NORTHERN ARIZONA UNIVERSITY

To: Alarick Reiboldt, MENG, EIT

From: Intersection Redesign – Roundabout Team

Date: 5/10/2016

Re: CENE 487C – Final Report Draft

Here is a draft copy of our Final Report for CENE 486C. If you could please look over the report and make any comments on changes you would like to see we would really appreciate that. The hard copy report provided here does not have our appendix attached due to the expense involved in printing the extra sheets. I have sent you an email with the full report if you wish to look over the appendix.

When you have finished please email one of the group members and we will come by and pick it up.

Thank you for your time,

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NAU Spring 2016 Capstone: Intersection Redesign - Roundabout

Old Walnut Canyon Road/Oakmont Drive and Country Club Drive

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Project:	Intersection Redesign – Country Club and Old Walnut Canyon
Date:	Thursday, May 12, 2016
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Acknowledgements

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1. Project Description

This project was assigned by the City of Flagstaff to improve the intersection of Old Walnut Canyon and Country Club Dr. Two different design options were assigned for this intersection. This report will be focused on installing a roundabout in the intersection, and J3Z Engineering will have a report on installing a signalized intersection.

1.1. Project Purpose

The goal of the project is to redesign the intersection of Old Walnut Canyon Road/Oakmont Drive and Country Club Drive. The purpose of redesigning the intersection is to improve the sight distance, and improve the intersection safety. As, the sight distance in the intersection is poor due to the presence of large grades on the southern leg. The intersection has to be redesigned, in order to make it safer, and easier for vehicle drivers to merge smoothly with other traffic.

1.1.1. Background

This project is a budgeted project by the City of Flagstaff Capital Improvement Program for the fiscal year of 2018-2019. Currently, the intersection of Old walnut Canyon Road/Oakmont Drive and Country Club Drive is a two-way stop controlled intersection in both of the east and west directions. The safety of the intersection is poor due to the ineffective sight distance, due to the presence of large grades on the southern leg.

1.1.2. Location

The intersection of Old Walnut Canyon and Country Club Drive is located in the east side of Flagstaff city, as shown in Figure 1.1. The intersection is surrounded by a residential area. The intersection serves homeowners, as well as other businesses such as, Wyndham Flagstaff resort, Flagstaff Athletics Club, and the golf courses in the area. Wyndham Flagstaff Resort and a golf course are located on North Country club Dr. next to the intersection, as shown in Figure 1.2. The intersection also serves vehicle drivers going to Flagstaff Athletics Club, which is located along North Country club drive, at the north side of the intersection.

1.1.3. Stakeholders

The stakeholders in the redeveloping of the intersection of Walnut Canyon Road/Oakmont Drive and Country Club Drive are the people who live in the surrounding neighborhoods and other users of the intersection, such as the people going to use Continental Golf Course. The people that will be most effective by the redesign will be the people who live in the surrounding house of the intersection. These people are stakeholders because they will be the ones that are using the new intersection on a day-to-day base. The local businesses and their customers in the surrounding area will need to be managed during design, such as the Continental Golf Course, Oakmont Restaurant, the driving range, and the Kation RV and Boat Storage. The City of Flagstaff will also be a stakeholder because they own the intersection and have to keep up with the maintenance.

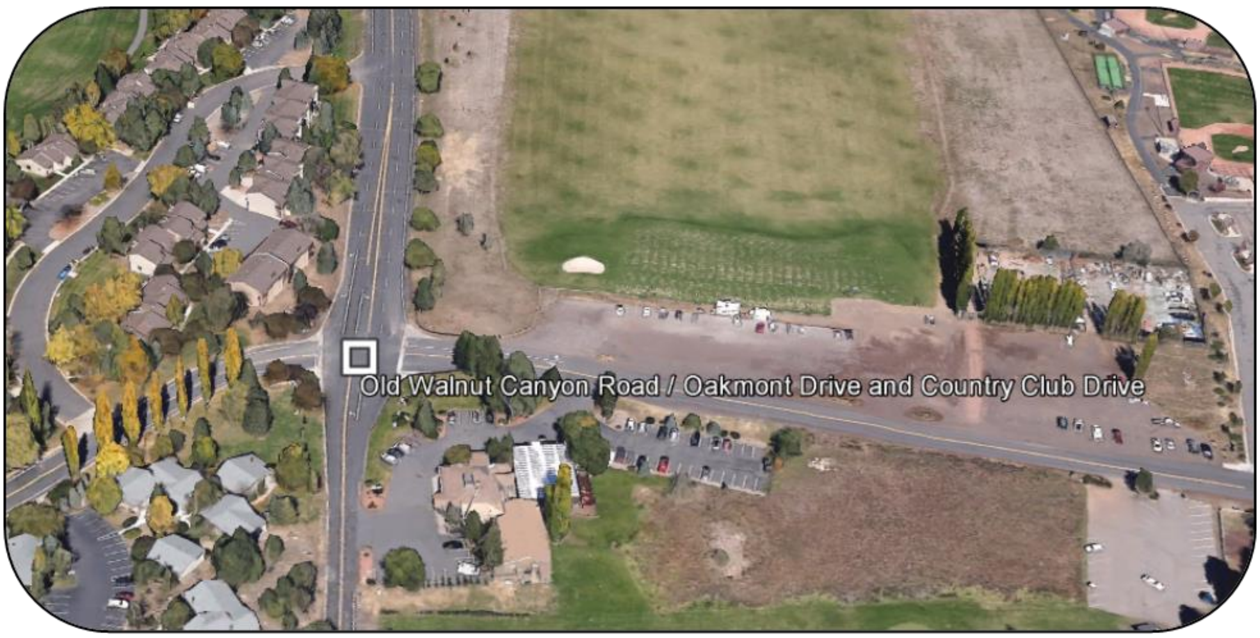

Figure 1.1. *The Intersection of Old Walnut Canyon Rd and Country Club Dr*

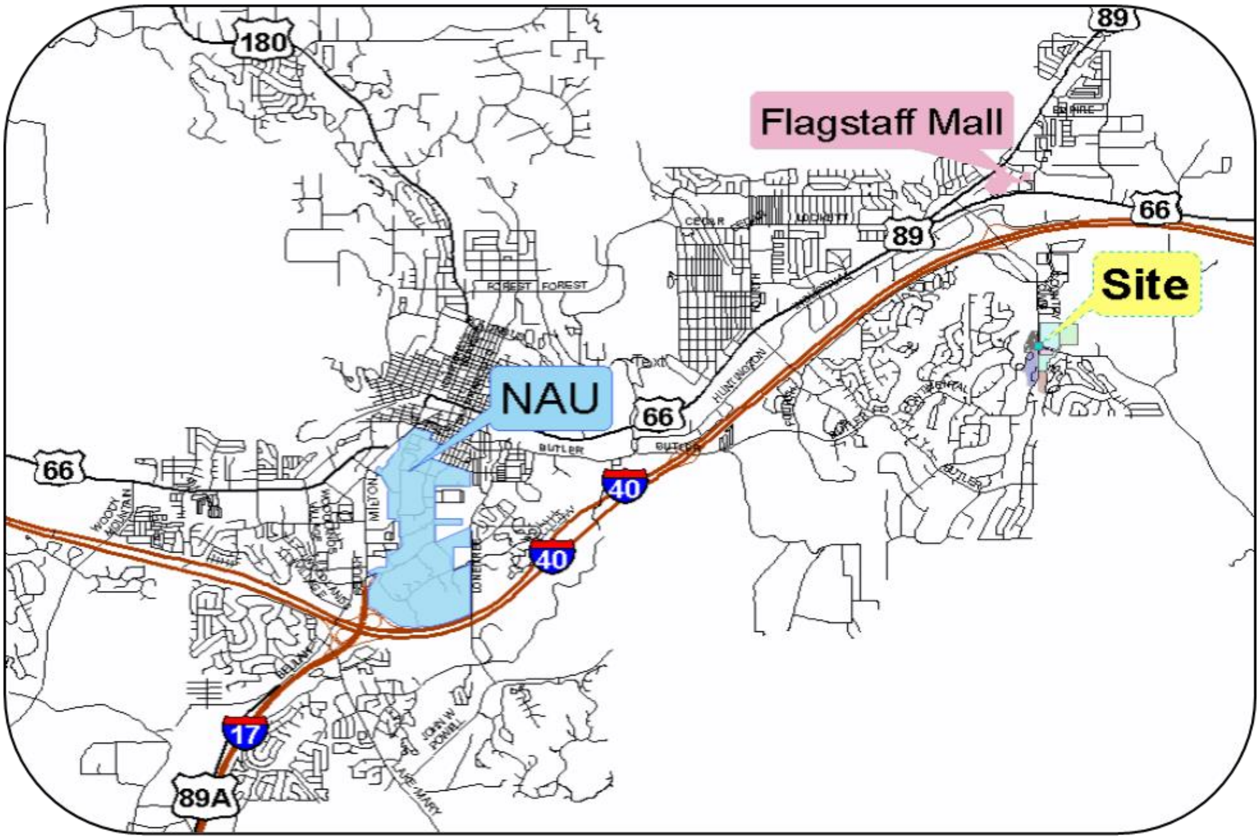

Figure 1.2. *City of Flagstaff Overview*

2. Data Analysis

A topographic survey was conducted in house to gather existing features including trees, bushes and utility valve boxes. Lidar data was given to us by the City of Flagstaff, this data consists of contours for the whole city of flagstaff. Together these surveys will be used to build the roundabout in AutoCAD Civil 3D, a computer aided drafting software.

Traffic data collection, including turning movements and vehicle classification count, was conducted by J3Z Engineering. The traffic data is used to find the level of service (LOS) of the intersection; this tells how well the intersection is working, A being the best and F being the worst. At the request of the client all traffic data was projected 20 years with a growth rate of 1.4%. The growth rate of 1.4% was taken from the 2013 edition of the City of Flagstaff Parks and Recreation Organizational Master Plan [K1] which estimates an average growth of 1.4% between 2010 and 2030. The growth rate was applied to the turning movements by:

$$F = E * (1 + i)^n \quad \text{(Equation 1)}$$

where F is the future value, E is the existing value, i is the annual growth rate, and n is the design life. For the LOS analysis only the peak hour is used for imputing data. From the peak hour the peak hour factor (PHF) is calculated by:

$$PHF = \frac{V}{4 * V_{15}} \quad \text{(Equation 2)}$$

This is where V is the peak hour volume and V_{15} is the peak 15 minute volume. The PHF used for the LOS analysis is an average of the PHF each movement, thru, left, right, in each direction. The peak hour was found by summing all movements in an hour period and then comparing it to every other hour period, i.e. 7:15-8:15 compared to 7:30-8:30, etc. The peak hour was found to be 5:00pm to 6:00pm and the peak 15 minute was 5:30pm to 5:45pm. The full list of grown turning movement counts and PHF's can be found in the Appendix as Figure 6.1. The vehicle classification count is used to find the percentage of heavy vehicles using the road. For this analysis heavy vehicles are classes 4 and 6-13 as defined by Jamar Technologies as buses and vehicles with three or more axels [K2]. J3Z Engineering identified class 14 vehicles as mostly golf carts, thus they were not included in the heavy vehicle percentage. The full list of vehicle classifications can be found in the Appendix as Figure 6.2.

