NORTHERN ARIZONA UNIVERSITY

# *Traffic Signal Redesign Final Design Report*

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CENE 486 Capstone

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NORTHERN ARIZONA UNIVERSITY

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# Acknowledgements

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## 1.0 Project Description

The intersection of N. Country Club Dr. and E. Old Walnut Rd. has been determined to be a hazardous intersection by the City of Flagstaff. The two-way road Country Club Drive is an uncontrolled (free-flow) multi-lane road with a large average daily traffic (ADT). Old Walnut Canyon Road is a two-way road with stop-control for all movements (left, right and through) at the intersection. The City of Flagstaff has identified the intersection of N. Country Club Dr. and E. Old Walnut Canyon Rd. as an intersection that requires re-evaluation because of its volume and poor safety record. The City of Flagstaff has requested that the intersection be re-evaluated for use of a traffic signal. The intersection re-design must meet industry standards and the standards set by the City of Flagstaff and Arizona Department of Transportation (ADOT).

### 1.1 Project Purpose

The purpose behind the intersection redesign of N. Country Club Dr. and E. Old Walnut Canyon Rd. is to improve the safety and efficiency of the intersection. Currently the intersection has safety concerns due to sight distances and Right-of-Way, among other criteria. These concerns will be mitigated by the implementation of a traditional traffic signal.

### 1.2 Project Location

The project site is located on the East side of Flagstaff, AZ at N. Country Club Dr. And E. Old Walnut Canyon Rd. The project site location in relation to Flagstaff, AZ is shown in Figure 1.1.

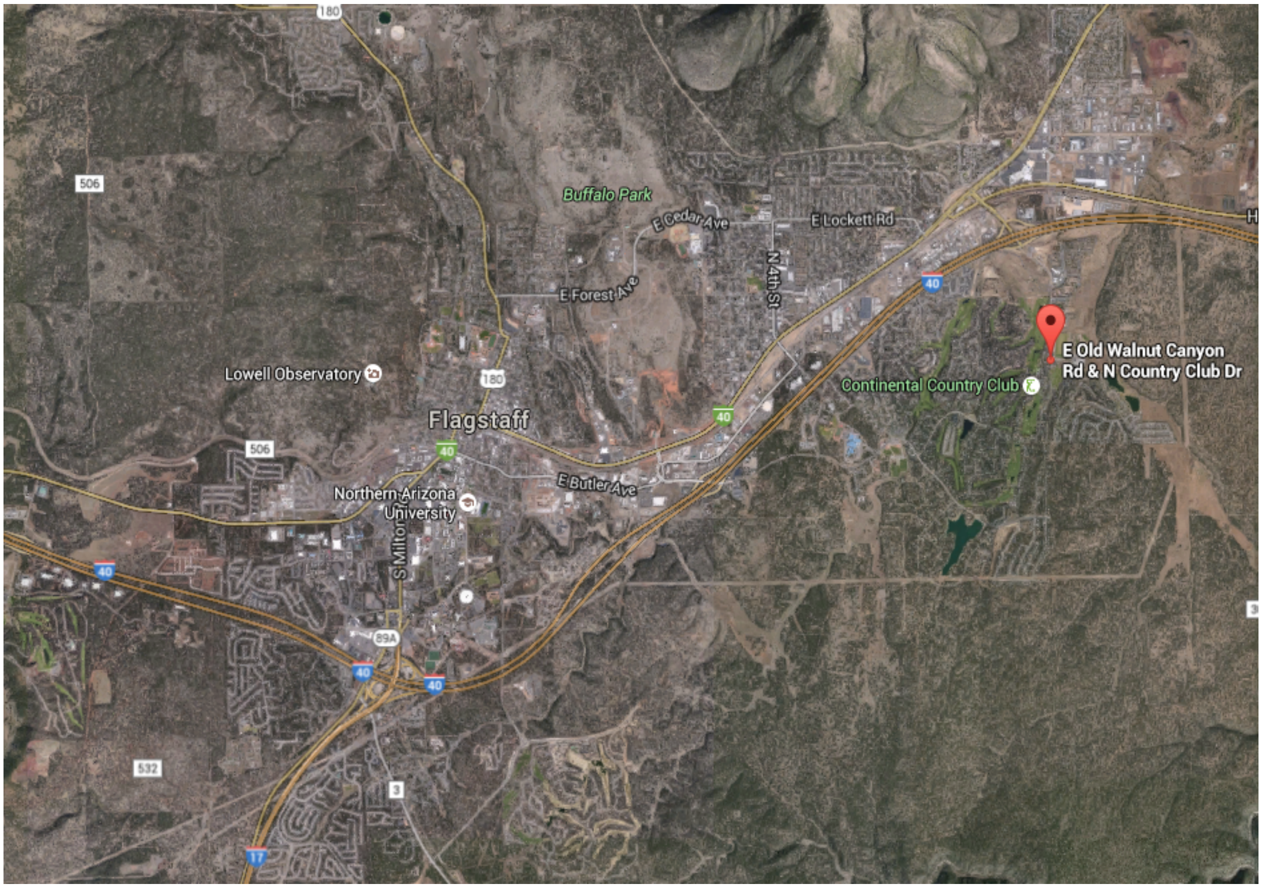


*Figure 1.1: Broad Location of Project Site Location [1]*

For additional reference, the project site is located South of the Flagstaff city mall and the Purina dog food tower. The project location in relation to the Purina dog food tower is shown in Figure 1.2.

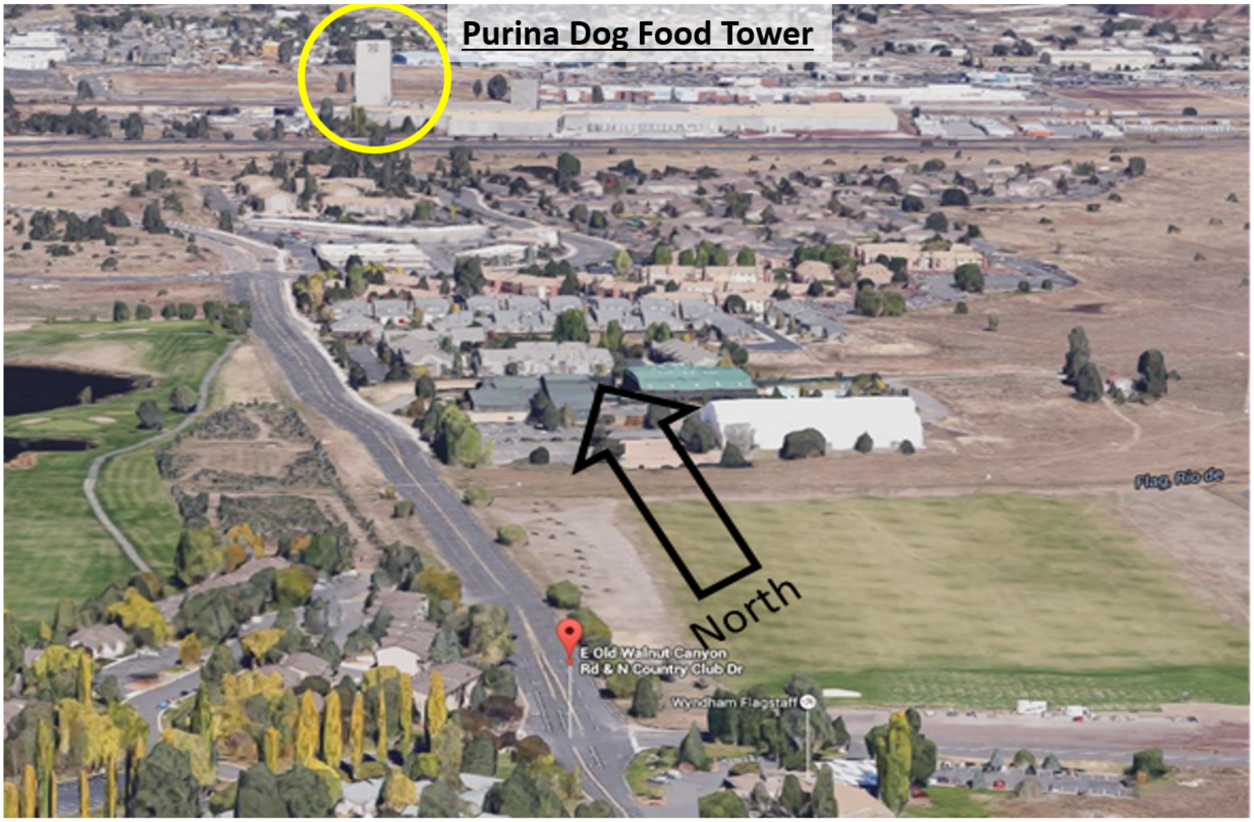



*Figure 1.2: Project Site Location in relation to the Purina Dog Food Tower [1]*

## 2.0 Technical Sections

The following sections outlines the various studies completed according to the agreed scope of work. All studies were completed per applicable ADOT and MUTCD standards.

### 2.1 Traffic Studies

In order to determine the current performance and level of service of the intersection, various traffic studies were conducted. The traffic studies consisted of a volume/speed/classification study, 12 hour turning movement count, stop sign delay study, and a sight distance study. Analysis and warranting of the intersection were done based upon these studies.

#### 2.1.1 Volume/Speed/Classification Study

Vehicle volumes, speeds, and classifications were collected using JAMAR Technologies TRAX pneumatic counters. These counters use two rubber hoses that span the width of the road and are a set a specified distance apart from each other. Connected to the end of the hoses is a data recorder that measures the speed, volume and classification of vehicles as they roll over them by calculating the axle distance as a function of time [2]. The tubes were placed on each of the four legs of the intersection. This study was performed in October to avoid winter driving conditions that affect the performance of the counters. The counts were taken Tuesday through Thursday to capture peak driving conditions. Figure 2.1 shows the location of the counters, the average daily traffic (ADT) and the 85% speeds. The 85th percentile is the speed at, or below, which 85 percent of vehicles travel.

