Performance Evaluation of Non-Intrusive Methods for Traffic Data Collection

Kamal Banger, Ministry of Transportation of Ontario &

Nancy Adriano, P.Eng., Ministry of Transportation of Ontario

Abstract

Over the years methods and technologies for traffic data collection have evolved. For a long period of time, intrusive data collection methods like imbedded loops have been the traditional solution for accurate traffic data collection. However; with technological advancements, new alternative non-intrusive traffic data collection methods and devices have emerged. Technologies such as radar devices and video analytics software have gained popularity with transportation agencies around the world.

The traditional solution of imbedded loops is expensive to install and maintain, the loops damage the pavement and are prone to wear and tear. The Ministry of Transportation of Ontario (MTO) initiated a study where alternative technologies were tested for their accuracy. Under this study, validation of accuracy for intrusive and non-intrusive devices was undertaken. Traffic volume data was collected using recorded video and a video analytics software, two different radar devices and also taken from MTO's current imbedded loops system. All methods of data collection were validated for their accuracy.

1. Introduction

The Ministry of Transportation of Ontario (MTO) initiated a comprehensive evaluation study on the accuracy and reliability of both intrusive and non-intrusive data collection technologies. Four traffic volume data collection technologies were tested including: recorded video for a video analytics software, two radar devices and MTO's current inductive loop system. With the use of recorded video, manual counts were also conducted at each site to provide ground truth volume data for the validation of accuracy during various traffic conditions.

This paper focuses on the findings from the study, the reliability of the various technologies and a comparison of their accuracy. This paper summarizes the analytical observations through various traffic conditions and on two highways with different road configurations. The results from this study provided MTO with a comprehensive evaluation of each device and its limitations. Moving forward, the findings from this study will help with future data collection technology choices.

2. Devices and Technology

2.1 Recorded Video

Pan-Tilt-zoom (PTZ) cameras were deployed at both locations to provide recorded video. The PTZ cameras were mounted on streetlight poles on overpasses overlooking the highway for both test sites. Each camera had its own complete system that included a cabinet that housed a computer, a modem, an external hard drive and power.

The recorded video was used as a source for the Video Analytics Software. The recorded video was also used to conduct manual counts to obtain ground truth volume data. This data was utilized to validate the accuracy of the different data collection technologies tested within this study.

2.2 Video Analytics Software

A non-intrusive method of data collection was a video-based traffic monitoring technology that provides traffic volume counts using a Video Analytics Software. PTZ cameras provided recorded video which was a source for the Video Analytics Software. The vendor had developed algorithms that track each vehicle and their algorithms can be used with PTZ or fixed cameras.

The Video Analytics Software provides historical and real-time traffic data such as: volume, lane occupancy, level of service and vehicle length. At the same time, the Video Analytics Software is also capable of incident detection and provides real-time detection of stopped vehicles, slowed traffic, pedestrians, wrong-way vehicles and debris.

For the purpose of this study, MTO only tested the Video Analytics Software's ability to count vehicles and only collected volume counts. Data was not analyzed in real time. The recorded video was analyzed using the Video Analytics Software after the data collection period ended.

Picture 1 – The cameras and computer system used for the collection of recorded video

2.3 Radar Device 1 and Radar Device 2

This study tested two non-intrusive radar devices from two separate vendors. Both Radar Device 1 and Radar Device 2 use radar technology to provide detection of stationary and free-flowing vehicles. Both devices are side fire, pole-mounted devices that collect volume, occupancy, speed and vehicle length data. Both devices have the ability to detect up to 22 lanes or a maximum of 250 feet (76.2m).

Representatives from both vendors were present for the deployment of their device. Each vendor calibrated its own device and ensured the optimal height and setbacks were achieved.

For the purpose of this study, MTO only tested Radar Device 1 and Radar Device 2's ability to count vehicles and only collected volume counts.

2.4 MTO's Current Inductive Loop System

Historically and presently, reliability in traffic data collection has been accomplished through intrusive loop data collection technology used on MTO freeways. Loops detect vehicles using imbedded loops in the pavement and a microprocessor located on the side of the highway.

The inductive loop detector system consists of loops embedded in the pavement with multiple wires; the loop wire is connected to the loop detector amplifier through a lead-in cable; and the electrical energy produced by the detector loop is intensified by the detector amplifier.

Loops are capable of capturing traffic volumes, speed, lane occupancy and vehicle lengths. MTO's Loops are equipped with a communication system and the information is transmitted to the Central Computer System located at the Traffic Operations Centre. The communication system provides real-time traffic data that is used to monitor traffic patterns and identify traffic incidents.

For the purpose of this study, MTO only tested loops ability to count vehicles and only collected volume counts.

Picture 2 – Intrusive Loops on MTO's Highways

MTO worked with CIMA + to deploy the video cameras and to conduct manual counts. Manual counts were counted by MTO staff and by Ontario Traffic Inc. CIMA+ took the lead and worked closely with the video analytics vendor and deployed and calibrated the video cameras to meet the vendor’s requirements. Radar Device 1 and Radar Device 2 each sent a representative to help deploy and calibrate their device to achieve all of their installation requirements.

3. Test Site Locations

The study took place at two test sites for a total of ten days, from August 19 to August 29th, 2014. Two test site locations with different highway configurations were chosen for the study, Queen Elizabeth Way between Dorval Drive and Trafalgar Road and Highway 401 at Liverpool Road.

3.1 QEW between Dorval Drive and Trafalgar Road

The first test site, the Queen Elizabeth Way (QEW) between Dorval Drive and Trafalgar Road, is a simple freeway that runs east and west and is within a High Occupancy Vehicle (HOV) lane corridor. QEW has a single HOV lane in both directions and four general purpose (GP) lanes, in each direction. The HOV lane is not physically separated from the GP lanes. The HOV lane is separated by a painted solid buffer. Data was collected from Radar Device 1; Radar Device 2; four loop stations, one station per stream of travel: (1) Eastbound HOV lane, (2) Eastbound GP lanes, (3) Westbound HOV lane and (4) Westbound GP lanes; and from two video cameras facing west, one camera per direction.

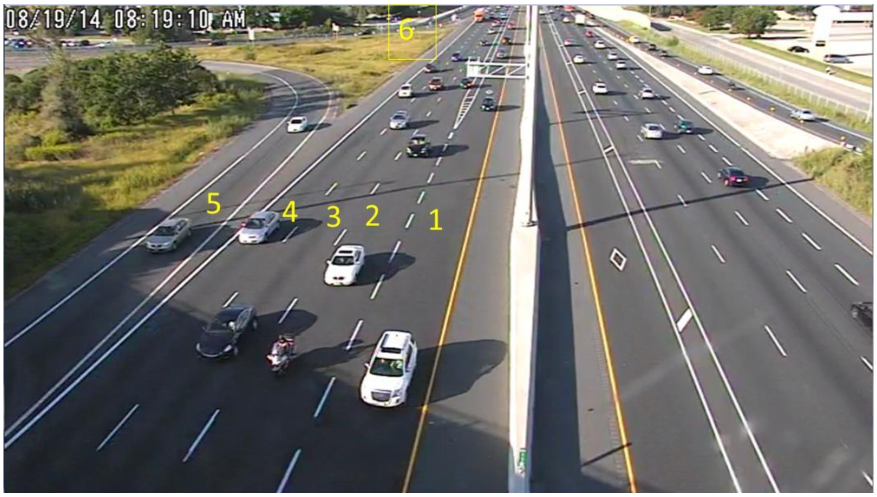
Radar Device 1 and Radar Device 2 were mounted on the same pole located on the south side of the highway. Both radar devices collected data for all four streams of travel. The Loops are also located in very close proximity to the two radar devices. Both radar devices and the Loops are located between Dorval Drive and Trafalgar Road. In both directions, a single HOV lane and four GP lanes exist.

The video cameras were mounted on the streetlight pole located on the Trafalgar Road overpass, overlooking the QEW. At this location, there is one HOV lane and three GP lanes in the Eastbound direction and one HOV lane and four GP lanes in the Westbound direction.

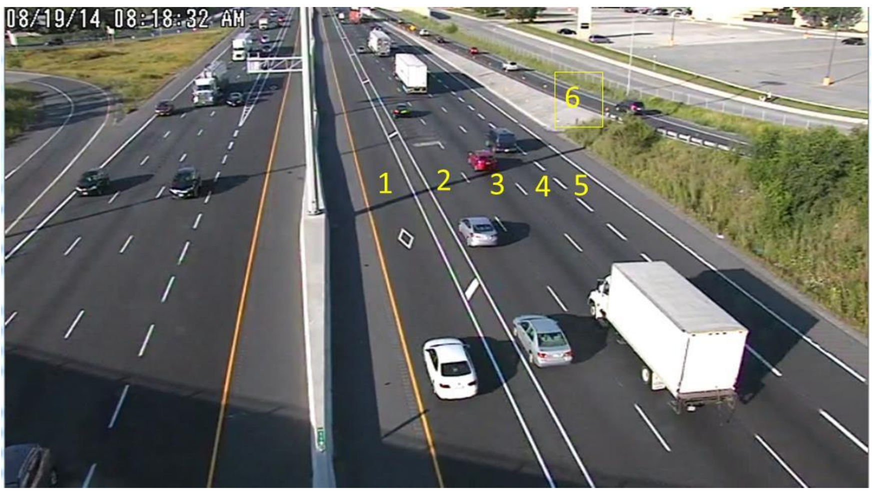
The highway configuration at the video camera site is different compared to the location of the radar devices and Loops. The location of the radar devices and Loops are approximately 1 km apart from where the video cameras were deployed, in both directions In the eastbound direction, the extra GP lane where the radar devices and Loops were mounted, directed traffic to the off-ramp at Trafalgar Road. A screenshot from the recorded video shows the lane configuration. As seen in Picture 3, lane 1 is the HOV lane; lanes 2, 3, 4 and 6 are known as the GP lanes in this study. Lane 5 is an on-ramp to QEW eastbound from Trafalgar Road, and the volume from this lane was not used in this study. The location of the radar devices and Loops are not seen in the picture. In order to achieve consistency among traffic at both locations, the analysis included lane 6 and eliminated lane 5.

In the westbound direction, the extra GP lane where the radar devices and Loops were mounted is from an on-ramp to QEW Westbound from Trafalgar Road. As seen in Picture 4 lane 1 is the HOV lane; lanes 2, 3, 4, 5, and 6 comprise the GP lanes. In this study, the on-ramp volumes were used as the 6th GP Lane and have been accounted for by all technologies.

Picture 3 – QEW Eastbound Lane Configuration – View from the Video



Picture 4 – QEW Westbound Lane Configuration – View from the Video



In both directions, there is no egress or ingress access for the HOV lane. A vehicle traveling in the HOV lane should be present throughout the entire duration of the HOV lane. A violation would occur if a vehicle enters or exits the HOV lane. Hence the vehicles traveling in the HOV lane should be accounted for by all technologies. There should be little or no change in the HOV lane volume between the two test sites.

Picture 5 – The location of each device at QEW between Dorval Drive and Trafalgar Road

3.2 Highway 401 and Liverpool Road

The second test site, Highway 401 and Liverpool Road, is a complex freeway with an express -collector system that runs east and west. There are a total of four different streams of travel: (1) Eastbound Collectors, (2) Eastbound Express, (3) Westbound Express and (4) Westbound Collectors.

On and off-ramps to and from Highway 401 Eastbound Collectors and Liverpool Road do not exist. Therefore there is no change in traffic for the Eastbound Collectors stream. However, on and off-ramps to and from Highway 401 Westbound Collectors and Liverpool Road exist.

The study only collected and analyzed data in the three steams of travel that are continuous and unaffected by transfers and ramps. Therefore, this study only collected and analyzed data for three streams of travel: Eastbound Collectors, Eastbound Express and Westbound Express; please refer to Picture 6, Picture 7 and Picture 8. Although data was collected for all four streams of travel by Loops and recorded video, the Westbound Collectors data was not analyzed.

Picture 6 – Highway 401Eastbound Collector Lane Configuration – View from the Video

Picture 7 – Highway 401Eastbound Express Lane Configuration – View from the Video

Picture 8 – Highway 401 Westbound Express Lane Configuration – View from the Video

This study analyzed data collected from Radar Device 1; Radar Device 2; three Loops, one per stream of travel; and from three video cameras, one video recording per stream of travel: Eastbound Collectors, Eastbound Express and Westbound Express.

Radar Device 1 collected data in all three streams of travel: Eastbound Collectors, Eastbound Express and Westbound Express. Radar Device 2 collected data in only the Eastbound streams: Eastbound Collectors and Eastbound Express. It is important to mention that the third stream was missed due to a calibration error and the device was more than capable of collecting the third stream of travel.

Picture 9 illustrates the technologies deployed at the Highway 401 test site, the two radar devices were not mounted onto the same pole. Instead Radar Device 1 was mounted on a pole east of Liverpool Road and Radar Device 2 was mounted onto a pole west of Liverpool Road. Both poles were located on the south side of the highway.

Data was collected from one Loop station for each stream of travel and the Loops are scattered throughout the detection zone. The video cameras were mounted onto the streetlight poles at the Liverpool Road overpass that overlooked Highway 401 with one video camera, per stream of travel.

Picture 9 – The location of each device at Highway 401 and Liverpool Road

4. Ground Truth and Traffic Conditions

Ground truth data was acquired by conducting manual counts in fifteen minute intervals. Manual counts were completed by watching the recorded video and manually counting each vehicle on a lane-by-lane basis. In total, 624 fifteen minute intervals were manually counted, which is equivalent to 156 hours of video. The validation of the accuracy of the different devices will be measured against the ground truth data.

Data collected from each device was validated for its accuracy under various traffic conditions. Various traffic conditions include AM and PM peak periods, free-flow conditions, traffic conditions during the weekend, nightly conditions and periods of inclement weather such as rainfall. It was imperative to measure the accuracy during various traffic conditions in order to assess the strengths and weaknesses of each technology.

Chart 1 – Manual Count Breakdown by each Traffic Condition in Fifteen Minute Intervals

	AM Peak	PM Peak	Rain	Free-flow	Night	Total
EB QEW	32	16	8	28	20	104
WB QEW	32	20	12	24	12	100
EB Collector	24	36	12	50	16	138
EB Express	24	36	12	50	16	138
WB Collector	0	0	0	0	0	0
WB Express	32	8	16	68	20	144
					TOTAL	624

5. Results

Accurate volume data, especially during peak periods, is essential for engineering, operational and road safety, forecasting, planning and design. This study focused on the accuracy of volume data collected during various traffic conditions in order to better evaluate each technology. Majority of the manual counts were allocated to validate the accuracy during peak periods.

The two test sites were chosen due to their different highway configurations. Each highway configuration is unique and requires specific data requirements. For example, apart from a directional volume, QEW’s configuration requires accurate data that separates vehicles travelling in the HOV lane with vehicles traveling in the GP lanes. On the other hand, Highway 401’s configuration does not contain a HOV lane but is physically larger and wider compared to QEW. Highway 401 also has four streams that are physically separated from one another. Therefore Highway 401 requires accurate data to be collected for each stream. In order for Highway 401 data to be collected accurately each device must accurately allocate each vehicle into the correct stream of travel.

The study analyzed the ground truth data with the counts collected by each technology in fifteen minute intervals. The Average Percent Error is calculated by taking the absolute value of the percent over or under between the results from each device compared to the ground truth data as shown below,

$$Average\ Percent\ Error = \left(\frac{Devices\ Results}{Ground\ Truth\ Results} - 1\right) \times\ 100 \qquad (1)$$

The Standard Deviation (σ) is calculated to capture the variance between the difference between the devices results and the ground truth data, as demonstrated in Equation 2,

$$\sigma = \sqrt{\frac{\sum(x-\bar{x})^2}{N}} \qquad (2)$$

where x is each value , $\bar{x}$ is the mean of the values, and N is the number of values. Additionally, Equation 3 represents the Range of Error. The Range of Error is calculated by subtracting the highest percent error to the lowest percent error,

$$Range\ of\ Error = (Highest\ Percent\ Error - Lowest\ Percent\ Error) \times\ 1 \qquad (3)$$

This paper graphs the Average Percent Error and Standard Deviation for each traffic condition analyzed. At the same time, the Average Percent Error, Standard Deviation and Range of Error are summarized in chart form for each traffic condition. Accuracy is achieved if the results across all three categories of measurement are low. When analyzing the graphs, the devices closest to the X and Y intercept are considered to be the most accurate.

5.1 Results during Peak Periods

Majority of the data analysis required for engineering, operational and road safety, forecasting, planning and design is done using volumes collected during the peak hours. Therefore, it is essential to heavily evaluate each device during peak periods.

QEW requires accurate traffic data that differentiates the HOV lane volume from the GP lanes. Figure 1 and Table 1 summarizes the accuracy of each technology with ground truth data during peak periods for QEW. The results indicate that the Loops and Radar Device 2 outperformed the other devices. Upon further examination it is evident that Radar Device 2 outperformed the Loops. Loops achieved a lower Average Percent Error of 7.01% compared to Radar Device 2's 7.64%; however, the Standard Deviation for Radar Device 2 was lower at 0.08, compared to 0.14. Although the Loops and Radar Device 2 results were close, Radar Device 2's Range of Error of 0.42 is significantly lower than Loop's Range of Error of 1.26; hence improving the accuracy for Radar Device 2. The Video Analytics Software and Radar Device 1 did not perform well when analyzed for their accuracy during peak periods.