The LOS for the existing two way stop sign controlled (TWSC) intersection was conducted using Highway Capacity Software (HCS) [K3]. This software allows users to find the LOS of the approaches leading to the intersection. The user inputs the hourly volumes, the PHF and intersection geometry, and the software outputs the delay in seconds per vehicle and the LOS. Using HCS, the LOS was found for the existing TWSC with no growth rate and then it was analyzed again with the growth rate. These values are summarized in Table 2.2 below. The table shows that the eastbound, northbound, and southbound directions all have a LOS A currently and in the future. While the westbound direction has a LOS C, currently, and a LOS D for the future. This shows that the intersection currently sees a large amount of delay in the westbound direction and that the delay will only worsen over time. Analyzing the HCS reports illustrates that most of the delay comes from the left and thru lanes with 29.3 seconds per vehicle (s/veh) while the right turn lane has a delay of 9.3 s/veh. The both HCS reports can be found in the Appendix; Figure 6.3 and Figure 6.4.

Table 2.1. Delay and LOS for Existing TWSC using HCS

Year		Eastbound	Westbound	Northbound	Southbound
2015	**Approach Delay (s/veh)**	8.9	17.1	1.8	1.3
	Approach LOS	A	C	A	A
2035	**Approach Delay (s/veh)**	9.3	29.3	1.9	1.3
	Approach LOS	A	D	A	A

The roundabout LOS was found using roundabout specific software; Rodel Interactive [K4]. The inputs for Rodel are roundabout specific including: approach geometry, entry geometry, circle geometry, and exit geometry. Due to the fact that the LOS is dependent on the geometry of the roundabout we had to wait until after the roundabout geometry was finished before starting with the LOS.

To get the LOS all of the above mentioned geometry data had to me entered into the software. After that the turning volumes and the percent trucks was inputted into the software. The bypass volumes refer to the right hand bypass lanes on the westbound and southbound legs of the intersection. Again, for the roundabout the LOS was found for the current condition as well as the 20 year design life. The current roundabout LOS had an A rating with an average intersection delay of 3.82 seconds. The future roundabout LOS also had an A rating with an average intersection delay of 4.59 seconds. The full LOS inputs and outputs can be found in Appendix A as Figure 6.5, current, and Figure 6.6, future.

Section 6, Impacts and Benefits, will go into more depth on the reduction in delay between the TWSC and the roundabout.

3. Design Analysis

3.1. Landscaping Design Alternatives

Landscaping can be done on the central islands, splitter islands, and along the approaches. Landscaping has many benefits, which include public safety and enhancing the community. In order to determine the type and quantity of the landscaping to be done at a roundabout, three aspects need to be considered; maintenance, sight distance at the intersection, and available planting zones.

3.1.1. Design Alternative 1: Not having Landscaping:

One of the design alternatives is no landscaping and there are some advantages and disadvantages associated with that design option. The advantages of not having an intersection with landscape is that there will be no need for maintenance, and a reduction in the construction cost. The disadvantages of not designing a landscaped intersection is that there will be less visibility for drivers approaching the intersection compared to a landscaped intersection.

3.1.2. Design Alternative 2: Having Landscaped Intersection:

The second design alternative is to have a landscaped intersection. This design option has multiple advantages and disadvantages. The advantages of having a landscaped intersection is that it enhances the safety of the intersection, by improving the visibility for drivers approaching the intersection, and it encourages the pedestrians to use the intersection properly by discouraging them to cross through the central island. Another advantage of having a landscaped intersection is that it would be aesthetically pleasing. The disadvantage of having a landscaped intersection is that it will increase the cost of construction and will require maintenance.

3.1.3. Central Island Landscaping

The landscaping of the central island could be made of low-level shrubs, grass, or groundcover. According to the *National Cooperation Highway Research Program for Roundabouts* (NCHRP), it is preferred to use low level plants than using fixed objects, such as trees, or walls, due to the negative effect fixed objects could have on the sight distance at the intersection [A1]. Another design alternative at the central island is to place statues, such as public art, or a fountain in the inner central island. Placing a large item in the inner central island will indicate to the drivers that they cannot pass straight through the intersection, and will improve the visibility of the center island at night. Designing a landscaped central island will require a realistic maintenance program to be considered; as a result, agreements need to be made with local civic groups and garden clubs to maintain the planting area of the roundabout.

3.1.4. Splitter Island Landscaping

Landscaping can be installed at the splitter islands, done properly this would encourage the pedestrians to cross the intersection at the proper crosswalk areas. The landscaping at the splitter island could be made of low shrubs, low gross plants, or grass. Large plants should not be used at the splitter island, because it will affect the visibility of the drivers.

3.2. Drainage

There are two design options for placing drainage at the roundabout. Drainage can be placed either on the outer curb line of the roundabout or along the central island for a roundabout. According to the NCHRP, drainage inlets are usually placed on the outer curb line of the roundabout [A2]. However, if the grade through the intersection is constant, the drainage inlets may be placed in the central island. Inlets also cannot be placed along the crosswalks.

3.3. Roundabout Size alternatives – TJ

When considering the appropriate size of the roundabout for the intersection we consider one two options; (1) single-lane roundabout and (2) a mini-roundabout. Both features of the roundabout are listed in Table T1 and both will satisfy our roundabout configurations. Each of the roundabouts has their own pros which will provide an adequate intersection flow, speed, alignment, and safety. We ultimately choose the single lane roundabout for its inscribed diameter size which will accommodate a larger design vehicle and for its higher speed limit range to accommodate the speed limit already existing.

Table 3.1. Parameters and Guidelines for the Design of a Roundabout

	Single-Lane	Mini
Inscribed Circle Diameter	90 to 150 ft	45 to 90 ft
Speed Limit	20 – 25 mph	15 mph
Entry Width	14 to 18 ft	14 to 18 ft
Circulatory Roadway Width	100% to120% of Entry Width	100% of Entry Width

3.4. Signage and Striping Options

With accordance to the NCHRP manual which coincides with the MUTCD manual there are different types of signs to choose from for a roundabout. The figure you see below is an example of how the intersection could look. It will all depend on the City of Flagstaff on which signs they like to use for their roundabouts. For example the one way sign in the middle of the roundabout could be exchanged for just an arrow sign.

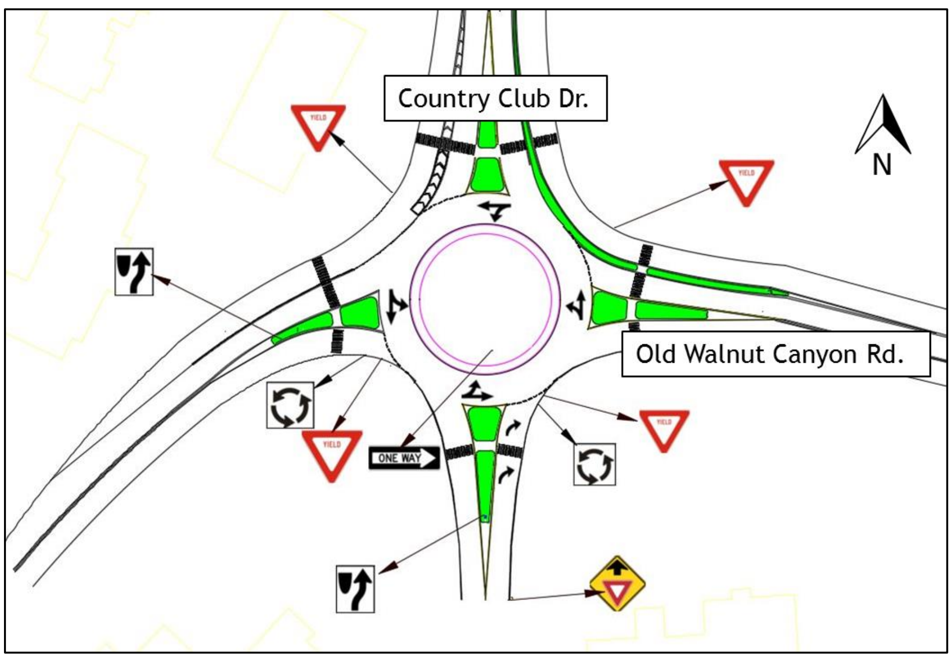

Figure 3.1. Proposed Options for the Selected Roundabout

3.5. Pedestrian and Bike Considerations

Also in the NCHRP manual it doesn't allow the use of bike lanes within a roundabout, so the bike will have to enter the roundabout as a vehicle or use the sidewalk. For pedestrian, crosswalks are installed through the splitter islands but like the signage the different stripping for the crosswalks are up to the City of Flagstaff. The NCHRP offers a couple of different options. In our final design we will talk about which one we chose but it is all up to the City.

4. Final Design

4.1. Final Geometry Design

The principle design objectives when designing a roundabout must follow and guide National Cooperative Highway Research Program: Report 672 (NCHRP 672). The overall design goal for our roundabout has taken in the several design principles that accompanied by NCFRP 672 are

- Speed Management: Provide slow entry speeds and consistent speeds through the roundabout by using deflection.
- Lane arrangements: Provide the appropriate number of lanes and lane assignment to achieve adequate capacity, lane volume balance, and lane continuity.
- Path Alignment: Provide smooth channelization that is intuitive to drivers and results in vehicles naturally using the intended lanes.
- Design Vehicle: Provide adequate accommodation for the largest vehicle that will use the roundabout.
- Non-Motorized Design Users: Design to meet the needs of pedestrians and cyclists.
- Location: Provide appropriate of roundabout center to existing intersection.

Each of the above principles will directly affect the safety and efficiency of a roundabout.

To serve an appropriate speed management, hatched in Figure 4.1, our single lane roundabout design implements a inter island diameter of 110 feet. This roundabout size will directly influence a 20 mile per hour speed limit at which a vehicle can transverse through the intersection.

