MEMORANDUM

To: Mark Taylor
From: Avenue Consultants
Date: September 26, 2018
Subject: Yellow and Red Actuation ATSPM Study

1 PURPOSE AND NEED

The Yellow and Red Actuation (YRA) is a metric found in the Utah Department of Transportation's (UDOT) Automated Traffic Signal Performance Measures (ATSPM) that shows the number of vehicles passing thru a signalized intersection in the yellow and red clearance intervals and during the red phase of a given movement. Figure 1 shows an example of this metric with several detector activations (black dots). Initial review of the YRA metric at several intersections showed an excessive number of vehicles traveling through the red phase.

To determine if the number of vehicles passing the stop bar on red is unrealistic, UDOT asked Avenue Consultants to verify if a latency exists from the time a vehicle passes through the intersection to the time the controller logs the event. **The goal of this study is to determine if a standard latency value could be applied at all intersections with the YRA ATSPM to calibrate the output to show more realistic results.**

As part of this study, we:

1. Determined the latency's sources and magnitude,
2. Identified trends, and
3. Calculated a recommended speed for the filter used in the detector zone for the YRA ATSPM, which will ensure that vehicles displayed in the ATSPM are not stopping but are passing thru the intersection.

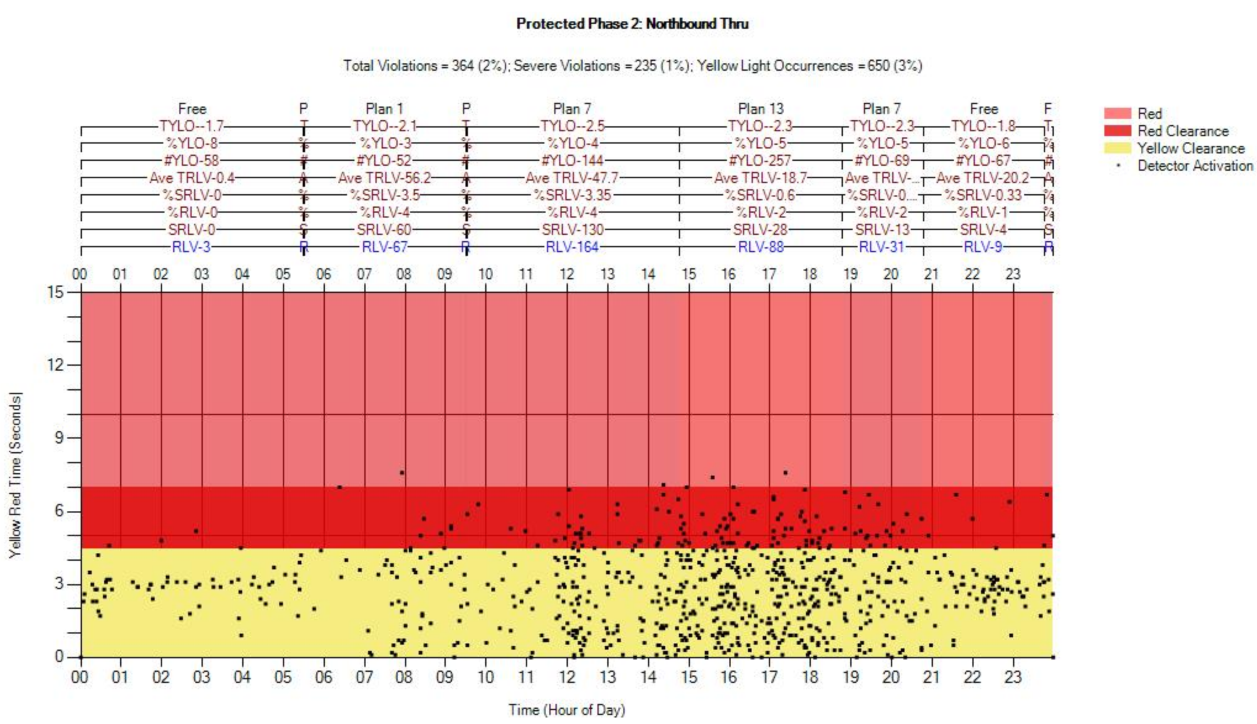


Figure 1: Yellow and Red Actuation ATSPM (5600 W & 2700 South intersection)

2 METHODOLOGY

2.1 Data Collection

Data was collected using two different methods to determine if latency exists in the system. For the first method, data was collected at the Traffic Operations Center (TOC) using the communications network that connects the traffic signals to the central computer system (MaxView) at the TOC. For the second method, data was collected onsite at the study intersections using webcams. This method was performed to eliminate any latency between the traffic signal and the TOC's central computer system, which could negatively affect the results.

2.1.1 Traffic Control Center (TOC) Data

At the TOC, yellow and red actuation ATSPM data was collected over UDOT's communications network from the software programs summarized in Table 1 using Snagit, a screen capture software.

Table 1: TOC Data Collection Software

Software	Purpose
Wavetronix SmartSensor Manager	To identify when the Wavetronix Matrix detector located a vehicle and places a call
Transuite VCS	To record when vehicle arrive at the detector (UDOT's traffic camera program)
Controller Front Panel Software	To determine when the controller receives the call from the sensor
Online Stopwatch	To measure time between when vehicle arrives to when the sensor logs the call and when the controller receives that call.

Recording these items allowed for the latency to be tracked following the path outlined in Figure 2 below.

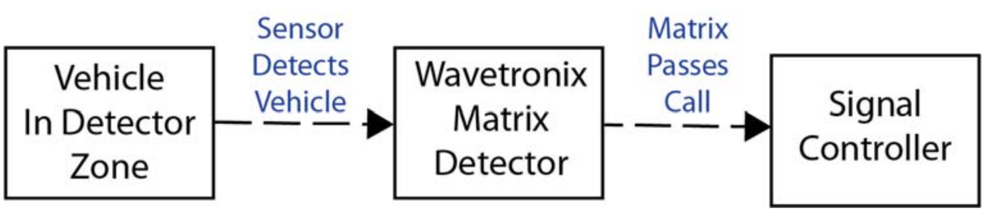


Figure 2: Detector Call Path Tracked at TOC

We measured two latencies at the TOC to be able to determine the overall latency between the vehicle arriving at the detector zone and the controller receiving the call, they latency measured included:

1. Actual vehicle arrivals at the detection zone near the intersection stop bar (using UDOT's CCTV traffic cameras) and when the detector acknowledges a vehicle arrival (using the SmartSensor software), and
2. When the detector acknowledges a vehicle arrival and when the controller receives the detection call (using the Front Panel software).

The latency in the system was then measured by calculating the difference in timestamps between each event in the process described above and then averaging all events (minus outliers). The average latency calculated using this method was an average 1.5 seconds.

While the data collection at the TOC provided some initial measurements and confirmed the presence of latency in the system, concerns were identified about the data collection method. In particular, collecting data over the communications network could be adding to the latency due to the delay between the data source and the

TOC. Each of the data sources could have different delays, causing the latency measurements between the recorded events to be affected. Based on this concern video data was collected in the field to provide a more accurate, "real-time" measurement.

2.1.2 Field Video Recording

The data in the field was collected using four webcams connected directly to a laptop at the intersection and then screen captured using the Snagit software. The webcams used were Logitech C922, selected due to their ability to capture at 60 frames per second. The webcams were focused on the (1) intersection stop bar, (2) signal controller detector screen, (3) signal load switches, and (4) Click 650. Table 2 describes the purpose for each item recorded, including the webcams.

Table 2: Field Data Collection Recorded Items

No.	Item Recorded	Purpose
1	Intersection Stop Bar	Identify when the vehicle arrives at the detector zone location that is used for the YRA ATSPM
2	Signal Controller Detector Screen	Determine when the controller receives and logs the call from the sensor.
3	Wavetronix SmartSensor Manager v2.1.0	Identify when the Wavetronix Matrix detector located a vehicle and placed a call.
4	Signal Load Switches	Determine the signal state when each vehicle passes through the intersection. (Not always recorded)
5	Click 650	Record the intermediate step between the sensor logging the call and the controller receiving that call.
6	1/10 of a second timer	To determine a timestamp that will allow measurement of latency between the steps to a 1/10 of second

Figure 3 is a screenshot of the laptop showing how the data from Table 2 was recorded using the screen capture software.

Figure 3: Field Data Collection Screenshot

To ensure that the location of the detector zone in the Wavetronix SmartSensor Manager software was correct, the zone was determined by physically walking the location, which showed up on the SmartSensor software. Recording these items allowed for the latency to be tracked following the path outlined in Figure 4 below.

