NAU TRAFFIC STUDY

Final Report

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CENE 486C

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List of Acronyms

Acronym	Description
TSE	Transportation & Systems Engineering
NAU	Northern Arizona University
AOI	Area of Interest
ADOT	Arizona Department of Transportation
MUTCD	Manual on Uniform Traffic Control Devices
AASHTO	American Association of State Highway and Transportation Officials
CAD	Computer Aid Draft
LIDAR	Light Detection and Ranging
LOS	Level Of Service
PHF	Peak Hour Factor
HCS	Highway Capacity Software

Acknowledgements

Transportation Systems & Engineering would like to express our deepest gratitude to Professor Edward Smaglik and Professor Brendan Russo, for their patient guidance and advice on their constructive recommendations on this project. We would also like to thank Alarick Reiboldt in his assistance in keeping our progress on schedule.

1.0 Project Understanding

This section includes background research of what the project entails and developed technical aspects to serve as a basis of the overall implications throughout the course of project. The understanding of this project will provide the overall purpose, background, and the primary stakeholders. The following sections will provide further details of these topics.

1.1 Project Purpose

The purpose of this project is to mitigate the heavy discharge of traffic and pedestrians on McConnell Drive, Pine Knoll Drive and Huffer Lane around class start/end times. Currently, Pine Knoll has two, one-way roads that divert traffic out to McConnell and Lone Tree. A second northbound lane is reserved for campus transportation vehicles until the intersection of Pine Knoll Drive and McConnell Drive. The team will perform a traffic impact analysis in order to make recommendations to best serve both vehicle and pedestrian traffic.

Figure 1.1.1 Traffic congestion from McConnell Drive onto Pine Knoll Drive [1].

Figure 1.1.1, displays the traffic congestion occurring on the project site, located on East Pine Knoll Drive during the weekday of 2017 spring semester.

1.2 Project Location

The project site is located southwest of Northern Arizona University (NAU) south campus in Flagstaff, Arizona showing in Figure 1.2. The current conditions of the Northern Arizona University’s roadway network requires the need for maintenance and improvements. It is understood that based on the background research, the major roads along McConnell Drive, Pine Knoll Drive and minor street Huffer Lane contain limited lanes that are shared with the public and public transportation. In addition to the traffic, parking lots (P61, P62, P47, and P46) will be included as part of the study.

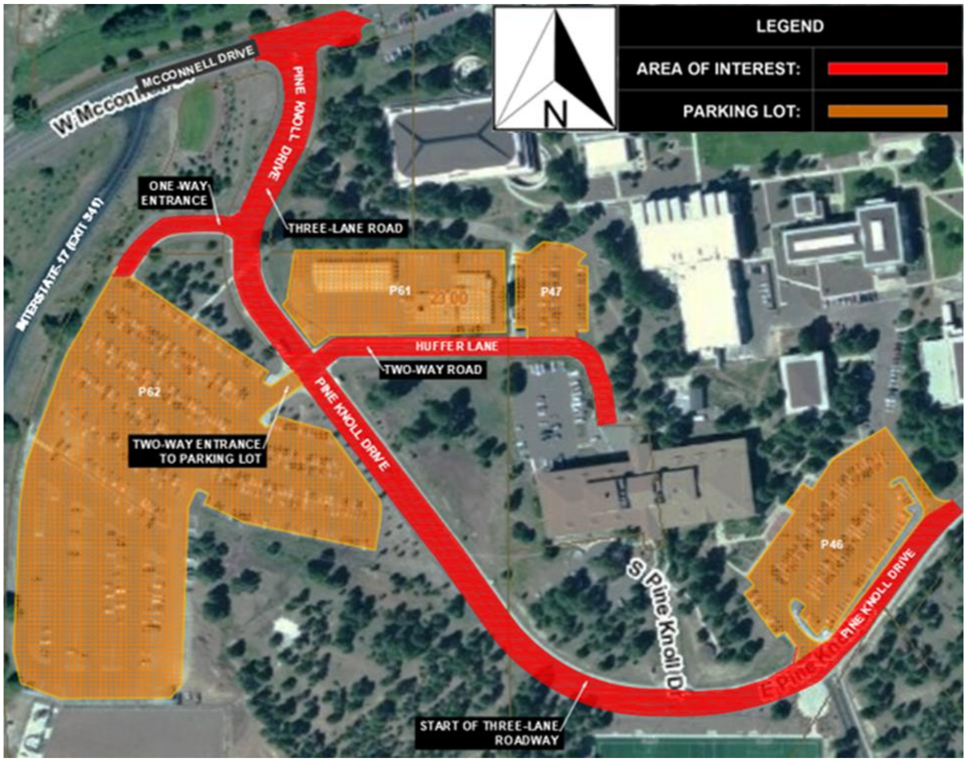

Figure 1.2. Project location at NAU South Campus [7].

Figure 1.2., reveals the project location on the NAU south campus. The hatched areas, represent the designated areas of interest, red indicating the roadways and orange indicates the parking lots. All hatched areas, are within the NAU property boundaries, the major roads are McConnell Drive and Pine Knoll Drive and the minor road is Huffer Lane.

1.3 Stakeholders

The projects client is Greg Mace, who is the Facility Service: Engineer & Inspection Associate Director of the project. The stakeholders affected by the project are the city of Flagstaff residents, establishments along the vicinity, NAU students & faculty, users exiting the freeway ramp, Arizona Department of Transportation (ADOT), and NAU itself, being that it is within their property line.

In identifying the project context, involves the community and stakeholders in identifying the current conditions of a project. The understanding of the current conditions helps in understanding the legal boundaries and constraints in order to determine the feasible solutions and sustainability goals.

2.0 Current Conditions

2.1 Analysis of Existing Data

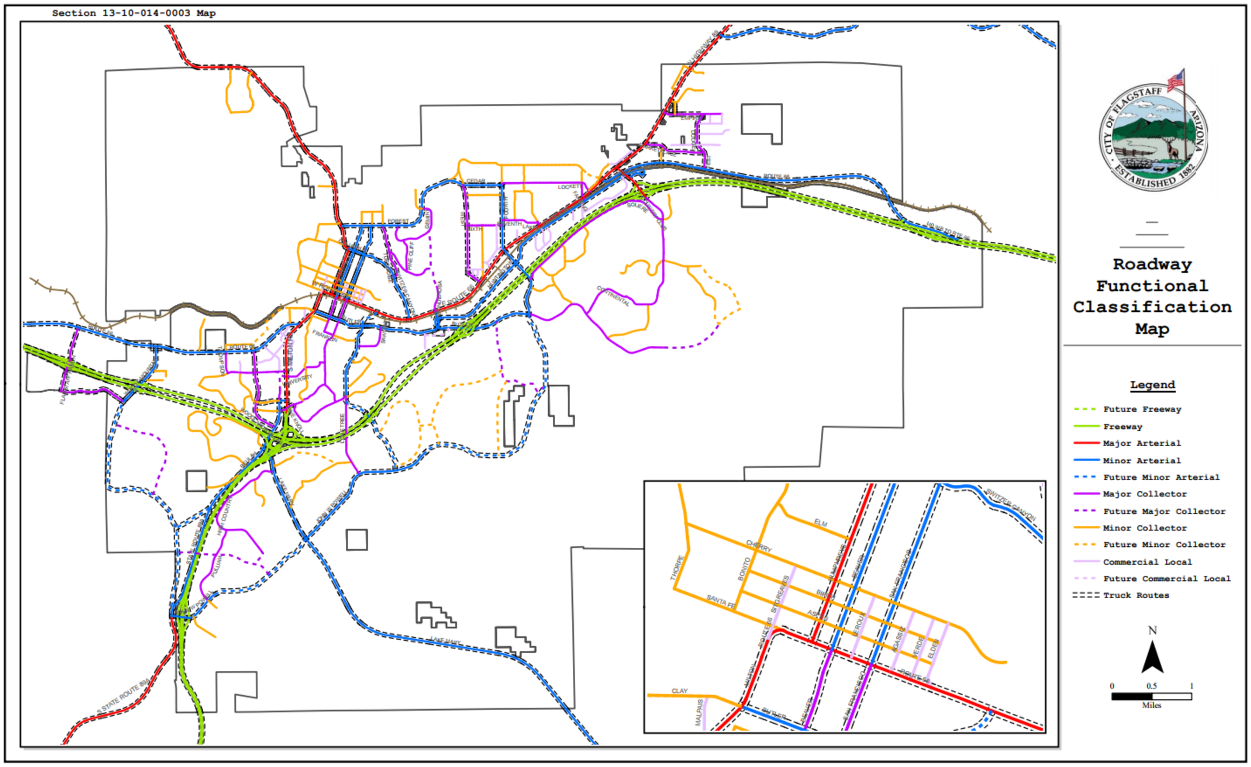

Figure 2.1. Roadway function classification map [2].

According to the City of Flagstaff, regarding figure 2.1 above, McConnell Drive and Pine Knoll Drive are considered a major collector. The topography of the area is classified as a level urban collector. A collector street links neighborhoods or areas of homogenous land use with the arterial street system.

Figure 2.2.1 McConnell Drive and Pine Knoll Drive intersection [7].

The current conditions consist of 3 intersections, and 4 parking lots, and minimal access to sidewalk usage. The figure above, is the intersection at McConnell Drive and Pine Knoll Drive, which is a common three-leg (T-intersection).

Figure 2.1.2. Pine Knoll Drive and Huffer Lane intersection [7].

The second intersection is a normal form of an unchannelized four-leg intersection. Pine Knoll Drive provides access around south campus, which contains majority of through traffic, and Huffer Lane provides access to parking lots (P62, P61, and P47) only.

Figure 2.3. Four-Lane intersection [7].

The third intersection (Figure 2.2) is another unchannelized four-leg intersection. Pine Knoll Drive continues to provide access around south campus, the northwest direction provides access to parking lot (P46) and the south direction (S Huffer Lane) provides access to the South Village apartments.

