The National Academies of
SCIENCES · ENGINEERING · MEDICINE

TRANSPORTATION RESEARCH BOARD

Turbo-charged: Turbo roundabout advancements

Wednesday, January 29, 2020
2:00-3:30 PM ET

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Providers Program. Credit earned on completion of this program will be reported to RCEP. A certificate of completion will be issued to participants that have registered and attended the entire session. As such, it does not include content that may be deemed or construed to be an approval or endorsement by RCEP.

RCEP

REGISTERED CONTINUING EDUCATION PROGRAM

Purpose

To discuss international experiences with turbo roundabouts and identify key considerations for U.S. implementation.

Learning Objectives

At the end of this webinar, you will be able to:

- Describe the multilane roundabout crash patterns that prompted implementation of turbo roundabouts
- Describe the geometric and operational characteristics of turbo roundabouts
- Identify public outreach strategies for turbo roundabouts
- Locate available resources to inform turbo roundabout implementation in the U.S.

TURBO ROUNDABOUT BASICS

Brian Moore, PE and Jaap Tigelaar

January 29, 2020

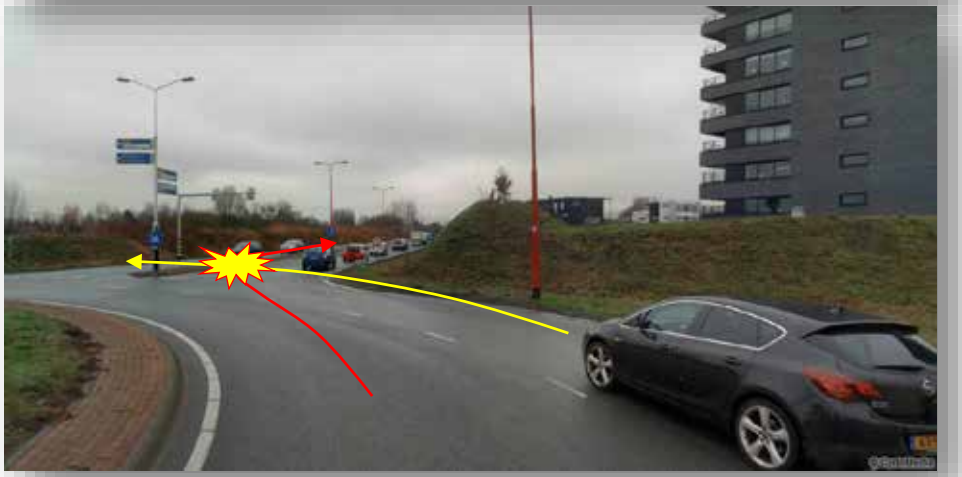
Travel to Netherlands

One Potential Solution…

- Different solutions to 2x2 problem
- Turbo roundabout is one of those
- Solution will depend on specific location

History of the Turbo Roundabout

- Single lane roundabouts introduced in the eighties in the Netherlands
- With the increase of traffic volumes, single lane roundabouts replaced by multilane roundabouts
- Standard multilane roundabout has safety issues: weaving conflicts



Why Turbo Roundabouts?

- **Challenge:** design a layout which eliminates the safety conflicts and increases capacity
- **Result:** spiral shaped Turbo Roundabout without lane changing on the roundabout
- **Why the name Turbo Roundabout?** Refers to the improved traffic flow (compared to a standard multilane roundabout)

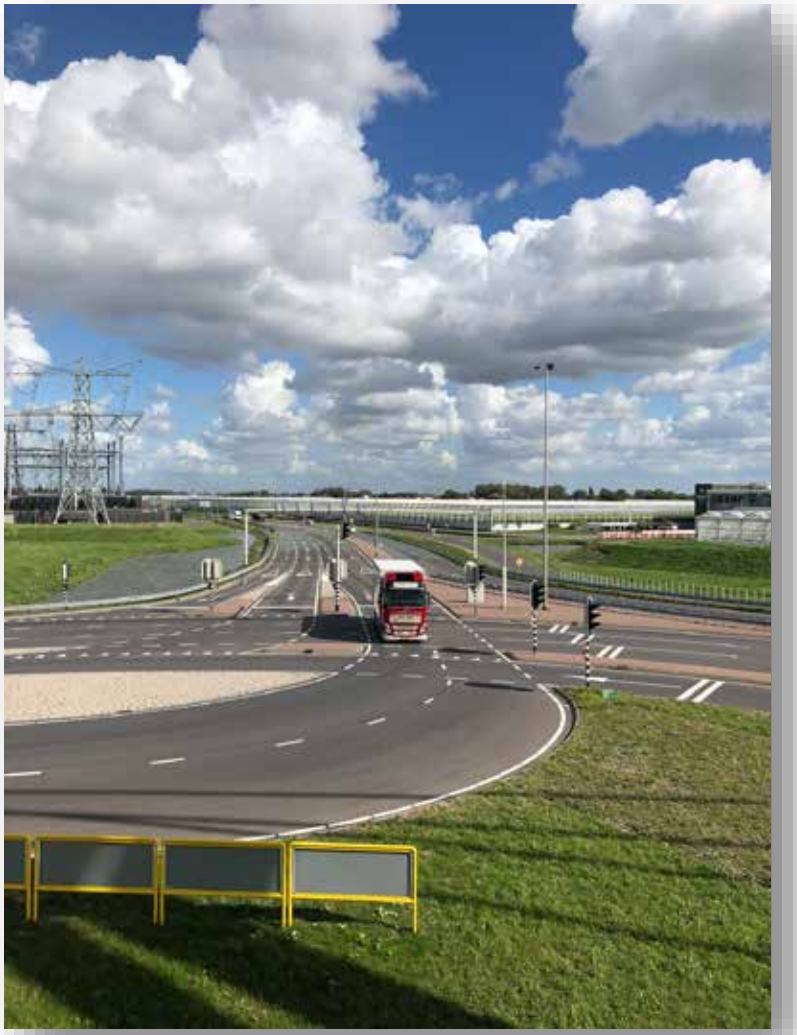
Turbo Roundabout Basics

Turbo Roundabout characteristics:

- No lane changing
- Lane choice upstream
- Spiral layout
- Radial approaches

© CROW Guideline: turborotondes

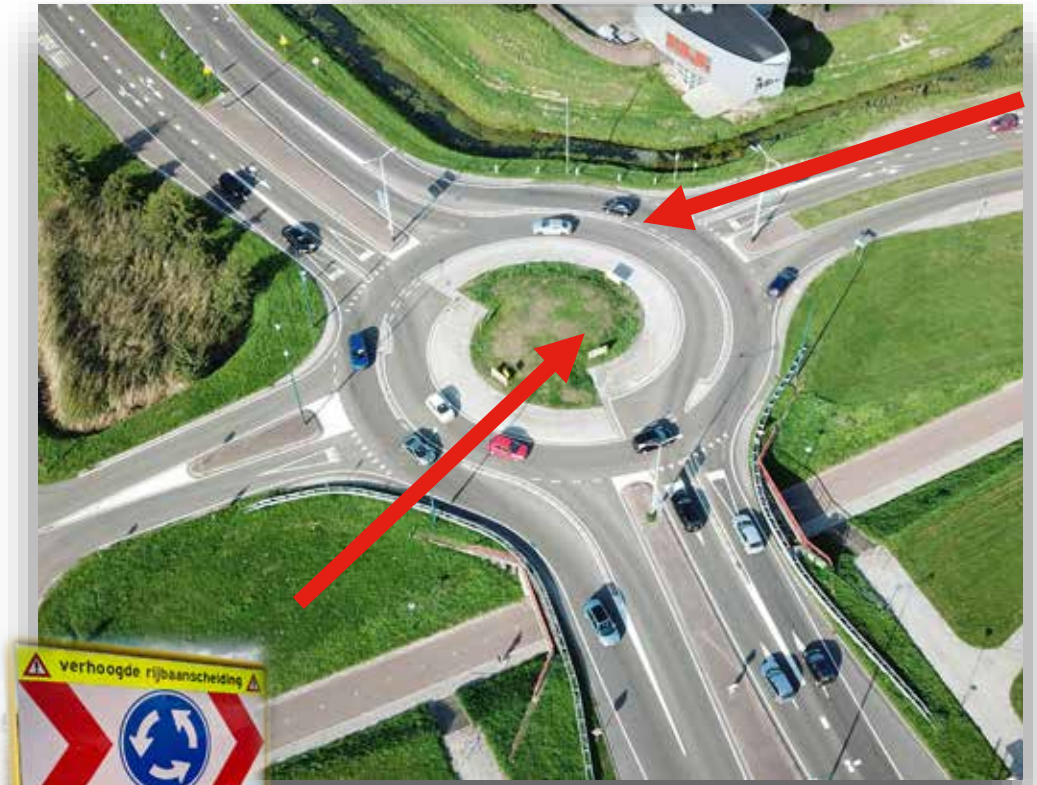
Number of Entry Lanes



Number of Exit Lanes

Radial Design

- Signage in front of driver is important
- Use on low speed and high-speed approaches
- Smaller crossing than most in the US



Design Philosophy

- A safe design by geometry
- Radial design results in:
  - Short crossing distance to the middle lane of the Turbo Roundabout
  - Small conflict area
  - Good sight lines (don’t need to look over the shoulder)
- Low speeds on the Turbo Roundabout and a short crossing distance are also beneficial for capacity!

Spiral Lay-Out

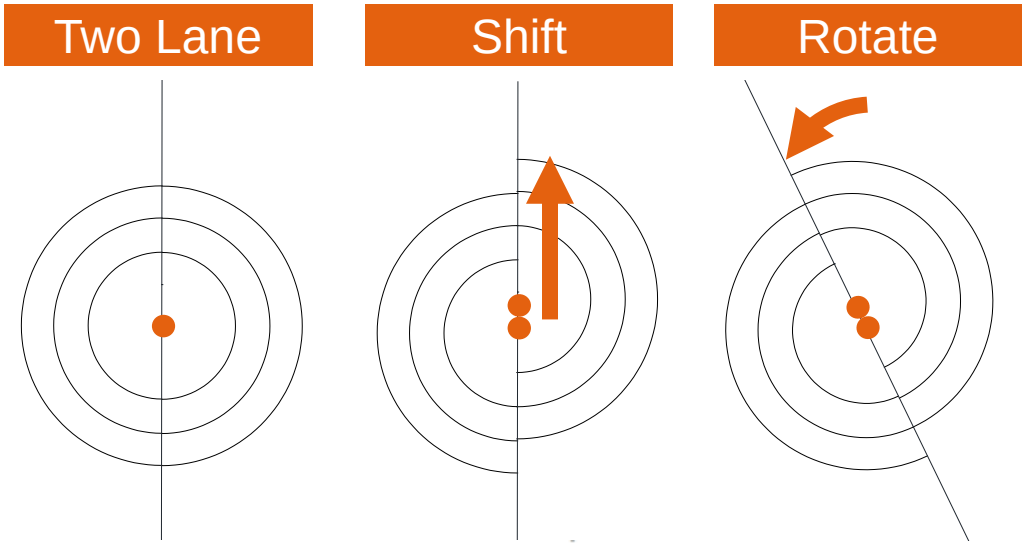
Create the spiral:

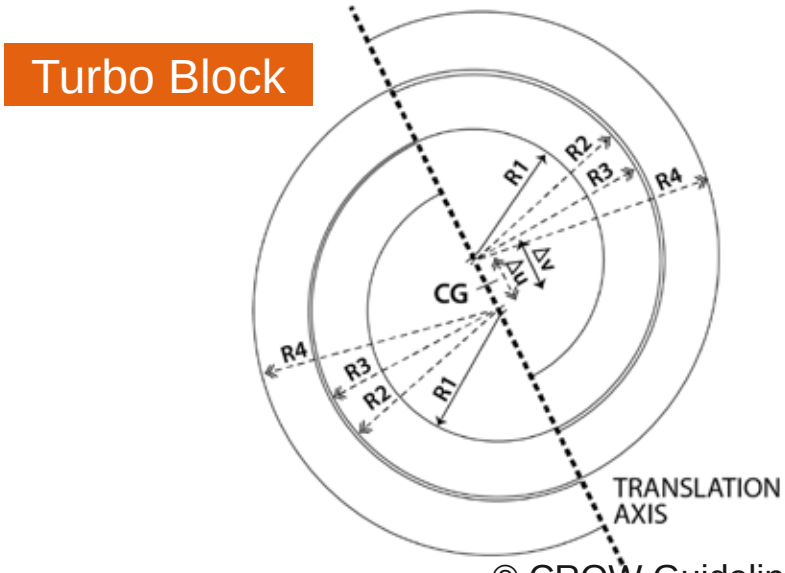
1. Two lane roundabout
2. Shift center a lane
3. Rotate

Translation axis:

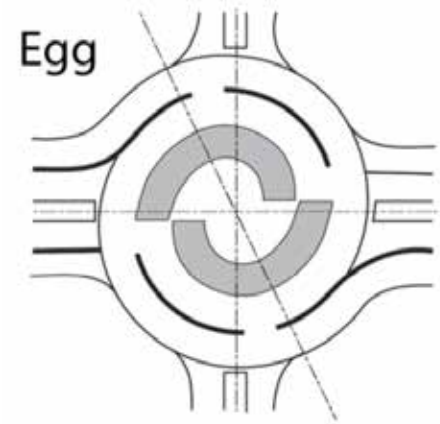
- Based on the major approaches
- Similar curvature all trough traffic

“Turbo-Block”

