Too Many Crashes at Your Roundabout? Design Techniques to Optimize Safety

Mark T. Johnson, PE
MTJ Roundabout Engineering

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Papers by: MTJ Academy:

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

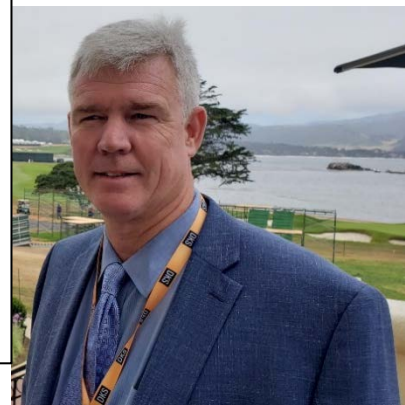
TRB Annual Meeting – January, 2015, Washington, DC ***Published in TRB Transportation Research Record 2017***

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***



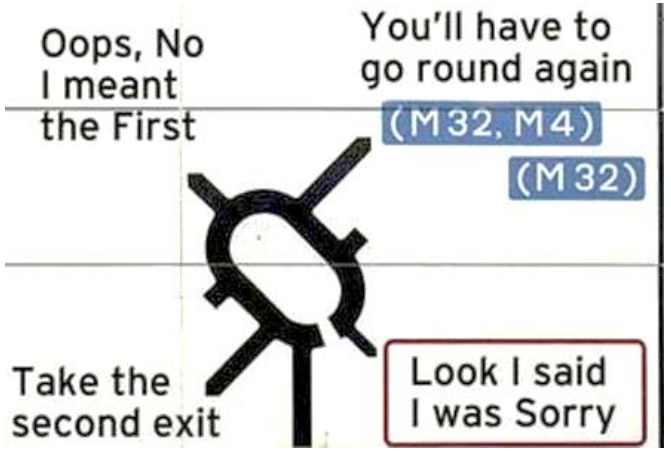
PRESENTATION OUTLINE

1) ‘Foundational’ - Safety Design Principles
   - Importance
   - Successful Projects

2) Design Optimization Bringing it all together

Don Quixote by Pablo Picasso

3)Signing and Markings:



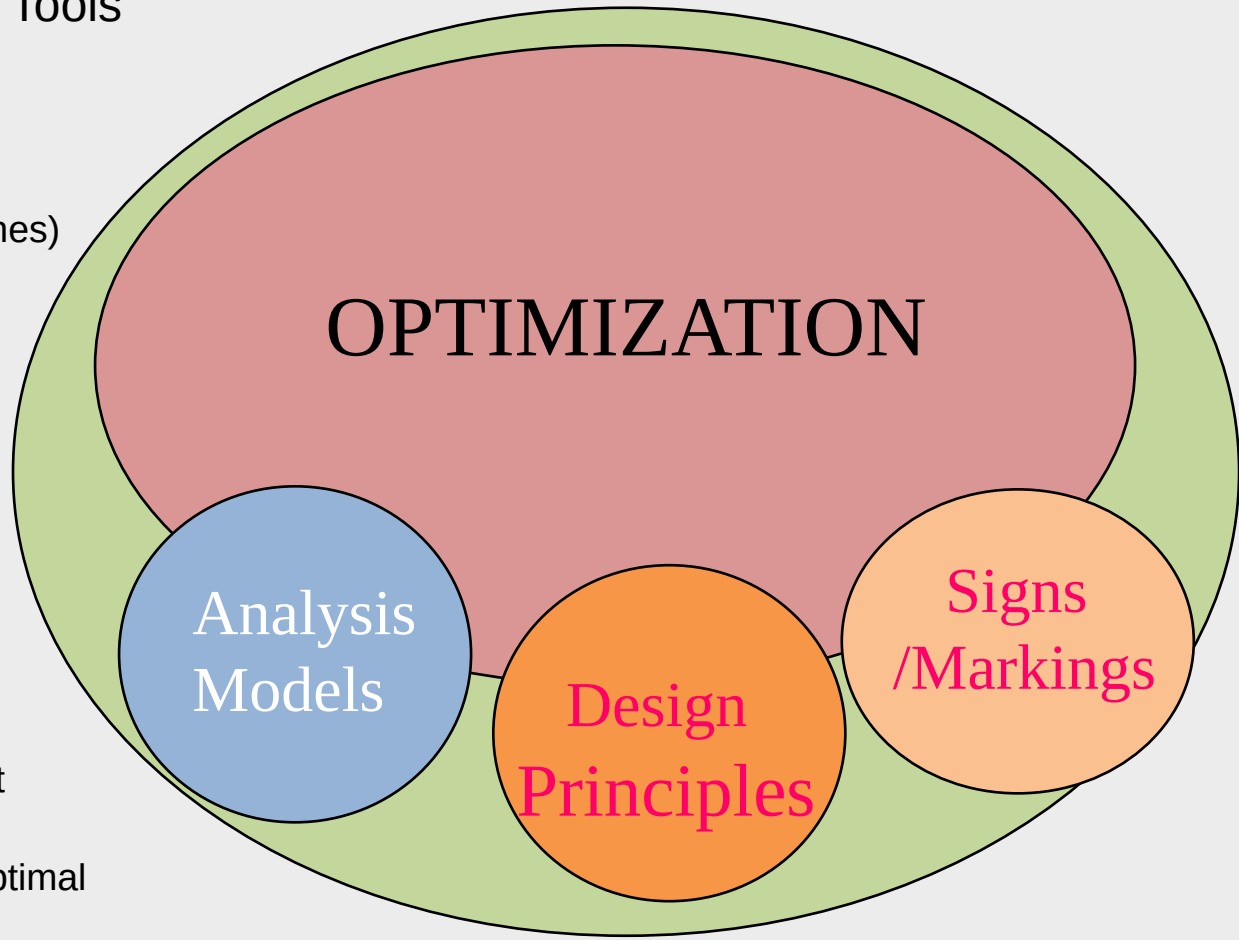
Roundabout Design for Safety - INTRODUCTION

Safety and Operations:

1. 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)

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

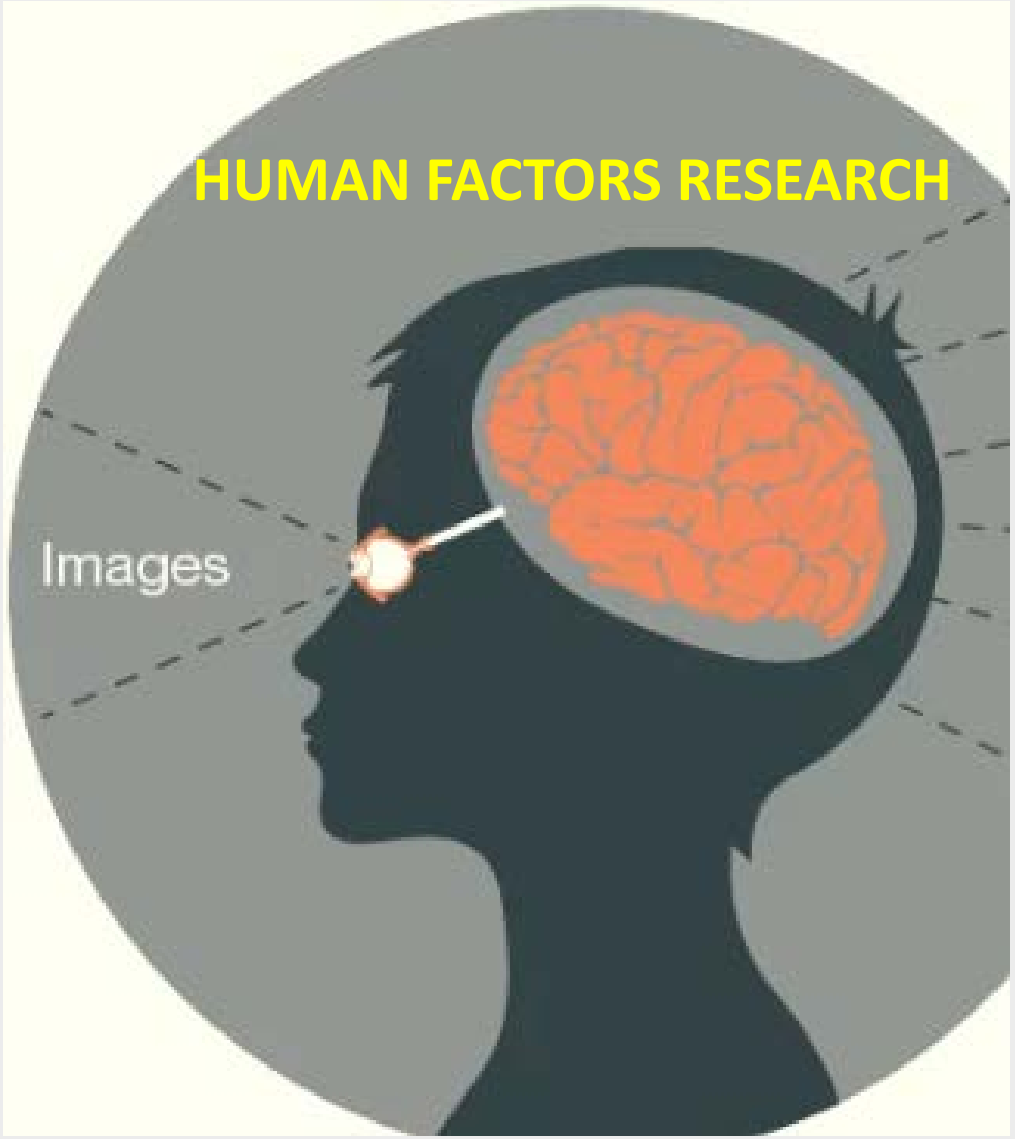
3. Information Processing – Signing Markings / Way finding..
   i. Too much/little no good
   ii. Must be correct for the project/context (lanes directions ect.) not always the same
   iii. Human Factors Principles vs prescribed standards to achieve optimal results



Roundabout Design for Safety - INTRODUCTION

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

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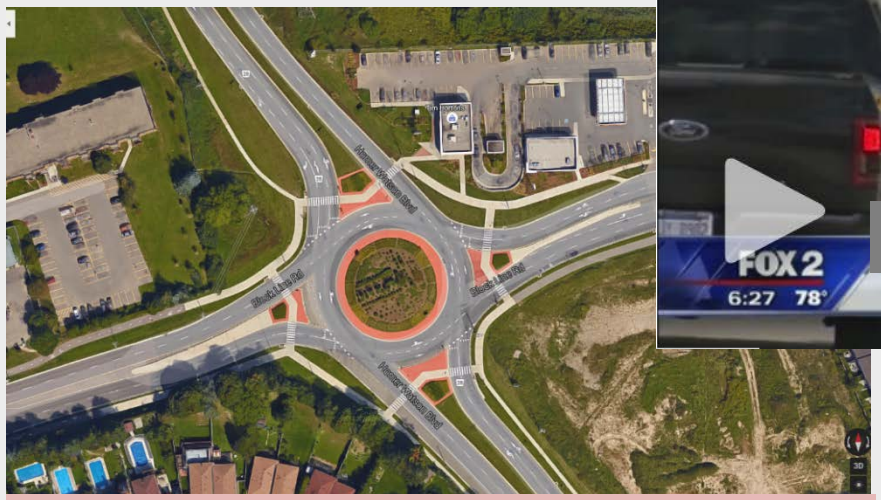
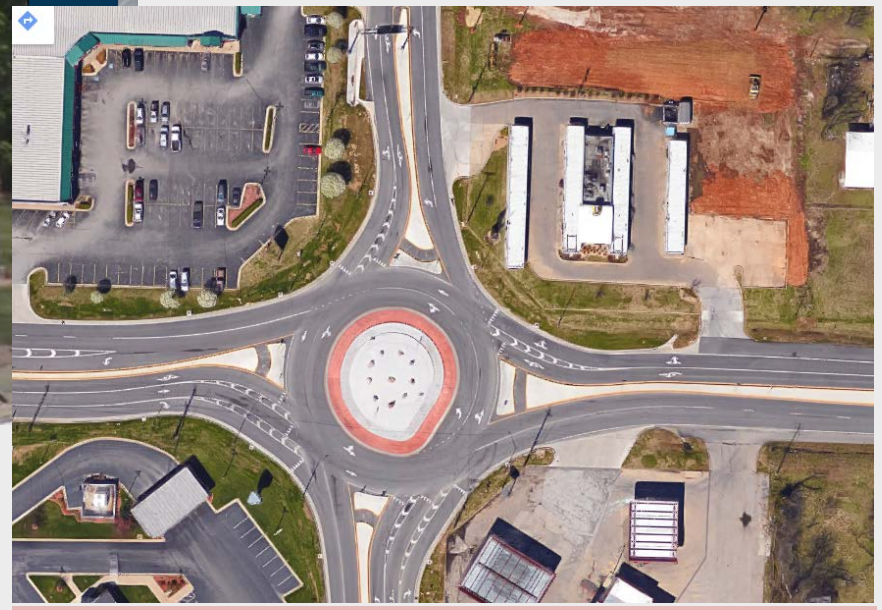
Safety Design Principles

160 PDO crashes in first year of operation



~130 PDO collisions
"This roundabout must be fixed"

Source: Roundabout List Serve
NOT MTJ DESIGNS



~110 PDO collisions/year opened
August 2014

Roundabout Design for Safety - INTRODUCTION

Rural High Speed Application: Single Vehicle Fatalities

[redacted] woman killed in roundabout wreck

By: Jeff Stahl | Thalia Bricker
Posted: Aug 01, 2019 07:27 AM PDT
Updated: Aug 01, 2019 08:13 AM PDT

2 dead after car hits boulders, catches fire in [redacted] traffic circle

by Brittany Reese | Wednesday, July 24th 2019

Two Little Rock residents are dead after a car hit the center boulders of a Little Rock traffic circle and caught on fire Saturday. (KATV Photo)

POLL QUESTION #1

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HOW

Foundational - Safety Design Principles

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Roundabout Design for Safety – Urban Multi-Lane

Average < 5 crashes/yr

Average < 7 crashes/yr,

Adherence to Foundational Safety Design Principles:

Average < 20 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

Roundabout Design for Safety – Rural Multi-Lane

1) Foundational - Safety Design Principles

Safety Principles Research Basis

Summary of Each Foundational Principle

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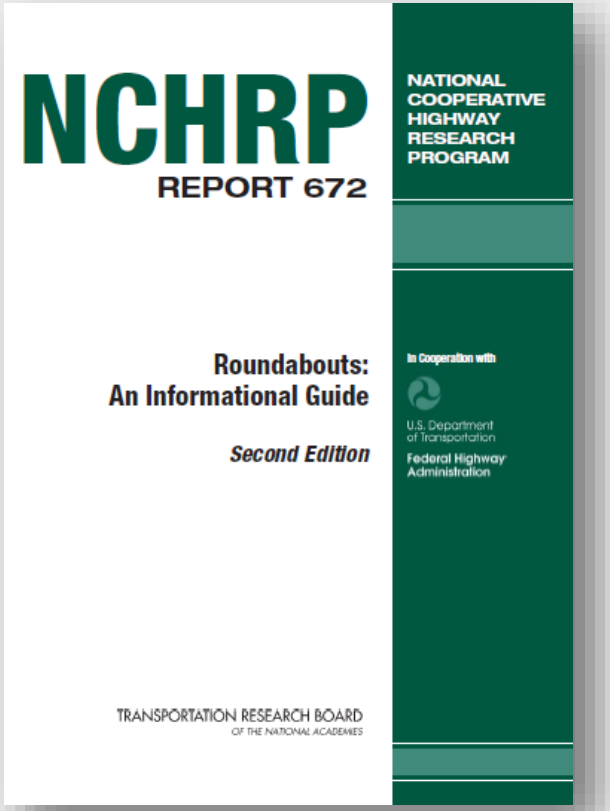
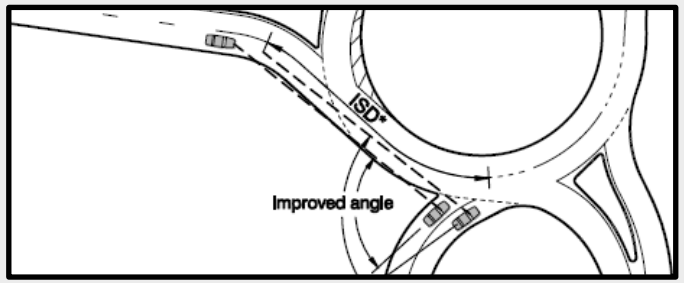
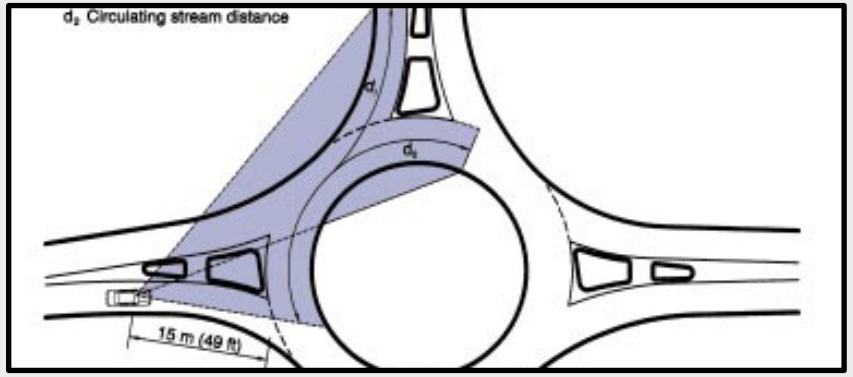
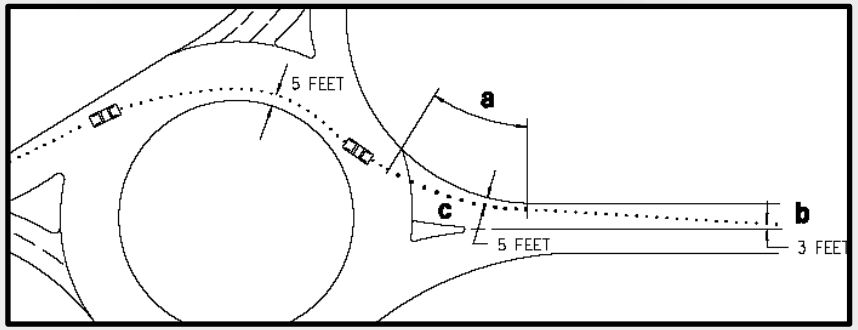
Roundabout Design – Principles – NCHRP 672

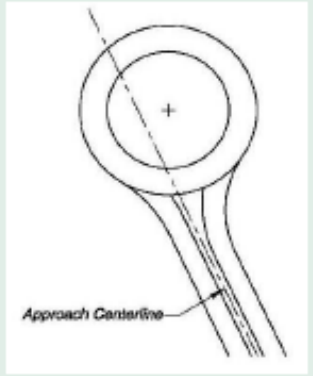








Alternative 1: Offset Alignment to the Left of Center



ADVANTAGES:

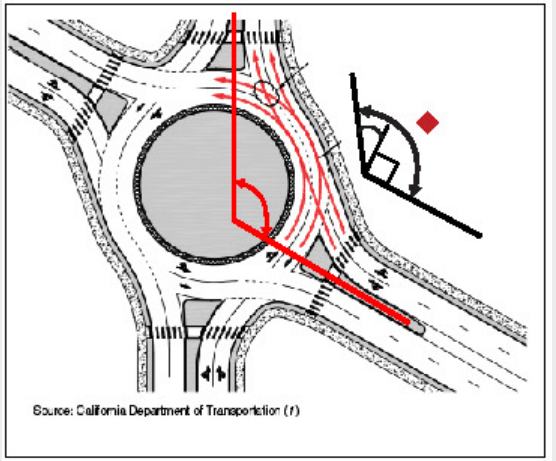
- Allows for increased deflection
- Beneficial for accommodating large trucks with small inscribed circle diameter—allows for larger entry radius while maintaining deflection and speed control
- May reduce impacts to right-side of roadway

TRADE-OFFS

- Increased exit radius or tangential exit reduces control of exit speeds and acceleration through crosswalk area
- May create greater impacts to the left side of the roadway

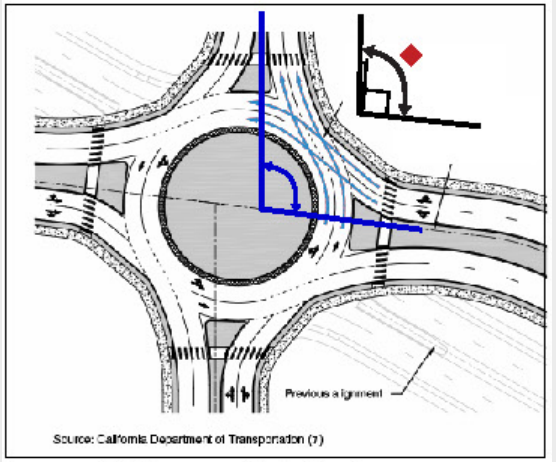
FHWA DESIGN PRINCIPLES

6.3.3 - Angles Between Approach Alignment ◆



Problematic Geometry - Paths Merging

Ex. 6-33 (Large separation between approach alignment)



Recommended Geometry - Paths Crossing

Ex. 6-35 (Closer to 90°)

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**

TRL Kimber / Hollis (LR 942)

