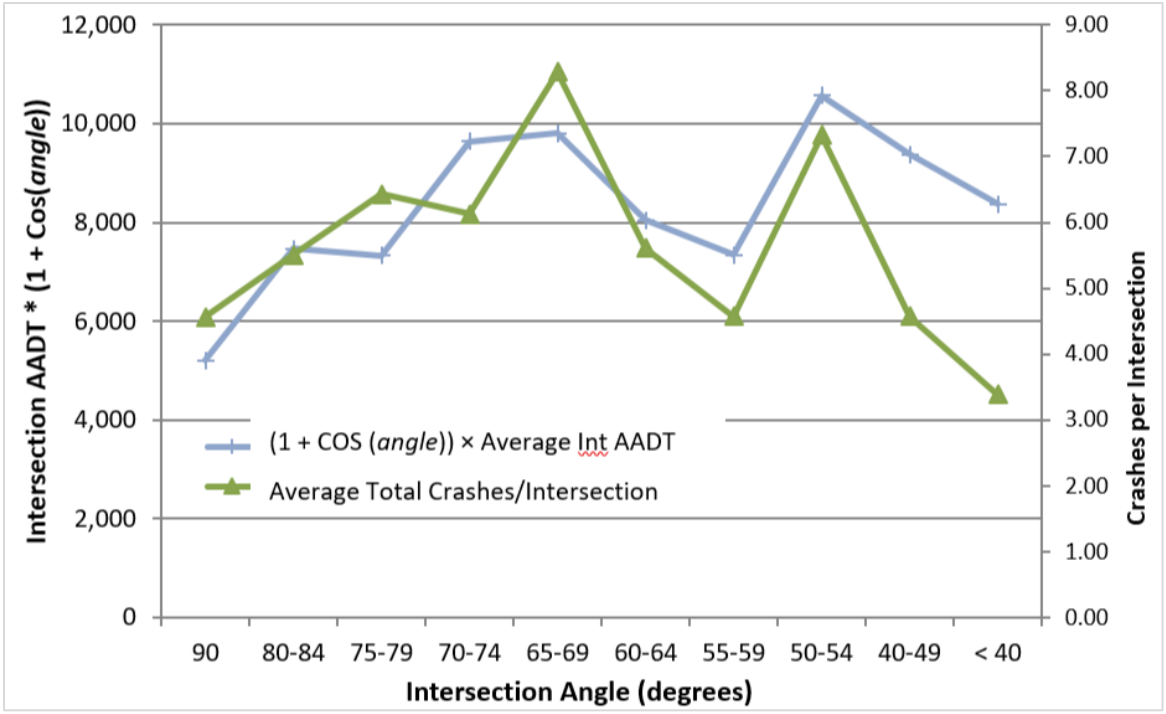
Total Crashes for Three-Leg Intersections

For the MN dataset, the base models revealed that the variable for intersection angles was not significant. From the plot of crash rate (per 100 million entering vehicles) versus intersection angle category in figure 16 and figure 18, it is apparent that this is not a monotonic relationship. For all three-leg intersections (rural and urban combined), the highest crash rates occurred in the categories of 55–59 degrees and less than 40 degrees. Crash rates for intersections with angles between 70–84 degrees were less than the crash rates for right-angle intersections. Similar to what was done for four-leg intersections, a more flexible form model 1 was desired that better replicated raw data. Recall that the final term chosen for the four-leg intersections was $1 + \cos(angle)$. For right-angle intersections, the value of the function becomes 1.0 as the $\cos(90\ degrees)$ equals 0.0. As the intersection angle decreases, the value of the function increases.

One plot (figure 28) shows the functional form when multiplied by the average intersection AADT values for three-leg intersections within the angle categories, while the other plot, figure 29, shows the average number of total crashes per intersection for three-leg intersections across the same categories. The patterns of peaks and valleys in the two lines across the range of intersection angles are very similar. The correlation coefficient ($r = 0.385$) indicates a moderate association.

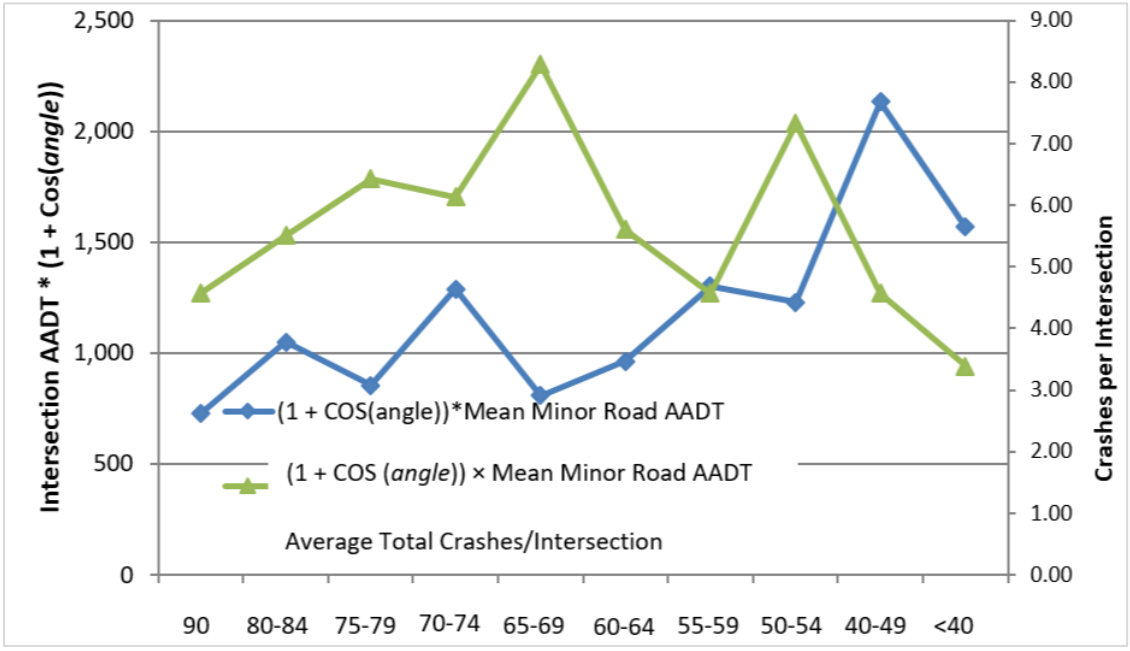
Figure 29 shows two lines. One line is the plot of $1 + \cos(angle)$ multiplied by the average minor road AADT values from the angle categories. The other line is the plot of the average number of total crashes per intersection for three-leg intersections. The patterns exhibited for the two lines across the range of intersection angles are less similar for minor road AADT than for intersection AADT. The strength of association ($r = 0.281$) between this variable and crashes is much smaller when compared to the same variable comparison for four-leg intersections ($r = 0.478$).

However, the strength of the association between intersection AADT and crashes was strong enough to justify inclusion of the variable $1 + \cos(angle)$ into the model.



Source: FHWA.

Figure 28. Graph. Average total crashes per intersection for all three-leg intersections in MN and functional form of [(1 + cos(*angle*)) × *intersection AADT*] as distributed across the range of intersection angles.



Source: FHWA.

Figure 29. Graph. Average total crashes per intersection for all three-leg intersections in MN and functional form of [(1 + cos(*angle*)) × *minor road AADT*] as distributed across the range of intersection angles.

The results from flexible form model 1 are shown in table 41. Intersection angle (*min_angle*) is now included in this model and is significant with a *p*-value of <0.0001. The estimate for this variable is 0.011. The additional variables incorporating the 1 + cos(*angle*) terms and AADT are both significant with a *p*-value of <0.0001. The sum of the estimates for these two parameters is 1.0707.

Table 41. Flexible form model 1 results for total crashes at all three-leg intersections for MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−10.4104	0.2515	−10.9034	−9.9175	1,713.46	<0.0001
lgcos_int	0.8717	0.0297	0.8135	0.9299	862.72	<0.0001
lgcos_mi	0.199	0.0265	0.1471	0.2509	56.47	<0.0001
mi_int	1.187	0.4819	0.2425	2.1314	6.07	0.0138
ma_lane_wd0	0.0087	0.0019	0.005	0.0124	21.16	<0.0001
spec_env_cat (0)	−0.2377	0.0601	−0.3555	−0.1199	15.63	<0.0001
spec_env_cat (1)	−0.3307	0.0514	−0.4315	−0.2299	41.34	<0.0001
spec_env_cat (2)	−0.5184	0.0542	−0.6246	−0.4121	91.46	<0.0001
spec_env_cat (3)	0	0	0	0	—	—
min_angle	0.011	0.001	0.009	0.0131	113.73	<0.0001
Dispersion	0.6031	0.041	0.5279	0.689	—	—
Goodness-of-fit parameters: AIC (smaller is better)	14,289	—	—	—	—	—
Goodness-of-fit parameters: BIC (smaller is better)	14,358	—	—	—	—	—

—No data available.

As with the four-leg intersections, disaggregated three-leg intersection SPFs were developed using OH data. Total rural three-leg model specifications are shown in table 42. Flexible form model 1 was used for this dataset because the AIC value for that model (23,489.2110) was slightly smaller than that of the Hoerl Curve (23,492.2450). Several variables were retained in this model because of the large sample size. In addition to the *lgcos_int*, *lgcos_mi*, and *min_angle* terms required for flexible form model 1, *lgma_aadt*, *ma_division*, and *ma_rodwycls_cat* were retained in the model as explanatory variables. The large sample size also benefitted the angle categories, allowing the model not to be truncated for smaller-angle measures.

Table 42. Model fit statistics for OH for rural three-leg all intersections.

Parameter Description	Category	Estimate	Standard Error	Statistical Significance
Intercept	N/A	−16.0384	1.5532	<0.0001
lgcos_int	N/A	1.5072	0.1675	<0.0001
lLgcos_mi	N/A	0.0941	0.0286	0.0010
lgma_aadt	N/A	−0.6397	0.1440	<0.0001
min_angle	N/A	0.0139	0.0017	<0.0001
ma_division	Divided	−0.4365	0.1339	0.0011
ma_division	Undivided	Base category	—	—
ma_rodwycls_cat	Local	−0.1220	0.1223	0.3182
ma_rodwycls_cat	Major Collector	0.1476	0.0462	0.0014
ma_rodwycls_cat	Minor Arterial	0.0561	0.0459	0.2217
ma_rodwycls_cat	Minor Collector	0.0843	0.0809	0.2973
ma_rodwycls_cat	Principal Arterial	Base category	—	—
Dispersion	N/A	0.4426	0.0188	—
Goodness-of-fit parameters: AIC (smaller is better)	23,489.2110	—	—	—
Goodness-of-fit parameters: BIC (smaller is better)	23,564.5241	—	—	—

—No data available.
N/A = not applicable.

A model was also developed for the total urban three-leg intersection subset. A partial flexible form model 1 that excluded the *lgcos_mi* variable provided the best fit; the Hoerl Curve was unable to fit the data. The statistically significant variables in the model included *lgcos_int*, *min_angle*, and *ma_division*. All angle categories greater than 10 degrees were sufficiently populated for this dataset.

Table 43. Model fit statistics for OH for urban three-leg, all intersections.

Parameter Description	Category	Estimate	Standard Error	Statistical Significance
Intercept	N/A	−10.0343	0.3837	<0.0001
lgcos_int	N/A	1.0339	0.0382	<0.0001
min_angle	N/A	0.0059	0.0014	<0.0001
ma_division	Divided	−0.4967	0.1450	0.0006
ma_division	Undivided	Base category	—	—
Dispersion	N/A	0.5668	0.0286	—
Goodness-of-fit parameter: AIC (smaller is better)	8,625.2848	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	8,652.4205	—	—	—

—No data available.
N/A = not applicable.

Several other model forms were attempted, including an interaction term and the base term, but the research team found for most models that flexible form model 1 provided the best functional form fit, so that model, or a partial form of it, was used to develop most of the CMFunctions to be shown. One other functional form was attempted while comparing the MN results to those in

OH: the Hoerl Curve. The derivation of this model is presented in greater detail in the next section. Further model derivations for specific intersection types are shown in appendix E.

DEVELOPMENT OF CMFs AND FUNCTIONS

One of the principal goals of this study was to develop CMFs or CMFunctions that could be used by road-safety professionals to assess the change in crashes associated with changes in intersection angles. The coefficients from the NB models were used to derive the CMFunctions and show the relationship between crashes and intersection angles. The CMFunctions derived from the base models include a single regression coefficient applied to the intersection angle variable and is, therefore, a simple CMFunction. The CMFunctions from the flexible form and interaction models include multiple regression coefficients applied to different forms of the variable intersection angle as well as AADT variables. Many of the comparative plots simply use CMFunction value on the vertical axis, which is consistent with the presentation of the CMFs in the HSM.[24]

The remainder of the discussion in this section of the report focuses on intersection angle CMFunctions developed for total crashes for four-leg and three-leg intersections. Intersection angles in all CMFunctions were defined as the smallest angle between any two adjacent legs at an intersection. This angle (in degrees) was denoted as α in the CMFunction equations in figure 30 and figure 31. Additional CMFunctions were developed for injury crashes and PDO crashes at four-leg intersections. All CMFunctions derived are shown in table 45.

Each CMFunction developed had a nominal value of 1.0 for the base condition of intersection angle equal to 90 degrees. A CMFunction with a value greater than 1.0 indicated more crashes would be expected when compared to the base condition. A CMFunction with a value less than 1.0 indicated fewer crashes would be expected when compared to the base condition. Each CMFunction was calculated using the equation shown in figure 30.

$$CMF(\text{model form}) = F(\alpha)/F(90)$$

Figure 30. Equation. CMFunction calculation.

Where:

CMF = crash modification factor or function for a specific model form.
$F(\alpha)$ = effectiveness factor for intersection angle α, expressed in degrees.
$F(90)$ = effectiveness factor for intersection angle of 90 degrees.

This equation in figure 30 provides the CMF associated with changing the intersection angle from 90 degrees to angle α, which is less than 90 degrees. This was mainly done for convenience. However, agencies would be interested in doing the opposite (i.e., converting from an intersection angle α to 90 degrees), and the safety effect associated with this change would be the inverse of the value from this equation.

The calculations in the remainder of the report are expressed as a CMFunction for each model form, with an understanding that the CMFunction values produced are normed to the nominal base condition of intersection angles equal to 90 degrees. The conditions under which each

developed CMFunction is applicable are clearly indicated in the appropriate figures and tables in the remainder of this report. These conditions include crash level (i.e., total, injury, PDO), intersection level (i.e., all, rural, urban), and number of lanes (i.e., two-lane, multilane).

Two different functional forms derived from figure 23, figure 24, figure 28, and figure 29 and the SPFs presented in Safety-Prediction Models were used to develop each of the CMFunctions presented in the next section. The first functional form, flexible form model 1, was previously introduced to account for the non-log–linear relationship between traffic volume and intersection angle. Its functional form is shown in figure 31.

$$CMF(\text{flex1}) = \{\text{EXP}(\beta_1\alpha) \times [(1+\cos(\alpha)]^{(\beta_2+\beta_3)}\}/\{\text{EXP}(\beta_1 90) \times \left[1+\cos(90)\right]^{(\beta_2+\beta_3)}\}$$
$$= \text{EXP}[(\beta_1(\alpha-90)] \times [(1+\cos(\alpha)]^{(\beta_2+\beta_3)}$$

Figure 31. Equation. CMFunction flexible form model 1 calculation for total crashes at all four-leg intersections.

Where:

α = intersection angle, expressed in degrees.
β_1 = coefficient estimate for intersection angle.
β_2 = coefficient estimate for *lgcos_int.*
β_3 = coefficient estimate for *lgcos_mi.*

The only noteworthy difference between the use of flexible form model 1 for the MN data and the OH data is that certain OH intersection types required a partial form of the equation that excluded the *lgcos_mi* term to fit the data. In these cases, the estimate of the *lgcos_int* term typically compensated for the lack of a *lgcos_mi* term and was sufficient for capturing the curved shape of the data. The key difference between the Hoerl Curve functional form and the flexible form models is the use of both a minimum angle and log minimum angle to capture a curve shape. The Hoerl curve equation is shown in figure 32.

$$CMF(\text{Hoerl}) = \text{EXP}[\beta_1 \times \alpha + \beta_2 \times \ln(\alpha)]$$

Figure 32. Equation. General form of Hoerl Curve.

Where:

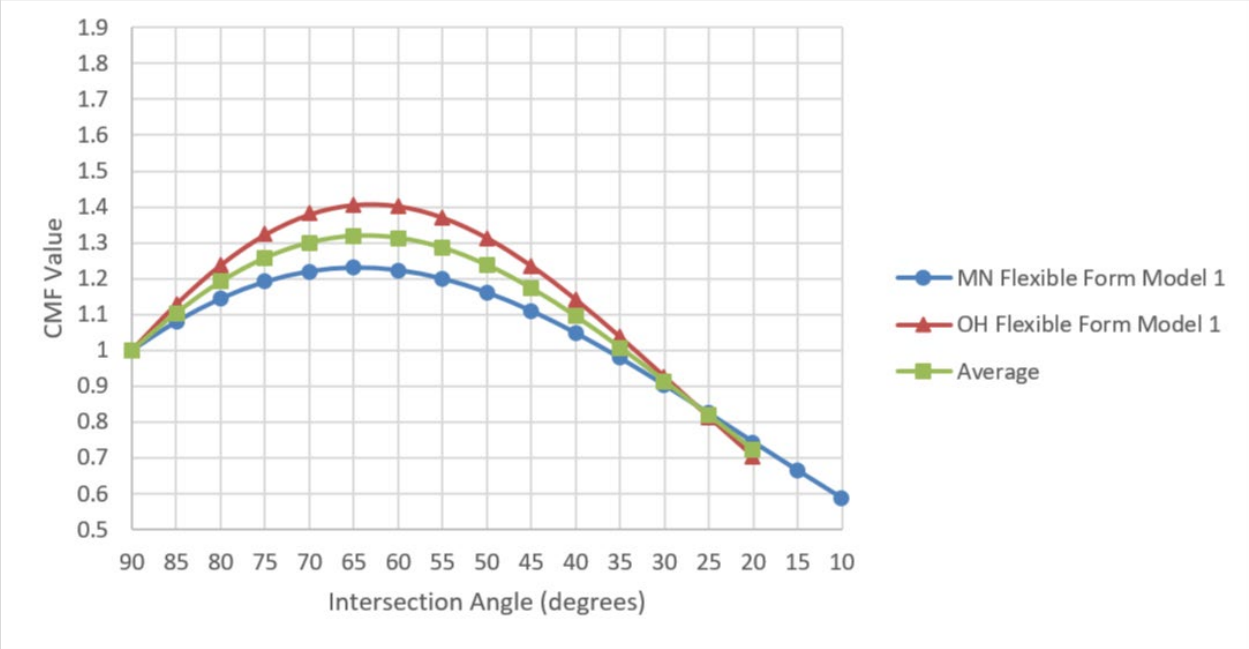
β_1 = NB estimate for minimum angle variable.
β_2 = NB estimate for natural log of minimum angle.

This section shows the predicted CMFunction for each of the OH intersection types compared to the final model selected for each of the MN intersection types. All CMFunctions shown are for total crashes. Where applicable, average curves were developed for the OH and MN data. These average curves account for the occasionally conflicting minimum angle identifications of the two States. It is encouraging that, in most cases, the shapes of the CMFunctions from the two States are very similar. Hence, the research team thought that taking the average of the curves was a reasonable option.

In each figure, the intersection angle axis refers to the minimum angle of each intersection used to identify that intersection's skew. For example, an intersection with a minimum angle equal to 50 degrees would be considered to have an intersection angle of 50 degrees.

All Rural Four-Leg CMFunctions

Figure 33 shows a comparison between the MN and OH total rural four-leg CMFunction for total crashes. The MN curve predicts slightly lower CMFunction values for nearly all angle categories than the OH curve, but both peak at the same minimum angle. The minimum angle at which the CMFunction values peak for both the OH dataset and the MN dataset is 65 degrees. This peak is also reflected in the average CMFunction. The OH CMFunction inclines and declines more rapidly than the MN curve, eventually predicting a lower CMFunction value than the MN curve between 30 degrees and 10 degrees. Both OH and average curves are truncated at 20 degrees because of a small sample size below this point. Both the MN and OH curves were developed using flexible form model 1.

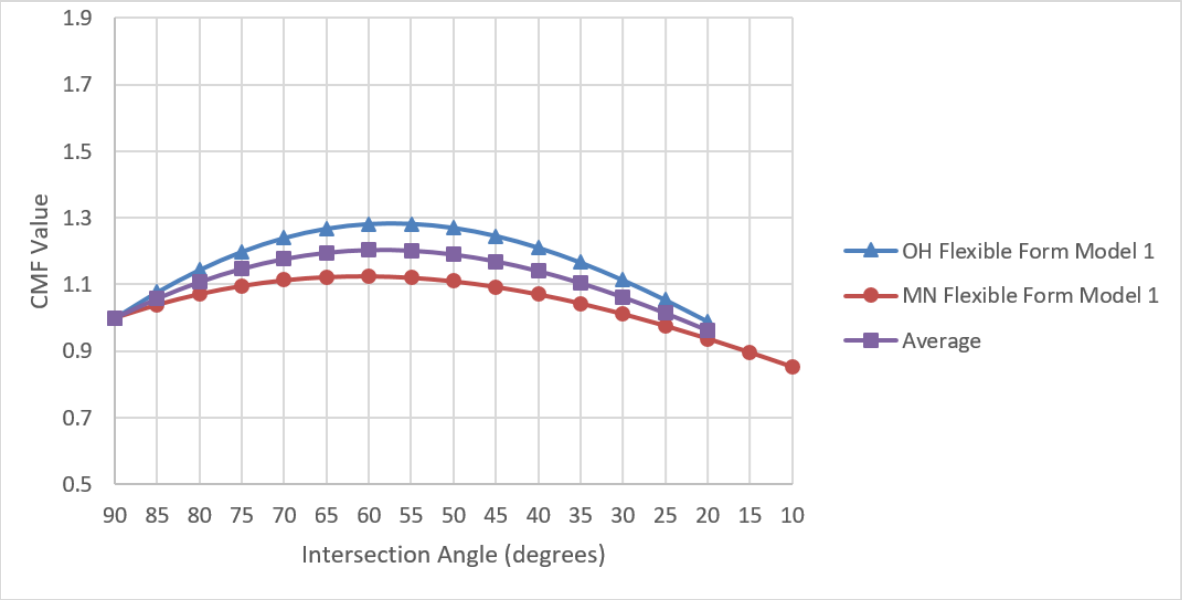


Source: FHWA.

Figure 33. Graph. CMF for all rural four-leg intersections.

Rural Four-Leg Two-Lane CMFunctions

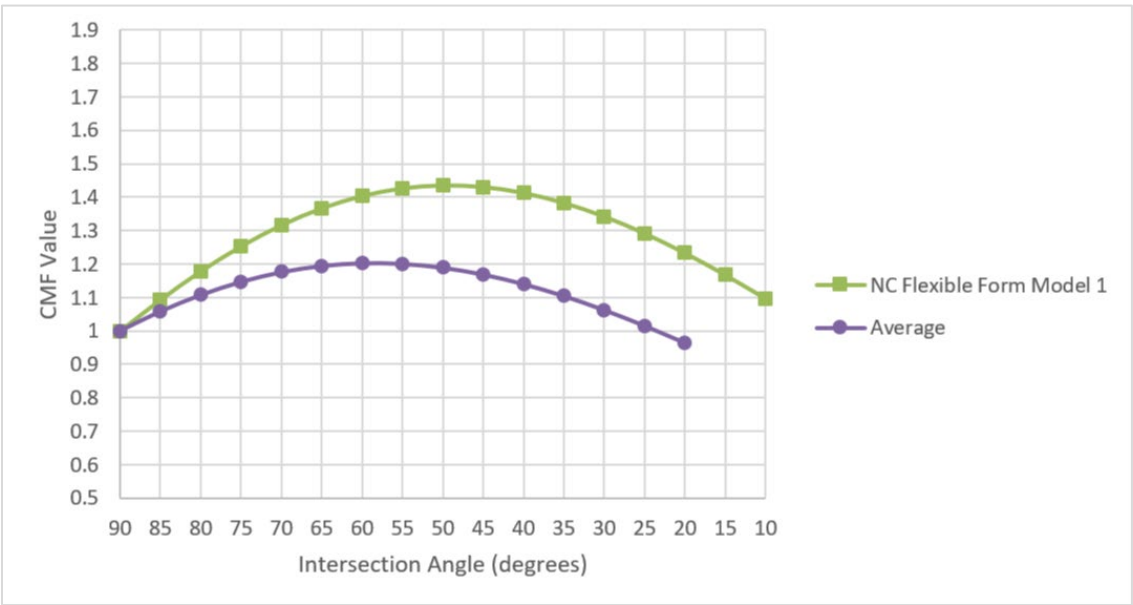
The CMFunctions for total crashes on rural four-leg intersections with two-lane major roadways are shown in figure 34. As with the CMFunctions for total rural four-leg intersections, the OH curve predicts more crashes than the MN curve, with nearly 20 percent difference between the two at their peak values. The OH curve peaks at 55 degrees, and the MN curve peaks at 60 degrees. The OH dataset was truncated at 20 degrees; therefore, the average curve does not show predictions for angles below this measure. Although the OH curve only dips below a CMFunction value of 1 at approximately 20 degrees, the MN curve shows a potential crash-reduction effect for minimum angles below 30 degrees.



Source: FHWA.

Figure 34. Graph. CMFunctions for rural four-leg two-lane intersections.

During this analysis, a small sample of intersection data were acquired from facilities in North Carolina (NC). Although this dataset was too small to provide an adequate comparison for all roadway types, a flexible form model 1 equation was derived for rural four-leg two-lane intersections. This CMFunction peaked at 50 degrees and predicted higher CMFunction values than either of the other two State datasets or the average curve (which does not include data from NC); however, it does verify the shape of the CMFunction.

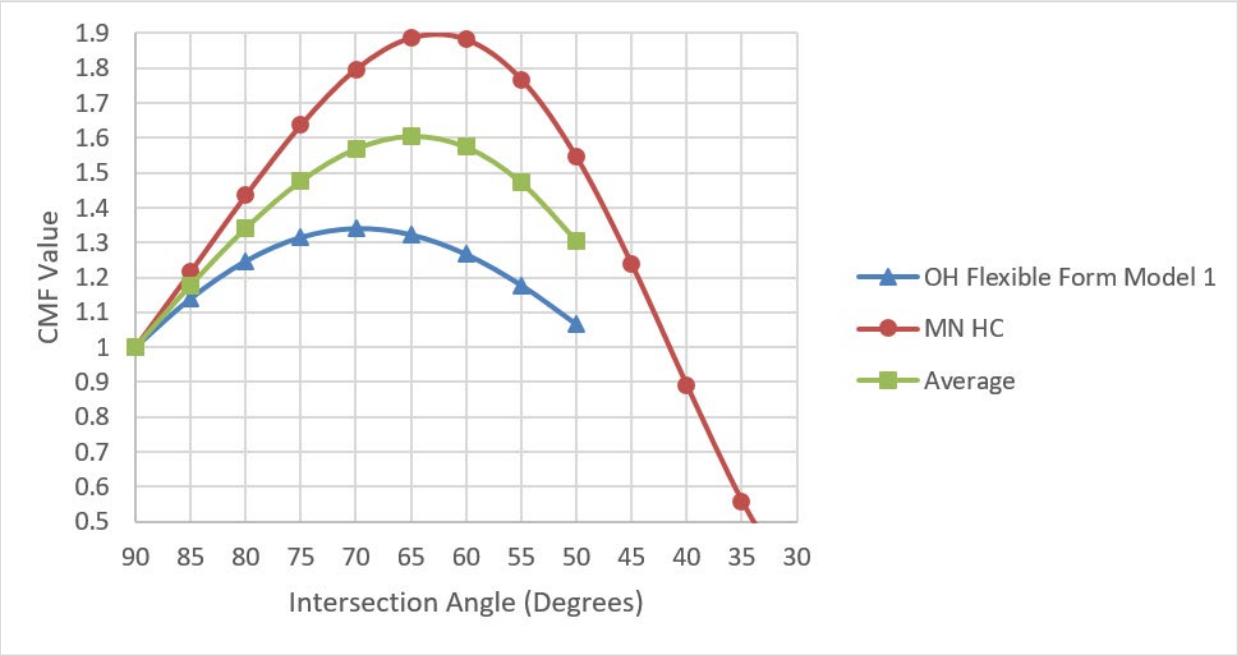


Source: FHWA.

Figure 35. Graph. CMFunctions for rural four-leg two-lane intersections with NC data.

Rural Four-Leg Multilane CMFunctions

For comparison, a Hoerl Curve model was developed for MN data for rural four-leg intersections with multilane major-road approaches. This model had comparably low AIC and BIC values and allowed for comparison between the OH data and the MN data. This MN CMFunction developed using the Hoerl Curve predicts more crashes at each intersection-angle category than the OH CMFunction, which was developed using flexible form model 1. The MN CMFunction, which peaks at 65 degrees, predicts an increase in total crashes at this facility type by 88 percent. Comparatively, the OH CMFunction, which peaks at 70 degrees, predicts only a 34 percent increase in crashes at this minimum angle. The OH function and the average function, which follows the shape of the OH function, are both truncated at 50 degrees due to a small number of sample sites below this. The inclines and declines of the MN function are sharper than those of the OH function; the percentage of predicted crashes changed by approximately 20 percent with each 5-degree change in minimum angle. The MN function also shows a protective effect on crashes below 40 degrees. Although this MN function predicts higher CMFunction values than the OH function predicts, this result is not consistent with the other intersection types. The high MN values may be due to either some inherent population differences between the two States or some other bias introduced into the data-selection process. Still, the functions for both States follow roughly the same shape.



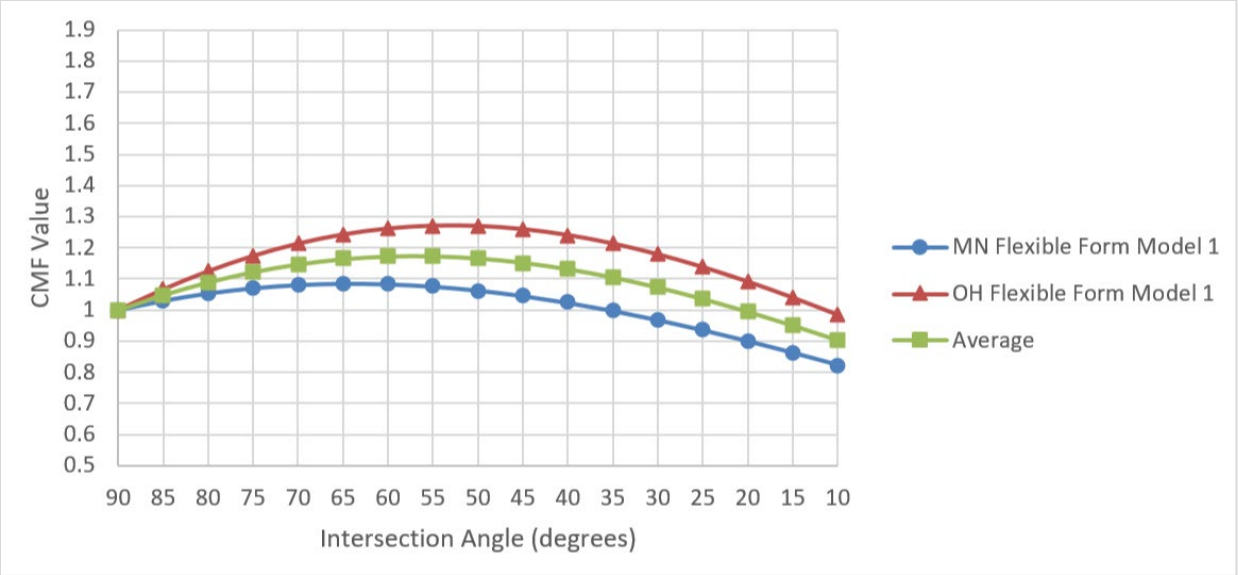
Source: FHWA.

Figure 36. Graph. CMFunctions for rural four-leg multilane intersections.

All Rural Three-Leg CMFunctions

The CMFunctions for total crashes at all rural three-leg intersections are shown in figure 37. As shown in the figure, the OH CMFunction predicts more crashes per intersection angle than the MN curve predicted; the OH CMFunction shows an increase or decrease in crashes of roughly five percent per five degrees. The MN CMFunction is flatter and shows a reduction in crashes

for minimum angles below 35 degrees. Both CMF curves were developed using flexible form model 1, but the curves peak at slightly different angles. The OH curve peaks at 55 degrees, and the MN curve peaks at 65 degrees. CMFunction values peak at 1.27 and 1.09 percent at these angle measures, respectively. The average curve peaks at 55 degrees like the OH curve with a CMFunction value equal to 1.17.

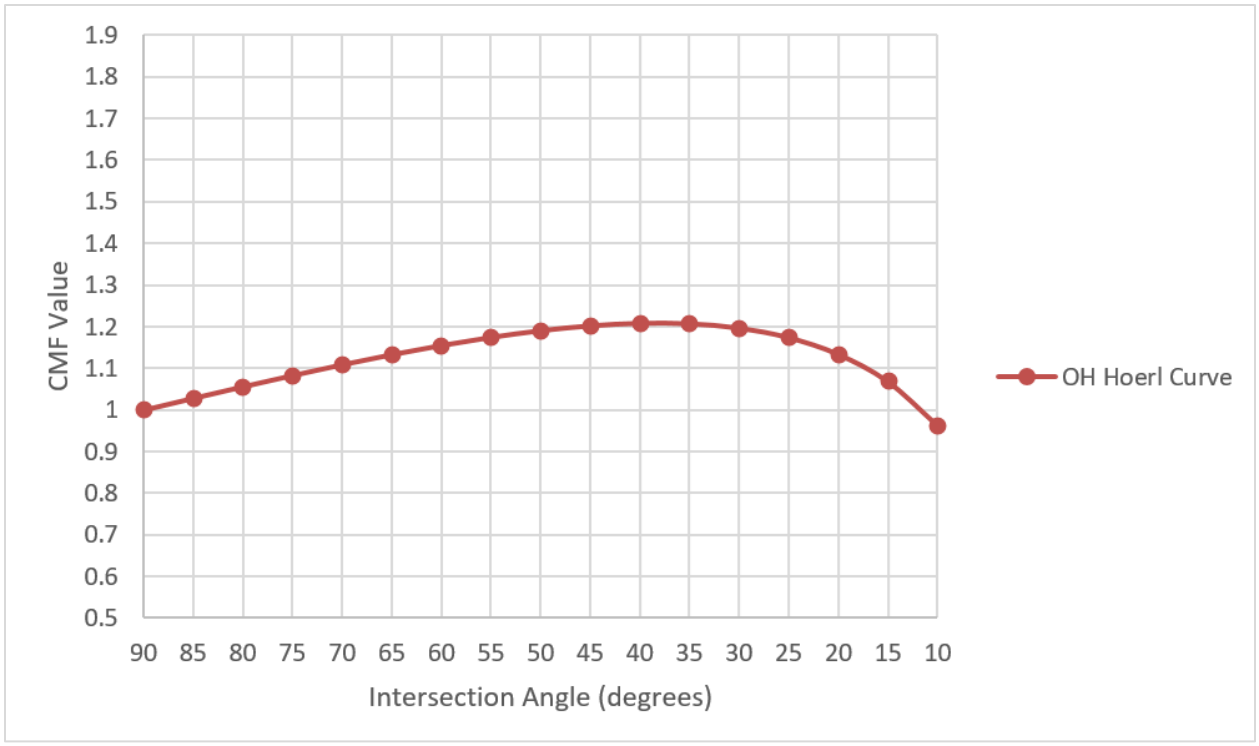


Source: FHWA.

Figure 37. Graph. CMFunctions for rural three-leg total intersections.

Rural Three-Leg Two-Lane CMFunctions

The CMFunction for rural three-leg intersections with two-lane major approaches is shown in figure 38. Due to a lack of data, only a single curve for the OH data could be derived. This curve differs from many of the other CMFunctions because it was derived using the Hoerl Curve equation. The curve also shows lower variation in CMFunction value than many of the other CMFunctions developed for other intersection types. The CMFunction value only changes approximately 10 percent between 90 degrees and 70 degrees. The curve peaks at 40 degrees at a CMFunction value of 1.21. It then declines quickly, as the CMFunction value decreases by almost 10 percent over 10 degrees. There is a protective effect for a minimum angle of 10 degrees, and no angle measures are truncated from the model.

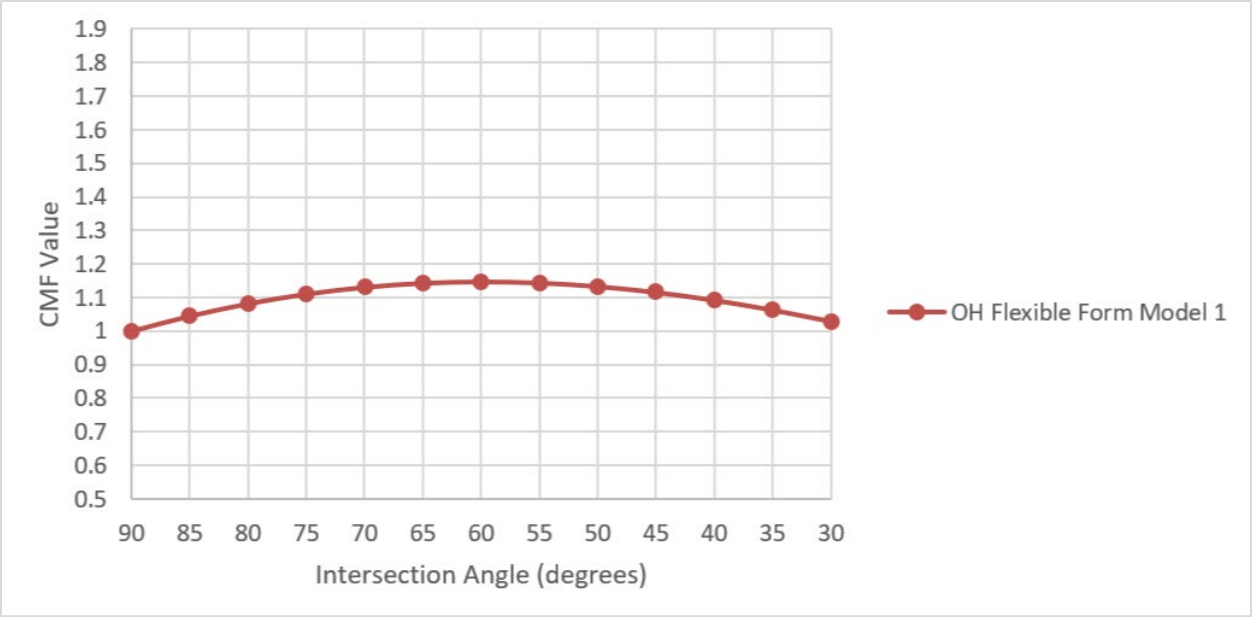


Source: FHWA.

Figure 38. Graph. CMFunction for rural three-leg two-lane intersections.

Total Urban Four-Leg CMFunctions

Only the OH data could be used to produce a CMFunction for all urban four-leg intersections. The CMFunction was developed using estimates from the flexible form model 1 for this facility type for OH data. The function is shown in figure 39. The curve is relatively symmetrical around the 60-degree peak and shows only minimal changes in CMFunction values between angle measurements. A 5-degree increase or decrease in minimum angle resulted in only a 2- or 3-percent change in the CMFunction value. The peak CMFunction value was approximately 1.15. The results were truncated at 30 degrees, but with the 3-percent decrease in CMFunction value on the declining tail of the curve, a protective effect may have been observed at low-angle measurements.

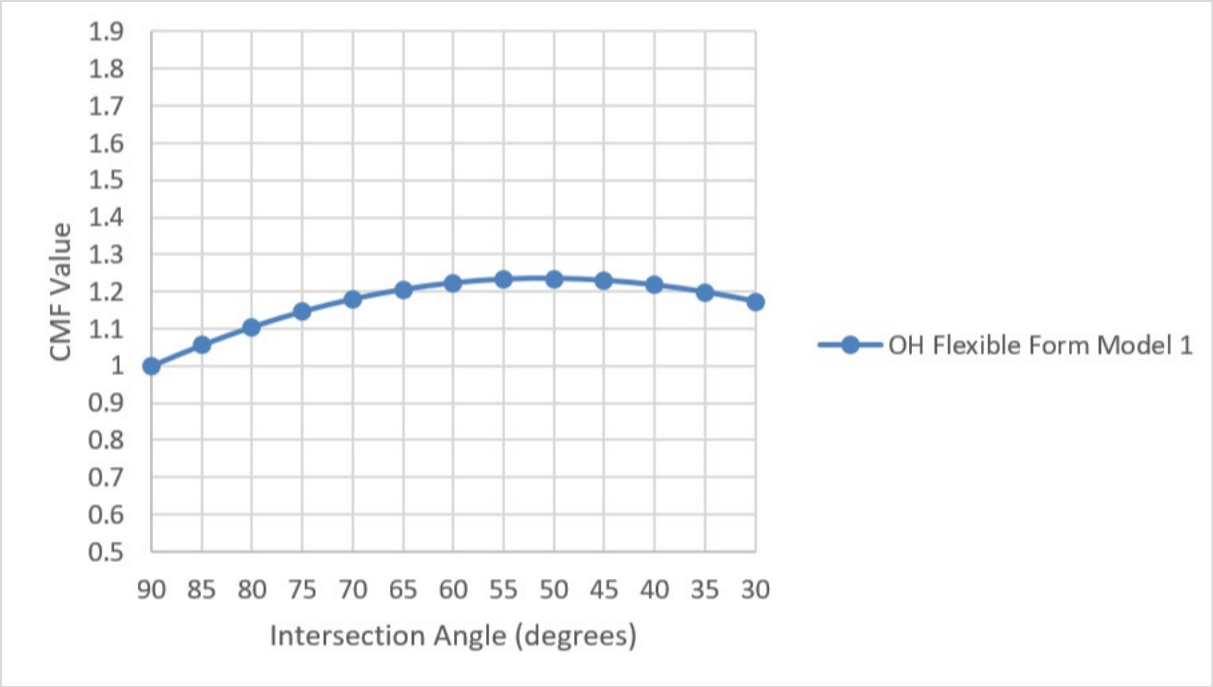


Source: FHWA.

Figure 39. Graph. CMFunction for urban four-leg total intersections.

Urban Four-Leg Two-Lane CMFunctions

The CMFunction for urban four-leg intersections with two-lane major approaches developed using data from OH is shown in figure 40. This curve was developed using the flexible form model 1. No CMFunction was developed using MN data; therefore, no average curve could be graphed. This curve's lowest CMFunction value corresponds to a minimum angle of 90 degrees, and the curve peaks at a minimum angle of 50 degrees with a CMFunction value equal to 1.23. The initial increase in CMFunction value per five-degree decrease in minimum angle is approximately 5 percent, but the curve slightly flattens at the top, which results in one-percent or two-percent changes in CMFunction value per 5-degree change in minimum angle. The curve is truncated at 30 degrees because of small sample size, and at this cutoff point, the CMFunction value is still roughly 17 percent greater than the value at 90 degrees.

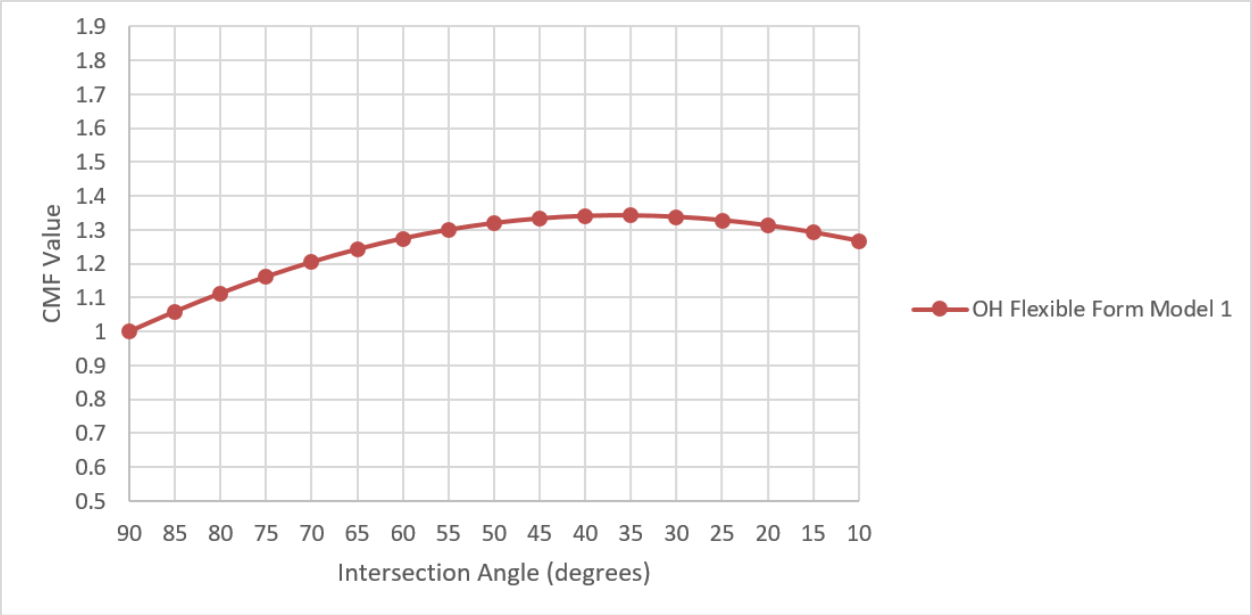


Source: FHWA.

Figure 40. Graph. CMFunction for urban four-leg two-lane intersections.

All Urban Three-Leg CMFunctions

The CMFunction for total crashes at all urban three-leg intersections is shown in figure 41. This curve was developed using the OH dataset and the flexible form model 1. This curve shows a consistent change of three percent to four percent in the CMFunction value per change in five degrees of the minimum angle. The lowest CMFunction value occurs at 90 degrees; the highest CMFunction value occurs at 35 degrees. This peak CMFunction value is 1.34, signifying a 34-percent increase in total crashes at this minimum angle. At 60 degrees, the CMFunction value is 27-percent higher than the base value at 90 degrees. There is no truncation in this dataset.

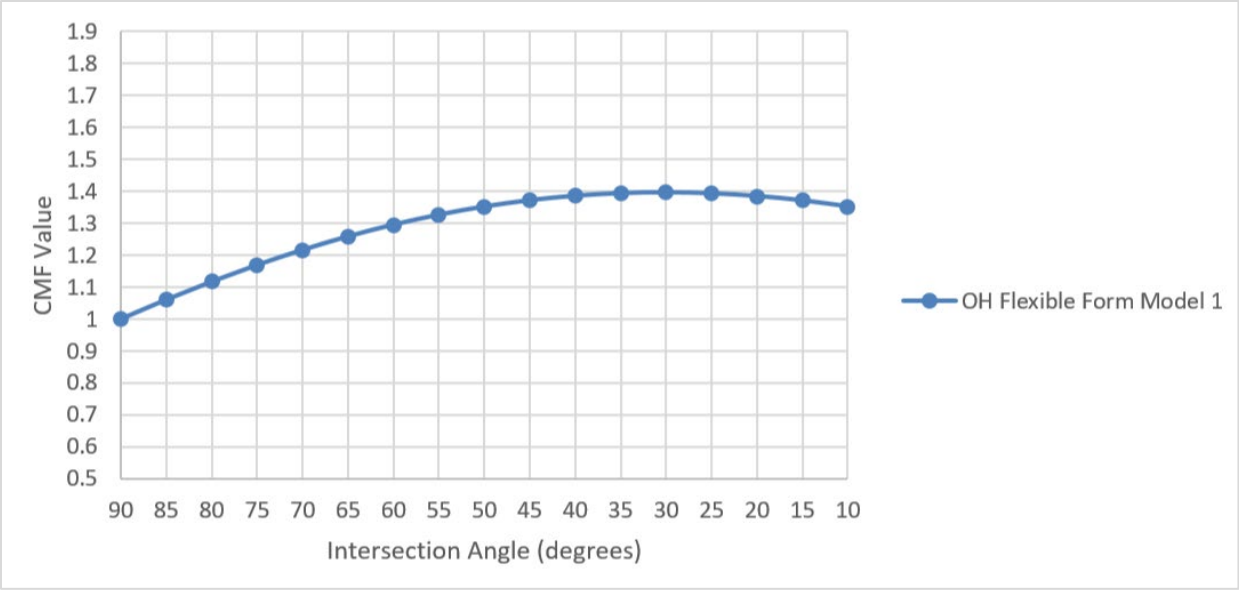


Source: FHWA.

Figure 41. Graph. CMFunction for urban three-leg total intersections.

Urban Three-Leg Two-Lane CMFunctions

The CMFunction for total crashes at urban three-leg intersections with two lanes on the major approach, as shown in figure 42, is similar to that of all urban three-leg intersections. This CMFunction was developed using only data from OH sites, and the model form used to derive the estimates was flexible form model 1. The lowest CMFunction value predicted by the curve occurs at 90 degrees, and the highest occurs at 30 degrees; the peak CMFunction value is approximately 1.40. The CMFunction value at 60 degrees is approximately 1.29. There is no truncation in this dataset.