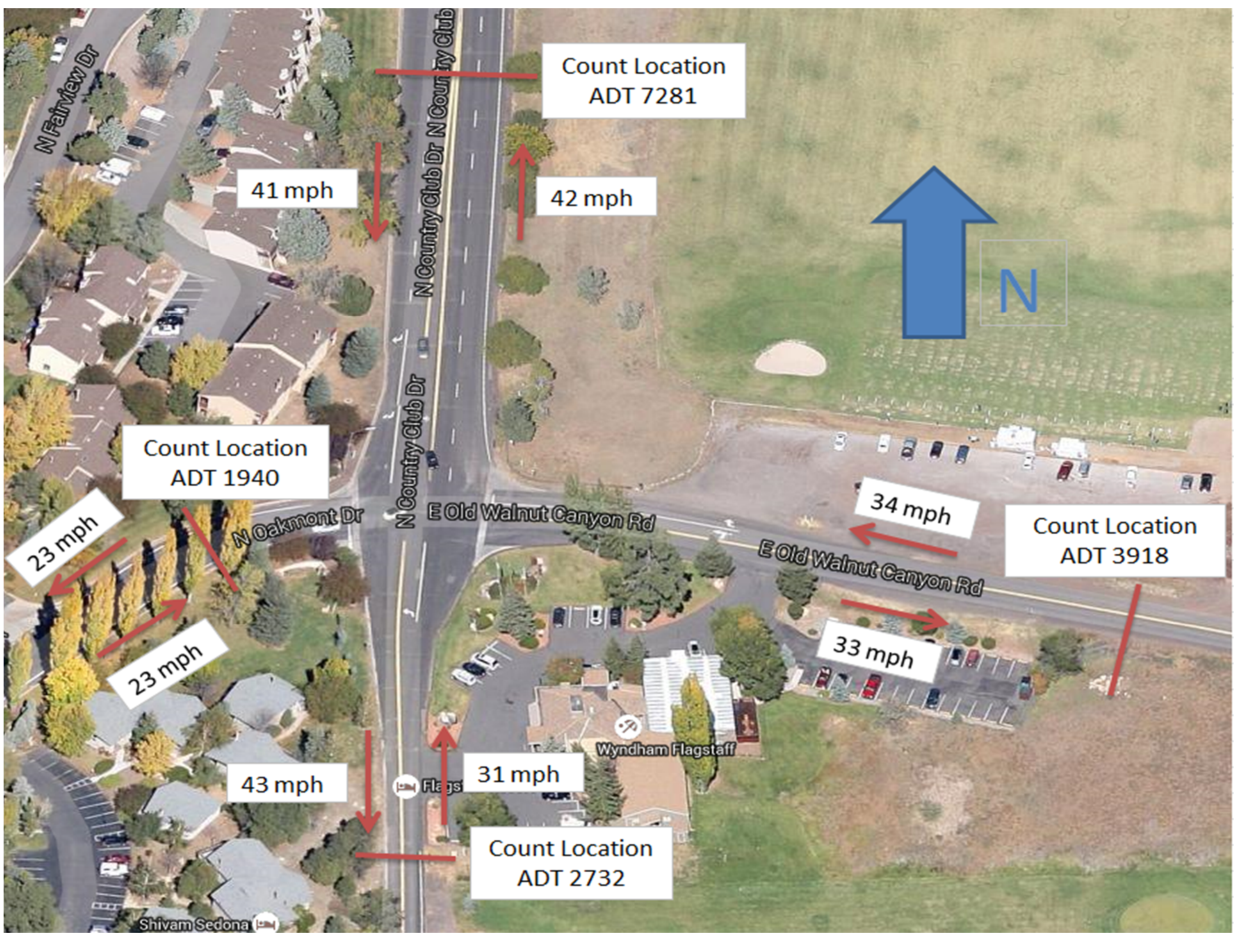



*Figure 2.1: Count Locations, Average Daily Traffic, and Speeds [1]*

Vehicle classification is an important set of data that shows what kind of vehicles are moving through the intersection. The layout of the redesigned intersection will primarily depend on what types of vehicles will use it. The TRAX counters give an accurate classification of what vehicles pass over the tubes based on the distance between the axles. The graph in Figure 2.2 shows the vehicle classifications based on percentages. Class 2 represents passenger cars. Class 3 represents pickups, vans and other two-axle, four-tire single unit vehicles. Class 5 represents two-axle, six-tire single unit trucks. Class 5 is significant because it is the largest vehicle to use the intersection with a regular frequency, therefore a single unit truck is to be used as the design vehicle to make sure all turning radii will accommodate the large vehicle. Class 14 represents unclassified vehicles, which are vehicles that do not fall into the other thirteen classes [3]. As a rule, a high percentage of vehicles in class 14 can indicate faulty equipment or setup. In the case of this particular intersection, golf carts travel from the driving range on the Northeast corner of the intersection to the Country Club Golf Course on the West side, over the installed TRAX counters and account for the class 14 volumes as golf carts do not fall into a traditionally vehicle category. A full description of each class of vehicle is provided in Appendix A.

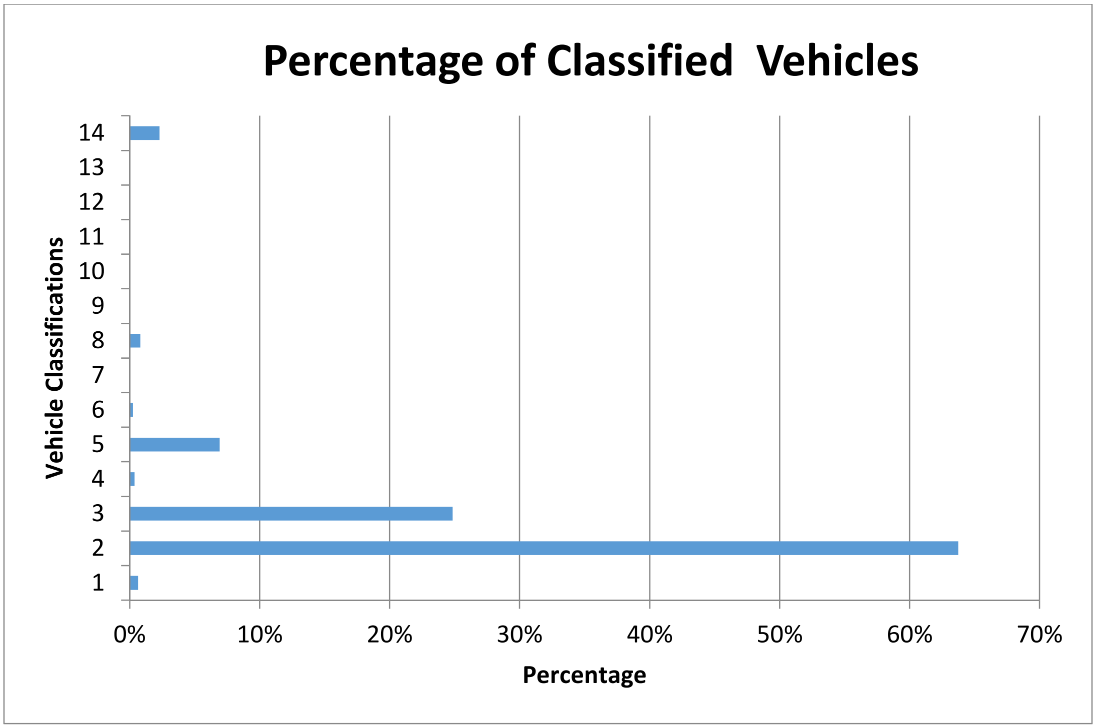



*Figure 2.2: Percentage of Classified Vehicles*

### 2.1.2 Turning Movement Counts

Vehicle turning movement counts were collected using a JAMAR Technologies board. For this study, all vehicles that travelled through the intersection were manually recorded on the JAMAR board using buttons that corresponded to left, right and through movements for each of the four approaches. The study was conducted over a 12 hour period on a weekday in order to collect data from an average day. This study took place on October 14$^{th}$, 2015. This date for the turning movement counts was used in order to avoid winter driving conditions. Furthermore, this date fell on a Wednesday which is optimal because traffic engineering studies dictate that the studies must fall on or between a Tuesday and Thursday because all other days are considered to have abnormal driving patterns. Table 2.1 shows the turning movement counts the intersection encountered during the 12 hour turning movement count.

*Table 2.1: Turning movement counts for all approaches of the intersection*

| SB | | | | WB | | | |
|---|---|---|---|---|---|---|---|
| RT | THR | LT | PED | RT | THR | LT | PED |
| 683 | 897 | 1355 | 4 | 1412 | 147 | 130 | 6 |
| NB | | | | EB | | | |
| RT | THR | LT | PED | RT | THR | LT | PED |
| 193 | 1067 | 76 | 1 | 39 | 143 | 633 | 1 |

A turning movement count is primarily used to determine the flow of traffic for each approach of the intersection. Furthermore, this data can be used as inputs for programs such as Synchro and VISSIM which are both microscopic vehicle simulation software, and Highway Capacity System (HCS) software which is based off design standards for the Highway Capacity Manual to create level of service simulations and three dimensional driver simulations.

### 2.1.3 Stop Sign Delay Study

Currently, the East and Westbound legs of the intersection are controlled using stop signs. In order to determine the average delay users are experiencing at this stop signs, a stop sign delay study was conducted. This study again utilized JAMAR Technology boards and took place on a Wednesday during the PM peak hour from 5:00-6:00. To complete the study, each vehicle who approached the intersection and came to a stop because of the stop sign or another stopped user was counted as a "stop". As the users made their respective turns they were counted as a "go" and the results give an average delay in seconds for users that result from the stop signs. The stop sign delay study is important to determine if a change is needed to the intersection.

### 2.1.4 Sight Distance Study

A sight distance study was performed in order to determine the length of roadway users have when they see another vehicle about to make a turning movement. This study was conducted for vehicles travelling on N. Country Club Dr. for when they can see a vehicle making a turning movement on E. Old Walnut Canyon Rd. The study is important in determining the overall safety of the intersection, for example, if a user decides to turn when he/she cannot see if another vehicle is approaching, there is a chance for a high impact collision. To complete this study, neon orange cones were placed where vehicles stop on E. Old Walnut Canyon Rd. when making a turning movement and then an individual drove along N. Country Club Dr. and marked along the roadway where they were able to see the neon orange cone, using GPS. Figure 2.3 shows the sight distances that were calculated using a GPS system. The study found that four specific movements in the intersection do not meet the standards set by the American Association of State Highway and Transportation Officials (AASHTO).