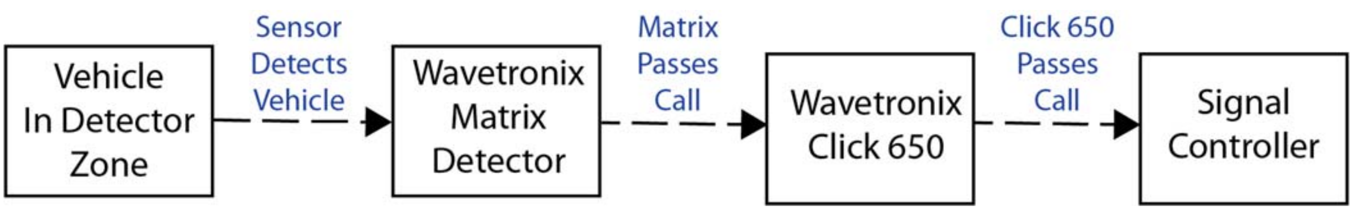


Figure 4: Detector Call Path Tracked in the Field

We measured three latencies in the field to be able to determine the overall latency between the vehicle arriving at the detector zone and the controller receiving the call, they latency measured included:

1. Between the actual vehicle arrivals at the detection zone near the intersection stop bar (using a webcam) and when the detector acknowledges a vehicle arrival (using the SmartSensor software),
2. Between when the detector acknowledges a vehicle arrival and when the Click 650 receives the call from the detector (using a webcam), and
3. Between when the Click 650 receives the call and when the controller receives the detection call (using a webcam).

Another item of concern is that there are likely other variables that effect the latency that could not be considered in this study, including the type of controller and the sensor version and the presence of a Click 650 (all of the locations used in this study had a Click 650). Information about each of the locations recorded including the date and type of software are shown in Table 3.

Table 3: Field Data Collection Summary

Location	Traffic Movement	Dates	Controller Type	Controller Application Version	Wavetronix Matrix Version	Click 650 Version
5600 W & 2700 S	SBT	11-02-2017 12-07-2017	Econolite ASC/3	2.26.10	2.1.0	1.1.0
5600 W & 2700 S	SBL	11-02-2017 12-07-2017	Econolite ASC/3	2.26.10	2.1.0	1.1.0
5600 W & 2700 S	WBT	11-14-2017	Econolite ASC/3	2.26.10	2.1.0	1.1.0
5600 W & 2700 S	WBL	11-14-2017	Econolite ASC/3	2.26.10	2.1.0	1.1.0
3300 S & West Temple	WBT	12-05-2017	Econolite ASC/3	2.26.10	2.1.0	1.1.0
10600 S & 700 E	NBT	01-31-2018	Econolite ASC/3	2.62.10	2.1.0	1.1.0
10600 S & 700 E	WBT	01-31-2018	Econolite ASC/3	2.26.10	2.1.0	1.1.0

2.1.3 Speed Filter Data Collection

Additionally, 5 mph, 10 mph, and 15 mph speed filters were tested in each lane to determine what speed filter should be applied to the detector zones to avoid registering vehicles that have stopped in the detector zone. The detector zones were placed on top of each other at the stop bar and were compared against a detector zone without a speed filter. Due to limitations in the number of detector channels at some of the intersections, it was not always possible to test all three speed filters at the same time. In those cases, the speed filters were rotated through until all were utilized to collect data. Two intersections were added during this step; 2700 West on Bangerter Hwy, and 4420 West on 5400 South. 2700 West on Bangerter Hwy was selected to represent an intersection with higher speeds and 4420 West on 5400 South represents an intersection with lower speeds.

2.2 Data Processing

The latency measurements from the data recorded at the TOC and in the field was processed using the same method. The videos were watched through the Snagit Editor to allow for frame by frame viewing. The timestamps for each event was then documented for each vehicle passing through the detector during the video. From these timestamps the latency was calculated. In order to investigate if there was a measurable relationship between the speed of the vehicle and the latency, the speed for each vehicle was estimated by documenting the timestamp when the vehicle reached the stop bar and when it passed through the other side of the crosswalk. Using the distance between these two locations and the timestamps, the speed of vehicle was calculated. This collection method for the speed is only an estimate as the short measurement distance added to the inaccuracy of the speeds.

3 STUDY RESULTS

3.1 YRA Metric Detector Location

For the YRA metric, the detector zone should be placed on the stop bar to avoid categorizing a vehicle that enters the intersection during a yellow light as a red-light runner (which could occur if the detector is placed beyond the stop bar in the intersection). Placing the detector zone on the stop bar will also help avoid categorizing a vehicle that enters the intersection on a red light as entering on yellow light (if the detector is placed upstream of the stop bar).

3.2 Latency measurements

The calculated latency values from the field video data collection are found in Table 4 arranged by movement. Overall, the mean latency was 1.24 seconds with a standard deviation of 0.31 seconds. While the average latency varied by approach, from 0.89 seconds to 1.82 seconds, the 95% confidence intervals indicate that the mean latency across all sites is likely between 1.22 seconds and 1.26 seconds.

Table 4: Field Data Collection Results

Intersection	Movement	Posted Speed Limit (mph)	Mean Latency (sec)	Standard Deviation (sec)	95% Confidence Interval (sec)
5600 W & 2700 S	SBT	45	1.49	0.23	±0.03
5600 W & 2700 S	SBL	45	1.82	0.28	±0.08
5600 W & 2700 S	WBT	35	0.94	0.19	±0.05
5600 W & 2700 S	WBL	35	0.89	0.13	±0.04
3300 W & West Temple	WBT	35	1.15	0.24	±0.04
10600 S & 700 E	NBT	40	1.11	0.21	±0.04
10600 S & 700 E	WBT	35	1.35	0.15	±0.05
Bangerter Hwy & 2700 W	WBT	60	1.11	0.19	±0.02
5400 S & 4420 W	SBT	25	1.39	0.47	±0.15
Combined	--	--	1.24	0.31	±0.02

The distribution of calculated latency values is shown in figure 5 below. Overall, this distribution shows a spread of latency values centered around the average of 1.24 and with most values within a standard deviation. Some of the variation in latency values can be accredited to the data collection method since it required a visual determination of when the vehicle arrived at the detection zone and was limited to intervals of 1/10 of a second. Additionally, some can be attributed to there being a 1/10 of the second interval at which the controller is able to process the data.

Histograms which show the distribution for the thru movements at each individual signal can be found in the appendix.

