Creating a Process to Identify Unsignalized Intersections with a Limited Field of Vision

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Abstract

Many unsignalized intersections are the scenes of vehicle accidents. Often the cause of the accident can be attributed to an obstruction that reduces a driver's field of vision thus giving them less time to react to a potential threat. This study presents a process that uses a Geographical Information System (GIS) along with street centerline data, digital terrain models, and 3D building models to create sight triangles and perform a basic field of vision assessment at uncontrolled intersections, specifically looking at buildings as a source of visual obstruction. Intersection Total Field of Vision and Intersection Combined Leg Lengths were used to evaluate and compare intersections. Results show intersections with lower field of vision scores trend toward more accidents.

Introduction

Unsignalized Intersections in Winona

In 2014, the city of Winona, Minnesota had 120 unsignalized intersections (Rogers, 2017). These intersections were the locations of only a fraction of the accidents that occurred in Winona, but that can be attributed to lower traffic volume rather than safe intersection design. Many of these intersections and the buildings around them were constructed many years ago, before the current rules regarding building setbacks were enacted. Since 1959, new construction is required to be 25 feet back from the lot edge (Winona Planning and Zoning Department, 2017). Many of the older buildings were built much closer to the edge and inadvertently created sight obstructions at the intersections.

While putting stop signs at all of the current unsignalized intersections is possible, the Winona City Council, who decides where stop signs are placed, has followed a procedure of placing new stop signs only after a public request is made and an examination of the accident history has been made.

Field of Vision

An unobstructed field of vision is essential to a driver's ability to correctly evaluate the situation when approaching an intersection (Ceunynck, Daniels, Brijs, Hermans, and Wets, 2011). A driver must be able to see potential threats while still far enough away from an intersection to identify, evaluate, and react appropriately. Approach Sight Triangles are a tool used by safety engineers to evaluate a driver's potential field of vision when approaching an intersection.

The Useful Field of Vision (UFOV) is the visual area from which a person can identify and process information without moving their head or eyes (Wolf, Dobres, Rozenholtz, and

Darren Omoth. 2018. Creating a Process to Identify Unsignalized Intersections with a Limited Field of Vision. Volume 21, Papers in Resource Analysis. 12 pp. Saint Mary's University of Minnesota University Central Services Press. Winona, MN. Retrieved (date) http://www.gis.smumn.edu

Reimer, 2017). A driver should have natural or corrected vision of at least 20/40 and 105 degrees of peripheral vision (Minnesota Department of Public Safety Driver and Vehicle Services Division, 2017). Peripheral vision exists mostly outside the UFOV but is still important in the early identification of possible hazards when driving (Wolfe *et al*., 2017). Physical conditions that reduce a driver's field of vision, such as cataracts or glaucoma have been linked to higher vehicle collision rates (Owsley and McGwin, 2010).

Vehicle Stopping Distance

A vehicle's stopping distance is broadly defined as the distance the vehicle travels from the time the driver receives a stimulus until the vehicle comes to a complete stop (Bokare and Maurya, 2016). The distance travelled has a direct correlation to the speed the vehicle is travelling at the time the driver first sees a hazard.

The vehicle stopping process is made up of several components: Mental Time, Movement Time, and Device Response Time (Green, 2000). The Mental component consists of three parts. Sensation is the portion where the driver detects a hazard. Perception is the time to recognize and understand what has been sensed. Reaction is the time required to decide upon and initiate a course of action. The Movement Time component is the time it takes to physically perform the action, such as moving a foot from the accelerator to the brake pedal.

Numerous studies have shown perception and reaction times vary according to the driver's age, experience, anticipation, time of day, and weather (Green, 2000). The safety industry uses a conservative value of 2.5 seconds for perception-response time in its calculations of stopping distances (National Academies of Sciences, Engineering, and Medicine, 2018).

Finally, the Device Response Time is the time it takes for the mechanical device to perform its function. This is the portion when the vehicle is actively decelerating. The standard rate for deceleration is 11.2 ft./sec^2 (3.4 m./sec^2).