Source: FHWA.

Figure 42. Graph. CMFunction for urban three-leg two-lane intersections.

CRITICAL ANGLE ASSESSMENT

In addition to the development of CMFunctions, the other objective of this research was to determine if there is a critical minimum angle at which safety is substantially diminished. Recall that the Green Book (page 9-27) currently recommends a minimum angle of 60 degrees: "…an angle of at least 60 degrees provides most of the benefits of a 90-degree intersection while reducing the right-of-way takings and construction costs often associated with providing a right-angle intersection."[(1)] The purpose of this assessment was to determine if the policy requiring a minimum angle of 60 degrees is appropriate.

Table 44 shows intersection angles at which CMFunction values peaked for OH curves and MN curves and average curves, where applicable. It also shows the CMFunction value for these peak intersection angles. All CMFunction values shown are solely for total crashes. As seen in the table, the results of this analysis question the conventional wisdom of a minimum intersection angle of 60 degrees providing most of the benefits of a 90-degree intersection.[(1)] In fact, two of the CMFunctions developed showed crashes peaking at 60 degrees, namely for rural four-leg intersections with two lanes on the major approach and for all urban four-leg intersections. The CMFunction values at these two peaks were 1.20 and 1.15, respectively. Several other CMFunctions, specifically those for all rural four-leg intersections, rural four-leg intersections with more than two lanes on the major approach, all rural three-leg intersections, and urban four-leg intersections with two lanes on the major approach, peaked within five or ten degrees of this prescribed minimum CMFunction value. Based on these curves for total crashes, the design recommendation of a minimum angle of 60 degrees should be reconsidered.

Table 44. Peak CMFunction values and corresponding angles for total crashes for all intersection types.

Intersection Type	Peak Intersection Angle (OH, MN, Avg)	Peak CMF Value (OH, MN, Avg)
Rural four-leg total	65, 65, 65	1.40, 1.23, 1.32
Rural four-leg two-lane	55, 60, 60	1.13, 1.28, 1.20
Rural four-leg multilane	70, 65, 65	1.34, 1.89, 1.61
Rural three-leg total	55, 65, 55	1.27, 1.09, 1.17
Rural three-leg two-lane	40, —, —	1.21, —, —
Urban four-leg total	60, —, —	1.15, —, —
Urban four-leg two-lane	50, —, —	1.23
Urban three-leg total	35, —, —	1.34
Urban three-leg two-lane	30, —, —	1.40

—No data available.
Avg = average.

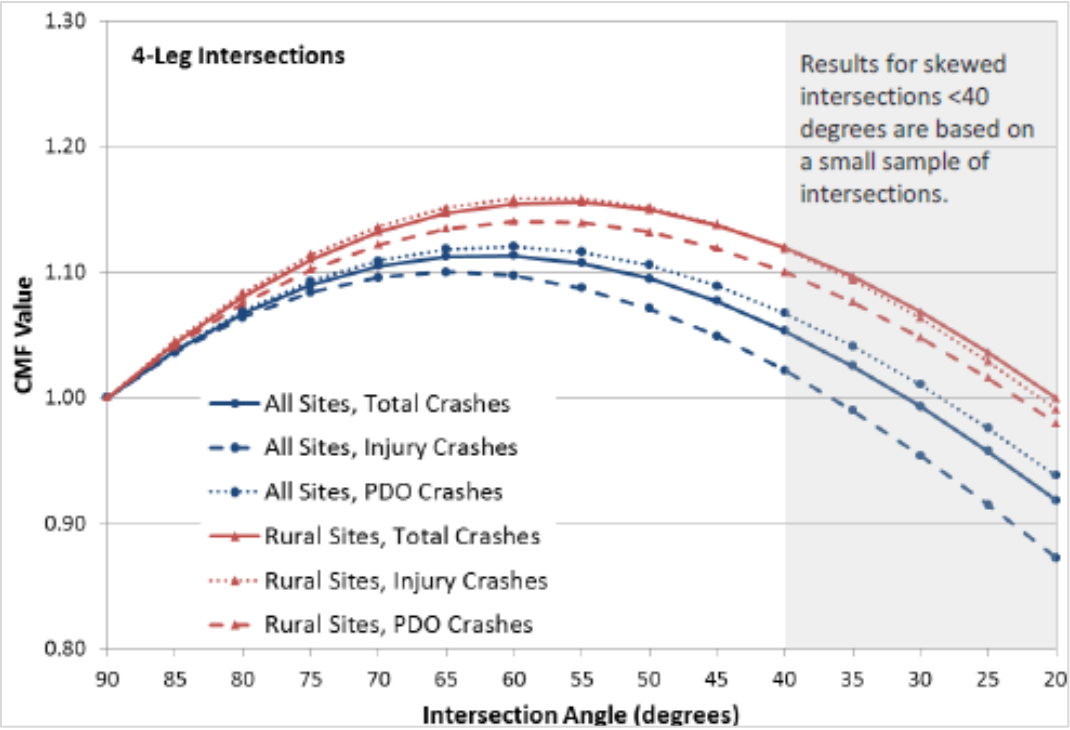
The CMFunction values for total crashes at different angle categories, as identified either by an average CMFunction or an OH function when other data were unavailable, are shown in table 45. Aside from rural three-leg intersections with two lanes on the major approach, total urban three-leg intersections, and urban three-leg intersections with two-lanes on the major approach, all intersection types for which CMFunction were developed for total crashes showed crashes peaking between 65 degrees and 50 degrees. These results question design recommendations that intersections with minimum angles equal to 60 degrees are suitable and have minimal impacts on safety. In fact, for at least one intersection type (rural four-leg multilane), the crashes at a 60-degree intersection angle were 57 percent higher than they were at a 90-degree angle. Although the intersection types with unshaded columns have CMFunctions that peaked at much lower intersection-angle values, most of these curves show fewer crashes at severe-angle skews or even protective effects for severe skews. These results confirm that remedial efforts may show the greatest safety benefits if targeted at intersections with minimum angles in the range of 65–50 degrees.

These results are also confirmed by the CMFunction analysis specifically conducted using MN data for crashes of different severities at four-leg rural intersections as reported in appendix F in table 117. As shown in figure 43 and figure 44, the largest crash reductions occur between the intersection angles of 80 and 55 degrees. Depending on the scenario, the maximum value occurs between 65 degrees and 55 degrees.

Table 45. CMFunction values derived from all models for total crashes at all intersections.

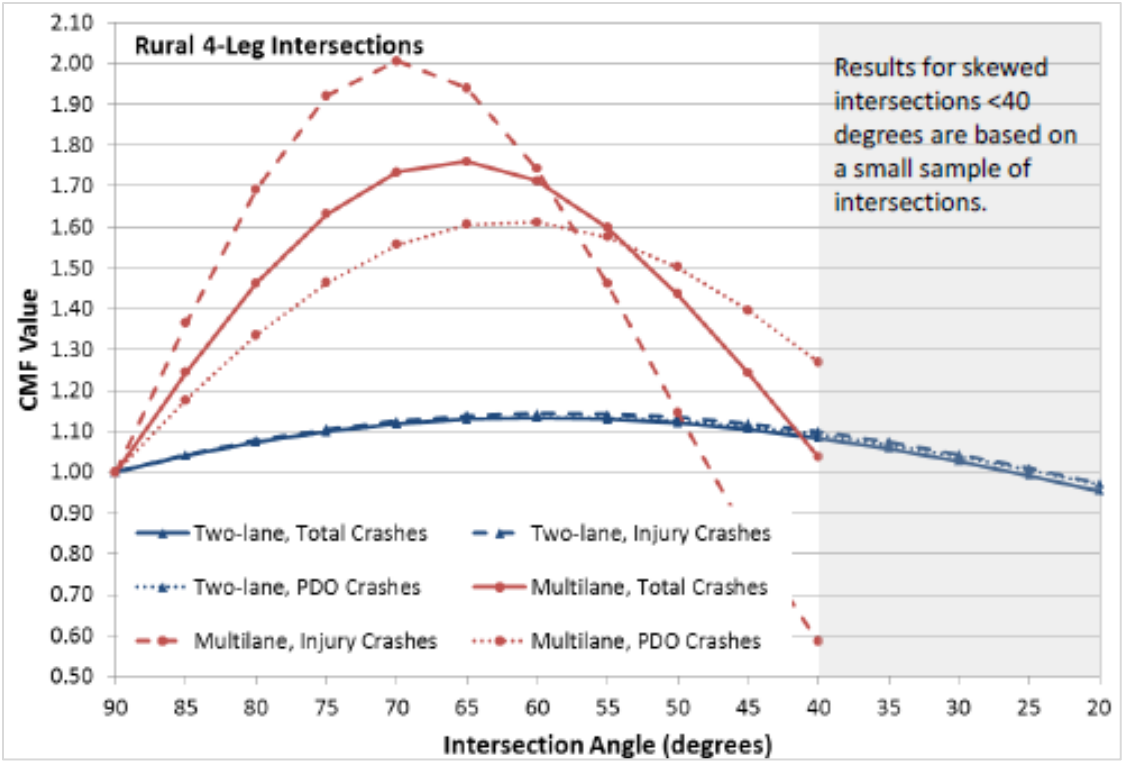
Intersection Scenario	80 Degrees	75 Degrees	70 Degrees	65 Degrees	60 Degrees	55 Degrees	50 Degrees
Rural four-leg total (avg)	1.19	1.26	1.30	1.32*	1.31	1.29	1.24
Rural four-leg two-lane (avg)	1.11	1.15	1.18	1.20*	1.20*	1.20*	1.19
Rural four-leg multilane (avg)	1.34	1.48	1.57	1.61*	1.57	1.47	1.31
Rural three-leg total (avg)	1.09	1.12	1.15	1.16	1.17*	1.17*	1.17*
Rural three-leg two-lane (OH)	1.06	1.08	1.11	1.13	1.15	1.17	1.19
Urban four-leg total (OH)	1.08	1.11	1.13	1.14	1.15*	1.14	1.13
Urban four-leg two lane (OH)	1.10	1.15	1.18	1.20	1.22	1.23*	1.23*
Urban three-leg total (OH)	1.11	1.16	1.20	1.214	1.27	1.30	1.32
Urban three-leg two-lane (OH)	1.12	1.17	1.22	1.26	1.29	1.33	1.35

*Peak CMFunction values for each facility type.
Avg = average.



Source: FHWA.

Figure 43. Graph. MN CMFs derived from the flexible form models for four-leg intersections, considering different severities.



Source: FHWA.

Figure 44. Graph. CMFunctions derived from the MN flexible form models for rural four-leg intersections with different severities.

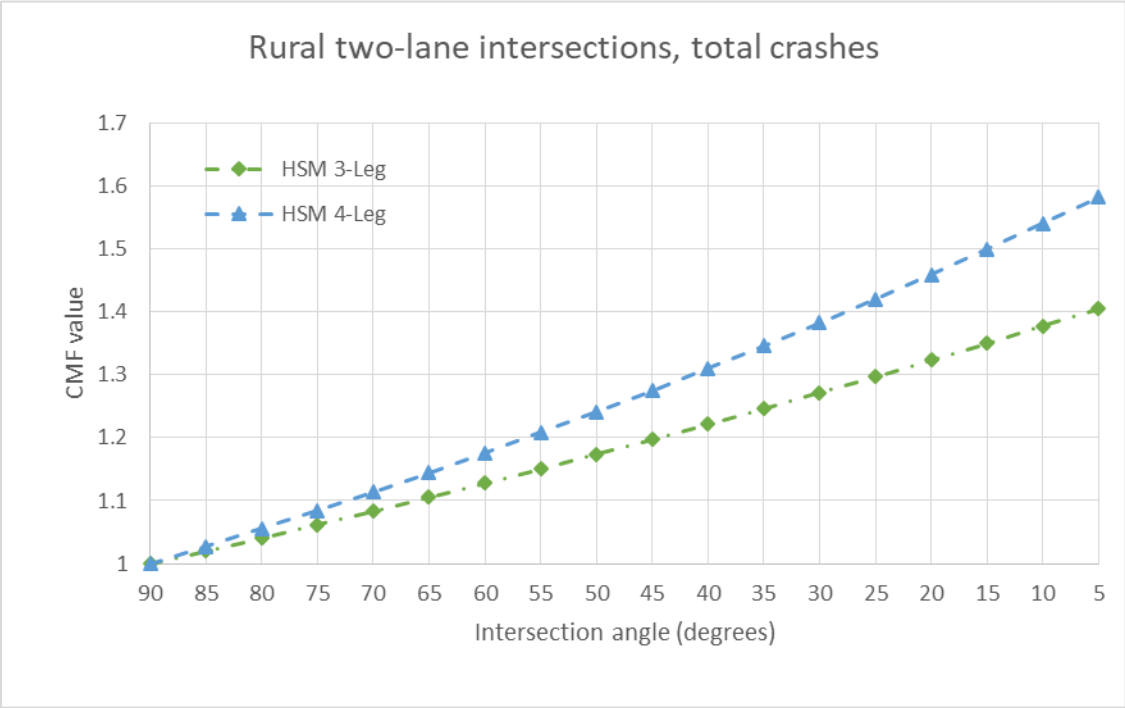
The fact that the largest angle at which the CMFunction values peak is 65 degrees warrants consideration of a critical minimum angle greater than 65 degrees if the goal is to select an angle at which safety is not substantially compromised in a right-angle intersection. Predictive models and CMFunctions indicate that any angle between 90 degrees and the current design policy value of 60 degrees will have a negative impact on safety; therefore, the policy of right-angle intersections being preferred still holds for both two-lane and multilane intersections.[(1)]

For this study, the research team examined the intersection angle that should be established as a minimum for instances in which a right-angle intersection cannot be achieved. Selection of this angle was subjective and based on the level of diminished safety considered acceptable. For example, for rural four-leg intersections on two-lane roads, an intersection angle of 65 degrees resulted in a CMF no greater than 1.2. However, for the same intersection type, an intersection angle of at least 80 degrees was needed if the CMF was no greater than about 1.1. The research team suggests that the decision regarding the acceptable level of diminished safety should be made by a specific agency or a combination of AASHTO and FHWA. The practitioner can use the CMFunctions to determine the expected safety benefit of changing the intersection angle.

COMPARISON OF RESULTS TO PRIOR CMFs

Previously developed CMFs for intersection angle are few. As discussed in chapter 2, there are CMFs present in the HSM for total crashes at stop-controlled intersections on rural two-lane roads. These CMFs were derived from cross-sectional regression models in a manner similar to

the approach used in this research.[25] These CMFs were for use in chapter 10 of the HSM to develop safety predictions for rural two-lane roads. Separate CMFs were available for four-leg and three-leg intersections as shown in figure 45. Values were provided in the HSM for intersection angles between 5 degrees and 90 degrees. The predicted impact of intersection angle on safety was greater for four-leg intersections compared to three-leg intersections. Both CMFs were derived from exponential models and assume a log–linear relationship between crashes and intersection angle.



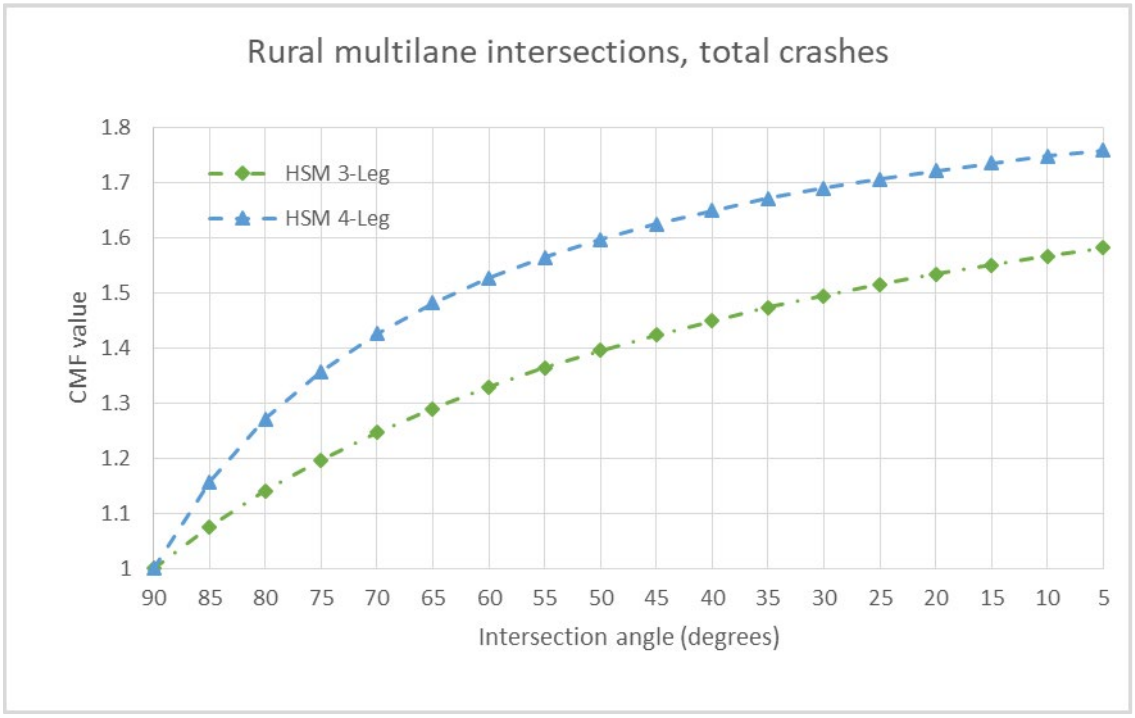
Source: FHWA.

Figure 45. Graph. CMFs from the HSM for total crashes at rural two-lane roadway intersections.[24]

The HSM also includes CMFs to calculate the effects of intersection angle at rural multilane intersections. As noted in chapter 2, these CMFs were developed as part of an FHWA study to validate and calibrate the crash prediction statistical models for rural intersections within IHSDM.[26] Separate CMFs are available for four-leg and three-leg intersections. The range of intersection angles for which values are provided extend from 15 to 90 degrees. As shown in figure 45, the predicted effect of intersection angle on safety is greater for four-leg intersections compared to three-leg intersections.

Another model discussed in chapter 2 included a component for intersection angles.[28] After further review of the study, the research team determined it was not appropriate for comparison to the models of the current study. The model developed had a small sample size (29 skewed and 39 nonskewed intersections) and a limited range of traffic volumes on the major roadway (up to 5,200 vpd). The model was also for three- and four-leg intersections combined.

The first comparison made was for the CMFunctions developed for rural two-lane intersections. Figure 46 shows the HSM four-leg CMF and the recommended CMFunction from the current study. The CMFunction was developed by taking an average of the values predicted for the MN and OH datasets for total crashes at rural two-lane intersections. The recommended CMFunctions for both States were those developed from the flexible form model. The recommended study CMFunction produced values greater than the HSM function for angles between 60 and 90 degrees but lower values for angles less than 60 degrees. As previously noted, the HSM CMF also extended to a range that included a skew angle as small as five degrees and assumed a monotonic relationship between the CMF and intersection angle. However, the range of data available by angle of intersection at the study sites was not documented in the relevant research. As discussed in the remaining text of this section, data used for the CMFunction derived from the current study do not have this same range and there are specific recommendations for the lower end of the intersection-angle spectrum.



Source: FHWA.

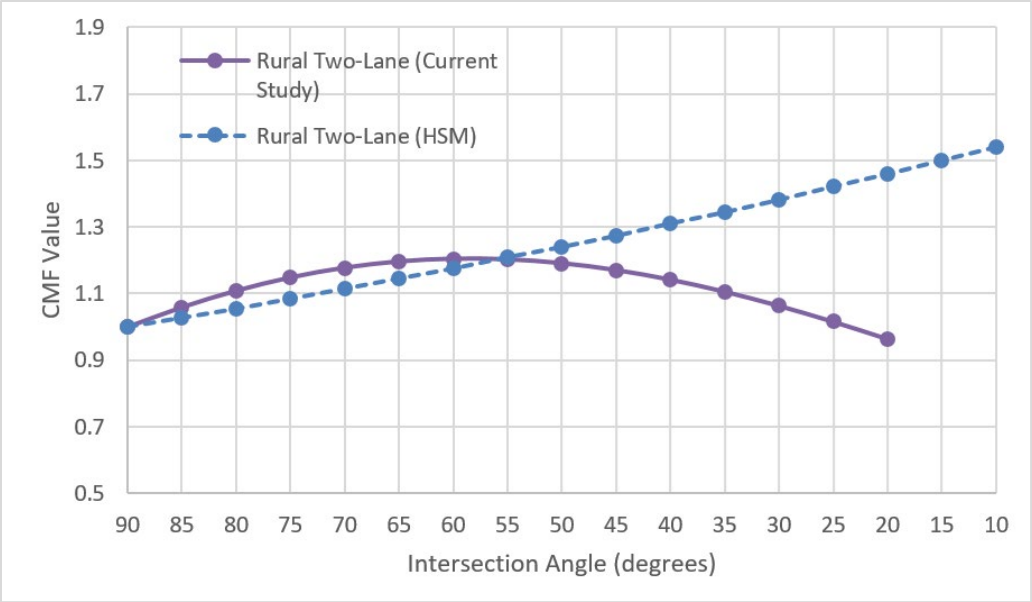
Figure 46. Graph. CMFs from the HSM for total crashes at rural multilane roadway intersections.[24]

While both the current study CMFunction and the HSM CMF were derived from an NB regression model, there were differences in the methodology. The variables included in the model that produced the HSM CMF were required to be statistically significant at a significance level of 0.15 or less. Skew angle in that model had a *p*-value of 0.108. The comparative model from this study required all variables to be statistically significant at a significance level of 0.05 or less. Intersection angle in this model had a *p*-value less than 0.0001 for both MN and OH data. This difference in the statistically significant requirements can obviously affect the parameters included in the NB models and the regression coefficients of the derived CMFunctions. Regardless of the reasons, the base CMFunction from the current study produces comparable

values of the effect of intersection angle on safety for angles greater than 60 degrees and more conservative values for angles less than 60 degrees.

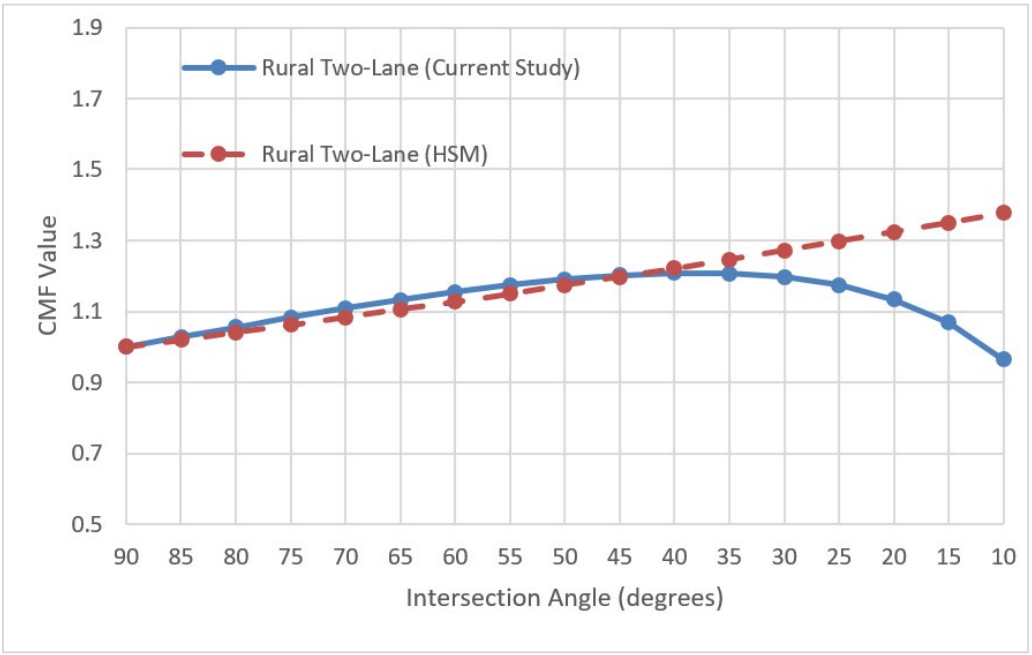
The CMFunction developed using OH data for the rural three-leg two-lane intersections also deviated from that prescribed in the HSM, as seen in figure 47 and figure 48. Between 90 degrees and 45 degrees, the two curves ran parallel and predicted nearly identical values. However, for an intersection angle less than 45 degrees, the HSM CMF estimated a much larger CMF value. The CMFunction developed using OH data followed an upward convex-curved shape while the HSM curve follows a monotonic relationship. Differences in statistical significance existed for the intersection-angle variable between the study used to develop the HSM curve and the study used to develop the OH curve. The *p*-value for the minimum-angle variable in the OH study was 0.0023. As with the rural four-leg two-lane intersections, the study curve was more conservative in predicted values at small intersection-angle measures.

The second comparison was for the CMFunctions developed for rural multilane intersections. Figure 49 shows the HSM four-leg CMF and the recommended average CMFunction from the current study for total crashes at rural multilane intersections. The recommended CMFunction was the average of the two curves developed using the flexible form model 1 for OH and the Hoerl Curve model for MN. There were obvious differences in the shape of these two functions. The CMFunction recommended by this study produced values much greater than the HSM function for angles between 60 and 90 degrees. At a peak of 65 degrees, CMFunction values from the current study began to decline. For intersection angles below approximately 62 degrees, the current study CMFunction produced values less than the values produced by the HSM CMF. The HSM CMF also extended to a range that included a skew angle as small as 15 degrees with an exponential relationship across all intersection angles. However, the range of data available by angle of intersection at the study sites was not documented in the relevant research. The data used for the CMFunction derived from the current study do not have this same range in MN and OH. There are specific recommendations for the lower end of the intersection angle spectrum, which are examined in the next section of this report.



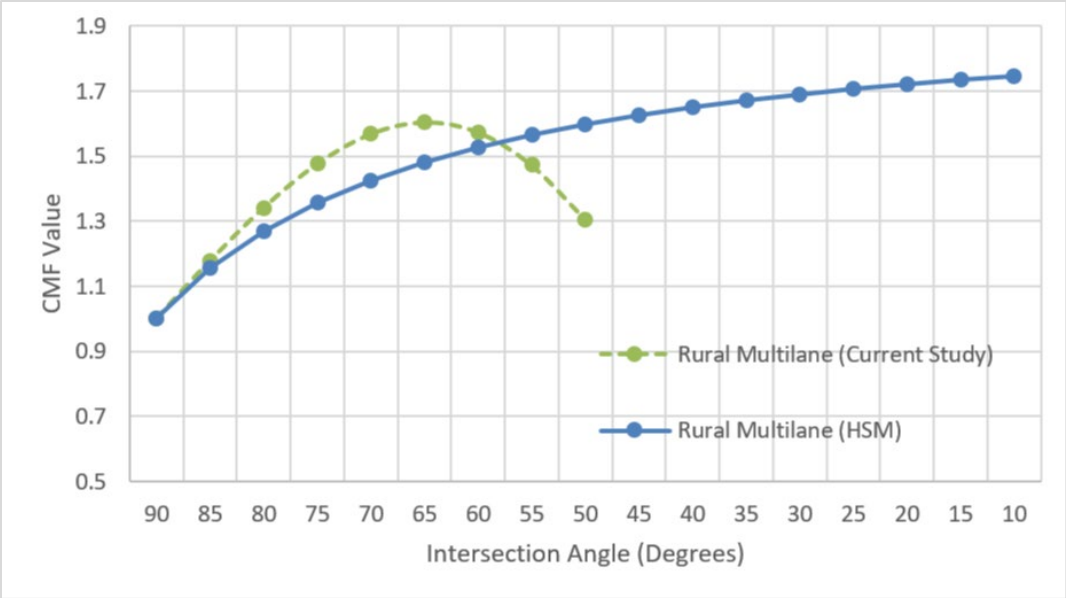
Source: FHWA.

Figure 47. Graph. CMFs from the current study and the HSM for total crashes at rural four-leg two-lane intersections.



Source: FHWA.

Figure 48. Graph. CMFs from the current study and the HSM for total crashes at rural three-leg two-lane intersections.

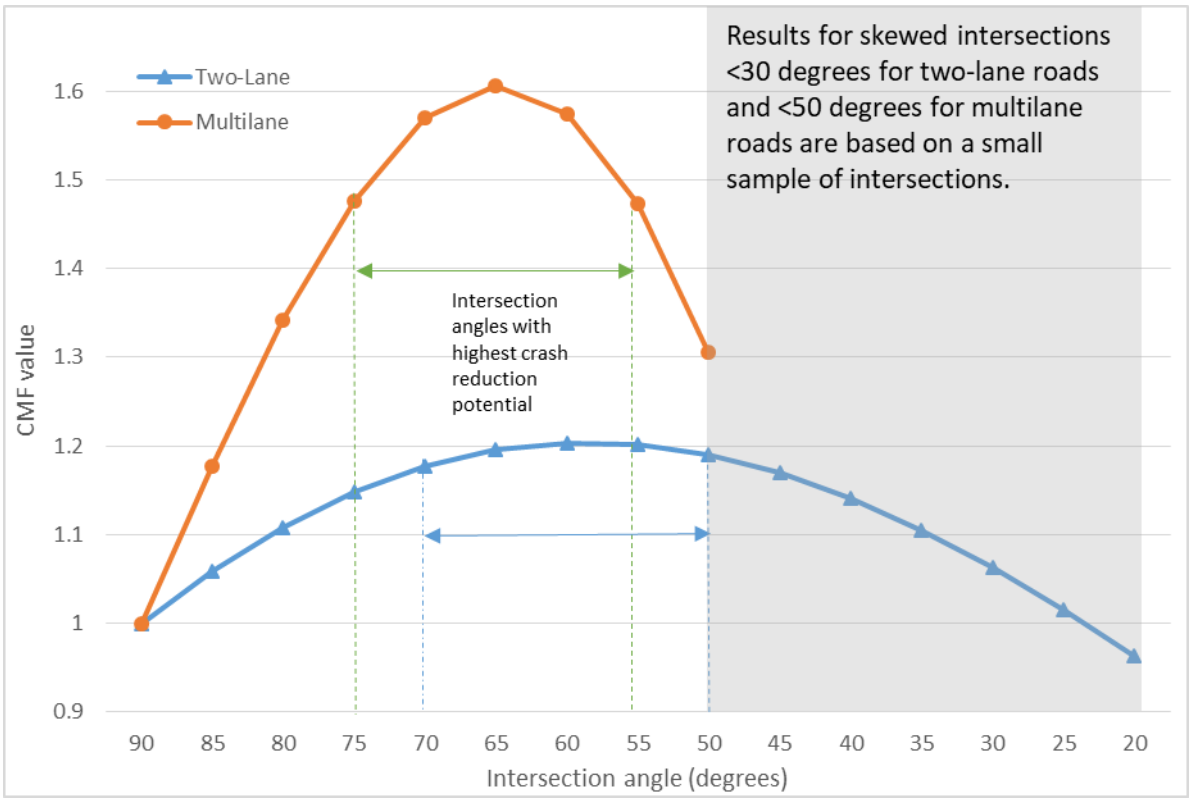


Source: FHWA.

Figure 49. Graph. CMFs from the current study and the HSM for total crashes at rural four-leg multilane intersections.

In summary, the CMFunctions for intersection angles derived from the models developed in the current study and those included in the current edition of the HSM have some differences regarding the range of intersection angles. The current study and HSM CMFs for rural four-leg two-lane intersections produced similar values for the range of angles between 90 and 60 degrees. The HSM CMF, however, continued to show a decrease in safety for intersections with angles below 60 degrees. Current research does not support this finding as indicated by the lower CMFunction values below 60 degrees. A similar finding was observed for rural three-leg two-lane roads, although the intersection angle at which findings of this research and the HSM CMF diverge is 45 degrees and lower. The rural multilane CMFunctions from the current study, compared to HSM CMFs, showed a more-pronounced effect of intersection angle on safety at locations with angles as small as five degrees. However, unlike HSM CMFs, the current study results did not show a continuing degradation in safety as a function of intersection angle as the angle continued to decrease.

The final point on the assessment of the critical angle focuses on the shape of the derived CMFunction and its meaning for practical applications. Prior to this study, the limited research attempting to relate crashes to intersection angles produced relationships that showed a continuous increase in crashes as the angle of the intersection decreased below 90 degrees. The CMFs currently included in the HSM indicate that this relationship existed from 90 degrees to an intersection angle of 5 degrees for rural two-lane intersections and 15 degrees for rural multilane intersections (figure 45 and figure 46). The results of this research produced a curvilinear relationship between crashes and intersection angle (figure 50).



Source: FHWA.

Figure 50. Graph. Crash-reduction potential based on CMFs for rural two-lane and multilane intersections.

One result of the shape of the CMF(flex) curve and CMF Hoerl Curve is the curve peaks for most intersection types between 50 and 65 degrees (table 45). Figure 50 shows the greatest potential for achieving crash reductions based on this CMF-angle relationship is to have intersections with intersecting angles on either side of this peak. For rural two-lane roads, the highest crash-reduction potential is between intersection angles of approximately 50 and 70 degrees. The two-lane CMFunction values in this range are at or greater than 1.15. For rural multilane roads, the highest crash-reduction potential falls between angles of approximately 55 and 75 degrees. The multilane CMFunction values in this range are at or greater than 1.45.

Acute angle intersections (less than 40 degrees) show reductions in crashes are much less than the high potential ranges previously addressed. The sample of intersections in this lower-angle range was limited in this study to the OH dataset. Certain subsets of the MN data also had low-angle truncations. Subsequently, the recommendations in the next chapter reflect this restriction in the data. Nonetheless, there were enough sites in the remainder of the angle spectrum for both States to have confidence in the shape of this relationship and the fact that there is a peak in crash reductions between 50 and 65 degrees followed by a lesser effect at more severe angles. The shape of the function is similar to the shape discovered in the raw crash data.

The reason for this shape is not fully understood. One possible explanation may be human behavior and an understanding by drivers that these locations with more acute angles require one to exercise additional caution. Another reason could be that many intersections in the lower

intersection-angle categories that had poor safety records had been improved over time. Thus, the safety performance for intersections that remain in these low-angle categories is better than the safety performance in the high-angle categories where systemically fewer improvements may have occurred over time. Finally, the results might also be an artifact of current policy. With 60 degrees as the current threshold for the minimum critical angle in many States, the focus of past interventions related to intersection-angle issues was on locations that fall below this threshold. The result of the last two possibilities may be a migration in high crash locations from locations with acute angles (less than 40 degrees) to locations in the new high potential range (50–75 degrees). Regardless of the reason, the results of this research indicate that there may be a greater benefit in addressing intersections with angles greater than 60 degrees as opposed to those with angles less than 60 degrees.

CHAPTER 6. SUMMARY AND CONCLUSIONS

SUMMARY

The preferred design for intersections includes adjacent legs that intersect at 90 degrees. However, there are occasions where physical constraints result in intersection angles less than 90 degrees, producing skewed intersections. These intersections create potential safety and operational problems for both motorists and nonmotorists. To date, the crash-based safety research on this issue has been limited.

A review of geometric design policies confirmed that there is consensus within the highway-design field that intersecting roadways should be aligned to meet at 90 degrees. There was also a common recognition of the safety and operational problems introduced for different modes of travel once an intersection becomes skewed. However, there are differences among these policies regarding the critical minimum angle: the angle at which consideration should be given to realigning the intersection or implementing additional traffic control measures. That angle currently ranges from 60 to 75 degrees, depending on the reference.

A review of the research literature revealed that there have been very few studies that attempted to define the safety relationship of intersection angle to crashes. One study that derived CMFs for intersection angle did so for rural two-lane roads only and assumes a monotonic relationship between crashes and intersection angle.[25] A second study derived intersection angle CMFs for rural multilane roads, assuming a similar relationship between crashes and the angle of the intersection.[26] The CMFs from both of these studies are included in the HSM.[24]

Additional noncrash-based research has produced evidence that intersection angle can impact drivers and pedestrians whose physical capabilities have diminished. Older persons who have reduced flexibility may have difficulty turning their heads and necks to judge gaps in traffic at skewed intersections. Older or disabled pedestrians who walk at slower speeds will be exposed to traffic for a longer period of time at crossings that are lengthened as a result of the intersection angle. These research findings led to the critical minimum angle recommendation of 75 degrees in FHWA's *Highway Design Handbook for Older Drivers and Pedestrians* as a practice to accommodate age-related performance deficits.[6]

The objective of this study was to derive quantitative relationships between intersection angle and safety, where intersection crashes define safety. The relationships were used to determine appropriate CMFs for reducing or eliminating the skew angle of an intersection, determine if there is a critical minimum angle at which safety is substantially diminished, and assess the need for revising current geometric design policies and practices.

The data for this research were acquired from the FHWA HSIS, MNDOT, and ODOT. HSIS included intersection files from MN that allow the crash data, intersection geometric data, and traffic volumes to be linked by location. MNDOT provided the GIS base map and the GIS point file that allowed for the collection of supplemental data elements, including the measured angle of each intersection. The scope of the MN analysis was limited to minor leg stop-controlled intersections. The final MN database included 1,669 four-leg intersections and 1,109 three-leg intersections. The numbers of crashes included in the analysis over a 7-yr period was 8,482 for

four-leg intersections and 4,746 for three-leg intersections. ODOT provided data in road and intersection files that were linked in GIS to a crash dataset also provided by ODOT. The final OH database included 3,766 four-leg intersections and 6,122 three-leg intersections. The analysis period for the OH data was 5 yr and included 16,051 crashes at four-leg intersections and 22,895 crashes at three-leg intersections.

The approach for this evaluation was to develop a series of cross-sectional models using NB regression. Prior to the development of the MN models, researchers conducted data-mining efforts to determine the most important predictor variables from the many independent variables in the final database and the interactions among the important predictor variables. The results of the conditional RF and regression tree data-mining analyses were then used to develop safety-prediction models. The OH data were not analyzed through a data-mining process, but the data's significantly larger sample size allowed for greater diversity of developed models.

NB regression models were separately developed for total crashes for four-leg and three-leg intersections. When sample sizes permitted, additional models were developed for rural intersections and two-lane and multilane locations. MN data afforded different severity models including fatal-and-injury and PDO crashes, and the OH data allowed select urban models to be developed for total three- and four-leg intersections as well as urban two-lane intersections. Several combinations of variables related to intersection angle were explored to determine which models resulted in the best fit of the data. The model form that was most often the best fit for four-leg intersections was one that incorporated two angle variables: minimum intersection angle and 1 + cos(minimum intersection angle), although some models followed a function form referred to as the Hoerl Curve, which included a logarithmic term for the minimum angle.

The regression coefficients or estimates from the models were used to derive CMFunctions for four-leg intersections. Four-leg intersection CMFunctions included total, fatal-and-injury, and PDO collision categories for the following intersection types:

- All intersections.
- Rural intersections.
- Rural two-lane intersections.
- Rural multilane intersections.
- Urban intersections (total crashes only).
- Urban two-lane intersections (total crashes only).

The regression coefficients or estimates from the models were also used to derive CMFunctions for three-leg intersections but only for total crashes. This CMFunction for three-leg intersections applied to the following intersection types:

- All intersections.
- Rural intersections.
- Rural two-lane intersections.
- Urban intersections.
- Urban two-lane intersections.

RESEARCH CONCLUSIONS

The first objective of this research was to determine the relationship between intersection angle and safety. The previously developed NB regression models and the subsequently derived CMFunctions established the relationship for minor leg stop-controlled four-leg and three-leg intersections for the combinations of intersection types and collision categories in the previous section of this report. The CMFunctions for each of these scenarios are provided in figure 51 through figure 67. The sample of skewed four-leg intersections on two-lane roads with intersection angles less than 30 degrees was limited; therefore, the research team could not make specific recommendations regarding the safety aspects of intersection angles less than 30 degrees. The number of severely skewed intersections was even more limited for the multilane intersections. For intersections on multilane roads, the research team was unable to make specific recommendations regarding the safety aspects of intersection angles less than 50 degrees. Beyond the angles less than 50 degrees, the research team could not predict the CMFunction values because of small sample size. Moreover, intersections with extremely small angles are rare in practice. Therefore, State DOTs should use their discretion and engineering judgment in trying to address changes at intersections with extremely small angles. Due to the OH data, three-leg intersections were not as restricted at smaller angle measurements.

Results of this study showed that a 90-degree intersection angle is associated with the lowest expected number of crashes. Practitioners can use the CMFunctions estimated in this study to determine the safety effect of changing minimum intersection angle for a specific type of intersection. For example, if the practitioner is considering changing the minimum intersection angle at rural four-leg intersections on two-lane roads from 55 to 80 degrees (if 90 degrees is not possible), then the expected CMF associated with this change would be the ratio of the CMF for 80 degrees to the CMF for 55 degrees, which is 1.11/1.20 = 0.93 and represents a seven-percent reduction in crashes. If, however, the intersection angle can be changed to 90 degrees from 55 degrees, the CMF for that change would be 1.00/1.20 = 0.83 and represents a 17-percent reduction in crashes. The other objectives of the research were to determine if there was a critical minimum angle at which safety is substantially diminished and assess the need for revision of current geometric design policies and practices. The results of the analysis indicated that the largest CMFunction values for total, injury, or PDO crashes, regardless of the intersection types included (all, rural, rural two-lane, and rural multilane), most often occur at an angle of 65 degrees, with nearly all CMFunction peaks from both datasets falling between 50 and 65 degrees.

Researchers wanted to address the issue of what intersection angle should be established as a minimum for those exceptions where a right-angle intersection cannot be achieved. Selection of this angle is subjective and based on the level of diminished safety that is considered acceptable. For example, for rural four-leg intersections on two-lane roads, an intersection angle of 65 degrees will result in a CMF no greater than 1.2. However, for the same intersection, an intersection angle of at least 80 degrees is needed if the CMF is no greater than 1.1. The research team feels that the decision regarding the acceptable level of diminished safety should be made by a specific agency or a combination of AASHTO and FHWA.

$$CMF = \text{EXP}[0.0137(\alpha - 90)] \times [1 + \cos(\alpha)]^{1.2423}$$

Figure 51. Equation. Recommended CMFunction for all four-leg intersections, fatal-and-injury crashes.

$$CMF = \text{EXP}[0.0119(\alpha - 90)] \times [1 + \cos(\alpha)]^{1.1609}$$

Figure 52. Equation. Recommended CMFunction for all four-leg intersections, PDO crashes.

$$CMF_1 = \text{EXP}[0.0298(\alpha - 90)] \times [1 + \cos(\alpha)]^{2.7022}$$
$$CMF_2 = \text{EXP}[0.0432(\alpha - 90)] \times [1 + \cos(\alpha)]^{4.03055}$$
$$CMF = (\text{CM}F_1 + CMF_2)/2$$

Figure 53. Equation. Recommended CMFunction for rural four-leg intersections, total crashes.

$$CMF = \text{EXP}[0.0119(\alpha - 90)] \times [1 + \cos(\alpha)]^{1.2432}$$

Figure 54. Equation. Recommended CMFunction for rural four-leg intersections, injury-and-fatal crashes.

$$CMF = \text{EXP}[0.0112(\alpha - 90)] \times [1 + \cos(\alpha)]^{1.1523}$$

Figure 55. Equation. Recommended CMFunction for rural four-leg intersections, PDO crashes.

$$CMF_1 = \text{EXP}[0.0123(\alpha - 90)] \times [1 + \cos(\alpha)]^{1.2017}$$
$$CMF_2 = \text{EXP}[0.0198(\alpha - 90)] \times [1 + \cos(\alpha)]^{2.0774}$$
$$CMF = (\text{CM}F_1 + CMF_2)/2$$

Figure 56. Equation. Recommended CMFunction for rural four-leg two-lane intersections, total crashes.

$$CMF = \text{EXP}[0.0118(\alpha - 90)] \times [1 + \cos(\alpha)]^{1.2037}$$

Figure 57. Equation. Recommended CMFunction for rural four-leg two-lane intersections, fatal-and-injury crashes.

$$CMF = \text{EXP}[0.0113(\alpha - 90)] \times [1 + \cos(\alpha)]^{1.1473}$$

Figure 58. Equation. Recommended CMFunction for rural four-leg two-lane intersections, PDO crashes.

$$CMF_1 = \text{EXP}[(-0.1381 \times \alpha) + (8.6579 \times \ln(\alpha))]/332498818865.70$$
$$CMF_2 = \text{EXP}[0.0691(\alpha - 90)] \times [1 + \cos(\alpha)]^{5.6961}$$
$$CMF = (\text{CM}F_1 + CMF_2)/2$$

Figure 59. Equation. Recommended CMFunction for rural four-leg multilane intersections, total crashes.

$$CMF = \text{EXP}[0.1661(\alpha - 90)] \times [1 + \cos(\alpha)]^{13.6599}$$

Figure 60. Equation. Recommended CMFunction for rural four-leg multilane intersections, fatal-and-injury crashes.

$$CMF = [1 + \cos(\alpha)]^{0.9039}$$

Figure 61. Equation. Recommended CMFunction for rural four-leg multilane intersections, PDO crashes.

$$CMF = \text{EXP}[0.0133(\alpha - 90)] \times [1 + \cos(\alpha)]^{1.3249}$$

Figure 62. Equation. Recommended CMFunction for urban four-leg intersections total crashes.

$$CMF = \text{EXP}[0.0108(\alpha - 90)] \times [1 + \cos(\alpha)]^{1.2948}$$

Figure 63. Equation. Recommended CMFunction for urban four-leg two-lane intersections, total crashes.

$$CMF_1 = \text{EXP}[0.0113(\alpha - 90)] \times [1 + \cos(\alpha)]^{1.0349}$$
$$CMF_2 = \text{EXP}[0.0139(\alpha - 90)] \times [1 + \cos(\alpha)]^{1.6013}$$
$$CMF = (\text{CM}F_1 + CMF_2)/2$$

Figure 64. Equation. Recommended CMFunction for rural three-leg intersections, total crashes.

$$CMF = \text{EXP}[(-0.0099 \times \alpha) + (0.3771 \times \ln(\alpha))]/2.2387$$

Figure 65. Equation. Recommended CMFunction for rural three-leg two-lane intersections, total crashes.

$$CMF = \text{EXP}[0.0059(\alpha - 90)] \times [1 + \cos(\alpha)]^{1.0339}$$

Figure 66. Equation. Recommended CMFunction for urban three-leg intersections, total crashes.

$$CMF = \text{EXP}[0.0046(\alpha - 90)] \times [1 + \cos(\alpha)]^{0.9766}$$

Figure 67. Equation. Recommended CMFunction for urban three-leg two-lane intersections, total crashes.

In figure 51 through figure 67, α is the intersection angle (in degrees) and defined as the smallest angle between any two adjacent legs at an intersection.

METHODOLOGY CONCLUSIONS

In addition to the research results in the previous section, there were two elements of this research project that should be noted for future efforts. First, the supplemental data-collection effort for MN made use of GIS files combined with traditional intersection-inventory data to locate the intersections of interest for the study. Once located, the COGO tool within ArcGIS was used to acquire all angles at each intersection. The tool was accurate and easy to use. The GIS data were also used with online aerial imagery from Google Maps to confirm the accuracy of the information and to collect supplemental data. The use of the aerial images identified errors in the GIS data for a few locations. The aerial images were used to acquire several supplemental data elements. The collection of these data was efficient unless the image resolution was low enough that the street-level view was required. In the latter cases, the collection time required for an intersection can be increased several times depending on the number of elements to be collected.

The other unique component of this research was the use of data-mining tools for determination of variables from the MN dataset to be included in the development of the safety-prediction models. Classification and regression trees are not unique to the field of road safety. Several references were cited in chapter 3 that used these methods in road safety. However, the use of conditional RF methods and conditional regression trees for assessing variable importance and interaction effects is unique. The approach used in this study allowed the list of predictor variables for consideration in the MN NB models to be trimmed from 34 to 39 to a manageable range of 10 to 16 depending on the intersection scenario being modeled. There is a learning curve for using these tools efficiently, including understanding the limitations of computer memory on setting certain analysis parameters. Once mastered, the tools are effective for allowing researchers to create a short list of the most important predictors and visually ascertain some of the interaction effects that may warrant further consideration during the development of cross-sectional regression models.

CHAPTER 7. FUTURE RESEARCH

This research study developed new CMFunctions for intersection angles and recommended a change in policy regarding the critical minimum angle currently used in the Green Book and other resources.[1] Several recommendations follow that build on the work of this study.

First, the data acquired and used for the study were limited to the State road network in MN and OH. There are always concerns with crash-based research about the transferability of results from a single State to the other States or the Nation. The research team recommends the methodology applied in this study be replicated in additional States to determine if similar results can be obtained and if those results support the recommendations of this effort. Although this study verified the results using datasets from two different States, further validation will lend strength to the predictive models.

Second, the intersections in the study were predominately rural because the sites were part of the two States' road networks. The results were therefore less comprehensive for urban intersections. The research team recommends additional urban data be acquired to supplement urban data collected for MN and OH or that a separate study be conducted using sites from an urban area only. The city of Charlotte, NC, which is now part of HSIS and whose data include GIS information, could be a candidate for a supplemental study.