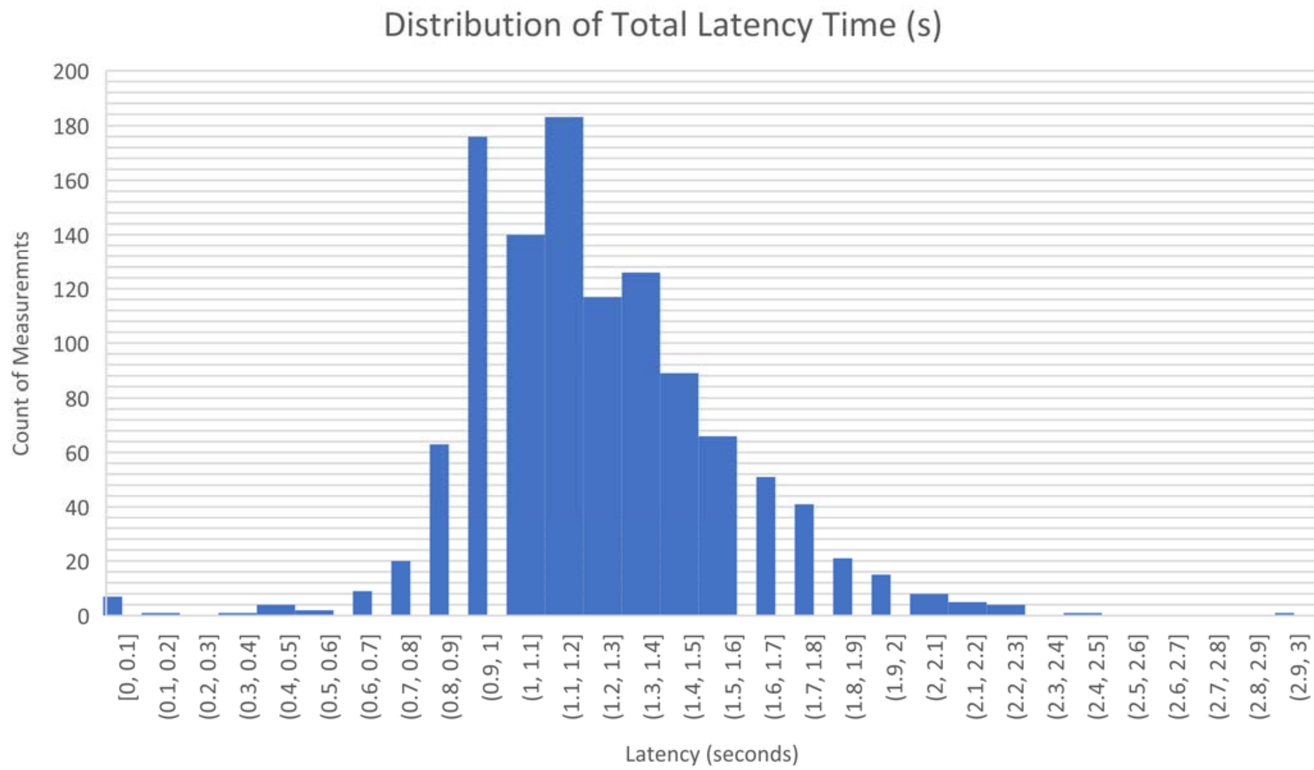


Figure 5: Distribution of Latency Measurements

3.3 Speed vs. Latency

Initially it was believed that vehicle speed had some level of influence on the latency. To identify if there was a relationship between speed and latency, the speed of each vehicle was calculated by measuring the time a vehicle traveled between two fixed points in the video. The results of the calculated latency and speed for each vehicle is shown in Figure 6.

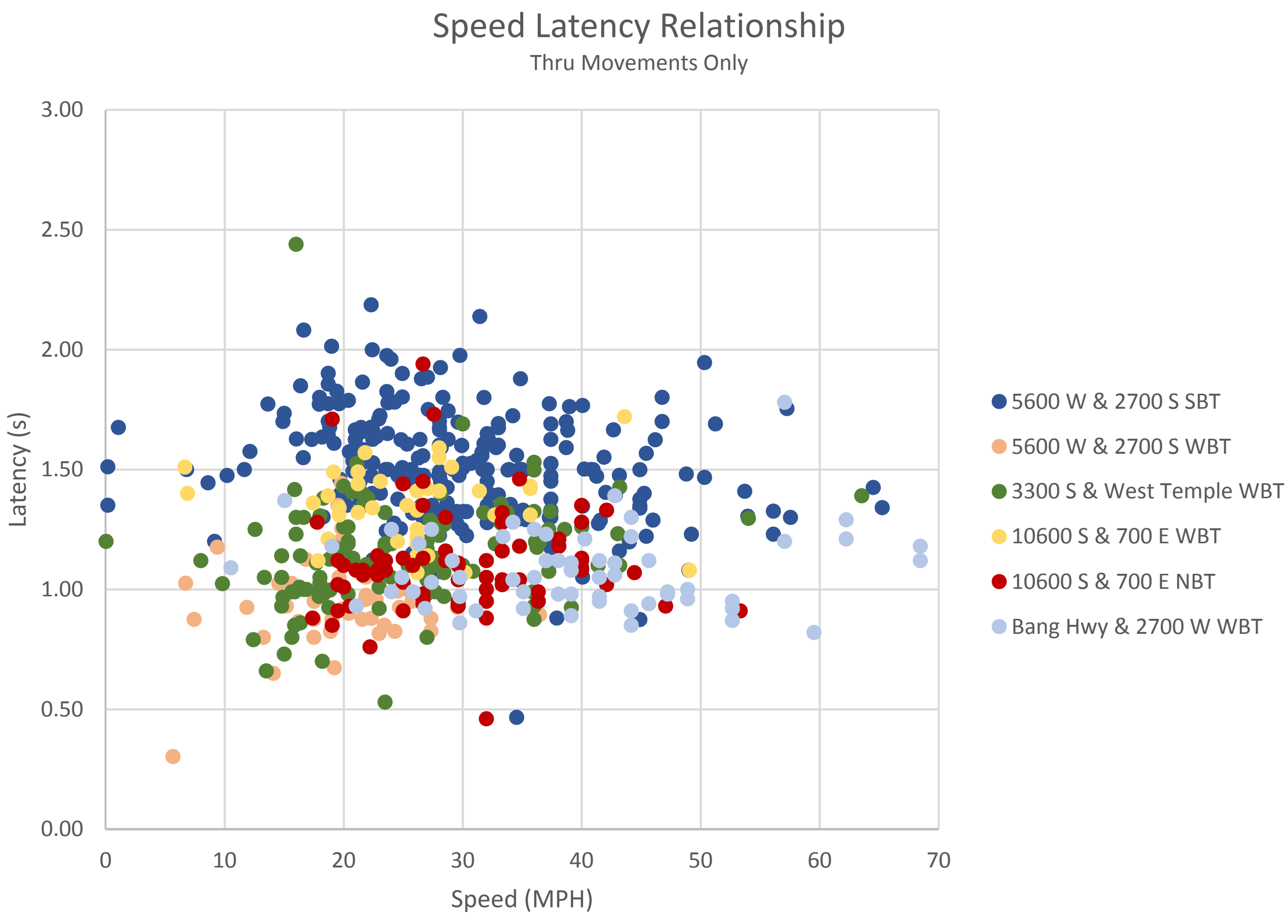


Figure 6: Speed Latency Relationship for all Thru Measurements

In an attempt to better understand the relationship between speed and latency, scatter plots were generated separately for each intersection, specifically for the through movements. Figure 7 shows the speed-latency relationship at Bangerter Highway and 2700 West. A trendline was plotted on the scatterplot and an R^2 value was calculated, which statistically measures how well the trendline correlates with the data points. The closer the R^2 value is to 1, the more accurately the trendline explains the relationship between the data points. A review of these scatterplots and the resulting R^2 values ($R^2 = 0.003$ for the data at Bangerter Highway and 2700 West) did not show a conclusive relationship between speed and latency. The inconclusive results may partially be due to the inaccuracies in how the speeds were measured within a short distance (typically around 15 ft). The speeds were calculated using the original video footage, which was not set up for the intent of collecting speeds and had a limited view of the roadway.

The scatter plots for the through movements at the remaining intersections, which produced similar results, can be found in the appendix.