Figure 2.4. No sidewalk access at intersection of Pine Knoll Drive and McConnell Drive [7].

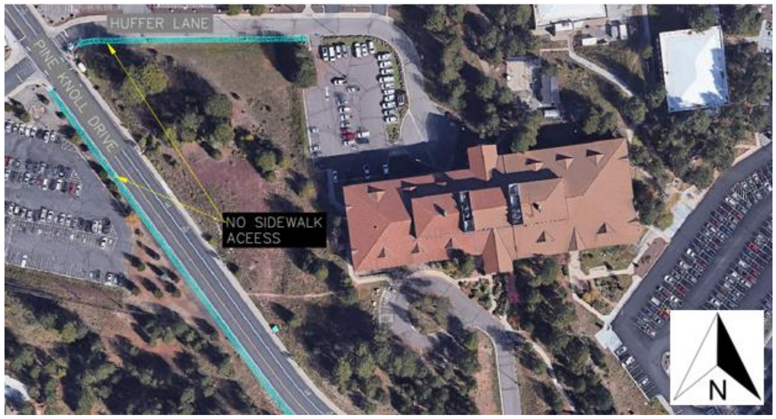

Figure 2.5. No sidewalk access along Pine Knoll Drive and Huffer Lane [7].

Access to pedestrian facilities are minimal all throughout south campus, very few sidewalk usage along the roadway, crosswalks, traffic control features, or permissible mobility impairment access. Refer to Figures 2.3 and 2.4 (above), regarding the street layout of the current issues.

There are two bus stops in the AOI, both of which were observed to increase vehicular delay. The bus stops are located in both the North and South approaches of the intersection of Pine Knoll and Huffer Lane. There is also a parking kiosk in the East approach of the intersection of Pine Knoll and McConnell. It was observed that vehicles accessing this kiosk from the east approach also impacted vehicular delay.

2.2 LIDAR Data

With the assistance from Mark Lamer, professor at Northern Arizona University; TSE obtained Lidar data from the Geographic Information System (GIS) department at the City of Flagstaff. Lidar stands for Light Detection & Ranging which is an optical remote sensing technique that uses a laser light to densely sample the surface of the earth, producing highly accurate (x,y,z) measurements [10]

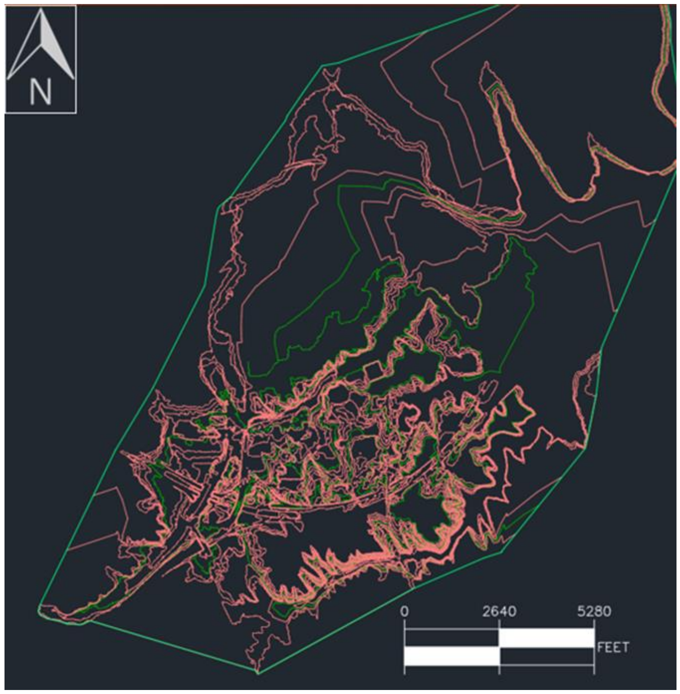

Figure 15. Contours of City of Flagstaff from LIDAR data [8].

The figure above, displays the created contours, based on the LIDAR data obtained from the City of Flagstaff. This data was imported into AutoCAD Civil 3D Imperial, to create a surface and contours of the existing ground with elevations.

2.3 Parking Lots

Current structures in the area are the parking lots (P62, P61, P47), which gives access to the Social & Behavioral Sciences West building, Huffer Lane Acquisition building, Engineering Building and the Southwest Forest Science Complex building. The parking facilities at parking lot (P62) is a resource not only for students and faculty, but for game days, summertime events in the south quadrangle and other programmable spaces on campus. The surrounding land use around south campus also contains access to the forestry, business, engineering, and social and behavioral sciences buildings, residential housing and the Walkup Skydome [9].

2.4 Transportation Behavior

First, several turning movement counts have been taken of the AOI to model the existing behavior of pedestrian and vehicular traffic. In addition to vehicular activity, the number of pedestrians and heavy vehicles was also recorded to use in further stages of the analysis. After the current traffic behavior was recorded, the data was input into HCS (Highway Capacity

Software) to calculate the current level of service. The results from HCS indicated that the intersection is currently operating at a level of service of "B." On the surface, this is presumed to be an acceptable result. However, there is a rapid discharge of pedestrian and vehicular traffic in the 20-25-minute intervals between classes which skews the results of this data. The very high delay experienced in these intervals is offset by the very low delay experienced in off peak hours. The calculated peak hour is consistent with urban streets.

The City of Flagstaff Traffic Volume Excel spreadsheet was used to determine 10 year traffic volume growth. Average daily traffic volume in the AOI in the year 2003 was 6,000 vehicles per day (veh/day). The average daily traffic for the year 2012 was 6,800 veh/day. 2012 is the most recent year traffic data is offered. Assuming the growth is consistent on a year to year basis, an approximate 10-year design volume would be 7,600 vehicles.

Information from the Police Records Coordinator, Bobbi J. Ortega and Corporal University Police, Joe Tritschler; provided traffic collision reports from 2013 to 2016. The collisions involve the area of interest, collisions by month, by day and collision classification. TSE has evaluated the crash factors and incorporated within the geometric study.

2.5 2015 NAU Landscape Master Plan

The topography of the current location, contains mountainous characteristics, containing hillock type topography and varies in elevation. The geographic features contain a Kaibab limestone, which is commonly shallow and impacts the topography with a rise in elevations. The soils throughout the location primarily consist of silty sand, along with clay present on south campus. The current vegetation on south campus is the Ponderosa Pine forest.

The mountainous terrain and natural rock outcroppings of South Campus provide a framework for the type and density of vegetation in this area. The permeable soils lend themselves to a different vegetation type and the hills and valleys provide natural variability by controlling moisture and drainage [9]. Future building development should respect the topographic characteristics of the Campus. This in combination with the preservation of mature Ponderosa Pine stands, including the native understory, is one of the most important steps to ensuring the Mountain South Campus retains its rustic character and experience [9].

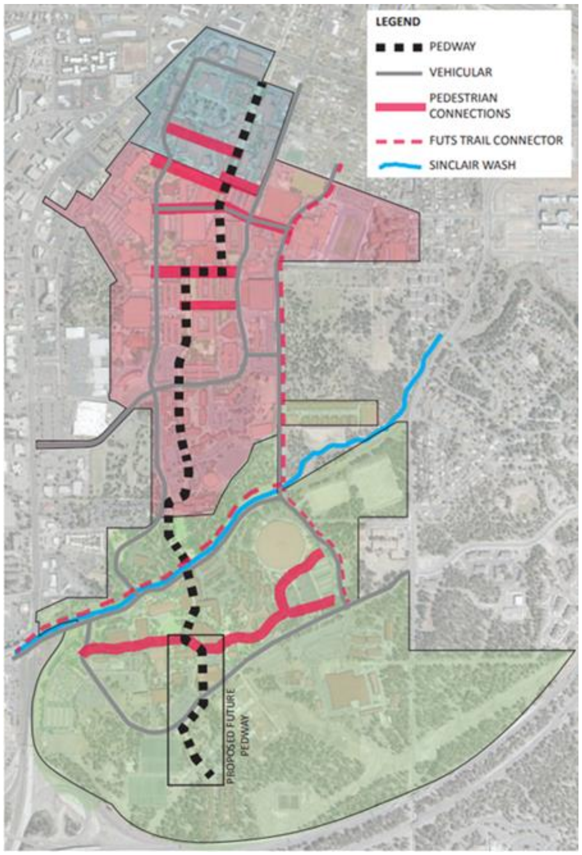

Figure 2.6. Pedway extension consideration, according to the NAU Landscape Master Plan [9].

The landscape master plan is taken into consideration due to its testimony, pertaining to campus circulation, landscape, architectural design, sustainability, seasonal considerations, and accessibility to accommodate traffic users, pedestrians and bicyclists. The campus circulation and hierarchy map for Pedway, vehicular network, pedestrian connections, and Flagstaff Urban Trails System (FUTS) trail connector, which is displayed in the figure above. Figure 2.5, displays the extension proposal, according to the NAU Landscape Masterplan. The extension connects after the McConnell Bridge and extends through south campus towards the south village apartments.

According to the 2015 Landscape Masterplan, the campus circulation's primary concern is concentrated on the Pedway which extends across north to south campus. The Pedway consist of foot traffic and bike lane with striping, but the Pedway ends a little after McConnell Drive. This leaves south campus entirely without Pedway access.

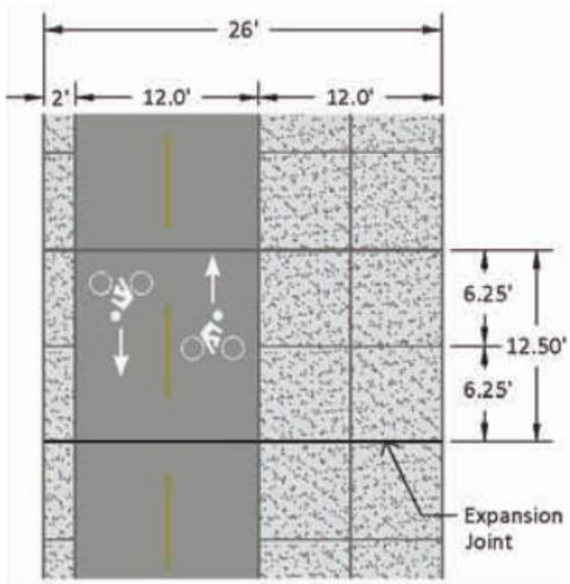

Figure 2.7. Pedway standard design from NAU [9].