- 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)*

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POLL QUESTION #2

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A. MINIMIZE CONFLICT PTS

Operational Analysis

Match Capacity to Demand / Avoid under or over design

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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)
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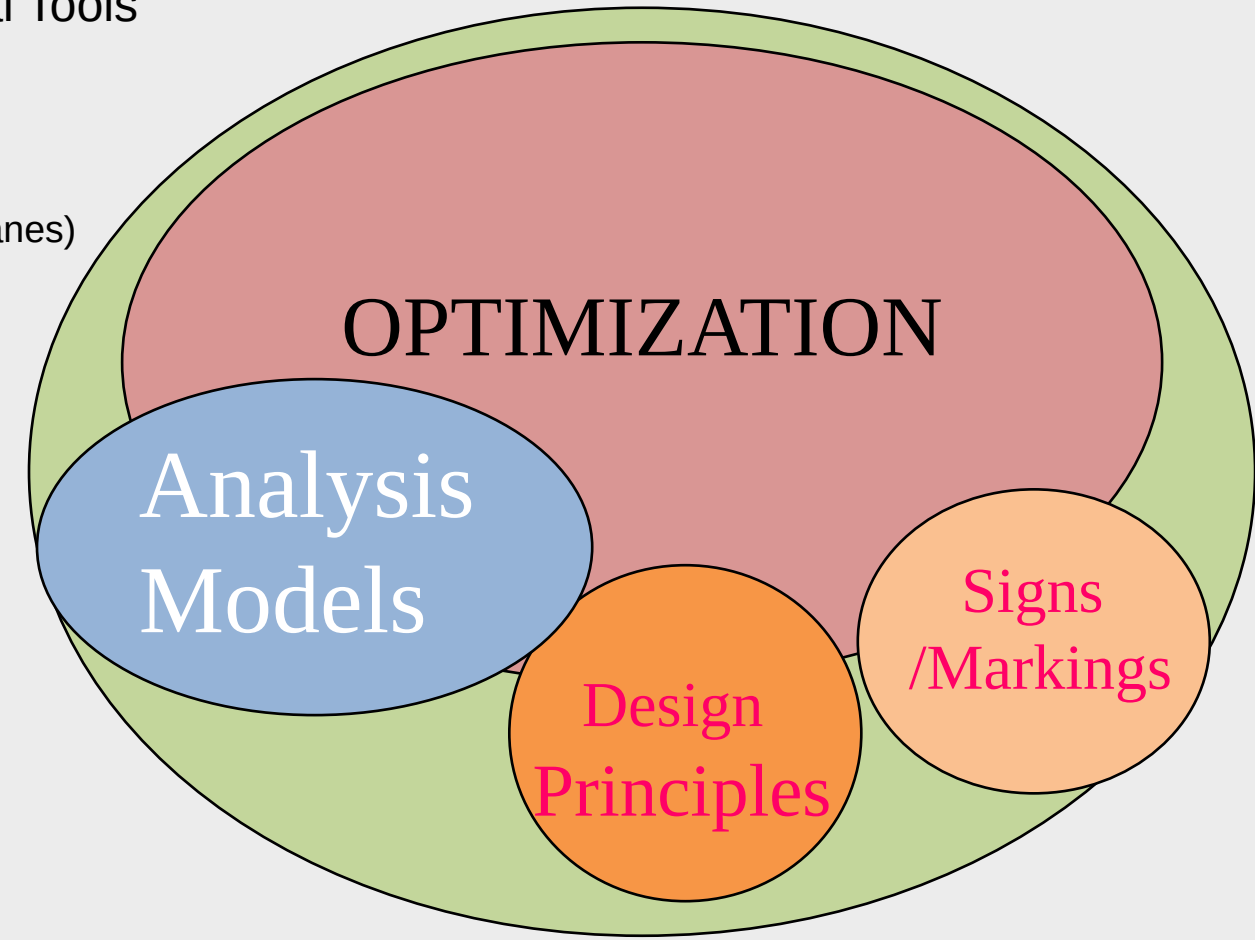
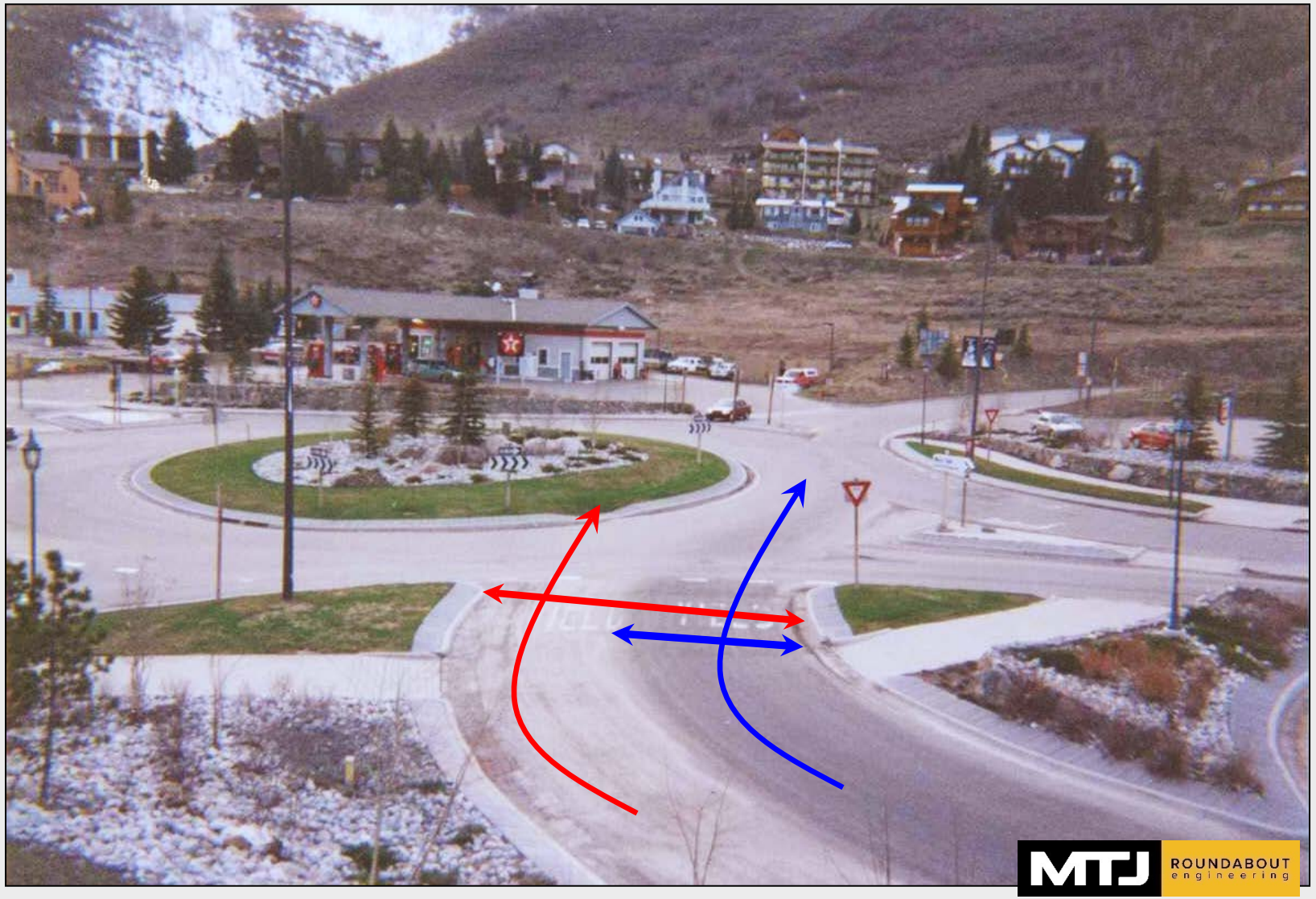


Foundational Design Principles –

A) Minimize Conflict Points

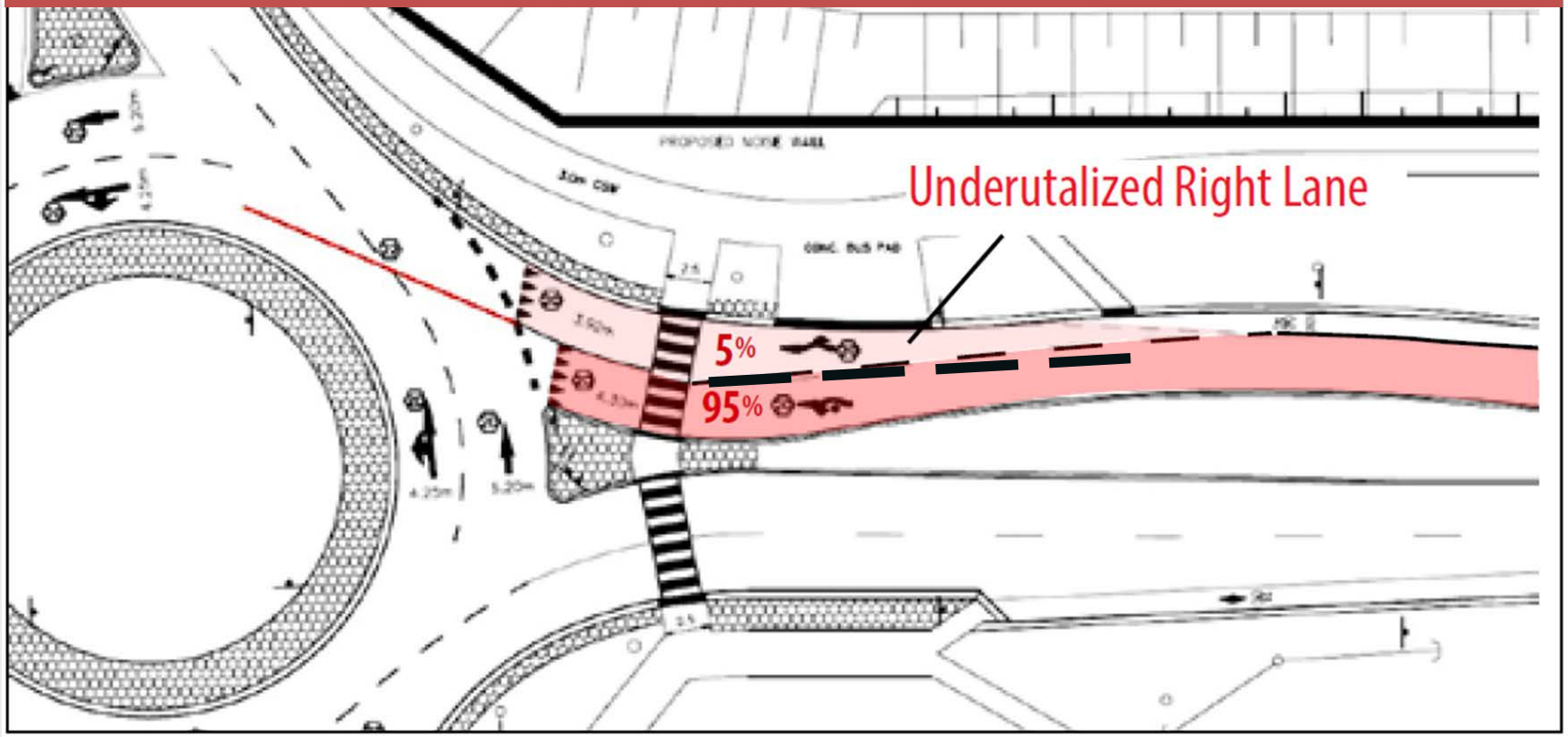
Effective Geometry for Operations- Ineffective Lane Utilization



Foundational Design Principles –

Ineffective Lane Utilization

Misaligned entry and pavement marking



Underutilized right lane in two-lane flared entry roundabout.
Ira Needles Blvd. & Erb St., Kitchener, ON. Source: Region of Waterloo, ON

https://www.mtjengineering.com/synthesis-roundabout-design-operations-multi-lane-flared-entries/

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Geometric Variation

Small Urban Compact

- 80’ ICD
- Narrow entry width E= 12’
- Small entry radii R = 25’
- Perpendicular entries Phi ~ 60 deg.

Larger Curvilinear Single-Lane

- 145’ ICD
- Wider entry width E = 14’
- Larger entry radii R = 60’
- Curvilinear entry Phi ~ 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)

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B-2) KIMBERS GEOMETRIC MODEL OVERVIEW

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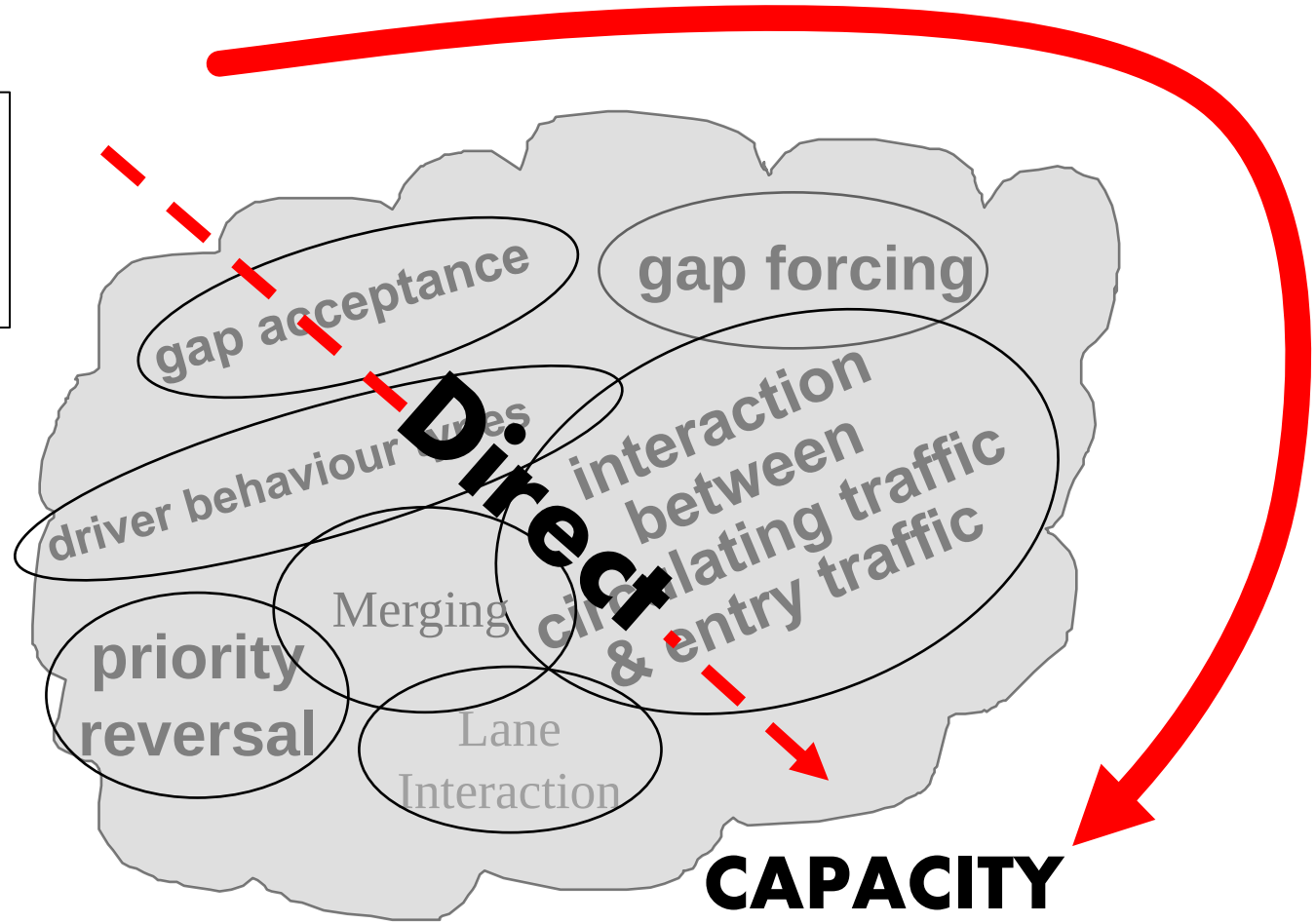
Basis of Geometric Model

Kimber's Equations

Driver behavior /capacity via the geometrics directly

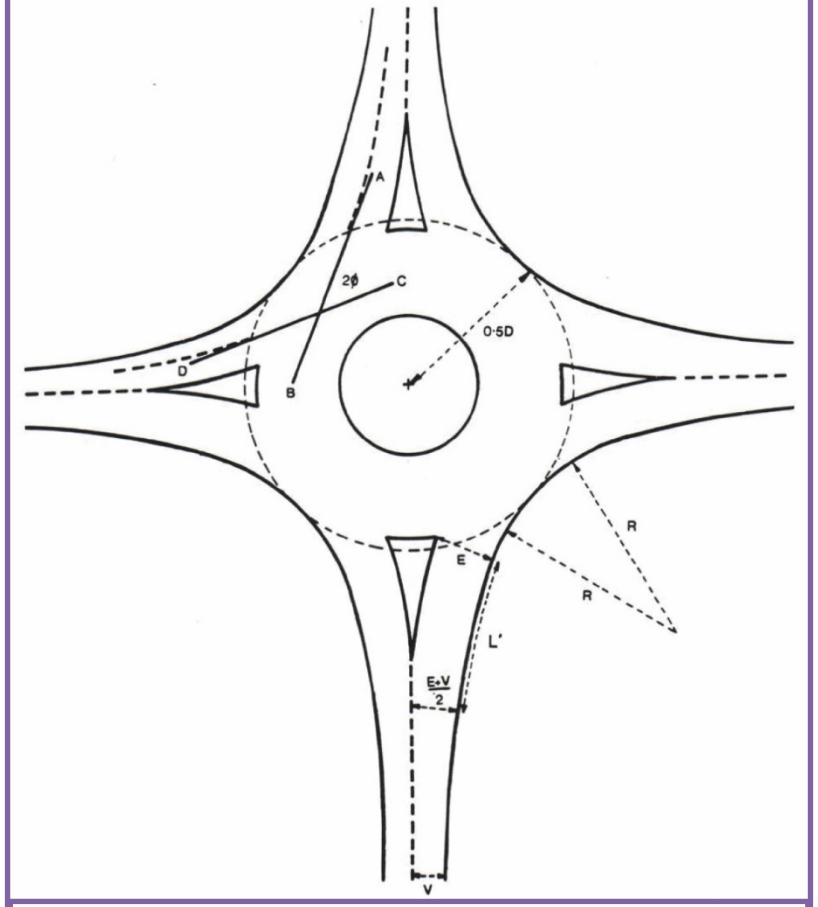


Basis of Geometric Model

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.**

6 Geometric Inputs



TRL Kimber / Hollis (LR 942)

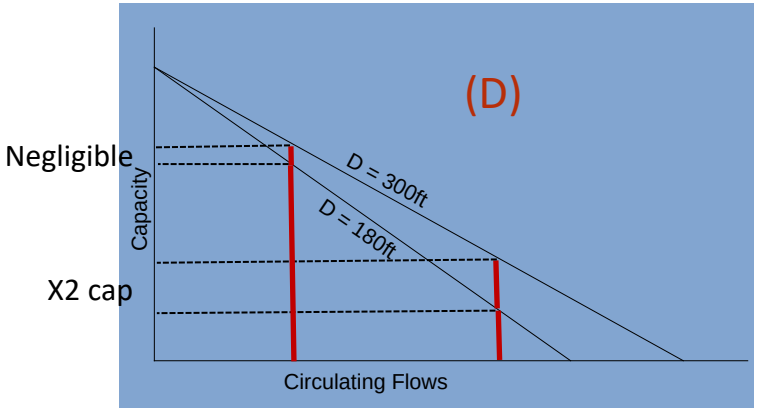
Basis of Geometric Model

3 Major Capacity Variables

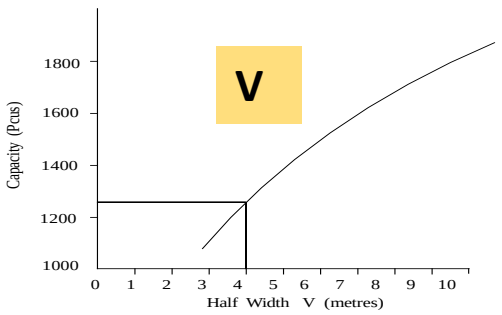
- Entry Width (E)
- Approach Width (V)
- Effective Flare Length (L')

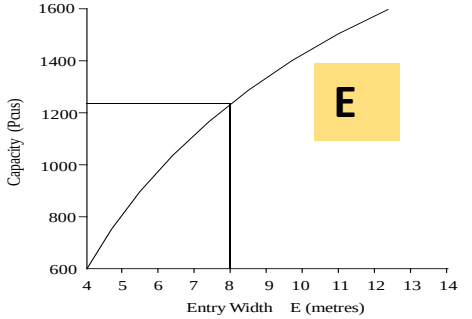
3 Minor Capacity Variables

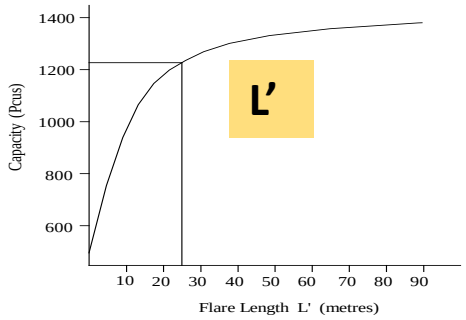
- Entry Radius (R)
- Entry Angle (Φ)
- Diameter (D)

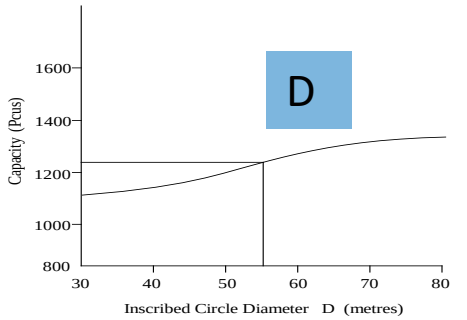


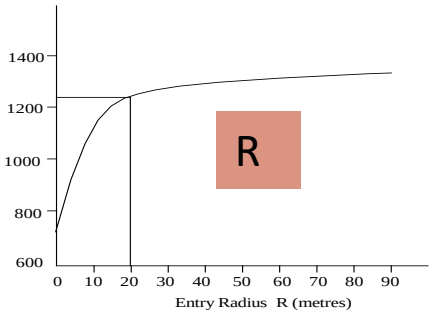
6 Geometric Inputs

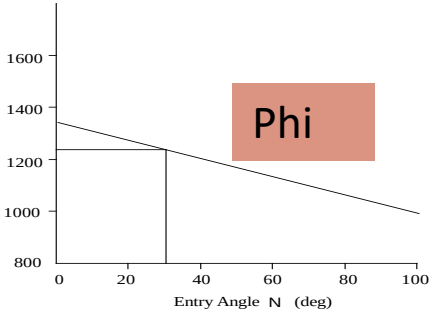






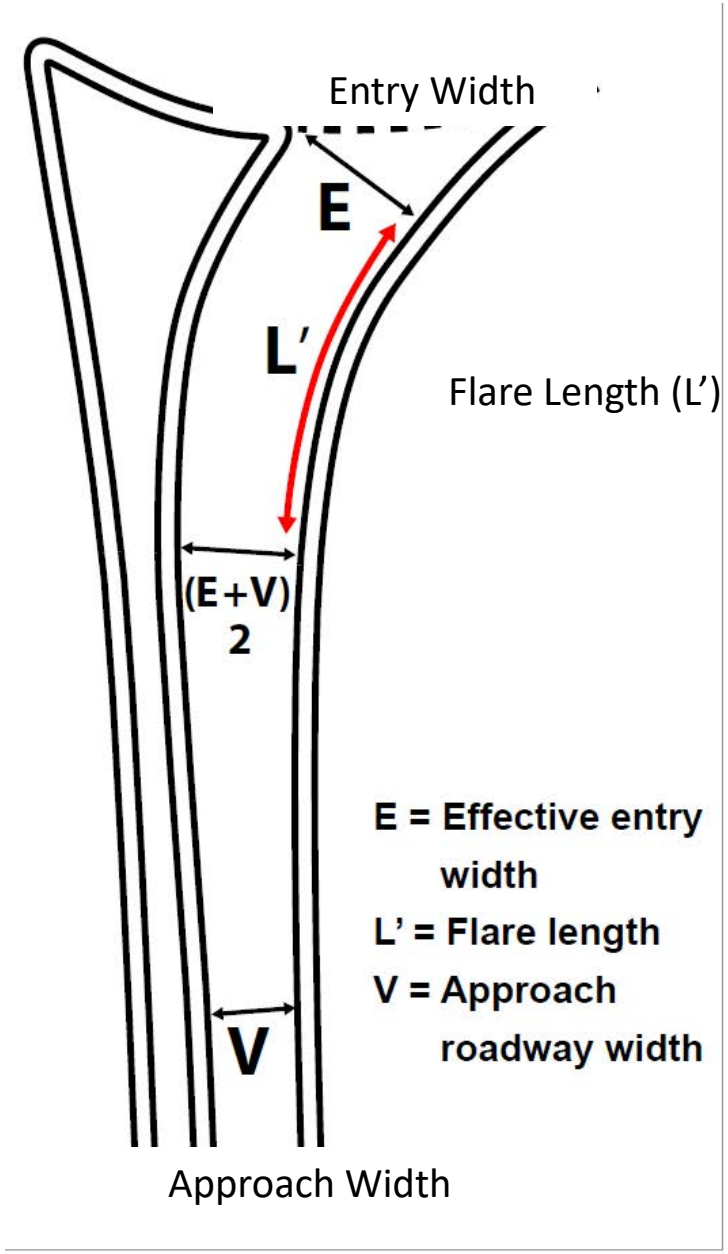






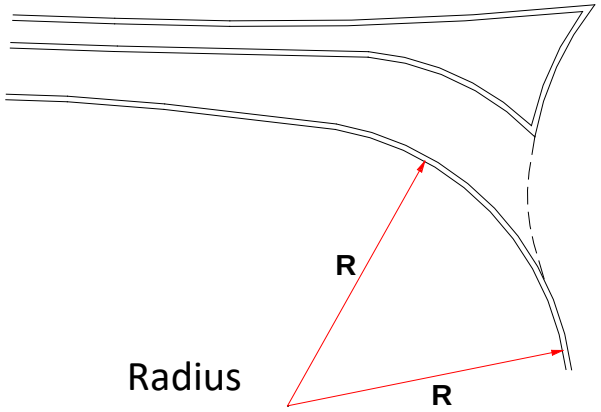
Basis of Geometric Model

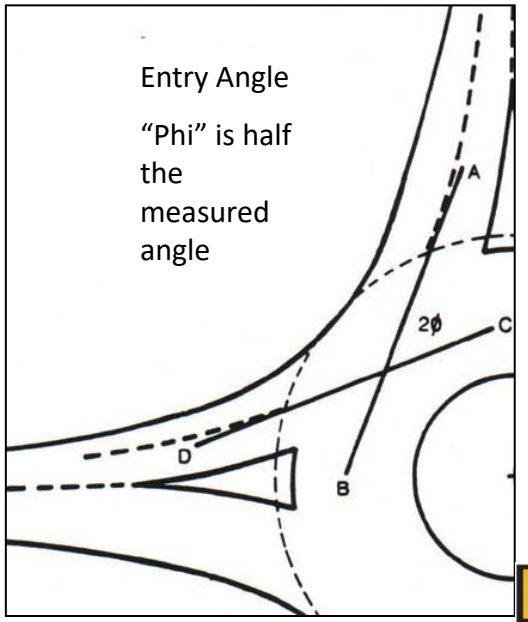
3 Major Capacity Variables



Basis of Geometric Model

Minor Capacity Variables





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Basis of Geometric Model

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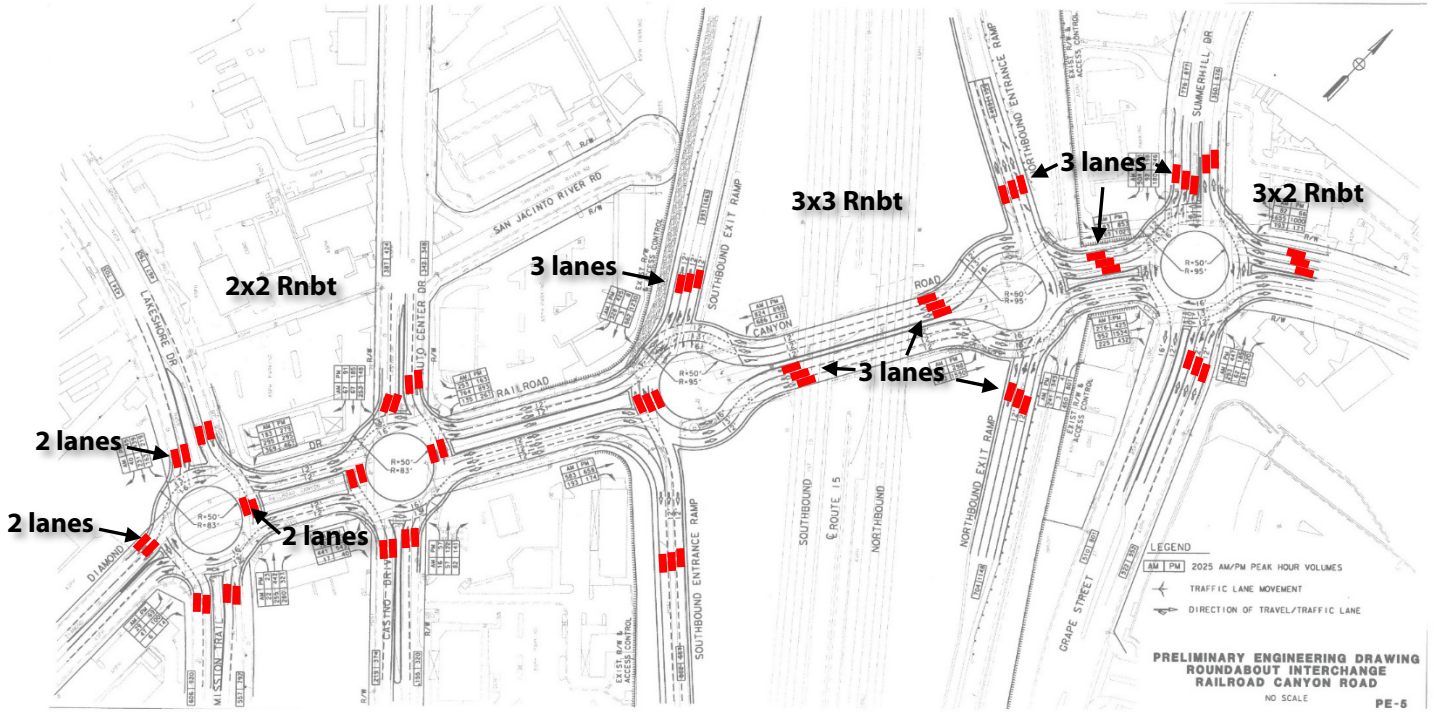
A) Minimize Conflict Points