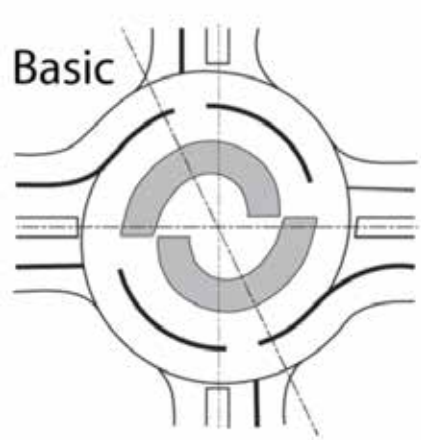




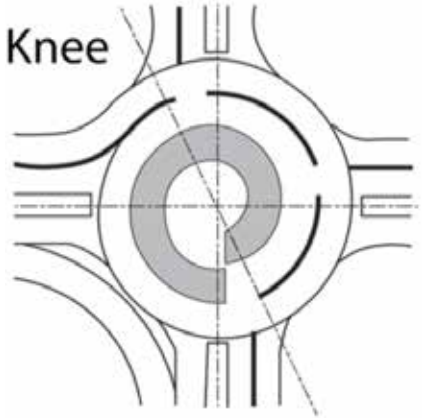
Five Common Geometries



Capacity: 2800 pcu/h



Capacity: 3500 pcu/h



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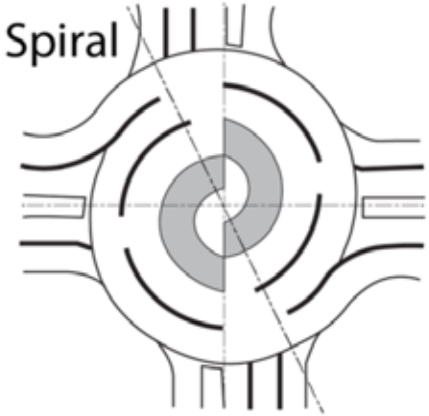
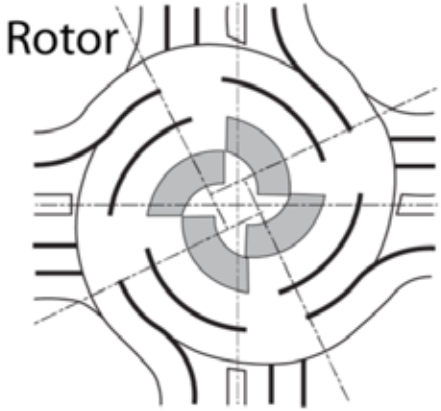


Capacity: 4000 pcu/h

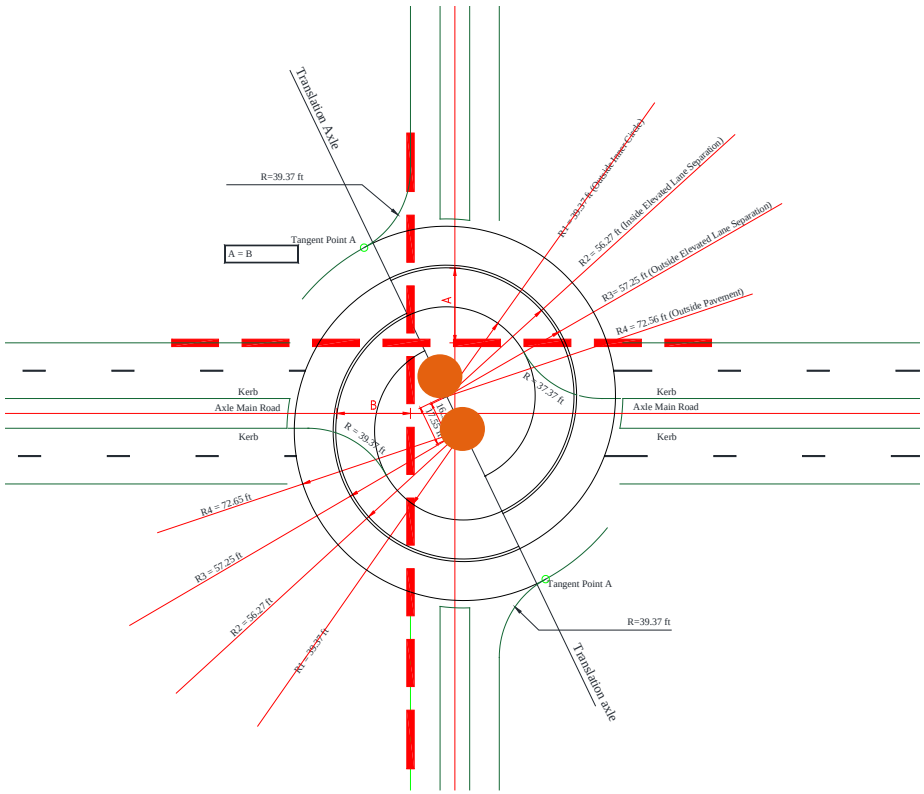


Capacity: 4500 pcu/h

Images based on Vasconcelos et al (2014)

Size

- Dependent on:
  - Number of lanes
  - Design vehicle
  - Roadway widths
- Keep it small to reduce speeds
- Typically design speeds between 23 and 25 mph



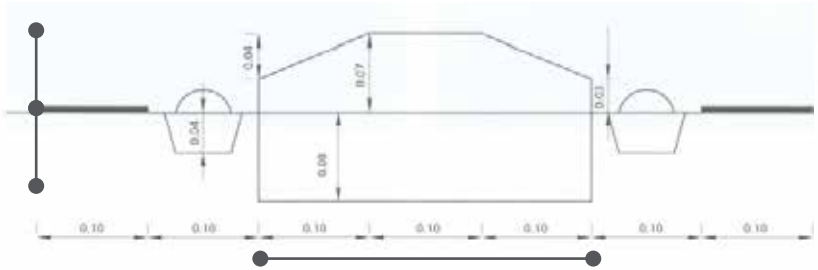
	Small	Standard	Large
Radius Inner	34.5 ft	**39.4 ft**	65.5 ft
Outer diameter (min and max)	140 ft	**148 ft**	197 ft
	155 ft	**165 ft**	213 ft

Lane Divider

Elevated lane separation

2.75 inch

3.15 inch



11.8 inch

Signing and Marking

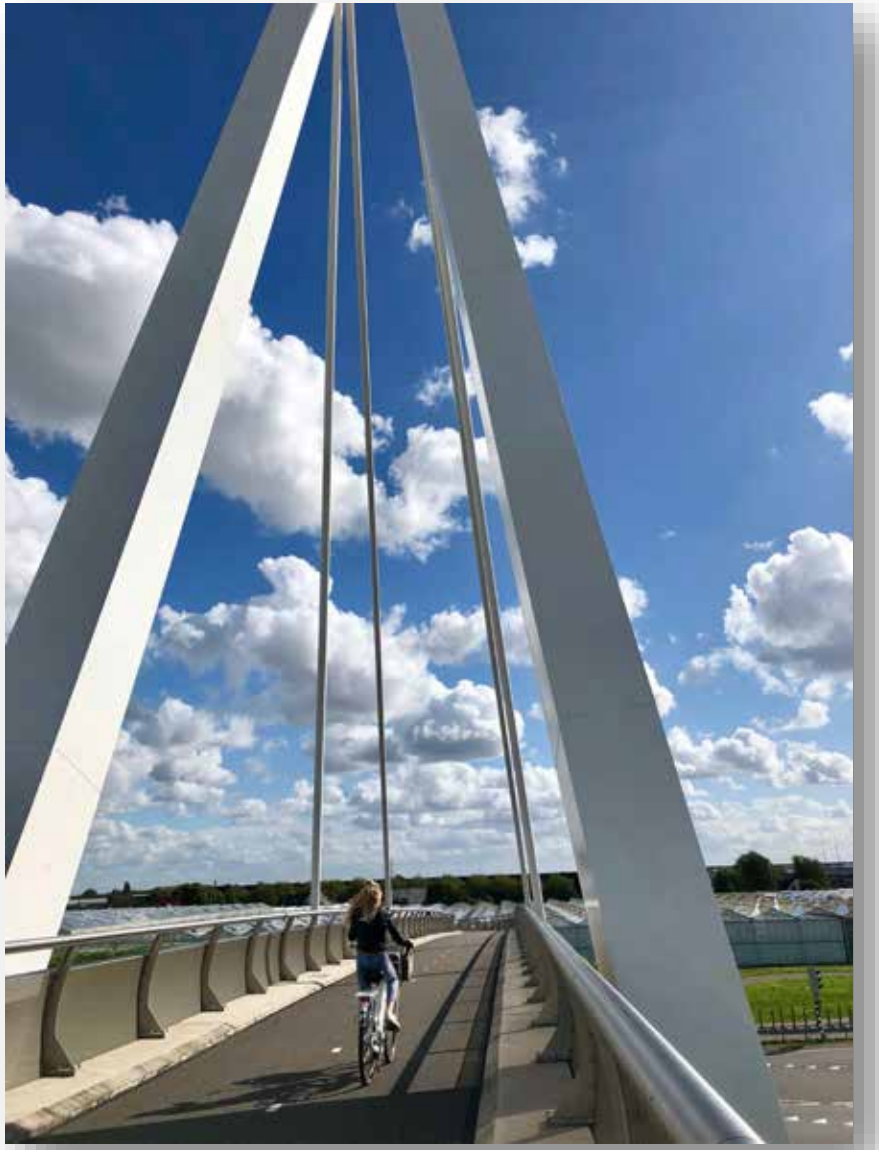
Trucks

- Truck apron
- Different type of material
- Cars stay off

- This truck: 82.8 ft
- Roundabout: 190 ft

©2020 Google Earth®.

Bikes and Peds



Traffic Safety

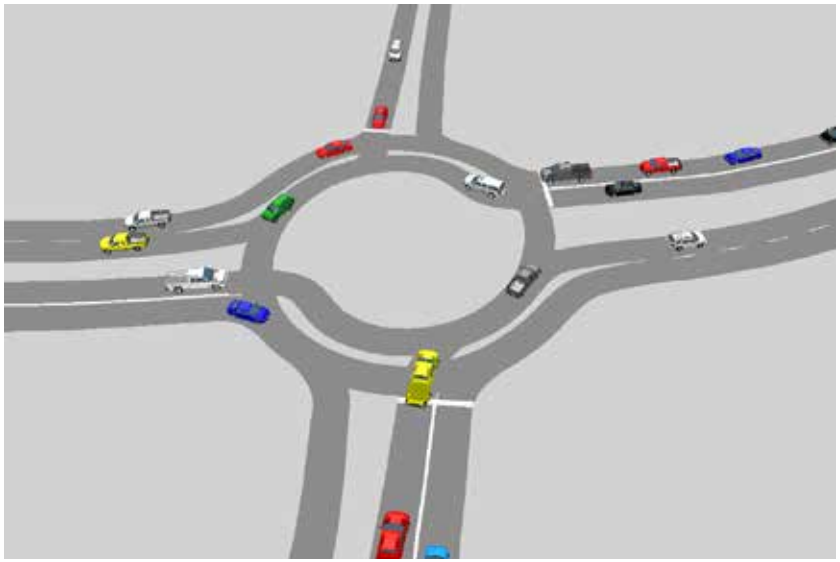
Evaluation study in NL

- Study by Christiaan Vos (2016, high school Windesheim).
- Before and after study injury crashes

From	n	before	after	reduction
Unsignalized	54	76	19	-75%
Signalized	46	73	19	-74%
Single Lane	26	18	7	-61%
Multi Lane	17	17	8	-53%

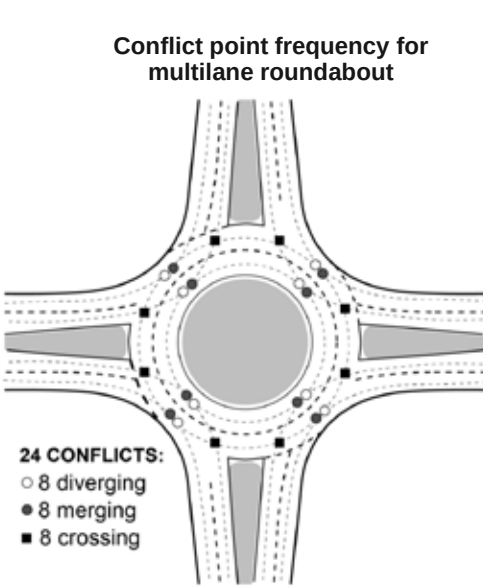
Simulation studies

- Micro simulation and SSAM
- Fewer conflicts
- Lower sever conflicts

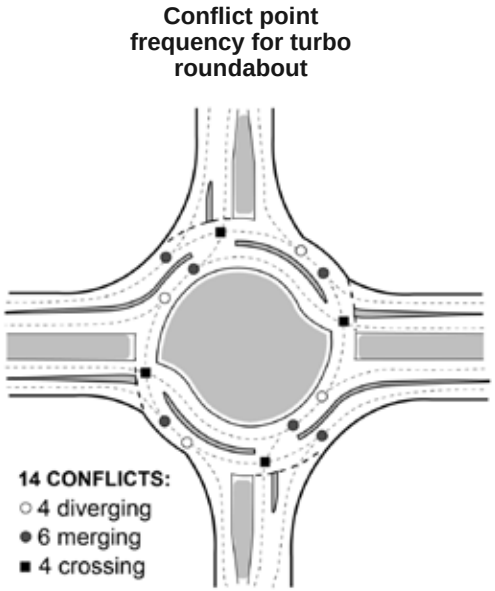


Conflict Reduction

- Turbo Roundabout reduces the number of conflict points
- Multilane roundabout to turbo roundabout
  - Multilane: 24 conflicts
  - Turbo: 14 conflicts
  - Reduction: 10 conflicts = - 42%
- Evaluation study:
  - -53% injury crashes
- Fewer side swipes



Source: FHWA.



Source: FHWA.