The figure above, displays the standard design for a Pedway design on the Northern Arizona University campus. The entire width of the Pedway is 26 foot, to account for the fire lane width requirement, the bike lane and pedestrian walkway is 12 foot each.

2.6 Signage

The signage around the area of interest provide explicit roadway safety to users and provide very minimal uncertainties pertaining to direction. The figures displayed below, provide explicit detail of the features. Striping/Curb and Pavement Markings

TSE has evaluated the existing striping conditions and pavement markings around the area of interest. The conditions discovered within the roadway and parking lots contain ‘crack sealing’ which is a tar like substance, to seal cracks on the road. The parking lots and roadway are properly painted and visible to users. The sidewalks throughout the area, contain minor chips, cracks and displacement which requires improvements.

TSE has taken the 2015 Landscape Masterplan comments regarding Priority Implementation Projects which are bulleted below.

- Consider including a sidewalk from P62 to the South Rec Fields.
- P62 could be analyzed using a turn radius program to make sure semi-trucks are able to turn around in the parking lot.

- Consider circulation at the intersection of McConnell and San Francisco.

3.0 Traffic Impact Analysis

The volume analysis begin on September 11, 2017 through October 20, 2017 during the peak hours of the week and days of the week (Monday through Friday). The data collected will determine the design service flow rate versus the design volume, measures of congestion, and other factors that affect operating conditions and provide the levels of services (LOS).

The level of services provide the quality of traffic services and is used to analyze a particular area of interest. This information will help TSE in determining the traffic flow, assigning the quality levels that range from A to F (A being best, and F being bad).

The volume analysis, provides TSE to determine the key elements in access management for the various types of users utilizing the area of interest, which includes pedestrians, vehicles and bicyclists. Other factors, is considering the Peak Hour Factor (PHF) of the current operating conditions. The PHF is a ratio of the total hourly volume to the number of vehicles during the highest 15 minute period multiplied by 4 [13]. This PHF ratio should not be more than 1.0 and it's normal range is between 0.75 – 0.95, and this determines if the total hourly volume can be accommodated at the service level during a 15 minute congested period.

The following equation was used to compute the peak hour factor, crash modification factor and Empirical Bayes estimates:

Peak Hour Factor: Equation 1

$$PHF = \frac{V_h}{4 * V_{15}}$$

V_h: Hourly Volume

V_{15}: Highest 15 minute peak hour

Crash Modification Factor: Equation 2

$$CMF_{lr} = (CMF_{ra} - 1)P_{ra} + 1.0$$

CMF_{lr}: Crash modification for the effect of lane width on total crashes

CMF_{ra}: Crash modification for the effect of lane width on single-vehicle run-off-the-road and/or related crashes on two-lane roads

P_{ra}: Proportion of total crashes constituted by single-vehicle run-off-the-road and/or related crashes on two-lane roads. HSM default value is 0.574, but a value based on actual local data is preferable when available.

3.1 Occupancy Data

The purpose of collecting occupancy data is to estimate the amount of vehicular volume the parking lots in the area of interest contribute to overall roadway volume. To present data that accurately represents traffic conditions throughout the day, TSE performed five separate occupancy studies at both, different times of the day and different days of the week. Traffic conditions on campus are subject to repeat behavior due to the nature of class times and days.

Table 1. Parking lot occupancy data.

Parking Lot	Spaces	Average Vacancies	Occupancy
P46	55	4	51
P47	96	6	90
P62	708	97	611
P61	94	2	92

The parking lot data is a representation of the average data collected over the five day period. The data under the "Parking Lot" column corresponds to the parking lot locations. "Number of spaces" represent the total number of parking spaces available in the corresponding parking lots. "Average Occupancy" is the 5 day average of the number of vehicles parked in the corresponding parking lot.

3.2 Volume Analysis

The purpose of conducting a volume analysis is the estimate the total number of vehicles that pass through the roads in the AOI. The collected volume data occurred on different days of the week and at different times of day. The results of the volume analysis indicate that approximately 600 vehicles per hour pass through the AOI.

The table below, displays the title and description for the particular intersection legs at the intersection of East Pine Knoll Drive and South Huffer Lane.

Table 2. Description of intersection leg at Pine Knoll Drive and Huffer Lane.

Title:	Description:
SW	From P62 Parking Lot
SE	From South Fields (Pine Knoll Dr)
NE	From P61 Parking Lot
NW	From McConnell Dr/Pine Knoll Dr (Intersection)

The average peak hour factor at the intersection of Pine Knoll Drive and Huffer Lane is followed, by the intersection leg (SE, SW, NE, and NW) is 0.63, 0.62, 0.64 and 0.59, respectively. Table 3 displays the overall raw data used. The columns within the table indicate the start time data was taken place. Green indicates data collected and red indicates no data collected. The intersection leg (SE, SW, NE, and NW) each contain recordings of vehicle and pedestrian movements. The acronyms RT, TH, LT pertain to vehicle movements only, signifying the direction of the vehicle as such: right, through, and left. PED, pertains to pedestrian movement only, during the time of crossing at the intersection.

Table 3. PHF at Pine Knoll Drive and Huffer Lane.

	SE				SW				NE				NW			
Start Time	RT	TH	LT	PED	RT	TH	LT	PED	RT	TH	LT	PED	RT	TH	LT	PED
11:30:00 AM	1	36	2	0	3	1	8	0	18	1	2	0	4	30	5	0
11:45:00 AM	6	39	3	0	1	1	10	0	17	1	3	0	5	30	6	0
12:00:00 PM	5	40	5	0	2	1	12	0	13	1	3	0	5	30	7	0
12:15:00 PM	3	42	4	0	4	1	6	0	15	1	4	0	6	30	6	0
12:30:00 PM	11	38	3	0	4	1	5	0	15	1	6	0	6	35	8	0
12:45:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1:00:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1:15:00 PM	3	74	2	12	3	1	34	15	21	0	10	10	9	53	24	21
1:30:00 PM	1	13	3	6	0	1	9	3	6	0	2	5	0	12	3	18
1:45:00 PM	6	51	11	9	5	0	47	27	11	4	9	8	2	56	20	29
2:00:00 PM	7	68	2	4	12	0	44	12	24	3	4	5	1	45	15	8
2:15:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2:30:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2:45:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3:00:00 PM	1	39	0	0	1	2	10	0	25	0	7	0	6	35	1	0
3:15:00 PM	3	37	1	0	0	1	12	0	25	1	6	0	8	35	2	0
3:30:00 PM	2	38	1	0	1	1	7	0	25	1	7	0	7	35	2	0
3:45:00 PM	3	39	0	0	0	2	6	0	18	0	7	0	4	25	3	0
4:00:00 PM	2	41	2	0	3	0	12	0	20	0	5	0	8	35	5	0
4:15:00 PM	3	44	3	0	1	0	11	0	19	0	4	0	6	35	3	0
4:30:00 PM	1	46	3	0	3	1	10	0	20	1	4	0	8	34	4	0
4:45:00 PM	2	46	3	0	1	1	10	0	15	0	3	0	9	25	4	0
5:00:00 PM	2	46	3	0	1	1	12	0	19	0	1	0	5	24	3	0
	SE				SW				NE				NW			
	RT	TH	LT	PED	RT	TH	LT	PED	RT	TH	LT	PED	RT	TH	LT	PED
	62	777	51	31	45	16	265	57	326	15	87	28	99	604	121	76
Hourly Volume	15	190	11	31	8	5	44	57	88	3	21	28	29	146	20	76
15min Peak	5	81	5	12	3	2	19	27	38	1	9	10	13	63	8	29
PHF:	0.75	0.59	0.55		0.67	0.63	0.58		0.58	0.75	0.58		0.56	0.58	0.63	
		0.63				**0.62**				**0.64**				**0.59**		

3.3 Delay Analysis

The average delay was computed using HCS (Highway Capacity Software). The purpose of determining vehicular delay is a baseline of delay to be used when recommending potential design solutions. For example, if delay is not a problem, then TSE will not recommend a design solution that is more appropriate to address issues with delay.

3.4 Vehicle Classification Study

The purpose of a vehicular classification study is to determine the design vehicle for the area of interest. This study was performed by observation and utilizing the 2015 NAU Master Plan, in respects to the campus bus system, 'this encourages students to utilize the existing campus transit and reduces traffic and the need for parking within the campus core.' For the purpose of a geometric design, a vehicle is selected to accommodate its weight, dimensions and operational situations.

The table below, displays the raw data of the number and percentage of vehicles per classification. The standard follows, the Federal Highway Administration (FHWA) class group and definition. The vehicles collected, is based off each intersection leg at Pine Knoll Drive and Huffer Lane, with the number of vehicles passing through and its respected class. The intersection leg titles (NE, SE, NW, and SW) follow the description from Table 2. For instance, NW pertains to the vehicles entering from the McConnell Drive and Pine Knoll Drive intersection. The total number of vehicles for a given hour, that entered was 245 vehicles. The pink highlight, indicates the high percentage and high number of vehicles, which was Class 2, 3, and 4.

Table 4. Vehicle classification data at Pine Knoll Drive and Huffer Lane intersection.