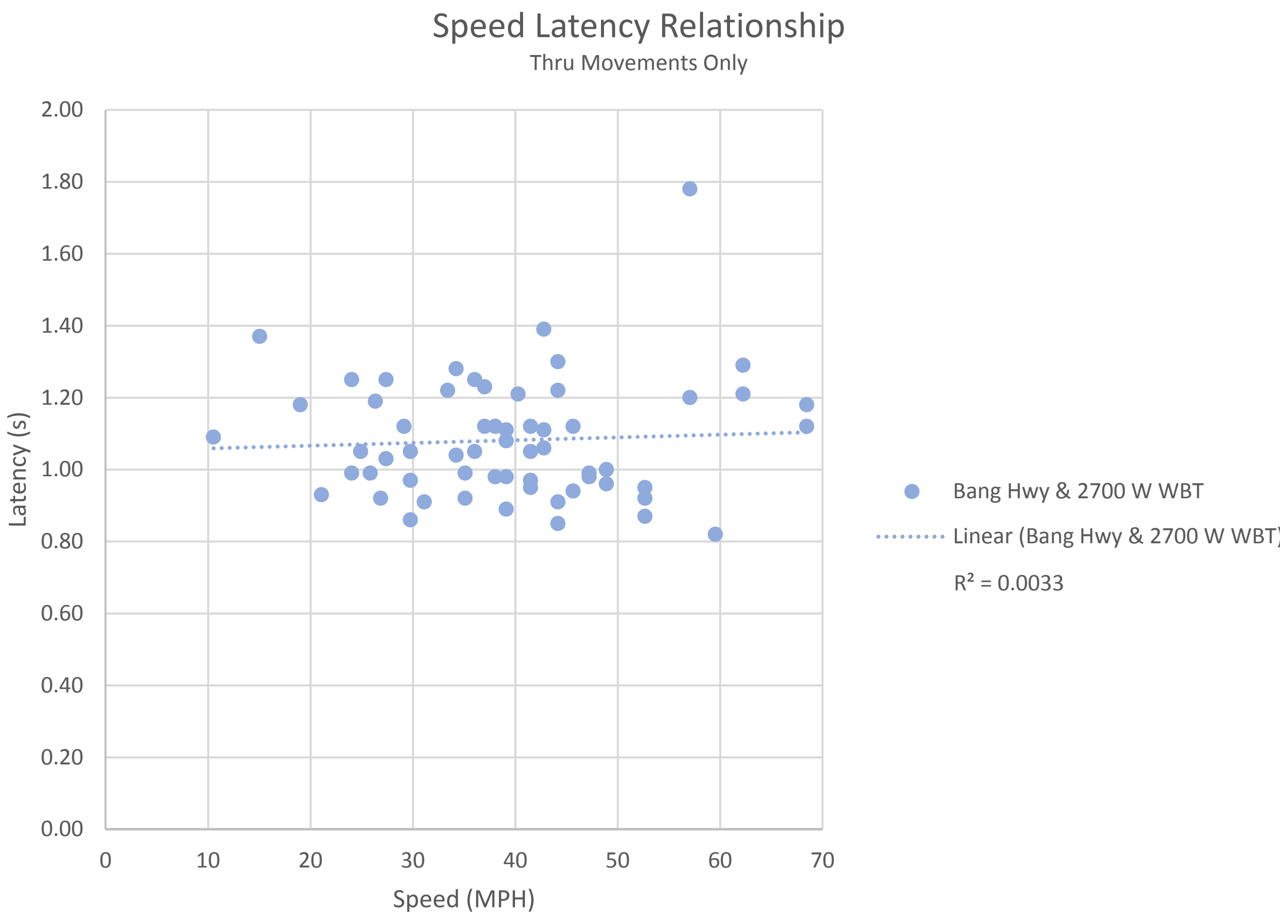


Figure 7: Speed Latency Relationship for WBT at Bangerter Hwy and 2700 W

3.4 Speed Filter

A speed filter is utilized within the Matrix sensor for YRA zones to ensure that only vehicles entering the intersection are registered and that vehicles slowing to a stop at the stop bar are not registered. To determine the ideal speed filter for the YRA for both thru and left turn lanes, 5 mph, 10 mph and 15 mph speed filter settings were tested by stacking detector zones for each speed filter on top of each other at the stop bar in each lane. The results showed that vehicles that stopped on the stop bar were not registered by any of the speed filters. One consideration is that in the recorded samples all vehicles slowed down at a normal rate and did not have to make an emergency stop. Nor did any vehicles, while slowing to a stop, pass through the detector and into the crosswalk or partway into intersection. Although rare, in these cases there is the possibility that vehicles could be detected. In the majority of cases any of the speed filters will remove vehicles stopping at the stop bar from the YRA metric.

3.5 Conclusion

Based on the results of this evaluation, below are three recommendations for improving the accuracy of the YRA metric:

1. Adjust the detector actuations according to the average latency of 1.2 seconds
2. Locate the YRA detector zone on the stop bar
3. Set the YRA speed filter to 5 mph for both thru and left turn lanes

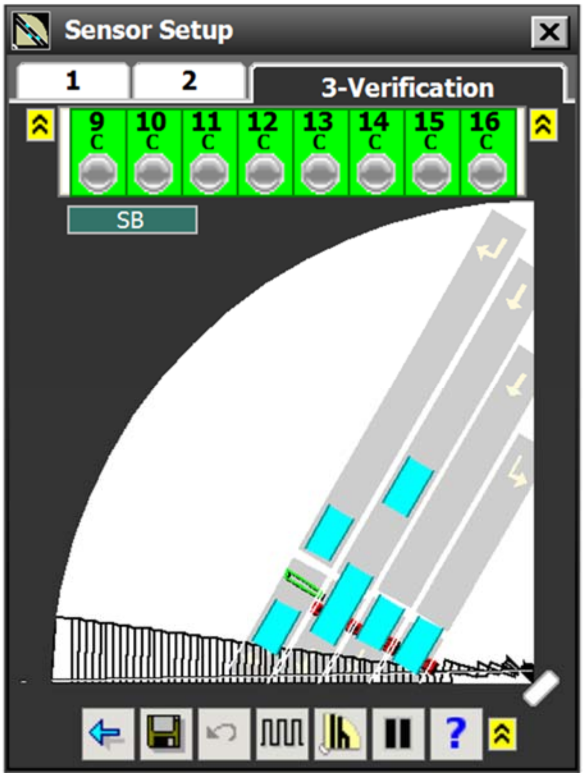
Adjusting the ATSPM data based on this latency measurement will help to improve the Yellow and Red Actuation ATSPM and provide a more accurate comparison of signal with potential red-light running issues. However, variations are still inherent in the latency calculations, which could be due to vehicle speeds, but is inconclusive with the available data. Other factors such as weather, vehicle type, distance of the sensor from the cabinet, software type, and vehicle accelerating or decelerating were not considered in this study but could have an impact on latency.

Placing the detector at the stop bar will provide a more accurate representation of when vehicles cross the stop bar and enter the intersection. Placing the detector farther into the intersection or upstream of the stop bar may result in an inaccurate number of red light actuations.

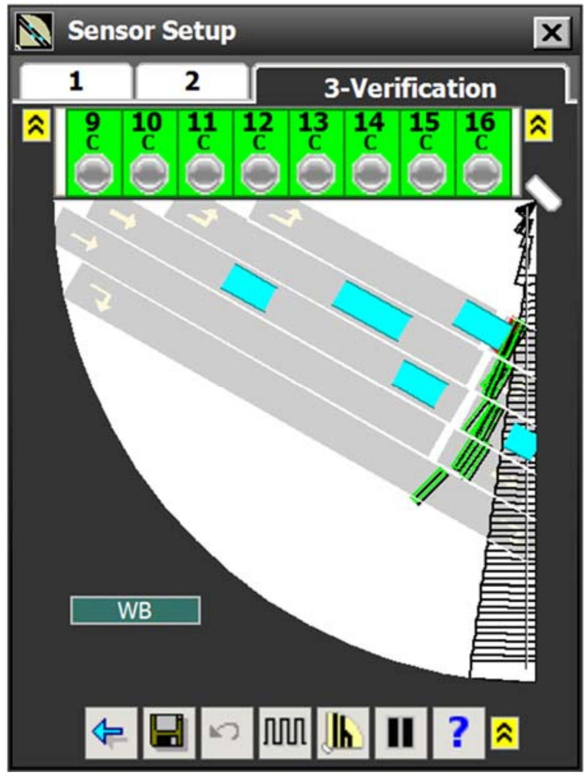
The purpose of the speed filter is to ensure that vehicles coming to a stop at the stop-bar do not actuate the detectors to avoid a false reading in the YRA metric. The results of the speed filter analysis indicate that vehicles passing over the detector but stopping before entering the intersection are likely to be filtered out by any of the three speed filter settings evaluated (5, 10, and 15 mph). Therefore, the 5 mph speed filter should prevent vehicles stopping at the stop bar from showing up on the YRA metric.