A safe stopping distance can be calculated using the following formula (American Academy of State Highway and Transportation Officials (AASHTO), 2011):

$$SSD = 1.47\,Vt + \frac{V^2}{30\left(\frac{a}{32.2} \pm g\right)}$$

where

SSD = stopping sight distance, in ft.
V = speed, in mph
t = perception-reaction time, usually 2.5 seconds
a = deceleration rate, 11.2 ft./sec^2
g = grade

To find the safe stopping distance for the recommended 30 miles per hour speed limit for residential streets in Winona, the formula was:

$$SSD = 1.47 \times 30 \times 2.5 + \frac{30^2}{30\left(\frac{11.2}{32.2} \pm 0\right)}$$

SSD = 196.63 feet

Sight Triangles

To assess visibility at intersections engineers, use a concept called sight triangles. The sight triangle measures the field of vision of a driver when approaching an intersection (Figure 1). A measurement is taken from a point that represents the position of the driver's eye

(Observer Point) at a distance (Safe Stopping Distance) they could safely stop if travelling at the recommended speed limit. The furthest point from the center of the intersection along the perpendicular centerline where the observer has an unobstructed view of the target is recorded. The distance from this point to the center of the intersection is called the leg and represents the maximum distance from the intersection another vehicle is visible from the observer point.

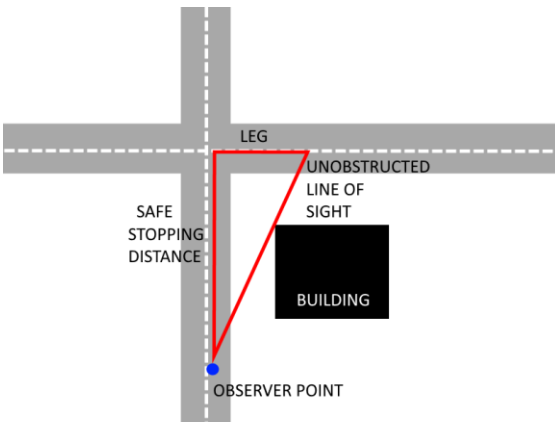

Figure 1. Sight Triangle measurement at an uncontrolled intersection.

The Safe Stopping Distance would normally be set as the observer point. Field research has shown, however, that drivers who know they are approaching an uncontrolled intersection will slow down to approximately 50% of the mid-block speed (Harwood, Mason, Brydia, Pietrucha, and Gittings, 1996). Since one or both vehicles are likely to be travelling at slower than the posted speed, AASHTO recommends a shorter safe stopping distance when measuring Sight Triangles. For vehicles travelling 30 miles per hour, the calculated Safe Stopping Distance is 196.63 feet, but the recommended observer point for measuring uncontrolled intersections is 140 feet.

Purpose of Research

This study created a process to calculate a driver's field of vision and created sight triangles using a Geographical Information System (GIS). This assessment was done in 3D to simulate the real-world locations. Assessments were made as to overall visibility for each intersection as well as an exploration of the combined sight triangles of intersecting vehicles. The number of accidents at each intersection was looked at to see if the process identified historically dangerous intersections.

Methods

Data

The software used for this project was ArcMap 10.4, ArcScene 10.4, and ArcGIS Pro. LiDAR data for Winona was downloaded from the Minnesota Geospatial Commons. The street centerline data was obtained from the City of Winona Engineering Department. The building footprint data was obtained from the Winona County GIS Department. Accident data was obtained from the Winona Police Department.

Process

A Digital Terrain Model (DTM) was created from the LiDAR data to provide a ground surface level that did not contain any buildings or vegetation. The DTM, street centerline, and building footprints were then clipped to a smaller area of interest to make processing more manageable.

