Emergency Signal Warrant Evaluation: A Case Study in Anchorage, Alaska

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Abstract
The Manual on Uniform Traffic Control Devices (MUTCD), Chapter 4G "Traffic Control Signals and Hybrid Beacons for Emergency-Vehicle Access" addresses emergency-vehicle signalization (EVS) of driveways or streets that access emergency responder stations (ERS) such as fire, ambulance, or police stations. While the MUTCD provides details on the use and installation requirements for these types of signals, the description of warrants for when and where these signals apply are very general and are written in the form of guidance.

The MUTCD's Section 4G.01 indicates three conditions in which EVS should be considered. The first would be if the access satisfies the signalization warrants under Chapter 4C of the MUTCD. At a location where the Chapter 4C warrants are met, the recommendation would be to install a traffic signal.

At locations where the Chapter 4C warrants for full signals are not met, the 4G.01 guidance cites (1) inadequate major roadway stopping sight distance (SSD) and (2) insufficient gap lengths to "permit the timely entrance of emergency vehicles" onto the roadway as a basis to consider EVS. For these conditions, an emergency-vehicle beacon is recommended, if warranted. The issue with this guidance becomes the interpretation of "gap adequacy," which without specific thresholds may be reduced to opinion or judgement. To further complicate the matter, the ERS staff and organization may have a different definition of gap adequacy (one that weights emergency response time heavily) from the definition held by operators of the roadway and signal system (one that weights cost of the system and congestion/operations of the roadway more heavily).

The case study involves a warrant analysis for an EVS at a driveway for a newly-constructed fire station on a 4-lane urban arterial in Anchorage, Alaska. Our literature review did not find a consistent methodology for addressing gap adequacy. As such, we collected gap, speed, and volume data for key hours of the day and generated gap simulation models. The gap simulation models were applied to two response conditions: code red response for the vehicle entering the traffic stream under lights and sirens, and code yellow response for vehicles entering the traffic stream as normal traffic. We found that code red response vehicles had minimal delays while waiting for the main street vehicles to clear the driveway or stop to yield to the emergency vehicle. However, simulation results found code yellow response vehicles may experience very long delays turning left out of the fire station driveway. This delay is exacerbated by reduced acceleration performance for emergency vehicles and sight distance restrictions for the site that, while meeting SSD, did not provide turning gap sight distance. Because code red delay was minimal and code yellow left turns could instead safely turn right and travel an indirect route to their destination, EVS was not recommended.

1 Introduction
This case study discuses emergency-vehicle signalization (EVS) warrants for Anchorage Fire Department's Fire Station 3. Fire Station 3 service area is within the northeast part of Anchorage Alaska. In 2016, Station 3 was relocated to a new facility with a driveway directly accessing Bragaw Street, a four-lane arterial with a posted speed of 35 miles per hour (mph), and an average annual daily traffic (AADT) volume of about 19,000 vehicles per day. The relocation was necessary to improve response times for the service area (enabled by the extended Bragaw Street corridor), and because the original station was reaching the end of its useful life. At its original location on Airport Heights Drive, an arterial with AADT of 12,000 vehicles per day, the station had an emergency-vehicle traffic control signal that was activated during response mobilization to stop traffic and allow unimpeded egress from the station. However, the relocated Station 3 on Bragaw Street did not include any signalization. Because of the higher traffic volumes and limited sight distance of the new station location, Anchorage Fire Department (AFD) requested that the Municipality of Anchorage Traffic Department install an EVS. Kinney Engineering, LLC (KE) was retained by the Traffic Department during the spring of 2016 to evaluate warrants for an emergency-vehicle traffic control signal at the new Fire Station 3 location.