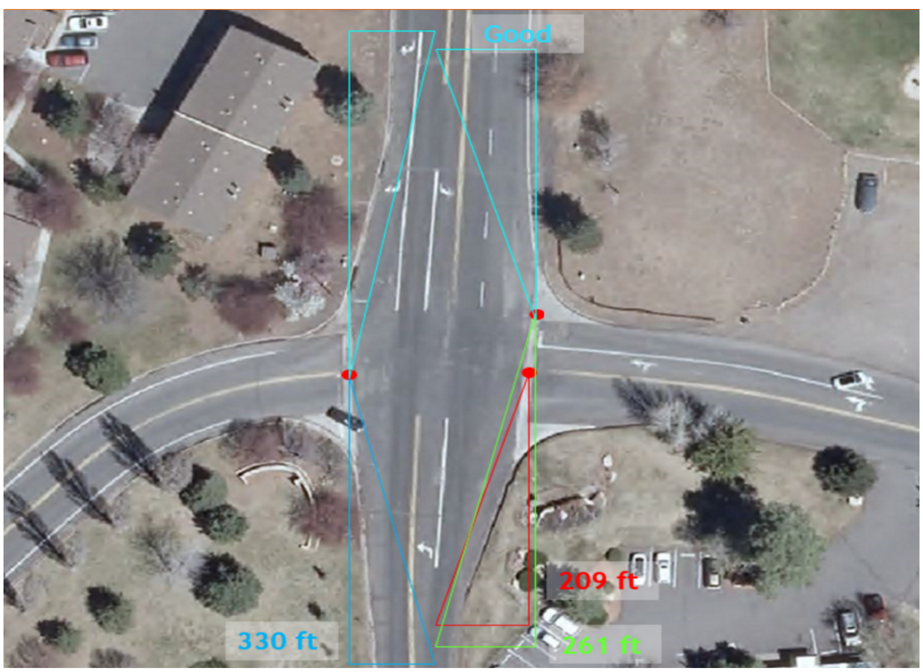



*Figure 2.3: Sight Distances measured using GPS [1]*

It is important to perform a sight distance study to calculate sight triangles of the current intersection layout. In the case of large obstructions or sudden changes in grade due to vertical curves, grade changes may be recommended to increase the safety and visibility for drivers using the intersection. It was determined that the current sight triangles are not up to standards. For the NB approach on N. Country Club Dr., the WB left turning lane represented in red on

Figure 2.3 should have a sight distance of 390 ft., the WB right turning lane represented in green on Figure 2.3 should have a sight distance of 335 ft., and the EB right turning lane represented in blue should be 330 ft.

## 2.2 Analysis

The following sub-sections outline the types of analyses used in determining the current operational conditions of the intersection.

### 2.2.1 Peak Hour Analysis

The amount of users travelling through the intersection of N. Country Club Dr. and E. Old Walnut Canyon fluctuates due to weather conditions, business hours, residential events, etc. Peak hours are determined when user volumes at the intersection are the highest. To complete this study, the volume study data was utilized to determine what hours on a normal day have the highest volumes. Table 2.2 shows the AM and PM peak hours on each approach for the intersection.

*Table 2.2: Synchro Peak Hour Volumes*

| Peak Hour Volume | | | | |
|---|---|---|---|---|
| **Leg of Intersection** | **AM Peak Hour** | **AM Volume** | **PM Peak Hour** | **PM Volume** |
| NB Country Club | 8:00-9:00 | 228 | 4:30-5:30 | 263 |
| SB Country Club | 7:15-8:15 | 540 | 5:00-6:00 | 687 |
| EB Oakmont | 11:00-12:00 | 142 | 3:00-4:00 | 174 |
| WB Old Walnut Canyon | 8:00-9:00 | 284 | 5:00-6:00 | 399 |

It is important to determine peak hours of the intersection for the warranting process. Warrant's 1, 2, and 3 utilize peak hours when determining if a traffic signal is warranted at the intersection.

### 2.2.2 Existing Level of Service

The Level of Service (LOS) is used to determine how well the intersection N. Country Club Dr. and E. Old Walnut Canyon is functioning. LOS values that can be assigned consist of: A, B, C, D, E, and F. Level of service "A" pertains to a roadway that is functioning at its optimal abilities, meaning there are short wait times or low volumes of vehicles travelling at free flow speed. Level of service "F" pertains to a roadway that is functioning poorly and is experiencing large amounts of delay or high volumes of vehicles with slow travel speeds. The existing LOS was determined using two different software programs, Synchro and Highway Capacity Software (HCS). The output data sheets from both these Synchro and HCS are shown in Appendices B and C respectively. Figure 2.4 shows the difference between a roadway with a LOS "A" and a roadway with a LOS "F". Level of service is important to determine because it is used to measure the amount of delay that the intersection is experiencing due to congestion.

*Figure 2.4: Examples of LOS A and LOS F respectively [4], [5]*

### 2.2.3 Right-of-Way

The Right-of-Way (ROW) is the land that is owned by the City of Flagstaff. The ROW shown in Figure 2.5 was determined using an ArcMap provided by the City of Flagstaff. As seen in Figure 2.5, the City of Flagstaff owns land on either side of the paved road. This extra land is used for things such as public sidewalks, streetlights, utilities, street parking, and control devices. Also, for widening or altering the roadway in the future. Based on the ROW owned by the City of Flagstaff, the intersection of N. Country Club Dr. and E. Walnut Canyon Rd. will be able to be redesigned without acquiring more ROW.

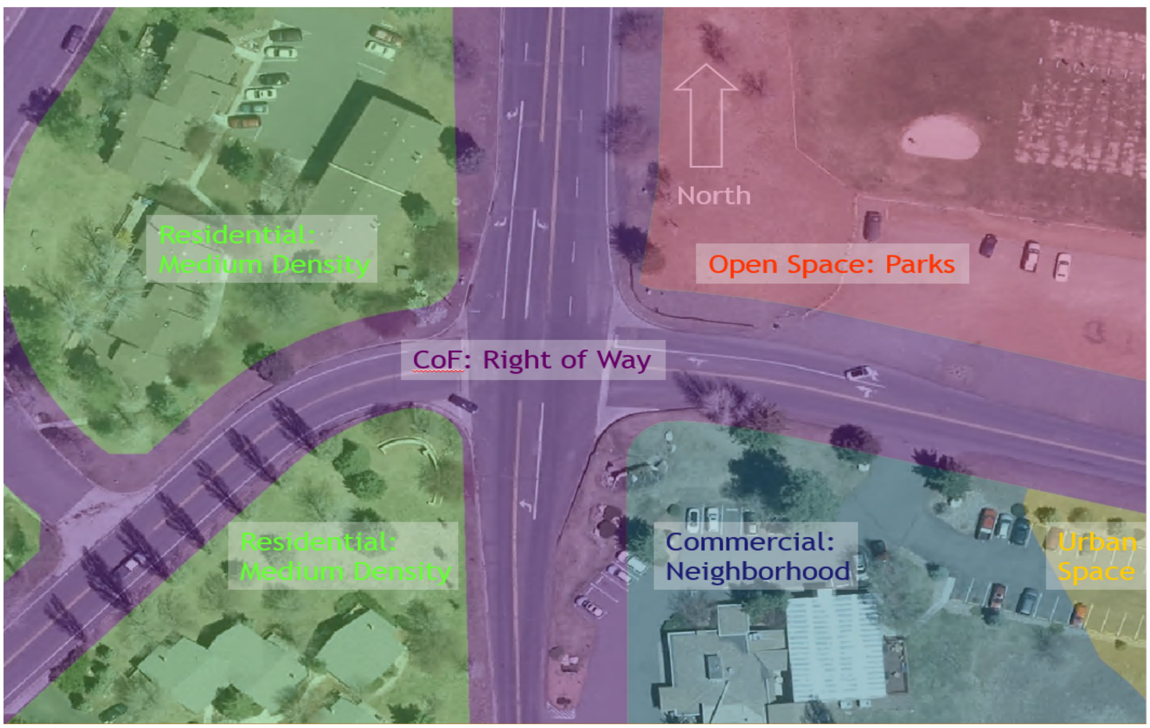



*Figure 2.5: Project Location Property Lines [6]*

### 2.2.4 Existing VISSIM Model

VISSIM is three dimensional optimization software for roadways. In addition to its ability to model virtual vehicles based on real-world traffic volumes, it can also simulate free flow, stop controlled and signalized intersections. VISSIM produces a real-time model of how traffic will flow during different times of the day, allowing the designer to optimize the signal timing plan and placement to a high degree.

### 2.2.5 Existing Synchro Model

Synchro is an analysis and optimization software application. Synchro supports the Highway Capacity Manual's methodology (2000 & 2010 methods) for signalized intersections [7]. Synchro uses the turning movement count data as well as the geometry of the intersection. Upon analyzation of the input data, Synchro outputs important information such as delay times and LOS. Table 2.3 shows the delay time for each leg of the intersection. These numbers reflect the peak hour volumes. Due to uncontrolled traffic flows moving north and south, the eastbound and westbound left and through traffic movements experience moderate delays. In particular the eastbound has the highest delay due to traffic being restricted to only one lane for all three movements. From the Table 2.3, the eastbound route experiences the most delay per vehicle followed by the westbound.

*Table 2.3: Synchro Delays*

| Direction | EB | WB | NB | SB | All |
|---|---|---|---|---|---|
| Volume (vph) | 108 | 236 | 169 | 411 | 924 |
| Control Delay / Veh (s/v) | 47 | 12 | 1 | 4 | 11 |
| Queue Delay / Veh (s/v) | 0 | 0 | 0 | 0 | 0 |
| Total Delay / Veh (s/v) | 47 | 12 | 1 | 4 | 11 |
| Total Delay (hr) | 1 | 1 | 0 | 0 | 3 |
| Stops / Veh | 1.00 | 1.00 | 0.11 | 0.82 | 0.76 |

Synchro determined the LOS of the intersection at a LOS of B. All legs of the intersection scored adequate LOS except for the eastbound movement which scored and LOS of E. This again is due to traffic being restricted to only one lane for all three movements.

## 2.3 Warranting

Warranting is what traffic engineers use when determining what type of traffic control is appropriate for the intersection in question. For the intersection of N. Country Club Dr. and E. Old Walnut Canyon Rd., the intersection warrants were determined for a traffic control signal. The Manual of Uniform Traffic Control Devices (MUTCD) outlines the different types of warrants there are along with how the warrants should be interpreted and used. This is an important technical aspect for this project as it ensures that a traffic control signal is the optimal design for the intersection along with determining how the intersection will primarily function. For the intersection N. Country Club Dr. and E Old Walnut Canyon Rd.

### 2.3.1 Warrant 1: Eight-Hour Vehicular Volume

Warrant 1 consists of compiling volume counts for both the minor and major streets and comparing the peak hours of each of any eight hours of an average day [8]. The MUTCD has two conditions (A and B) that if either is met, a signal may be warranted. The eight-hour vehicle warrant was conducted by analyzing the eight highest vehicle volumes. Figure 2.6 shows conditions A and B for Warrant 1: Eight-Hour Vehicular Volume.