Traffic Capacity

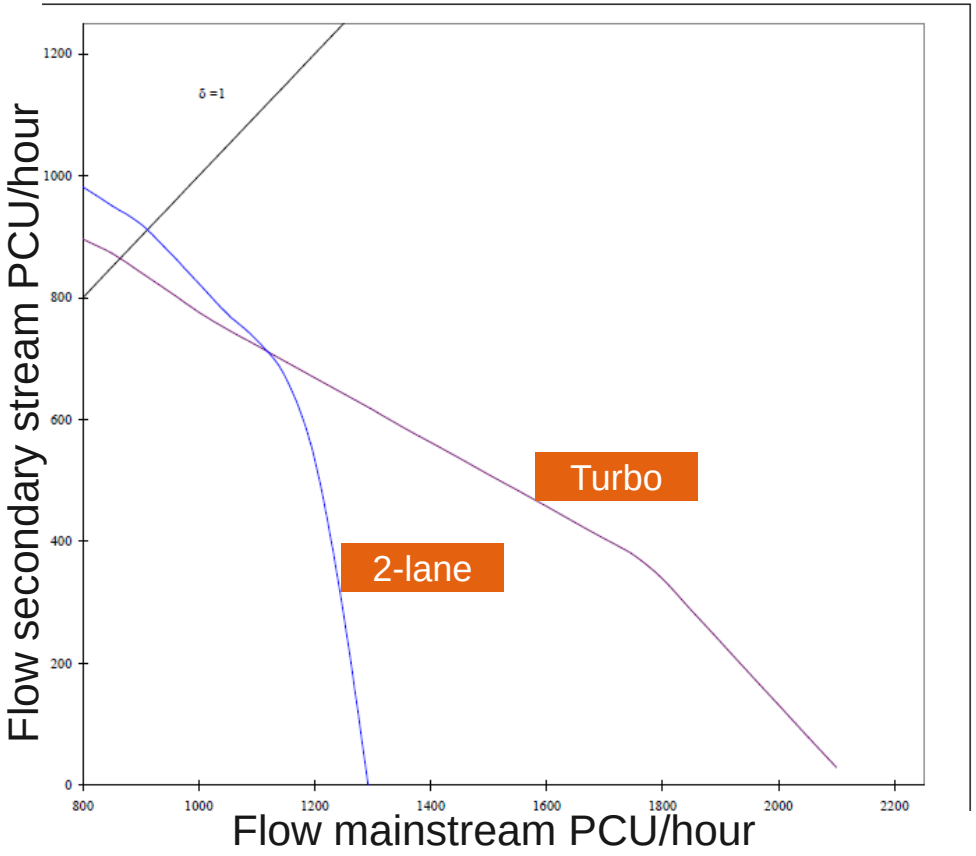
Capacity of intersection alternatives (peak hour volumes in pcu/hr)

Intersection Alternative		Practice Capacity	Theoretical Capacity	Conflicting Traffic
Single Lane Roundabout		2,000	2,700	1,350 - 1,500
Multi Lane Roundabout	2 entry + 1 exit	3,000	3,600	1,800 - 2,000
	2 entry + 2 exit	3,500	4,000	2,100 - 2,400
Turbo Basic Shape		**3,500**	**3,800**	**1,900 - 2,100**
Spiral Roundabout (Turbo)		4,000	4,300	2,000 - 2,300
Rotor Roundabout (Turbo)		4,500	5,000	2,500 - 2,800
Signalized Turbo Roundabout (360 ft)		8,500	11,000	4,200
Minor Road Stop/Yield with Left Turn		1,500	1,800	1,100
Traffic Signal	Entries 3’1 travel	3,500	4,000	3,800
	Entries 3’2 travel	7,500	8,000	3,800

Traffic Capacity

Turbo Roundabout vs Standard Two-Lane Roundabout

- Turbo Roundabout has higher capacity in situations where volume on **main** road is larger than volume on **secondary** road
- Better lane utilization
- Traffic entering are less hesitant
- Radial approach



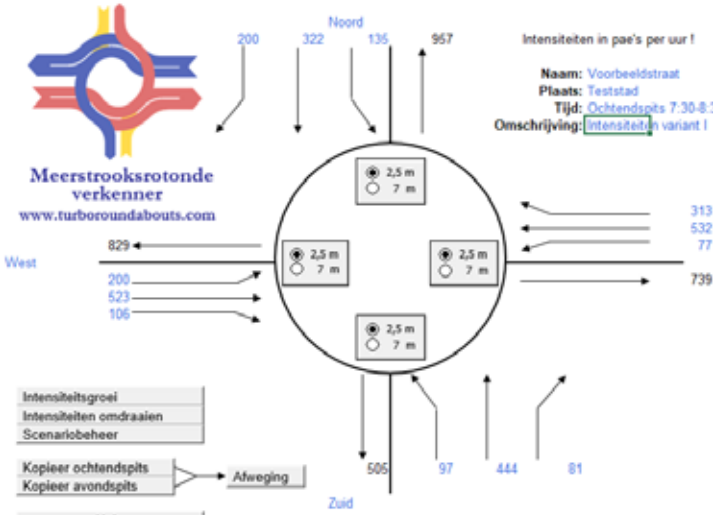
Traffic Capacity

Meestrooksrotonde verkenner

Traffic flow calculation sheet in MS Excel

- **Compares various types of roundabouts:** 1-lane roundabouts, different types of Turbo Roundabouts
- **Input:** traffic flows, 3 of 4 legs, geometry
- **Output:** saturation rate (max 80%), average waiting time (max 50 seconds)

Tool determines the appropriate (turbo) roundabout type

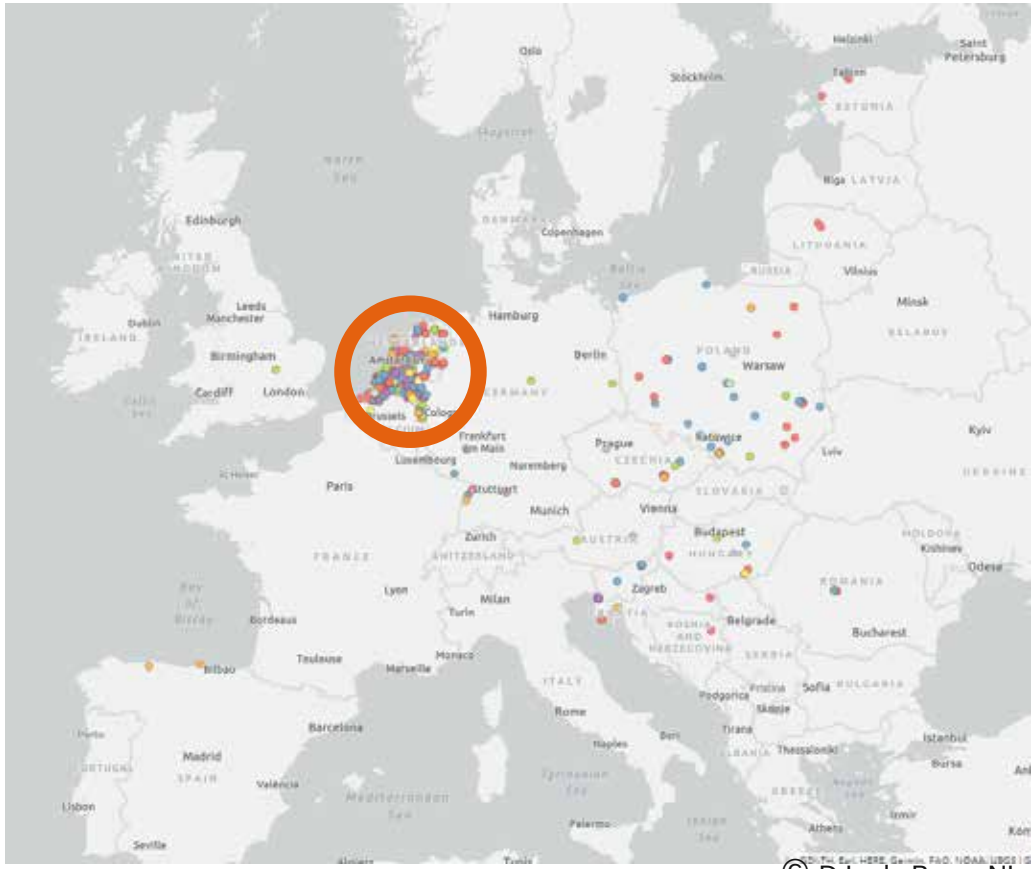


Resultaten		VG	ri.	Tgem	ri.
1str. rotonde		1.22	O	999999.9	O
Passeerb. rotonde	OK	0.79	O	21.6	O
Partiële eirotonde |		1.22	O	999999.9	O
Partiële eirotonde --		0.90	OR	44.9	N
Partiële turborotonde |		0.80	OL	24.3	OL
Partiële turborotonde --		0.90	OR	37.0	OR
Eirotonde |		1.17	O	999999.9	O
Eirotonde --		0.87	N	35.1	N
Turborotonde |	OK	0.79	WL	20.5	OL
Turborotonde --	OK	0.72	ZL	17.0	ZL
Knierotonde '-	OK	0.73	ZL	17.7	ZL
Knierotonde ,-		0.99	OR	684.4	OR
Knierotonde -,	OK	0.71	WL	13.6	ZR
Knierotonde -'	OK	0.78	OL	21.1	OL
Spiraalrotonde |	OK	0.63	OM	11.8	OM
Spiraalrotonde --	OK	0.57	ZM	10.6	ZM
Rotorrotonde	OK	0.34	WL	6.4	ZL
Specifieke 3-taks rotondes:					
Gestr. knie -'-		nvt	nvt	nvt	nvt
Gestr. knie I-		nvt	nvt	nvt	nvt
Gestr. knie -,-		nvt	nvt	nvt	nvt
Gestr. knie -I		nvt	nvt	nvt	nvt
Sterrotonde -'-		nvt	nvt	nvt	nvt
Sterrotonde I-		nvt	nvt	nvt	nvt
Sterrotonde -,-		nvt	nvt	nvt	nvt
Sterrotonde -I		nvt	nvt	nvt	nvt
				in s/pae	

Global Appearance

Turbo Roundabouts

- Almost 500 in the world
- 371 of them in the Netherlands
- Others are mainly located in Eastern Europe



Questions?

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Motivation for Turbo Roundabout Consideration

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Hilliard, Ohio

- Suburb of Columbus , OH
- Population: ~35,000
- Metro Area Population: ~2M

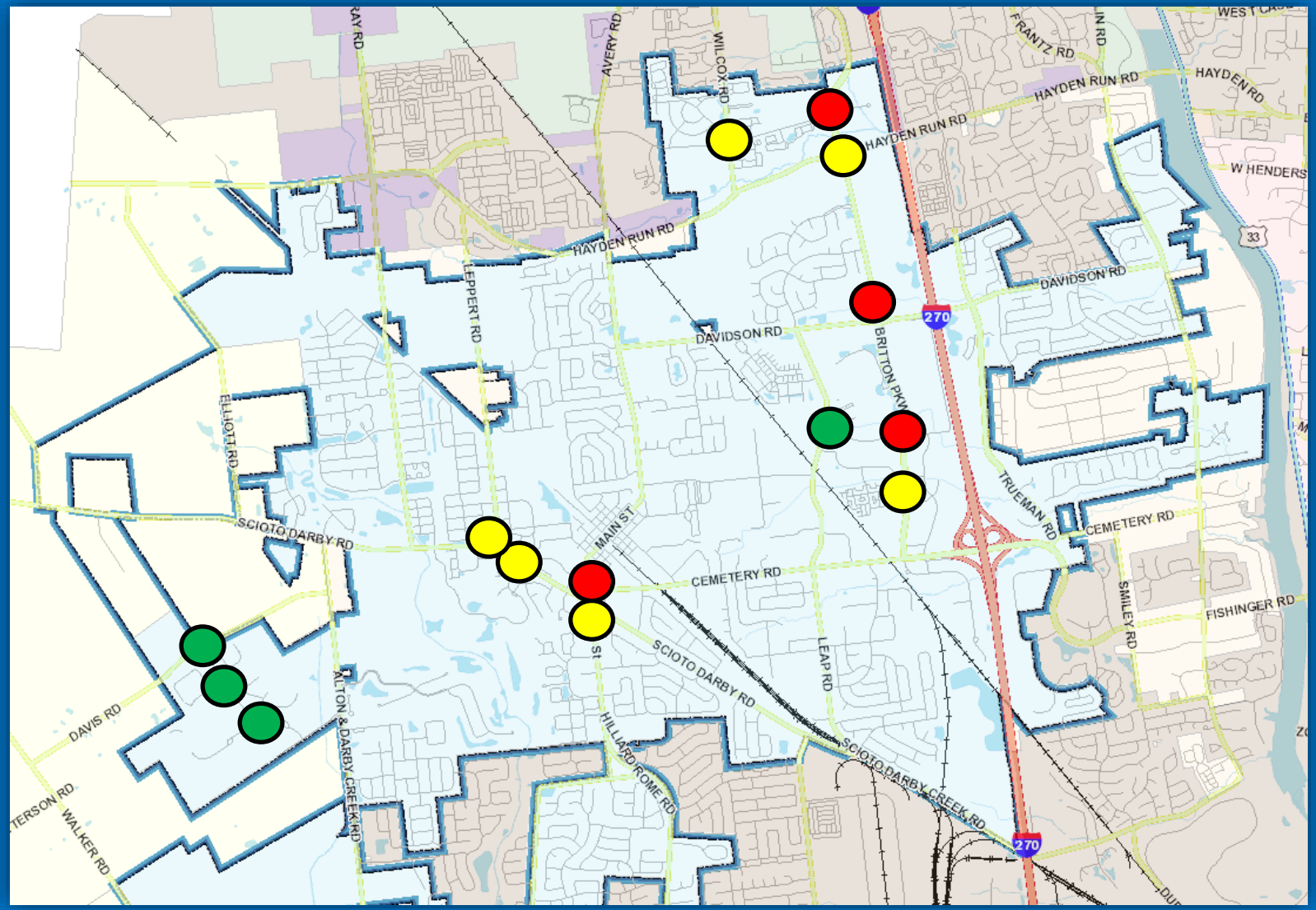
Hilliard, Ohio Roundabouts

2006 - 2019

- Single Lane (4)
- 2x1 (hybrid) Multi-lane (6)
- 2x2 Multi-lane (4)

2020 - 24

~ 9 more in planning, design or construction



Roundabouts: What's Not to Love????

