KEY GEOMETRIC DESIGN PRINCIPLES FOR ROUNDABOUT SAFETY

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Papers:

Safety Design Principles for Multi-lane Roundabouts – Improving Driver Comprehension and Reducing PDO Crashes
TRB International Roundabout Conference – May, 2017, Green Bay, WI

Synthesis of Roundabout Design and Operations with Flared Entries
TRB Annual Meeting – January, 2015, Washington, DC Published in TRB Transportation Research Record 2017

Impact of Geometric Factors on the Capacity of Single-Lane Roundabouts (M.T. Johnson, T. Lin)
TRB Annual Meeting – January, 2018, Washington, DC. Published in TRB Transportation Research Record 2018

Safety Impacts of Signing and Pavement Markings on Property-Damage-Only Crashes at Multi-lane Roundabouts
TRB Annual Meeting – January, 2019, Washington, DC. Published in TRB Transportation Research Record 2019
POLL QUESTION #1
1) ‘Foundational’ - Safety Design Principles
   - Importance
   - Successful Projects

2) Design Optimization
   Bringing it all together

3) Signing and Markings:

Don Quixote by Pablo Picasso
Safety and Operations:

A. Understand Strengths and weaknesses' of Operational Tools
   – Accuracy in Predictions (Gap, Empirical, Micro Sim)
   i. What is an acceptable LOS on Design Year Traffic
   ii. Avoid Over or Under Design (Expandable Capacity)
   iii. Select safe geometrics (flared entries, channelization and RT lanes)

B. Adhere to Principles - Not prescribed methods
   i. Offset left, radial, lane widths, ICD must = X for….
   ii. Use design flexibility to meet Safety Principles

C. Information Processing – Signing Markings / Way finding..
   i. Too much/little no good
   ii. Must be correct for the project/context (lanes directions ect.) not always the same
   iii. Human Factors Principles vs prescribed standards to achieve optimal results
Information Processing

“Negotiating intersections involves the absorption and processing of visual information presented to the driver, via Geometrics Signs and Pavement Markings”
WHY?

Foundational - Safety Design Principles
Safety Design Principles

160 PDO crashes in first year of operation
roundabout most accident-prone in

~130 PDO collisions
“This roundabout must be fixed”

Source: Roundabout List Serve
NOT MTJ DESIGNS

~110 PDO collisions/year opened
August 2014

~110 PDO collisions
Roundabout Design for Safety - INTRODUCTION

**Rural High Speed Application: Single Vehicle Fatalities**

- woman killed in roundabout wreck
- 2 dead after car hits boulders, catches fire in traffic circle
POLL QUESTION #2
HOW

Foundational - Safety Design Principles
Roundabout Design for Safety – Urban Multi-Lane

Average < 5 crashes/yr

Adherence to Foundational Safety Design Principles:

Average < 20 crashes/yr

Average < 7 crashes/yr,
Roundabout Design for Safety – Urban Multi-Lane

Average <15 crashes/yr (5 yrs of data)

Three-Lane Entry:
Ave annual PDO crashes ~ 15 crashes per year (over 5 year period). 40k ADT

I – 43 / Moorland Rd. Interchange
Roundabout Design for Safety – Rural Multi-Lane

Rural High Speed Application

Ave 3 PDO crashes per year,
3 possible injury over 5 years of data
25k ADT

Address Context/Driver Expectancy

MTJ ROUNDABOUT Engineering
1) Foundational - Safety Design Principles

Safety Principles Research Basis
Summary of Each Foundational Principle
Roundabout Design For Safety and Operations - Design Principles

**UK Research Basis**

- 1960-70s congestion relief - national imperative in the UK
- Significant design experimentation was conducted
- DESIGN AND ANALYSIS methodology anchored to the geometrics to address high flow, and constrained conditions

Accidents At 4-Arm Roundabouts, TRRL Report LR 1120, 1984. (Maycock, G and Hall, RD)

Database for Safety Principles:
- 84 roundabouts were studied
- 1,427 injury accidents studied
- Over 5 years of accident data at each roundabout
- Very Large Data Base/Statistically Valid

Modifications to large congested roundabouts
1. Foundational Safety Principles:

A. Minimize Conflict Pts / Operational Analysis (minimize # of arms (3 vs 6))

B. Speed Control

C. Maximize angle between approach alignments (90 deg)

D. Entry (Phi) / View Angle Left

E. Approach Alignment & Driver Expectancy (high speed applications)

Source:
- Accidents at Four Arm Roundabouts,
- Maycock and Hall, LR1120, TRL, 1984
- FHWA Roundabout Guide (NCHRP 672)
POLL QUESTION #3
POLL QUESTION #4
A. MINIMIZE CONFLICT PTS

Operational Analysis
Match Capacity to Demand / Avoid under or over design
Operational Analysis

Safety and Operations:

A. Understand Strengths and weaknesses' of Operational Tools
   – Accuracy in Predictions (Gap, Empirical, Micro Sim)
     i. What is an acceptable LOS on Design Year Traffic
     ii. Avoid Over or Under Design (Expandable Capacity)
     iii. Select safe geometrics (flared entries, channelization and RT lanes)
Effective Geometry for Operations—Ineffective Lane Utilization

Foundational Design Principles –

A) Minimize Conflict Points
Ineffective Lane Utilization

Geometric Variation

- **Small Urban Compact**
  - 80’ ICD
  - Narrow entry width $E = 12’$
  - Small entry radii $R = 25’$
  - Perpendicular entries $\Phi \sim 60$ deg.

- **Larger Curvilinear Single-Lane**
  - 145’ ICD
  - Wider entry width $E = 14’$
  - Larger entry radii $R = 60’$
  - Curvilinear entry $\Phi \sim 20$ deg.
Geometric Variation

- 125’ ICD
- Flared Two-Lane Entry
- Single-Lane Entry
- Aux RT Lanes (two types)

- 225’ ICD
- Flared Off-Ramp Entry
- Two and Three-Lane
- Aux RT Lanes (two types)
B-2) KIMBERS GEOMETRIC MODEL OVERVIEW
Kimber’s Equations

Basis of Geometric Model

Driver behavior/capacity via the geometrics directly
Basis of Geometric Model

Geometric capacity model developed by Kimber and Hollis ‘80 (LR 942)

- Kimber’s analytical framework based on statistical-regression analysis methodology
- Model derives Capacity from 6 geometric Parameters
- This diverged from ex. gap based traffic theoretical models.
Basis of Geometric Model

3 Major Capacity Variables

- Entry Width (E)
- Approach Width (V)
- Effective Flare Length (L')

3 Minor Capacity Variables

- Entry Radius (R)
- Entry Angle (Φ)
- Diameter (D)

6 Geometric Inputs

<table>
<thead>
<tr>
<th>Entry Width (E)</th>
<th>Approach Width (V)</th>
<th>Effective Flare Length (L')</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200</td>
<td>1000</td>
<td>800</td>
</tr>
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</table>

Basis of Geometric Model

- D = 180ft
- D = 300ft

Circulating Flows

Negligible

X2 cap

Circulating Flows

Negligible

X2 cap

Negligible

X2 cap

Negligible

X2 cap

Negligible

X2 cap

Negligible

X2 cap

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Negligible

X2 cap
Basis of Geometric Model

3 Major Capacity Variables

- **E** = Effective entry width
- **L'** = Flare length
- **V** = Approach roadway width

![Diagram showing geometric model variables](image)
Basis of Geometric Model

Minor Capacity Variables

"Phi" is half the measured angle.
Basis of Geometric Model

- Exit Roadway Width (Ex) Number of Lanes (n)
- Circulatory Roadway Width (c) Number of Lanes (n)
- Entry Width (E) Number of Lanes (n)
- Approach Width (V) Number of Lanes (n)
- Flare Length (L)
- Rad
- Phi

E = 22'
V = 12'
L = 150'

Foundational Design Principles –

A) Minimize Conflict Points

- Operational Analysis is Foundational
- Minimize Conflicts / # of Lanes
- Acceptable LOS?

