Roundabout Peer Review

I-95/Temple Avenue Interchange

Colonial Heights, Virginia

January 2013

KITTELSON & ASSOCIATES, INC.
TRANSPORTATION ENGINEERING/PLANNING

Roundabout Peer Review

I-95/Temple Avenue Interchange

Colonial Heights, Virginia

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January 2013

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Section 1
Executive Summary

EXECUTIVE SUMMARY

Kittelson & Associates, Inc. (KAI) reviewed the interim and ultimate designs for the proposed I-95/Temple Avenue roundabout as described in the draft *Interchange Modification Report for I-95/Temple Avenue Interchange Improvement Project* (IMR). The review was conducted in accordance with the guidance provided in *NCHRP Report 672, Roundabouts: An Informational Guide, Second Edition*. Key KAI findings and recommendations are provided below.

FINDINGS AND RECOMMENDATIONS

Operations Review

- A review of the draft IMR, traffic volumes (Excel Workbook), and SIDRA files provided by VDOT identified minor discrepancies.
  - The design year 2037 weekday p.m. peak hour eastbound right-turn volume is shown as 594 vehicles in the SIDRA file and draft IMR, and 534 in the provided Excel workbook.
  - The basic lane configurations were different between the VDOT SIDRA files and IMR SIDRA file preliminary geometric designs (both interim and ultimate designs).
- Roundabout operations were independently verified by KAI using the Highway Capacity Manual (HCM) 2010 model in SIDRA Intersection 5.1.
  - The interim roundabout design (draft IMR lane configuration) is projected to operate at LOS A and B under opening year 2015 weekday a.m. and p.m. peak hour conditions, respectively.
  - The ultimate roundabout design (draft IMR lane configuration) is projected to operate at LOS A and C under design year 2037 weekday a.m. and p.m. peak hour conditions, respectively.
  - These results differ from reported operational results in the draft IMR because:
    - KAI used the HCM 2010 Model in SIDRA rather than the SIDRA Standard Model with an applied environment factor of 1.2. The HCM 2010 Model is based on empirical data at roundabouts in the United States.
    - The westbound through bypass lane was modeled as a non-yielding right-turn bypass lane in SIDRA to account for geometric delay incurred by this movement.

- The lane configuration shown in the draft IMR was used for the KAI analysis, which is different than the lane configuration used in the SIDRA files provided by VDOT.

- Removing the extra exit lane on the northbound approach (south leg) in the interim design allows for better lane continuity and simplifies potential weaving maneuvers downstream of the roundabout.
- If traffic projections hold true, the ultimate roundabout design would need to be implemented in approximately year 2030.
- The ultimate roundabout design is projected to operate with a volume-to-capacity (v/c) ratio of 0.99 during the design year 2037 weekday p.m. peak hour assuming the ultimate design configuration.
  - While NCHRP Report 672 suggests a maximum v/c ratio in the range of 0.85 to 0.90, in this case the ultimate design is considered adequate to accommodate design year traffic volumes given to the 25 year design life, unpredictability of future volume growth, and potential improvements in roundabout performance as drivers become more familiar with roundabouts over time.

Geometric Review

- The current interim and ultimate roundabout designs both have substantial path overlap. KAI recommends incorporating design modifications and techniques discussed in the Design Modifications section to minimize path overlap.
- With the exception of single-lane westbound entry (interim design), all fastest-path entry radii were found to exceed the recommended entry speeds, though in most cases by only two miles per hour, which is generally within the tolerance of the procedure.
  - Since geometric changes are necessary to address path overlap issues, the modifications should also work to reduce fastest path speeds to within desirable thresholds. KAI recommends adopting measures to reduce the entry speeds as discussed in the Design Modifications section.

- WB-67 design vehicle off-tracking was noted in the review of the interim and ultimate designs. KAI recommends adopting the measures discussed in the Design Modifications section to minimize the impacts of off-tracking heavy vehicles.
- KAI recommends providing low-growth landscaping on the edges of the central island to appropriately limit sight distance.
- As the project moves forward, KAI recommends following guidance regarding roundabout signing and pavement markings provided in the 2009 MUTCD.
- KAI recommends intersection lighting at the roundabout per guidance provided in Chapter 8 of NCHRP Report 672.

- KAI recommends adjusting radii and offsets on the splitter islands and providing a northbound splitter island extending a minimum of 150 feet back from the roundabout.

Section 2
Introduction

INTRODUCTION

PROJECT DESCRIPTION

Pursuant to the request of the Virginia Department of Transportation (VDOT) Kittelson & Associates, Inc. (KAI) peer-reviewed the proposed roundabout designs, provided by VDOT, for the I-95/Temple Avenue Interchange in Colonial Heights, Virginia. Figure 1 shows the site vicinity map. The analysis consisted of reviewing the operational analysis and proposed geometrics at the I-95/Temple Avenue Interchange as shown in the draft *Interchange Modification Report for I-95/Temple Avenue Interchange Improvement Project* (IMR) dated October 2012 (Reference 1). The purpose of the analysis was to confirm that the lane configurations and proposed geometrics are adequate and that the roundabout provides an acceptable level-of-service (LOS) through the design year of 2037.

Figure 2 and Figure 3 display the current preliminary opening-year 2015 and design-year 2037 roundabout designs, respectively.

KAI reviewed the proposed roundabout in accordance with the guidance provided in *NCHRP Report 672, Roundabouts: An Informational Guide, Second Edition* (Reference 2).

SCOPE OF THE REPORT

This report evaluates traffic operations and preliminary geometric design of the proposed I-95/Temple Avenue roundabout. A summary of analyses performed are detailed below.

- Review current operational analysis and identify any concerns/discrepancies
- Review and confirm the peak-hour traffic analyses for the opening year 2015 and design year 2037 alternatives using the Highway Capacity Manual (HCM) 2010 model in SIDRA Intersection 5.1.
    - Identify and confirm lane configurations, for entering, circulating, and exiting the roundabout to provide acceptable roundabout operations and lane continuity for both opening year and design-year traffic conditions.
- Evaluate the fastest paths of the current roundabout design.
- Evaluate the natural entry paths of the current roundabout design.
- Review sight distance for the current roundabout design on approaches and circulating lanes.
- Analyze design vehicle paths for the current roundabout design.
- Suggest modifications to the current preliminary design as needed.

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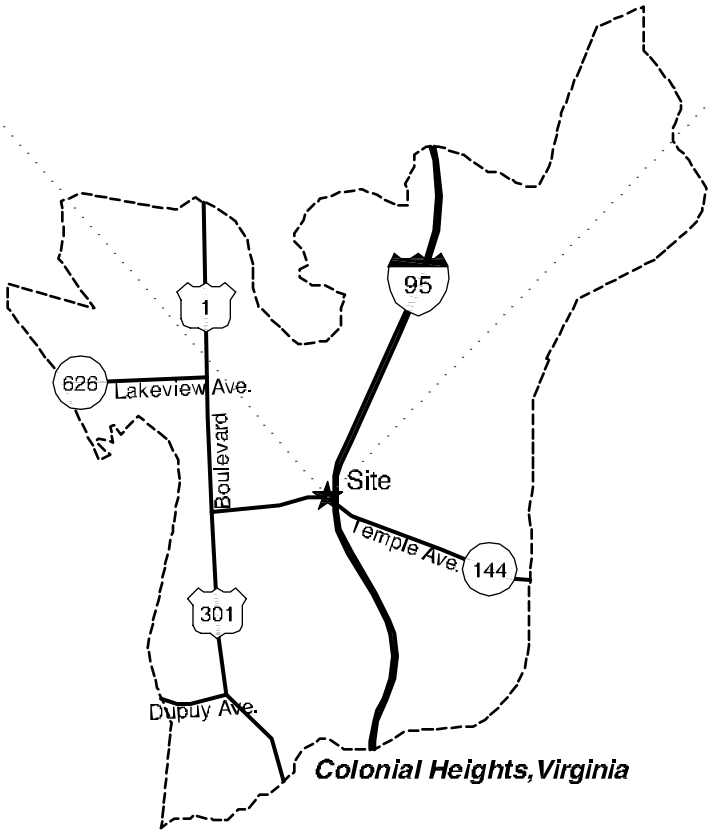

SITE VICINITY MAP
COLONIAL HEIGHTS, VIRGINIA

FIGURE 1

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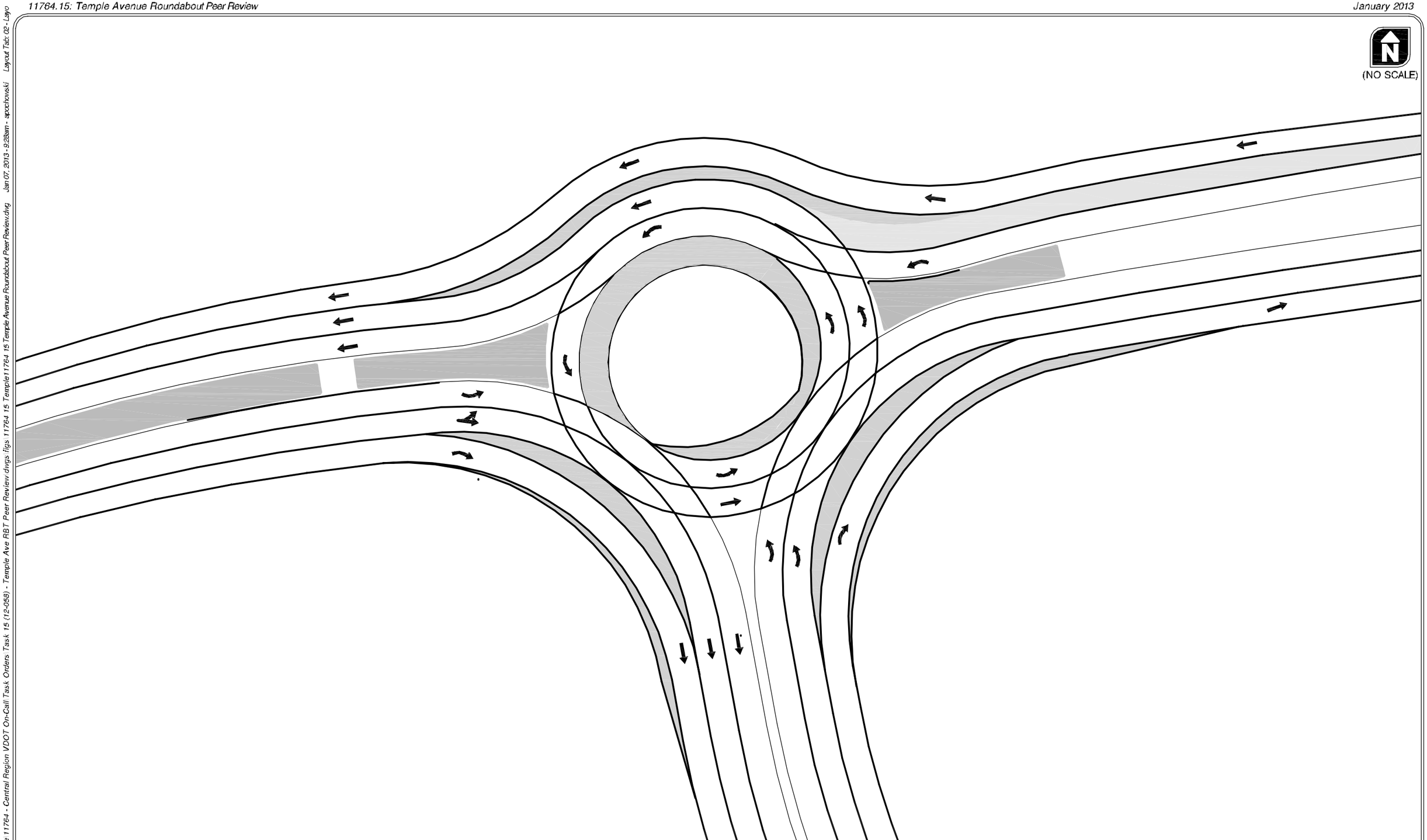

DRAFT IMR INTERIM ROUNDABOUT DESIGN
I-95/TEMPLE AVENUE INTERCHANGE
COLONIAL HEIGHTS, VIRGINIA

FIGURE 2

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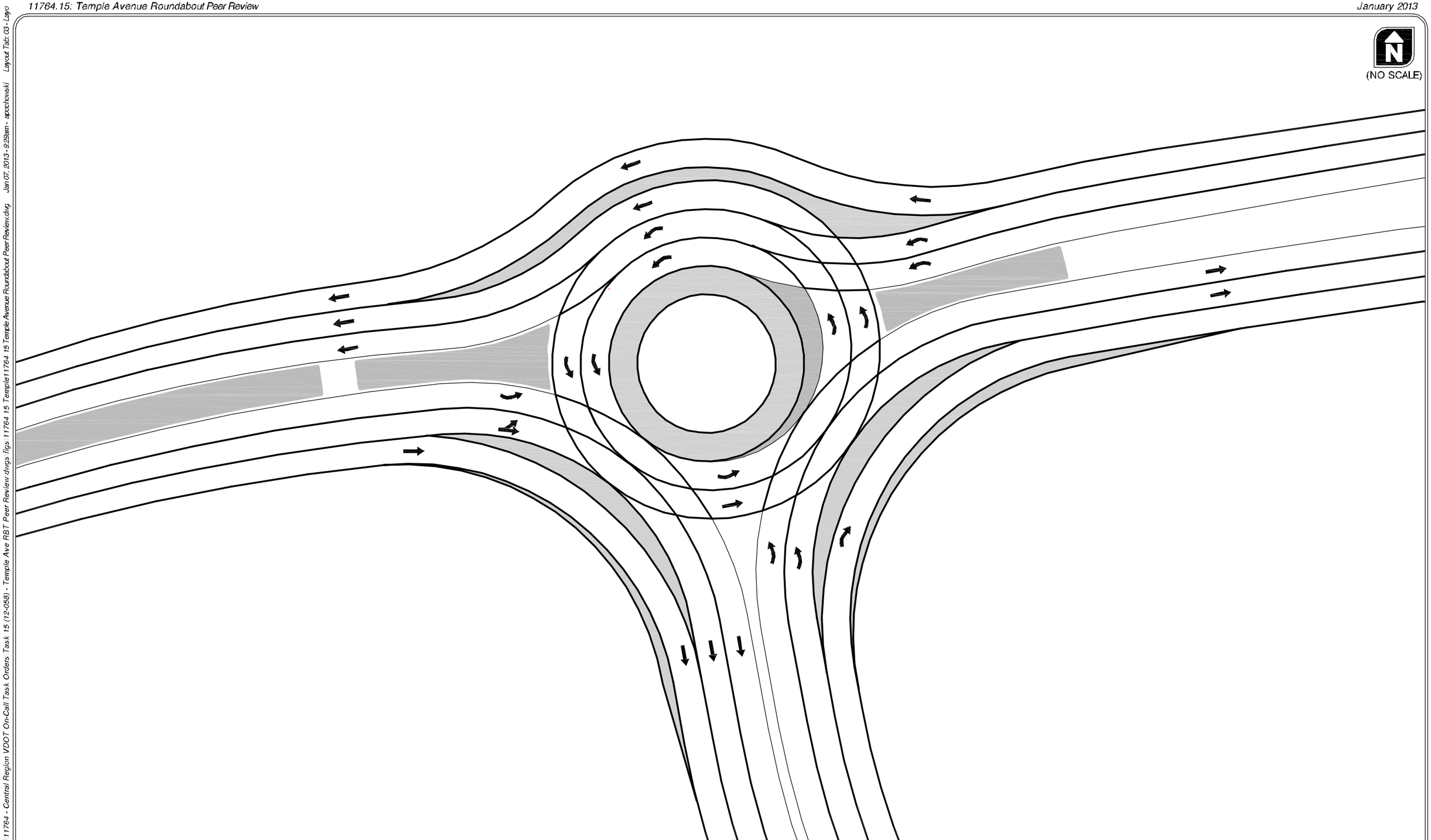

DRAFT IMR ULTIMATE ROUNDABOUT DESIGN
I-95/TEMPLE AVENUE INTERCHANGE
COLONIAL HEIGHTS, VIRGINIA

FIGURE
3

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Section 3
Operations Review

OPERATIONS REVIEW

KAI reviewed the projected traffic operations for the proposed I-95/Temple Avenue Roundabout design under 2015 opening-year and 2037 design-year traffic conditions to ensure acceptable operations and investigate any opportunities to reduce the number of entry, circulating and/or exit lanes.

OPERATIONS ANALYSIS

Roundabout operations were independently verified using SIDRA Intersection 5.1 (SIDRA) with the HCM 2010 model. Reported traffic volumes contained in the draft IMR, SIDRA analyses files, and a Microsoft Excel workbook provided by VDOT were reviewed for consistency. One discrepancy in the traffic volumes between these source files was noted. The eastbound year 2037 p.m. peak hour right-turn volume of 594 shown in the SIDRA file and the draft IMR differed from the 534 vehicles shown in the Excel workbook. The volume from the SIDRA file and draft report (594) was used in the KAI analysis because it was the more conservative volume. Additionally, this movement was not a critical movement in the analysis and therefore did not influence the overall operations of the roundabout. *Appendix A includes the provided traffic volumes.*

Table 1 and Table 2 provide a side-by-side comparison of operational results from the outputs of the provided draft IMR SIDRA analyses files and KAI analysis under opening year 2015 and design year 2037 traffic conditions. The KAI analysis assume the lane configurations shown in the draft IMR as illustrated in Figure 2 and Figure 3, respectively.

Table 1 Opening Year 2015 Traffic Operation Comparisons: Draft IMR Lane Configuration: KAI Analysis and IMR SIDRA Analysis

	West Leg (Eastbound) Temple Avenue		East Leg (Westbound) Temple Avenue		South Leg (Northbound) I-95	
Weekday AM Peak Hour						
	KAI Analysis	IMR SIDRA	KAI Analysis	IMR SIDRA	KAI Analysis	IMR SIDRA
V/C ratio	0.56	0.56	0.41	0.37	0.42	0.42
Approach Delay, (seconds)	3.2	2.3	3.2	2.8	4.6	3.7
Approach LOS	A	A	A	A	A	A
95th Percentile Queue (feet)[1]	50	50	50	50	50	50
Weekday PM Peak Hour						
	KAI Analysis	IMR SIDRA	KAI Analysis	IMR SIDRA	KAI Analysis	IMR SIDRA
V/C ratio	0.51	0.41	0.76	0.78	0.77	0.67
Approach Delay, (seconds)	7.4	5.1	11.2	12.1	15.3	10.2
Approach LOS	A	A	B	B	C	B
95th Percentile Queue (feet)[1]	75	100	100	175	125	150

[1]Queue lengths rounded up to the nearest 25 feet (rounded down to the nearest 25 feet if <5 above closest 25)

Table 2 Design-Year 2037 Traffic Operations: Draft IMR Lane Configuration: KAI Analysis and IMR SIDRA Analysis

	West Leg (Eastbound) Temple Avenue		East Leg (Westbound) Temple Avenue		South Leg (Northbound) I-95	
Weekday AM Peak Hour						
	KAI Analysis	IMR SIDRA	KAI Analysis	IMR SIDRA	KAI Analysis	IMR SIDRA
V/C ratio	0.65	0.67	0.49	0.46	0.51	0.49
Approach Delay, (seconds)	3.3	2.9	2.6	1.8	6.4	4.9
Approach LOS	A	A	A	A	A	A
95th Percentile Queue (feet)[1]	50	50	25	25	50	75
Weekday PM Peak Hour						
	KAI Analysis	IMR SIDRA	KAI Analysis	IMR SIDRA	KAI Analysis	IMR SIDRA
V/C ratio	0.61	0.57	0.54	0.50	0.99	0.88
Approach Delay, (seconds)	8.9	7.5	7.1	5.4	34.8	21.2
Approach LOS	A	A	A	A	D	C
95th Percentile Queue (feet)[1]	75	100	50	75	325	250

[1]Queue lengths rounded up to the nearest 25 feet (rounded down to the nearest 25 feet if <5 above closest 25)

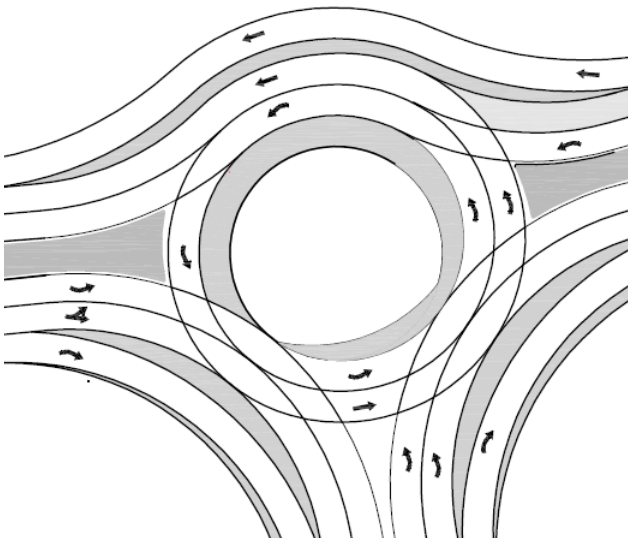
As shown in Table 1 and Table 2, the KAI analysis with the IMR Lane Configuration projects the interim roundabout design to operate with an overall LOS of A and B under year 2015 a.m. and p.m. peak hours, respectively. The KAI analysis with the IMR Lane Configuration projects the ultimate roundabout design to operate with an overall LOS of A and C under year 2037 a.m. and p.m. peak hours, respectively.