Figure 1 – QEW's Average Percent Error and Standard Deviation during Peak Periods

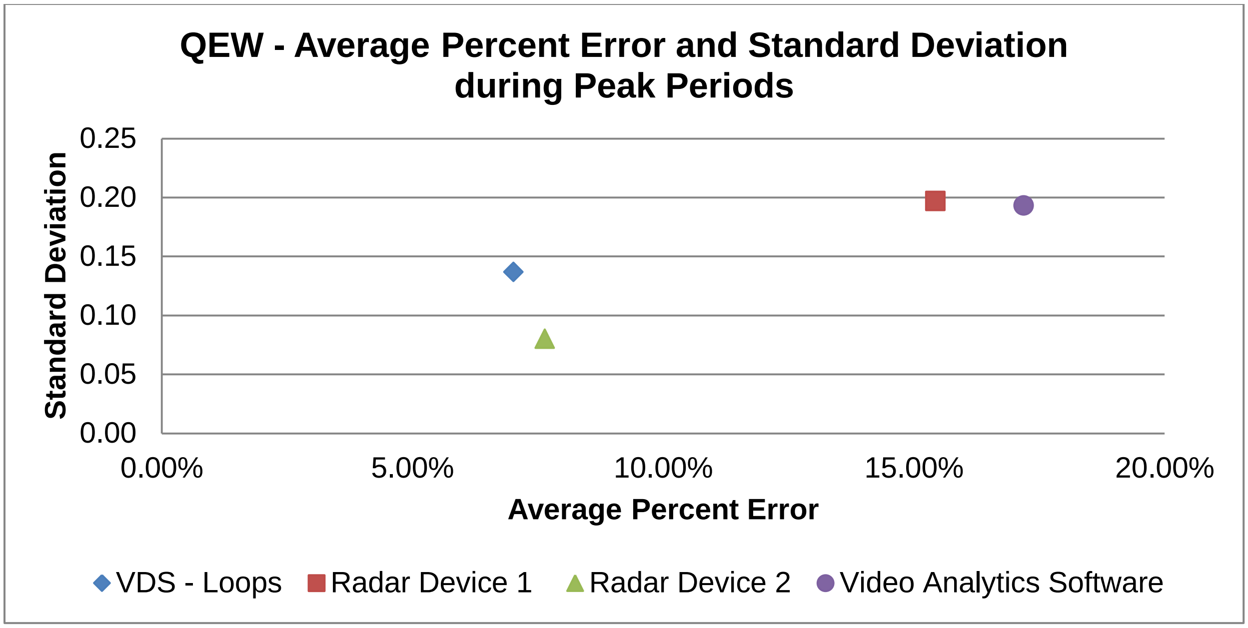


Table 1 – QEW's Percent Error, Standard Deviation and Range of Error during Peak Periods

	Loops	Video Analytics Software	Radar Device 1	Radar Device 2
Average Percent Error	7.01%	17.19%	15.43%	7.64%
Standard Deviation	0.14	0.19	0.20	0.08
Range of Error	1.26	0.86	1.08	0.42

Figure 2 and Table 2 summarizes the accuracy of each technology with ground truth data for Highway 401. It is evident that Radar Device 2 outperformed all other technologies. Radar Device 2 achieved the most accurate results across all three categories of measurement. Radar Device 2 achieved an Average Percent Error of 3.20%, a Standard Deviation of 0.04, and a Range of Error of 0.25. Loops and Radar Device 1 had very similar results; however Loops has a slight edge over Radar Device 1. Loops achieved an Average Percent Error of 8.09% compared to 8.84% and a Standard Deviation of 0.11 compared to 0.12. Although Radar Device 1 achieved a lower Range of Error of 0.68 compared to 0.72, Loops slightly outperformed Radar Device 2 based on its lower Average Percent Error and Standard Deviation. The Video Analytics Software did not perform well when analyzed for its accuracy during peak periods.

Figure 2 – Highway 401's Average Percent Error and Standard Deviation during Peak Periods

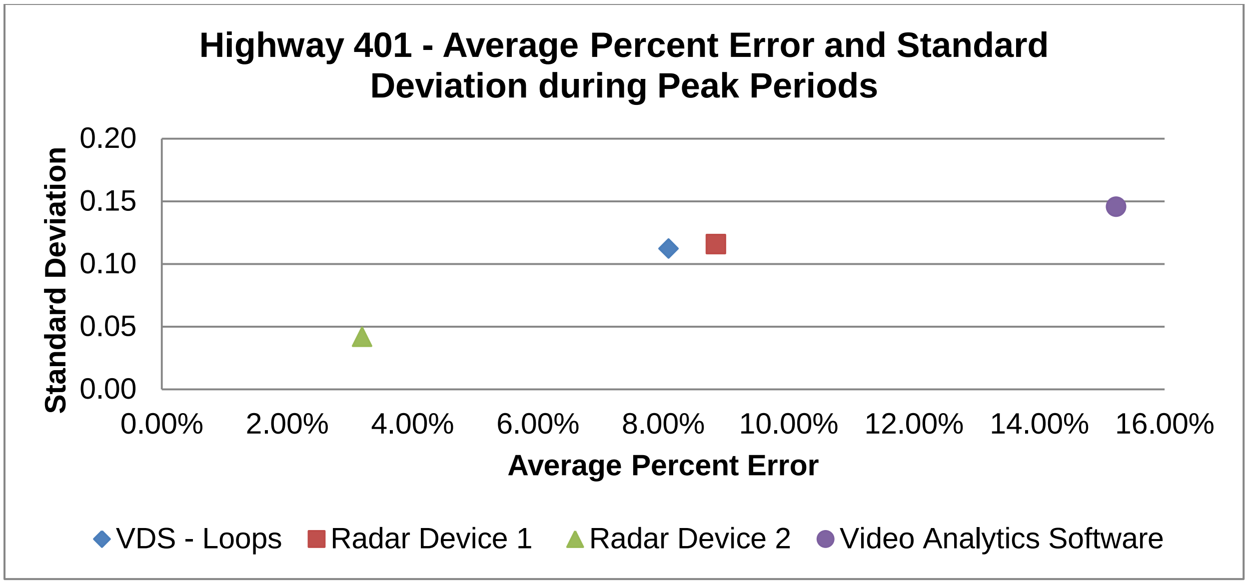


Table 2 – Highway 401's Percent Error, Standard Deviation and Range of Error during Peak Periods

	Loops	Video Analytics Software	Radar Device 1	Radar Device 2
Average Percent Error	8.09%	15.23%	8.84%	3.20%
Standard Deviation	0.11	0.15	0.12	0.04
Range of Error	0.72	0.59	0.68	0.25

5.2 Results during AM and PM Peak Periods

Traffic data collection during the AM and PM peak periods is essential for analytical purposes. It is imperative to examine the peak directional AM and PM period for the portion of the highway being analyzed. This study analyzed the results during both peak periods and also during the directional peak periods.

QEW traffic peaks in the AM period in the Eastbound direction and peaks in the PM in the Westbound direction. Highway 401 traffic peaks in the AM period in the Westbound direction and peaks in the PM in the Eastbound direction.

Figure 3 and Table 3 summarizes the accuracy of each technology with ground truth data during the AM peak period for the QEW Eastbound HOV lane. The results indicate that Radar Device 2 outperformed all other devices and achieved the most accurate results across all three categories of measurement. Radar Device 2 achieved an Average Percent Error of 5.65%, a Standard Deviation of 0.06 and a Range of Error of 0.20. Loops also performed well with an Average Percent Error of 9.07%, a Standard Deviation of 0.14 and a Range of Error of 0.97. The Video Analytics Software and Radar Device 1 did not perform well when analyzed for its accuracy during the AM peak periods for QEW's Eastbound HOV Lane.

Figure 3 – QEW Eastbound HOV lane's Average Percent Error and Standard Deviation during the AM Peak Period

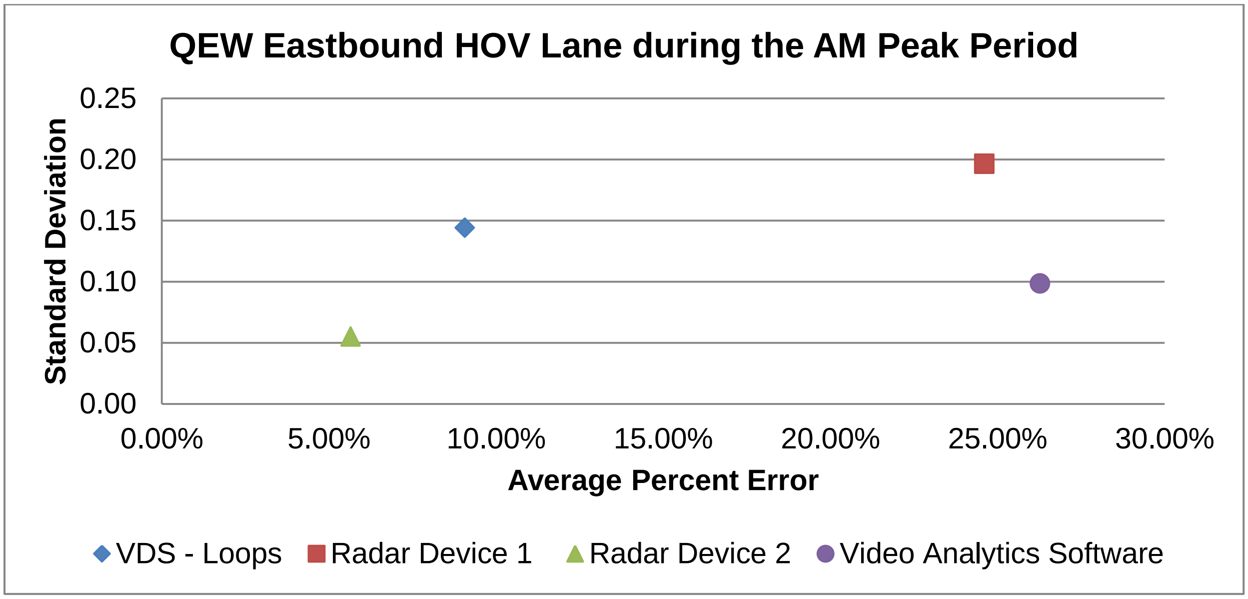


Table 3 – QEW Eastbound HOV lane's Percent Error, Standard Deviation and Range of Error during the AM Peak Period

	Loops	Video Analytics Software	Radar Device 1	Radar Device 2
Average Percent Error	**9.07%**	**26.28%**	**24.61%**	**5.65%**
Standard Deviation	**0.14**	**0.10**	**0.20**	**0.06**
Range of Error	**0.97**	**0.57**	**0.89**	**0.20**

Figure 4 and Table 4 summarizes the accuracy of each technology with ground truth data during the AM peak period for the QEW Eastbound GP lanes. The results indicate that Radar Device 2 outperformed all other devices and achieved the most accurate results across all three categories of measurement. Radar Device 2 achieved an Average Percent Error of 7.44%, a Standard Deviation of 0.02 and a Range of Error of 0.07. Radar Device 1 and Loops also performed well. Radar Device 1 achieved an Average Percent Error of 8.72%, a Standard

Deviation of 0.06 and a Range of Error of 0.29. Loops achieved an Average Percent Error of 9.67%, a Standard Deviation of 0.15 and a greater Range of Error of 1.04. The Video Analytics Software did not perform well when analyzed for its accuracy during the AM peak period for QEW's Eastbound GP lanes.

Figure 4 – QEW Eastbound GP lanes Average Percent Error and Standard Deviation during the AM Peak Period

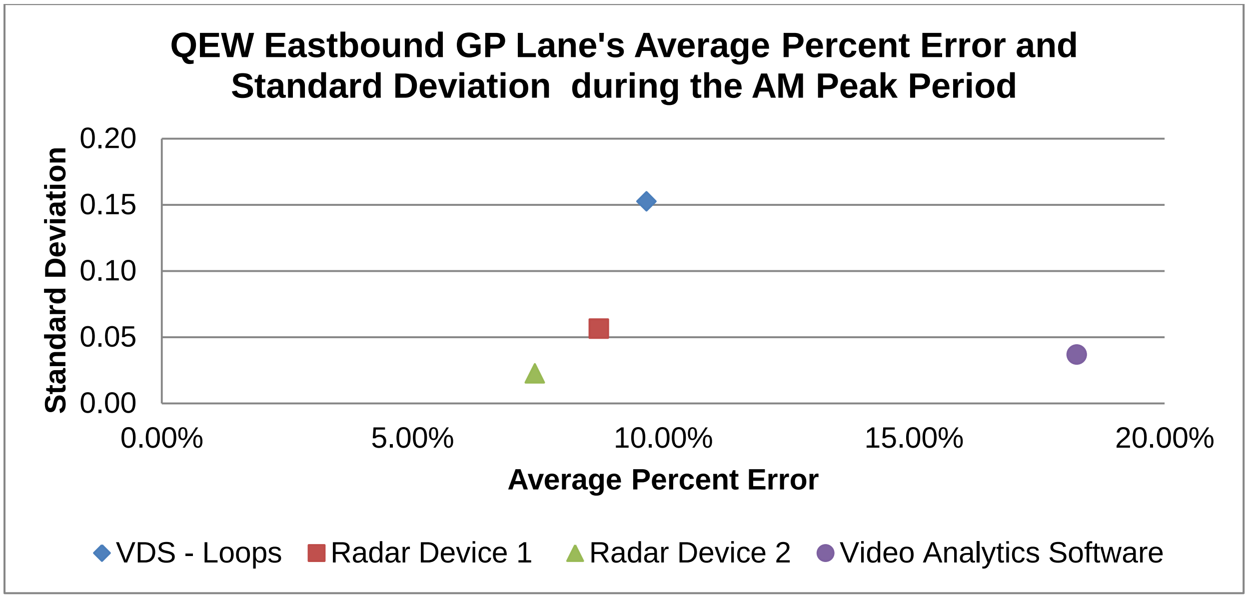


Table 4 – QEW Eastbound GP lanes Percent Error, Standard Deviation and Range of Error during the AM Peak Period

	Loops	Video Analytics Software	Radar Device 1	Radar Device 2
Average Percent Error	**9.67%**	**18.25%**	**8.72%**	**7.44%**
Standard Deviation	**0.15**	**0.04**	**0.06**	**0.02**
Range of Error	**1.04**	**0.16**	**0.29**	**0.07**

Figure 5 and Table 5 summarizes the accuracy of each technology with ground truth data during the PM peak period for the QEW Westbound HOV lane. All four devices performed well in all categories of measurement. All devices achieved an Average Percent Error of 7.92% or lower, a Standard Deviation of 0.09 or lower and a Range of Error of 0.36 or lower. The results indicate that the Video Analytics Software achieved the most accurate results across all three categories of measurement. The Video Analytics Software achieved an Average Percent Error of 2.25%, a Standard Deviation of 0.02 and a Range of Error of 0.05. Loops achieved an

Average Percent Error of 4.30%, a Standard Deviation of 0.06 and a Range of Error of 0.23. Radar Device 1 achieved an Average Percent Error of 7.27%, a Standard Deviation of 0.09 and a Range of Error of 0.36. Radar Device 2 achieved an Average Percent Error of 7.92%, a Standard Deviation of 0.04 and a Range of Error of 0.12.

Figure 5 – QEW Westbound HOV lane's Average Percent Error and Standard Deviation during the PM Peak Period

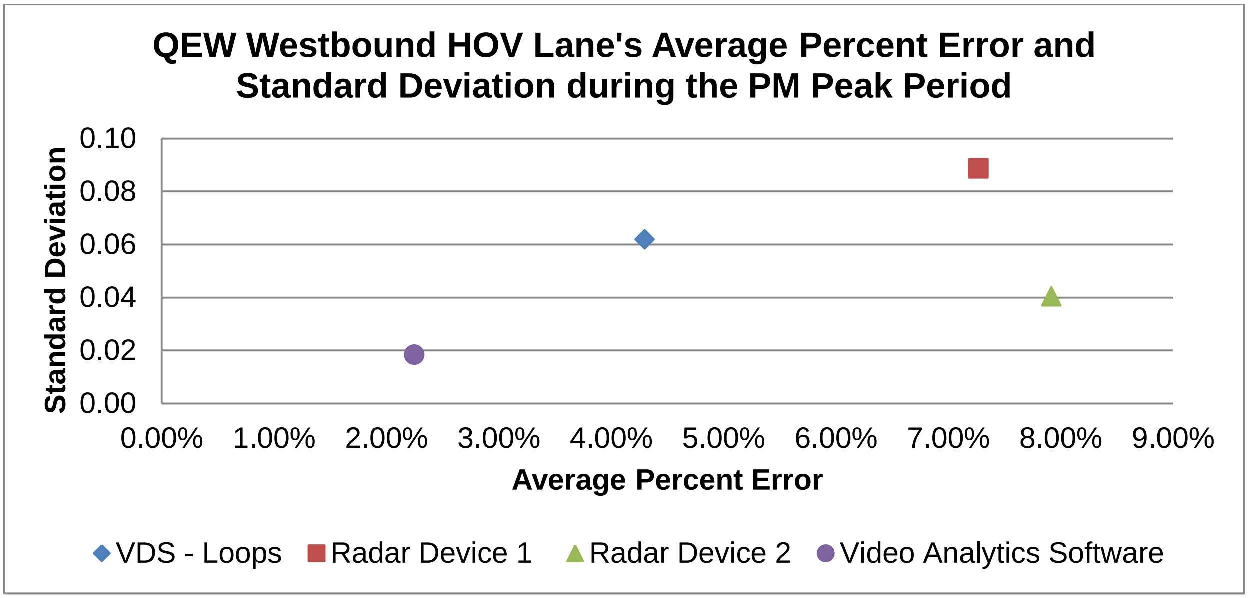


Table 5 – QEW Westbound HOV lane's Percent Error, Standard Deviation and Range of Error during the PM Peak Period

	Loops	Video Analytics Software	Radar Device 1	Radar Device 2
Average Percent Error	4.30%	2.25%	7.27%	7.92%
Standard Deviation	0.06	0.02	0.09	0.04
Range of Error	0.23	0.05	0.36	0.12

Figure 6 and Table 6 summarizes the accuracy of each technology with ground truth data during the PM peak period for the QEW Westbound GP lanes. The results indicate that Loops outperformed all other devices. Loops achieved an Average Percent Error of 2.38%, a Standard Deviation of 0.05 and a Range of Error of 0.18. Both Radar Device 1 and Radar Device 2 performed well. Radar Device 1 achieved an Average Percent Error of 6.31%, a Standard Deviation of 0.05 and a Range of Error of 0.19. Radar Device 2 achieved an Average Percent Error of 9.67%, a Standard Deviation of 0.05 and a Range of Error of 0.16. The Video

Analytics Software did not perform well when analyzed for its accuracy during the PM peak period for QEW's Westbound GP lanes.