Third, the research team noted in the methodology chapter that the desired sample of intersections would range in terms of skew severity. This was true for both States. The data in this study included almost all stop-controlled intersections in the roadway inventory files of MNDOT and ODOT. While comprehensive in terms of geographic coverage of these States, the number of intersections with angles less than 40 degrees was limited, particularly for four-leg intersections. Further research is recommended to better define the safety implications for intersections with more severe (acute) angles.

Fourth, cutting edge safety evaluation research indicates that propensity scores may provide the most comprehensive analysis of CMFs by comparing the general properties, including traffic volume and speed limit, of treated sites to untreated sites by using relative, weighted scores. A propensity score analysis could be conducted by considering right-angle intersections as treated sites and skewed intersections as untreated sites. This type of analysis may better capture differences in traffic volumes across different angle categories.

Fifth, this report focused solely on intersections with angle measurements of 90 degrees or less. The OH dataset had several three-leg intersections with one angle greater than 90 degrees; these intersections were excluded from the analysis, but some exploratory analysis not reported in this document identified questionable crash performance for angles greater than 90 degrees. Future research should be conducted to develop an appropriate CMF functional form that can capture the safety effects when intersection angles exceed 90 degrees.

Finally, the analysis conducted in this study focused on intersections. The dependent variable in the study was crash frequencies for the intersection, which was defined as any crash on any approach within 250 ft of the intersection. This was done because it was difficult to assign crashes to a specific approach using only the information available in the HSIS database.

The research team recommends a feasibility study be conducted to determine if an approach-level analysis is possible and if the analysis might result in more refined results regarding the intersection angle's effect on safety. For example, it might be possible to determine specific collision types and vehicle maneuvers most susceptible to problems at skewed intersections. Other data that would be beneficial to such an analysis are intersection-turning movement counts. As a first step in this feasibility study, a sample of police crash reports from both skewed and nonskewed intersections should be reviewed to determine if there are any collision patterns that are related to the angle of the intersection.

APPENDIX A. HSIS DATA VARIABLES

The FHWA HSIS was one source of data for this project. As discussed in chapter 4, a preliminary assessment of the HSIS guidebooks showed that MN is the only HSIS State that included an intersection file with a geometric variable to indicate if an intersection is skewed.[56] Requested data for this study included variables from the crash, roadlog, and intersection files for MN. This appendix includes variables available from HSIS in each of these files. The variables required for linkages between files or deemed most appropriate for this analysis are noted by an asterisk (*) in these tables and were acquired from HSIS.

Table 46. List of variables available from the HSIS MN crash file.

Variable Name	Description
*acc_date**	Date accident occurred
*accdigm**	Diagram of accident code (collision type)
*acctype**	Type of accident
*accyr**	Year accident occurred
ambl_nbr	Ambulance number
*caseno**	Accident number
*county**	County
*div_code**	Road design
hazmat	Hazardous material carried
*hit_run**	Hit and run
*hour**	Hour accident occurred
interch	Interchange element code
*light**	Light conditions
loc_bike	Location of pedestrian/bike accident
*loc_harm**	Location of first harmful event
*loc_narr**	Location description
*loc_type**	Relation to intersection
*loc_wrk_zne**	Location of acc in workzone
*locn_rel**	Location reliability
*milepost**	Modified reference point
*numvehs**	Number of vehicles involved
object1	Fixed object struck
off_type	Type of investigating officer
on_brdg	Accident occurred on bridge
*pop_grp**	Urban/rural population codes
pubdmg	Public property damage
*rd_char1**	Road characteristics
*rdsurf**	Road surface conditions
rdwork	Road work being performed
*rodwycls**	Roadway classification
*rte_nbr**	Route number
*rte_sys**	Route system
rtsysnbr	Combined route system/route number
schlbus	School bus involved accident
*severity**	Accident severity
*speed**	Posted speed limit
tot_inj	Number of persons injured
tot_kill	Number of persons killed
*trf_cntl**	Traffic control devices

Variable Name	Description
*trfcntlw**	Traffic control working
*trvl_dir**	Travel direction
twnship	Township number
veh_mov1	Vehicle movement
wast_mat	Waste material carried
*weather**	Weather conditions
*weather1**	Weather conditions
*weather2**	Weather conditions
*weekday**	Day of week accident occurred
*work_zone**	Workzone marked
*wrks_presnt**	Worker present

*Variables acquired from HSIS and required for linkages between files or deemed most appropriate for this analysis.

Table 47. List of variables available from the HSIS MN roadlog file.

Variable Name	Description
*aadt**	Calculated average AADT
access	Control of access
adln_rd1	Additional lanes—road 1
adln_rd2	Additional lanes—road 2
bas_tkr1	Base thickness—road 1
*begmp**	Calculated begin milepost
brk_cd	Break code
*comm_adt**	Calculated average commercial AADT
county	County
*curb1**	Curbs—road 1
*curb2**	Curbs—road 2
*dir_cde**	Direction code
endmp	Calculated ending milepost
fed_aid	Federal aid system
fed_sysd	Federal aid system—designated
fed_sysr	Federal aid system—regular
*func_cls**	Functional class
h_count	Number of count stations per section
inte_cat	Intersection category
inv_dte	Inventory date
*lanewid**	Lane width
*lshl_ty2**	Left-shoulder type—road 2
*lshl_typ**	Left-shoulder type—road 1
*lshl_wd2**	Left-shoulder width—road 2
*lshldwid**	Left-shoulder width—road 1
*med_type**	Median type
*medwid**	Median width (in feet)
mvmt	Million vehicle miles traveled
nbrvolb	Number of blank traffic volume counts
nbrvol	Total Number of traffic volume counts
nbrvolf	Number of full traffic volume counts
no_lane1	Number through lanes toward increasing milepoints
no_lane2	Number through lanes toward decreasing milepoints
no_lanes	Total number of lanes
oneway	Divided and one-way code
parking1	Parking on road 1
parking2	Parking on road 2

Variable Name	Description
ref_pst	Reference post
remark	Remarks—type of record
*rodwycls**	Roadway classification
row	Right-of-way width
*rshl_ty2**	Right-shoulder type—road 2
*rshl_typ**	Right-shoulder type—road 1
*rshl_wd2**	Right-shoulder width—road 2
*rshldwid**	Right-shoulder width—road 1
*rte_nbr**	Route number
*rte_sys**	Route system
*rtsysnbr**	Combined route system/route number
seg_lng	Calculated section length
side_wlk	Sidewalks
stm_sew	Storm sewers
suf_typ1	Surface specification number—road 1
suf_typ2	Surface specification number—road 2
sur_tkr1	Surface thickness—road 1
sur_tkr2	Surface thickness—road 2
surf_ty2	Surface type—road 2
surf_typ	Surface type—road 1
*surf_wd2**	Surface width—road 2 (in ft)
*surf_wid**	Surface Width—road 1 (in ft)
turn_ln	Turning lanes toward increasing mileposts
turn_ln2	Turning lanes toward decreasing mileposts
*update_*	Date of update
*urb_mnc**	Urban/municipal code
volgrp	Traffic volume group
voltyp	Traffic volume type
*year**	Year of traffic

*Variables acquired from HSIS and required for linkages between files or deemed most appropriate for this analysis.

Table 48. List of variables available from the HSIS MN intersection file.

Variable Type	Variable Name	Description
N/A	*rte_sys**	Route system
	*rte_nbr**	Route number
	*int_synb**	Combined rte_sys/rte_nbr
	*milepost**	Modified reference point location
	*ref_pnt**	Reference point
	elem_nbr	Interchange element code
	*endmp**	Calculated ending milepost
	*int_type**	Intersection type
	desc	Intersection description
	*typedesc**	Intersection description—revised
	rail_nbr	Railroad crossing number
	*traf_dev**	Traffic control devices
	*trf_cntl**	Traffic control devices—revised
	sign_pro	Traffic signals progression
	sign_tim	Traffic signals timing
	sign_con	Traffic signals construction
	sign_pla	Signal head placement
	sign_ped	Traffic signals pedestrian signals
	traf_tmo	Flashing signal time on

Variable Type	Variable Name	Description
	traf_tmf	Flashing signal time off
	traf_phs	Traffic signals number of phases
	traf_pre	Traffic signals preemption
	*rdwy_lgh**	Roadway lighting
	*gen_eniv**	General environment
	*spec_env**	Specific environment
	dist_cat	Category assigned by district
	cntl_cat	Central office category
	*sfty_imy**	Safety improvement year
	*sfty_imd**	Safety improvement district
	*sfty_prj**	Safety improvement project number
	*sfty_cls**	Safety improvement classification
	efec_dte	Date of accident geocoding
	nbr_rtes	Number of routes into intersection
	nbr_legs	Number of legs into intersection
	*trafcntl**	Traffic-control devices
Segment (route)-specific	*rtesys1**	Route system—route 1
	*rtenbr1**	Route number—route 1
	*refpnt1**	Reference point—route 1
	rdesc1	Road description
	lolimt1	Segment 1 lower limit
	uplimt1	Segment 1 upper limit
	nbr_leg1	Number of legs on segment 1
	*rtesys1**	Route system—route 1
	*rtenbr1**	Route number—route 1
	*refpnt1**	Reference point—route 1
	rdesc1	Road description
	lolimt1	Segment 1 lower limit
	uplimt1	Segment 1 upper limit
Leg (approach)-specific	*legnbr11**	Segment 1, leg number 1
	*direct11**	Segment 1, leg 1 direction
	*aadt111**	Segment 1, leg 1, year 1 AADT
	*adtyr111**	Segment 1, leg 1, year 1
	*aadt112**	Segment 1, leg 1, year 2 AADT
	*adtyr112**	Segment 1, leg 1, year 2
	*aadt113**	Segment 1, leg 1, year 3 AADT
	*adtyr113**	Segment 1, leg 1, year 3
	*aadt114**	Segment 1, leg 1, year 4 AADT
	*adtyr114**	Segment 1, leg 1, year 4
	*aadt115**	Segment 1, leg 1, year 5 AADT
	*adtyr115**	Segment 1, leg 1, year 5
	*ap_spd11**	Segment 1, leg 1, approach speed limit
	*apcntl11**	Segment 1, leg 1, approach traffic control
	nbr_rtes	Number of routes into intersection
	nbr_legs	Number of legs into intersection
	*trafcntl**	Traffic-control devices
	*legnbr11**	Segment 1, leg number 1
	*direct11**	Segment 1, leg 1 direction
	*aadt111**	Segment 1, leg 1, year 1 AADT
	*adtyr111**	Segment 1, leg 1, year 1
	*aadt112**	Segment 1, leg 1, year 2 AADT
	*adtyr112**	Segment 1, leg 1, year 2

Variable Type	Variable Name	Description
	*aadt113**	Segment 1, leg 1, year 3 AADT
	*adtyr113**	Segment 1, leg 1, year 3
	*aadt114**	Segment 1, leg 1, year 4 AADT
	*adtyr114**	Segment 1, leg 1, year 4
	*aadt115**	Segment 1, leg 1, year 5 AADT
	*adtyr115**	Segment 1, leg 1, year 5
	*ap_spd11**	Segment 1, leg 1, Approach speed limit
	*apcntl11**	Segment 1, leg 1, Approach traffic control

*Variables acquired from HSIS and required for linkages between files or deemed most appropriate for this analysis.

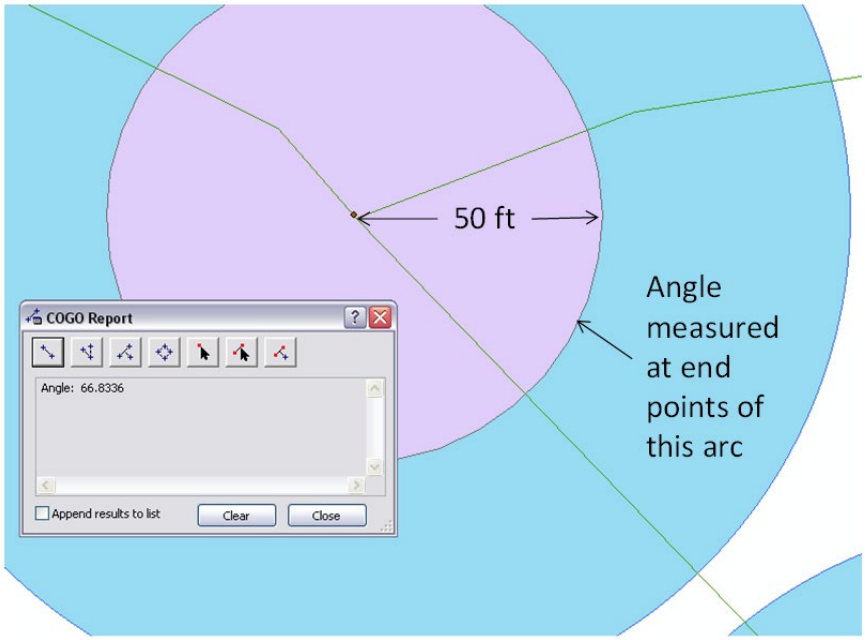
APPENDIX B. SUPPLEMENTAL DATA-COLLECTION PROCEDURE AND ISSUES

MN DATA-COLLECTION PROCEDURE

The protocol followed for nonskewed intersections for determining if the intersection was indeed not skewed was the same as the protocol used to collect intersection data with one additional step. Between steps 4 and 5 in chapter 4, researchers used the COGO tool to measure the most acute angle between all intersecting legs (as determined by visual inspection). If that angle was 85 degrees or greater, the intersection was deemed nonskewed, and the data collector proceeded to step 6. If the angle was less than 85 degrees, the data collector proceeded to step 5 and collected angle measurements for all legs of the intersection. This decision expedited the data-collection process and allowed more data to be collected for intersections with lesser angles. In part, this value was chosen because it is likely that an angle of 85 to 89 degrees was not discernible from a 90-degree angle to a driver, pedestrian, or bicyclist and thus not likely to impact their behaviors at such intersections.

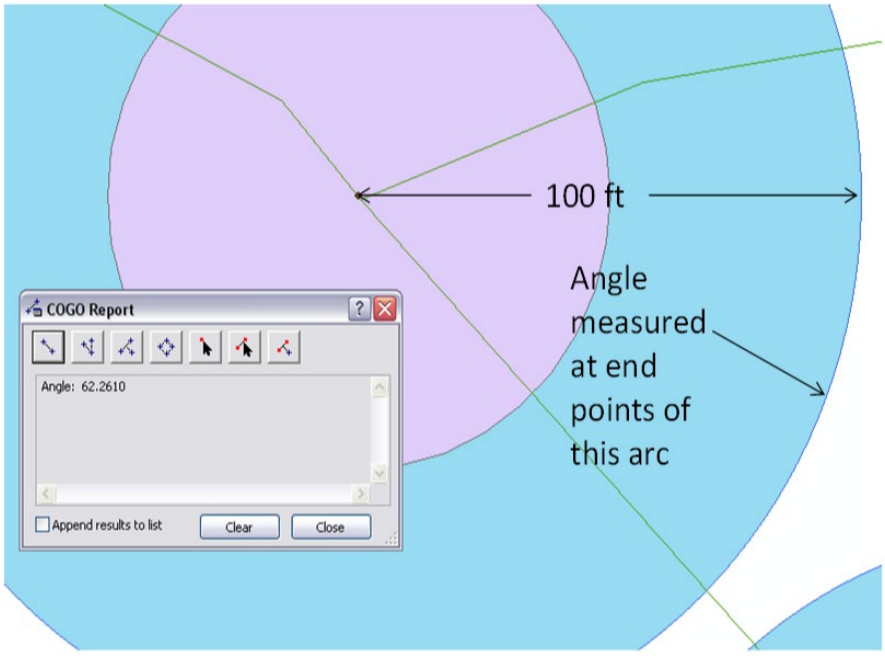
ArcGIS includes COGO that allows a user to measure angles between lines. This tool was used to obtain the angle between all legs at each intersection. During the test phase of experimenting with this tool, researchers discovered that the measured angle between adjacent legs could range widely depending on the points chosen on each leg to represent the end points of the arc. For two legs that continue in straight lines from the intersection, the distance matters little. However, for a leg with a curve starting close to the intersection, the angle measurement could vary depending on how far along the leg the data collector chooses to select the arc points. Figure 68 and figure 69 illustrate this issue with ArcGIS screenshots for one of the study intersections. Figure 68 shows a 50-foot buffer drawn around the intersection and used as a guide to locate the endpoints of the arc for measuring the angle. Figure 69 shows a 100-foot buffer for the same intersection. One of the legs of the intersection included a curve near the junction point. The angle measured at the 100-foot radius was 62 degrees, while the angle measured at the 50-foot radius was 67 degrees. Based on these initial tests, researchers employed a 50-foot distance from the point of intersection for all angle measurements. This distance ensured that angle measurements did not include nearby curves (or only a portion of the curve), matched the angle experienced by the first two drivers in the queue and provided a consistent method for all intersections.

Per step 7 in the data-collection protocol outlined in chapter 4, many supplemental data elements were collected using a combination of aerial (satellite) view and street-level images (StreetView) within Google Maps. The quality of the image available at a given intersection determined whether the data could be acquired from the aerial view only or if the street-level view was required. For some locations, the street-level view was necessary to record any sight obstructions, check for turning lanes, crosswalks, sidewalks and other features, and confirm the type of driveways that are present.



Portions of this document include intellectual property of Esri and its licensors and are used under license. © 2020 Esri and its licensors. All rights reserved.
Modifications: FHWA.

Figure 68. Illustration. Measured intersection angle with the ArcGIS COGO tool and a 50-foot radius (67 degrees).[(59)]



Portions of this document include intellectual property of Esri and its licensors and are used under license. © 2020 Esri and its licensors. All rights reserved.
Modifications: FHWA.

Figure 69. Illustration. Measured intersection angle with the ArcGIS™ COGO tool and a 100-foot radius (62 degrees).[(59)]

One of the lessons learned in this supplemental data-collection effort was the amount of time it takes to acquire information from this source of aerial imagery. At the start of this supplemental data-collection effort, researchers estimated that the additional data elements could be acquired and entered into the Excel workbook at a pace of 5 min per intersection. The effort required approximately 400 hr for the 4,780 intersections in the sample set. Within the first month of data acquisition, researchers learned that the initial estimate was not accurate. The number of low-resolution satellite images and the need to use street-level views to acquire many of the elements kept the pace closer to 12 min per intersection. Consequently, the number of intersections with all supplemental data for this study was reduced to meet budget and time constraints. Using the 12-min pace, researchers established a goal to spend no more than 600 hr, resulting in collection of supplemental data for 3,000 intersections.

Researchers discovered additional issues in the course of the data-collection effort related to the accuracy and completeness of the spatial data. The issues ranged from intersections misclassified as skewed locations to intersections that were separated by grade.

During the supplemental data collection, the research team discovered several issues that warrant discussion and may benefit future researchers using spatial data and aerial imagery. These issues were discovered because the GIS shapefiles and the aerial images did not match. Researchers learned about the importance of using two sources of information to verify the data collected. Whenever these issues were discovered in this study, the intersection in question was flagged and a comment was added in the Excel workbook describing the problem. No further data were collected for the flagged intersections because they were eliminated from the final dataset. Approximately eight percent of intersections viewed were flagged for various reasons.

The remainder of this appendix includes five specific issues discovered during the supplemental data-collection effort. For each issue, an illustration shows both the roadway network lines from ArcGIS and the aerial image from Google Earth Maps.

Issue 1—Corrected Skewed Intersection

Figure 70 shows a typical skewed intersection from the GIS data. The roadway-network files show a four-leg intersection with two roadways crossing at an intersecting angle approximately 30 degrees. The aerial image, however, shows two three-leg intersections. The intersection appears to have been converted from a skewed four-leg intersection to two three-leg intersections with right-angle approaches.



© 2015 Google Earth. Modified by FHWA.
Note: The GIS image was inserted by the research team to demonstrate that the intersection was incorrectly depicted in the GIS data as a four-leg intersection with two roadways crossing.

Figure 70. Illustration. Intersection shown as skewed four-leg location in the GIS roadway network and as two three-leg intersections in the aerial image.(75)

Issue 2—Missing Approach Legs

In some cases, one or more of the approach legs was missing from the GIS roadway network. The example in figure 71 illustrates an intersection for which the GIS file shows a divided roadway with a three-leg intersection on one side of the roadway. The aerial image, however, shows a four-leg intersection including a paved connector in the median that allows turning movements in all directions.



© 2015 Google Earth. Modified by FHWA.
Note: The GIS image was inserted by the research team to demonstrate that the intersection was incorrectly depicted in the GIS data as a divided roadway with one three-leg intersection.

Figure 71. Illustration. Intersection shown with a single minor leg approach in the GIS roadway network but with two minor leg approaches and a median connector in the aerial image.[(76)]

Issue 3—Misclassification

On divided roadways, there were several cases showing that the spatial data incorrectly indicated that the intersection had full access to all turning movements. In figure 72, the GIS roadway network includes a four-leg intersection at a divided roadway, complete with a paved connector in the median to allow crossing and left turns from the minor road in each direction. However, no such connector exists in the aerial image, which shows two three-leg intersections on either side of the divided roadway. The approaches were aligned with each other.



© 2017 Google Earth. Modified by FHWA.
Note: The GIS image was inserted by the research team to demonstrate that the intersection was incorrectly depicted in the GIS data as a divided roadway with a paved connector.

Figure 72. Illustration. Intersection shown as a full access four-leg location in the GIS roadway network but as two three-leg intersections (no median connector) in the aerial image.[(77)]

Issue 4—Grade Separation

The original HSIS data acquired for this study were filtered based on minor leg stop-control; therefore, a grade-separated intersection should not have been included in the original dataset. Figure 73, however, shows exactly that type of intersection. The GIS roadway network correctly shows the two roads crossing. However, the aerial image shows that this is not an at-grade crossing. Figure 73 illustrates the value of aerial images for confirming the accuracy of traditional digital data sources.

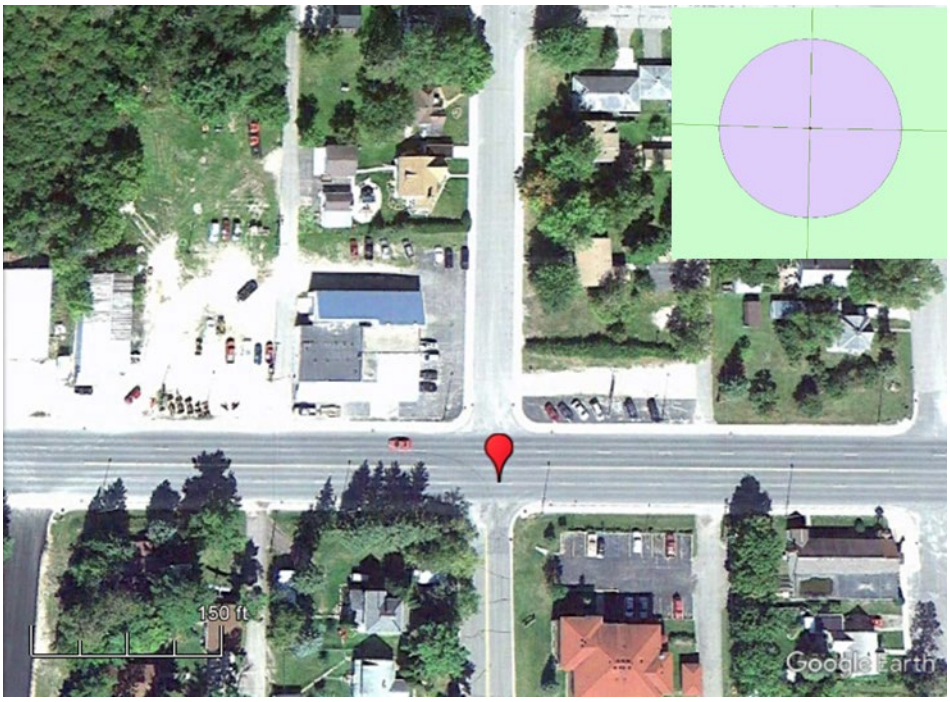


© 2015 Google Earth. Modified by FHWA.
Note: The GIS image was inserted by the research team to demonstrate that the intersection was incorrectly depicted in the GIS data as an at-grade crossing.

Figure 73. Illustration. Grade-separated intersection that should not have been included in the original HSIS data received.[(78)]

Issue 5—Incorrect Classification

The MN HSIS data includes an intersection descriptor to indicate whether the intersection is skewed or not. This variable was used in this study to preliminarily determine the number of sites available in each of these categories for three- and four-leg intersections. Figure 74 shows an example of an intersection categorized as a skewed four-leg intersection within the HSIS data. Both the GIS roadway network and the aerial image show that the intersection is at a right-angle location. The supplemental data-collection effort was used to correct these misclassifications in both directions: skewed to right angle and right angle to skewed.



© 2011 Google Earth. Modified by FHWA.
Note: The GIS image was inserted by the research team to demonstrate that the intersection is a right-angle intersection that was incorrectly classified in the HSIS database as a skewed intersection.

Figure 74. Illustration. Intersection that was classified as skewed in the HSIS database but is a right-angle intersection in both the GIS roadway network and the aerial imagery.[79]

APPENDIX C. DATA TABLES

Table 47 through table 72 were developed from the final database used in this research study. The tables provide descriptive statistics for many of the key variables used in the analysis. In the following tables, a right angle is defined as having an intersecting angle greater than or equal to 85 degrees.

Table 49. Four-leg intersections by angle classification and area type in MN.

Angle Classification	Number of Rural Intersections	Rural (%)	Number of Urban Intersections	Urban (%)	Total
Right angle	892	60.6	123	62.4	1,015
Skewed	580	39.4	74	37.6	654
Total	**1,472**	**100.0**	**197**	**100.0**	**1,669**

Table 50. Total crashes (2003–2009) at four-leg intersections by angle classification and area type in MN.

Angle Classification	Number of Rural Intersections	Rural (%)	Number of Urban Intersections	Urban (%)	Total
Right angle	4,349	74.1	2,124	81.3	6,473
Skewed	1,519	25.9	490	18.7	2,009
Total	**5,868**	**100.0**	**2,614**	**100.0**	**8,482**

Table 51. Four-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Number of Rural Intersections	Rural (%)	Number of Urban Intersections	Urban (%)	Total
<40	42	2.9	2	1.0	44
40–49	67	4.6	10	5.1	77
50–54	50	3.4	6	3.0	56
55–59	67	4.6	5	2.5	72
60–64	63	4.3	6	3.0	69
65–69	75	5.1	10	5.1	85
70–74	79	5.4	13	6.6	92
75–79	70	4.8	12	6.1	82
80–84	67	4.6	10	5.1	77
≥85	892	60.6	123	62.4	1,015
Total	**1,472**	**100.0**	**197**	**100.0**	**1,669**

Table 52. Total crashes (2003–2009) at four-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Number of Rural Intersections	Rural (%)	Number of Urban Intersections	Urban (%)	Total
<40	114	1.9	35	1.3	149
40–49	259	4.4	93	3.6	352
50–54	328	5.6	82	3.1	410
55–59	250	4.3	79	3.0	329
60–64	330	5.6	57	2.2	387
65–69	582	9.9	122	4.7	704
70–74	378	6.4	186	7.1	564
75–79	404	6.9	123	4.7	527
80–84	295	5.0	129	4.9	424
≥85	2,928	49.9	1,708	65.3	4,636
Total	**5,868**	**100.0**	**2,614**	**100.0**	**8,482**

Table 53. Fatal-and-injury crashes (2003–2009) at four-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Number of Rural Intersections	Rural (%)	Number of Urban Intersections	Urban (%)	Total
<40	48	2.1	11	1.3	59
40–49	96	4.1	29	3.3	125
50–54	117	5.0	25	2.9	142
55–59	108	4.6	31	3.6	139
60–64	141	6.0	20	2.3	161
65–69	267	11.4	42	4.8	309
70–74	157	6.7	68	7.8	225
75–79	167	7.2	44	5.1	211
80–84	110	4.7	44	5.1	154
≥85	1,124	48.1	553	63.8	1,677
Total	**2,335**	**100.0**	**867**	**100.0**	**3,202**

Table 54. PDO crashes (2003–2009) at four-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Number of Rural Intersections	Rural (%)	Number of Urban Intersections	Urban (%)	Total
<40	66	1.9	23	1.3	89
40–49	160	4.6	63	3.7	223
50–54	205	5.9	55	3.2	260
55–59	141	4.0	47	2.7	188
60–64	188	5.4	37	2.2	225
65–69	310	8.9	79	4.6	389
70–74	218	6.3	117	6.8	335
75–79	232	6.7	79	4.6	311
80–84	183	5.3	85	4.9	268
≥85	1,781	51.1	1,135	66.0	2,916
Total	**3,484**	**100.0**	**1,720**	**100.0**	**5,204**

Table 55. Intersection AADT for four-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Rural Min	Rural Avg	Rural Max	Urban Min	Urban Avg	Urban Max
<40	622	3,876	26,514	18,772	22,943	27,114
40–49	163	4,912	25,985	5,113	9,395	19,839
50–54	640	5,678	26,462	4,586	13,737	36,710
55–59	805	4,258	25,467	6,369	11,370	21,563
60–64	787	4,675	22,204	4,642	13,904	37,000
65–69	643	6,222	30,172	5,821	13,226	29,631
70–74	995	4,985	28,146	10,632	21,786	52,827
75–79	527	4,988	19,683	5,491	11,753	32,625
80–84	767	4,812	17,869	2,474	18,215	36,781
≥85	178	3,847	31,056	3,440	15,023	53,108
Average	**613**	**4,825**	**25,356**	**6,734**	**15,135**	**34,720**

Min = minimum; Avg = average; Max = maximum.

Table 56. Minor road AADT for four-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Rural Min	Rural Avg	Rural Max	Urban Min	Urban Avg	Urban Max
<40	13	318	1,951	650	1,011	1,372
40–49	5	443	2,418	650	1,480	2,543
50–54	33	627	4,035	129	860	1,603
55–59	14	684	11,195	539	1,079	1,495
60–64	20	562	5,632	128	608	824
65–69	23	630	2,657	456	748	1,881
70–74	23	549	2,677	377	1,296	3,225
75–79	22	617	3,183	552	1,114	2,375
80–84	42	542	3,168	56	651	1,348
≥85	4	505	3,421	34	1,057	2,953
Average	**20**	**548**	**4,034**	**357**	**990**	**1,962**

Min = minimum; Avg = average; Max = maximum.

Table 57. Major road AADT for four-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Rural Min	Rural Avg	Rural Max	Urban Min	Urban Avg	Urban Max
<40	588	3,558	25,662	17,400	21,932	26,464
40–49	125	4,469	25,662	2,821	7,915	17,300
50–54	492	5,051	25,662	3,788	12,878	35,107
55–59	529	3,574	20,161	5,245	10,291	20,069
60–64	601	4,113	19,525	4,116	13,295	36,286
65–69	600	5,592	29,893	5,171	12,478	27,750
70–74	835	4,436	27,043	9,275	20,490	50,429
75–79	498	4,371	18,996	4,937	10,639	30,250
80–84	685	4,270	17,596	1,917	17,564	35,433
≥85	124	3,343	30,118	2,515	13,966	52,071
Average	**508**	**4,278**	**24,032**	**5,719**	**14,145**	**33,116**

Min = minimum; Avg = average; Max = maximum.

Table 58. Total crash rates (per 100 M entering vehicles) for four-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Rural Min	Rural Avg	Rural Max	Urban Min	Urban Avg	Urban Max
<40	0.00	29.13	200.25	24.54	31.03	37.53
40–49	0.00	32.65	211.67	0.00	36.17	74.93
50–54	0.00	48.24	299.69	12.07	54.68	140.39
55–59	0.00	34.47	161.56	11.09	52.71	106.82
60–64	0.00	37.62	177.05	5.33	34.46	59.02
65–69	0.00	49.09	237.99	0.00	29.54	68.69
70–74	0.00	43.01	285.27	0.00	32.66	120.84
75–79	0.00	37.55	178.93	0.00	34.00	74.86
80–84	0.00	33.10	165.44	9.58	34.03	116.03
≥85	0.00	34.17	216.64	0.00	39.34	160.73
Average	**0.00**	**37.90**	**213.45**	**6.26**	**37.86**	**95.98**

Min = minimum; Avg = average; Max = maximum.

Table 59. Fatal-and-Injury crash rates (per 100 M entering vehicles) for four-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Rural Min	Rural Avg	Rural Max	Urban Min	Urban Avg	Urban Max
<40	0.00	11.31	72.82	7.22	9.86	12.51
40–49	0.00	14.60	125.08	0.00	12.39	32.11
50–54	0.00	14.60	61.15	0.00	20.25	54.94
55–59	0.00	14.12	80.78	5.54	20.00	41.09
60–64	0.00	15.32	68.85	0.00	10.85	23.87
65–69	0.00	24.21	216.36	0.00	10.94	23.36
70–74	0.00	18.80	120.80	0.00	12.68	65.32
75–79	0.00	14.70	107.36	0.00	11.75	27.25
80–84	0.00	13.75	118.17	3.19	12.55	42.19
≥85	0.00	13.24	119.14	0.00	12.98	49.33
Average	**0.00**	**15.47**	**109.05**	**1.60**	**13.43**	**37.20**

Min = minimum; Avg = average; Max = maximum.

Table 60. PDO crash rates (per 100 M entering vehicles) for four-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Rural Min	Rural Avg	Rural Max	Urban Min	Urban Avg	Urban Max
<40	0.00	17.82	127.43	17.32	20.13	22.93
40–49	0.00	17.81	87.59	0.00	23.13	55.05
50–54	0.00	32.77	239.75	8.53	33.23	79.35
55–59	0.00	20.28	80.78	3.17	32.35	65.74
60–64	0.00	22.11	108.20	5.29	23.61	50.59
65–69	0.00	24.75	100.82	0.00	18.39	47.55
70–74	0.00	23.89	213.95	0.00	19.82	55.52
75–79	0.00	22.39	89.58	0.00	22.25	54.44
80–84	0.00	19.17	85.83	0.00	21.47	73.84
≥85	0.00	20.61	144.42	0.00	25.86	118.98
Average	**0.00**	**22.16**	**127.84**	**3.43**	**24.02**	**62.40**

Min = minimum; Avg = average; Max = maximum.

Table 61. Three-leg intersections by angle classification and area type in MN.

Angle Classification	Number of Rural Intersections	Rural (%)	Number of Urban Intersections	Urban (%)	Total
Right angle	538	60.6	101	45.7	639
Skewed	350	39.4	120	54.3	470
Total	**888**	**100.0**	**221**	**100.0**	**1,109**

Table 62. Total crashes (2003–2009) at three-leg intersections by angle classification and area type in MN.

Angle Classification	Number of Rural Intersections	Rural (%)	Number of Urban Intersections	Urban (%)	Total
Right angle	2,236	79.0	1,341	70.5	3,577
Skewed	593	21.0	560	29.5	1,153
Total	**2,829**	**100.0**	**1,901**	**100.0**	**4,730**

Table 63. Three-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Number of Rural Intersections	Rural (%)	Number of Urban Intersections	Urban (%)	Total
<40	53	6.0	17	7.7	70
40–49	24	2.7	9	4.1	33
50–54	30	3.4	10	4.5	40
55–59	32	3.6	5	2.3	37
60–64	30	3.4	9	4.1	39
65–69	39	4.4	17	7.7	56
70–74	41	4.6	16	7.2	57
75–79	48	5.4	20	9.0	68
80–84	53	6.0	17	7.7	70
≥85	538	60.6	101	45.7	639
Total	**888**	**100.0**	**221**	**100.0**	**1,109**

Table 64. Total crashes (2003–2009) at three-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Number of Rural Intersections	Rural (%)	Number of Urban Intersections	Urban (%)	Total
<40	191	6.8	129	6.8	320
40–49	51	1.8	108	5.7	159
50–54	81	2.9	24	1.3	105
55–59	90	3.2	53	2.8	143
60–64	62	2.2	63	3.3	125
65–69	123	4.3	95	5.0	218
70–74	153	5.4	113	5.9	266
75–79	156	5.5	158	8.3	314
80–84	180	6.4	141	7.4	321
≥85	1,742	61.6	1,017	53.5	2,759
Total	**2,829**	**100.0**	**1,901**	**100.0**	**4,730**

Table 65. Fatal-and-injury crashes (2003–2009) at three-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Number of Rural Intersections	Rural (%)	Number of Urban Intersections	Urban (%)	Total
<40	82	8.0	49	7.5	131
40–49	20	1.9	36	5.5	56
50–54	26	2.5	10	1.5	36
55–59	30	2.9	15	2.3	45
60–64	21	2.0	22	3.4	43
65–69	37	3.6	34	5.2	71
70–74	55	5.3	35	5.4	90
75–79	57	5.5	59	9.0	116
80–84	70	6.8	49	7.5	119
≥85	631	61.3	344	52.7	975
Total	**1,029**	**100.0**	**653**	**100.0**	**1,682**

Table 66. PDO crashes (2003–2009) at three-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Number of Rural Intersections	Rural (%)	Number of Urban Intersections	Urban (%)	Total
<40	109	6.1	77	6.3	186
40–49	31	1.7	71	5.8	102
50–54	55	3.1	14	1.1	69
55–59	58	3.3	38	3.1	96
60–64	41	2.3	40	3.3	81
65–69	85	4.8	59	4.8	144
70–74	97	5.4	75	6.1	172
75–79	98	5.5	98	8.0	196
80–84	108	6.1	90	7.4	198
≥85	1,102	61.8	661	54.0	1,763
Total	**1,784**	**100.0**	**1,223**	**100.0**	**3,007**

Table 67. Intersection AADT for three-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Rural Min	Rural Avg	Rural Max	Urban Min	Urban Avg	Urban Max
<40	531	4,606	22,026	1,735	12,903	27,057
40–49	658	5,000	25,755	4,817	14,773	40,475
50–54	549	5,193	25,849	6,210	10,855	20,770
55–59	1,055	4,043	20,593	8,179	19,053	35,955
60–64	710	4,400	19,196	5,689	10,736	27,724
65–69	674	3,938	17,110	5,821	15,232	36,971
70–74	380	6,200	24,998	4,066	14,268	43,288
75–79	400	6,548	31,433	4,836	17,418	40,718
80–84	1,005	5,592	25,643	6,228	16,352	36,857
≥85	322	5,393	31,520	3,480	20,256	57,975
Average	**628**	**5,091**	**24,412**	**5,106**	**15,185**	**36,779**

Min = minimum; Avg = average; Max = maximum.

Table 68. Minor road AADT for three-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Rural Min	Rural Avg	Rural Max	Urban Min	Urban Avg	Urban Max
<40	11	850	4,579	36	1,006	8,437
40–49	20	595	2,759	349	2,996	19,021
50–54	31	720	4,055	6	881	3,686
55–59	55	564	3,362	747	2,626	4,605
60–64	79	568	2,261	397	950	2,823
65–69	24	523	2,182	36	714	2,701
70–74	4	726	4,391	95	1,647	12,184
75–79	8	638	2,793	73	842	2,370
80–84	6	865	7,061	73	1,101	7,358
≥85	3	640	7,013	81	1,191	7,443
Average	**24**	**669**	**4,046**	**189**	**1,395**	**7,063**

Min = minimum; Avg = average; Max = maximum.

Table 69. Major road AADT for three-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Rural Min	Rural Avg	Rural Max	Urban Min	Urban Avg	Urban Max
<40	318	3,756	21,936	1,498	11,898	26,407
40–49	287	4,405	25,662	4,186	11,777	24,139
50–54	519	4,473	25,662	3,437	9,974	20,764
55–59	779	3,479	20,179	7,432	16,426	33,393
60–64	365	3,832	18,729	5,057	9,786	24,901
65–69	624	3,415	17,056	5,171	14,518	36,321
70–74	370	5,474	24,850	3,319	12,621	42,643
75–79	318	5,910	31,343	4,186	16,576	39,286
80–84	644	4,727	20,161	5,485	15,251	36,143
≥85	318	4,753	31,464	3,121	19,065	55,786
Average	**454**	**4,423**	**23,704**	**4,289**	**13,789**	**33,978**

Min = minimum; Avg = average; Max = maximum.

Table 70. Total crash rates (per 100 M entering vehicles) for three-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Rural Min	Rural Avg	Rural Max	Urban Min	Urban Avg	Urban Max
<40	0.00	30.26	107.13	0.00	19.67	52.08
40–49	0.00	21.22	66.83	3.19	31.72	62.04
50–54	0.00	26.75	190.74	0.00	8.67	21.78
55–59	0.00	32.21	159.32	0.00	16.29	34.83
60–64	0.00	24.48	76.00	0.00	17.36	59.29
65–69	0.00	29.81	129.62	0.00	15.55	68.36
70–74	0.00	23.56	168.40	4.60	22.70	86.23
75–79	0.00	24.29	175.51	0.00	19.35	66.25
80–84	0.00	20.69	92.49	2.57	20.76	63.43
≥85	0.00	25.79	443.80	0.00	20.10	116.16
Average	**0.00**	**25.91**	**160.98**	**1.04**	**19.22**	**63.05**

Min = minimum; Avg = average; Max = maximum.

Table 71. Fatal-and-injury crash rates (per 100 M entering vehicles) for three-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Rural Min	Rural Avg	Rural Max	Urban Min	Urban Avg	Urban Max
<40	0.00	14.84	73.71	0.00	7.07	26.04
40–49	0.00	7.47	54.59	0.00	10.77	21.73
50–54	0.00	9.90	114.44	0.00	4.02	10.99
55–59	0.00	10.09	51.50	0.00	4.52	10.47
60–64	0.00	7.66	29.81	0.00	5.54	22.59
65–69	0.00	9.05	44.82	0.00	5.46	19.14
70–74	0.00	8.78	79.77	0.00	6.53	40.24
75–79	0.00	11.17	175.51	0.00	7.02	27.10
80–84	0.00	7.42	38.94	0.00	8.59	25.14
≥85	0.00	9.31	169.07	0.00	7.09	38.72
Average	**0.00**	**9.57**	**83.21**	**0.00**	**6.66**	**24.22**

Min = minimum; Avg = average; Max = maximum.

Table 72. PDO crash rates (per 100 M entering vehicles) for three-leg intersections by intersection angle and area type in MN.

Intersection Angle (Degrees)	Rural Min	Rural Avg	Rural Max	Urban Min	Urban Avg	Urban Max
<40	0.00	15.42	67.89	0.00	11.80	37.75
40–49	0.00	13.75	59.48	1.60	20.84	53.18
50–54	0.00	16.86	95.60	0.00	4.65	13.07
55–59	0.00	21.58	132.76	0.00	11.77	25.04
60–64	0.00	16.82	57.00	0.00	11.66	35.29
65–69	0.00	20.25	109.67	0.00	9.79	49.22
70–74	0.00	14.56	98.27	3.62	15.76	45.99
75–79	0.00	13.03	76.00	0.00	12.27	39.14
80–84	0.00	13.16	64.37	0.00	11.96	44.57
≥85	0.00	16.25	274.73	0.00	12.81	73.14
Average	**0.00**	**16.17**	**103.58**	**0.52**	**12.33**	**41.64**

Min = minimum; Avg = average; Max = maximum.

APPENDIX D. DATA DESCRIPTORS AND DATA-MINING RESULTS

DATA MINING: BACKGROUND AND APPLICATION

RF regression was used to determine the variables most likely to be the best predictors of crashes. Breiman and Cutler developed the RF algorithm for the framework of classification and regression trees.[46] Instead of having one tree, multiple trees are produced using a resampling method (500 regression trees are included by default in RF package in R), and the aggregate results are then combined. Breiman and Cutler believed that a single decision tree may not reveal all the important variables that contribute to the dependent variable (e.g., crashes) because some important variables can be masked by other important variables at a specific splitting node. In this case, RFs can help identify important predictors that may not appear in the output of a single classification or regression tree but are nevertheless highly predictive of the target variable.

There are very few studies in road-safety literature that have applied RF methods. Harb et al. employed RF to explore precrash maneuvers associated with rear-end, angle, and head-on crashes.[80] Rossi et al. concluded that the RF variable importance rankings are more stable than those produced by stepwise logistic regression.[81] Strobl, Malley, and Tutz also note that high-ranked variables on an list detailing the importance of RFs as a result of a complex interaction that cannot be captured in a regression model.[49]

The research team used the regression tree analysis as the data-mining method for this study to explore interactions among independent variables. Regression tree analysis is a robust data-mining and data-analysis tool that automatically searches for important patterns and relationships and quickly uncovers hidden structure even in highly complex data. It has been an active analytical technique in many scientific areas for many years. The analysis method does not require any predefined underlying relationship between targets (dependent variables) and predictors (independent variables) and has been shown to be a powerful tool to find the more important factors that contribute to the target variable. It also provides the ability to determine the level and type of interaction between independent variables as opposed to having to predefine such interactions when developing regression models.

There are two types of tree analysis. One type is a classification tree in which the dependent variable is binary, and the other type is a regression tree in which the dependent variable can be continuous or count data. The output is a tree that shows the most important predictor variables at the top of the tree in addition to combinations of variables that best predict the outcome variable. The analysis can also identify and explain the complex patterns associated with crash risk; it can effectively handle multicollinearity problems and observations with missing values.

It should be noted that Brieman's RF requires that the continuous dependent variables be normally distributed. Crash data are not normally distributed; therefore, more advanced techniques, known as conditional tree and conditional RF, were selected for this research effort.

There have been limited applications of tree analysis and other similar classification techniques in transportation. Council et al. employed classification trees to develop a speed-related crash typology to identify the crash, vehicle, and driver characteristics associated with speeding-related crashes.[82] In this effort, the target variable was a binary variable crash that was either speeding

related or not speeding related. Classification trees were also used in a more extensive study for NHTSA on this same topic in which the goal was the development of a speed-related crash taxonomy for different types of crashes.[83]

A few studies have used regression trees to examine the safety of different roadway features. For example, Abdel-Aty et al. used regression trees to identify factors associated with different types of crashes at signalized intersections.[84] Park and Saccomanno used a tree-based partitioning method to classify intersections and then applied generalized linear regression techniques to identify contributing factors associated with crashes at railroad grade crossings.[85]

Kuhnert, Dob, and McClure employed logistic regression, classification, and regression trees (CART) and multivariate adaptive regression splines (MARS) to analyze motor-vehicle injury data.[86] The aim of the study was to determine if taking risks was a significant contributor to crashes resulting in serious injury or death. By comparing the analysis results from logistic regression, the research team demonstrated that CART and MARS, which are capable of graphically displaying the analysis results and identifying the groups of people with potential high-crash risk, are informative and attractive models for motor-vehicle crash analysis. The research team also suggested that CART and MARS can be used as a precursor to a more-detailed logistic regression. However, the research team did not combine these methods for their study.

Other studies have used classification and regression trees for relating injury levels or specific types of crashes to drivers, vehicles, and environmental variables.[87–93] These studies used the classification tree method in which the dependent variable was a binary variable.