A buildings multi-patch layer was created by extruding the footprints layer to 30 feet and then running the Layer 3D to Feature Class tool. The height of 30 feet was chosen simply as a number that allows the buildings to be modeled as an obstruction to a driver. An intersections multipoint layer was created representing all the intersections chosen for the study from the centerlines layer. A stopping distance layer was created by applying a buffer of 140 feet to the intersections layer. For a vehicle traveling 30 miles per hour, 140 feet is the minimum recommended stopping sight distance (AASHTO, 2011).

A centerline buffer layer was created with a buffer of three feet around the street centerlines layer. Three feet from the centerline is the approximate position of driver's eye on a two-way residential street.

Four intersections along 7th street were selected for this study because they provided a sequence of intersections that would likely be crossed by a driver travelling along 7th street. The intersection at 4th and High Forest was used because a request for a stop sign was made to the city because of the high number of accidents at the intersection. The observer points layer was created using the Intersect tool to locate the points where the stopping distance and centerline buffer layers intersected. These points represented the location of the driver's eye, 140 feet from the intersection and 3 feet from the centerline, for all four directions of travel at each intersection.

The Construct Sight Lines tool requires an input of a single point, so four observer point layers were created for each intersection. For consistency a template was created with the new field named HEIGHT with a default value of 3.543 feet which is the standard height of a driver's eye (Layton and Dixon, 2012). Individual observer points were placed by snapping to the corresponding point on the multipoint observer points layer.

Two target layers were created for each intersection to represent the vehicles that a driver might see. One was created for the East-West section and one for the North-South. They run from one edge of the stopping distance polygon along the street centerlines layer to the other edge. Each target line is 280 feet long which covers the safe stopping distance of 140 feet from each opposing direction. A HEIGHT field was added with a default value of 4.5 feet, which is the average height of a passenger vehicle (NASEM, 2018). Figure 2 shows the basic setup for each intersection.

Figure 2. Diagram showing the principle components of the initial setup for the intersection of 7th and Laird streets. The components are the Stopping Distance Buffer (red), the Centerline Buffer (yellow), Observer Points (green) and the Target Lines (blue).

Sight Lines were created using the Construct Sight Lines (3D Analyst) tool (Figure 3). Checking the Output the Direction checkbox adds two fields, AZIMUTH and VERT_ANGLE. The AZIMUTH field was used for a later step in the process.

The resulting layer displayed sight lines from the observer point to points along the target line (Figure 4). The tool created a sight line every half meter (1.640 ft.) along the target line for a total of 172 sight lines. These sight lines do not take any obstructions into account.

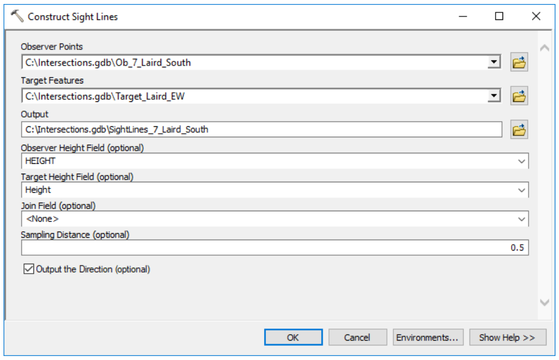

Figure 3. Construct Sight Lines dialog box.

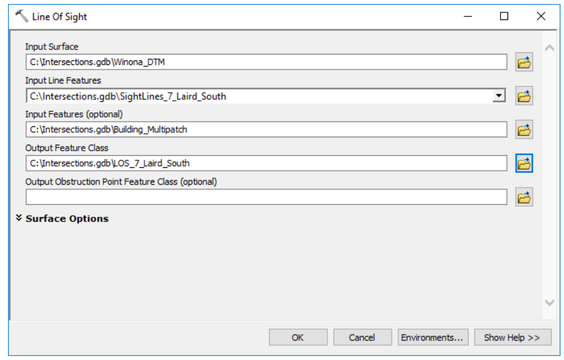

Figure 5. Line of Sight dialog box.