Figure 6 – QEW Westbound GP lanes Average Percent Error and Standard Deviation during the PM Peak Period

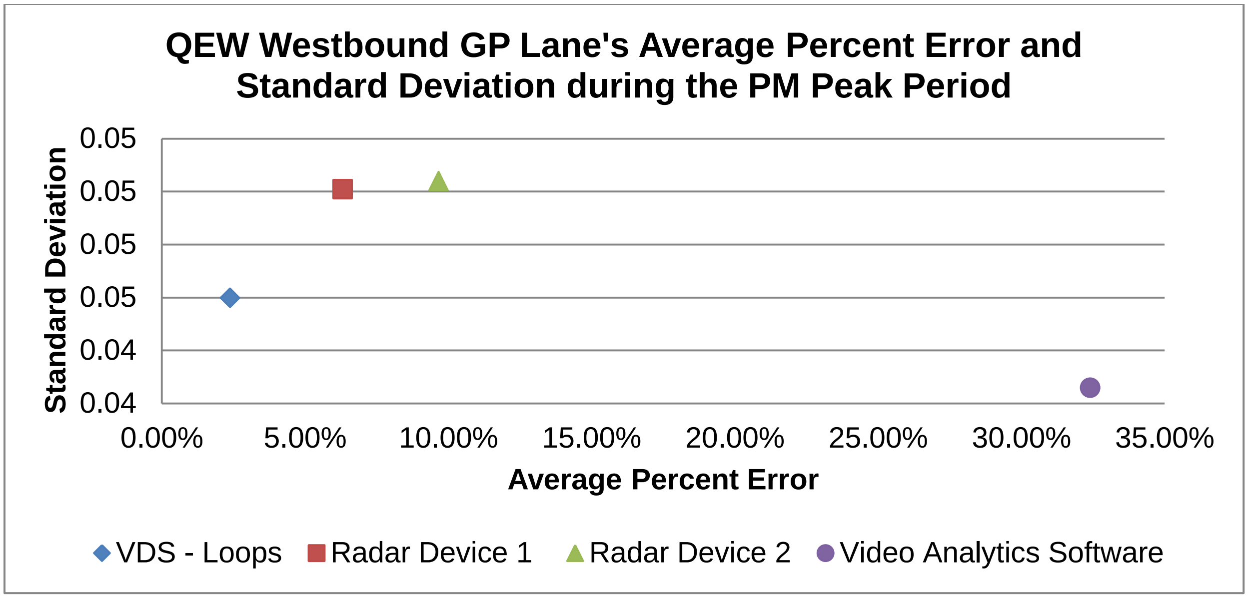


Table 6 – QEW Westbound GP lanes Percent Error, Standard Deviation and Range of Error during the PM Peak Period

	Loops	Video Analytics Software	Radar Device 1	Radar Device 2
Average Percent Error	**2.38%**	**32.41%**	**6.31%**	**9.67%**
Standard Deviation	**0.05**	**0.04**	**0.05**	**0.05**
Range of Error	**0.18**	**0.16**	**0.19**	**0.16**

Figure 7 and Table 7 summarizes the accuracy of each technology with ground truth data during the PM peak period for Highway 401's Eastbound Collectors. The results indicate that Radar Device 2 achieved the most accurate results across all three categories of measurement. Radar Device 2 achieved an Average Percent Error of 3.12%, a Standard Deviation of 0.03 and a Range of Error of 0.15. Radar Device 1 performed very well. Radar Device 1 achieved an Average Percent Error of 5.92%, a Standard Deviation of 0.07 and a Range of Error of 0.34. Loops also performed well with an Average Percent Error of 10.79%, a Standard Deviation of 0.13 and a Range of Error of 0.50. The Video Analytics Software did not perform well when analyzed for its accuracy during the PM peak period for Highway 401's Eastbound Collectors.

Figure 7 – Highway 401's Eastbound Collectors Average Percent Error and Standard Deviation during the PM Peak Period

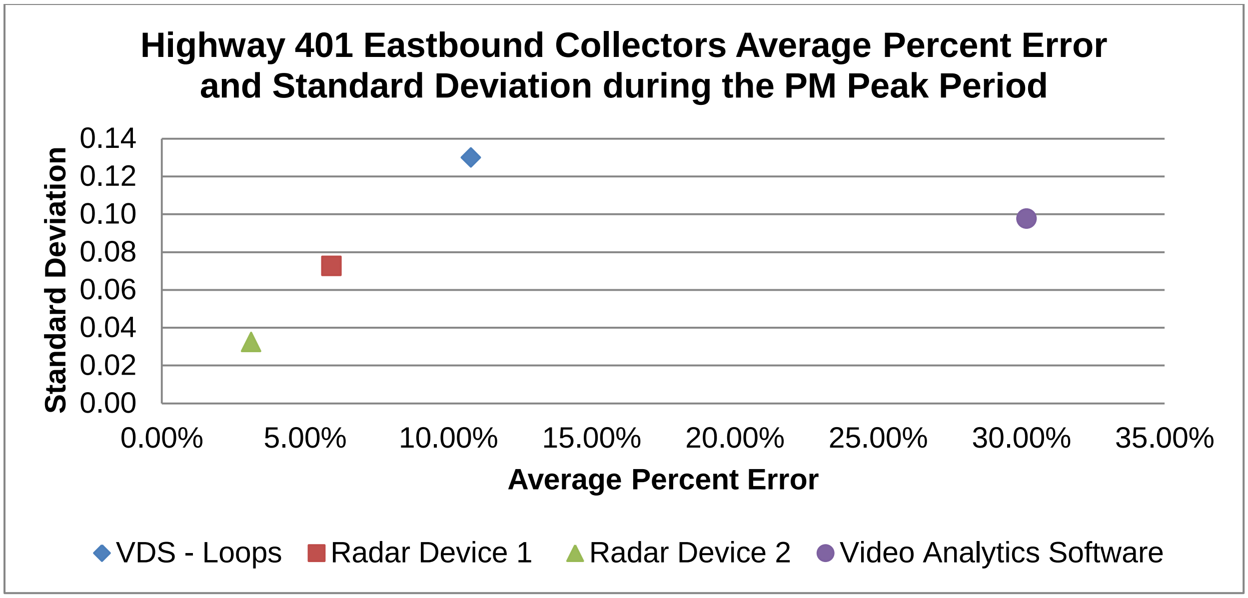


Table 7 – Highway 401's Eastbound Collectors Percent Error, Standard Deviation and Range of Error during the PM Peak Period

	Loops	**Video Analytics Software**	**Radar Device 1**	**Radar Device 2**
Average Percent Error	**10.79%**	**30.19%**	**5.92%**	**3.12%**
Standard Deviation	**0.13**	**0.10**	**0.07**	**0.03**
Range of Error	**0.50**	**0.50**	**0.34**	**0.15**

Figure 8 and Table 8 summarizes the accuracy of each technology with ground truth data during the PM peak period for Highway 401's Eastbound Express .The results indicate that Radar Device 2 achieved the most accurate results across all three categories of measurement. Radar Device 2 achieved an Average Percent Error of 4.33%, a Standard Deviation of 0.06 and a Range of Error of 0.25. The other three devices did not perform well in terms of accuracy during the PM peak period for Highway 401 Eastbound Express.

Figure 8 – Highway 401's Eastbound Express Average Percent Error and Standard Deviation during the PM Peak Period

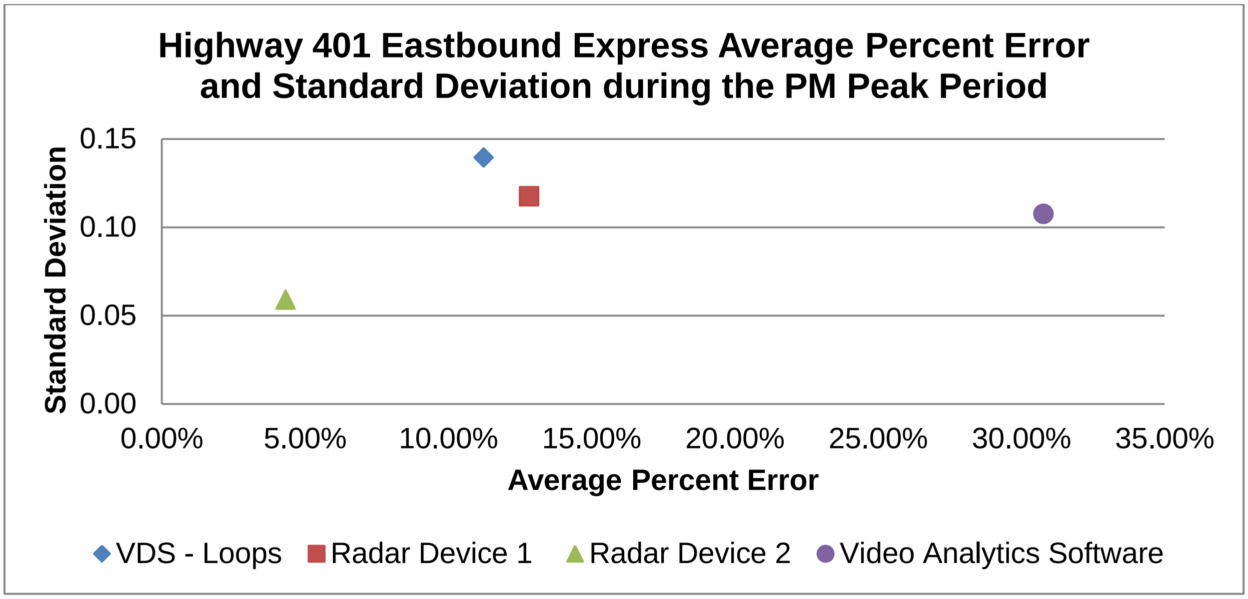


Table 8 – Highway 401's Eastbound Express Percent Error, Standard Deviation and Range of Error during the PM Peak Period

	Loops	**Video Analytics Software**	**Radar Device 1**	**Radar Device 2**
Average Percent Error	**11.24%**	**30.78%**	**12.82%**	**4.33%**
Standard Deviation	**0.14**	**0.11**	**0.12**	**0.06**
Range of Error	**0.56**	**0.43**	**0.46**	**0.25**

Figure 9 and Table 9 summarizes the accuracy of each technology with ground truth data during the AM peak period for Highway 401's Westbound Express .The results indicate that all three devices performed well and all three devices achieved an Average Percent Error of 8.31% or lower, a Standard Deviation of 0.11 or lower and a Range of Error of 0.44 or lower. Radar Device 1 achieved the lowest Average Percent Error compared to the other two devices; however the Video Analytics Software achieved a lower Standard Deviation and a lower Range of Error; thus giving the Video Analytics Software a slight edge over Radar Device 1. The Video Analytics Software achieved an Average Percent Error of 6.76%, a Standard Deviation of 0.03 and a Range of Error of 0.19. Radar Device 1 achieved an Average Percent Error of 5.40%, a Standard Deviation of 0.07 and a Range of Error of 0.33. Loops achieved an Average Percent Error of 8.31%, a Standard Deviation of 0.11 and a Range of Error of 0.44.

Figure 9 – Highway 401's Westbound Express Average Percent Error and Standard Deviation during the AM Peak Period

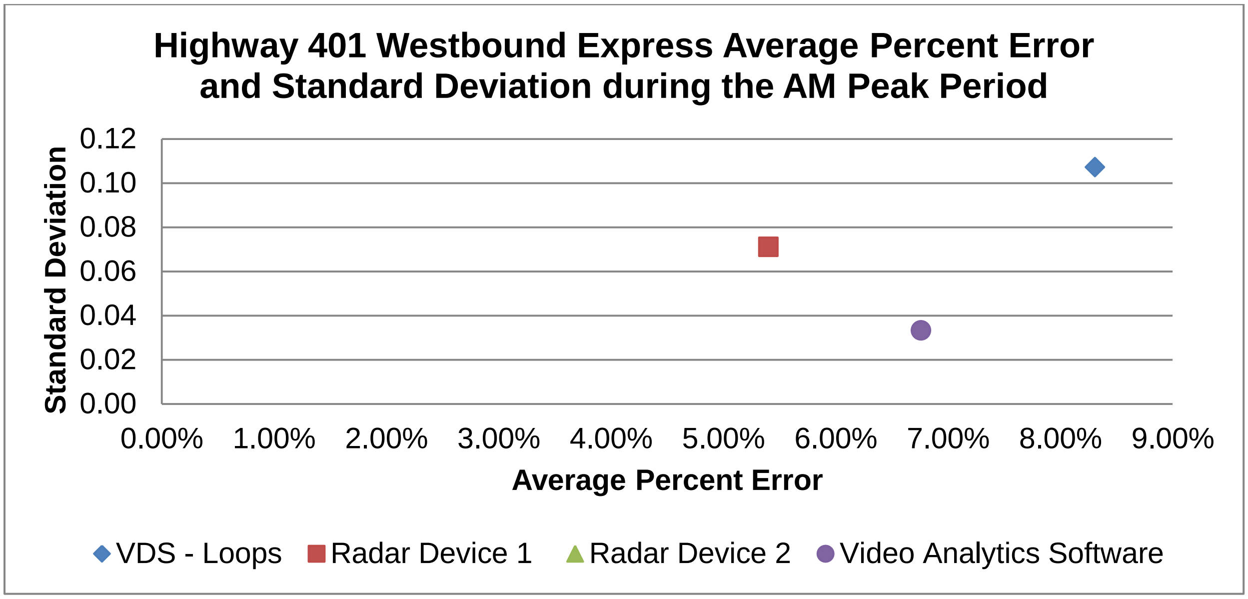


Table 9 – Highway 401's Westbound Express Percent Error, Standard Deviation and Range of Error during the AM Peak Period

	Loops	Video Analytics Software	Radar Device 1
Average Percent Error	8.31%	6.76%	5.40%
Standard Deviation	0.11	0.03	0.07
Range of Error	0.44	0.19	0.33

5.3 Results during Free-flow Traffic Conditions

Figure 10 and Table 10 summarizes the accuracy of each technology with ground truth data during free-flow traffic conditions for QEW. Loops outperformed all other technologies with an Average Percent Error of 6.35%, a Standard Deviation of 0.08 and a Range of Error of 0.32. Radar Device 2 also performed well. Radar Device 2 achieved an Average Percent Error of 8.92% and a Standard Deviation of 0.09 and Range of Error of 0.31. The Video Analytics Software and Radar Device 1 did not perform well when analyzed for its accuracy during free-flow traffic conditions for QEW.

Figure 10 – QEW's Average Percent Error and Standard Deviation during Free-flow Conditions

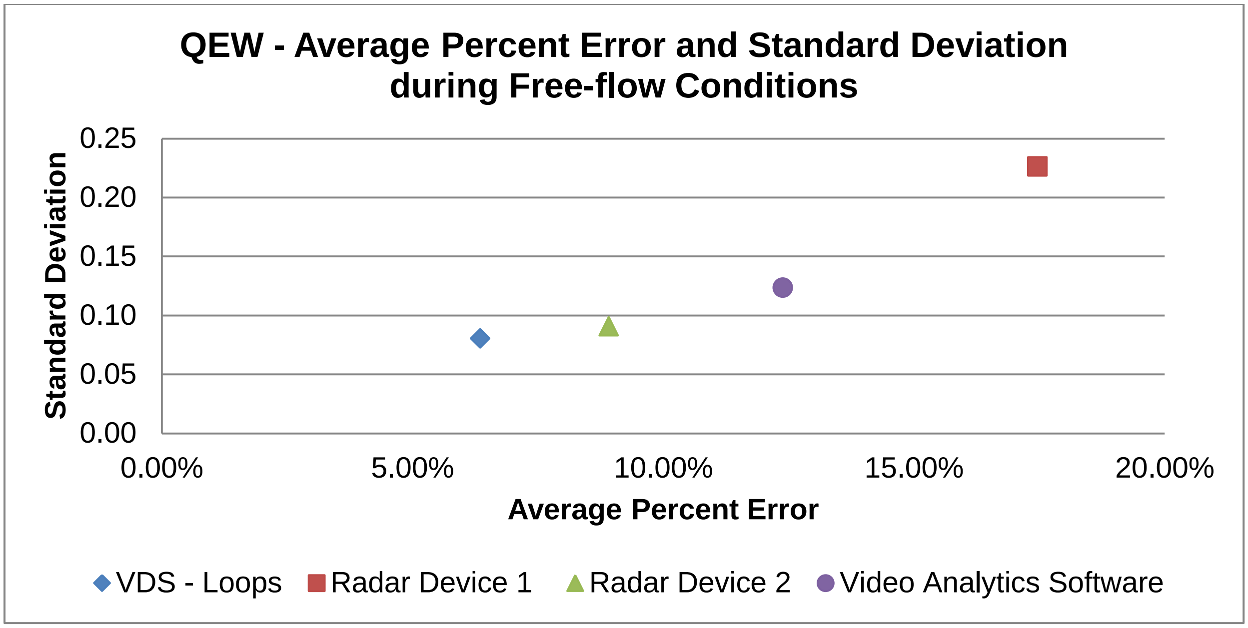


Table 10 – QEW's Percent Error, Standard Deviation and Range of Error during Free-flow Conditions

	Loops	Video Analytics Software	Radar Device 1	Radar Device 2
Average Percent Error	6.35%	12.39%	17.47%	8.92%
Standard Deviation	0.08	0.12	0.23	0.09
Range of Error	0.32	0.42	0.92	0.31

Figure 11 and Table 11 summarizes the accuracy of each technology with ground truth data during free-flow traffic conditions for Highway 401. It is evident that Radar Device 2 outperformed all other devices as it achieved the most accurate results across all three categories of measurement. Radar Device 2 achieved an Average Percent Error of 3.22%, a Standard Deviation of 0.03 and a Range of Error of 0.15.

All four technologies performed well under free-flow traffic conditions on Highway 401. The Video Analytics Software also performed well; it achieved an Average Percent Error of 5.00%, a Standard Deviation of 0.03 and a Range of Error of 0.16. Radar Device 1 achieved an Average Percent Error of 7.19%, a Standard Deviation of 0.10 and a Range of Error of 0.58. Loops achieved an Average Percent Error of 7.53%, a Standard Deviation of 0.09 and a Range of Error of 0.39.