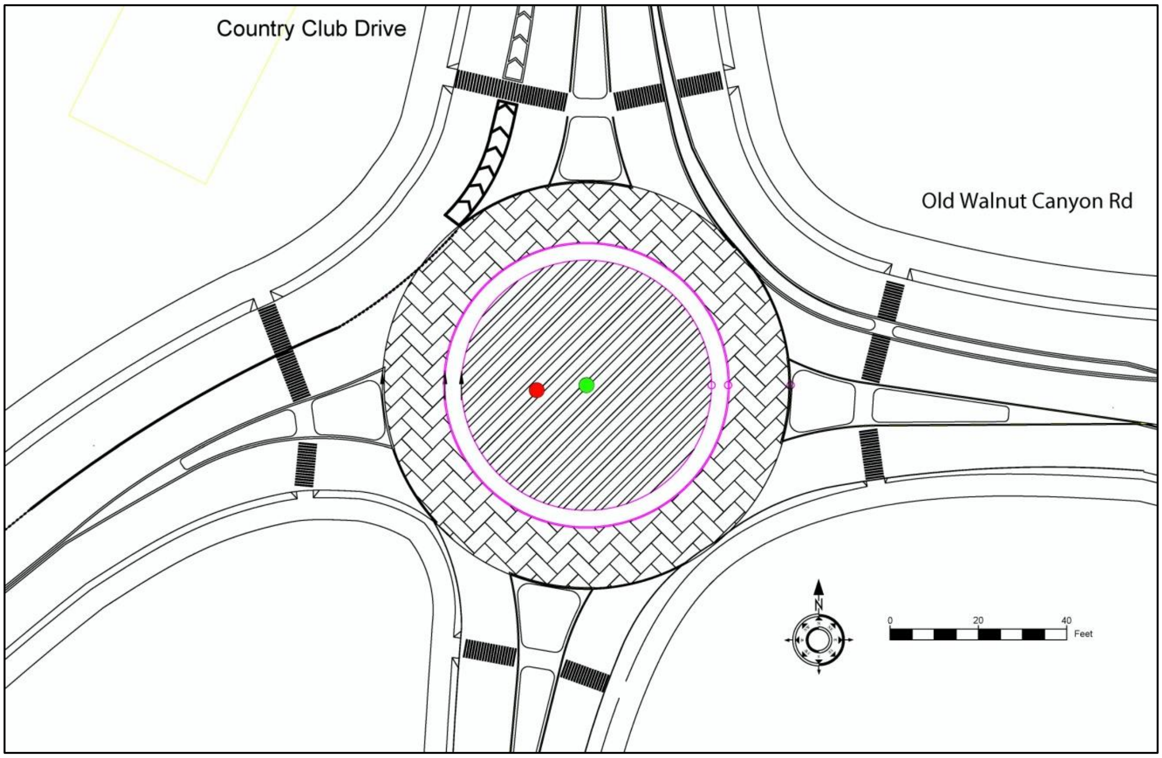

Figure 4.1. *Roundabout-Inscribed Diameter.*

To serve an appropriate lane arrangement our team implemented hatched at the top of Error! Reference source not found. a right-turn only lane from northbound Country Club Drive onto westbound Old Walnut Canyon Road. Also, hatched on the right of Error! Reference source not found. a right-turn by pass lane from westbound Old Walnut Canyon Drive onto northbound Country Club Drive. This right-turn only was original to the old intersection while the right-turn by pass was an addition. Since, at specific time of the day and year there had been high amounts of traffic and crashes in this direction. These two features of the roundabout made sure the traffic from the original intersection design now is safer and familiar.

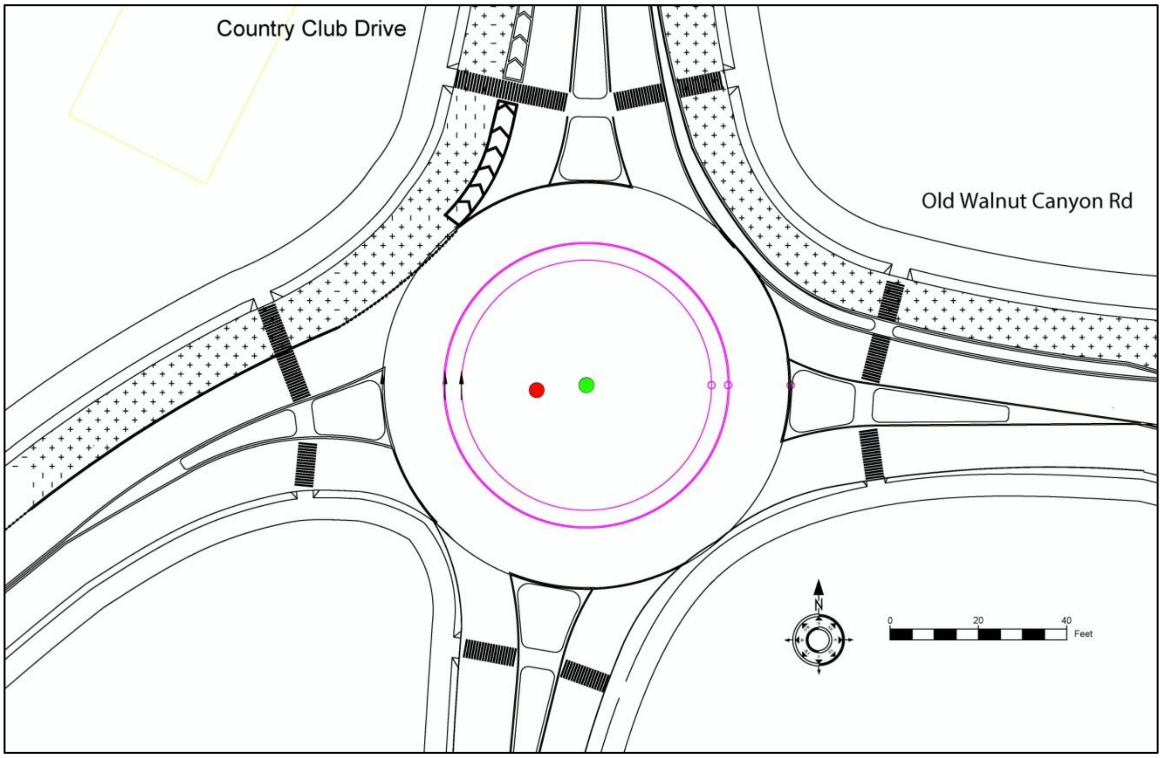

Figure 4.2. *Right-turn Only and Right-turn By Pass.*

To serve an appropriate path alignment our team kept the same arrangement of lanes and existing turning movements. Seen in Figure 4.3 there are four on the north side of the intersection, three lane east of the intersection, and two lanes both south and west of the intersection. Each lane is 16 feet in width for entering lanes, exiting lanes, and the circulatory roadway. In addition, splitter islands, hatched just outside of the inscribed circle diameter in Figure 4.3, will separate entering and exiting traffic, deflect and slow entering traffic, and provide a pedestrian refuge.

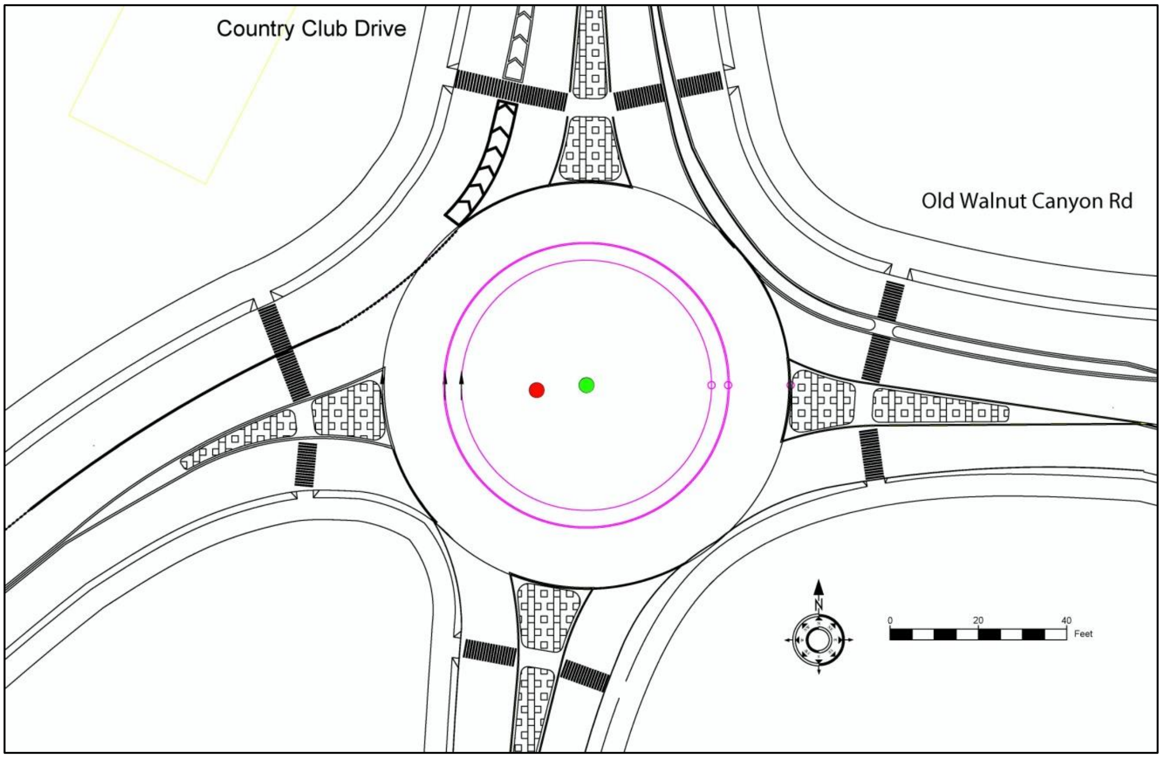

Figure 4.3. *Roundabout- Island Splitters*

To serve the appropriate design vehicle of a class 5 single-truck trailer (50 feet in length). The NCHRP has insured us that with 16 foot exiting and enter lanes, a 16 foot circulatory roadway, and a 110 foot inscribed circle diameter the turning requirements for our design vehicle will be meet, see Figure 4.1 and Figure 4.3. However if there is a new design vehicle such as fire engines, transit vehicles, or single-unit delivery vehicles the addition of an apron can be provided. The apron provides additional paved surface to accommodate the wide path of the trailer, but keeps the actual circulatory roadway width narrow enough to maintain speed control for smaller passenger vehicles.

To serve non-motorized design users our roundabout design has provided sidewalks hatched on the outside of the roundabout in Figure 4.4 of 9 feet in width with a 2 foot landscape buffer. The sidewalk width will provide a large enough space in the future where both pedestrians and cyclists can travel, while, the landscape buffer will provide additional safety for pedestrians by separating vehicular and pedestrian traffic. The sidewalk will all so assist with guiding pedestrians to the designated crossing locations. The crosswalks within our roundabout design are set back from the entrance line, and the raised splitter islands have cuts to allow pedestrians, wheelchairs, strollers, and bicycles to pass through safely.