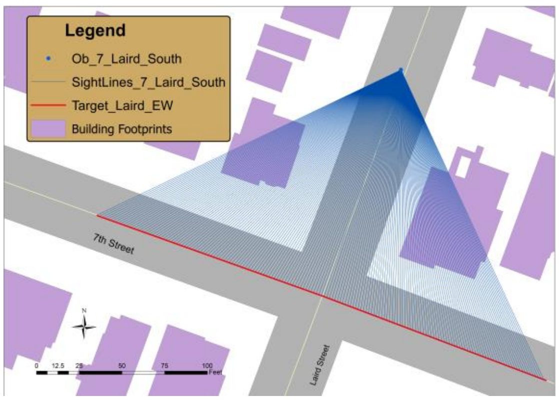

Figure 4. Sight Lines (in blue) for the intersection of 7th and Laird heading South.

Lines of Sight (LOS) were constructed using the Line of Sight (3D Analyst) tool (Figure 5). The Line of Sight tool determines if any obstructions, in this case the buildings, would block the line of sight between the observer point and the target line. The tool run a check for each of the Sight Lines created in the previous step. The VisCode field for each Line of Sight is given either a value of 1 if the target is visible or a 0 if the target is not visible.

The resulting Line of Sight layer (Figure 6) created lines that identified which points along the target line were visible from the observer point. Lines in green were visible and the red lines indicated points that were obstructed and not visible from the observer point.

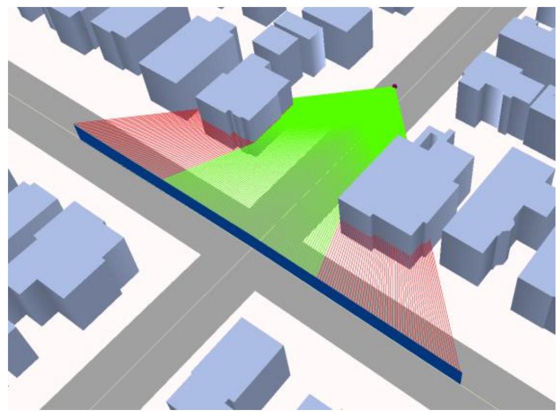
Figure 6. Line of Sight assessment for the intersection of 7th and Laird streets heading South. The green lines show areas where the driver has an unobstructed view of the target line (dark blue line). The red lines show where the driver cannot see the target. To estimate scale, the dark blue line is 280 feet.

Field of Vision

By identifying the first sight lines that are visible along the Target line to the driver's left and right, a table was constructed with the Azimuth for right, center, and left. The segment lengths for the right and left sight lines were recorded.

The Azimuth data was used to determine a Field of Vision (FOV) by subtracting the lower azimuth reading from the higher reading. A FOV was calculated to the right and left for each direction using the same process and the center azimuth reading. The right and left FOVs were used later in the construction of the sight triangles.

To compare intersections to each other, the Total FOV for all four directions was added together to get the Intersection Total Field of View (Figure 7).

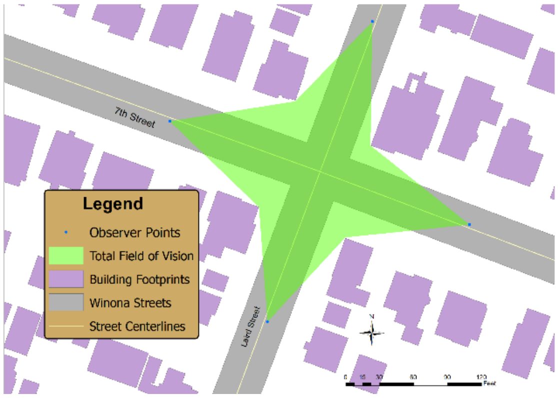

Figure 7. The diagram of the Intersection Total Field of View for the intersection at 7th and Laird. The Total Field of Vision is 187.47°.