- ü Saves lives
- ü Moves traffic efficiently
- ü Slows traffic down
- ü Community focal point
- ü Beautification
- ü Environmentally-friendly

Then Why Do We See This?

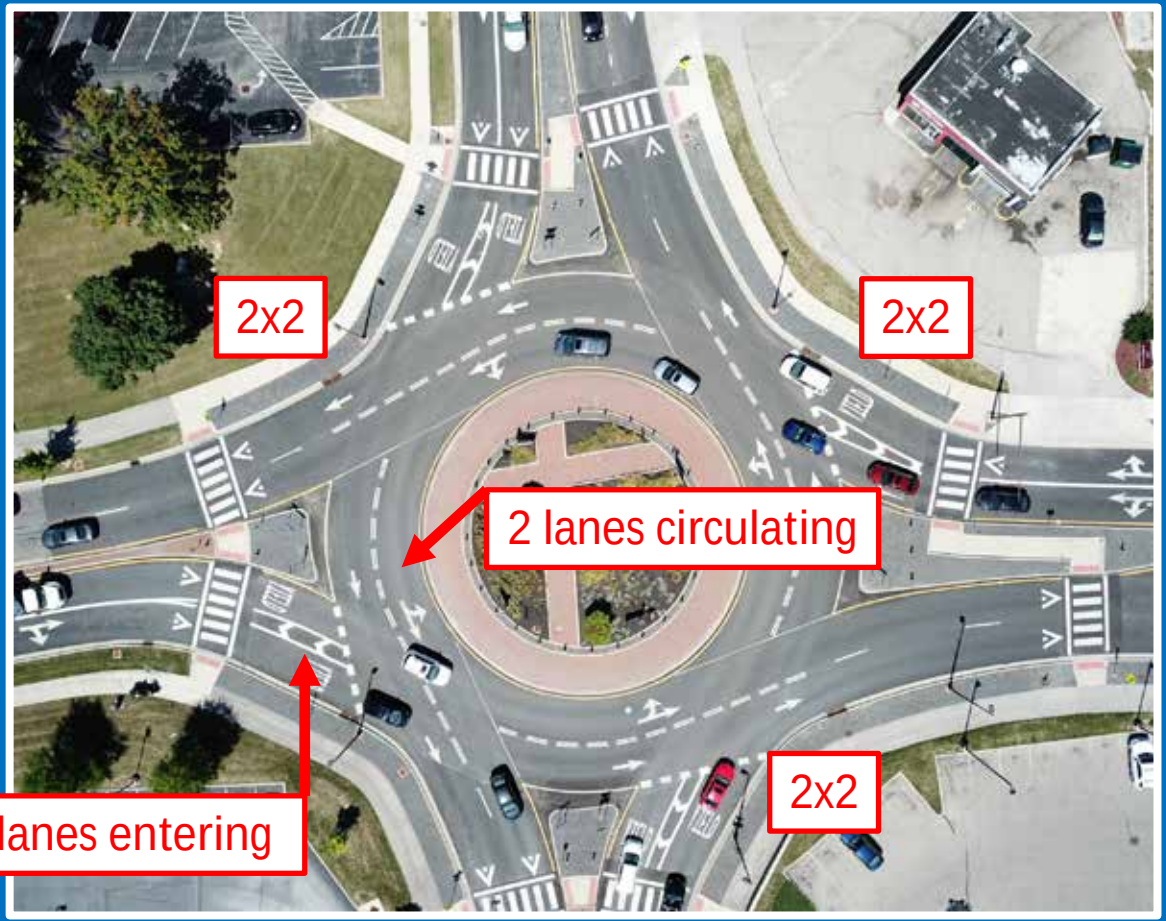
Engineers: Where Did We Go Wrong?

- We did not understand the dangers of overbuilding, making some roundabouts larger, faster & more complicated than they needed to be

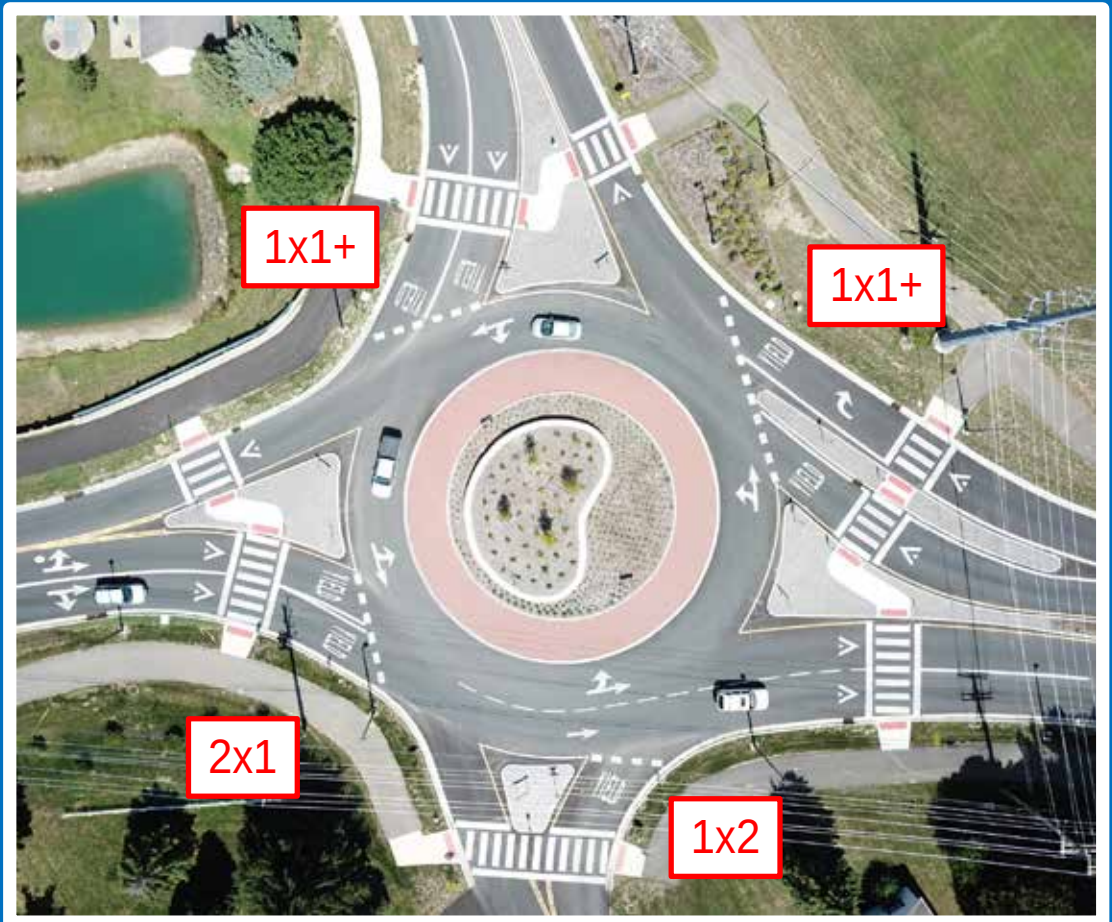
- We underestimated the driver learning curve and did not address education & outreach on a broad scale

- We lumped all multi-lane roundabouts into one category and did not identify the “2x2 problem” quick enough

2x2 Roundabout

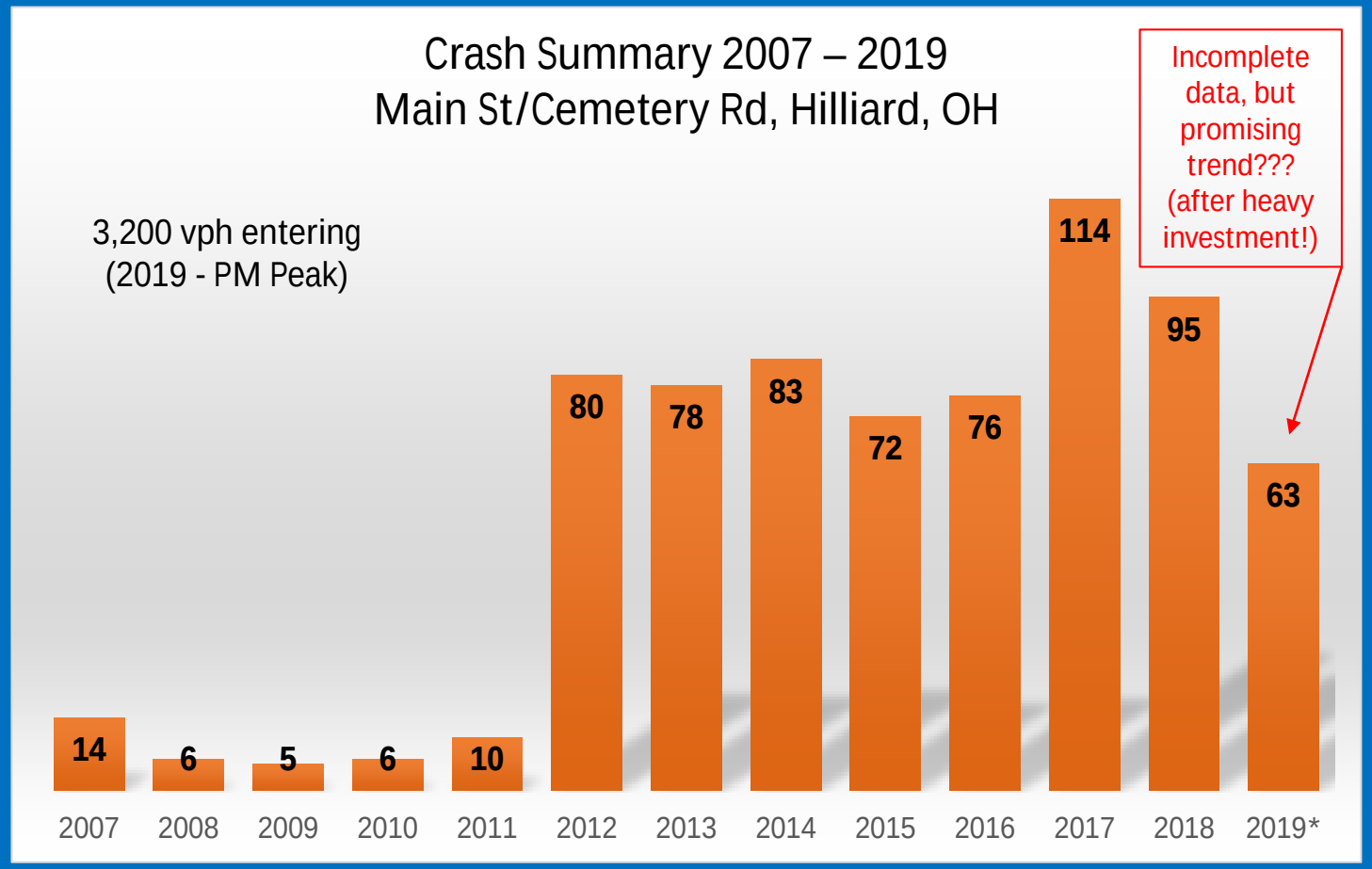


NOT a 2x2 Roundabout



[2x1 (Hybrid) Multi-Lane]

2x2 Roundabouts: Our Dirty Little Secret



January 2020 Message Board Discussions
Re: Crash prone 'modern roundabouts'

Author | Topic: Crash prone 'modern roundabouts' (Read 263871 times)

tradephoric
Turnpike
Offline
Posts: 1992
Last Login: January 04, 2020, 10:25:43 AM

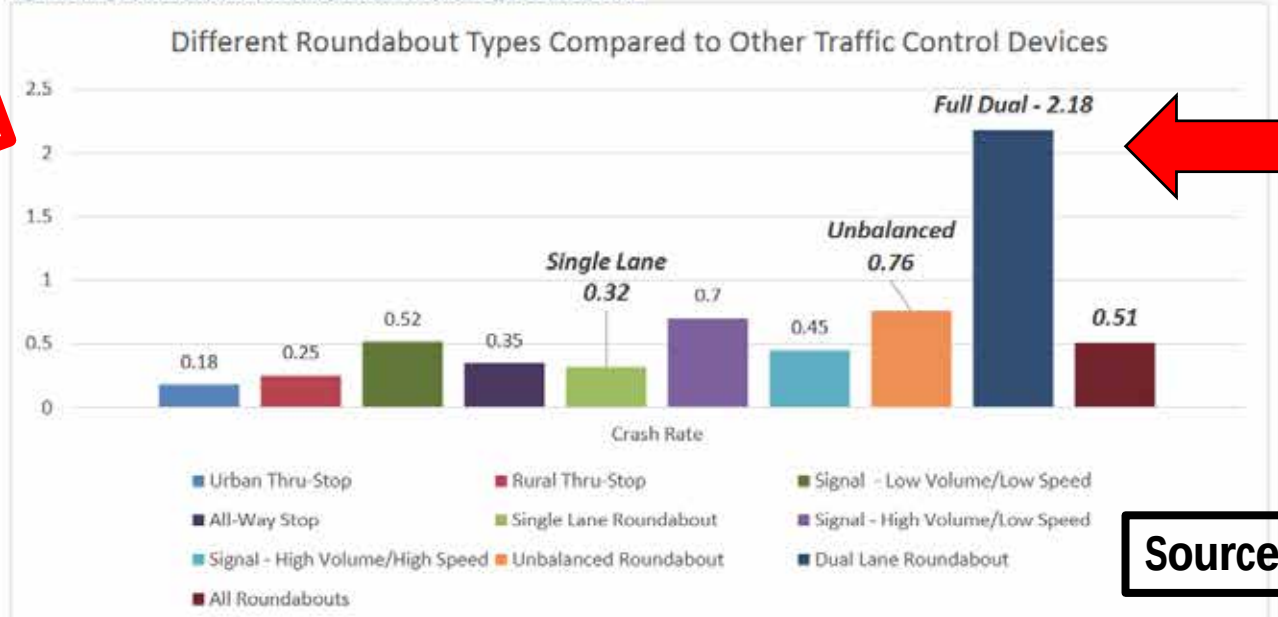
Re: Crash prone 'modern roundabouts'
« Reply #2375 on: December 26, 2019, 02:28:56 PM »

Quote from: DaBigE on December 24, 2019, 12:13:25 PM
The larger agencies are looking at the numbers and trying to figure out what went wrong. But in most cases, since the serious injury crashes are down and traffic is generally flowing better than before, they're going to move on to one of their many other fires they have to put out. Unfortunately, real-world engineering becomes a balancing act - there are always going to be trade-offs and compromises.