	NW		SE		NE		SW	
Class	**Number of Vehicles:**	**Percent of Vehicles**	**Number of Vehicles:**	**Percent of Vehicles**	**Number of Vehicles:**	**Percent of Vehicles**	**Number of Vehicles:**	**Percent of Vehicles**
1	1	0.4%	0	0.0%	1	1.9%	0	0.0%
2	98	40.0%	81	39.5%	38	71.7%	71	66.4%
3	85	34.7%	63	30.7%	14	26.4%	36	33.6%
4	60	24.5%	61	29.8%	0	0.0%	0	0.0%
5	1	0.4%	0	0.0%	0	0.0%	0	0.0%
6	0	0.0%	0	0.0%	0	0.0%	0	0.0%
7	0	0.0%	0	0.0%	0	0.0%	0	0.0%
8	0	0.0%	0	0.0%	0	0.0%	0	0.0%
9	0	0.0%	0	0.0%	0	0.0%	0	0.0%
10	0	0.0%	0	0.0%	0	0.0%	0	0.0%
11	0	0.0%	0	0.0%	0	0.0%	0	0.0%
12	0	0.0%	0	0.0%	0	0.0%	0	0.0%
13	0	0.0%	0	0.0%	0	0.0%	0	0.0%
14	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total:	245		205		53		107	

The selected design vehicle is class 4, which is a bus with two axles and six tires or three or more axles [8]. The table shows the highest percentage and total number of classified vehicles overall that pass through the intersection of Pine Knoll Drive and Huffer Lane.

Table 5. Classified vehicles at the intersection of Pine Knoll Drive and Huffer Lane.

Class	Total # of Vehicles	Total Percent of Vehicles
2	288	47.2%
3	198	32.5%
4	121	19.8%

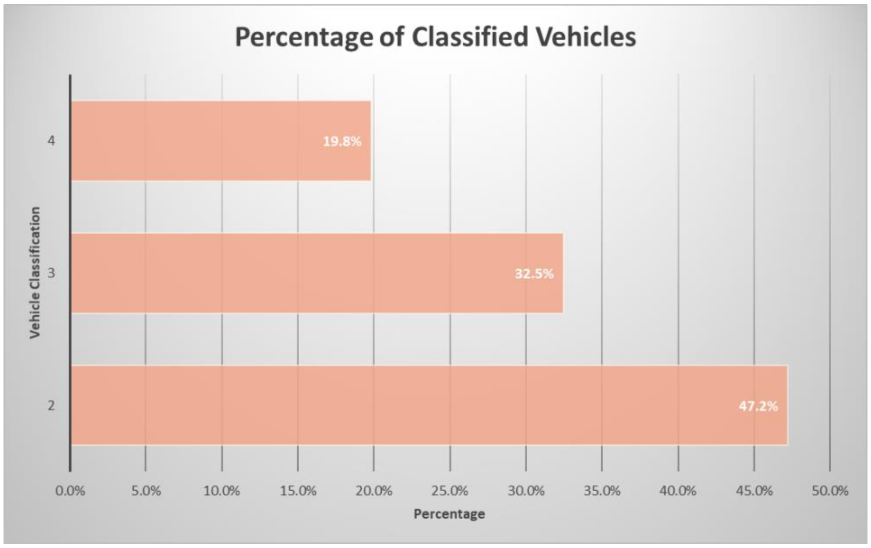

Figure 3.1. Graphical representation of Table 5.

The figure above, reveals the graphical representation of table 5. Table 6, below reveals the class types dimensions, which will be considered as a constraint for the design alternatives and ensure adequate performance throughout the project site.

Table 6. Class type dimensions.

			Dimensions (ft)								
Class	Type	Symbol	Height	Width	Length	Front	Rear	Minimum Design Radius	Centerline Turning Radius	Minimum Inside Radius
2	Passenger Cars	P	4.25	7	19	3	5	24	21	14.4
3	Single Unit Truck	SU	11-13.5	8	30	4	6	42	38	28.3
4	Buses	S-BUS-36	10.5	8	35.8	2.5	12	38.9	34.9	23.8

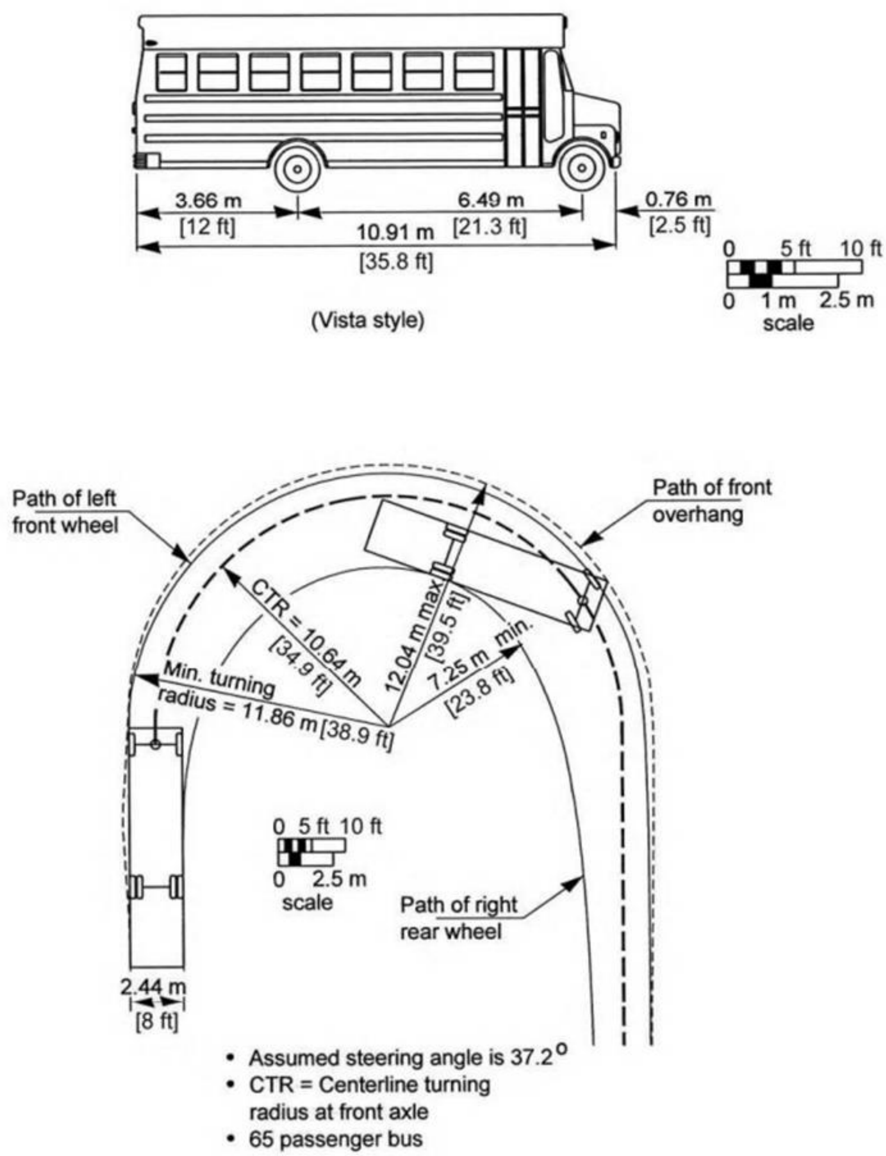

Exhibit 2-8. Minimum Turning Path for Conventional School Bus (S-BUS-11 [S-BUS-36]) Design Vehicle

Figure 3.2. Class 4 minimum turning path [8].

Figure 3.2 shows the minimum turning path, steering angle and radius of the front axle for a class 4 vehicle type.

4.0 Design Alternatives

Considering the current conditions, background information and traffic impact analysis collected along with abiding by the NAU landscape master plan, the proposed design alternatives considered are a roundabout, and pedestrian footbridge.

4.1 Roundabout

The first design criteria is design traffic volume. This has already been accounted for in a previous step. The 10-year design traffic volume is 7,600 vehicles per day.

Design speed – The ASSHTO Green Book calls for a design speed of 30mph on collector streets.

Sight Distance – Exhibit 6-1 from the AGB indicates that a design speed of 30mph warrants a stop sight distance of 200ft and crest/sag rates of 19 and 37%, respectively. By Exhibit 6-4, the maximum grade is 9% and the minimum drainage is .5% to facilitate drainage. The alignment in residential areas should fit closely with the existing topography to minimize the need for cut/fill sections. The pavement cross slope should be between 1.5 to 3%. The width of the roadway, as well as any additional lanes should be 10-12ft. Additional consideration should be given to the design vehicle for the area of interest. The design vehicle was determined to be the NAU bus via a vehicle classification study. Parking lanes have been excluded from consideration due to the proximity of parking lots P61, P62, P46 and P47.

Sidewalks should be provided on both sides of the urban collector streets that are used for pedestrian access to schools. The minimum sidewalk width is 4ft. The vertical clearance at underpasses should be 14ft over the width of the roadway.

Other design criteria for the urban collector includes horizontal clearance, right of way width, provision for utilities, border area, intersection design, street and roadway lighting, traffic control devices, erosion control and landscaping.

4.2 Pedestrian Bridge

The pedestrian bridge will abide by the AASHTO Proposed Guide Specifications for the Design of FRP Pedestrian Bridges. The general design criteria applied, for the design load for the main supporting members, including girders, trusses, and arches, will be designed for a pedestrian live load of 85 pounds per square foot (psf). The secondary members such as the bridge deck and supporting floor system and floor beams will be designed for a pedestrian live load of 85 psf, with no reduction allowed. The vehicle load will conform to the AASHTO standard H-5 Truck at 10,000 pounds (lbs), based on the clear deck width from 6 to 10 feet. The deflection due to the service pedestrian live load should not exceed 1/500 of the length of span. The clearance will be at 14 feet above Pine Knoll Drive roadway, minimize the impact on the existing utilities and abide by the ADA standards to minimize costs. The bridge structure will comply with the ADA standard of an access ramp, with the grade being more than 5% but less than or equal to 8.3% and will contain a pedestrian access route.

5.0 Final Design

5.1 Geometric Design

The geometric design for the proposed roundabout and pedestrian bridge, describe the full details regarding the engineering aspects of each design.

