FL Consultants

Pawnee Nation Intersection of Agency and Heritage Circle

Final Report

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1. Team Information

Overall, four members were assigned to work on this project. Each team member and their description are listed below.

1.1. Team Members

Dalton Wiseman is a senior majoring in civil engineering at Oklahoma State University. He grew up in Edmond, Oklahoma. From previous internships, he has experience in transportation, hydrology, and hydraulics. He also completed multiple survey internships. He plans to use the knowledge he has learned from these internships to complete this project. After graduation, he plans to stay in Oklahoma and work for Crossland Heavy Contractors as a Field Engineer.

Nathan Brooks is a senior majoring in civil engineering at Oklahoma State University. He grew up in Plano, Texas and is in his final semester studying civil engineering. After graduation, he plans to work with Kimley-Horn as a roadway design / traffic engineer-in-training. He did a combination of both subjects over summer 2021 in an internship with this company, and the knowledge gained from this experience benefits the scope and subject of this senior design project. Nathan has developed attention to detail, MicroStation, AutoCAD, and other industry-standard program skills, team communication skills, and organization pertaining to large projects.

Hussain Al Lashit is a senior majoring in civil engineering at Oklahoma State University. He grew up in a small town in Saudi Arabia called Qatif. He came to the United States in 2016. He started to learn English before enrolling in Oklahoma State University. He enrolled in Oklahoma State University in spring 2018 and will be graduating this semester. Hussain has gained experience from previous classes that could contribute towards completing the objective of this project such as working with AutoCAD. Hussain developed his skills using Microsoft Office during his time in the university. After graduation, he plans to go back to Saudi Arabia to work at the ministry of transportation as a railroad engineer.

Chenwei Huang is a senior majoring in civil engineering at Oklahoma State University. He grew up in Suzhou, China before moving to the United States in 2008. Upon graduation, he plans to attend graduate school at an out of state institution with the goal of obtaining a Master of Science degree in transportation engineering. While at OSU, he worked on several transportation engineering projects as an undergraduate research assistant. Specifically, he got to work on a project about autonomous vehicles (AVs), where he used the PTV VISSIM microscopic simulator to evaluate the impact of AVs on traffic mobility. This past year, he attended two transportation research conferences to present his research work. In addition, he also wrote a conference paper about the project. Overall, the research experience has enhanced his problem solving, analytical, and communication skills. He believes these traits will be a necessary component to his senior design project.

2. Project Problem Statement and Project Proposal

Based on the information provided by the initial project description, the team came up with a description of the problem occurring at the intersection of Agency Road and Heritage Circle in Pawnee Nation. Furthermore, a meeting was held with the project client, Mr. Chris McCray, to develop potential solutions to the problem. The problem description and project proposal are discussed below.

2.1. Problem Description

The intersection of Agency Road and Heritage Circle in Pawnee Nation has caused problems for vehicle movements. Specifically, since both roads meet each other in a curve, vehicles must make a sharp 90 degree turn onto Agency Road. Moreover, Heritage Circle is an entrance to Pawnee Nation. Thus, many drivers use the road to enter the tribe. The Pawnee Indian Health center is also located on Heritage Circle, so many elderly drivers also use the road to get to the clinic. Therefore, both elderly drivers and larger trucks have high difficulties in making the turn at the intersection. To alleviate the problem, the intersection must be redesigned and realigned. Ultimately, the goal is to design an intersection that provides safety and efficiency for drivers traveling through the area. Figure 1 depicts a map of the intersection and its geometry.

Figure 1: Satellite view of Agency Rd. and Heritage Circle Intersection

2.2. Team Project Proposal

During the meeting with Pawnee Nation's Transportation & Safety Manager Mr. Chris McCray, several designs to the intersection were discussed. More exactly, a roundabout or a Y-intersection were the preferred method for the design.

Furthermore, there was discussion to straighten the curved section on the southbound approach of Agency Road. A vehicle general flow report was also obtained, which gave the team a grasp of the traffic and speed flows passing through the intersection. The site visit allowed the team to survey the area and develop a better understanding of the problem. As a result, the team was able to gain a deeper insight into designs that would provide optimal safety and efficiency at the intersection. It was decided that a roundabout is the best solution for redesign.

2.3. Contact Information for Client

- Chris McCray
  Transportation & Safety Manager
  (918) 762-3655 (Office)
  cmccray@pawneenation.org

- Sky Gawhega
  Planning and Development Coordinator
  (918) 762-3621 (Office)
  sg0195@pawneenation.org

3. Applicable Codes and Standards

The following are the codes and standards the team used for the redesign of the intersection.

- ODOT 2009 Traffic Engineering Standards & Specifications
  - T-501 Traffic Control Construction Notes
  - T-508-520 Construction Signs
  - T-521 Construction Zone Pavement Markings
  - T-612 Centerline Rumble Strip (Non-interstate system only)
- ODOT 2009 Roadway Design Standards & Specifications
  - R-11 Asphalt Surfacing Construction Details
  - R-20 Pavement Edge Drain
  - R-21 Pavement Safety Edge
  - R-70 Superelevation
  - R-71 Superelevation Tables (low speed urban streets)
  - R-72 Superelevation Tables (e max = 6%)
  - R-73 Superelevation Tables (e max = 8%)
- ODOT 2014 Roadway Drainage Manual
- AASHTO Policy on Geometric Design of Highways and Streets 2018 ed.
  - Chapter 9 Intersections
    - Table 9-3 Roundabout designs
- Roundabouts: An Informational Guide 1st Edition
- Roundabouts: An Informational Guide 2nd Edition
- TxDOT 2020 Roadway Design Manual

4. Project Constraints

While at the site, there were several constraints discovered for the redesign of the intersection. The project constraints are described below.

4.1. Utilities

Although utilities such as sanitary sewers, waterlines, and storm water sewer could be moved to accommodate the redesign of the intersection, several utilities discovered at the site have a higher difficulty of being moved. Specifically, fiber-optic cables are a utility that is difficult to move. They are often privately-owned, expensive to replace or move, and require time-consuming clearances. Therefore, it will be in the team's best interest to avoid them, because there is enough space for our purposes. Power lines will likely have to be moved to create space, as the existing ones are close to the edge of the existing pavement. This is easier to move than fiber-optic cables or gas lines. Figure 2 shows the existing power line arrangement near the intersection.

Figure 2: Power line arrangement at the intersection

4.2. Drainage Ditches

The client has expressed his wishes that the drainage ditches should not be altered and must remain in place. The cost of altering the drainage ditch will be costly, not to mention the process of its environmental clearance. It may also affect the efficacy of the culverts in the ditch area. Figure 3 shows the existing drainage structure at the intersection.

Figure 3: Existing drainage structure at the intersection

4.3. Traffic Control Plan

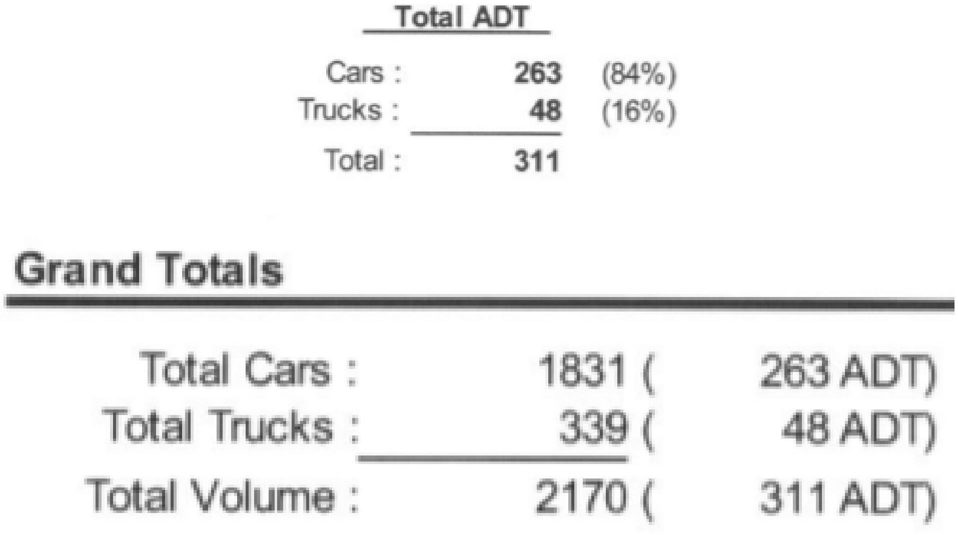
Traffic flow must be maintained throughout the construction process. This will either be done by creating an alternative detour route or by shifting traffic to one side of the site and then the other. However, this can cause problems. Specifically, creating a detour route would cause unfamiliarity to people that plan to visit Pawnee Nation. Moreover, shifting traffic to one lane can cause several issues. Due to the narrow lane width on the road, larger vehicles such as trucks and school buses will face difficulty in driving past the work zone. In addition, traffic delays at the construction site will occur.

5. Summary of Data Gathered and Analyzed

During both the virtual meeting and the site visit, both the traffic information and the 2002 Plan of Proposed Roadway Improvements containing surveying data for the intersection were provided by the client. This section highlights the traffic and survey data that was obtained.

5.1. Traffic Data

During the first virtual meeting, the client was able to provide information about the traffic data at the intersection. Figure 4 highlights the Total ADT and Grand Total Volumes that were observed at the intersection. Furthermore, Figure 5 shows a copy of the vehicle general flow report that was obtained. As shown in the report, the average daily traffic (ADT), speed totals, peak hour totals, and grand totals were collected at the intersection. The ADT data shows that the intersection experienced busier traffic during the weekdays than the weekends. Based on the grand vehicle totals, it can be inferred that smaller vehicles frequented the intersection more than larger vehicles. Furthermore, from the speed totals data, trucks drove past the intersection at a higher speed than cars. This could be attributed to the low volume of trucks observed at the intersection. Moreover, many Pawnee Nation facilities are located on Heritage Circle. As a result, to get to these facilities, a large volume of cars (including elderly drivers) reduced their speed to make turning movements onto Heritage Circle. Ultimately, this resulted in a lower speed average for cars.



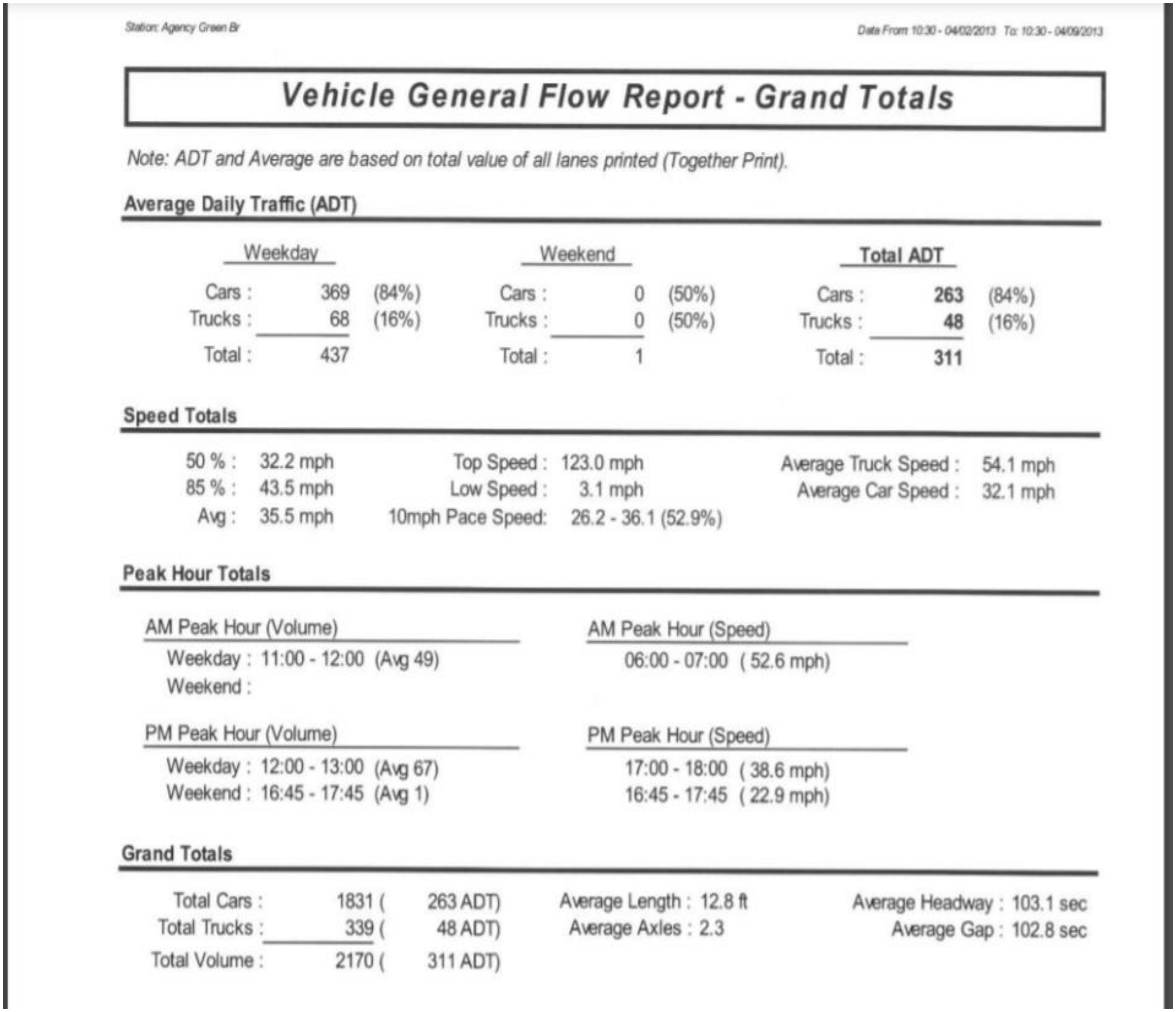
Total ADT

Cars :	**263**	(84%)
Trucks :	**48**	(16%)
Total :	**311**	

Grand Totals

Total Cars :	1831 (	263 ADT)
Total Trucks :	339 (	48 ADT)
Total Volume :	2170 (	311 ADT)

Figure 4: Total ADT and Grand Total Volumes from Vehicle General Flow Report



Station: Agency Green Br

Data From 10:30 - 04/02/2013 To: 10:30 - 04/09/2013

Vehicle General Flow Report - Grand Totals

Note: ADT and Average are based on total value of all lanes printed (Together Print).

Average Daily Traffic (ADT)

Weekday			Weekend			**Total ADT**		
Cars :	369	(84%)	Cars :	0	(50%)	Cars :	**263**	(84%)
Trucks :	68	(16%)	Trucks :	0	(50%)	Trucks :	**48**	(16%)
Total :	437		Total :	1		Total :	**311**	

Speed Totals

50 % : 32.2 mph
85 % : 43.5 mph
Avg : 35.5 mph

Top Speed : 123.0 mph
Low Speed : 3.1 mph
10mph Pace Speed: 26.2 - 36.1 (52.9%)

Average Truck Speed : 54.1 mph
Average Car Speed : 32.1 mph

Peak Hour Totals

AM Peak Hour (Volume)
Weekday : 11:00 - 12:00 (Avg 49)
Weekend :

AM Peak Hour (Speed)
06:00 - 07:00 (52.6 mph)

PM Peak Hour (Volume)
Weekday : 12:00 - 13:00 (Avg 67)
Weekend : 16:45 - 17:45 (Avg 1)

PM Peak Hour (Speed)
17:00 - 18:00 (38.6 mph)
16:45 - 17:45 (22.9 mph)

Grand Totals

Total Cars :	1831 (	263 ADT)
Total Trucks :	339 (	48 ADT)
Total Volume :	2170 (	311 ADT)

Average Length : 12.8 ft
Average Axles : 2.3

Average Headway : 103.1 sec
Average Gap : 102.8 sec

Figure 5: Traffic data collected at the intersection from Vehicle General Flow Report

5.2. Survey Data

During the site visit at Pawnee Nation, the client was able to provide the team with a plan set for the initial construction of the intersection. Figure 6 shows a plan view of accurate elevation points at the intersection. Moreover, the figure also shows culverts, underground electric lines, power lines, power poles, past pavement, radius of curves, centerlines, stationing, and general location information. It will be immensely useful to the team in producing viable alternatives as far as workable area and constraints go in a detailed manner.

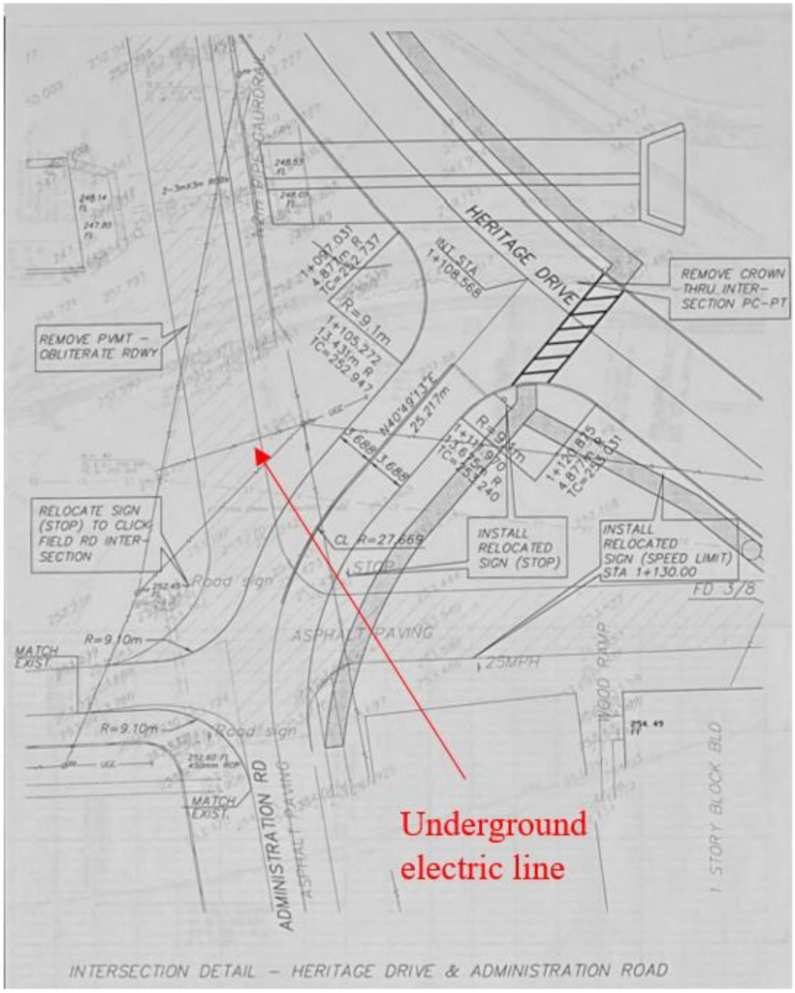


Figure 6: Plan view of intersection from Pawnee Nation's Roadway Plan Set

Figure 7 shows a profile view of Heritage Circle along the centerline as well as a broader view of the study area. It provides detailed stationing, elevations, and by extension, relative distances. This will be useful in planning out alternatives that take up more space and need consideration further down each affected road.