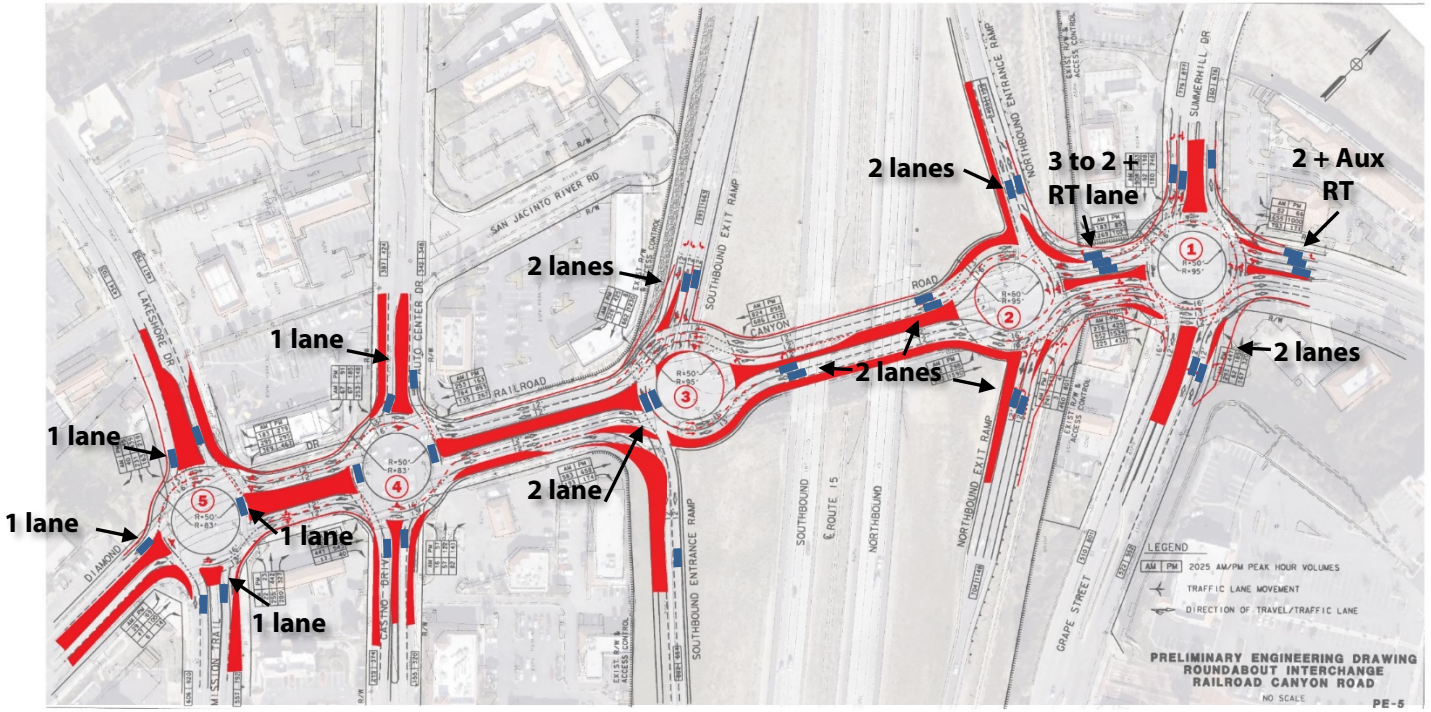
- **Operational Analysis is Foundational**
- **Minimize Conflicts / # of Lanes**
- **Acceptable LOS?**



Laneage = 98 Conflict Points

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**

POLL QUESTION #3

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B. SPEED CONTROL (FAST PATH CRITERIA)

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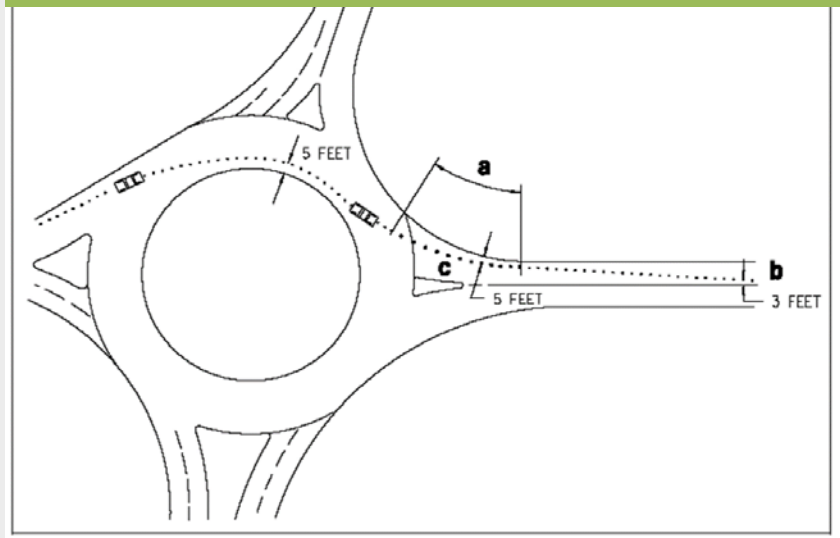
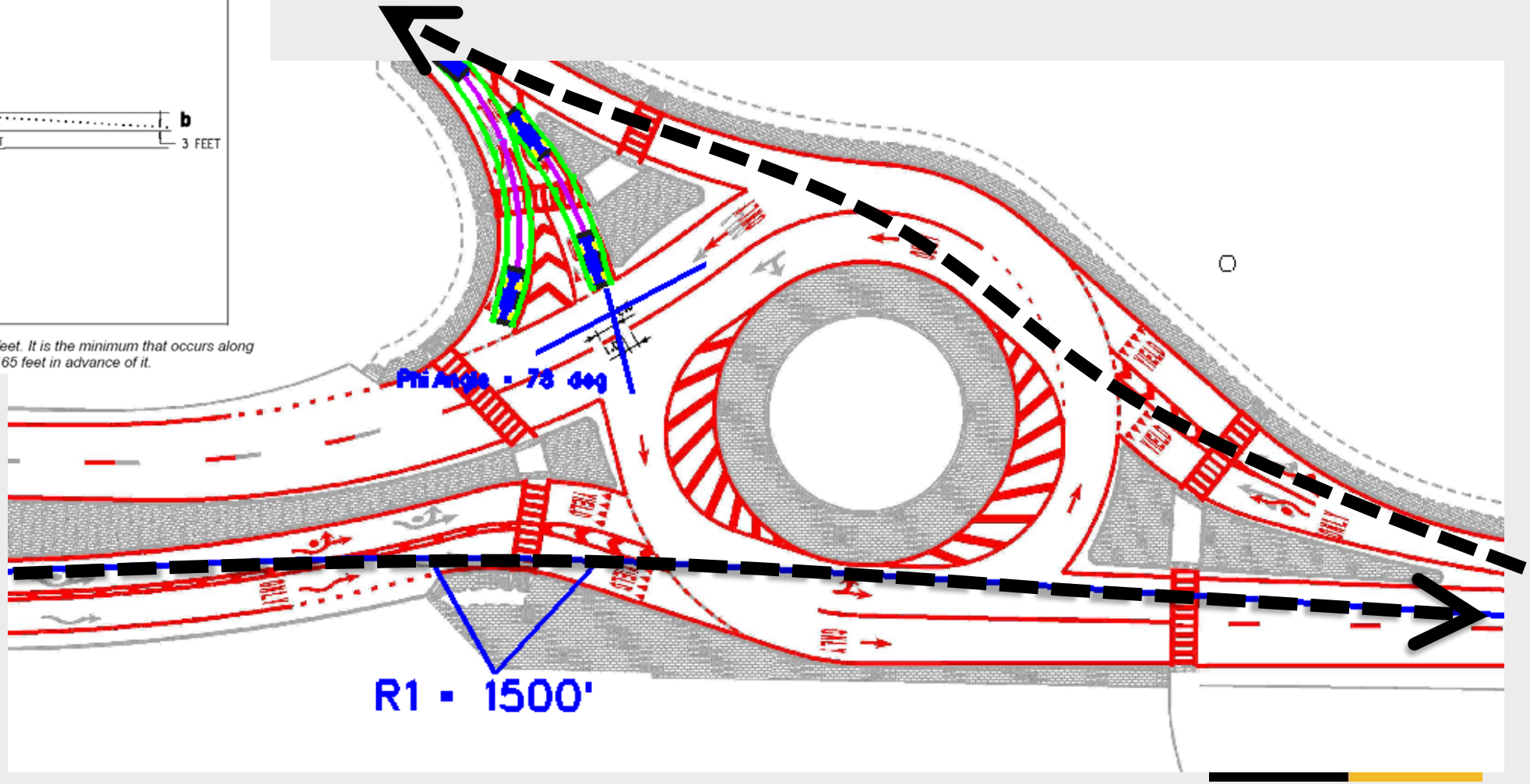
Foundational Safety Design Principles

B) Speed Control

Speed control



a - The radius should be measured over a distance of 65 to 80 feet. It is the minimum that occurs along the approach entry path near the yield point but not more than 165 feet in advance of it.



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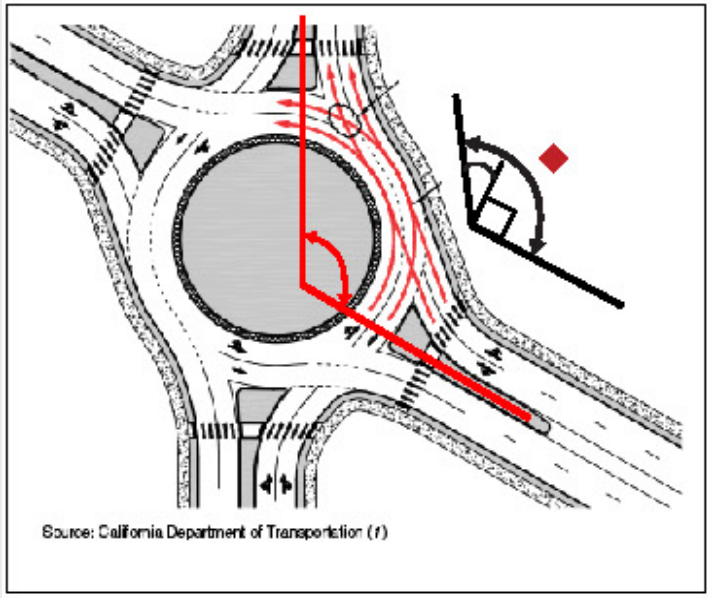
C. MAXIMIZE ANGLE BETWEEN APPROACH ALIGNMENTS (90 DEG)

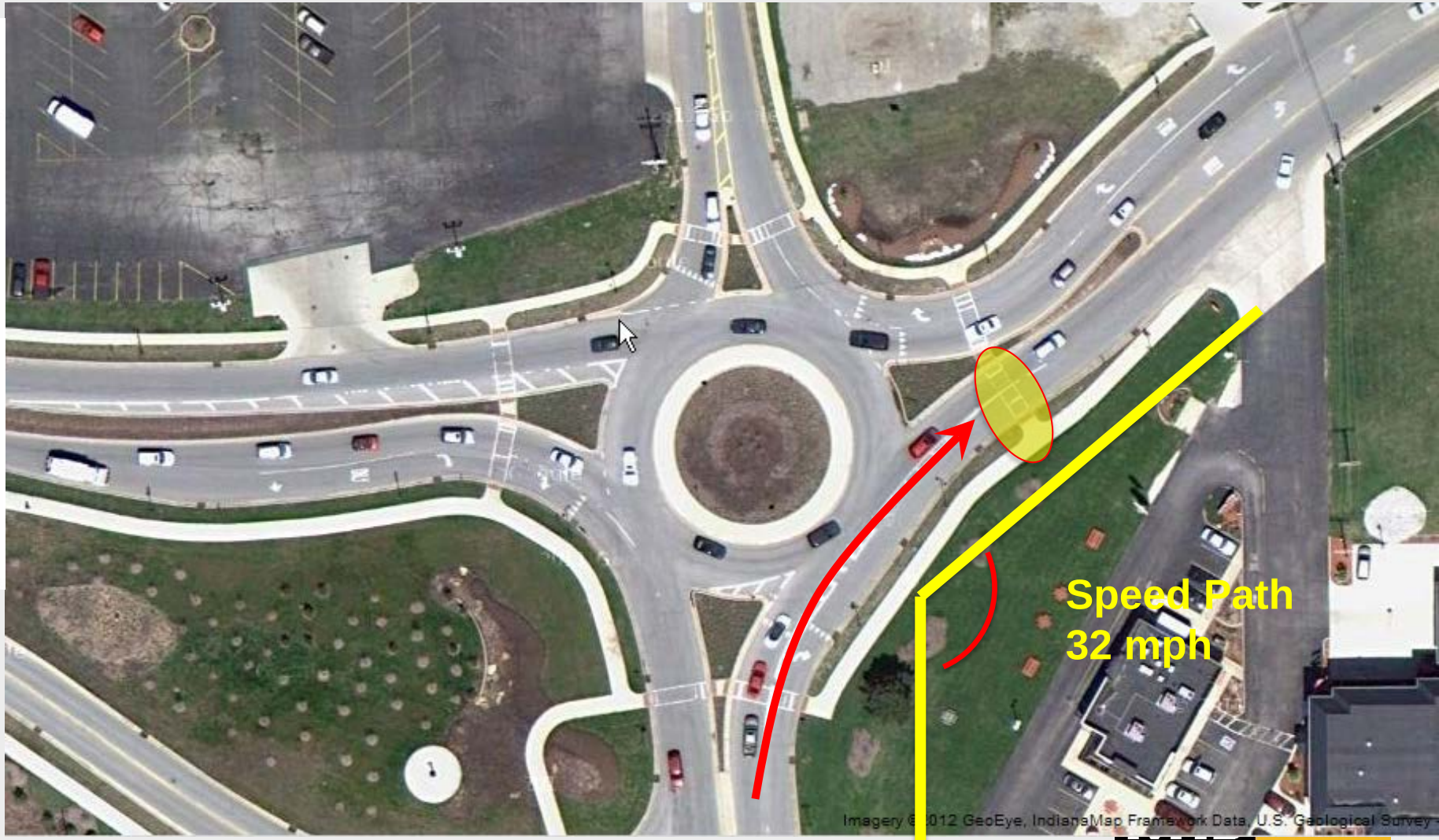
C) Angle Between Legs / Alignments

FHWA DESIGN PRINCIPLES

6.3.3 - Angles Between Approach Alignment ◆



Source: California Department of Transportation (f)



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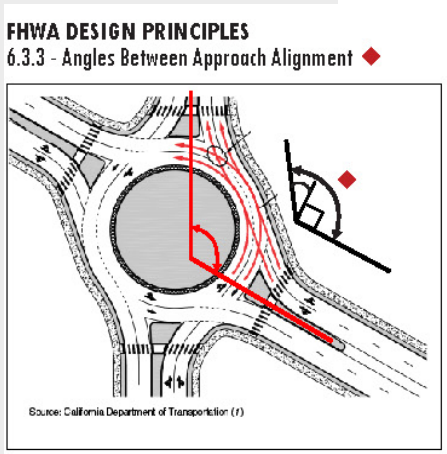
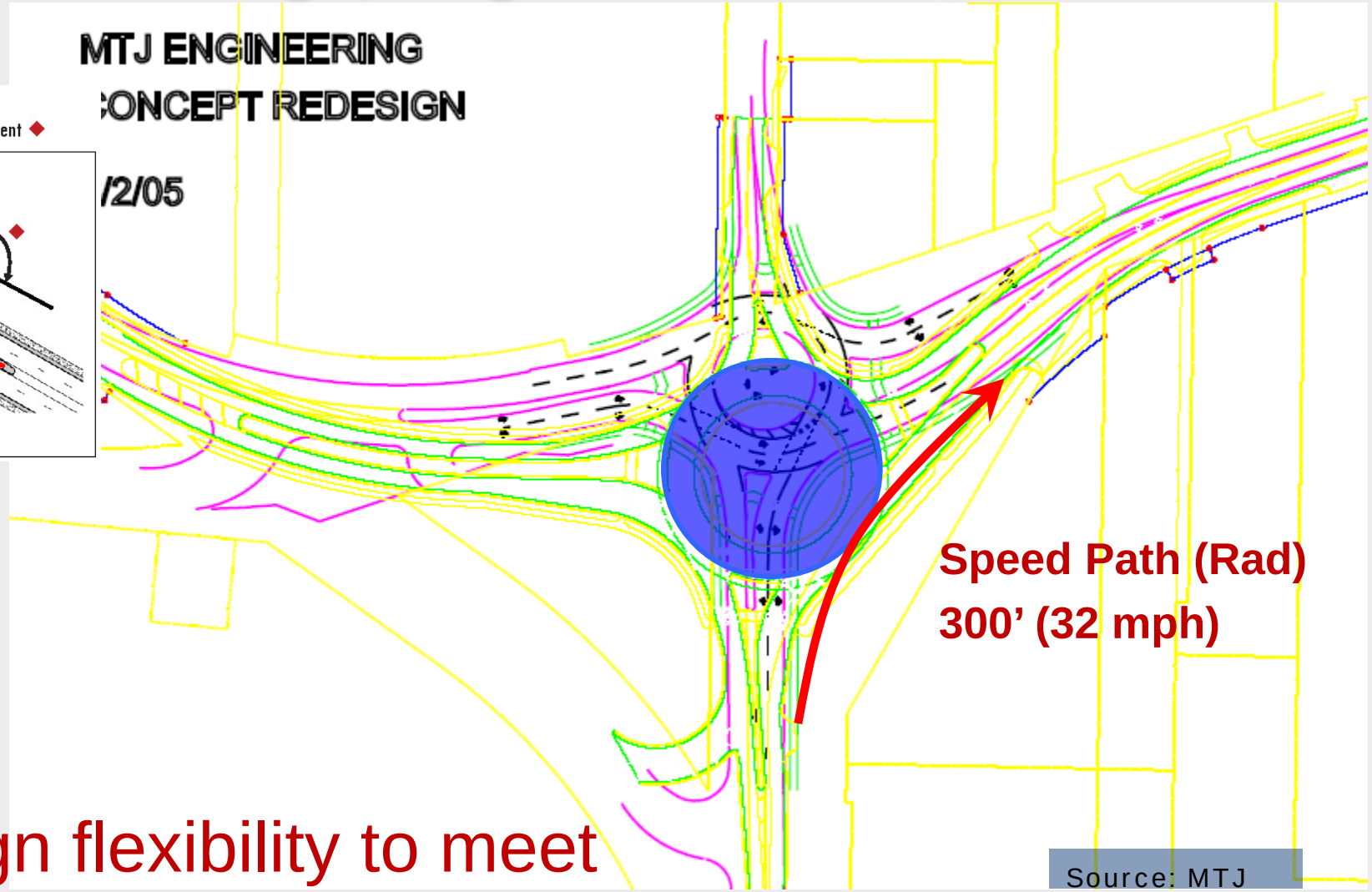
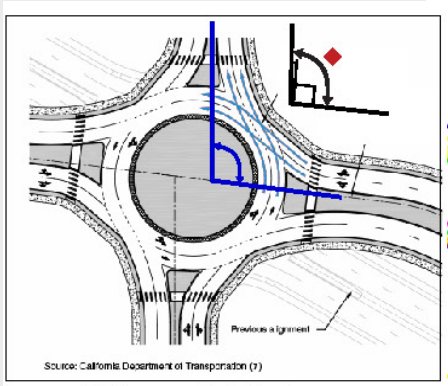
C) Angle Between Legs / Alignments