**Table 4C-1. Warrant 1, Eight-Hour Vehicular Volume**

**Condition A—Minimum Vehicular Volume**

| Number of lanes for moving traffic on each approach | | Vehicles per hour on major street (total of both approaches) | | | | Vehicles per hour on higher-volume minor-street approach (one direction only) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Major Street | Minor Street | 100%[a] | 80%[b] | 70%[c] | 56%[d] | 100%[a] | 80%[b] | 70%[c] | 56%[d] |
| 1 | 1 | 500 | 400 | 350 | 280 | 150 | 120 | 105 | 84 |
| 2 or more | 1 | 600 | 480 | 420 | 336 | 150 | 120 | 105 | 84 |
| 2 or more | 2 or more | 600 | 480 | 420 | 336 | 200 | 160 | 140 | 112 |
| 1 | 2 or more | 500 | 400 | 350 | 280 | 200 | 160 | 140 | 112 |

**Condition B—Interruption of Continuous Traffic**

| Number of lanes for moving traffic on each approach | | Vehicles per hour on major street (total of both approaches) | | | | Vehicles per hour on higher-volume minor-street approach (one direction only) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Major Street | Minor Street | 100%[a] | 80%[b] | 70%[c] | 56%[d] | 100%[a] | 80%[b] | 70%[c] | 56%[d] |
| 1 | 1 | 750 | 600 | 525 | 420 | 75 | 60 | 53 | 42 |
| 2 or more | 1 | 900 | 720 | 630 | 504 | 75 | 60 | 53 | 42 |
| 2 or more | 2 or more | 900 | 720 | 630 | 504 | 100 | 80 | 70 | 56 |
| 1 | 2 or more | 750 | 600 | 525 | 420 | 100 | 80 | 70 | 56 |

*Figure 2.6: Tables showing conditions A and B for warrant 1 in the MUTCD [8]*

Table 2.4 shows the actual volumes of the major and minor streets. The volume of both the major approaches must be greater than 600 vehicles per hour (vph). The volume of the minor street approach in one direction must be greater than 150 vph. Since none of the volumes for the major street were high enough, Warrant 1 did not meet.

Table 2.4: Summary of 8 Hr. Volumes at the Country Club-Old Walnut Intersection

| Time | Country Club Traffic Volumes | CC>600 vph | Old Walnut Volumes | Old Walnut>150 vph | Warrant |
|---|---|---|---|---|---|
| **8:00** | 368 | Not Met | 202 | Met | Not Met |
| **18:00** | 361 | Not Met | 169 | Met | Not Met |
| **9:00** | 362 | Not Met | 165 | Met | Not Met |
| **17:00** | 411 | Not Met | 152 | Met | Not Met |
| **7:00** | 417 | Not Met | 144 | Not Met | Not Met |
| **11:00** | 328 | Not Met | 131 | Not Met | Not Met |
| **10:00** | 302 | Not Met | 127 | Not Met | Not Met |
| **14:00** | 301 | Not Met | 122 | Not Met | Not Met |

### 2.3.2 Warrant 2: Four-Hour Vehicular Volume

The four-hour vehicle volume warrant consists of compiling volume counts for both the major and minor streets and comparing the peak hours for each of any four hours of an average day to determine if the volume of intersecting traffic is high enough to warrant a signal [8]. The four-hour vehicle warrant will be conducted once volumes are counted and analyzed. The four-hour vehicle warrant was conducted by analyzing the four highest vehicle volumes. Figure 2.7 shows the chart used when warranting warrant 2.

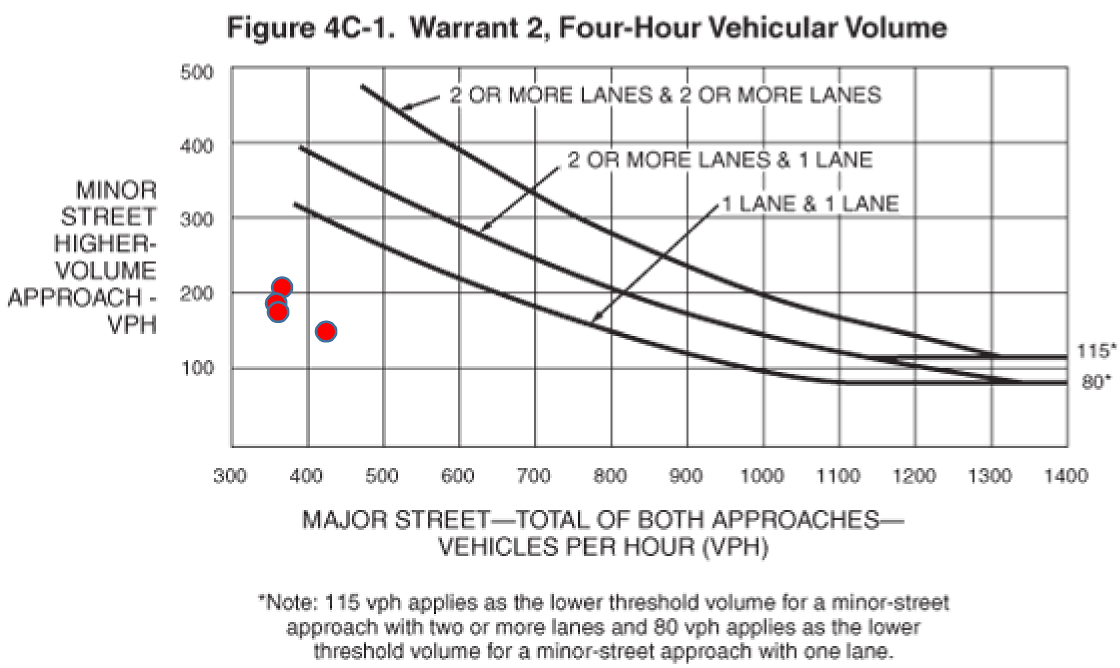



Figure 2.7: Major and Minor street volume chart from the MUTCD [8]

Table 2.5 shows the actual volumes for the four highest hours. Warrant 2 did not meet as none of the volumes were high enough on either the major or minor streets. In Figure 2.7, red dots correspond with the actual volumes in Table 2.5.

*Table 2.5: Summary of 4 Hr. Volumes at the Country Club-Old Walnut Intersection*

| Time | Country Club Traffic Volumes | Major Street (Figure 2.7) | Old Walnut Traffic Volumes | Minor Street (Figure2.7) | Warrannt |
|---|---|---|---|---|---|
| 11:00 | 368 | Not Met | 202 | Not Met | Not Met |
| 16:00 | 361 | Not Met | 169 | Not Met | Not Met |
| 12:00 | 362 | Not Met | 165 | Not Met | Not Met |
| 14:00 | 411 | Not Met | 152 | Not Met | Not Met |

### 2.3.3 Warrant 7: Crash Experience

Crash data was obtained and analyzed to determine if the intersection warrants a signal due to crash experience. According to the MUTCD an intersection may warrant a signal if alternate methods do not reduce the crash rate, and if five or more crashes occur in any twelve month period [8]. The volume of both the major and minor streets must also be high enough to where it meets the 80 percent columns of condition A and B from the eight-hour vehicle volume warrant [8]. Figure 2.8 shows the crash history from 2001 to 2014.

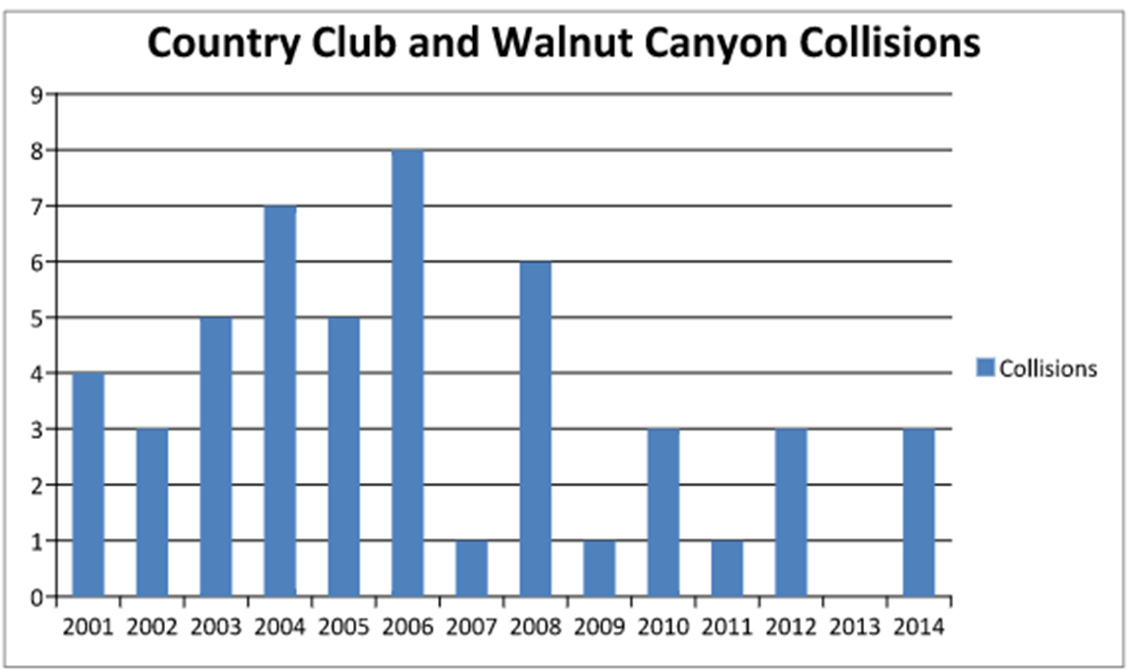



*Figure 2.8: Crash History*

Figure 2.8 shows that five different years met the crash criteria for the Warrant 7. The volumes in Table 2.4 however did not meet the 80% requirements shown in figure 2.6. Since the volumes weren't high enough, Warrant 7 did not meet.

#### 2.3.4 Warrant Summary

The current state of the intersection does not meet any of the MUTCD Warrants. Although no Warrants were met, due to poor sight distance and engineering judgement it's recommended that a signal be installed to improve the overall safety of the intersection. Signalizing the intersection will eliminate the poor sight distance and also allow for safer pedestrian access.

### 2.4 Identify Design

Identifying the final design began with the constraint that the intersection shall be controlled via a traffic signal therefore, no decision matrix was needed. J3Z Engineering then identified all components according to the Arizona Department of Transportation (ADOT) standards that are needed in order to control an intersection with a traffic signal. Components consisted of but are not limited to: signal heads, mast arms, and Right of Way (ROW); see pole schedule in Figure 2.9 for the complete list of design materials. It is noted that bike lanes and sidewalks were added to the intersection upon request from the City of Flagstaff. Components were chosen based on the engineering studies completed during analysis and the future geometric conditions of the intersection.

### 2.5 Final Design

The final design of the intersection will improve the overall safety of the intersection by eliminating sight distance problems and allow for safer crossing for pedestrians. The final design will consist of a new striping layout and fully signalized control.