Agencies aren't just moving on when they see a big spike in crashes at these complex roundabouts. The reality is many of these 3x2 complex roundabouts have been downsized to 2x2 or even 2x1 roundabouts (Superior Street & 14th St roundabout in Lincoln). Drastically reducing the capacity of the roundabout just years after it was built doesn't sound like nothing. The roundabouts that haven't been downsized end up near the top of crash prone intersection lists (last year 3 of the top 5 most crash prone intersections in Michigan were at 3x2 roundabouts) and agencies are left defending what is almost indefensibly high crash rates.

It's true, serious injury crashes and fatalities are down at the complex roundabouts analyzed in the Minnesota study, but total injury crashes rose by 6%. Not to mention there was a 212% increase in PDO crashes. Doing a before/after crash cost analysis, the social impacts of the roundabouts are worse than the intersections they replaced. Similar case if you look at the social impacts of the complex roundabouts in the Region of Waterloo in the 2018 crash report that was just released. You seem to be underestimating the impacts these problematic complex roundabouts are having. Look at this chart of crash rates that was included in the Minnesota study. Full dual roundabouts far and away have worse crash rates than other traffic control devices in Minnesota.

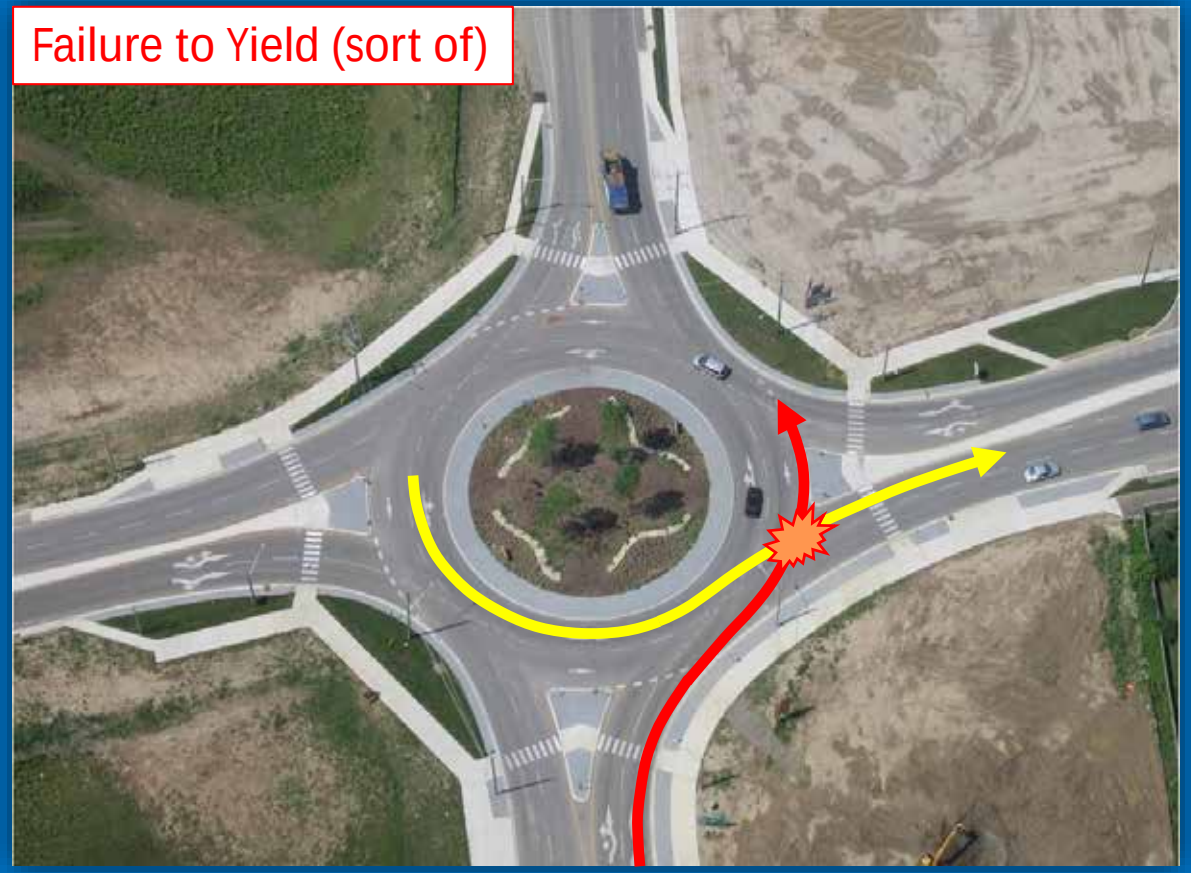
Figure 6: A graphical representation of crash rates, by traffic control device

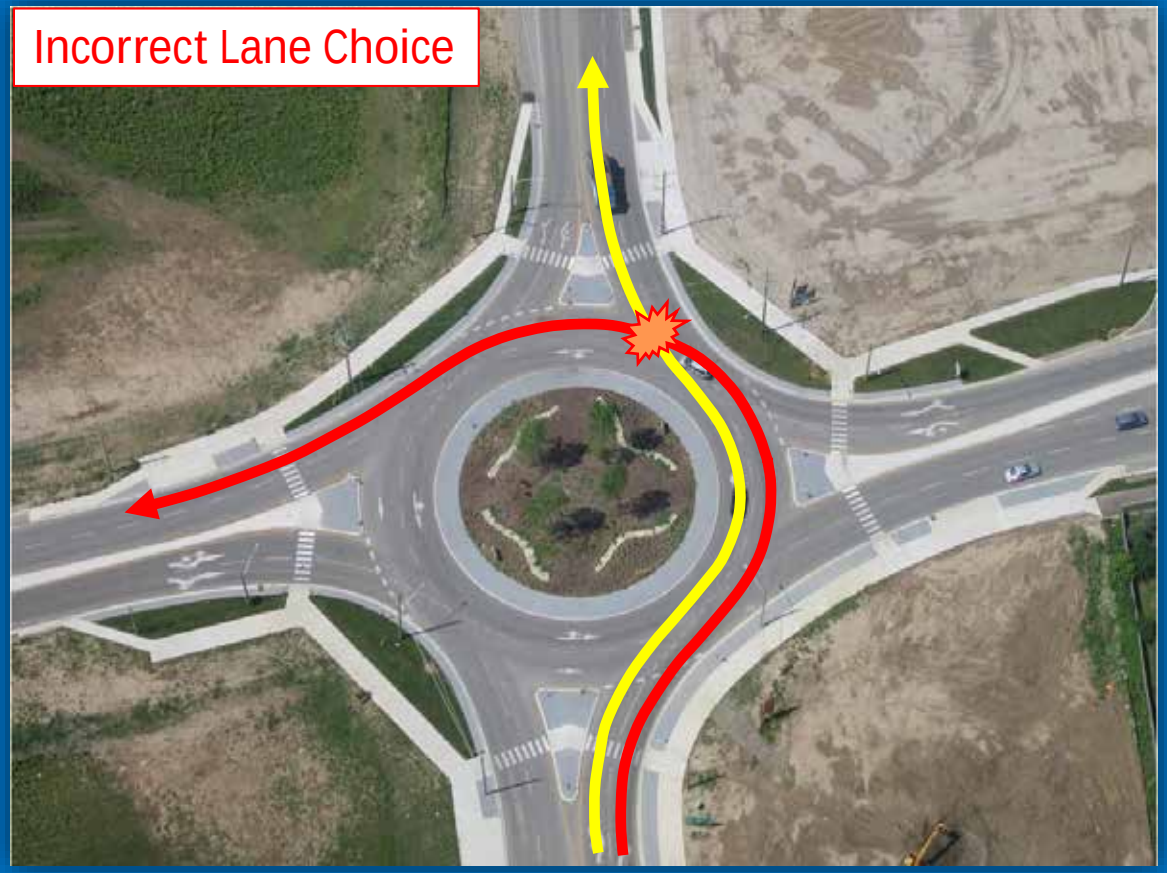


We are not alone!

Source: MnDOT

Lots of PDO Crashes at 2x2s – Same Two Causes





Many drivers do not ***understand*** that the <u>inside lane can exit</u> at some roundabouts

[Note: many of these drivers think that the “other guy” is wrong]

Human Factors & Lack of Education

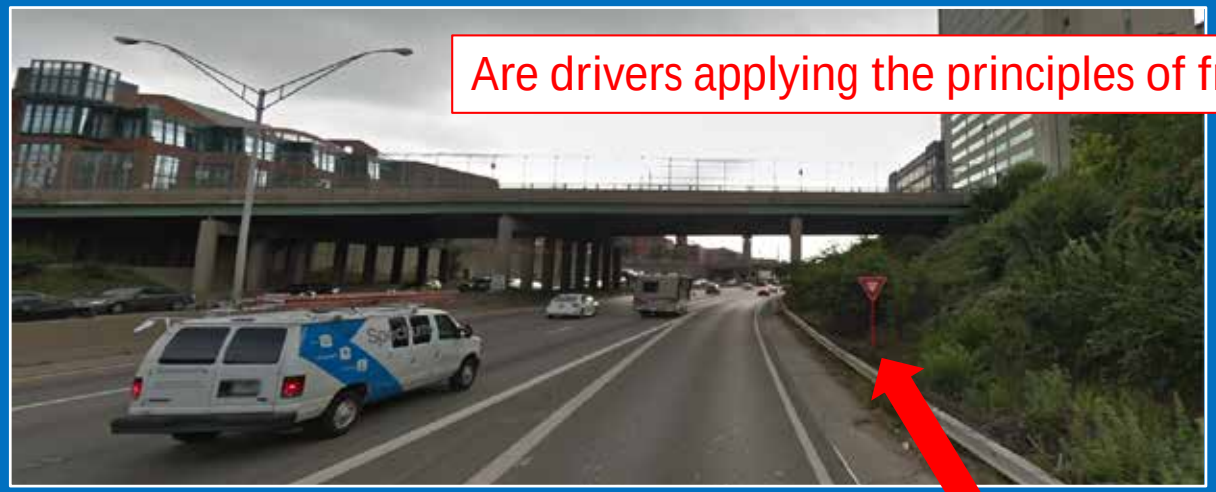
"Some of these roundabouts are confusing... well, not for *me* – but for the other guys"

...perhaps drivers are *conditioned* to do the *wrong* thing

Are Drivers Conditioned to do the Wrong Thing?

vs

Are drivers applying the principles of freeway entries & exits to roundabouts?

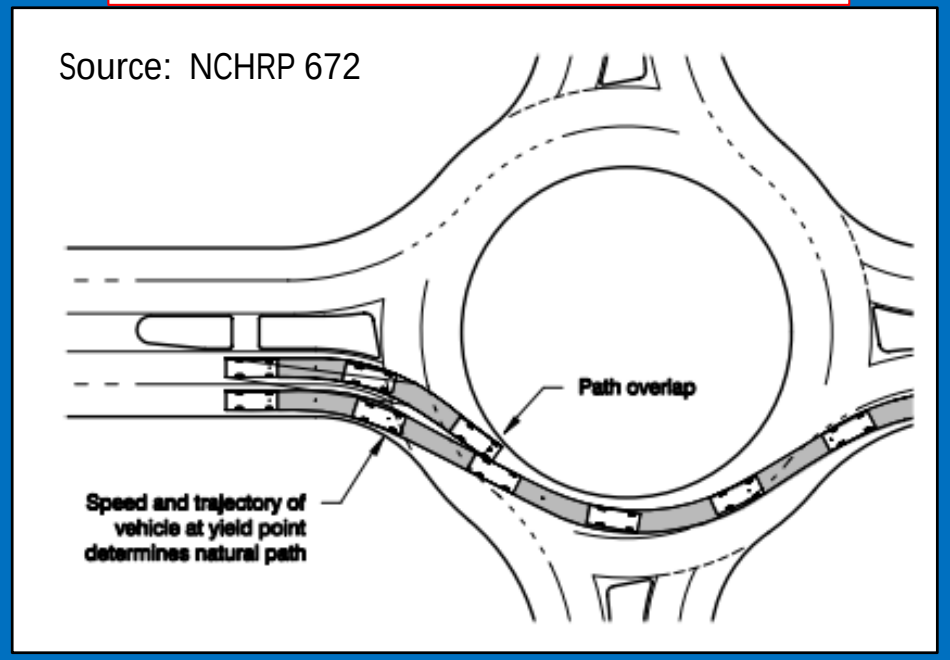


Yield on freeway ramp entries?