Operational results from the KAI analysis differ from those reported in the provided IMR SIDRA outputs, for the following reasons:

- KAI used the US HCM 2010 Model in SIDRA, while the results provided in the IMR SIDRA files were based on the SIDRA Standard Model with an applied environment factor of 1.2. *Appendix B describes fundamental differences in roundabout models.*
- SIDRA does not have the capability to model through bypass lanes. The roundabout analyses included in the IMR SIDRA files did not account for traffic volume using the westbound right-turn bypass lane. KAI modeled the continuous westbound through bypass lane as a non-yielding westbound right-turn bypass lane to account for geometric delay introduced by a continuous bypass lane.
- Five percent of the total westbound through traffic was reassigned and assumed to navigate through the roundabout rather than use the westbound through bypass lane. The remaining 95 percent was assumed to use the bypass lane.
- Identified discrepancies in basic lane configuration between the VDOT SIDRA files and IMR SIDRA file geometric designs (both interim and ultimate designs) were noted and are discussed in detail below, and shown in Figures 4 and 5.

- Interim Design (see Figure 4, below): The westbound approach of the draft IMR design shows a single exclusive left-turn lane and separate westbound through bypass lane, along with three receiving lanes on the eastbound approach. The three receiving lanes on the eastbound approach accommodate the dual northbound left-turn lanes and the westbound through bypass lane. By comparison, the IMR SIDRA file shows the westbound through lane traveling through the roundabout rather than a separate bypass lane. As previously noted, the westbound through bypass lane is not accounted for in the SIDRA file, while the draft IMR design shows only the exclusive westbound left-turn lane circulating through the roundabout..

Draft IMR, Interim Design Lane Configuration



VDOT SIDRA file, Interim Design Lane Configuration

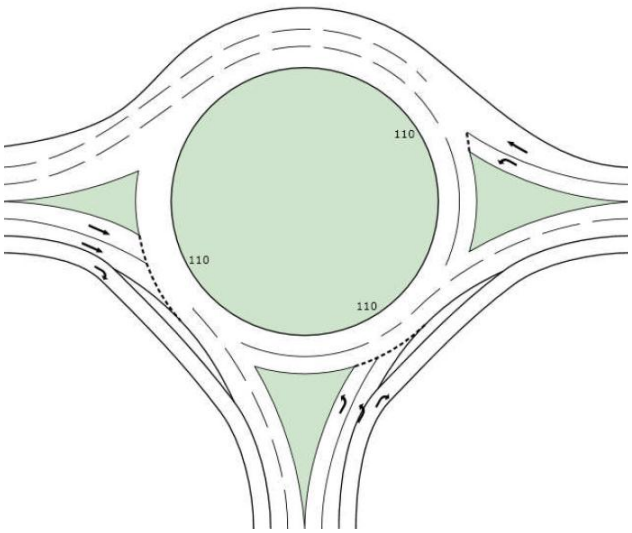


Figure 4 Draft IMR and VDOT SIDRA file, Interim Design Lane Configurations

- Ultimate Design (see Figure 5, below): The westbound approach of the IMR design shows dual westbound left-turn only lanes and a separate westbound through bypass lane, along with three circulating lanes and three receiving lanes on the eastbound approach. The third circulating lane is necessary to accommodate the concurrent double left-turn lanes on the northbound and westbound approaches. By comparison, the IMR SIDRA file shows two exclusive westbound left-turn only lanes *and* a westbound through lane circulating through the roundabout (no bypass lane). Once again, the westbound through bypass lane is not accounted for in the SIDRA file, while the draft IMR design shows only the exclusive westbound left-turn lanes circulating through the roundabout.

Draft IMR, Ultimate Design Lane Configuration **VDOT SIDRA file, Ultimate Design Lane Configuration**

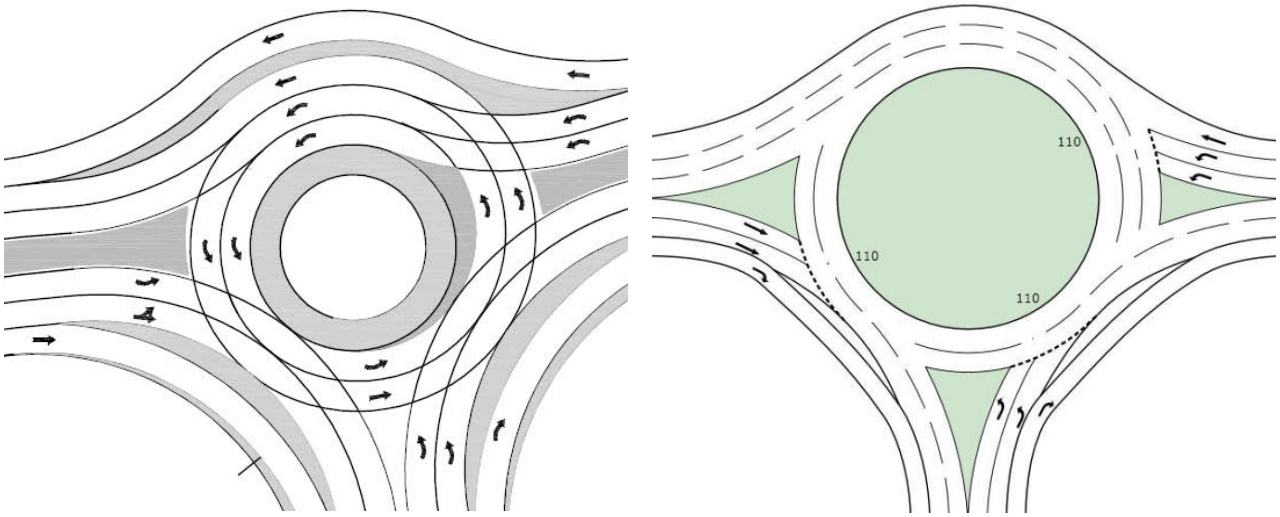


Figure 5 Draft IMR and VDOT SIDRA file, Ultimate Design Lane Configurations

LANE CONTINUITY

Opportunities to reduce the overall number of circulating, entry, and exit lanes were explored for both the interim and ultimate designs. Consistency of entry, circulating, and exit lanes were also reviewed.

KAI identified one opportunity to remove an exit lane on the northbound approach in the interim design. The interim lane configuration shown in the draft IMR (see Figure 2) shows one circulating lane in front of the west splitter island feeding two exit lanes on the south leg, which then join with the eastbound right-turn bypass lane for a total of three exit lanes on the northbound approach. Removing the extra exit lane in the interim design allows for better lane consistency and simplifies potential weaving maneuvers downstream of the roundabout.

UPDATED ANALYSIS

An updated operational analysis was performed using the SIDRA HCM 2010 model assuming these geometric modifications. Figures 6 and 7 illustrate the assumed lane configurations (as schematically illustrated in SIDRA) for the interim and ultimate designs, respectively.

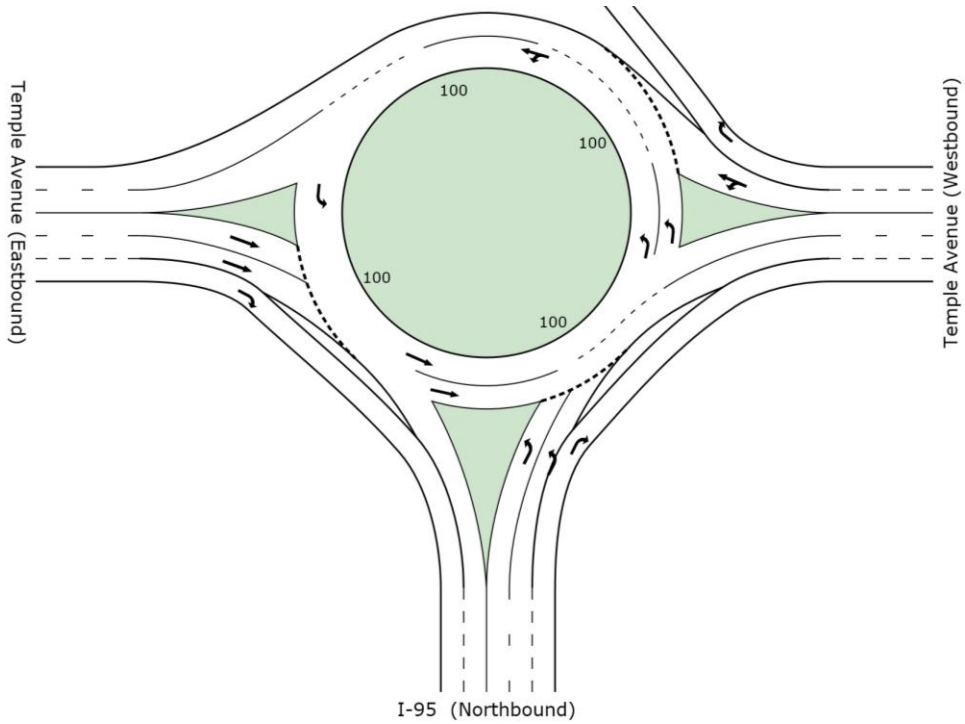


Figure 6 KAI Revised Lane Configuration – Interim Design

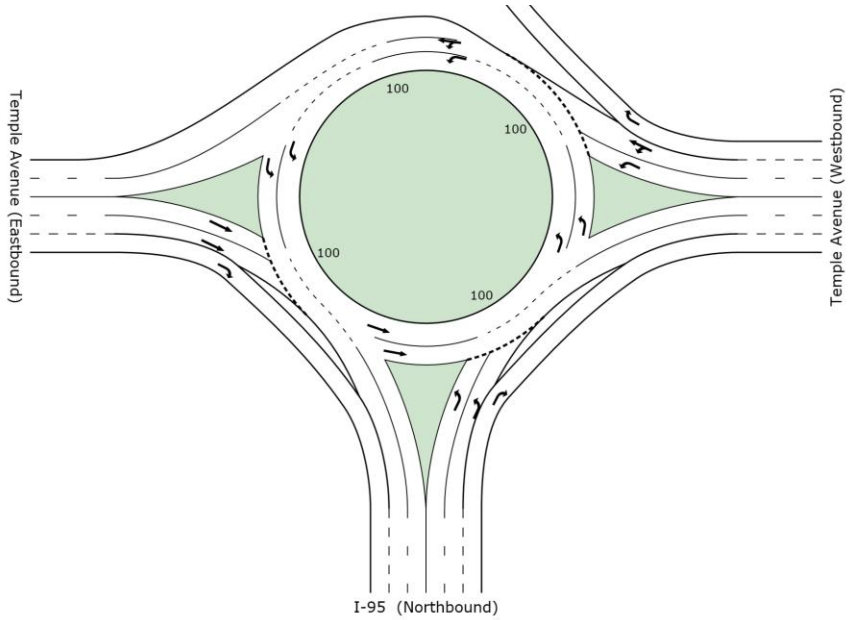


Figure 7 KAI Revised Lane Configuration – Ultimate Design

Table 3 and Table 4 display the results of the operational analysis using the revised lane configurations for the proposed I-95/Temple Avenue roundabout under opening year 2015 and design year 2037 traffic conditions.

Table 3 Opening Year 2015 Traffic Operations: KAI Lane Configuration – SIDRA HCM 2010

	West Leg (Eastbound) Temple Avenue	East Leg (Westbound) Temple Avenue	South Leg (Northbound) I-95
Weekday AM Peak Hour			
V/C ratio	0.56	0.41	0.42
Approach Delay, (sec)	3.2	3.2	4.6
Approach LOS	A	A	A
95th Percentile Queue (ft)[1]	50	50	50
Weekday PM Peak Hour			
V/C ratio	0.51	0.76	0.77
Approach Delay, (sec)	7.4	11.2	15.3
Approach LOS	A	B	C
95th Percentile Queue (ft)[1]	75	100	125

[1]Queue lengths rounded up to the nearest 25 feet (rounded down to the nearest 25 feet if <5 above closest 25)

Table 4 Design-Year 2037 Traffic Operations: KAI Lane Configuration – SIDRA HCM 2010

	West Leg (Eastbound) Temple Avenue	East Leg (Westbound) Temple Avenue	South Leg (Northbound) I-95
Weekday AM Peak Hour			
V/C ratio	0.65	0.49	0.51
Approach Delay, (sec)	3.3	2.6	6.4
Approach LOS	A	A	A
95th Percentile Queue (ft)[1]	50	25	50
Weekday PM Peak Hour			
V/C ratio	0.61	0.54	0.99
Approach Delay, (sec)	8.9	7.1	34.8
Approach LOS	A	A	D
95th Percentile Queue (ft)[1]	75	50	325

[1]Queue lengths rounded up to the nearest 25 feet (rounded down to the nearest 25 feet if <5 above closest 25)

As shown in Table 3 and Table 4, the eastbound approach is critical during the weekday a.m. peak hour, and the northbound approach is critical during the weekday p.m. peak hour under both opening year and design year traffic conditions. Under design year 2037 traffic conditions, the northbound approach is forecast to operate at a volume-to-capacity (v/c) ratio of 0.99 during the weekday p.m. peak hour assuming the ultimate design configuration.

Based upon domestic and international experience, NCHRP Report 672 suggests a maximum v/c ratio in the range of 0.85 to 0.90 for providing satisfactory operations. While a 0.85 v/c ratio is not an absolute threshold, the operations of the approach become more sensitive to small increases in volume as the v/c approaches 1.0 and may result in substantial impacts to delay or queues. However, a higher v/c ratio may be acceptable for a variety of reasons, including:

- A high v/c ratio for one or two hours of a day may be acceptable when considering the impact of additional lanes and increased physical or environmental impacts.
- A high v/c ratio is forecast at the end of the design horizon, when the reliability of forecast traffic volumes are most unpredictable.
- Forecast design year 95th percentile queues during the weekday p.m. peak hour on the northbound approach are not that long even with a projected v/c ratio of 0.99, and should not adversely impact the interchange.

In this case, the assumed growth rates used to forecast year 2037 traffic volumes in the draft IMR are considered conservative. Given the assumed 25 year design life, unpredictability of future volume growth, and potential improvements in roundabout performance as drivers become more familiar with roundabouts over time, the ultimate design is considered adequate to accommodate design year traffic volumes. *Attachment C contains the updated SIDRA HCM 2010 Model roundabout analysis worksheets.*

Sensitivity Analysis

The expected lifespan of the interim design was estimated by growing opening year 2015 volumes for each individual movement to determine when the interim roundabout design would reach capacity. Based on this analysis, it was determined that the interim roundabout design would reach capacity in the year 2030, with the weekday p.m. peak hour westbound approach would reach 0.99 with an average delay of 66.2 seconds. Therefore, if traffic projections hold true, the ultimate roundabout design would need to be implemented in approximately year 2030.

Section 4
Geometric Review

GEOMETRIC REVIEW

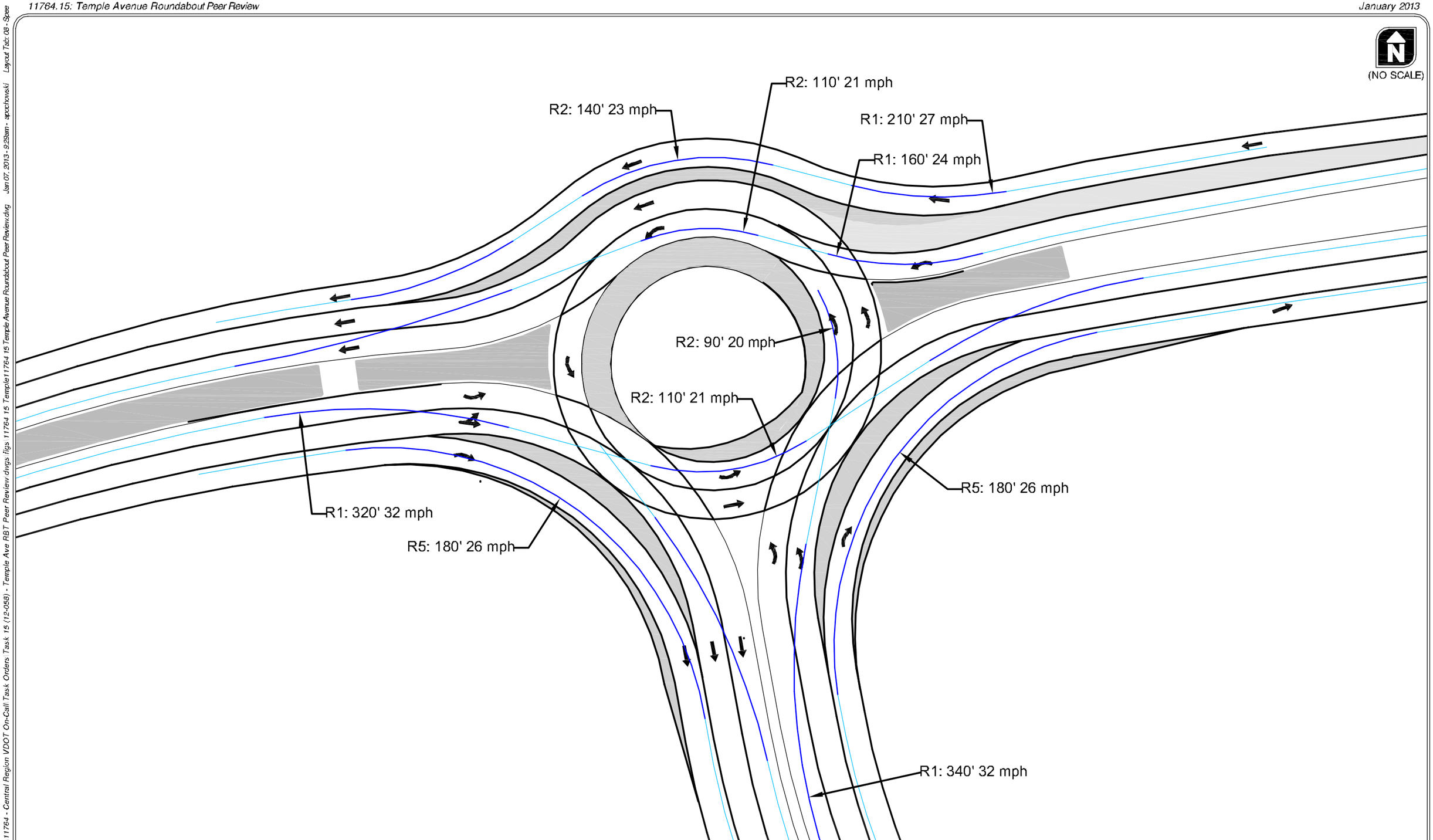
Geometric design features of the proposed interim and ultimate roundabouts designs were reviewed to ensure the roundabout provides appropriate speed control, design-vehicle accommodations, natural-entry paths and appropriate sight distance. The results of the geometric review are provided in the subsequent section.