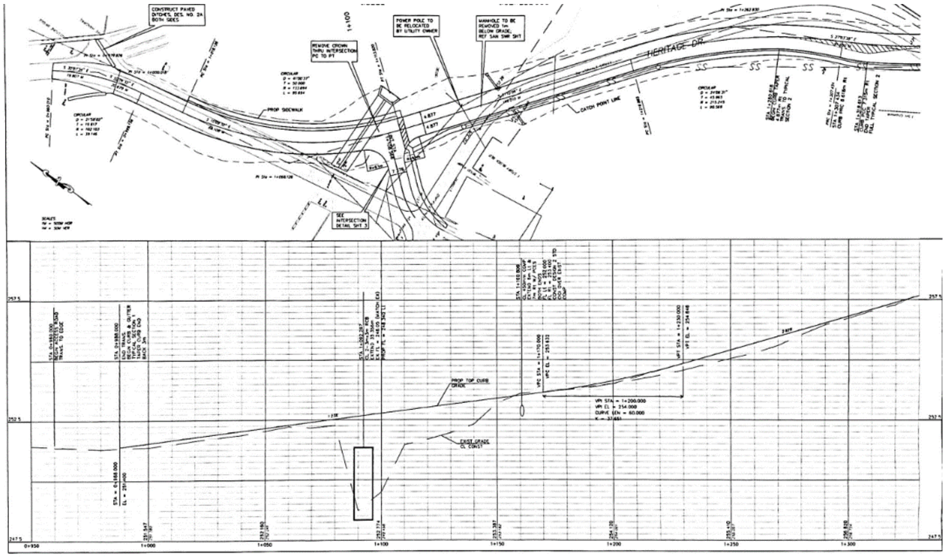


Figure 7: Profile view of Heritage Circle from Pawnee Nation's Roadway Plan Set

5.3. Utility Lines

Based on the third page of the plan set, the arrangement of several utility lines around the intersection were provided. Specifically, the arrangement of power poles, power lines, and sanitary sewers are shown in Figure 8. Furthermore, the underground electric lines are shown in Figure 6. Based on the figure, it can be seen that the power lines and poles are crossing the intersection, creating some challenges in the redesign of the intersection. It can also be seen that the sanitary sewers are located near the intersection. However, since they are built below the ground, they would not interfere with the redesign.

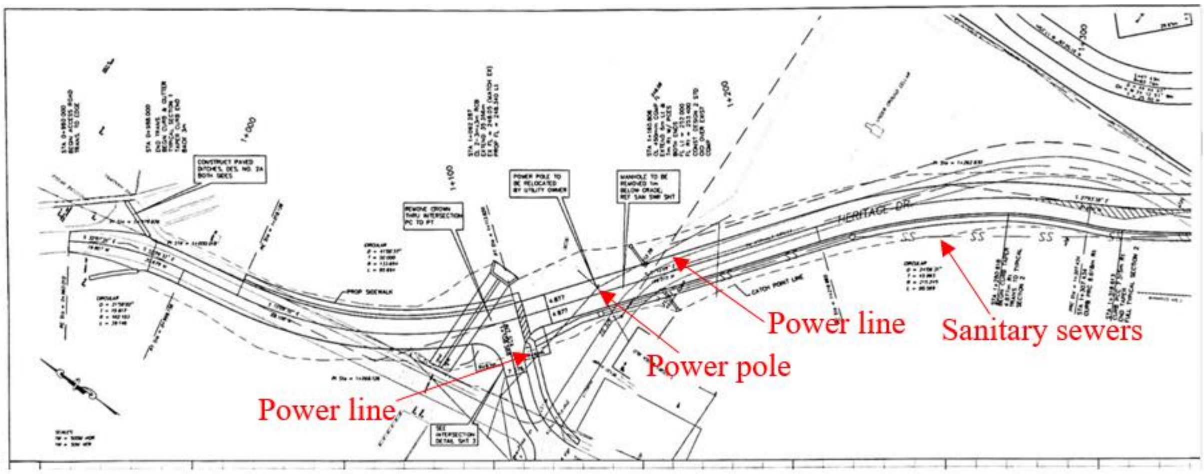


Figure 8: Utility lines in profile view of Heritage Circle from Pawnee Nation's Plan Set

6. Alternatives Analysis

Through both a discussion with the client and deliberation among the team, three alternatives were proposed for the redesign of the intersection. The following discusses these alternatives.

6.1. Roundabout

The first alternative proposed is a roundabout design at the intersection. Specifically, the intersection will consist of a single lane roundabout running from both roads. This option would allow both large and smaller vehicles to operate at lower speeds with improved safety. At the same time, both vehicle to vehicle and vehicle to pedestrian conflict points will be reduced at the intersection. With a smooth circular curved design of the roundabout, both larger trucks and elderly drivers will not have to make sharp abrupt turns. Moreover, this option eliminates the possibility of stop and go traffic, reducing vehicle pollution. In addition to the geometric design, a center island with a 110-ft diameter inscribed circle will be designed to accompany green space and landscaping opportunities. More exactly, a symbolization of Pawnee Nation will be placed on the center island to represent entrance to the tribe. Figure 9 shows a sketch of the planned roundabout design at the intersection.

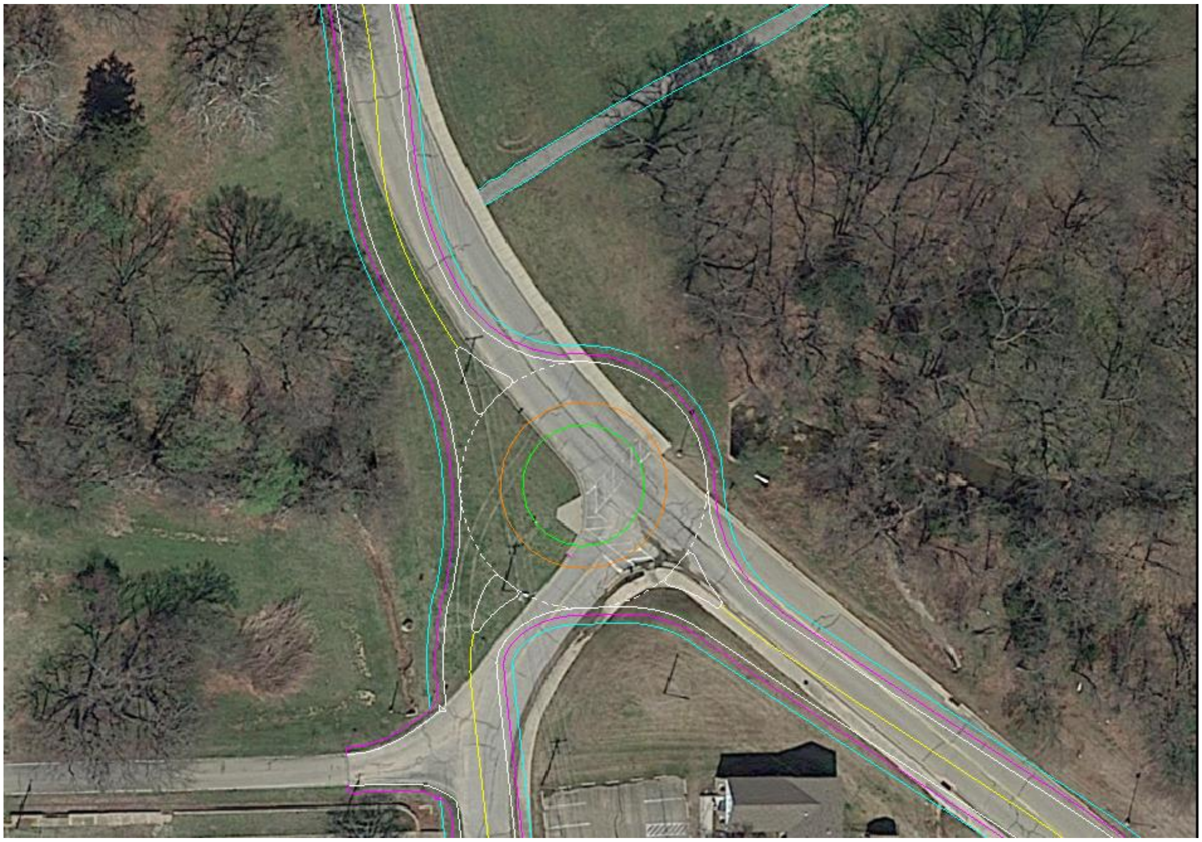


Figure 9: Roundabout design at the intersection

6.2. Y-Intersection

The second alternative proposed is a Y-intersection design. To successfully complete this design, the agency road will be straightened out first. Designing a Y-intersection will fix the main problem of this project, which is having a very sharp right turn (90' turn). The new intersection consists of a smooth right turn, which will allow elderly drivers and trucks to turn easily to the Heritage Circle. In addition, the new Y-intersection design will provide more safety for elderly drivers and trucks as well as decreasing the probability of car accidents. Moreover, a Y-intersection sign will be placed in order to inform drivers of the coming turn. Figure 10 shows a sketch of the planned Y-intersection design at the intersection.

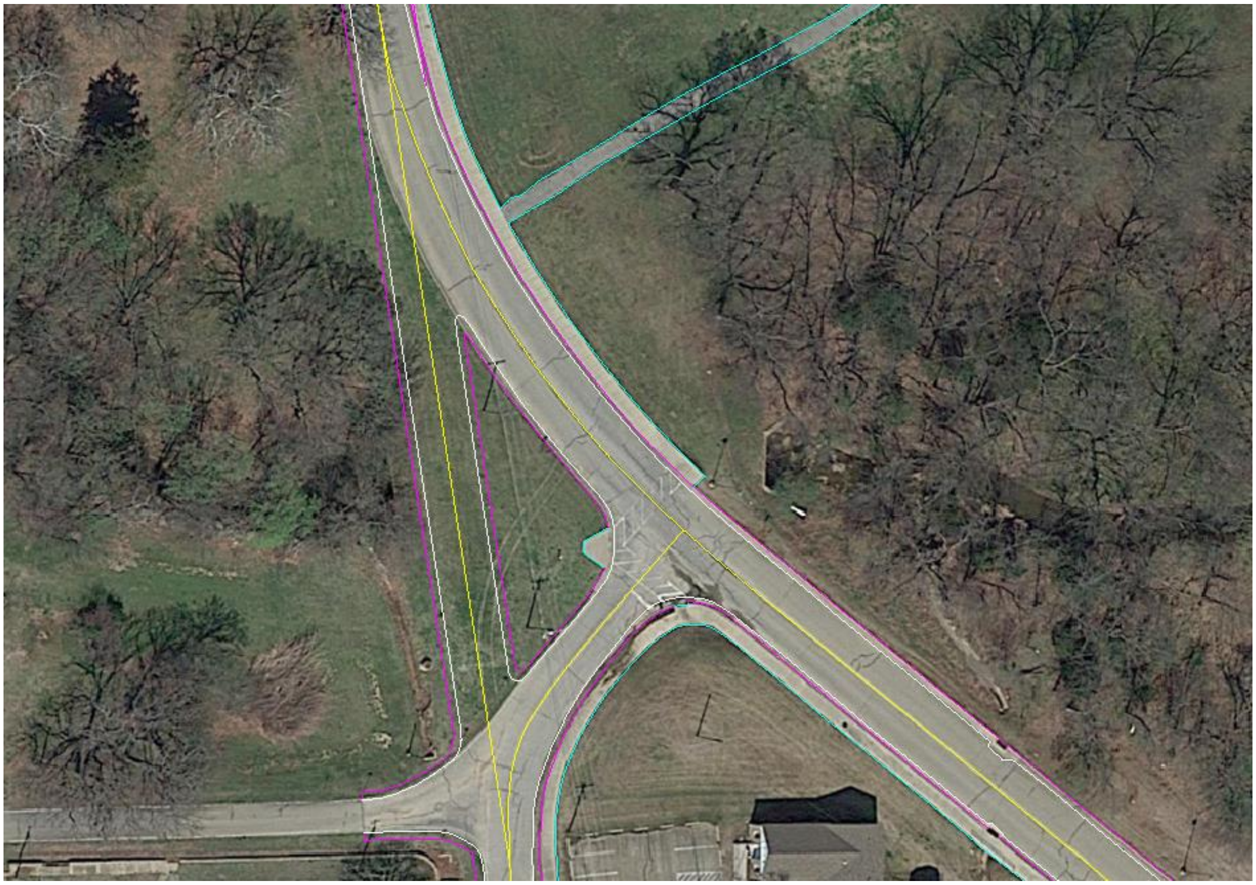


Figure 10: Y-Intersection design at the intersection

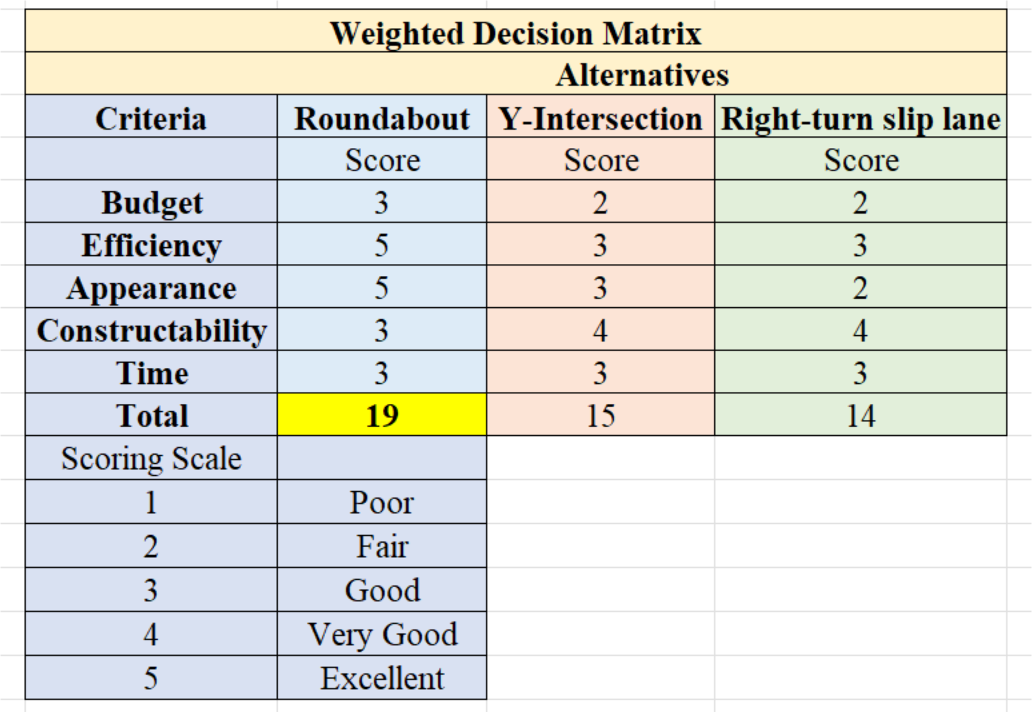
6.3. Right-Turn Slip Lane

The third alternative proposed is to add a right-turn slip lane on Agency Road. A corner island will be placed on the intersection to separate the right turn movements from through movements on Agency Road. A compound radius will be designed for the right turn lane. This will increase sight visibility and allow vehicles to operate at slower but safer speeds. Furthermore, vehicles will be able to make smoother turns with this design. A right turn sign will be also added at the intersection to make drivers aware of the right-turn slip lane. Ultimately, having this design will allow drivers, specifically elderly drivers, to have an easier time in making right turns. Figure 11 shows a sketch of the planned right-turn slip lane design at the intersection.

Figure 11: Right-turn slip lane design at the intersection

6.4. Decision Matrix

To determine which design was the best alternative for the redesign of the intersection, a decision matrix was created. A total of five criteria were used to evaluate the alternatives. These criteria were budget, efficiency, appearance, constructability, and time. An equal weighting scale was assigned to each criterion. Furthermore, a scoring scale from 1 to 5 was used to score the criteria under each alternative. The final score was computed by summing all the weighted total score under each criterion. The alternative with the highest score was determined to be the winner. Based on the results, it was determined that the roundabout was the preferred alternative. Figure 12 shows the decision matrix and the results.



Weighted Decision Matrix			
	Alternatives		
Criteria	**Roundabout**	**Y-Intersection**	**Right-turn slip lane**
	Score	Score	Score
Budget	3	2	2
Efficiency	5	3	3
Appearance	5	3	2
Constructability	3	4	4
Time	3	3	3
Total	**19**	15	14
Scoring Scale			
1	Poor		
2	Fair		
3	Good		
4	Very Good		
5	Excellent		

Figure 12: Decision Matrix

7. Description of Selected Approach

After a thorough discussion with the client about the possible alternatives, the client has expressed his desires to implement a roundabout design for the intersection. The team has also decided to choose this design because it provides the best benefits among the three designs. Specifically, the roundabout will provide the highest likelihood for both the elderly and truck drivers to operate at lower speeds, which would improve safety at the intersection.

Unlike the Y-Intersection and Right-turn slip lane, the roundabout design will be able to limit accidents more effectively due to a reduction in vehicle to vehicle and vehicle to pedestrian conflict points. Furthermore, the design will increase sight visibility for the drivers because it will be able to illuminate lighting at roads upstream. In addition to the benefits it provides, the roundabout design was chosen because it provides the best sustainability. For example, the center island of the design will bring landscaping opportunities for Pawnee Nation. Moreover, the roundabout will reduce vehicle pollutant emissions and stop delays through its no stop traffic.

Ultimately, the cost played a significant role in choosing the roundabout design. Although the roundabout design will be the most expensive among the intersection designs, the client has informed the team that the roundabout will be able to be funded through FHWA. Thus, funding is not expected to hinder the design.

8. Summary of Engineering Design and Analysis

A detailed engineering design and analysis was performed to construct the roundabout. The main roundabout design was performed using transportation engineering principles. In addition, hydrologic and hydraulic principles were used to design drainage systems.

8.1. Roundabout Design using Transportation Engineering Principles

To design the roundabout, MicroStation GEOPAK V8i (MicroStation) was used as the design software. Based on the field traffic volumes observed at the intersection, the roundabout was designed as an urban single lane roundabout. Furthermore, due to a grand total of 311 ADT observed from Pawnee Nation's General Vehicle Flow Report, a Level of Service A was assumed at the intersection. The team has selected WB-50 (WB-15) as the design vehicle since it is considered the largest vehicle along urban collectors and arterials. Overall, NCHRP Report 672's Roundabouts: An Informational Guide Second Edition was used throughout the design process. To design the roundabout, the basic geometric features of a roundabout were observed. Specifically, the team utilized Exhibit 6-2 from the NCHRP Report 672 to develop a basis for the minimum geometric features that should be included in the roundabout. Figure 13 provides the geometric elements of a roundabout.