Signal, move over & exit on the right?

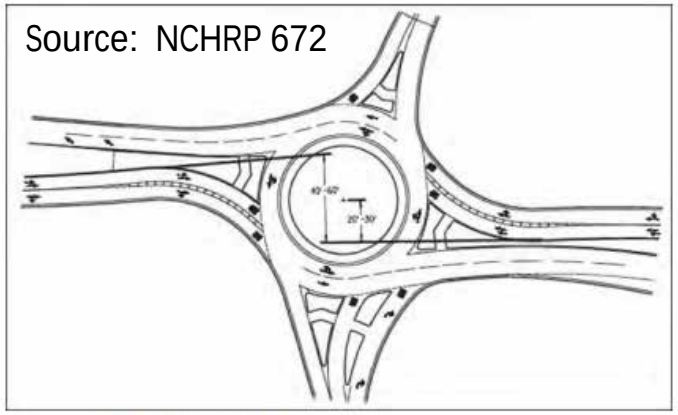
Do our Geometric Design Principles Reinforce Bad Behavior?

Late 2000s – Problem: Path Overlap



Did we go too far to "fix" path overlap?

Solutions: Increase Deflection, Tangent on Entries



Source: Wisconsin Department of Transportation (7)

Exhibit 6-31
Example of Major Approach Offset to Increase Entry Deflection

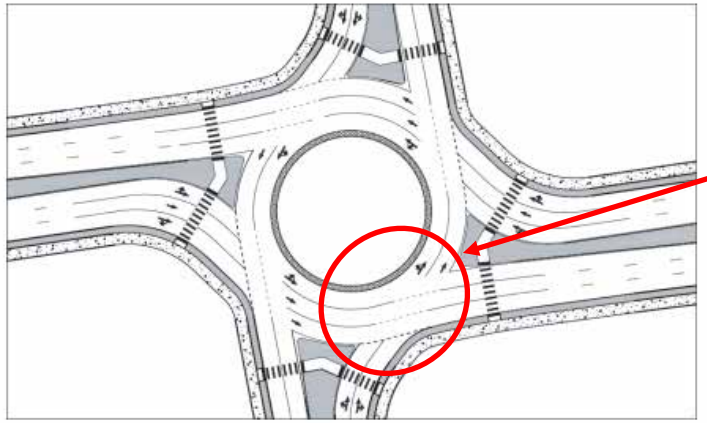


Exhibit 6-32
Example of a Partial Three Lane Roundabout with an Offset Approach Alignment

Result:
Did we create a *feeling* of **merge**?

- Entry radius too big?
- Tangent too long?
- Offset too great?
- Too much deflection?
- Distance to cross too long?

Is it next to impossible to find a gap?

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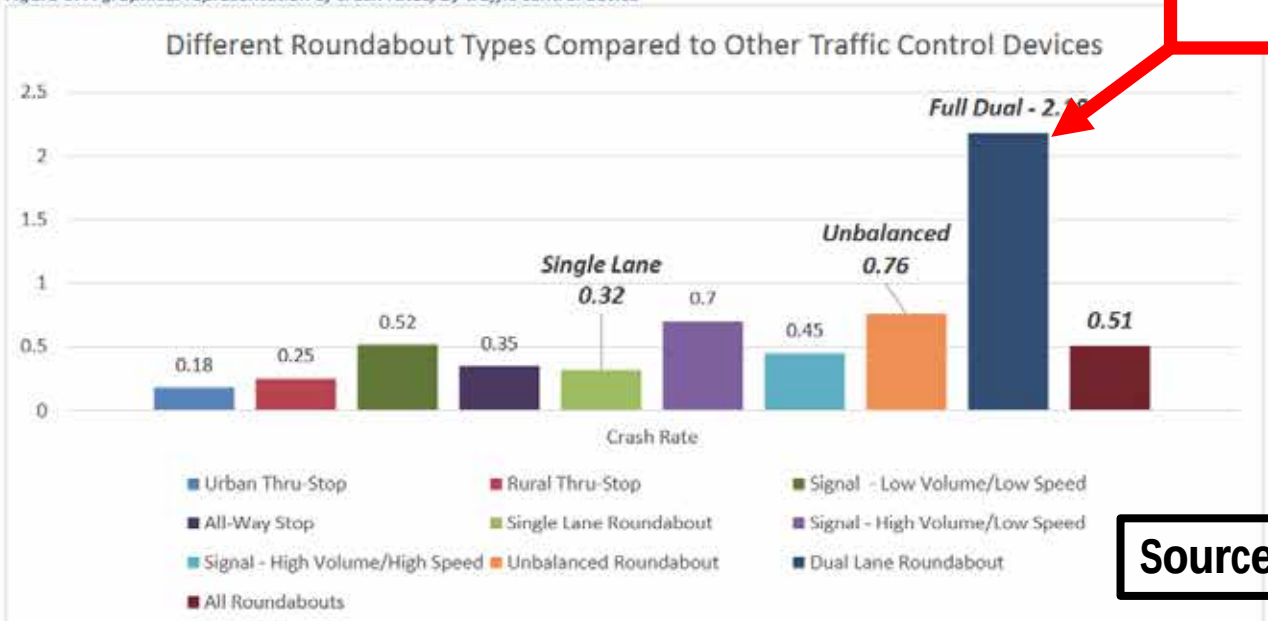

Bottom Line:
How can we continue to justify the high crash rates that seem to be common at 2x2 roundabouts?

Source: MnDOT

My Roundabout Journey

Turbo-Roundabouts???

What can we learn from others that might help address high PDO crash rates at 2x2s?

Turbo Roundabouts: Considerations for U.S. Implementation

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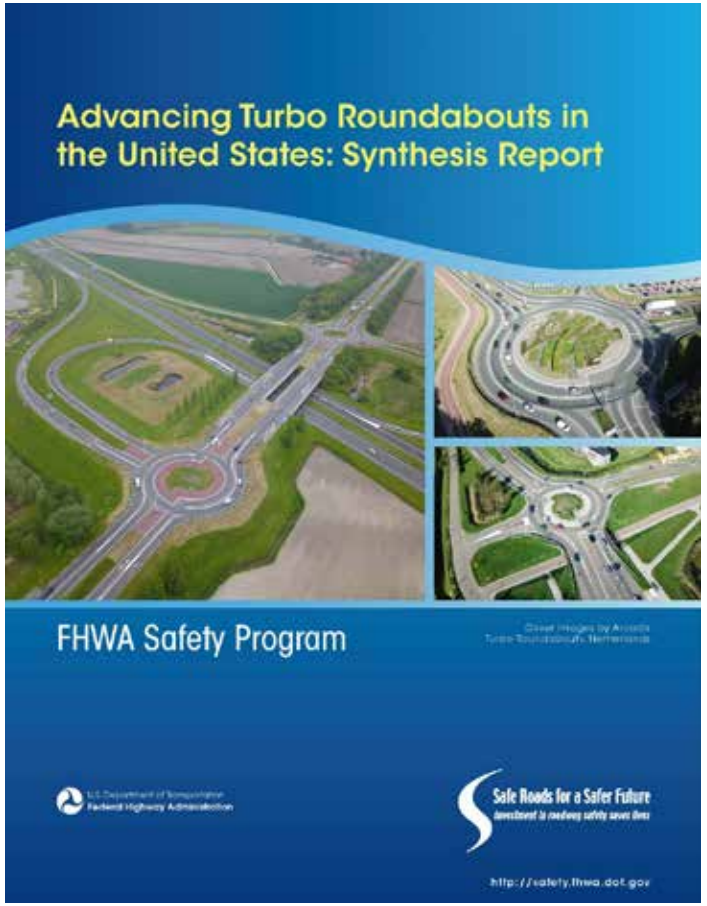
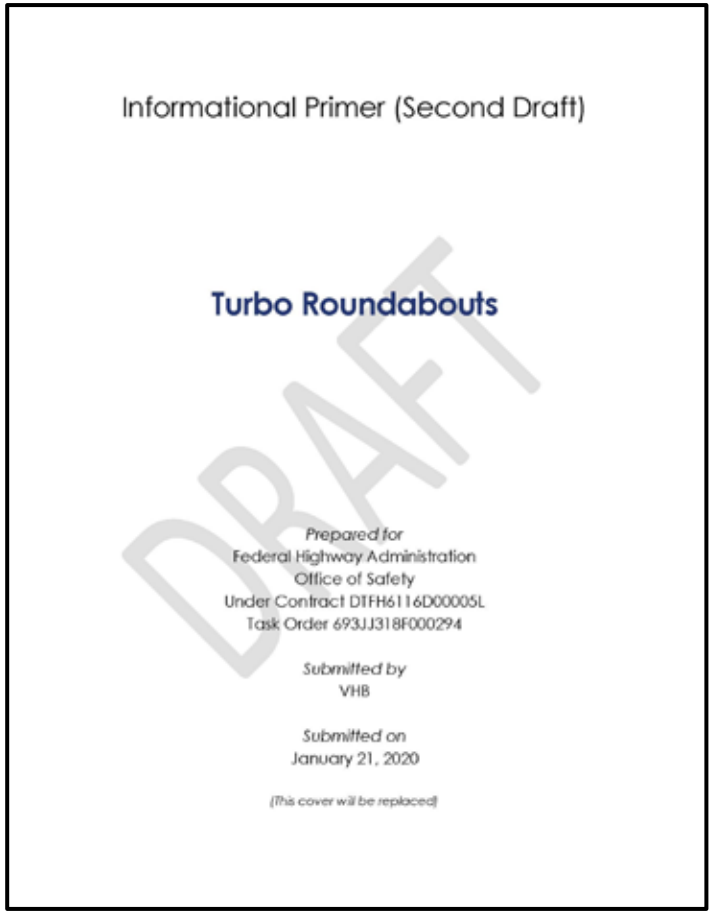
Two Products Developed for FHWA

Synthesis of International Practices Report No. FHWA-SA-19-027



Source: FHWA.

Informational Primer (coming soon)



Source: FHWA.

Synthesis Report

- Reviewed design, safety, and operations research and policy documents developed in 18 countries
- Employed professional translation services for Dutch, Croatian materials
  - Used Google translation tools for relevant sections of Slovenian and Czech materials
- Synthesis cites 78 references

Cited Works from Countries Including:

Australia	New Zealand
Bosnia & Herzegovina	Poland
Canada	Portugal
Colombia	Serbia
Croatia	Slovenia
Czech Republic	Sweden
Germany	Switzerland
Italy	United Kingdom
The Netherlands	United States

Selected Synthesis Takeaways – Lane Dividers

- Some countries have implemented turbo roundabouts **without raised lane dividers** (e.g., Germany, Poland, Canada)
- Reasons include potential concerns with:

motorcycle safety

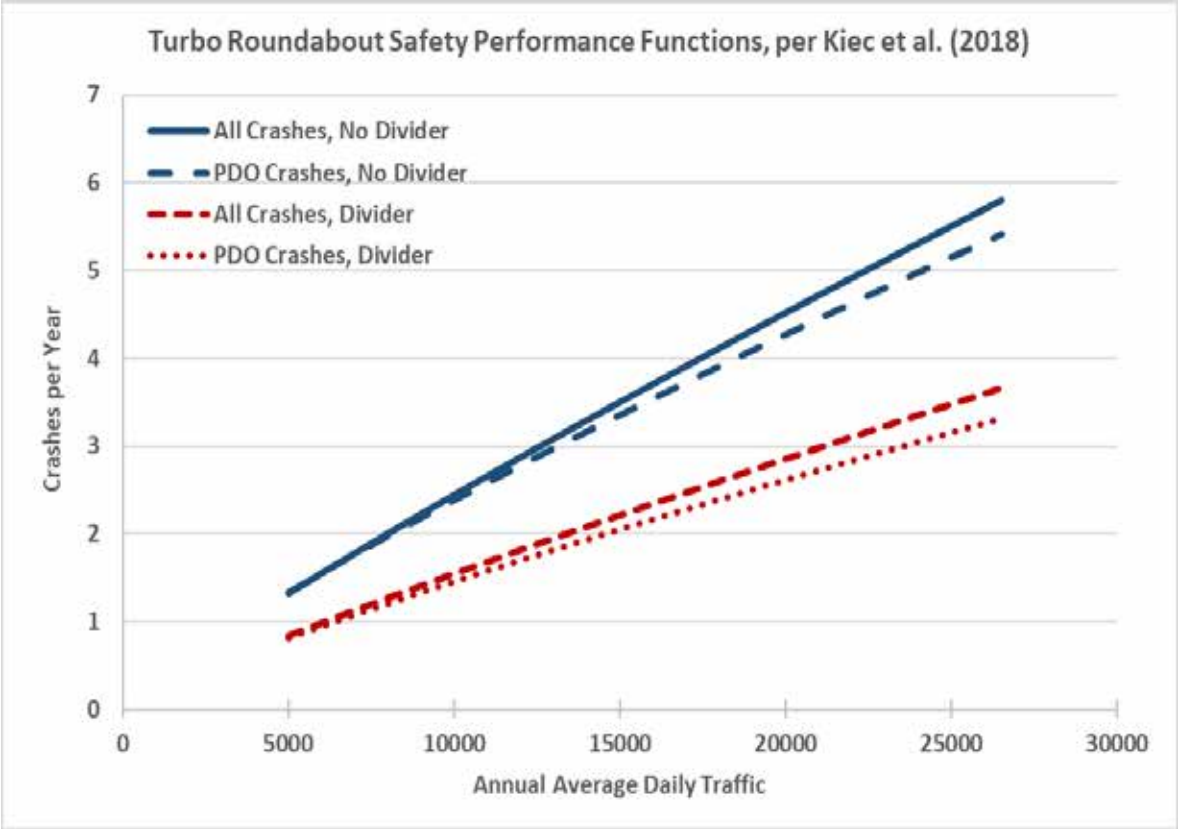
Maintenance

snow clearing operations

- Crash-based safety evaluations with/ without dividers still relatively limited…

Selected Synthesis Takeaways – Lane Dividers

- Macioszek (2015) – Polish turbo roundabouts without raised lane dividers experience more crashes
- Polish SPFs developed by Kiec et al. (2018) show that turbo roundabouts without raised lane dividers are expected to experience more crashes
  - Severity tends to be low with both options



Source: FHWA.