Laneage = 98 Conflict Points
Foundational Safety Design Principles

A) Minimize Conflict Points

- Operational Analysis: Rodel
- 48% less conflicts

- Phased Implementations
  - Match Capacity to Demand
  - Allow for capacity expansion

Revised Laneage = 51 Conflict Points = 48% Reduction

ITE 2020 Annual Meeting and Exhibition - #ITE2020
POLL QUESTION #5
POLL QUESTION #6
POLL QUESTION #7
POLL QUESTION #8
B. SPEED CONTROL
(FAST PATH CRITERIA)
Foundational Safety Design Principles

B) Speed Control

- Speed control

- Red circle with text: R1 - 1500'

- Diagram showing a roundabout with various design elements.
C. MAXIMIZE ANGLE BETWEEN APPROACH ALIGNMENTS (90 DEG)
Foundational Safety Design Principles –

C) Angle Between Legs / Alignments

FHWA DESIGN PRINCIPLES
6.3.3 - Angles Between Approach Alignment

Speed Path 32 mph
Use design flexibility to meet Safety Principles

Source: MTJ

Speed Path (Rad)
300’ (32 mph)
Foundational Safety Design Principles –

C) Angle Between Leg Alignments

RT Speed Path (Rad)
100’ (20mph) 35% Reduction
D) ENTRY ANGLE (PHI) & VIEW ANGLE LEFT
D) Entry Angle (Phi) & View Angle Left

**Entry (Phi) Angle**

Source: WIDOT Guide

**View Angle Left**

Source: MTJ

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**FHWA Design Principles**

- **6.5.4 - Entry Geometry & Approach Alignment**
  - **Phi Angles Recommendation**
    - Preferred Minimum: \( \Phi = 40^\circ \div 2 = 20^\circ \)
    - Absolute Minimum: 16°

- **View Angles to Left**
  - Preferred Maximum: 12°
Example #1

- Entry Angle Phi
- Drivers View Angle Left
Roundabout Design – Entry and View Angles

- Severe Neck turning
- Merging Condition
- High Speeds
- Confuses Priority Message
- Circulating Vehicles Out of View
Roundabout Design – Entry and View Angles

- Confuses Priority Message
- Merging Condition
- Promotes Higher Speeds
- Circulating Vehicles Out of View
Example #2

- Alignment Angle
- Entry Angle Phi
- Drivers View Angle Left
- Speed Control
Initial Concept

- Alignment Angle
- Speed Control
- Ped/Bike Safety

Source MTJ
Initial Concept

- Entry Angle (Phi)
- View Angle Left
Roundabout Design Optimization

**Revised Concept**

Alignment / Angle between Legs

Reduced Skewed Angle
Entry Angle (Phi) & View Angle Improved =
Correct Priority Message
Roundabout Design Optimization

Slower Vehicular speeds = Improved Safety for all users
E) APPROACH ALIGNMENT & DRIVER EXPECTANCY

Context:
- Rural High Speed
- Transitional Speed Applications (Suburban/Ex Urban)
Foundational Safety Design Principles –

E) Approach Alignment & **Driver Expectancy**

**Rural / High Speed Applications**

Roundabout *out of Approach*

*Drivers Line of Sight*
Foundational Safety Design Principles –

E) Approach Alignment & **Driver Expectancy**

Rural / High Speed Applications

Approach Drivers Line of Sight = Driver Expectancy Principle Terminal Vista
Conspicuity on Approach for high/Transitional speed applications

Central Island Landscaping:
- Mounded
- Appropriate Plant Materials
2) Design Composition

Don Quixote by Pablo Picasso
Example #1

Ex Urban Transitional Speed Context
ICD and Placement

125’ ICD

150’ ICD
THIS IS THE CRITICAL APPROACH
ACHIEVING FAST PATH CRITERIA
WITH THE REVERSE CAMBER CURVE DICTATES THE DESIGN

400' Rad

R1=240

150' ICD

125' ICD

400' RAD

600' RAD

600' RAD

MTJ ROUNDABOUT engineering
Example #2

High Speed Example
High Speed Example

City of Dodgeville
High Speed Example
Adherence to Foundational Safety Principles:

Rural High Speed Application

Ave 3 PDO crashes per year,
3 possible injury over 5 years of data
25k ADT

Video Link of Operations:
https://drive.google.com/file/d/1A5hST2fKLDGWZdkxj5IFxlMLRI8Jgewl/view?usp=sharing
Example #3
Meeting All Geometric Principles Simultaneously
Design Principles for Safety and Operations

