Roundabout Design

TGP Engineering
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[4570 WEST & RIVERTON BOULEVARD]

Executive Summary

Riverton, Utah is planning for future residential and commercial growth in the area between Bangerter Highway, Mountain View Corridor, 12600 South, and 13400 South. A roundabout is the ideal intersection for planned alignments in this area because it provides efficient traffic control, keeps vehicles at safe speeds, and is visually appealing. The site for this roundabout design is located at the intersection of 4570 West and the proposed alignment of Riverton Blvd. This area is expected to develop into high density residential and regional commercial uses in the next 3-5 years.

Traffic volumes were projected for the year 2040 using the CUBE model. After analyzing the outputs from CUBE, assumptions needed to be made to more accurately project expected conditions. Adjustments to volumes entering the roundabout were made based on these assumptions.

With the results from the CUBE model and the assumptions made, an analysis was conducted to determine the number of lanes needed in the roundabout, the number of bypass lanes, the resulting capacity, and the resulting level of service (LOS). A spreadsheet was created to allow design iteration and consideration of design alternatives. The analysis was performed using the methodology found in the 2010 Highway Capacity Manual (HCM). Once an acceptable LOS was achieved the results were used as the geometric design parameters.

Synchro was used to provide a visual simulation of traffic flow at the roundabout. Synchro uses a different analysis method than the 2010 HCM. This allowed a different approach to the design and showed potential problems and benefits of the design.

Design drawings were created in AutoCAD Civil 3D. To determine the appropriate geometry for the roundabout and additional features the, National Cooperative Highway Research Program (NCHRP) Report 672: *Roundabouts: An Informational Guide* was used.

The proposed design includes a single lane roundabout with one entry lane for each approach. Each approach also has a right-turn or through bypass lane. 4570 West should be re-striped as a 2-lane road from the roundabout north to 12600 South. In addition, residential access on 4570 West near the roundabout should be re-built as a right-in, right-out only access point.

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Problem Statement

Purpose and Need

The city of Riverton is planning for future commercial and residential growth. The area surrounding the future intersection of 4570 West and Riverton Boulevard is slated to become a regional commercial center. In order to accommodate expected traffic volumes, minimize the impact of traffic on the area, and prevent congestion, it has been decided to place a roundabout at this intersection. The purpose of the roundabout is to provide a safe, functional, and cost effective solution to the city of Riverton.

Site Description

The roundabout will be located at 4570 West and the future alignment of Riverton Boulevard. Currently, 4570 West is only partially constructed and terminates at the proposed intersection. This road has a 66 foot right-of-way, with a median located in the center, and space for parking along the side. A current view of the area can be seen in Figure 1. There are currently only residential homes located around the site. However, within 3-5 years there will be high density residential and regional commercial uses built on the surrounding land. The Riverton master plan calls for 4570 West to be continued south to 13400 South when development of the area occurs. The entire street will have a 66 foot right-of-way with a median in the middle. A four lane road to be named Riverton Boulevard is also planned to come in to the intersection from the east, and will have an 88 foot right-of-way. The future alignments can be seen in Figure 2. The site is boxed in by four major arterials: Bangerter Highway to the east, Mountain View Corridor to the west, 12600 South to the north, and 13400 South to the south.

Figure 1: Current view of the roundabout site.

Figure 2: Overhead view of proposed alignments.

Traffic Engineering

Volume Data

Horrocks Engineers recently helped to compile Riverton City's master plan. As part of this work, they modeled future traffic volumes for the city. TGP engineering met with Horrocks staff to discuss projected traffic volumes for the site based on future development of the area. This information came from CUBE, a regional traffic model that includes all communities along the Wasatch Front.

CUBE Model

For the CUBE model traffic volume is projected to the year 2040. Model results were available from previous work, however, after examining the area surrounding the site, it was determined that a centroid connector had been inappropriately placed. This error was corrected and the model was run again to provide updated volumes. Figure 3 shows projected 2040 traffic facilities and volumes for the area surrounding the site. The red circle in Figure 3 shows the location of the roundabout. As Figure 3 illustrates, the traffic projection shows a significant volume of traffic entering the roundabout from the east, which originates primarily from centroid connectors placed along Riverton Boulevard. The volumes presented are for peak hour travel, which will allow the roundabout to be designed to accommodate traffic levels during the times of highest demand.