Selected Synthesis Takeaways – Capacity

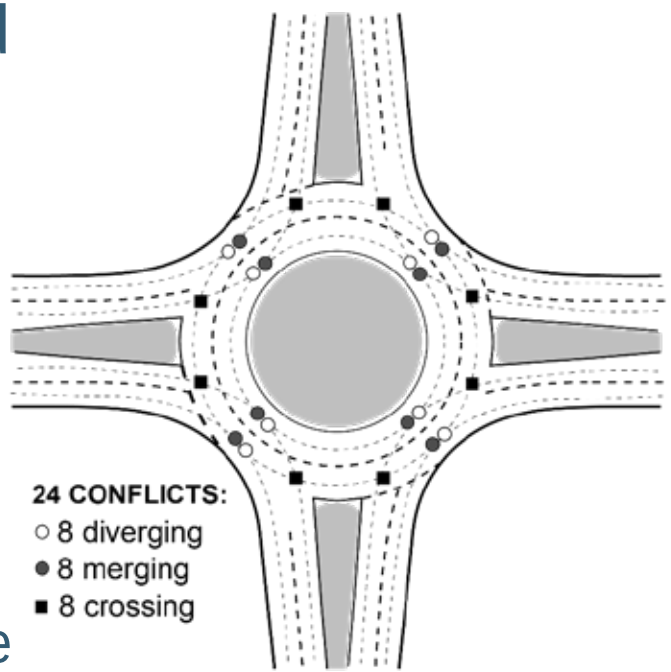
Measurement	Multilane Roundabouts in the U.S.[3]	Turbo Roundabouts in Slovenia[4]	Turbo Roundabouts in the Netherlands[5,6,7]
Critical Headway[1] (seconds)	4.3 – 5.5	4.03 – 5.48	3.15 – 3.80
Follow-Up Time[2] (seconds)	2.1 – 2.7	2.52 – 2.71	2.25 – 2.80

1. "The minimum headway in the major traffic stream that will allow the entry of one minor-street vehicle (TRB, 2016, p9-6).
2. "The time between the departure of one-vehicle from the minor street and the departure of the next vehicle using the same major-street headway under a condition of continuous queuing on the minor street" (TRB, 2016, p9)
3. Rodegerdts, L., Bansen, J., Tiesler, C., Knudsen, J., Myers, E., Johnson, M., … O'Brien, A.. (2010). *Roundabouts: An Informational Guide.* Transportation Research Board, NCHRP 672, National Research Council, Washington, DC.
4. Guerrieri, M., Mauro, R., Parla, G., & Tollazzi, T. (2018). Analysis of Kinematic Parameters and Driver Behavior at Turbo Roundabouts. Journal of Transportation Engineering, Part A: Systems, 144(6), 04018020.
5. Fortuijn, L. (2009). Turbo roundabouts: estimation of capacity. Transportation Research Record: Journal of the Transportation Research Board, (2130), 83-92.
6. Fortuijn, L. G., & Hoogendoorn, S. P. (2015). Capacity estimation on turbo roundabouts with gap acceptance and flow level methods. Transportation Research Record: Journal of the Transportation Research Board, (2517), 71-79.
7.

Macioszek (2016) found HCM roundabout capacity models adequately estimated capacity on Polish turbo roundabouts

Selected Synthesis Takeaways – Safety Evaluations

- Crash-based studies relatively limited
  - One Dutch study: 76% reduction in number of crashes after conversion from yield/signalized/“old-style rotary”
- Significant number of studies based on safety surrogates (e.g., conflicts from simulation, speed, lane keeping)
  - Included turbo and traditional multilane comparisons
  - Concluded fewer conflicts, improved lane keeping, and lower speeds in turbo roundabouts



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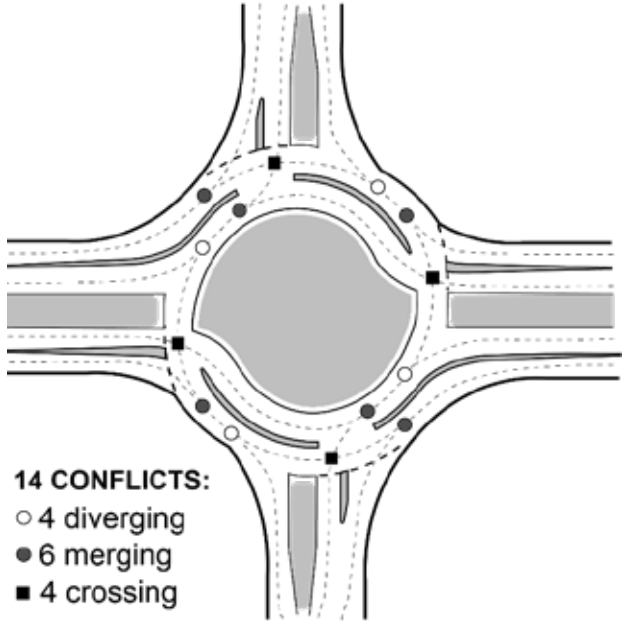
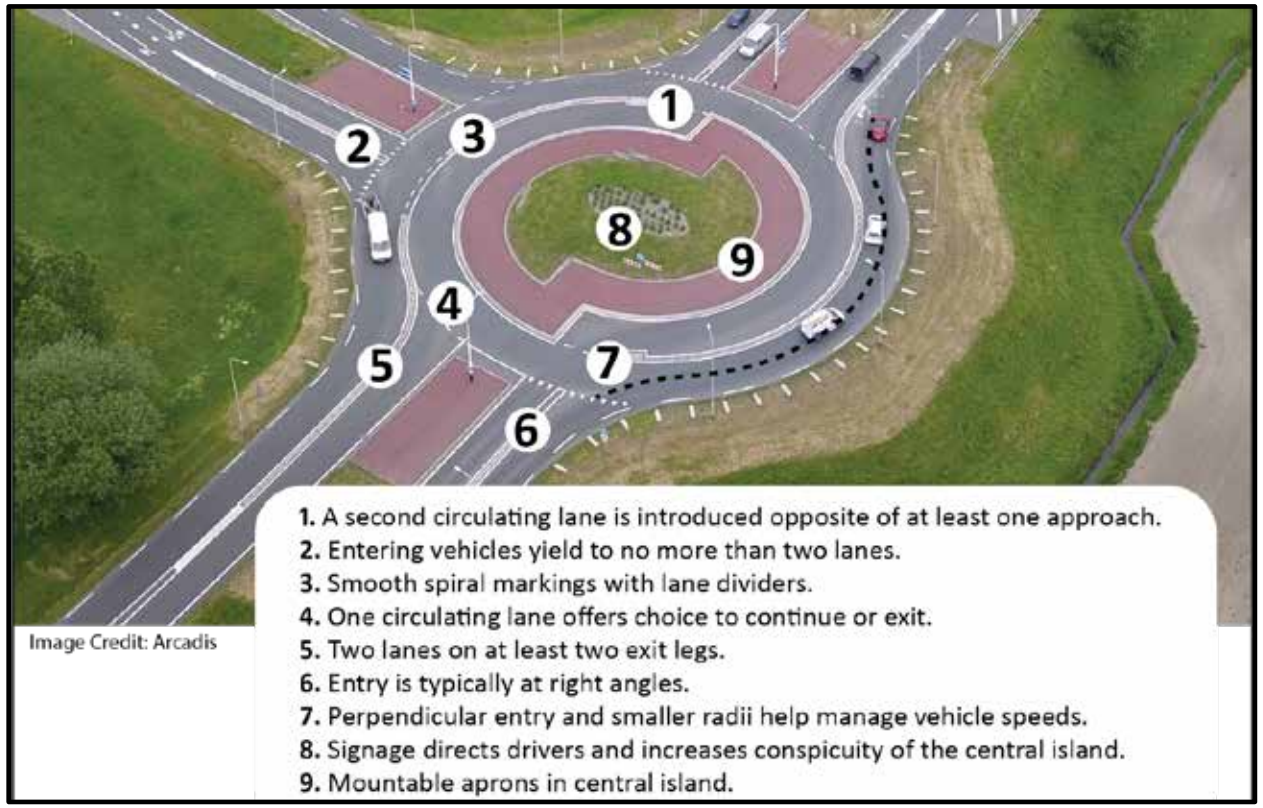


Source: FHWA.

Informational Primer

- Draws on information from the synthesis
- Draws on key U.S. references
  - E.g., Roundabouts Informational Guide, Crossing Solutions for Pedestrians with Vision Disabilities, State DOT design guidance, MUTCD
- Makes links to U.S. context
  - E.g., traffic control devices, design vehicles, approach geometry
- Content modeled after FHWA's Roundabout and Mini Roundabout technical summaries



Source: FHWA.

Informational Primer Outline of Topics

- Characteristics of a Turbo Roundabout
- Potential Benefits of a Turbo Roundabout
- User Considerations
  - Motorists
  - Pedestrians
  - Bicyclists
  - Motorcyclists
  - Freight/Large Vehicles
- Location Considerations
- Safety Analysis Methods and Results
- Operational Analysis
- Design Considerations
  - Horizontal Design
  - Sight Distance and Visibility
  - Signage and Pavement Markings
  - Pedestrian Design Treatments
  - Bicycle Design Treatment
  - Vertical Design
  - Lighting
  - Landscaping
  - Other Design Considerations
  - Comparison to United States Roundabout Design Principles
- Costs
- Education and Public Involvement

User Considerations - Pedestrians

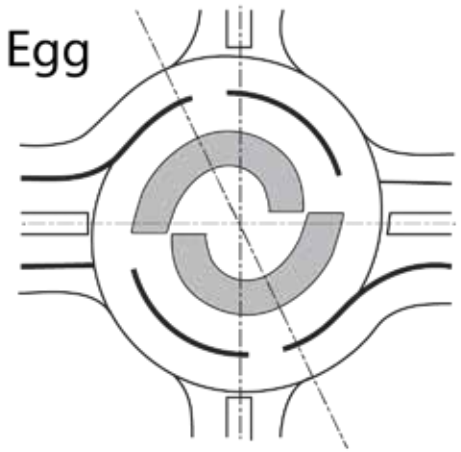
- Primer reemphasizes principles from Roundabout Informational Guide and NCHRP 834 (Crossing Solutions at Roundabouts…)
  - Sidewalks/crosswalks along the perimeter with buffering
  - Splitter islands for refuge/multi-stage crossing
  - Crosswalk set back from circulatory roadway to separate conflicts
  - TCD applications

User Considerations - Bicyclists

- Primer reemphasizes principles from U.S. references
- Bicyclists can either mix with traffic or utilize separate facilities (if available)
- Terminating bicycle lanes/shoulders prior to roundabout
- If crossing is necessary, provide pavement level cut-through of splitter island
  - Dutch use chicane in splitter island to encourage two stage crossing, provide more time for exiting drivers to identify crossing bicyclist

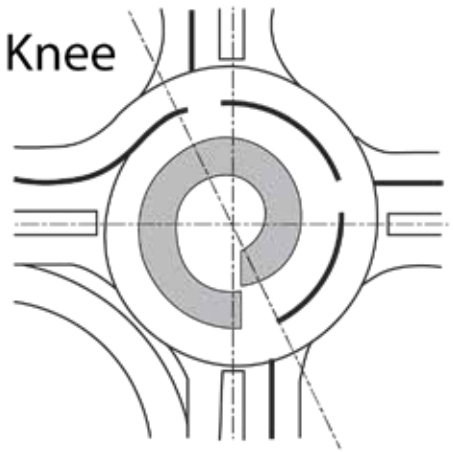
User Considerations – Motorists

- Provide sufficient signage on approach for motorists to select their desired lane
  - Spiral alignment directs drivers to their exit, lane divider prevents lane changes
- Use Roundabout Directional Arrow sign to direct approaching drivers right and increase conspicuity of central island
- U-turns may not be available based on approach, roundabout design