1.1 Guidance from the MUTCD
Section 4G.01 of the Manual on Uniform Traffic Control Devices (MUTCD) provides the following Guidance paragraph on whether emergency –vehicle traffic signal controls should be applied:

“04 *If a traffic control signal is not justified under the signal warrants of Chapter 4C and if gaps in traffic are not adequate to permit the timely entrance of emergency vehicles, or the stopping sight distance for vehicles approaching on the major street is insufficient for emergency vehicles, installing an emergency-vehicle traffic control signal should be considered. If one of the signal warrants of Chapter 4C is met and a traffic control signal is justified by an engineering study, and if a decision is made to install a traffic control signal, it should be installed based upon the provisions of Chapter 4D.*

05 *The sight distance determination should be based on the location of the visibility obstruction for the critical approach lane for each street or drive and the posted or statutory speed limit or 85th-percentile speed on the major street, whichever is higher.*”

Station 3 will not generate enough traffic volume to meet any of the traffic volume-based signalization warrants (Warrants 1-4) described in Chapter 4C, and none of the other five warrants (pedestrian, school crossing, system, crashes, grade crossing) would apply. As such, the application of an emergency-vehicle signal relies largely on the above MUTCD 4G.01 guidance which cites the inadequacy of stopping sight distance (SSD) for vehicles approaching the station or inadequate gaps to permit timely entrance of emergency vehicles as justification for signalization.

1.2 Literature Review for EVS Warrants

A web based search was conducted on EVS warrants in 2016 and again in 2017. For the EVS warrant studies that were found, agencies generally used the above MUTCD guidance in determining feasibility of an EVS. However, Oregon provides a practical alternative to observing and evaluating acceptable gaps in that they cite AADT thresholds (exceeding 8,850 for 2-lane highways, or exceeding 10,600 for 4-lane highways) as surrogate measures on whether emergency vehicles will have sufficient gaps to enter the roadway.

1.3 AFD Response Codes and Operational Assumptions

There are three response codes for AFD and Station 3. The first being Code Red, in which a responding vehicle emerges from the station under sirens and lights. It would be expected that the main roadway vehicles would yield and make way for Code Red responding vehicles. Sight distance, primarily SSD for major road vehicles approaching the station, would be of a paramount consideration in whether a signal is needed. Code Red responses are less sensitive to the availability of adequate gaps, since sirens and lights will create the gap they need to enter the roadway. However, there may be some delay if some of the main roadway vehicles are too close to the driveway to stop, and then travel past the driveway while braking.

The second response mode is Code Yellow. Under this mode, the emergency responder is without sirens and lights and yields to major road traffic and only enters the major road upon the availability of adequate gaps. The minimum sight distance would be SSD, but a desirable sight distance would allow the Code Yellow responder to perceive, react, and turn into the acceptable gap without disrupting the major traffic flow. Desirable sight distance is modelled in this analysis as American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (PGDHS) Case B1- Left-turn from stop, and Case B2-Right-turn from stop.

Table 1: Station 3 2015 Frequency of Activity

Priority Description	Total
Code Red	889
Code Red/Yellow	2,041
Code Yellow	2,267
Grand Total	**5,197**

The third response is Code Red/Yellow in which the first vehicle to leave the station does so with emergency lights and sirens on and the following vehicles proceed under civilian traffic laws.

As Table 1indicates, about 56 percent of all calls, averaging about 8 per day, required at least one vehicle to leave the fire station under emergency lights and sirens (Code Red). There were about 6 code yellow responses daily on average. And, on average, Station 3 personnel respond to approximately 14 calls per day of all codes.

2 Station 3 Emergency Vehicles

Emergency vehicles assigned to Station 3, presented in Figure 1, include Engine 3 (Fire Engine), Truck 3 (Ladder Truck), and Medic 3 (Mobile Intensive Care). A battalion chief vehicle (Suburban-type passenger sport utility vehicle) may be at the Station on occasion.