### 2.5.1 Future Level of Service (Synchro)

Using the same turning movement data as was used in the existing synchro model, a new model was created with signalized control instead of two way stop control. Table 2.6 shows the new LOS and Total Delay for each movement. The LOS on the eastbound approach improved from LOS F to LOS B. The westbound approach improved from LOS C to LOS B. The LOS dropped slightly on the northbound and southbound approaches as they were changed from free flowing to signalized. The overall LOS of the intersection remained a B which is the same as it was before.

*Table 2.6: Synchro Level of Service & Total Delay with Signalized Intersection*

| INTERSECTION WITH TRAFFIC SIGNAL IMPLEMENTED | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STREET | OAKMONT DR | | | OLD WALNUT CANYON RD | | | COUNTRY CLUB DR | | | | | |
| DIRECTION | EBL↗ | EBT→ | EBR↘ | WBL↙ | WBT← | WBR↖ | NBL↖ | NBT↑ | NBR↗ | SBL↘ | SBT↓ | SBR↙ |
| TRAFFIC VOLUME (VPH) | 78 | 20 | 9 | 20 | 20 | 196 | 12 | 128 | 29 | 209 | 120 | 82 |
| LEVEL OF SERVICE | B | B | B | B | B | A | A | B | A | A | B | A |
| TOTAL DELAY (S) | 15.3 | 15.3 | 15.3 | 13.4 | 13.4 | 4.7 | 8.8 | 18 | 0.3 | 10.4 | 11.6 | 3.4 |

The two major movements of the intersection which are the westbound right (WBR) and southbound left (SBL), both decreased in total delay. The WBR went from 10.3 seconds to 4.7 seconds and the SBL went from 14 seconds to 10.4 seconds. This is a significant improvement as they are the most common movements.

### 2.5.2 Striping Plan

The striping plan utilizes ADOT and AASHTO standards. The intersection will feature a pork chop island for the right turn movement on the westbound approach. This will allow the vehicles in this movement to safely enter the intersection. This is due to the pork chop island's ability to service the movement from the westbound approach without impeding the vehicle path from the northbound approach. The pork chop island will improve the safety and efficiency of the intersection. A right turn movement on the northbound approach will be implemented to further improve the efficiency of the intersection. The intersection will feature crosswalks on all approaches and bike lanes all shoulders. This will allow for pedestrians and bicyclists to safely use the intersection. For further details regarding the striping plan, refer to Sheet 3 of the project plan set in Appendix E.

### 2.5.3 Signal Plan

The signal plan uses ADOT signal standards. The pole schedule in Figure 2.9 shows what types and sizes of poles, mast arms, and signal heads are used. It also shows details for lighting and pedestrian equipment. The location of each traffic pole and cabinet can be found in Figure 2.10. For further details, please see the project plan set.

| TRAFFIC SIGNAL CONTROLLER | | | | REMARKS | LOCATION |
|---|---|---|---|---|---|
| CABINET | TYPE | CONTROLLER | AUX. CONTROL | | |
| A | IV W/ELEV, BASE ECONOLITE TS-2, TYPE 1 | ECONOLITE ASC 3-2100 | ADD PEC AND CONTACTOR TO CONTROL LPS LIGHTING | ADD RTC MODEL TR-4 GPS TIME SOURCE WITH ANTENA | TO BE FIELD LOCATED BY CITY TS INSPECTOR, BEHIND FUTURE SIDEWALK |
| P | COMBONATION METER/UPS PEDESTAL | MEUG-UPS-M100-AZ (DWG #526321) | UPS SYSTEM IN MEUG PEDESTAL WITH 92 Ah BATTERIES | LIGHTING & TRAFFIC SIGNALS ON SINGLE METERED SERVICE | TO BE FIELD LOCATED BY CITY TS INSPECTOR, BEHIND FUTURE SIDEWALK |

| POLE | | MAST ARM | | SIGNALS | | P.B. SIGN | REAMRKS | LOCATION |
|---|---|---|---|---|---|---|---|---|
| | TYPE | SIG. | LUM. | MTG | FACE | | | |
| B (11' 17') | W | 60' | 20' | 3-II V ADA P.B. | G,F F M/H | T.S. 11-4 RIO-4B (L) | 240V LED LUMINAIRE W/PEC VIDEO DETECTION ON SL MAST ARM | TO BE FIELD LOCATED BY CITY TS INSPECTOR, BEHIND FUTURE SIDEWALK |
| C | A 10' | | | VI V ADA P.B. | R,G M/H | T.S. 11-4 RIO-4B (R) | | TO BE FIELD LOCATED BY CITY TS INSPECTOR, BEHIND FUTURE SIDEWALK |
| D | F | 20' | 20' | II VI ADA P.B. | F,G M/H | T.S. 11-4 RIO-4B (L) | 240V LED LUMINAIRE W/PEC VIDEO DETECTION ON SL MAST ARM | TO BE FIELD LOCATED BY CITY TS INSPECTOR, BEHIND FUTURE SIDEWALK |
| E | A 10' | | | VI V ADA P.B. | G,F M/H | T.S. 11-4 RIO-4B (R) | | TO BE FIELD LOCATED BY CITY TS INSPECTOR, BEHIND FUTURE SIDEWALK |
| F (12') | Q | 40' | 20' | 3-II V ADA P.B. | G,F F M/H | T.S. 11-4 RIO-4B (L) | 240V LED LUMINAIRE W/PEC VIDEO DETECTION ON SL MAST ARM | TO BE FIELD LOCATED BY CITY TS INSPECTOR, BEHIND FUTURE SIDEWALK |
| G | A 10' | | | VI V ADA P.B. | F,F M/H | T.S. 11-4 RIO-4B (R) | | TO BE FIELD LOCATED BY CITY TS INSPECTOR, BEHIND FUTURE SIDEWALK |
| H | Q | 25' | 20' | II VI ADA P.B. | F,F M/H | T.S. 11-4 RIO-4B (L) | 240V LED LUMINAIRE W/PEC VIDEO DETECTION ON SL MAST ARM | TO BE FIELD LOCATED BY CITY TS INSPECTOR, BEHIND FUTURE SIDEWALK |
| I | A 10' | | | VI V ADA P.B. | G,F M/H | T.S. 11-4 RIO-4B (R) | | TO BE FIELD LOCATED BY CITY TS INSPECTOR, BEHIND FUTURE SIDEWALK |

*Figure 2.9: Signal Pole Schedule*

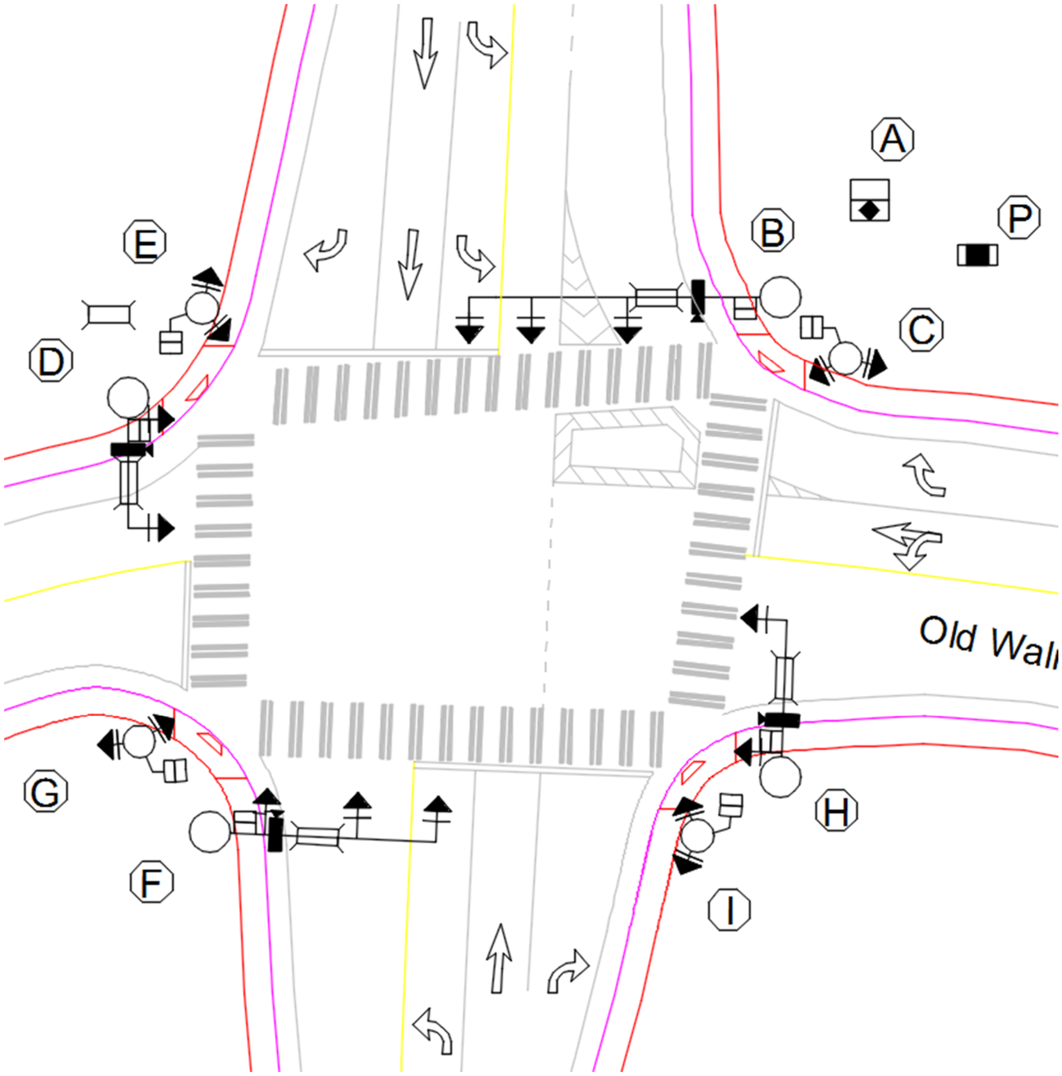



*Figure 2.10: Signal Plan*

The intersection will feature two flashing yellow left turn movements for the north and southbound approaches. The flashing arrows will allow for permissive left turns when oncoming traffic is clear. The flashing yellow arrows will help improve the safety and efficiency of the intersection. The intersection also features pedestrian crossing phases for each leg of the intersection. Since the intersection is located in a community with a high number of elderly residents, the walking speed was reduced from 4 fps to 3 fps to allow for more time to cross. See Appendix F for intersection timing card.