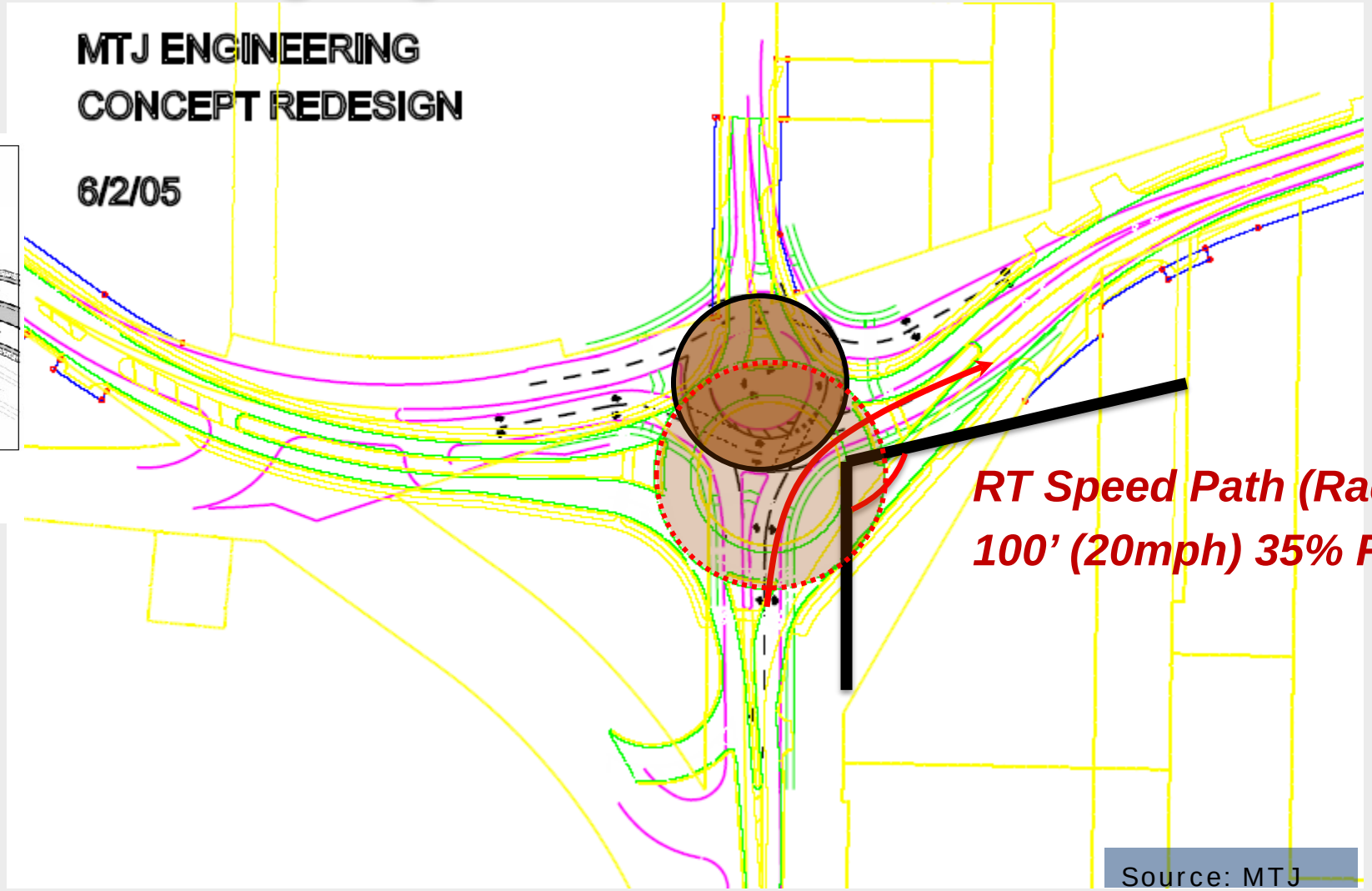


Use design flexibility to meet Safety Principles

C) Angle Between Leg Alignments



Recommended Geometry - Paths Crossing
Ex. 6-35 (Closer to 90°)

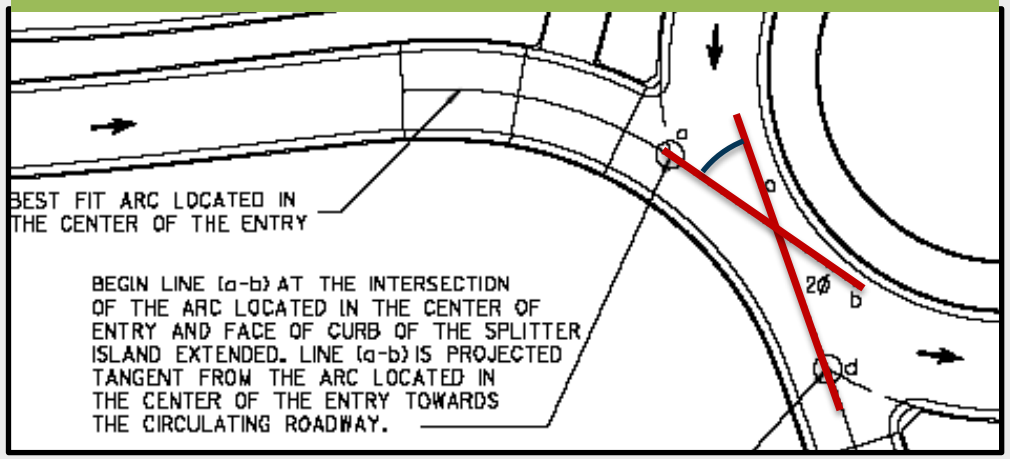


D) ENTRY ANGLE (PHI) & VIEW ANGLE LEFT

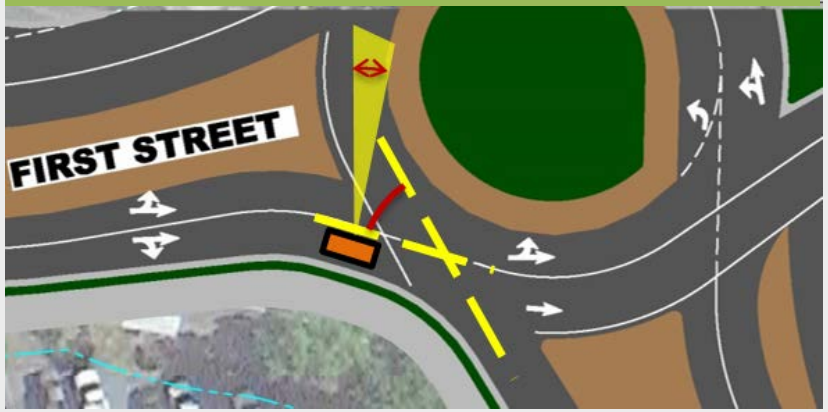
Foundational Safety Design Principles –

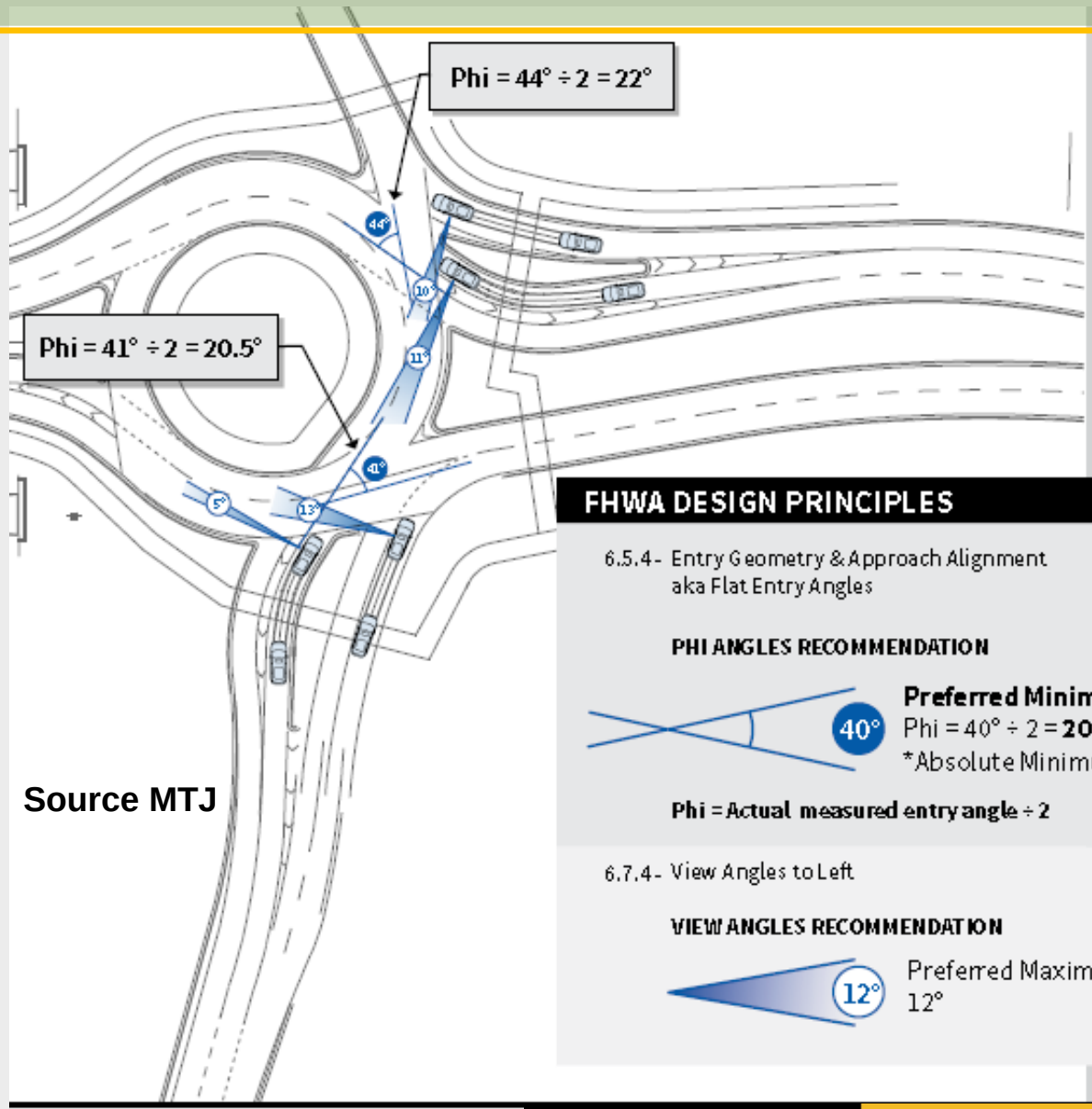
D) Entry Angle (Phi) & View Angle Left

Entry (Phi) Angle — Source WIDOT Guide



View Angle Left — Source MTJ





Source MTJ

FHWA DESIGN PRINCIPLES

6.5.4 - Entry Geometry & Approach Alignment
aka Flat Entry Angles

PHI ANGLES RECOMMENDATION

Preferred Minimum
Phi = 40° ÷ 2 = **20°**
*Absolute Minimum 16°

Phi = Actual measured entry angle ÷ 2

6.7.4 - View Angles to Left

VIEW ANGLES RECOMMENDATION

Preferred Maximum
12°

ES

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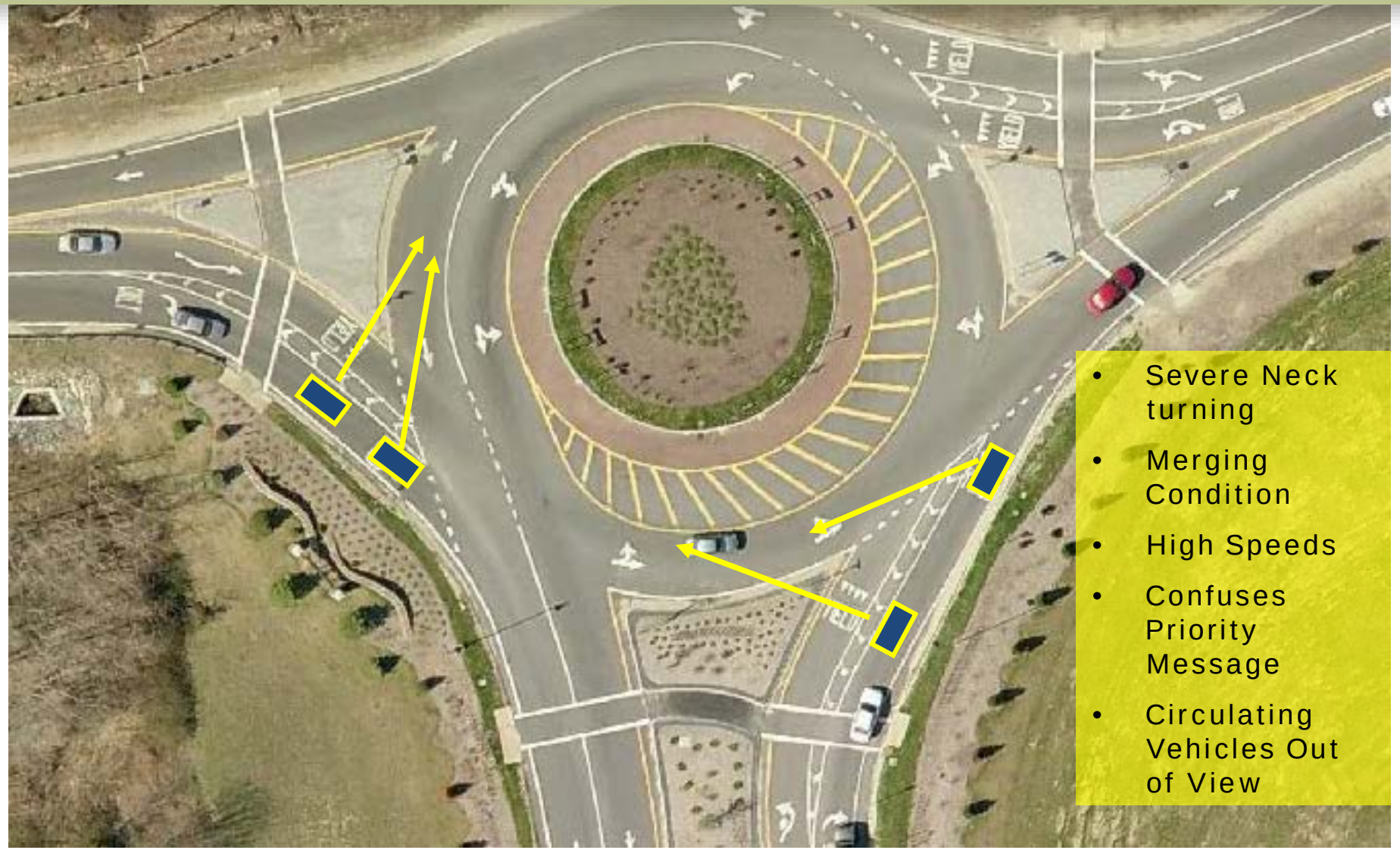
Example #1

- 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

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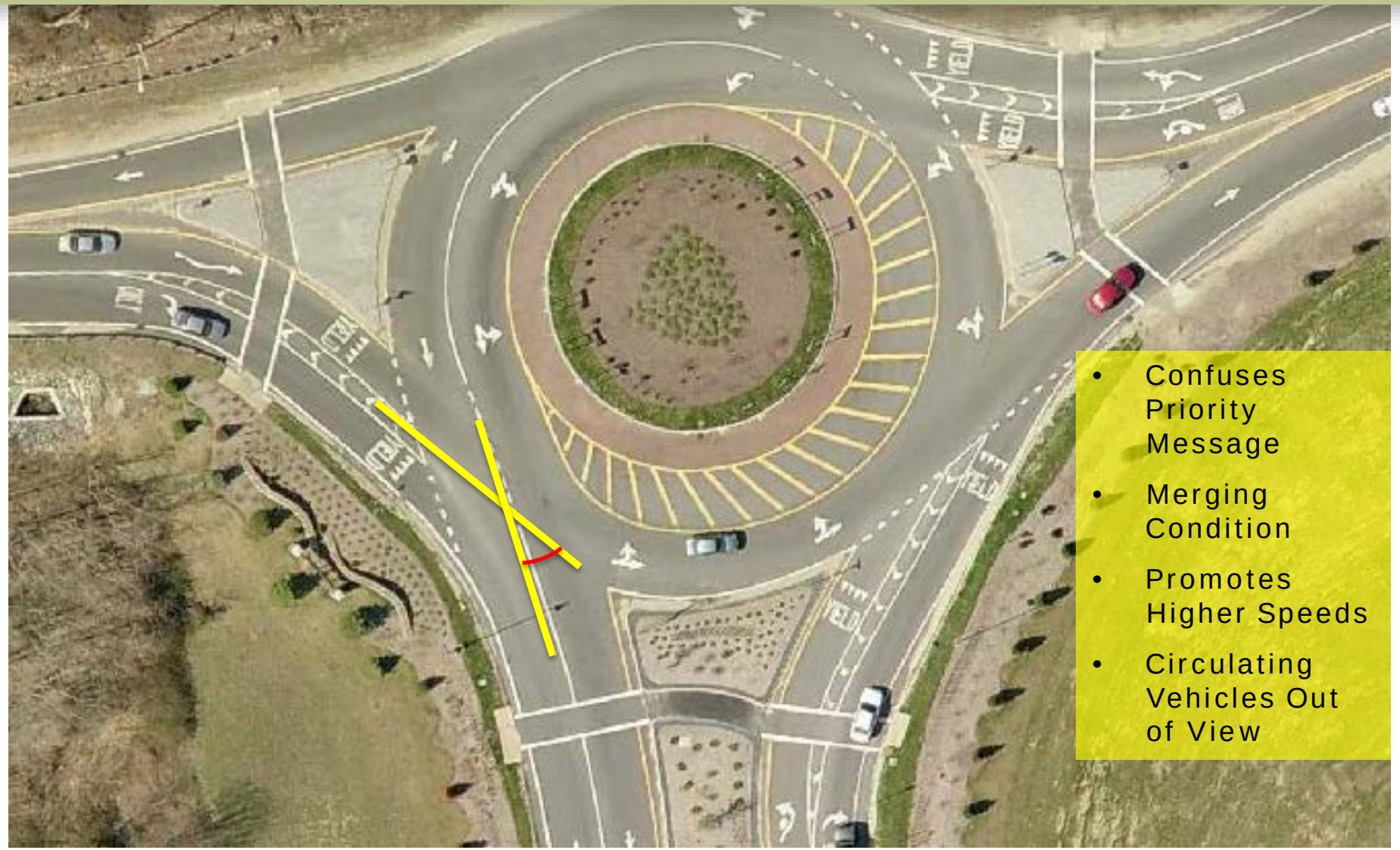
Roundabout Design – Entry and View Angles



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

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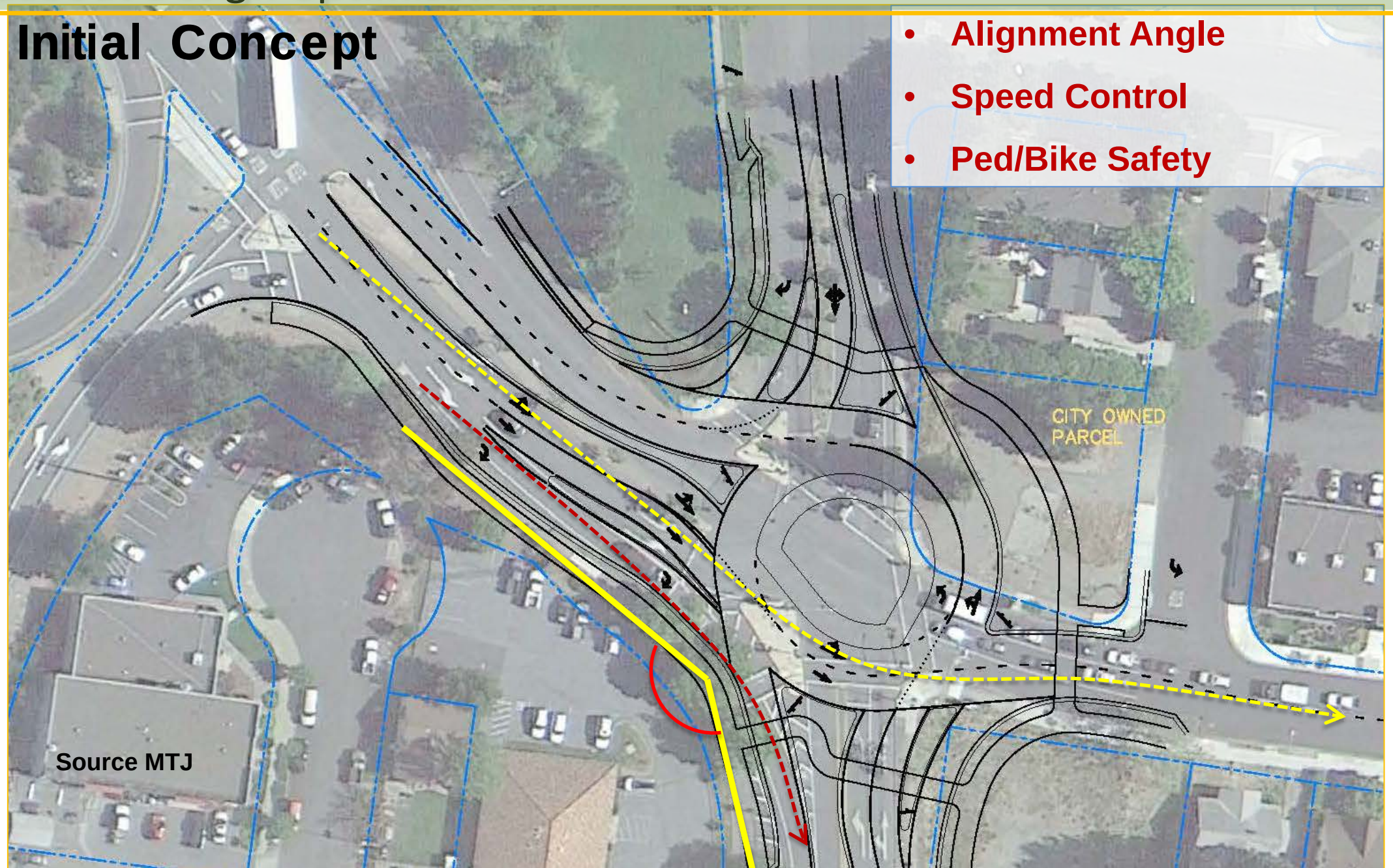
Example #2