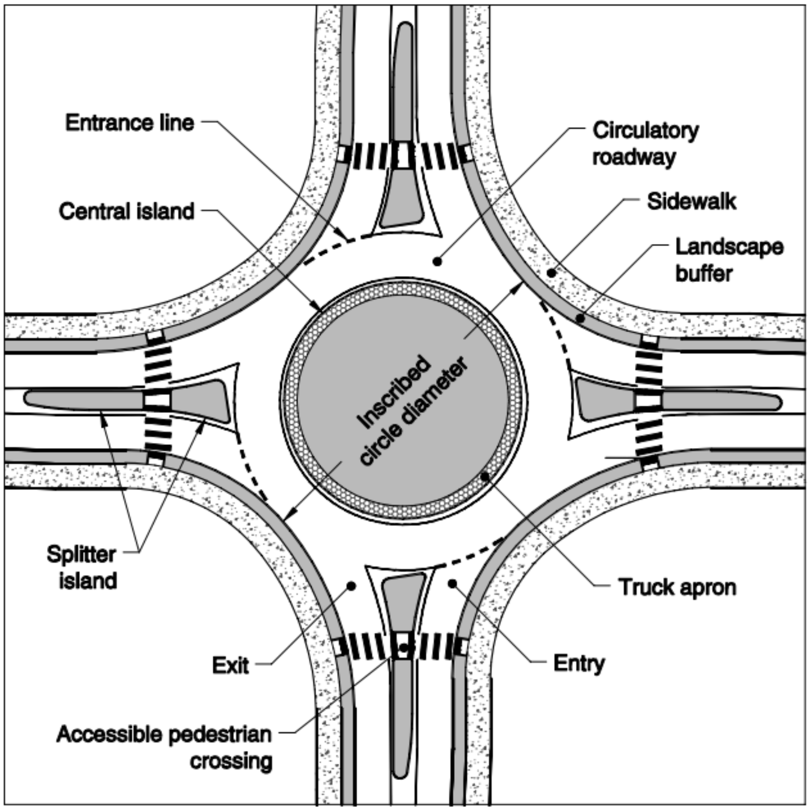
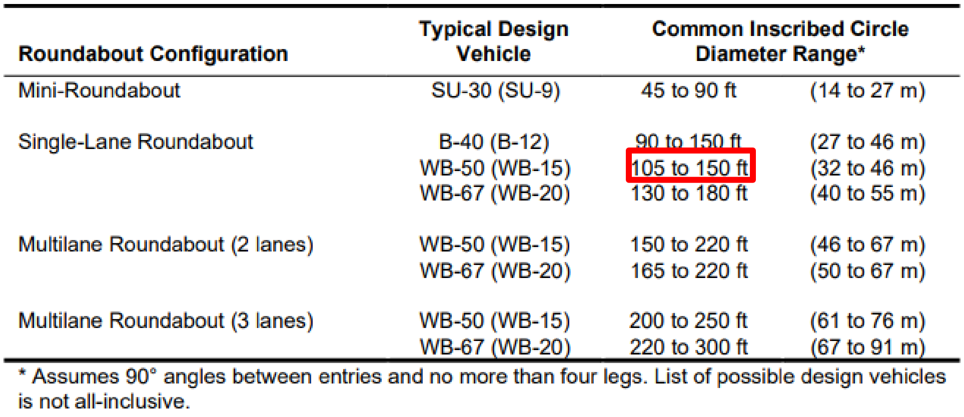


Figure 13: Minimum geometric features of a roundabout as specified by NCHRP Report 672

After taking note of the geometric features needed for a roundabout, the team selected the inscribed circle diameter based on the roundabout configuration and typical design vehicle. Figure 14 provides a table of common inscribed circled diameter ranges.



Roundabout Configuration	Typical Design Vehicle	Common Inscribed Circle Diameter Range*	
Mini-Roundabout	SU-30 (SU-9)	45 to 90 ft	(14 to 27 m)
Single-Lane Roundabout	B-40 (B-12)	90 to 150 ft	(27 to 46 m)
	WB-50 (WB-15)	105 to 150 ft	(32 to 46 m)
	WB-67 (WB-20)	130 to 180 ft	(40 to 55 m)
Multilane Roundabout (2 lanes)	WB-50 (WB-15)	150 to 220 ft	(46 to 67 m)
	WB-67 (WB-20)	165 to 220 ft	(50 to 67 m)
Multilane Roundabout (3 lanes)	WB-50 (WB-15)	200 to 250 ft	(61 to 76 m)
	WB-67 (WB-20)	220 to 300 ft	(67 to 91 m)

* Assumes 90° angles between entries and no more than four legs. List of possible design vehicles is not all-inclusive.

Figure 14: Common Inscribed Circle Diameter Ranges specified by NCHRP Report 672

Since a single-lane roundabout and WB-50 (WB-15) was chosen as the configuration and design vehicle respectively, the team decided to use a minimum diameter of 105 feet for the design. Subsequently, the team chose to align the roundabout approaches through the center of the inscribed circle. Specifically, the team believes this will provide many advantages at the intersection. For example, it will allow elderly and truck drivers to navigate through the exit at slower speeds. Ultimately, this would bring increased safety and caution at the intersection. Furthermore, the team has also chosen perpendicular legs for the angular design between the approach legs because it provides slow and consistent vehicular speeds at the roundabout, which would be very suitable for elderly and truck drivers.

Based on Section 6.4.1 in NCHRP Report 672, the splitter islands of the roundabout were designed. As specified by the report, the team designed the roundabout’s splitter island dimensions according to the minimum required. This includes designing a 25-foot front splitter island, 10-foot-wide pedestrian crossing, and 50-foot total island length. Moreover, the minimum splitter island nose radii and offsets were also designed according to the minimum specifications. Figures 15 and 16 provide the minimum dimensions of the splitter island and radii dimensions for the roundabout. Figure 17 shows the actual splitter design using MicroStation. Figure 17 also provides the representation for each line.

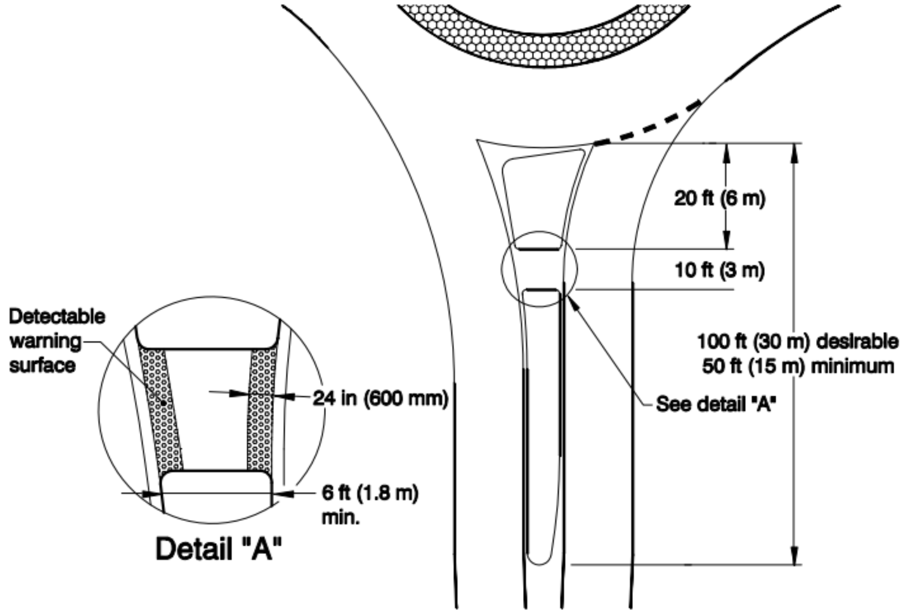


Figure 15: NCHRP Report 672 roundabout splitter island dimensions used in design

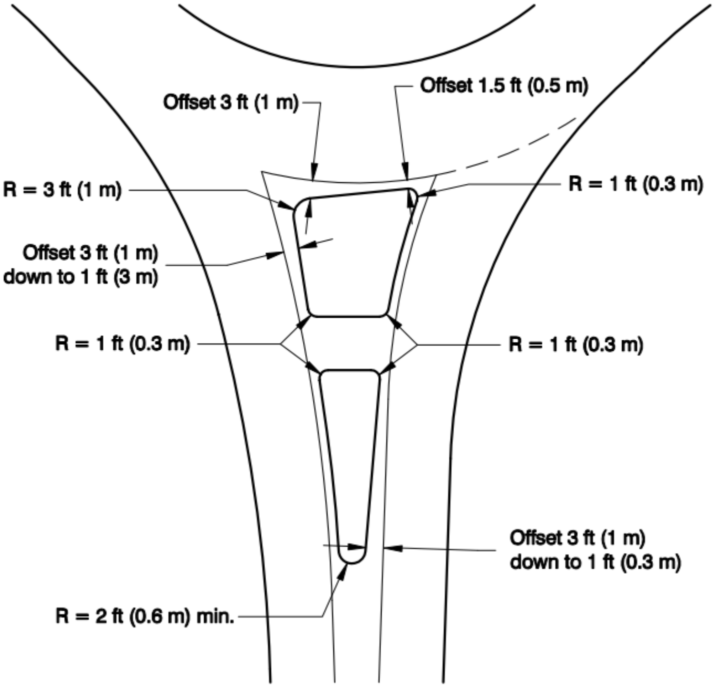


Figure 16: NCHRP Report 672 splitter island radii dimensions used in design

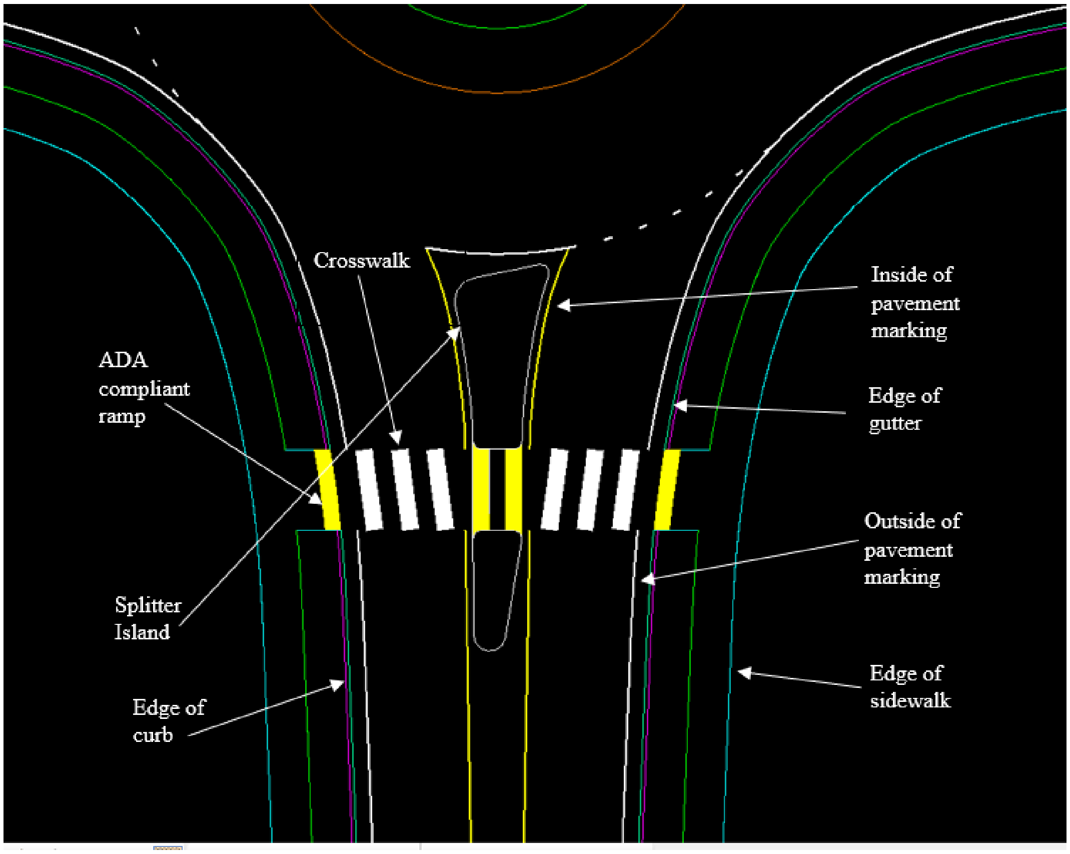


Figure 17: Splitter Island design of roundabout in MicroStation

Under Section 6.4.3 of the report, the required width of the circulatory roadway was determined for the single lane roundabout. More specifically, the report specifies that circulatory roadway widths for a single-lane roundabout should be designed in the ranges of 16 to 20 feet. As a result, the team used 20 feet for the circulatory roadway design to accompany larger trucks passing through the intersection. Furthermore, 12 feet was for the approach design to match the existing roadway width at the intersection.

Based on the AASHTO policy, the team designed a 2 feet distance between the edge of the roadway line and the edge of the curb. Moreover, the team utilized sections 6.4.5 and 6.4.6 to design the entry curb radius for the roundabout. A single curb radius of 50 feet was designed for both the entry and exit curve path. Specifically, the team believes this entry design would allow the vehicles to achieve the desired entry speed objectives. The team also believes this exit design would enforce slow exit path speeds at an optimal level. Ultimately, this would provide increased safety for pedestrians crossing the intersection. Figure 18 shows the entry and exit curb designs using MicroStation.

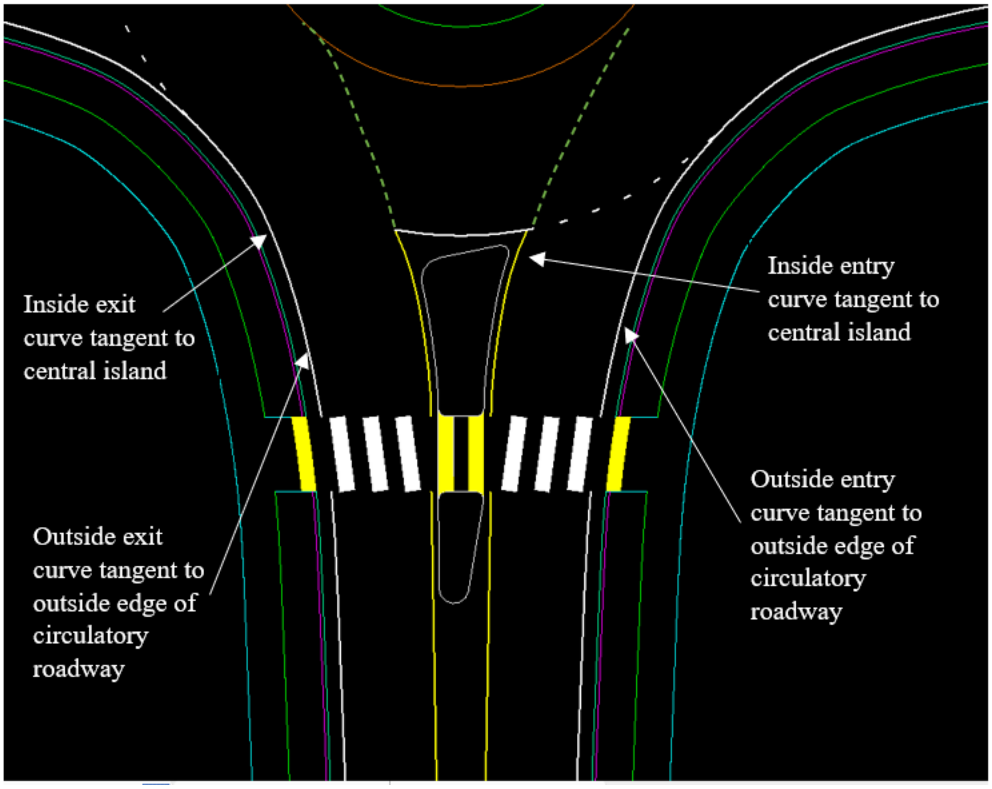
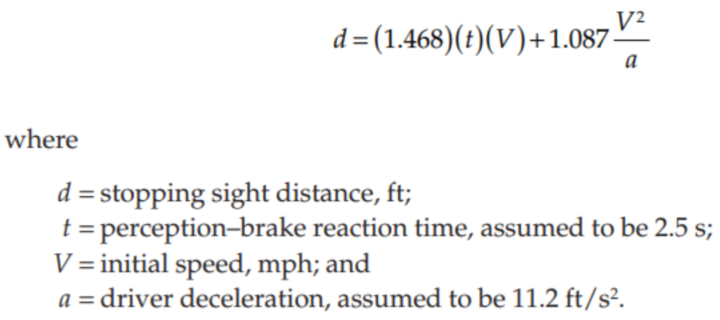


Figure 18: Entry and exit curve design for roundabout using MicroStation

Utilizing Exhibit 6-47 from the NCHRP Report 672, the maximum theoretical entry design speeds for the roundabout were determined based on the site category. Based on the site category of being a single lane roundabout, the maximum theoretical entry speed was determined to be 25 mph. However, since a minimum inscribed circle diameter of 105 feet was used, a speed of 25 mph would cause vehicles to navigate through the roundabout at an exceedingly higher speed. To provide additional safety, the team decided to choose 20 mph as the maximum design entry speed for the single lane roundabout. Under Section 6.7.3.1, the stopping sight distance was determined and incorporated in the roundabout design. Equation 6-5 was used to compute this distance.



$$d = (1.468)(t)(V) + 1.087\frac{V^2}{a}$$

where

d = stopping sight distance, ft;
t = perception–brake reaction time, assumed to be 2.5 s;
V = initial speed, mph; and
a = driver deceleration, assumed to be 11.2 ft/s^2.

Figure 19: NCHRP Report 672 Equation 6-5 Stopping sight distance

Based on Equation 6-5, a perception and reaction time of 2.5 seconds was used, the existing speed limit of 35 mph was used as the initial speed, and 11.2 ft/s^2 was used as the driver acceleration. Through these values, the stopping distance was computed to be 247.8 feet, but 248 feet was used for the design. Overall, the designed sight distance of 248 feet will accompany the minimum requirement of the approach sight distance, sight distance on the circulatory roadway, and the sight distance to crosswalk on the exit. Under Exhibit 7-18, a specification for the regulatory and warning signs for the roundabout is provided. As a result, the team used this specification to design the sign layouts at the roundabout intersection. Specifically, yield signs, direction of travel signs, and pedestrian crosswalk signs were laid out on the roundabout design. Figure 20 provides the regulatory and warning signs used at an approach in the roundabout.