Figure 11 – Highway 401's Average Percent Error and Standard Deviation during Free-flow Conditions

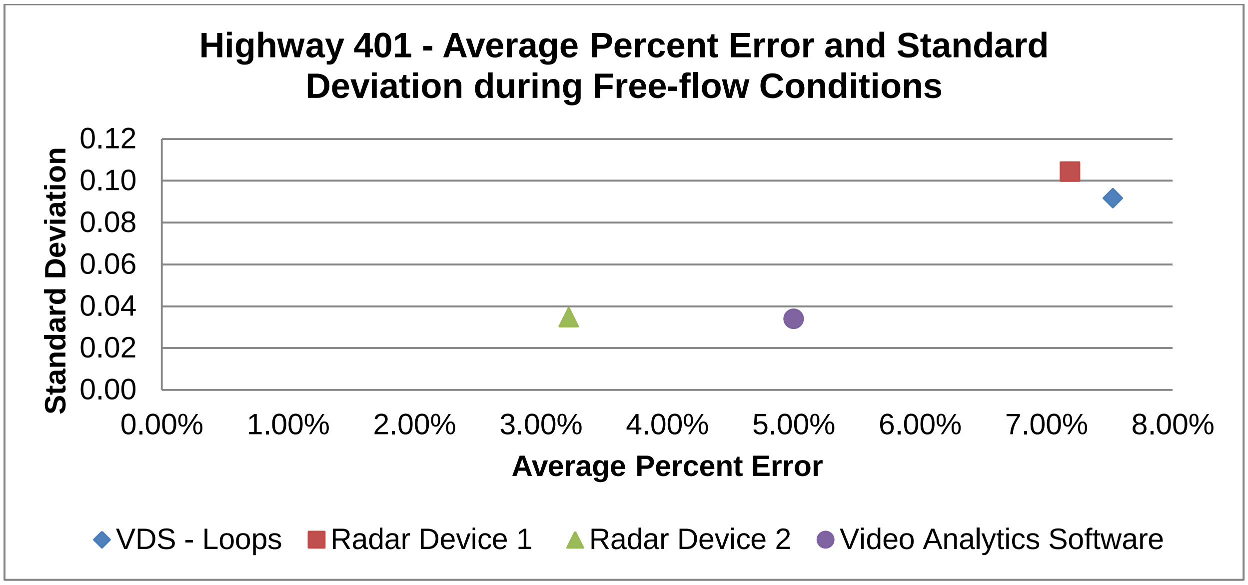


Table 11 – Highway 401's Percent Error, Standard Deviation and Range of Error during Free-flow Conditions

	Loops	Video Analytics Software	Radar Device 1	Radar Device 2
Average Percent Error	7.53%	5.00%	7.19%	3.22%
Standard Deviation	0.09	0.03	0.10	0.03
Range of Error	0.39	0.16	0.58	0.15

5.4 Results during Weekend Traffic Conditions

Weekend traffic patterns differ from weekday patterns as the peaks can be spread out throughout the day and traffic patterns vary from one weekend to the next. Therefore, manual counts were undertaken throughout the entire weekend. This included before, during and after regular weekday AM and PM peak periods.

Figure 12 and Table 12 summarizes the accuracy of each technology with ground truth data during weekend traffic conditions for QEW. Loops and Radar Device 2 achieved the best accuracy when compared with the other two technologies. The Loops achieved a lower Average Percent Error and Standard Deviation of 4.40% and 0.07; compared to Radar Device 2's Average Percent Error and Standard Deviation of 5.95% and 0.07, respectfully. Under the two categories of measurement Loops have a slight edge over Radar Device 2. However, the

Loop's Range of Error of 0.41 is much higher than Radar Device 2's 0.29. Nevertheless, both devices performance of accuracy outperformed the Video Analytics Software and Radar Device 1. The Video Analytics Software and Radar Device 1 did not perform well when analyzed for its accuracy during weekend traffic conditions.

Figure 12 – QEW's Average Percent Error and Standard Deviation during Weekend Traffic Conditions

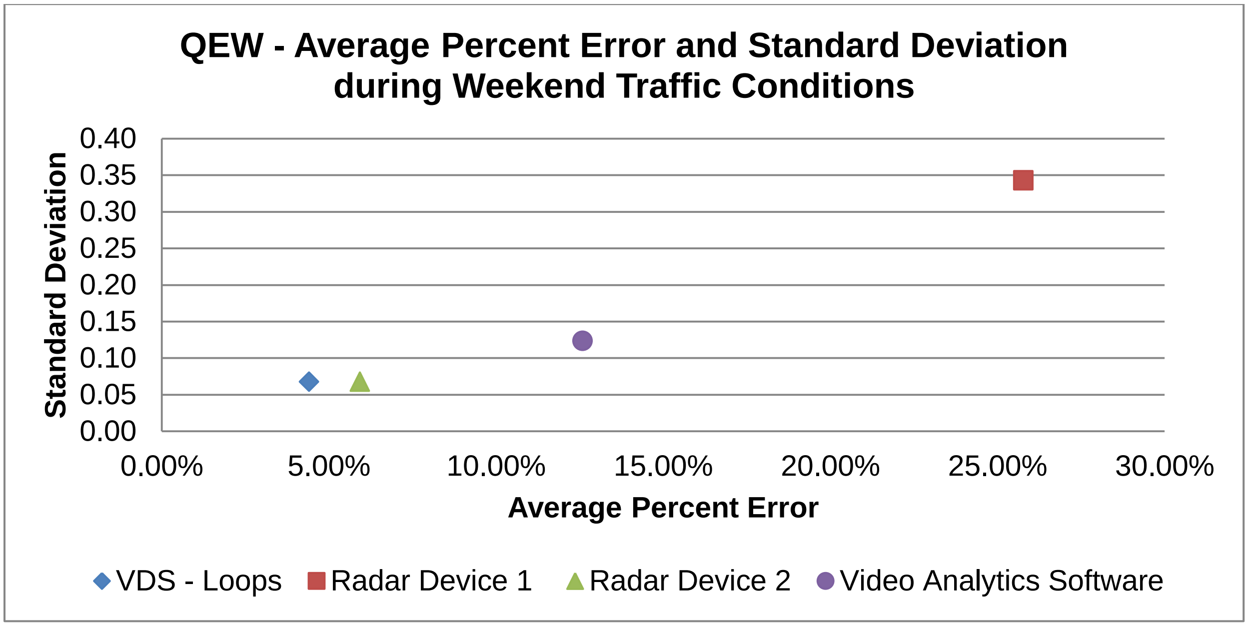


Table 12 – QEW's Percent Error, Standard Deviation and Range of Error during Weekend Traffic Conditions

	Loops	**Video Analytics Software**	**Radar Device 1**	**Radar Device 2**
Average Percent Error	4.40%	12.59%	25.78%	5.93%
Standard Deviation	0.07	0.12	0.34	0.07
Range of Error	0.41	0.56	1.07	0.29

Figure 13 and Table 13 summarizes the accuracy of each technology with ground truth data during weekend traffic conditions for Highway 401. It is evident that all four devices performance in accuracy, during weekend traffic conditions, was outstanding. All devices recorded an Average Percent Error of 6.62% or lower, a Standard Deviation of 0.09 or lower; and a Range of Error of 0.48 or lower.

It is also evident that when compared, Radar Device 2 outperformed all other devices and achieved highly accurate results. Radar Device 2 achieved an Average Percent Error of 2.16%, a Standard Deviation of 0.02 and a Range of Error of 0.10. Radar Device 1 achieved an Average Percent Error of 4.55%, a Standard Deviation of 0.06 and a Range of Error of 0.31. The Video Analytics Software achieved an Average Percent Error of 5.90%, a Standard Deviation of 0.02 and a Range of Error of 0.09. Loops achieved an Average Percent Error of 6.62%, a Standard Deviation of 0.09 and a Range of Error of 0.48. All four devices performed well, however among the great results, Radar Device 2's accuracy was superior.

Figure 13 – Highway 401's Average Percent Error and Standard Deviation during Weekend Traffic Conditions

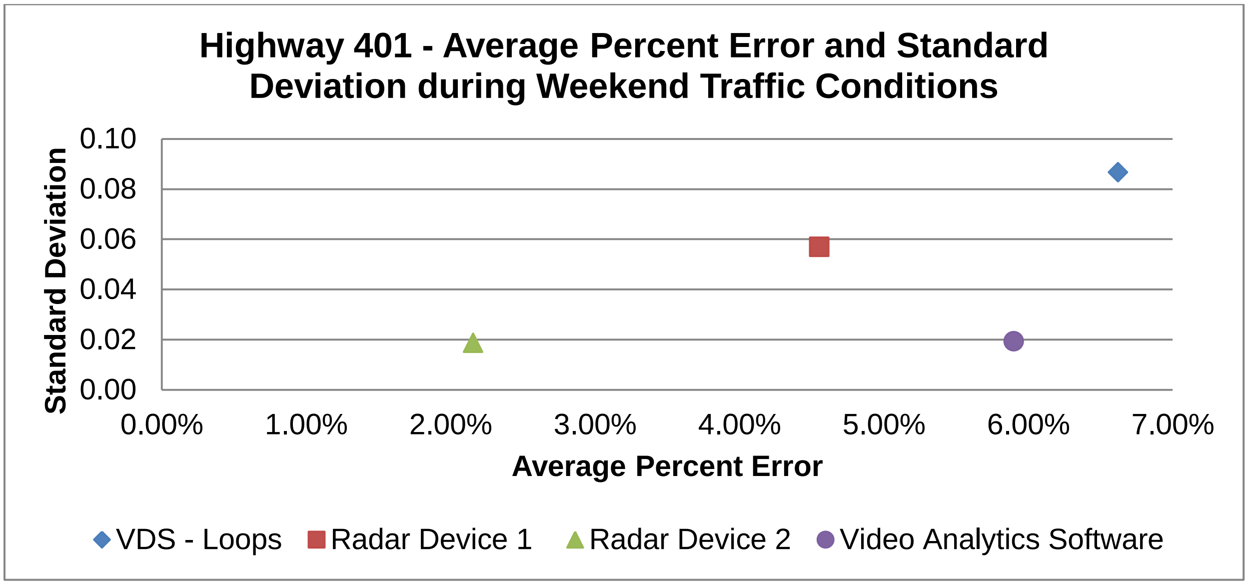


Table 13 – Highway 401's Percent Error, Standard Deviation and Range of Error during Weekend Traffic Conditions

	Loops	**Video Analytics Software**	**Radar Device 1**	**Radar Device 2**
Average Percent Error	6.62%	5.90%	4.55%	2.16%
Standard Deviation	0.09	0.02	0.06	0.02
Range of Error	0.48	0.09	0.31	0.10

5.5 Results during Rainfall Conditions

It is imperative to analyze traffic conditions during rainfall when validating the accuracy of any Video Analytics Software that gets its source from recorded video. Rainfall introduces complications when analyzing recorded video as the quality of the recorded video deteriorates, leading to difficulties for the Video Analytics Software to count vehicles. Difficulties play a significant factor in the overall accuracy during periods of rainfall. These difficulties include the glare off the roadway's wet surface, visibility issues, swaying of the video cameras due to heavy rain and/or winds; as seen in Picture 10.

Picture 10 – A screenshot from the Video Camera during Periods of Rainfall on QEW

Figure 14 and Table 14 summarizes the accuracy of each technology with ground truth data during periods of rainfall for QEW. Video Analytics Software's performance was satisfactory, given the circumstances stated earlier. The Video Analytics Software achieved an Average Percent Error of 13.92%, a Standard Deviation of 0.14 and a Range of Error of 0.51. The Video Analytics Software performed better than Loops and Radar Device 1 as it outperformed both technologies. Loops achieved an Average Percent Error of 14.71%, a Standard Deviation of 0.16 and a Range of Error of 0.61. Radar Device 1 achieved an Average Percent Error of 19.48%, a Standard Deviation of 0.25 and a Range of Error of 1.00.

As evident, Radar Device 2 outperformed all technologies by achieving the most accurate results across all three categories of measurement. Radar Device 2 achieved an Average Percent Error of 7.55%, a Standard Deviation of 0.08 and a Range of Error of 0.29.

Figure 14 – QEW's Average Percent Error and Standard Deviation during Rainfall

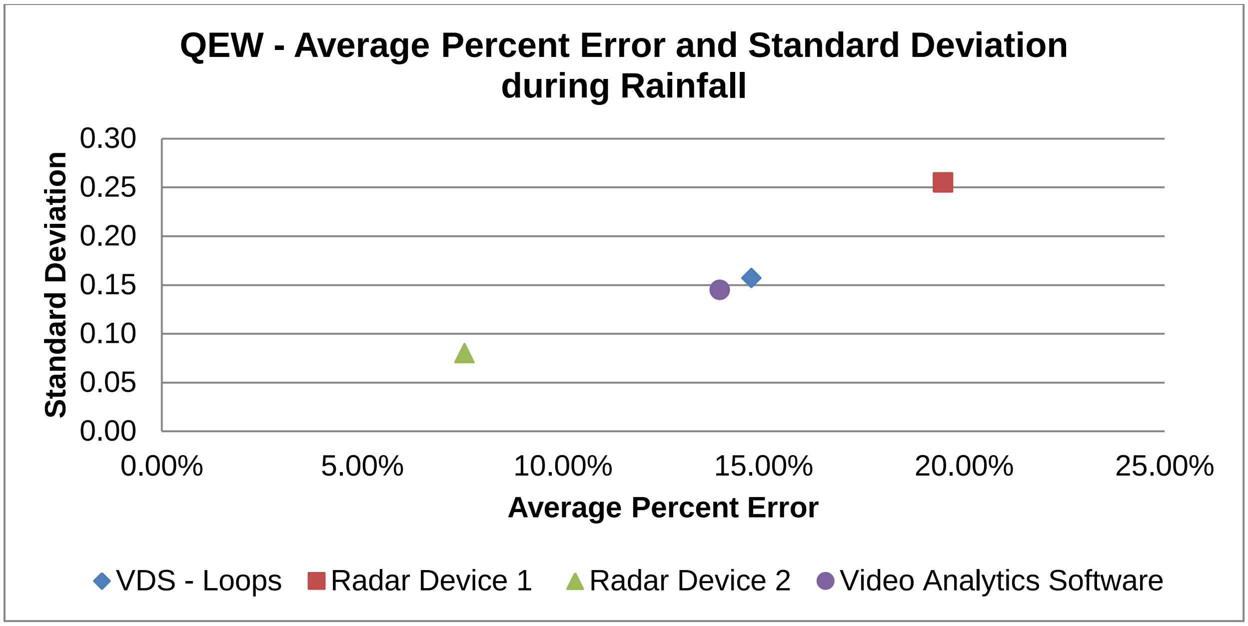


Table 14 – QEW's Average Percent Error, Standard Deviation and Range of Error during Rainfall

	Loops	**Video Analytics Software**	**Radar Device 1**	**Radar Device 2**
Average Percent Error	14.71%	13.92%	19.48%	7.55%
Standard Deviation	0.16	0.14	0.25	0.08
Range of Error	0.61	0.51	1.00	0.29

Figure 15 and Table 15 summarizes the accuracy of each technology with ground truth data during periods of rainfall at the Highway 401 location. Similar to QEW, the Video Analytics Software's performance was satisfactory, given the traffic conditions. The Video Analytics Software achieved an Average Percent Error of 10.28%, a Standard Deviation of 0.14 and a Range of Error of 0.74.

It is evident that Radar Device 2 significantly outperformed all other devices and its accuracy was excellent during periods of rainfall. Radar Device 2 achieved the most accurate results across all three categories of measurement with an Average Percent Error of 1.97%, a Standard Deviation of 0.03 and a Range of Error of 0.14. Moreover, Loops also performed well with an Average Percent Error of 6.54%, a Standard Deviation of 0.08 and a Range of Error of

0.24. Radar Device 1 achieved an Average Percent Error of 10.10%, a Standard Deviation of 0.12 and a Range of Error of 0.52.

Figure 15 – Highway 401's Average Percent Error and Standard Deviation during Rainfall

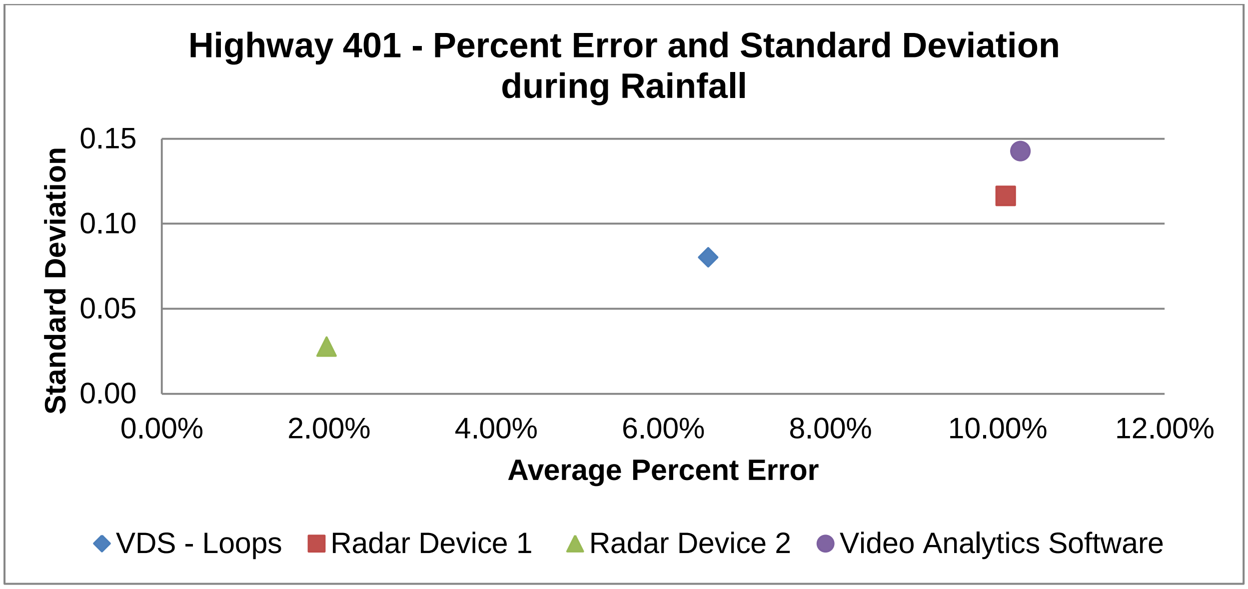


Table 15 – Highway 401's Average Percent Error, Standard Deviation and Range of Error during Rainfall

	Loops	**Video Analytics Software**	**Radar Device 1**	**Radar Device 2**
Average Percent Error	6.54%	10.28%	10.10%	1.97%
Standard Deviation	0.08	0.14	0.12	0.03
Range of Error	0.24	0.74	0.52	0.14

5.6 Night Conditions

Similar to the analysis during periods of rainfall, the analysis during traffic conditions at night are also imperative when analyzing any Video Analytics Software. Due to the lack of natural light; a greater source of light from high mast lighting fixtures; and the glare from vehicle's headlight and taillights; it is very imperative to analyze the data during the period of nightfall. The Video Analytics Software received its data source from recorded video; therefore, a detailed analysis during this period is required.

Figure 16 and Table 16 summarizes the accuracy of each technology with ground truth data during night conditions at QEW. All devices struggled across all three categories of measurement. It is evident that Range of Error is very high across all four devices. The Loops achieved the most accurate results with an Average Percent Error of 12.66%, a Standard Deviation of 0.27 and a Range of Error of 2.47. The Video Analytics Software came in second, in terms of accuracy, with an Average Percent Error of 18.85%, a Standard Deviation of 0.41 and a Range of Error of 3.10. Both Radar Device 1 and Radar Device 2 failed in terms of accuracy during period of rainfall.