Sight Triangles

A sight triangle was constructed using the collected data and the Pythagorean Theorem since the lengths of two sides of a right triangle was known. The distance between the center of the intersection and the driver's eye was set at 140 feet (42.67 meters). The hypotenuse was the segment length of the first Line of Sight to reach the Target. The segment length was found in the DIST_ALONG field in the Lines of Sight attribute table. The remaining side, which represents the distance of a vehicle perpendicular to the observer from the intersection can be calculated with the following formula:

$$b = \sqrt{c^2 - a^2}$$

where a = distance to intersection
b = unknown leg length
c = segment length

The linear units of the NAD_1983_UTM_Zone_15 projected coordinate system is meters, so the calculations were done in meters and the result was converted to feet (1 meter = 3.28084 feet).

Example: 7th and Laird heading south looking to the right (Figure 8)

where a = 42.67 m.
b = unknown leg length
c = 46.84 m.

$$b = \sqrt{46.84^2 - 42.67^2} \text{ x } 3.28084$$

$$b = 63.39 \text{ ft.}$$

This means that the earliest a driver who is 140 feet away from the intersection could see the other vehicle is when it is only 63 feet from the intersection. A driver with an unobstructed field of vision could see an approaching vehicle when it is 140 feet way from the intersection.

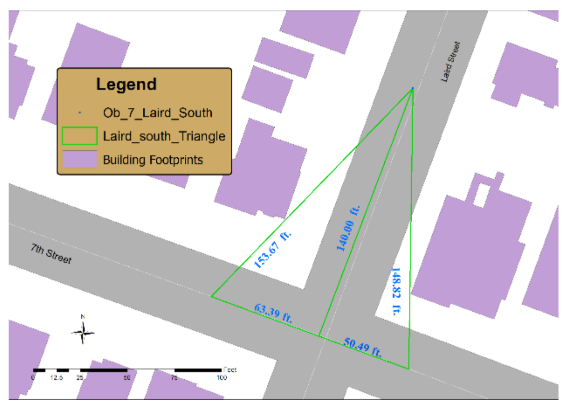

Figure 8. Approach Sight Triangle constructed for the intersection of 7th and Laird heading South.

The most dangerous intersections are those that have at least one corner where two vehicles meet at a perpendicular angle and both drivers have an obstructed sight triangle (Harwood *et al.*, 1996).

The Combined Leg Length (CLL) is the sum of the two intersecting sight triangle legs. Four Combined Leg Lengths were calculated for each intersection (Figure 9). The CLL represents the combined distance both vehicles are from the intersection when each vehicle is first seen the by other as the two drivers approach the intersection at a perpendicular angle. Ideally, both vehicles would be 140 feet away from the intersection when the drivers see each other meaning an unobstructed corner would have an Intersecting Leg Length sum of 280 feet.

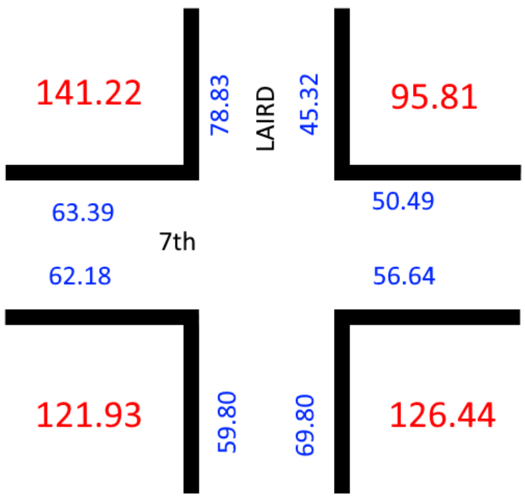

Figure 9. Diagram of the intersection at 7th and Laird with individual sight triangle leg lengths in blue and the combined leg lengths in red. All measurements are in feet.

Data used to construct the Sight Triangles can be found in Appendix A.

Results

Intersection Total Field of View

The Total Field of Vision was calculated by adding the four Field of Views for each intersection. The Total Fields of Vision were ranked from lowest (least visibility) to highest (most visibility). The number of accidents reported at each intersection from 2012 to 2017 was added to the table to see if there was any correlation between low Total Field of Vision and higher numbers of accidents (Table 1). All of the data used to calculate the Total Field of Vision figures is provided in Appendix B.