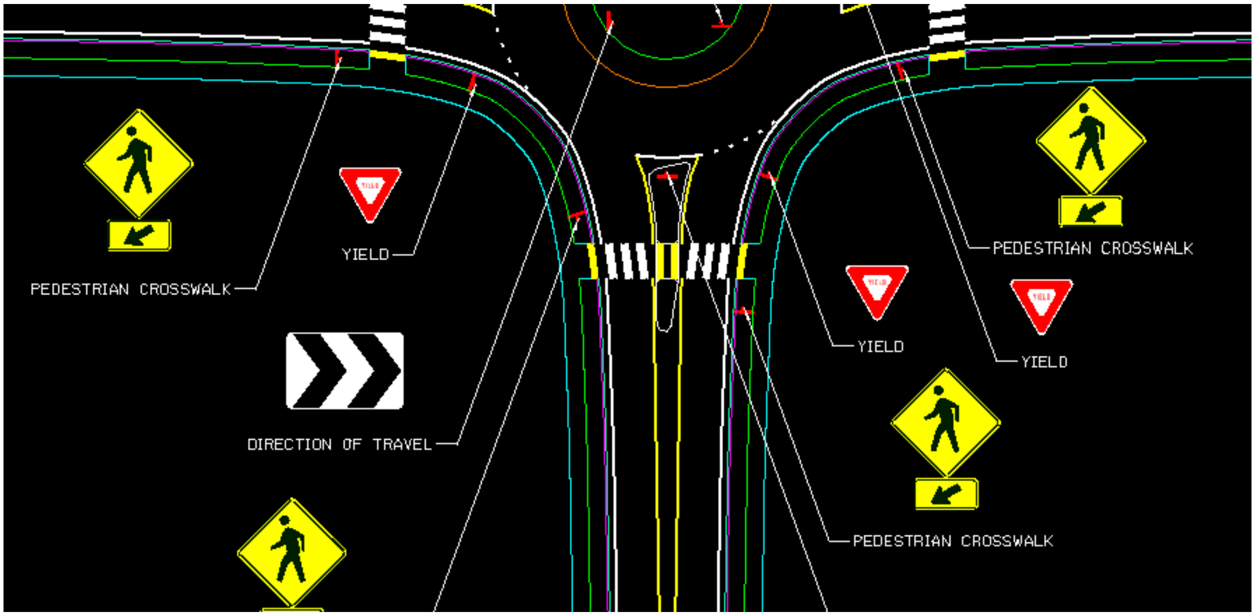


Figure 20: Layout of regulatory and warning signs for roundabout design in MicroStation

Under Section 6.8.1.1, the team designed the roundabout's sidewalks based on the pedestrian design considerations. As such, the sidewalk width of 5 feet was used for the design. A recommended width of 5 feet was used landscaping strip design to accommodate the placement of signs and provide additional benefits such as increased comfort for pedestrians and allow large vehicles to overhang as they travel through the roundabout. Furthermore, the alignment of the pedestrian crosswalk was also designed. The crosswalk was placed perpendicular to the centerline of the approach roadway. To accommodate this design, the crossings on both the entry and exit lanes were angled. This alignment was chosen because it provides a shorter walking distance for pedestrians traversing the intersection. Figure 21 shows a subsection of the designed sidewalk, landscaping strip, and pedestrian crossing in MicroStation.

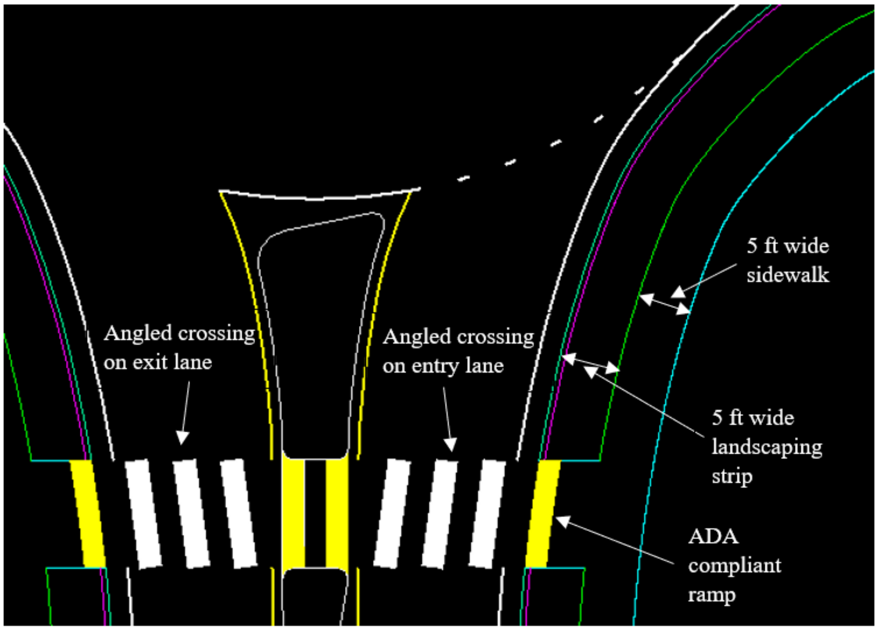


Figure 21: Pedestrian designs of roundabout in MicroStation

Under Section 6.4.7.1, the specifications for the truck apron design of a roundabout are provided. An 8-foot-wide truck apron was designed for the roundabout, which meets the minimum required width range of 3 to 15 feet. Ultimately, the truck apron will allow the larger vehicles to navigate through the intersection without difficulty and prevent them from striking objects at the intersection. Figure 22 shows the truck apron design of the roundabout in MicroStation. Figure 23 details the cross-section view of the roundabout roadway with truck apron, where a cross slope of 2% was used.

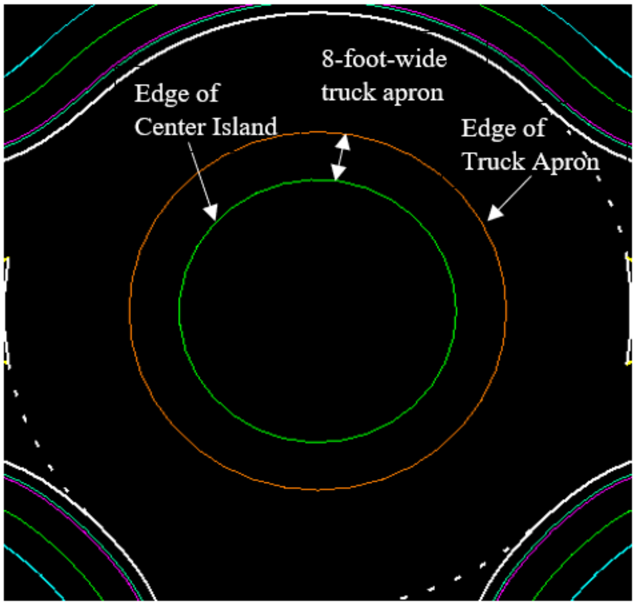


Figure 22: Profile of truck apron design for roundabout using MicroStation

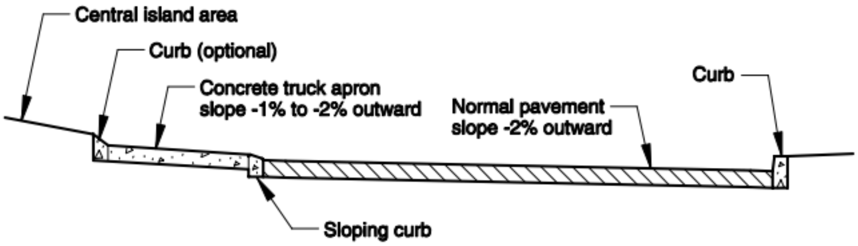


Figure 23: Cross-sectional roadway view with truck apron according to NCHRP Report 672

The Roundabouts: An Informational Guide First Edition was utilized to design the entry width for the roundabout as it contained more detailed information than its successor. To meet the capacity requirement for the roundabout, the entry width design was increased. To do this, the entry geometry was widened by flaring the approach. A 15-foot entry width was designed for the roundabout. Based on the specifications, an 80-foot flare length was designed at the roundabout approaches. Figure 24 shows the entry width design at the roundabout using MicroStation.

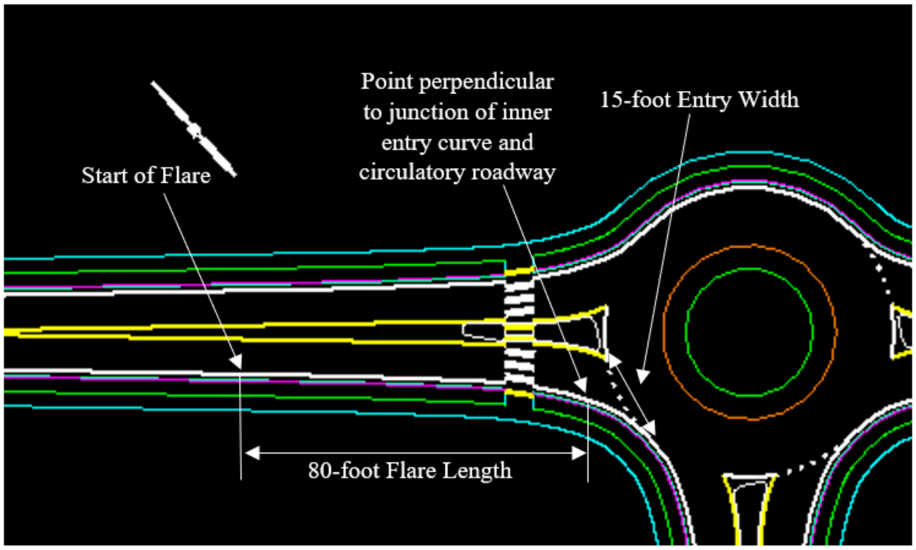
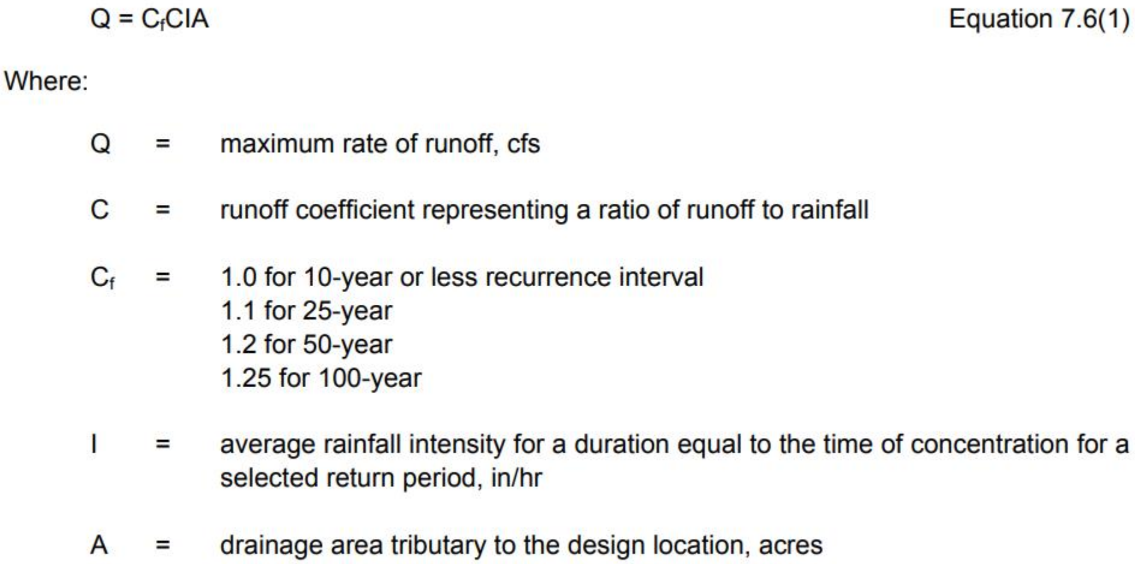


Figure 24: Entry width design for roundabout in MicroStation

Based on the ODOT Roadway Design Manual, Table 5.5B, the minimum design turning radius for our design vehicle, the WB-50 (WB-15), is 45 feet, which works because the smallest curve radius in the roundabout is 50 feet. Additionally, it can accommodate larger vehicles such as the WB-67, since its minimum design turning radius is also 45 feet.

8.2. Drainage Systems using Hydrologic and Hydraulic Principles

In addition to the geometric design of the roundabout, the drainage system design was also incorporated into the roundabout using hydrologic and hydraulic principles from the 2014 ODOT Roadway Drainage Manual. The first thing the team did was to calculate the amount of water flow the drainage system inlet would have to intake. Specifically, the Rational Method from section 7.6 of the manual was used to estimate the design storm peak water flow. Figure 25 provides the Rational equation that was used to compute the peak water flow.



$Q = C_fCIA$ Equation 7.6(1)

Where:

Q = maximum rate of runoff, cfs

C = runoff coefficient representing a ratio of runoff to rainfall

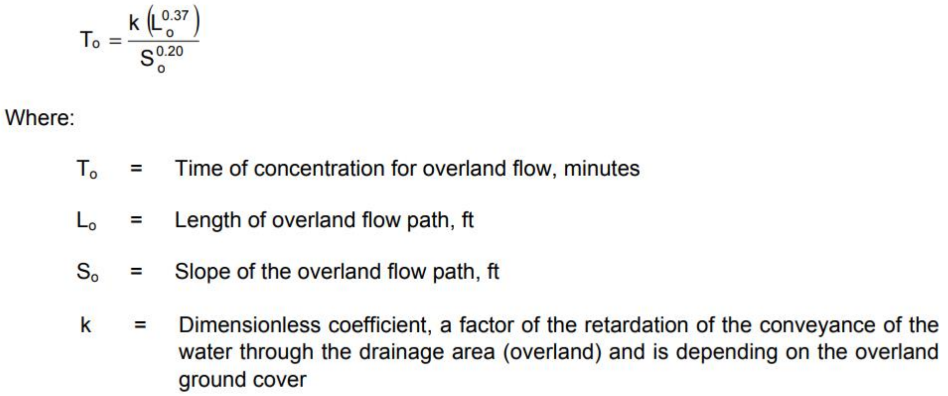
C_f = 1.0 for 10-year or less recurrence interval
1.1 for 25-year
1.2 for 50-year
1.25 for 100-year

I = average rainfall intensity for a duration equal to the time of concentration for a selected return period, in/hr

A = drainage area tributary to the design location, acres

Figure 25: Rational equation from Section 7.6 in ODOT Roadway Drainage Manual

To compute the peak stormwater flow Q, each variable in the equation was determined. Based on the client's decision and the team's desire to reduce costs, the team has chosen to use a 10-year storm design. As a result, a C_f factor of 1.0 was used. Since the intersection design will be comprised of both concrete and asphalt, a runoff coefficient of 0.95 was used based on the typical range of coefficients given in the drainage manual. This value was chosen because it would be conservative and allow the stormwater design to account for risks. A drainage area of 0.96 acres was estimated based on the area at the roundabout intersection because the roadway is curbed, and all other areas will drain into the nearby creek. To determine the average rainfall intensity I, the time of concentration was computed. Since the water will flow on a watershed boundary at the intersection, only the time of concentration for the overland flow was considered. Figure 26 provides the time of concentration for the overland flow.



$$T_o = \frac{k\left(L_o^{0.37}\right)}{S_o^{0.20}}$$

Where:

T_o = Time of concentration for overland flow, minutes

L_o = Length of overland flow path, ft

S_o = Slope of the overland flow path, ft

k = Dimensionless coefficient, a factor of the retardation of the conveyance of the water through the drainage area (overland) and is depending on the overland ground cover

Figure 26: Overland flow time of concentration from 7.6.6.1 in ODOT Drainage Manual

Based on the surface type of concrete and asphalt being the overland ground covers at the intersection, a dimensionless coefficient k of 0.372 was used. A roadway grade of 2% was used as the slope of the overland flow. MicroStation was used to estimate the farthest path the stormwater could travel to the drainage area at the roundabout. As a result, this overland flow length was determined to be 389 feet. Ultimately, the time of concentration was computed as 7.39 minutes. However, 10 minutes was chosen as the value since it is the minimum time required for well-developed flat slopes urban areas. Subsequently, the IDF curve was utilized to determine the rainfall intensity based on the time of concentration and the 10-year storm design. As the intersection is in Pawnee, the Zone 4 IDF curve was utilized. Through this IDF curve shown in Figure 27, the final rainfall intensity was estimated to be 6.2 inches/hr.

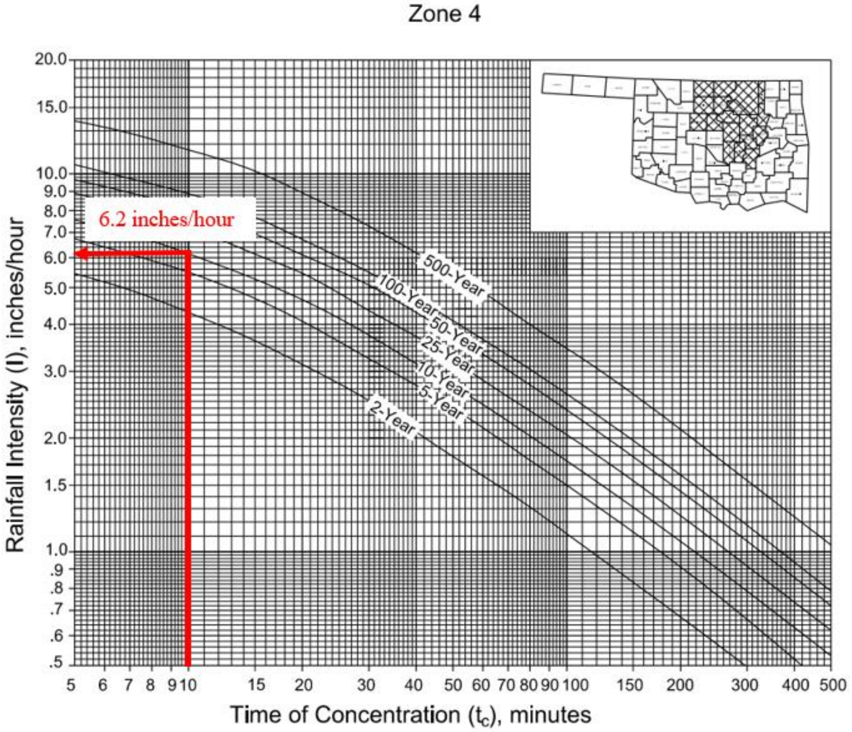


Figure 27: Zone 4 IDF curve in ODOT Roadway Drainage Manual

Using all the crucial variables in the Rational equation, the overall design storm peak water flow Q at the roundabout intersection was determined. Based on the results from the Rational equation, the team estimated that the roundabout area will incur around 5.7 cfs of peak storm water flow. After determining the storm water flow at the roundabout, the curb-opening inlet was designed to facilitate drainage for the roundabout. Figure 28 shows a curb-opening inlet as detailed by the ODOT Roadway Drainage Manual.