Figure 16 – QEW's Average Percent Error and Standard Deviation during Night Conditions

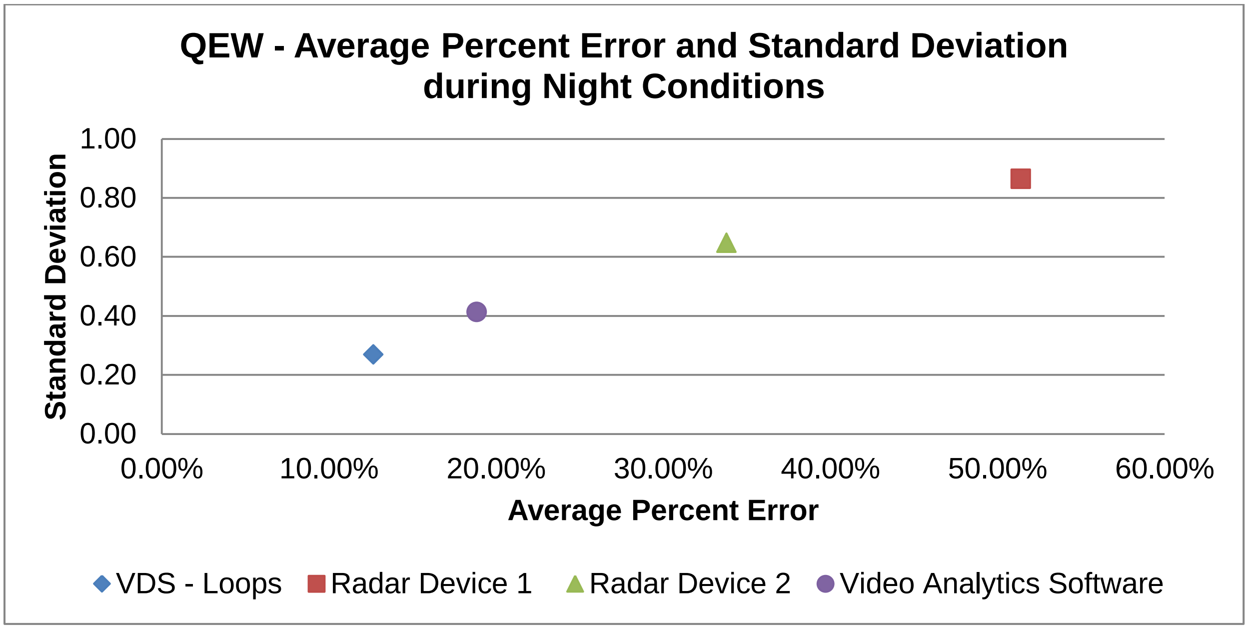


Table 16 – QEW's Percent Error, Standard Deviation and Range of Error during Night Conditions

	Loops	**Video Analytics Software**	**Radar Device 1**	**Radar Device 2**
Average Percent Error	12.66%	18.85%	51.40%	33.80%
Standard Deviation	0.27	0.41	0.86	0.65
Range of Error	2.47	3.10	5.61	3.50

However, it is important to take into consideration any construction or maintenance work that may have occurred during the night. Upon further analysis it was determined that QEW Eastbound experienced periodic lane closures and a full rolling closure, as illustrated in Picture 11 and Picture 12. During our analysis period, the HOV lane was closed and a full rolling closure occurred where all lanes were closed, periodically, to QEW Eastbound travellers.

Picture 11 – QEW Eastbound HOV Lane Closed

Picture 12 – QEW Eastbound HOV Lane and GP Lanes Closed

This study also analyzed the results during the lane closures. Figure 17 and Table 17 summarizes the accuracy of each technology with ground truth data during the lane closures in QEW Eastbound direction. A total of 1.5 hours of data was analyzed during lane closures. It is evident that all four devices are not accurate during lane closures. Loops performed the best, when compared to the other technologies, with an Average Percent Error of 42.80%, a Standard Deviation of 0.66 and a Range of Error of 2.47.

Figure 17 – QEW's Average Percent Error and Standard Deviation during Night Conditions with Lane Closures

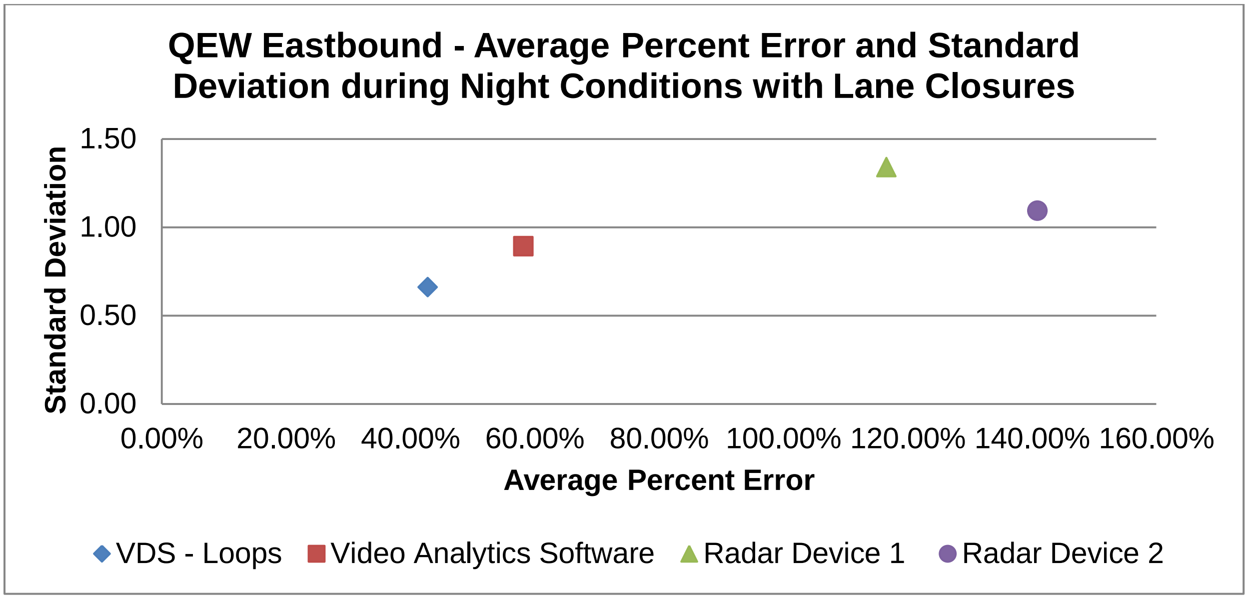


Table 17 – QEW's Percent Error, Standard Deviation and Range of Error during Night Conditions with Lane Closures

	Loops	Video Analytics Software	Radar Device 1	Radar Device 2
Average Percent Error	42.80%	58.19%	116.59%	140.90%
Standard Deviation	0.66	0.89	1.34	1.09
Range of Error	2.47	2.60	3.60	3.10

All four devices did not perform well and their accuracy was non-existent. Therefore, it is important to further analyze the data during night conditions but without lane closures. Figure 18 and Table 18 summarizes the accuracy of each technology with ground truth data during the night when all lanes were open for QEW. It is evident that all four devices performed significantly better when all lanes were open to motorist.

The Loops outperformed all other technologies and achieved the most accurate results across all three categories of measurement. Loops achieved an Average Percent Error of 8.19%, a Standard Deviation of 0.14 and a Range of Error of 0.70. The Video Analytics Software's accuracy was satisfactory with an Average Percent Error of 13.02%, a Standard Deviation of 0.18 and a Range of Error of 1.15. Both Radar Device 1 and Radar Device 2 did not perform well with high results across all three categories of measurement. Radar Device 2 achieved an Average Percent Error of 17.93%, a Standard Deviation of 0.31 and a Range of Error of 2.21. Radar Device 1 achieved an Average Percent Error of 41.74%, a Standard Deviation of 0.77 and a Range of Error of 5.51.

Figure 18 – QEW's Average Percent Error and Standard Deviation during Night Conditions with All Lanes Open

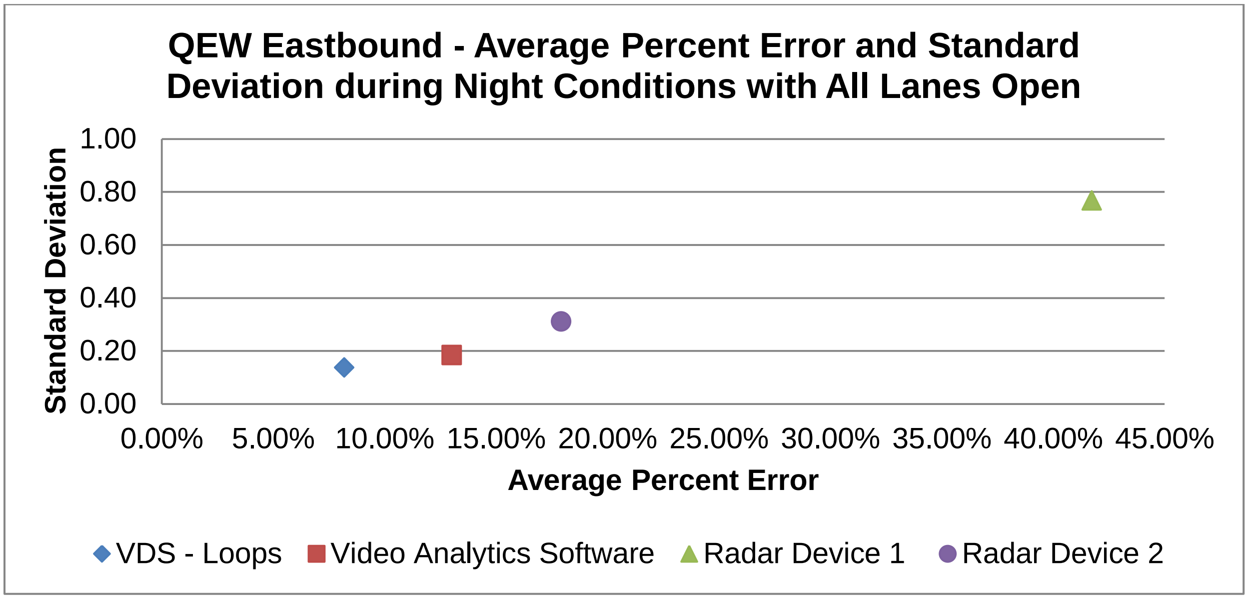


Table 18 – QEW's Percent Error, Standard Deviation and Range of Error during Night Conditions with All Lanes Open

	Loops	**Video Analytics Software**	**Radar Device 1**	**Radar Device 2**
Average Percent Error	8.19%	13.02%	41.74%	17.93%
Standard Deviation	0.14	0.18	0.77	0.31
Range of Error	0.70	1.15	5.51	2.21

Figure 19 and Table 19 summarizes the accuracy of each technology with ground truth data during traffic conditions at night at Highway 401. The Video Analytics Software performed well. The Video Analytics Software achieved an Average Percent Error of 6.24%, a Standard Deviation of 0.05 and a Range of Error of 0.23. The Video Analytics Software's performance is in line with results from Loops. Loops achieved a lower Average Percent Error of 4.48%; however a higher Standard Deviation of 0.09 and a greater Range of Error of 0.45, when compared to the Video Analytics Software.

Furthermore, during traffic conditions at night, Radar Device 2 achieved the most accurate results and outperformed all other devices. Radar Device 2 achieved the most accurate results across all three categories of measurement with an Average Percent Error of 2.35%, a Standard Deviation of 0.03 and a Range of Error of 0.10. Radar Device 1 achieved an Average Percent Error of 12.43%, a Standard Deviation of 0.23 and a Range of Error of 1.87. Highway 401 did not experience any lane closures during the duration of our study.

Figure 19 – Highway 401's Average Percent Error and Standard Deviation during Traffic Conditions at Night

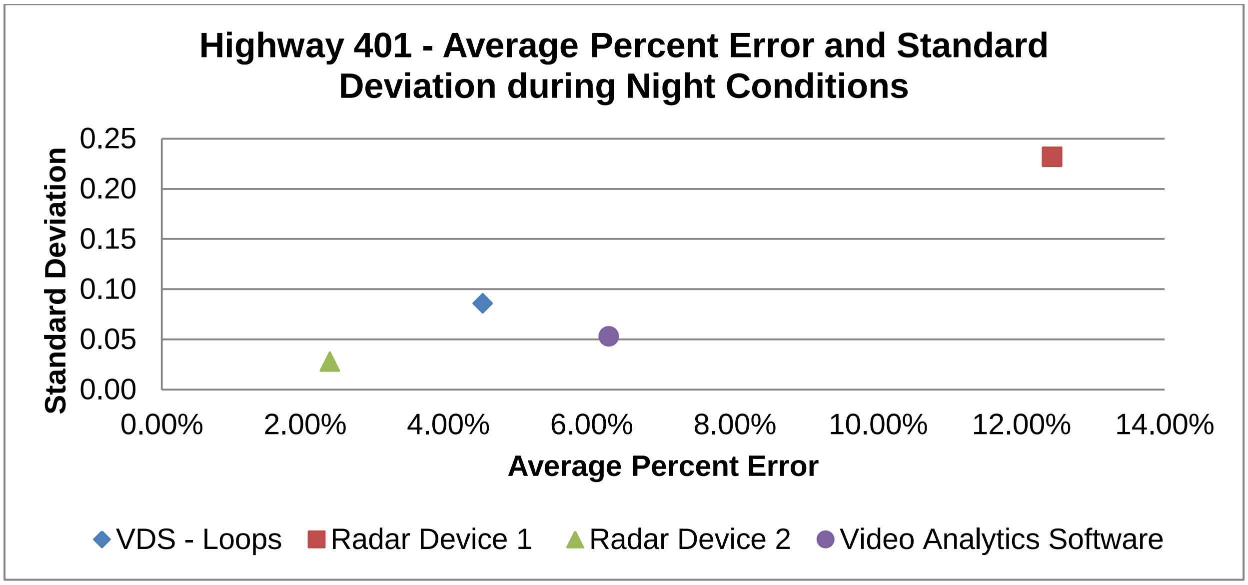


Table 19 – Highway 401's Percent Error, Standard Deviation and Range of Error during Traffic Conditions at Night

	Loops	**Video Analytics Software**	**Radar Device 1**	**Radar Device 2**
Average Percent Error	4.48%	6.24%	12.43%	2.35%
Standard Deviation	0.09	0.05	0.23	0.03
Range of Error	0.45	0.23	1.87	0.10

5.7 QEW Eastbound GP Lanes

A highway configuration with an HOV and GP lanes has different data requirements compared to a complex highway like Highway 401's Collectors-Express system. To analyze data at QEW, it is imperative to separate the data into various streams and separate the HOV lane data with the GP lanes.

This study provided sufficient data that allowed for a detailed analysis by stream of travel. Four streams of travel were analyzed: Eastbound GP lanes, Eastbound HOV, Westbound HOV and Westbound GP lanes.

Figure 20 and Table 20 summarizes the accuracy of each technology with ground truth data in the Eastbound GP lanes at QEW. Both Loops and Radar Device 2 performed well. However Radar Device 2 performed to be more accurate when compared to Loops. Even though Loops achieved a lower Average Percent Error of 8.81% compared to 9.83%; Radar Device 2 achieved a lower Standard Deviation of 0.07 compared to 0.12; and a significantly lower Range of Error of 0.48 compared to 1.08. The Video Analytics Software achieved an Average Percent Error of 17.26%, a Standard Deviation of 0.09 and a Range of Error of 0.58. Radar Device 1 achieved an Average Percent Error of 19.90%, a Standard Deviation of 0.46 and a significantly high Range of Error of 5.51.

Figure 20 – Eastbound GP Lanes Average Percent Error and Standard Deviation during all Traffic Conditions

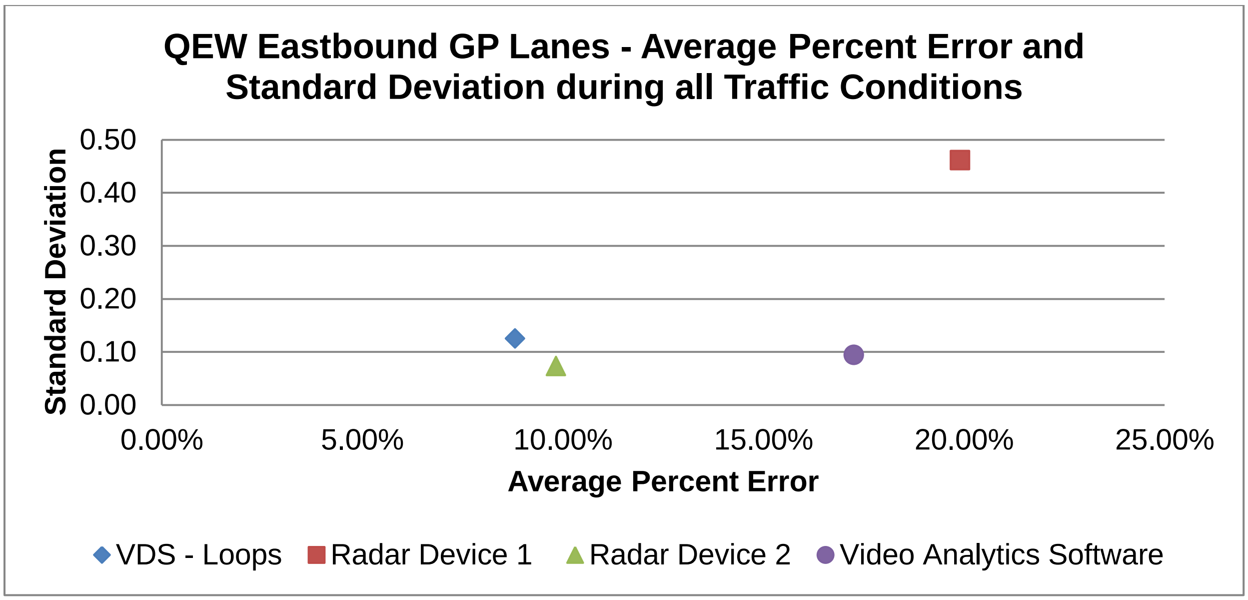


Table 20 – Eastbound GP Lanes Average Percent Error, Standard Deviation Range of Error during all Traffic Conditions

	Loops	Video Analytics Software	Radar Device 1	Radar Device 2
Average Percent Error	8.81%	17.26%	19.90%	9.83%
Standard Deviation	0.12	0.09	0.46	0.07
Range of Error	1.08	0.58	5.51	0.48

5.8 QEW Eastbound HOV Lane

Figure 21 and Table 21 summarizes the accuracy of each technology with ground truth data in the Eastbound HOV lane at QEW. The Loops outperformed all other devices. Loops achieved the most accurate results across all three categories of measurement. The Loops achieved an Average Percent Error of 11.32%, a Standard Deviation of 0.23 and a Range of Error of 2.47. The Video Analytics Software achieved an Average Percent Error of 19.31%, a Standard Deviation of 0.31 and a Range of Error of 2.82. Radar Device 2 achieved an Average Percent Error of 19.54%, a Standard Deviation of 0.53 and a Range of Error of 3.21. Radar Device 1 achieved an Average Percent Error of 47.31%, a Standard Deviation of 0.47 and a Range of Error of 3.60. The Video Analytics Software, Radar Device 1 and Radar Device 2 did not perform well in terms of accuracy in the QEW HOV lane. The Range of Error was substantially high for all four devices. Upon further analysis, it is concluded that the high Range of Errors is due to the data collected during lane closures. The Eastbound HOV lane was closed and also full rolling closures were conducted within our data collection period.