### 2.5.4 Needed Right of Way

Right of Way (ROW) is a term used to describe the zoning purposes of a section of land and who owns it. To implement the proposed design, the ROW will have to be acquired by the City of Flagstaff is located on the Northwest corner and Southwest region to allow for the addition of bike lanes, sidewalks, and traffic poles. For further details regarding the ROW acquisition, refer to Sheet 7 of the project plan set in Appendix E.

## 3.0 Project Cost

The project cost will include the cost implementation and cost of design. The City of Flagstaff's bid history was utilized to predict the cost of the proposed design and hourly rates by title for J3Z Engineering. The project cost for the City of Flagstaff Signal Redesign Project is $272,000.

### 3.1 Cost of Implementation

Using the Arizona Department of Transportation standards for the design of an intersection, components for the redesign of N. Country Club Dr. and E. Old Walnut Canyon Rd. were chosen. The City of Flagstaff's bid history for intersection redesigns was then analyzed to determine the predicted costs of each component within the intersection redesign J3Z Engineering is completing. Tables 3.1 and 3.2 represents the expected costs of the each component along with the final cost of the intersection. It is noted these costs include both material and construction for the intersection, not including design costs.

*Table 3.1: Civil Plan Costs*

| Item No. | Description | Unit | QTY | Unit Price ($) | Amount ($) |
|---|---|---|---|---|---|
| | **Civil Plans** | | | | |
| 1 | Traffic control | LS | 1 | 10000 | 10000 |
| 2 | Remove Curb & Gutter | LF | 1068 | 4 | 4272 |
| 3 | Obliterate Pavement Marking (Stripe) (4" Equivalent Width) | LF | 128 | 2 | 256 |
| 4 | Asphalt Rubber Material | Ton | N/A | 650 | |
| 5 | Aggregate Base, Class 2 | CY | N/A | 105 | |
| 6 | Sidewalk | SF | 1102 | 7.03 | 7747.06 |
| 7 | Sidewalk Ramp (10-10-035) | EA | 4 | 1200 | 4800 |
| 8 | Pavement Marking (Porkchop) | EA | 1 | 500 | 500 |
| 9 | Pavement Marking (Crosswalk) | EA | 49 | 250 | 12250 |
| 10 | ROW Acquisition | N/A | N/A | N/A | N/A |
| 11 | Pavement Symbols (Turn Arrows) | EA | 13 | 250 | 3250 |

Table 3.1 shows the civil plan descriptions and costs of the intersection. Civil plans consist of: the removal of materials at the currents existing intersection, projected installation of pavement markings, ROW acquisition, and the traffic control that will be needed for the installation of the intersection.

*Table 3.2: Signal Plan Costs*

| | **Signal Plans** | | | | |
|---|---|---|---|---|---|
| 12 | SIGN POST U-CHANNEL ASSEMBLY (GALVANIZED STEEL) | EA | 1 | 250 | 250 |
| 13 | W3-3 SIGN (30" X 30") | EA | 1 | 150 | 150 |
| 14 | STREET NAME SIGN (D3 WITH MTG HARDWARE) | EA | 4 | 300 | 1200 |
| 15 | Pole (TYPE A) 10' | EA | 4 | 700 | 2800 |
| 16 | POLE FOUNDATION (TYPE W) | EA | 1 | 3000 | 3000 |
| 17 | POLE FOUNDATION (TYPE F) | EA | 1 | 1500 | 1500 |
| 18 | POLE FOUNDATION (TYPE Q) | EA | 2 | 2500 | 5000 |
| 19 | MAST ARM LIGHTING (20 FT.) (TAPERED) | EA | 4 | 300 | 1200 |
| 20 | MAST ARM (20 FT.) (TAPERED) | EA | 1 | 800 | 800 |
| 21 | MAST ARM (25 FT.) (TAPERED) | EA | 1 | 800 | 800 |
| 22 | MAST ARM (40 FT.) (TAPERED) | EA | 1 | 850 | 850 |
| 23 | MAST ARM (60 FT.) (TAPERED) | EA | 2 | 1050 | 2100 |
| 24 | ELECTRICAL CONDUIT (2") (PVC) | LF | 80 | 12 | 960 |
| 25 | ELECTRICAL CONDUIT (2 1/2") (PVC) | LF | 30 | 25 | 750 |
| 26 | ELECTRICAL CONDUIT (3") (PVC) | LF | 60 | 20 | 1200 |
| 27 | ELECTRICAL CONDUIT (2-3") (PVC) (DIRECTIONAL DRILLED) | LF | 400 | 50 | 20000 |
| 28 | PULL BOX (NO.7) | EA | 3 | 750 | 2250 |
| 29 | PULL BOX (NO.7) (W/EXTENSION) | EA | 1 | 1200 | 1200 |
| 30 | CONDUCTORS | LS | 1 | 18000 | 18000 |
| 31 | TRAFFIC SIGNAL FACE (TYPE F) | EA | 11 | 900 | 9900 |
| 32 | TRAFFIC SIGNAL FACE (TYPE G) | EA | 6 | 1100 | 6600 |
| 33 | TRAFFIC SIGNAL FACE (TYPE R) | EA | 1 | 1000 | 1000 |
| 34 | TRAFFIC SIGNAL MOUNTING ASSEMBLY (TYPE II) | EA | 6 | 175 | 1050 |
| 35 | TRAFFIC SIGNAL MOUNTING ASSEMBLY (TYPE V) | EA | 6 | 400 | 2400 |
| 36 | TRAFFIC SIGNAL MOUNTING ASSEMBLY (TYPE VII) | EA | 6 | 450 | 2700 |
| 37 | PEDESTRIAN SIGNAL (MAN/HAND) (LED) (COUNTDOWN) | EA | 8 | 900 | 7200 |
| 38 | PEDESTRIAN PUSH BUTTON (ADA POLARA BDLM2-B) (WITH SIGN) | EA | 8 | 250 | 2000 |
| 39 | CONTROL CABINET(ECONOLITE ASC/3-2100) | EA | 1 | 4000 | 4000 |
| 40 | VIDEO DETECTION SYSTEM (4-CAMERA SYSTEM) | LS | 1 | 22000 | 22000 |
| 41 | LUMINAIRE (LED) Cooper Model No. OVHA04LEDEUOO04 | EA | 4 | 700 | 2800 |
| 42 | MISCELLANEOUS ELECTRICAL (AS-BUILT DRAWINGS) | LS | 1 | 500 | 500 |
| 43 | FORCE ACCOUNT WORK (PROVIDE ELECTRICAL SERVICE) | LS | 1 | 250 | 250 |
| 44 | SERVICE PEDESTAL | EA | 1 | 300 | 300 |
| 45 | CONTRACT ALLOWANCE | LS | 1 | 18800 | 18800 |
| 46 | ALTERNATE NO. 1 | LS | 1 | 10000 | 10000 |
| Traffic Signal Material Costs | | | | | 198585.06 |

Table 3.2 shows the signal plan material descriptions along with their respective costs and the final material and construction costs of the projected intersection.

## 3.2 Design Cost

J3Z Engineering consisted of a Project Manager (PM), Senior Engineer (SENG), Traffic Engineer (TRAF), and an AutoCAD Technician (CAD) working on the signal redesign project. Table 3.3 shows the billing rate and design cost for each of the position. The total design cost for the City of Flagstaff Signal Redesign Project is $72,881.00.

*Table 3.3: Design Cost*

| Classification | Bas Pay Rate ($/hr) | Benefits of Base Pay Rate (%) | Actual Pay ($/hr) | OH of Base Pay (%) | Actual Pay + OH ($/hr) | Profit of Actual Pay + OH (%) | Billing Rate ($/hr) | Total Hours | Design Cost Per Position |
|---|---|---|---|---|---|---|---|---|---|
| **SENG** | 100.00 | 30 | 130.00 | 60 | 208.00 | 10 | 228.80 | 125 | $28,600.00 |
| **PM** | 75.00 | 40 | 105.00 | 10 | 115.50 | 10 | 127.05 | 132.5 | $16,834.13 |
| **TRAF** | 80.00 | 40 | 112.00 | 15 | 128.80 | 10 | 141.68 | 169 | $23,943.92 |
| **CAD** | 25.00 | 20 | 30.00 | 10 | 33.00 | 10 | 36.30 | 96.5 | $ 3,502.95 |
| | | | | | | **Total Design Cost** | | | **$72,881.00** |

## References

[1] Google, "Google Maps," [Online]. [Accessed 20 January 2016].

[2] *HCM 2000,* Transportaion Research Board of the National Acadamies.

[3] "Vehicle Classification Support," JAMAR Technologies, Inc., [Online]. Available: http://www.jamartech.com/S04008.html. [Accessed 3 2 2016].

[4] J. Deshaies, "THE I-81 CHALLENGE," [Online]. Available: http://thei81challengeblog.org/archive/learning-center-what-is-level-of-service-los/. [Accessed 08 March 2016].

[5] "How We Drive," [Online]. Available: http://www.howwedrive.com/2009/03/03/los-rip/. [Accessed 08 March 2016].

[6] C. o. Flastaff, "City of Flagstaff-Map-ArcReader," City of Flagstaff, Flagstaff, 2014.

[7] Trafficware, "Planning & Analysis Software," [Online]. Available: http://www.trafficware.com/synchro-studio.html. [Accessed 9 3 2016].

[8] FHWA, "2009 Edition Chapter 4C. Traffic Control Signal Needs Studies," MUTCD, 2009. [Online]. Available: http://mutcd.fhwa.dot.gov/htm/2009/part4/part4c.htm. [Accessed 08 March 2016].

## 4.0 Appendices

Appendix A: Vehicle Classification Sheet

Appendix B: Synchro Output Map

Appendix C: HCS Output Sheet

Appendix D: Information for Warrants 3-6 and 7-9

Appendix E: Project Plan Set

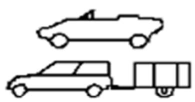
Appendix F: Signal Timing

Appendix A: Vehicle Classification Sheet

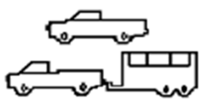
In traffic terms, a vehicle's 'classification' is the category it is sorted into based on its physical characteristics.

Most classification studies are done use the Federal Highway Administration's Scheme F as a basis.
This scheme contains 13 separate classes of vehicles, described below:

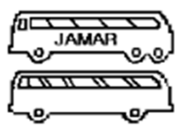
**Class 1 - Motorcycles**
This class includes all two- or three-wheeled motorized vehicles. These vehicles typically have a saddle-type of seat and are steered by handlebars rather than a steering wheel. This includes motorcycles, motor scooters, mopeds, motor-powered bicycles and three-wheel motorcycles.



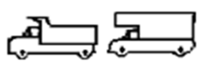
**Class 2 - Passenger cars**
This class includes all sedans, coupes and station wagons manufactured primarily for the purpose of carrying passengers, including those pulling recreational or other light trailers.