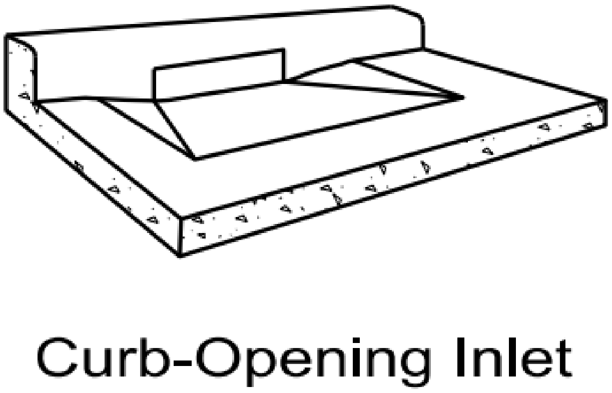


Figure 28: Curb-Opening Inlet in ODOT Roadway Drainage Manual

The team has chosen to design three inlets outside of the roundabout. As a result, each inlet will carry 1.9 cfs of the total peak storm water flow. To facilitate pavement drainage and allow the inlets to perform efficiently, all the curb-opening inlets were designed on grade. Utilizing Equation 10.12(10) from the drainage manual, the length required for total interception of gutter flow of a curb-opening inlet on grade was determined. Figure 29 provides the equation that was used to find this length.

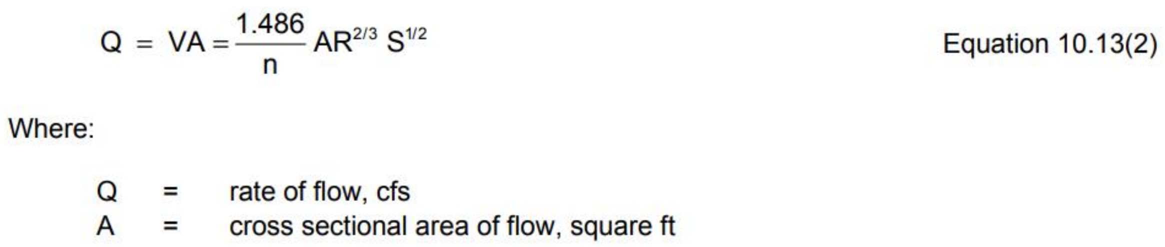
$$L_T = KQ^{0.42} (S_L)^{0.3} (1/(nS_x))^{0.6} \qquad \text{Equation 10.12(10)}$$

Where:

K = 0.6
L_T = curb-opening length required to intercept 100% of the gutter flow, ft

Figure 29: Equation 10.12(10) from Chapter 10 of ODOT Roadway Drainage Manual

To calculate the curb-opening length, the variables in the equation were determined. Specifically, 0.6 was used for the K factor and the roadway grade of 2% was used for the slope S_L. Figure 10.10-B from the drainage manual was used to determine the Manning’s number n for the gutters. Since the roundabout will be constructed from concrete gutters and asphalt pavements, a Manning’s number of 0.015 was chosen for the design. Furthermore, the equivalent cross slope for the depressed gutter section S_x was assumed to be 10%. Based on these variables, the final curb opening L_T for each inlet was determined to be 12 feet. Finally, the HEC-22 Design Method from section 10.13.2 of the drainage manual was used to design the stormwater pipe that will carry the water from the inlet to the creek. Specifically, Equation 10.13(2) was used to determine the rate of stormwater flow the design pipe can carry relative to the 1.9 cfs of flow that the curb-opening inlet will carry. Figure 30 provides the equation used to find the pipe water flow.



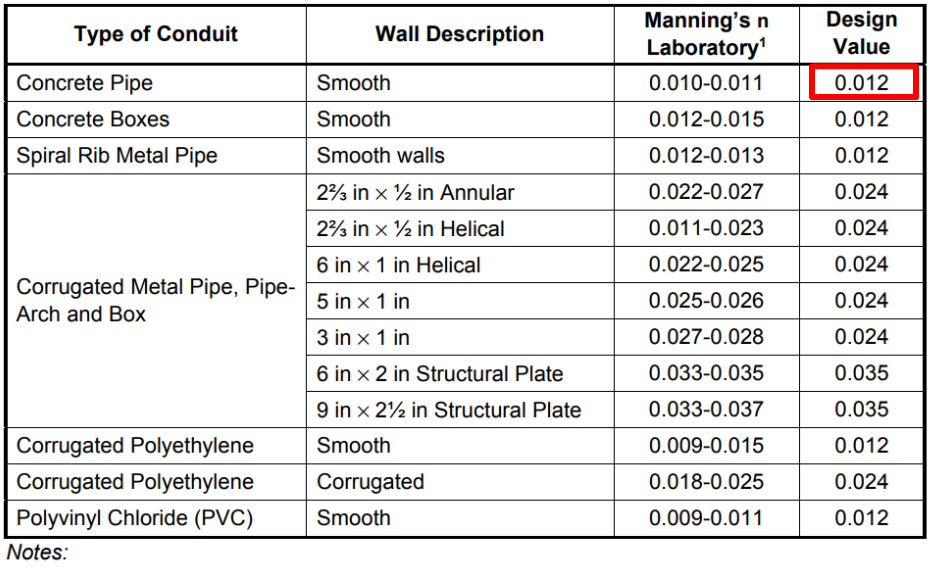
$$Q = VA = \frac{1.486}{n} AR^{2/3} S^{1/2} \qquad \text{Equation 10.13(2)}$$

Where:

Q = rate of flow, cfs
A = cross sectional area of flow, square ft

Figure 30: Equation 10.13(2) from Chapter 10 of ODOT Roadway Drainage Manual

Overall, the team has chosen to design a 1 feet diameter pipe with assumptions that it will have a half-full capacity. As a result, the cross-sectional area of the pipe's A was determined to be $\pi/4$ feet^2. The hydraulic radius R, based on the cross-sectional area and wetted perimeter of the pipe, was computed as ½ feet. Furthermore, the slope of the hydraulic grade line S was assumed to be 4%. To determine the Manning's roughness coefficient n for the pipe, the Manning's Values for Culverts from Chapter 9 of the drainage manual was used. Figure 31 shows the Manning's Values for Culverts.



Type of Conduit	Wall Description	Manning's n Laboratory[1]	Design Value
Concrete Pipe	Smooth	0.010-0.011	0.012
Concrete Boxes	Smooth	0.012-0.015	0.012
Spiral Rib Metal Pipe	Smooth walls	0.012-0.013	0.012
Corrugated Metal Pipe, Pipe-Arch and Box	2⅔ in × ½ in Annular	0.022-0.027	0.024
	2⅔ in × ½ in Helical	0.011-0.023	0.024
	6 in × 1 in Helical	0.022-0.025	0.024
	5 in × 1 in	0.025-0.026	0.024
	3 in × 1 in	0.027-0.028	0.024
	6 in × 2 in Structural Plate	0.033-0.035	0.035
	9 in × 2½ in Structural Plate	0.033-0.037	0.035
Corrugated Polyethylene	Smooth	0.009-0.015	0.012
Corrugated Polyethylene	Corrugated	0.018-0.025	0.024
Polyvinyl Chloride (PVC)	Smooth	0.009-0.011	0.012

Notes:

Figure 31: Manning's Values for Culverts from Chapter 9 of ODOT Drainage Manual

Since the pipe will be designed with concrete and contain a smooth wall, a design value of 0.012 was chosen as the Manning’s Value. Ultimately, the stormwater flow for the pipe’s Q was determined to be 12.25 cfs. Thus, the pipe will be able to carry the expected stormwater flow of 1.9 cfs.

8.3. Final Roundabout Design

After completing both the geometric and drainage system design for the roundabout, the team used MicroStation to place the roundabout design onto the project site. Specifically, the project limits were defined, and the roundabout was incorporated and tied into the existing roadway. To tie the roundabout into the existing roadway, curves were added and oriented accordingly. More exactly, the edge of the roundabout was oriented so that a sufficient clearance remained between the buildings near the site. Figure 32 shows the roundabout design after it was tied into the existing roadway. Figure 33 shows the roundabout design with all the signage.

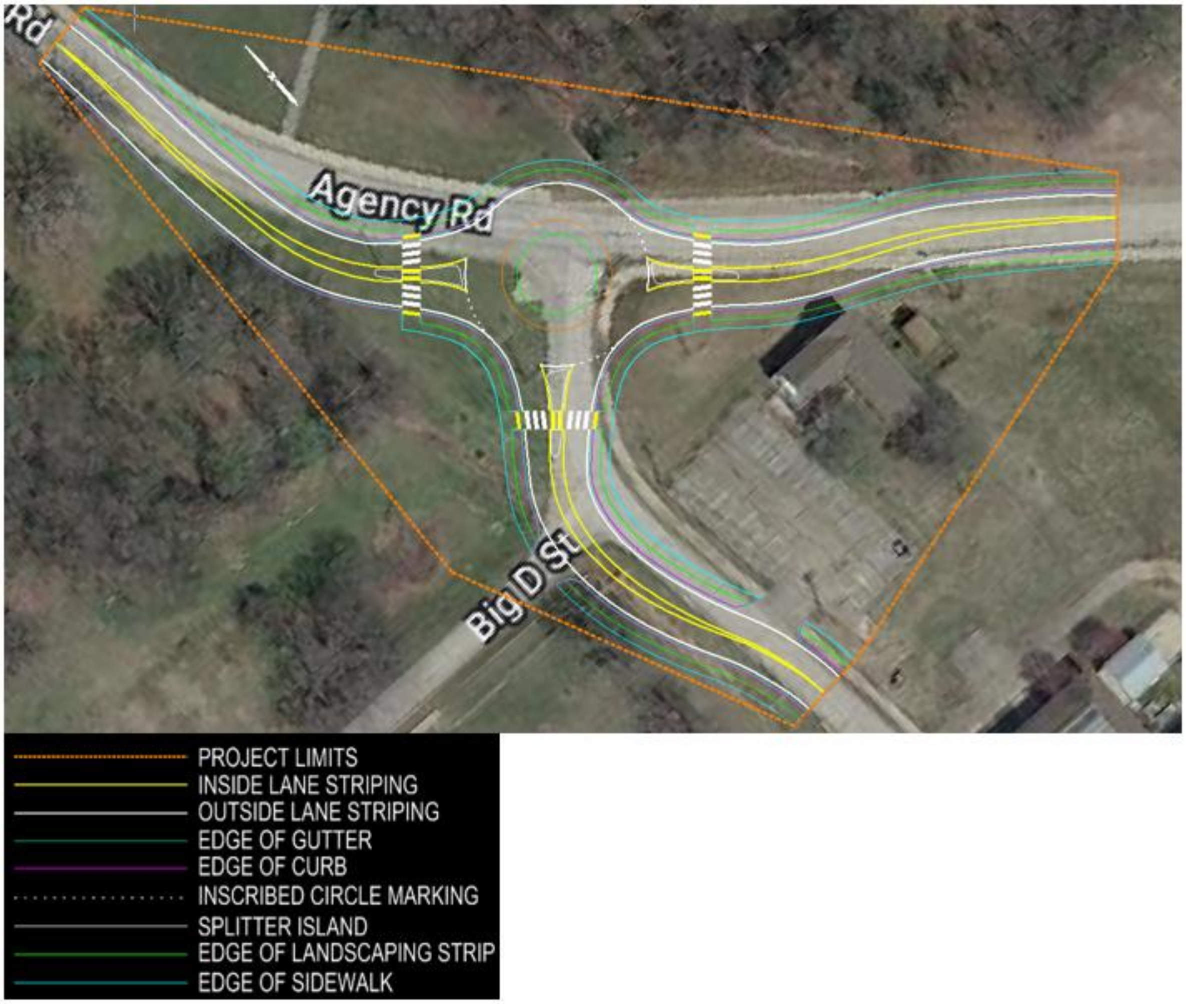


Figure 32: Roundabout design after tying into existing roadway in MicroStation

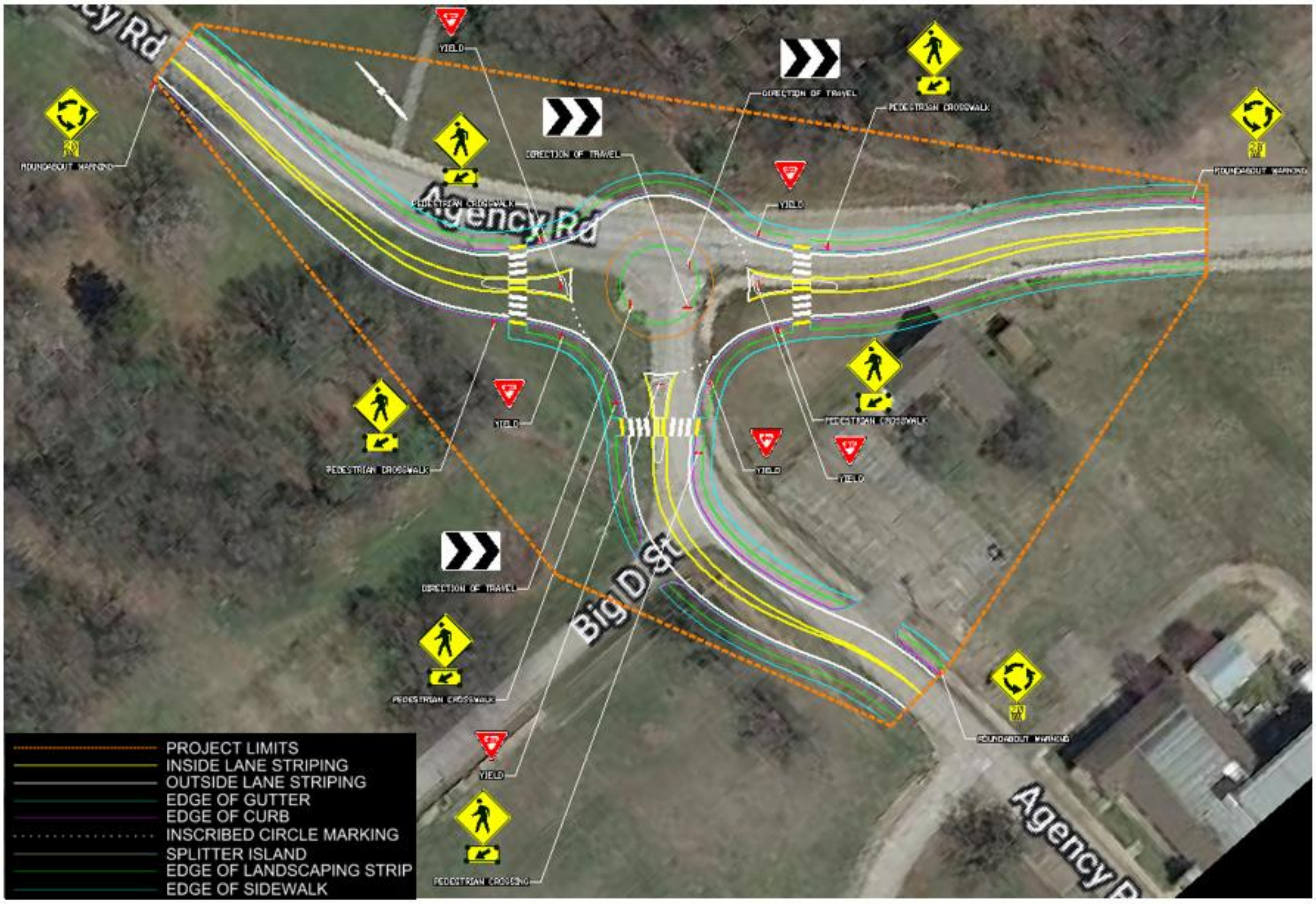


Figure 33: Roundabout design containing signage in MicroStation

Subsequently, the drainage system and existing utilities were added onto the roundabout. As such, the designed curb-inlets on grade and the storm drains were added. After incorporating the drainage system, the utilities were added onto the design. More specifically, the underground culvert, exposed culver/gutter, fiber optic cables, and overhead electric cables were added onto the roundabout. Moreover, the overhead electric cables were rerouted to accompany the roundabout design. The culvert at the south part of the intersection was also replaced so that it could go under the road tie-in. Figure 34 shows the roundabout design containing the drainage system and the utilities.

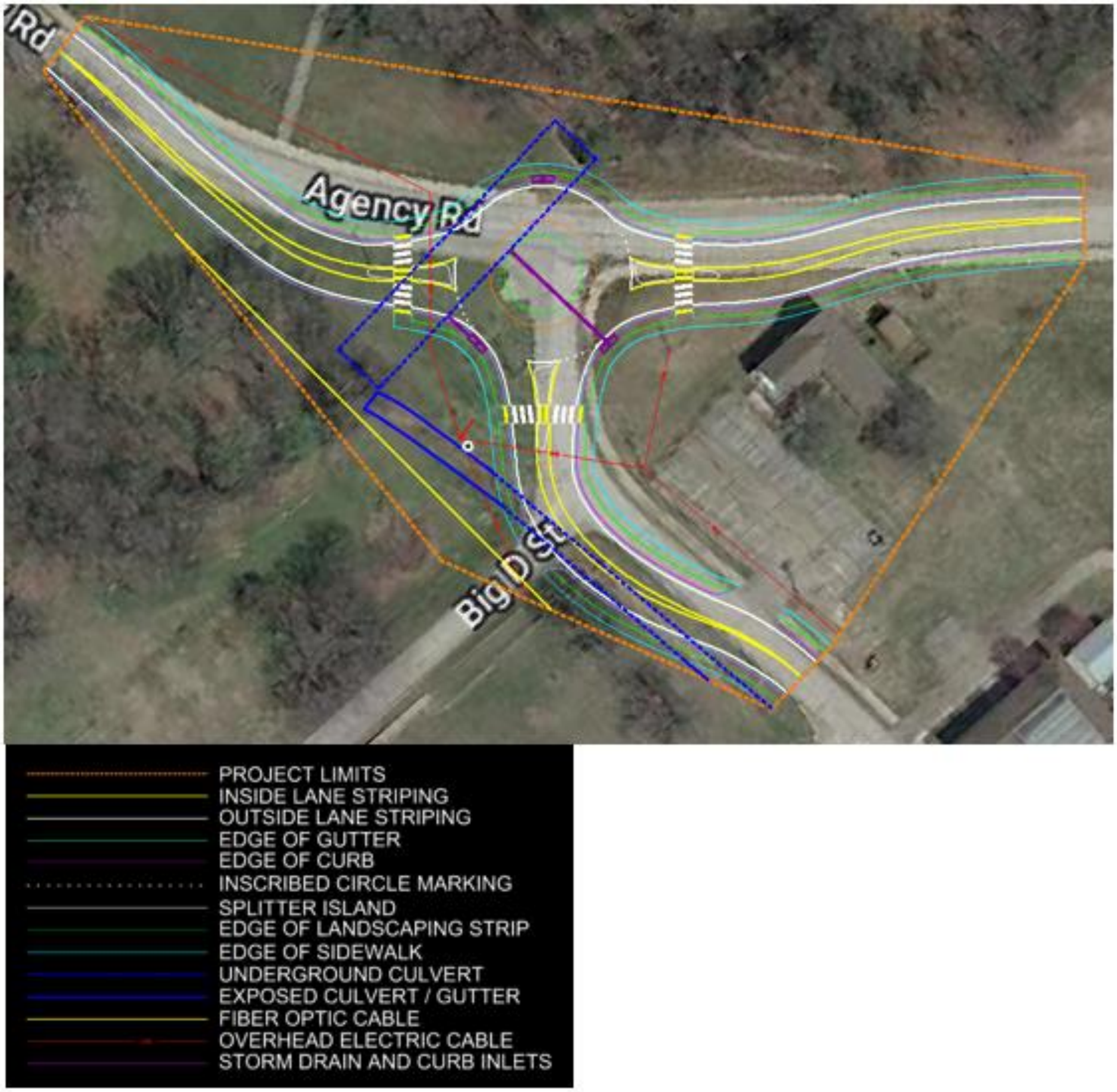


Figure 34: Roundabout design containing drainage system and utilities

9. Sustainability Analysis

A sustainability analysis was performed on the roundabout design. Specifically, the envision criteria and checklist was utilized to evaluate the sustainability of the roundabout through questions under the Quality of Life, Leadership, Resource Allocation, and Climate and Resilience.