DATA MINING: PROCEDURE AND ANALYSIS

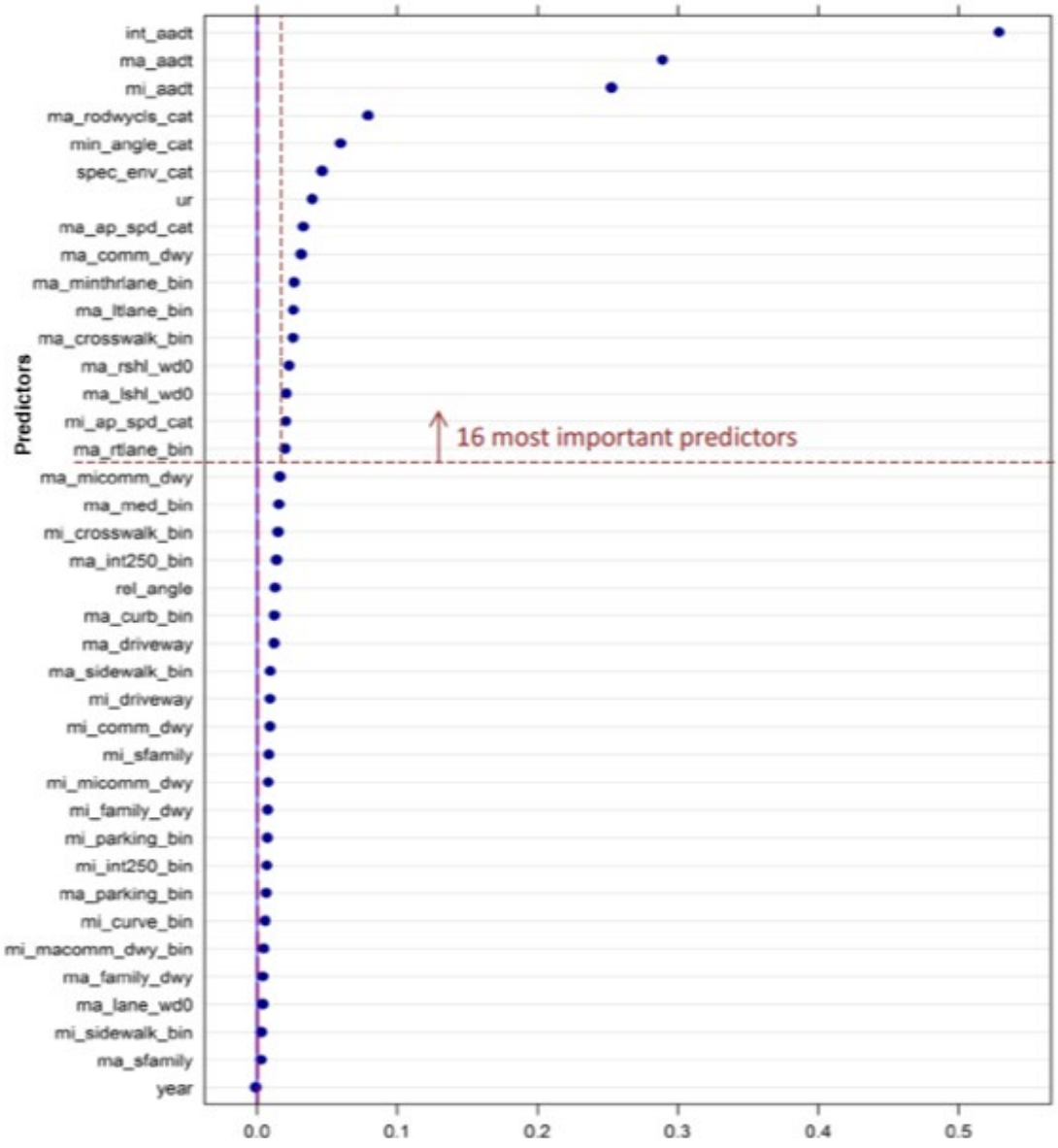
The parameter settings within the cforest algorithm were set to fit the type of predictor variables in the data and to develop the most robust results within the limits of the available computational power. For datasets that include different types (e.g., continuous versus categorical) of predictor variables, the recommendation is to use the default options *controls = cforest_unbiased* and permutation importance *varimp(obj)*.[49] For predictor variables that might be highly correlated, it is also recommended that the permutation importance setting be changed to conditional—*varimp(obj, conditional = TRUE)*. The computational power necessary for this latter condition is much greater than the default option. The computer on which the analysis was initially conducted included 16 gigabytes (GB) of random access memory (RAM) and was unable to produce results with the conditional permutation importance option because of the size of the database. A second attempt was made using a computer with 600 GB of RAM on the University of North Carolina campus; this attempt also failed to produce results. The program developer, Dr. Torsten Hothorn, confirmed through correspondence with another user that the application may not scale well. Thus, this option was not selected in the final analysis. Other options selected for the development of CRF results were generation of 1,500 trees, use of 15 randomly selected variables for each tree, and a splitting criterion based on a 5-percent significance level. In other words, 1,500 trees were produced for each RF analysis. The collective output from those 1,500 trees produced the final importance ranking of the predictor variables. For each of those 1,500 trees, 15 variables were randomly selected from the 39 and

34 variables available as candidates at each node. The permutation test statistic of 95 percent was exceeded to include a split in the computation of the importance value.

In addition to the parameter settings, the method of sampling also had to be established. The two options are bootstrap sampling with replacement and subsampling without replacement. Bootstrap sampling with replacement is the traditional method used in RF analysis, but it has recently been shown to artificially introduce associations between variables and produce bias toward the selection of predictor variables with more categories.[68] Thus, subsampling without replacement was selected as the chosen method. Specifically, the suggested default setting in function *cforest_unbiased ()* was adopted; 63.2 percent of the data were randomly sampled without replacement and were used as a training dataset while 36.8 percent were used as a test dataset.

The output from the CRF analysis for four-leg intersections with total crashes as the dependent or response variable is shown in figure 75. Variables can be considered informative and important if their variable importance value is greater than the absolute value of the lowest negative-scoring variable. The rationale for this is that the importance of irrelevant variables varies randomly around zero. The most important variables or strongest predictors are shown at the top of the plot. All variables to the right of the dashed line that extends the length of the chart are considered important. However, the farther a variable is from the top of the plot, the less predictive it is regarding the response variable (i.e., total crashes).

The goal of this analysis was to reduce the number of variables to a reasonable number for further consideration in the next phase of the analysis—development of NB models. Two criteria were established to produce this reduced list of variables. First, the number of variables selected had to be less than 50 percent of the starting number. For four-leg intersections, this meant the number of variables chosen could not exceed 19. For three-leg intersections, the maximum number of variables was 17. Second, the change in significance at the cutoff point between selected and nonselected variables was visually apparent on the plot. The goal of this criterion was to ensure that the breakpoint was not being chosen within a subset of variables with near identical importance values.



Source: FHWA.

Figure 75. Plot. Results of conditional RF (cforest) analysis for total crashes at four-leg intersections.

As shown in figure 75, the cutoff point was selected below the 16th most important predictor variable. There is an obvious change in the importance value between variables 16 and 17 in this list and the final number of variables selected is less than 19. Thus, both selection criteria are met. All the cforest plots for the six scenarios (three-leg and four-leg; total, fatal-and-injury, and PDO crashes) are provided in this appendix. Each plot shows the chosen cutoff point. A total of 16, 15, and 15 predictor variables, as shown in table 73, were selected for total, fatal-and-injury, and PDO crashes, respectively, for four-leg intersections. For three-leg intersections, a total of 10, 12, and 10 predictor variables were selected for total, fatal-and-injury, and PDO crashes, respectively.

With the most important predictor variables were identified through the CRF analysis, the next step in the data-mining process was the development and review of regression trees to either support or counter the CRF relative-importance findings and to identify interactions among these variables. Researchers used the ctree algorithm within Package party in R to develop the conditional inference trees within cforest. Thus, the same variable sets of 39 and 34 variables for four-leg and three-leg intersections, respectively, were used in the ctree analysis. In ctree, the permutation test was used to test the association between any of the input variables and the response. This association is measured by a *p*-value.

Three stopping criteria were established to define when the tree should no longer add branches. First, any split in the tree must be significant at a five-percent significance level ($p \leq 0.05$). Second, there must be a minimum number of data points in a node (N_{node}) to allow splitting to be considered. Third, there must be a minimum number of data points in a terminal node ($N_{terminal}$) to allow for a meaningful, but not overly complicated, tree to be generated. The starting number of data points for four-leg intersections was 11,683 (1,669 intersections multiplied by 7 yr). The starting number of data points for three-leg intersections was 7,763. For four-leg intersections, N_{node} and $N_{terminal}$ were set at 500 and 210, respectively. For three-leg intersections, N_{node} and $N_{terminal}$ were set at 300 and 140, respectively.

DATA DESCRIPTORS FOR MINNESOTA

Table 73 includes the variable names, data descriptors, and definitions or attributes for the data elements used in the analysis. The variable names are included in the tabular and graphical results from the data-mining analysis and the NB regression models. Graphical results from the data-mining analysis are included in this appendix. Figure 76 through figure 82 are the graphical results from the conditional RF analysis. Researchers used the cforest within Package party in R, version 1.0-6, statistical package. The four-leg intersections included 39 predictors in the dataset, while 34 predictors were included in the three-leg analysis. The most important predictors considered for inclusion in the NB models are shown in each figure. Figure 82 through figure 87 are the regression trees from the ctree analysis. Figures are provided for the following intersection configurations and crash severity classifications:

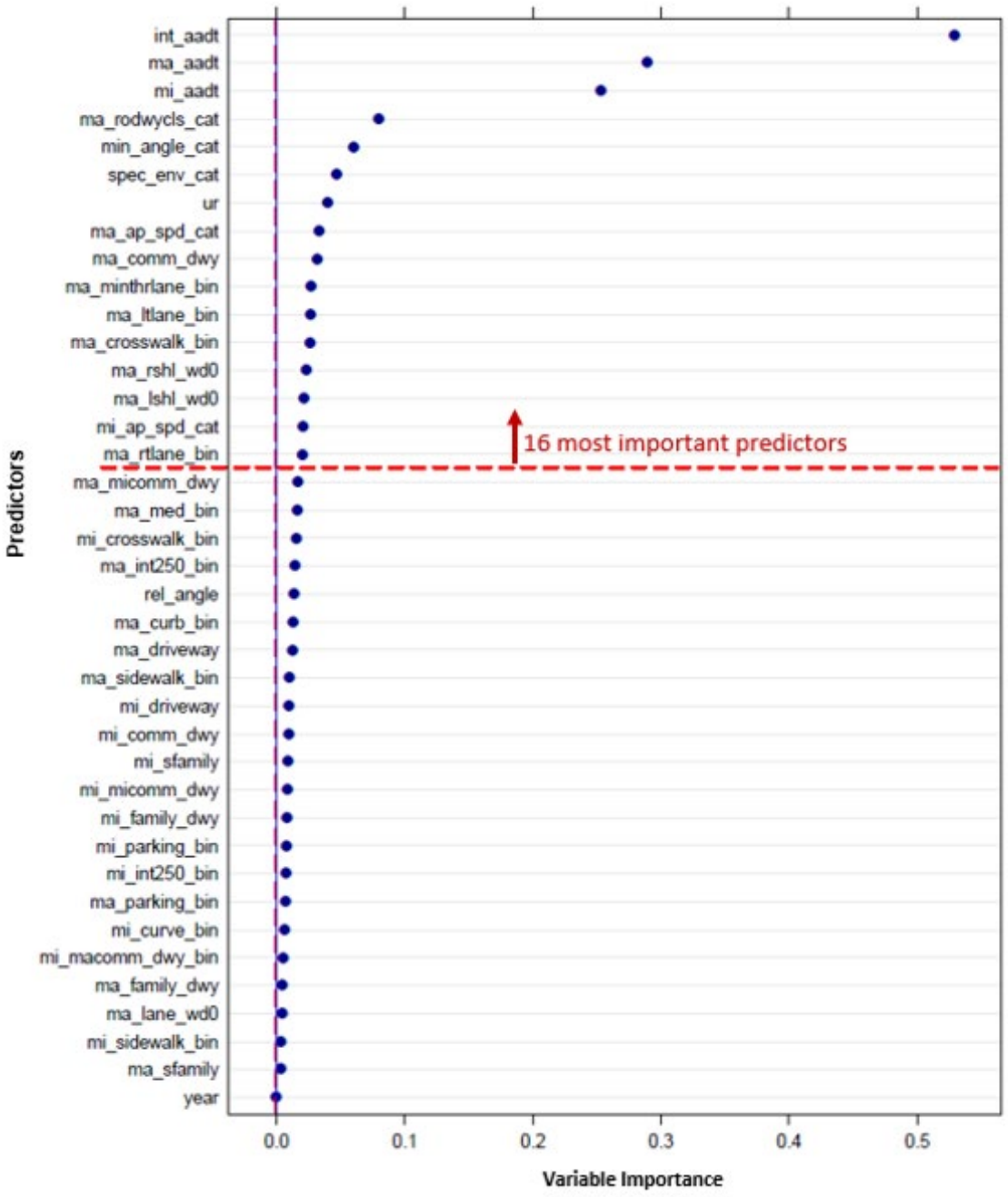
- Four-leg total crashes.
- Four-leg fatal-and-injury crashes.
- Four-leg PDO crashes.
- Three-leg total crashes.
- Three-leg fatal-and-injury crashes.
- Three-leg PDO crashes.

Table 73. Variable names, descriptors, definitions, and attributes for MN.

Variable Name	Descriptor	Definition and Attributes
tot	Total crashes—yearly	Total number of crashes occurring yearly across the 7-year study period (2003–2009)
pdo	Property-damage-only crashes—yearly	Total number of PDO crashes occurring yearly across the 7-year study period (2003–2009)
inj	Injury crashes—yearly	Total number of injury crashes occurring yearly across the 7-year study period (2003–2009)
year	Observation year—categorical variable	Crash and AADT observation year
rel_angle	Intersection angle complexity—categorical variable	Relative pattern of intersection angles (intersection complexity): 0 = no acute angle, 1 = 1 acute angle, 20 = 2 acute angles opposing, 21 = 2 acute angles adjacent
min_angle	Minimum angle	Minimum angle of intersection—smallest measured angle at the intersection (defined as intersection angle)
min_angle_cat	Minimum angle—category variable	10 categories: 1 = 1–39, 2 = 40–49, 3 = 50–54, 4 = 55–59, 5 = 60–64, 6 = 65–69, 7 = 70–74, 8 = 75–79, 9 = 80–84, 10 = 85+
ma_int250_bin	Intersection presence in 250 ft (minor road)—binary variable	0 = no, 1 = yes
mi_int250_bin	Intersection presence in 250 ft (major road)—binary variable	0 = no, 1 = yes
mi_curve_bin	Curve presence within 250 ft of intersection (minor road)—binary variable	0 = no curve, 1 = slight curve or sharp curve
ma_minthrlane_bin	Minimum number of through lanes (major road)—binary variable	0 = minimum number of through lanes on major approach is less than 3; 1 = otherwise
ma_ltlane_bin	Left-turn lane presence (major road)—binary variable	0 = no, 1 = yes
ma_rtlane_bin	Right-turn lane presence (major road)—binary variable	0 = no, 1 = yes
ma_med_bin	Median presence (major road)—binary variable	0 = no, 1 = yes
ma_crosswalk_bin	Crosswalk presence (major road)—binary variable	0 = no, 1 = yes
mi_crosswalk_bin	Crosswalk presence (minor road)—binary variable	0 = no, 1 = yes
ma_sidewalk_bin	Sidewalk presence (major road)—binary variable	0 = no, 1 = yes
mi_sidewalk_bin	Sidewalk presence (minor road)—binary variable	0 = no, 1 = yes
ma_parking_bin	Parking presence on major street (painted spaces visible or parked cars)—binary variable	0 = no, 1 = yes
mi_parking_bin	Parking presence on minor street (painted spaces visible or parked cars)—binary variable	0 = no, 1 = yes

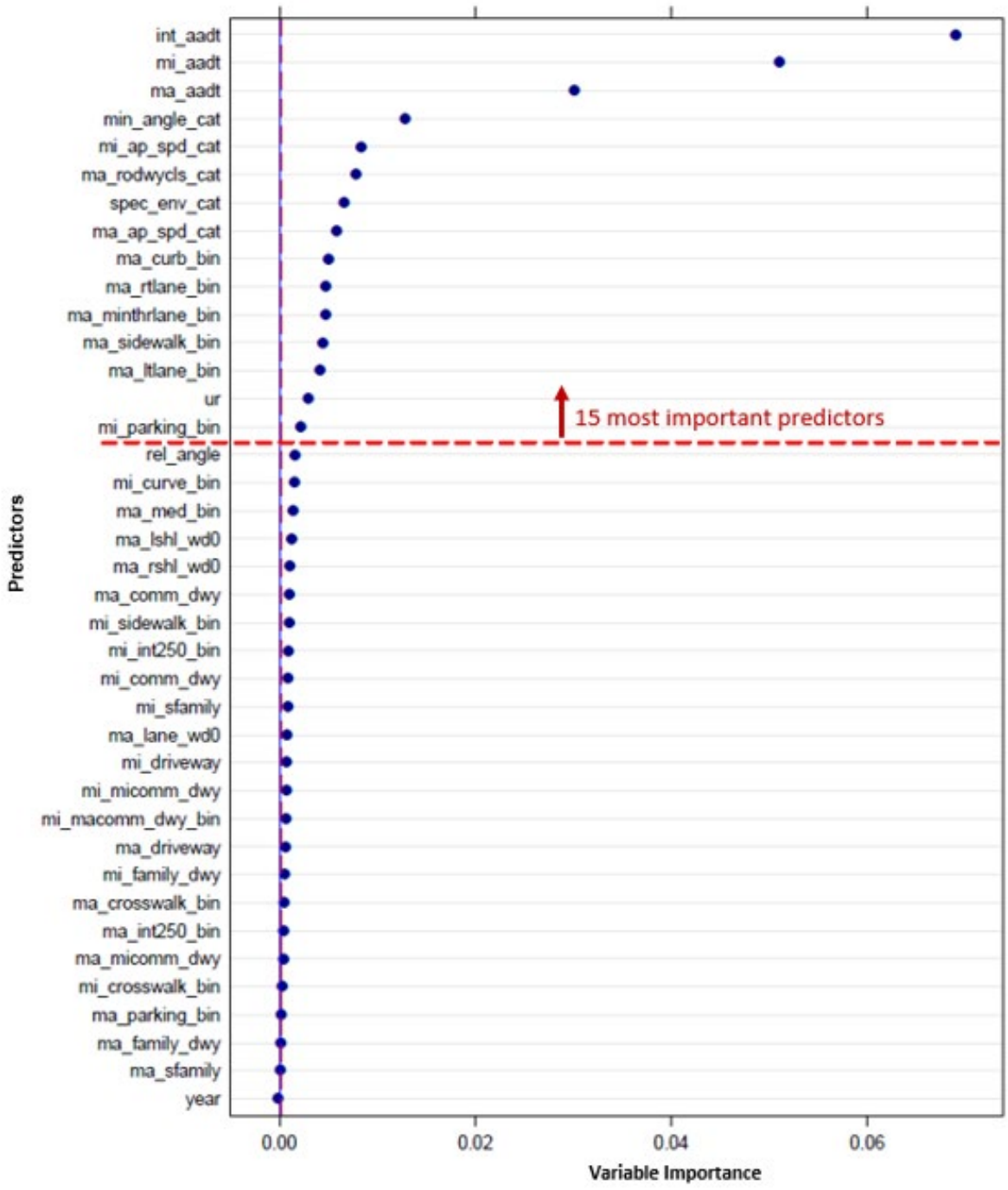
Variable Name	Descriptor	Definition and Attributes
ma_curb_bin	Curb presence (major road) —binary variable	0 = no, 1 = yes
ur	Urban or rural—binary variable	U = urban, R = rural
ma_rodwycls_cat	Roadway classification (major road)—categorical variable	1 = urban two-lane roads, 2 = urban multilane divided or nondivided nonfreeway, 3 = rural two-lane roads, 4 = rural multilane divided or nondivided nonfreeway
spec_env_cat	Specific environment—categorical variable	1 = strip commercial area or shopping center, 2 = residential area, 3 = agriculture, agriculture and isolated business/school, 0 = commercial business development or other
mi_macomm_dwy_bin	Major commercial driveway presence (minor road)—binary variable	0 = no, 1 = yes
ma_micomm_dwy	Number of minor commercial driveways—major road	Total number of minor commercial/industrial driveways on the major-road approaches within 250 ft of intersection.
mi_micomm_dwy	Number of minor commercial driveways—minor road	Total number of minor commercial/industrial driveways on the minor-road approaches within 250 ft of intersection
ma_comm_dwy	Number of commercial driveways—major road	Total number of commercial/industrial driveways on the major-road approaches within 250 ft of intersection
mi_comm_dwy	Number of commercial driveways—minor road	Total number of commercial/industrial driveways on the minor-road approaches within 250 ft of intersection
ma_sfamily	Number of single family residential driveways—major road	Total number of single family residential driveways on the major-road approaches within 250 ft of intersection
mi_sfamily	Number of single family residential driveways—minor road	Total number of single family residential driveways on the minor-road approaches within 250 ft of intersection
ma_family_dwy	Number of family residential driveways—major road	Total number of family residential driveways including single and multifamily driveways on the major-road approaches within 250 ft of intersection
mi_family_dwy	Number of family residential driveways—minor road	Total number of family residential driveways including single and multifamily driveways on the minor-road approaches within 250 ft of intersection
ma_driveway	Number of driveways—major road	Total number of all driveways on the major-road legs including major commercial/industrial driveways, minor commercial/industrial driveways, single family residential driveways, and multifamily residential driveways

Variable Name	Descriptor	Definition and Attributes
mi_driveway	Number of driveways—minor road	Total number of all driveways on the minor-road legs including major commercial/industrial driveways, minor commercial/industrial driveways, single family residential driveways, and multifamily residential driveways
ma_aadt	Total entering AADT—major road	Average of AADT on the two major-road legs
mi_aadt	Total entering AADT—minor road	Average of AADT on the two minor-road legs
int_aadt	Total entering AADT—intersection	int_AADT = ma_AADT + mi_AADT
ma_ap_spd_cat	Speed limit (major road)—categorical variable	1 = average speed limit on major road = 0–31, 2 = average speed limit = 31–54, 3 = average speed limit > = 55
mi_ap_spd_cat	Speed limit (minor road)—categorical variable	1 = average speed limit on minor road = 0–31, 2 = average speed limit = 31–54, 3 = average speed limit > = 55
ma_lshl_wd0	Major road left-shoulder width	Average left-shoulder width in ft on the major road
ma_rshl_wd0	Major road right-shoulder width	Average right-shoulder width in ft on the major road
ma_lane_wd0	Major road lane width	Average lane width in ft on the major road
mi_int	Minor road AADT Ratio	Ratio of minor road AADT to intersection AADT: mi_int = mi_aadt/int_aadt
lgmi_aadt	Log value of minor road AADT	*lgmi_aadt = ln(mi_aadt)*
lgint_aadt	Log value of intersection AADT	*lgint_aadt = ln(int_aadt)*
lgcos_int	Derived variable-cos(min_angle) and intersection AADT	Derived variable that incorporates intersection AADT and cosine of the intersection angle: lgcos_int = *ln*[(*int_aadt*) × (1 + *cos*(*min_angle*))]
lgcos_mi	Derived variable-cos(min_angle) and minor road AADT	Derived variable that incorporates minor road AADT and cosine of the intersection angle: *lgcos_mi* = *ln*[(*mi_aadt*) × (1 + *cos*(*min_angle*))]]
lgcos_1	Derived variable	*lgcos_1* = 1 + ln [1 + *cos*(*angle*)]
cos1_lgint	Interaction term of intersection AADT and cosine of the intersection angle	*cos1_lgint* = [1 + *cos*(*angle*)] × ln(*intersection aadt*)
cos1_mmiint	Interaction term of minor road to intersection AADT ratio and cosine of the intersection angle	*cos1_mmiint* = [1 + *cos*(*angle*)] × (*minor road aadt*/*intersection aadt*)
angR1_mint	Interaction term of intersection AADT and skew angle expressed in radians	*angR1_mint* = [1 + (90–angle)π/180] × ln(intersection aadt)



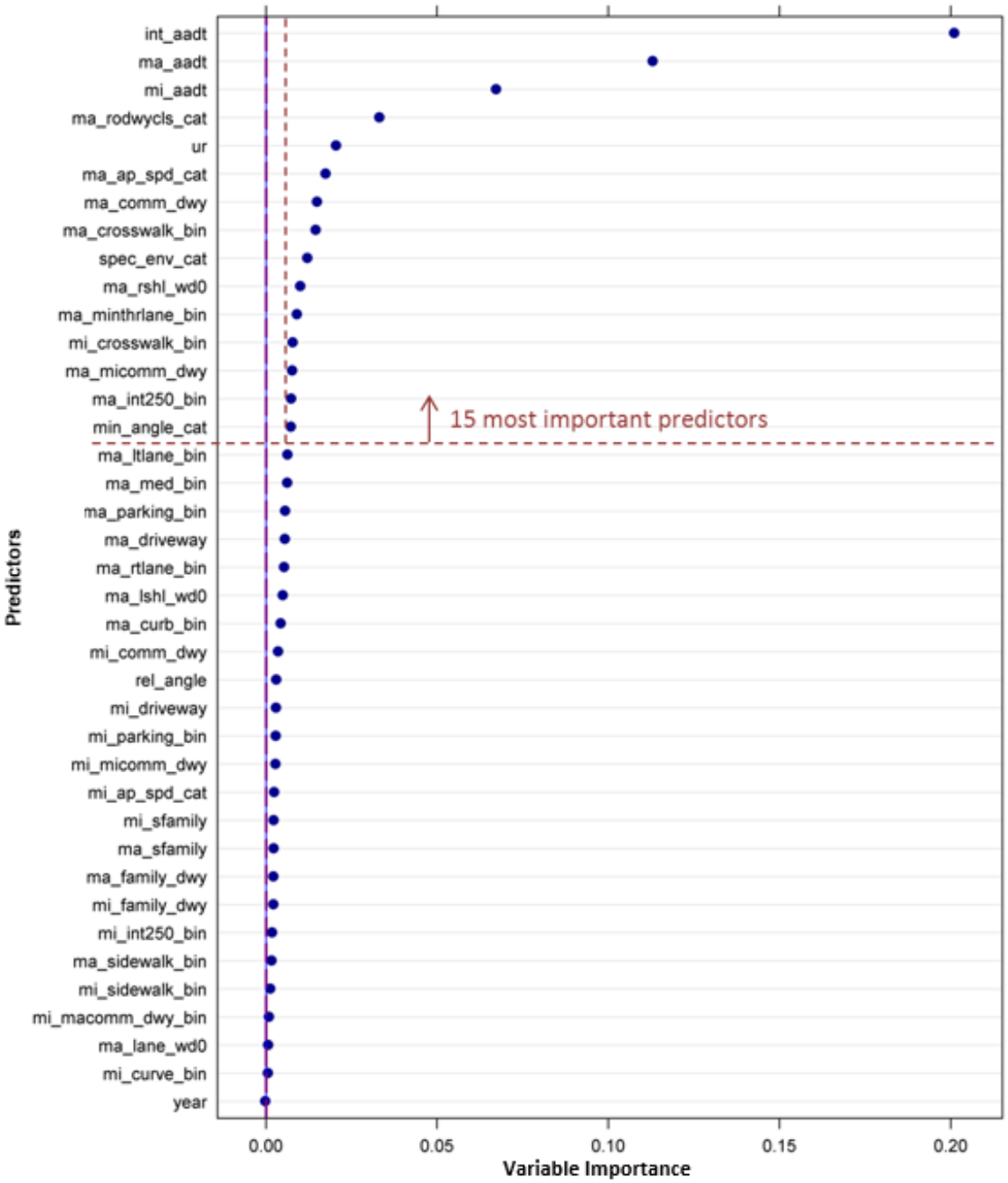
Source: FHWA.

Figure 76. Plot. Conditional RF (cforest) results for total crashes at four-leg intersections.



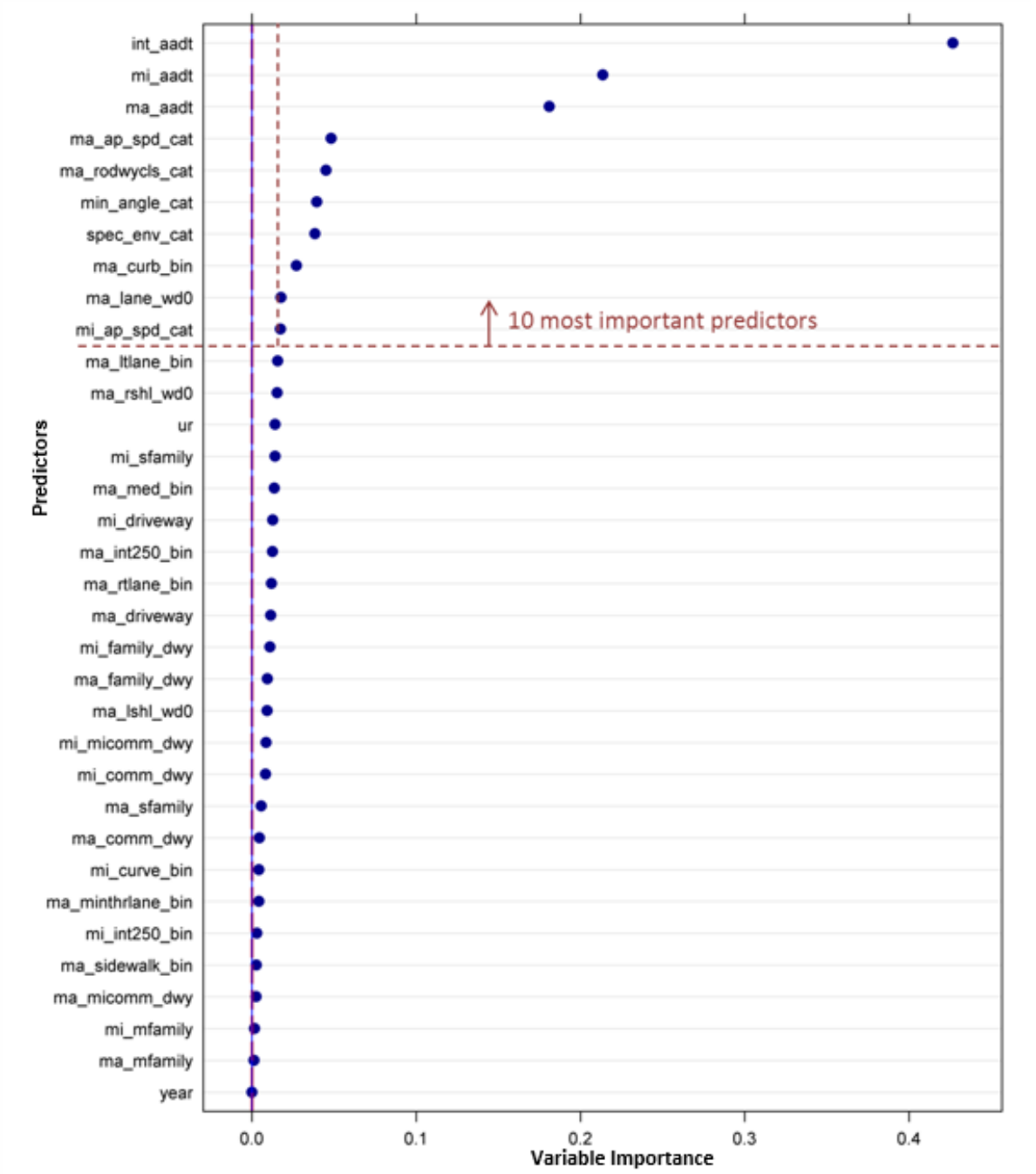
Source: FHWA.

Figure 77. Plot. Conditional RF (cforest) results for fatal-and-injury crashes at four-leg intersections.



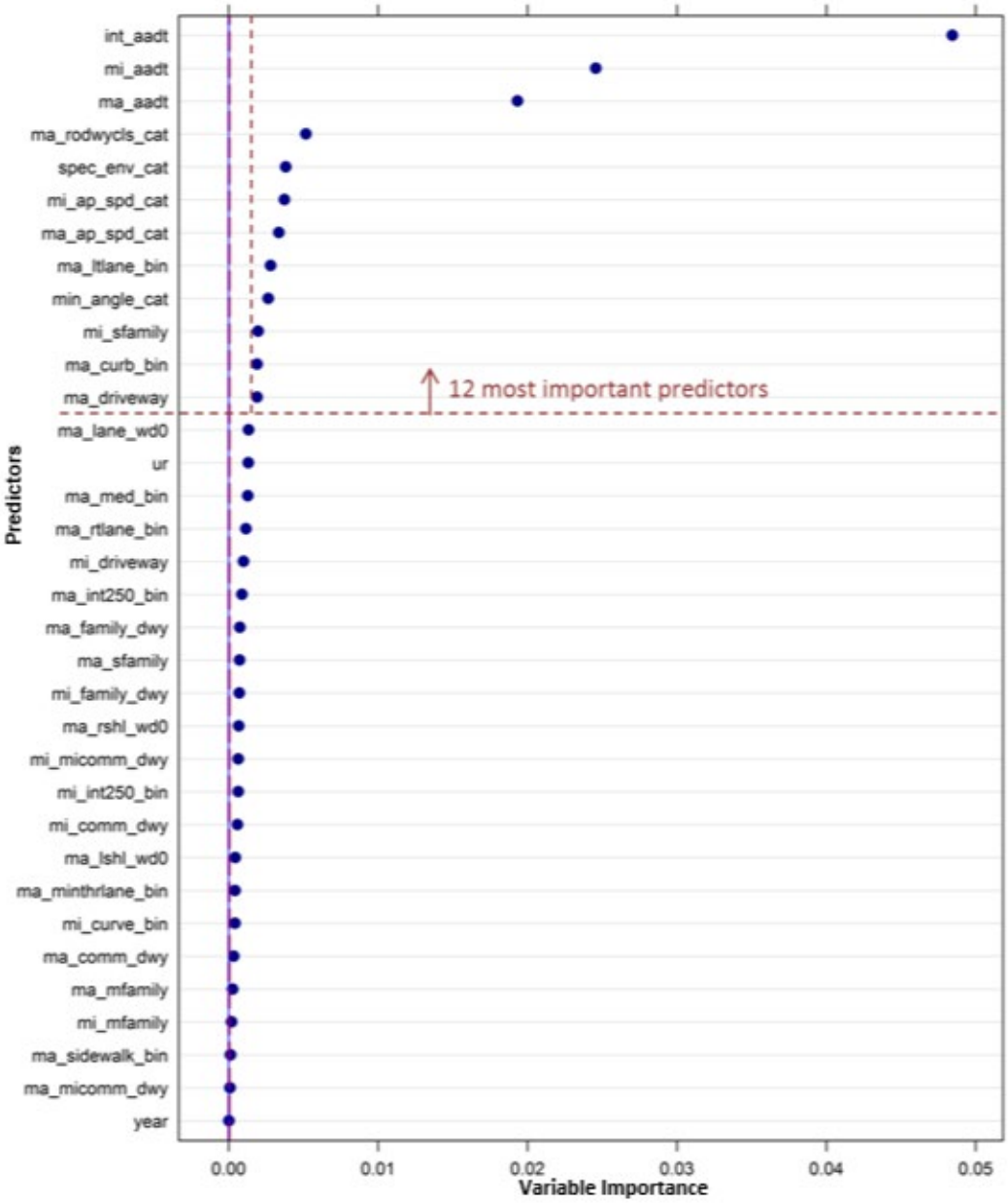
Source: FHWA.

Figure 78. Plot. Conditional RF (cforest) results for PDO crashes at four-leg intersections.



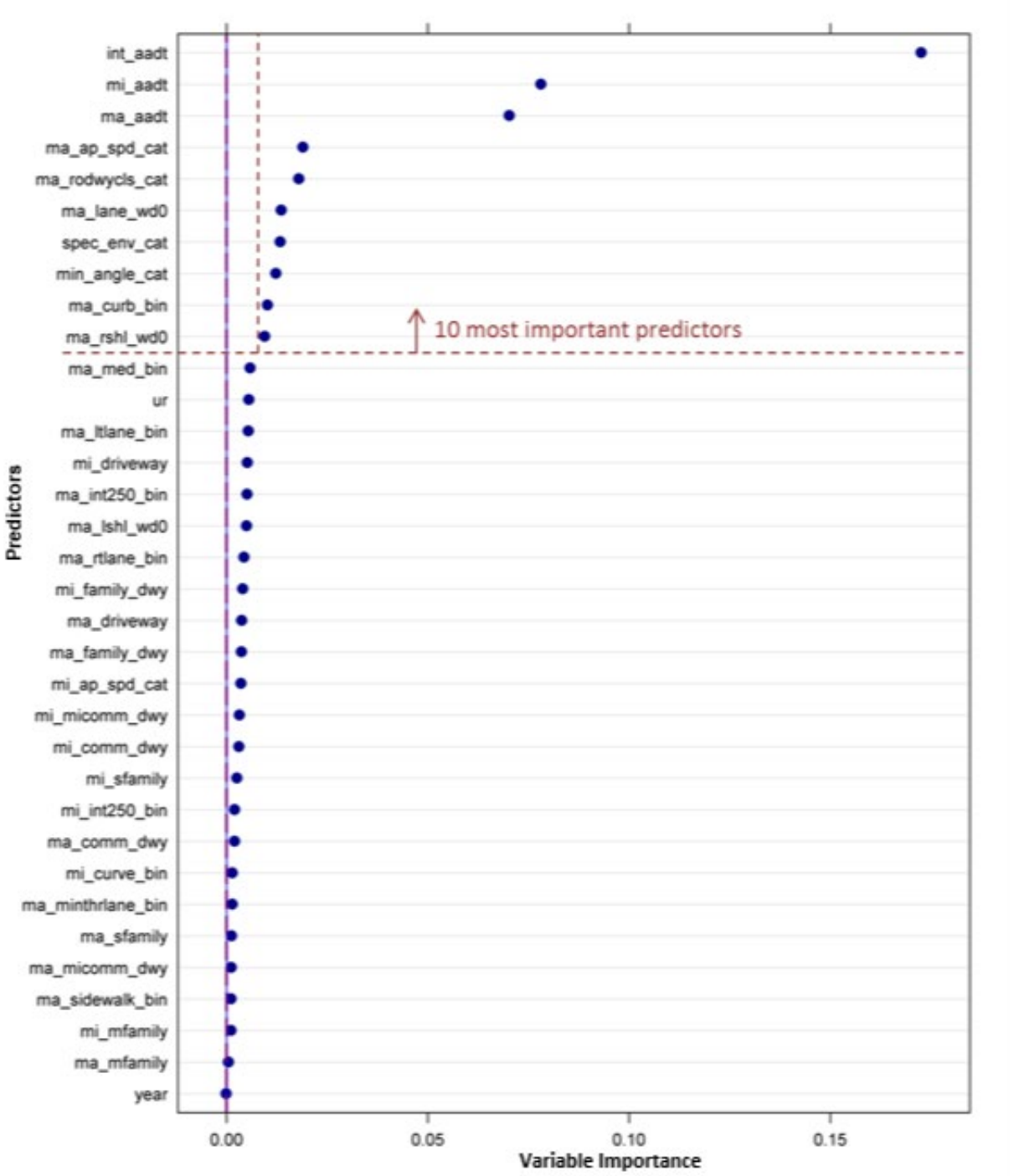
Source: FHWA.

Figure 79. Plot. Conditional RF (cforest) results for total crashes at three-leg intersections.



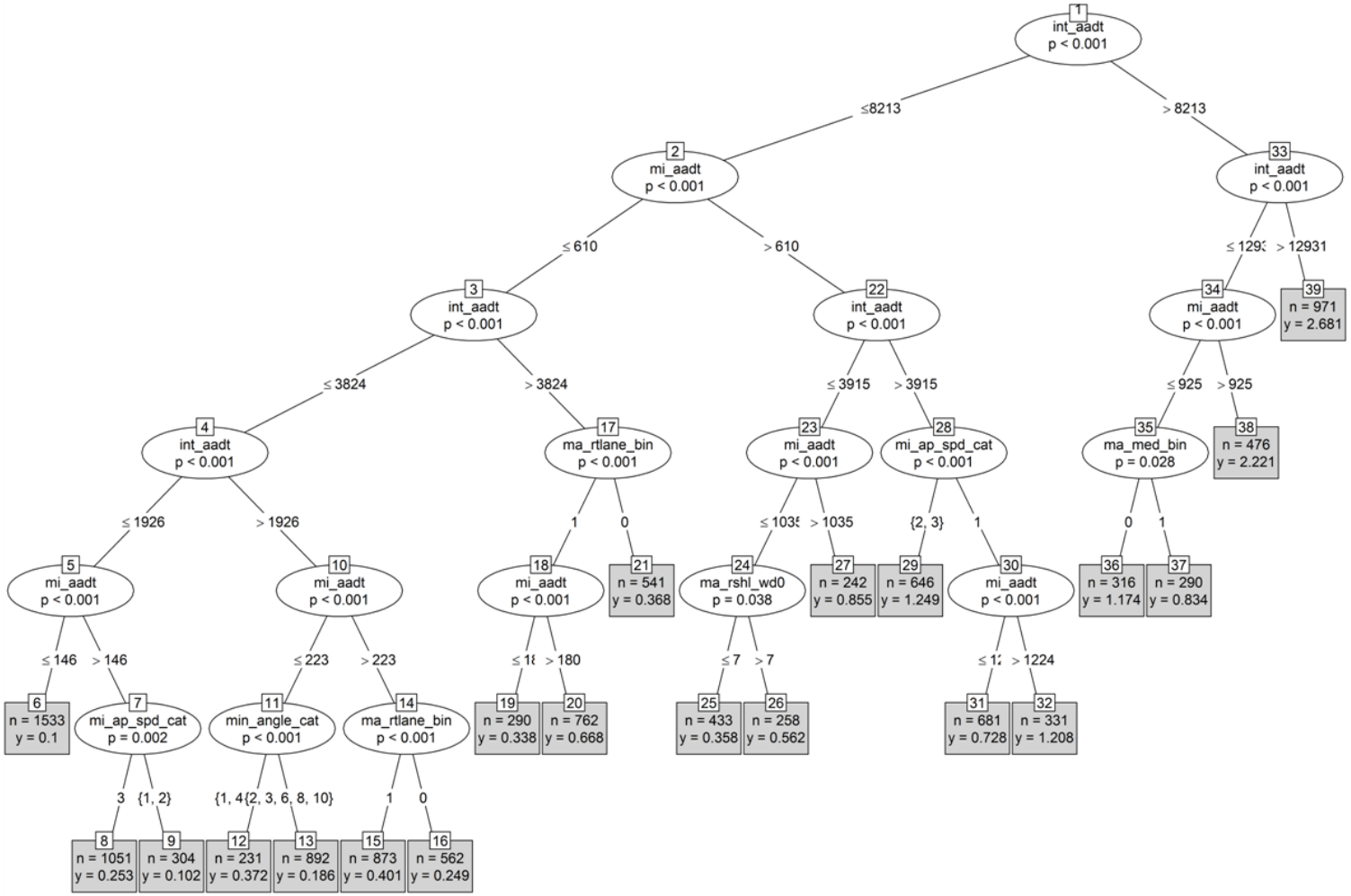
Source: FHWA.

Figure 80. Plot. Conditional RF (cforest) results for fatal-and-injury crashes at three-leg intersections.



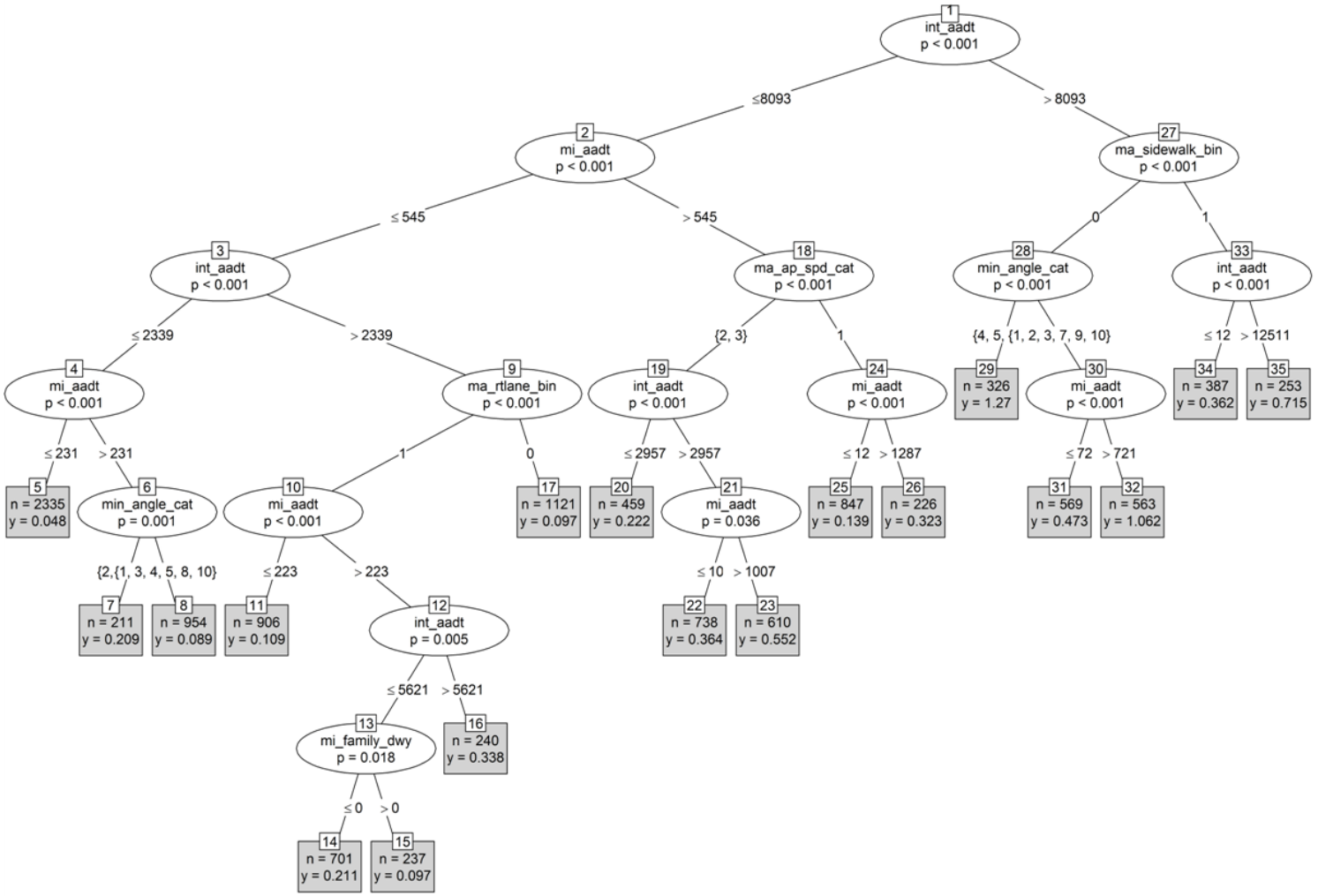
Source: FHWA.

Figure 81. Plot. Conditional RF (cforest) results for PDO crashes at three-leg intersections.



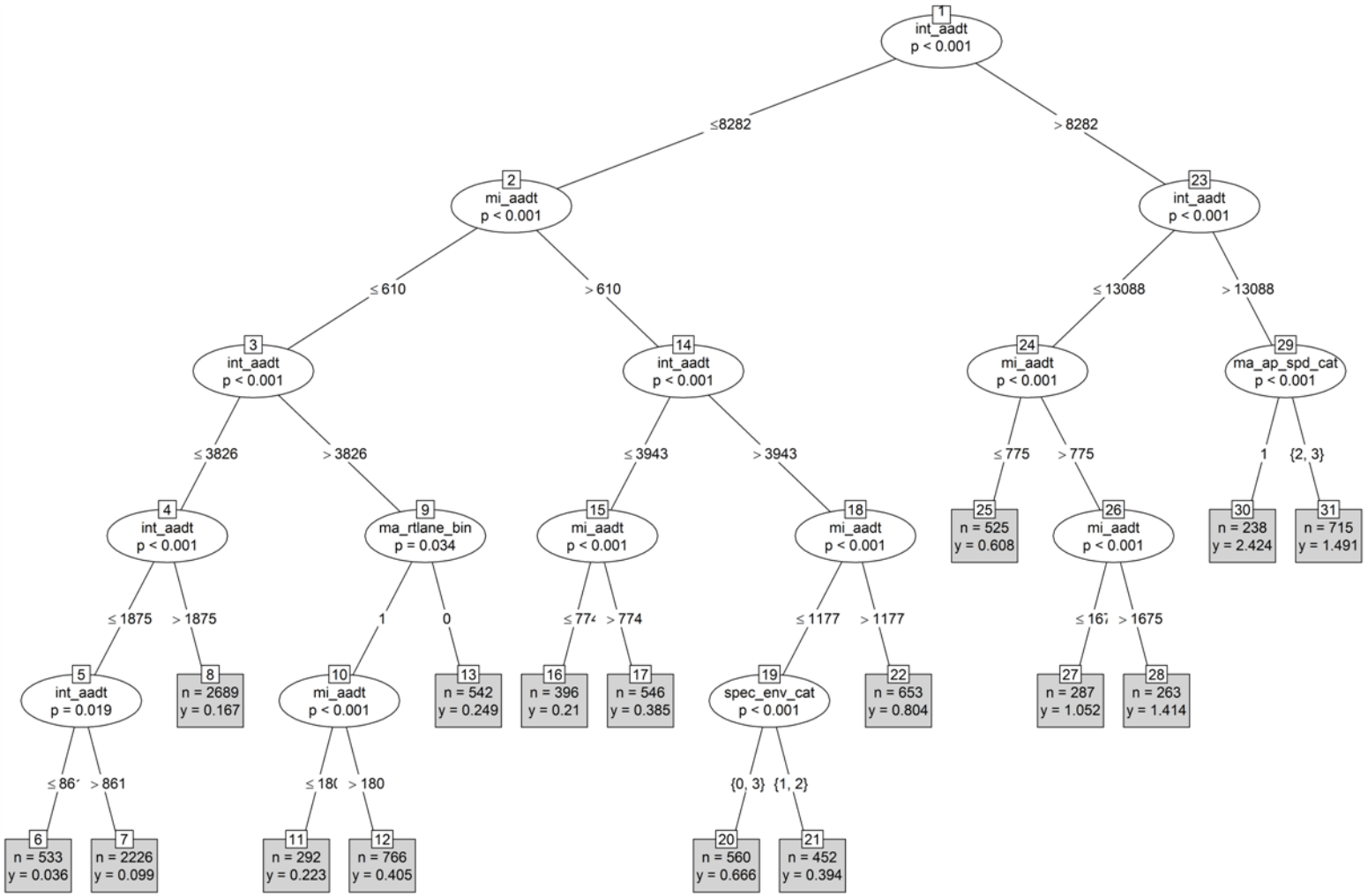
Source: FHWA.

Figure 82. Plot. Regression tree for total crashes at four-leg intersections (results from ctree analysis).