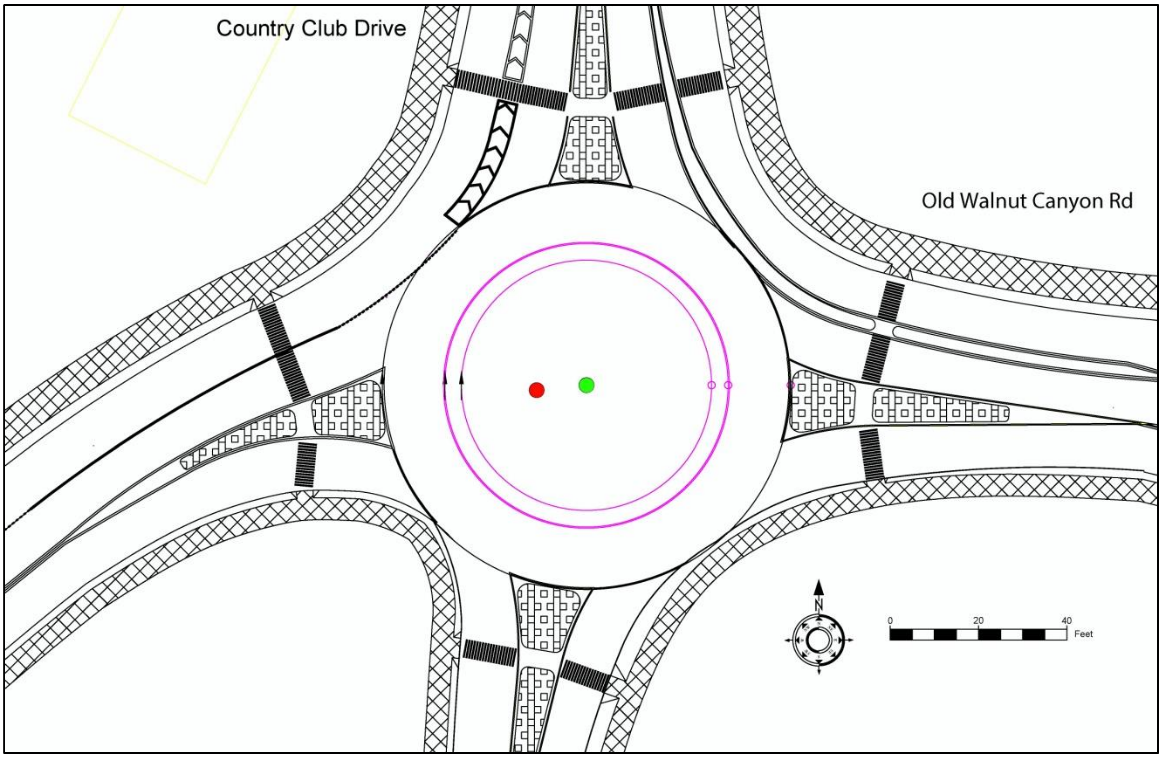

Figure 4.4. *Roundabout- Pedestrian Considerations*

Finally to serve the location of the roundabout or team kept a close relationship to the original location of the center, the red dot in Figure 4.1 of the intersection, and only offset the center of the roundabout intersection 1.5 feet north and 13.5 feet east to the new green dot in. This provides proper alignment for each leg of the roundabout and ensures of no faster path while through the roundabout. In addition, with such a close proximity of the old intersection location our design used approximately 5,475 square feet of right-away, seen in Figure 4.5.

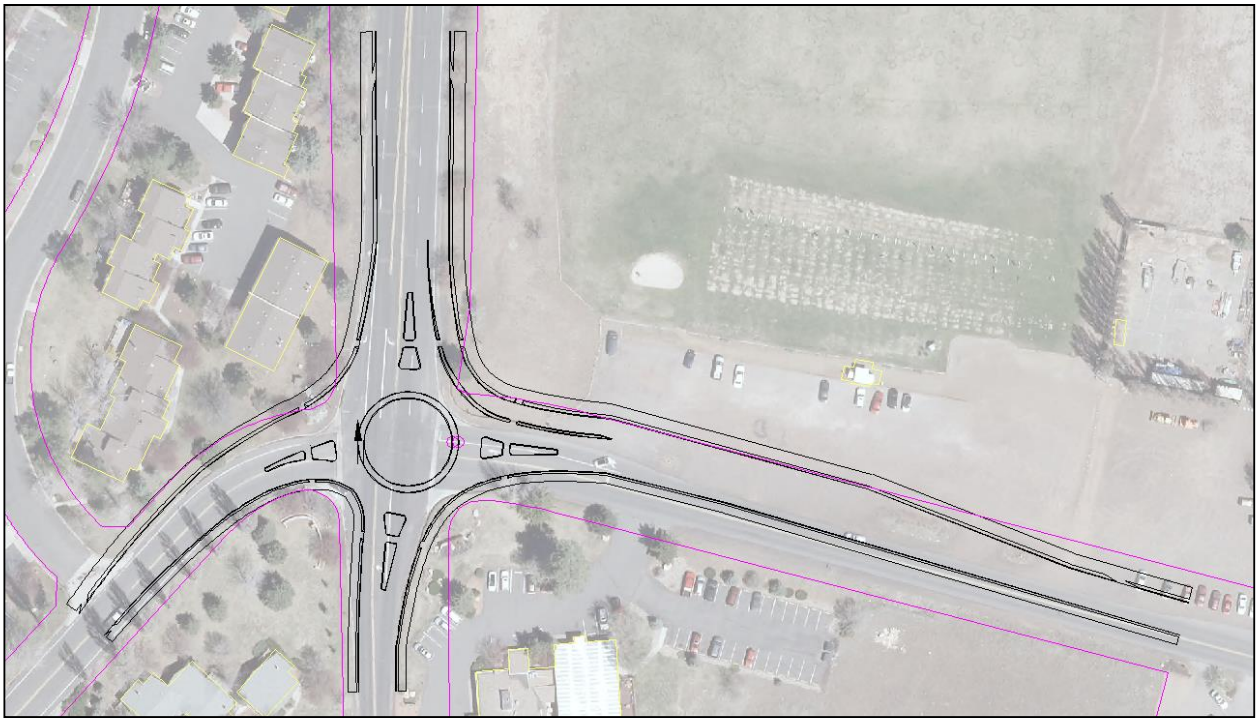

Figure 4.5. *Roundabout- Over Existing Conditions*

4.2. Grading

In Table 4.1, calculation from AutoCAD determined the volume summary of the cut and fill for the roundabout site. Here we determined that the site will have a net cut of 725.01 cubic yards.

Table 4.1. Volume Summary

	2d Area	**Cut**	**Fill**	**Net**
	(Sq. Ft.)	(Cu. Yd.)	(Cu. Yd.)	(Cu. Yd.)
Total	60671.01	1999.03	1274.02	725.01<Cut>

4.3. Signage and Striping

The signage and striping for this roundabout will apply with the guidelines found in the NCHRP and MUTCD Manual. The roundabout that has been chosen seen in Figure 3.1 will be having both signage applied before and around it. When approaching the roundabout from the south and westbound legs a roundabout circulation plaque (R6-5P) will be placed to let the upcoming drivers know that a roundabout is coming (Figure 6.5). It is going to help people traveling northbound traveling over the increase grade south of the roundabout. Since the splitter islands are less than 75^2 it will have a double yellow line leading up to the splitter and will proceed to go into one yellow line as seen in Figure 4.6.

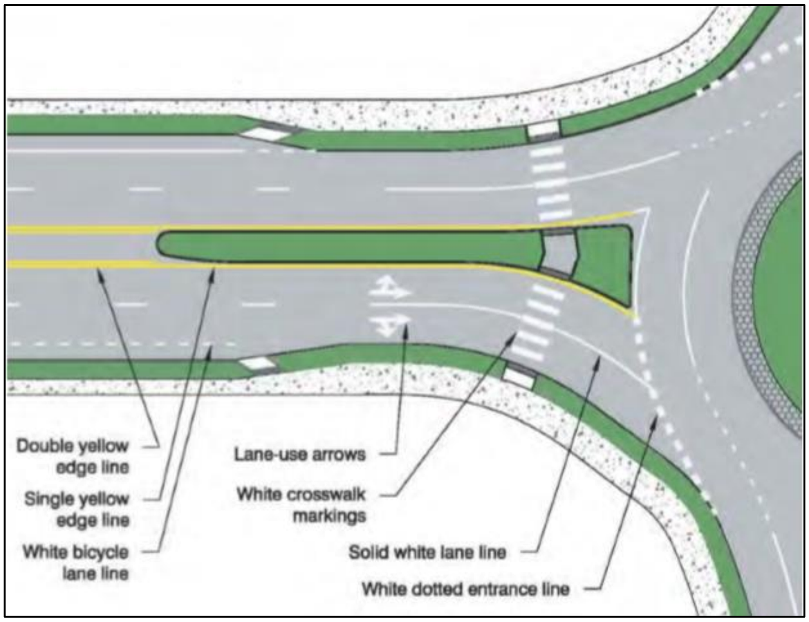

Figure 4.1. *Example of Stripping for Lanes in a Roundabout*

For the southbound and westbound splitter islands that separates the right only lane and the thru lane it will have a solid white lane starting at the beginning of the lanes splitting and will expand up to the splitter island. Also, in order to make sure people are in the correct lane arrows will be installed on the ground. Lane arrows are not required for a single lane roundabout; it will help with confusion. These arrows will be the normal arrows that are provided in the MUTCD manual see Figure 4.7 below.

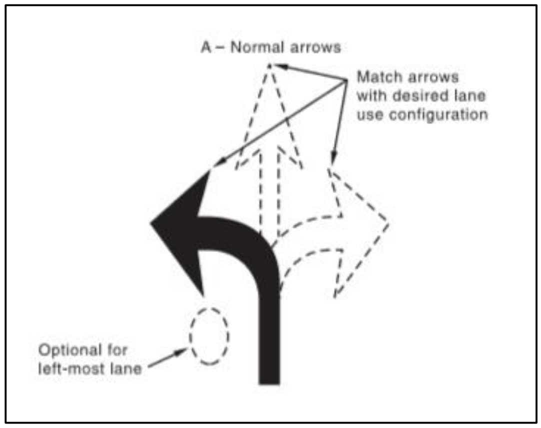

Figure 4.7. *Arrow Stripping*

Since flagstaff gets snow and heavy amounts of rain there will also be keep right sign (Figure 6.6) installed in the splitter island between the thru and right turn only lane (Figure 6.7), and one way signs (Figure 6.8) will be placed in the middle of the roundabout instead of directional arrow [R1]. Each approach leg will have a yield bar and yield sign (Figure 6.9) at the entrance of the roundabout. These are required by the NCHRP manual. A yield ahead sign (Figure 6.10) will be installed on the northbound approach on the other side of the hill so that people will be warned that they will know that a yield sign in coming. Dotted lines will be used on the entrances of the roundabout along with where the cars are willing to exit the roundabout. This can be seen in the Figure 4.8 below.