Figure 21 – Eastbound HOV Lane Average Percent Error and Standard Deviation during all Traffic Conditions

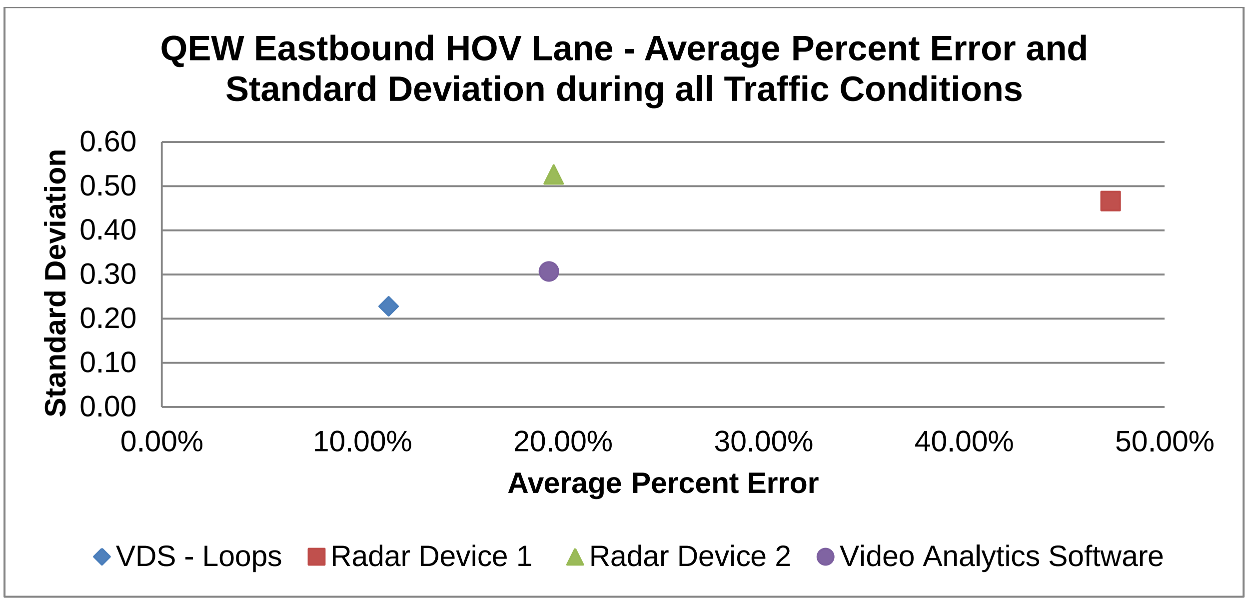


Table 21 – Eastbound HOV Lane Average Percent Error, Standard Deviation Range of Error during all Traffic Conditions

	Loops	Video Analytics Software	Radar Device 1	Radar Device 2
Average Percent Error	11.32%	19.31%	47.31%	19.54%
Standard Deviation	0.23	0.31	0.47	0.53
Range of Error	2.47	2.82	3.60	3.21

5.9 QEW Westbound HOV Lane

Figure 22 and Table 22 summarizes the accuracy of each technology with ground truth data in the Westbound HOV lane at QEW. It is evident that the Video Analytics Software outperformed all other devices. The Video Analytics Software achieved an Average Percent Error of 3.62%, a Standard Deviation of 0.07 and a Range of Error of 0.83. The Loops also performed well with an Average Percent Error of 7.12%, a Standard Deviation of 0.14 and a Range of Error of 1.27. Radar Device 2 achieved an Average Percent Error of 10.18%, a Standard Deviation of 0.08 and a Range of Error of 0.56. Radar Device 1 achieved an Average Percent Error of 15.26%, a Standard Deviation of 0.26 and a Range of Error of 2.09.

Figure 22 – Westbound HOV Lane Average Percent Error and Standard Deviation during all Traffic Conditions

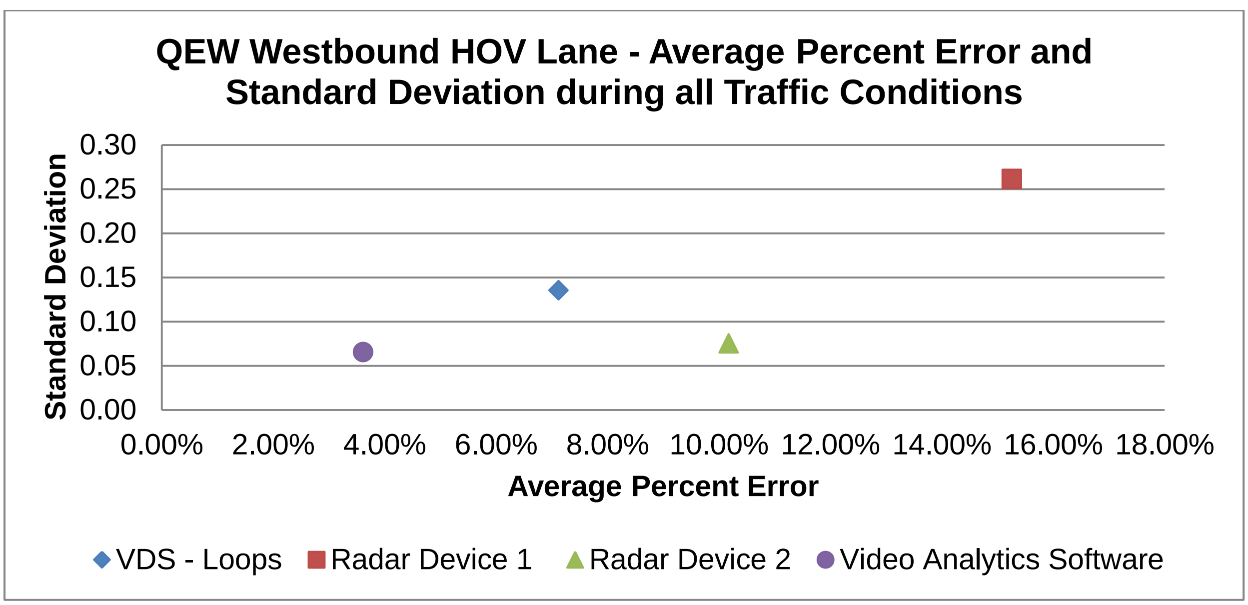


Table 22 – Westbound HOV Lane Average Percent Error, Standard Deviation Range of Error during all Traffic Conditions

	Loops	Video Analytics Software	Radar Device 1	Radar Device 2
Average Percent Error	7.12%	3.62%	15.26%	10.18%
Standard Deviation	0.14	0.07	0.26	0.08
Range of Error	1.27	0.83	2.09	0.56

5.10 QEW Westbound GP Lanes

Figure 23 and Table 23 summarizes the accuracy of each technology with ground truth data in the Westbound GP Lanes at QEW. Loops and Radar Device 2 performed well in the Westbound GP lanes. Loops achieved an Average Percent Error of 4.89%, a Standard Deviation of 0.09 and a Range of Error of 0.03. Radar Device 2 also performed well with an Average Percent Error of 6.84%, a lower Standard Deviation of 0.04 and a lower Range of Error of 0.03. Radar Device 1 achieved an Average Percent Error of 9.26%, a Standard Deviation of 0.12 and a Range of Error of 0.08. The Video Analytics Software achieved an Average Percent Error of 22.27%, a Standard Deviation of 0.08 and a Range of Error of 0.42.

Figure 23 – Westbound GP Lanes Average Percent Error and Standard Deviation during all Traffic Conditions

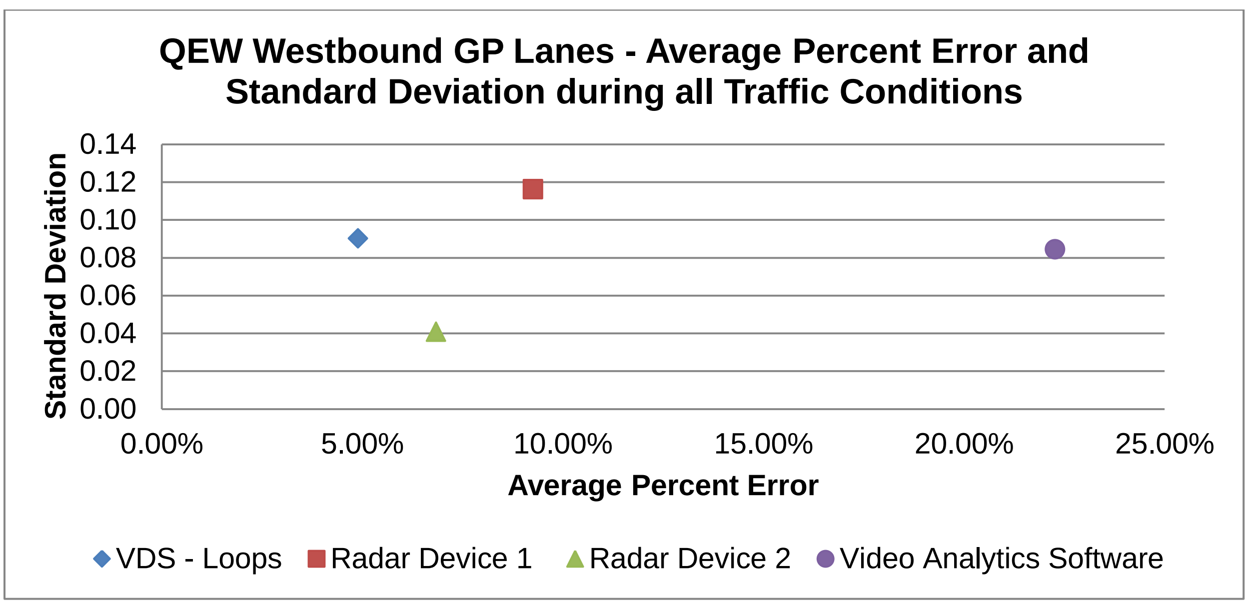


Table 23 – Westbound GP Lanes Average Percent Error, Standard Deviation Range of Error during all Traffic Conditions

	Loops	**Video Analytics Software**	**Radar Device 1**	**Radar Device 2**
Average Percent Error	4.89%	22.27%	9.26%	6.84%
Standard Deviation	0.09	0.08	0.12	0.04
Range of Error	0.03	0.42	0.08	0.03

5.11 Highway 401 Eastbound Collectors

Figure 24 and Table 24 summarizes the accuracy of each technology with ground truth data in the Eastbound Collectors at Highway 401. A total of 34.5 hours of data was analyzed for each device and it is evident that Radar Device 2 outperformed the other technologies. Radar Device 2 achieved the most accurate results across all three categories of measurement. Radar Device 2 achieved an Average Percent Error of 1.94%, a Standard Deviation of 0.02 and a Range of Error of 0.15.

Overall, all four devices performed well. Radar Device 1 and Loops each achieved an Average Percent Error of 5.99% and 6.32; a Standard Deviation of 0.08 and 0.09; and a Range of Error of 0.42 and 0.52, respectfully. The Video Analytics Software's performance was satisfactory with an Average Percent Error of 11.04%, a Standard Deviation of 0.12; however it achieved a high Range of Error of 0.71.

Figure 24 – Highway 401 Eastbound Collectors Average Percent Error and Standard Deviation during all Traffic Conditions

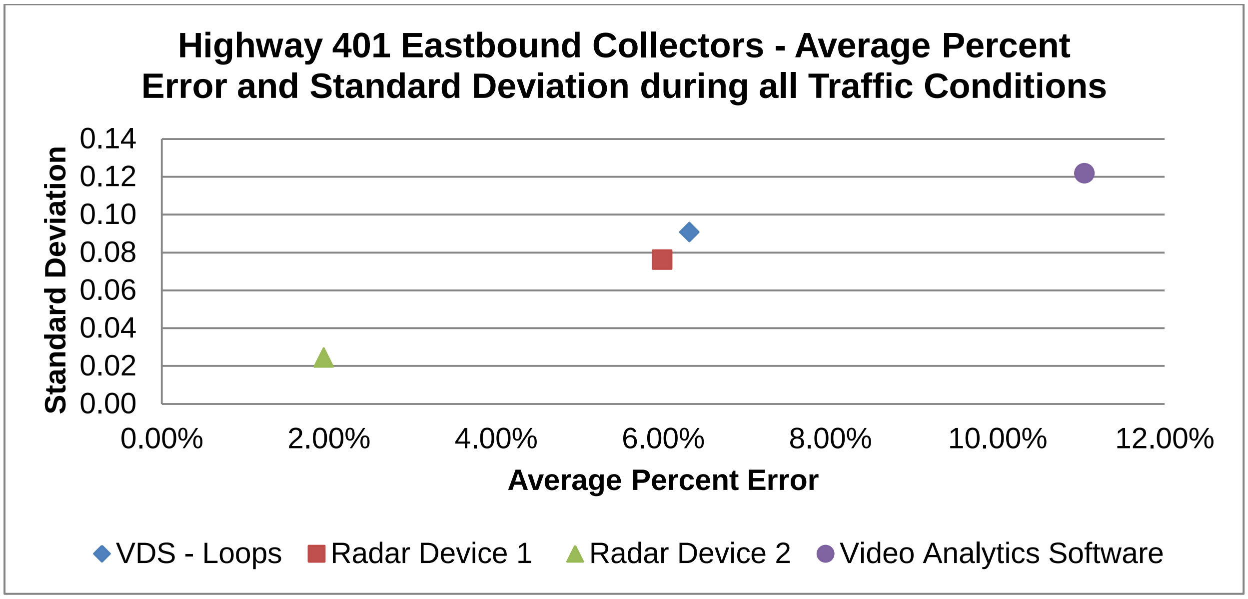


Table 24 – Highway 401 Eastbound Collectors Average Percent Error, Standard Deviation and Range of Error during all Traffic Conditions

	Loops	**Video Analytics Software**	**Radar Device 1**	**Radar Device 2**
Average Percent Error	6.32%	11.04%	5.99%	1.94%
Standard Deviation	0.09	0.12	0.08	0.02
Range of Error	0.52	0.71	0.42	0.15

5.12 Highway 401 Eastbound Express

Figure 25 and Table 25 summarizes the accuracy of each technology with ground truth data in the Eastbound Express at Highway 401. Again a total of 34.5 hours of data was analyzed for each device and, similar to the Eastbound Collectors, Radar Device 2 has outperformed all other devices in the Eastbound Express. Radar Device 2 achieved the most accurate results across all three categories of measurement with an Average Percent Error of 3.54%, a Standard Deviation of 0.04 and a Range of Error of 0.25.

Loops and Radar Device 1 also performed well and achieved similar results. When compared to Radar Device 1, Loops achieved a lower Average percent Error of 6.56% compared to 7.70%; both technologies achieved the same Standard Deviation of 0.10; however Loops Range of Error of 0.76 is greater compared to Radar Device 1's Range of Error of 0.47.

The Video Analytics Software's performance was satisfactory and achieved similar results compared to its performance in the Eastbound Collectors stream. The Video Analytics Software achieved an Average Percent Error of 12.76%, a Standard Deviation of 0.12 and a Range of error of 0.54.

Figure 25 – Highway 401 Eastbound Express Average Percent Error and Standard Deviation during all Traffic Conditions

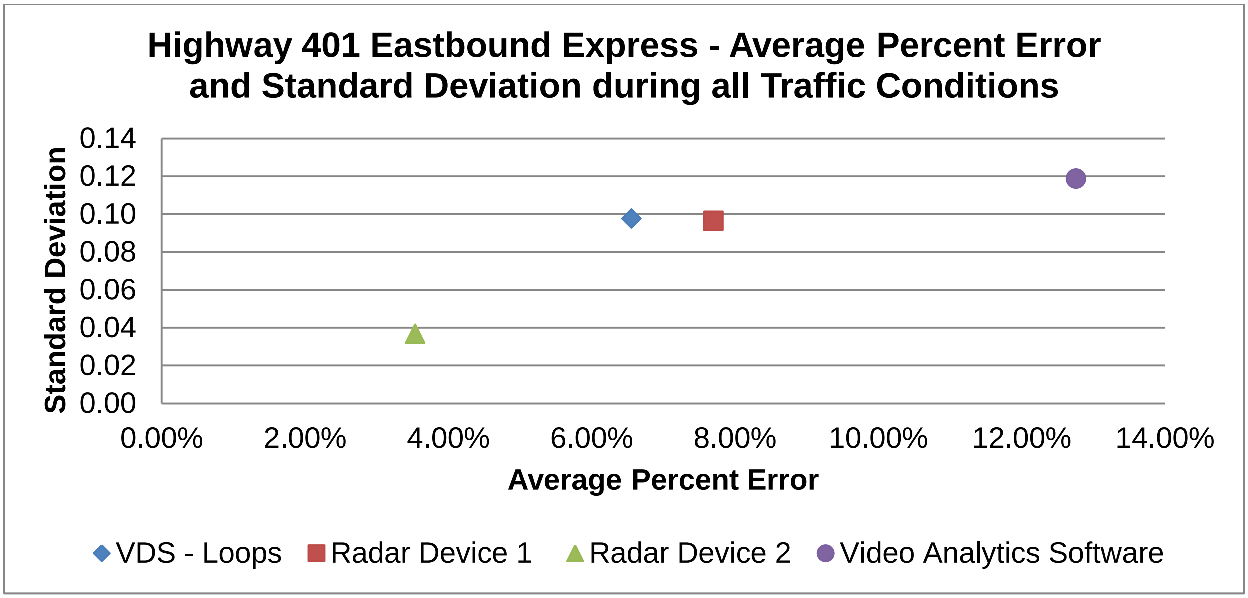


Table 25 – Highway Eastbound Express Average Percent Error, Standard Deviation and Range of Error during all Traffic Conditions

	Loops	**Video Analytics Software**	**Radar Device 1**	**Radar Device 2**
Average Percent Error	6.56%	12.76%	7.70%	3.54%
Standard Deviation	0.10	0.12	0.10	0.04
Range of Error	0.76	0.54	0.47	0.25

5.13 Highway 401 Westbound Express

Figure 26 and Table 26 summarizes the accuracy of each technology with ground truth data in the Westbound Express at Highway 401. A total of 33.5 hours of data was analyzed for each device. Radar Device 2 did not collect Westbound Express data and thus, only three devices are analyzed.