THEORETICAL FASTEST-PATH CHECKS

The fastest path allowed by the geometry of a roundabouts determines the negotiation speed for that particular movement into, through, and exiting the roundabout. It is the smoothest, flattest path possible for a single vehicle absent other traffic and ignoring all lane and pavement markings. Fastest path speeds do not represent expected vehicle speeds, but rather theoretical attainable speeds for design purposes. Actual speeds can vary substantially based on a vehicle's suspension, individual driving abilities, and tolerance for lateral gravitational forces.

Fastest path speeds were evaluated to determine if the current interim and ultimate roundabout designs meet performance objectives for speed control. NCHRP Report 672 recommends a maximum fastest path entering speed of 25 miles per hour (mph) for a single-lane approach and 30 mph for a multilane approach.

With the exception of single-lane westbound entry (interim design), all fastest-path entry radii were found to exceed the recommended entry speeds, though in most cases by only two miles per hour, which is generally within the tolerance of the procedure. Measures to reduce these speeds are further discussed in the Design Modifications section of this report. Figure 8 and Figure 9 display the theoretical fastest-path radii and speeds for the current interim and ultimate roundabout designs, respectively. *Appendix D contains the fastest path worksheets.*



THEORETICAL FASTEST PATH SPEEDS AND RADII - INTERIM DESIGN
I-95/TEMPLE AVENUE INTERCHANGE
COLONIAL HEIGHTS, VIRGINIA

FIGURE 8

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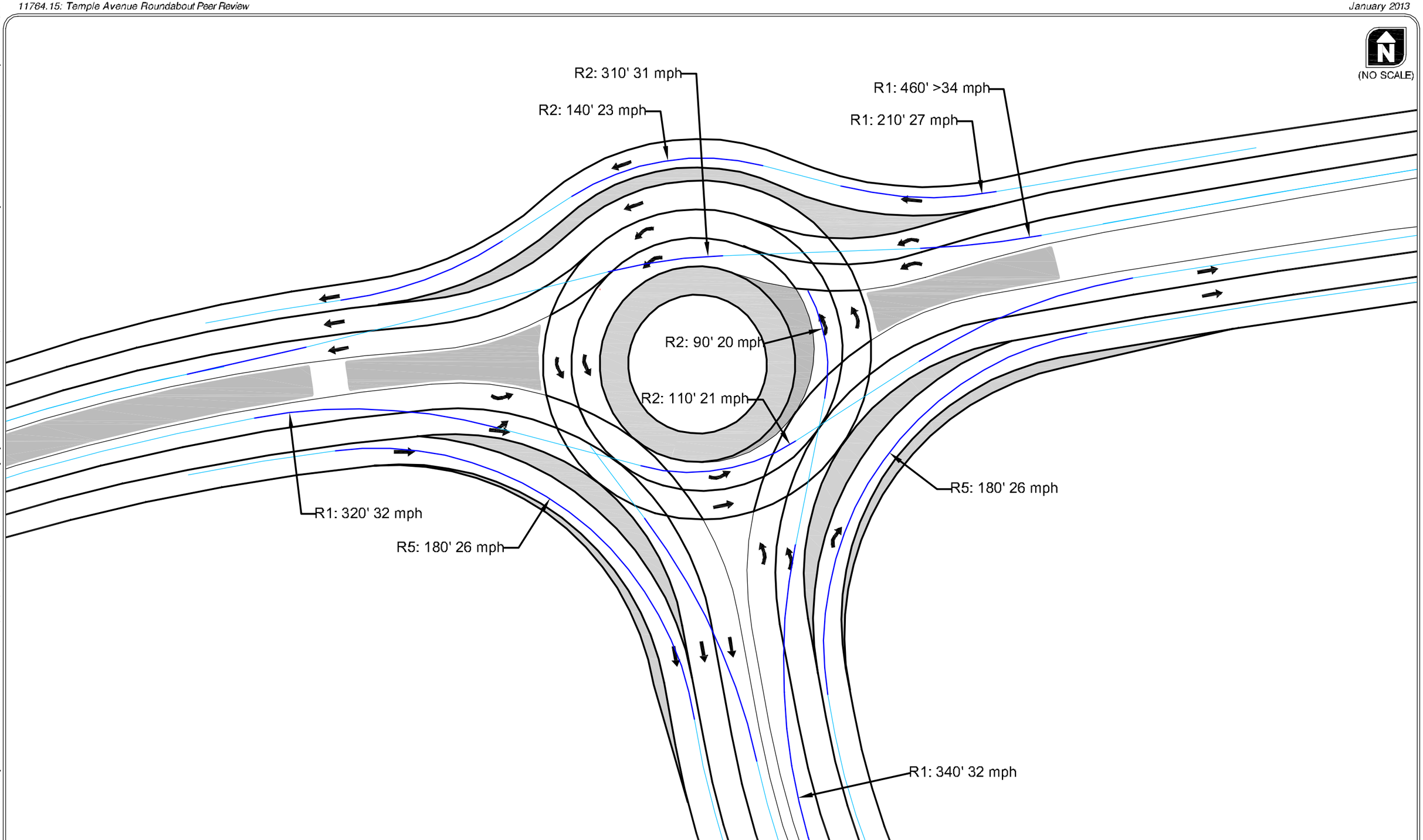

THEORETICAL FASTEST PATH SPEEDS AND RADII - ULTIMATE DESIGN
I-95/TEMPLE AVENUE INTERCHANGE
COLONIAL HEIGHTS, VIRGINIA

FIGURE 9

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DESIGN-VEHICLE CHECKS

Accommodation of the design vehicle was evaluated using the AutoTURN software tool and assumed a WB-67 design vehicle for all movements. Figure 10 and Figure 11 display the WB-67 design-vehicle checks for the interim and ultimate roundabout designs, respectively. WB-67 off-tracking was identified at the following locations in both the interim and ultimate roundabout designs:

- Northbound approach on the outside of the entry and the exit of the right-turn bypass
- Westbound approach on the outside of the entry and the outside of the exit of the through bypass
- Eastbound approach on the outside of the entry, on the outside of the exit and the exit of the right-turn bypass
- The truck apron

Off-tracking is appropriate on the truck apron, and if the outside medians between the entry approaches and right-turn bypasses are designed to accommodate off-tracking by heavy vehicles, off-tracking is appropriate there too. Both the current and proposed designs assume that WB-67 semi-trailers can use either lane on double-lane entries and in the circulatory roadway. In rare instances where two WB-67s may approach a double-lane entry simultaneously, most drivers will naturally stagger their entry and negotiation of the roundabout to avoid conflicts. Considering the low frequency of heavy vehicles reported in the draft IMR, this common phenomenon is anticipated and not perceived as problematic. Additional measures to minimize the impacts of off-tracking heavy vehicles are further discussed in the Design Modifications section.

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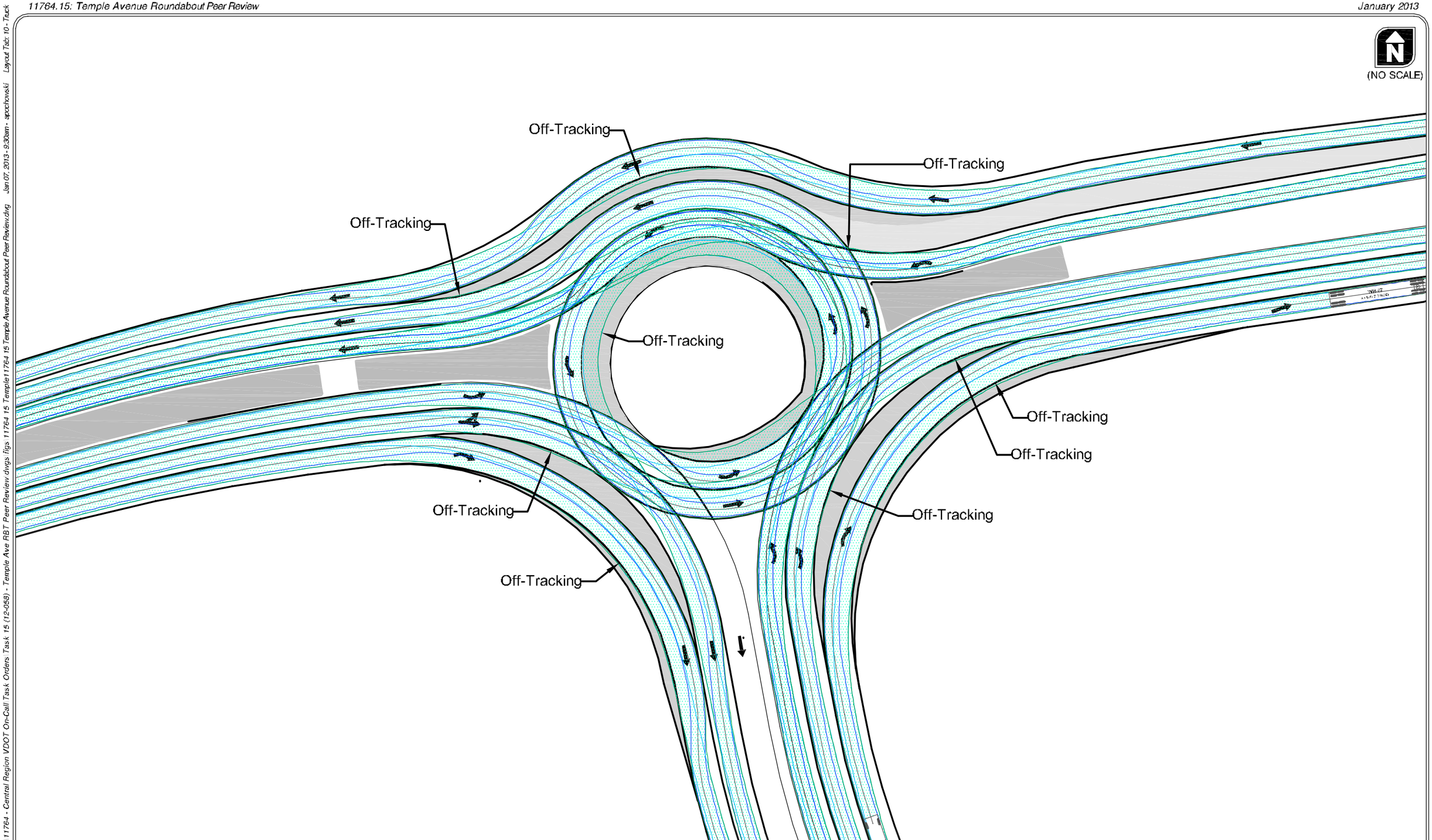

WB-67 DESIGN VEHICLE CHECKS - INTERIM DESIGN
I-95/TEMPLE AVENUE INTERCHANGE
COLONIAL HEIGHTS, VIRGINIA

FIGURE 10

KITTELSON & ASSOCIATES, INC.
TRANSPORTATION ENGINEERING / PLANNING

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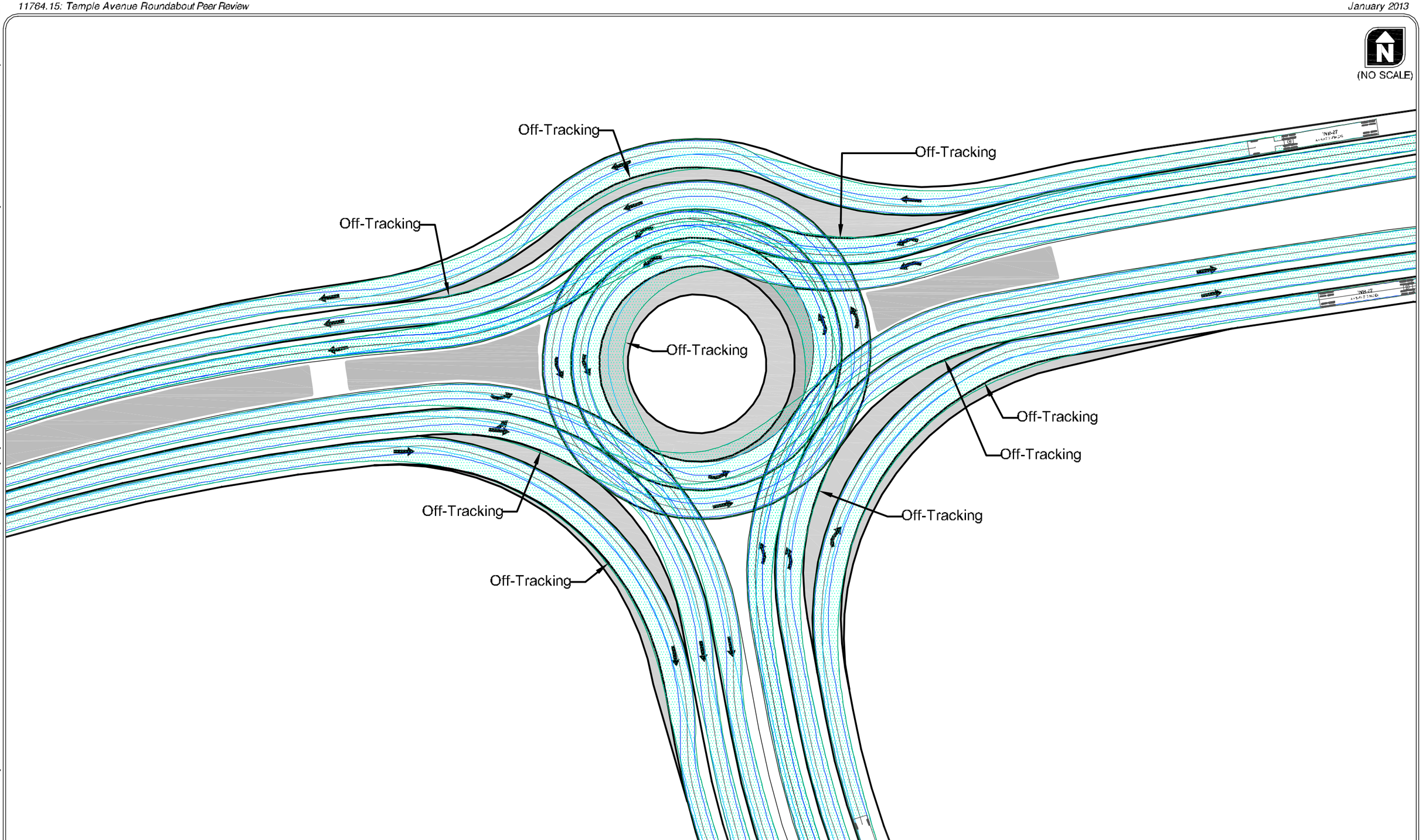


WB-67 DESIGN VEHICLE CHECKS - ULTIMATE DESIGN
I-95/TEMPLE AVENUE INTERCHANGE - ULTIMATE DESIGN
COLONIAL HEIGHTS, VIRGINIA

FIGURE 11

NATURAL PATH ENTRY CHECKS

Vehicle path overlap is a type of conflict that occurs when the natural path of the adjacent lanes cross one another. It occurs most commonly at entries, where the geometry of the right (outside) lane tends to lead vehicles into the left (inside) circulatory lane. However, vehicle path overlap can also occur at exits where the geometry tends to lead vehicles from the left-hand lane into the right-hand exit lane. Exhibit 6-28 in NCHRP Report 672 illustrates an example of entry vehicle path overlap.

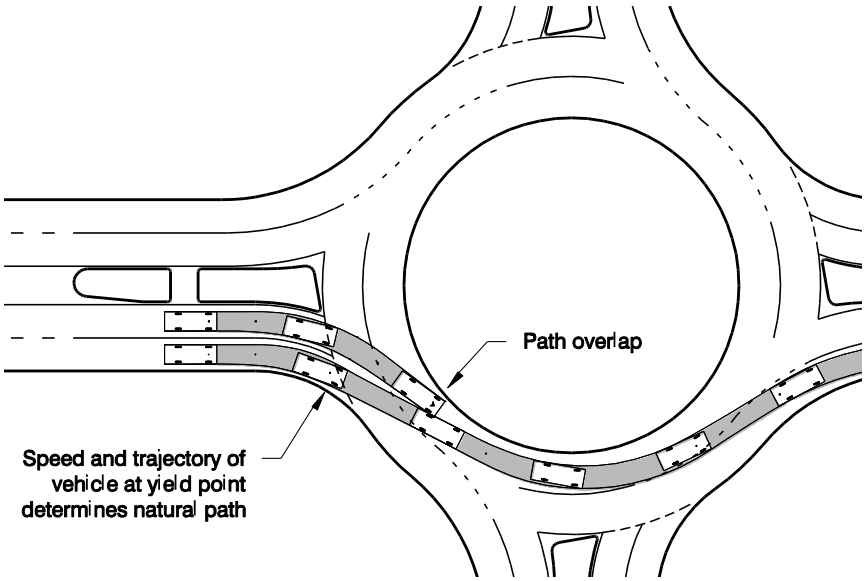
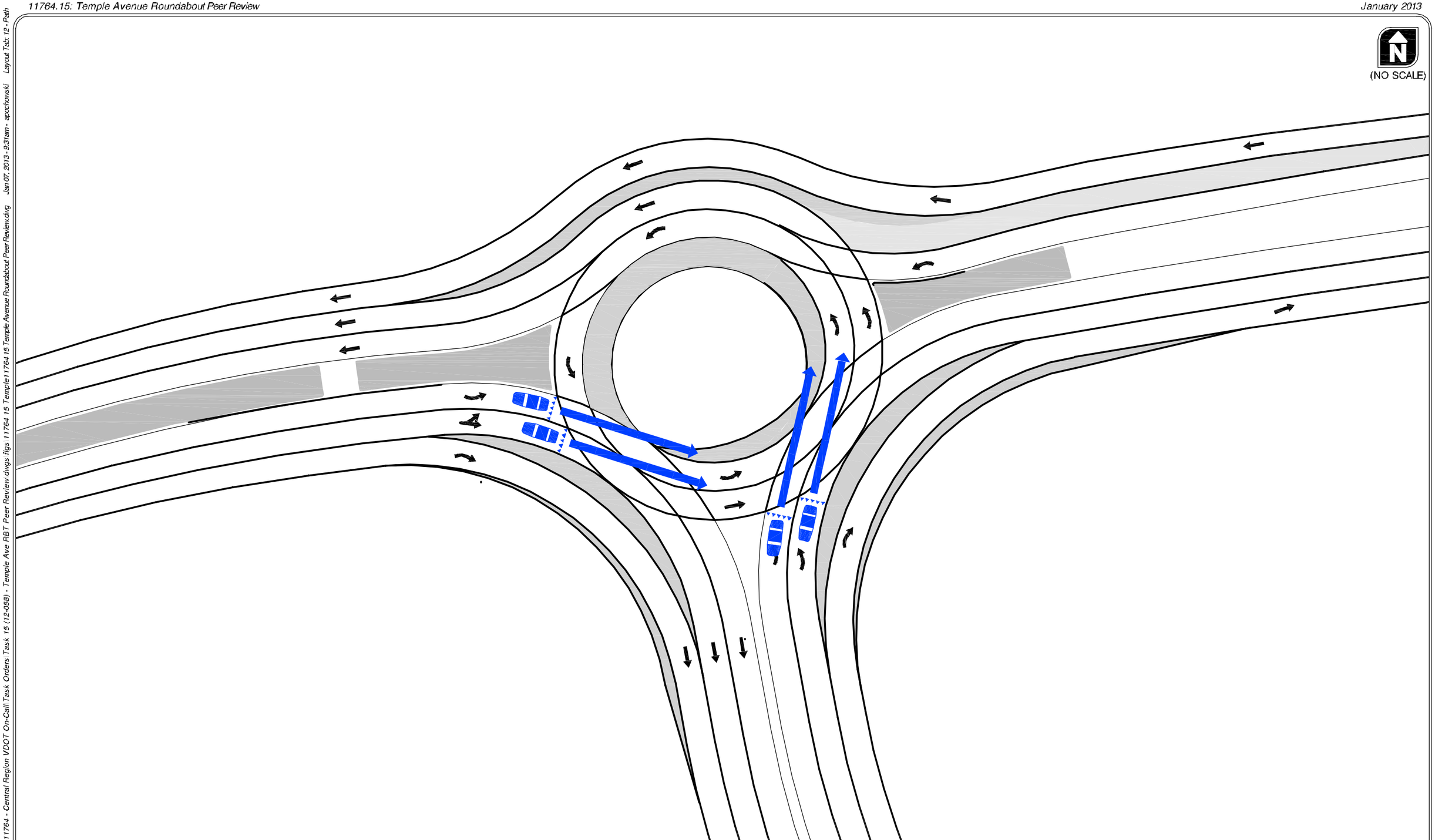


Exhibit 6-28 – NCHRP Report 672

Figure 12 and Figure 13 show that the interim and ultimate roundabout designs both have substantial path overlap as currently designed. Recommended design modifications and techniques that can be used to minimize path overlap are discussed in the Design Modifications section.