9.1. Quality of Life

QUALITY OF LIFE: WELLBEING

QL1.1 Improve Community Quality of Life

26

POINTS

INTENT

Improve the net quality of life of all communities affected by the project and mitigate negative impacts to communities.

METRIC

Measures taken to assess community needs and improve quality of life while minimizing negative impacts.

Figure 35: QL1.1 Improve Community Quality of Life

The team and the client have identified and considered the community needs, goals, and issues. The issue is that there is a sharp right turn at the intersection at agency road and heritage circle that is causing problems for elderly drivers and trucks when they need to make a right turn into the agency road. The team believes that the roundabout design will result in solving this issue.

As discussed above, the roundabout is designed to support the community's needs as well as achieving their goals by having a safer route. The team has assessed the social impact that the project will have on the community. The goal of the roundabout design is to improve the community's quality of life by providing safety for elderly drivers and trucks. The existing intersection has a high probability of causing car accidents as well as creating traffic. As a result, the roundabout will reduce the danger of car accidents and slow traffic.

The client has been very meaningfully engaged in identifying how the project meets community needs and he provided multiple helpful documents for the team. These documents include a plan set, traffic data, and survey data. The team has been able to identify multiple constraints for the design that could negatively affect the community. Specifically, one such constraint is the traffic control flow during the construction work. This is important and the team has produced a plan to facilitate this for the community.

The team and the client both agree that the roundabout is designed for the community's convenience. Thus, the roundabout design will provide and meet the community needs and goals. Furthermore, the design will not have a huge impact on the economy. However, it would have an impact on the environment and improve people's quality of life. In addition, having the roundabout instead of a sharp right turn means less stop, which leads to reduced vehicle exhaust emissions.


QUALITY OF LIFE: WELLBEING

QL1.2 Enhance Public Health and Safety

20

POINTS

INTENT

Protect and enhance community health and safety during operation.

METRIC

Measures taken to increase safety and provide health benefits on the project site, surrounding sites, and the broader community in a just and equitable manner.

Figure 36: QL1.2 Enhance Public Health and Safety

Since the roundabout design will be very efficient, it would be much safer than traditional intersections. Specifically, the roundabout will reduce the severity of the crashes. At a four way stop, drivers can crash head-on or T-bone other cars. Additionally, drivers can move through four way stops at high rates of speed, escalating the possibility and severity of a crash. In contrast, most crashes that occur at the roundabout will only be side swipes, a less severe crash. Furthermore, the roundabout design will also force drivers to slow down to a safer speed. Lastly, common crash and conflicts points between motorist and other motorist and motorist and pedestrians are drastically reduced at the roundabout.


QUALITY OF LIFE: MOBILITY

QL2.1 Improve Community Mobility and Access

14

POINTS

INTENT

Plan the project as part of a connected network that supports all transportation modes for the efficient movement of people, goods, and services.

METRIC

The extent to which the project broadens mode choices, reduces commute times, reduces vehicle distance traveled, and improves levels of service.

Figure 37: QL2.1 Improve Community Mobility and Access

The roundabout design was created with the current plan set as a resource to line up connections and determine appropriate sizing of the roundabout, as well as its effect on its surrounding and immediate area. The client wants to implement this design for the main reason of community mobility and access. Trucks and the elderly were having issues making turns on this tight T intersection (curve radius of only 35 feet) that can often be confusing, so this roundabout directly changes so that drivers can navigate the intersection with safety and ease. Moreover, the roundabout design will also increase capacity and reduce congestion by limiting stop times. Despite this, capacity and congestion were not necessarily an issue at the existing intersection. One negative about having the roundabout is that it will increase vehicle distance traveled. However, this is only caused by the reduction in the stop times. Most importantly, accident rates will be significantly reduced due to decreased collision points and the collision points that still exist are only sideswipes.

The team has worked with the community to expand mobility, access, and make more complete streets (curb and gutter, sidewalk, crosswalk, appropriate signage, center island potential landscaping) per the request of the client. He is very aware of the community's current and long-term needs. While the team was not provided with or have the resources to determine the traffic projections of the area, it is clear the roundabout design increases traffic efficiency and safety significantly. Access will remain the same as before. While roadway access points will remain the same, per the client's request, expanded sidewalk access will benefit the community for those who have no vehicles or are seeking exercise around the community.

QUALITY OF LIFE: MOBILITY

QL2.2 Encourage Sustainable Transportation

16

POINTS

INTENT

Expand accessibility to sustainable transportation choices including active, shared, and/or mass transportation.

METRIC

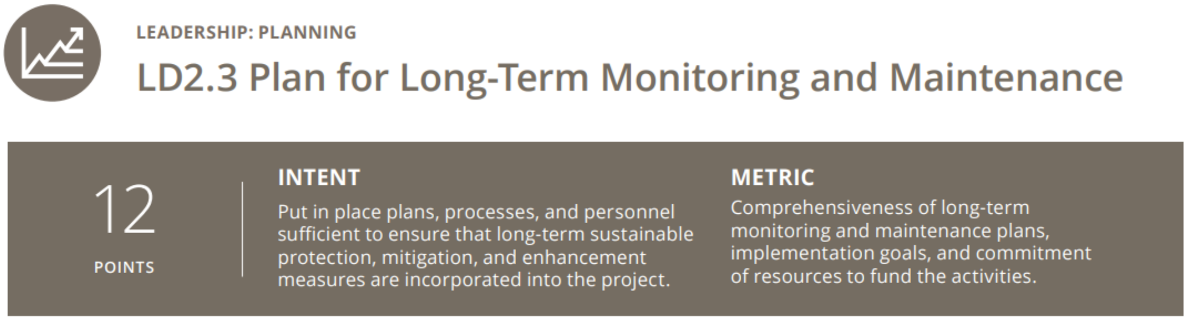
The extent to which active, shared, or mass transportation options are accessible, encouraged, and supported as part of a larger integrated transportation network.

Figure 38: QL2.2 Encourage Sustainable Transportation

Having the roundabout instead of a sharp right turn will provide more sustainable transportation and accessibility for drivers. This will reduce the traffic as well as providing more accessibility for pedestrians and cyclists. The roundabout is designed to encourage sustainable transportation as well as being safe, accessible, and environmentally friendly. The roundabout design will be more accessible and safer for elderly drivers and trucks as well as more environmentally friendly by reducing the traffic, which will result in less air pollution.

The main objective of this project is to solve the problem of a sharp right turn, where elderly drivers and trucks face difficulty turning into the agency road. However, the roundabout design will not only solve this issue, but it will also support the use of active transportation by providing a safer area for pedestrians and cyclists. The project aims to solve the issue of having a sharp right turn for elderly drivers and trucks. Therefore, the team is not concerned about creating a large integrated shared transportation.

9.2. Leadership


LEADERSHIP: PLANNING

LD2.3 Plan for Long-Term Monitoring and Maintenance

12

POINTS

INTENT

Put in place plans, processes, and personnel sufficient to ensure that long-term sustainable protection, mitigation, and enhancement measures are incorporated into the project.

METRIC

Comprehensiveness of long-term monitoring and maintenance plans, implementation goals, and commitment of resources to fund the activities.

Figure 39: LD2.3 Plan for Long-Term Monitoring and Maintenance

The team has considered how to reduce the ongoing operational impacts at the intersection. Specifically, the team has considered how to alleviate the visibility problem of elderly drivers so that they will be able to make smooth turns at the intersection. As a result, the roundabout design will improve this operational impact through its ability to increase visibility and reduce conflict points.

There is currently not a clear or set plan for long term monitoring and maintenance. However, possible ideas for the plan could include monitoring the vehicles' ability to navigate through the roundabout and recording traffic counts to see how significant turning movements are at the roundabout. Moreover, traffic crashes and delays will also be recorded to measure the efficiency of the roundabout. Once a concrete plan has been established, the team plans to tell the client about the plan and make necessary adjustments. There is currently a lack of resources for the long-term monitoring and maintenance of the completed project. However, Pawnee Nation has equipment to measure traffic counts and record traffic crashes. A plan has not been developed to reevaluate and modify the maintenance plan based on the monitored data.

9.3. Resource Allocation


RESOURCE ALLOCATION: MATERIALS

RA1.2 Use Recycled Materials

16

POINTS

INTENT

Reduce the use of virgin natural resources and avoid sending useful materials to landfills by specifying reused materials, including structures, and material with recycled content.

METRIC

Percentage of project materials that are reused or recycled. Plants, soil, rock, and water are not included in this credit.

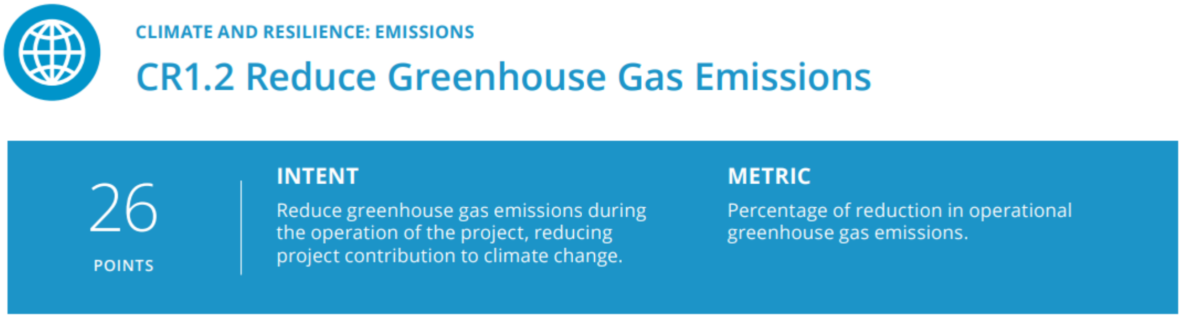
Figure 40: RA1.2 Use Recycled Materials

Asphalt is one of the most recyclable materials in the world, and it happens to be the medium of which the roadway is designed. Obliterated asphalt designated as reclaimed asphalt pavement (RAP) will be sent for recycling and recycled asphalt can be used for new construction in great amounts, depending on its availability, cost, and logistics from the supplier.

While not as easy as asphalt, the existing curb and gutter, constructed from concrete, can be recycled after obliteration. Depending on availability, cost, and logistics from the appropriate supplier, concrete from recycling may be used in the project (especially as curb and gutter design does not have intense strength requirements).

Existing road signs to be removed can be recycled according to the decision from Pawnee Nation, as according to MUTCD signs are to be made of aluminum, which is recyclable, and can be sold to a third-party recycler. Such information of Pawnee Nation’s policies on this matter do not seem to be publicly available, but the option will be made known to the client. Standard aluminum used in the new signage has a recycled component since aluminum is infinitely recyclable. Some pavement markings can be recycled and installed from recycled materials, too. Glass beads that create the retroreflective effect are endlessly recyclable and are recycled for transportation purposes, as well.

9.4. Climate and Resilience



CLIMATE AND RESILIENCE: EMISSIONS

CR1.2 Reduce Greenhouse Gas Emissions

26

POINTS

INTENT

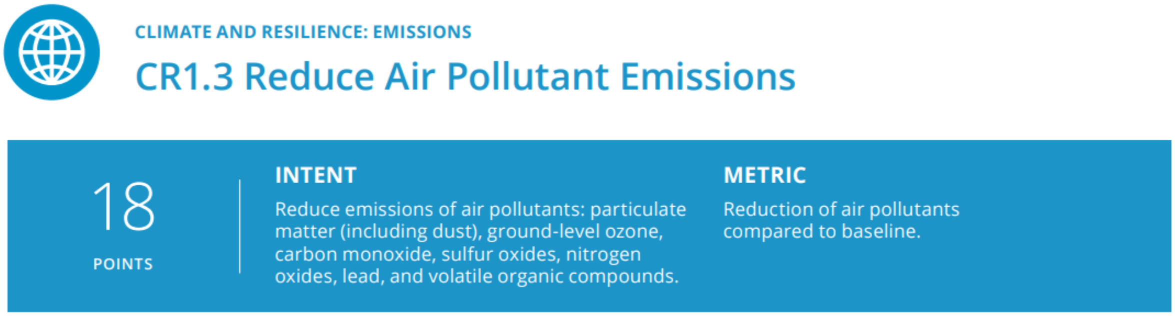
Reduce greenhouse gas emissions during the operation of the project, reducing project contribution to climate change.

METRIC

Percentage of reduction in operational greenhouse gas emissions.

Figure 41: CR1.2 Reduce Greenhouse Gas Emissions

Gas powered vehicles produce harmful greenhouse gases including carbon dioxide, nitrous oxide, and methane. Stop signs and stop lights increase travel and idle times for cars. This in return increases the amount of harmful gas cars give off every trip. Since the roundabout design will be more efficient and allow vehicles to navigate intersections without stopping, the idle time, trip duration, and the number of harmful gases produced will decrease.



CLIMATE AND RESILIENCE: EMISSIONS

CR1.3 Reduce Air Pollutant Emissions

18

POINTS

INTENT

Reduce emissions of air pollutants: particulate matter (including dust), ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, lead, and volatile organic compounds.

METRIC

Reduction of air pollutants compared to baseline.

Figure 42: CR1.3 Reduce Air Pollutant Emissions

Since vehicle transportation plays a significant role in air pollution emissions, designing a roundabout will result in the release of pollutants via cars. As a result, minimizing air pollutant emissions will be crucial for our roundabout design. Due to a lower traffic volume at the existing intersection, it is expected that the current intersection meets the minimum air quality standards and regulations. As a result, since it has been proven that roundabouts can limit air pollutant emissions, it can be anticipated that the roundabout design will meet the minimum air quality standards and regulations.

The existing intersection currently causes vehicles to make stops, which results in vehicle delays. Specifically, vehicle delays lead to an increase in fuel consumption. Thus, an increase in fuel consumption causes an increase in air pollutant emissions. As a result, the roundabout design will reduce both vehicle delays and fuel consumption. The roundabout design also eliminates the possibility of vehicles stopping. This will reduce the fuel needed to both accelerate and decelerate the vehicles, reducing common vehicle emissions such as particular matter, carbon monoxide, and volatile organic compounds.

Due to a lack of equipment and data, the roundabout design does not include the ongoing monitoring and management of direct air pollutant emissions. The team has not had the opportunity to the materiality of volatile organic compounds of direct air pollutant emissions to the health of construction workers and the project operators. The roundabout design will not be able to remove existing air pollutant sources. This can be attributed to the fact that the same type of motor vehicles will continue to drive past the intersection. As a result, the same air pollutant sources from these vehicles will still be emitted. However, the roundabout design will be able to limit the concentration of the air pollutant sources much more effectively compared to the existing intersection.

10. Risk and Uncertainty Considerations

Although designing the roundabout at the Pawnee Nation intersection brings a variety of benefits, there is some risk and uncertainty that should be considered. Specifically, driver negligence and reckless behavior will continue to pose a considerable risk and uncertainty even after implementing the roundabout design. Often, driver negligence can be attributed to human error and confusion. Even with a roundabout at the intersection, encountering drivers with high negligence remains a possibility. One such issue that may result in driver negligence is confusion about who has the right of way. As such, some drivers may not follow the yield rules and enter the roundabout without regarding other drivers that already have the right of way. Thus, this forces the right of way drivers to stop in the roundabout to accompany the negligent drivers. Subsequently, if the drivers do not have enough stopping distance, it would result in collisions.

In addition to the right of way problem, confusion on turning at the roundabout is another such issue that would cause reckless behavior from drivers. Since the designed roundabout is a single lane roundabout, drivers at the approaches may be confused on which way they should turn to enter the circle. As a result, drivers might make the wrong turn and end up on the opposite lane, causing potential collisions. This problem would have the highest effect on the elderly drivers, as they have much slower reaction times to make a proper stop.

Finally, drivers braking in the circle would also create conflicts within the roundabout. More specifically, confusion at the roundabout exit could result in drivers missing the exit entirely. Instead of navigating the circle again to find the exit, drivers may opt to stop immediately due to their confusion. Consequently, this would disrupt the continuous traffic flow. Furthermore, an immediate stop in the middle of the roundabout will bring instant unawareness to the driver behind, increasing the likelihood of an accident happening.