All three devices performed well. The Video Analytics Software outperformed the other two devices and achieved the most accurate results across all three categories of measurement. The Video Analytics Software achieved an Average Percent Error of 4.04%, a Standard Deviation of 0.03 and a Range of Error of 0.30.

Loops also performed well with an Average Percent Error of 8.20%, a Standard Deviation of 0.10 and a Range of Error of 0.59. Radar Device 1's performance was satisfactory and achieved an Average Percent Error of 10.54%, a Standard Deviation 0.19 and a high Range of Error of 1.87.

Figure 26 – Highway 401 Westbound Express Average Percent Error and Standard Deviation during all Traffic Conditions

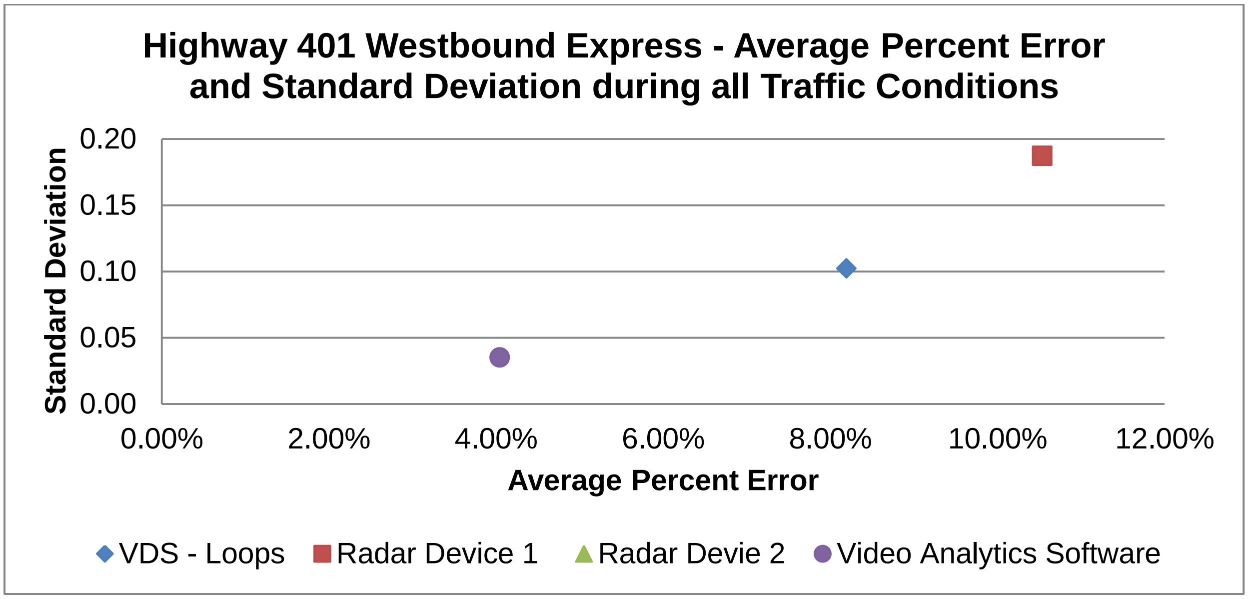


Table 26 – Highway 401 Westbound Express Average Percent Error, Standard Deviation and Range of Error during all Traffic Conditions

	Loops	Video Analytics Software	Radar Device 1
Average Percent Error	8.20%	4.04%	10.54%
Standard Deviation	0.10	0.03	0.19
Range of Error	0.59	0.30	1.87

5.14 Total volume

Figure 27 and Table 27 summarizes the accuracy of each technology with ground truth data in all directions and in all streams for QEW. It is evident that the Loops outperformed all other devices. The Loops achieved the most accurate results across all three categories of measurement. Loops achieved an Average Percent Error of 8.09%, a Standard Deviation of 0.16, and a Range of Error of 2.47. The Range of Error is significantly high for all four devices. However, the Range of Error is including the data collected during the HOV lane closure and the full rolling closing captured in the Eastbound direction.

Figure 27 – QEW's Average Percent Error and Standard Deviation during all Traffic Conditions

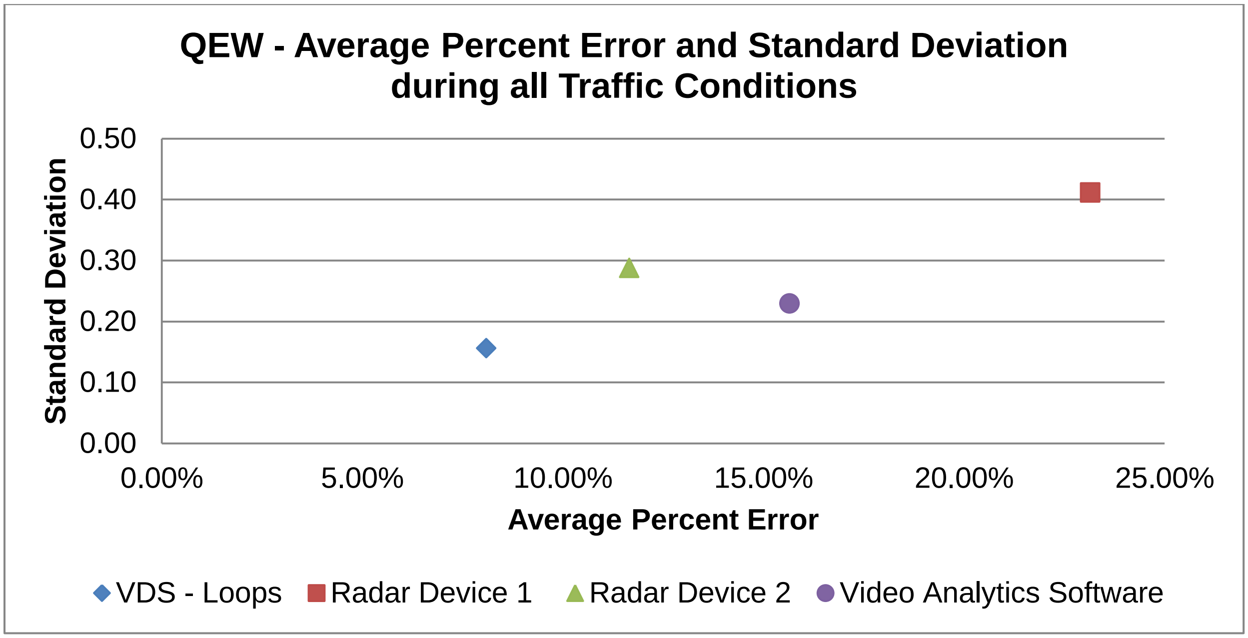


Table 27 – QEW's Average Percent Error, Standard Deviation and Range of Error during all Traffic Conditions Results

	Loops	Video Analytics Software	Radar Device 1	Radar Device 2
Average Percent Error	8.09%	15.65%	23.15%	11.66%
Standard Deviation	0.16	0.23	0.41	0.29
Range of Error	2.47	3.10	5.61	3.50

Figure 28 and Table 28 summarizes the accuracy of each technology with ground truth data in all directions and in all streams for Highway 401. It is evident that all devices performed well. All deceives achieved an Average Percent Error of 9.33% or lower and a Standard Deviation of 0.13 or lower. However, the Range of Error varied from 0.25 to 1.87.

Overall, Radar Device 2 outperformed all of the other devices at Highway 401. Radar Device 2 achieved an Average Percent Error of 2.74%, a Standard Deviation of 0.04 and a Range of Error of 0.25. Loops also performed well with an Average Percent Error of 7.01%, a Standard Deviation of 0.10 and a Range of Error of 0.76.

Figure 28 – Highway 401's Average Percent Error and Standard Deviation during all Traffic Conditions

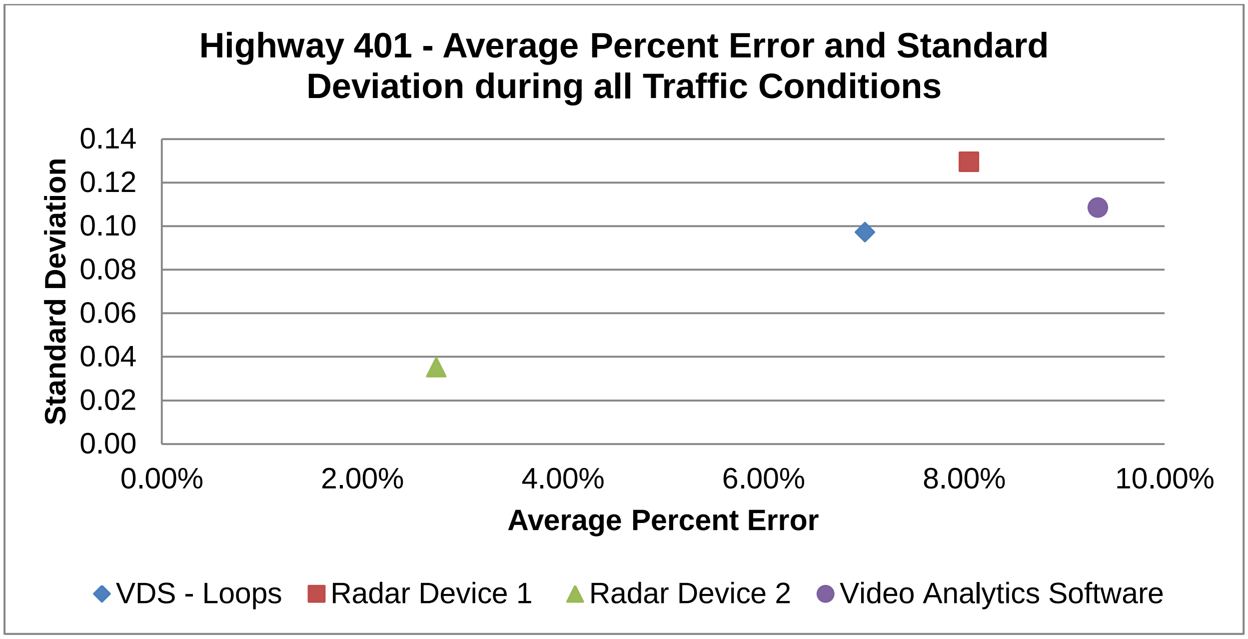


Table 28 – Highway 401's Average Percent Error, Standard Deviation and Range of Error during all Traffic Conditions Results

	Loops	**Video Analytics Software**	**Radar Device 1**	**Radar Device 2**
Average Percent Error	7.01%	9.33%	8.05%	2.74%
Standard Deviation	0.10	0.11	0.13	0.04
Range of Error	0.76	0.74	1.87	0.25

5.15 Accuracy of Radar Devices by Stream of Travel

Accurate data collection at a highway configuration with multiple steams like QEW and Highway 401 can be a challenge. Multiple streams of travel and a greater number of lanes can pose a challenge for radar devices and a Video Analytical Software. An analysis was completed to determine if the accuracy is affected by the distance between the radar device and the stream of travel

A wide highway configuration with multiple streams of travel and a greater number of lanes can be a challenge for collecting traffic data using a single radar device. This study only utilized a single radar device from two separate vendors. Each radar device was mounted on the south side of the highway and was utilized to capture as many streams as it can.

At the QEW test site, Radar Device 1 and Radar Device 2 collected all four streams of travel: Eastbound GP lanes, Eastbound HOV lane, Westbound HOV lane and Westbound GP lanes. At the Highway 401 test site, Radar Device 1 collected data in three streams of travel Eastbound Collectors, Eastbound Express and Westbound Express; whereas Radar Device 2 only collected data at two streams of travel: Eastbound Collectors and Eastbound Express.

QEW's results indicate no direct relationship between accuracy and the distance of the stream of travel. Figure 29 and Table 29 and Figure 30 and Table 30 summarize the accuracy of Radar Device 1 and Radar Device 2 and it is evident that there is no clear relationship between accuracy and the distance of the stream of travel for QEW. There is no pattern or relationship when analyzing the accuracy across all three categories of measurement.

An important observation about the accuracy is that the furthest stream of travel, Westbound GP lanes, achieved the most accurate results across all three categories of measurement for both Radar Device 1 and Radar Device 2. Radar Device 1 achieved an Average Percent Error of 9.26%, a Standard Deviation of 0.12 and a Range of Error of 0.08 in the Westbound GP lanes. Radar Device 2 achieved an Average Percent Error of 6.84%, a Standard Deviation of 0.04 and a Range of Error of 0.03. At the same time, Eastbound HOV achieved the least accurate results for both Radar Device 1 and Radar Device 2. As mentioned earlier in the report, the Eastbound HOV lane struggled to collect accurate data when the HOV lane was closed due to construction. The data was not taken out of the report, due to the fact that the purpose of this study is to evaluate each data collection technology under all traffic conditions.

Figure 29 – QEW's Radar Device 1 Accuracy by Stream of Travel

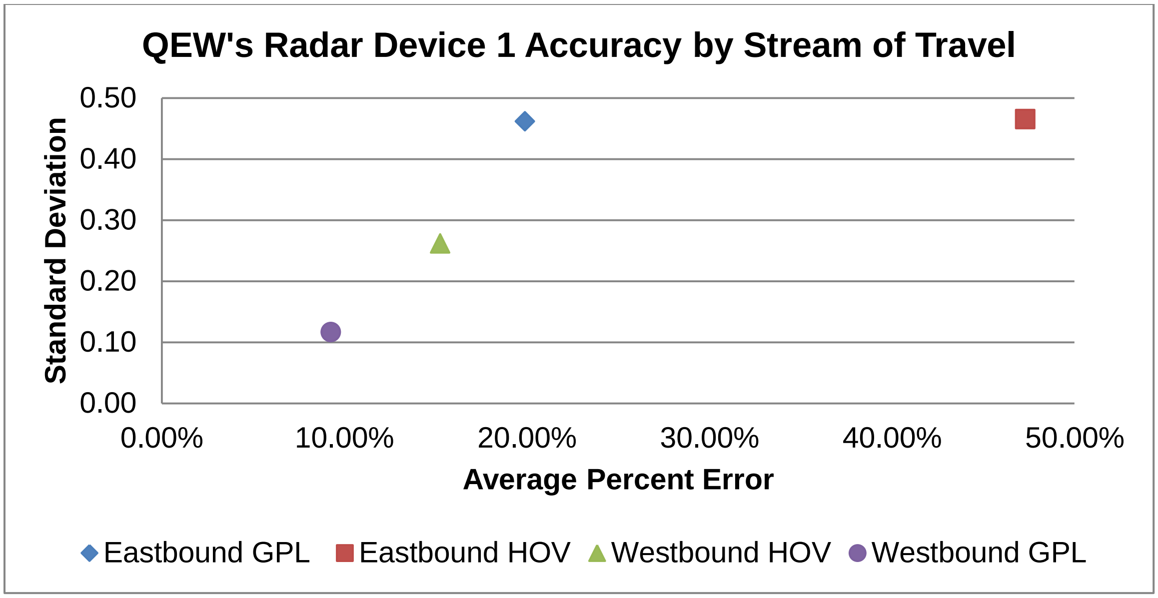


Table 29 – QEW's Radar Device 1 Accuracy by Stream of Travel

	Average Percent Error	Standard Deviation	Range of Error
Eastbound GPL	19.90%	0.46	5.51
Eastbound HOV	47.31%	0.47	3.60
Westbound HOV	15.26%	0.26	2.09
Westbound GPL	9.26%	0.12	0.08

Figure 30 – QEW's Radar Device 2 Accuracy by Stream of Travel

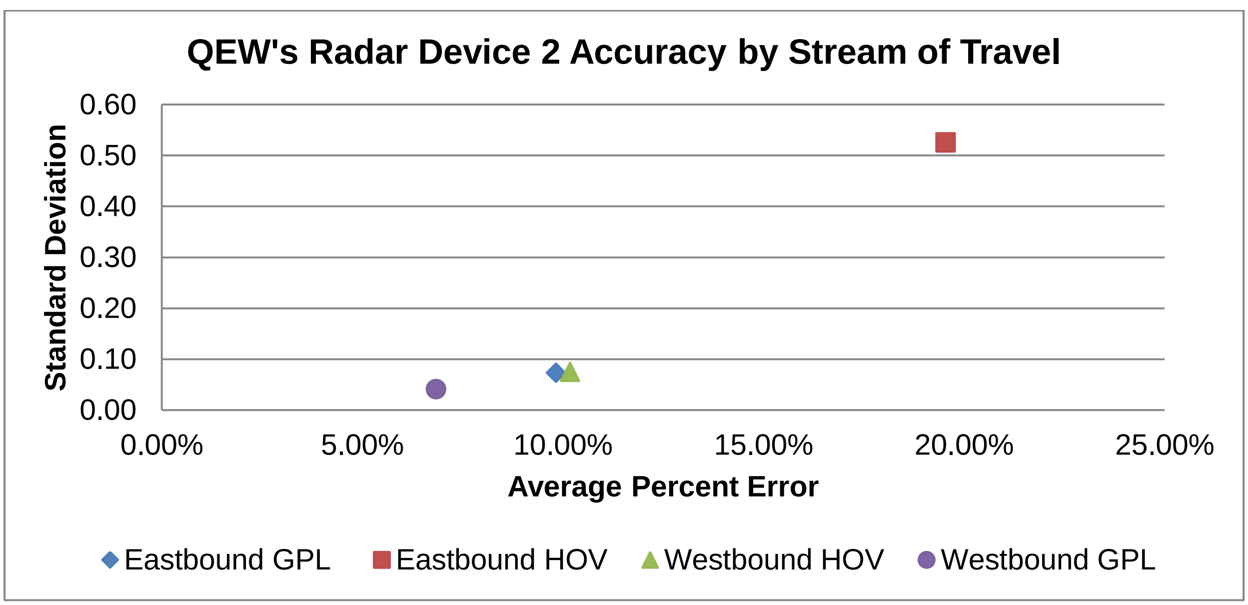


Table 30 – QEW's Radar Device 2 Accuracy by Stream of Travel

	Average Percent Error	Standard Deviation	Range of Error
Eastbound GPL	9.83%	0.07	0.48
Eastbound HOV	19.54%	0.53	3.21
Westbound HOV	10.18%	0.08	0.56
Westbound GPL	6.84%	0.04	0.03

Figure 31 and Table 31 and Figure 32 and Table 32 summarizes the accuracy of Radar Device 1 and Radar Device 2 with ground truth data during all traffic conditions for Highway 401. It is evident there is a direct relationship between the distance between the radar device and stream of travel. As the distance of the steam of travel increases from where the radar devices are mounted, the accuracy worsens as all three categories of measurement experience an increase.