Figure 1: Station 3 Emergency Vehicles- Mobile Intensive Care Unit (Left), Ladder Truck (Center), and Fire Engine (Right)

To perform the sight distance assessments for Code Yellow responses (civilian traffic laws), driver eye heights were established. Fire Department staff provided eye heights for the Mobile Intensive Care Unit and battalion chief vehicle as between 5.25 and 5.8 feet. The PGDHS indicates the driver eye height for a single-unit (SU) truck vehicle is about 5.25 feet; this eye height was used for analysis of the mobile intensive care unit vehicle and gaps requirements are assumed to be similar to the PGDHS passenger vehicle.

AFD did not provide eye heights for the engine or ladder truck. Based upon judgement after review of various sources, this analysis applies eye heights provided in the PGDHS for the combination truck vehicles to the engine and ladder truck vehicle. PGDHS indicates that a driver’s eye in a combination truck is 7.6 feet above the pavement. This eye height, as well as gap entrance requirements for combination truck vehicles, was used for the engine and ladder truck driver parameters.

Code Yellow gap requirements from PGDHS are:

- ***Fire engine and ladder truck*** vehicle gaps are assumed to be consistent with the AASHTO combination truck vehicle, with Case B1 gap of 12.2 seconds (adjusted for an additional lane to be crossed), and Case B2 gap of 10.5 seconds.
- ***Mobile intensive care unit*** vehicle gaps are modeled with AASHTO’s SU truck. Case B1 gap is 10.2 seconds adjusted for the 4-lane section, and Case B2 gap is 8.5 seconds.
- ***Battalion chief*** vehicle gaps are treated as passenger cars with a Case B1 gap of 8 seconds, adjusted for 4-lanes, and a Case B2 gap of 6.5 seconds.

3 Stopping and Intersection Sight Distance

3.1 Stopping Sight Distance

There is a crest vertical curve to the south of the Station 3, elevated above the Station, which limits sight distance between the driveway egress vehicle and northbound vehicles as shown in Figure 2. The grade for northbound vehicles that approach the driveway is about -2% (sloping down). Grades for southbound vehicles approaching the driveway are flat. Per PGDHS, grades are mild enough to be ignored in SSD computations.

Field measured sight distance for northbound vehicles approaching Station 3 is 335 feet, which is restricted by the crest vertical curve. Field measured sight distance for southbound vehicles approaching Station 3 is over 800 feet.

Eighty-fifth percentile speeds were sampled and observed to be 42 mph for both directions of travel on Bragaw Street, exceeding the posted speed limit of 35 mph. The MUTCD 4G.01 guidance indicates that the higher of the posted speed and 85th percentile speed should be used for SSD. Using the 85th percentile speed of 42 mph, yields a required SSD of 325 feet computed from PGDHS equations for SSD.

Also of interest to this analysis is the time for a vehicle to perceive, react, and brake to a complete stop. The perception-reaction time is fixed at 2.5 seconds. The braking time for the 85th percentile speed of 42 mph is computed as 5.51 seconds. The sum of the braking time (5.51 seconds) and the perception reaction time (2.5 seconds) is 8 seconds (rounded) for 42 mph.