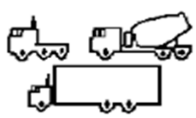
**Class 3 - Pickups, Vans and other 2-axle, 4-tire single unit vehicles**
This class includes all two-axle, four tire vehicles other than passenger cars, which includes pickups, vans, campers, small motor homes, ambulances, minibuses and carryalls. These types of vehicles which are pulling recreational or other light trailers are included.



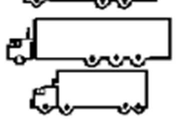

**Class 4 - Buses**
This class includes all vehicles manufactured as traditional passenger-carrying buses with two axles and six tires or three or more axles. This includes only traditional buses, including school and transit buses, functioning as passenger-carrying vehicles. All two-axle, four tire minibuses should be classified as Class 3. Modified buses should be considered to be trucks and classified appropriately.



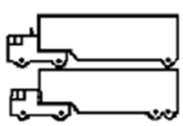
**Class 5 - Two-Axle, Six-Tire Single Unit Trucks**
This class includes all vehicles on a single frame which have two axles and dual rear tires. This includes trucks, camping and recreation vehicles, motor homes, etc.



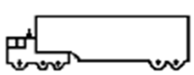
**Class 6 - Three-Axle Single Unit Trucks**
This class includes all vehicles on a single frame which have three axles. This includes trucks, camping and recreation vehicles, motor homes, etc.



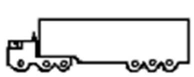
**Class 7 - Four or More Axle Single Unit Trucks**
This class includes all vehicles on a single frame with four or more axles.



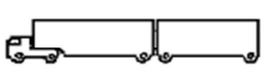
**Class 8 - Four or Less Axle Single Trailer Trucks**
This class includes all vehicles with four or less axles consisting of two units, in which the pulling unit is a tractor or single unit truck.



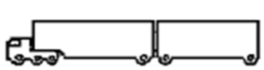
**Class 9 - Five-Axle Single Trailer Trucks**
This class includes all five-axle vehicles consisting of two units in which the pulling unit is a tractor or single unit truck.



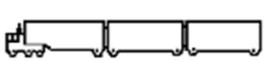
**Class 10 - Six or More Axle Single Trailer Trucks**
This class includes all vehicles with six or more axles consisting of two units in which the pulling unit is a tractor or single unit truck.



**Class 11 - Five or Less Axle Multi-Trailer Trucks**
This class includes all vehicles with five or less axles consisting of three or more units in which the pulling unit is a tractor or single unit truck.



**Class 12 - Six-Axle Multi-Trailer Trucks**
This class includes all six-axle vehicles consisting of three or more units in which the pulling unit is a tractor or single unit truck.



**Class 13 - Seven or More Axle Multi-Trailer Trucks**
This class includes all vehicles with seven or more axles consisting of three or more units in which the pulling unit is a tractor or single unit truck.

**What are unclassified vehicles?**
Most class studies also contain data for **Class 14 - Unclassified Vehicles**. This class includes all vehicles which could not process into one of the existing 13 classes. This data can be retained in your reports, or it can be redistributed by the software into the existing 13 classes based on the percentages in each of those classes.

NORTHERN ARIZONA UNIVERSITY

## Appendix B: Synchro LOS Table

| INTERSECTION WITHOUT TRAFFIC SIGNAL IMPLEMENTED | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STREET | OAKMONT DR | | | OLD WALNUT CANYON RD | | | COUNTRY CLUB DR | | | | | |
| DIRECTION | EBL↗ | EBT→ | EBR↘ | WBL↙ | WBT← | WBR↖ | NBL↖ | NBT↑ | NBR↗ | SBL↘ | SBT↓ | SBR↙ |
| TRAFFIC VOLUME (VPH) | 78 | 20 | 9 | 20 | 20 | 196 | 12 | 128 | 29 | 209 | 120 | 82 |
| LEVEL OF SERVICE | F | F | F | C | C | B | A | A | A | A | A | A |
| TOTAL DELAY (S) | 62.7 | 62.7 | 62.7 | 22.6 | 22.6 | 10.3 | 7.7 | 0 | 0 | 14 | 0 | 0 |

## Appendix C: HCS Output Sheet

| Vehicle Volumes and Adjustments | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Approach | Eastbound | | | | Westbound | | | | Northbound | | | | Southbound | | | |
| Movement | U | L | T | R | U | L | T | R | U | L | T | R | U | L | T | R |
| Priority | | 10 | 11 | 12 | | 7 | 8 | 9 | 1U | 1 | 2 | 3 | 4U | 4 | 5 | 6 |
| Number of Lanes | | 0 | 1 | 0 | | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 |
| Configuration | | | LTR | | | LT | | R | | L | | TR | | L | T | R |
| Volume (veh/h) | | 4 | 12 | 53 | | 118 | 13 | 11 | | 16 | 89 | 7 | | 57 | 75 | 113 |
| Percent Heavy Vehicles | | 9 | 9 | 9 | | 17 | 17 | 17 | | 9 | | | | 14 | | |
| Proportion Time Blocked | | | | | | | | | | | | | | | | |
| Right Turn Channelized | No | | | | Yes | | | | No | | | | Yes | | | |
| Median Type | Undivided | | | | | | | | | | | | | | | |
| Median Storage | | | | | | | | | | | | | | | | |
| **Delay, Queue Length, and Level of Service** | | | | | | | | | | | | | | | | |
| Flow Rate (veh/h) | | | 75 | | | 142 | | 12 | | 17 | | | | 62 | | |
| Capacity | | | 815 | | | 524 | | 918 | | 1473 | | | | 1412 | | |
| v/c Ratio | | | 0.09 | | | 0.27 | | 0.01 | | 0.01 | | | | 0.04 | | |
| 95% Queue Length | | | 0.3 | | | 1.1 | | 0.0 | | 0.0 | | | | 0.1 | | |
| Control Delay (s/veh) | | | 9.9 | | | 14.4 | | 9.0 | | 7.5 | | | | 7.7 | | |
| Level of Service (LOS) | | | A | | | B | | A | | A | | | | A | | |
| Approach Delay (s/veh) | 9.9 | | | | 13.7 | | | | 1.0 | | | | 1.8 | | | |
| Approach LOS | A | | | | B | | | | A | | | | A | | | |

# Appendix D: Warrant 3-6 and 8-9 Information / Charts

*Appendix D-1: Warrant 3: Peak Hour [8]*

**Standard:**

02 **This signal warrant shall be applied only in unusual cases, such as office complexes, manufacturing plants, industrial complexes, or high-occupancy vehicle facilities that attract or discharge large numbers of vehicles over a short time.**

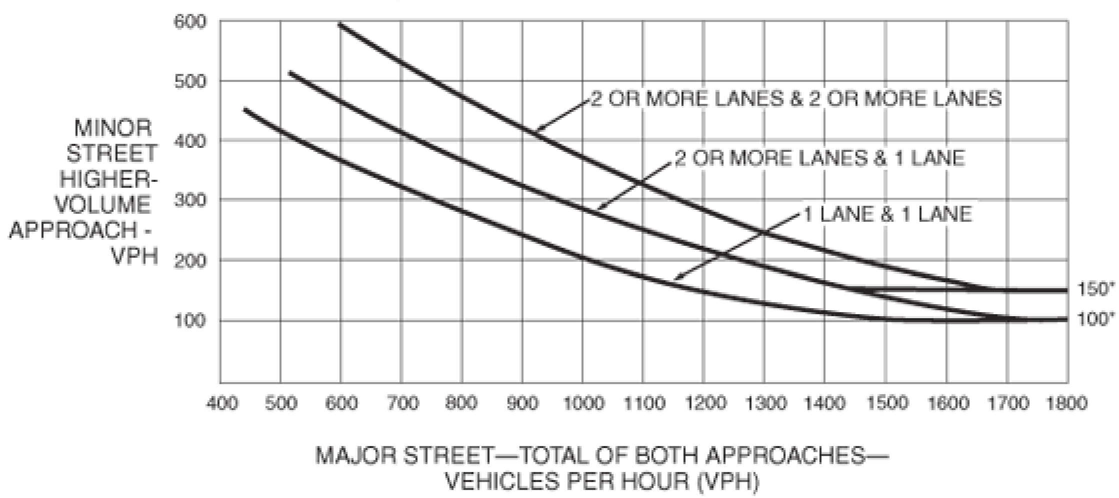
03 **The need for a traffic control signal shall be considered if an engineering study finds that the criteria in either of the following two categories are met:**

**A. If all three of the following conditions exist for the same 1 hour (any four consecutive 15-minute periods) of an average day:**

1. **The total stopped time delay experienced by the traffic on one minor-street approach (one direction only) controlled by a STOP sign equals or exceeds: 4 vehicle-hours for a one-lane approach or 5 vehicle-hours for a two-lane approach; and**
2. **The volume on the same minor-street approach (one direction only) equals or exceeds 100 vehicles per hour for one moving lane of traffic or 150 vehicles per hour for two moving lanes; and**
3. **The total entering volume serviced during the hour equals or exceeds 650 vehicles per hour for intersections with three approaches or 800 vehicles per hour for intersections with four or more approaches.**

**B. The plotted point representing the vehicles per hour on the major street (total of both approaches) and the corresponding vehicles per hour on the higher-volume minor-street approach (one direction only) for 1 hour (any four consecutive 15-minute periods) of an average day falls above the applicable curve in Figure 4C-3 for the existing combination of approach lanes.**

**Figure 4C-3. Warrant 3, Peak Hour**




*Note: 150 vph applies as the lower threshold volume for a minor-street approach with two or more lanes and 100 vph applies as the lower threshold volume for a minor-street approach with one lane.