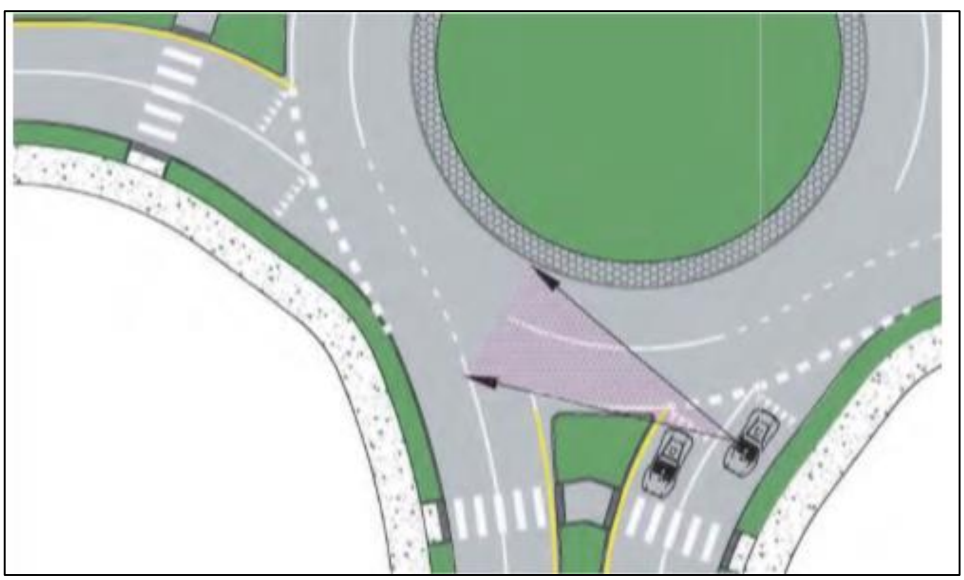

Figure 4.8. *Sight Distance*

Yellow edge lines will be installed on the inner part of the roundabout, and along the splitter islands. NCHRP and the MUTCD require that the line be installed and they need to be 4-6 inches wide. With accordance of Section 3C.03 of the MUTCD manual these lines are also to be installed outer part of the roundabout and roadway. An overview outline of our roundabout design and all stripping and signage will be completed after the final design is completed.

4.4. Final Landscaping Design

After comparing the advantages and the disadvantages of having landscaping versus not having landscaping at the intersection, the decision was made to have a landscaped intersection for the following reasons. First, the sight distance at the intersection is deficient, and having a landscaped intersection would help in improving the visibility of the roundabout for the approaching drivers. The landscape will decrease the headlight glare of the oncoming vehicles, and will help in reducing the speed of approaching vehicles.

The landscaping that was chosen for the center island was to plant grass, small shrubs, and some perennial flowers. This will make the center island visible to approaching vehicles and will be aesthetically pleasing to the eye. Some watering and maintenance will need to take place within the first couple of months of planting but the goal is to limit the amount of watering and maintenance that is required in the future.

4.5. Pedestrian and Bike Consideration

According the traffic analysis that was taken by J3Z Engineering there was a rather low amount of pedestrian traffic traveling through the intersection. But since there is some pedestrian traffic our roundabout design is going to accommodate them. There will be a section in the splitter islands where a sidewalk will be put through. The crosswalk markings that will be installed are the “Zebra” or “Continental” crosswalk markings [R1]. These markings where chosen due to the high degree of visibility, they will won’t be confused with entrance lines, and less maintenance. These markings will be a 6- 10 feet long, 12 to 24 inches wide, and will be spaced 12- 60 inches. An example of this can be seen in the figure below.

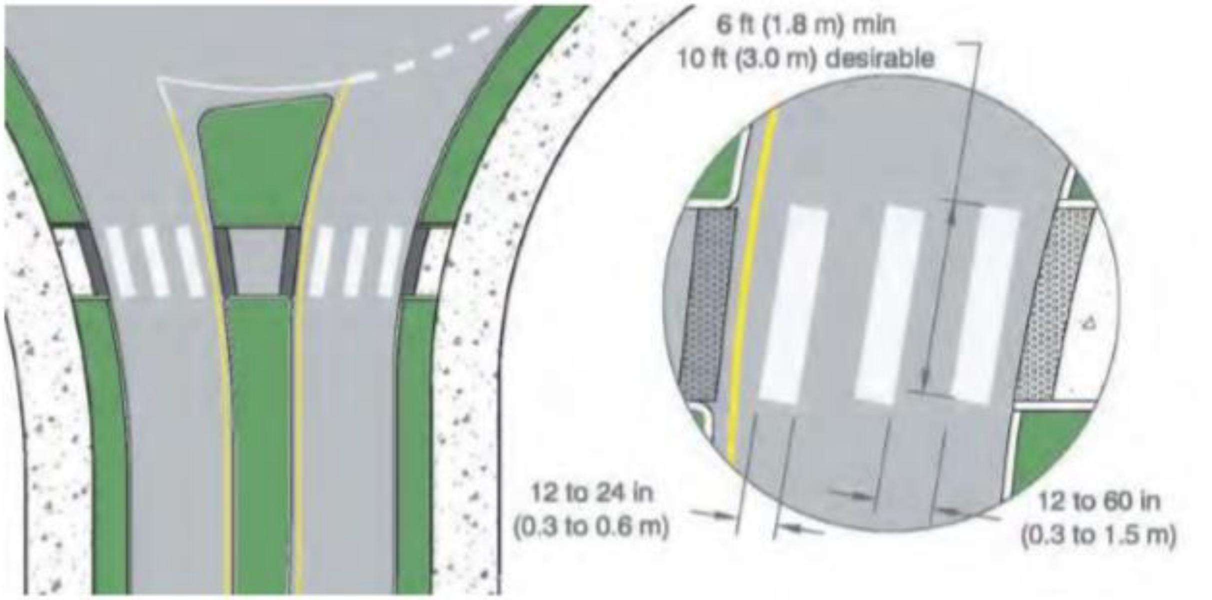

Figure 4.9. *Stripping for Pedestrian Cross-walks*

These crosswalks will be installed at ever leg of the roundabout. To insure the safety of the pedestrians and that these markings will be hard to see in the winter a pedestrian crossing sign (W11-2) will be installed in front of the crosswalk. With accordance to the MUTCD manual Section 6.8, prohibits the use of marked bicycle lanes within the roundabout. If there is bike traffic they will have to merge onto the sidewalk and cross a pedestrian or enter the roundabout at their own risk.

5. Engineering Services

The final Gantt chart for our design project can be found in Appendix A as Figure 11. About halfway through the project we realized that we had not allotted enough time for several tasks and had to push back some of the tasks. Specifically we pushed back the Economics task which included Construction Cost, Benefits and Impacts. The main cause of our setbacks was due to having compilations importing the GIS data into Civil 3D. Although this put us behind schedule for the Site Design, it did not negatively impact our Economics due to the shift in dates. During the project we also realized we needed to add a task to Data Analysis. The proposal listed the sub task as “Level of Service,” but we took that subtask and broke it into two tasks: “Level of Service: TWSC” and “Level of Service: Roundabout.”

Table 5.1 shows the predicted verse actual hours spent on the project as well as the billing rate for the respective job classification. Although the complications with the GIS data set us back our hours were still 2.5 times overestimated, 743 compared to 286. Having spent less time on the project the billing rate also went down from $47,400 to $18,245. Figure X in Appendix A shows a task by task breakdown of the hours.

Table 5.1. Predicted vs. Actual Engineering Services

	Senior Engineer	Engineer	Field Technician	Engineering Intern	Administrative Assistant	Total
Projected Hours	144	255	22	206	116	743
Projected Billing Rate	$20,160	$17,850	$1,210	$4,120	$4,060	$47,400
Actual hours	55	98	8	79	45	286
Actual billing Rate	$7,760	$6,871	$466	$1,586	$1,563	$18,245

Table 5.2 is our proposed cost for the final design. The Unit Prices were taken from a similar roundabout project in Flagstaff, City of Flagstaff provided the cost sheet for that project.

Table 5.2. Proposed Cost of the Final Design

Item Description	Unit	Quantity	Unit Price	Total
Landscape Removal	ACRE	0.5	$2,500.00	$1,250.00
Removal of Concrete Curb and Gutter	FT.	336	$15.00	$5,040.00
Removal (Sign)	EACH	6	$200.00	$1,200.00
Roadway Excavation	CU. YD.	1203	$20.00	$24,060.00
Aggregate Base, Class 2	CU. YD.	800	$105.00	$84,000.00
Asphalt Concrete (Asphalt-Rubber)	Ton	110	$40.00	$4,400.00
Asphalt Rubber Material	Ton	10	$650.00	$6,500.00
Mineral Admixture	Ton	1	$90.00	$90.00
Slip Base (Perforated Post)	EACH	16	$250.00	$4,000.00
Sign Post (Perforated)	FT.	96	$17.00	$1,632.00

Warning, Marker, or Regulatory Sign Panel	SQ. FT.	96	$35.00	$3,360.00
Pavement Markings (White Thermoplastic)	FT.	3480	$2.00	$6,960.00
Pavement Markings (Yellow Thermoplastic)	FT.	1464	$2.00	$2,928.00
Pavement Symbol (Extruded Thermoplastic)	EACH	6	$300.00	$1,800.00
Paint Bull Nose	EACH	4	$175.00	$700.00
Seeing (Class II)	ACRE	1	$4,500.00	$4,500.00
Concrete Curb (C-05.10)(Type G)	FT.	960	$23.00	$22,080.00
Concrete Curb and Gutter (C-05.10)(Type G)	FT.	2280	$27.00	$61,560.00
Concrete Sidewalk (C-05.20)	SQ. FT.	7000	$12.00	$84,000.00
Concrete Sidewalk Ramp (C-05.30 Type B)	EACH	8	$2,200.00	$17,600.00
			Total	$337,660.00

This cost sheet is excluding the price for relocating utilities, the cost of acquiring right a ways, labor cost, mobilization, and temporary road and signage. These prices are outside the scope of this project.

6. Impacts and Benefits

6.1. Safety Benefits

A roundabout will improve the safety of the intersection by reducing the total number of crashes. According to the Crash Modification Factors Clearinghouse (CMF) method a roundabout design will reduce the total number of crashes at the intersection by 78.2%. The injury crashes are expected to decrease by 77.6%. The CMF method is referenced in the NCHRP manual, which is used by ADOT. The CMF method estimates the reduction in the total number of crashes, and injury crashes based on the geometry of the intersection, the traffic control, the type of area where the intersection is located, and the roadway type. Roundabouts reduce the number of crashes significantly, because they help in minimizing the conflict points at the intersection, by eliminating left turn lanes. Also, due to the low speed at the intersection after installing the roundabout, that give drivers more time to detect their mistakes and correct it, before an accident occurs.