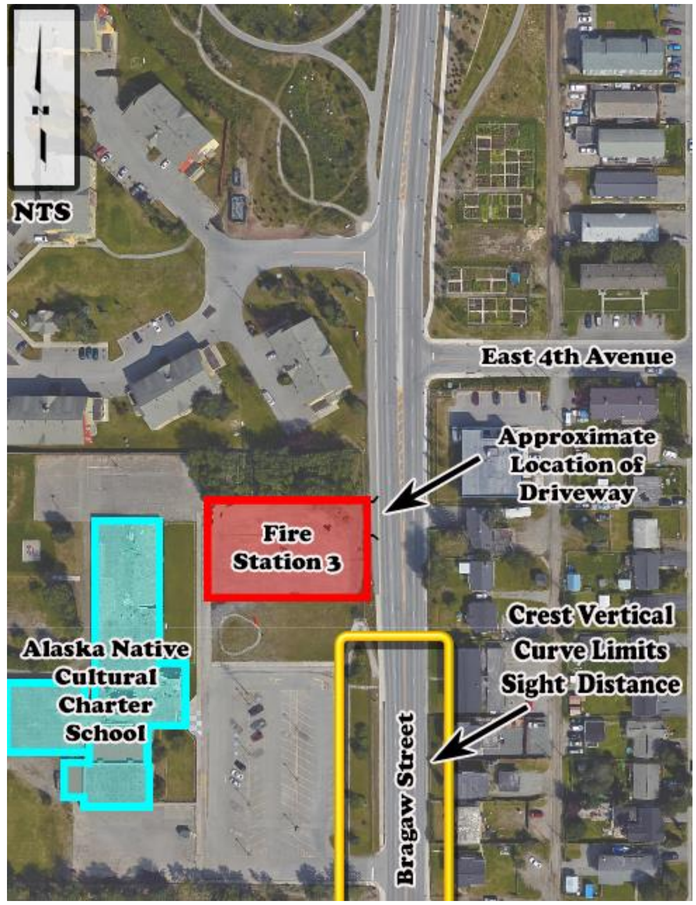

Figure 2: Station 3 Site and Roadway Conditions

The available sight distance, 335 feet, exceeds required SSD of 325 feet for 42 mph approach vehicles. Vehicles that are at or more than 325 feet from the driveway during a Code Red response stop prior to the driveway and will take about 8 seconds to do so. However, vehicles that are less than 325 feet from the driveway when the Code Red response vehicle appears may have to travel past the driveway while braking and stop on the far side of the driveway, thus delaying the responder from entering the roadway. The critical gap for an unimpeded code red response would be 8 seconds, or the time required for the approach vehicle that is 325 feet from the driveway to fully stop just prior to the driveway.

3.2 Intersection Sight Distance

A Code Yellow response requires that Station 3 vehicles follow the rules of the road as do civilian vehicles; that is perceiving and selecting adequate gaps for left- or right-turns from the driveway. The minimum intersection sight distance (ISD) is SSD, while desirable ISD is described in PGDHS Case B1 and B2. Table 2, on page 5, provides minimum and desirable ISD distances for the Station 3 emergency responder vehicles. The MUTCD 4G.01 guidance indicates that the higher of the posted speed and 85th percentile speed should be used for SSD, and by logic, this should extend to ISD as well. The speed for this analysis is the 85th percentile speed of 42 mph, and the ISD applied to the analysis is computed as such.

Table 2: Intersection Sight Distance Guidelines Summary

PGDHS Case	Fire Engine and Ladder Truck Vehicle		Mobile Intensive Care Unit Vehicle		Battalion Chief Vehicle	
	Gap, t_g, seconds	ISD, feet	Gap, t_g, seconds	ISD, feet	Gap, t_g, seconds	ISD, feet
Case B1- turn left onto Bragaw St., crossing SB lanes and into inside NB lane	12.2	753	10.2	630	8	494
Case B2- turn right onto Bragaw St., into SB lanes	10.5	648	8.5	525	6.5	401

As indicated in 3.1 above, the actual sight distance to the north from the driveway is greater than 800 feet, but sight distance to the south is restricted to 335 feet by a crest vertical curve. Measured sight distance from the driveway for the Fire Station 3 fleet is presented in the following table.

Table 3: Measured Intersection Sight Distance Station 3 Driveway Vehicles Turning Into Bragaw Street

Vehicle	Eye Height (ft.)	Measured ISD to South (ft.) (Northbound Vehicles)		Measured ISD to North (ft.) (Southbound Vehicles)	
		Required at 42mph Case B1	Measured, To South	Required at 42mph Case B2	Measured, To North
Fire Engine and Ladder Truck	7.6	753	355	648	>800
Mobile Intensive Care Unit	5.25	630	290	525	>800
Battalion Chief	5.25	494	290	401	>800

Code Yellow Case B1 left turns from the driveway do not have desirable ISD to the south to perceive and select adequate gaps within the northbound traffic stream.