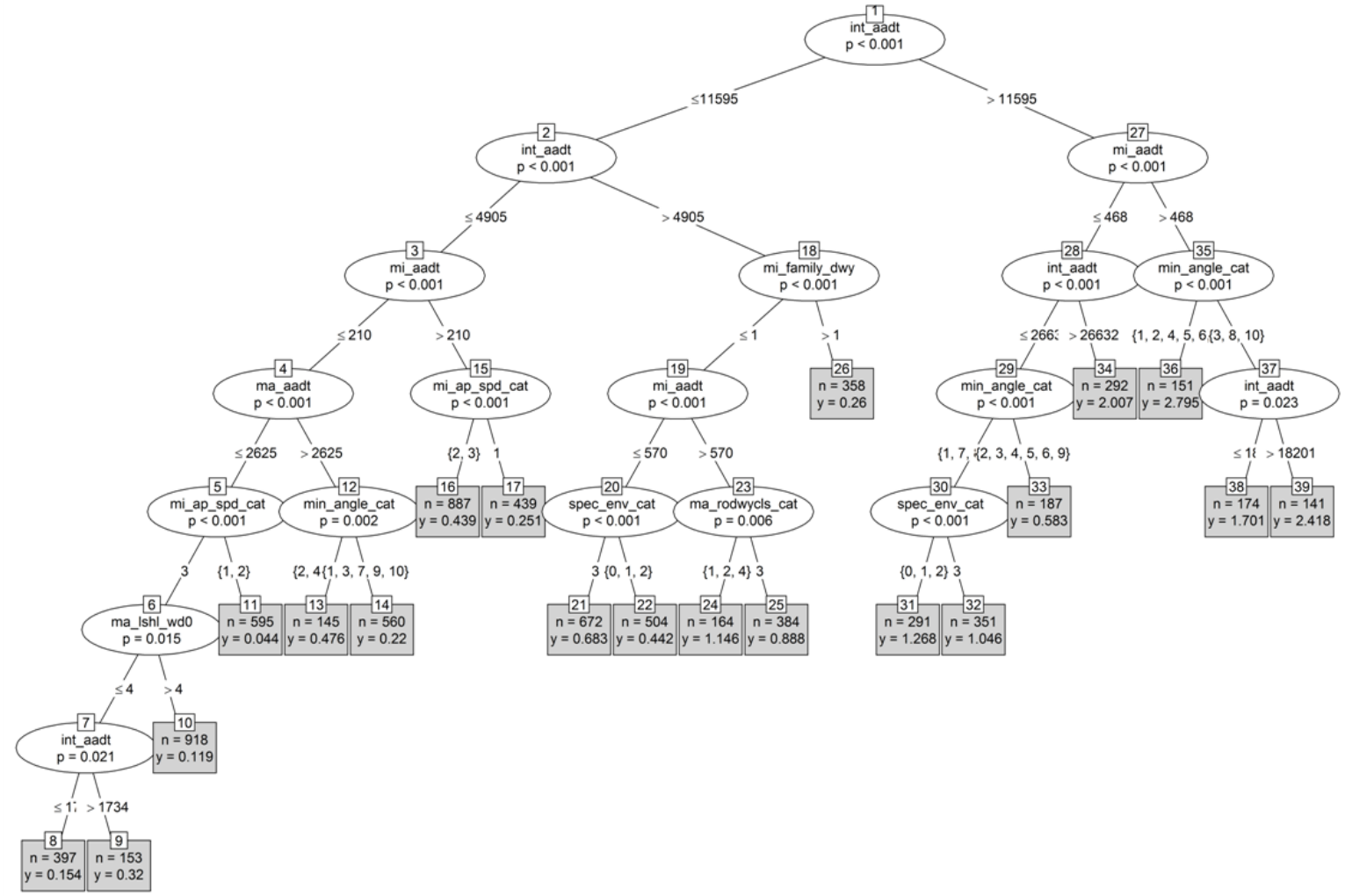
Source: FHWA.

Figure 83. Plot. Regression tree for fatal-and-injury crashes at four-leg intersections (results from ctree analysis).



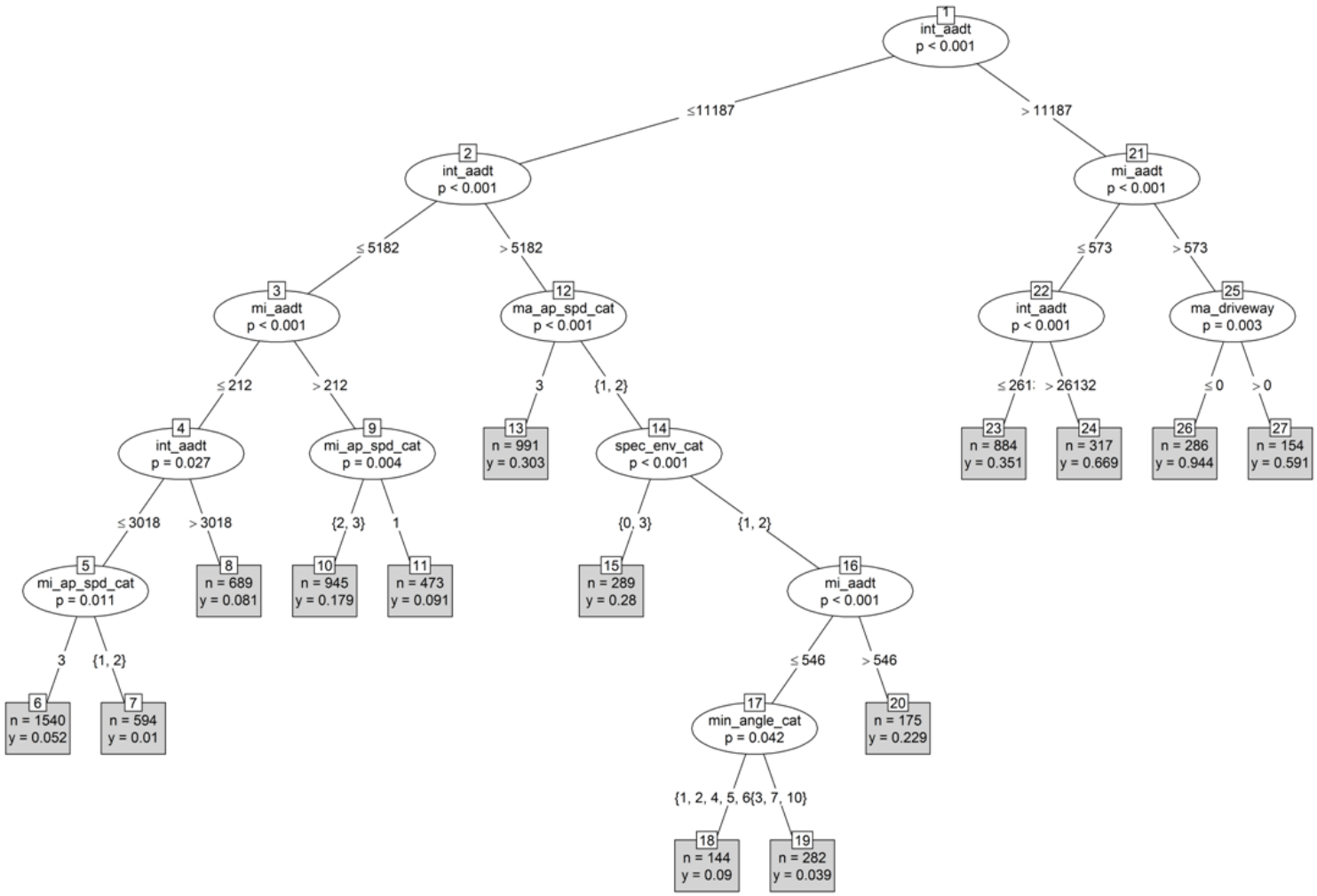
Source: FHWA.

Figure 84. Plot. Regression tree for PDO crashes at four-leg intersections (results from ctree analysis).



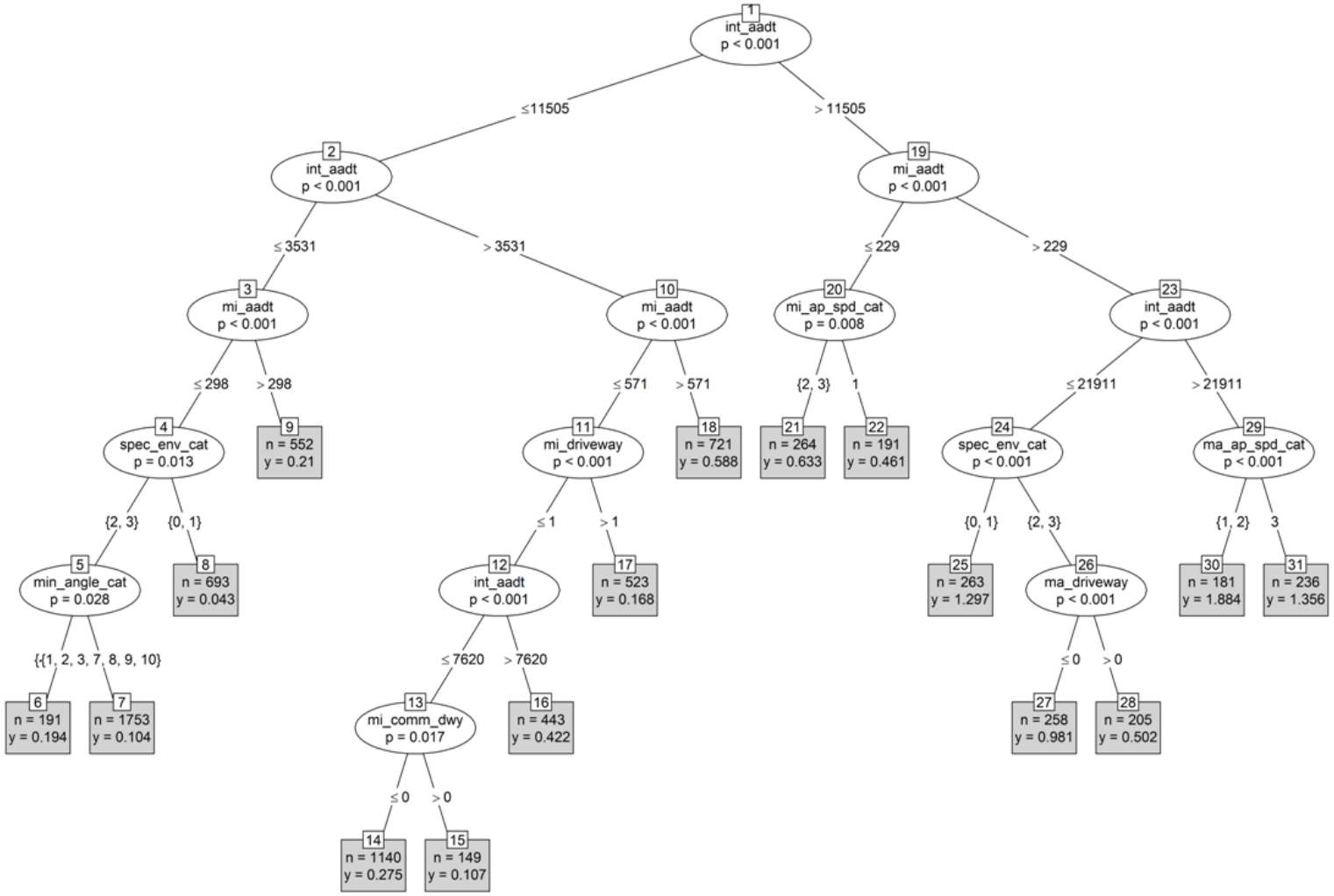
Source: FHWA.

Figure 85. Plot. Regression tree for total crashes at three-leg intersections (results from ctree analysis).



Source: FHWA.

Figure 86. Plot. Regression tree for injury crashes at three-leg intersections (results from ctree analysis).



Source: FHWA.

Figure 87. Plot. Regression tree for PDO crashes at three-leg intersections (results from ctree analysis).

DATA DESCRIPTORS FOR OHIO

Table 74. Variable names, descriptors, definitions, and attributes for OH.

Variable Name	Descriptor	Definition and Attributes
min_angle	Minimum angle	Minimum angle of intersection—smallest measured angle at the intersection (defined as intersection angle).
lighting	Lighting	A binary categorical variable capturing whether lighting is present at the intersection.
ma_division	Roadway division of major approach	A binary categorical variable capturing the division status of the major roadway at the intersection (D = divided; U = undivided).
ma_rodwycls_cat	Functional classification of major approach	A categorical variable capturing the functional classification of the roadway (e.g., local, minor collector, major collector, minor arterial, principal arterial).
ma_aadt	AADT of major approach	Average of AADT on the two major-road legs.
mi_aadt	AADT of minor approach	Average of AADT on the two minor-road legs.
int_aadt	Total intersection AADT	*int_aadt = ma_aadt + mi_aadt*
mi_int	Minor road/intersection AADT ratio	Ratio of minor road AADT to intersection AADT: *mi_int = mi_aadt/int_aadt*
lgma_aadt	Natural log of major approach AADT	*lgma_aadt = ln(ma_aadt)*
lgmi_aadt	Natural log of minor approach AADT	*lgmi_aadt = ln(mi_aadt)*
lgint_aadt	Natural log of total intersection AADT	*lgint_aadt = ln(int_aadt)*
lgmi_int	Natural log of minor road/intersection AADT ratio	*lgmi_int = ln(it_int)*
lgcos_int	Cosine term of the intersection AADT term	Derived variable that incorporates intersection AADT and cosine of the intersection angle: *lgcos_int* = ln[(*int_aadt*) × (1 + cos(*min_angle*))]
lgcos_mi	Cosine term of the minor approach AADT term	Derived variable that incorporates minor road AADT and cosine of the intersection angle: *lgcos_mi* = ln[(*mi_aadt*) × (1 + cos*(min_angle*)]]
lgmin_angle	Natural log of minimum angle	*lgmin_angle* = ln(*min_angle*)

Table 75. Number of sites in each angle bin for all rural, four-leg intersections in OH.

Minimum Angle Bin	Frequency	Percent
11–20	—	—
21–30	19	0.57
31–40	72	2.16
41–50	164	4.92
51–60	284	8.52
61–70	402	12.05
71–80	540	16.19
80+	1,854	55.59

—No data available.

Table 76. Number of sites in each angle bin for rural four-leg two-lane intersections in OH.

Minimum Angle Bin	Frequency	Percent
11–20	—	—
21–30	19	0.59
31–40	71	2.20
41–50	160	4.96
51–60	279	8.65
61–70	372	11.53
71–80	523	16.21
80+	1,803	55.87

—No data available.

Table 77. Number of sites in each angle bin for rural four-leg multilane intersections in OH.

Minimum Angle Bin	Frequency	Percent
11–20	—	—
21–30	—	—
31–40	—	—
41–50	—	—
51–60	5	4.85
61–70	30	29.13
71–80	17	16.50
80+	51	49.51

—No data available.

Table 78. Number of sites in each angle bin for rural three-leg total intersections in OH.

Minimum Angle Bin	Frequency	Percent
11–20	76	1.09
21–30	214	3.08
31–40	250	3.60
41–50	409	5.88
51–60	549	7.90
61–70	881	12.67
71–80	1,409	20.27
80+	3,163	45.50

Table 79. Number of sites in each angle bin for rural three-leg two-lane intersections in OH.

Minimum Angle Bin	Frequency	Percent
11–20	76	1.11
21–30	214	3.12
31–40	249	3.63
41–50	406	5.91
51–60	549	7.99
61–70	867	12.62
71–80	1,394	20.30
80+	3,113	45.33

Table 80. Number of sites in each angle bin for urban four-leg total intersections in OH.

Minimum Angle Bin	Frequency	Percent
11–20	—	—
21–30	—	—
31–40	11	2.59
41–50	23	5.42
51–60	41	9.67
61–70	55	12.97
71–80	94	22.17
80+	200	47.17

—No data available.

Table 81. Number of sites in each angle bin for urban four-leg two-lane intersections in OH.

Minimum Angle Bin	Frequency	Percent
11–20	—	—
21–30	—	—
31–40	11	2.95
41–50	23	6.17
51–60	36	9.65
61–70	47	12.60
71–80	81	21.72
80+	175	46.92

—No data available.

Table 82. Number of sites in each angle bin for urban three-leg total intersections in OH.

Minimum Angle Bin	Frequency	Percent
11–20	12	0.71
21–30	29	1.73
31–40	38	2.26
41–50	36	2.14
51–60	99	5.89
61–70	201	11.96
71–80	310	18.44
80+	956	56.87

Table 83. Number of sites in each angle bin for urban three-leg two-lane intersections in OH.

Minimum Angle Bin	Frequency	Percent
11–20	11	0.75
21–30	28	1.91
31–40	34	2.32
41–50	35	2.38
51–60	93	6.34
61–70	181	12.33
71–80	273	18.60
80+	813	55.38

APPENDIX E. SUPPLEMENTAL SAFETY-PREDICTION MODELS

The NB regression models developed for total crashes for four-leg and three-leg intersections were presented and discussed in chapter 5. Included in this appendix are the results for the remaining models developed as part of the analysis and used for the derivation of intersection angle CMFs. Models are only included if the intersection-angle parameters were significant and the models converged. Table 84 summarizes the additional severity models for MN and OH. All models were independently derived; therefore, the results from models for PDO crashes cannot be combined with results from models for fatal-and-injury models to produce an estimate equivalent to the estimate produced from the model for total crashes. Only total crash (all severities) models were developed for OH data.

Table 84. Summary of severity models included in appendix E.

State	Intersection Category	Collision Category	Model Type	Corresponding Table
MN	Four-leg—all sites, rural and urban	Total	Base	Table 85
MN	Four-leg—all sites, rural and urban	Total	Interaction	Table 86
MN	Four-leg—all sites, rural and urban	Total	Alternative base	Table 87
MN	Four-leg—all sites, rural and urban	Fatal and injury	Flexible form model 1	Table 92
MN	Four-leg—all sites, rural and urban	PDO	Alternative base	Table 93
MN	Four-leg—all sites, rural and urban	PDO	Flexible form model 1	Table 94
MN	Four-leg—all rural sites	Total	Alternative base	Table 95
MN	Four-leg—all rural sites	Total	Flexible form model 1	Table 96
MN	Four-leg—all rural sites	Fatal and injury	Alternative base	Table 97
MN	Four-leg—all rural sites	Fatal and injury	Flexible form model 1	Table 98
MN	Four-leg—all rural sites	PDO	Alternative base	Table 99
MN	Four-leg—all rural sites	PDO	Flexible form model 1	Table 100
MN	Four-leg—rural two-lane sites	Total	Alternative base	Table 101
MN	Four-leg—rural two-lane sites	Total	Flexible form model 1	Table 102
MN	Four-leg—rural two-lane sites	Fatal and injury	Flexible form model 1	Table 103
MN	Four-leg—rural two-lane sites	PDO	Alternative base	Table 104
MN	Four-leg—rural two-lane sites	PDO	Flexible form model 1	Table 104
MN	Four-leg—multilane rural sites	Total	Alternative base	Table 105
MN	Four-leg—multilane rural sites	Total	Flexible form model 1	Table 107
MN	Four-leg—multilane rural sites	Fatal and injury	Flexible form model 2	Table 108
MN	Four-leg—multilane rural sites	PDO	Alternative base	Table 109
MN	Four-leg—multilane rural sites	PDO	Flexible form model 2	Table 110
MN	Three-leg—all sites, rural and urban	Total	Base	Table 88
MN	Three-leg—all sites, rural and urban	Total	Alternative base	Table 89
MN	Three-leg—all sites, rural and urban	Total	Flexible form model 2	Table 90
MN	Three-leg—all sites, rural and urban	Total	Interaction model	Table 91
OH	Four-leg—rural two-lane sites	Total	Flexible form model 1	Table 111
OH	Four-leg—multilane rural sites	Total	Flexible form model 1	Table 112
OH	Four-leg—two-lane urban sites	Total	Flexible form model 1	Table 114
OH	Three-leg—rural two-lane sites	Total	Hoerl curve	Table 113
OH	Three-leg—two-lane urban sites	Total	Flexible form model 1	Table 115

MN SUPPLEMENTAL SAFETY-PREDICTION MODELS

All Four-Leg Intersections—Base Models for Total Crashes

The first set of models developed for four-leg intersections was for total crashes, including all rural and urban sites. The database included 8,482 crashes distributed across 1,669 intersections over a 7-year period. Intersection AADT, major road AADT, and minor road AADT were among the 16 most important predictors from the conditional RF analysis. Scatterplots of these variables are shown in figure 88 and figure 89. Major road AADT and intersection AADT are highly correlated; they each have a Pearson Correlation Coefficient (r) equal to 0.995. Minor road AADT and intersection AADT do not share the same level of correlation ($r = 0.380$). Intersection AADT and minor road AADT were also the two AADT variables that most frequently appeared in the regression tree results. Thus, intersection AADT and minor road AADT were selected for inclusion in the models. Major road AADT was not selected because of its strong correlation with intersection AADT.

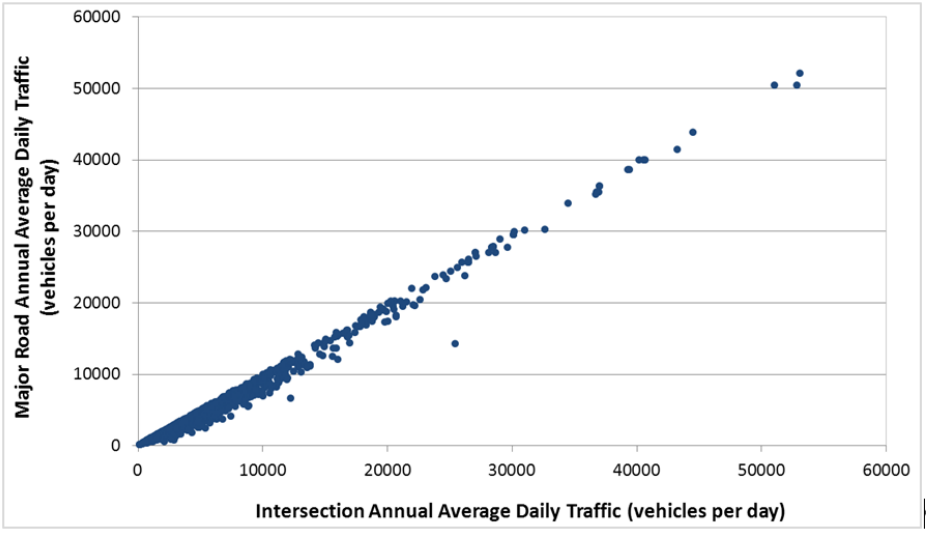
Additionally, each developed model was examined by substituting intersection AADT with major road AADT. The researchers confirmed that the model including intersection AADT better fits the data compared to the model with major road AADT in terms of lower value of AIC and BIC.

The initial base model, with only the significant variables ($p \leq 0.05$) retained, is shown in table 85. Both intersection AADT and minor road AADT are significant, predicting an increase in crashes as either value increases. Intersection angle (*min_angle*) is significant with a p-value of 0.0203. For each one degree increase in angle (i.e., moving toward a right angle), total crashes are estimated to decrease by 0.0021.

Major roadway class (*ma_rodwycls_cat*) is also significant for the category of rural two-lane roads compared to rural multilane roads. However, urban multilane roads and two-lane roads are not significantly different from rural multilane roads. Adjacent land use (*spec_env_cat*) is another significant variable, indicating significant differences between the rural agricultural land use and the other categories of central business district, commercial/strip development, and other. The speed limit on the major roadway (*ma_ap_spd_cat*) is significant, indicating a difference between intersections with a major road speed limit of 30 mph or less and those greater than 50 mph. Finally, the right-shoulder width on the major road is also significant, indicating a decrease in crashes as the shoulder width increases.

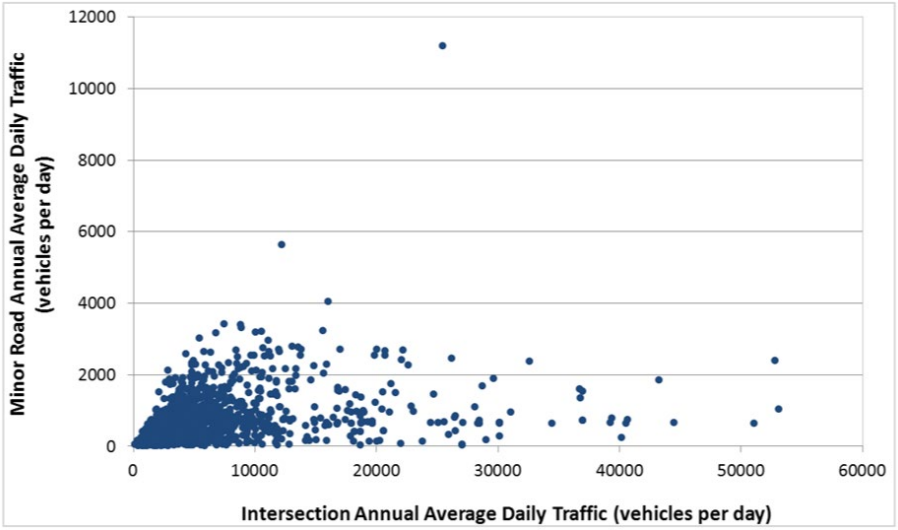
The next model developed was an alternative base model that included an additional variable for the ratio of minor road AADT to intersection AADT (*mi_int*). All other variables from the initial base model were retained. The model parameters are shown in table 86. The added variable is significant with a p-value of 0.0014. As the proportion of traffic on the minor road increases relative to total intersection AADT, total crashes are predicted to increase using this model. All variables that were significant in the initial base model are also significant in this alternative model. The parameter estimate for intersection angle is the same (−0.0021) in both models. There was very little change in the BIC for the two models, from 23,088 for the initial model to 23,087 for the alternative model. However, the improvement in the AIC was substantial, from

22,985 for the initial model to 22,977. Thus, the alternative model is considered an improved model.



Source: FHWA.

Figure 88. Graph. Scatterplot of intersection AADT versus major road AADT for all four-leg intersections in MN.



Source: FHWA.

Figure 89. Graph. Scatterplot of intersection AADT versus minor road AADT for all four-leg intersections in MN.

Table 85. Initial base model results for total crashes at all four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−9.1045	0.2269	−9.5493	−8.6597	1,609.38	<0.0001
lgint_aadt	0.7757	0.024	0.7287	0.8228	1,042.83	<0.0001
lgmi_aadt	0.4127	0.0161	0.3811	0.4443	655.73	<0.0001
ma_rodwycls_cat (1)	0.2081	0.0575	0.0954	0.3209	13.09	0.0003
ma_rodwycls_cat (2)	0.0957	0.0618	−0.0255	0.2168	2.39	0.1218
ma_rodwycls_cat (3)	−0.0402	0.0476	−0.1335	0.053	0.71	0.3979
ma_rodwycls_cat (4)	0	0	0	0	—	—
spec_env_cat (0)	−0.1283	0.0549	−0.2359	−0.0208	5.47	0.0194
spec_env_cat (1)	−0.1251	0.0539	−0.2308	−0.0194	5.38	0.0203
spec_env_cat (2)	−0.4892	0.0575	−0.6018	−0.3765	72.44	<0.0001
spec_env_cat (3)	0	0	0	0	—	—
min_angle	−0.0021	0.0009	−0.0039	−0.0003	5.38	0.0203
ma_ap_spd_cat (1)	−0.2434	0.0584	−0.3579	−0.1289	17.36	<0.0001
ma_ap_spd_cat (2)	−0.0814	0.0526	−0.1845	0.0218	2.39	0.1221
ma_ap_spd_cat (3)	0	0	0	0	—	—
ma_rshl_wd0	−0.021	0.0049	−0.0305	−0.0115	18.79	<0.0001
Dispersion	0.4323	0.0247	0.3866	0.4834	—	—
Goodness-of-fit parameter: AIC (smaller is better)	22,985	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	23,088	—	—	—	—	—

—No data available.

Table 86. Alternative base model results for total crashes at all four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−9.3507	0.2401	−9.8213	−8.88	1,516.36	<0.0001
lgint_aadt	0.8458	0.0325	0.7821	0.9096	676.14	<0.0001
lgmi_aadt	0.3383	0.0282	0.283	0.3936	143.63	<0.0001
mi_int	0.7304	0.2288	0.282	1.1788	10.19	0.0014
ma_rodwycls_cat (1)	0.2213	0.0576	0.1083	0.3343	14.74	0.0001
ma_rodwycls_cat (2)	0.1003	0.0618	−0.0209	0.2215	2.63	0.1048
ma_rodwycls_cat (3)	−0.044	0.0476	−0.1373	0.0494	0.85	0.3558
ma_rodwycls_cat (4)	0	0	0	0	—	—
spec_env_cat (0)	−0.1166	0.055	−0.2243	−0.0088	4.49	0.034
spec_env_cat (1)	−0.1194	0.054	−0.2251	−0.0136	4.89	0.0269
spec_env_cat (2)	−0.4781	0.0576	−0.5909	−0.3652	68.98	<0.0001
spec_env_cat (3)	0	0	0	0	—	—
min_angle	−0.0021	0.0009	−0.0039	−0.0003	5.39	0.0202
ma_ap_spd_cat (1)	−0.241	0.0584	−0.3555	−0.1265	17.02	<0.0001
ma_ap_spd_cat (2)	−0.0894	0.0527	−0.1927	0.0139	2.88	0.0898
ma_ap_spd_cat (3)	0	0	0	0	—	—
ma_rshl_wd0	−0.0206	0.0049	−0.0302	−0.0111	18.12	<0.0001
Dispersion	0.4326	0.0246	0.3869	0.4836	—	—
Goodness-of-fit parameter: AIC (smaller is better)	22,977	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	23,087	—	—	—	—	—

—No data available.

All Four-Leg Intersections—Interaction Model for Total Crashes

The final model developed was built on the results found in the flexible form models. The objective was to develop a model with an improved fit, but with parameters that accounted for the interaction between angle and traffic volume, knowing that traffic volume is commonly known to be the strongest predictor of crashes. These parameters could then be used to develop a more robust crash modification function (CMFunction) for intersection angle that accounts for changes in traffic volumes.

Through a series of trial and error experiments with varying interaction forms, the final set of interaction terms used in the model are shown in figure 90, figure 91, and figure 92.

$$cos1_lgint = [1 + \cos(angle)] \times \ln(\text{intersection aadt})$$

Figure 90. Equation. Interaction term of intersection AADT and cosine of the intersection angle.

$$cos1_mmiint = [1 + \cos(angle)] \times (\text{minor road aadt/intersection aadt})$$

Figure 91. Equation. Interaction term of minor road to intersection AADT ratio and cosine of the intersection angle.

$$angR1_mint = [1 + (90 - \text{angle})\pi/180] \times \ln(\text{intersection aadt})$$

Figure 92. Equation. Interaction term of intersection AADT and skew angle expressed in radians.

In all three of these variables in figure 90, figure 91, and figure 92, the angle term becomes 1.0 when the intersection angle is 90 degrees. Thus, the predicted effect on crashes for right-angle intersections is a function of the intersection and minor road AADT terms in the three variables.

The interaction model is provided in table 87. The same set of significant variables for roadway classification, land use, speed limit, and right-shoulder width exist in this model with the same directional effects as previously included in the flexible form models. The variable *min_angle* was not significant in the final model. Instead, the effects of intersection angle are being accounted for within the three interaction terms, all of which are significant (*p*-values of <0.0001).

The BIC and AIC for this interaction model are 23,072 and 22,954, respectively. The flexible form model 1 values for BIC and AIC were 23,073 and 22,954, respectively. The lack of a difference in these two criteria indicates a negligible improvement in the model fit.

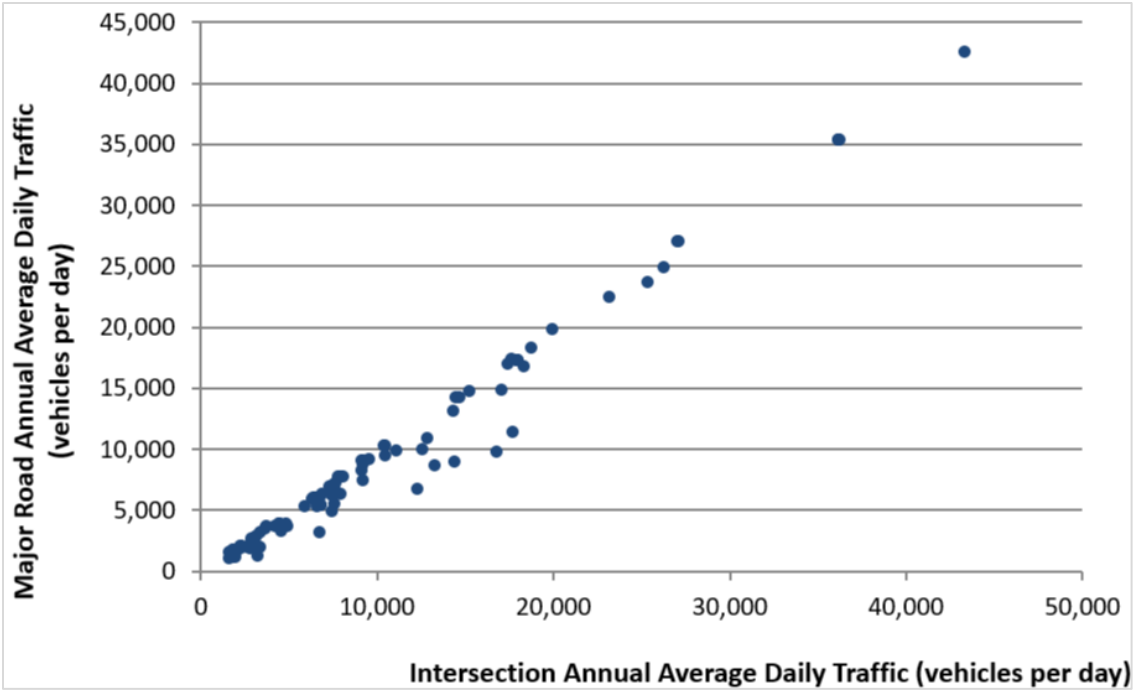
Table 87. Interaction model results for total crashes at all four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−9.4339	0.2234	−9.8719	−8.996	1,782.7	<0.0001
cos1_lgint	0.4688	0.0965	0.2797	0.6579	23.61	<0.0001
lgmi_aadt	0.3438	0.0263	0.2923	0.3954	170.86	<0.0001
lgint_aadt	0.7836	0.0361	0.7129	0.8543	471.96	<0.0001
angR1_mint	−0.4219	0.0882	−0.5947	−0.249	22.87	<0.0001
cos1_mmiint	0.5369	0.1712	0.2014	0.8725	9.84	0.0017
ma_rodwycls_cat (1)	0.2299	0.0575	0.1173	0.3426	16	<0.0001
ma_rodwycls_cat (2)	0.1145	0.0619	−0.0069	0.2358	3.42	0.0645
ma_rodwycls_cat (3)	−0.0354	0.0475	−0.1286	0.0578	0.55	0.4566
ma_rodwycls_cat (4)	0	0	0	0	—	—
spec_env_cat (0)	−0.1286	0.0549	−0.2363	−0.0209	5.48	0.0192
spec_env_cat (1)	−0.1273	0.0539	−0.2329	−0.0217	5.58	0.0182
spec_env_cat (2)	−0.48	0.0576	−0.5928	−0.3672	69.55	<0.0001
spec_env_cat (3)	0	0	0	0	—	—
ma_ap_spd_cat (1)	−0.229	0.0583	−0.3432	−0.1147	15.42	<0.0001
ma_ap_spd_cat (2)	−0.0898	0.0527	−0.1931	0.0135	2.9	0.0884
ma_ap_spd_cat (3)	0	0	0	0	—	—
ma_rshl_wd0	−0.0221	0.0049	−0.0317	−0.0126	20.8	<0.0001
Dispersion	0.4259	0.0244	0.3806	0.4766	—	—
Goodness-of-fit parameter: AIC (smaller is better)	22,954	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	23,072	—	—	—	—	—

—No data available.

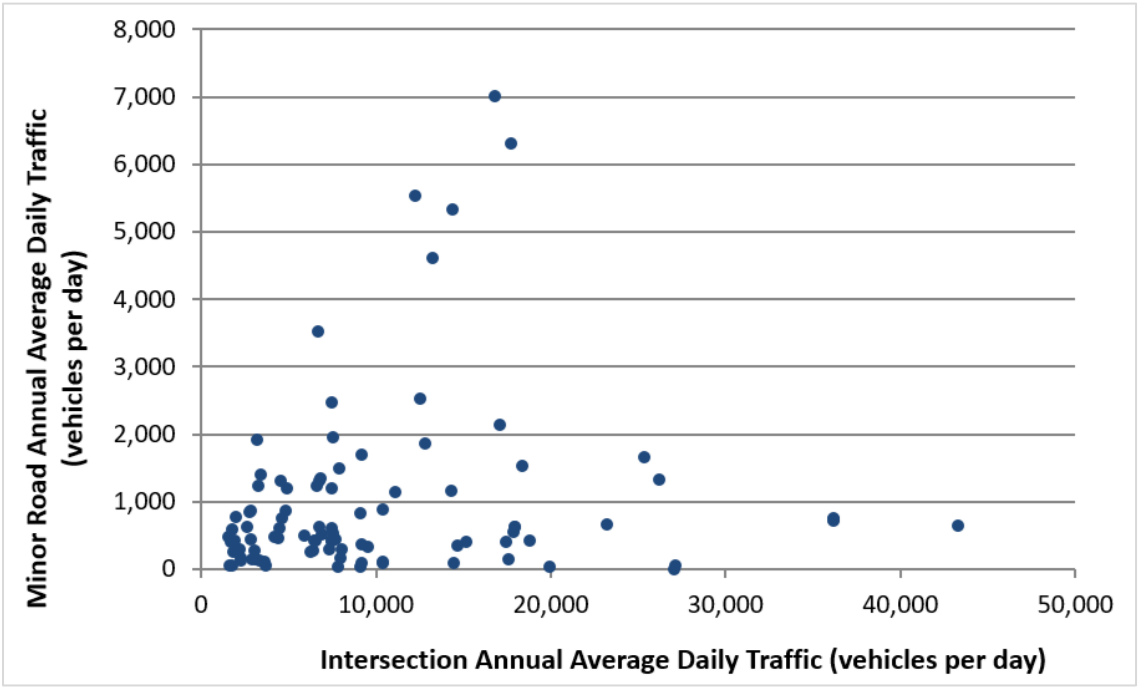
Three-Leg Intersections—Base Models for Total Crashes

The first set of models developed for three-leg intersections was for total crashes, which included all rural and urban sites. The database included 4,730 crashes distributed across 1,109 intersections over 7 yr. Intersection AADT, major road AADT, and minor road AADT were among the 10 most important predictors from the CRF analysis. Scatterplots of these variables are shown in figure 93 and figure 94. Major road AADT and intersection AADT were highly correlated and had a Pearson Correlation Coefficient (r) equal to 0.990. Minor road AADT and intersection AADT did not share the same level of correlation ($r = 0.296$). Intersection AADT and minor road AADT were also the two AADT variables that most frequently appeared in the regression tree results. Thus, intersection AADT and minor road AADT were selected for inclusion in the models. Major road AADT was not selected because of its strong correlation with intersection AADT.



Source: FHWA.

Figure 93. Graph. Scatterplot of intersection AADT versus major road AADT for all three-leg intersections in MN.



Source: FHWA.

Figure 94. Graph. Scatterplot of intersection AADT versus minor road AADT for all three-leg intersections in MN.

The initial base model, with only the significant variables ($p \leq 0.05$) retained, is shown in table 88. Both intersection AADT and minor road AADT were significant and predicted an increase in crashes as either value increased. Lane width on the major road was significant with a *p*-value <0.0001 and indicated an increase in crashes as the lane width increased. Adjacent land use (*spec_env_cat*) was another significant variable, which indicated significant differences between the rural agricultural land use and the other categories of central business district, commercial/strip development, and other.

The next model developed was an alternative base model that included an additional variable for the ratio of minor road AADT to intersection AADT (*mi_int*). All other variables from the initial base model were retained. Table 89 shows the results. The added variable was significant at a *p*-value of 0.0169. As the proportion of traffic on the minor road increased relative to intersection AADT, total crashes were predicted to increase using this model. All variables that were significant in the initial base model are also significant in this alternative model. The goodness-of-fit metrics moved in opposing directions for the two models. The BIC for the initial model is 14,329 compared to 14,332 for the alternative model, indicating that the initial model was a positive improvement over the alternative model. However, the AIC changed from 14,274 for the initial model to 14,270 for the alternative model. The magnitude of the change in the AIC was substantial. Thus, the alternative model was an improved model.

Table 88. Initial base model results for total crashes at all three-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−9.1882	0.1962	−9.5726	−8.8037	2,194.21	<0.0001
lgint_aadt	0.8246	0.0217	0.782	0.8672	1,438.19	<0.0001
lgmi_aadt	0.2527	0.0162	0.2209	0.2845	242.04	<0.0001
ma_lane_wd0	0.0087	0.0019	0.005	0.0124	21.34	<0.0001
spec_env_cat (0)	−0.2407	0.0599	−0.3581	−0.1233	16.14	<0.0001
spec_env_cat (1)	−0.3289	0.0512	−0.4293	−0.2284	41.2	<0.0001
spec_env_cat (2)	−0.5306	0.0537	−0.6359	−0.4254	97.65	<0.0001
spec_env_cat (3)	0	0	0	0	—	—
Dispersion	0.5938	0.0407	0.5191	0.6792	—	—
Goodness-of-fit parameter: AIC (smaller is better)	14,274	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	14,329	—	—	—	—	—

—No data available.

The results from flexible form model 2 are shown in table 90. Again, the same variables significant in the base models remained significant in this model. Intersection angle (*min_angle*) was included in the model as before and is significant with a *p*-value of <0.0001. The estimate for this variable was 0.0269. The additional variable 1 + cos(*angle*) was significant with a *p*-value of <0.0001 and an estimate of 2.3765.

Table 89. Alternative base model results for total crashes at all three-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−9.4144	0.2185	−9.8426	−8.9862	1,856.81	<0.0001
lgint_aadt	0.8726	0.0296	0.8146	0.9306	868.93	<0.0001
lgmi_aadt	0.2024	0.0265	0.1505	0.2542	58.49	<0.0001
mi_int	1.1477	0.4803	0.2063	2.0891	5.71	0.0169
ma_lane_wd0	0.0087	0.0019	0.005	0.0124	21.13	<0.0001
spec_env_cat (0)	−0.2341	0.06	−0.3517	−0.1164	15.21	<0.0001
spec_env_cat (1)	−0.3296	0.0513	−0.43	−0.2291	41.34	<0.0001
spec_env_cat (2)	−0.5161	0.054	−0.622	−0.4102	91.23	<0.0001
spec_env_cat (3)	0	0	0	0	—	—
Dispersion	0.5939	0.0407	0.5193	0.6793	—	—
Goodness-of-fit parameter: AIC (smaller is better)	14,270	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	14,332	—	—	—	—	—

—No data available.

The variable that was not significant, and therefore not included in either model, was intersection angle (*min_angle*). When this variable was added to the initial model, its *p*-value was 0.4149. When added to the alternative model, its *p*-value was 0.4957.

Table 90. Flexible form model 2 results for total crashes at all three-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−8.2597	0.5037	−9.2469	−7.2726	268.94	<0.0001
lgint_aadt	0.8707	0.0296	0.8127	0.9286	866.96	<0.0001
lgmi_aadt	0.2036	0.0265	0.1517	0.2554	59.23	<0.0001
lgcos_1	−1.0909	0.4454	−1.9639	−0.2179	6	0.0143
mi_int	1.0752	0.4812	0.1322	2.0183	4.99	0.0254
ma_lane_wd0	0.0087	0.0019	0.005	0.0124	21.17	<0.0001
spec_env_cat (0)	−0.2301	0.06	−0.3478	−0.1124	14.69	0.0001
spec_env_cat (1)	−0.3224	0.0513	−0.4228	−0.2219	39.55	<0.0001
spec_env_cat (2)	−0.5144	0.0541	−0.6204	−0.4085	90.56	<0.0001
spec_env_cat (3)	0	0	0	0	—	—
min_angle	−0.0125	0.0049	−0.0222	−0.0029	6.47	0.011
Dispersion	0.5884	0.0406	0.5141	0.6736	—	—
Goodness-of-fit parameter: AIC (smaller is better)	14,267	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	14,344	—	—	—	—	—

—No data available.

Three-Leg Intersections—Interaction Model for Total Crashes

While the flexible form model did not result in an improvement over the base model, an interactive model was developed to see if the addition of the interaction terms resulted in significant intersection angle terms within an improved model. The same three terms previously used for the four-leg models were used for the three-leg model. In all three of these variables, the angle term became 1.0 when the intersection angle was 90 degrees. Thus, the predicted effect on crashes for right-angle intersections was a function of the intersection and minor road AADT terms in the three variables.

The interaction model is provided in table 91. The same significant variables for land use and major road lane width existed in this model with the same directional effects previously found in the flexible form models. The variable *min_angle* was not significant in the final model. Instead, the effects of angle were accounted for within the two significant interaction terms.

The BIC and AIC for this interaction model were 14,338 and 14,268, respectively. The alternative base values for BIC and AIC were 14,332 and 14,270, respectively. The difference in the BIC values indicated a positive improvement in model fit for the base model over the interaction model. The AIC difference indicated an indistinguishable difference in the two models. Thus, the alternative base model without a variable for intersection angle is still considered to be the best predictive model.

Table 91. Interaction model results for total crashes at all three-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−9.1818	0.1959	−9.5657	−8.7979	2,197.31	<0.0001
lgint_aadt	0.847	0.0245	0.799	0.895	1,194.87	<0.0001
lgmi_aadt	0.2497	0.0163	0.2178	0.2816	235.68	<0.0001
cos1_lgint	−0.1685	0.0579	−0.282	−0.055	8.46	0.0036
angR1_mint	0.1476	0.0491	0.0513	0.2439	9.03	0.0027
ma_lane_wd0	0.0086	0.0019	0.0049	0.0123	20.85	<0.0001
spec_env_cat (0)	−0.2396	0.0599	−0.357	−0.1221	15.99	<0.0001
spec_env_cat (1)	−0.318	0.0512	−0.4184	−0.2176	38.52	<0.0001
spec_env_cat (2)	−0.528	0.0537	−0.6333	−0.4227	96.65	<0.0001
spec_env_cat (3)	0	0	0	0	—	—
Dispersion	0.5865	0.0405	0.5122	0.6716	—	—
Goodness-of-fit parameter: AIC (smaller is better)	14,268	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	14,338	—	—	—	—	—

—No data available.

Four-Leg Intersections—Additional Models

Additional four-leg intersection models were developed for the following subsets of data:

- All Intersections—Fatal-and-Injury Crashes.
- All Intersections—PDO Crashes.
- Rural Intersections—Total Crashes.
- Rural Intersections—PDO Crashes.
- Rural Two-Lane Intersections—Total Crashes.
- Rural Two-Lane Intersections—Fatal-and-Injury Crashes.
- Rural Two-Lane Intersections—PDO Crashes.
- Rural Multilane Intersections—Total Crashes.
- Rural Multilane Intersections—Fatal-and-Injury Crashes.
- Rural Multilane Intersections—PDO Crashes.

The rural two-lane intersection models include locations where there are two lanes on all four approach legs. The rural multilane intersection models include locations where the major road includes four lanes on each approach leg and the minor road includes two lanes on each approach. An attempt was made to also develop urban models for total crashes. The sample of urban intersections, especially the number of skewed intersections, in the database was not large enough to produce separate models for urban crashes.

Table 92. Flexible form model 1 results for fatal-and-injury crashes at all four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−12.0101	0.2959	−12.5902	−11.4301	1,646.89	<0.0001
lgcos_int	0.745	0.0266	0.693	0.7971	786.8	<0.0001
lgcos_mi	0.4973	0.0238	0.4507	0.5439	438.09	<0.0001
spec_env_cat (0)	−0.2561	0.0831	−0.419	−0.0933	9.5	0.0021
spec_env_cat (1)	−0.1544	0.0769	−0.3051	−0.0036	4.03	0.0448
spec_env_cat (2)	−0.5595	0.0856	−0.7272	−0.3918	42.75	<0.0001
spec_env_cat (3)	0	0	0	0	—	—
ma_ap_spd_cat (1)	−0.3427	0.0835	−0.5064	−0.179	16.83	<0.0001
ma_ap_spd_cat (2)	−0.1955	0.0753	−0.343	−0.048	6.75	0.0094
ma_ap_spd_cat (3)	0	0	0	0	—	—
mi_parking_bin (0)	0.1975	0.0808	0.0391	0.3559	5.97	0.0145
mi_parking_bin (1)	0	0	0	0	—	—
Min_angle	0.0137	0.0014	0.0109	0.0165	93.88	<0.0001
Dispersion	0.5681	0.0542	0.4712	0.6849	—	—
Goodness-of-fit parameter: AIC (smaller is better)	13,233	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	13,314	—	—	—	—	—

—No data available.