SIGHT DISTANCE CHECKS

Sight distance checks were performed on the interim and ultimate roundabout designs to ensure adequate stopping and intersection sight distance is provided for all movements and approach vehicles. Based on the sight-distance checks shown in Figure 14 and Figure 15, low-growth landscaping should be provided on the edges of the central island to appropriately limit sight distance.



NATURAL PATH CHECKS - INTERIM DESIGN
I-95/TEMPLE AVENUE INTERCHANGE
COLONIAL HEIGHTS, VIRGINIA

FIGURE
12

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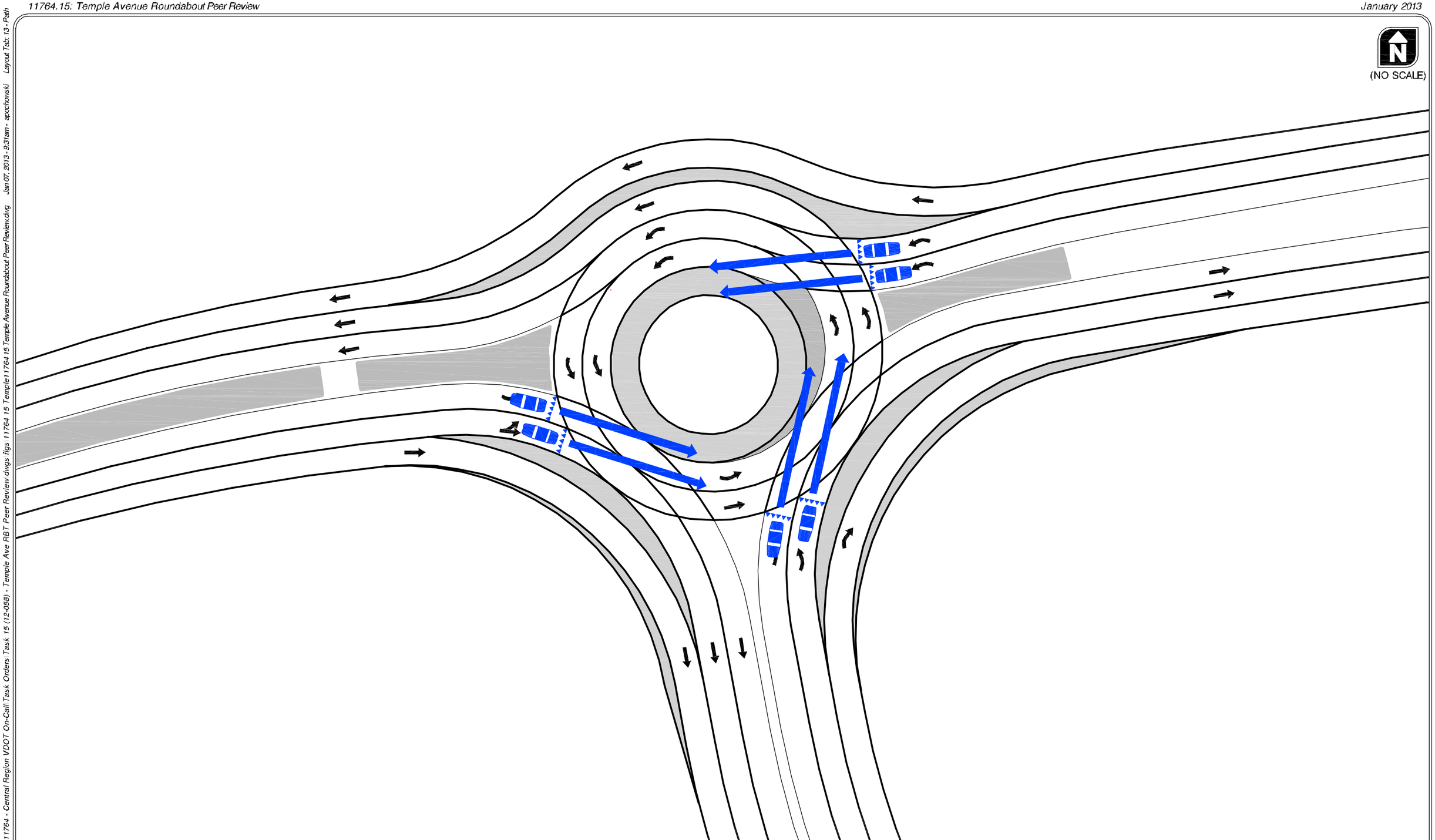

NATURAL PATH CHECKS - ULTIMATE DESIGN
I-95/TEMPLE AVENUE INTERCHANGE
COLONIAL HEIGHTS, VIRGINIA

FIGURE 13

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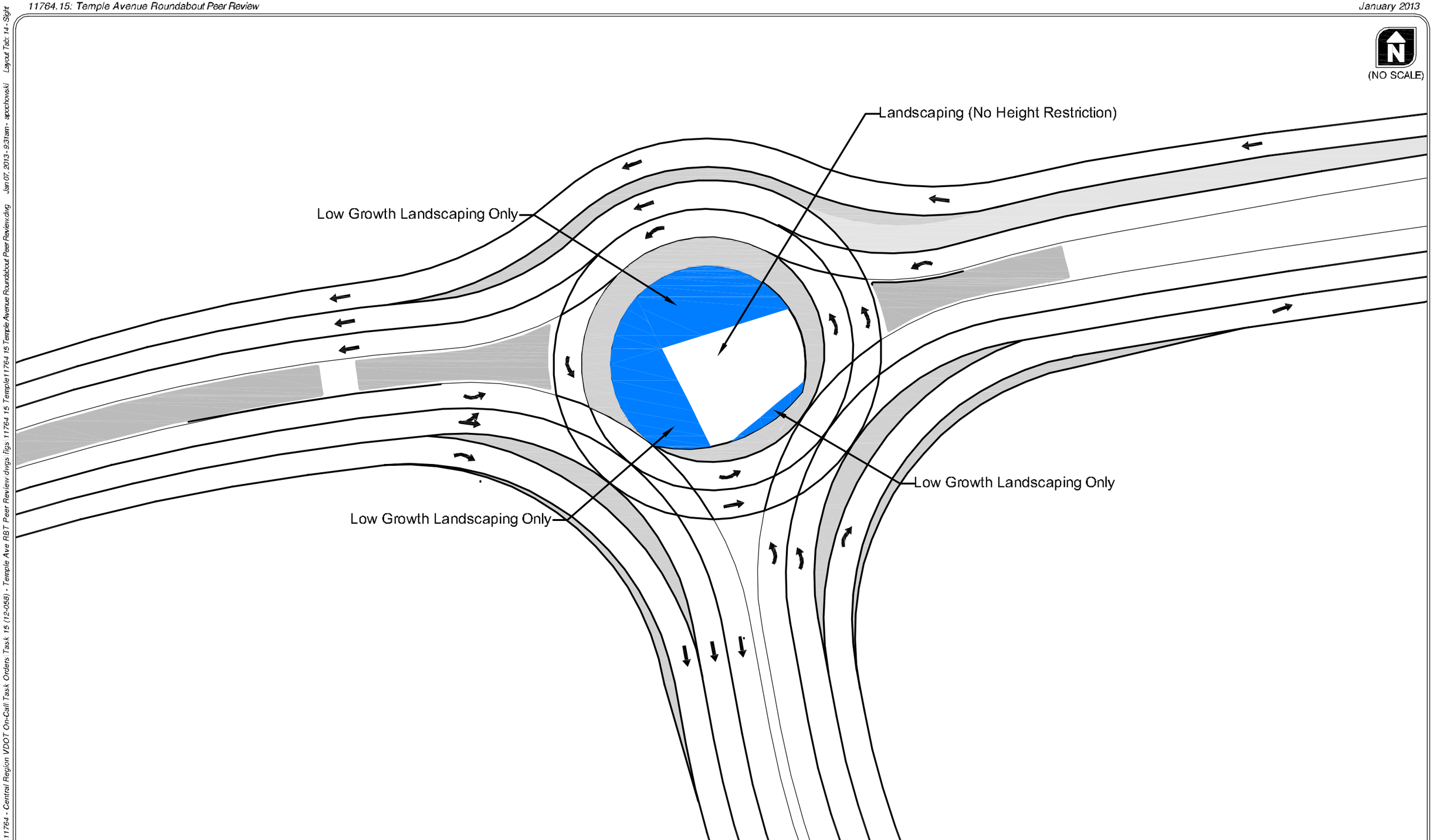

SIGHT DISTANCE CHECKS - INTERIM DESIGN
I-95/TEMPLE AVENUE INTERCHANGE
COLONIAL HEIGHTS, VIRGINIA

FIGURE 14

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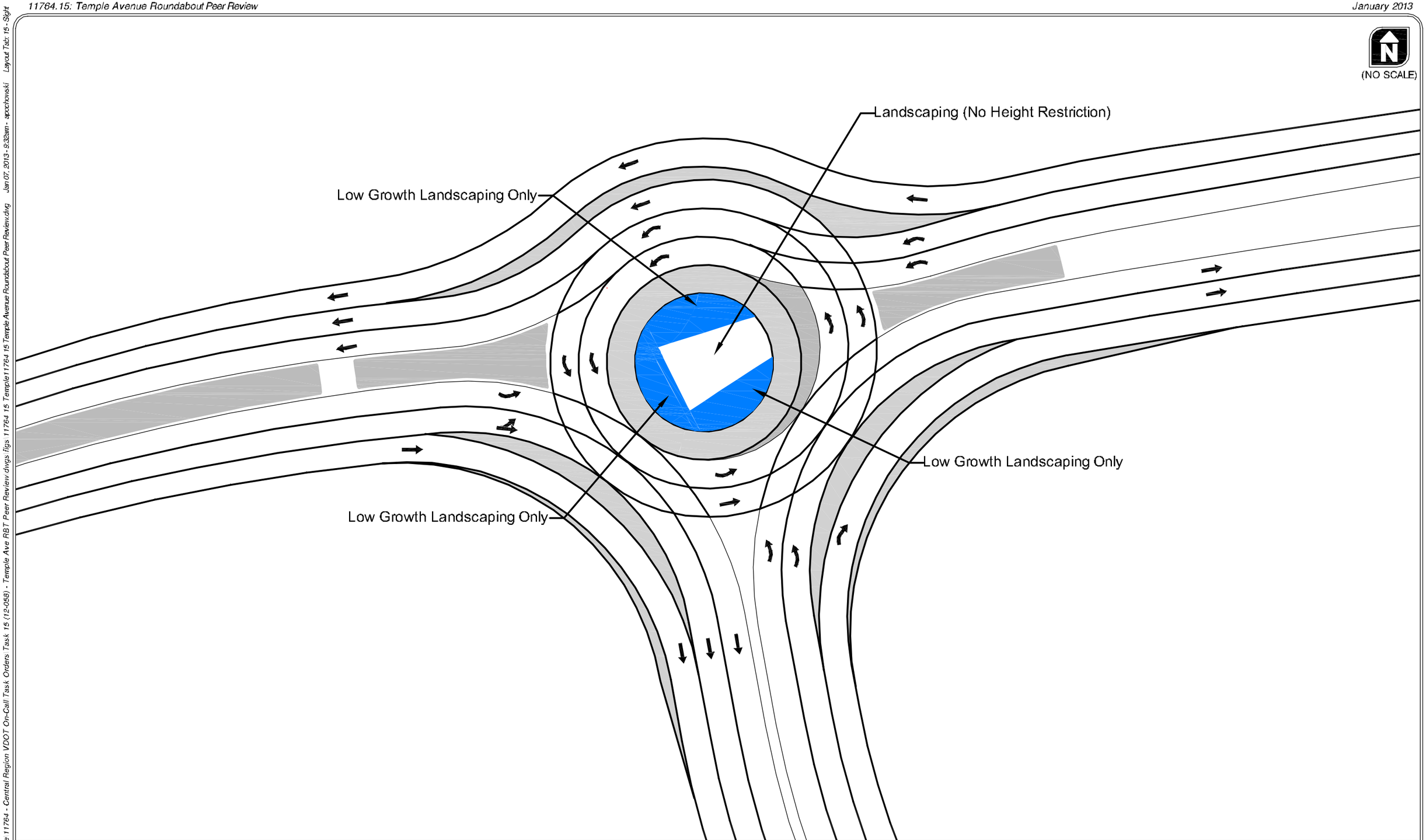

SIGHT DISTANCE CHECKS - ULTIMATE DESIGN
I-95/TEMPLE AVENUE INTERCHANGE
COLONIAL HEIGHTS, VIRGINIA

FIGURE 15

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BICYCLE AND PEDESTRIAN TREATMENTS

As noted in the draft IMR, the I-95/Temple Avenue intersection falls within the limited access area of the interchange. As such, bicycle and pedestrian accommodations are not provided in the current roundabout design. However, a review of the surrounding area reveals Temple Avenue provides one of only a few crossings of the Appomattox River, and the interchange is situated between Southpark Mall to the east and residential development to the west. Given the surrounding land use context, it may be appropriate for the final design to include features (such as a break in the splitter island and provision for future ADA accessible curb ramps, etc.) to accommodate a future a pedestrian crossing of at least the south leg of the intersection to accommodate pedestrian movements along Temple Avenue should a future project be developed by VDOT (or others) that includes pedestrian improvements in this area.

SIGNING AND PAVEMENT MARKING

Signing and pavement marking plans have not yet been developed to a degree that would allow for thorough review. As the project moves forward, we recommend following guidance regarding roundabout signing and pavement marking provided in the 2009 *Manual of Uniform Traffic Control Devices* (Reference 4).

INTERSECTION LIGHTING

The draft IMR does not discuss intersection lighting and it is unclear in the preliminary design whether or not intersection lighting is planned. Intersection lighting is an important consideration at roundabouts since the roundabout introduces geometry and channelization that a driver may not expect unless it is visible at all times. In addition, the effectiveness of vehicle headlights is limited in a roundabout due to the constrained curve radius, making the roadway lighting system important for nighttime visibility of obstructions and hazards. We recommend following guidance regarding lighting found in Chapter 8 of NCHRP Report 672.

SPLITTER ISLAND DESIGN

Splitter islands provide refuge for pedestrians, assist in controlling speeds, guide traffic into the roundabout, physically separate entering and exiting traffic streams, and deter wrong-way movements. A review of the proposed splitter islands designs reveal that recommended radii and offsets are not provided on the east and west splitter islands, and no splitter island on the northbound approach. Exhibit 6-13 of NCHRP Report 672 provides an illustration and detailed discussion of appropriate splitter island designs. We recommend that a northbound splitter island be provided and extend back from the roundabout a minimum of 150 feet.

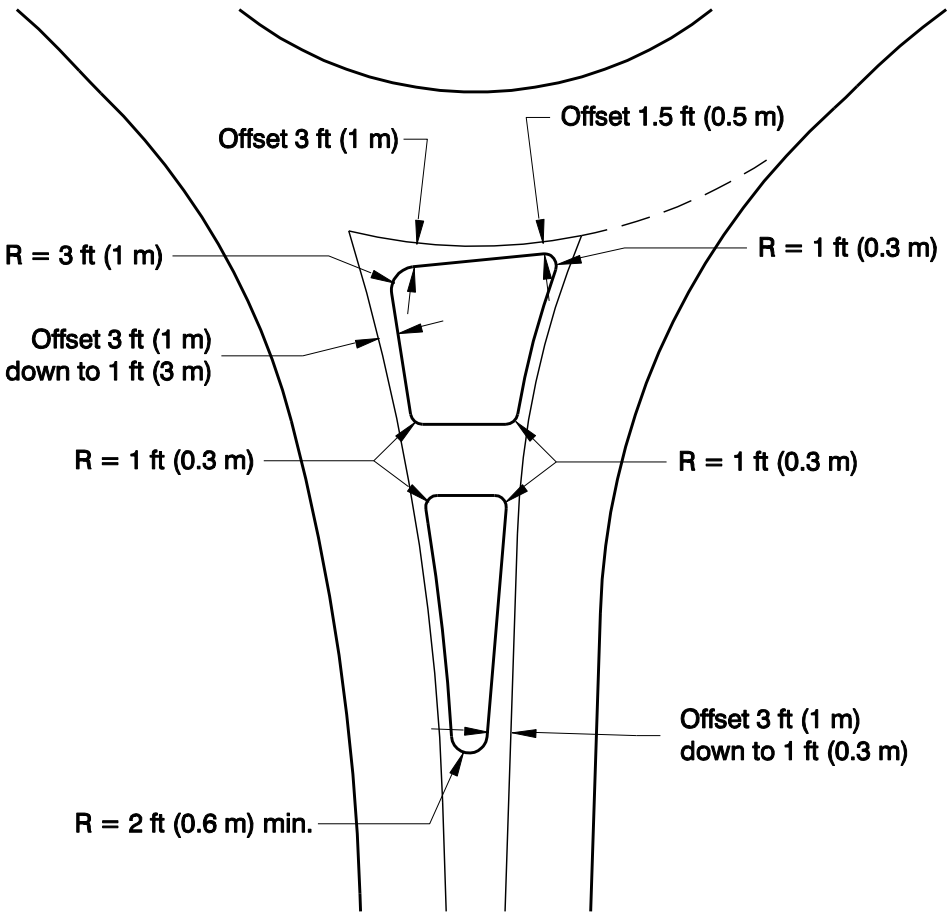

Exhibit 6-13 – NCHRP Report 672

Section 5
Design Modifications

DESIGN MODIFCATIONS

Recommended modifications to the current draft IMR roundabout designs are illustrated in Figure 16 (interim lane configuration) and Figure 17 (ultimate lane configuration). These modifications are primarily focused on addressing path overlap. Since geometric changes are necessary to address path overlap issues, the modifications should also work to reduce fastest path speeds to within desirable thresholds. Key features and principles of the suggested design modifications are summarized below:

- As shown in the sketches, the suggested technique at this site for enhancing the entry deflection is to shift the approach alignments towards the left of the roundabout center. This approach appears most appropriate in this case as it minimizes impacts to adjacent properties and does not require wholesale design changes such as shifting the roundabout or adjusting the current inscribed circle diameter. By offsetting the eastbound and westbound approach alignments, as shown, the R1 fastest path curve radii are reduced to approximately 250 feet, resulting in corresponding entry speeds of approximately 29 mph.
- The recommended design technique to reduce path overlap at multilane entries is illustrated in Exhibit 6-30 of NCHRP Report 672. The design technique consists of a small-radius curve, approximately 75 feet, set back from the edge of the circulatory roadway. A short section of tangent is then provided between the entry curve and the outside edge of the circulatory roadway to align vehicles into the proper lane at the entrance line.