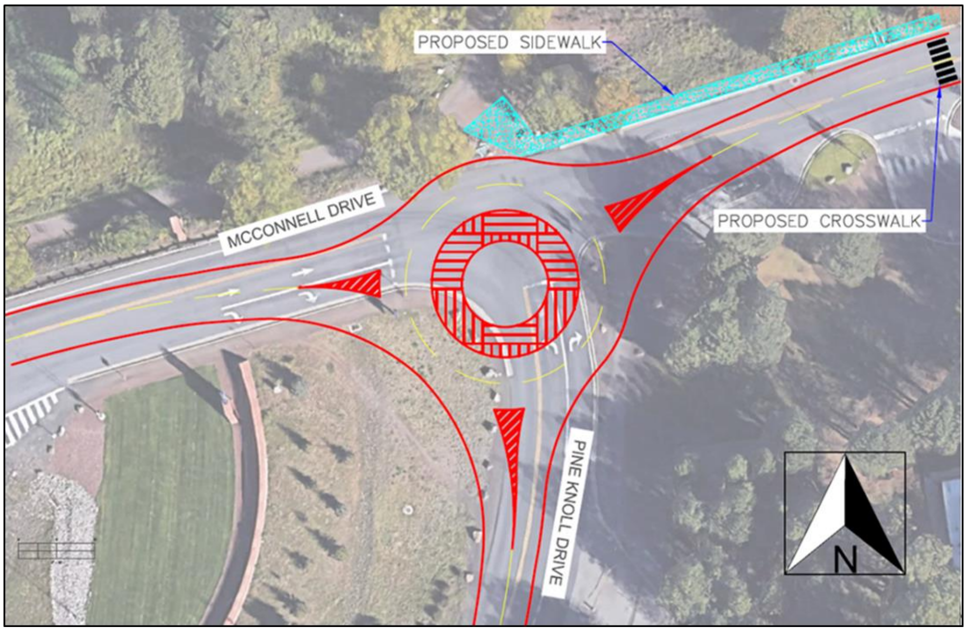

Figure 5.1. Proposed roundabout general design and location at McConnell Drive and Pine Knoll Drive intersection [6&7].

Figure 5.1, provides the general design layout and location for the proposed roundabout. The following dimensions for the roundabout shown above, has an entry radius of 110 feet for each arm, the center island contains a diameter of 37.82 feet and apron diameters of 64.06 feet. The entry angles for each arm, starting from the McConnell Drive East, Pine Knoll Drive South, and McConnell Drive West entrances, contain angles of 32.899, 31.799, and 30.674 degrees, respectively. For further details, regarding the roundabout design, refer to Appendix B.

Table 7, provides the Level of Service results for the proposed roundabout, based on the current conditions, without pedestrian conflicts, which resulted in a LOS of A. The LOS of A; defines the qualitative measures of operational conditions with a traffic stream and the letter A, signifies traffic free flows for the given speed parameters and have completed mobility between lanes. The HCS software, does not account for speed, but based on the current conditions from the data collected at McConnell Drive and Pine Knoll Drive intersection, with the input of the peak hour factor, determines the appropriate algorithm to determine the results. The table below provides the representation of Figure 5.1, revealing there is no North bound arm for Pine Knoll Drive.

Table 7. Roundabout Level of Service outputs.

	Roundabout Analysis (Current Conditions)											
	Intersection: Pine Knoll Drive & McConnell Drive											
	Analysis Year: 2017						Project ID: NAU Traffic Study					
	McConnell Drive						**Pine Knoll Drive**					
	EASTBOUND			WESTBOUND			NORTHBOUND			SOUTHBOUND		
	LEFT	THRU	RIGHT	LEFT	THRU	RIGHT	LEFT	THRU	RIGHT	LEFT	THRU	RIGHT
Volume:	84		162	154		212				322		95
PHF:	0.86			0.86						0.86		
PEDS:	0			0						0		
Flow Rate:	101		194	184		254				386		114
	Capacity and Level of Service											
V/C Ratio:	0.11		0.21	0.27		0.25				0.38		0.1
Lane Delay:	5		6	8.6		6.1				7.7		4.2
Lane LOS:	A			A						A		
95% Queue	0.4		0.8	1.1		1				1.8		0.3
	Approach:											
Delay:	5.64			7.13						6.9		
LOS:	A			A						A		

Software: Highway Capacity Software 2010 Roundabouts 6.1

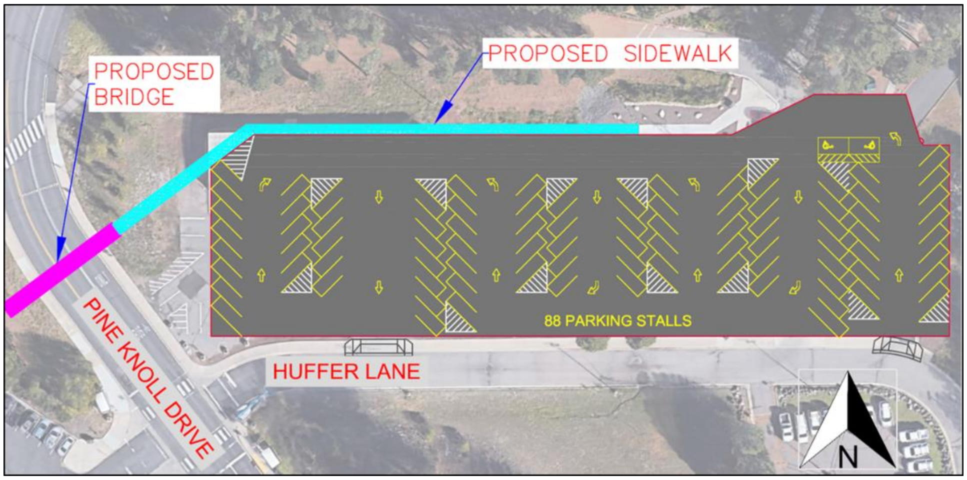

Figure 5.2. Proposed location of the pedestrian bridge and redesign of parking lots (P61 & P47) at Pine Knoll Drive and Huffer Lane intersection [6&7].

Figure 5.2, displays the proposed location for the pedestrian bridge, near the Pine Knoll Drive and Huffer Lane intersection. In order for the pedestrian bridge to be implemented, the following conditions, need to be considered: relocation of the bus stops, removal of all existing crosswalks, removal of the Acquisition Lane Building, redesign of the parking lots (P61 and P47) and a proposed sidewalk that ties into the proposed bridge and existing sidewalk north of the parking lot, displayed in the figure above. The parking lots, abide by the City of Flagstaff parking standards regarding a one-way drive aisle with parking stalls angled at 45 degrees. The reasoning for the redesign of the parking lots, is due to the parking facilities at this proximity is a resource not only for students and faculty, but during athletic events, graduation, public events, the parking lot can be utilized as a source of transporting users, the parking lot is not curbed and is free to drive across the parking stalls. The reason for this, is to accommodate for the heavy snow storms and allow the NAU snow plow, to have free access, throughout the parking lot. The determination of student or faculty parking lot, is entirely up to the NAU campus Parking and Shuttle Services.

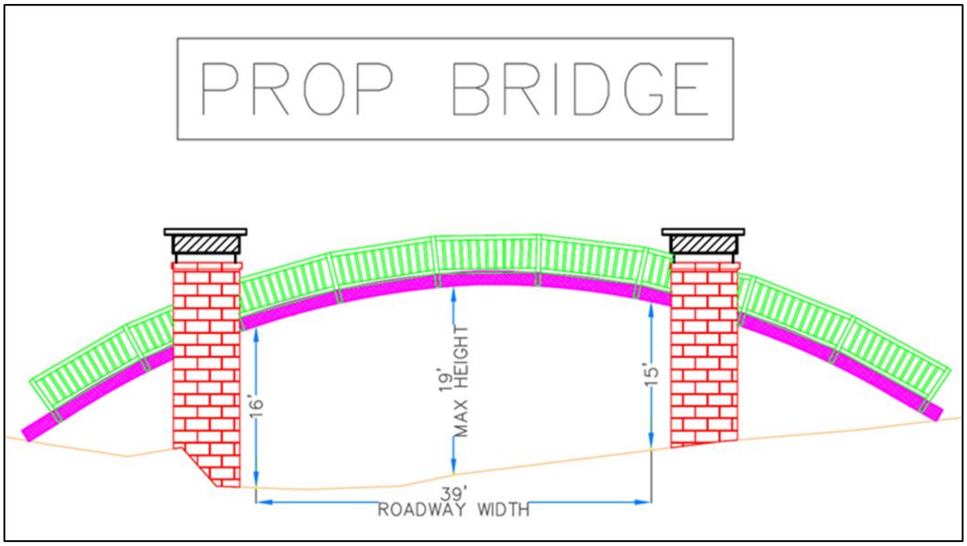

Figure 5.3. Proposed bridge design [8].

Figure 5.3, demonstrates the proposed bridge at the intersection of Pine Knoll Drive and Huffer Lane. The bridge is arced, since the existing roadway will not be adjusted, with a maximum height of 19 feet above the existing roadway centerline. The access ramp from the left (based on Figure 5.3) contains a grade slope of 6.23% and the access ramp to the right contains a grade slope of 5.70%; which will accommodate for ADA accessibility. The length of the bridge is 89 feet and the arc length is 95 feet. For further details, regarding the plan and profile of the proposed bridge can be seen in Appendix A.

5.2 Impact Assessment

The features needed to be protected is the existing roadways of Pine Knoll Drive and Huffer Lane. The emergency route North East of Pine Knoll Drive cannot be modified as it provides a route for emergency medical response to both the Engineering building and Social and Behavioral Sciences – West.

The features needed to be enhanced are the parking lots of P62, P61, and P47. Included, is the ground work for cut and fill, to accommodate a pedestrian footbridge and roundabout at the designated locations. There will be a provided sidewalk access at parking lot P62, along Pine Knoll Drive to the South Fields, and tie back into both proposed pedestrian footbridges. Both the bus stop locations will be enhanced, at the intersection of Pine Knoll Drive and Huffer Lane for pedestrians to have access to the proposed pedestrian footbridge.

The features needed to be amended is the Huffer Lane Acquisition building to be removed and/or replaced, due to the limited space to accommodate the pedestrian footbridge and Pedway access. The crosswalk will also be amended between, McConnell Drive and Huffer Lane intersection.