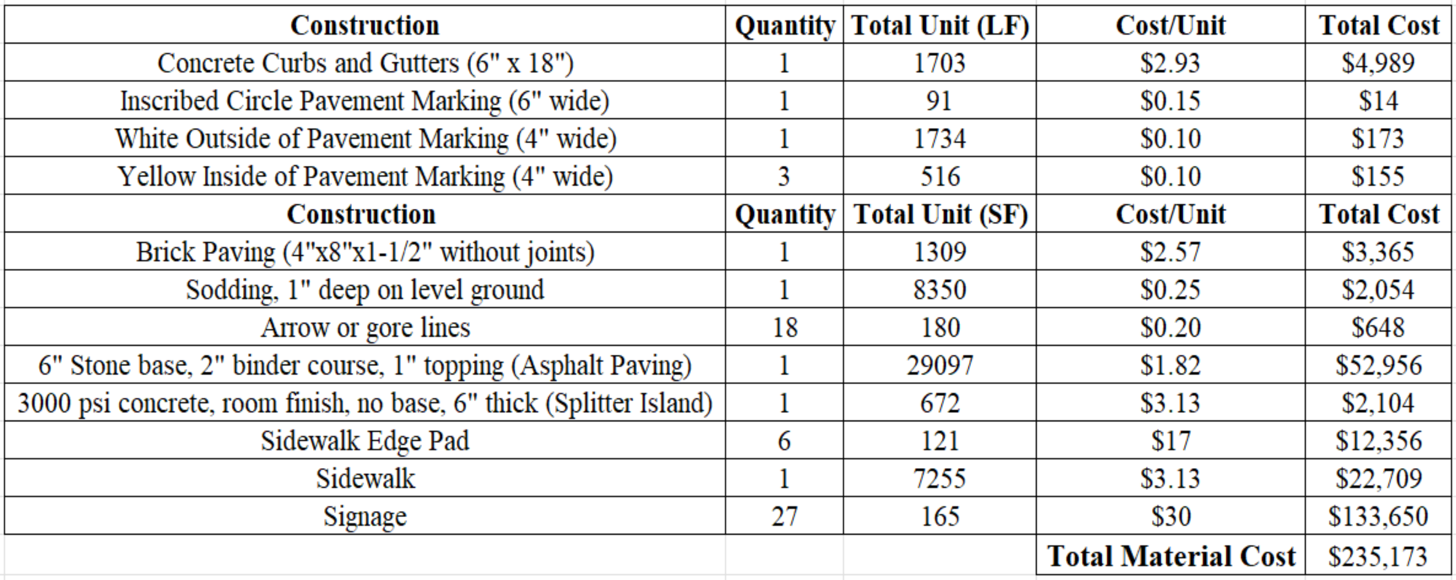
As the roundabout design brings potential driver negligence issues, the drainage system that was designed also poses its own risk and uncertainty. Since the team only chose to design the drainage system with a 10-year design, the drainage system would only be able to intake the rainfall amounts based on the 10-year design frequency. However, due to the random nature of rainfall patterns, there is a possibility that Pawnee receives rainfall exceeding the amounts identified on the 10-year design frequency. As a result, this would create significant issues for the drainage system designed in the roundabout. More specifically, the drainage system may not be able to intake that amount of rainfall, which would result in overflows of the inlet and pipes. Thus, this could potentially cause flooding at the intersection.

11. Project Cost Estimate

In the final phase of the roundabout design, the team estimated the total cost for the project. As such, the material cost for the construction of the roundabout was estimated. To determine the unit cost for the construction materials, the 2018 Building Construction Costs with RSMeans data. It should be noted that the RSMeans data was only able to provide the unit cost data based on the US National average in 2018. As a result, the team made additional cost adjustments to each material cost to produce a more accurate site cost.

11.1. Cost Estimate of Construction Materials in Roundabout

As mentioned above, the team first estimated the construction material cost based on the US National average provided by the 2018 RSMeans data. Specifically, MicroStation was utilized to determine the required sizing of the construction materials in terms of square foot (SF) and linear foot (LF). Moreover, the quantity for these materials were also determined. Subsequently, RSMeans was used to find the unit cost for these materials. Based on these initial parameters, the total material cost estimate for the roundabout was computed. Figure 43 provides a summary of the total material cost for the roundabout.



Construction	**Quantity**	**Total Unit (LF)**	**Cost/Unit**	**Total Cost**
Concrete Curbs and Gutters (6" x 18")	1	1703	$2.93	$4,989
Inscribed Circle Pavement Marking (6" wide)	1	91	$0.15	$14
White Outside of Pavement Marking (4" wide)	1	1734	$0.10	$173
Yellow Inside of Pavement Marking (4" wide)	3	516	$0.10	$155
Construction	**Quantity**	**Total Unit (SF)**	**Cost/Unit**	**Total Cost**
Brick Paving (4"x8"x1-1/2" without joints)	1	1309	$2.57	$3,365
Sodding, 1" deep on level ground	1	8350	$0.25	$2,054
Arrow or gore lines	18	180	$0.20	$648
6" Stone base, 2" binder course, 1" topping (Asphalt Paving)	1	29097	$1.82	$52,956
3000 psi concrete, room finish, no base, 6" thick (Splitter Island)	1	672	$3.13	$2,104
Sidewalk Edge Pad	6	121	$17	$12,356
Sidewalk	1	7255	$3.13	$22,709
Signage	27	165	$30	$133,650
			Total Material Cost	$235,173

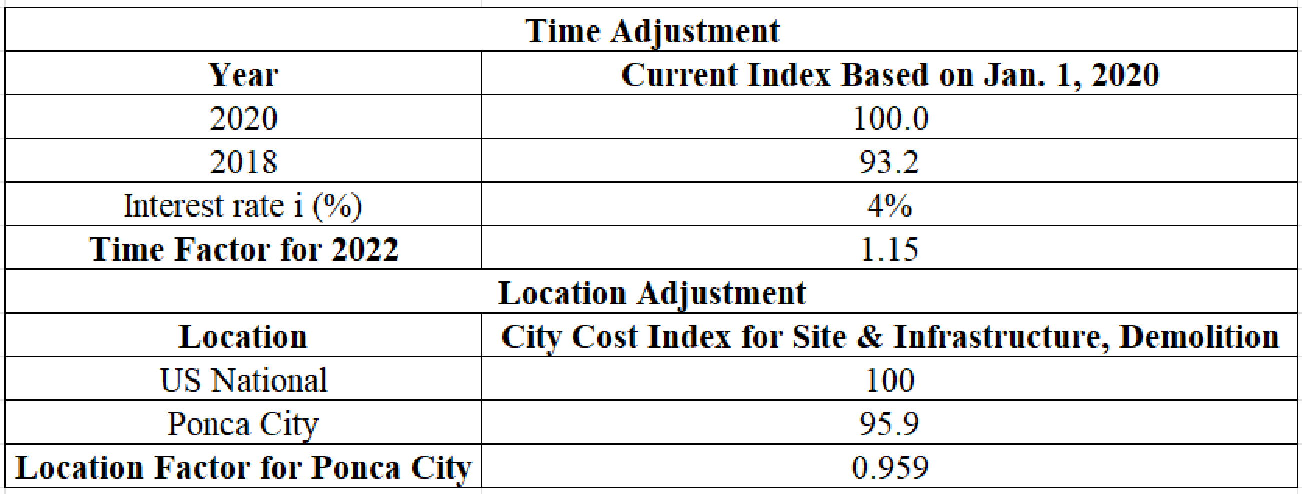
Figure 43: Total Material Cost for construction of the roundabout

As shown in Figure 43, the sizing for the curbs, gutters, and pavement markings were estimated in terms of LF. On the other hand, the sizing for the different paving, sidewalks, signage, etc. were estimated in terms of SF. Despite the road pavement markings having the exact unit cost, the outside edge of the pavement will be marked white while the inside edge of the pavement will be marked yellow. Furthermore, the unit cost for arrow or gore lines was chosen for the crosswalk stripes.

Brick paving will be used to construct the truck apron. With the chosen brick paving requiring 4.5 bricks per unit, the team estimated that roughly 4582 bricks will be needed for the truck apron paving. Subsequently, landscaping construction at the roundabout was also implemented into the material costs. Specifically, a 1 inch deep on level ground sodding was chosen for both landscaping on the center island and the landscaping strip. Asphalt paving at the roundabout was also added into the material cost. As such, the 6-inch stone base, 2-inch binder course, and 1-inch topping was chosen and includes paving on the leg asphalt and the inscribed circle. For the signage, the roundabout warning signs, yield signs, pedestrian crosswalk signs, and direction of travel signs were all considered in the construction material costs. Based on the RSMeans data, the team estimated that the total materials cost for construction of the roundabout will cost around $235,173.

11.2. Total Materials Cost with Adjustments

After estimating the total materials cost based on the 2018 US National Average, the team utilized the 2020 RSMeans Indexes to make additional cost adjustments. More specifically, time and location adjustments were made to give a more realistic material cost for the roundabout construction at Pawnee Nation. Figure 44 illustrates the time and location adjustments that was conducted using the RSMeans Indexes.



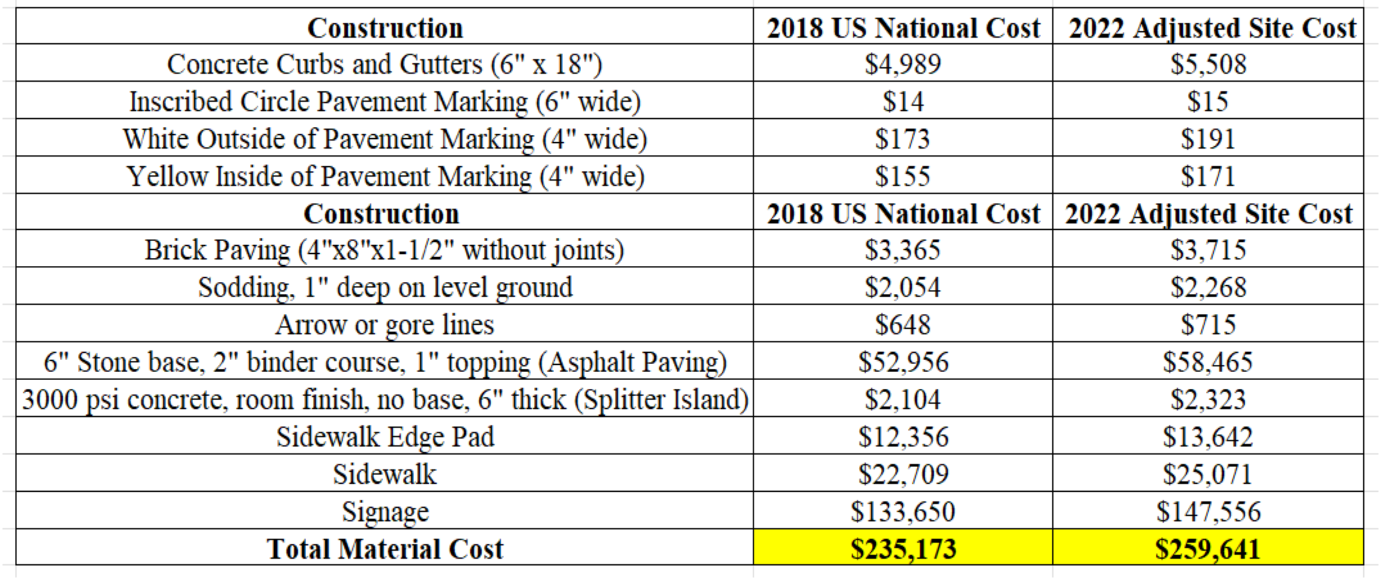
Time Adjustment	
Year	**Current Index Based on Jan. 1, 2020**
2020	100.0
2018	93.2
Interest rate i (%)	4%
Time Factor for 2022	1.15
Location Adjustment	
Location	**City Cost Index for Site & Infrastructure, Demolition**
US National	100
Ponca City	95.9
Location Factor for Ponca City	0.959

Figure 44: Time and location adjustments using 2020 RSMeans Indexes

It can be seen from Figure 44 that both the time and location factors were determined using the provided indexes. For the time adjustment, the current index was used instead of the historical cost index based on 1993. It should be noted that the provided current time indexes only go up to the year 2020. As a result, using these indexes, the future worth equation $FV = PV(1+i)^n$ was utilized to determine the equivalent compound interest rate i between the years 2018 and 2020. Since the RSMeans data provided only the materials cost for 2018, a period n of 4 years was used in the time factor equation $(1+i)^n$ for adjustment from 2018 to 2022. With both the compound interest rate and the 4-year period, the time factor was determined to be 1.15.

After determining the time adjustment, the team computed the location adjustment. Similarly, the RSMeans Indexes were used to locate the city cost indexes. As such, the city cost index for the US National Average materials cost was treated as 100, the base location cost. On the other hand, the cost index for the city of Pawnee was not provided by RSMeans. As a result, the team decided to use the cost index for Ponca City due to its geographic proximity to Pawnee. Subsequently, the cost index for the site & infrastructure, demolition division was used to accurately represent the construction materials cost. Therefore, the location factor for adjustment to Pawnee was determined to be 0.959.

Finally, the time and location factors were applied to each individual material cost. The adjusted individual material cost was summed together to bring a total cost estimate. Figure 45 shows the comparison between the unadjusted and adjusted total cost estimate for construction of the roundabout at Pawnee Nation.



Construction	**2018 US National Cost**	**2022 Adjusted Site Cost**
Concrete Curbs and Gutters (6" x 18")	$4,989	$5,508
Inscribed Circle Pavement Marking (6" wide)	$14	$15
White Outside of Pavement Marking (4" wide)	$173	$191
Yellow Inside of Pavement Marking (4" wide)	$155	$171
Construction	**2018 US National Cost**	**2022 Adjusted Site Cost**
Brick Paving (4"x8"x1-1/2" without joints)	$3,365	$3,715
Sodding, 1" deep on level ground	$2,054	$2,268
Arrow or gore lines	$648	$715
6" Stone base, 2" binder course, 1" topping (Asphalt Paving)	$52,956	$58,465
3000 psi concrete, room finish, no base, 6" thick (Splitter Island)	$2,104	$2,323
Sidewalk Edge Pad	$12,356	$13,642
Sidewalk	$22,709	$25,071
Signage	$133,650	$147,556
Total Material Cost	**$235,173**	**$259,641**

Figure 45: Comparison of unadjusted and adjusted total material cost estimate for roundabout

As shown in Figure 45, the total adjusted material cost estimate for the construction of the roundabout at Pawnee Nation in 2022 is approximately $259,641. Compared to the 2018 US National Average Cost, the site cost saw around a $25,000 increase. This can be mainly attributed to the time adjustment, due to the constant change in the unit of currency. Overall, only the construction materials cost was considered for the cost estimation. The labor and equipment cost were not factored into the estimate because, knowing this is a Design-Bid-Build project, this will be handled by construction estimators at each respective bidding construction company, who will be responsible for determining the cost of the roundabout construction they can work with through placing a bid on the project. Each company will have their own resources and wages. The lowest bidder will win the project based off said bids.

12. Project Summary and Conclusions

In conclusion, the team identified three possible alternatives to address the existing turning problem at the intersection of Agency Road and Heritage Circle in Pawnee Nation. These alternatives were a roundabout, Y-intersection, and right-turn slip lane. Based on both the client's desire and the outweighing benefits it offers, the team proceeded to choose the roundabout design as the proposed solution for the intersection.

During the roundabout design process, the team utilized MicroStation GEOPAK V8i and the NCHRP Report 672's Roundabouts: An Informational Guide Second Edition to design the geometric layout of the roundabout. This includes designing a 105-foot inscribed circle, 50-foot-long splitter island, 8-foot-wide truck apron, and a 20-foot circulatory roadway. Furthermore, new pedestrian facilities were also designed on the roundabout. Specifically, 5-foot-wide pedestrian sidewalks and 10-foot-wide pedestrian crossings with ADA compliant ramps were added to the layout. Following the design of the roundabout layout, the team utilized the 2014 ODOT Roadway Drainage Manual to design the drainage system. As such, the overall stormwater peak flow the roundabout would incur was determined using the Rational Equation. Based on this value, the team designed three 12-foot-long curb opening inlet on grade and 1-foot diameter stormwater pipes with half-full capacity using a 10-year design storm.

In the final design process, the team adapted the roundabout design into the existing intersection. Specifically, this includes adding utilities such as culverts and powerlines. Moreover, the necessary utilities including powerlines were also moved. Subsequently, both the required roundabout signages and the designed drainage system were incorporated into the final design.

In addition to the design, a sustainability analysis was also performed to assess the roundabout. Based on this analysis, the team believes the roundabout provides sustainability in areas like safety, community mobility and access, and air pollution. More exactly, the roundabout will reduce the severity of crashes from head-on collisions to only sideswipes. The newly added pedestrian sidewalks and crossings will benefit people with no vehicles and individuals who exercise daily in Pawnee Nation. Furthermore, a reduction in the vehicle idle times at the roundabout reduces fuel consumption, resulting in less air pollutant emissions.

In the final phase of the project, the team performed a cost estimate analysis using the 2018 RSMeans data. Using RSMeans, the unit cost for the construction materials used in the roundabout was determined. Using additional time and location cost adjustments, the team estimated that the final construction material cost for the roundabout will cost around $260,000. Ultimately, the team believes the roundabout design will alleviate existing problems at the intersection, providing optimal benefits to both truck drivers and the elderly.

13. Appendices

13.1. References

Google Earth. https://earth.google.com/web

Google Maps. https://www.google.com/maps

N.A. 2009. “Traffic Engineering Standards & Specifications.” *Oklahoma Department of Transportation*. https://www.odot.org/traffic/standards.htm

N.A. 2000. “ROUNDABOUTS: An Informational Guide.” *U.S. Department of Transportation Federal Highway Administration*. 1st edition. https://www.fhwa.dot.gov/publications/research/safety/00067/00067.pdf

N.A. 2010. “Roundabouts: An Informational Guide.” *National Cooperative Highway Research Program*. 2nd edition. https://nacto.org/docs/usdg/nchrprpt672.pdf

N.A. 1992. “ODOT Roadway Design Manual.” *Oklahoma Department of Transportation*. https://www.odot.org/OK-GOV-DOCS/DOING-BUSINESS/Consultant-Contract-Info/1992%20Roadway%20Design%20Manual%20complete_both%20volumes%20comprest.pdf

N.A. 2014. “ODOT Roadway Drainage Manual.” *Oklahoma Department of Transportation*. https://oklahoma.gov/odot/business-center/pre-construction-design/roadway-design/support-units/oklahoma-roadway-drainage-manual.html

N.A. 2002. “Plan of Proposed Roadway Improvements for Pawnee Health Center Pawnee Nation.”

N.A. 2013. “Vehicle General Flow Report Pawnee Nation.”

N.A. 2018. “Building Construction Costs with RSMeans data.” *The Gordian Group Inc*. 76th annual edition.

N.A. 2018. “Heavy Construction Costs with RSMeans data.” *The Gordian Group Inc.* 32nd annual edition.

N.A. 2020. “RSMeans Indexes.”

13.2. Meetings With Client

1/26/22 – Virtual Kick Off

Meeting Summary:

A virtual Microsoft Teams meeting was held with Mr. Chris McCray, who is the Transportation & Safety Manager for the Pawnee Nation. During the meeting, Mr. McCray gave a detailed elaboration on the ongoing problems at the intersection. Moreover, a list of potential solutions to alleviate the problems at the intersection was discussed with him. The applicable design codes were also discussed. Lastly, Mr. McCray provided a vehicle general flow report of the intersection.