Assumptions

After an examination of the data provided by the CUBE model, it was determined that several assumptions needed to be made regarding the traffic volumes given. First, it appears that the locations of several centroid connectors near the future roundabout are not correct. Specifically, the centroid connector located to the east of 4150 West should not be connected directly to 12600 South. Also, the centroid connectors shown in Figure 4 which enter intersection B should be situated such that they are away from the intersection. Consequently, it was assumed that the connector east of 4150 West should actually attach to 4150 West, not 12600 South. In addition, the connector entering intersection B from the east should be attached to Riverton Boulevard south of the intersection. The dashed lines in Figure 4 present these changes to the connectors originating from centroid A.

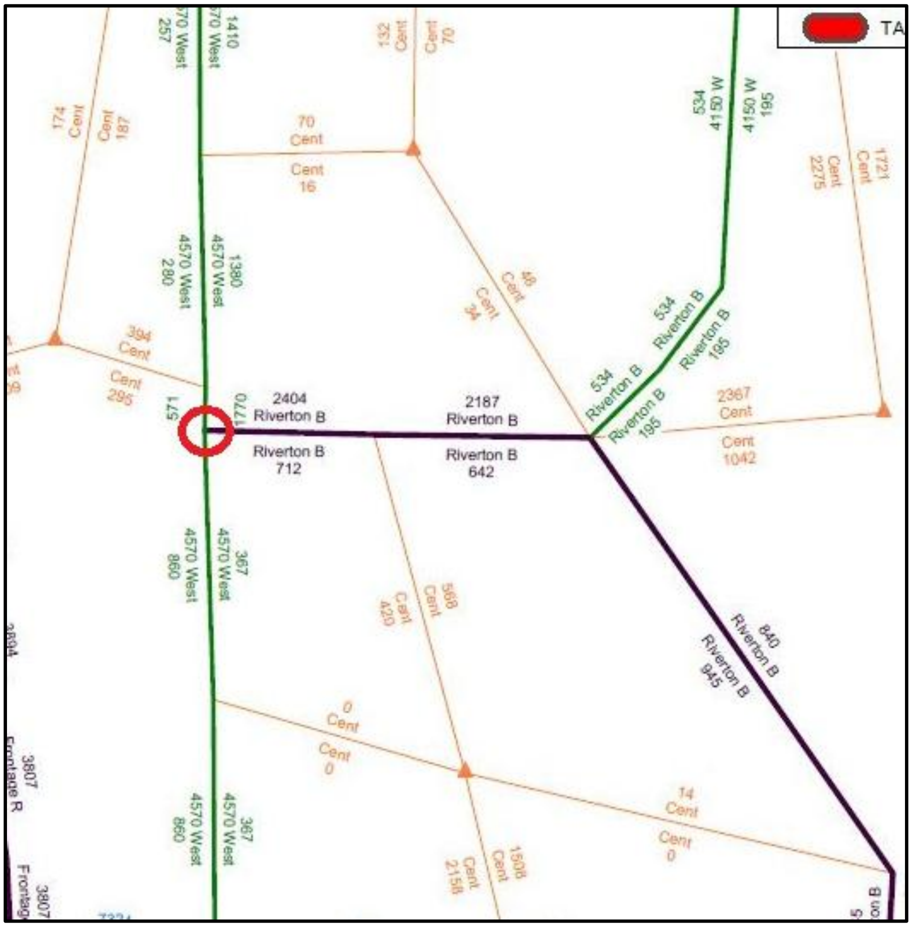

Figure 3: CUBE model printout showing 2040 traffic volumes.

As a result of the change of the centroid connector locations, adjustments to traffic volumes on several roadways needed to be made manually. It was assumed that all of the traffic entering 4150 West from the newly located centroid connector travels north to 12600 South, so these volumes do not affect the roundabout. For the other displaced connector, it was assumed that about half of the traffic travels south on Riverton Boulevard and does not pass through the future roundabout. These assumptions were then used to balance traffic volumes in the area and determine now volumes for the roundabout. The eastbound volume decreased from 2404 vehicles per hour to 1311 vehicles per hour, as can be seen in Figure 4. The remaining volumes shown earlier in Figure 3 were left unchanged. These finalized values were then used to determine approximate turning volumes so that the traffic analysis could be performed. The turning volumes used in the analysis are shown in Table 1.