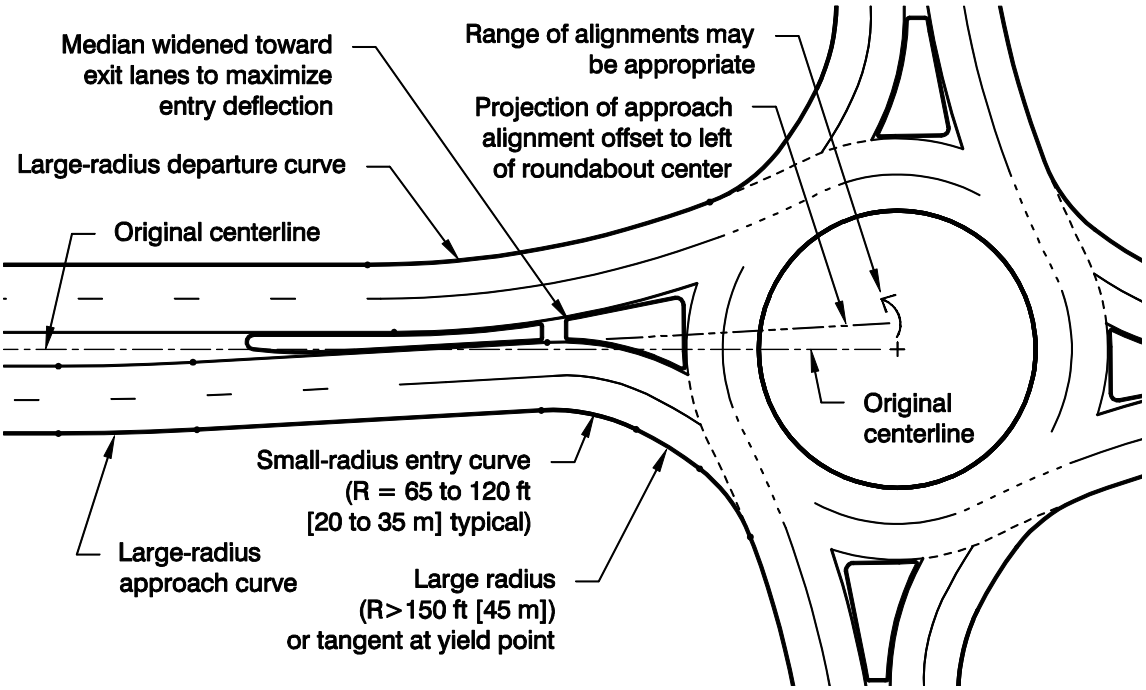

Exhibit 6-30 – NCHRP Report 672

- Tangential exits allow for better entry deflection, reduced path overlap on multilane exits, and reduced off-tracking of larger vehicles.
- As shown in Figure 16, the interim lane configuration is achieved by constructing wider medians on the east and south legs and by expanding the central island (through temporary striping or widened truck apron). In the future, median widths can be reduced and the circulatory striping can be adjusted, as shown in Figure 17, to add a second westbound left-turn lane and develop the ultimate lane configuration.
- Provide a northbound splitter island to extend back from the roundabout a minimum of 150 feet to provide for a potential future pedestrian refuge, assist in controlling speeds, guide traffic into the roundabout, physically separate entering and exiting traffic streams, and deter wrong-way movements.
- Preliminary truck turning paths are illustrated in Figures 18 through 20. As shown, the proposed design assumes that WB-67 semi-trailers will use both lanes within the double-lane entries and circulatory roadway. Considering the relatively low frequency of these vehicles, this technique is common and typically not problematic.

PROPOSED KAI INTERIM DESIGN
I-95/TEMPLE AVENUE INTERCHANGE
COLONIAL HEIGHTS, VIRGINIA

FIGURE 16

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PROPOSED KAI ULTIMATE DESIGN
I-95/TEMPLE AVENUE INTERCHANGE
COLONIAL HEIGHTS, VIRGINIA

FIGURE 17

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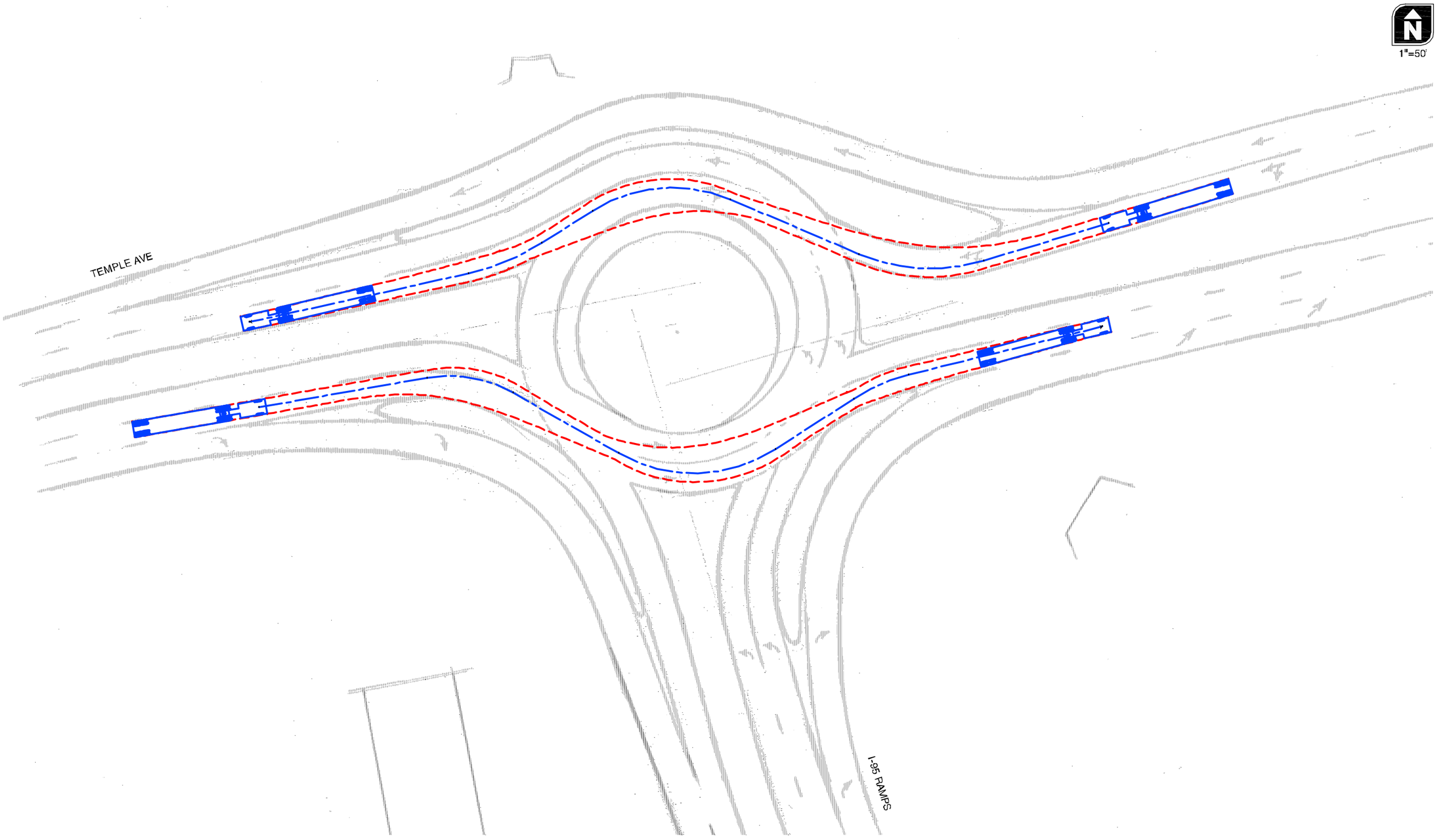

KAI INTERIM DESIGN WB-67 DESIGN VEHICLE CHECKS
I-95/TEMPLE AVENUE INTERCHANGE
COLONIAL HEIGHTS, VIRGINIA

FIGURE 18

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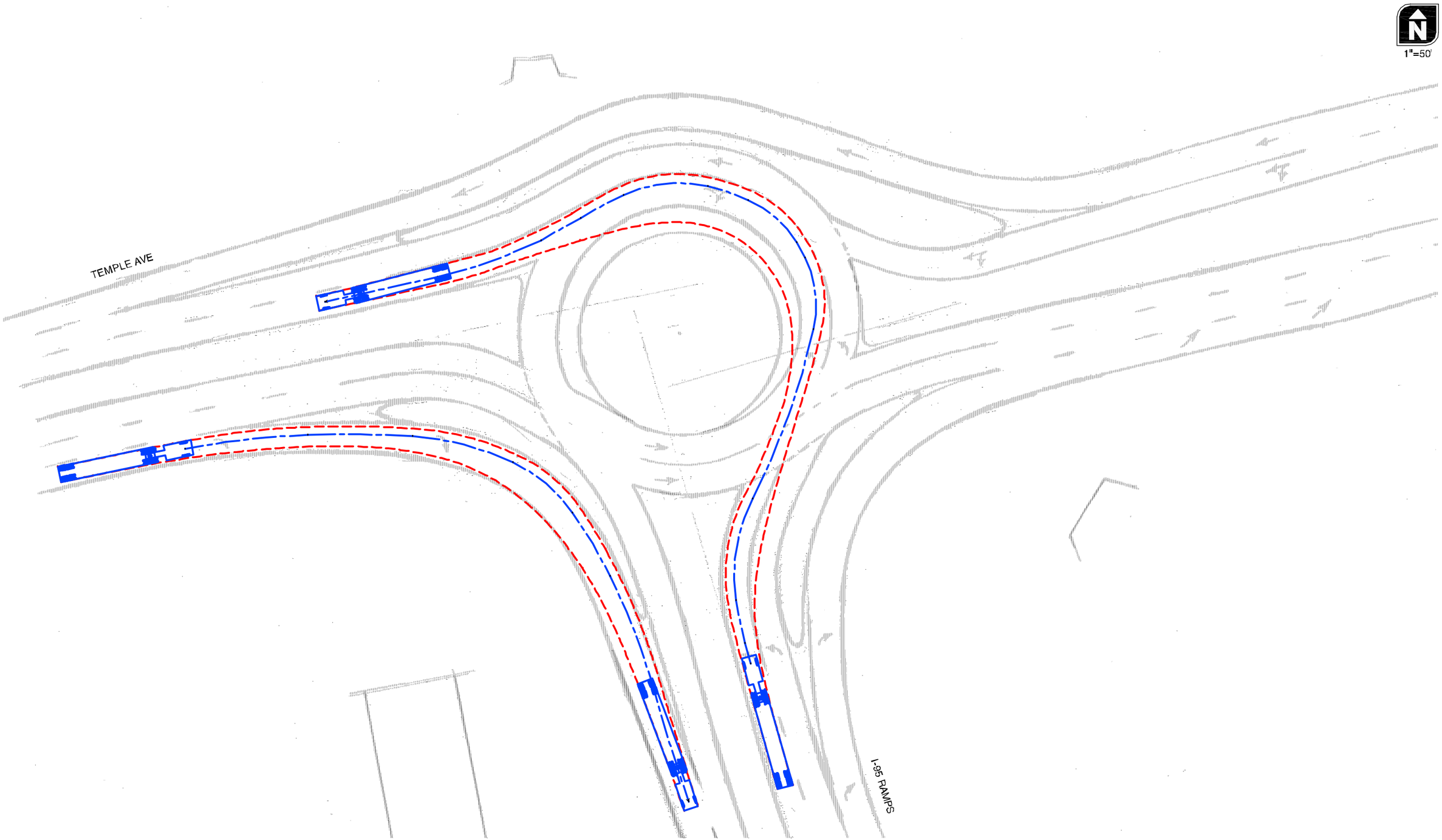

KAI INTERIM DESIGN WB-67 DESIGN VEHICLE CHECKS
I-95/TEMPLE AVENUE INTERCHANGE
COLONIAL HEIGHTS, VIRGINIA

FIGURE 19

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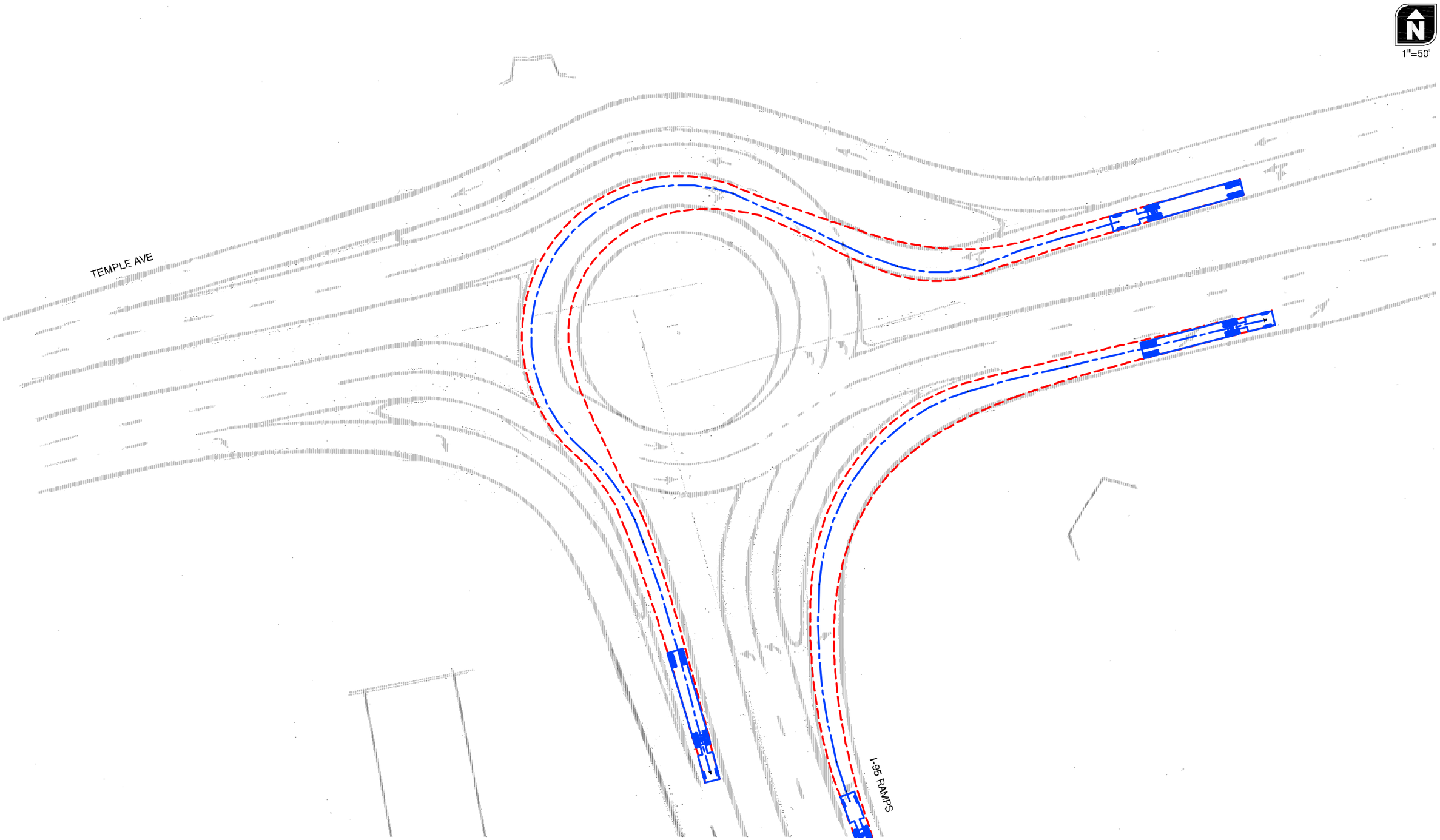

KAI INTERIM DESIGN WB-67 DESIGN VEHICLE CHECKS
I-95/TEMPLE AVENUE INTERCHANGE
COLONIAL HEIGHTS, VIRGINIA

FIGURE 20

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Section 6
Conclusions and Recommendations

CONCLUSIONS AND RECOMMENDATIONS

Our review of the I-95/Temple Avenue roundabout operational analysis and geometric design resulted in the following findings and recommendations.

Operations Review

- A review of the draft IMR, traffic volumes (Excel Workbook), and SIDRA files provided by VDOT identified minor discrepancies.
  - The design year 2037 weekday p.m. peak hour eastbound right-turn volume is shown as 594 vehicles in the SIDRA file and draft IMR, and 534 in the provided Excel workbook.
  - The basic lane configurations were different between the VDOT SIDRA files and IMR SIDRA file preliminary geometric designs (both interim and ultimate designs).
- Roundabout operations were independently verified by KAI using the Highway Capacity Manual (HCM) 2010 model in SIDRA Intersection 5.1.
  - The interim roundabout design (draft IMR lane configuration) is projected to operate at LOS A and B under opening year 2015 weekday a.m. and p.m. peak hour conditions, respectively.
  - The ultimate roundabout design (draft IMR lane configuration) is projected to operate at LOS A and C under design year 2037 weekday a.m. and p.m. peak hour conditions, respectively.
  - These results differ from reported operational results in the draft IMR because:
    - KAI used the HCM 2010 Model in SIDRA rather than the SIDRA Standard Model with an applied environment factor of 1.2. The HCM 2010 Model is based on empirical data at roundabouts in the United States.
    - The westbound through bypass lane was modeled as a non-yielding right-turn bypass lane in SIDRA to account for geometric delay incurred by this movement.
    - The lane configuration shown in the draft IMR was used for the KAI analysis, which is different than the lane configuration used in the SIDRA files provided by VDOT.
- Removing the extra exit lane on the northbound approach (south leg) in the interim design allows for better lane continuity and simplifies potential weaving maneuvers downstream of the roundabout.