4 Observed and Simulated Gaps

Gap data were collected continuously for the northbound only and southbound only directions by the automatic traffic data collectors. Additional bi-directional gaps were collected manually during parts of the hours between 7:15 a.m. to 8:15 a.m. (morning peak), 12:15 p.m. to 1:15 p.m. (midday peak), and 4:30 p.m. to 5:30 p.m. (evening peak). The data was synthesized to generate gap distributions to be used in the analysis. There was a total of nine distributions generated that included northbound gaps, southbound gaps, and bi-directional gaps for each of the three analysis periods.

Gap models were created in which an emergency vehicle in response mode would be presented with a random series of gaps simulated to match the nine observed gap distributions. Six gap models were created for northbound and southbound flow separately, in the three time periods between 7:15 a.m. to 8:15 a.m. (morning peak), 12:15 p.m. to 1:15 p.m. (midday peak), and 4:30 p.m. to 5:30 p.m. (evening peak). These individual northbound and southbound models were used for the Code Red response mode analyses. For the Code Red response mode, gaps that are less than 8 seconds indicate that the Bragaw Street vehicle is too close to the driveway to stop before the driveway and thus would delay emergency responder while it clears. Gaps that are 8 seconds or more should allow the responder to proceed without delay into the intersection. The maximum delay for the Code Red mode is eight seconds, since any vehicles further away in time will stop for the lights and sirens.

Three gap models were created for the Cold Yellow mode, one per morning, noon, and evening time period. These gap models were based on the bi-direction manual data collection and apply only to the Case B1 left turn model. Case B2 (right turn) used the southbound gap models.

For the gap models, visual comparison and the Chi-square test were used to indicate goodness of fit. As an example, the gap model for one of the observed distributions and simulated distribution is presented in Figure 4. In this case, the simulated gap distribution visually matched the actual distribution well, and the Chi-square test for a 0.05 level of significance provided statistical evidence of a good fit. It should be noted that the simulated (orange) bars continually change with each simulation (the figure shows one unique simulation), and some of the simulated fits are not considered visually good, nor a significant fit.

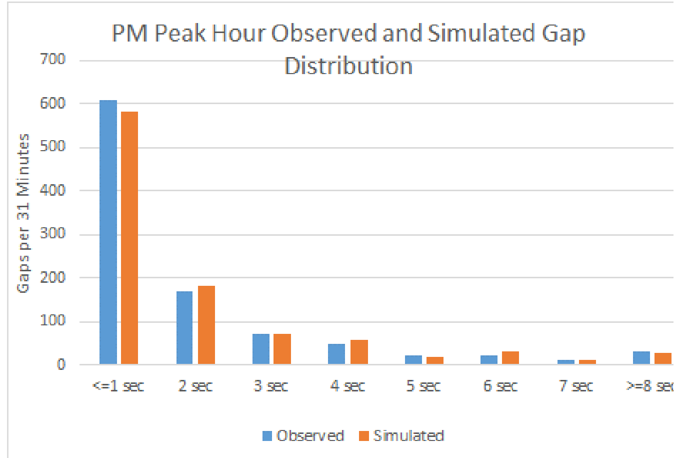

Figure 3: Example of Observed and Modeled Gap Distribution, PM Peak, Bi-Directional

5 Analysis

The analysis scenarios are Code Red response mode and Code Yellow response mode. Other trips into and out of the driveway (employee, deliveries, etc.) are treated as ordinary trips which should have been addressed in the site development and design.