APPENDIX

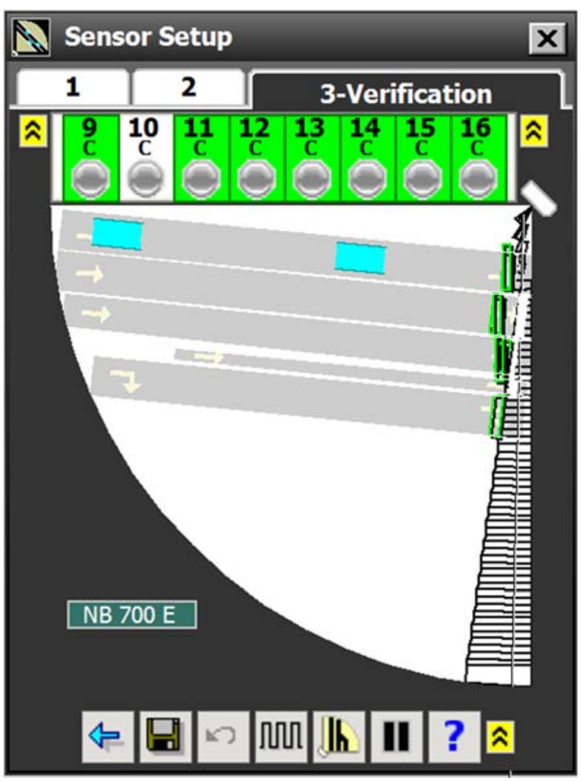
1 STUDY LOCATION DETECTOR ZONE SETUP



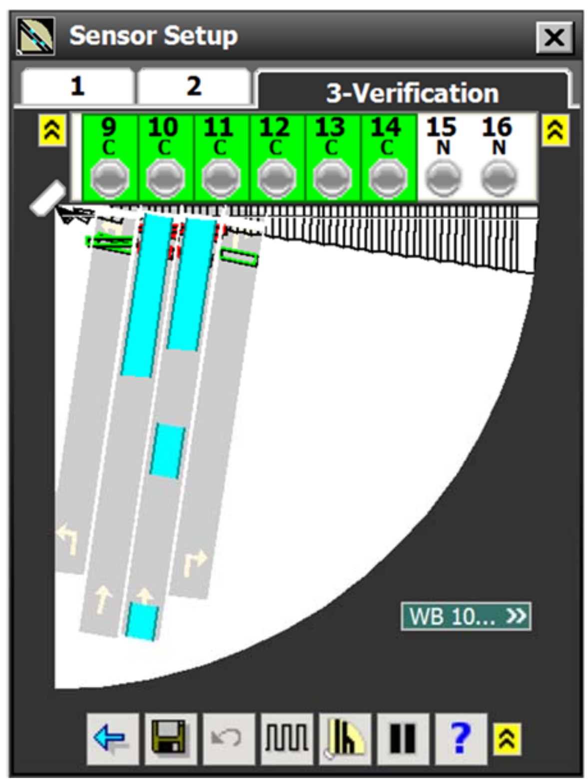
SB 5600 W and 2700 S



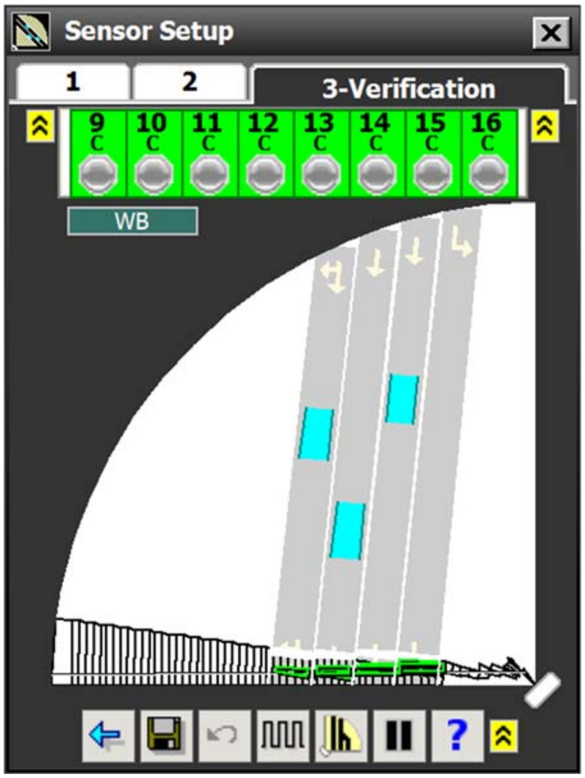
WB 5600 W and 2700 S



NB 10600 S and 700 E

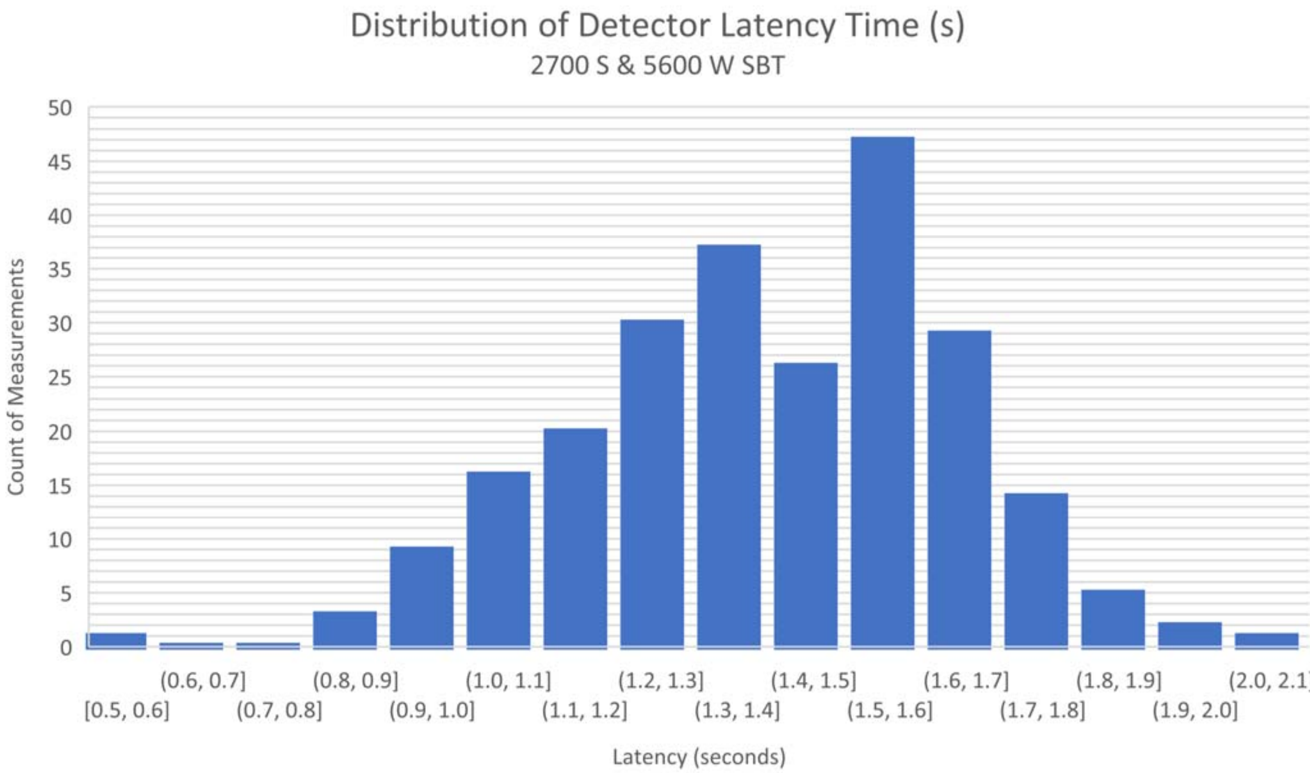


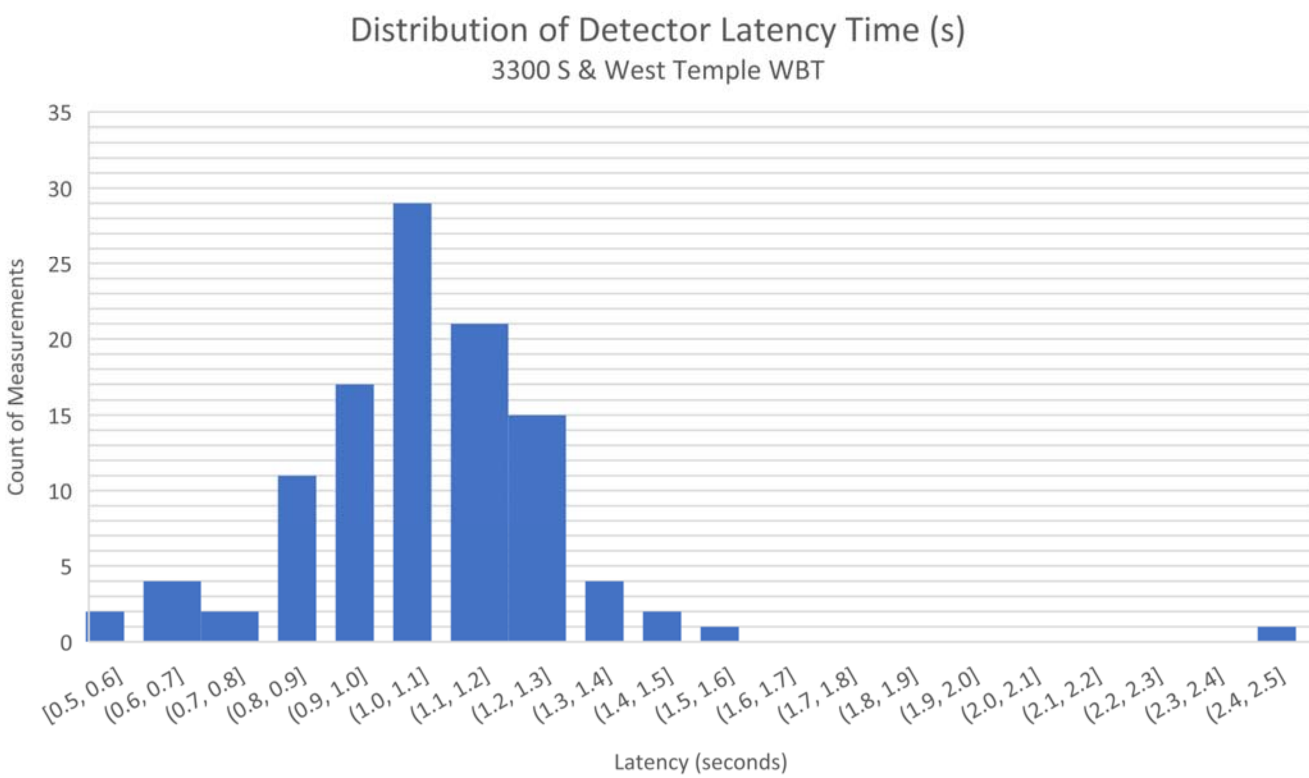
WB 10600 S and 700 E