*Appendix D-2 Warrant 4: Pedestrian Volume [8]*

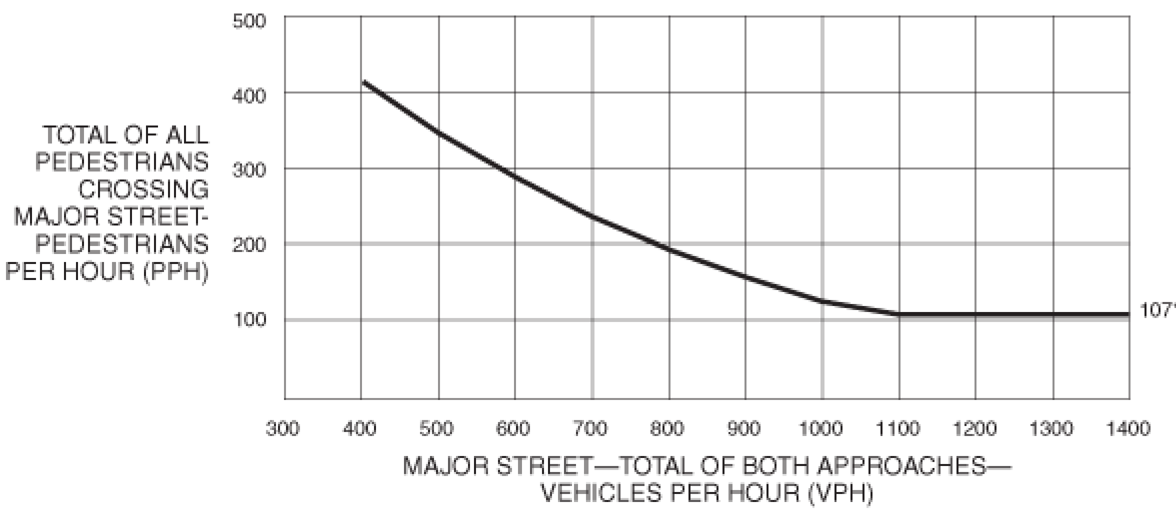
**Standard:**

02 **The need for a traffic control signal at an intersection or midblock crossing shall be considered if an engineering study finds that one of the following criteria is met:**

**A. For each of any 4 hours of an average day, the plotted points representing the vehicles per hour on the major street (total of both approaches) and the corresponding pedestrians per hour crossing the major street (total of all crossings) all fall above the curve in Figure 4C-5; or**

**B. For 1 hour (any four consecutive 15-minute periods) of an average day, the plotted point representing the vehicles per hour on the major street (total of both approaches) and the corresponding pedestrians per hour crossing the major street (total of all crossings) falls above the curve in Figure 4C-7.**

**Figure 4C-5. Warrant 4, Pedestrian Four-Hour Volume**




*Note: 107 pph applies as the lower threshold volume.

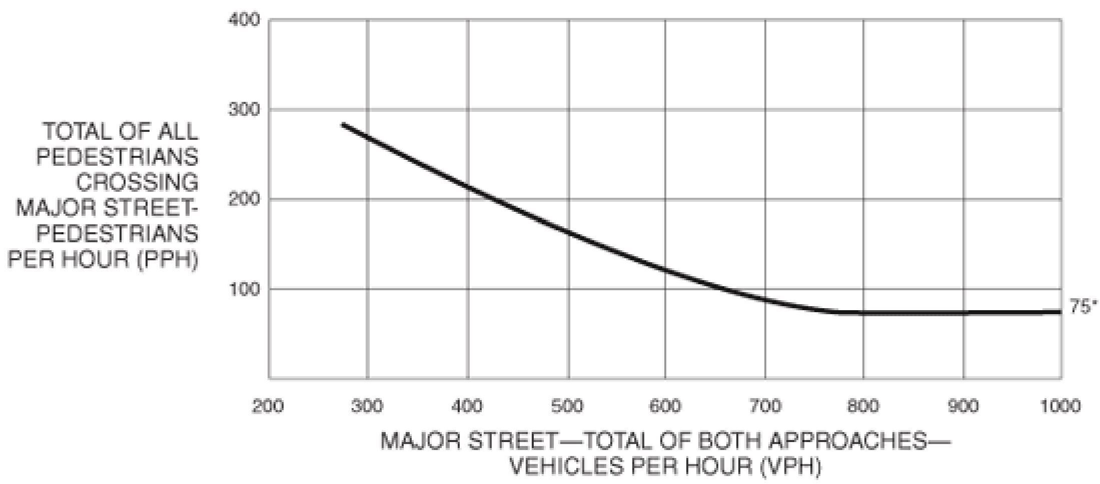
Appendix D-3 Warrant 5: School Crossing [8]

**Standard:**

02 **The need for a traffic control signal at an intersection or midblock crossing shall be considered if an engineering study finds that one of the following criteria is met:**

- **A. For each of any 4 hours of an average day, the plotted points representing the vehicles per hour on the major street (total of both approaches) and the corresponding pedestrians per hour crossing the major street (total of all crossings) all fall above the curve in Figure 4C-5; or**
- **B. For 1 hour (any four consecutive 15-minute periods) of an average day, the plotted point representing the vehicles per hour on the major street (total of both approaches) and the corresponding pedestrians per hour crossing the major street (total of all crossings) falls above the curve in Figure 4C-7.**

Figure 4C-6. Warrant 4, Pedestrian Four-Hour Volume (70% Factor)




*Appendix D-4 Warrant 6: Coordinated Signal System [8]*

## Section 4C.07 Warrant 6, Coordinated Signal System

Support:

01 Progressive movement in a coordinated signal system sometimes necessitates installing traffic control signals at intersections where they would not otherwise be needed in order to maintain proper platooning of vehicles.

**Standard:**

02 **The need for a traffic control signal shall be considered if an engineering study finds that one of the following criteria is met:**

- **A. On a one-way street or a street that has traffic predominantly in one direction, the adjacent traffic control signals are so far apart that they do not provide the necessary degree of vehicular platooning.**
- **B. On a two-way street, adjacent traffic control signals do not provide the necessary degree of platooning and the proposed and adjacent traffic control signals will collectively provide a progressive operation.**

*Appendix D-5 Warrant 8: Roadway Network [8]*

**Standard:**

**02 The need for a traffic control signal shall be considered if an engineering study finds that the common intersection of two or more major routes meets one or both of the following criteria:**

**A. The intersection has a total existing, or immediately projected, entering volume of at least 1,000 vehicles per hour during the peak hour of a typical weekday and has 5-year projected traffic volumes, based on an engineering study, that meet one or more of Warrants 1, 2, and 3 during an average weekday; or**

**B. The intersection has a total existing or immediately projected entering volume of at least 1,000 vehicles per hour for each of any 5 hours of a non-normal business day (Saturday or Sunday).**

**03 A major route as used in this signal warrant shall have at least one of the following characteristics:**

**A. It is part of the street or highway system that serves as the principal roadway network for through traffic flow.**

**B. It includes rural or suburban highways outside, entering, or traversing a city.**

**C. It appears as a major route on an official plan, such as a major street plan in an urban area traffic and transportation study.**

*Appendix D-6 Warrant 9: Intersection near a Grade Crossing [8]*

**Standard:**

**03 The need for a traffic control signal shall be considered if an engineering study finds that both of the following criteria are met:**

**A. A grade crossing exists on an approach controlled by a STOP or YIELD sign and the center of the track nearest to the intersection is within 140 feet of the stop line or yield line on the approach; and**

**B. During the highest traffic volume hour during which rail traffic uses the crossing, the plotted point representing the vehicles per hour on the major street (total of both approaches) and the corresponding vehicles per hour on the minor-street approach that crosses the track (one direction only, approaching the intersection) falls above the applicable curve in Figure 4C-9 or 4C-10 for the existing combination of approach lanes over the track and the distance D, which is the clear storage distance as defined in Section 1A.13.**

## Appendix E: Final Plan Set

PLAN SET GOES HERE

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## Appendix F: Signal Timing

# CITY OF FLAGSTAFF
# TRAFFIC SIGNAL TIMING CARD

**LOCATION:** Country Club & Old Walnut **SIGNAL NUMBER:** XXX

**DATE:** 4/27/2016

| **PHASE** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
|---|---|---|---|---|---|---|---|---|
| **MOVEMENT** | EBLT | WB | SBLT | NB | WBLT | EB | NBLT | SB |
| FLASH | R | R | R | R | R | R | R | R |
| START-UP | | R | | | | R | | |
| MIN. GREEN | 5 | 10 | 5 | 10 | 5 | 10 | 5 | 10 |
| PASSAGE TIME (EXT) | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 |
| MAX 1 | 20 | 20 | 15 | 30 | 15 | 20 | 35 | 40 |
| MAX 2 | | | | | | | | |
| MAX 3 | | | | | | | | |
| YELLOW | 3.0 | 3.0 | 3.0 | 4.0 | 3.0 | 3.0 | 3.6 | 4.0 |
| RED CLEARANCE | 1.0 | 2.8 | 1.0 | 1.6 | 1.0 | 2.8 | 1.0 | 1.6 |
| WALK | | 4 | | 4 | | 4 | | 4 |
| PED CLEARANCE | | 31 | | 22 | | 28 | | 20 |
| | | | | | | | | |
| RECALL MODE | | | | | | | | |
| CNA I | | | | | | | | |
| CNA II | | | | | | | | |
| DUAL ENTRY | | ON | | ON | | ON | | ON |
| DETECTOR MEMORY | | | | | | | | |
| DETECTOR ASSIGNMENT | | | | | | | | |
| LOOP/CAMERA DELAY | | | | | | | | |
| LOOP/CAMERA EXTEND | | | | | | | | |
| CONTROLLER DELAY | | | | | | | | |
| CONTROLLER EXTEND | | | | | | | | |
| BACK UP PROTECT | | NO | | NO | | NO | | NO |
| LEFT TURN OPERATION | | | | FYA Lag | | | | FYA Lag |

Flash Start-up timing: 0 seconds

All Red Start-up timing: 6 seconds

Coordination: none

Intersection Notes: Lagging Flashing Yellow Arrow left turns for NB and SB, Video detection all phases

# Yellow, Red Clearance, and Pedestrian Timing Formula Sheet

**Through Movement Yellow Interval Timing**

$$Y = t + \frac{1.47V}{(2a + 64.4g)} \quad [1]$$

where:

Y = yellow vehicle change interval

t = driver perception/reaction time, assumed to be 1.0 second

V = posted speed limit, mph

a = deceleration rate, assumed to be 10 ft/sec$^2$

g = % grade divided by 100 (downhill is negative grade)

**Through Movement Red Clearance Interval Timing**

$$R = \frac{W + L}{1.47V} \quad [2]$$

where:

R = length of red clearance, to the nearest 0.1 seconds

W = intersection width, as defined in ARS 28-601

L = length of vehicle, assumed to be 20 ft

V = posted speed limit, mph

**Pedestrian Timing**

Ped Walk = at least 7 seconds in length

$$\text{Ped Clearance Time} = \frac{P}{w} - Y \quad [3]$$

where:

P = distance from curb to curb or wheelchair ramp to center of wheelchair ramp along center of crosswalk, ft

w = normal walking speed, assumed to be 3.5 fps

Y = yellow vehicle change interval

**Left Turn Change & Clearance Interval Timing**

For "simple standard" intersections use:
Yellow Change = 3 sec
Red Clearance = 1 sec

For "complex/nonstandard" intersections use engineering judgment (adding time to red in 0.5 sec increments), or the "Through Movement Interval Timing" equation.