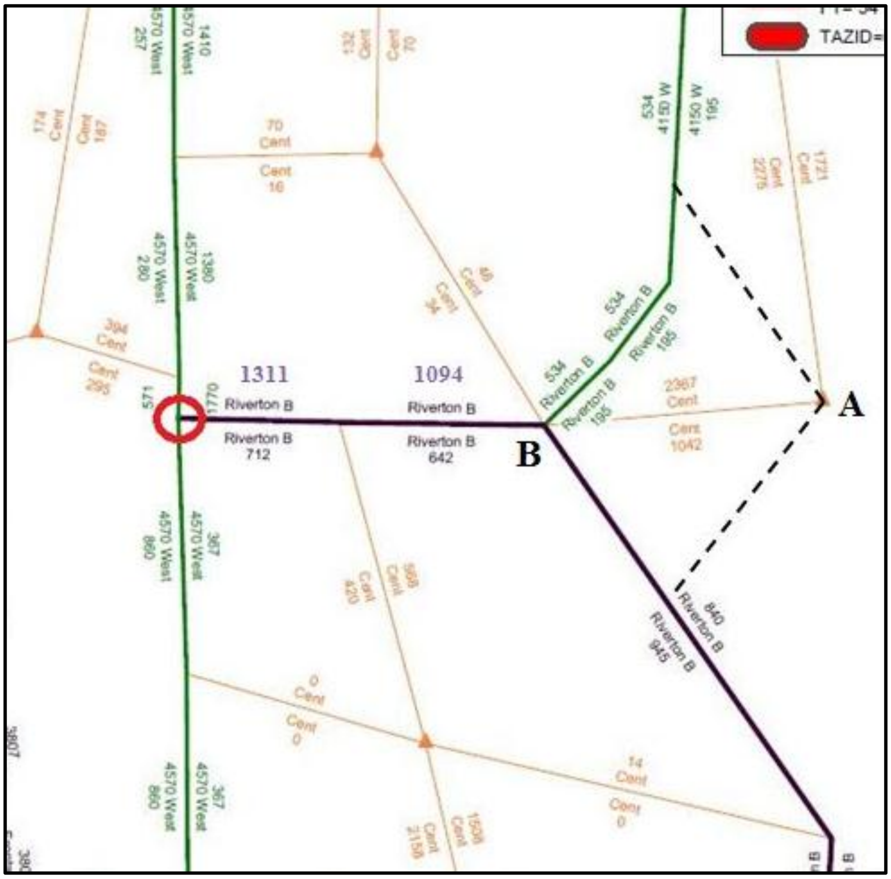

Figure 4: CUBE model printout showing assumption changes.

Table 1: Intersection Turning Movements (vehicles per hour)

Approach	Right Turn	Through	Left Turn	U-Turn	TOTAL
Northbound	265	100	-	2	367
Southbound	-	100	469	2	571
Westbound	865	-	446	2	1313

Traffic Design

Analysis Spreadsheet

It was determined that the software available to TGP engineering did not accurately accommodate an analysis of a roundabout; therefore it was decided that the analysis would be done by hand following the steps provided in the 2010 Highway Capacity Manual (HCM) (*1*). This analysis is somewhat tedious and requires iteration to optimize the design. To facilitate this, a spreadsheet was designed to perform the calculations contained in the HCM methodology.

The spreadsheet was developed to accommodate design of a 3-leg or 4-leg roundabout with lane configurations of up to two entry lanes, including bypass lanes, and up to two circulating lanes. This allows the spreadsheet to be used for this design, as well as for the design of future roundabouts by Riverton City as desired. The spreadsheet requires the input of traffic movement volumes, lane configurations, and design parameters such as percent trucks and peak hour factor. Design outputs are automatically generated upon entering the required information. This allowed iteration of the design to achieve the optimal lane configuration and will allow Riverton City to optimize future roundabout designs.

Figure 5 shows the interface for the analysis spreadsheet. The spreadsheet was designed to be user friendly for analysts that are familiar with roundabout analysis, and also provides basic instructions for those not experienced in roundabout design.