6.2. Operational performance benefits

The vehicular flow at the intersection will significantly improve after installing the intersection. The level of service at the intersection will significantly improve, due to the reduction in delay time. Vehicles experience less amount of delay time at a roundabout intersection compared to other design alternatives. For the intersection of Old Walnut canyon, and Country Club drive installing a roundabout at the intersection, at the current time, will reduce the delay time by a 58% compared to the current condition of the intersection. At the year 2035, having a roundabout at the intersection will reduce the delay time by 81% compared to leaving the intersection at its current state.

6.3. Cost benefits

The cost benefits of the roundabout was calculated based on the National Cooperative Highway Research Program Manual (NCHRP). It was calculated based on two factors, which are the reduction in delay time, and the reduction in number of crashes.

6.3.1. Cost benefits due to the reduction in delay time

The reduction in delay time was calculated with accordance to the NCHRP Manual. First, the average delay time for the TWSC was calculated for each year from 2015 to 2035. The delay time for the TWSC intersection was calculated using the Highway Capacity Software (HCS). Then, the delay time experienced by vehicle users after installing the roundabout was calculated for each year from 2015 to 2035. The delay time in sec/ vehicle after installing the roundabout was calculated using RODEL software. After the calculation of the delay times, the value of time for passenger vehicles, and trucks were determined for the City of Flagstaff. The values of time were determined with accordance to the U.S. Department of Transportation. The hourly value of time were found to be $12.3 per hour for passenger vehicles, and $25.4 for trucks. The hourly values of time were converted to $/ second in order to multiply it by the average delay time in sec/ vehicle, to compare the cost of delay at the current intersection condition, and after installing the roundabout. Then, the cost of delay time after installing the roundabout was subtracted from the cost of delay at the TWSC for each year along the 20 years design period, in order to determine the total cost savings due to the reduction in delay time. The cost savings over the 20 years design period for the reduction in delay time was about $21,000. See Figure 6.14 in Appendix A for the calculations that were done to determine the total cost savings due to reduction in delay time experienced by vehicle drives.

6.3.2. Cost benefits due to the reduction in number of crashes

6.3.2.1. Estimating the number of annual crashes at TWSC

The reduction in the number of total crashes, and injury crashes before installing the roundabout was calculated with accordance to the NCHRP Manual. It was calculated using the method of Accident Modification Factors. First, the predicted expected number of crashes per year for the TWSC intersection was calculated. The expected total and injury crashes per year at the TWSC intersection were calculated using equations 3, and 4 respectively:

$$\text{Total crashes/ year} = (\exp(-1.62))(\text{AADT})^{0.22} \quad \textit{(Equation 3)}$$

$$\text{Total crashes/ year} = (\exp(-1.62))(\text{AADT})^{0.22} \quad \textit{(Equation 4)}$$

Then, the factors of the weight and the estimated eastbound for the total crashes, and injury crashes were calculated using equations 5, and 6. Where “P” is the total crashes per year which was calculated using equation 3, and n is the year period where the observed crashes at the intersection was calculated. The crash data was provided by the City of Flagstaff for the year period between 2001 and 2014, as a result an “n” value of 14 years was used. According to the Highway Safety Manual, a “k” value of 0.24 was used in the calculations.

$$w_1 = \frac{P}{\left(\frac{1}{k}\right)+np} \quad \textit{(Equation 5)}$$

$$w_2 = \frac{\left(\frac{1}{k}\right)}{\left(\frac{1}{k}\right)+np} \quad \textit{(Equation 6)}$$

After that, the expected annual total crashes, and injury crashes were calculated using equation 7.

$$\text{m}= w_1\text{x}+ w_2\ \text{P} \quad \textit{(Equation 7)}$$

Because the volumes are expected to increase in the after period, an adjustment factor was calculated using equation 8, in order to adjust for the increased volumes.

$$\frac{(\text{AADT After})^{0.22}}{(\text{AADT before})^{0.22}} \qquad \textit{(Equation 8)}$$

Finally, the total number of crashes, and injury crashes at the TWSC intersection were calculated taking into account the modification factor. It was found that the total number of crashes per year is 3.2, and the total number of injury crashes per year is 1.1.

6.3.2.2. Expected annual number of crashes after converting the intersection to a roundabout

The expected annual total crashes, and injury crashes were calculated after converting the intersection to a roundabout intersection. CMF method was used to determine the percent of reduction in crashes after installing the roundabout. According to the CMF, the total number of annual crashes is expected to decrease by a 78.2% after installing the roundabout. While, the total number of injury crashes is expected to decrease by 77.6%. Then, these reduction percentages were multiplied by the total number of crashes, and injury crashes that were calculated in the previous step. Then, it was found that the total annual number of crashes at the roundabout intersection is 2.94 crashes/ year. While, number of injury crashes is 0.89 crashes/ year after installing the roundabout.

Then, the expected reduction value of the PDO crashes was estimated by subtracting the number of injury crashes per year from the total annual crashes. The expected PDO crashes was found to be 2.054 crashes/ year.

6.3.2.3. Calculating Annual Economic Benefit

After estimating the total reduction in crashes per year, the annual economic cost benefit was calculated. The annual economic cost benefits were calculated using the unit costs for crashes provided in the National Safety Council. The costs presented in the National Safety Council illustrate the cost impact on the society due to accidents. A cost of each injury crash is equal to $298,000, and the cost of possible injury is equal to $21, 000 per crash. Multiplying the values of the unit costs by the reduction in number of crashes, it was found that the annual economic benefit as a result of the reduction in crashes is equal to $307162. See Figure 6.15 in Appendix A for the calculations done to estimate the cost savings by installing a roundabout at the intersection due to the reduction in number of crashes.

6.4. Environmental Impacts

Roundabouts provide positive Environmental impacts. As roundabouts reduce the time of delay experienced by vehicle drivers, the number of accelerations and decelerations, and the duration of stops, compared to other design alternatives, such as a stop controlled or signalized intersection. Because, roundabouts don't require vehicles to stop, even when there are high volumes, vehicles can yield and circulate slowly without having to completely stop. The reduction in delay time, and in number of stops made by vehicles reduces the noise and air pollution at the intersection. The air quality at the intersection will be improved due to the consumption of less amount of fuel.

6.5. Cost Impacts

The cost for installing a roundabout is high, compared to other design alternatives, such as a traffic signal. However, the installation cost of a roundabout is high, it is a cost effective option. Because roundabouts require minimum amount of maintenance along the design life. The maintenance required will be for landscaping at the Central Island, and Splitter Island.

6.6. Societal Impacts

A roundabout will have impacts on the society because of multiple factors. First, installing a roundabout can lead to public confusion, due to the unexpected change in traffic patterns. Therefore, the public has to be informed before installing the roundabout through public meetings, providing handouts to vehicle drivers, or through online resources. Also, in order to reduce confusion variable messages have to be installed during the construction of the roundabout, and signing messages need to be installed during the construction, and after it to warn the intersection users of the change in traffic patterns.

Another societal impact of a roundabout is the impact it will have on the surrounding areas during the construction time. Roundabouts take a long time to get constructed, which can lead to negative impacts on the surrounding businesses in the area, such as Wyndham Flagstaff. Therefore, the time of construction has to minimized as much as possible, and accesses to the business the area has to be maintained through alternative route accesses.

7. Works Cited

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8. Appendix A

Figure 6.1: Grown Turning Movements and PHF

	SB				WB				NB				EB			
Start Time	LT	Thr	RT	Ped	LT	Thr	RT	Ped	LT	Thr	RT	Ped	LT	Thr	RT	Ped
07:15 AM	3	5	13	0	36	4	2	0	2	25	1	0	1	4	12	0
07:30 AM	6	20	11	0	41	8	0	0	2	23	1	0	1	1	13	0
07:45 AM	8	9	14	0	56	1	1	0	3	33	0	0	0	4	15	0
08:00 AM	14	12	24	0	55	6	4	0	0	31	2	0	0	1	17	0
8:15 AM	6	17	16	0	44	3	4	0	6	30	1	0	0	6	10	0
08:30 AM	10	15	16	0	28	3	3	0	3	34	3	0	0	4	11	0
08:45 AM	21	18	21	0	41	5	3	0	6	21	3	0	1	2	7	0
09:00 AM	19	20	17	0	35	1	6	0	4	31	1	0	0	4	11	0
09:15 AM	7	16	19	0	24	3	3	0	4	24	2	0	0	5	9	0
09:30 AM	10	12	22	0	23	5	6	0	3	23	1	0	0	4	15	0
09:45 AM	8	20	15	0	35	5	3	0	3	29	3	0	0	3	11	0
10:00 AM	15	14	19	0	26	3	2	0	1	22	1	0	1	1	13	0
10:15 AM	12	12	21	0	34	1	1	0	3	22	2	0	0	3	8	0
10:30 AM	10	20	26	0	22	1	0	0	3	17	0	0	1	0	15	0
10:45 AM	15	13	19	0	29	3	2	0	3	26	2	0	0	0	12	0
11:00 AM	9	16	12	0	31	6	4	0	2	15	2	0	0	3	13	0
11:15 AM	8	17	21	0	23	2	1	0	2	13	1	0	1	3	16	0
11:30 AM	16	15	24	0	26	5	2	0	2	35	5	0	0	0	13	0
11:45 AM	20	11	20	0	17	2	5	0	2	21	2	0	0	2	13	0
12:00 PM	15	17	20	0	19	1	1	0	2	16	0	0	0	2	8	0
12:15 PM	14	13	17	0	33	3	1	0	6	28	2	0	3	4	12	0
12:30 PM	15	20	23	0	21	1	2	0	3	19	1	0	2	3	11	0
12:45 PM	10	18	22	0	25	1	2	0	6	17	1	0	3	3	16	1
01:00 PM	14	22	27	1	20	4	4	0	5	18	0	0	1	4	17	0
01:15 PM	19	28	25	0	33	7	4	1	5	13	0	0	0	7	18	0
01:30 PM	15	15	36	0	43	1	0	0	7	27	3	0	2	3	13	0
01:45 PM	12	15	25	0	21	2	2	0	4	35	0	0	0	3	11	0
02:00 PM	13	18	17	0	22	4	1	0	4	24	2	0	1	1	16	0
02:15 PM	11	20	32	1	17	5	1	1	5	16	2	0	0	1	19	0
02:30 PM	13	18	27	0	24	1	3	0	6	19	4	0	0	0	15	0
02:45 PM	12	17	27	0	29	1	5	0	0	19	0	0	1	0	7	0
03:00 PM	17	15	24	0	40	0	2	0	3	15	2	0	4	4	11	0
03:15 PM	18	22	34	0	16	3	3	0	3	14	3	0	0	3	26	0
03:30 PM	15	19	38	0	21	1	1	0	6	16	0	0	0	5	12	0
03:45 PM	19	26	33	0	29	6	2	0	5	28	0	0	4	4	25	0
04:00 PM	19	21	39	0	25	6	3	2	5	19	1	0	0	4	15	0
04:15 PM	17	24	46	0	23	3	4	0	5	21	0	0	0	2	18	0
04:30 PM	18	25	37	0	25	5	4	1	5	24	2	0	0	4	9	0
04:45 PM	20	18	43	0	33	2	5	0	7	19	0	1	2	2	7	0
05:00 PM	27	23	59	2	25	2	6	0	8	20	1	0	1	2	12	0
05:15 PM	10	33	47	0	31	3	5	0	5	34	1	0	2	4	8	0
05:30 PM	17	35	60	0	33	8	3	0	8	17	2	0	0	2	17	0
05:45 PM	13	29	43	0	39	1	3	0	8	23	2	0	1	4	14	0
06:00 PM	23	22	41	0	26	1	2	0	5	17	2	0	0	6	12	0
06:15 PM	19	18	45	0	26	1	3	0	4	20	3	0	0	4	6	0
06:30 PM	22	26	59	0	42	2	2	1	4	23	3	0	2	6	11	0
06:45 PM	11	24	35	0	25	3	2	0	4	19	2	0	1	4	14	0
07:00 PM	18	14	24	0	20	2	2	0	1	12	4	0	3	2	19	0
	SB				WB				NB				EB			
	LT	THR	RT	PED	LT	THR	RT	PED	LT	THR	RT	PED	LT	THR	RT	PED
	683	897	1355	4	1412	147	130	6	193	1067	76	1	39	143	633	1
Hourly Volume	67	120	209	2	128	14	17	0	29	94	6	0	4	12	51	0
Peak 15	17	35	60	0	39	8	6	0	8	34	2	0	1	4	17	0
PHF	0.985	0.857	0.871		0.821	0.438	0.708		0.906	0.691	0.750		1.000	0.750	0.750	
		0.904				0.655				0.782				0.833		