- If traffic projections hold true, the ultimate roundabout design would need to be implemented in approximately year 2030.
- The ultimate roundabout design is projected to operate with a volume-to-capacity (v/c) ratio of 0.99 during the design year 2037 weekday p.m. peak hour assuming the ultimate design configuration.
    - While NCHRP Report 672 suggests a maximum v/c ratio in the range of 0.85 to 0.90, in this case the ultimate design is considered adequate to accommodate design year traffic volumes given to the 25 year design life, unpredictability of future volume growth, and potential improvements in roundabout performance as drivers become more familiar with roundabouts over time.

Geometric Review

- The current interim and ultimate roundabout designs both have substantial path overlap. KAI recommends incorporating design modifications and techniques discussed in the Design Modifications section to minimize path overlap.
- With the exception of single-lane westbound entry (interim design), all fastest-path entry radii were found to exceed the recommended entry speeds, though in most cases by only two miles per hour, which is generally within the tolerance of the procedure.
    - Since geometric changes are necessary to address path overlap issues, the modifications should also work to reduce fastest path speeds to within desirable thresholds. KAI recommends adopting measures to reduce the entry speeds as discussed in the Design Modifications section.
- WB-67 design vehicle off-tracking was noted in the review of the interim and ultimate designs. KAI recommends adopting the measures discussed in the Design Modifications section to minimize the impacts of off-tracking heavy vehicles.
- KAI recommends providing low-growth landscaping on the edges of the central island to appropriately limit sight distance.
- As the project moves forward, KAI recommends following guidance regarding roundabout signing and pavement markings provided in the 2009 MUTCD.
- KAI recommends intersection lighting at the roundabout per guidance provided in Chapter 8 of NCHRP Report 672.
- KAI recommends adjusting radii and offsets on the splitter islands and providing a northbound splitter island extending a minimum of 150 feet back from the roundabout.

Section 7
References

REFERENCES

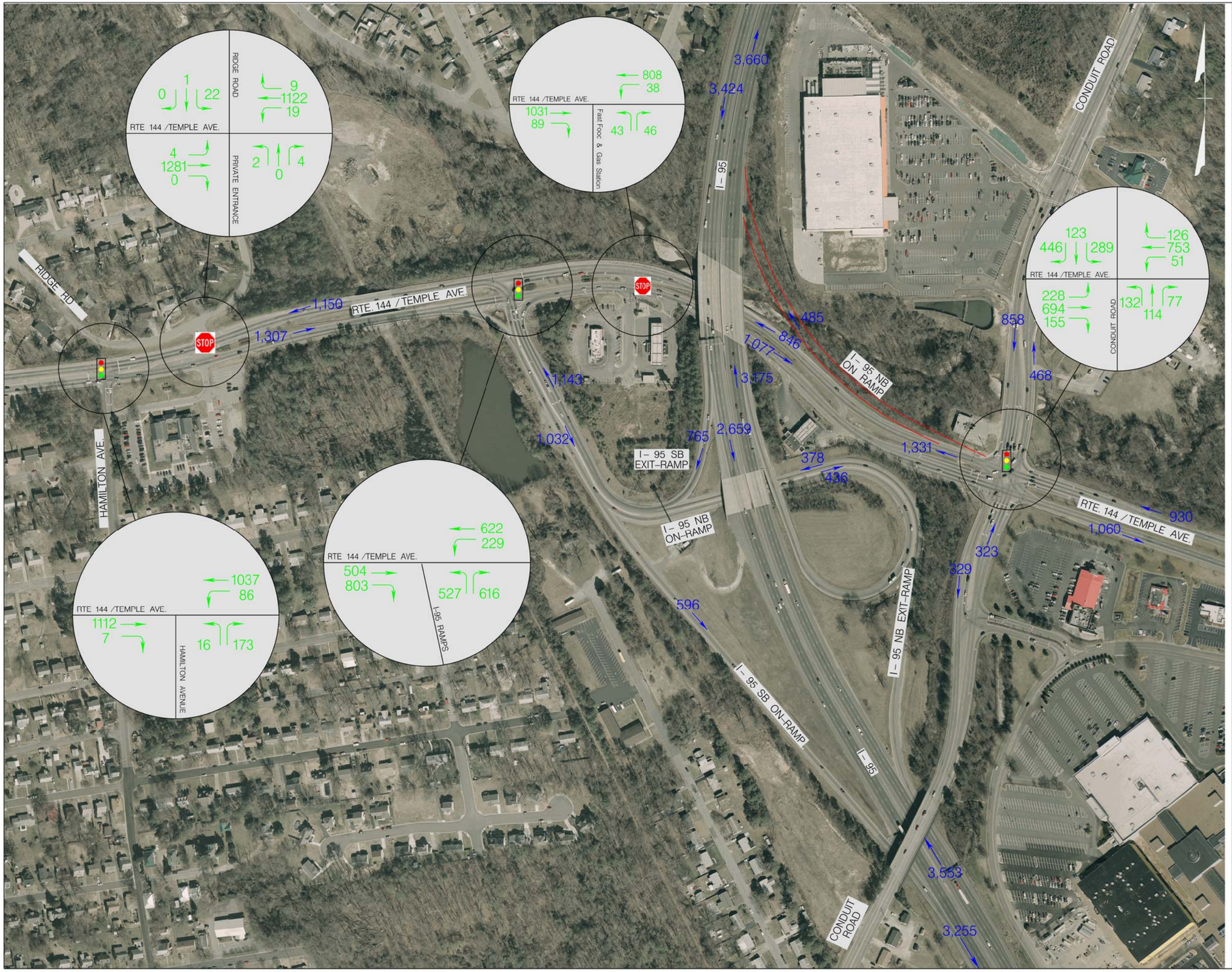
1. Virginia Department of Transportation. *Draft Interchange Modification Report for I-95/Temple Avenue Interchange Improvement Project.* October 2012.

2. Rodegerdts, L., J. Bansen, C. Tiesler, J. Knudsen, E. Myers, M. Johnson, M. Moule, B. Persaud, C. Lyon, S. Hallmark, H. Isebrands, R. B. Crown, B. Guichet, and A. O'Brien. *NCHRP Report 672: Roundabouts: An Informational Guide*, 2nd ed. Transportation Research Board of the National Academies, Washington, D.C., 2010.

3. Transportation Research Board. *Highway Capacity Manual 2010.* Transportation Research Board of the National Academies, Washington, D.C., 2010.

4. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*. Federal Highway Administration, Washington, D.C., 2009.