Roundabout Analysis

Traffic volumes shown in Table 1 were used for the roundabout design. Other design values and assumptions included 2.0% trucks for all movements, a peak hour factor of 0.92 as recommended by the HCM, and 110 pedestrians per hour because of high-density residential located in the area (*1*). It is desired that the roundabout be designed to a Level of Service (LOS) C for the design year of 2040.

The initial design included the approach configurations of one lane from the north and south, and two lanes from the east. This configuration resulted in an unacceptable LOS for the westbound and southbound approaches, and a LOS C for the northbound approach. To improve the LOS, right turn bypass lanes were added for the northbound and westbound approaches. A through movement bypass lane was also added for the southbound approach. All of these improvements helped to bring the northbound approach LOS to A and the southbound approach

LOS to C. Technically, the northbound approach would not require a bypass lane, but because there are two receiving lanes on the eastbound approach the bypass lane is easy to install, and it matches the rest of the intersection design. Adding the westbound right bypass lane did not improve the LOS because vehicles in the bypass lane are still forced to merge in order to return to the main traffic stream with only one northbound receiving lane.

The final design includes adding a second lane to 4570 West north of the roundabout. This added lane will allow right turns to continue past the intersection without any yielding, which improved the LOS to C. The additional lane can be accommodated with paint alone because the roadway is already over 22 feet of asphalt width. It was assumed that the additional lane will continue north to 12600 South. A lane could also be added to the other side of 4570 West with striping for uniformity, but this is not essential for the design.