Table 1. Total Field of Vision. This table shows the combined field of vision for each intersection and the number of accidents at the intersection from 2012 to 2017.

Rank	Intersection	Total Field of Vision	Accidents 2012-2017
1	7th & Laird	187.45	5
2	4th& High Forest	198.50	6
3	7th & Chestnut	200.57	2
4	7th & Vine	208.10	2
5	7th & Liberty	275.88	5

Combined Intersecting Leg Lengths

A table was constructed listing all four intersecting legs for each of the five intersections, the Combined Intersecting Leg Lengths and the number of accidents per intersection for a five-year span (Table 2). Each of the five intersections had four separate Combined Intersecting Leg Length combinations for a total of twenty. See Appendix C for Combined Intersecting Leg Lengths diagrams of all intersections.

Discussion

The Total Field of Vision showed that, except for the intersection at 7th and Liberty, lower Total Field of Vision numbers trended toward higher incidents of accidents. The intersection at 7th and Liberty has a park on its northwest corner so two approaches are unobstructed by buildings. Field observations at the intersection found several trees and fences that may obstruct the drivers' field of view.

Table 2. Combined Intersecting Leg Lengths. This table ranks intersecting sight triangle leg from smalles (least visibility) to largest (most visibility).

Rank	Intersections	Combined Intersecting Leg Lengths	Accidents 2012-2017
1	7th South & Laird West	95.81	5
2	4th North & High Forest East	112.26	6
3	4th South & High Forest West	119.18	6
4	7th North & Chestnut West	121.8	2
5	7th North & Laird East	121.93	5
6	7th North & Vine East	123.63	2
7	7th South & Chestnut West	124.76	2
8	7th North & Laird West	126.44	5
9	4th South & High Forest East	129.09	6
10	7th North & Chestnut East	131.08	2
11	7th South & Vine East	131.54	2
12	7th South & Laird East	141.22	5
13	7th North & Vine East	142.23	2
14	7th South & Chestnut East	143.55	2
15	7th South & Liberty West	145.89	5
16	7th South & Vine West	153.18	2
17	4th North & High Forest West	159.29	6
18	7th North and Liberty West	179.42	5
19	7th North & Liberty East	180.03	5
20	7th South and Liberty East	279.87	5

The Intersection Combined Leg Lengths breaks each intersection down into four perpendicular collision paths. It was originally intended to match these individual corners with the direction of travel of vehicles involved in accidents at these intersections. This would have provided a clearer picture of exactly which corners were the most dangerous. Accident data that provided vehicle direction for these intersections was not available during the time of this project.

This study explored buildings as the only obstructions to visibility at the intersections. The study also focused on other vehicles as the only potential collision threats. Pedestrians and bicycles are also common participants in unsignalized intersection accidents but because of their variability of size and speed only data involving two vehicle accidents was used in this work.

Future analysis related to this work could include:

- integrating traffic counts when such data becomes available
- automating the process to make it more efficient
- including foliage from LAS point cloud data that may act as an obstruction
- correlating the direction of vehicle travel with Combined Intersecting Leg Lengths

Conclusions

This project was started to determine if it would be possible to identify intersections that are dangerous because of buildings that obstruct a driver's field of vision. It has been shown that it is possible to create sight triangles using the same specifications that city engineers use to assess intersections.

In the intersections that were studied in this project, many of the intersections had buildings that caused obstructions to driver visibility. The number of other of variables which were left unknown throughout this study and the small sample size made it impossible to attribute the number of accidents solely to the position of the buildings surrounding the intersection.

Acknowledgements

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Appendix A. Data Used to Construct Sight Triangles.