The current economic impacts correspond to the design alternatives. The current Operations & Maintenance cost is based off the Planning, Design, and Construction Capital Project Report from October 4, 2017; regarding Asphalt Parking Lots 2017, Asphalt Streets 2017, and Campus-Wide Curb Replacement Assessment. The budget for Asphalt Parking Lots 2017 is $500,000, which entails funding for the annual campus wide parking lot maintenance and repair. The Asphalt Streets 2017 is $509,000, which also entails the funding to continue to implement annual paving related improvements on the streets around NAU’s Mountain Campus. The Campus-Wide Curb Replacement Assessment budget is $25,000, which involves a design professional to provide an assessment of damaged curb throughout campus, requiring engineered design such as tunnel interface, storm drain network, or ADA curb ramps and sidewalks [16].

The expected project budget for an Asphalt 2018 Streets, will be funded $325,000 in funding to implement annual paving related improvements on streets around the NAU campus. According to the Planning, Design, and Construction Capital Project Report, the proposed 2018 repair and maintenance locations have not yet been assessed and scoped but will likely includes various asphalt maintenance treatments including Chip Seals, Full-Depth Asphalt Patching, Crack Fill, & misc. Concrete repairs. NAU's roadway infrastructure is a critical component to campus transit, safety, and overall exterior aesthetics to campus [16].

In the previous completions, the planning was dated in February 2016 was the North/South Pedway Improvements was funded a total budget of $4,059,092. This entailed the removal and replacement of the existing Pedway surfaces (asphalt and pavers) for replacement with new decorative concrete hardscape, new surrounding landscape, new site furnishings, minor utility repairs, storm drainage improvements, ADA improvements, & site lighting improvements in accordance with the new Campus Landscape Master Plan [16].

5.3 Cost of Implementing Design

5.3.1 Roundabout

The expected project budget to construct a roundabout is $250,000. This figure includes the cost of concrete, striping, construction and other construction related materials. The roundabout has been designed to accommodate for 25 years of growth. Maintenance costs will include pavement resurfacing, potential landscaping and lane striping maintenance. The AASHTO Green Book is the primary reference for this design. Specifically, chapters 2, 3, 6 and 9 were used for this design.

5.3.2 Pedestrian Footbridge

The determination of the cost, is supported by the National Cooperative Highway Research Program (NCHRP) Report 552: Guidelines for analysis of investments in Bicycle Facilities. The benefit cost analysis tool, consist of determining the preliminary cost estimates for new bicycle facilities such as costs, demand and benefits. The pedestrian footbridge is incorporated into the benefit cost analysis tool, using the overpass maximum range of $250 per square foot. The cost model provides capital costs, including construction, procurement and installation of equipment, design and project administration costs [15]. The costs are based on the standard facilities constructed in the continental United States, representing the year 2002 dollars. The tool adjusts for the inflation to the project build year and variations in the construction costs, to account for contingencies such as the preliminary cost and unexpected project specifications. The total build year capital costs is 2022, due to the midpoint of the construction; accounting for “if construction is predicted to take 4 years and will start in 3 years (from 2017), the project completion year will be 2022.”

The total build year capital cost is $985,524 for a pedestrian footbridge. Tables 7 and 8 below, reveals the itemized facility costs regarding the construction costs, equipment costs, overall project contingency, base year capital costs, build year capital costs and operations and maintenance costs. The total construction cost is $476,865; the total equipment cost is $920 and the total operations and maintenance is $593 per year.

Table 8. Facility cost for a pedestrian footbridge [13].

Facility Costs								
		Input	Itemized COSTS					
ITEM	DESCRIPTION	Units	Length (Feet)	Width (Feet)	Depth (Inches)	Default Unit Cost (2002)	UNIT	Itemized Cost
	City	Flagstaff						
	State Code	AZ						
	Build Year	2017						
1	Roadway Construction							
1.1	Earthwork							
1.11	Clearing and Grubbing		482	6		$1,703	ACRE	$113
1.12	Excavation		443	6	6	$15	CU YD	$738
1.13	Grading		443	6		$2,555	MILE	$129
1.14	Pavement Removal		24	6	6	$14	CU YD	$37
1.15	Curb/Gutter Removal		6			$4	L FT	$1
-	Earthwork Contingency					10%		$98
1.2	Pavement							
1.21	Portland Cement Concrete Pavement		482	6	5	$142	CU YD	$6,337
1.22	Bituminous Concrete Pavement				3	$135	CU YD	$0
1.23	Crushed Stone Surface				3	$37	CU YD	$0
1.24	Aggregate Base		482	6	4	$28	CU YD	$1,000
1.25	Curbing		24			$22	L FT	$524
1.26	Curb Ramps	0				$1,068	EACH	$0
1.3	Drainage							
1.31	Storm Drains		1			$113	L FT	$113
1.4	Pavement Markings							
1.41	Bicycle Arrow	0				$53	EACH	$0
1.42	Bicycle Symbol	0				$71	EACH	$113
1.43	Bicycle Box (colored pavement)	0	8	5		$9	SQFT	$0
1.44	Lane Striping		0			$3,266	MILE	$0
1.45	Shared Lane Marking (sharrow)	0				$71	EACH	$0
1.5	Landscaping							
1.51	Landscaping - Grass		0	0		$1,363	ACRE	$0
1.52	Landscaping - Trail		0			$27,188	MILE	$0
1.53	Root Dams		0			$11	L FT	$0
2	Structures							
2.1	Bridge							
2.12	Bridge Deck (concrete or steel)	1	135	10		$250	SQFT	$337,500
2.13	Abutments	2				$17,273	EACH	$34,545
-	Bridge Contingency					10%		$9,418
2.2	Underpass							
2.21	Underpass		0			$3,840	L FT	$0
-	Construction Estimate							$112,690
-	Location Index					100%		$0
-	Construction Contingency					10%		$11,269
	TOTAL CONSTRUCTION COST							$476,865

Table 9. Facility cost for a pedestrian footbridge [13].

3	Equipment							
3.1	Signs							
3.12	Sign with Post	2				$200	EACH	$400
3.2	Traffic Signals							
3.21	Bicycle Signal	0				$10,000	EACH	$0
3.22	Pedestrian Signal Activation - 4 Way	0				$3,900	EACH	$0
3.23	Pedestrian Signal Activation - 2 Way	0				$1,900	EACH	$0
3.24	Loop Detector	0				$1,500	EACH	$0
3.3	Barriers							
3.31	Trail Gates	0				$1,500	EACH	$0
3.32	Trail Bollards	4				$130	EACH	$520
3.33	Fencing		0			$13	L FT	$0
3.4	Parking							
3.41	Bicycle Rack (Inverted U, 2 bicycles)	0				$190	EACH	$0
3.42	Bicycle Rack (Ribbon or similar, 6 bicycles)	0				$65	PER BIKE	$0
3.43	Bicycle Locker (2 bicycles)	0				$1,000	EACH	$0
3.44	Bike Station					$200,000	EACH	$0
3.5	Conveyance							
3.51	Bus Rack	0				$570	EACH	$0
3.52	Interior Train Rack					$0	EACH	$0
3.6	Lighting							
3.61	Street Lights	2				$3,640	EACH	$7,280
3.7	Security							
3.71	Emergency Call Boxes	1				$5,590	EACH	$5,590
3.72	Security Cameras	1				$7,500	EACH	$7,500
	TOTAL EQUIPMENT COST							$920
-	Administration (Construction)					6%		$28,667
-	Planning (Construction)					2%		$9,556
-	Design/Engineering					10%		$47,778
-	Field Inspection					2%		$9,556
	SUBTOTAL PROJECT COST							$573,341
-	Project Contingency					30%		$172,002
	TOTAL BASE YEAR CAPITAL COST					1	2002	$745,344
	TOTAL BUILD YEAR CAPITAL COST					0	0	$985,524
5	Operations and Maintenance							
5.1	Maintenance		482			$6,500	MILE/YR	$593
	TOTAL OPERATIONS AND MAINTENANCE							$593

The Demand and Benefits Results account for the Facility Costs for a pedestrian footbridge (Table 7 and 8), the existing commuter bicyclists near the proposed design alternative and the induced number of new bicyclists due to the number of existing commuters. The steps require a demand of the commute share within a 1.5 miles of the facility, followed by the residential density of the location per square mile and facility length of the proposed facility length. Based off the demand, the following assumptions are determined: daily existing bicycle commuters, new commuters, which then determines the readily-available census commute shares to extrapolate total adult bicycling rates (low, mid, and high estimates) according to the U.S. Census commute shares to National Household Transportation Survey (NHTS). Next, the annual benefits are determined regarding recreation, mobility, health, and decreased auto use, in respects to their total adult bicycle rates (low, mid and high estimates).

The benefits for mobility, reveals the amount of reduced compensation, based on the number of daily existing and induced commuters, going to and from work or school per trip, daily and annually, assuming the hourly value of time is $12. The health and recreation benefits, it is assumed that pedestrian facilities would generate $128 per year in health to new pedestrians who did not formerly engage in physical activity [15]. The decreased auto use benefit provides a decrease in vehicular and pedestrian congestion, improved air quality, decrease in the use of non-renewable energy and reduced monetary benefits in health.

According to the City of Flagstaff Multimodal Transportation Information, regarding the percent mode bicycle commute share for NAU students is .60%. The population density of Flagstaff, Arizona is 831.9 people per square mile, according to the Statistical Atlas. The proposed facility length in linear feet is 482 feet (146.9 meters).