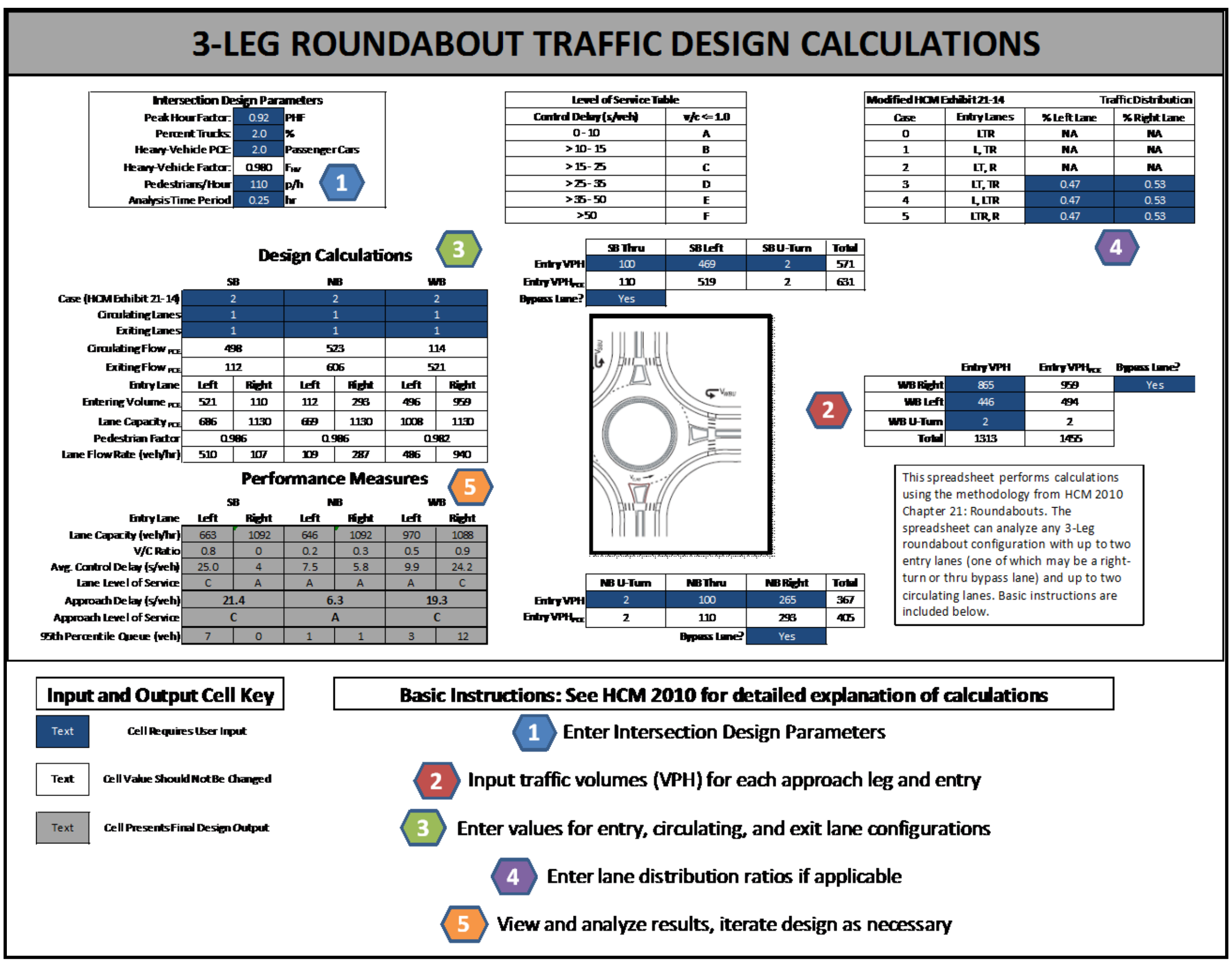

Figure 5: Excel interface for HCM analysis.

Based on the HCM analysis, it is recommended that the final design include a roundabout with one circulating lane. The northbound approach should have one entry lane in addition to a right turn bypass lane. The southbound approach should have one entry lane in addition to a through movement bypass lane. The westbound approach includes a right turn bypass that exits to a new lane on 4570 West. This design will result in a LOS C or better at this intersection for the design year. Final design output calculations are shown in Table 2. These outputs and the associated traffic engineering design were used for the roundabout geometric design.

Table 2: HCM Analysis Design Outputs from Spreadsheet

	SB		NB		WB	
Entry Lane	Left	Right	Left	Right	Left	Right
Lane Capacity (veh/hr)	663	1092	646	1092	970	1088
V/C Ratio	0.8	0	0.2	0.3	0.5	0.9
Avg. Control Delay (s/veh)	25.0	4	7.5	5.8	9.9	24.2
Lane Level of Service	C	A	A	A	A	C
Approach Delay (s/veh)	**21.4**		**6.3**		**19.3**	
Approach Level of Service	**C**		**A**		**C**	
95th Percentile Queue (veh)	7	0	1	1	3	12

Synchro Analysis

Synchro 7, produced by Trafficware®, was used for modeling of the intersection and its operational characteristics. Trafficware® also recently released Synchro 8, which incorporates the new analysis methodologies from HCM 2010, but TGP Engineering does not have access to this software. The Synchro 7 model was used primarily to visualize the intersection, and verify that the traffic design described in the previous section would be effective. No reports or outputs from Synchro were directly used in the design.

One advantage of using the old HCM methodology found in Synchro 7 is that it is based on critical gaps rather than entry conflicts, as is the case with the 2010 HCM method (*1*). Using the critical gap criterion can more accurately represent the uncertainty many drivers sometimes feel when using roundabouts. This was evident in the model results.

Figure 6 shows the first version of the Synchro model. This design does not include the additional lane that was added at the northbound exit. Because of this, there is still a merge conflict that creates a large queue in the westbound right turn lane.

The southbound lane has a through movement bypass lane. The model in Figure 6 shows through traffic having to merge before exiting the roundabout. It is preferred that this merge point actually be moved past the roundabout to reduce conflict. This could not be represented in Synchro, but will be used in the geometric design. As can be seen, the southbound left turn is very congested. Because of this congestion, it is recommended that the left-turn storage bay be designed to fit at least the 95th percentile queue determined using the HCM analysis.