Gap models were created in which an emergency vehicle in response mode at the driveway would be presented with a random series of gaps simulated to match the nine observed gap distributions. The model generates sequential gaps, which would be rejected if of not suitable length for the response mode that is under analysis. The critical gaps (8 seconds for the Code Red response or values from Table 2 on page 5 for Case B1 left turn and B2 right turn for Code Yellow) were entered into the models. The models simulated 30 observations of a response vehicle entering Bragaw Street gaps. Each gap in series is summed as delay until a gap equal to or greater than the critical gap is encountered, at which point the emergency vehicle is released. The maximum delay for Code Red mode is 8 seconds as previously described, whereas the Code Yellow maximum delay is theoretically infinite.

There were 30 runs of the 30 simulated observations (a total of 900 observations). An overall average delay, standard error of the mean, and confidence intervals were generated from the 30 runs.

In addition to delay, the model also presented percent of the time in which a responder would encounter traffic delay. Essentially if the first gap encountered was large enough to enter, there would be no delay; all others of any size less than the critical gap produced delay. Then the number of observations that had delay were divided by 30 observations to compute that run's percentage of time the vehicle would be delayed. An overall average percent time delayed, standard error of the mean, and confidence intervals were generated from the 30 runs.

5.1 Code Red Response Mode

Approaching vehicles have adequate SSD from the northbound and southbound directions of travel on Bragaw Street. An emergency vehicle that emerges from the station with lights and sirens will be seen in time for vehicles to stop. The delay presented is delay to the fire vehicle expected while the Bragaw Street traffic that is too close to the driveway to fully stop clears the driveway. Delay computations were extracted from the simulation model and are summarized below.

Table 4: Code Red Response Mode Emergency Vehicle Delay by Simulation

Time of Day	Southbound		Northbound	
	Mean Percent Likelihood Emergency Vehicle is Delayed by SB vehicle [confidence interval]	Mean Delay (Seconds) with [confidence interval]	Mean Percent Likelihood Fire Vehicle is Delayed by NB vehicle [confidence interval]	Mean Delay (Seconds) with [confidence interval]
Morning peak	**80% [77%,82%]**	**4.9 [4.7, 5.1]**	72% [70%,75%]	3.7 [3.5,3.9]
Noon peak	76% [73%,78%]	4.8 [4.5,5.0]	**80% [78%,83%]**	**4.8 [4.6, 5.1]**
Evening peak	82% [80%,85%]	5.5 [5.3, 5.7]	**90% [88%,93%]**	**6.4 [6.2, 6.7]**

1. **Bolded and underlined** text are the critical value of the two directions during the peak hour.
2. Lower and upper confidence limits (confidence interval) are present in the brackets [x, y] for a 95 percent level of confidence for simulation runs.

In summary, there is very high likelihood that Code Red response mode vehicles will be delayed. However, the delay is relatively brief and will be under 7 seconds.

5.2 Code Yellow Response Mode

The ISD to the north from the station driveway is greater than needed for the Code Yellow responder to judge and enter gaps without impacting Bragaw Street southbound vehicles. However, ISD to the south is restricted and is substantially less than needed for safe left-turns from the driveway. In fact, left-turns from the driveway will likely impact northbound vehicles most of the time since the emergency vehicle cannot see far enough to the south to find acceptable gaps. The following table summarizes simulation results for delay by vehicle type and by time of the day while making a Code Yellow left turn from the driveway.

Table 5: Code Yellow Response Mode Emergency Vehicle Delay by Simulation, Case B1 Left Turns through Northbound and Southbound Gaps

Code Yellow Vehicle	Gap Requirements Case B1	Time of Day	Average Number of Acceptable Gaps per Hour	Average Delay per Vehicle (sec) [95% Confidence Interval Simulation Runs]
Battalion Chief Vehicle	8 Seconds	Morning peak	108	21 [19,23]
		Noon peak	89	33 [30,35]
		Evening peak	61	59 [55,63]
Mobile Intensive Care Unit Vehicle	10.2 Seconds	Morning peak	78	34 [31,36]
		Noon peak	65	42 [38,45]
		Evening peak	40	80 [73,86]
Fire Engine and Ladder Truck Vehicle	12.2 Seconds	Morning peak	63	49 [45,52]
		Noon peak	34	95 [88,102]
		Evening peak	25	149 [140,158]

1. Lower and upper confidence limits (confidence interval) are present in the brackets [x, y] for a 95 percent level of confidence for simulation runs.