7th & Liberty				
Direction	**Left Seg (m)**	**Right Seg (m)**	**Left Leg (ft)**	**Right Leg (ft)**
North	51.68	50.19	95.66	86.70
East	61.00	49.82	143.02	84.37
South	48.75	59.67	77.35	136.85
West	51.18	47.51	92.72	68.54
7th & Chestnut				
Direction	**Left Seg (m)**	**Right Seg (m)**	**Left Leg (ft)**	**Right Leg (ft)**
North	47.79	45.87	70.61	55.22
East	49.16	46.48	80.09	60.47
South	46.41	46.85	59.88	63.46
West	47.25	47.03	66.58	64.88
7th & Laird				
Direction	**Left Seg (m)**	**Right Seg (m)**	**Left Leg (ft)**	**Right Leg (ft)**
North	46.69	46.03	62.18	56.64
East	48.97	46.40	78.83	59.80
South	45.36	46.84	50.49	63.39
West	47.68	44.85	69.80	45.32
7th & Vine				
Direction	**Left Seg (m)**	**Right Seg (m)**	**Left Leg (ft)**	**Right Leg (ft)**
North	47.82	45.99	70.83	56.29
East	48.69	47.90	76.94	71.40
South	49.45	45.80	81.99	54.60
West	47.35	47.87	67.34	71.19
4th & High Forest				
Direction	**Left Seg (m)**	**Right Seg (m)**	**Left Leg (ft)**	**Right Leg (ft)**
North	46.32	48.03	59.13	72.34
East	47.79	45.64	70.61	53.13
South	46.36	46.24	59.47	58.45
West	50.23	46.39	86.95	59.72

Appendix B. Azimuth and Field of Vision Data.

7th and Liberty						
Direction	**Left Az.**	**Center Az.**	**Right Az.**	**Left FOV**	**Right FOV**	**FOV**
North	345.68	19.81	52.35	34.13	32.54	66.67
East	64.63	110.11	140.89	45.48	30.78	76.26
South	171.54	200.36	244.42	288.82	44.06	72.88
West	256.28	290.79	316.35	34.51	25.56	60.07
					Total FOV	275.88
7th and Chestnut						
Direction	**Left Az.**	**Center Az.**	**Right Az.**	**Left FOV**	**Right FOV**	**FOV**
North	354.17	20.24	40.65	26.07	20.41	46.48
East	78.79	110.45	133.90	31.66	23.45	55.11
South	176.00	199.55	225.44	23.55	25.89	49.44
West	265.01	290.05	314.55	25.04	24.50	49.54
					Total FOV	200.57
7th and Laird						
Direction	**Left Az.**	**Center Az.**	**Right Az.**	**Left FOV**	**Right FOV**	**FOV**
North	355.80	20.48	42.82	24.68	22.34	47.02
East	81.02	109.69	133.86	28.70	24.17	52.87
South	180.85	200.16	224.09	19.31	23.93	43.24
West	264.11	290.25	308.43	26.14	18.18	44.32
					Total FOV	187.45
7th and Vine						
Direction	**Left Az.**	**Center Az.**	**Right Az.**	**Left FOV**	**Right FOV**	**FOV**
North	353.83	19.87	41.57	26.04	21.70	47.74
East	80.99	110.53	137.19	29.54	26.66	56.20
South	169.29	199.66	221.12	30.37	21.46	51.83
West	264.43	289.42	316.76	24.99	27.34	52.33
					TOTAL FOV	208.1
4th and High Forest						
Direction	**Left Az.**	**Center Az.**	**Right Az.**	**Left FOV**	**Right FOV**	**FOV**
North	356.96	19.83	47.76	22.87	27.93	50.8
East	83.66	109.73	130.92	26.07	21.19	47.26
South	177.45	200.30	222.54	22.85	22.24	45.09
West	258.25	290.09	313.60	258.25	23.51	55.35
					TOTAL FOV	198.5

Appendix C. Intersecting Leg Lengths.

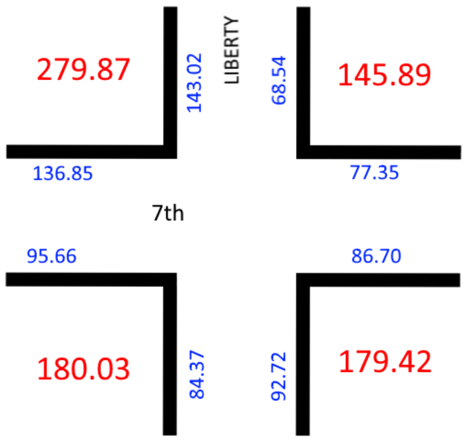

Figure A. Diagram of the Intersecting Leg Lengths for the intersection of 7th and Liberty streets.