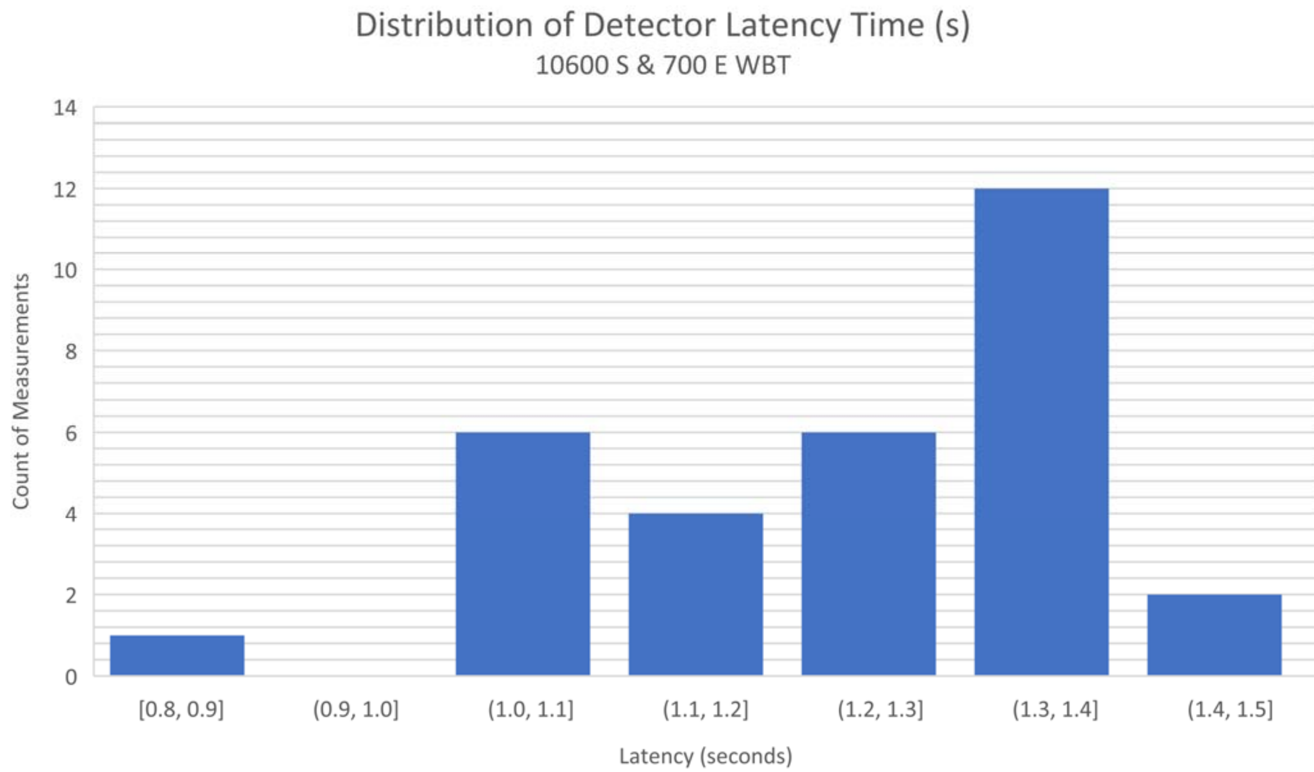


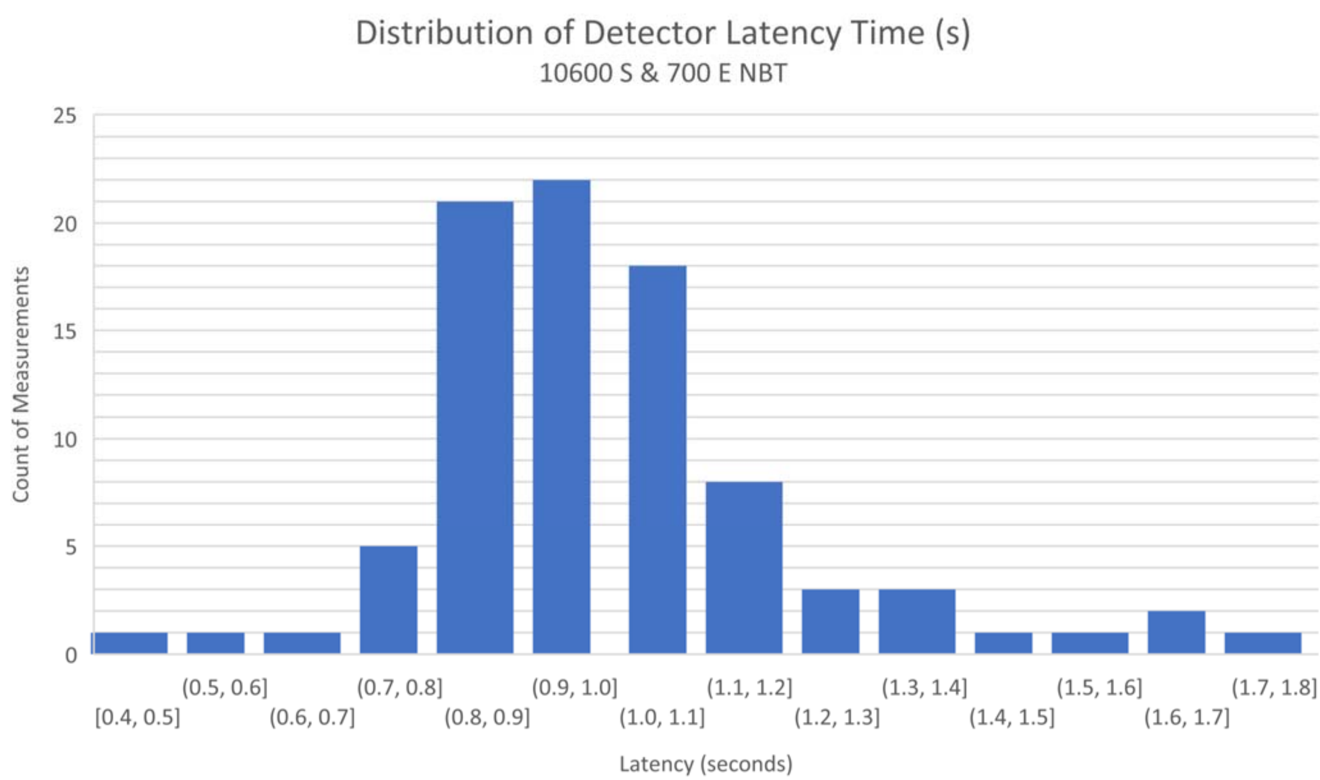
WB 3300 S and West Temple

2 HISTORGRAMS OF LATENCY MEASUREMENTS






Distribution of Detector Latency Time (s)
10600 S & 700 E WBT
Count of Measurements
0
2
4
6
8
10
12
14
[0.8, 0.9]
(0.9, 1.0]
(1.0, 1.1]
(1.1, 1.2]
(1.2, 1.3]
(1.3, 1.4]
(1.4, 1.5]
Latency (seconds)