Table 93. Alternative base model results for PDO crashes at all four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−10.0577	0.294	−10.634	−9.4815	1,170.36	<0.0001
lgint_aadt	0.9153	0.0392	0.8385	0.9921	545.65	<0.0001
lgmi_aadt	0.2484	0.0338	0.1822	0.3145	54.13	<0.0001
mi_int	0.9698	0.2775	0.426	1.5137	12.22	0.0005
ma_rodwycls_cat (1)	0.2451	0.0673	0.1132	0.3769	13.27	0.0003
ma_rodwycls_cat (2)	0.1648	0.0718	0.0241	0.3054	5.27	0.0217
ma_rodwycls_cat (3)	0.0358	0.0581	−0.0782	0.1497	0.38	0.5384
ma_rodwycls_cat (4)	0	0	0	0	—	—
spec_env_cat (0)	−0.0371	0.054	−0.143	0.0688	0.47	0.4923
spec_env_cat (1)	−0.1134	0.0498	−0.211	−0.0159	5.19	0.0227
spec_env_cat (2)	−0.4237	0.0562	−0.5337	−0.3136	56.92	<0.0001
spec_env_cat (3)	0	0	0	0	—	—
ma_rshl_wd0	−0.0205	0.0049	−0.0302	−0.0108	17.18	<0.0001
min_angle	−0.0023	0.0011	−0.0045	−0.0002	4.56	0.0327
Dispersion	0.4751	0.0361	0.4094	0.5514	—	—
Goodness-of-fit parameter: AIC (smaller is better)	17,633	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	17,729	—	—	—	—	—

—No data available.

Table 94. Flexible form model 1 results for PDO crashes at all four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−11.3261	0.3203	−11.9539	−10.6984	1,250.5	<0.0001
lgcos_int	0.9144	0.0391	0.8377	0.9911	546.39	<0.0001
lgcos_mi	0.2465	0.0337	0.1805	0.3126	53.51	<0.0001
mi_int	0.9805	0.2771	0.4373	1.5237	12.52	0.0004
ma_rodwycls_cat (1)	0.2481	0.0672	0.1164	0.3798	13.63	0.0002
ma_rodwycls_cat (2)	0.1698	0.0717	0.0293	0.3103	5.61	0.0179
ma_rodwycls_cat (3)	0.0376	0.0581	−0.0762	0.1515	0.42	0.5171
ma_rodwycls_cat (4)	0	0	0	0	—	—
spec_env_cat (0)	−0.04	0.054	−0.1458	0.0659	0.55	0.4591
spec_env_cat (1)	−0.1153	0.0497	−0.2128	−0.0179	5.38	0.0204
spec_env_cat (2)	−0.4243	0.0561	−0.5344	−0.3143	57.12	<0.0001
spec_env_cat (3)	0	0	0	0	—	—
ma_rshl_wd0	−0.0219	0.0049	−0.0316	−0.0122	19.58	<0.0001
Min_angle	0.0119	0.0012	0.0096	0.0142	102.05	<0.0001
Dispersion	0.4728	0.036	0.4073	0.5489	—	—
Goodness-of-fit parameter: AIC (smaller is better)	17,625	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	17,721	—	—	—	—	—

—No data available.

Table 95. Alternative base model results for total crashes at all rural four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−8.8488	0.2495	−9.3379	−8.3598	1,257.51	<0.0001
lgint_aadt	0.7231	0.027	0.6703	0.7759	719.79	<0.0001
lgmi_aadt	0.4638	0.0178	0.4289	0.4987	677.22	<0.0001
ma_ap_spd_cat (1)	−0.5262	0.0497	−0.6237	−0.4287	111.97	<0.0001
ma_ap_spd_cat (2)	−0.2434	0.0541	−0.3494	−0.1374	20.26	<0.0001
ma_ap_spd_cat (3)	0	0	0	0	—	—
ma_minthrlane_bin (0)	−0.1282	0.0516	−0.2293	−0.0271	6.18	0.0129
ma_minthrlane_bin (1)	0	0	0	0	—	—
ma_rshl_wd0	−0.0158	0.0057	−0.0269	−0.0047	7.73	0.0054
Min_angle	−0.0032	0.001	−0.0052	−0.0013	10.35	0.0013
Dispersion	0.4083	0.0306	0.3525	0.4731	—	—
Goodness-of-fit parameter: AIC (smaller is better)	18,122	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	18,187	—	—	—	—	—

—No data available.

Table 96. Flexible form model 1 results for total crashes at all rural four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−10.1291	0.2729	−10.664	−9.5941	1,377.26	<0.0001
lgcos_int	0.7205	0.0268	0.6679	0.7731	721.34	<0.0001
lgcos_mi	0.4626	0.0178	0.4278	0.4975	676.26	<0.0001
ma_ap_spd_cat (1)	−0.5231	0.0496	−0.6204	−0.4258	111.05	<0.0001
ma_ap_spd_cat (2)	−0.2452	0.054	−0.351	−0.1394	20.62	<0.0001
ma_ap_spd_cat (3)	0	0	0	0	—	—
ma_minthrlane_bin (0)	−0.1254	0.0515	−0.2262	−0.0245	5.93	0.0149
ma_minthrlane_bin (1)	0	0	0	0	—	—
ma_rshl_wd0	−0.0168	0.0057	−0.0279	−0.0057	8.77	0.0031
Min_angle	0.0112	0.0011	0.0091	0.0133	106.32	<0.0001
Dispersion	0.4031	0.0305	0.3475	0.4675	—	—
Goodness-of-fit parameter: AIC (smaller is better)	18,107	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	18,172	—	—	—	—	—

—No data available.

Table 97. Alternative base model results for fatal-and-injury crashes at all rural four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−10.2182	0.3049	−10.8158	−9.6206	1,123.26	<0.0001
lgint_aadt	0.6929	0.0341	0.626	0.7597	412.07	<0.0001
lgmi_aadt	0.556	0.0267	0.5036	0.6083	433.33	<0.0001
ma_ap_spd_cat (1)	−0.9992	0.0696	−1.1355	−0.8629	206.32	<0.0001
ma_ap_spd_cat (2)	−0.4946	0.0827	−0.6567	−0.3325	35.77	<0.0001
ma_ap_spd_cat (3)	0	0	0	0	—	—
Min_angle	−0.0033	0.0015	−0.0062	−0.0004	4.9	0.0269
Dispersion	0.5711	0.0668	0.4542	0.7183	—	—
Goodness-of-fit parameter: AIC (smaller is better)	10,334	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	10,385	—	—	—	—	—

—No data available.

Table 98. Flexible form model 1 results for fatal-and-injury crashes at all rural four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−11.5581	0.337	−12.2187	−10.8975	1,175.99	<0.0001
lgcos_int	0.6885	0.034	0.6219	0.7551	410.31	<0.0001
lgcos_mi	0.5547	0.0267	0.5024	0.607	432.55	<0.0001
ma_ap_spd_cat (1)	−0.9909	0.0695	−1.1271	−0.8547	203.19	<0.0001
ma_ap_spd_cat (2)	−0.4961	0.0826	−0.6581	−0.3341	36.03	<0.0001
ma_ap_spd_cat (3)	0	0	0	0	—	—
Min_angle	0.0119	0.0016	0.0087	0.015	54.67	<0.0001
Dispersion	0.5644	0.0665	0.4481	0.7109	—	—
Goodness-of-fit parameter: AIC (smaller is better)	10,325	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	10,376	—	—	—	—	—

—No data available.

Table 99. Alternative base model results for PDO crashes at all rural four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−9.9049	0.2786	−10.4509	−9.359	1,264.38	<0.0001
lgint_aadt	0.8482	0.0421	0.7657	0.9307	405.7	<0.0001
lgmi_aadt	0.3096	0.0386	0.2339	0.3853	64.28	<0.0001
mi_int	0.7183	0.301	0.1283	1.3083	5.69	0.017
ma_ap_spd_cat (1)	−0.1573	0.0486	−0.2526	−0.0621	10.48	0.0012
ma_ap_spd_cat (2)	−0.1105	0.0667	−0.2412	0.0201	2.75	0.0972
ma_ap_spd_cat (3)	0	0	0	0	—	—
min_angle	−0.0029	0.0012	−0.0053	−0.0004	5.23	0.0222
Dispersion	0.4841	0.0486	0.3977	0.5893	—	—
Goodness-of-fit parameter: AIC (smaller is better)	13,641	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	13,699	—	—	—	—	—

—No data available.

Table 100. Flexible form 1 model results for PDO crashes at all rural four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−11.1462	0.3031	−11.7402	−10.5523	1,352.77	<0.0001
lgcos_int	0.8452	0.042	0.7628	0.9276	404.53	<0.0001
lgcos_mi	0.3071	0.0385	0.2316	0.3826	63.52	<0.0001
mi_int	0.7293	0.3006	0.1402	1.3185	5.89	0.0153
ma_ap_spd_cat (1)	−0.1489	0.0486	−0.2441	−0.0538	9.41	0.0022
ma_ap_spd_cat (2)	−0.1124	0.0666	−0.243	0.0182	2.85	0.0915
ma_ap_spd_cat (3)	0	0	0	0	—	—
min_angle	0.0112	0.0013	0.0086	0.0138	70.08	<0.0001
Dispersion	0.4795	0.0484	0.3935	0.5844	—	—
Goodness-of-fit parameter: AIC (smaller is better)	13,634	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	13,692	—	—	—	—	—

—No data available.

Table 101. Alternative base model results for total crashes at rural two-lane, four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−9.518	0.2815	−10.0696	−8.9663	1,143.57	<0.0001
lgint_aadt	0.8455	0.049	0.7495	0.9416	297.81	<0.0001
lgmi_aadt	0.3543	0.0423	0.2714	0.4372	70.17	<0.0001
mi_int	0.8111	0.2901	0.2425	1.3796	7.82	0.0052
ma_ap_spd_cat (1)	−0.5648	0.053	−0.6687	−0.4609	113.49	<0.0001
ma_ap_spd_cat (2)	−0.3057	0.0595	−0.4223	−0.1891	26.4	<0.0001
ma_ap_spd_cat (3)	0	0	0	0	—	—
ma_rshl_wd0	−0.0136	0.006	−0.0254	−0.0019	5.17	0.023
min_angle	−0.0025	0.0011	−0.0046	−0.0003	5.01	0.0252
Dispersion	0.4158	0.0372	0.3488	0.4956	—	—
Goodness-of-fit parameters: AIC (smaller is better)	15,445	—	—	—	—	—
Goodness-of-fit parameters: BIC (smaller is better)	15,509	—	—	—	—	—

—No data available.

Table 102. Flexible form model 1 results for total crashes at rural two-lane, four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−10.8054	0.3052	−11.4035	−10.2072	1,253.57	<0.0001
lgcos_int	0.8445	0.049	0.7486	0.9405	297.48	<0.0001
lgcos_mi	0.3513	0.0423	0.2684	0.4341	69.07	<0.0001
mi_int	0.8229	0.2899	0.2548	1.391	8.06	0.0045
ma_ap_spd_cat (1)	−0.5602	0.053	−0.664	−0.4565	111.94	<0.0001
ma_ap_spd_cat (2)	−0.3104	0.0595	−0.4269	−0.1938	27.23	<0.0001
ma_ap_spd_cat (3)	0	0	0	0	—	—
ma_rshl_wd0	−0.0147	0.006	−0.0265	−0.0029	6.01	0.0142
min_angle	0.012	0.0012	0.0097	0.0144	102.71	<0.0001
Dispersion	0.4137	0.0371	0.347	0.4932	—	—
Goodness-of-fit parameter: AIC (smaller is better)	15,437	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	15,502	—	—	—	—	—

—No data available.

Table 103. Flexible form model 1 results for fatal-and-injury crashes at rural two-lane, four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−11.2025	0.4135	−12.013	−10.392	733.83	<0.0001
lgcos_int	0.6425	0.0476	0.5493	0.7358	182.35	<0.0001
lgcos_mi	0.5612	0.0318	0.4988	0.6236	310.63	<0.0001
mi_ap_spd_cat (1)	−0.4156	0.1119	−0.6348	−0.1963	13.8	0.0002
mi_ap_spd_cat (2)	0.0529	0.1418	−0.2251	0.3309	0.14	0.7091
mi_ap_spd_cat (3)	0	0	0	0	—	—
ma_ap_spd_cat (1)	−0.6677	0.1275	−0.9177	−0.4178	27.41	<0.0001
ma_ap_spd_cat (2)	−0.334	0.1142	−0.5577	−0.1102	8.56	0.0034
ma_ap_spd_cat (3)	0	0	0	0	—	—
min_angle	0.0118	0.0018	0.0083	0.0153	43.37	<0.0001
Dispersion	0.555	0.0826	0.4145	0.743	—	—
Goodness-of-fit parameter: AIC (smaller is better)	8,559	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	8,624	—	—	—	—	—

—No data available.

Table 104. Alternative base model results for PDO crashes at rural two-lane, four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−10.2505	0.3515	−10.9393	−9.5616	850.61	<0.0001
lgint_aadt	0.9521	0.0603	0.8338	1.0703	249	<0.0001
lgmi_aadt	0.1984	0.0507	0.0991	0.2977	15.34	<0.0001
mi_int	1.301	0.3565	0.6024	1.9996	13.32	0.0003
min_angle	−0.0027	0.0013	−0.0053	0	3.92	0.0477
Dispersion	0.5487	0.0601	0.4428	0.6801	—	—
Goodness-of-fit parameter: AIC (smaller is better)	11,592	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	11,635	—	—	—	—	—

—No data available.

Table 105. Flexible form model 1 results for PDO crashes at rural two-lane, four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−11.4997	0.3818	−12.248	−10.7513	907.18	<0.0001
lgcos_int	0.9508	0.0603	0.8326	1.069	248.66	<0.0001
lgcos_mi	0.1965	0.0506	0.0972	0.2958	15.06	0.0001
mi_int	1.3078	0.3563	0.6095	2.0062	13.47	0.0002
min_angle	0.0113	0.0014	0.0085	0.0141	62.06	<0.0001
Dispersion	0.5461	0.0599	0.4405	0.677	—	—
Goodness-of-fit parameter: AIC (smaller is better)	11,587	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	11,630	—	—	—	—	—

—No data available.

Table 106. Alternative base model results for total crashes at rural multilane four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−7.068	0.7781	−8.5931	−5.5428	82.5	<.0001
lgint_aadt	0.5307	0.07	0.3934	0.6679	57.41	<.0001
lgmi_aadt	0.5073	0.0414	0.4262	0.5884	150.34	<.0001
min_angle	−0.0095	0.0026	−0.0145	−0.0044	13.58	0.0002
Dispersion	0.346	0.055	0.2534	0.4726	—	—
Goodness-of-fit parameter: AIC (smaller is better)	2,206	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	2,229	—	—	—	—	—

—No data available.

Table 107. Flexible form model 1 results for total crashes at rural multilane four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−7.6378	0.6268	−8.8663	−6.4092	148.47	<0.0001
lgcos_int	0.4979	0.0606	0.3791	0.6168	67.46	<0.0001
lgcos_mi	0.5017	0.0406	0.4221	0.5814	152.42	<0.0001
Dispersion	0.3391	0.0545	0.2475	0.4646	—	—
Goodness-of-fit parameter: AIC (smaller is better)	2,200	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	2,218	—	—	—	—	—

—No data available.

Table 108. Flexible form model 2 results for fatal-and-injury crashes at rural multilane four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−24.2717	3.1456	−30.4369	−18.1065	59.54	<0.0001
lgint_aadt	0.5125	0.1031	0.3104	0.7146	24.71	<0.0001
lgmi_aadt	0.6025	0.063	0.4791	0.726	91.45	<0.0001
ma_ap_spd_cat (1)	−0.6391	0.2052	−1.0412	−0.2369	9.7	0.0018
ma_ap_spd_cat (2)	0.4578	0.2267	0.0136	0.9021	4.08	0.0434
ma_ap_spd_cat (3)	0	0	0	0	—	—
lgcos_1	13.6599	2.5214	8.7181	18.6017	29.35	<0.0001
min_angle	0.1661	0.032	0.1034	0.2289	26.95	<0.0001
Dispersion	0.4461	0.1046	0.2817	0.7064	—	—
Goodness-of-fit parameter: AIC (smaller is better)	1,432	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	1,468	—	—	—	—	—

—No data available.

Table 109. Alternative base model results for PDO crashes at rural multilane four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−6.7533	0.9048	−8.5266	−4.9799	55.71	<0.0001
lgint_aadt	0.5024	0.0818	0.342	0.6628	37.7	<0.0001
lgmi_aadt	0.4155	0.0479	0.3216	0.5095	75.12	<0.0001
min_angle	−0.01	0.0029	−0.0158	−0.0042	11.51	0.0007
Dispersion	0.2682	0.0793	0.1502	0.4789	—	—
Goodness-of-fit parameter: AIC (smaller is better)	1,693	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	1,715	—	—	—	—	—

—No data available.

Table 110. Flexible form model 2 results for PDO crashes at rural multilane four-leg intersections in MN.

Parameter Description	Estimate	Standard Error	Lower 95% CL	Upper 95% CL	Chi-Square	Statistical Significance
Intercept	−12.5641	2.3483	−17.1667	−7.9615	28.63	<0.0001
lgint_aadt	0.5014	0.0812	0.3423	0.6605	38.16	<0.0001
lgmi_aadt	0.4072	0.0474	0.3144	0.5001	73.93	<0.0001
lgcos_1	5.2021	1.9258	1.4276	8.9767	7.3	0.0069
min_angle	0.0544	0.0241	0.0072	0.1015	5.11	0.0239
Dispersion	0.2433	0.0771	0.1308	0.4528	—	—
Goodness-of-fit parameter: AIC (smaller is better)	1,687	—	—	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	1,715	—	—	—	—	—

—No data available.

OH SUPPLEMENTAL SAFETY-PREDICTION MODELS

SPFs were only developed for total crashes for OH; therefore, all supplemental OH SPFs are grouped and shown in table 111 through table 115.

Table 111. Model fit statistics for OH for rural four-leg two-lane intersections in OH.

Parameter Description	Category	Estimate	Standard Error	Statistical Significance
Intercept	N/A	−20.3179	2.0484	<0.0001
lgcos_int	N/A	1.9211	0.2224	<0.0001
lgcos_mi	N/A	0.1563	0.0396	<0.0001
lgma_aadt	N/A	−1.0479	0.1887	<0.0001
min_angle	N/A	0.0198	0.0025	<0.0001
ma_rodwycls_cat	Local	0.1798	0.1367	0.1883
ma_rodwycls_cat	Major collector	0.2105	0.0615	0.0006
ma_rodwycls_cat	Minor arterial	0.1390	0.0612	0.0232
ma_rodwycls_cat	Minor collector	0.3346	0.1013	0.0010
ma_rodwycls_cat	Principal arterial	Base category	—	—
Dispersion	N/A	0.4676	0.0210	—
Goodness-of-fit parameter: AIC (smaller is better)	14,243.2137	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	14,304.0068	—	—	—

—No data available.
N/A = not applicable.

Table 112. Model fit statistics for OH for rural four-leg multilane intersections in OH.

Parameter Description	Category	Estimate	Standard Error	Statistical Significance
Intercept	N/A	−59.1611	12.7590	<0.0001
lgcos_int	N/A	5.6961	1.2066	<0.0001
lgma_aadt	N/A	−4.6540	1.1136	<0.0001
min_Angle	N/A	0.0691	0.0186	0.0002
Dispersion	N/A	0.3647	0.0797	—
Goodness-of-fit parameter: AIC (smaller is better)	549.7794	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	562.9530	—	—	—

—No data available.
N/A = not applicable.

Table 113. Model fit statistics for OH for rural three-leg two-lane intersections in OH.

Parameter Description	Category	Estimate	Standard Error	Statistical Significance
Intercept	N/A	−1.1299	0.5186	0.0293
lgint_aadt	N/A	0.9586	0.228	<0.0001
mi_int	N/A	1.4695	0.1195	<0.0001
min_Angle	N/A	−0.0099	0.0032	0.0023
lgmin_angle	N/A	0.3771	0.1754	0.0315
ma_rodwycls_cat	Local	−1.537	0.1224	0.2092
ma_rodwycls_cat	Major collector	0.1560	0.0471	0.0009
ma_rodwycls_cat	Minor arterial	0.0639	0.0472	0.1759
ma_rodwycls_cat	Minor collector	0.0796	0.0813	0.3280
ma_rodwycls_cat	Principal arterial	Base category	—	—
Dispersion	N/A	0.4427	0.0191	—
Goodness-of-fit parameter: AIC (smaller is better)	23,124.2373	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	23,192.5836	—	—	—

—No data available.

Table 114. Model fit statistics for OH for urban four-leg two-lane intersections in OH.

Parameter Description	Category	Estimate	Standard Error	Statistical Significance
Intercept	N/A	−12.5185	2.7113	<0.0001
lgcos_int	N/A	1.2948	0.2573	<0.0001
lgma_aadt	N/A	−0.6912	0.2331	0.0030
min_angle	N/A	0.0108	0.0043	0.0111
Dispersion	N/A	0.5187	0.0497	—
Goodness-of-fit parameter: AIC (smaller is better)	2,260.8867	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	2,280.4945	—	—	—

—No data available.

Table 115. Model fit statistics for OH for urban three-leg two-lane intersections in OH.

Parameter Description	Category	Estimate	Standard Error	Statistical Significance
Intercept	N/A	−9.4208	0.4562	<0.0001
lgcos_int	N/A	0.9766	0.0458	<0.0001
lin_angle	N/A	0.0046	0.0015	0.0028
Dispersion	N/A	0.5722	0.0319	—
Goodness-of-fit parameter: AIC (smaller is better)	7,251.6243	—	—	—
Goodness-of-fit parameter: BIC (smaller is better)	7,272.7909	—	—	—

—No data available.

APPENDIX F. CMFUNCTION DEVELOPMENT AND ADDITIONAL MODELS

MN CMFUNCTIONS

Four-Leg Intersections—Total Crashes at All Intersections

The first CMF developed for total crashes across all four-leg intersections (both rural and urban) is from the alternative base model and takes the form shown in figure 95.

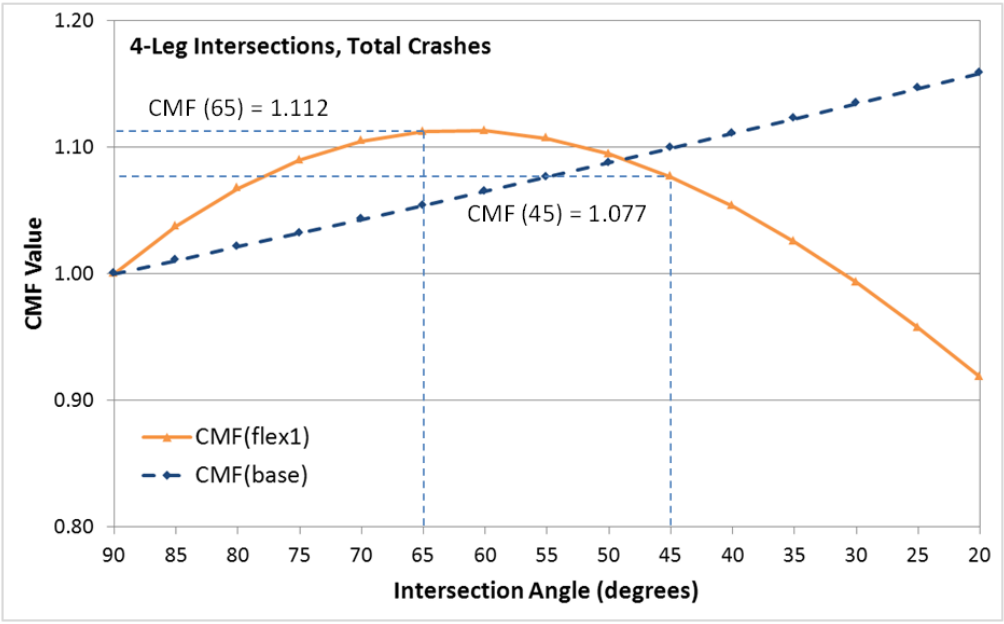
$$CMF(\text{base}) = \frac{\text{EXP}(\beta\alpha)}{\text{EXP}(\beta 90)} = \text{EXP}[\beta(\alpha - 90)]$$

Figure 95. Equation. CMF base model calculation for total crashes at all four-leg intersections.

Where:

α = intersection angle in degrees.
$\beta = -0.0021$ for four-leg total crashes.

The log−linear relationship between the derived *CMF(base)* values and intersection angle is shown in figure 96. As the angle of the intersection decreased from 90 to 20 degrees, the CMF increased, as shown in figure 96. At an angle of 65 degrees, total intersection crashes were predicted to increase by 5.4 percent over what would be expected at a right-angle intersection. At 45 degrees, the predicted increase is 9.9 percent. The largest CMF value is 1.158 at 20 degrees, which is the smallest angle in the database for four-leg intersections.



Source: FHWA.

Figure 96. Graph. CMFs derived from the flexible form model 1 and alternative base model for total crashes at all four-leg intersections in MN.

The CMF derived for total crashes at all four-leg intersections is from the flexible form model 2, which takes the form shown in figure 97.

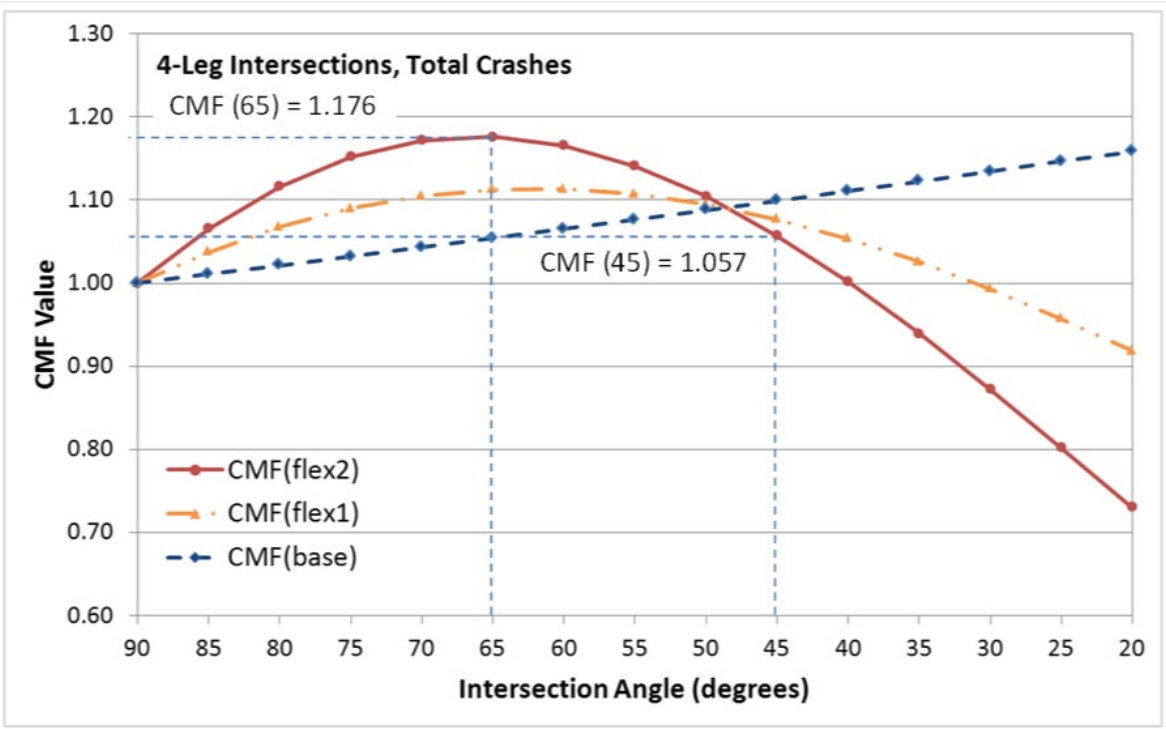
$$CMF(\text{flex2}) = \{\text{EXP}(\beta_1 \alpha) \times [1 + \cos(\alpha)]^{\beta_2}\} / \{\text{EXP}(\beta_1 90) \times [1 + \cos(90)]^{\beta_2}\}$$
$$= \text{EXP}[(\beta_1 (\alpha - 90)] \times [1 + \cos(\alpha)]^{\beta_2}$$

Figure 97. Equation. CMF flexible form model 2 calculation for total crashes at all four-leg intersections.

Where:

α = intersection angle, expressed in degrees.
β_1 = 0.0269 for total crashes at all four-leg intersections.
β_2 = 2.3675 for total crashes at all four-leg intersections.

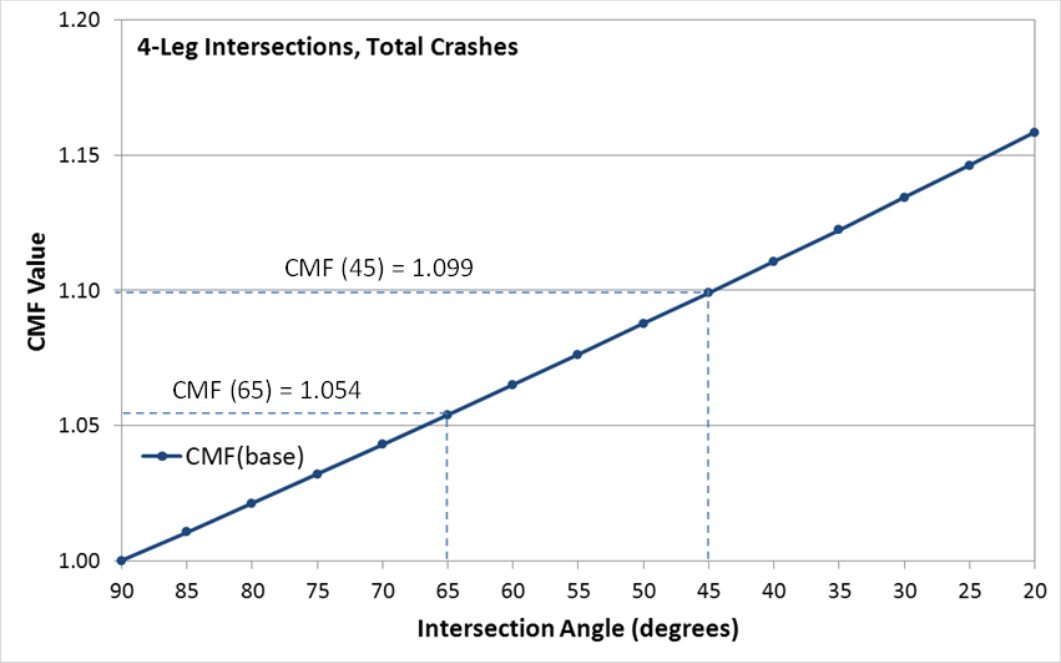
The CMF as distributed across the range of intersection angles is shown in figure 98. The shape of the function is similar to the shape produced for CMF(flex1). As the angle of the intersection decreased from 90 to approximately 65 degrees, total crashes increased. The rate of increase for CMF(flex2) was greater than the rate of increase for CMF(flex1). The result was higher CMF values for the CMF(flex2) function compared to the flex1 function in this upper range of angles. For example, total intersection crashes are predicted to increase by 17.6 percent at an intersection with an angle of 65 degrees over what would be expected at a right-angle intersection using the flex2 function. This value compares to 11.2 percent when using the flex1 function.



Source: FHWA.

Figure 98. Graph. CMFs derived from the flexible form models 1 and 2 and alternative base model for total crashes at all four-leg intersections in MN.

At approximately 65 degrees, the direction of the curve turned downward and crashes continued to decrease as the intersection angle decreases. The rate of decrease for the CMF(flex2) function was greater than the rate for the flex1 function. This resulted in lower predicted CMF values for the flex2 function when compared to the CMF(flex1) function in this lower range of intersection angles. At 45 degrees, the predicted increase over a right-angle intersection was 5.7 percent from CMF(flex2) compared to 7.7 percent from CMF(flex1). Finally, this escalating rate of decrease for CMF(flex2) resulted in CMF values of less than 1.0 for intersections with angles approaching 40 degrees or less. By comparison, CMF(flex1) did not result in values of less than 1.0 until the angles reach 30 degrees or less.



Source: FHWA.

Figure 99. Graph. CMF derived from the alternative base model for total crashes at all four-leg intersections in MN.

Four-Leg Intersections—Total Crashes at Rural Intersections

The first CMF developed for total crashes at four-leg rural intersections is from the alternative base model with the form shown in figure 100.

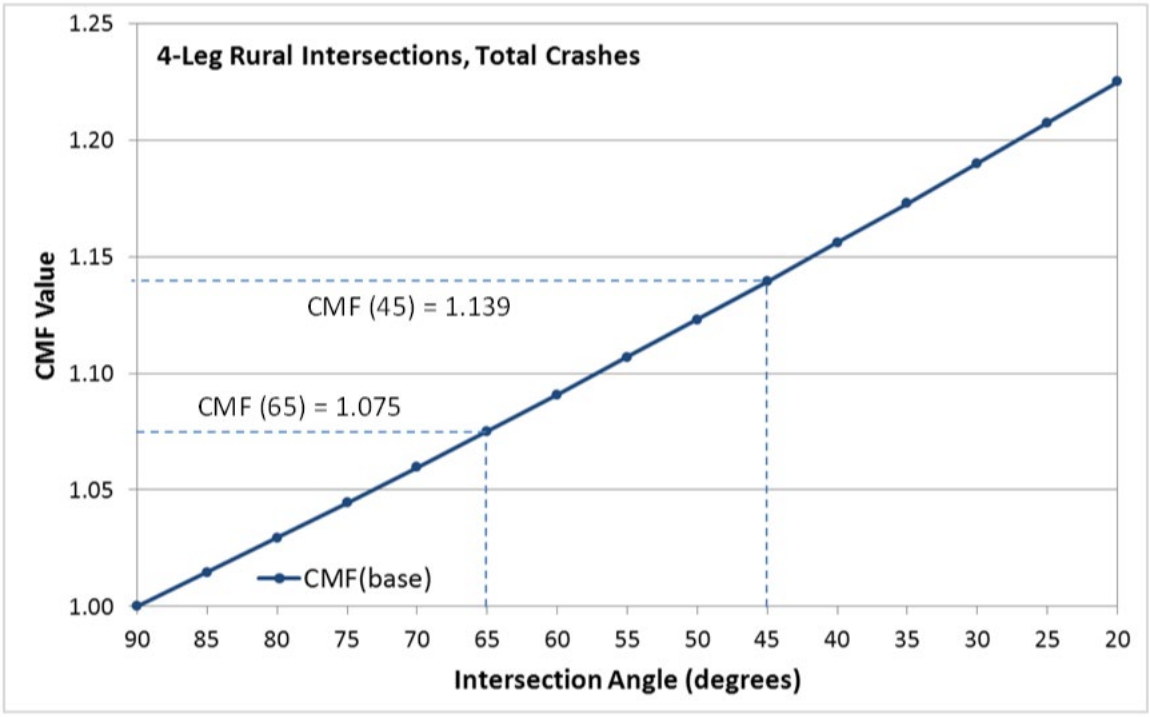
$$CMF(\text{base}) = \text{EXP}[\beta(\alpha - 90)]$$

Figure 100. Equation. CMF base model calculation for total crashes at rural four-leg intersections.

Where:

α = intersection angle, expressed in degrees.
β = −0.0029 for total crashes at rural four-leg intersections.

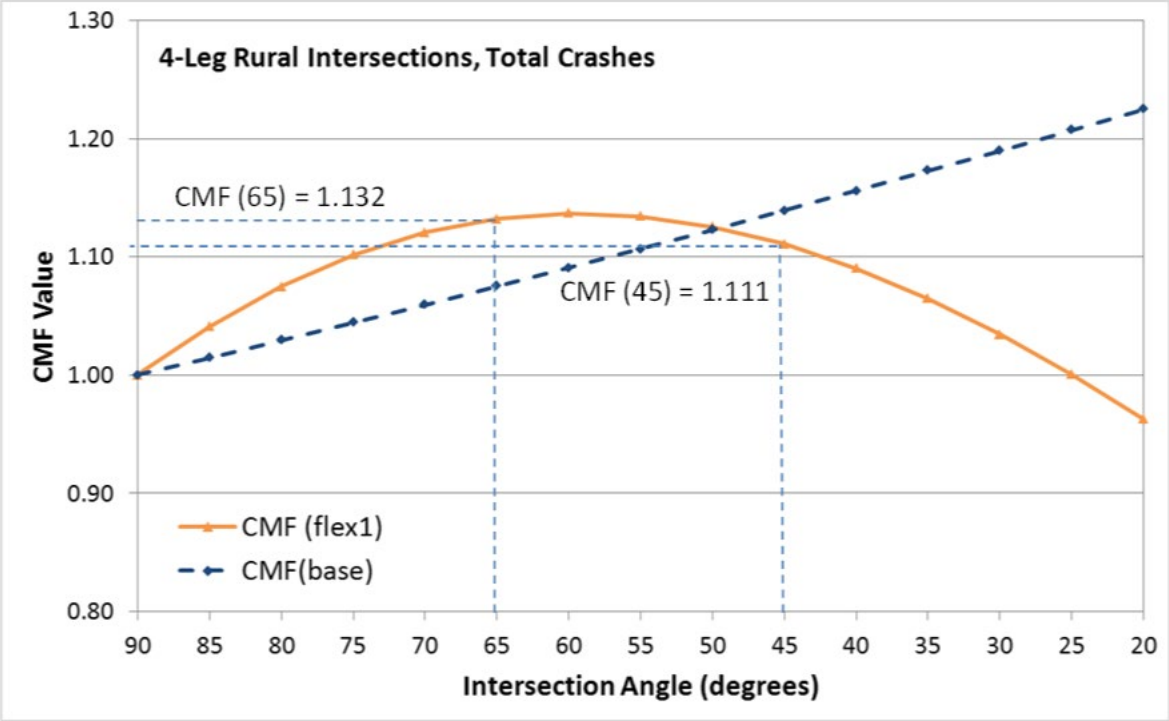
The log–linear relationship between the derived CMF and intersection angles is shown in figure 101. As the angle of the intersection decreased from 90 to 20 degrees, total crashes increased (figure 101). At an angle of 65 degrees, total intersection crashes were predicted to increase by 7.5 percent over what would be expected at a right-angle intersection. At 45 degrees, the predicted increase was 13.9 percent. The largest CMF value was 1.225 at 20 degrees, which was the smallest angle in the database. The rate of increase for rural intersections was greater than what was previously shown for all intersections; hence, the CMF value for any given intersection angle less than 90 degrees is larger for rural intersections compared to all intersections.



Source: FHWA.

Figure 101. Graph. CMF derived from the alternative base model for total crashes at rural four-leg intersections in MN.

The CMF as distributed across the range of intersection angles is shown in figure 102. The results were nonlinear and in the shape of an upward convex parabola. As the angle of the intersection decreased from 90 to approximately 60 degrees, total crashes increased. At that point, the direction of the curve turned downward, and crashes continued to decrease as the intersection angle decreased. At an angle of 65 degrees, total intersection crashes were predicted to increase by 13.2 percent over what would be expected at a right-angle intersection. At 45 degrees, the predicted increase was 11.1 percent. The CMF was less than 1.0 for intersections with angles reaching 25 degrees or less. The CMF(flex1) function for rural intersections produced CMF values greater than those produced by the same function for all intersections.



Source: FHWA.

Figure 102. Graph. CMFs derived from the flexible form model 1 and alternative base model for total crashes at rural four-leg intersections in MN.

Four-Leg Intersections—Total Crashes at Two-Lane Rural Intersections

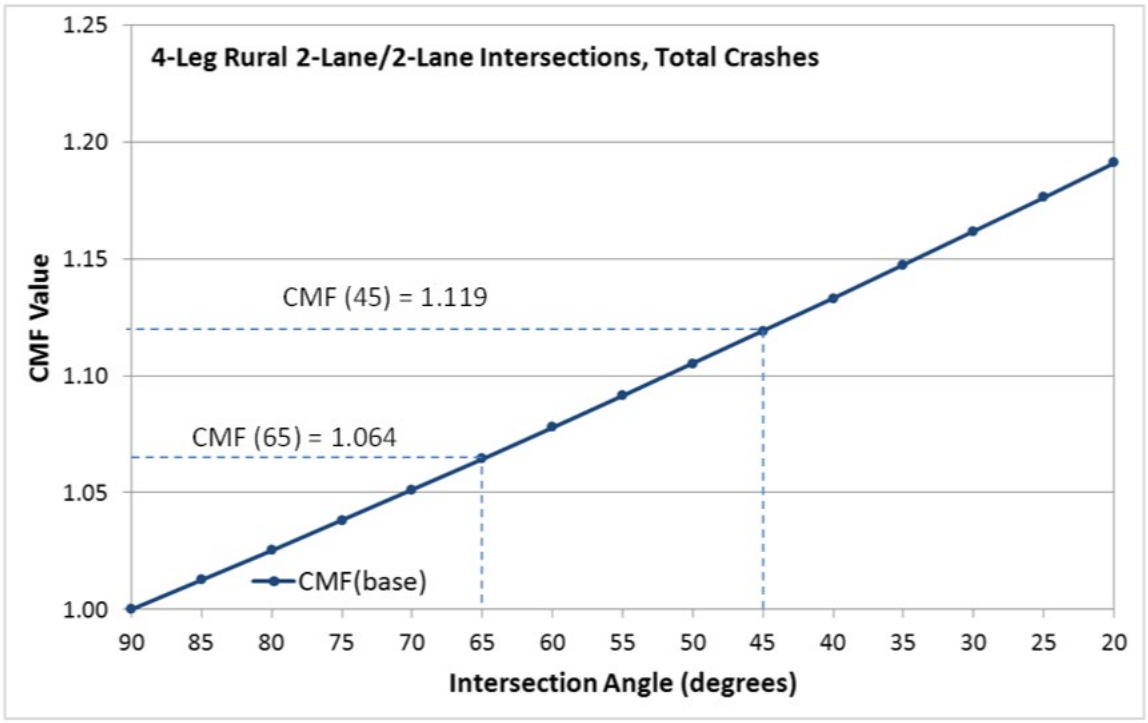
The next set of CMFs developed for four-leg intersections was for rural two-lane intersections. These locations had two lanes on major-road approach legs. (All intersections had two lanes on the minor-road approach legs.) The first CMF developed for total crashes was from the alternative base model and took the form shown in figure 103.

$$CMF(\text{base}) = \text{EXP}[\beta(\alpha - 90)]$$

Figure 103. Equation. CMF base-model calculation for total crashes at rural four-leg two-lane intersections.

Where:

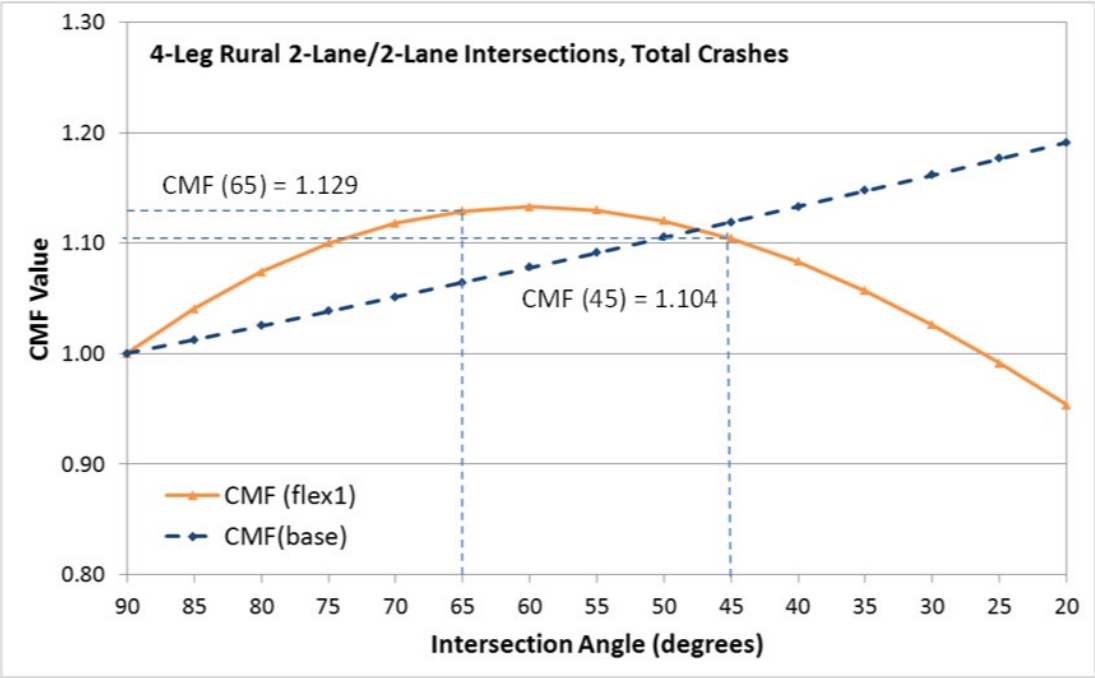
α = intersection angle in degrees.
β = −0.0025 for rural four-leg two-lane total crashes.



Source: FHWA.

Figure 104. Graph. CMF derived from the alternative base model for total crashes at rural four-leg two-lane intersections in MN.

The log–linear relationship between the derived CMF and intersection angles is shown in figure 104. As the angle of the intersection decreased from 90 to 20 degrees, total crashes increased, as shown in figure 104. At an angle of 65 degrees, total intersection crashes were predicted to increase by 6.4 percent over what would be expected at a right-angle intersection. At 45 degrees, the predicted increase was 11.9 percent. The largest CMF value was 1.191 at 20 degrees, which is the smallest angle in the database.



Source: FHWA.

Figure 105. Graph. CMFs derived from the flexible form model 1 and alternative base model for total crashes at rural four-leg two-lane intersections in MN.

The CMF as distributed across the range of intersection angles is shown in figure 105. The results are nonlinear and in the shape of an upward convex parabola. As the angle of the intersection decreased from 90 to approximately 60 degrees, total crashes increased. At that point, the direction of the curve turned downward, and crashes continued to decrease as the intersection angle decreases. At an angle of 65 degrees, total intersection crashes were predicted to increase by 12.9 percent over what would be expected at a right-angle intersection. At 45 degrees, the predicted increase was 10.4 percent. The CMF was less than 1.0 for intersections with angles approaching 25 degrees or less.

Four-Leg Intersections—Total Crashes at Multilane Rural Intersections

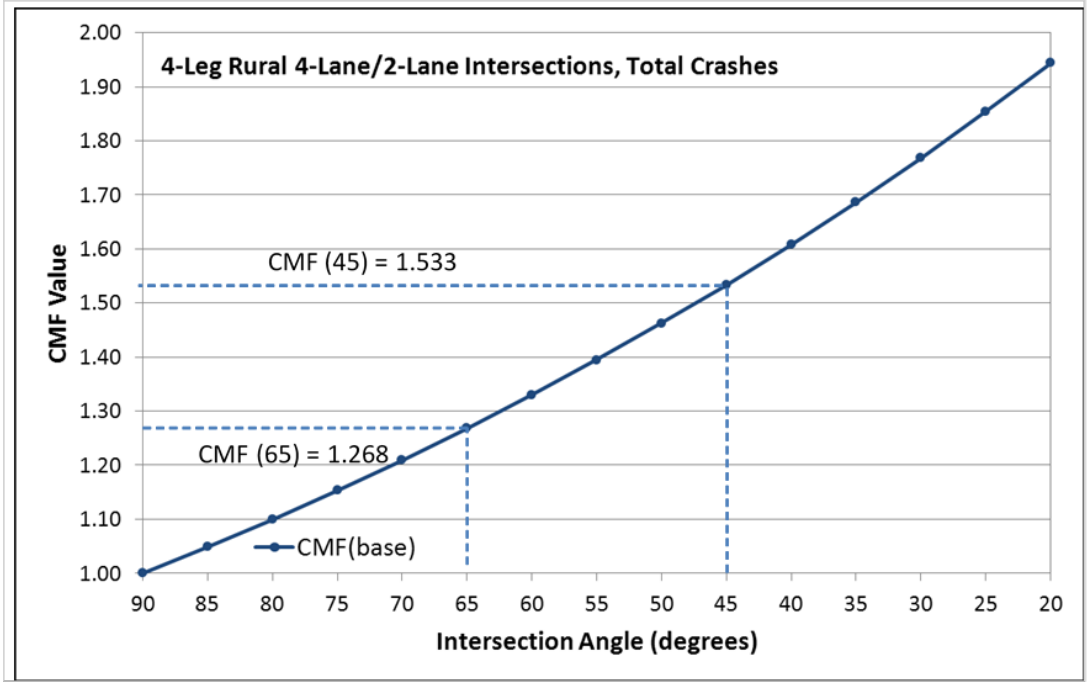
The final set of CMFs developed was for four-leg rural intersections with four lanes on the major-road approach legs and two lanes on the minor-road approach legs. The first CMF developed for total crashes was from the alternative base model and took the form shown in figure 106.

$$CMF(\text{base}) = \text{EXP}[\beta(\alpha - 90)]$$

Figure 106. Equation. CMF base model calculation for total crashes at rural four-leg multilane intersections.