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

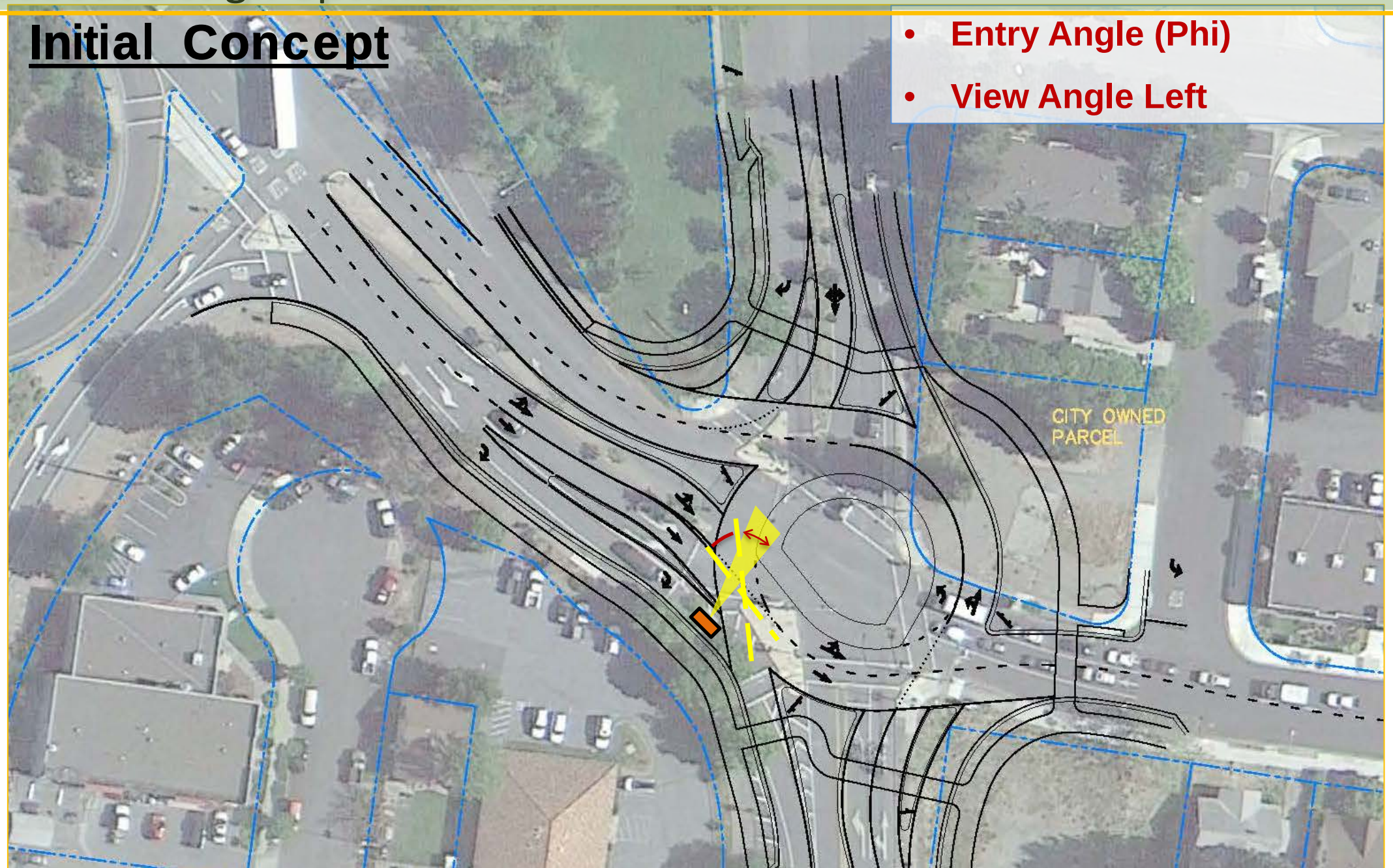
Roundabout Design Optimization



Roundabout Design Optimization

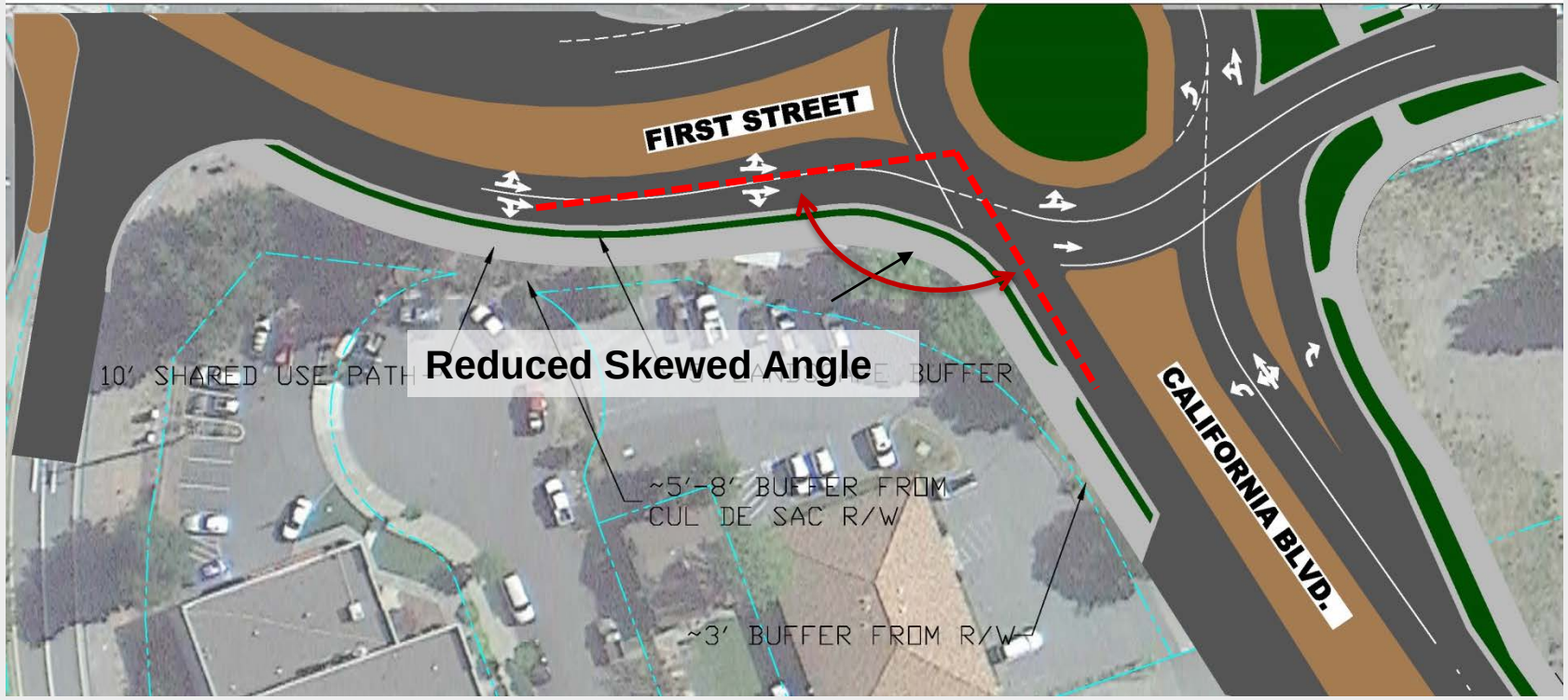
Initial Concept

- Entry Angle (Phi)
- View Angle Left



Revised Concept

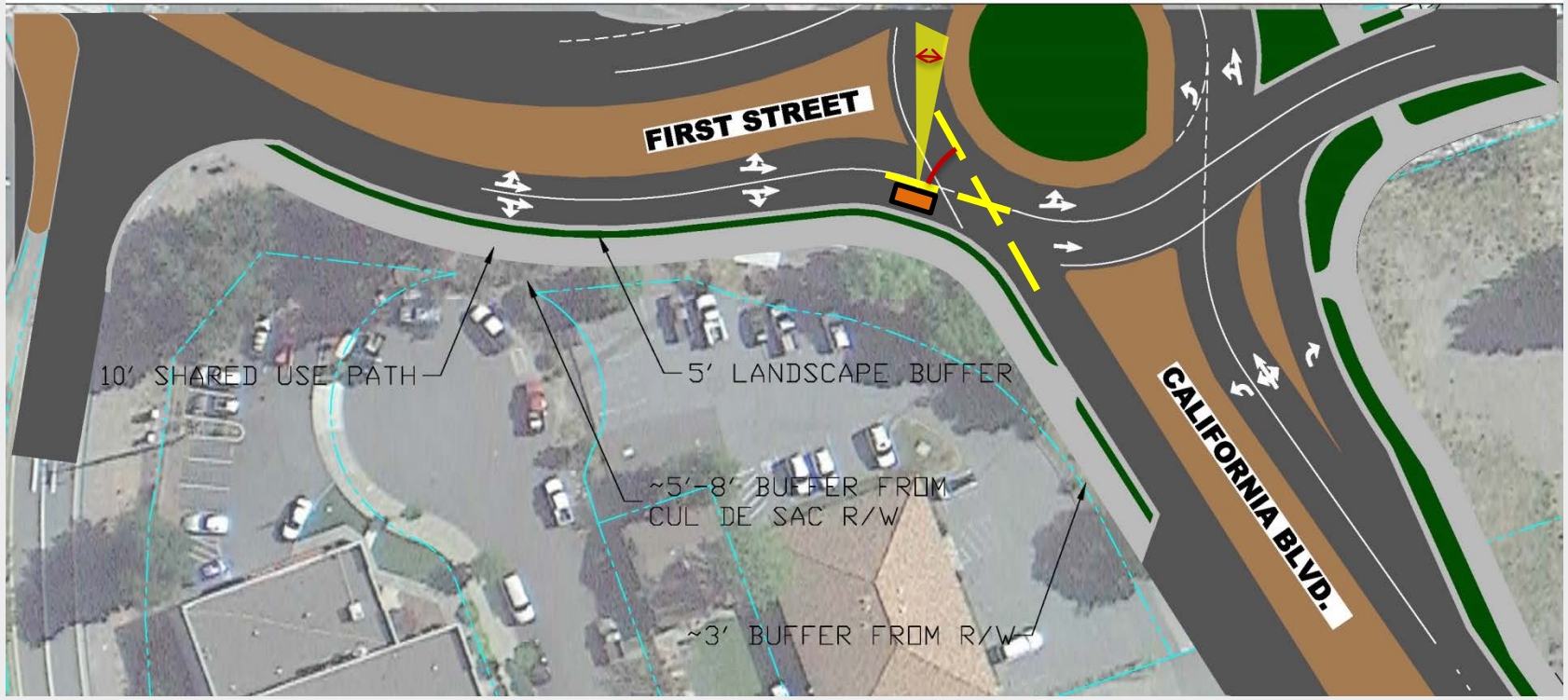
Alignment / Angle between Legs



Roundabout Design Optimization

Entry Angle (Phi) & View Angle Improved =

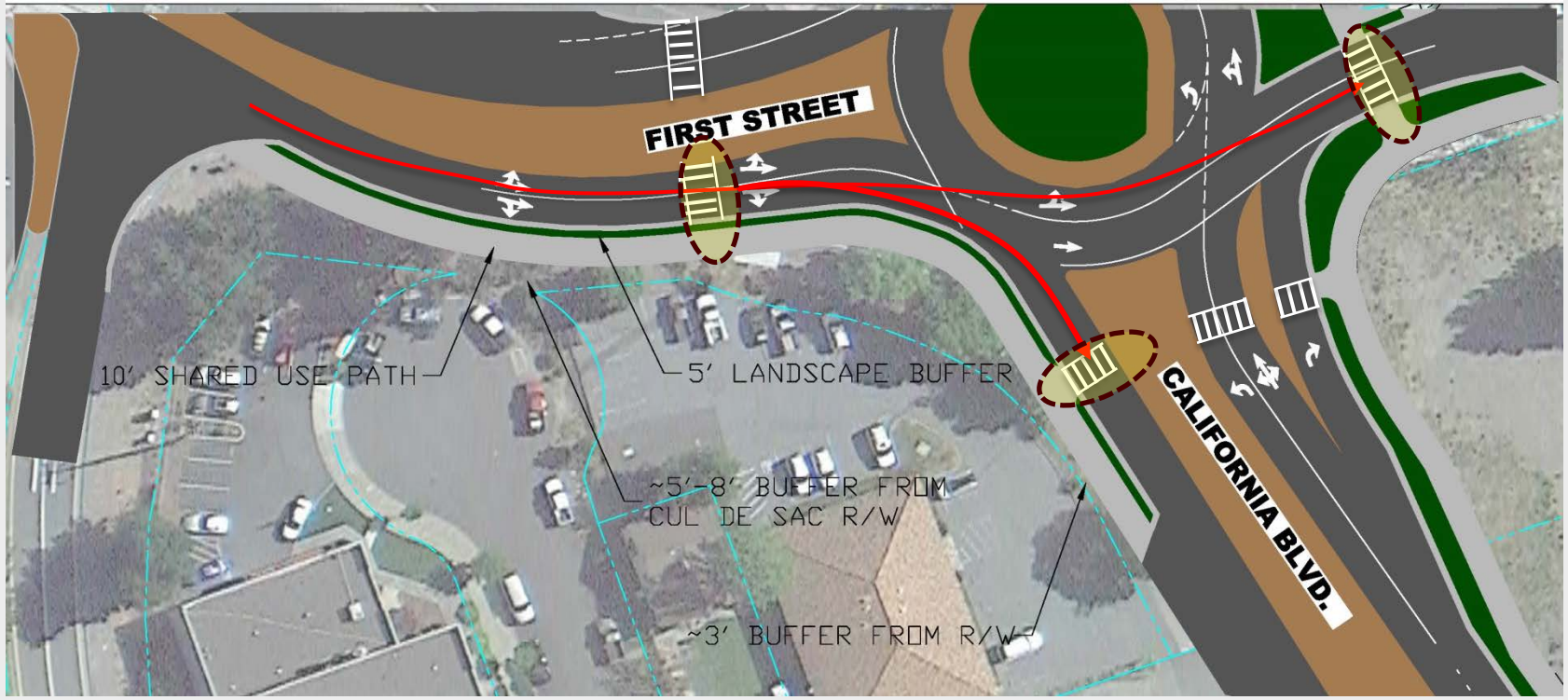
Correct Priority Message



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)**

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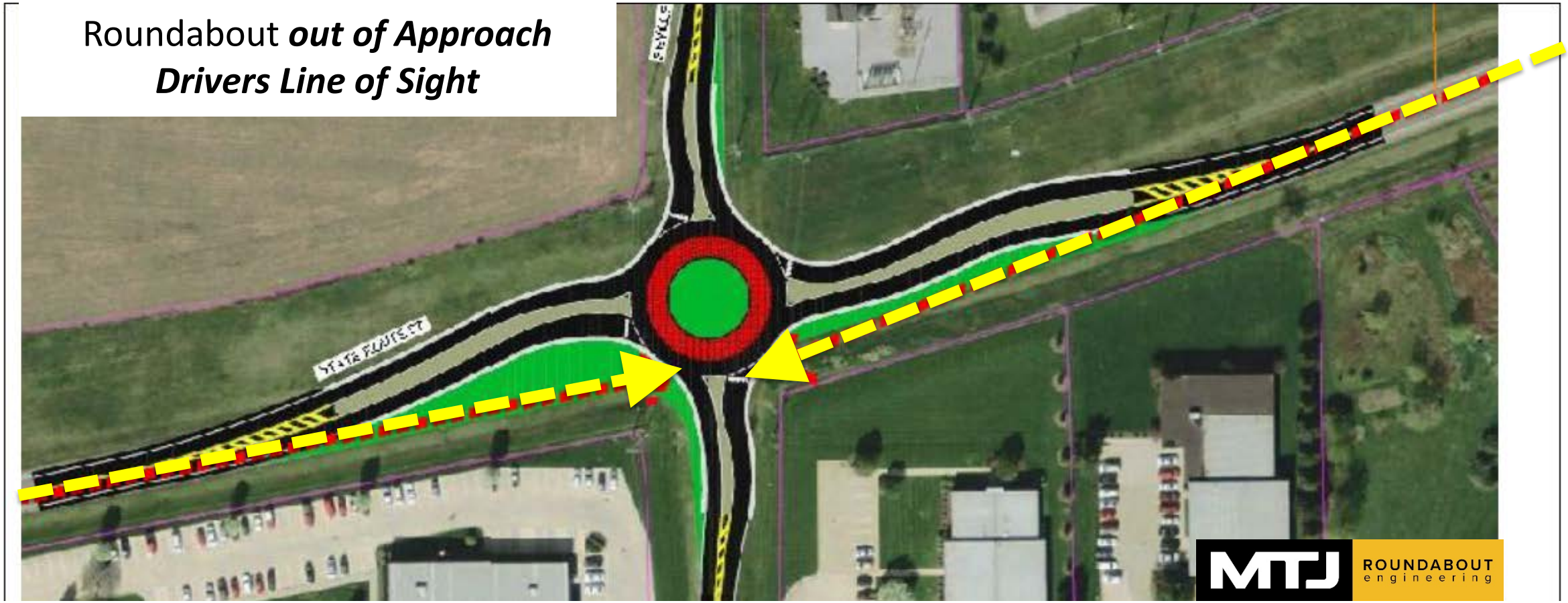
E) Approach Alignment & *Driver Expectancy*

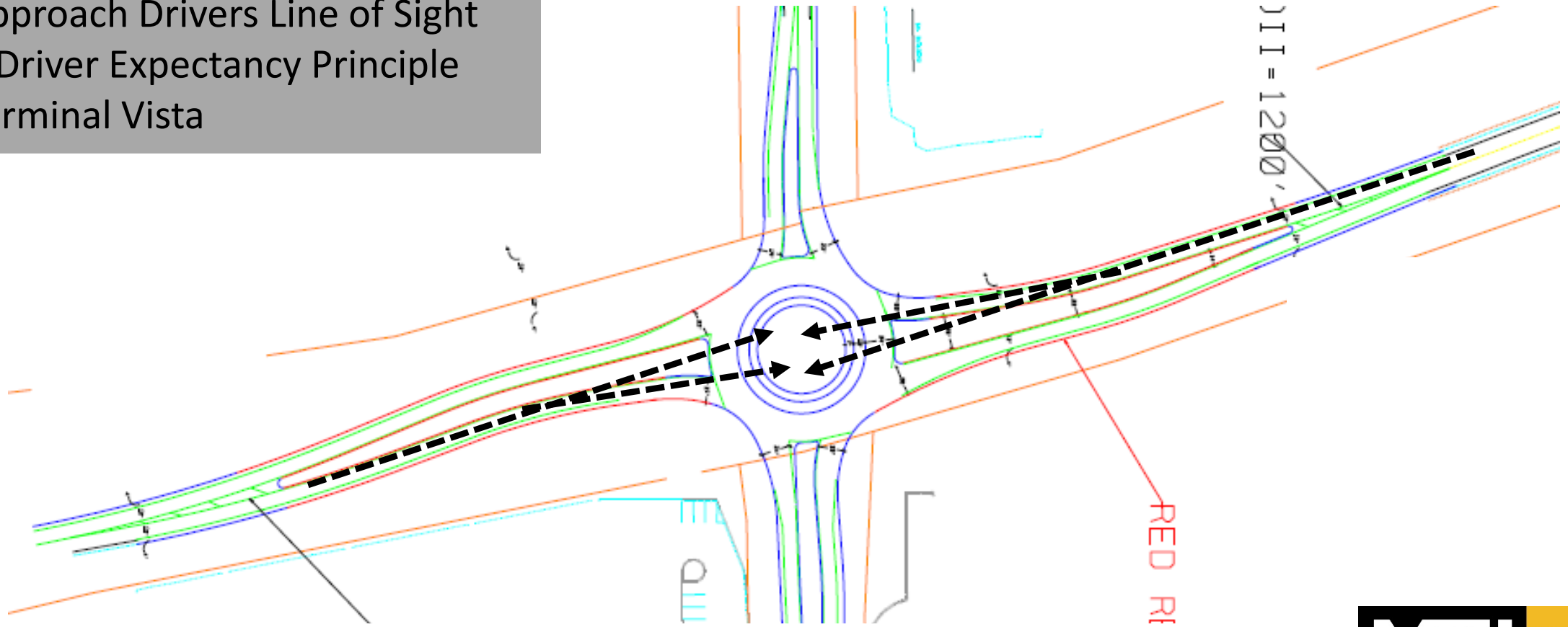
Rural / High Speed Applications



E) Approach Alignment & *Driver Expectancy*

Rural / High Speed Applications

Approach Drivers Line of Sight
= Driver Expectancy Principle
Terminal Vista



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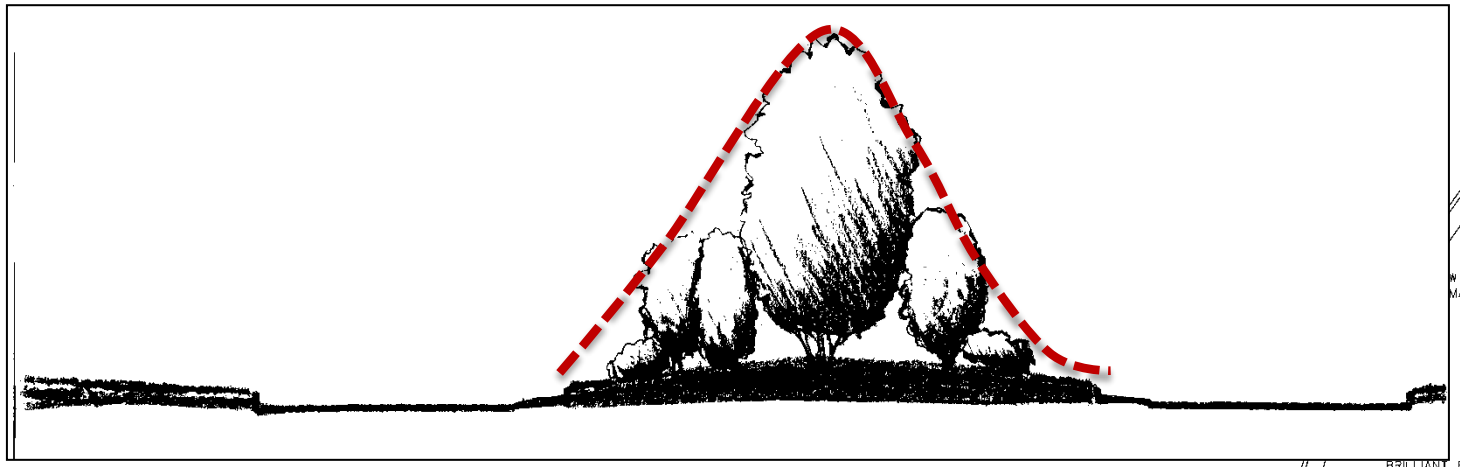
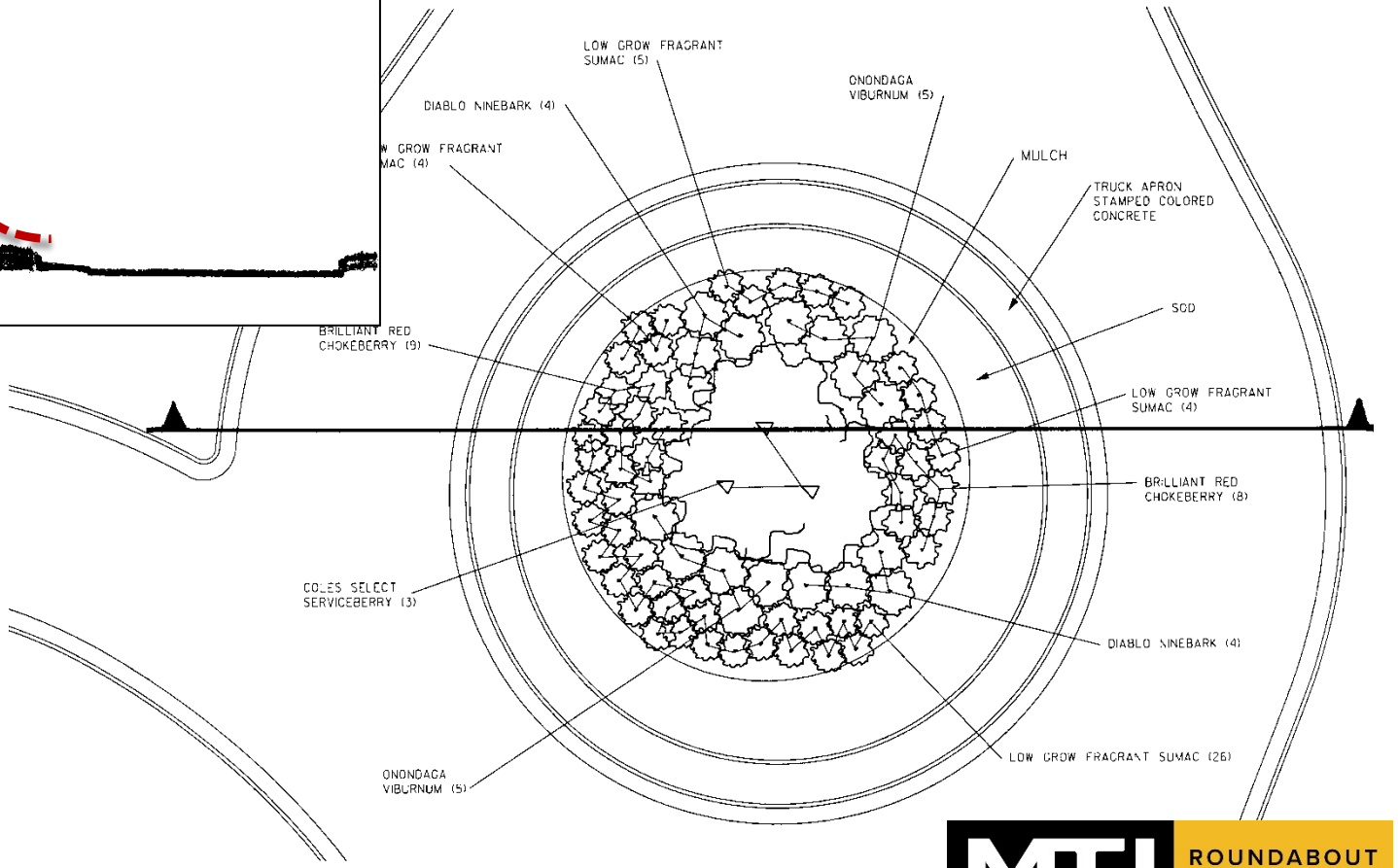
Conspicuity on Approach for high/Transitional speed applications





Central Island Landscaping:

- **Mounded**
- **Appropriate Plant Materials**

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2) Design Composition

Don Quixote by Pablo Picasso

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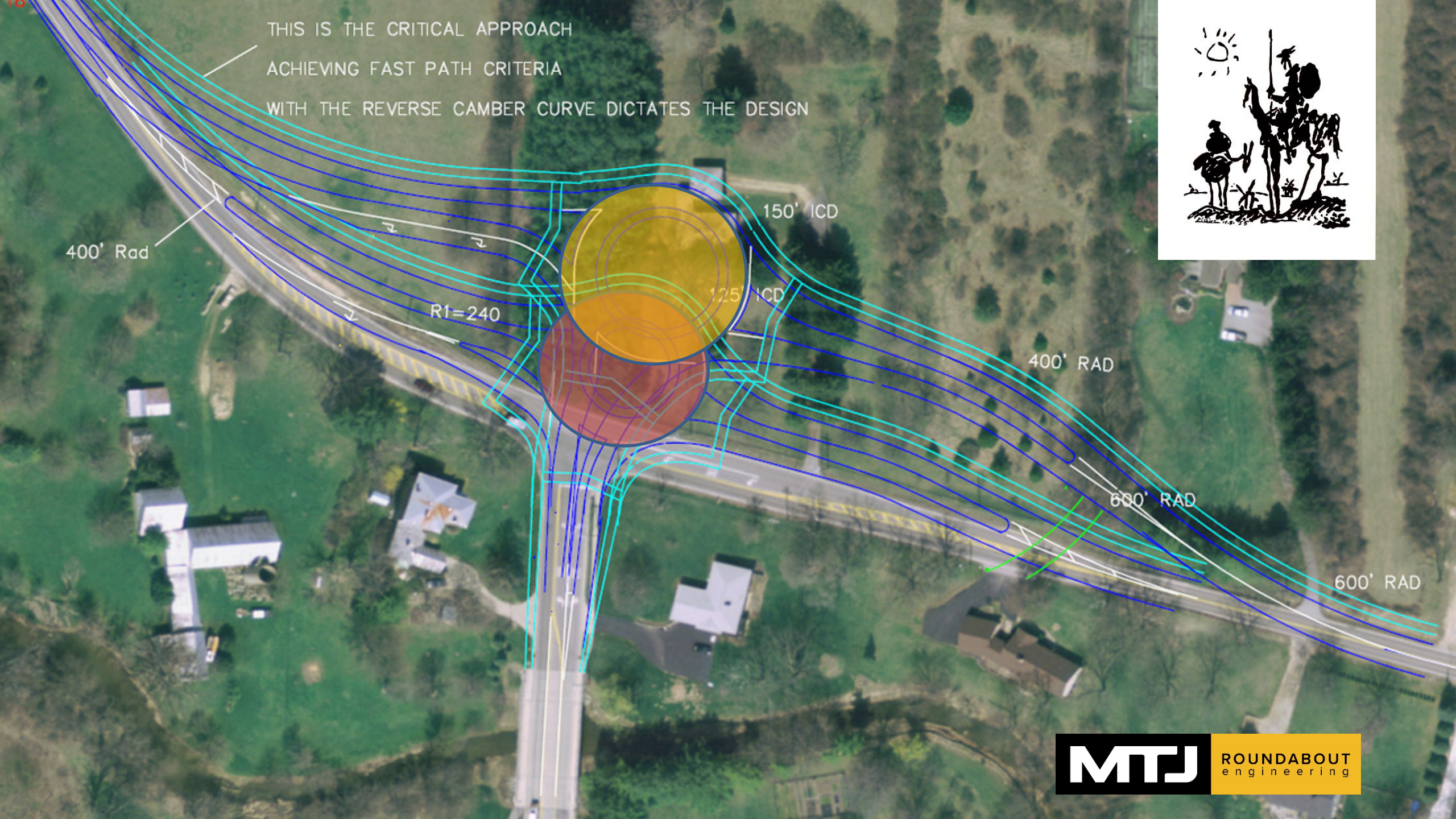
Example #1

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
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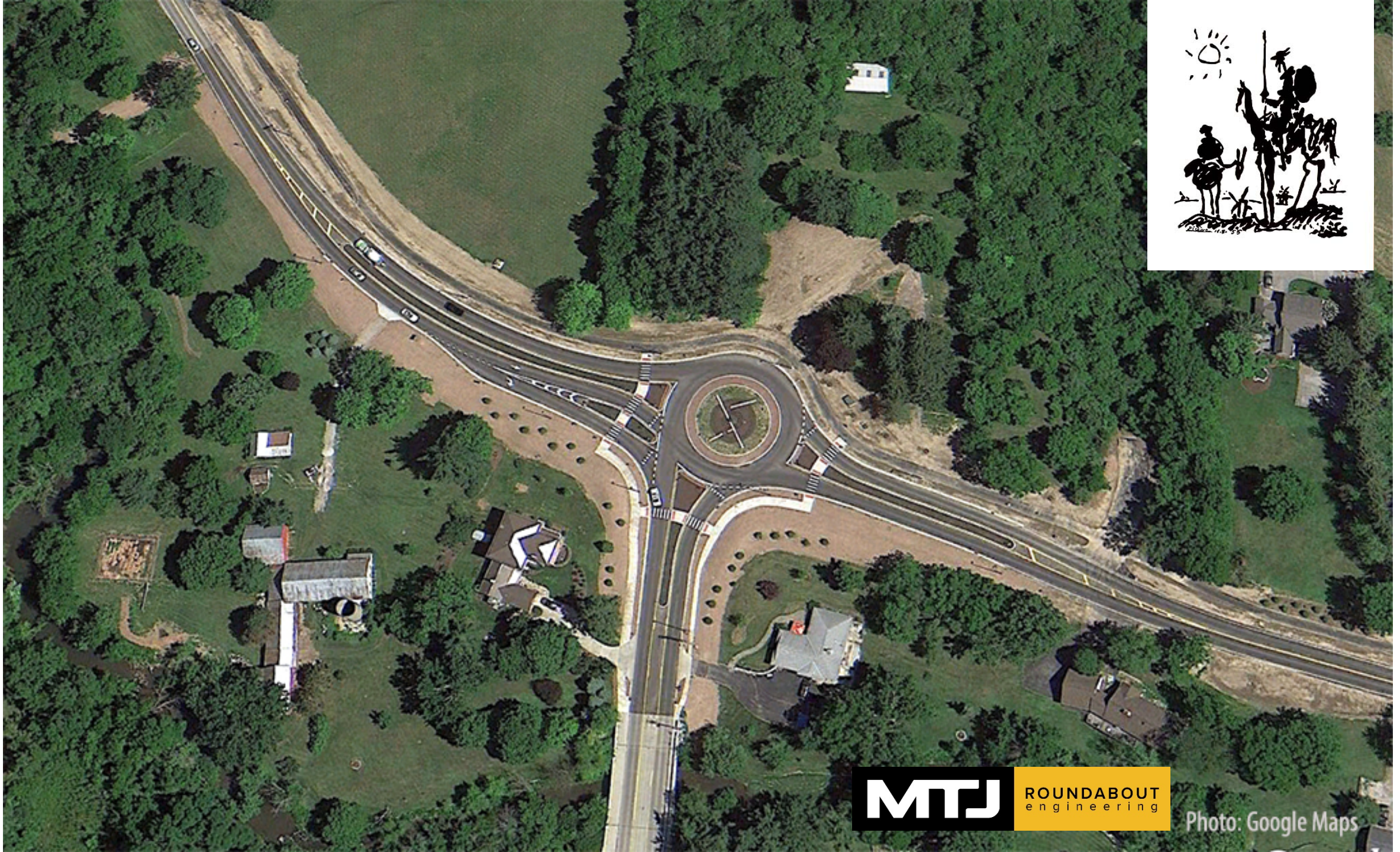
engineering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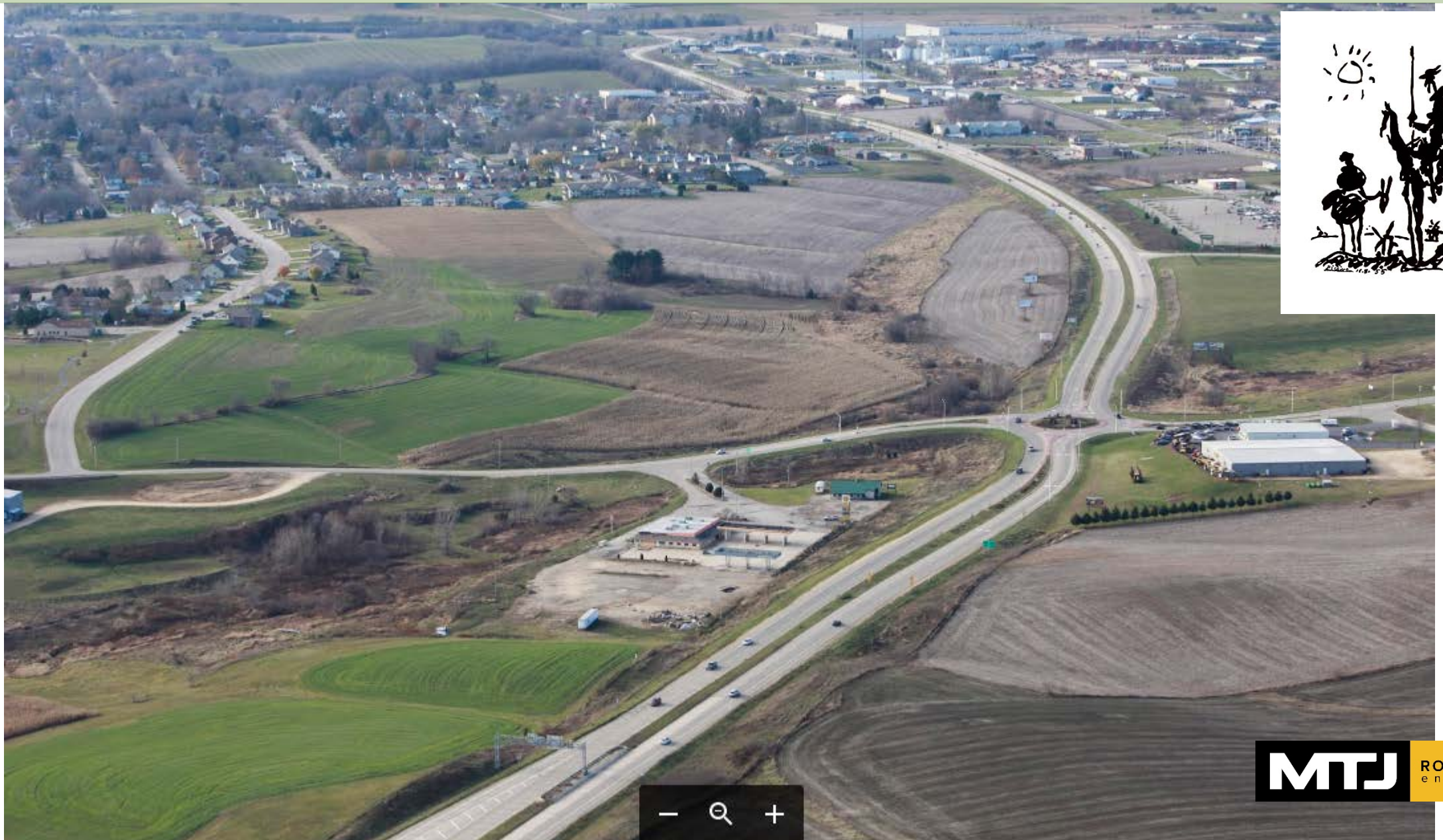
engineering
Photo: Google Maps

Example #2

High Speed Example

High Speed Example

High Speed Example



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High Speed Example – Placement-Sight Lines

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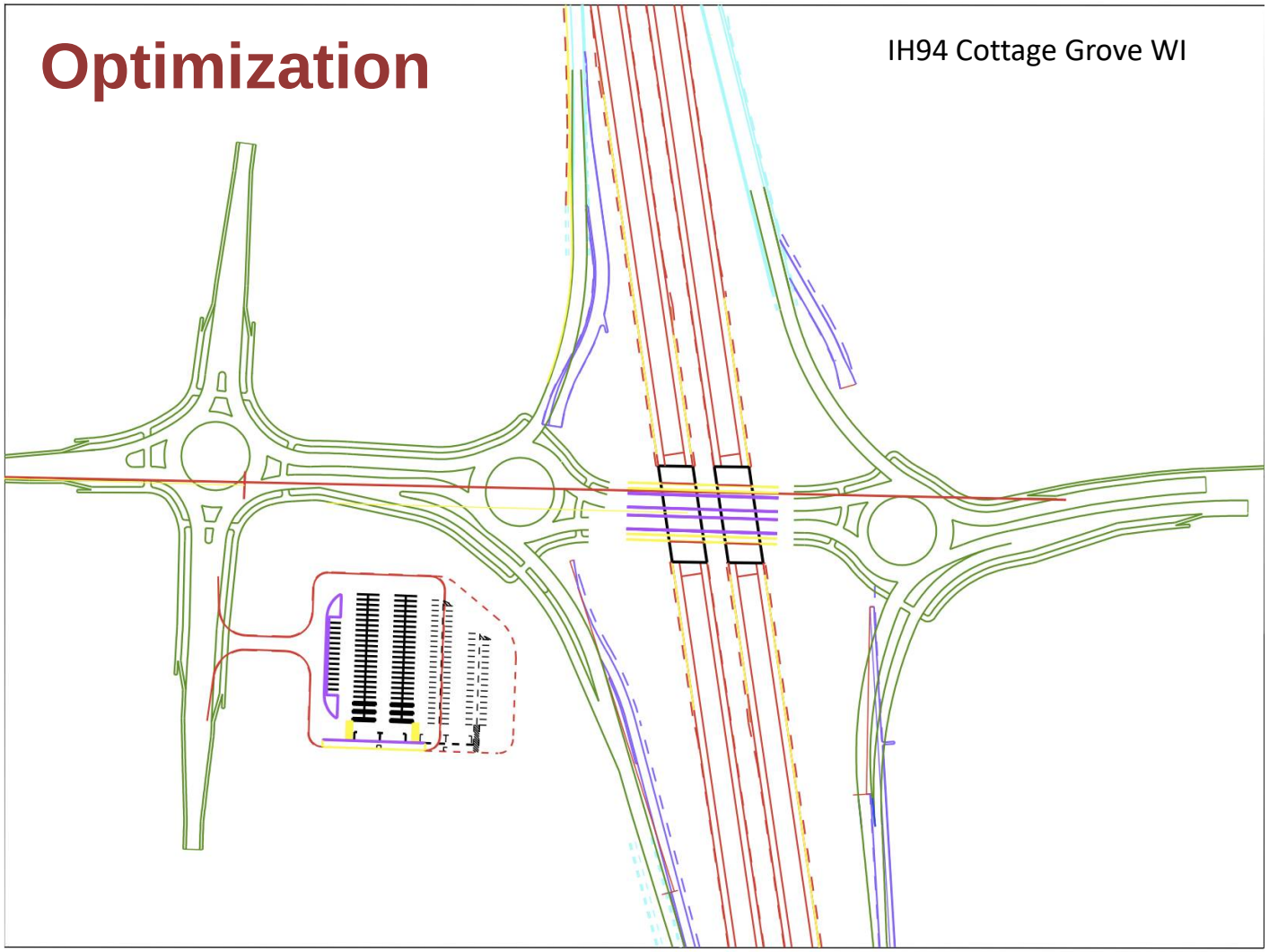
Adherence to Foundational Safety Principles:

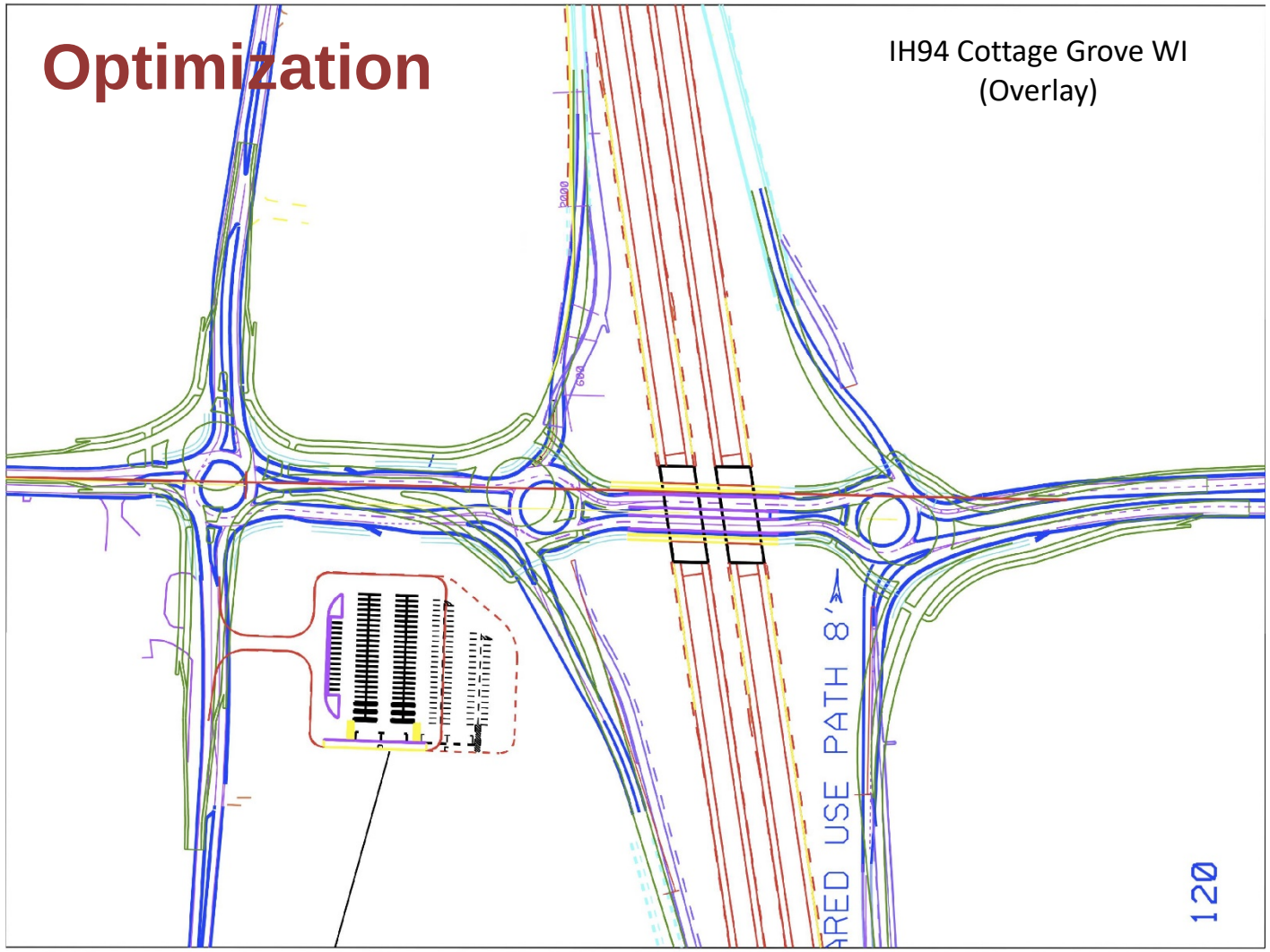
Example #3

Meeting All Geometric Principles Simultaneously

Design Principles for Safety and Operations



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

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gineering

POLL QUESTION #4

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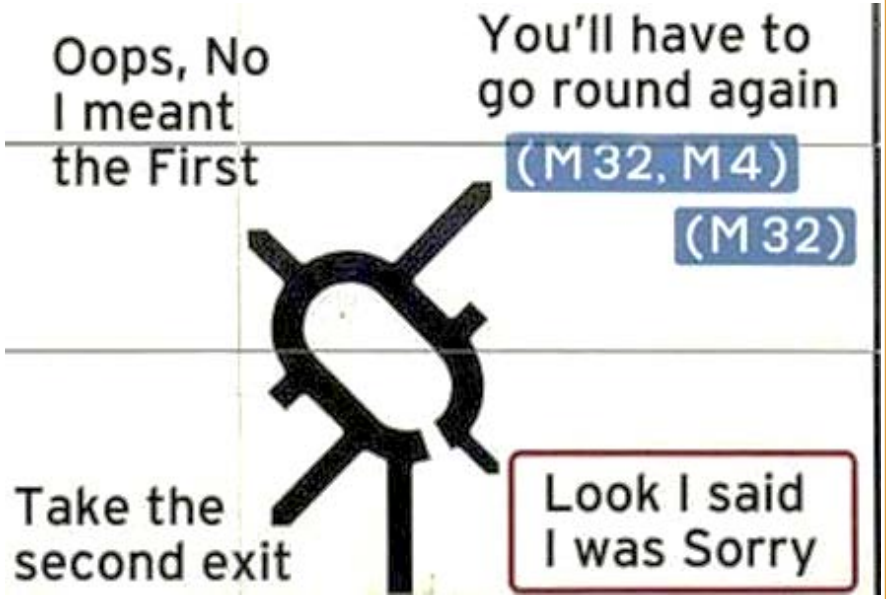
3) SIGNING AND MARKINGS

https://www.mtjengineering.com/safety-impacts-of-signing-and-pavement-markings-on-property-damage-only-crashes-at-multi-lane-roundabouts/



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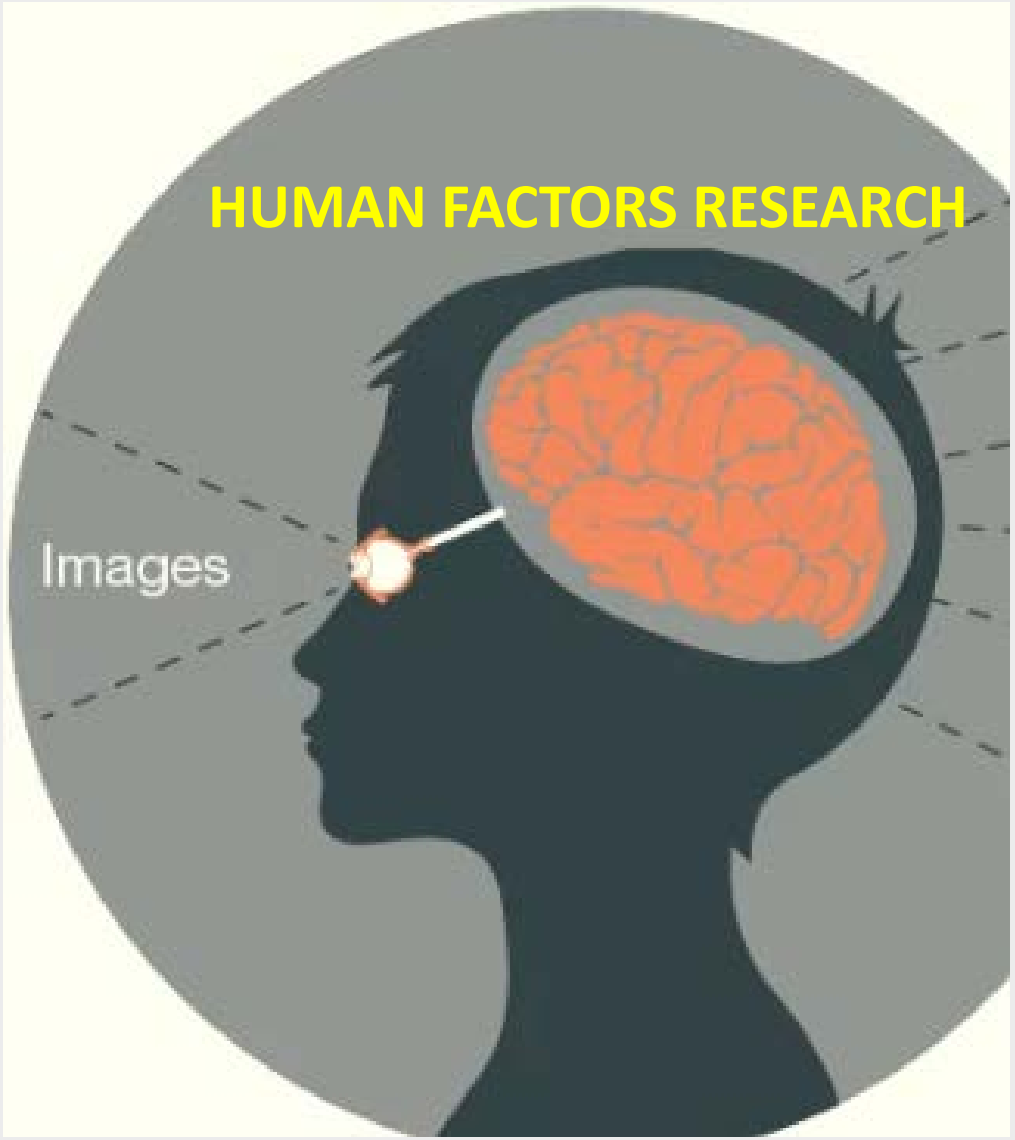
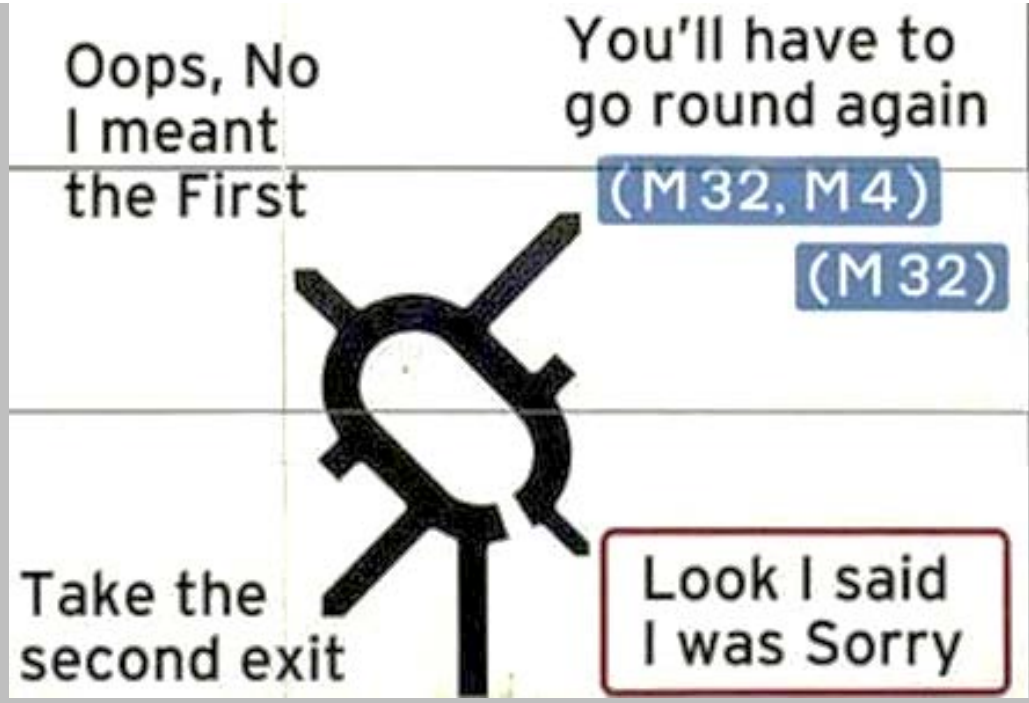
INTRODUCTION