Figure 31 – Highway 401's Radar Device 1 Accuracy by Stream of Travel

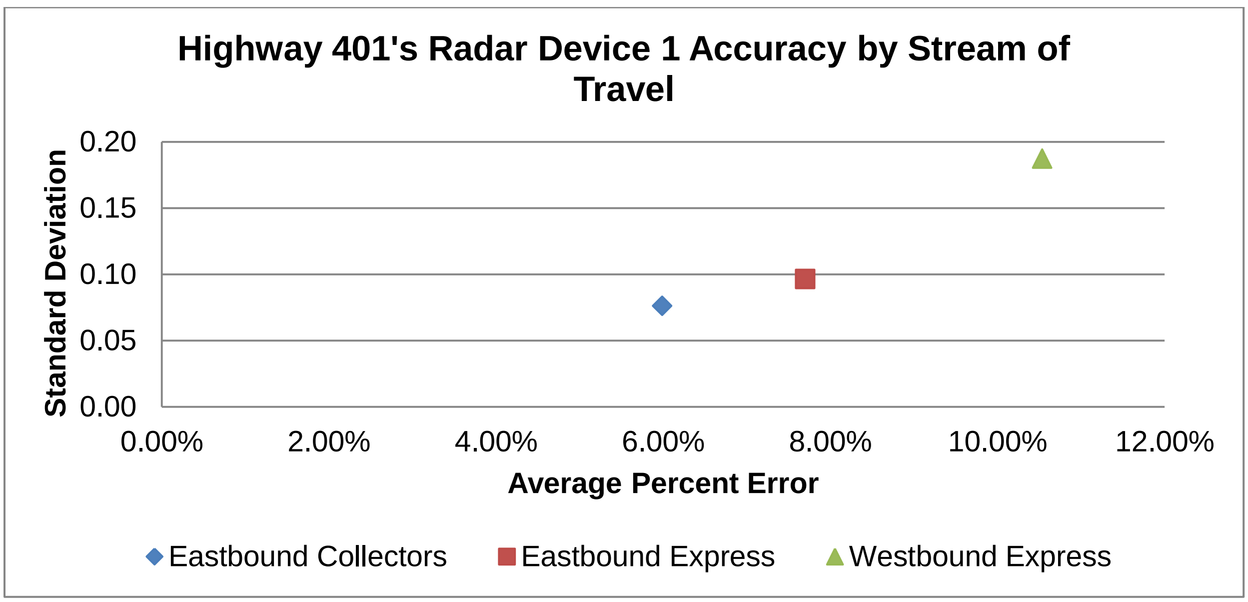


Table 31 - Highway 401's Radar Device 1 Accuracy by Stream of Travel

	Average Percent Error	Standard Deviation	Range of Error
Eastbound Collectors	5.99%	0.08	0.42
Eastbound Express	7.70%	0.10	0.47
Westbound Express	10.54%	0.19	1.87

Figure 32 – Highway 401's Radar Device 2 Accuracy by Stream of Travel

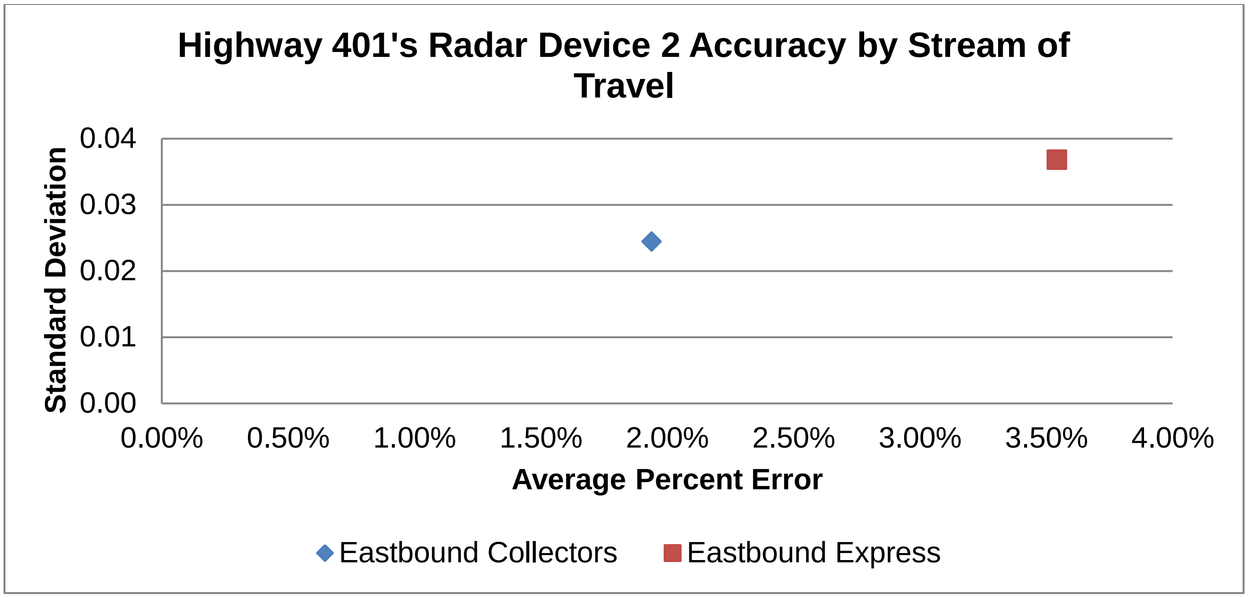


Table 32 - Highway 401's Radar Device 2 Accuracy by Stream of Travel

	Average Percent Error	Standard Deviation	Range of Error
Eastbound Collectors	1.94%	0.02	0.15
Eastbound Express	3.54%	0.04	0.25
Westbound Express	n/a	n/a	n/a

5.16 Accuracy of the Video Analytics Software by Stream of Travel

The Video Analytics Software is dependent on the installation of the video cameras. The angles of the camera, height of the camera, and focal resolution are factors that contribute to the accuracy of the Video Analytics Software.

Additionally, due to the width of the highway and different streams of travel, it is difficult for a single video camera to recorded video that will be analyzed using a Video Analytics Software. Mounting cameras at a location that will provide the best angle, height and resolution can be a challenge. The optimal location of the video camera can vary depending on the location and the detection zones. The vendor, that provided the Video Analytics Software, was asked to assist in the installation of the cameras. The vendor also calibrated the cameras and set the optimal detection zones to obtain the most accurate results for both test sites.

The two cameras on QEW were deployed, one per direction of travel. One camera recorded and analyzed data for both the HOV lane and GP lanes for each direction of travel. Figure 33 and Table 33 summarize the accuracy achieved by the Video Analytics Software across all four streams of travel on QEW. The results indicate that there is no distinct pattern or relationship. The Video Analytics Software's performed well in the Westbound HOV lane;

however the accuracy significantly decreased in the Westbound GPL stream. Even though a single camera was deployed for both streams a substantial variation in the Average Percent Error exists. Additionally, the accuracy in both streams of travel in the eastbound direction underperformed as they both achieved a high Average Percent Error of 17.26% and 19.31%, respectfully.

Figure 33 – QEW's Video Analytics Software's Accuracy by Stream of Travel

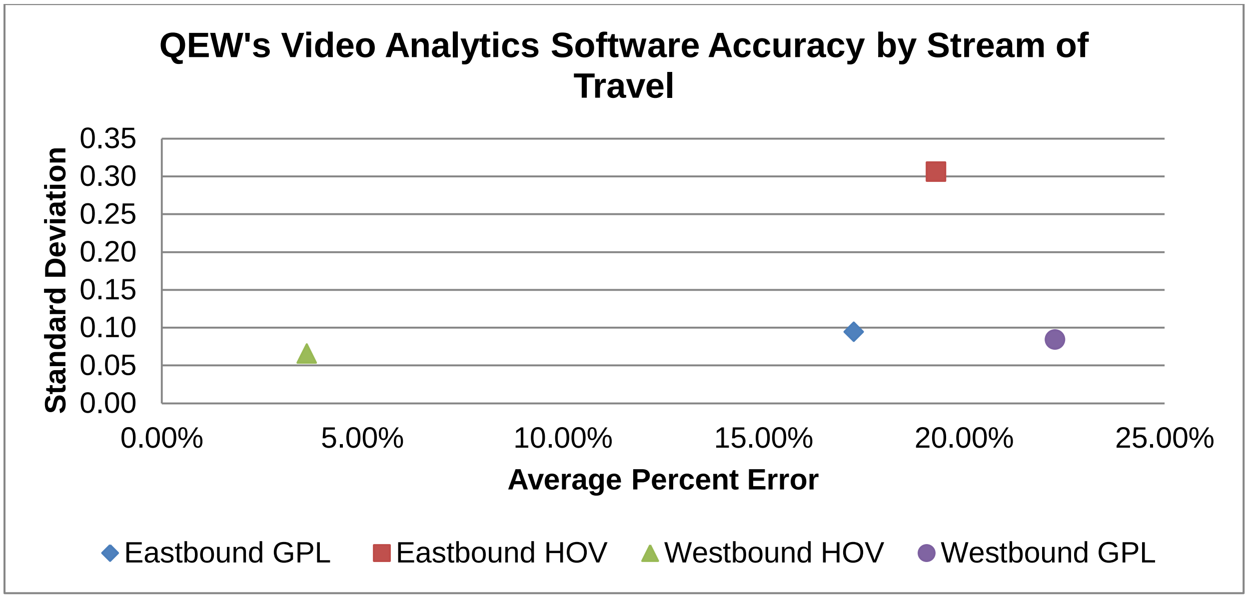


Table 33 – QEW's Video Analytics Software's Accuracy by Stream of Travel

	Average Percent Error	Standard Deviation	Range of Error
Eastbound GPL	17.26%	0.09	0.58
Eastbound HOV	19.31%	0.31	2.82
Westbound HOV	3.62%	0.07	0.83
Westbound GPL	22.27%	0.08	0.42

Figure 34 and Table 34 summarizes the accuracy achieved by the Video Analytics Software with ground truth data across three streams of travel at Highway 401. Similar to the Video Analytics Software's results on QEW, the results indicate that the Average Percent Error, Standard Deviation and Range of Error for the Video Analytics Software vary for each stream of travel. No pattern or relationship is evident. These inconsistencies in results were expected because each camera was independent and only recorded video for one stream of travel. Given the results, it is evident that it is difficult to predict the Video Analytics Software's accuracy. The Video Analytics Software was accurate in the Westbound Express direction and performed very well. The Video Analytics Software achieved an Average percent Error of 4.04%, a Standard Deviation of 0.03 and a Range of Error of 0.30 at Highway 401 Westbound Express. At the same time, the Video Analytics Software's underperformed in terms of accuracy in the Eastbound Collectors and Eastbound Express.

Figure 34 – Highway 401's Video Analytics Software's Accuracy by Stream

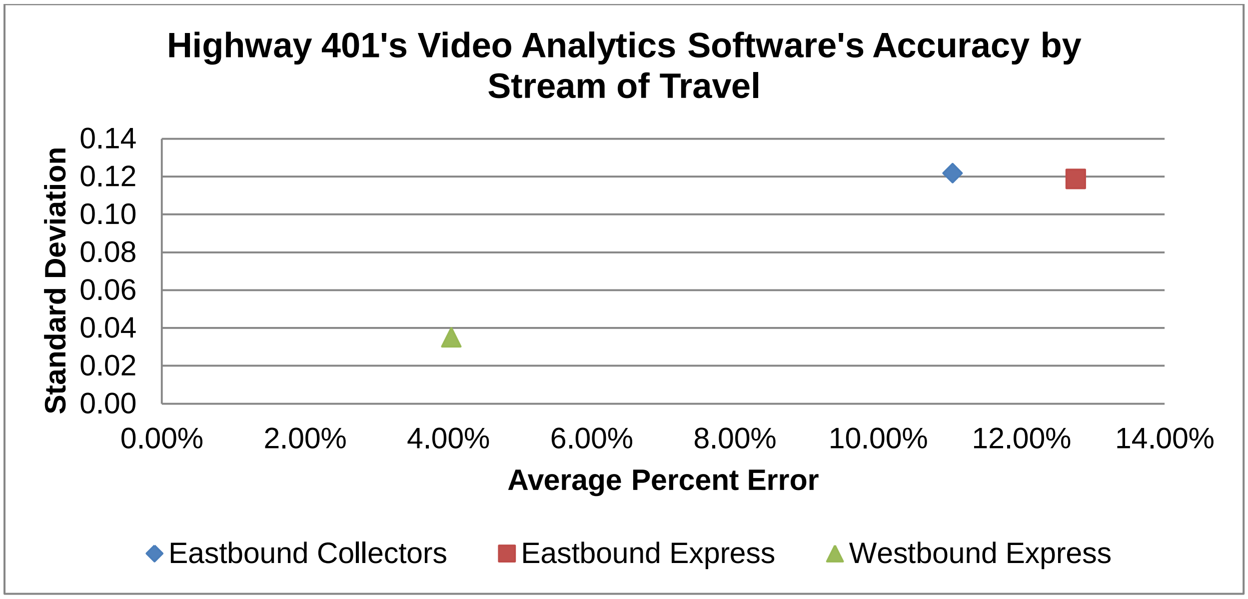


Table 34 – Highway 401's Video Analytics Software's Accuracy by Stream of Travel

	Average Percent Error	Standard Deviation	Range of Error
Eastbound Collectors	11.04%	0.12	0.71
Eastbound Express	12.76%	0.12	0.54
Westbound Express	4.04%	0.03	0.30

6. Lessons Learned and Recommendations

The purpose of this study was to validate the accuracy of the different data collection technologies across various traffic conditions. Two different highway configurations were selected as test sites. The goal for this study was to evaluate the accuracy of each technology across the two test sites and to determine if the same technology can be used for both highway configurations, or if different technologies are preferred for different highway configurations.

Majority of the data analysis for engineering, operations, road safety and forecasting is done using volumes collected during the peak hours. Therefore, extra emphasis was placed on evaluating technologies during peak periods.

Loops are the only technology out of the four that has been tested all year round by MTO. Loops have their limitations in terms of accuracy, as seen in this paper, but it is still a proven and reliable traffic data collection technology. Loops are widely used by MTO and other transportation agencies and data is collected all year round, across all seasons and under various weather conditions. Before a proven traffic data collection technology like loops can be replaced with a non-intrusive traffic data collection technology, an expanded and longer-term study should be undertaken.

The results indicate that there is a direct relationship between accuracy of the device and the distance between the radar device and the vehicles it is capturing. Therefore, it is recommended that a radar device be installed for each direction of travel. On Highway 401 a radar device should be deployed on the south side of the highway to capture both Eastbound Collectors and Eastbound Express traffic; and a second device be mounted on the north side of the highway to capture both Westbound Collectors and Westbound Express traffic.

At the QEW test site the results indicate that there was no clear relationship between accuracy and the distance of the stream of travel to the location of the radar devices for both Radar Device 1 and Radar Device 2. Compared to Loops, both radar devices struggled in separating the volumes for the HOV lanes and GP lanes. For future installations it is recommended that the vendor alter the height and setback distances in order for the device to differentiate the two streams of travel. Also, similar to Highway 401, it is recommended that a radar device is installed for each direction. A radar device should be deployed on the south side of the highway to capture both the Eastbound GP lanes and the Eastbound HOV lane; and a second device mounted on the north side of the highway to capture both Westbound GP lanes and the Westbound HOV lane traffic.

The accuracy of the Video Analytics Software is heavily dependent on the location of the cameras and the calibration process that sets the detection zones in the Video Analytics Software. There are many factors that influence accuracy; therefore each location will have an unique setup and calibration requirement.

PTZ cameras were deployed to record video and provide a source for the Video Analytics Software. PTZ cameras have the ability to pan, tilt and zoom; and agencies similar to MTO will deploy PTZ cameras for incident detection and monitoring. The cameras can also be used as a source to capture recorded video to be processed using a Video Analytics Software. Agencies, similar to MTO with traffic control centres, have control over their PTZ cameras to observe an incident or monitor the highway in real time. In doing so, the video frame that has been calibrated for the optimal detection of vehicles will change.

If the recorded video used for the Video Analytics Software is obtained from cameras used for incident detection and monitoring; then, it would be beneficial for the Video Analytics Software to have the functionality to save pre-set calibration and detection zones. Thus no additional calibration is required for the collection of traffic data.

The accuracy of the QEW data was influenced by the fact that the QEW ultimately had two test sites: the first, the location of the video cameras; and second, the location of the Loops, Radar Device 1 and Radar Device 2. The data analyzed at QEW’s test site posed a challenge due to the 1km distance between the two sites. The data was analyzed in fifteen minute intervals and due to the distance of the two sites; there is a chances for a vehicle being detected across two separate intervals. This could be a challenge during peak periods under stop-and-go traffic conditions. Thus, affecting the accuracy of data collected and captured in each fifteen minute interval.

It is recommended that a similar test be conducted at a site where all technologies can be installed in closer proximity to one another. This can be a challenge as each technology has its own installation requirements and it may be difficult to meet all of the requirements at one test site location. The test site should include multiple streams of travel like Highway 401 and QEW.

This study was undertaken for 10 days and during the summer month of August. During the data collection period, weather conditions were clear and sunny with little rain. Fog, snow and heavy winds were not observed during this study. Therefore, it is recommended to complete the same study for a longer period of time and across various seasons in order to capture all weather conditions. At the same time, this will provide a platform to test the maintenance requirements, and other challenges along with the performance of each technology.

7. Conclusion

This study has not only provided validation of accuracy among different data collection technologies; but also indicates that different technologies may be appropriate for different highway configurations. The use of a single data collection technology or method may not be efficient for a transportation agency like MTO. Before implementing a data collection solution, MTO should understand the data needs and then select the best data collection technology that will meet its needs and provide a sufficient level of accuracy. The results from this study will assist MTO with the future selection of data collection technology on its highway network.

In conclusion, it is recommended that a further study be undertaken, taking into account all of the above recommendations, and at a test site where all of the technologies are in very close proximity to one another. Additionally, the study should be for a longer term in order to span multiple seasons and across multiple weather conditions.

Authors Information:

Kamal Banger
Traffic Specialist
Traffic Office, TIRS, Central Region
Ministry of Transportation
1201 Wilson Avenue, 6th floor, Bldg D
Toronto, ON, M3M 1J8
Tel: 416-235-5601
Email: Kamal.banger@ontario.ca