Appendix A
Traffic Volume Data



I–95 / Temple Avenue Interchange Modification Report

URS VDOT

U.S. Department of Transportation
Federal Highway Administration

LEGEND

XXX TURNING MOVEMENT VOLUMES

XXX DIRECTIONAL VOLUME

NEWLY CONSTRUCTED RAMP

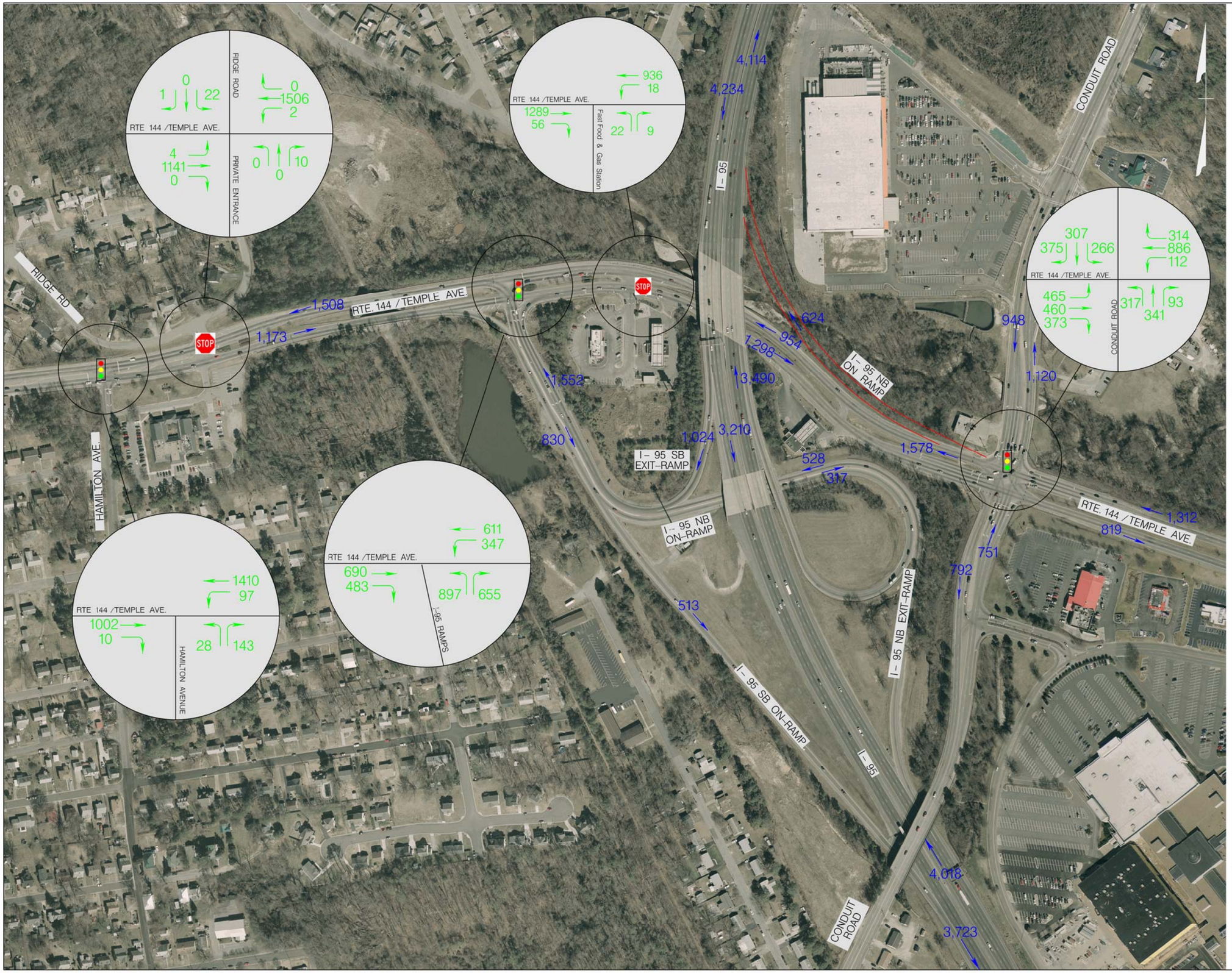
SIGNALIZED INTERSECTION

STOP UNSIGNALIZED INTERSECTION

2015
AM PEAK
HOUR VOLUMES

FIGURE VI.1

October 2012



I–95 / Temple Avenue Interchange Modification Report

URS VDOT

U.S. Department of Transportation
Federal Highway Administration

LEGEND

XXX TURNING MOVEMENT VOLUMES

XXX DIRECTIONAL VOLUME

NEWLY CONSTRUCTED RAMP

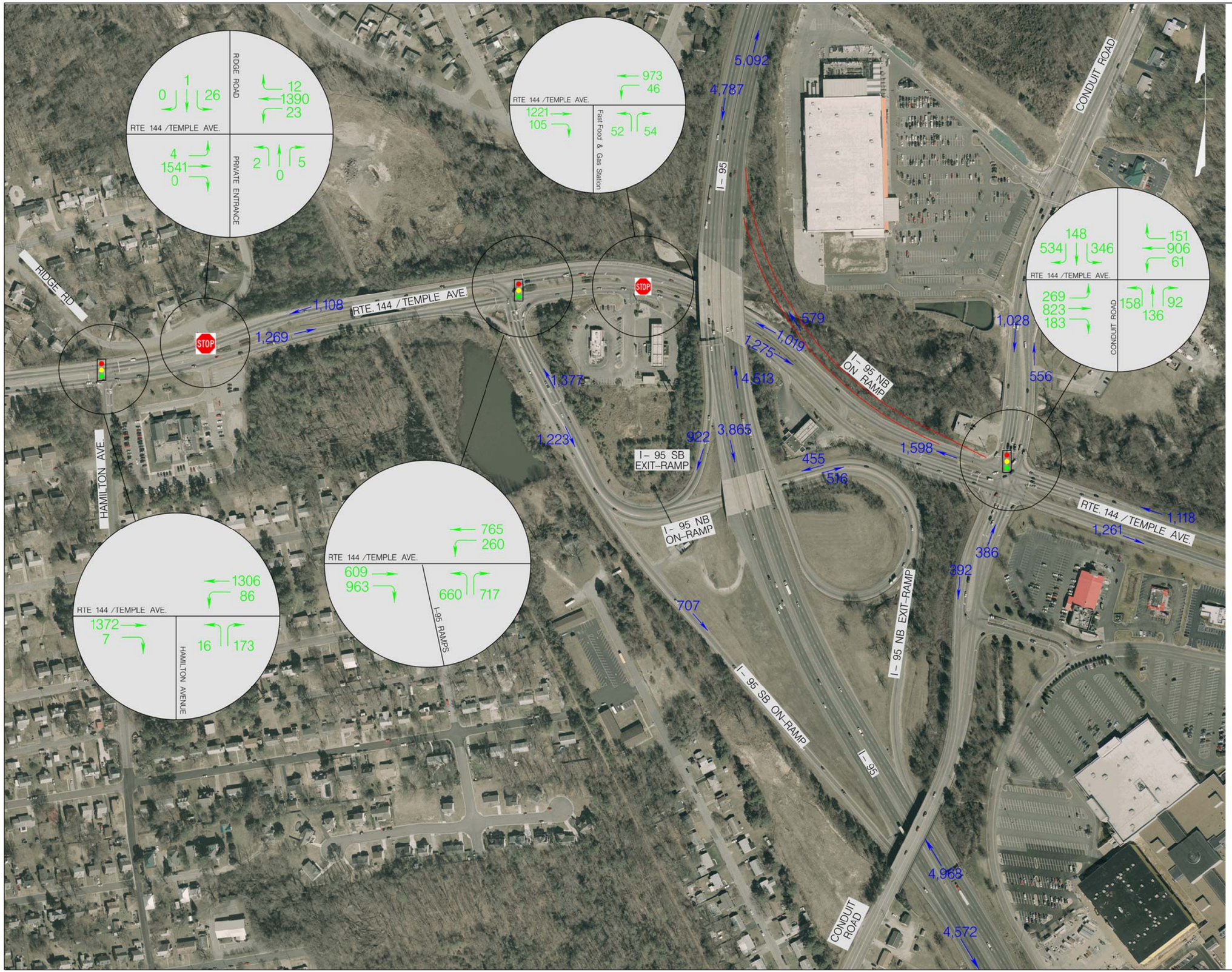
SIGNALIZED INTERSECTION

STOP UNSIGNALIZED INTERSECTION

2015
PM PEAK
HOUR VOLUMES

FIGURE VI.2

October 2012



I–95 / Temple Avenue Interchange Modification Report

URS VDOT

U.S. Department of Transportation
Federal Highway Administration

LEGEND

XXX TURNING MOVEMENT VOLUMES

XXX DIRECTIONAL VOLUME

NEWLY CONSTRUCTED RAMP

SIGNALIZED INTERSECTION

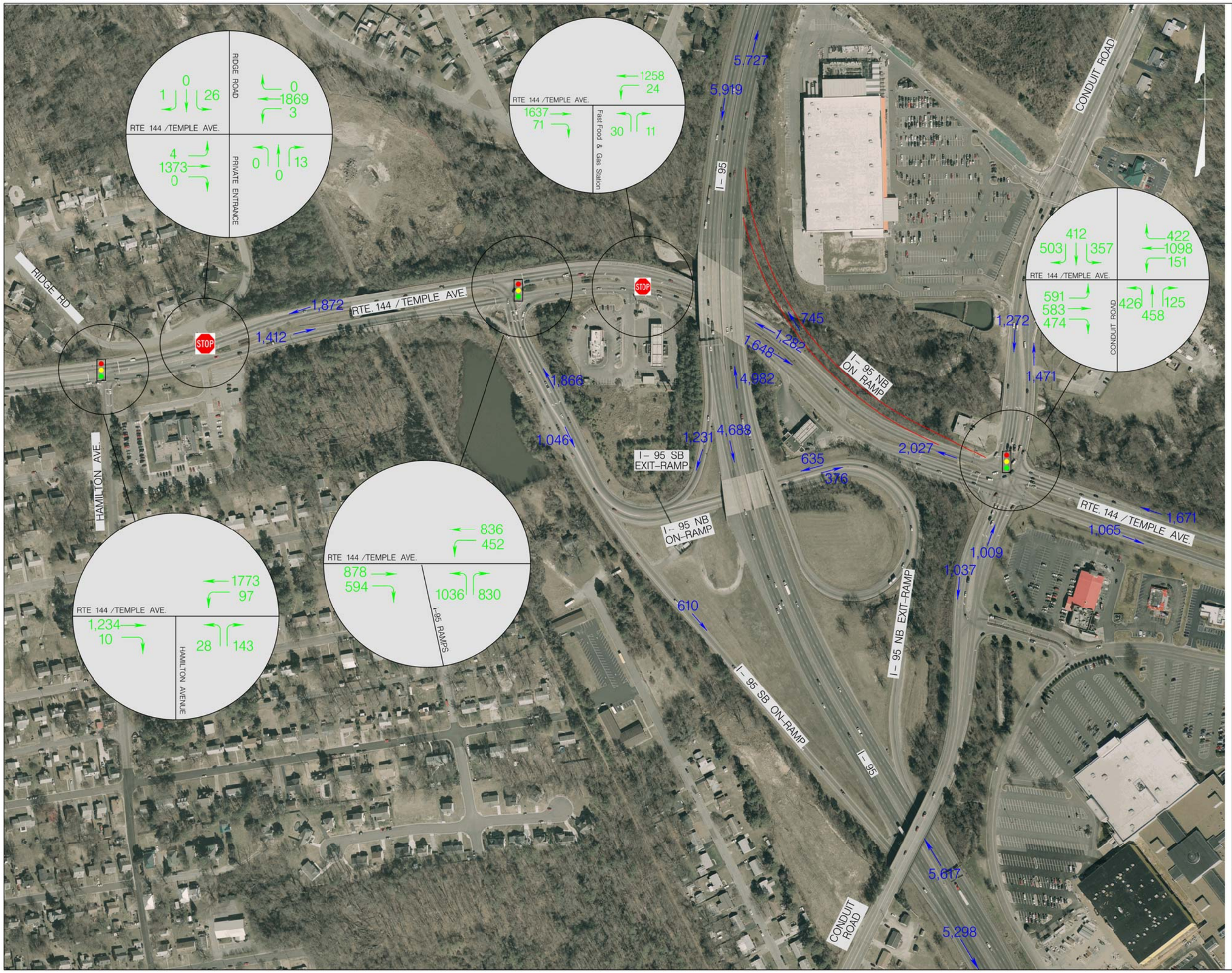
STOP UNSIGNALIZED INTERSECTION

2037
AM PEAK
HOUR VOLUMES

FIGURE VI.4

October 2012

I–95 / Temple Avenue Interchange Modification Report



U.S. Department of Transportation
Federal Highway Administration

LEGEND

XXX TURNING MOVEMENT VOLUMES

XXX DIRECTIONAL VOLUME

NEWLY CONSTRUCTED RAMP

SIGNALIZED INTERSECTION

STOP UNSIGNALIZED INTERSECTION

2037
PM PEAK
HOUR VOLUMES

FIGURE VI.5

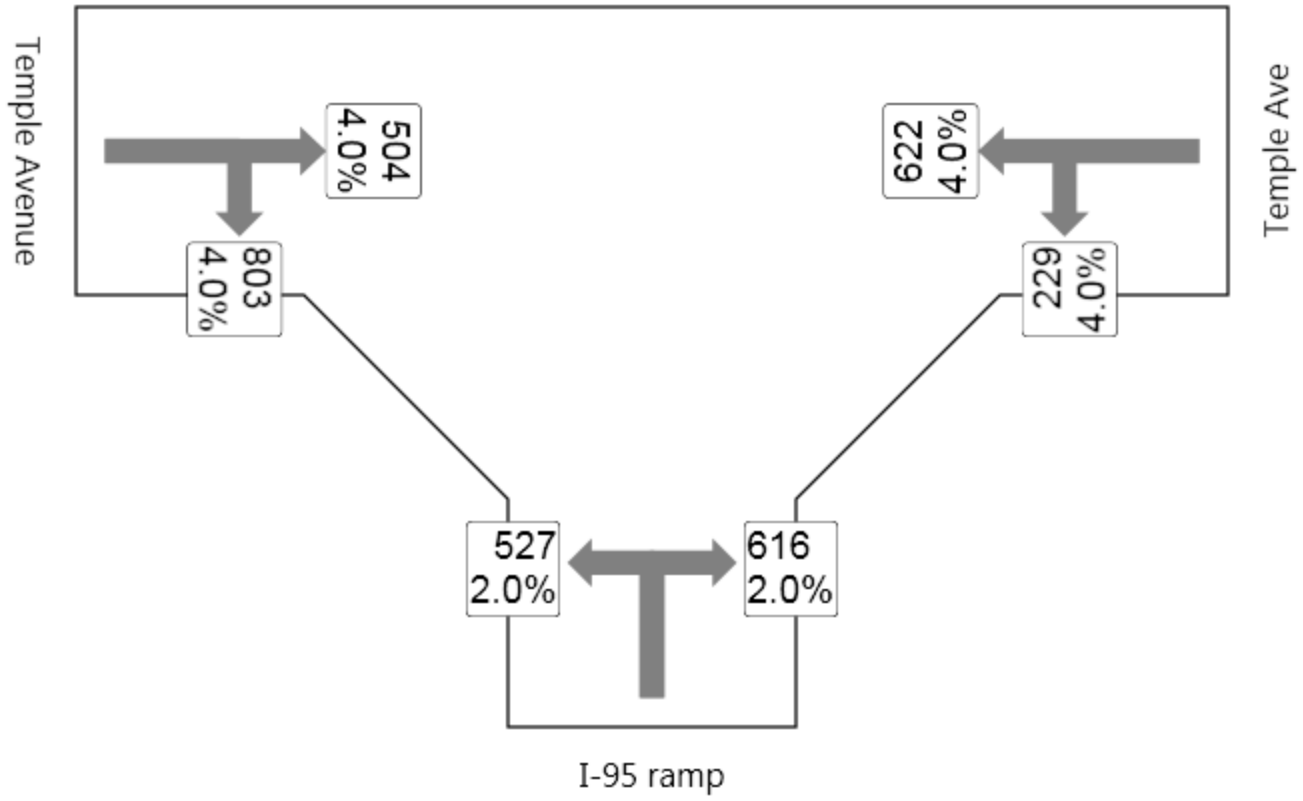
October 2012

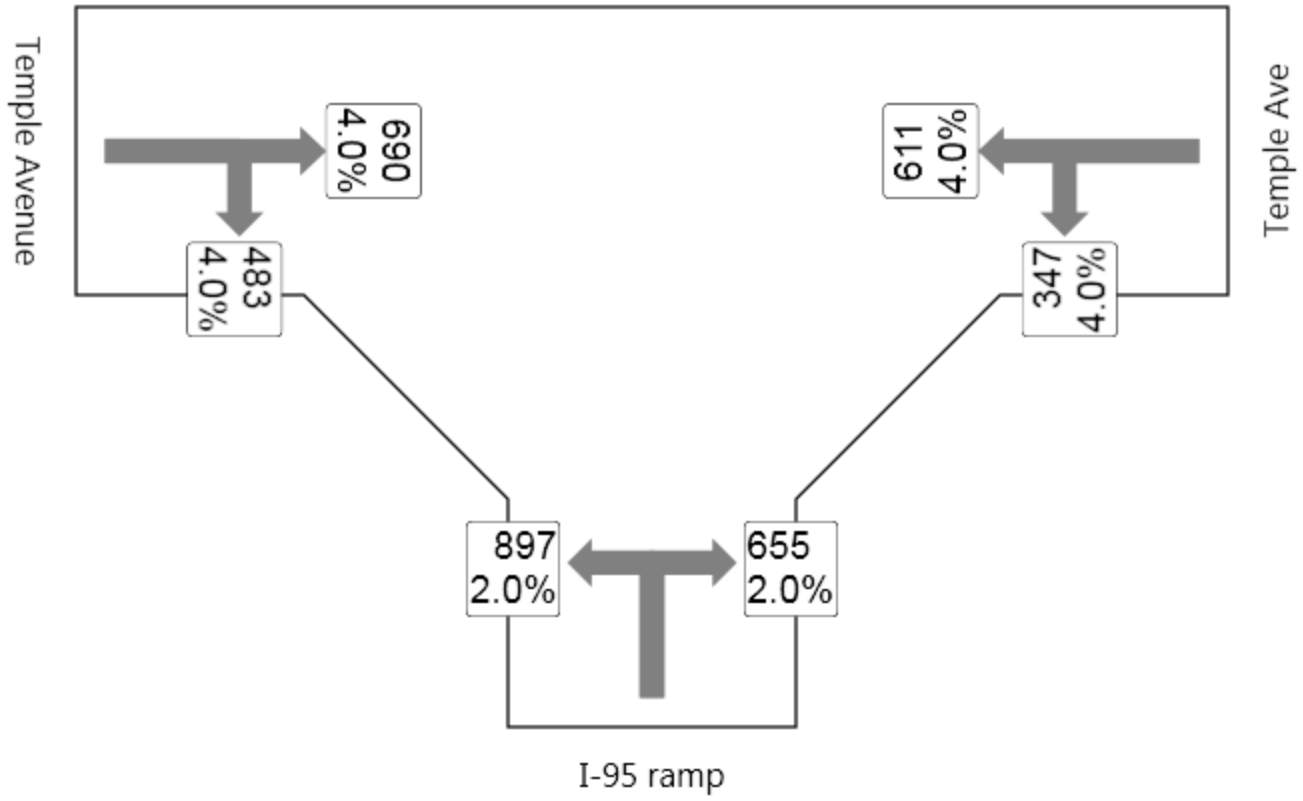
	I-95 & Temple Avenue							
		2011	2015	2020	2025	2030	2033	2037
			4	9	14	19	22	26
PM	**I-95 Ramps**							
	NBL	873	897	928	960	993	1004	1036
	NBR	632	655	685	716	749	796	830
	Temple Ave							
	WBL	333	347	365	385	405	432	452
	WBT	580	611	652	696	743	787	836
	Temple Ave							
	EBT	664	690	724	760	797	840	878
	EBR	475	483	493	504	514	524	534

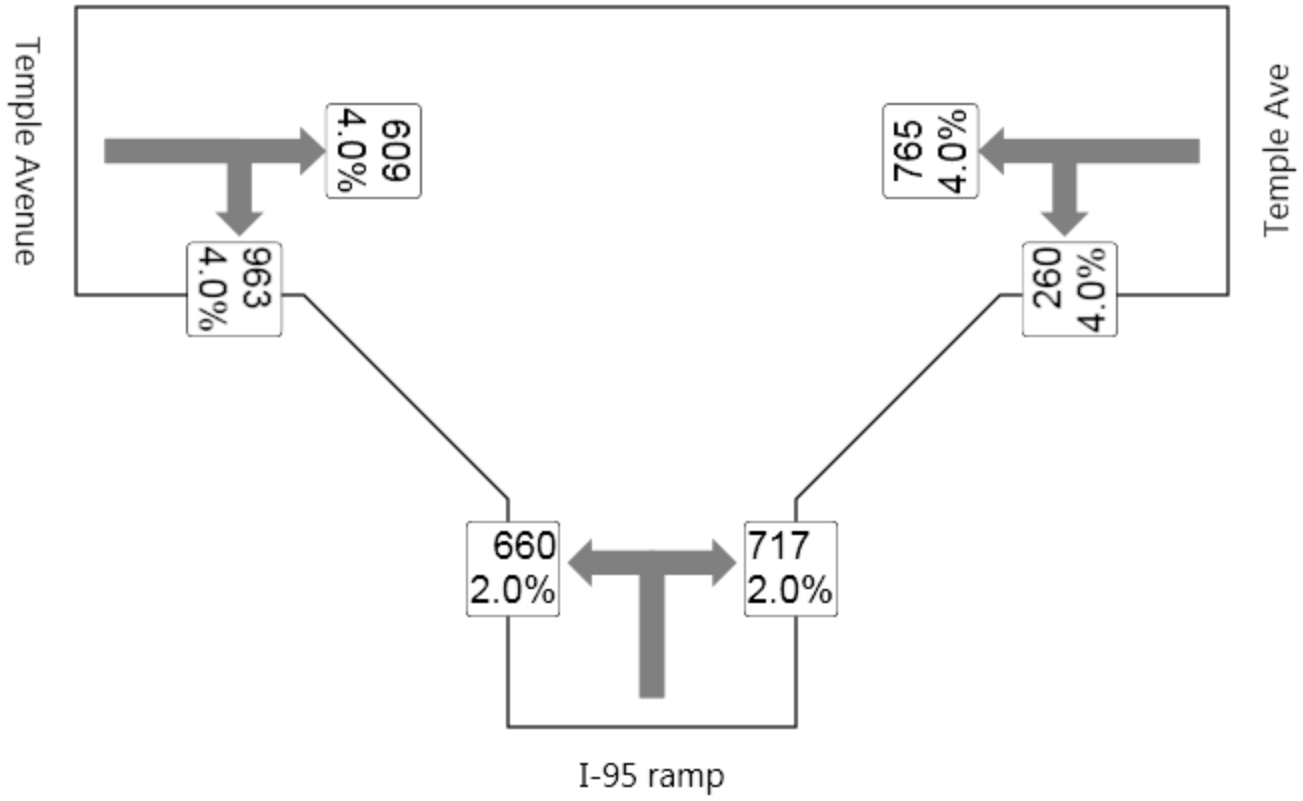
Westbound Bypass Volumes

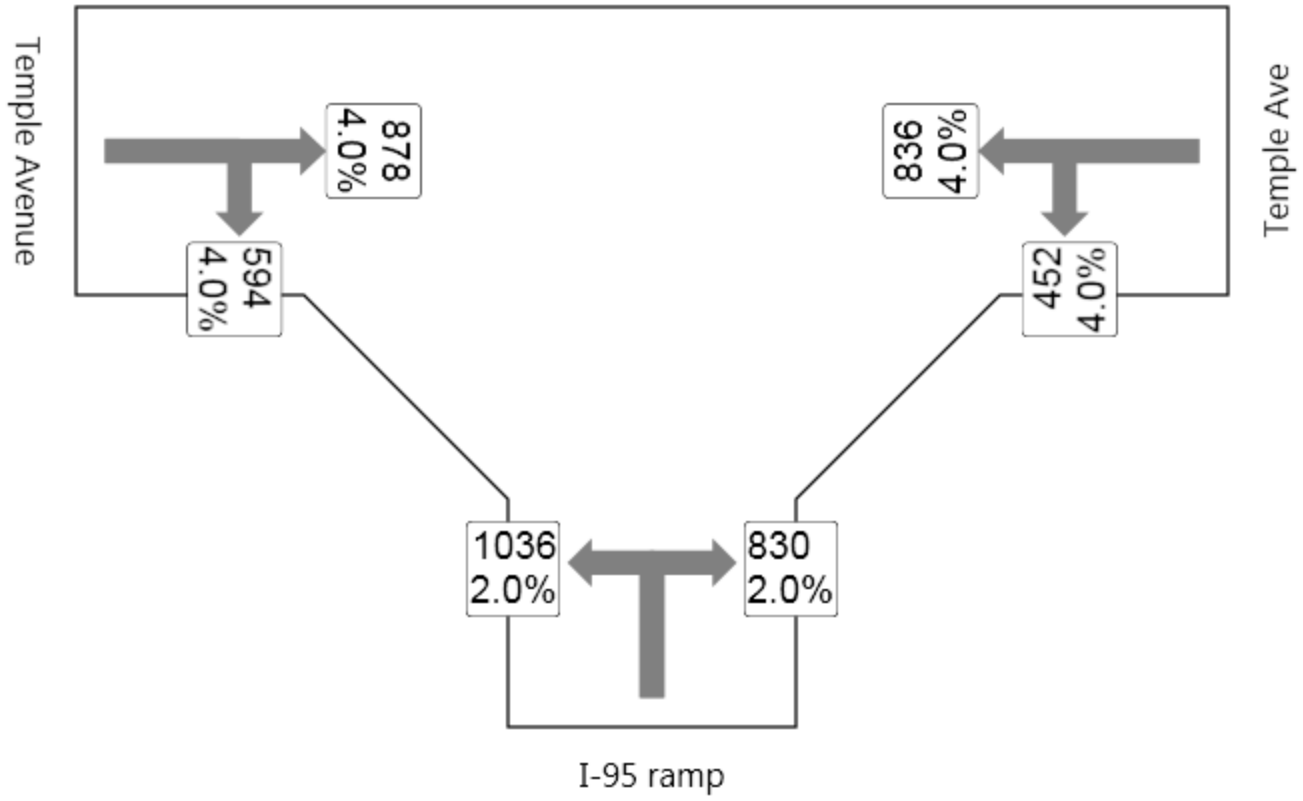
2015 Volumes		PM		AM	
Westbound	Total	611		622	
Bypass	0.95	580.45	580	590.9	591
Through	0.05	30.55	31	31.1	31

2037 Volumes		PM		AM	
Westbound	Total	836		765	
Bypass	0.95	794.2	794	726.75	727
Through	0.05	41.8	42	38.25	38


Temple Ave
622
4.0%
229
4.0%
616
2.0%
I-95 ramp
527
2.0%
803
4.0%
504
4.0%
Temple Avenue


Temple Ave
611
4.0%
347
4.0%
655
2.0%
897
2.0%
I-95 ramp
690
4.0%
483
4.0%
Temple Avenue


765
4.0%
Temple Ave
260
4.0%
717
2.0%
I-95 ramp
660
2.0%
963
4.0%
Temple Avenue
609
4.0%


Temple Ave
836
4.0%
452
4.0%
830
2.0%
I-95 ramp
1036
2.0%
594
4.0%
878
4.0%
Temple Avenue

Appendix B
Roundabout Model Comparison

HCM, HCS 2010 AND SIDRA STANDARD COMPARISON

Several roundabout software packages have been recently updated to reflect the methodology presented in the 2010 HCM. As new versions of software are released, it is important to understand how each package reflects the 2010 HCM, which is commonly recognized as the standard of traffic capacity analysis in the United States. In this particular case it may be of interest to understand how using the 2010 HCM procedure in Sidra 5.1 compares to the Sidra Standard procedure.

The graph below compares single-lane roundabout capacities across a range of traffic volumes between HCM 2010 equations (which are consistent with the models used in HCS 2010), the US HCM setting in Sidra 5.1, the Sidra Standard procedure in Sidra 5.1, and the Sidra Standard procedure with an environment factor of 1.2 in Sidra 5.1.

As shown below, the HCM 2010 equations and US HCM setting in Sidra 5.1 predict lower entering capacities than either Sidra Standard procedure. At circulating flows greater than 1,000, the US HCM setting in Sidra 5.1 diverges to a constant upper bound capacity of just less than 400 vehicles per hour, while the HCM 2010 equation continues to decline consistent with empirical data collected in the United States. This should be considered when selecting an appropriate analysis tool for evaluating roundabouts with circulating flows in this range.

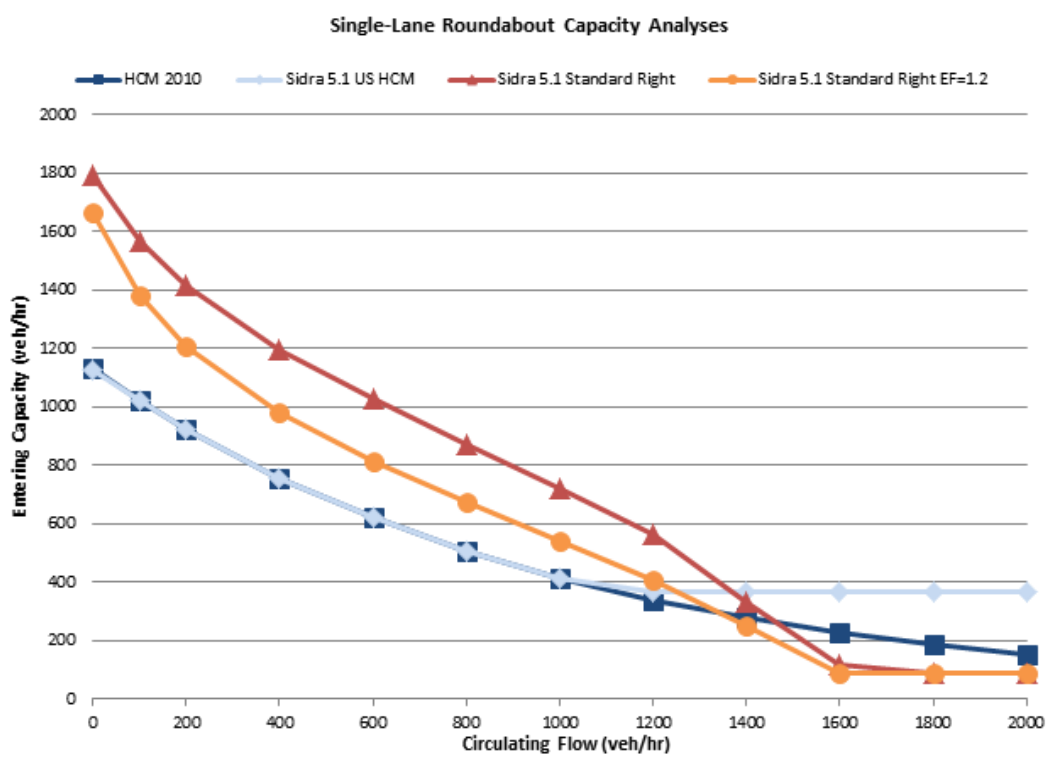


Exhibit 1 Roundabout Model Comparison

Appendix C
Roundabout Operations Analysis Worksheets

MOVEMENT SUMMARY

Site: 2015 AM

I-95/Temple Avenue
Year 2015 - Weekday AM Peak Hour
Proposed Configuration
Roundabout

Movement Performance - Vehicles

Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance ft	Prop. Queued	Effective Stop Rate per veh	Average Speed mph
South: I-95 (Northbound)											
3	L	573	2.0	0.391	10.0	LOS A	1.4	35.5	0.51	0.87	25.0
18	R	670	2.0	0.422	0.1	X	X	X	X	0.50	34.0
Approach		1242	2.0	0.422	4.6	LOS A	1.4	35.5	0.23	0.67	29.0
East: Temple Avenue (Westbound)											
1	L	249	4.0	0.392	10.1	LOS B	1.3	33.6	0.50	0.89	25.0
6	T	34	4.0	0.392	10.1	LOS B	1.3	33.6	0.50	0.70	27.1
16	R	642	4.0	0.410	0.1	X	X	X	X	0.48	34.2
Approach		925	4.0	0.410	3.2	LOS A	1.3	33.6	0.15	0.60	30.7
West: Temple Avenue (Eastbound)											
2	T	548	4.0	0.327	8.0	LOS A	1.4	35.4	0.44	0.60	28.9
12	R	873	4.0	0.557	0.2	X	X	X	X	0.49	33.9
Approach		1421	4.0	0.557	3.2	LOS A	1.4	35.4	0.17	0.54	31.8
All Vehicles		3588	3.3	0.557	3.7	LOS A	1.4	35.5	0.19	0.60	30.5

X: Not applicable for Continuous movement.