Where:

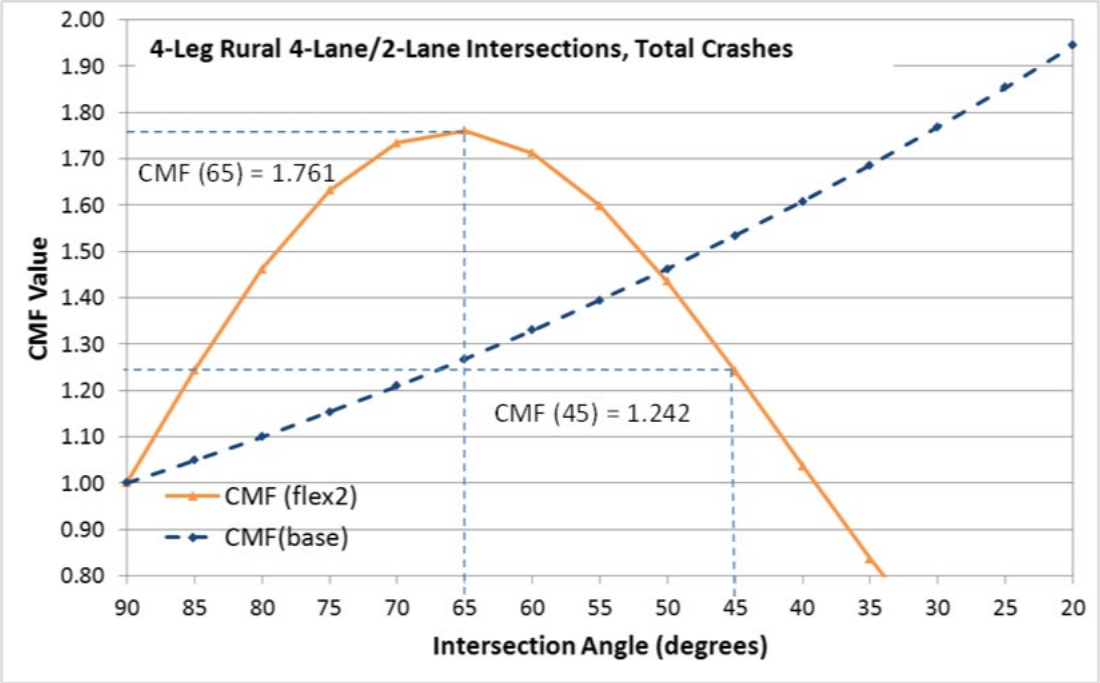
α = intersection angle in degrees.
β = −0.0095 for rural four-leg multilane total crashes.



Source: FHWA.

Figure 107. Graph. CMFs derived from the alternative base model for total crashes at rural four-leg multilane intersections in MN.

The log between the derived CMF and intersection angles is shown in figure 107. As the angle of the intersection decreased from 90 to 20 degrees, total crashes increased, as shown in figure 107. At an angle of 65 degrees, total intersection crashes were predicted to increase by 26.8 percent over what would be expected at a right-angle intersection. At 45 degrees, the predicted increase was 53.3 percent. The expected increases in crashes were much greater at the multilane intersections compared to the two-lane intersections.



Source: FHWA.

Figure 108. Graph. CMFs derived from the flexible form model 1 and alternative base model for total crashes at rural four-leg multilane intersections.

Initial CMFunction results based on just the MN data are shown in table 116. Table 117 shows CMF results with shaded peak angles for the different injury severities based on the MN data.

Table 116. CMFunctions derived by NB model form for MN.

Intersection and Collision Category	Alternative Base	Flexible Form 1	Flexible Form 2
Four-leg all sites, total crashes	X	X	X
Four-leg all sites, fatal-and-injury crashes	—	X	—
Four-leg all sites, PDO crashes	X	X	—
Four-leg rural sites, total crashes	X	X	—
Four-leg rural sites, fatal-and-injury crashes	X	X	—
Four-leg rural sites, PDO crashes	X	X	—
Four-leg rural two-lane sites, total crashes	X	X	—
Four-leg rural two-lane sites, fatal-and-injury crashes	—	X	—
Four-leg rural two-lane sites, PDO crashes	X	X	—
Four-leg rural multilane sites, total crashes	X	—	X
Four-leg rural multilane sites, fatal-and-injury crashes	—	—	X
Four-leg rural multilane sites, PDO crashes	X	—	X
Three-leg all sites, total crashes	X	—	—
Three-leg rural sites, total crashes	X	—	—

—Sufficient data not present.
X = sufficient data present.

Table 117. CMF values derived from the flexible form models for four-leg rural intersections.

Intersection Scenario and Collision Category	80 Degrees	75 Degrees	70 Degrees	65 Degrees	60 Degrees	55 Degrees
All sites, total	—	1.09	1.1*	1.11*	1.11*	1.11*
All sites, injury	—	1.08	1.1*	1.1*	1.1*	1.09
All sites, PDO	—	1.09	1.11	1.12*	1.12*	1.12*
Rural sites, total	1.08	1.11	1.13	1.15	1.15	1.16*
Rural sites, injury	1.08	1.11	1.14	1.15	1.16*	1.16*
Rural sites, PDO	1.08	1.1	1.12	1.13	1.14*	1.14*
Rural two-lane sites, total	—	1.1	1.12	1.13*	1.13*	1.13*
Rural two-lane sites, injury	1.08	1.11	1.13	1.14*	1.14*	1.14*
Rural two-lane sites, PDO	—	1.1	1.12	1.13*	1.13*	1.13*
Rural multilane sites, total	1.46	1.63	1.73	1.76*	1.71	1.6
Rural multilane sites, injury	1.69	1.92	2.01	1.94*	1.74	1.46
Rural multilane sites, PDO	1.34	1.46	1.56	1.61*	1.61*	1.58

—Data not available.
*Intersection angles in each intersection scenario/collision category with the highest CMF values.

ACKNOWLEDGMENTS

The research team would like to express appreciation to the following State departments of transportation for granting permission to share information and data used in this report:

- Ohio.
- Minnesota.
- North Carolina.

This project used data from the HSIS.

Some of the map figures in this document were modified by the authors. The original maps are the copyright property of Google Earth and can be accessed from https://www.google.com/earth.[75–79] GIS images were inserted by the research team to demonstrate that the intersection was incorrectly depicted in the GIS data as an at-grade crossing.

REFERENCES

1. American Association of State Highway and Transportation Officials. (2011). *A Policy on Geometric Design of Highways and Streets*, Sixth Edition, AASHTO, Washington, DC.

2. Institute of Transportation Engineers. (2009). *Traffic Engineering Handbook*, Sixth Edition, ITE, Washington, DC.

3. Institute of Transportation Engineers. (2003). *Neighborhood Street Design Guidelines*, ITE, Washington, DC.

4. Institute of Transportation Engineers. (1999). *Traffic Engineering Handbook*, Fifth Edition, ITE, Washington, DC.

5. Institute of Transportation Engineers. (1984). *Recommended Guidelines for Subdivision Streets*, ITE, Washington, DC.

6. Staplin, L., Lococo, K., Byington, S., and Harkey, D. (2001). *Highway Design Handbook for Older Drivers and Pedestrians*, Report No. FHWA-RD-01-103, Federal Highway Administration, Washington, DC.

7. National Highway Traffic Safety Administration. (2009). *Traffic Safety Facts 2009: A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System*, Report No. DOT HS 811 402, United States Department of Transportation, Washington, DC.

8. Kuciemba, S.R. and Cirillo, J.A. (1992). *Safety Effectiveness of Highway Design Features, Volume V: Intersections*, Report No. FHWA-RD-91-048, Federal Highway Administration, Washington, DC.

9. Bauer, K.M. and Harwood, D.W. (1996). *Statistical Models of At-Grade Intersection Accidents*, Report No. FHWA-RD-96-125, Federal Highway Administration, Washington, DC.

10. Council, F. and Nujjetty, A.P. (2015). "Highway Safety Information System Guidebook for the Minnesota State Data Files." (website) Available online: https://www.hsisinfo.org/guidebooks/minnesota.cfm, last accessed April 15, 2020.

11. The University of North Carolina Highway Safety Research Center. (2010). Focus State Analysis Tables (Technical Memorandum), Chapel Hill, NC.

12. National Highway Traffic Safety Administration. (2017). "NCSA Data Resource Website: Fatality Analysis Reporting System (FARS) Encyclopedia." (website) Available online: https://www-fars.nhtsa.dot.gov/Main/index.aspx, last accessed March 13, 2020.

13. Antonucci, N.D., Hardy, K.K., Slack, K.L., Pfefer, R., and Neuman, T.R. (2004). *Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Volume 12: A Guide for Reducing Collisions at Signalized Intersections*, NCHRP Report 500 Series, The National Academies of Science, Engineering, and Medicine. National Academies Press, Washington, DC.

14. Harkey, D.L., Carter, D.L., Barlow, J.M., and Bentzen, B.L. (2007). *Accessible Pedestrian Signals: A Guide to Best Practice*, NCHRP Web-only Document 117A. (website) Available online: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w117a.pdf, last accessed March 13, 2020.

15. Neuman, T.R., Pfefer, R., Slack, K.L., Hardy, K.K., Harwood, D.W., Potts, I.B., Torbic, D.J., and Kohlman Rabbani, E.R. (2003). *Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Volume 5: A Guide for Reducing Collisions at Unsignalized Intersections*, NCHRP Report 500 Series, The National Academies of Science, Engineering, and Medicine, National Academies Press, Washington, DC.

16. Neuman, T. (1985). *Intersection Channelization Design Guide*, NCHRP Report 27, The National Academies of Science, Engineering, and Medicine, National Academies Press, Washington, DC.

17. American Association of State Highway and Transportation Officials. (1966). *A Policy on Geometric Design of Rural Highways*, AASHTO, Washington, DC.

18. Iowa Department of Transportation. (2012). "Design Manual." (website) Available online: https://iowadot.gov/design/design-manual, last accessed March 13, 2020.

19. Montana Department of Transportation. (2004). "Road Design Manual." (website) Available online: http://www.mdt.mt.gov/publications/manuals.shtml, last accessed March 13, 2020.

20. Illinois Department of Transportation Bureau of Local Roads and Streets. (2005). *Bureau of Local Roads and Streets Manual*, Illinois Department of Transportation, Springfield, IL. Available online: http://www.idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Guides-&-Handbooks/Highways/Local-Roads-and-Streets/Local%20Roads%20and%20Streets%20Manual.pdf, last accessed March 13, 2020.

21. California Department of Transportation. (2009). *Highway Design Manual*. Available online: https://dot.ca.gov/-/media/dot-media/programs/design/documents/hdm-complete-14dec2018.pdf#page=807, last accessed March 13, 2020.

22. Chandler, B., Myers, M., Atkinson, J., Bryer, T., Retting, R., Smithline, J., Peter, W., Thomas, G., Venglar, S., Sunkari, S., Malone, B., and Izadpanah, P. (2013). *Signalized intersections: Informational Guide*, Second Edition, Report No. FHWA-SA-13-027, Federal Highway Administration, Washington, DC.

23. American Association of State Highway and Transportation Officials. (2004). G*uide for the Planning, Design, and Operation of Pedestrian Facilities*. AASHTO, Washington, DC.

24. American Association of State Highway and Transportation Officials. (2010). *Highway Safety Manual*, First Edition, AASHTO, Washington, DC.

25. Harwood, D.W., Council, F.M., Hauer, E., Hughes, W.E., and Vogt, A. (2000). *Prediction of the Expected Safety Performance of Rural Two-Lane Highways*, Report No, FHWA-RD-99-207, Federal Highway Administration, Washington, DC.

26. Washington, S., Persaud, B., Lyon, C., and Oh, J. (2005). *Validation of Accidents Models for Intersections*, Report No, FHWA-RD-03-037, Federal Highway Administration, Washington, DC.

27. Vogt, A. (1999). *Crash Models for Rural Intersections: Four-Lane by Two-Lane Stop-Controlled and Two-Lane by Two-Lane Signalized*, Report No. FHWA-RD-99-128, Federal Highway Administration, Washington, DC.

28. McCoy, P.T., Tripi, E.J., and Bonneson, J.A. (1994). *Guidelines for Realignment of Skewed Intersections*, Research Project Number RES1 (0099) P471, Nebraska Department of Roads, Lincoln, NE.

29. Hanna, J.T., Flynn, T.E., and Webb, L.T. (1976). "Characteristics of intersection accidents in rural municipalities." *Transportation Research Record: Journal of the Transportation Research Board*, No. 601, pp. 79–82, The National Academies of Science, Engineering, and Medicine. National Academies Press, Washington, DC.

30. Kulmala, R. (1995). *Safety at Rural Three- and Four-Arm Junctions. Development and Application of Accident Prediction Models*, VTT Publications 233. VTT Technical Research Centre of Finland, Espoo, Finland.

31. Gattis, J.L. and Low, S.T. (1998). "Intersection angle geometry and the driver's field of view." *Transportation Research Record: Journal of the Transportation Research Board, No.* 1612, pp. 10–16, The National Academies of Science, Engineering, and Medicine, National Academies Press, Washington, DC.

32. Gattis, J.L. and Low, S.T. (1997). *Intersection Angles and the Driver's Field of View*, Report No. MBTC 97.73, Arkansas State Highway and Transportation Department, Little Rock, AR.

33. Son, Y., Kim, S., and Lee, J. (2002). "Methodology to calculate sight distance available to drivers at skewed intersections." *Transportation Research Record: Journal of the Transportation Research Board*, *1796*(1): pp. 41–47, The National Academies of Science, Engineering, and Medicine, National Academies Press, Washington, DC.

34. Garcia, A. (2005). "Lateral vision angles and skewed intersections design." *Proceedings, 3rd International Symposium on Highway Geometric Design*, Chicago, IL.

35. García, A. and Libreros, L. (2007). "Safety effect of the skew angle in right turn maneuvers." *Proceedings, 3rd International Symposium on Highway Geometric Design*, Seattle, WA.

36. Harkey, D., Staplin, L., Lococo, K., Srinivasan, R., Baek, J., Daul, M. McGee, H., et al. (2011). *2011 Handbook for Designing Roadways for the Older Population* (Draft Publication), Federal Highway Administration, Washington, DC.

37. Smith, B.H. and Sethi, P.K. (1975). "Aging and the nervous system." *Geriatrics*, *30*, pp. 109–115, Magnus Med Club, Westerville, OH.

38. Isler, R.B., Parsonson, B.S., and Hansson, G.J. (1997). "Age related effects of restricted head movements on the useful field of view of drivers." *Accident Analysis & Prevention, 29*(6), pp. 793–801, Elsevier, Amsterdam, Netherlands.

39. Ostrow, A.C., Shaffron, P., and McPherson, K. (1992). "The effects of a joint range-of-motion physical fitness training program on the automobile driving skills of older adults." *Journal of Safety Research, 23*, pp. 207–219, Elsevier, Amsterdam, Netherlands.

40. Yee, D. (1985). "A survey of the traffic safety needs and problems of drivers age 55 and over." In *Needs and Problems of Older Drivers: Survey Results and Recommendations*. American Automobile Association Foundation for Traffic Safety, Washington, DC.

41. Staplin, L., Harkey, D., Lococo, K., and Tarawneh, M. (1997). *Intersection Geometric Design and Operational Guidelines for Older Drivers and Pedestrians, Volume I, Final Report*, Report No. FHWA-RD-96-132, Federal Highway Administration, Washington, DC.

42. Classen, S., Shechtman, O., Stephens, B., Davis, E., Justiss, M., Bendixen, R., Belchior, P., et al. (2007). "The impact of roadway intersection design on driving performance of young and senior adults." *Traffic Injury Prevention*, *8*, pp. 69–77, Taylor & Francis Online, London.

43. Wilson, D.G. and Grayson, G.B. (1980). *Age-Related Differences in the Road Crossing Behavior of Adult Pedestrians*, Report No. TRRL-L-933, Transport and Road Research Laboratory, Crowthorne, England.

44. Stollof, E.R., McGee, H., and Eccles, K. (2007). *Pedestrian Signal Safety for Older Persons*. American Automobile Association Foundation for Traffic Safety, Washington, DC.

45. Federal Highway Administration (2009). *Manual on Uniform Traffic Control Devices, 2009 Edition*. FHWA, Washington, DC.

46. Brieman, L. and Cutler, A. (2013). *Random Forests*. (website) Available online: http://www.stat.berkeley.edu/~breiman/RandomForests, last accessed March 13, 2020.

47. Breiman, L., Freidman, J.H., Olshen, R.A., and Stone, C.J. (1984). *Classification and Regression Trees*, Wadsworth, Belmont, CA.

48. Loh, W. (2011). "Classification and regression trees." *WIREs Data Mining and Knowledge Discovery*, *1*, pp. 14–23, Wiley Periodicals, Hoboken, NJ.

49. Strobl, C., Malley, J., and Tutz, G. (2009). *An Introduction to Recursive Partitioning*, Technical Report No. 55, Department of Statistics, University of Munich, Munich, Germany.

50. Hauer, E. (2004). "Statistical road safety modeling." *Transportation Research Record: Journal of the Transportation Research Board,* No. 1897, pp. 81–87, The National Academies of Science, Engineering, and Medicine, National Academies Press, Washington, DC.

51. Bauer, K.M. and Harwood, D.W. (2013). *Safety Effects of Horizontal Curve and Grade Combinations*. Available online: https://www.fhwa.dot.gov/publications/research/safety/13077/index.cfm, last accessed April 15, 2020.

52. Lord, D. and Mannering, F. (2010). "The statistical analysis of crash-frequency data: a review and assessment of methodological alternatives." *Transportation Research Part A: Policy and Practice*, *44*, pp. 291–305, Elsevier, Amsterdam, Netherlands.

53. Federal Highway Administration. (2013). Available online: www.cmfclearinghouse.org, last accessed March 13, 2020.

54. Gross, F., Persaud, B., and Lyon, C. (2010). *A Guide to Developing Quality Crash Modification Factors*, Report No. FHWA-SA-10-032, Federal Highway Administration, Washington, DC.

55. Highway Safety Information System. (website) Available online: www.hsisinfo.org, last accessed April 15, 2020.

56. Council, F.M. and Mohamedshah, Y. (2007). *Highway Safety Information System Guidebook for the Minnesota State Data Files*. Federal Highway Administration, Washington, DC.

57. Minnesota Department of Transportation. (2013). "GIS BaseMap." (website) Available online: https://www.dot.state.mn.us/maps/gdma/index.html, last accessed March 13, 2020.

58. Google Maps. (2012). Available online: https://www.google.com/maps, last accessed March 13, 2020.

59. ESRI. (2102). ArcGIS, Version 10. Redlands, CA.

60. Federal Highway Administration. (2016). *Summary of State SPF Calibration and Development Efforts*. Available online: http://www.cmfclearinghouse.org/resources_spf.cfm, last accessed April 15, 2020.

61. Minnesota Department of Public Safety (2016). *Minnesota Motor Vehicle Crash Facts 2015*. Available online: https://dps.mn.gov/divisions/ots/reports-statistics/Documents/2015-crash-facts.pdf, last accessed April 15, 2020.

62. Minnesota Department of Transportation. (2017). "Transportation Fact Cards." (website) Available online: www.dot.state.mn.us/trafficeng/publ/triviacard, last accessed March 13, 2020.

63. Ohio Department of Transportation. (2017). "Highway Safety Improvement Program: Crash Data Analysis & Tools." (website) Available online: www.dot.state.oh.us/Divisions/Planning/ProgramManagement/HighwaySafety/HSIP/Pages/Crash-Data-Analysis-Tools.aspx, last accessed March 13, 2020.

64. Liaw, A. and Wiener, M. (2002). "Classification and regression by randomforest." *R News 2*(3), pp. 18–22.

65. Hothorn, T., Hornik, K., Strobl, C., and Zeileis, A. (2020). *party: A laboratory for recursive partytioning*. (website) Available online: http://cran.r-project.org/web/packages/party/index.html, last accessed March 13, 2020.

66. Hothorn, T., Buehlmann, P., Dudoit, S., Molinaro, A. and Van Der Laan, M. (2006). "Survival ensembles." *Biostatistics, 7*(3), pp. 355–373.

67. Strobl, C., Boulesteix, A., Zeileis, A., and Hothorn, T. (2007). (website) "Bias in random forest variable importance measures: Illustrations, sources and a solution." *BMC Bioinformatics, 8*(25). Available online: http://www.biomedcentral.com/1471-2105/8/25, last accessed March 13, 2020.

68. Strobl, C., Boulesteix, A., Kneib, T., Augustin, T., and Zeileis, A. (2008). "Conditional variable importance for random forests." *BMC Bioinformatics, 9*(307). Available online: http://www.biomedcentral.com/1471-2105/9/307, last accessed March 13, 2020.

69. SAS (2011). *SAS/STAT® 9.3 User's Guide*. SAS Institute Inc., Cary, NC.

70. Akaike, H. (1973). "Information theory and an extension of the maximum likelihood principle," In Petrov, B.N. and F. Csaki (Eds.), *Second International Symposium on Information Theory*, pp. 267–281. Academiai Kiado, Budapest, Hungary.

71. Schwarz, G.E. (1978). "Estimating the dimension of a model." *Annals of Statistics, Vol 6*(2), pp. 461–464, Institute of Mathematical Statistics, Cleveland, OH.

72. Burnham, K.P. and Anderson, D.R. (2002). *Model selection and multi-model inference: A practical information-theoretic approach*, Second Edition, Springer-Verlag, New York, NY.

73. Raftery, A.E. (1999). "Bayes factors and BIC." *Sociological Methods & Research, 2*(3), 411–427, SAGE Journals, Thousand Oaks, CA.

74. Hauer, E. (2015). *The Art of Regression Modeling in Road Safety*. Springer International, Switzerland.

75. "3-leg Intersection." Map. Google Earth. Maxar Technologies, USDA Farm Service Agency. Fremont, CA. Accessed April 15, 2020. https://www.google.com/maps/place/47%C2%B046'05.7%22N+96%C2%B035'59.9%22W/@47.7682221,96.601233,627m/data=!3m1!1e3!4m5!3m4!1s0x0:0x0!8m2!3d47.7682528!4d-96.5999831. Scale 165 ft.

76. "Divided Roadway with Connector." Map. Maxar Technologies, USDA Farm Service Agency. Fremont, CA. Accessed April 15, 2018. https://www.google.com/maps/place/47%C2%B030'20.5%22N+94%C2%B056'56.3%22W/@47.5056944,94.9511609,630m/data=!3m2!1e3!4b1!4m5!3m4!1s0x0:0x0!8m2!3d47.505675!4d-94.9489622. Scale 250 ft.

77. "Divided Roadway." Map. Maxar Technologies, U.S. Geological Survey, USDA Farm Service Agency. Google Maps. Fremont, CA. Accessed April 15, 2020. https://www.google.com/maps/place/44%C2%B042'09.7%22N+93%C2%B001'40.4%22W/@44.7026944,93.0300776,663m/data=!3m2!1e3!4b1!4m5!3m4!1s0x0:0x0!8m2!3d44.702690 3!4d-93.0278875. Scale 250 ft.

78. "Grade-separated Intersection." Map. Google Earth. Fremont, CA. Accessed May 31, 2018. https://www.google.com/maps/place/44%C2%B007'21.7%22N+92%C2%B031'15.5%22W/@44.1226944,92.5231609,670m/data=!3m2!1e3!4b1!4m5!3m4!1s0x0:0x0!8m2!3d44.122683 3!4d-92.5209758.

79. Google. "Right-angle Intersection." Map. Maxar Technologies, USDA Farm Service Agency. Google Earth. Fremont, CA. Accessed April 15, 2020. https://www.google.com/maps/place/47%C2%B031'18.4%22N+95%C2%B024'16.8%22W/@47.5217778,95.4068554,630m/data=!3m2!1e3!4b1!4m5!3m4!1s0x0:0x0!8m2!3d47.521775!4d-95.4046533. Scale 150 ft.

80. Harb, R., Yan, X., Radwan, E., and Su, X. (2009). "Exploring precrash maneuvers using classification trees and random forests." *Accident Analysis and Prevention, 41*, pp. 98–107, Elsevier, Amsterdam, Netherlands.

81. Rossi, A., Amaddeo, F., Sandri, M., and Tansella, M. (2005). "Determinants of once-only contact in a community-based psychiatric service." *Social Psychiatry and Psychiatric Epidemiology, 40*(1), pp. 50–56, Springer, Switzerland.

82. Council, F.M., Reurings, M., Srinivasan, R., Masten, S., and Carter, D. (2010). *Development of a Speeding-Related Crash Typology*, Report No. FHWA-HRT-10-024, Federal Highway Administration, Washington, DC.

83. Thomas, L.J., Srinivasan, R., Lan, B., and Council, F.M. (2012). *Speeding Related Crash Taxonomy: Crash Types and Factors Associated with Driving Too Fast for Conditions, Volume I*, Draft Report submitted to National Highway Traffic Safety Administration, Washington, DC.

84. Abdel-Aty, M., Keller, J., and Brady, P.A. (2005). "Analysis of types of crashes at signalized intersections by using complete crash data and tree-based regression." *Transportation Research Record: Journal of the Transportation Research Board, No. 1908*, pp. 37–45, The National Academies of Science, Engineering, and Medicine, National Academies Press, Washington, DC.

85. Park, Y. and Saccomanno, F. (2005). "Collision frequency analysis using tree-based stratification," *Transportation Research Record: Journal of the Transportation Research Board, No. 1908*, 121–129, The National Academies of Science, Engineering, and Medicine, National Academies Press, Washington, DC.

86. Kuhnert, P.M., Do, K., and McClure, R. (2000). "Combining non-parametric models with logistic regression: an application to motor vehicle injury data." *Computational Statistics & Data Analysis, 34*, pp. 371–386, Elsevier, Amsterdam, Netherlands.

87. Miller, J.S., Garber, N. J., and Korukonda, S. K. (2010). *Causal Factors for Intersection Crashes in Northern Virginia*, Report No. FHWA/VTRC 10-R22, Virginia Transportation Research Council, Charlottesville, VA.

88. Chang, L.Y. and Wang, H.W. (2006). "Analysis of traffic injury severity: An application of non-parametric classification tree techniques." *Accident Analysis and Prevention, 38*, pp. 1019–1027, Elsevier, Amsterdam, Netherlands.

89. Chang, L.Y. and Chen, W.C. (2005). "Data mining of tree-based models to analyze freeway accident frequency." *Journal of Safety Research, 36*, pp. 365–375, Elsevier, Amsterdam, Netherlands.

90. Karlaftis, M. G. and Golias, I. (2002). "Effects of road geometry and traffic volumes on rural roadway accident rates." *Accident Analysis and Prevention, 34*, pp. 357–365, Elsevier, Amsterdam, Netherlands.

91. Mohaymany, A.S., Kashani, A.T., and Ranjbari, A. (2010). "Identifying driver characteristics influencing overtaking crashes." *Traffic Injury Prevention, 11*, pp. 411–416, Taylor & Francis Online, London.

92. Yan, X. and Radwan, E. (2006). "Analyses of rear-end crashes based on classification tree models." *Traffic Injury Prevention, 7*(3), pp. 276–282, Taylor & Francis Online, London.

93. Stewart, J.R. (1996). "Applications of classification and regression tree methods in roadway safety studies." *Transportation Research Record: Journal of the Transportation Research Board, No. 1542*, 1–5, The National Academies of Science, Engineering, and Medicine, National Academies Press, Washington, DC.

Recycled
Recyclable

HRDS-20/01-21(WEB)E

Oregon Department of Transportation
Traffic Management Section
Traffic Engineering Services Unit
October 30, 2001

Safety Comparison of 4-Way Cross and Offset T Intersections

File Code: TRA 10-05-12

Recently, the Traffic Engineering Services Unit was asked to review the research on the safety differences between 4-way and offset T-intersections at rural locations. This document is a summary of those findings.

In general, the research indicates that crash rates at T-intersections are usually lower than those of 4-way cross intersections but is dependent on volumes and other factors. Separating cross intersections to T-intersections is a possible safety countermeasure for high crash cross intersections. The number of conflict points at a standard cross intersection is 32 which is reduced to 22 at two offset T-intersections. The offset T-intersections can be classified as either right-left or left-right depending on the turning movements required for a through movement on the minor road. Figure 1 shows the conflict points at a 4-way and a right-left offset T-intersection.

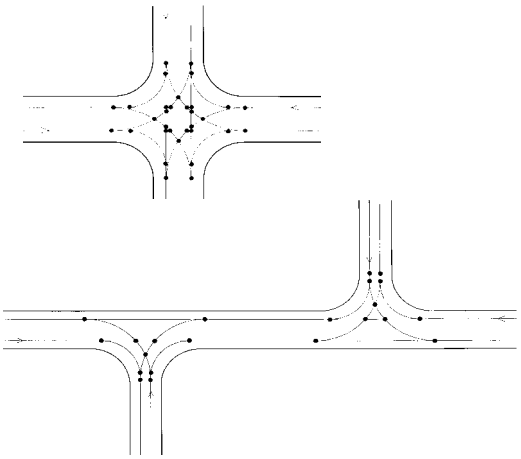


Figure 1 Conflict Points of Cross and R-L Offset T Intersections (From Bared and Kaisar)

In a study by Hanna et al., 300 intersections in 42 rural Virginia cities (population average of 15,000) were analyzed and the crash rates for various intersection geometries were reported (*1*). A total of 2,300 crashes from 24 months (1969-1973) were considered. No data was presented on the operating speeds, volumes, or type of stop control (two-way, three-way, four-way). For all intersection types (including Y's and offset) crash rates were higher at signalized approaches. Crash rates were lower at T-intersections than cross intersections in all cases. A roundabouts brochure by Leif Ourston includes 1989 crash data from California state highways (*2*). Crash rates were reported for rural, suburban, urban 4-way and T-intersections (*3*). The California data does include some multi-leg, Y-type and offset intersections mixed with T and 4-way types. Again, crash rates of T-intersections are lower. Ogden presents fatality rates presented by Barton from research in Australia that are shown in Table 1(*4*). Again, T-intersections have lower rates. All of these studies are summarized in Table 1.

Other international studies (presented in Ogden) report that paired t-intersections are 1.5 to 2.0 times as safe as cross-intersections for the same traffic flow and that the injury consequence is 1.5 times greater at cross intersections (Hedman). In another study in Australia, Nairn reports a 47 percent reduction in crashes when replacing cross intersections with staggered T intersections.

In an unpublished paper, Bared and Kaisar discuss the operational and safety advantages of offset t-intersections (*5*).Their paper includes a discussion of research by Mahalel et al. who preferred operation right-left layout staggered T's for operational concerns (although crash reductions were better at left-right layouts). In addition, Bared et al. include a discussion of the maximum offsets between the two intersection that minimize interference on the major road based on equations in the 2001 AASHTO Green Book. For example, the maximum offset (not including storage for a left-turn pocket) for a right-left offset T intersections with a 55 mph major road speed is 186 feet.

Table 1 Crash Rates of T and 4-way Intersections

Intersection Type	Traffic Control	Crash rate (MEV)				Fatality Rate (10^7EV)	
		Hanna et al. (Rural City)	CalTrans (Suburban)	CalTrans (Urban)	CalTrans (Rural)	Barton (Rural)	Barton (Urban)
4-Way Cross	Signalized	1.47	0.77	0.54	0.98	2.5[1]	1.7
	Stop or Yield	1.27	0.42	0.32	0.40	5.2	2.4
T-intersection	Signalized	0.82	0.47	0.37	0.49	2.1[1]	1.4
	Stop or Yield	0.79	0.26	0.17	0.26	3.3	1.5

Notes: [1] High speed

Two FHWA studies developed crash prediction models for rural two and four-lane highway intersections. Models were developed for both T-intersection and 4-way intersections from HSIS data in California and Minnesota (*6*, *7*). While not specifically developed to analyze offset T's, the safety of two T's should be similar if the proper offset is used to minimize interference between the minor roads. The two-lane major highway model predicts crash frequency based on ADT of the major and minor roads, presence of horizontal or vertical curves, average posted speed limits, roadside hazard rating, right turn lane on major road, number of driveways, and skew type for both T-intersection and 4-way intersection. Application of the model with assumptions constant between the T-intersection and 4-way yield predicted crash frequencies greater for 4-way than T-intersections. A graph, showing predicted crash frequencies, based on a minor road ADT or 2,000, posted speed on the major road of 55 mph, no curves, no right turn lane, and 90 degree intersection is shown in Figure 2. No graphs were generated from the 4-lane major highway model.

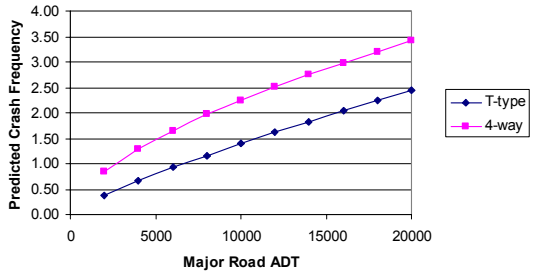


Figure 2 Predicted Crash Frequency (Vogt)

Kulmula studied the safety performance of 4-way cross intersections and offset T-intersection. Kumula analyzed 2,700 junctions in Finland (*8*). Separate models were developed for three-leg and four-leg intersections. Five years of crash data were collected and models to predict the crash frequency were developed. Kumula found that the crash rates were 1.4-1.3 times as high at 4-way than T intersections. Results of the model were used to predict crash rates at 4-way and staggered T's, which are are shown in Figure 3.

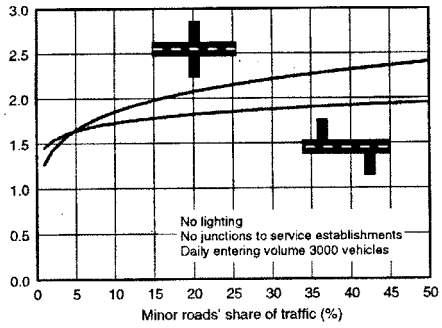


Figure 3 Expected number of injury collisions in five years (Kumula)

Research by Sayed and Rodriguiez studied 419 urban unsignalized intersections (186 T-Leg and 233 four-leg) in British Columbia and found similar results (*9*). Sayed developed a GLIM model based on AADT of the major and minor roads. The predicted crash frequencies based on the model results are shown in Figure 4.

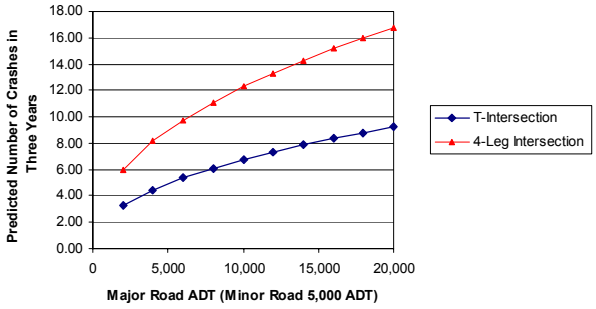


Figure 4 Predicted Crash Frequencies (Sayed)

REFERENCES

1 Hanna, J.T., Flynn, T, Tyler, W. *Characteristics of Intersection Accidents in Rural Municipalities*. In *Transportation Research Record 601*, TRB, National research Council, Washington D.C. 1976, pp 79-81.

2 Ourston Roundabout Engineering, http://www.roundabout-interchange.com/safety.html. Accessed 10/17/2001

3 1988 Accident Data on California State Highways, California Department of Transportation, 1989. p. 27

4 Ogden, K.W. *Safer Roads: A Guide to Road Safety Engineering*. Aldershot, Hants, England ; Brookfield, Vt. : Avebury Technical, 1996.

5 Bared, J. and E. Kaisar, *Advantages of Offset T-Intersections with Guidelines*. Unpublished Draft Paper, Obtained from J. Bared via email 10.18.2001.

6 Vogt, Andrew and Joe G. Bared . *Accident Prediction Models on Two-Lane Rural Roads: Segments and Intersections*. FHWA-RD-98-133, FHWA, Washington D.C. October 1998

7 Crash Models for Rural Intersections: Four-Lane by Two-lane Stop-Controlled and Two-Lane by Two-lane Signalized, FHWA-RD-99-128, FHWA, Washington D.C. October 1999.

8 Kumula, R. *Safety at Highway Junctions Based on Predictive Accident Models*. Presented at Third International Symposium on Intersections Without Traffic Signals, Portland OR, 1997. pp 151-157.

9 Sayed, T, Rodriguez, F. Accident Prediction Models For Urban Unsignalized Intersections In British Columbia. In *Transportation Research Record 601*, TRB, National Research Council, Washington D.C. 1999, pp 93-99

Chris Monsere, Ph.D., Transportation Engineer

Attachment C

CITY OF REDMOND
Engineering Division

243 East Antler Avenue, Suite 100
Redmond, OR 97756

(541) 504-2002
Fax: (541) 548-0253
www.redmondoregon.gov

TO: MEGAN PENINGER, *Planning Division/Community Development Dept*

FROM: JESSICA MACCLANAHAN, LINDSEY CROMSIGT & DAVID PILLING, *Engineering Div./Public Works Dept*

DATE: November 25, 2025

SUBJECT: **711-24-000216-PLNG-PUD, 25-086-PLNG-SUB & 25-087-PLNG-CU: 333-Lot Horizon Pointe Sub**
MonteVista Homes/Redmond Land Group LLC/Hickman, Williams & Associates Inc.
Nathan & Jessica Hadfield/Ronald Nelson/Richard & Meghan Holmes
Tax Lots 15-13-19-1100, 1101 & 1102

Subject property located west of SW Helmholtz Way, north of Wickiup Ave. and south of Obsidian Avenue. 2571, 2577 and 2897 SW Helmholtz Way and tax lots. The Engineering Division provides the following recommendations based on the submitted Tentative Plat & Utility Plan set revised 11-18-25 per Redmond Development (COR) Code Section 8.0275, 8.0600, 8.0305, 8.1015(1)(C) and 8.2000-2840 and City of Redmond Standards and Specifications (CORSS).

Prerequisite Requirements and Conditions of Land Use Approval:

1) Prior to final plat approval of all affected phases, suitable fire access must be maintained for all project phases. Temporary turn-arounds may be required at the termination of streets longer than 150' as required by Redmond Fire.
2) Prior to final plat approval of all affected phases, local streets and cul-de-sacs shall be dedicated as a 60 foot public right-of-way (30-feet from centerline) and 54 foot cul-de-sac radius public right-of-way and constructed as full width street section per CORSS Standard Drawing 2-1 and 2-4 where possible. A partial street section will be required where a full width street section is not feasible. Horizontal curves will not be permitted to be less than 198-ft radius per Standards and Specifications. Substandard centerline curve radii are identified (but may not be limited to) along Celestial Way, Horizon Peak Rd, Dawn Meadow St and Horizon Light Road. All intersection spacing and intersection sight distance/stopping sight distance must meet City of Redmond Development Code Section 8.2820 - Access Management Standards. Substandard intersection spacing are identified (but may not be limited to) along Horizon Peak Rd between Morning Vista Rd, Dusk Valley Rd and Horizon Light Road. Directional curb ramps shall be required at all intersections serving crossings in all directions. End of roadway signs shall be installed at each street/phase terminus per City standards, until streets are extended.
3) Prior to final plat approval of all affected phases, a separated multiuse path conforming to City of Redmond Standards and Specifications shall be required along the COID Canal Lateral B and B-5 (identified as B67) and along SW Helmholtz Way (identified as B1) per City Transportation System Plan (TSP). Accessible ramps, continental crosswalks, illumination and advanced warning signs are required where the path intersects with any roadway(s). The path will be required to connect and align with the path proposed along SW 45th St. within the Little Texas subdivision located to the north.
4) Prior to final plat of Phase 3, a pedestrian pathway shall be constructed and right of way or easement shall be dedicated between Horizon Peak Road and Helmholtz Way, located between Lot 284 and 285. The right of way or easement shall be a minimum of twenty feet wide, with a paved surface a minimum of ten feet wide per COR Std Dwg 2-6, constructed and centered within the right-of-way/easement.
5) Prior to final plat of Phase 1 and 2, a pedestrian pathway shall be constructed and right of way or easement shall be dedicated between Morning Vista Road and Horizon Peak Road, located between Lots 222, 223, 234, and 235. The right of way or easement shall be a minimum of twenty feet wide, with a paved surface a minimum of ten feet wide per COR Std Dwg 2-6, constructed and centered within the right-of-way/easement.
6) Prior to final plat of Phase 3 and 4, a pedestrian pathway shall be constructed and right of way or easement shall be dedicated between Horizon Peak Road and Horizon Peak Road, located between Lots 160, 161, 257 and 258. The right of way or easement shall be a minimum of twenty feet wide, with a paved surface a minimum of ten feet wide per COR Std Dwg 2-6, constructed and centered within the right-of-way/easement.

7) Prior to final plat approval of all affected phases, alleys shall be identified as privately owned and maintained and shall meet City of Redmond Standards and Specification requirements. Backup distance minimum of 24 ft. from face of garage or edge of parking stall to opposite side of alley shall be required for turnaround purposes.
8) Prior to Phase 1 final plat approval, SW Helmholtz Way shall be dedicated to minor arterial street standards per CORSS Standard Drawing 2-1 to achieve a total public right-of-way width of 100 feet (minimum of 50-feet west from centerline) and 5-foot-wide minimum public utility easement along project/property frontage. No direct vehicular/truck access to SW Helmholtz Way shall be permitted unless required by Redmond Fire and Rescue (RFR) for emergency access only with approved locked, removable bollards.
9) Prior to Phase 1 final plat approval, SW 45th St. shall be dedicated to local street standards per CORSS Standard Drawing 2-1 and in coordination and alignment with Little Texas North Subdivision to achieve a total of 60-feet minimum width public right-of-way (or 30 feet west from centerline) and 5-foot-wide minimum public utility easement along project/property frontage. No direct vehicular/truck access to SW 45th St shall be permitted due to proximity to the future roundabout at SW 45th St. and Helmholtz Way.
10) Prior to Phase 1 final plat approval, SW Helmholtz Way shall be improved and constructed along Phase 1 frontage to minor arterial street standards (3-lane) per CORSS Standard Drawing 2-1 and Development Code requirements, to achieve 50-feet of pavement with travel lanes and center turn lane, striping, curb and curb ramps on both sides, sidewalks, and street trees on the west side.
11) Prior to Phase 1 final plat approval, a southbound right-turn lane and northbound left-turn lane shall be installed at SW Helmholtz Way/SW Dusk Valley Rd. A stop bar and stop sign shall be installed for eastbound traffic at the intersection
12) Prior to Phase 1 final plat approval, an enhanced pedestrian crossing shall be installed in SW Helmholtz Way at SW Dusk Valley Rd on the north side of the intersection. This crossing shall include continental crosswalk striping, a raised pedestrian refuge island, and a Rectangular Rapid Flashing Beacon to increase awareness of the crossing, signage, and overhead illumination.
13) Prior to Phase 1 final plat approval, a total proportionate share of $199,686 shall be required for development impacts to; OR 126/SW 27th Street, based on the cost of the parallel route improvements at OR 126/SW 35th Street; a northbound right turn lane at SW Helmholtz Way/SW Obsidian Avenue; a northbound right turn lane at SW Helmholtz Way/SW Quartz Avenue; and a northbound right turn lane at Helmholtz Way/Antler Ave. The proportionate share, or portions of the payment, will not be required if the City adopts a separate funding mechanism that addresses the impacts in their entirety prior to final plat of Phase 1. The total payment is either due prior to final plat approval of Phase 1 or $28,526.57 may be paid prior to final plat approval of each individual phase.
14) Prior to Phase 1 final plat approval, applicant shall coordinate with Cascades East Transit (CET) and City to site a location of bus stop and associated infrastructure, if required by CET. If required, construction shall occur prior to final plat of Phase 1.
15) Prior to Phase 3 final plat approval, SW Helmholtz Way shall be improved and constructed along Phase 3 frontage to minor arterial street standards (3-lane) per CORSS Standard Drawing 2-1 and Development Code requirements, to achieve 50-feet of pavement with travel lanes and center turn lane, striping, curb and curb ramps on both sides, sidewalks, and street trees on the west side.
16) Prior to Phase 3 final plat approval, SW 45th St. shall be improved and constructed along Phase 3 frontage to City local street standards per CORSS Standard Drawing 2-1 and Development Code requirements in coordination with the Little Texas Subdivision, if not constructed already.
17) Prior to final plat approval of all affected phases, all infrastructure connections, design, and construction shall be coordinated with the Little Texas subdivision located to the north.
18) Prior to final plat approval of all affected phases, the 12-inch minimum diameter water main identified as P4640 west of Helmholtz Way per City Water System Master Plan (WSMP) shall be extended and constructed in Horizon Peak Rd., Dusk Valley Rd., Horizon Crest Lane, Horizon Peak Rd., Celestial Ridge Way and SW 51st St. for a looping connection between Little Texas North Subdivision and SW Helmholtz Way.
19) Prior to final plat approval of all affected phases, 8-inch minimum diameter water mains shall otherwise be extended and constructed along public streets and project/lot frontages. One water service shall be provided to each proposed lot or tract. Abandonment of any existing water well, cistern or other private water facility located on subject properties shall be in accordance with City Municipal Code, Standards and Specifications, and any applicable Oregon requirements.
20) Prior to final plat of all affected phases, 8-inch minimum diameter gravity sewer mains shall be extended and constructed along all public streets and project frontages per City standards. One sewer service shall be provided to each proposed lot. Abandonment of any existing sewage drill hole, septic tank or other private sewer facility located on subject properties shall be in accordance with City Municipal Code, Standards and Specifications, and any applicable Oregon requirements.

21) Prior to engineering plan approval for all affected phases, the proposed location, alignment and depth of the Obsidian Interceptor (Interceptor) through the project/property shall be reviewed and approved by the City Engineer. A cash contribution will be required for the standard eight (8) inch pipe portion of the Interceptor at ten (10) foot average depth in lieu of constructing the Interceptor extension through the project/property frontage per current Redmond Collection System Master Plan (CSMP) due to the incontiguous nature for the Interceptor in relation to this development.
22) Prior to final plat of all affected phases, a combined gravity, pump station, and interim pressure system within the proposed development and sewer discharge to the existing 15-inch SW Helmholtz Way sewer main shall be reviewed and approved by the City Engineer. The interim pump station shall be located near the proposed location of Obsidian Interceptor and the low point of the development near the north project/property boundary. The interim pump station and force main must meet City of Redmond and DEQ standards. The plans must conceptually demonstrate how the development will connect to the Obsidian Interceptor once the Lift Station is decommissioned. Alternatively, the development may discharge to the Little Texas Subdivision pump station, provided capacity is available at the pump station and a proportionate payment is provided prior to connection and/or private cost sharing is established with Little Texas. The proportionate share will be determined based on actual design and construction costs of the pump station, relative to the sewer demand (gallons per minute) required by Horizon Pointe.
23) Prior to building permit issuance and after land use decision issuance, a separate set of construction drawings shall be submitted directly to the City Engineering Division along with a Site Development (SD) Review Application for design review and approval of all proposed and/or required public infrastructure improvements, water/sewer service connections, subdivision-site grading/drainage and utilities per City of Redmond Standards and Specifications.

REDMOND FIRE & RESCUE

341 NW Dogwood Avenue, Redmond, OR 97756
Phone: (541) 504-5000 Fax: (541) 526-1254
www.rdmfire.org

September 22, 2025

Megan Peninger
Associate Planner
City of Redmond
411 SW 9th street
Redmond, OR 97756

Re: 711-24-000216-PLNG (PUD), 711-25-000086-PLNG (SUB), & 711-25-000087-PLNG (CU) | Horizon Pointe
Tax Lot ID: 1513190001100, 1513190001102, and 1513190001101

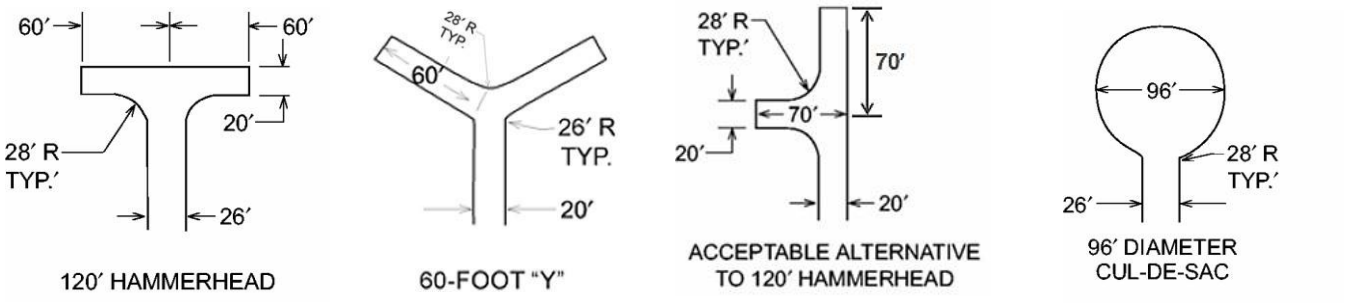
Dear Meagan,

Thank you for the opportunity to review the proposed site plan surrounding the above-named development project. These notes are provided in regard to the plans received September 17, 2025. There may be more or less requirements needed based upon the final project design, however, Redmond Fire & Rescue will endorse this proposal predicated on the following criteria and conditions of approval.

FIRE APPARATUS ACCESS:

1. **FIRE APPARATUS ACCESS ROAD DISTANCE FROM BUILDINGS AND FACILITIES:** Access roads shall be within 150 feet of all portions of the exterior wall of the first story of the building as measured by an approved route around the exterior of the building or facility. An approved turnaround is required if the remaining distance to an approved intersecting roadway, as measured along the fire apparatus access road, is greater than 150 feet. (OFC 503.1.1)

2. **DEAD END ROADS AND TURNAROUNDS:** Dead end fire apparatus access roads in excess of 150 feet in length shall be provided with an approved turnaround. Diagrams of approved turnarounds are shown below: (OFC 503.2.5 & D103.1)



Turnaround at lot 28 is acceptable.