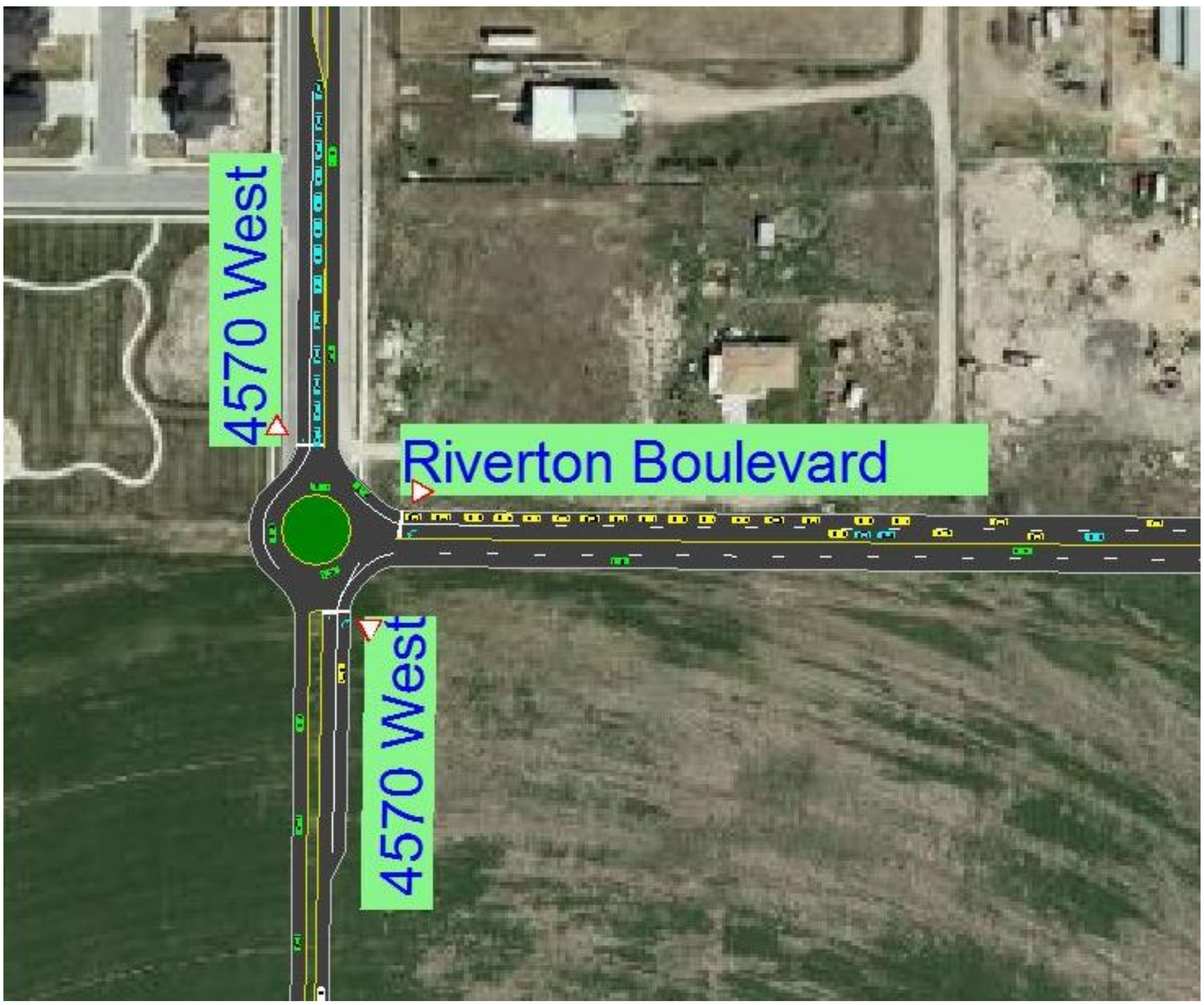

Figure 6: Initial Synchro Simulation

Figure 7 shows the second version of the Synchro model with the added northbound exit lane. It is clear from this simulation that the addition of a northbound exit lane significantly reduces delay for westbound right turns as they now have a completely free movement. A somewhat unexpected result of this is a reduced queue in the southbound left turn lane. This is most likely because of the critical-gap based methodology used in Synchro 7. In the initial model, the right turn vehicles created a perceived conflict with southbound left turns, meaning the gap was not large enough for them to enter the intersection. With the by-pass lane added, that conflict is no longer present, and southbound vehicles can enter the intersection more quickly. Even though this improvement for southbound left turns is not represented in the HCM 2010 methods, it is valuable evidence of the need for the added northbound exit lane on 4570 West.