The existing sight distance does not meet Case B1 desirable ISD requirements, and Code Yellow responders only have 5 to 6 seconds of sight distance gap, much less than the 8 to 12.2 seconds needed for the respective vehicles. However, even if sight distance were attainable, the simulation indicates long delays during the afternoon and evening times; probably to the extent that precludes left-turns during evening peak hours.

Table 6: Code Yellow Response Mode Emergency Vehicle Delay by Simulation, Case B2 Right Turns through Southbound Gaps

Code Yellow Vehicle	Gap Requirements Case B2	Time of Day	Average Number of Acceptable Gaps per Hour	Average Delay per Vehicle (sec) [95% Confidence Interval Simulation Runs]
Battalion Chief	6.5 Seconds	Morning peak	130	8 [7,9]
		Noon peak	172	6 [5,6]
		Evening peak	139	9 [8,10]
Mobile Intensive Care Unit	8.5 Seconds	Morning peak	99	14 [13,15]
		Noon peak	120	12 [11,13]
		Evening peak	99	16 [15,17]
Fire Engine and Ladder Truck	10.5 Seconds	Morning peak	86	17 [16,18]
		Noon peak	90	20 [18,21]
		Evening peak	72	27 [25,29]

1. Lower and upper confidence limits (confidence interval) are present in the brackets [x, y] for a 95 percent level of confidence for simulation runs.

Code Yellow right-turns experience low to moderate delay. Full ISD is available to the north.

5.3 Performance and MUTCD Guidelines for Emergency Vehicle Signalization

The MUTCD guidelines on this matter are repeated below (Section 4G.01 of the MUTCD):

> "04 *If a traffic control signal is not justified under the signal warrants of Chapter 4C and if gaps in traffic are not adequate to permit the timely entrance of emergency vehicles, or the stopping sight distance for vehicles approaching on the major street is insufficient for emergency vehicles, installing an emergency-vehicle traffic control signal should be considered. If one of the signal warrants of Chapter 4C is met and a traffic control signal is justified by an engineering study, and if a decision is made to install a traffic control signal, it should be installed based upon the provisions of Chapter 4D.*
>
> 05 *The sight distance determination should be based on the location of the visibility obstruction for the critical approach lane for each street or drive and the posted or statutory speed limit or 85th-percentile speed on the major street, whichever is higher.*"

Recall that signalization under the warrants of Chapter 4C are not satisfied.

Under Code Red response mode, the sight distance and the gaps are such that an emergency vehicle with lights and sirens can safely enter Bragaw Street in a timely manner. Available SSD exceeds SSD for 42 mph, and delay was modelled to be on the order of 5 to 7 seconds while some of the Bragaw Street vehicles clear the driveway. As such, Code Red responses do not require a EVS.

Code Yellow response mode right turns have similar performance; an emergency vehicle without lights and sirens has good ISD and gaps to enter Bragaw Street with low to moderate delay. Code Yellow response left-turns do not have adequate ISD, and gaps cannot be adequately judged prior to selection and entry. Moreover, acceptable gaps are limited and long delays will be a result. As such Code Yellow left-turns will not have a timely entry, and will not be without risk. If Code Yellow response modes are of critical importance to Station 3, then the guidelines above point us towards signalization as a feasible solution.

The Municipality of Anchorage Traffic Department and AFD ultimately choose not to install a signal given SSD is adequate and Code Red responses experience little delay. A Code Yellow response to the north that would normally require a left turn from the driveway could turn right on Bragaw Sreet and reach their destination on an alternate, indirect route.

6 References

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