Distribution of Detector Latency Time (s)
10600 S & 700 E NBT
Count of Measurements
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5
10
15
20
25
[0.4, 0.5]
(0.5, 0.6]
(0.6, 0.7]
(0.7, 0.8]
(0.8, 0.9]
(0.9, 1.0]
(1.0, 1.1]
(1.1, 1.2]
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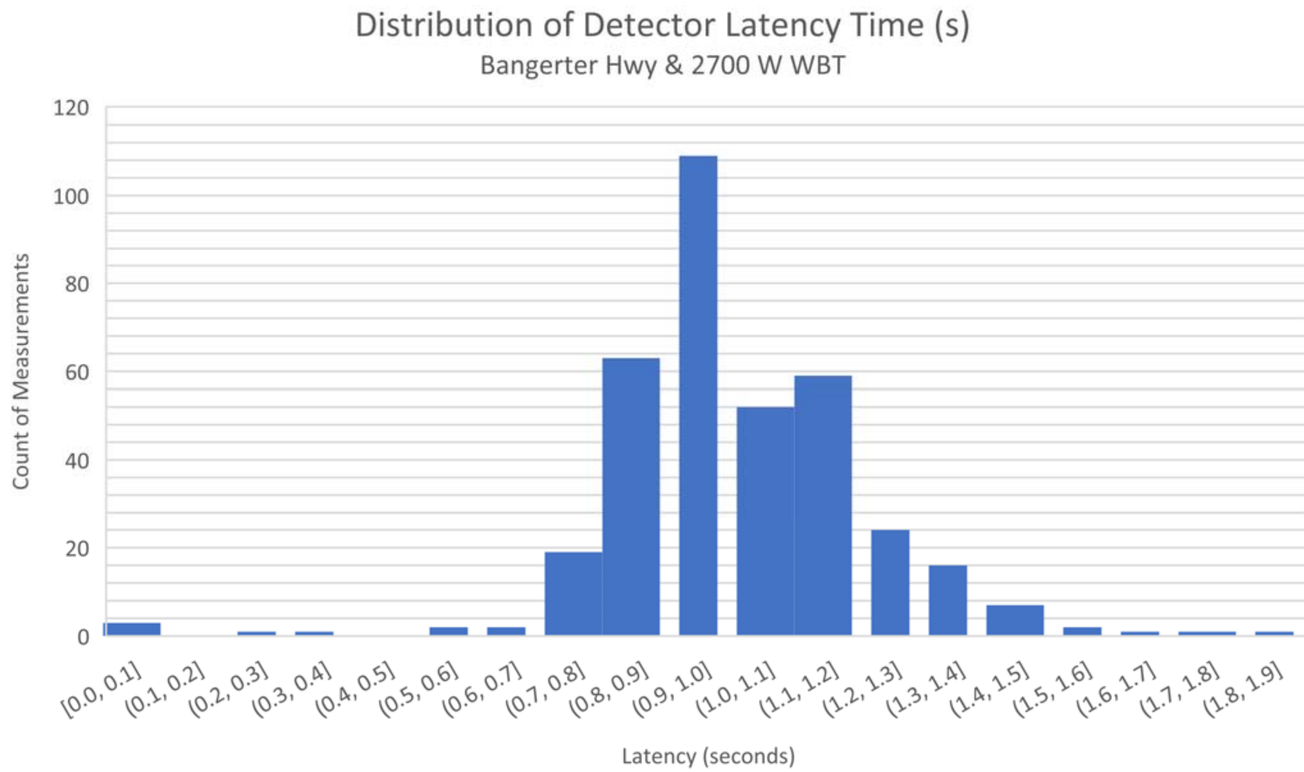
(1.5, 1.6]
(1.6, 1.7]
(1.7, 1.8]
Latency (seconds)