Figure 7: Final Synchro Simulation

Geometric Design

Using the information obtained from the HCM and Synchro analyses, TGP Engineering created a geometric design for the roundabout using AutoCAD Civil 3D. The design incorporates the outputs from both analyses, and accommodates a WB-67 vehicle classification. A view of the finished design can be seen in Figure 8. All necessary design parameters were selected based on recommendations of the National Cooperative Highway Research Program (NCHRP) Report 672: *Roundabouts: An Informational Guide* and the American Association of State Highway and Transportation Officials (AASHTO) publication: *A Policy on Geometric Design of Highways and Streets*, also known as the Green Book (*2*,*3*). When specific values were not identified in the guide, a reasonable value was chosen based on recommended values. Specific NCHRP report parameters and criteria used are presented in Table 3.

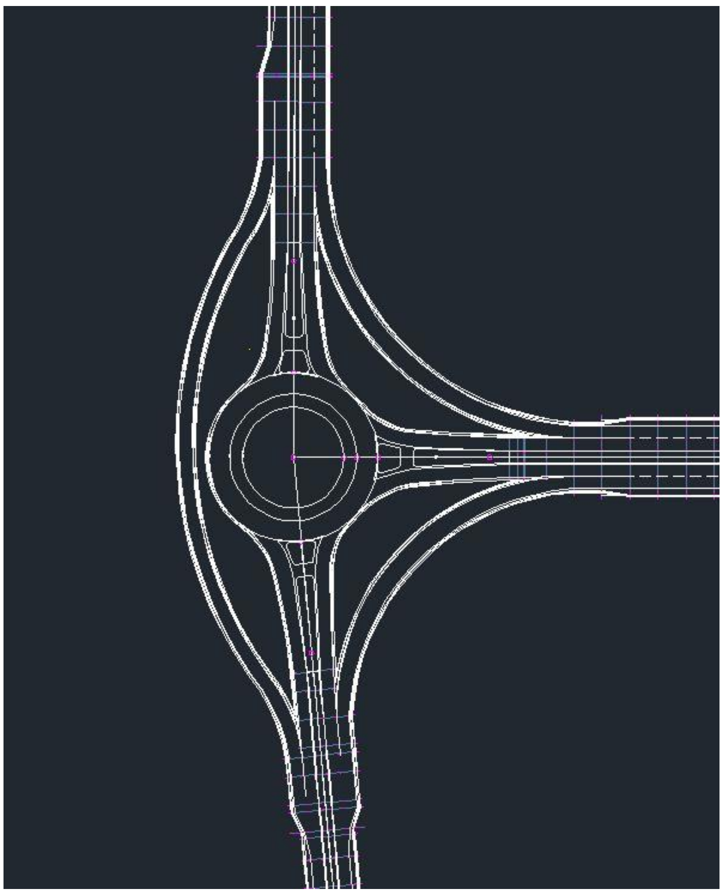

Figure 8: AutoCAD rendition of the roundabout design.

Table 3: Geometric Design Parameters (*2*)

Parameter	Value	NCHRP 672 Page Number
Diameter	150 ft	6-18
Circulatory Roadway Width	18 ft	6-24/25
Truck Apron Width	12 ft	6-31
Entry Width	15 ft	6-24
Exit Width	16 ft	6-28
Entry Radius	55 ft	6-26
Exit Radius	75 ft	6-28
Crosswalk Length	10 ft	6-23
Island Base Length	20 ft	6-22

The first, and most important, parameter used in the design of this roundabout was the inscribed circle diameter. The NCHRP Report recommends a diameter in the range of 130-180 feet for a single-lane roundabout and a WB-67 design vehicle. A midpoint value of 150 feet was selected. The Report further states that a circulatory roadway width of 16-20 feet is typical for this particular situation (*2*). A value of 18 feet was chosen because it lies in the middle of the recommended range. Next, the track width of the design vehicle was determined using the Green Book, and was found to be 30 feet (*3*). Using this information, the truck apron width was determined by subtracting the circulatory roadway width from the track width, resulting in a value of 12 feet. This lies well within the 3-15 feet range specified by the NCHRP Report (*2*).