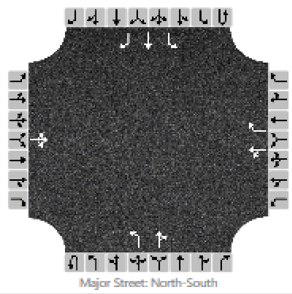
Figure 6.2: Vehicle Classifications

	South Leg Country Club		North Leg Country Club		East Leg Old Walnut		West Leg Oakmont	
Class	# of Vehicles	% of Vehicles	# of Vehicles	% of Vehicles	# of Vehicles	% of Vehicles	# of Vehicles	% of Vehicles
1	51	0.62%	109	0.50%	115	0.98%	28	0.48%
2	3916	47.77%	14855	67.91%	8066	68.62%	3537	60.76%
3	3103	37.85%	4957	22.66%	2497	21.24%	1284	22.06%
4	33	0.40%	82	0.37%	19	0.16%	49	0.84%
5	839	10.23%	1315	6.01%	532	4.53%	613	10.53%
6	19	0.23%	57	0.26%	35	0.30%	11	0.19%
7	1	0.01%	4	0.02%	1	0.01%	0	0.00%
8	98	1.20%	199	0.91%	77	0.66%	17	0.29%
9	2	0.02%	11	0.05%	7	0.06%	0	0.00%
10	0	0.00%	1	0.00%	0	0.00%	0	0.00%
11	0	0.00%	4	0.02%	1	0.01%	0	0.00%
12	2	0.02%	2	0.01%	0	0.00%	0	0.00%
13	0	0.00%	1	0.00%	0	0.00%	0	0.00%
14	134	1.63%	279	1.28%	404	3.44%	282	4.84%
Total	8198		21876		11754		5821	
	Percent Heavy Vehicles							
Heavy	155		361		140		77	
Percent	1.89%		1.65%		1.19%		1.32%	

Figure 6.3: HCS Report for TWSC – No Growth

General Information		Site Information	
Analyst	Kevin Farrell	Intersection	Country CLub Dr
Agency/Co.		Jurisdiction	City of Flagstaff
Date Performed	3/1/2016	East/West Street	Country Club Dr
Analysis Year	2016	North/South Street	Old Walnut Canyon
Time Analyzed		Peak Hour Factor	0.78
Intersection Orientation	North-South	Analysis Time Period (hrs)	0.25
Project Description	No Growth		

Lanes



Vehicle Volumes and Adjustments

Approach	Eastbound				Westbound				Northbound				Southbound			
Movement	U	L	T	R	U	L	T	R	U	L	T	R	U	L	T	R
Priority		10	11	12		7	8	9	1U	1	2	3	4U	4	5	6
Number of Lanes		0	1	0		0	1	1	0	1	1	0	0	1	1	1
Configuration			LTR			LT		R		L		TR		L	T	R
Volume (veh/h)		4	12	51		128	14	17		29	94	6		67	120	209
Percent Heavy Vehicles		2	2	2		2	2	2		2				2		
Proportion Time Blocked																
Right Turn Channelized	No				No				No				No			
Median Type	Left Only															
Median Storage	1															

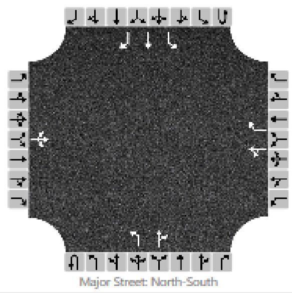
Delay, Queue Length, and Level of Service

Flow Rate (veh/h)			85			182		22		37				86		
Capacity			1015			484		922		1131				1449		
v/c Ratio			0.08			0.38		0.02		0.03				0.06		
95% Queue Length			0.3			1.7		0.1		0.1				0.2		
Control Delay (s/veh)			8.9			16.9		9.0		8.3				7.6		
Level of Service (LOS)			A			C		A		A				A		
Approach Delay (s/veh)	8.9				17.1				1.8				1.3			
Approach LOS	A				C				A				A			

Figure 6.4: HCS Report for TWSC – 2035 Growth

General Information		**Site Information**	
Analyst	Kevin Farrell	Intersection	Country CLub Dr
Agency/Co.		Jurisdiction	City of Flagstaff
Date Performed	3/1/2016	East/West Street	Country Club Dr
Analysis Year	2016	North/South Street	Old Walnut Canyon
Time Analyzed		Peak Hour Factor	0.78
Intersection Orientation	North-South	Analysis Time Period (hrs)	0.25
Project Description	2035 Growth		

Lanes



Vehicle Volumes and Adjustments

Approach	Eastbound				Westbound				Northbound				Southbound			
Movement	U	L	T	R	U	L	T	R	U	L	T	R	U	L	T	R
Priority		10	11	12		7	8	9	1U	1	2	3	4U	4	5	6
Number of Lanes		0	1	0		0	1	1	0	1	1	0	0	1	1	1
Configuration			LTR			LT		R		L		TR		L	T	R
Volume (veh/h)		4	14	65		167	16	19		36	122	6		87	157	274
Percent Heavy Vehicles		2	2	2		2	2	2		2				2		
Proportion Time Blocked																
Right Turn Channelized	No				No				No				No			
Median Type	Left Only															
Median Storage	1															

Delay, Queue Length, and Level of Service

	EB U	EB L	EB T	EB R	WB U	WB L	WB T	WB R	NB U	NB L	NB T	NB R	SB U	SB L	SB T	SB R
Flow Rate (veh/h)			106			235		24		46				112		
Capacity			945			376		882		1012				1407		
v/c Ratio			0.11			0.63		0.03		0.05				0.08		
95% Queue Length			0.4			4.1		0.1		0.1				0.3		
Control Delay (s/veh)			9.3			29.3		9.2		8.7				7.8		
Level of Service (LOS)			A			D		A		A				A		
Approach Delay (s/veh)	9.3				29.3				1.9				1.3			
Approach LOS	A				D				A				A			

Figure 6.5: Rodel Interactive Report for Roundabout - Current

	Approach Geometry						Entry Geometry					Circ Geom			Exit Geometry				Entry Capacity Mods	
	Leg Name	•	Bearing	G	V	n	E	n	L'	R	Φ	D	C	n	Ex	n	Vx	n	-+ Cap (v/h)	Xwalk Fact
1	Northbound	Y	0	0	12.00	1	14.00	1	100.00	85.00	38.00	110.00	16.00	1	16.00	1	12.00	1	0	1.000
2	Eastbound	Y	90	0	12.00	1	14.00	1	90.00	47.00	42.00	110.00	16.00	1	16.00	1	12.00	1	0	1.000
3	Southbound	Y	180	0	12.00	1	14.00	1	85.00	51.00	38.00	110.00	16.00	1	15.00	1	12.00	1	0	1.000
4	Westbound	Y	270	0	12.00	1	14.00	1	100.00	56.00	39.00	110.00	16.00	1	15.00	1	12.00	1	0	1.000

	Volume Modifiers			Turning Volumes (veh/hr)							Arrival Volume Ratios			Arrival Volume Times (min)			PHF
	Leg Name	%Truck	Factor			U-Turn	Exit-3	Exit-2	Exit-1	Bypass	Ratio1	Ratio2	Ratio3	Time1	Time2	Time3	
1	Northbound	5.0	1.00			0	6	94	0	29							0.78
2	Eastbound	5.0	1.00			0	51	12	4	0							0.81
3	Southbound	5.0	1.00			0	209	120	87	0							0.90
4	Westbound	5.0	1.00			0	17	14	0	128							0.63

Calibration | Accidents | Economics | Bypass | Run

	Peak 60min Results	Bypass Type	Flow Rate (veh/hr)		Opp Rate (veh/hr)		Capacity (veh/hr)		Ave VCR		Ave Del (sec/veh)			Max Q (veh)		Max Q95% (veh)		LOS A-F		
			Entry	Bypass	Entry	Bypass	Entry	Bypass	Entry	Bypass	Entry	Bypass	Leg	Entry	Bypass	Entry	Bypass	Entry	Byp	Leg
1	Northbound	Free	100	29	240	0	953	1264	0.1091	0.0236	3.94	0.00	3.05	0.15	0.00	0.40	0.00	A	A	A
2	Eastbound	None	67		117		971		0.0711		3.72		3.72	0.09		0.24		A		A
3	Southbound	None	416		69		1015		0.4168		5.48		5.48	0.77		1.99		A		A
4	Westbound	Free	31	128	380	0	860	1264	0.0410	0.1129	4.05	0.00	0.79	0.06	0.00	0.16	0.00	A	A	A
All	Intersection												3.95							A