Key Principles:

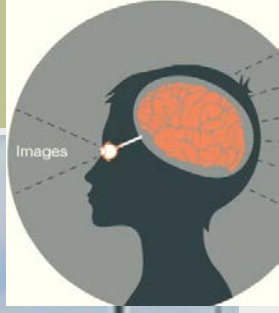
- Simplify Decision-Making
- Clear - Concise Information
- Minimize detection, reading and processing time
- Intuitive & Easy to Understand



Examples

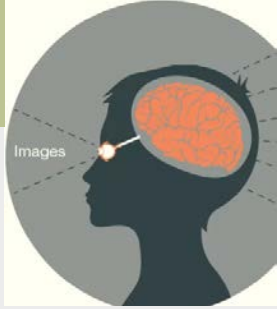

Oops, No
I meant
the First
You'll have to
go round again
(M32, M4)
(M32)
Take the
second exit
Look I said
I was Sorry

Information Processing



- **Information Overload**

Information Processing



➢**Information Overload**

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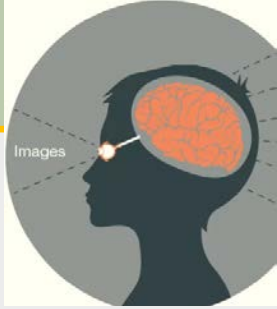
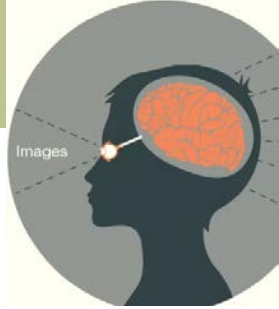
Information Processing

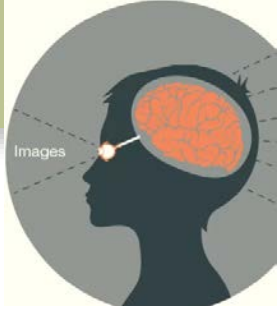


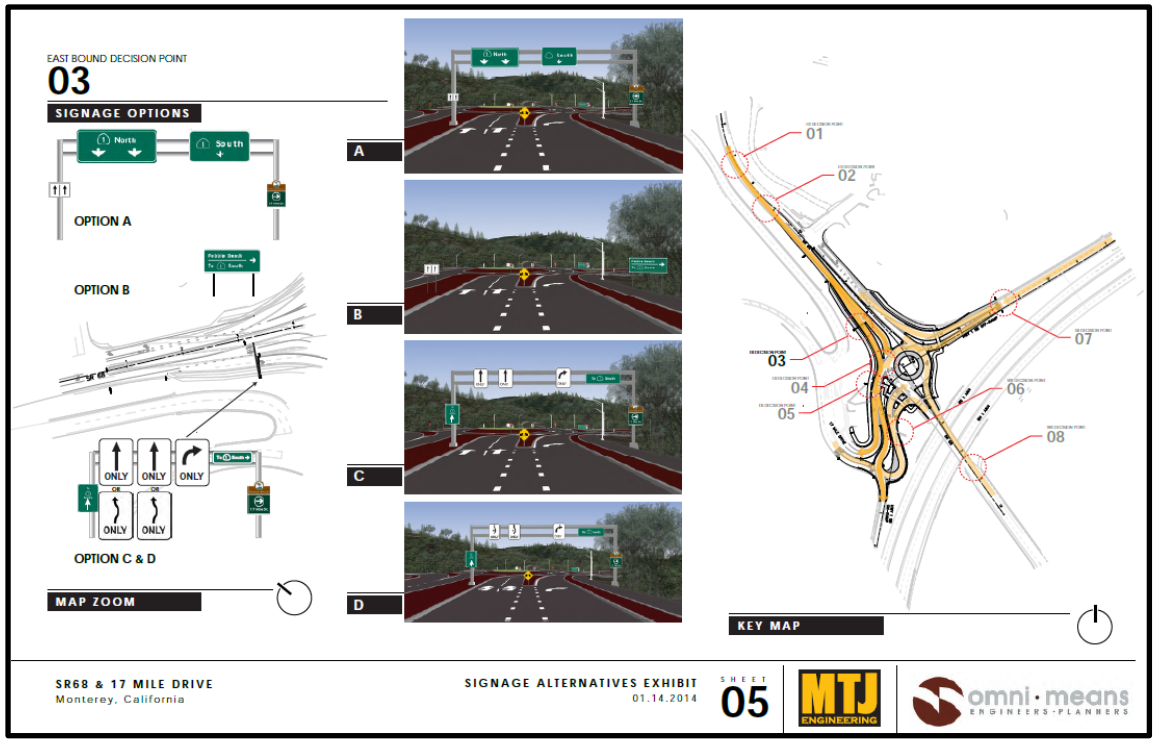
- **Information Overload**

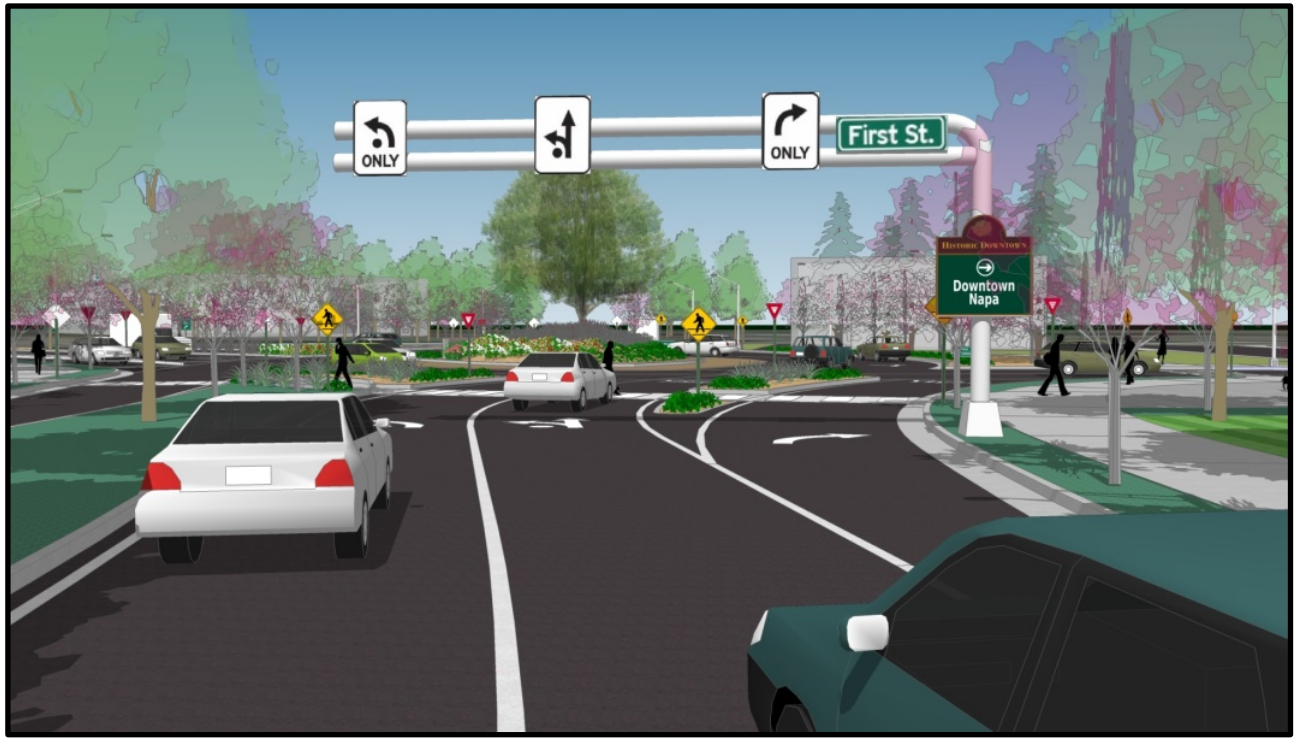


Advance Directional Signing

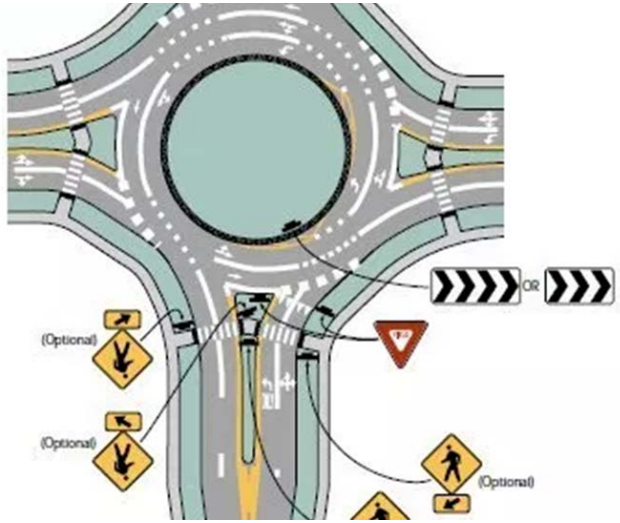
Roundabout Design - Information Processing







MUTCD



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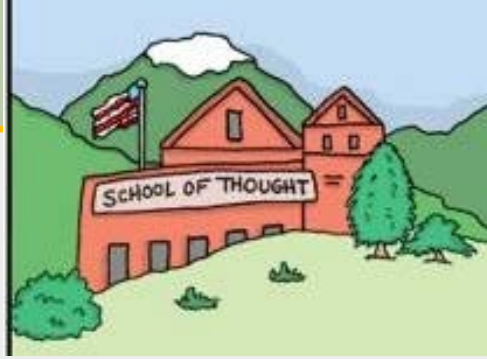
MUTCD *2009*



1. Lane Use Assignment

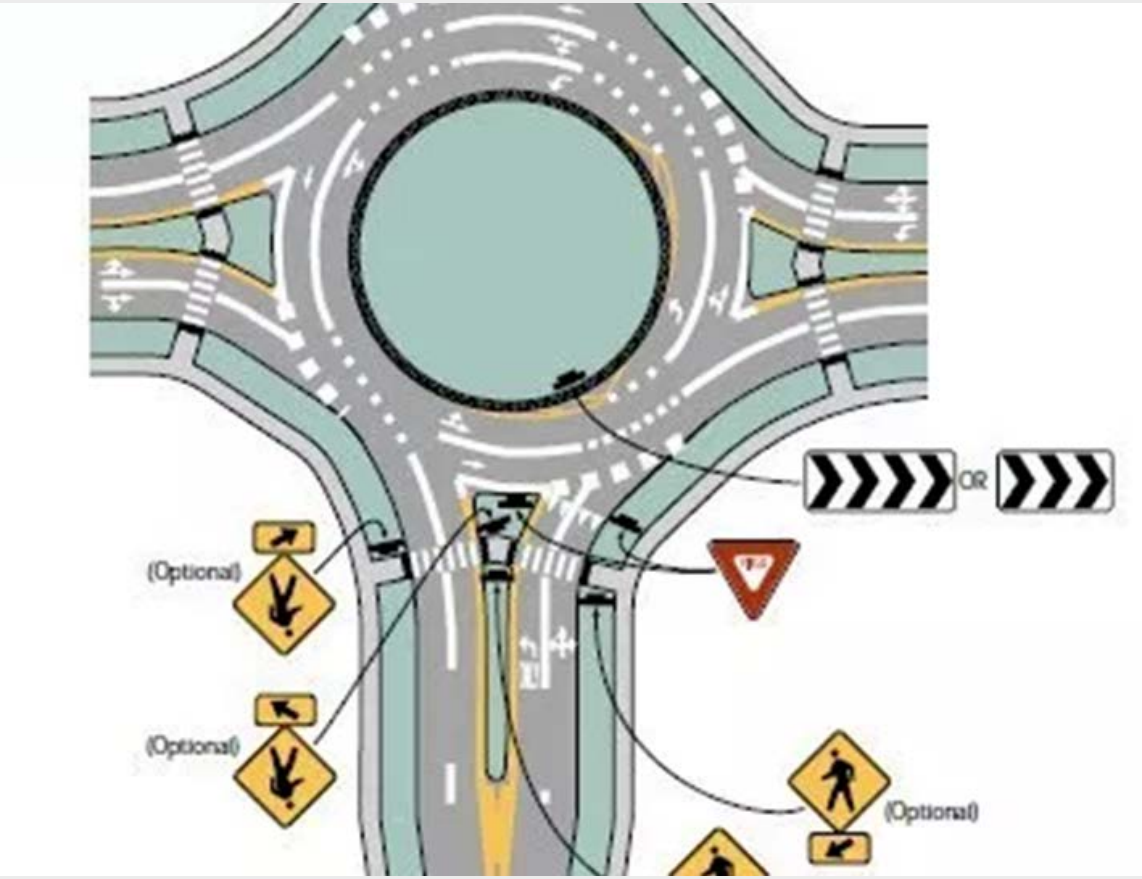
- Fish Hook or
- Standard

2. Circulatory Roadway Markings

- Solid/Skip vs
- Consistent Line

3. Yield/ Entry Markings

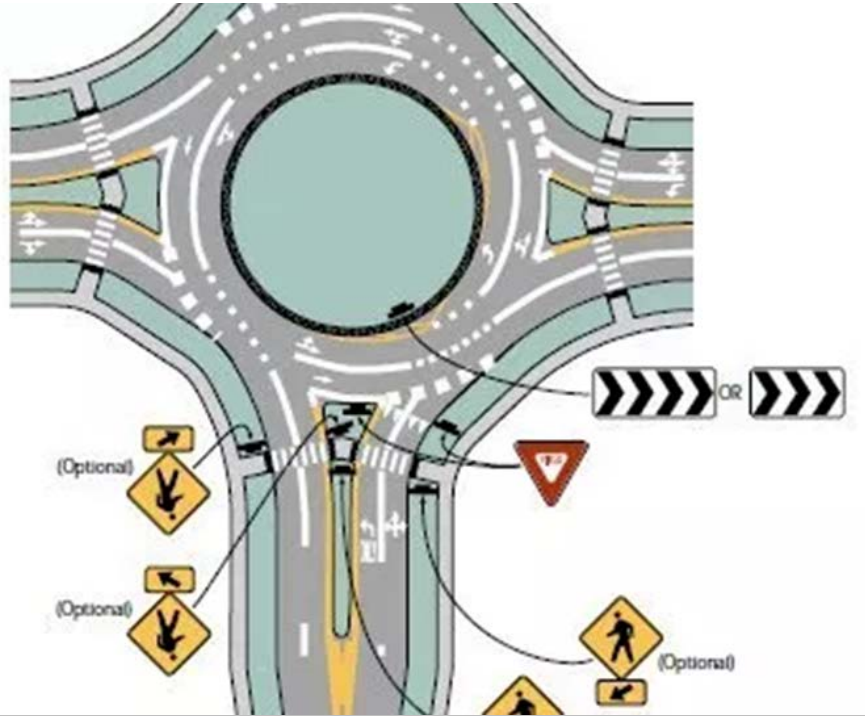
- Edge Line Extended, and Sharks Teeth
- vs Singular Heavy Demarcation



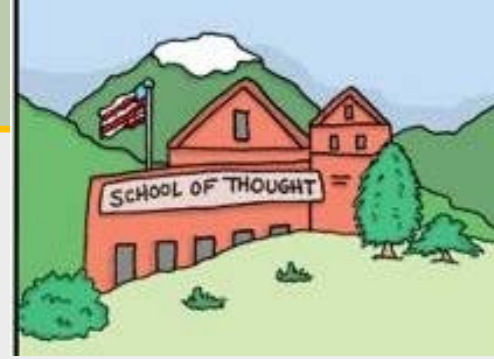
MTJ ROUNDABOUT engineering

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

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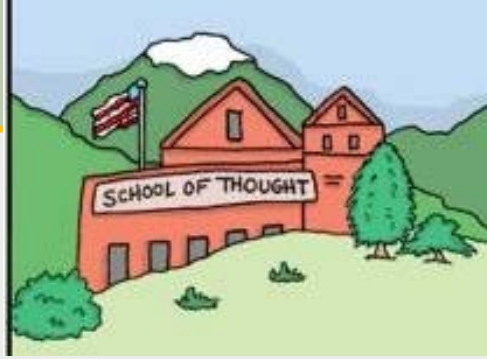
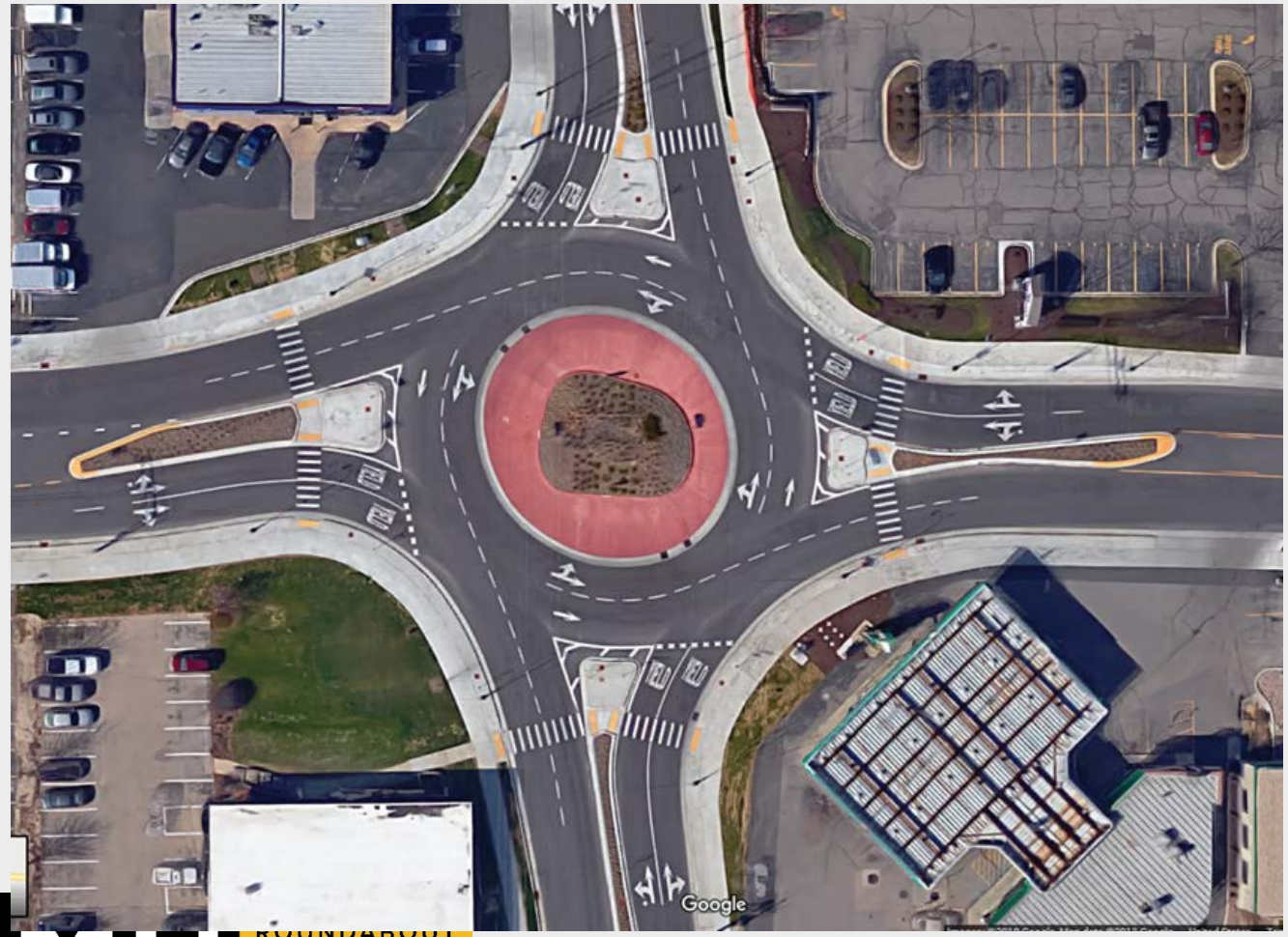
1. MUTCD Lane Use Assignment



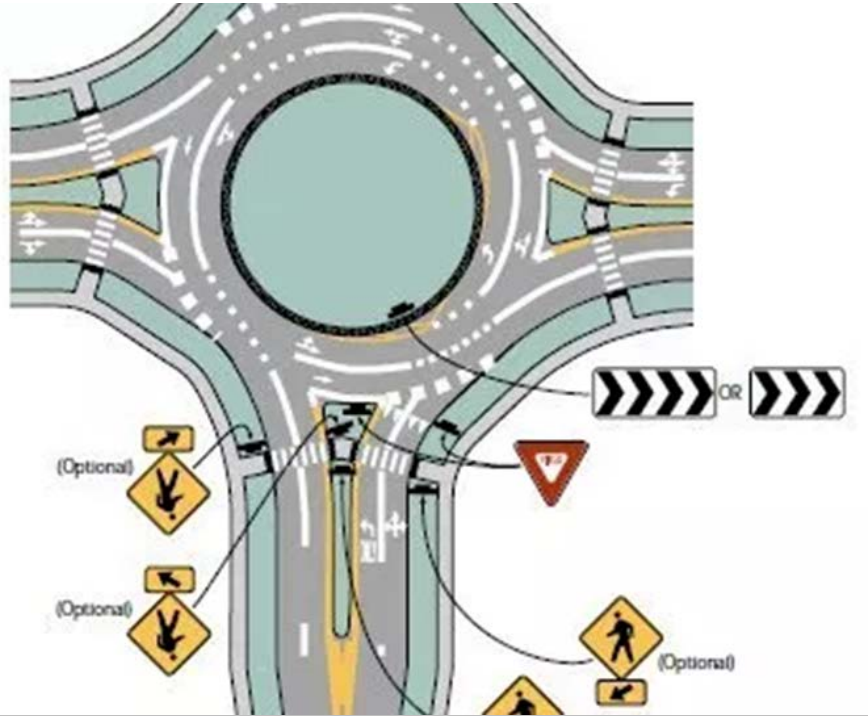
Standard Pavement Marking Arrows



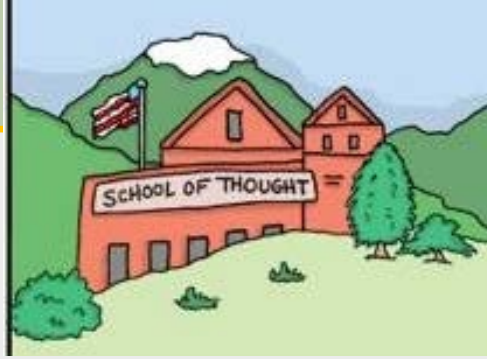
Standard Lane-Use Assignments

2. Circulating Roadway Markings

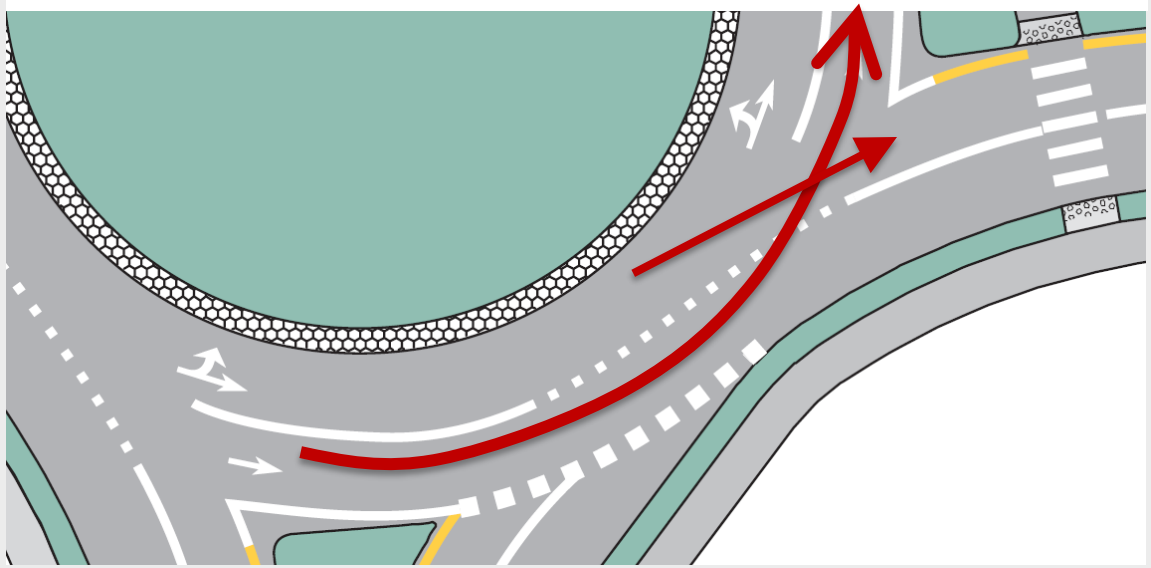
- Solid and Skip
- Consistent Line Type
- Lane Widths (equal or un-equal)