The design of the approaches was considered after the circulatory design was completed. The values selected for this portion of the design fall within the range of values recommended by the NCHRP Report (*2*). The judgment and knowledge of the design engineers were used to determine the specific value selected from within the stated ranges. This includes the design of each of the splitter islands. For further investigation of these values, refer to the NCHRP Report using the page numbers listed in Table 3 (*2*).

The design parameters for the bypass lanes can be seen in Table 4. The Green Book was used to determine the minimum acceptable radius for the bypass lanes based on a design speed of 25 miles per hour, and assuming that the two percent crown is retained throughout the curve. With these assumptions, the minimum radius is 167 feet (*3*). All three bypass lanes featured in the design have radii which are at least the minimum value. The bypass lane width was designed assuming Case I in the Green Book, which specifies a one lane turning roadway with no provision for passing a stalled vehicle. It was also assumed that traffic condition B exists at this intersection, which states that there are just enough large vehicles present in the traffic flow to be considered in the design. These assumptions result in a width of 15 feet for the bypass lanes (*3*).

Table 4: Bypass Lane Parameters (*3*)

Parameter	Value	Green Book Reference
Lane Width	15 ft	Exhibit 3-51
Radius	>167 ft	Exhibit 3-16

Currently, there is residential access to 4570 West just north of the roundabout site as seen in Figure 2. As part of this design, it is recommended that this entry be removed or reconstructed as a right-in, right-out only access. Having access so close to the roundabout could result in dangerous traffic conflicts and create congestion that clogs the roundabout. A right-in, right-out access will prevent this without eliminating convenient access to residential areas.

Budget

TGP Engineering estimates that the cost of construction for this roundabout design will be approximately $400,000. New construction roundabouts typically cost anywhere from $100,000 to $500,000. The lower value corresponds to roundabouts with small central island radii, while the higher value is typically for roundabouts with larger radii and bypass lanes. This cost estimation was determined by comparing this design with other roundabout design projects.

When roundabouts are compared with signalized intersections, signalized intersections nearly always cost more. The only exception to this is retrofitted roundabouts. Retrofitted roundabouts are significantly more expensive than a traffic signal retrofit because they require alignment modifications and acquisition of right-of-way. Non-retrofit roundabouts are typically about one half the cost of a signalized intersection.

Because the land around the proposed intersection has not been developed yet the cost for construction could be less than expected. The roundabout design and right-of-ways could be secured with development agreements, meaning Riverton City would not have to directly purchase any property. Because of this, the cost estimate does not include cost of right-of-way acquisition. The budget for the entire project, which includes design work already performed by TGP Engineering, is presented in Table 5.

Table 5: Estimated Design and Construction Costs

Project Phase	Total Hours	Total Cost
Site Evaluation/Sponsor Meeting	12	$760.00
Data Analysis and Research	72	$3,420.00
Synchro Modeling	36	$1,710.00
AutoCAD and Civil 3D Design Work	60	$2,850.00
Report and Deliverables Preparation	72	$3,420.00
Construction	---	$400,000.00
Team Meetings	64	$3,040.00
	Grand Total	**$415,200.00**

Design Recommendations

TGP Engineering recommends that a roundabout be constructed at 4570 West and Riverton Boulevard with a single circulatory lane. The northbound, westbound, and southbound approaches should each consist of one roundabout entry lane. In addition, the northbound and westbound approaches should feature a right turn bypass lane, and the southbound approach should include a through-movement bypass lane.

An additional lane should be added to 4570 West from the roundabout north to 12600 South to accommodate high right-turn movements from the westbound approach. This lane can be added by re-striping the road because there is already 22 feet of asphalt. In addition, the residential access to 4570 West just north of the roundabout should be reconstructed to a right-in, right-out only access point. TGP recommends that the geometric design parameters presented in Table 3 and Table 4 be used for the roundabout, approach, and bypass lanes.

The roundabout designed in this report will meet the traffic demands through the 2040 design year. The capacity of this design was verified by both a HCM analysis and Synchro modeling assuming a WB-67 design vehicle and a target serviceability of LOS C.

References

1. Transportation Research Board. *Highway Capacity Manual 2010.* Washington, D.C., 2010.
2. National Cooperative Highway Research Program. *Roundabouts: An Informational Guide, Second Edition.* Washington, D.C., 2010.
3. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets, 6th Edition.* Washington, D.C., 2011.