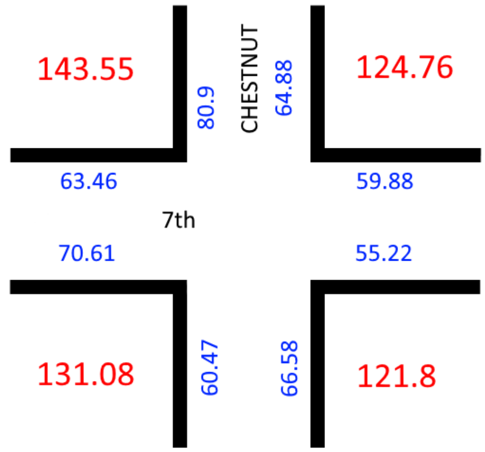

Figure C. Diagram of the Intersecting Leg Lengths for the intersection of 7th and Chestnut streets.

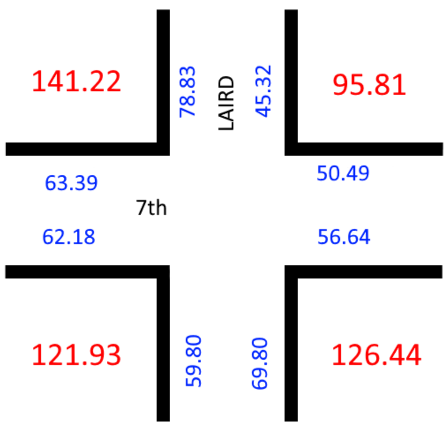

Figure B. Diagram of the Intersecting Leg Lengths for the intersection of 7th and Laird streets.

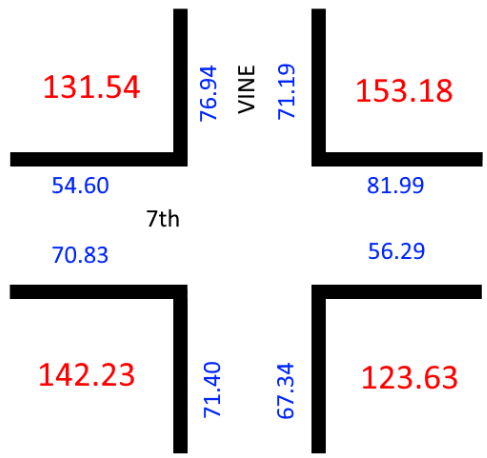

Figure D. Diagram of the Intersecting Leg Lengths for the intersection of 7th and Vine.

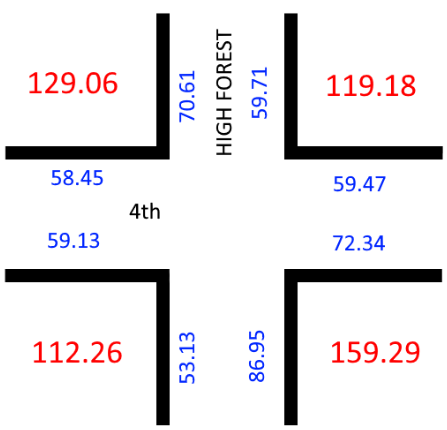

Figure 3. Diagram of the Intersecting Leg Lengths for the intersection of 4th and High Forest streets.

These diagrams show the sight triangle leg lengths in blue and the Intersecting Leg Lengths in red. The Intersecting Leg Length is the sum of the two intersecting sight triangle legs. An unsignalized intersection designed for vehicles travelling at 30 miles per hour would need an Intersecting Leg Length value of 280 feet to meet recommended AASHTO design recommendations.