Demand and Benefits Results

Costs

Total build year capital cost	$985,524
Annual operations and maintenance	$593

Demand

In a one and half mile (2,400 m) radius around the proposed facility:

	Low Estimate	Mid Estimate	High Estimate
Residents	6,039	6,039	6,039
Existing Commuters	14	14	14
New Commuters	4	4	4
Total Existing Cyclists	75	1,044	1,553
Total New Cyclists	26	307	454

Annual Benefits

	Low Estimate	Mid Estimate	High Estimate
Recreation	$79,180	$1,103,921	$1,642,345

Mobility - Proposed Facility Type	Per Trip	Daily	Annually
Off Street bicycle trail	$4.08	$76	$17,923

	Low Estimate	Mid Estimate	High Estimate
Health	$3,314	$39,250	$58,132
	Urban	**Suburban**	**Rural**
Decreased Auto Use	$23	$14	$2

Figure 5.4. Demand and benefits results for a pedestrian footbridge [13].

The figure above, displays the demand and benefits of the proposed pedestrian footbridge, based on the current demands within the City of Flagstaff. The total build year capital cost is $985,524, reflecting the year 2022. The demand displays the increase in bicyclists for Flagstaff on the NAU campus, based on the current population density and existing bicyclists around a one and half mile radius of the proposed facility. The annual benefits reveal an increase in recreation, mobility, health and decreased auto use for a given trip, daily commute and annual commute;

which would save the NAU campus thousands of dollars from their current operations and maintenance due to mobility, decreases the auto use, which respects NAU's environmental issues in respecting the topographic characteristics of the campus, preserving the vegetation and ensuring south campus retains its rustic character. Overall, the pedestrian footbridge provides a resolution in alleviating the traffic congestion, in providing pedestrian and bicyclist's access through south campus without disrupting the vehicular flow.

6.0 Summary of Project Costs

The summary of the overall project, reflects back from the proposal and the project actually carried out throughout the course.

6.1 Gantt Chart Comparison (Proposal & Final)

Table 10, demonstrates the proposed hours based on the proposal for completing the overall project, which is displayed at 600 hours, in the Total Hours column. The actual hours performed throughout the fall 2017 semester, totaled at 473 hours. The following hours adjusted due to the unexpected contingencies, for instance Task 2, in regards to Mapping and Surveying due to the City of Flagstaff GIS department providing the latest LIDAR data of the existing conditions of the project site.

Table 10. Projected hour's comparison from proposal to actual hours.

Projected Hours						
Task	Senior Engineer	Project Engineer	Engineer in Training	Intern	Total Hours	Actual Hours
Task 1: Field Evaluation						
1.1 Analysis of Existing Data	10	20	35	35	100	70
Task 2: Mapping and Surveys						
2.1 Establish Survey Control	2	8	8	8		
2.2 Topographic Surveys	2	8	32	32	100	25
Task 3: Site Characterization						
3.1 Traffic Impact Analysis	Total Sum:	28	66	131		
3.1.1 Occupancy Data	3	8	25	35		
3.1.2 Volume Analysis	3	8	16	35		
3.1.3 Delay Analysis	2	8	15	35		
3.1.4 Vehicle Classification Study	1	4	10	26	234	207
Task 4: Design						
4.1 Geometric Study	3	5	20	20		
4.2 Environmental	2	8	15	16		
4.3 Social	2	6	15	16		
4.4 Economical	2	8	20	8	166	171
				Total	600	473

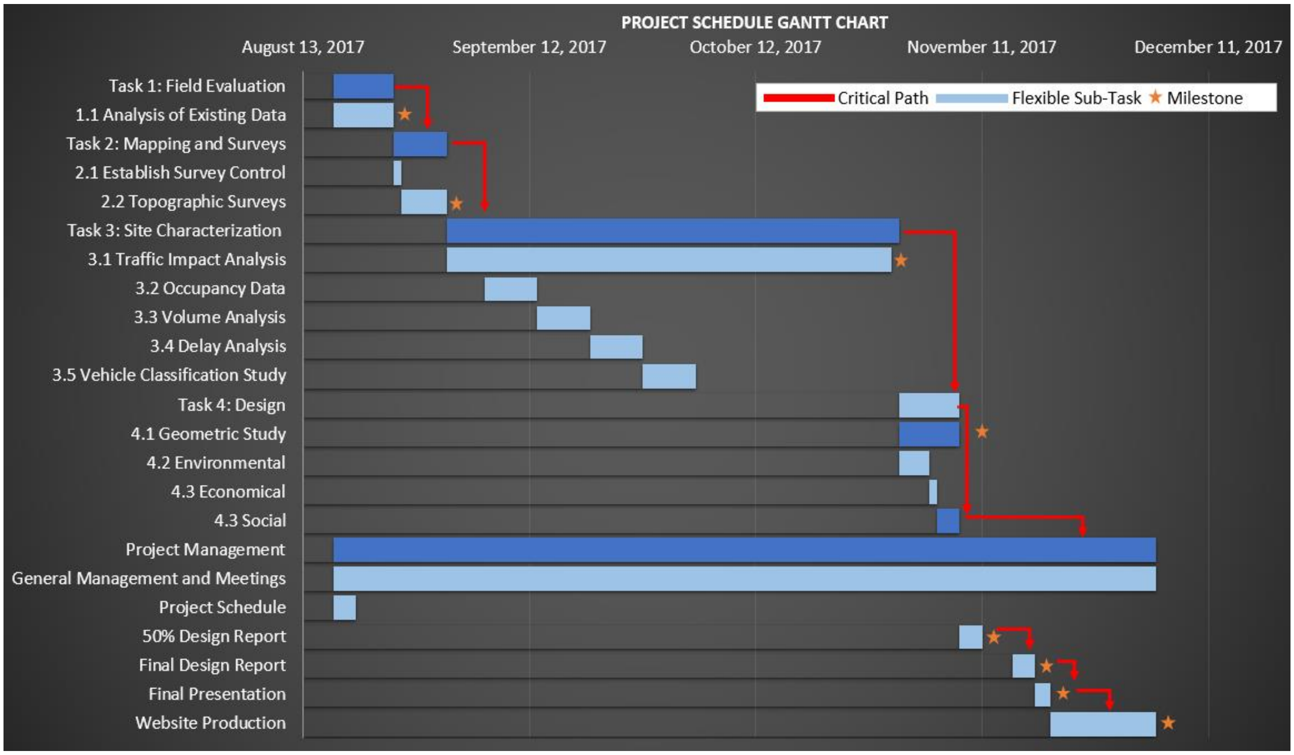

Figure 5.5. Original Gantt chart from proposal.

Figure 5.5, displays the original Gantt chart from the proposal prescribed to the client regarding the project schedule. The hours are associated to Table 10, in respects to the total hours of 600. The Gantt chart is used in project management, in displaying specific tasks and their expected deadlines, in order to managing time within a team.

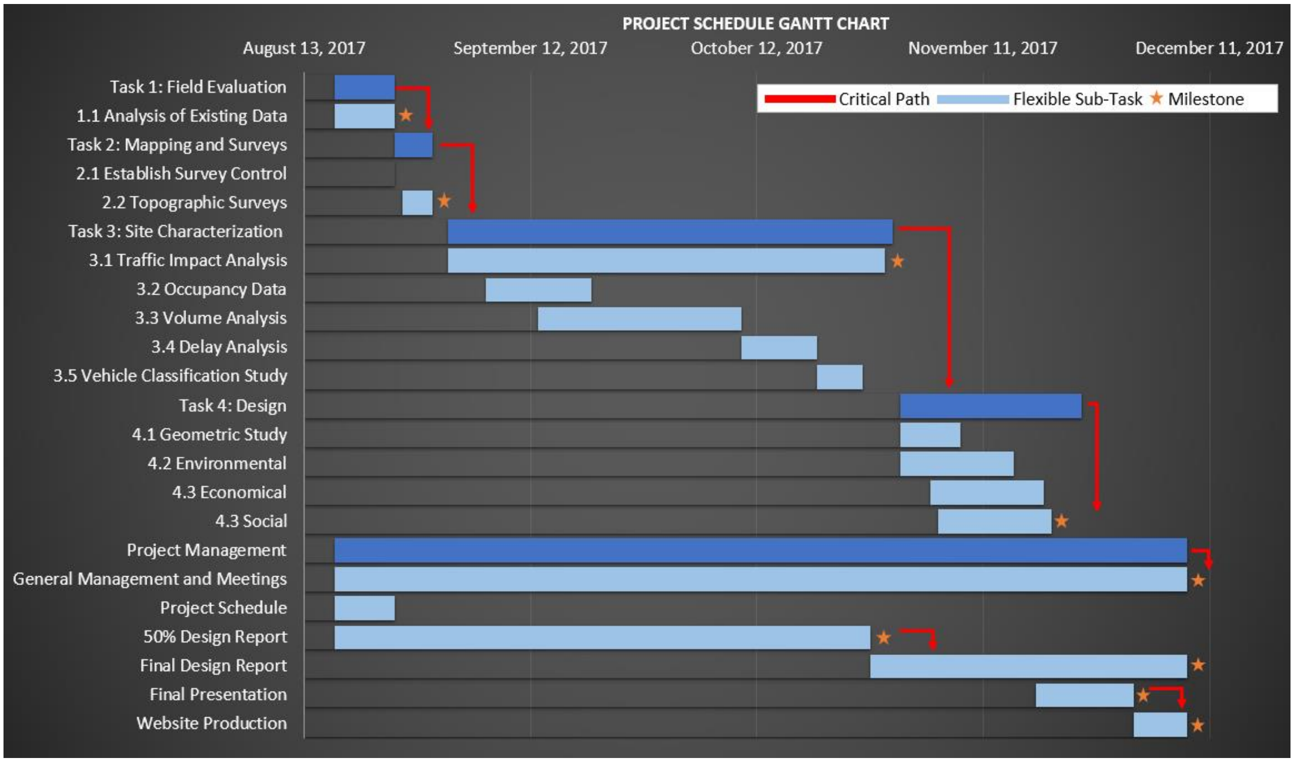

Figure 5.6. Final Gantt chart from after completion of project.

Figure 5.6, displays the final Gantt chart after the completion of the overall project. The hours are associated to Table 10, in respects to the actual hours of 473. The comparison between the original and final Gantt chart, reveals major changes from the overall tasks. This is due to the amount of the unexpected contingencies throughout the course of the project, such as the amount of hours or days a task was needed to get done, the additional resources or research required on specifics regarding the proposed design alternatives and the deadline demands for project updates.