Meeting Notes:

- Drivers are having trouble turning right on Agency Rd.
- Mr. McCray wants multiple options to choose from
- A roundabout interested Pawnee the most. Help improve the look of the area.
- Moving culvert and fiber optic lines are not options
- The roadway used to be a straight road and was curved to the east during a previous project.
- Traffic data was provided, Mr. McCray is going to look for current as-builts

2/1/22 – Site Visit

Meeting Summary:

A site visit was conducted with the client, Mr. Chris McCray, at the Intersection of Agency and Heritage Circle in Pawnee Nation. During the visit, Mr. McCray explained in detail what the problem that the city is having. The problem is that elderly drivers and trucks are having problems turning right into Agency Road because the right turn is very sharp. He expressed his wishes that certain utilities must not be moved such as the fiber-optic cables, drainage ditches, and culverts. The group members took several pictures of the site which will be included in our report. Plus, a driving simulation was conducted at the site to show the difficulty that elderly drivers and trucks have when they turn right to Agency rd. Finally, Mr. McCray provided the team with a plan set of the intersection that contains lots of useful information such as survey data and the locations of all the utilities.

Meeting Notes:

- Detailed description of the problems that drivers have
- Project constraints were defined by Mr. McCray
- Several pictures were taken at the site including pictures of the utility lines
- A driving simulation was conducted
- A plan set was provided by Mr. McCray, including helpful data

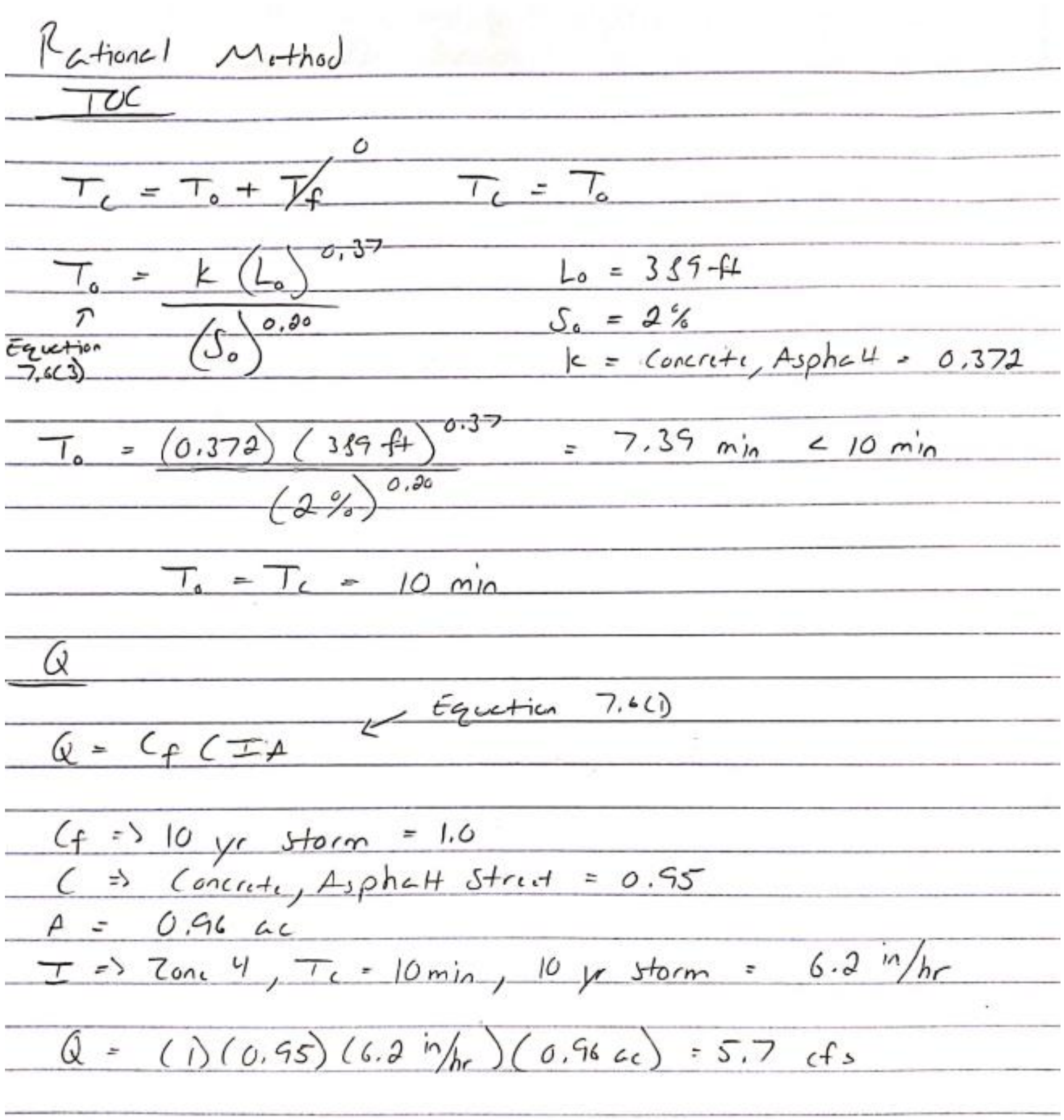
4/11/22-Client Feedback

Once the team finished the final roundabout design, the team showed Mr. McCray the overall design. As a result, he provided some feedback after reviewing our final design. Specifically, he said our design is very detailed and looks very professional. Here are the two main pieces of feedback he provided:

- Mr. McCray said we should replace the large culvert directly above the building
- Mr. McCray also asked us to show the new design overlay and wants it to be “landscaped out” to show the old roadway that will be removed

13.3. Supporting Hand Calculations

Calculations for Drainage Systems design



Rational Method

TOC

$T_c = T_o + \cancel{T_f}^{0}$ $\quad T_c = T_o$

$$T_o = \frac{k\,(L_o)^{0.37}}{(S_o)^{0.20}}$$

$\uparrow$ Equation 7.6(3)

$L_o = 389\text{-ft}$

$S_o = 2\%$

k = Concrete, Asphalt = 0.372

$$T_o = \frac{(0.372)\,(389\text{ ft})^{0.37}}{(2\%)^{0.20}} = 7.39 \text{ min} < 10 \text{ min}$$

$T_o = T_c = 10$ min

Q

$Q = C_f\, C\, I A$ $\leftarrow$ Equation 7.6(1)

C_f => 10 yr storm = 1.0

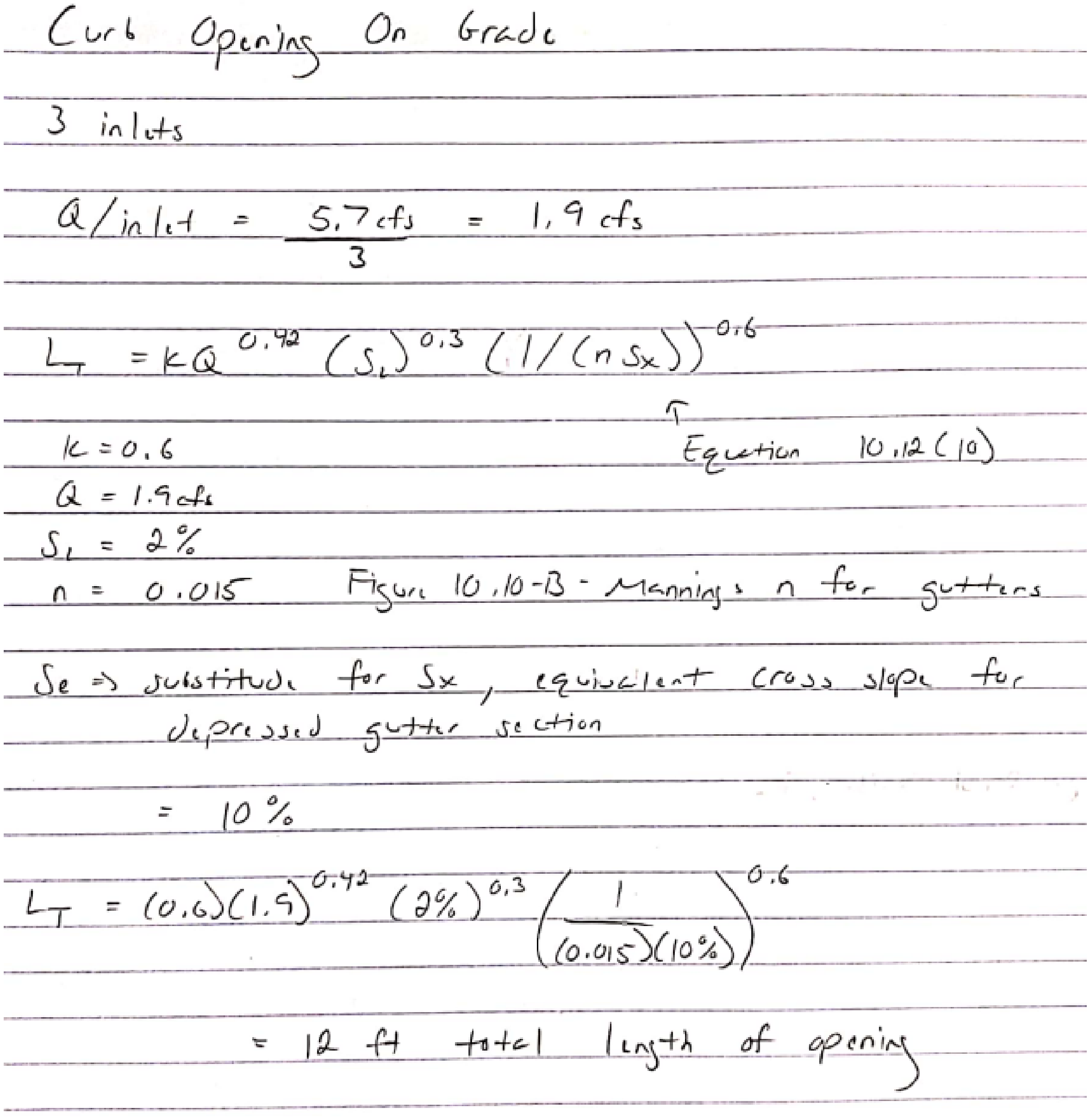
C => Concrete, Asphalt Street = 0.95

A = 0.96 ac

I => Zone 4, T_c = 10 min, 10 yr storm = 6.2 in/hr

$Q = (1)(0.95)(6.2 \text{ in/hr})(0.96 \text{ ac}) = 5.7$ cfs

Figure 46: Calculations for design peak water flow at the roundabout using Rational Method



Curb Opening On Grade

3 inlets

$$Q/\text{inlet} = \frac{5.7\ \text{cfs}}{3} = 1.9\ \text{cfs}$$

$$L_T = KQ^{0.42}(S_L)^{0.3}(1/(n S_x))^{0.6}$$

↑ Equation 10.12 (10)

$K = 0.6$

$Q = 1.9$ cfs

$S_L = 2\%$

$n = 0.015$ Figure 10.10-B - Mannings n for gutters

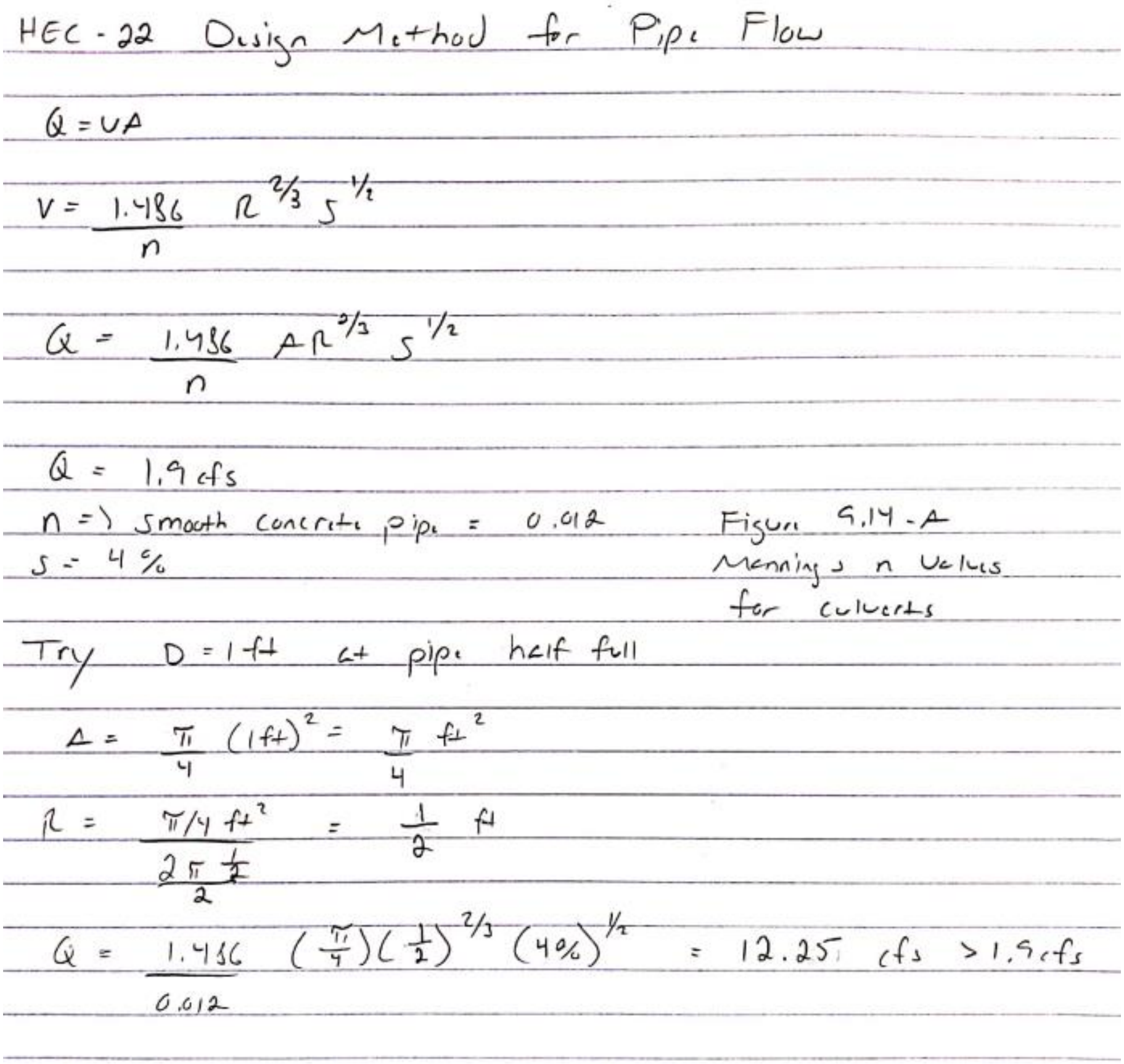
$S_e \Rightarrow$ substitute for S_x, equivalent cross slope for depressed gutter section

$= 10\%$

$$L_T = (0.6)(1.9)^{0.42}(2\%)^{0.3}\left(\frac{1}{(0.015)(10\%)}\right)^{0.6}$$

= 12 ft total length of opening

Figure 47: Calculations for Curb-Opening Inlet on grade design



HEC-22 Design Method for Pipe Flow

$Q = VA$

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

$$Q = \frac{1.486}{n} A R^{2/3} S^{1/2}$$

$Q = 1.9$ cfs

n => smooth concrete pipe = 0.012 Figure 9.14-A Manning's n Values for culverts

$S = 4\%$

Try $D = 1$ ft at pipe half full

$$A = \frac{\pi}{4} (1 ft)^2 = \frac{\pi}{4} ft^2$$

$$R = \frac{\pi/4\ ft^2}{\frac{2\pi \frac{1}{2}}{2}} = \frac{1}{2} ft$$

$$Q = \frac{1.486}{0.012} \left(\frac{\pi}{4}\right)\left(\frac{1}{2}\right)^{2/3} (4\%)^{1/2} = 12.25 \text{ cfs} > 1.9 \text{ cfs}$$

Figure 48: Calculations for Stormwater Pipe design

13.4. Team Management Plan

Team Name

FL Consultants

Team Members

Dalton Wiseman

- Hometown: Edmond, Oklahoma
- Background: internships in surveying, transportation, hydrology, and hydraulics
- Skills: Communication, problem solving, and design skills

Nathan Brooks

- Hometown: Plano, Texas
- Background: internships in roadway design and traffic engineering
- Skills: Microstation, AutoCAD, communication, and organizational

Hussain Al Lashit

- Hometown: Qatif, Saudi Arabia
- Background: previous Civil Engineering courses including courses related to transportation engineering
- Skills: AutoCAD, Microsoft Office, communication, and problem solving

Chenwei Huang

- Hometown: Suzhou, China
- Background: undergraduate research assistant in transportation engineering
- Skills: research, Microsoft Excel, communication, and problem solving

Leadership Plan

To ease communication with Chris McCray, the team designated Dalton as the main point of contact. All team members have basic civil engineering experience. This experience was developed from multiple internships with local consulting firms, as well as research. Finally, all team members will contribute to the project equally according to their skills sets.

Communication Plan

The team agreed to use Microsoft Teams and external locations to hold out-of-class meetings. Regular communication will be conducted using GroupMe. Furthermore, the team will use the allotted lecture and lab time to discuss and work on the project. As stated previously, Dalton will be the main point of contact between Chris McCray and the team.

COVID-19 Safety Plan

The team agreed to wear masks when necessary to protect all parties involved. If someone tests positive, the appropriate protocols will be followed. If someone is quarantined, the remaining members will work with this member virtually so that everyone contributes equally and to the best of their abilities.

Meeting Schedule

The team agreed to conduct most meetings during class time and schedule additional meeting times as necessary. During the meetings, the team plans to delegate and communicate effectively to maintain productivity and team dynamics.

Preliminary Team Goals

- Exceed the expectations of the client
- Complete all course and assignment objectives
- Delegate work and communicate effectively
- Maintain safety for all parties involved
- Uphold and elevate public health, safety, and welfare

Tasks and Milestone Plan

The first task is to define the project scope, which will be defined after the client / site visit on January 26th. To meet milestones, the team will begin each week communicating what has been accomplished in the previous week as well as what needs to be accomplished in the week ahead to remain on track or ahead of schedule.

Team Vision

The team believes it will require hard work and dedication to achieve the desired project goals. The team will operate within its competence to design solutions that are economically feasible and that satisfy the client’s needs and expectations. Each member is expected to contribute equally to the work that will bring success to the project. Moreover, it is anticipated that each member will communicate and discuss their ideas and solutions. Ultimately, the team believes the diversity of each member’s backgrounds will be a strong asset to creating an impactful final design. Despite tough challenges ahead, the team believes the solutions developed will exceed expectations made by the client.