Figure 6.6: Rodel Interactive Report for Roundabout – 2035 Grown

	Approach Geometry						Entry Geometry					Circ Geom			Exit Geometry				Entry Capacity Mods	
	Leg Name	•	Bearing	G	V	n	E	n	L'	R	Φ	D	C	n	Ex	n	Vx	n	-+ Cap (v/h)	Xwalk Fact
1	Northbound	Y	0	0	12.00	1	14.00	1	100.00	85.00	38.00	110.00	16.00	1	16.00	1	12.00	1	0	1.000
2	Eastbound	Y	90	0	12.00	1	14.00	1	90.00	47.00	42.00	110.00	16.00	1	16.00	1	12.00	1	0	1.000
3	Southbound	Y	180	0	12.00	1	14.00	1	85.00	51.00	38.00	110.00	16.00	1	15.00	1	12.00	1	0	1.000
4	Westbound	Y	270	0	12.00	1	14.00	1	100.00	56.00	39.00	110.00	16.00	1	15.00	1	12.00	1	0	1.000

	Volume Modifiers			Turning Volumes (veh/hr)							Arrival Volume Ratios			Arrival Volume Times (min)			PHF
	Leg Name	%Truck	Factor			U-Turn	Exit-3	Exit-2	Exit-1	Bypass	Ratio1	Ratio2	Ratio3	Time1	Time2	Time3	
1	Northbound	5.0	1.00			0	6	122	0	36							0.78
2	Eastbound	5.0	1.00			0	65	14	4	0							0.81
3	Southbound	5.0	1.00			0	274	157	87	0							0.90
4	Westbound	5.0	1.00			0	19	16	0	167							0.63

Calibration | Accidents | Economics | Bypass | Run

	Peak 60min Results	Bypass Type	Flow Rate (veh/hr)		Opp Rate (veh/hr)		Capacity (veh/hr)		Ave VCR		Ave Del (sec/veh)			Max Q (veh)		Max Q95% (veh)		LOS A-F		
			Entry	Bypass	Entry	Bypass	Entry	Bypass	Entry	Bypass	Entry	Bypass	Leg	Entry	Bypass	Entry	Bypass	Entry	Byp	Leg
1	Northbound	Free	128	36	309	0	918	1264	0.1454	0.0292	4.25	0.00	3.32	0.21	0.00	0.56	0.00	A	A	A
2	Eastbound	None	83		147		956		0.0895		3.85		3.85	0.12		0.31		A		A
3	Southbound	None	518		85		1007		0.5245		6.60		6.60	1.20		3.06		A		A
4	Westbound	Free	35	167	496	0	801	1264	0.0500	0.1473	4.40	0.00	0.76	0.07	0.00	0.19	0.00	A	A	A
All	Intersection												4.59							A

Figure 6.7: Roundabout Circulation Plaque (R6-5P)

Figure 6.8: Keep Right Plaque (R4-7)

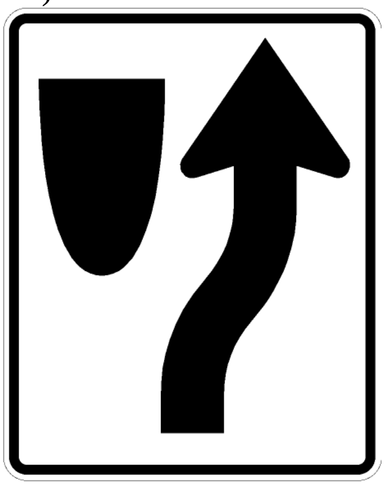


Figure 6.9: Right Turn Only Plaque (R3-5R)

Figure 6.10: One Way Plaque (R6-1R)

Figure 6.11: Yield Plaque (R1-2)

Figure 6.12: Yield Ahead (W3-2)

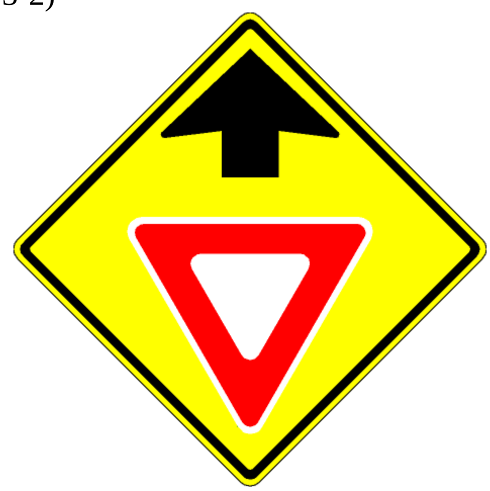


Figure 6.13 – Billing Rate and Hours Spent on the Design Project

Classification	Senior Engineer	Engineer	Field Technician	Engineering Intern	Administrative Assistant
Base Pay	$ 80	$ 40	$ 30	$ 18	$ 20
Real Cost	$ 125	$ 65	$ 50	$ 20	$ 35
Billing Rate	$ 140	$ 70	$ 55	$ 20	$ 35
Tasks					
Data Collection	4	8	1	6	3
Roadway Design Guidelines	3	5	0	4	2
Data Analysis	3	6	1	5	3
Site Design	19	33	3	27	15
Economics	6	10	1	8	5
Project Management	20	36	3	29	16
Total Hours	55	98	8	79	45
Total Billing Rate	$ 7,760	$ 6,871	$ 466	$ 1,586	$ 1,563
Total cost of Project	**$ 18,245**				

Figure 6.14: Cost Benefit due to Reduction in Delay Time

Year	AADT	Passenger Vehicles	Trucks	Passenger Vehicle Value of Time ($/hr)	Value of Time for Truck ($/hr)	Passenger Vehicle Value of Time ($/sec)	Value of Time for Truck ($/sec)	TWSC Average Delay Time (s/veh)	Roundabout Average Delay Time (s/veh)	Cost of Delay TWSC ($)	Cost of Delay Roundabout ($)
2015	13550	12084	1466	12.30	25.40	0.0034	0.0071	9.50	3.82	490.49	197.23
2016	13740	12253	1487	12.67	26.16	0.0035	0.0073	9.73	3.86	524.41	215.16
2017	13932	12425	1507	13.05	26.95	0.0036	0.0075	9.90	3.88	557.56	225.84
2018	14127	12599	1528	13.44	27.76	0.0037	0.0077	10.05	3.92	591.15	238.81
2019	14325	12775	1550	13.84	28.59	0.0038	0.0079	10.30	3.95	632.77	251.26
2020	14525	12954	1572	14.26	29.45	0.0040	0.0082	10.63	3.98	681.73	264.99
2021	14729	13135	1594	14.69	30.33	0.0041	0.0084	10.95	4.01	733.79	278.77
2022	14935	13319	1616	15.13	31.24	0.0042	0.0087	11.30	4.04	790.88	293.96
2023	15144	13506	1638	15.58	32.18	0.0043	0.0089	11.80	4.09	862.56	310.67
2024	15356	13695	1661	16.05	33.14	0.0045	0.0092	12.15	4.12	927.60	327.52
2025	15571	13886	1685	16.53	34.14	0.0046	0.0095	12.70	4.16	1012.65	345.26
2026	15789	14081	1708	17.03	35.16	0.0047	0.0098	13.28	4.20	1105.52	364.76
2027	16010	14278	1732	17.54	36.21	0.0049	0.0101	13.98	4.24	1215.51	385.31
2028	16234	14478	1756	18.06	37.30	0.0050	0.0104	14.75	4.28	1339.91	406.06
2029	16462	14681	1781	18.60	38.42	0.0052	0.0107	15.75	4.33	1494.30	429.79
2030	16692	14886	1806	19.16	39.57	0.0053	0.0110	16.98	4.37	1682.07	452.85
2031	16926	15094	1831	19.74	40.76	0.0055	0.0113	18.38	4.43	1901.67	479.17
2032	17163	15306	1857	20.33	41.98	0.0056	0.0117	21.20	4.48	2291.50	506.94
2033	17403	15520	1883	20.94	43.24	0.0058	0.0120	23.75	4.53	2681.16	536.23
2034	17647	15737	1909	21.57	44.54	0.0060	0.0124	26.93	4.57	3174.61	567.13
2035	17894	15958	1936	22.22	45.88	0.0062	0.0127	32.40	4.59	3989.83	565.23
									Total	28681.67	7642.93
									Saving in cost of delay		21038.74

Figure 6.15: Cost Benefit due to reduction in Crashes

Step A

Total crashes/ year= (exp(-1.62))$(AADT)^{0.22}$

Total crashes/ year= (exp(-1.62))$(13550)^{0.22}$= 1.6049

Injury crashes/ year= (exp(-3.04))$(AADT)^{0.22}$

Injury crashes/ year= (exp(-3.04))$(13550)^{0.22}$= 0.3879

Calculation of weights and EB estimate:

Total crashes:

$$w_1 = \frac{P}{\left(\frac{1}{k}\right)+np} = \frac{1.6049}{\left(\frac{1}{0.24}\right)+14(1.6049)} = 0.06025$$

$$w_2 = \frac{(\frac{1}{k})}{\left(\frac{1}{k}\right)+np} = \frac{(\frac{1}{0.24})}{\left(\frac{1}{0.24}\right)+14(1.6049)} = 0.156$$

m= w_1x+ w_2 P= (0.062025)(47)+ (0.156)(1.6049)= 3.166 total crashes/ year

Injury crahses:

$$w_1 = \frac{P}{\left(\frac{1}{k}\right)+np} = \frac{0.3879}{\left(\frac{1}{0.24}\right)+14(0.3879)} = 0.0404$$

$$w_2 = \frac{(\frac{1}{k})}{\left(\frac{1}{k}\right)+np} = \frac{(\frac{1}{0.24})}{\left(\frac{1}{0.24}\right)+14(0.3879)} = 0.43415$$

m= w_1x+ w_2 P= (0.0404)(10)+ (0.43415)(1.6049)= 1.1 injury crashes/ year

Volumes are expected to increase in the after period, an adjustment factor need to be calculated a follows:

$$\frac{(AADT\ After\ )^{0.22}}{(AADT\ before)^{0.22}} = (13740\ )^{0.22}/(13550)^{0.22}= 1.003$$

The adjustment m, using this factor is now equal to:

3.166 * 1.003 = 3.176 for total crashes

1.1 *1.003 = 1.1033 for injury crashes

The estimated number of total crashes per year if a conversion does not take place is 3.176 total crashes per year, and 1.1 injury crashes per year.

Step B

Calculating the expected annual number of crashes after converting the intersection to a Roundabout intersection

Total crashes= 3.176 (78.2//100)= 2.94

Injury crashes= 1.1033 (80.3/100)= 0.886

Step C

The expected reduction in PDO accidents= 2.94-0.886= 2.054

Annual economic benefit = (0.866)($298000)+(2.054)($21000) = **$307162**