6.2 Engineering Services (Projected Costs)

Table 11, displays the project personnel's positions and qualifications in completing this project. The Senior Engineer is responsible for reviewing the overall work of the Project Engineer. The Project Engineer developed the final designs, with the assistance of the Engineer in Training (E.I.T.) and Intern. The E.I.T. reviewed the data obtained by the intern, with the respects of their qualifications, evaluated and finalized a traffic impact analysis in determining a feasible solution, in order to alleviate the traffic congestion.

Table 11. Project personnel position and qualifications.

Positions	Qualifications
Senior Engineer	Transportation Specialty
Project Engineer	Traffic & Systems Specialty
Engineer In Training (E.I.T)	Traffic Systems Specialty
Intern	Traffic Data Collector Specialty

Table 12, reveals the engineering services for the completion of the project, in respects to the personnel and the actual hours performed from Table 10. The actual hours for the overall project, totaled at 473 hours, and the difference in decreased hours is 127; which decreased the cost of $16,020. This was due to the elimination of the rental fee in completing Task 2, since the City of Flagstaff provided the necessary survey data. Overall, the final designs for the project was completed and submitted on time.

Table 12. Engineering services for completion of project.

Personnel	Classification	Hours	Base Pay Rate ($/Hour)	Benefits of Base Pay Rate	Actual Pay ($/Hour)	Billing Rate ($/Hour)	Cost
	Senior Engineer	34	$ 120.00	50%	$ 185.00	$ 220.00	$ 7,480.00
	Project Engineer	79	$ 100.00	20.00%	$ 133.00	$ 160.00	$ 12,640.00
	Engineer In Training (E.I.T)	172	$ 50.00	25.00%	$ 95.00	$ 140.00	$ 24,080.00
	Intern	188	$ 25.00	30.00%	$ 83.00	$ 110.00	$ 20,680.00
Total:							$ 64,880.00

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Appendices

Appendix A

Appendix B

Appendix A: Proposed Arc Bridge

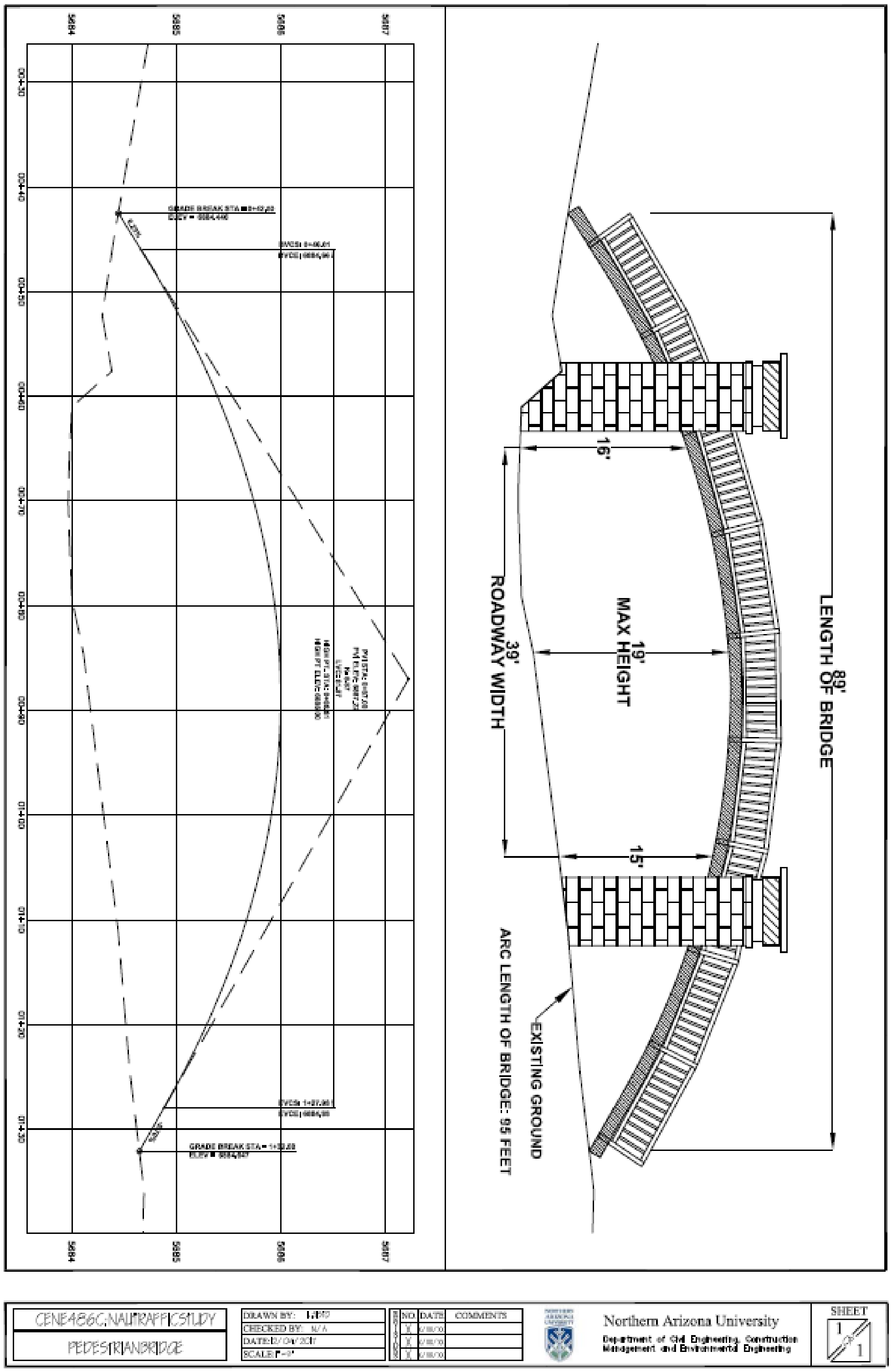

Figure A.1. Proposed arc bridge dimensions and design plan.

Appendix B: Proposed Roundabout

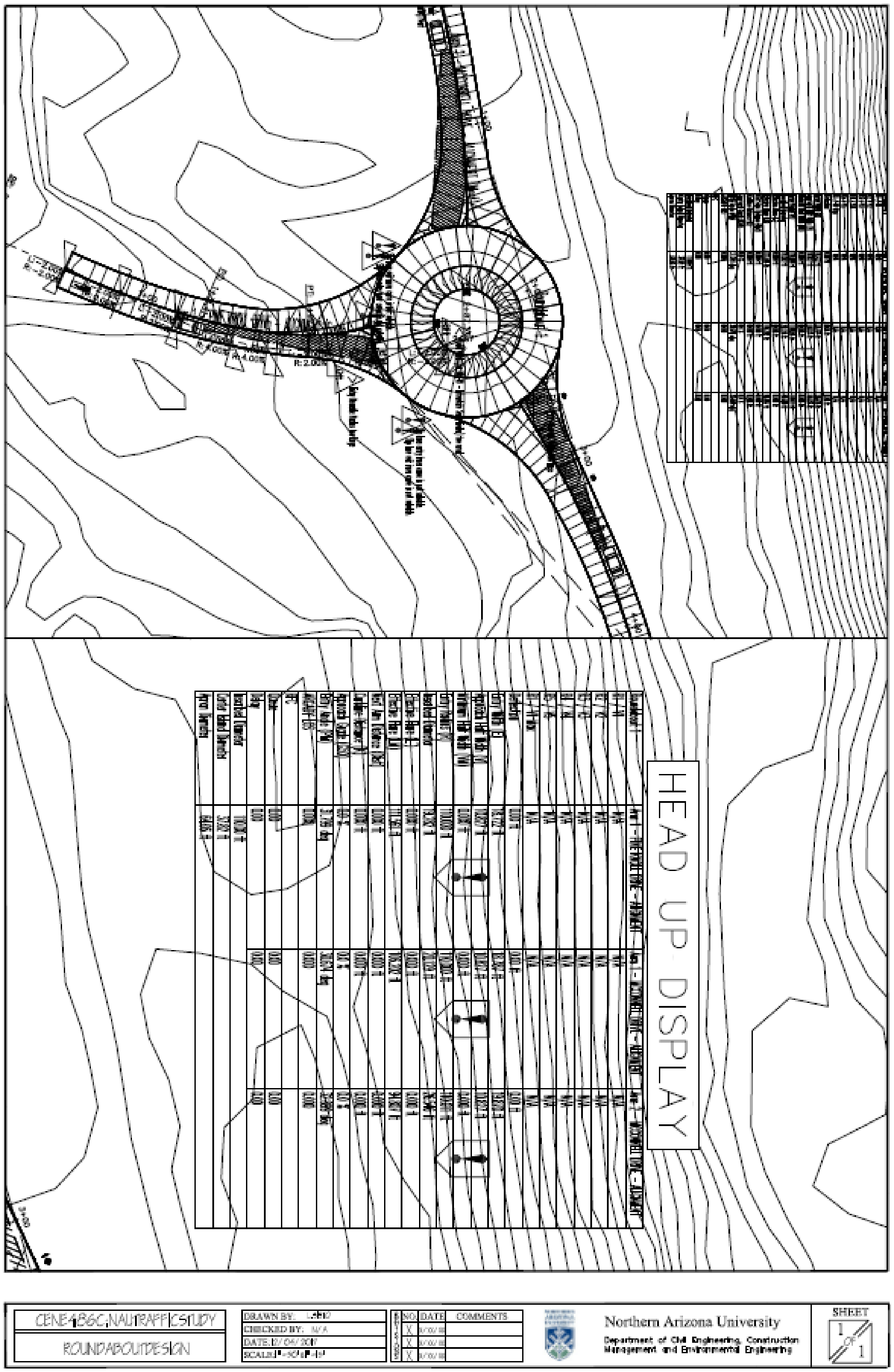

Figure B.2. Proposed roundabout design plan.