Optimization

IH94 Cottage Grove WI
Design Principles for Safety and Operations
Design Principles for Safety and Operations

- Ensure Optimal safety and ease of use and comfort *for all modes*
- Incorporate operational benefits into our traffic planning/design processes
- Ensure public acceptance
POLL QUESTION #9
POLL QUESTION #10
3) SIGNING AND MARKINGS

Key Principles:
- Simplify Decision-Making
- Clear - Concise Information
- Minimize detection, reading and processing time
- Intuitive & Easy to Understand
Examples

Oops, No I meant the First
You’ll have to go round again

(M32, M4)

Take the second exit

Look I said I was Sorry

(M32)
Information Overload
Information Processing

- Information Overload
Information Processing

➢ Information Overload
Information Processing

Advance Directional Signing
Roundabout Design - Information Processing
1. Lane Use Assignment
   - Fish Hook or
   - Standard

2. Circulatory Roadway Markings
   - Solid/Skip vs
   - Consistent Line

3. Yield/ Entry Markings
   - Edge Line Extended, and Sharks Teeth
   - vs Singular Heavy Demarcation
1. Lane Use Assignment
   - Fish Hook or
   - Standard
1. MUTCD Lane Use Assignment

Standard
Familiar Driver Convention

Fish Hook Style
New Convention
Not used at other intersections
Standard Pavement Marking Arrows

Standard Lane-Use Assignments
2. Circulating Roadway Markings

- Solid and Skip
- Consistent Line Type
- Lane Widths (equal or un-equal)
2. MUTCD Circulatory Roadway Markings

Solid / Skip = Problematic - Violates Driver Expectancy

Consistent Line Type = Driver Expectancy
2. MUTCD Circulatory Roadway Markings

Circulating Marking Type and Alignment

Existing Confusing Messaging

Clarity in Priority Messaging

Before

AFTER

Driver Messaging via Pavement Markings
Consistent Circulatory Markings

11’ Inside
17’ Outside
- Effective lane utilization at entry
- Improved Entry/View Angles at entry
- Correct Priority Message, Yielding Behavior
3. Entry Markings / Yield Line

- Edge Line Extended, and Sharks Teeth vs.
- Singular Heavy Demarcation
3. MUTCD Entry Markings - Yield Lines

- “edge line extended” line guidance on a highway -
- exacerbates poor view angle left, = flatter entries = merging = Priority Message confused
- Too much information compressed into short distance = Information Overload

Edge Line Extended, and Sharks Teeth
CLEAR MESSAGE AT ENTRY

**Existing Confusing Messaging**

Before

**Singular Bold Priority Line**

After

MUTCD Entry Markings - Yield Lines Driver Messaging via Pavement Markings
3. MUTCD Entry Markings - Yield Lines

- Simplified Messaging via line types, weights & arrangement.
- Improves view angle left,
- Entry priority clear

**Singular Bold Priority Line**
3. MUTCD Entry Markings - Yield Lines
Roundabout Design – Safety

80% Reduction of wrong movements from outside lane

Consistent circulating markings
Roundabout Design –

25-30% IMPROVEMENT YIELDING RATES w/R1-6

Source: John Hourdos
Minnesota Traffic Observatory, University of MN
POLL QUESTION #11
POLL QUESTION #12
SUMMARY

Don Quixote by Pablo Picasso

Oops, No I meant the First
You’ll have to go round again
(M32, M4)

Take the second exit
Look I said I was Sorry

(M32)
Summary

Design For Safety and Operations:

A. Match Capacity to Demand / Avoid under or over design.
   i. Appropriate LOS?
   ii. Understand strengths and weaknesses of operational tools

B. Adhere to Foundational Safety Design Principles –
   i. Not prescribed methods

C. Composition – “Bringing it All Together”
   i. Design for Context
   ii. Roadway and Roundabout Working Together

D. Optimize Information Processing - Signing-Markings /Way finding
   i. Must be correct for the project/context
   ii. Not always the same implement principles
Driver behavior is strongly influenced by signs and pavement markings.

- Simplify Decision-Making
- Provide Clear - Concise Information
- Intuitive & Easy to Understand
- Adhere to Driver Expectations
Thank You/Questions

Mark T. Johnson