Distribution of Detector Latency Time (s)
Bangerter Hwy & 2700 W WBT
Count of Measurements
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100
80
60
40
20
0
[0.0, 0.1]
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(0.3, 0.4]
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(0.6, 0.7]
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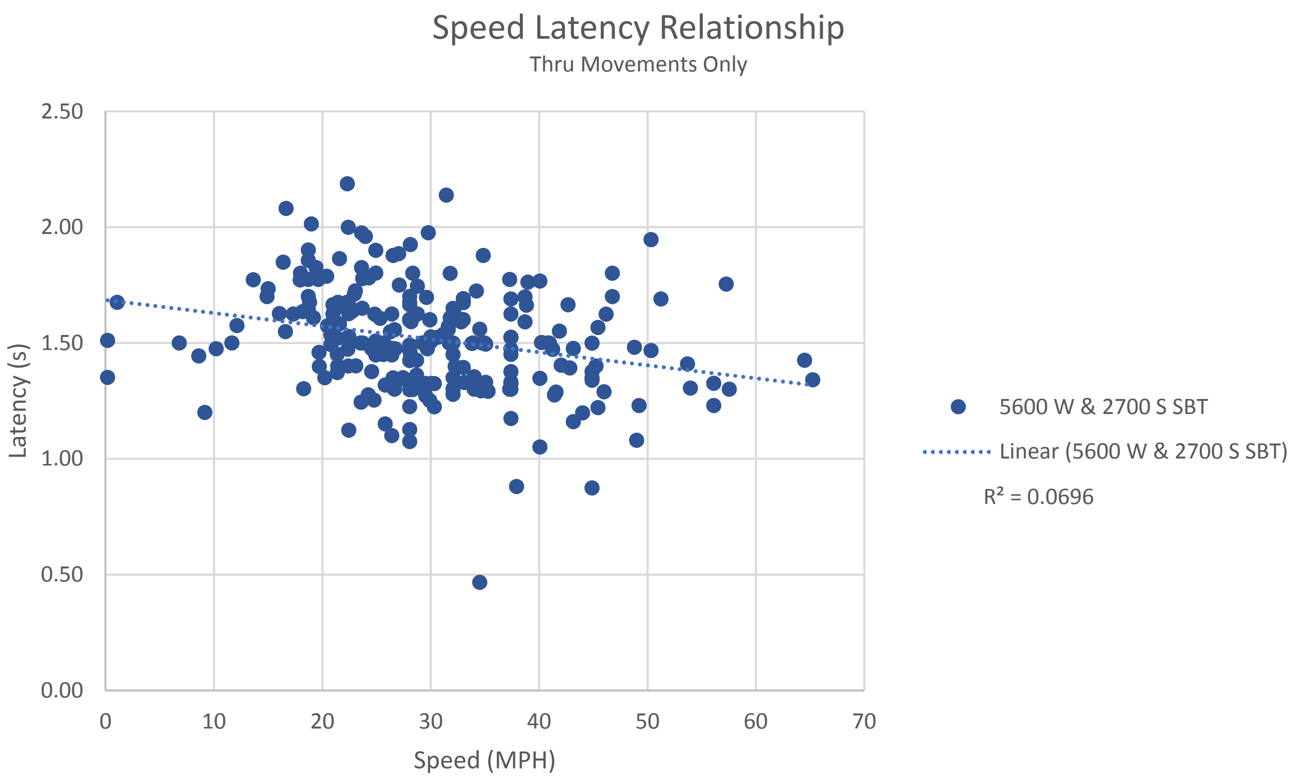
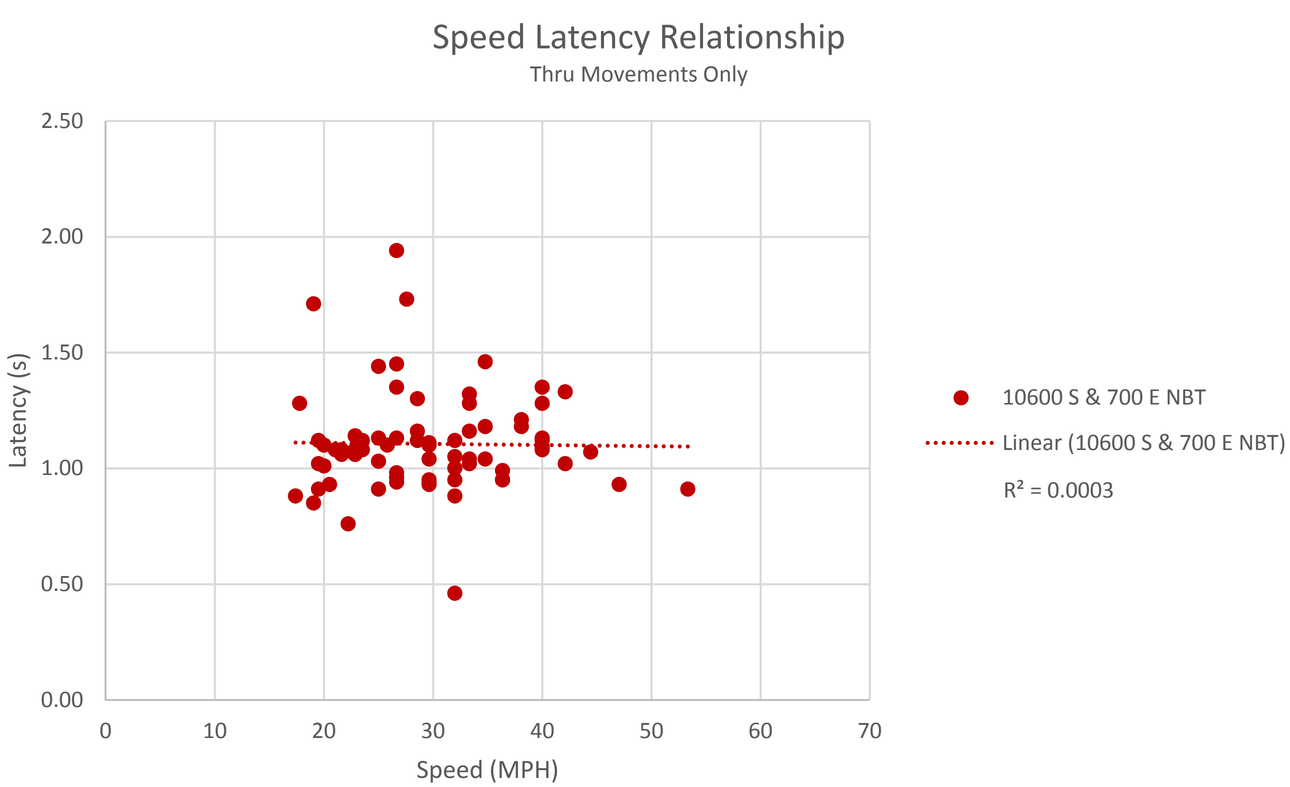
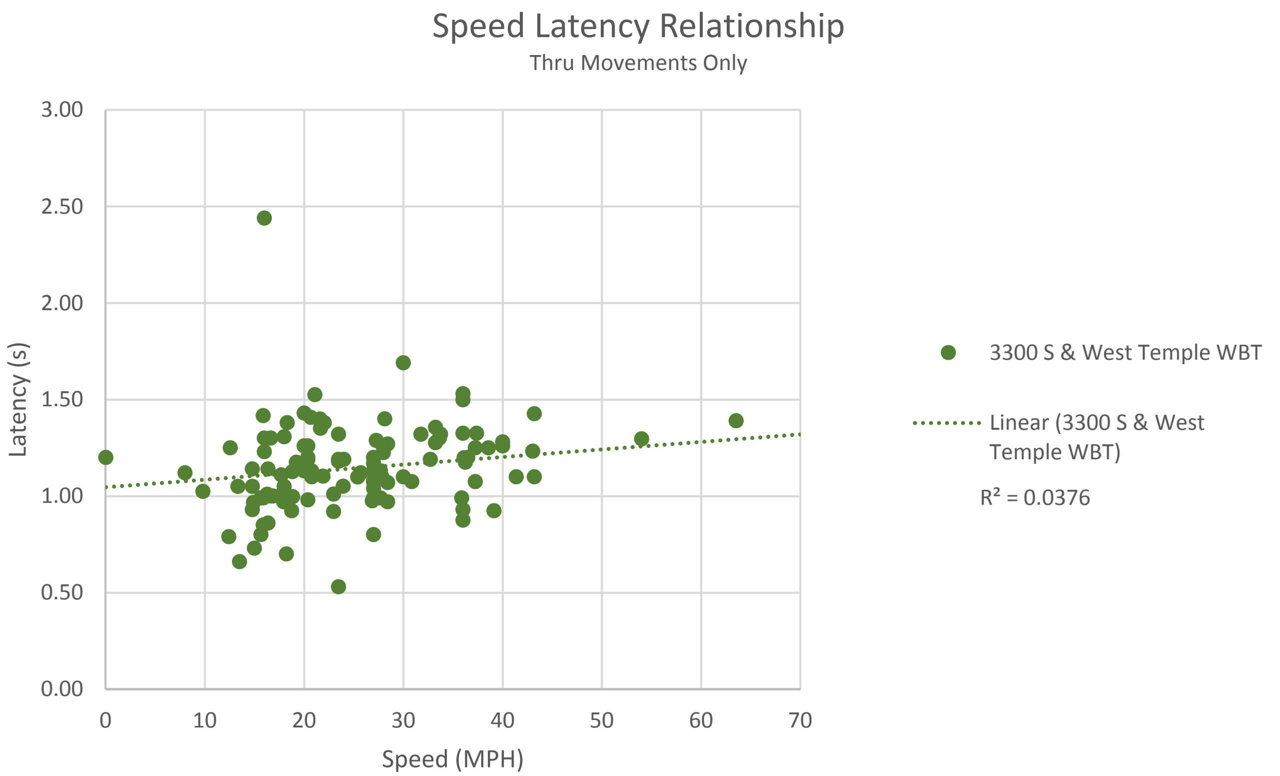
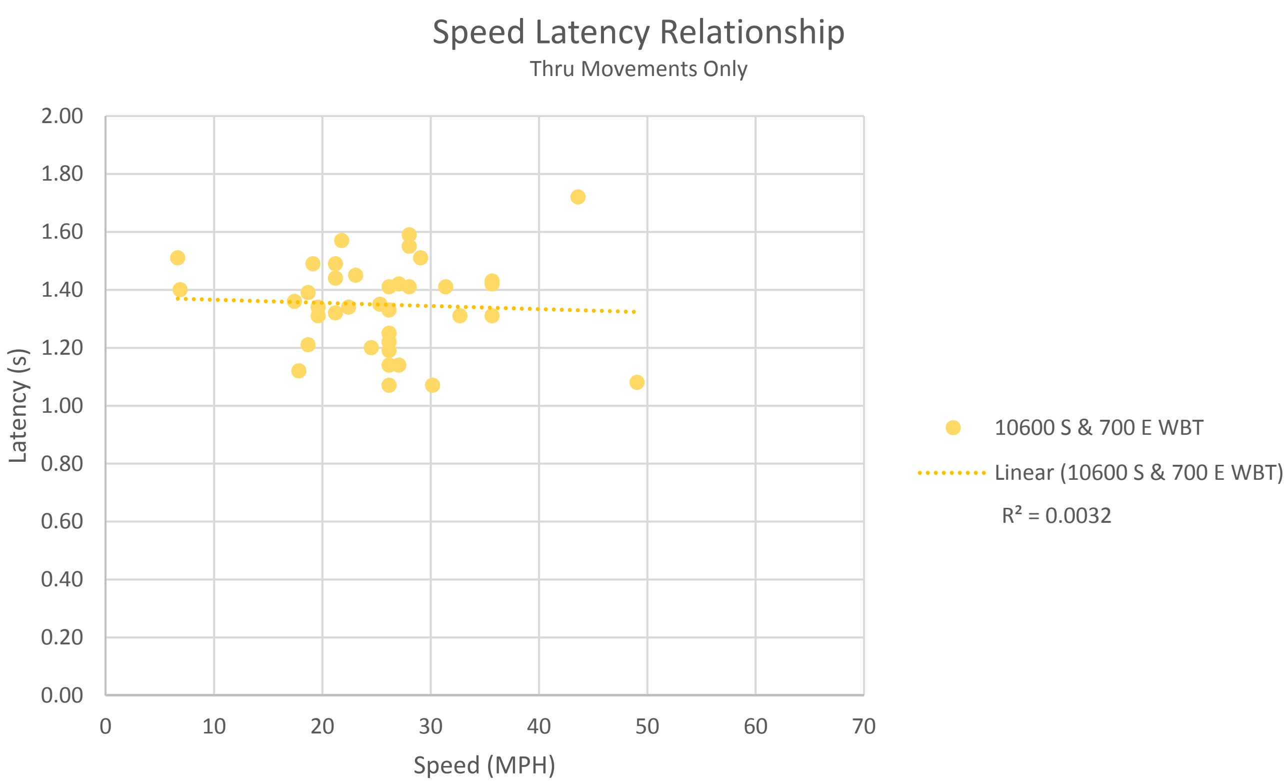
(0.8, 0.9]
(0.9, 1.0]
(1.0, 1.1]
(1.1, 1.2]
(1.2, 1.3]
(1.3, 1.4]
(1.4, 1.5]
(1.5, 1.6]
(1.6, 1.7]
(1.7, 1.8]
(1.8, 1.9]
Latency (seconds)

3 SPEED LATENCY RELATIONSHIP GRAPHS






Speed Latency Relationship
Thru Movements Only
Latency (s)
Speed (MPH)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
70
3300 S & West Temple WBT
Linear (3300 S & West Temple WBT)
R² = 0.0376


Speed Latency Relationship
Thru Movements Only
Latency (s)
Speed (MPH)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
10
20
30
40
50
60
70
10600 S & 700 E WBT
Linear (10600 S & 700 E WBT)
R² = 0.0032