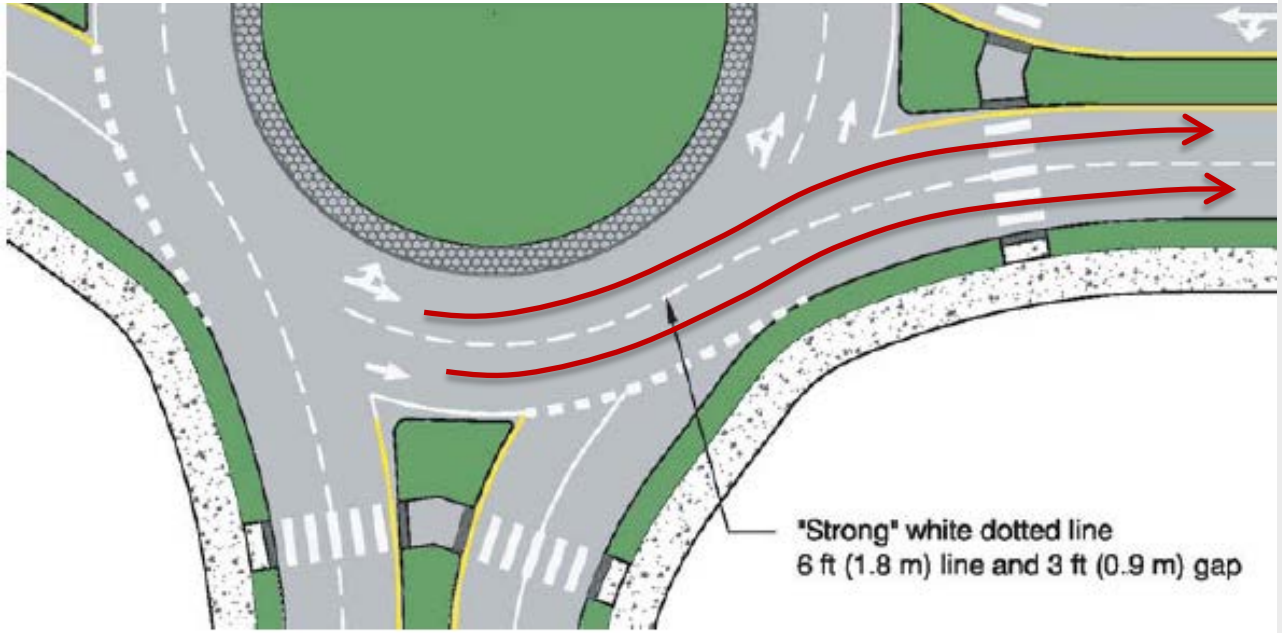
2. MUTCD Circulatory Roadway Markings



Solid / Skip = Problematic - Violates Driver Expectancy



Consistent Line Type = Driver Expectancy



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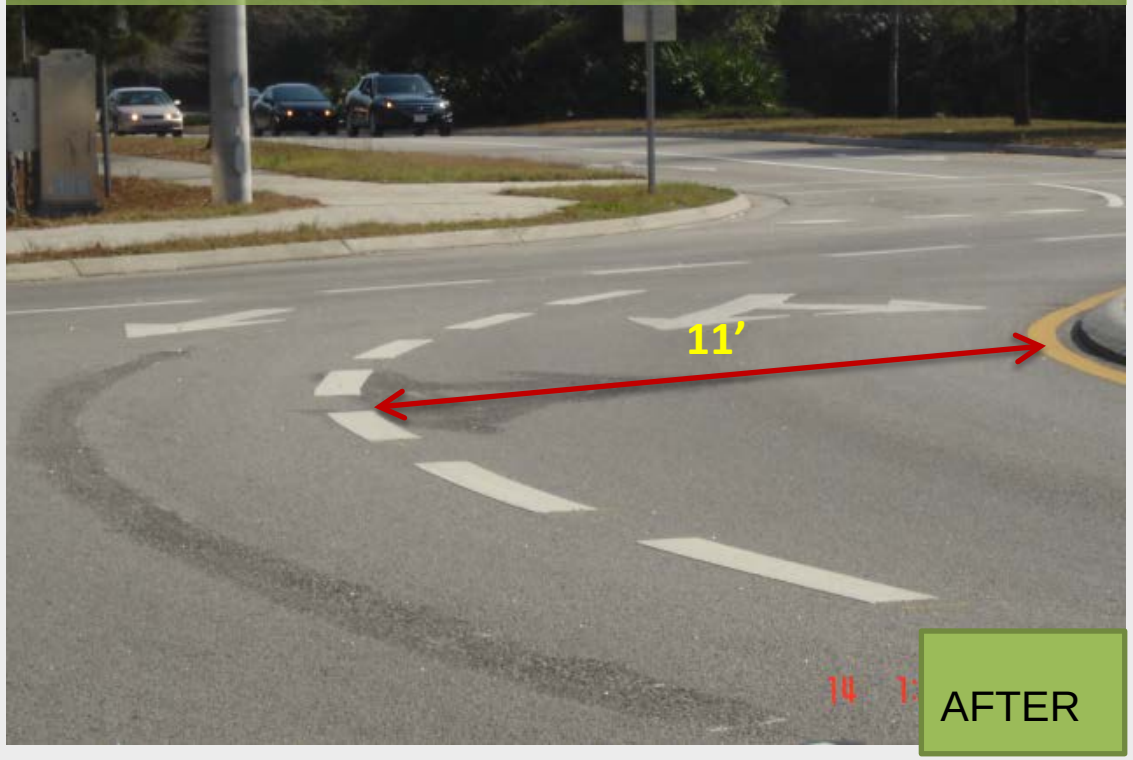
2. MUTCD Circulatory Roadway Markings

Circulating Marking Type and Alignment

Existing Confusing Messaging

Clarity in Priority Messaging



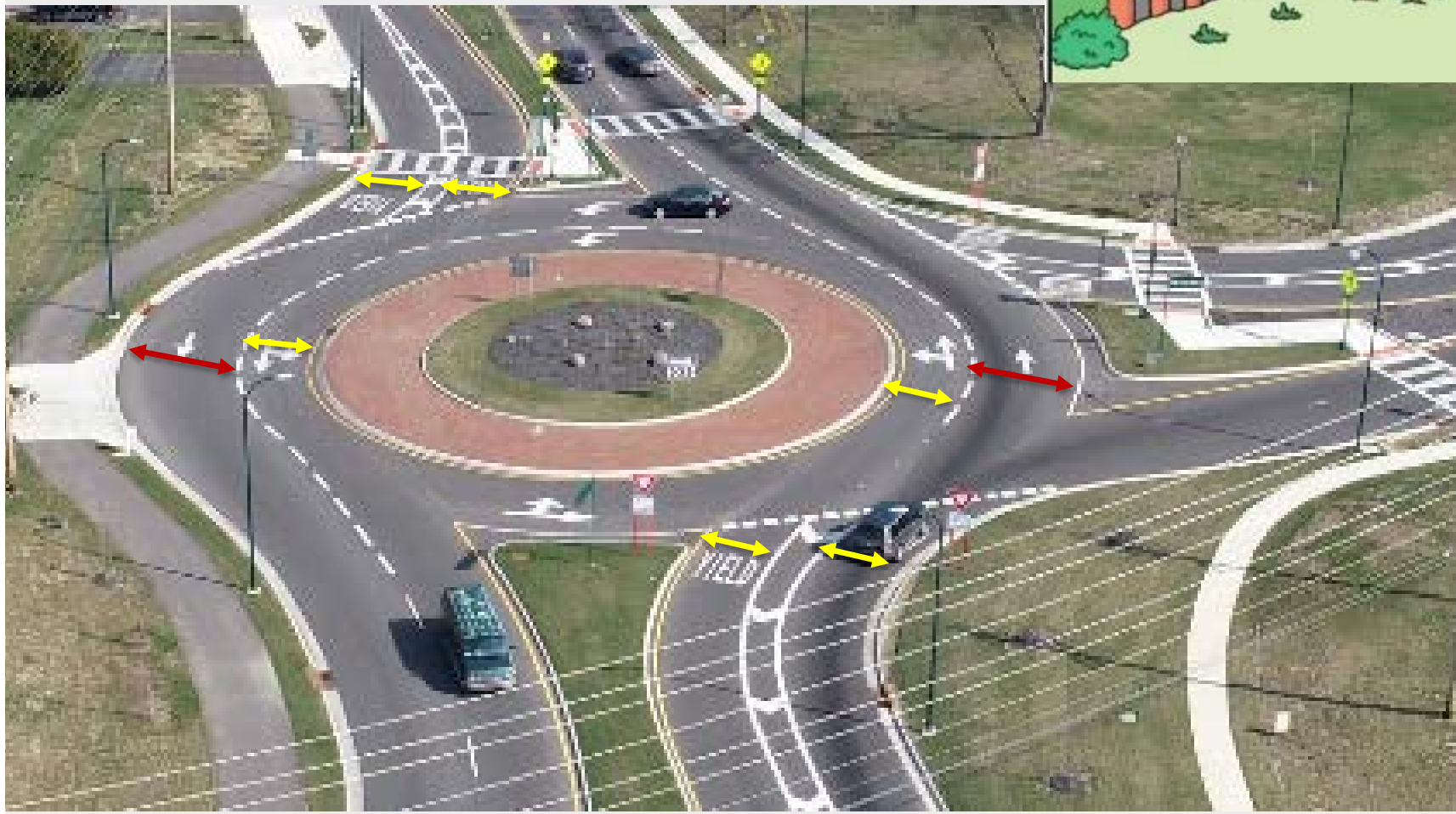
2. MUTCD Circulatory Roadway Markings

Consistent Circulatory Markings

11’ Inside

17’ Outside

- Effective lane utilization at entry
- Improved Entry/View Angles at entry
- Correct Priority Message, Yielding Behavior



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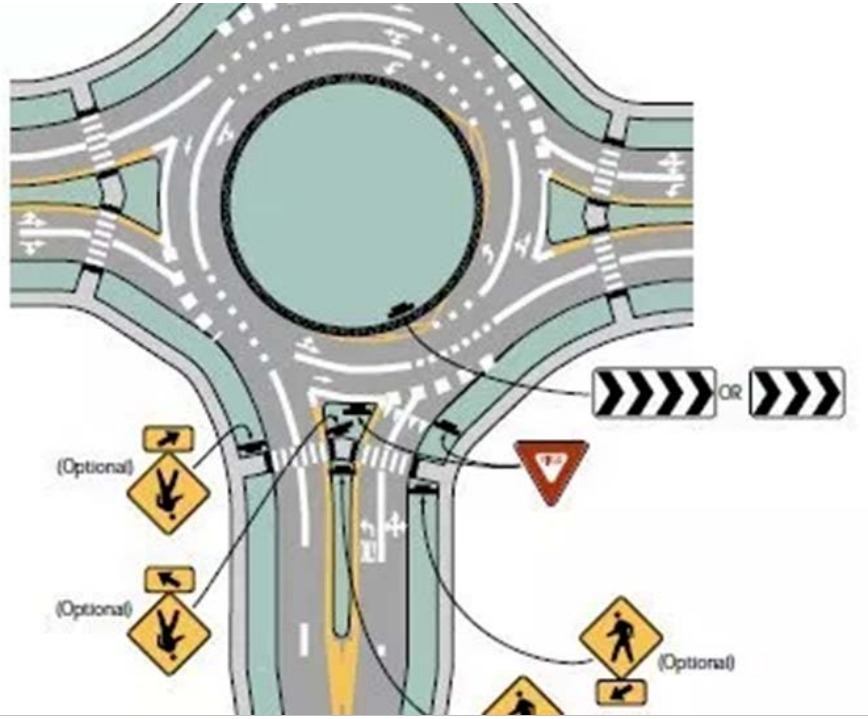
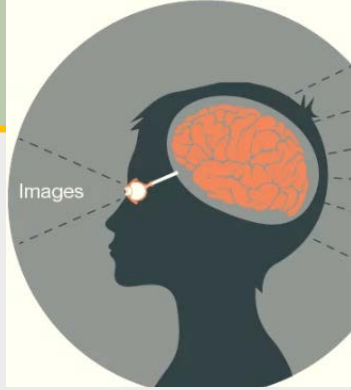
3. Entry Markings / Yield Line

- 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

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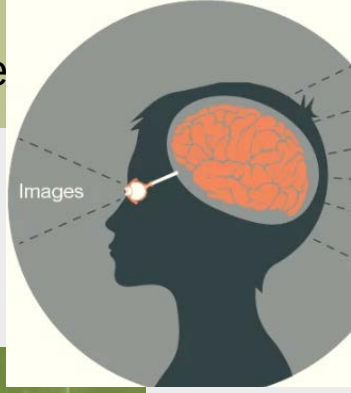
3. MUTCD Entry Markings - Yield Lines

Driver Messaging via Pave



CLEAR MESSAGE AT ENTRY

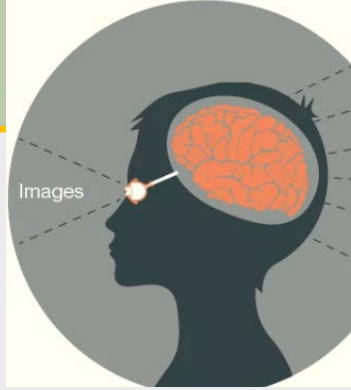
Existing Confusing Messaging

Before

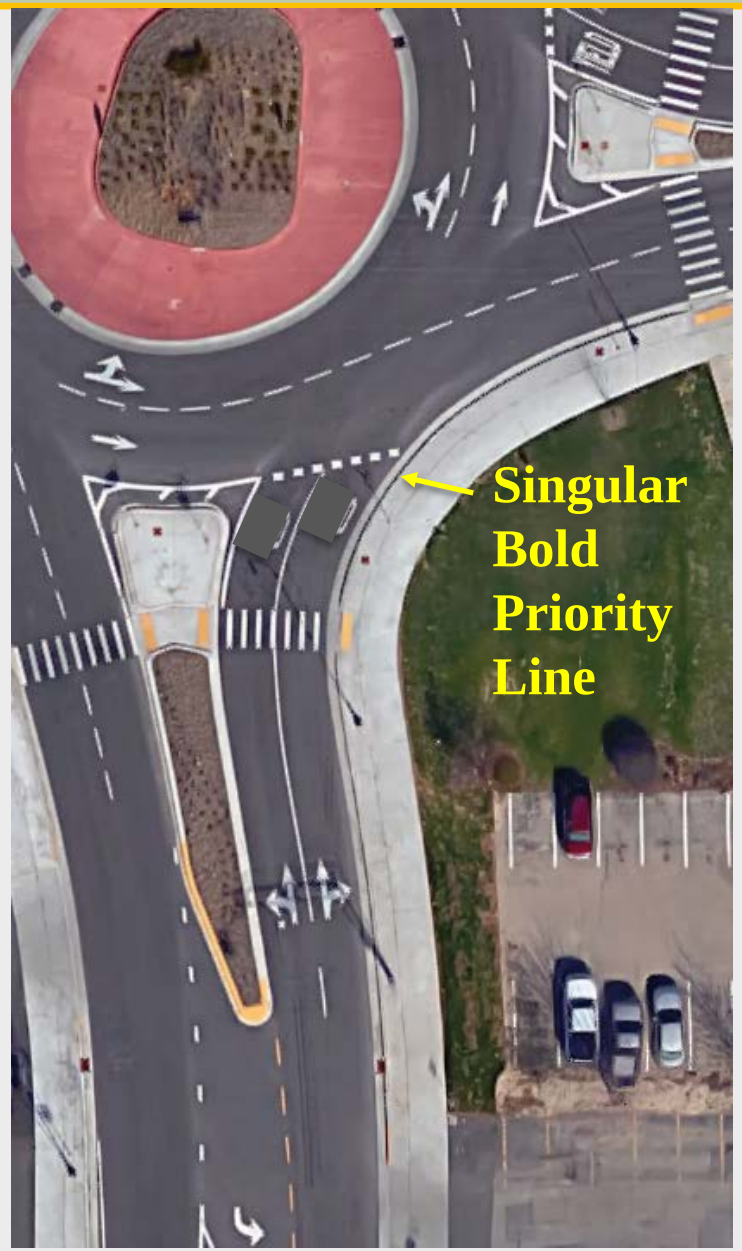
Singular Bold Priority Line

After

3. MUTCD Entry Markings - Yield Lines



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



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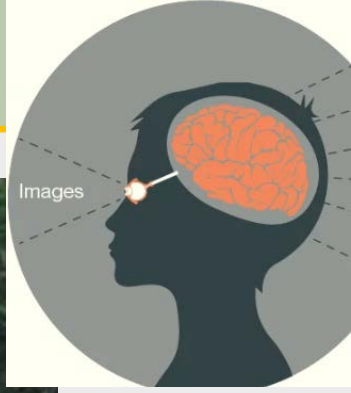
3. MUTCD Entry Markings - Yield Lines



Roundabout Design – Safety

80% Reduction of wrong movements from outside lane

Consistent circulating markings

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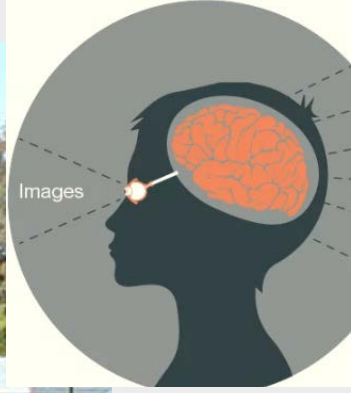
Roundabout Design –



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

Source: John Hourdos
Minnesota Traffic Observatory, University of MN

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POLL QUESTION #5

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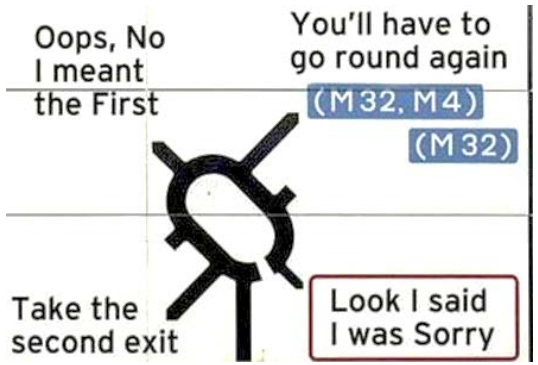
SUMMARY

Don Quixote by Pablo Picasso



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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

Don Quixote by Pablo Picasso

C. Composition – "Bringing it All Together"

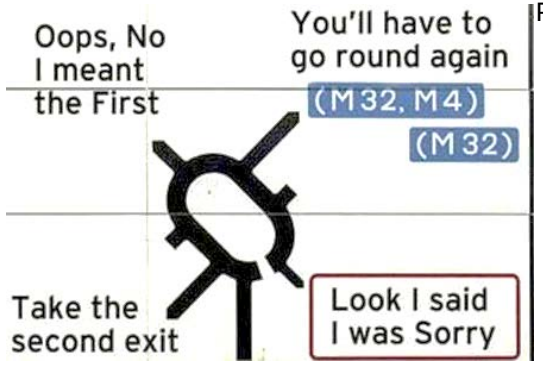
i. Design for Context

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**



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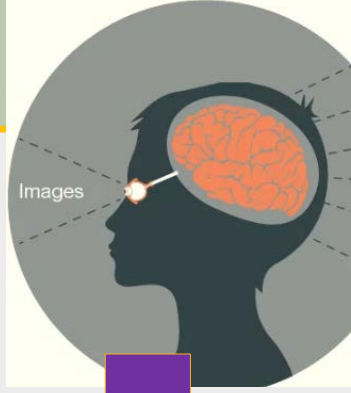
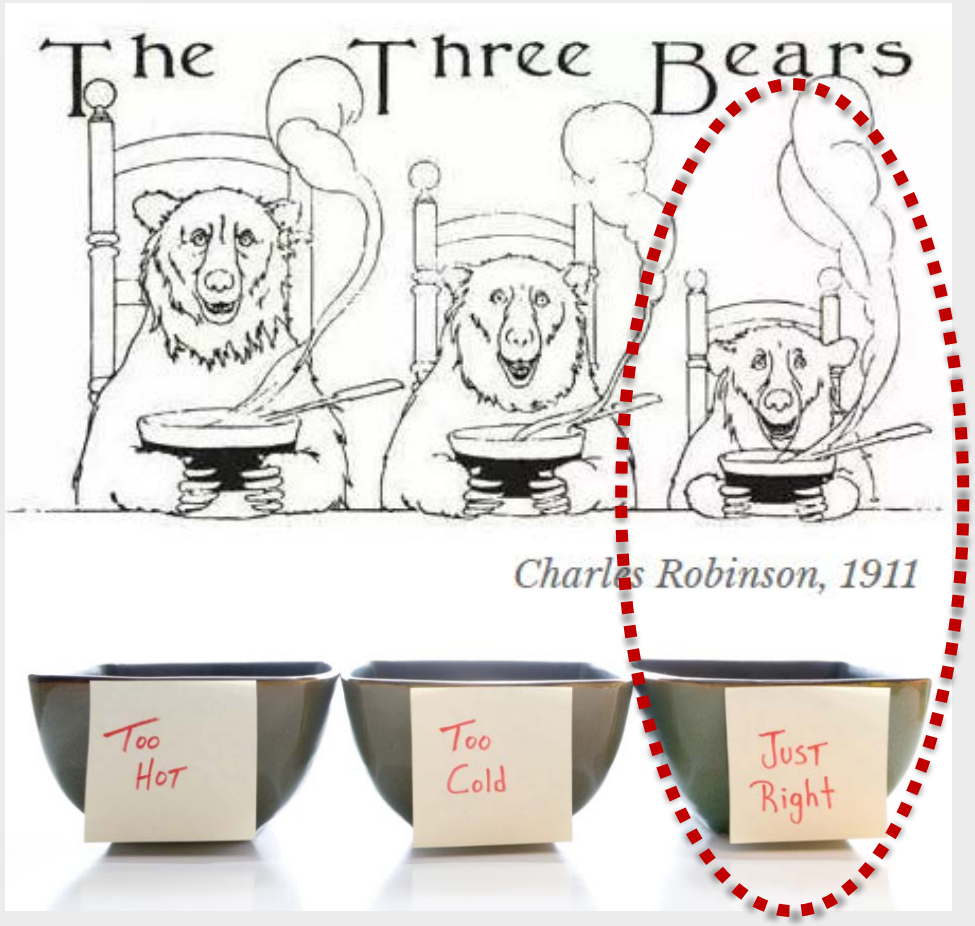
SUMMARY – Signs and Markings



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**



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Thank You/ Questions