Level of Service (LOS) Method: Delay & v/c (HCM 2010).
Roundabout LOS Method: Same as Sign Control.
Vehicle movement LOS values are based on average delay and v/c ratio (degree of saturation) per movement
LOS F will result if v/c > 1 irrespective of movement delay value (does not apply for approaches and intersection).
Intersection and Approach LOS values are based on average delay for all movements (v/c not used as specified in HCM 2010).
Roundabout Capacity Model: US HCM 2010.
HCM Delay Model used. Geometric Delay not included.

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MOVEMENT SUMMARY

Site: 2015 PM

I-95/Temple Avenue
Year 2015 - Weekday PM Peak Hour
Proposed Configuration
Roundabout

Movement Performance - Vehicles

Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance ft	Prop. Queued	Effective Stop Rate per veh	Average Speed mph
South: I-95 (Northbound)											
3	L	975	2.0	0.774	26.4	LOS D	4.9	123.9	0.77	1.07	19.5
18	R	712	2.0	0.448	0.1	X	X	X	X	0.50	34.0
Approach		1687	2.0	0.774	15.3	LOS C	4.9	123.9	0.45	0.83	23.6
East: Temple Avenue (Westbound)											
1	L	377	4.0	0.759	28.4	LOS D	3.9	101.5	0.79	1.08	19.1
6	T	34	4.0	0.759	28.4	LOS D	3.9	101.5	0.79	1.01	19.8
16	R	630	4.0	0.402	0.1	X	X	X	X	0.48	34.2
Approach		1041	4.0	0.759	11.2	LOS B	3.9	101.5	0.31	0.72	25.8
West: Temple Avenue (Eastbound)											
2	T	750	4.0	0.511	12.5	LOS B	2.7	70.2	0.62	0.81	26.4
12	R	525	4.0	0.335	0.1	X	X	X	X	0.50	34.0
Approach		1275	4.0	0.511	7.4	LOS A	2.7	70.2	0.36	0.68	29.1
All Vehicles		4003	3.2	0.774	11.7	LOS B	4.9	123.9	0.38	0.75	25.7

X: Not applicable for Continuous movement.

Level of Service (LOS) Method: Delay & v/c (HCM 2010).
Roundabout LOS Method: Same as Sign Control.
Vehicle movement LOS values are based on average delay and v/c ratio (degree of saturation) per movement
LOS F will result if v/c > 1 irrespective of movement delay value (does not apply for approaches and intersection).
Intersection and Approach LOS values are based on average delay for all movements (v/c not used as specified in HCM 2010).
Roundabout Capacity Model: US HCM 2010.
HCM Delay Model used. Geometric Delay not included.

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MOVEMENT SUMMARY

Site: 2015 AM - IMR

I-95/Temple Avenue
Year 2015 - Weekday AM Peak Hour
IMR Configuration
Roundabout

Movement Performance - Vehicles

Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance ft	Prop. Queued	Effective Stop Rate per veh	Average Speed mph
South: I-95 (Northbound)											
3	L	573	2.0	0.391	10.0	LOS A	1.4	35.5	0.51	0.87	25.0
18	R	670	2.0	0.422	0.1	X	X	X	X	0.50	34.0
Approach		1242	2.0	0.422	4.6	LOS A	1.4	35.5	0.23	0.67	29.0
East: Temple Avenue (Westbound)											
1	L	249	4.0	0.392	10.1	LOS B	1.3	33.6	0.50	0.89	25.0
6	T	34	4.0	0.392	10.1	LOS B	1.3	33.6	0.50	0.70	27.1
16	R	642	4.0	0.410	0.1	X	X	X	X	0.48	34.2
Approach		925	4.0	0.410	3.2	LOS A	1.3	33.6	0.15	0.60	30.7
West: Temple Avenue (Eastbound)											
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12	R	873	4.0	0.557	0.2	X	X	X	X	0.49	33.9
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All Vehicles		3588	3.3	0.557	3.7	LOS A	1.4	35.5	0.19	0.60	30.5

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Level of Service (LOS) Method: Delay & v/c (HCM 2010).
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Roundabout Capacity Model: US HCM 2010.
HCM Delay Model used. Geometric Delay not included.

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MOVEMENT SUMMARY

Site: 2015 PM - IMR

I-95/Temple Avenue
Year 2015 - Weekday PM Peak Hour
IMR Configuration
Roundabout

Movement Performance - Vehicles

Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance ft	Prop. Queued	Effective Stop Rate per veh	Average Speed mph
South: I-95 (Northbound)											
3	L	975	2.0	0.774	26.4	LOS D	4.9	123.9	0.77	1.07	19.5
18	R	712	2.0	0.448	0.1	X	X	X	X	0.50	34.0
Approach		1687	2.0	0.774	15.3	LOS C	4.9	123.9	0.45	0.83	23.6
East: Temple Avenue (Westbound)											
1	L	377	4.0	0.759	28.4	LOS D	3.9	101.5	0.79	1.08	19.1
6	T	34	4.0	0.759	28.4	LOS D	3.9	101.5	0.79	1.01	19.8
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Approach		1041	4.0	0.759	11.2	LOS B	3.9	101.5	0.31	0.72	25.8
West: Temple Avenue (Eastbound)											
2	T	750	4.0	0.511	12.5	LOS B	2.7	70.2	0.62	0.81	26.4
12	R	525	4.0	0.335	0.1	X	X	X	X	0.50	34.0
Approach		1275	4.0	0.511	7.4	LOS A	2.7	70.2	0.36	0.68	29.1
All Vehicles		4003	3.2	0.774	11.7	LOS B	4.9	123.9	0.38	0.75	25.7

X: Not applicable for Continuous movement.

Level of Service (LOS) Method: Delay & v/c (HCM 2010).
Roundabout LOS Method: Same as Sign Control.
Vehicle movement LOS values are based on average delay and v/c ratio (degree of saturation) per movement
LOS F will result if v/c > 1 irrespective of movement delay value (does not apply for approaches and intersection).
Intersection and Approach LOS values are based on average delay for all movements (v/c not used as specified in HCM 2010).
Roundabout Capacity Model: US HCM 2010.
HCM Delay Model used. Geometric Delay not included.

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MOVEMENT SUMMARY

Site: 2037 AM

I-95/Temple Avenue
Year 2037 - Weekday AM Peak Hour
Proposed Configuration
Roundabout

Movement Performance - Vehicles

Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance ft	Prop. Queued	Effective Stop Rate per veh	Average Speed mph
South: I-95 (Northbound)											
3	L	695	2.0	0.508	13.1	LOS B	2.1	53.9	0.59	0.92	23.7
18	R	755	2.0	0.475	0.1	X	X	X	X	0.50	34.0
Approach		1449	2.0	0.508	6.4	LOS A	2.1	53.9	0.28	0.70	27.9
East: Temple Avenue (Westbound)											
1	L	274	4.0	0.241	8.5	LOS A	0.7	17.8	0.49	0.87	25.7
6	T	40	4.0	0.241	8.4	LOS A	0.7	17.0	0.48	0.67	28.2
16	R	765	4.0	0.489	0.1	X	X	X	X	0.50	33.9
Approach		1079	4.0	0.489	2.6	LOS A	0.7	17.8	0.14	0.60	31.0
West: Temple Avenue (Eastbound)											
2	T	641	4.0	0.363	8.2	LOS A	1.2	32.1	0.37	0.59	28.8
12	R	1014	4.0	0.647	0.2	X	X	X	X	0.49	33.9
Approach		1655	4.0	0.647	3.3	LOS A	1.2	32.1	0.14	0.53	31.7
All Vehicles		4183	3.3	0.647	4.2	LOS A	2.1	53.9	0.19	0.61	30.1

X: Not applicable for Continuous movement.

Level of Service (LOS) Method: Delay & v/c (HCM 2010).
Roundabout LOS Method: Same as Sign Control.
Vehicle movement LOS values are based on average delay and v/c ratio (degree of saturation) per movement
LOS F will result if v/c > 1 irrespective of movement delay value (does not apply for approaches and intersection).
Intersection and Approach LOS values are based on average delay for all movements (v/c not used as specified in HCM 2010).
Roundabout Capacity Model: US HCM 2010.
HCM Delay Model used. Geometric Delay not included.

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MOVEMENT SUMMARY

Site: 2037 PM

I-95/Temple Avenue
Year 2037 - Weekday PM Peak Hour
Proposed Configuration
Roundabout

Movement Performance - Vehicles

Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance ft	Prop. Queued	Effective Stop Rate per veh	Average Speed mph
South: I-95 (Northbound)											
3	L	1091	2.0	0.988	62.6	LOS F	12.8	325.9	0.97	1.61	13.2
18	R	874	2.0	0.550	0.1	X	X	X	X	0.49	33.9
Approach		1964	2.0	0.988	34.8	LOS D	12.8	325.9	0.54	1.11	17.8
East: Temple Avenue (Westbound)											
1	L	476	4.0	0.536	18.4	LOS C	2.0	51.6	0.72	0.99	21.9
6	T	44	4.0	0.536	17.9	LOS C	1.9	50.0	0.71	0.88	23.4
16	R	836	4.0	0.534	0.1	X	X	X	X	0.49	33.9
Approach		1356	4.0	0.536	7.1	LOS A	2.0	51.6	0.28	0.68	27.9
West: Temple Avenue (Eastbound)											
2	T	924	4.0	0.609	14.9	LOS B	3.1	79.3	0.60	0.82	25.3
12	R	625	4.0	0.399	0.1	X	X	X	X	0.50	34.0
Approach		1549	4.0	0.609	8.9	LOS A	3.1	79.3	0.36	0.69	28.2
All Vehicles		4869	3.2	0.988	18.9	LOS C	12.8	325.9	0.41	0.86	22.7

X: Not applicable for Continuous movement.

Level of Service (LOS) Method: Delay & v/c (HCM 2010).
Roundabout LOS Method: Same as Sign Control.
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HCM Delay Model used. Geometric Delay not included.

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MOVEMENT SUMMARY

Site: 2037 AM - IMR

I-95/Temple Avenue
Year 2037 - Weekday AM Peak Hour
IMR Configuration
Roundabout

Movement Performance - Vehicles

Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance ft	Prop. Queued	Effective Stop Rate per veh	Average Speed mph
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6	T	40	4.0	0.241	8.4	LOS A	0.7	17.0	0.48	0.67	28.2
16	R	765	4.0	0.489	0.1	X	X	X	X	0.50	33.9
Approach		1079	4.0	0.489	2.6	LOS A	0.7	17.8	0.14	0.60	31.0
West: Temple Avenue (Eastbound)											
2	T	641	4.0	0.363	8.2	LOS A	1.2	32.1	0.37	0.59	28.8
12	R	1014	4.0	0.647	0.2	X	X	X	X	0.49	33.9
Approach		1655	4.0	0.647	3.3	LOS A	1.2	32.1	0.14	0.53	31.7
All Vehicles		4183	3.3	0.647	4.2	LOS A	2.1	53.9	0.19	0.61	30.1

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Intersection and Approach LOS values are based on average delay for all movements (v/c not used as specified in HCM 2010).
Roundabout Capacity Model: US HCM 2010.
HCM Delay Model used. Geometric Delay not included.

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MOVEMENT SUMMARY

Site: 2037 PM - IMR

I-95/Temple Avenue
Year 2037 - Weekday PM Peak Hour
IMR Configuration
Roundabout

Movement Performance - Vehicles

Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance ft	Prop. Queued	Effective Stop Rate per veh	Average Speed mph
South: I-95 (Northbound)											
3	L	1091	2.0	0.988	62.6	LOS F	12.8	325.9	0.97	1.61	13.2
18	R	874	2.0	0.550	0.1	X	X	X	X	0.49	33.9
Approach		1964	2.0	0.988	34.8	LOS D	12.8	325.9	0.54	1.11	17.8
East: Temple Avenue (Westbound)											
1	L	476	4.0	0.536	18.4	LOS C	2.0	51.6	0.72	0.99	21.9
6	T	44	4.0	0.536	17.9	LOS C	1.9	50.0	0.71	0.88	23.4
16	R	836	4.0	0.534	0.1	X	X	X	X	0.49	33.9
Approach		1356	4.0	0.536	7.1	LOS A	2.0	51.6	0.28	0.68	27.9
West: Temple Avenue (Eastbound)											
2	T	924	4.0	0.609	14.9	LOS B	3.1	79.3	0.60	0.82	25.3
12	R	625	4.0	0.399	0.1	X	X	X	X	0.50	34.0
Approach		1549	4.0	0.609	8.9	LOS A	3.1	79.3	0.36	0.69	28.2
All Vehicles		4869	3.2	0.988	18.9	LOS C	12.8	325.9	0.41	0.86	22.7

X: Not applicable for Continuous movement.

Level of Service (LOS) Method: Delay & v/c (HCM 2010).
Roundabout LOS Method: Same as Sign Control.
Vehicle movement LOS values are based on average delay and v/c ratio (degree of saturation) per movement
LOS F will result if v/c > 1 irrespective of movement delay value (does not apply for approaches and intersection).
Intersection and Approach LOS values are based on average delay for all movements (v/c not used as specified in HCM 2010).
Roundabout Capacity Model: US HCM 2010.
HCM Delay Model used. Geometric Delay not included.

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Appendix D
Fastest-Path Worksheets

KITTELSON & ASSOCIATES, INC.
TRANSPORTATION ENGINEERING/PLANNING

Theoretical Fastest Path Calculations

Project: Temple Avenue Roundabout Peer Review
Project Number: 11764.15
Date: 12/13/2012
Analyst: ALP
Location: Colonial Heights, Virginia
Intersection: I-95/Temple Avenue
Alternative: Interim "Two-Lane" Design

Approach	Curve	Radius (feet)	Speed (mph)
Eastbound (West) Temple Avenue	R1	320	32
	R2	110	21
	R3	320	32
	R4	90	20
	R5	180	26
Northbound (South) I-95	R1	340	32
	R2	90	20
	R3		
	R4	90	20
	R5	180	26
Westbound (East) Temple Avenue	R1	160	24
	R2	110	21
	R3	900	>34
	R4	90	20
	R5		
Westbound (East) Temple Avenue (Bypass Lane)	R1	210	27
	R2	140	23
	R3	220	28
	R4		
	R5		
Southbound (North) N/A	R1		
	R2	90	20
	R3	350	33
	R4		
	R5		

Accel. Rate (ft/s^2)

Acceleration Calculations for R3

Dist. Between Mid R2 & Exit X-Walk (ft)
Speed (mph) 21

Dist. Between Mid R2 & Exit X-Walk (ft)
Speed (mph)

Dist. Between Mid R2 & Exit X-Walk (ft)
Speed (mph) 21

Dist. Between Mid R2 & Exit X-Walk (ft)
Speed (mph)

Dist. Between Mid R2 & Exit X-Walk (ft)
Speed (mph)

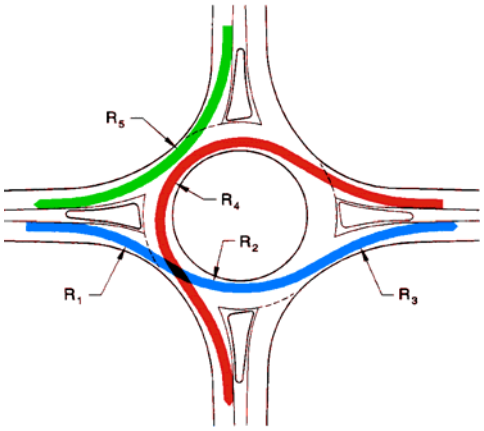

Exhibit 6-46 from NCHRP 672: Roundabouts an Informational Guide, Second Edition

Exhibit 6-46 from *NCHRP 672* illustrates the five critical path radii checked for each approach. R1, the entry path radius, is the minimum radius on the fastest through path prior to the entrance line. R2, the circulating path radius, is the minimum radius on the fastest path around the central island. R3, the exit path radius, is the minimum radius on the fastest through path into the exit. R4, the left-turn path radius, is the minimum radius on the path of the conflicting left-turn movement. R5, the right-turn path radius, is the minimum radius on the fastest path of a right-turning vehicle. It is important to note that these vehicular path radii are not the same as the curb radii. The R1 through R5 radii represent the vehicle centerline in its path through the roundabout.

KITTELSON & ASSOCIATES, INC.
TRANSPORTATION ENGINEERING/PLANNING

Theoretical Fastest Path Calculations

Project: Temple Avenue Roundabout Peer Review
Project Number: 11764.15
Date: 12/13/2012
Analyst: ALP
Location: Colonial Heights, Virginia
Intersection: I-95/Temple Avenue
Alternative: Final "Three-Lane" Design

Approach	Curve	Radius (feet)	Speed (mph)
Eastbound (West)	R1	320	32
	R2	110	21
	R3	320	32
Temple Avenue	R4	90	20
	R5	180	26
Northbound (South)	R1	340	32
	R2	90	20
	R3		
I-95	R4	90	20
	R5	180	26
Westbound (East)	R1	460	>34
	R2	310	31
	R3	1600	>34
Temple Avenue	R4	90	20
	R5		
Westbound (East)	R1	210	27
	R2	140	23
	R3	220	28
Temple Avenue (Bypass Lane)	R4		
	R5		
Southbound (North)	R1		
	R2	90	20
	R3	350	33
N/A	R4		
	R5		

Accel. Rate (ft/s^2)

Acceleration Calculations for R3

Dist. Between Mid R2 & Exit X-Walk (ft)
Speed (mph) 21

Dist. Between Mid R2 & Exit X-Walk (ft)
Speed (mph)

Dist. Between Mid R2 & Exit X-Walk (ft)
Speed (mph) 31

Dist. Between Mid R2 & Exit X-Walk (ft)
Speed (mph)

Dist. Between Mid R2 & Exit X-Walk (ft)
Speed (mph)

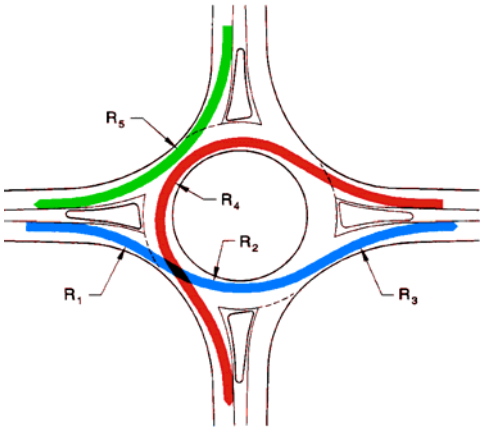

Exhibit 6-46 from NCHRP 672: Roundabouts an Informational Guide, Second Edition

Exhibit 6-46 from *NCHRP 672* illustrates the five critical path radii checked for each approach. R1, the entry path radius, is the minimum radius on the fastest through path prior to the entrance line. R2, the circulating path radius, is the minimum radius on the fastest path around the central island. R3, the exit path radius, is the minimum radius on the fastest through path into the exit. R4, the left-turn path radius, is the minimum radius on the path of the conflicting left-turn movement. R5, the right-turn path radius, is the minimum radius on the fastest path of a right-turning vehicle. It is important to note that these vehicular path radii are not the same as the curb radii. The R1 through R5 radii represent the vehicle centerline in its path through the roundabout.