Capacity: 2800 pcu/h

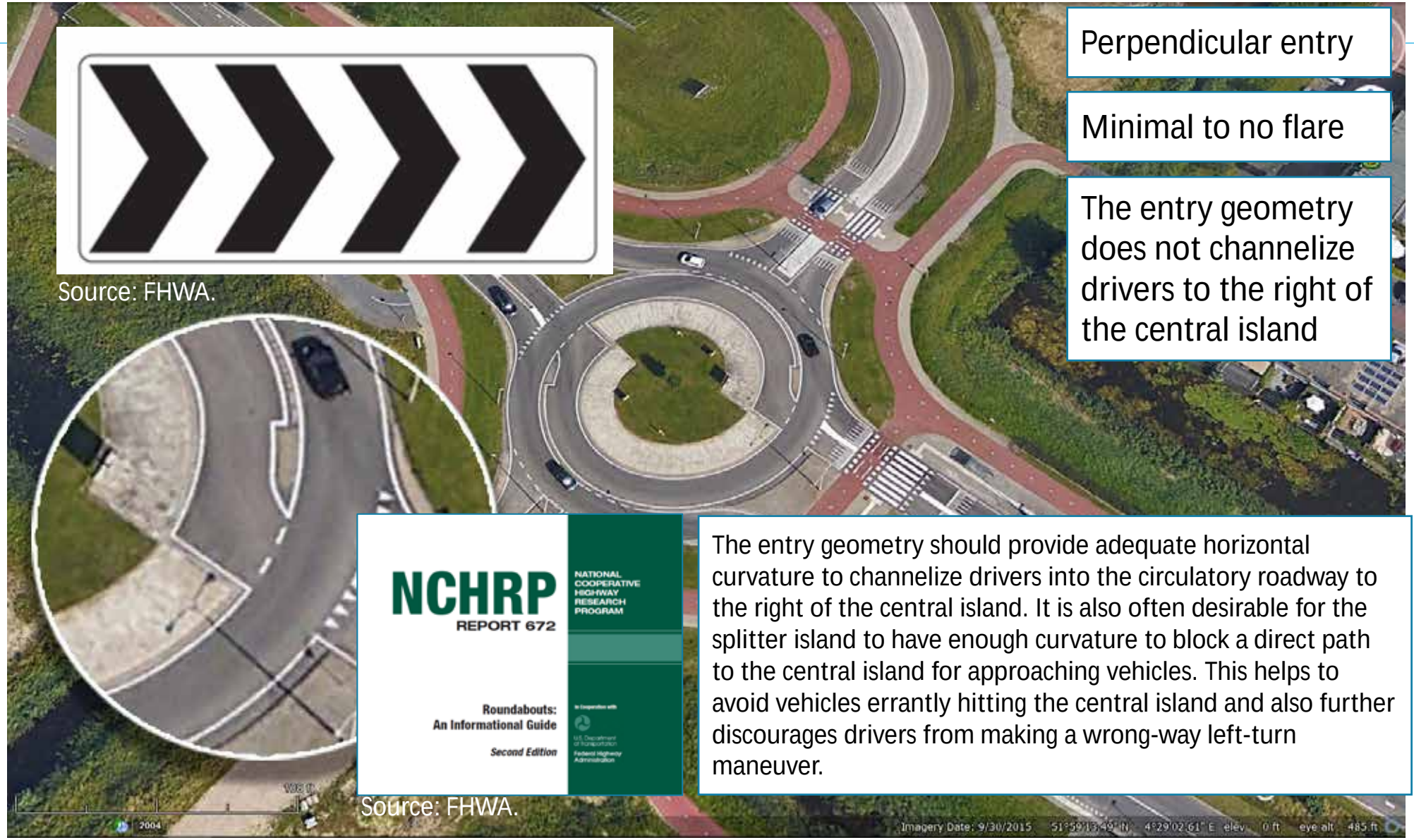
Source: FHWA.



Capacity: 3500 pcu/h

Source: FHWA.

Approach Geometry



Source: FHWA.

Source: FHWA.

Perpendicular entry

Minimal to no flare

The entry geometry does not channelize drivers to the right of the central island

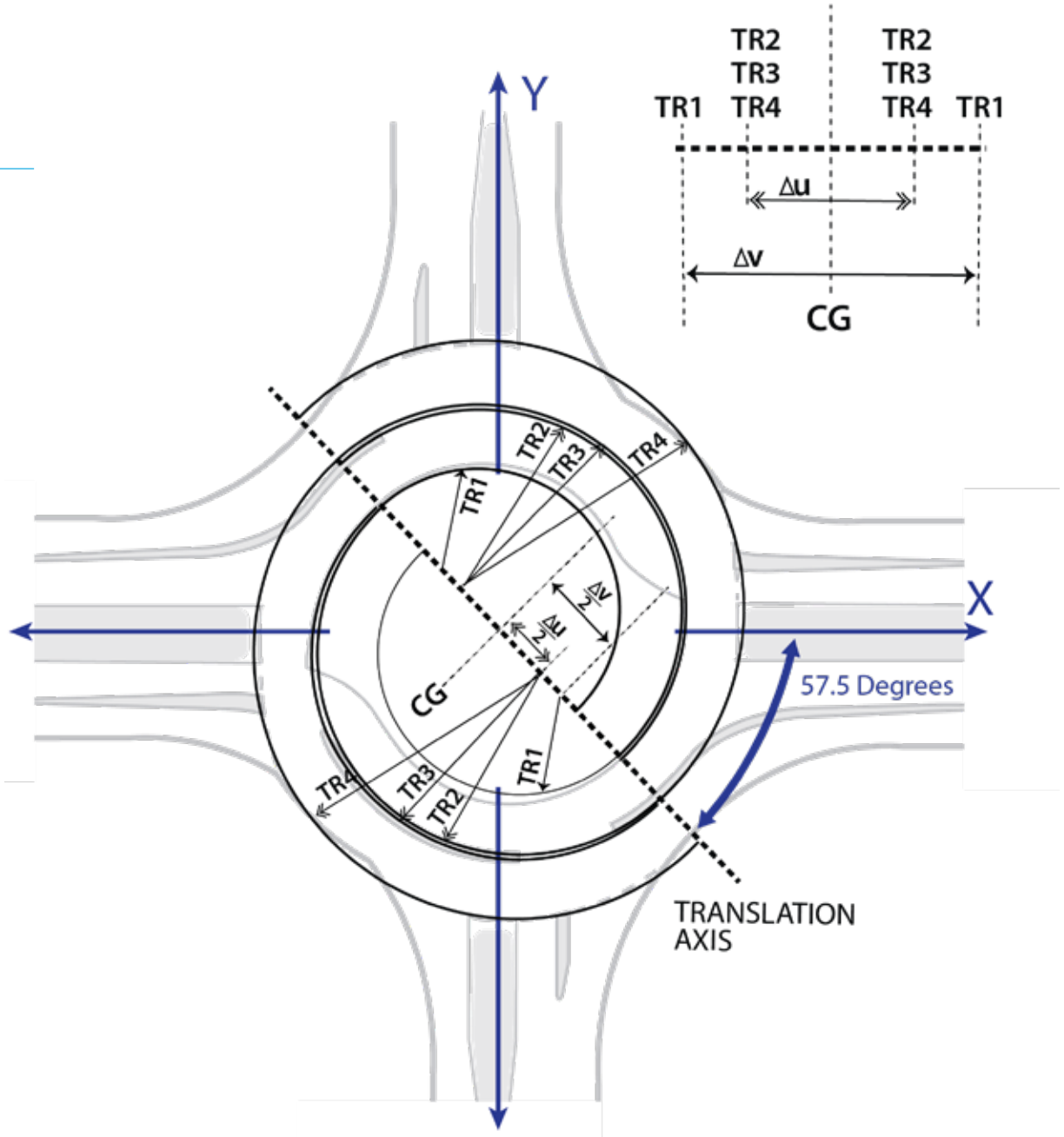
The entry geometry should provide adequate horizontal curvature to channelize drivers into the circulatory roadway to the right of the central island. It is also often desirable for the splitter island to have enough curvature to block a direct path to the central island for approaching vehicles. This helps to avoid vehicles errantly hitting the central island and also further discourages drivers from making a wrong-way left-turn maneuver.

User Considerations – Freight/Large Vehicles

- European turbo roundabouts built for smaller design vehicles than in the United States
- "Multilane roundabouts are designed either to allow large vehicles to track across more than one lane while entering, circulating, and exiting or to stay within their lane" – NCHRP 672
  - Balance with other lane-width considerations (right-of-way, performance for all users)
  - Truck volumes/operations can influence type and design of lane divider
- Provide mountable apron for central island to better accommodate design vehicles
  - Can be provided on the perimeter as well

Geometric Design

- Use the turbo block and translation axis to achieve spiral
  - Translation axis based on number/alignment of approach legs
  - Aligned roughly with intersection of curb radius and outside of circulatory roadway
  - Adjust angle to achieve desired spiral alignment
- Roadway widths and resulting “shifts” informed by design vehicle and other key lane width considerations

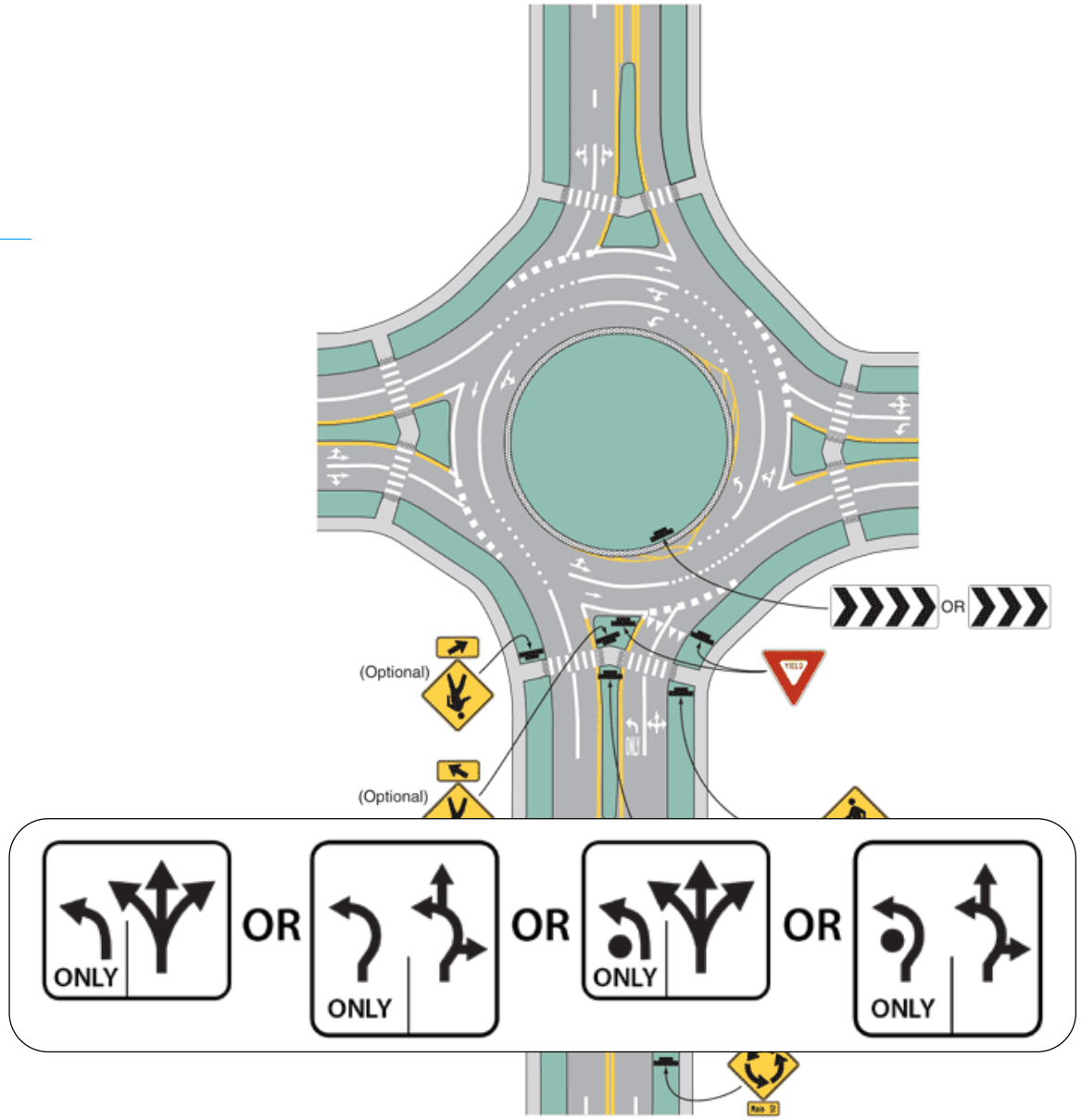


Source: FHWA.

Signage and Pavement Markings

- Reemphasizes lane use messaging and directional arrow signage from MUTCD
- Provide lane usage signage far enough upstream for users to select their desired lane (Section 2D.38 in MUTCD)
- Use R6-4B sign placed in line with approach to direct drivers to the right and increase central island conspicuity

Figure 2B-23. Example of Regulatory and Warning Signs for a Two-Lane Roundabout with Consecutive Double Lefts



Source: FHWA.

Lane Divider

- Primer discusses possible raised and flush options
  - Colored pavement
  - Double solid white line
  - Textured pavement with white solid lines
  - Raised pavement markings
  - Rumble strips or stripes
- Identifies U.S. and Canadian examples of lane dividers in existing roundabouts
  - Top: Conway, Arkansas
  - Bottom: Alta, Utah

Education and Public Involvement

- Highlighting benefits and "the why" of the benefits
- Navigation principles for all users
  - Including lane selection and lane use principles
- Incorporating feedback as U.S. experience is gained
- Consider decision matrix to select preferred media for communication with different audiences

Audience	Organization	Informational Primer	Real-time Video/Simulations	Signage	Slide Decks	Social Media	Education Guide	Fact Sheets and Flyers	Webinars
Local and State Transportation Agencies	Roadway Designers & Engineers	X	X		X		X	X	X
	Maintenance Crews	X					X		X
	Land Use Planners	X	X		X		X	X	X
User Groups	Drivers		X	X	X	X	X	X	
	Large Vehicle/Freight Drivers		X	X	X	X	X	X	
	Motorcyclists		X	X	X	X	X	X	
	Bicyclists & Pedestrians		X	X	X	X	X	X	

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Today's Speakers

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- Letty Schamp, *City of Hilliard, OH,* lschamp@hilliardohio.gov
- Brian Moore, *Arcadis,* Brian.K.Moore@arcadis.com
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- RJ Porter, *VHB,* rporter@vhb.com

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