3. **ADDITIONAL ACCESS ROADS – ONE- OR TWO-FAMILY RESIDENTIAL DEVELOPMENTS:** Developments of one- or two-family dwellings, where the number of dwelling units exceeds 30, shall be provided with separate and approved fire apparatus access roads and shall meet the requirements of Section D104.3.
   Exception: Where there are more than 30 dwelling units on a single public or private fire apparatus access road and all dwelling units are equipped throughout with an approved automatic sprinkler system in accordance with section 903.3.1.1, 903.3.1.2, or 903.3.1.3 of the International Fire Code, access from two directions shall not be required. (OFC D107)

4. **MULTIPLE ACCESS ROADS SEPARATION:** Where two access roads are required, they shall be placed a distance apart equal to not less than one half of the length of the maximum overall diagonal dimension of the area to be served (as identified by the Fire Marshal), measured in a straight line between accesses. (OFC D104.3)

5. **FIRE APPARATUS ACCESS ROAD WIDTH AND VERTICAL CLEARANCE:** Fire apparatus access roads shall have an unobstructed driving surface width of not less than 20 feet (26 feet adjacent to fire hydrants (OFC D103.1)) and an unobstructed vertical clearance of not less than 13 feet 6 inches. (OFC 503.2.1)

6. **NO PARKING SIGNS:** Where fire apparatus roadways are not of sufficient width to accommodate parked vehicles and 20 feet of unobstructed driving surface, "No Parking" signs shall be installed on one or both sides of the roadway and in turnarounds as needed. Signs shall read "NO PARKING - FIRE LANE" and shall be installed with a clear space above grade level of 7 feet. Signs shall be 12 inches wide by 18 inches high and shall have red letters on a white reflective background. (OFC D103.6)

7. **NO PARKING:** Parking on emergency access roads shall be as follows (OFC D103.6.1-2):
   1. 20-26 feet road width – no parking on either side of roadway
   2. 26-32 feet road width – parking is allowed on one side
   3. Greater than 32 feet road width – parking is not restricted

8. **PAINTED CURBS:** Where required, fire apparatus access roadway curbs shall be painted red (or as approved) and marked "NO PARKING FIRE LANE" at 25-foot intervals. Lettering shall have a stroke of not less than one inch wide by six inches high. Lettering shall be white on red background (or as approved). (OFC 503.3)

   See marked plans for location of painted curbs.

9. **FIRE APPARATUS ACCESS ROADS WITH FIRE HYDRANTS:** Where a fire hydrant is located on a fire apparatus access road, the minimum road width shall be 26 feet and shall extend 20 feet before and after the point of the hydrant. (OFC D103.1)

10. **SURFACE AND LOAD CAPACITIES:** Fire apparatus access roads shall be designed and maintained to support the imposed loads of fire apparatus and shall be surfaced as to provide all-weather driving capabilities. (OFC 503.2.3)

11. **TURNING RADIUS:** The inside turning radius and outside turning radius shall not be less than 30 feet and 50 feet respectively, measured from the same center point. (OFC 503.2.4 & D103.3)

12. **ACCESS ROAD GRADE:** Fire apparatus access roadway grades shall not exceed 10%.

13. **ANGLE OF APPROACH/GRADE FOR TURNAROUNDS:** Turnarounds shall be as flat as possible and have a maximum of 5% grade with the exception of crowning for water run-off. (OFC 503.2.7 & D103.2)

14. **GATES:** Gates securing fire apparatus roads shall comply with all of the following (OFC D103.5, and 503.6):
    1. Minimum unobstructed width shall be not less than 20 feet (or the required roadway surface width).
    2. Gates serving three or less single-family dwellings shall be a minimum of 12 feet in width.
    3. Gates shall be set back at minimum of 30 feet from the intersecting roadway or as approved.
    4. Electric gates shall be equipped with a means for operation by fire department personnel
    5. Electric automatic gates shall comply with ASTM F 2200 and UL 325.

15. **BOLLARDS:** Where secondary fire access roads are required, they shall be secured utilizing a removable bollard. The *fire code official* is authorized to require the installation and maintenance of gates or other *approved* barricades across fire apparatus access roads, trails or other accessways, not including public streets, alleys or highways. The MaxiForce Removable Bollard MRRW-RS1-R, MRRW-RS2-R, MRSW-SS1-R, MRSW-SS2-R and MRSW-SS3-R are approved for use. maxiforcebollards.com (OFC 503.5)

16. **ACCESS DURING CONSTRUCTION:** Approved fire apparatus access roadways shall be installed and operational prior to any combustible construction or storage of combustible materials on the site. Temporary address signage shall also be provided during construction. (OFC 3309 and 3310.1)

17. **TRAFFIC CALMING DEVICES:** Shall be prohibited on fire access routes unless approved by the Fire Marshal. (OFC 503.4.1). Traffic calming measures linked here:

FIREFIGHTING WATER SUPPLIES:

18. **FIREFIGHTING WATER SUPPLY FOR INDIVIDUAL ONE- AND TWO-FAMILY DWELLINGS:** The minimum available fire flow for one and two-family dwellings served by a municipal water supply shall be 1,000 gallons per minute. If the structure(s) is (are) 3,600 square feet or larger, the required fire flow shall be determined according to OFC Appendix B. (OFC B105.2)

19. **FIRE FLOW WATER AVAILABILITY:** Applicants shall provide documentation of a fire hydrant flow test or flow test modeling of water availability from the local water purveyor if the project includes a new structure or increase in the floor area of an existing structure. Tests shall be conducted from a fire hydrant within 400 feet for commercial projects, or 600 feet for residential development. Flow tests will be accepted if they were performed within 5 years as long as no adverse modifications have been made to the supply system. Water availability information may not be required to be submitted for every project. (OFC Appendix B)

    Fire flow is acceptable.

20. **WATER SUPPLY DURING CONSTRUCTION IN MUNICIPAL AREAS:** In areas with fixed and reliable water supply, approved firefighting water supplies shall be installed and operational prior to any combustible construction or storage of combustible materials on the site. (OFC 3312.1)

FIRE HYDRANTS:

21. **FIRE HYDRANTS – ONE- AND TWO-FAMILY DWELLINGS & ACCESSORY STRUCTURES:** Where the most remote portion of a structure is more than 600 feet from a hydrant on a fire apparatus access road, as measured in an approved route around the exterior of the structure(s), on-site fire hydrants and mains shall be provided. (OFC 507.5.1)

22. **FIRE HYDRANT NUMBER AND DISTRIBUTION:** The minimum number and distribution of fire hydrants available to a building shall not be less than that listed in Table C 105.1. (OFC Appendix C)

    The utility plan Sheet 4.0, a large majority of the subdivision is missing fire hydrants. Show locations of proposed fire hydrants.

23. **FIRE HYDRANT(S) PLACEMENT:** (OFC C104)
    - Existing hydrants in the area may be used to meet the required number of hydrants as approved. Hydrants that are up to 600 feet away from the nearest point of a subject building that is protected with fire sprinklers may contribute to the required number of hydrants. (OFC 507.5.1)
    - Hydrants that are separated from the subject building by railroad tracks shall not contribute to the required number of hydrants unless approved by the Fire Marshal.
    - Hydrants that are separated from the subject building by divided highways or freeways shall not contribute to the required number of hydrants. Heavily traveled collector streets may be considered when approved by the Fire Marshal.

- Hydrants that are accessible only by a bridge shall be acceptable to contribute to the required number of hydrants only if approved by the Fire Marshal.

24. **FIRE HYDRANT DISTANCE FROM AN ACCESS ROAD:** Fire hydrants shall be located not more than 15 feet from an approved fire apparatus access roadway unless approved by the Fire Marshal. (OFC C102.1)

25. **CLEAR SPACE AROUND FIRE HYDRANTS:** A 3-foot clear space shall be provided around the circumference of fire hydrants. (OFC 507.5.5)

BUILDING ACCESS AND FIRE SERVICE FEATURES

26. **PREMISES IDENTIFICATION:** New and existing buildings shall have approved address numbers; building numbers or approved building identification placed in a position that is plainly legible and visible from the street or road fronting the property, including monument signs. These numbers shall contrast with their background. Numbers shall be a minimum of 4 inches high with a minimum stroke width of 1/2 inch. (OFC 505.1)

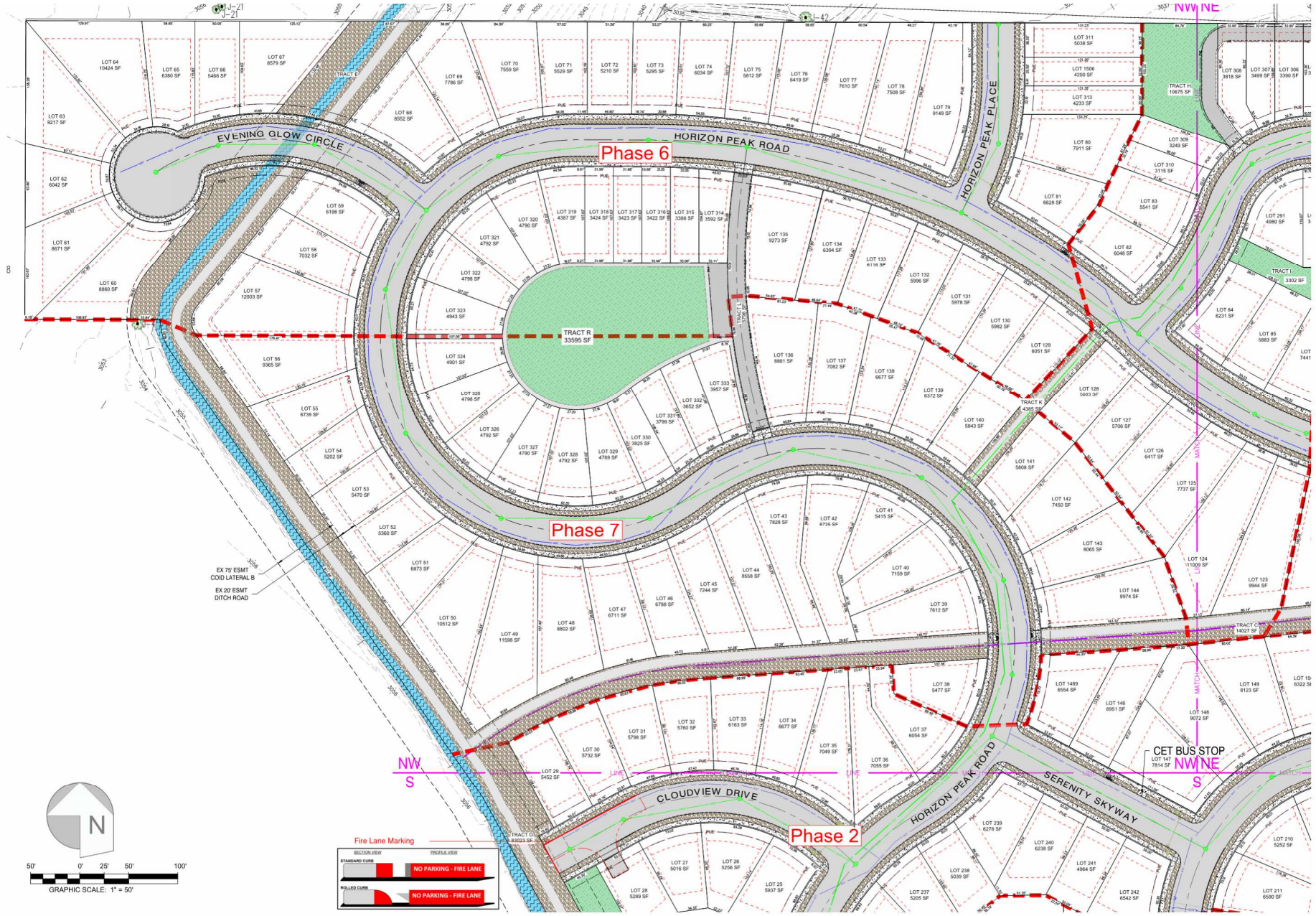
If you have questions or need further clarification or would like to discuss any alternate methods and/or materials, please feel free to contact me at 541-504-5010**.**

Sincerely,

Tom Mooney

Tom Mooney
Fire Marshal
Tom.mooney@rdmfire.org

Cc: File



MonteVista HOMES

DESIGNED BY: GWM/JH
DRAWN BY: GWM
CHECKED BY: JH
DATE: 9/12/2025

HORIZON POINTE

TENTATIVE UTILITY PLAN NW

No.	REVISIONS:	DATE:

SHEET: P4.1

Hi Megan,

I have a few notes after looking through these plans

1. I noticed that many segments of this development seem to have no street trees planned. Is there some reason for that?
2. They also seem to propose only 2 species of trees to be used throughout the project. I'd love to see more diversity for urban forest health.
3. In the larger "Tracts" ideally the developers utilize the largest trees possible when we have a lot of soil capacity like that. That helps us get more canopy coverage for the residents of that neighborhood. Often, these sites are dramatically under-planted as far as trees go. Minimizing the end product for the residents.
4. Please reference our Fee-in-Lieu of $500 for all 10" DBH trees that are not replaced.

If you need any suggestions for large canopy, drought tolerant trees just let me know.

Id be more than happy to chat about any of these comments with you in further detail. We are working toward getting more involved in planning review eventually, but as of late we have been pretty buried in CIP projects. I apologize for not responding on time.

Thanks!

Avery McChristian | City of Redmond
City Arborist
Certified Arborist
Tree Risk Assessment Qualified

phone **541-306-0829**
email **avery.mcchristian@redmondoregon.gov**

243 E. Antler, Suite 100
Redmond, Or 97756

Please consider the environment before printing this email.
DISCLOSURE NOTICE:
Messages to and from this email address may be subject to Oregon Public Records Law.

From: Megan Peninger <megan.peninger@redmondoregon.gov>
Sent: Friday, October 10, 2025 9:28 AM
To: David Pilling <David.Pilling@redmondoregon.gov>; Cassie Sigloh

From: DanDowning
To: Megan Peninger
Cc: Baxter Davies
Subject: RE: REVIEW: COID | Horizon Pointe COID"s comments
Date: Friday, October 10, 2025 2:04:40 PM
Attachments: image001.png
image002.png
image003.png
image004.png

[EXTERNAL]: This email originated from outside of the city. Do not click links or open attachments unless you recognize the sender and know the content is safe.

Please be advised that Central Oregon Irrigation District (COID) has reviewed the application received on September 19th, 2025, for the above referenced project located at 2571 & 2577 & 2897 SW HELMHOLTZ WAY, Redmond, OR 97756/tax lot(s): 1513190001101 & 1513190001100 1513190001102. The applicant is requesting a Redmond Code, Chapter 8 Developmental Regulations, Article I –Zoning Standards; Article II – Land Use Procedures; Article III – Land Division Standards.

There are 4.6 acres of mapped water rights appurtenant to tax lot 1513190001102, 1.2 of which are owned by COID as a pond right. There are 34.9 acres of mapped irrigation water rights appurtenant to tax lot 1513190001101. There are 15.0 acres of mapped irrigation water rights appurtenant to tax lot 1513190001100. The B lateral of the Pilot Butte Canal, traverses through western portion of tax lot(s) 1513190001101. It has a right of way of 50 feet, 25 feet either side of the centerline of the canal, along with an adjacent 20 ditch rider road right of way that runs to the east of the canal. In addition, the B-5 sub lateral runs through a portion of the listed properties. It has a right of way of 20 feet for the canal along with an adjacent 20-foot ditch rider road right of way on the south side of the canal. There are two delivery ditches on the property that both have a 20 foot right of way: B-5-1 and the B-9.

Listed below are COIDs initial comments to the provided application and site plan. All development affecting irrigation facilities shall be in accordance with COID's Development Handbook and/or as otherwise approved by the District.

Pursuant to ORS 92.090(6) Central Oregon Irrigation District (COID) certifies that the Tentative Plan lies within the boundary of COID and is subject to the fees and policies of COID.

Pursuant to ORS 92.103 (2) Central Oregon Irrigation District (COID) is providing comments (statements) containing information or recommended conditions for approval of the tentative plan for the proposed plat.

- Tax Map 1513190001102 has 3.4 acres of COID irrigation water mapped to a specific place of use. In addition, there are 1.2 acres of pond rights that are owned by COID on the property. Construction of a structure, driveway, or other impermeable surface on top of a mapped water right is not permitted.
  - COID will require the removal of all water rights on this property to follow the City of Redmond Annexation agreement guidelines. Contact COID's water rights department to begin the process.
- Tax Map 1513190001100 has 15.0 acres of COID irrigation water mapped to a specific place of use. Construction of a structure, driveway, or other impermeable surface on top of a mapped water right is not permitted.
  - COID may require the removal of all water rights on this property to follow the City of Redmond Annexation agreement guidelines. Contact COID's water rights department to discuss if this is the case.
- Tax Map 1513190001101 has 34.9 acres of COID irrigation water mapped to a specific place of use. Construction of a structure, driveway, or other impermeable surface on top of a mapped water right is not permitted.
  - COID will require the removal of all water rights on this property to follow the City of Redmond Annexation agreement guidelines. Contact COID's water rights department to begin the process.
- The applicant must provide all application materials to COID including all relevant linework. COID must review and approve all linework prior to approval of the application.
  - All water rights that may be impacted by development, ROW dedication, or other action as a result of the application or development must receive an approval letter from COID's water rights team. COID may require the removal of impacted water rights in any development or application.
- Irrigation infrastructure and rights-of-way are required to be identified on all maps and plans.
- COID holds an easement adjacent and within the subject property and has the right to install, pipe, maintain and operate its irrigation system above and below ground. COID has the right to operate and maintain all other related facilities within the canal irrigation easement. This includes the right of access to such facilities and the right to require the removal of any obstructions that may be placed within the canal easement at the lot owner's expense. At no time may permanent structures be placed within the canal easement or COID's property, nor may any other obstruction be placed within the easement which interferes with the use of the canal easement without prior written approval from COID.
- Crossings or encroachments within COID's easements are only permitted with approval from COID in the form of a recorded crossing/encroachment license.
  - All crossings must be installed during COID's offseason and accommodate stock water runs (Nov 1-March 31)
  - All crossings under COID's main B lateral must accommodate future piping depths and clearances.
  - All crossings under any future piping of the B-5 sub lateral must be at minimum of 18 inches beneath the bottom of the pipe to the top of the utility.
  - All crossings should cross at a perpendicular angle to COID's facilities.
  - COID has concerns over the proposed alignment for the future road near the northwest corner of the property along with the proposed crossing of utility lines
  - COID has concerns over the roadway proposal terminating near the edge of our canal easement (cloudview drive). COID may need to see the profile view of this to allow an encroachment into our easement with the approved licenses.
- Infrastructure improvements on the main B lateral may be needed to accommodate the realignment of the B-5 sub lateral.
- A piping easement will be required for this project if the B-5 sub lateral is to be realigned and piped
  - No paralleling easements are allowed within COID's easement
  - A minimum of 20 feet for the easement width will be required at all locations for the pipe easement.
  - COID developer handbook requirements for pipe installation need to be adhered to.
  - No woody roots vegetation is allowed within COID's easements.
  - Curb cuts may need to be installed to accommodate access into and out of our easements.
  - Any new piping must be installed during COID's offseason and accommodate stock water runs
  - The proposed pipe alignment needs to be centered within the piping easement
  - Traffic rated lids will be required to be installed over cleanout if they are under trails or roadways
  - COID does not like syphon pipes
  - COID has the right to deny the realignment of our canal.
- COID must approve any proposal to add a trail on top or within our easement.

    - If allowed, a crossing/ encroachment will be required along with the terms of a maintenance agreement.
- No swales are allowed within COID's easement
    - If placed adjacent near COID's easement, Geotech inspections may be required to ensure that no water from the swale enters into COID's facilities.
- The B-9 delivery ditch is not shown, it needs to be able to route through the subdivision to tie into the existing point of delivery for the neighboring tax lot to the north.
- Depending on when the adjacent project to the northeast (little Texas) is developed, the B-5-1 delivery ditch may be needed to be shown with an easement going to its current point of delivery.
- Any ground disturbance near COID's canal related to tree removal needs to be restored to existing or better conditions. COID will work with contractor about this in the future if needed.
- All property pins need to be installed outside of COID's easements
- The building envelopes need to be outside of COID's easements
- Any irrigation conveyance, District or private, which passes through the subject property shall not be encroached upon without written permission from this office.
- No structures of any kind, including fence, are permitted within COID property/easement/right of way without written permission from this office.
- All work within COID easements must be completed before the irrigation season begins on April 1st. This includes any work that may interfere with the delivery of water (excavation, piping, water control and measurement devices, backfill). Any claims that arise out of delayed water delivery to COID's patrons resulting from the development/project/site work will be applicant & developer's sole responsibility.
- Policies, standards and requirements set forth in the COID Developer Handbook must be complied with.
- Comply with Requirements of COID Developer Handbook including restriction on drilling / blasting and excavation within and adjacent to the existing canal embankment. No blasting is permitted within 100-feet of any open ditch or canal.
- Any beyond the scope of the project boundaries improvements that alter or change COID's facilities, need to be review and approved by COID.

Our comments are based on the information provided, which we understand to be preliminary nature at this time. Our comments are subject to change and additional requirements may be made as site planning progresses and additional information becomes available. Please provide updated documents to COID for review as they become available.

Central Oregon Irrigation District

Daniel S Downing| G.I.S Analyst
Central Oregon Irrigation District
Office: 541.548.6047

Direct Line
541.504.7579
Cell
541.598.4397

Attachment D

From: Natalie Cutsforth
To: Megan Peninger
Cc: jenniferoreilly@hotmail.com
Subject: Written Comments for Horizon Pointe public hearing Nov 12
Date: Sunday, November 9, 2025 9:17:33 AM

[EXTERNAL]: This email originated from outside of the city. Do not click links or open attachments unless you recognize the sender and know the content is safe.

Hello Megan,

I'm a property owner of 20.5 acres at 5753 SW Wickiup Ave Redmond with some concerns I would like addressed at the meeting. I'll be on a business trip and unable to be at the meeting Nov 12 . I'm copying another farmer neighbor Jennifer O'Reilly who will be impacted as we've discussed the Horizon Pointe project, and she will attend in person. I recognize development happens and yet there are several areas I believe our community should consider when taking a bite out of the land buffering the City of Redmond and the environmental corridor east of the Deschutes river.

1. **Noise reduction during construction**. There is significant noise when rock hammering is occurring which is a requirement for all development in this area. I would request the hours of operation be limited to weekdays and not into the evening.
2. **Night lights** with a development of this size have an impact on neighbors and wildlife. We have a significant owl breeding area in winter months and streetlights can disrupt this process. My request is that street lights be the type that are off certain hours of day and have bulbs that don't interfere with night vision for owls and other wildlife.
3. This is a **significant wildlife corridor** that is being narrowed by development and bounded by a hard stop at the Deschutes River to the west. We share land and have sited coyote, deer, fox, badger, porcupine, skunk, marmot, mountain lion who need the farmland buffer between the Deschutes River and dense development to survive and thrive. The development map provided shows no space for that corridor along the COID canal which is not safe for wildlife, nor any route through the housing development for wildlife to move and one tiny green space. With this in mind a solution would be to incorporate a walking path with grass and trees going north south to allow wildlife to navigate the many fenced yards during the night.
4. **Fire evacuation planned into the construction closures and development**. Two summers ago, all east/west evacuation options aside from north/south Helmholtz route were closed under construction at the same time for months: Obsidian, Wickiup/Reservoir and Coyote/Canal. Adding additional populations that need to be able to evacuate with wildfire needs to be considered AND coordinated.
5. Prevention of new residents from **trespass onto surrounding private lands**. It will be tempting for walkers and dog walkers to head west and trespass on private land, appropriate signs and awareness needs to be made that these are not public lands.
6. The **intersection of 126 and Helmholtz** has been neglected, adding more population will only make the intersection worse. At the minimum a northbound right hand turn lane from Helmholtz onto 126 headed toward Redmond needs to be added before any more population is added to this area.

Thank you for your consideration. As a side note. I'm a 5th generation Oregonian, farmer/rancher. While I have no problem with development I do feel we need to do so in a way that creates community rather than squeezes in a bunch more housing. What is the City of Redmond doing to create community connection and roots with all the new development?

Sincerely,

Natalie Cutsforth
720-560-9274
5753 SW Wickiup Ave
Redmond OR 97756

From: Mark Dodd
Subject: Re: Horizon Pointe Project
Date: Thursday, November 13, 2025 8:19:40 AM
Attachments: image001.png
image002.png
image003.png

[EXTERNAL]: This email originated from outside of the city. Do not click links or open attachments unless you recognize the sender and know the content is safe.

Hi Megan, Thanks for the update. I would add one thing: The cost and completion of either a traffic light or a roundabout at the intersection of 126 and Helmholtz Way should be completed before construction of the development.

Thanks,

Mark

From: Mark Dodd <markdodd70@gmail.com>
Sent: Friday, November 7, 2025 8:47 AM
To: Megan Peninger <megan.peninger@redmondoregon.gov>
Subject: Horizon Pointe Project

[EXTERNAL]: This email originated from outside of the city. Do not click links or open attachments unless you recognize the sender and know the content is safe.

Hi Megan, Thanks for the heads up on the project. The only concern I have is the traffic on Helmholtz Way, especially Helmholtz Way and 126 intersection. There needs to be either a traffic light or a roundabout. Horizon Pointe Development should be required to help pay for either a traffic light or a roundabout.

Thanks for your consideration,

Mark and Cathy Dodd

4757 SW Umatilla Ave

Redmond, Oregon 97756

From: Elizabeth Gallardo
To: Megan Peninger
Subject: Horizon Pointe
Date: Wednesday, November 12, 2025 12:49:30 PM

Hello,

I am a resident of Summit Crest (SW 49th St & Helmholtz) and we received the notification of the potential construction of Horizon Pointe in the mail.

I am a big supporter of the development of the City of Redmond, but I would like to request that the following traffic concern be taken into consideration with the planning of additional construction in the SW quadrant. The traffic/safety concern for the volume and speed of traffic at the intersection of Helmholtz and Hwy 126 is continually getting worse with the current population, and with an additional 300+ homesites in the area, the traffic problem is only going to compound. Can there please be consideration for adding a stop light or round-about at the intersection of SW Helmholtz and Hwy 126.

Are there any plans for zoning allowances for grocery or other services in the SW quadrant? With all the additional residential development in the past 10 years, we would hope that allowing a grocery store in the area would be in consideration. I understand that it is the decision of independent companies if they want to make that investment, however my question is whether or not the city would allow the zoning if there was interest.

Thanks,
Elizabeth Gallardo
503-341-4987

From: Erika Gurley
To: Megan Peninger
Subject: Horizon Pointe
Date: Tuesday, November 11, 2025 9:25:33 AM

[EXTERNAL]: This email originated from outside of the city. Do not click links or open attachments unless you recognize the sender and know the content is safe.

Good Morning,
I hope all is well. I live on the corner of Wickiup and Hemholtz. I am against creating a new housing development across the street. I moved out of Redmond for the peace it provides away from the city and people. Please DO NOT build a subdivision right across the street. It's already so busy with traffic coming from the rest of the Summit Crest subdivision and Redtail Ridge. I hate the traffic and noise that already exists here. I live off the walkway into the Summit Crest development. I fear their will be more transient bystandards, crime and theft if we bring more people to this part of Redmond. Please move these homes closer into town or by the airport. We don't need more people here. It will be congested with traffic getting onto Hemholtz which is already a busy highway. People go at least 65 to 70mph. I fear this will promote more traffic buildup and accidents. Please leave the free land alone for the wildlife and animals that are still here. We have already ripped away so much of their land already. Please I implore you NO MORE BUILDING.

Respectfully Submitted,
Erika R. Westlind
503-310-5554
2962 SW 50th Ct.
Redmond, OR 97756

From: Kristina Robertson
To: Megan Peninger
Subject: Opposition Letter – Horizon Pointe 333-Lot Development Proposal
Date: Friday, October 31, 2025 3:46:17 PM

[EXTERNAL]: This email originated from outside of the city. Do not click links or open attachments unless you recognize the sender and know the content is safe.

Kristina Robertson

2633 SW 50th St

Redmond, OR 97756

October 31, 2025

City of Redmond Community Development Department

Attn: Megan Peninger, Associate Planner

411 SW 9th Street

Redmond, OR 97756

Email: megan.peninger@redmondoregon.gov

Subject: Opposition to the Proposed Horizon Pointe 333-Lot Planned Unit Development (PUD)

Dear Ms. Peninger and Members of the Redmond Planning Commission,

I am writing as a resident of Northwest Redmond to respectfully but firmly oppose the proposed Horizon Pointe 333-lot residential subdivision along SW Helmholtz Way. While I understand the city's desire to accommodate growth, this particular development poses serious and immediate risks to public safety, neighborhood well-being, and the character of our community.

1. Severe Traffic and Safety Concerns

Helmholtz Way is already overburdened with heavy traffic, constant speeding, and excessive noise. Vehicles frequently rev their engines and race along this corridor, creating daily hazards for drivers, pedestrians, and cyclists alike. Adding hundreds of new homes would exponentially increase congestion and raise the likelihood of severe accidents and injuries. Many of us in the Summit Crest neighborhood already live in constant concern for our children's safety as cars speed near our backyards throughout the day and night.

2. Noise, Light, and Environmental Impact

The proposed development would bring substantial increases in vehicle noise, light pollution, and overall disruption to the peaceful environment that current homeowners sought when choosing this area. The glow from hundreds of new homes and streetlights would destroy the tranquil, rural feel of Northwest Helmholtz and Wikiup, where residents value quiet nights and natural beauty.

3. Loss of Natural Scenery and Community Character

This region's scenic views of the Cascade Mountains and surrounding open land are central to Redmond's identity and charm. The proposed subdivision would irreversibly alter this landscape, diminishing property values and robbing current residents of the natural vistas that define our community. Many of us purchased our homes outside the city center specifically for a ranch-style lifestyle—marked by calm, space, and connection to nature. This plan would undermine that entirely.

4. Impact on Existing Homeowners and Property Values

Residents in established neighborhoods like Summit Crest have made long-term commitments to the City of Redmond through property taxes and compliance with local regulations. To now approve a development that would reduce our property values, degrade safety, and alter our way of life would be deeply unfair and inconsistent with the city's duty to balance growth with the preservation of existing community standards.

In conclusion, I urge the Redmond Planning Commission to deny the Horizon Pointe development application or, at minimum, delay consideration until comprehensive traffic impact and environmental studies are completed. The current infrastructure simply cannot safely support an additional 333 homes without jeopardizing public safety, community integrity, and the natural character of Northwest Redmond.

Thank you for your time and consideration. I trust that the Commission will prioritize the safety, peace, and long-term welfare of Redmond's existing residents. Please reply that this email was received and keep me updated on all correspondence to this application process.

Sincerely,

Kristina Robertson

Redmond Resident

(602) 618-7995
kristina.robertson.2011@gmail.com

Mason Rodby

3155 SW 53rd CT, Redmond, OR. 97756

Why the Horizon Pointe Development Is Wrong for Redmond

The proposed Horizon Pointe subdivision at 2577 and 2571 SW Helmholtz Way threatens to undermine the very qualities that make Redmond a balanced and sustainable community. While the plan to add more than 300 new housing lots may appear to address growth, it does so at the expense of valuable farmland, public safety, and responsible city planning.

First and foremost, this area represents **prime agricultural land**—ground that has historically supported productive farming and contributes to Redmond's rural identity. Once this land is converted into dense residential development, it is gone forever. The city's comprehensive plan has long emphasized protecting high-value farmland on the urban fringe. Approving Horizon Pointe would contradict those values and accelerate the loss of open space that defines the community's character.

Safety is another major concern. **Helmholtz Way is already one of the most hazardous roads in Redmond**, with narrow shoulders, sharp curves, and limited visibility. The road was not designed to carry the volume of traffic a 333-lot subdivision would generate. Adding hundreds if not thousands of daily vehicle trips—school buses, commuters, and delivery trucks—will only amplify the risk of accidents along this corridor.

Equally troubling is the impact on the **Highway 126 and Helmholtz Way intersection**, which local drivers know as one of the most dangerous in the city. Increased congestion at this already overburdened intersection could result in more collisions, slower emergency response times, and higher costs for taxpayers to retrofit infrastructure that was never meant to support this scale of development.

Redmond's growth must be thoughtful, balanced, and safe. Approving Horizon Pointe in this location would sacrifice farmland, worsen traffic dangers, and strain public resources—all for a project that prioritizes expansion over sustainability. The City of Redmond should reject or significantly revise this proposal and instead focus new housing within existing urbanized areas where infrastructure already exists and farmland can be preserved for future generations.

Sincerely,

Mason Rodby,

Business Owner,

Born and Raised in Redmond.

From: Michael Romero
To: Megan Peninger
Subject: Horizon Pointe
Date: Monday, November 10, 2025 1:29:46 PM

[EXTERNAL]: This email originated from outside of the city. Do not click links or open attachments unless you recognize the sender and know the content is safe.

Summit Crest is the only subdivision without a substantial set back from Helmholtz. The others approved do. The Redmond Land Group 333 lot PUD residential subdivision will increase traffic flows.
Some drivers now feel a need to speed after the curves on Helmholtz. People turning onto Helmholtz from Wickiup and the new entrances being created will be more at risk unless speed is somehow decreased.
Knowing human drivers, Summit Crest needs to protect its residents by requesting a sound wall replacing our wood fences. Or...guardrail type structure. Bench style which could fit between existing fence and sidewalk. This protects those in or playing in their backyards from cars that may careen toward our wood fences to avoid oncoming speeders or traffic turning onto Helmholtz from the new entrances onto Helmholtz created by this PUD.
Since I moved here in 2017, 2 power poles were knocked down in a 2 week period and a Mustang wrapped itself around one of our trees and 2 trees are missing over time. Most were not insured.
Developers should pay for safety features. This creates Goodwill for the builder, the city and the residents. The City of Redmond and the developers with this approval WILL create more traffic. The profit margin hit is small versus one bad accident.

Michael Romero
2793 SW 50th STREET
Redmond
925-915-0300
michaelromero1955@gmail.com

From: Kristen Shadle
To: Megan Peninger
Subject: Comments on proposed Horizon Pointe development on Helmholtz
Date: Tuesday, November 11, 2025 10:08:25 PM

[EXTERNAL]: This email originated from outside of the city. Do not click links or open attachments unless you recognize the sender and know the content is safe.

Hello,

My husband and I received notice of the proposed Horizon Pointe housing development in late October and have a number of concerns regarding this proposal. We requested and received a copy of the plans and after review of the report we received and conversation around how a development of this size will impact our neighborhood directly, as well as our larger community, we felt it necessary to share these concerns with the Planning Commission. For reference, we live in the Summit Crest neighborhood across Helmholtz from where this project is proposed.

Our first concern is the significant increase in traffic this will create for our area. As is, Helmholtz is a busy road where people consistently speed. To pull out of our neighborhood and head towards the freeway, we have to make a left turn onto Helmholtz from Wickiup. With current traffic, this is already a risky turn to make due to the speed people drive on Helmholtz and the curves in the road that make traffic difficult to see until it is very close. This proposed project would significantly increase traffic, as reflected in the report, which will make Helmholtz more hazardous for drivers and pedestrians, particularly at the intersection of Helmholtz and Wickiup. In addition, this increase in traffic will significantly increase the noise level from traffic for the homes already in the area. Our home is very close to the Wickiup and Helmholtz intersection and traffic noise is already very noticeable, adding more traffic would decrease the peace of the neighborhood.

Our second concern is the impact a project of this size will have on our local school system. Per the plan, the proposed project would add 333 homes to our community. While I am unsure how to estimate how many school age children may move into these homes and be attending the local schools in the future, as a parent with two children at Sage Elementary school, I do not know how Sage would be able to accomodate a significant increase in student enrollment, as class sizes are already high, and I imagine will be further impacted by the other recent additions of apartment buildings and homes in the vicinity of the school. In addition, per discussion with other parents in the community, a number of children were being turned away when registering for their home schools this school year and being sent to other schools in town due to lack of space. It seems irresponsible to add such a large housing development to the area when there is already a lack of space in our schools.

Our final concerns are the level of noise and congestion the construction of a development this size will create in our neighborhood for an extended period of time and the loss of natural/rural/agricultural land. My husband is a superintendent for a local homebuilder and estimated that a development this size will take approximately 6 years. That is an extensive length of time for those of us who live nearby to have to cope with the noise and congestion construction creates. We fear that the addition of this proposed development will create significant disruption to our peaceful nearby neighborhoods. We also are saddened by the potential loss of the beautiful rural/agricultural setting that currently occupies the space. We love seeing this open natural space and are disappointed that we seem to be losing the land around our community bit by bit. As a community that values nature and agriculture, I feel that we should be protecting these spaces around our city with more care.

While we understand the need for an increase in housing in our rapidly growing community, moving forward with such a large project at this location seems unwise. We request that the Planning Commission consider these concerns prior to making a decision regarding this proposed community.

Sincerely,
Kristen and Michael Shadle

From: K S
To: Megan Peninger
Subject: Horizon Pointe - re: hearing scheduled for November 12, 2025 proposed developement
Date: Wednesday, October 29, 2025 11:50:06 AM

[EXTERNAL]: This email originated from outside of the city. Do not click links or open attachments unless you recognize the sender and know the content is safe.
Dear Megan, and others on the Redmond Community Development Committee:

In regards to the proposal for a 333 home unit development west of Helmholtz I have the following concern. The main concern is that the current road system along Helmholtz, Wickiup, and Obsidian are not currently constructed to handle the burgeoning addition of the traffic that would result as a result of the proposed construction. I am opposed to any development in the proposed area unless the following additions, improvements are FIRST implemented prior to the development.

I propose and insist (sorry for such strong language) that this be done first, otherwise, if the development is implemented first, then the roadways will never get improvements.
Again, I propose that along Helmholtz, from 126 then south towards Elkhorn be improved to include a turnout at Elkhorn, that there be improved shoulders on both sides of the road along Helmholtz, from 126, south to Elkhorn. A four way stop light needs to be put into place at 126 and helmholtz, and a four way stop light needs to be placed at Helmholtz and Wickiup. Both Wickiup and Obsidian east of Helmholtz need to be widened and have an actual shoulder strip on each side of the road, to allow for bike traffic. What considerations have been given to have additional roadways into this new subdivision other than an entrance off a helmholtz? Again, I am not necessarily opposed to the addition of homes, but I am opposed to the addition of 333 homes, without due consideration first and foremost to the influx of the new traffic this will create. So, if the city of Redmond will not first and foremost upgrade and put in the above road improvements, then there must not be a new housing development built in this area. I would only approve this new development if the above mentioned road improvements are first put into place.
Thank you.

Sincerely,
Kevin Stoltz
2714 SW 50th Street, Redmond, OR
541-280-5424

From: judy Stoltz
To: Megan Peninger
Subject: Project Name: Horizon Pointe. Planned Unit Development residential subdivision
Date: Wednesday, October 29, 2025 1:59:10 PM

[EXTERNAL]: This email originated from outside of the city. Do not click links or open attachments unless you recognize the sender and know the content is safe.

Thank you for allowing us to speak out as a resident of the City of Redmond.

Personally, I don't mind having another subdivision in Redmond. I do have a major concern that needs to be addressed before anymore housing development can be built on the property that is being considered. Looking at where the homes will be built, my major concern is the ROADS. As you know, subdivisions bring more cars on the roads. Before any excavation of the land occurs and the construction of houses begins, the roads MUST be improved. Helmholtz needs to be widened, from HWY 126 to Canal Ave. A stoplight needs to be put in place at HWY 126 and Helmholtz, and Wickiup and Helmholtz. Possibly put in a round-about at Helmholtz and Canal. Bike lanes should also be considered with the roads being widened as that area has many bikes on the road. The traffic in Southwest Redmond is already getting more and more busy due to the houses and apartments being constructed in the last 5 years.

As I have mentioned, I really don't mind more houses for people in Redmond. It makes me happy that we do not live in a dying community. My husband and I have lived in Redmond for 26 years and we love the community. I have lived in 2 different states besides OR and I do have to say that spending money on roads now will make for a success in the Planning of the new subdivision. If we don't spend the money now and think about the roads, FIRST, the housing division will be a disaster! It seems like roads are always a second thought and never get done for years later. Also, the students in that subdivision most likely would be going to Ridgeview High School and I guess Redmond, possibly.

I have heard this development has been under consideration for a few years. Please strongly consider what I have said about the roads around the area that you are considering. Thank you. I am unable to attend the meeting in person, because I am recovering from a bone marrow transplant and can not be in large crowds of people. Thanks again! Judy Stoltz

From: Erika Gurley
To: Megan Peninger
Subject: Horizon Pointe
Date: Tuesday, November 11, 2025 9:25:33 AM

[EXTERNAL]: This email originated from outside of the city. Do not click links or open attachments unless you recognize the sender and know the content is safe.

Good Morning,
I hope all is well. I live on the corner of Wickiup and Hemholtz. I am against creating a new housing development across the street. I moved out of Redmond for the peace it provides away from the city and people. Please DO NOT build a subdivision right across the street. It's already so busy with traffic coming from the rest of the Summit Crest subdivision and Redtail Ridge. I hate the traffic and noise that already exists here. I live off the walkway into the Summit Crest development. I fear their will be more transient bystandards, crime and theft if we bring more people to this part of Redmond. Please move these homes closer into town or by the airport. We don't need more people here. It will be congested with traffic getting onto Hemholtz which is already a busy highway. People go at least 65 to 70mph. I fear this will promote more traffic buildup and accidents. Please leave the free land alone for the wildlife and animals that are still here. We have already ripped away so much of their land already. Please I implore you NO MORE BUILDING.

Respectfully Submitted,
Erika R. Westlind
503-310-5554
2962 SW 50th Ct.
Redmond, OR 97756

Attachment E

Engineering Department
243 E. Antler Ave, Suite 100
Redmond, OR 97756-0100
541-504-2002
siteplan@redmondoregon.gov
www.redmondoregon.gov

TRANSPORTATION SYSTEM ANALYSIS APPLICATION

Applicability: Required when a proposed development involves either a Subdivision, Site and Design Review, Planned Unit Development, Master Plan, Comprehensive Plan Amendment, a change or expansion of use, or any other development that the City Engineer deems necessary. This application is not required for residential site plan review (4 units or less) or for partitions (3 lots or less).

This application must be approved prior to submitting a land use application for the project.

Applicant Information

Applicant: Scott Ferguson (Traffic Engineer) Email: gscott@traffic-team.us
Company: FERGUSON & ASSOCIATES, INC Phone: 541-788-6282
Address: PO BOX 1994 Redmond, OR 97756
Date Submitted: 5/10/2023

Owner Information

Owner: Erica Nelson (Applicant) Email: erican@mtvistahomes.com
Company: Monte Vista Homes Phone: 541-209-4866
Address: 2831 SW Helmholtz Way, 2577 SW Helmholtz Way, and 2571 SW Helmholtz Way

Project Information

Project Title: Nelson Farms Residential Tax Lot Number(s): 1513190001101 -- 1513190001102 -- 1513190001100
Project Address: 2831 SW Helmholtz Way, 2577 SW Helmholtz Way, and 2571 SW Helmholtz Way
Zone: Spit zoned: R3, R4, R5 Area (SF): 3,411,184
Existing Use: Farm and residential. 2 homes to remain on properties
Proposed Use(s) and code(s) per the Institute of Transportation Engineer's (ITE) Manual, 11th Edition:
SF Homes 210, Single Family Attached 215, and potentially 223 for cottages (40 units) pending city approval. Totals below reflect maximum. May be reduced as site plan is refined.
Total PM Peak Trips: 359 Average Daily Trips (ADT): 3739

Reserved for City of Redmond Approval

Reviewed by: Lindsey Cromsigt
Approved (date): 7/29/24
Approved PM Peak Trips: 295 (241 SFD (210), 21 Cottage (210), 34 SDA (215))
Approved ADT: 3046

CITY OF REDMOND
ENGINEERING APPROVAL
Lindsey Cromsigt 07/29/2024 4:09:04 PM

Revised 4/28/25 per revised phasing plan

CITY OF REDMOND
Engineering Department

243 East Antler Avenue, Suite 100
Redmond, OR 97756-0100
(541) 504-2002
Fax: (541) 548-0253
siteplan@redmondoregon.gov
www.redmondoregon.gov

July 29, 2024

Scott Ferguson
Ferguson and Associates, Inc.
gscott@traffic-team.us

Re: Approval Memo for Horizon Pointe Traffic Impact Analysis (TIA) (711-23-000046-PW)

The City and ODOT reviewed the subject TIA. Transportation mitigations for the subject project will be required as follows:

Preliminary issues identified on the plan that need to be addressed prior to land use submittal:

- All intersection spacing must meet City of Redmond Development Code Section 8.2820 - Access Management Standards. Confirm spacing is met on SW Helmholtz Way or request and justify exception to Development Code and/or Standards and Specification standards.
- Alley located at the NE corner of the development (Lots 260-264) does not meet spacing requirements to the intersection of future SW 45th St/Horizon Peak Rd.
- Culdesacs will not be permitted to have landscaping in the interior of the roadway. Culdesacs will be required to meet COR Standards and Specifications.

All Affected Phases:

- Suitable fire access must be maintained for all project phases. Temporary turn-arounds may be required at the termination of streets longer than 150' as required by Redmond Fire.
- Local streets shall be dedicated as a 60' public ROW (30-feet from centerline) and constructed as full width street section where possible. A partial street section will be required where a full width street section is not feasible.
- Directional curb ramps will be required at all intersections serving crossings in all directions.
- A separated multiuse path conforming to City of Redmond Standards and Specifications is required along the canal per the Transportation System Plan (identified as B67 in the TSP). Accessible ramps, continental crosswalks, illumination and advanced warning signs are required where the path intersects with any roadway(s). The path will be required to connect and align with the path proposed within the Little Texas subdivision located to the north.
- Alleys shall be privately owned and maintained and shall meet City of Redmond Standards and Specification requirements.
- All infrastructure connections shall be coordinated with the Little Texas subdivision located to the north.

Prior to plat of Phase 1:

- The applicant shall dedicate right-of-way along the frontage of the property on SW Helmholtz Way for a total of 100-feet of right-of-way (or 50 feet from centerline).
- The applicant shall dedicate right-of-way along the future SW 45th Street in coordination and alignment with the Little Texas subdivision located to the north to provide a total of 60 feet of right of way (or 30 feet from centerline), unless otherwise approved by the City Engineer.
- Install southbound right-turn lane and northbound left-turn lane at SW Helmholtz Way/SW Dusk Valley Rd. A stop bar and stop sign shall be installed for eastbound traffic.
- Helmholtz Way shall be improved to arterial roadway standards per City of Redmond Standards and Specifications and Development Code requirements.

CITY OF REDMOND
Engineering Department

243 East Antler Avenue, Suite 100
Redmond, OR 97756-0100
(541) 504-2002
Fax: (541) 548-0253
siteplan@redmondoregon.gov
www.redmondoregon.gov

- An enhanced pedestrian crossing shall be installed at SW Helmholtz Way at SW Helmholtz Way/SW Dusk Valley Rd, unless otherwise approved by the City Engineer. The specific location of the crossing shall be determined at time of site plan submittal. This crossing shall include continental crosswalk striping, a raised pedestrian refuge island, and a Rectangular Rapid Flashing Beacon to increase awareness of the crossing, and overhead illumination.
- A total proportionate share of $199,686 is required for impacts to OR 126/SW 27th Street, based on the cost of the parallel route improvements at OR 126/SW 35th Street; a northbound right turn lane at SW Helmholtz Way/SW Obsidian Avenue; a northbound right turn lane at SW Helmholtz Way/SW Quartz Avenue; and a northbound right turn lane at Helmholtz Way/Antler Ave. The proportionate share, or portions of the payment, will not be required if the City adopts a separate funding mechanism that addresses the impacts in their entirety prior to plat of Phase 1. The total payment is either due prior to final plat approval of Phase 1 or $ ~~22,187.33~~ $28,526.57 may be paid prior to final plat approval of each individual phase.
- Applicant shall coordinate with CET and City to site a location of bus stop and associated infrastructure, if required by CET. If required, construction shall occur prior to plat of Phase 1, unless otherwise approved by CET and the City Engineer.

Prior to plat of Phase 2:

- Install southbound right-turn lane and northbound left-turn lane at SW Helmholtz Way/SW Horizon Peak Road. A stop bar and stop sign shall be installed for eastbound traffic.
- Helmholtz Way shall be improved to arterial roadway standards per City of Redmond Standards and Specifications and Development Code requirements.

Prior to plat of Phase ~~9~~ 3:

- Helmholtz Way along the limits of Phase ~~9~~ 3 shall be improved to arterial roadway standards per City of Redmond Standards and Specifications and Development Code requirements.
- SW 45th Street along the limits of Phase 3 shall be improved to local roadway standards per City of Redmond Standards and Specifications and Development Code requirements in coordination with the Little Texas Subdivision, if not constructed already.

Please contact me with any questions.

Lindsey Cromsigt, PE
Assistant City Engineer
City of Redmond
Lindsey.Cromsigt@redmondoregon.gov | 541-306-1647