Performance Evaluation of Non-Intrusive Methods for Traffic Data Collection

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Abstract

For a long period of time, intrusive data collection methods like detector loops have been the solution for accurate and reliable 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 detector loops can be expensive to install and maintain, the loops can damage the pavement and are prone to damage. The Ministry of Transportation of Ontario (MTO) initiated a study to evaluate alternative non-intrusive devices for accuracy and reliability. Traffic volume data was collected using a variety of technologies including: recorded video and a video analytics software; two radar device technologies and MTO's existing detector loops. 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 and 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

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

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

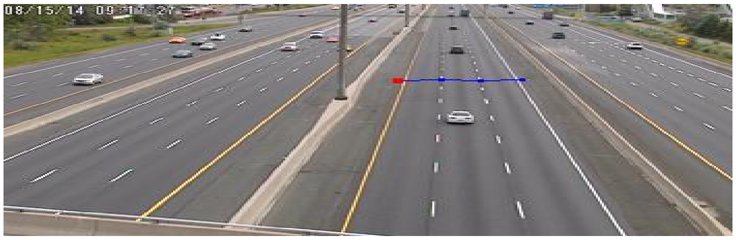
3.2 Highway 401 and Liverpool Road

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.

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 5 – Highway 401Eastbound Collector Lane Configuration – View from the Video

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



Picture 7 – 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.

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.

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,

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

where x is each value , $\overline{x}$ 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.

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

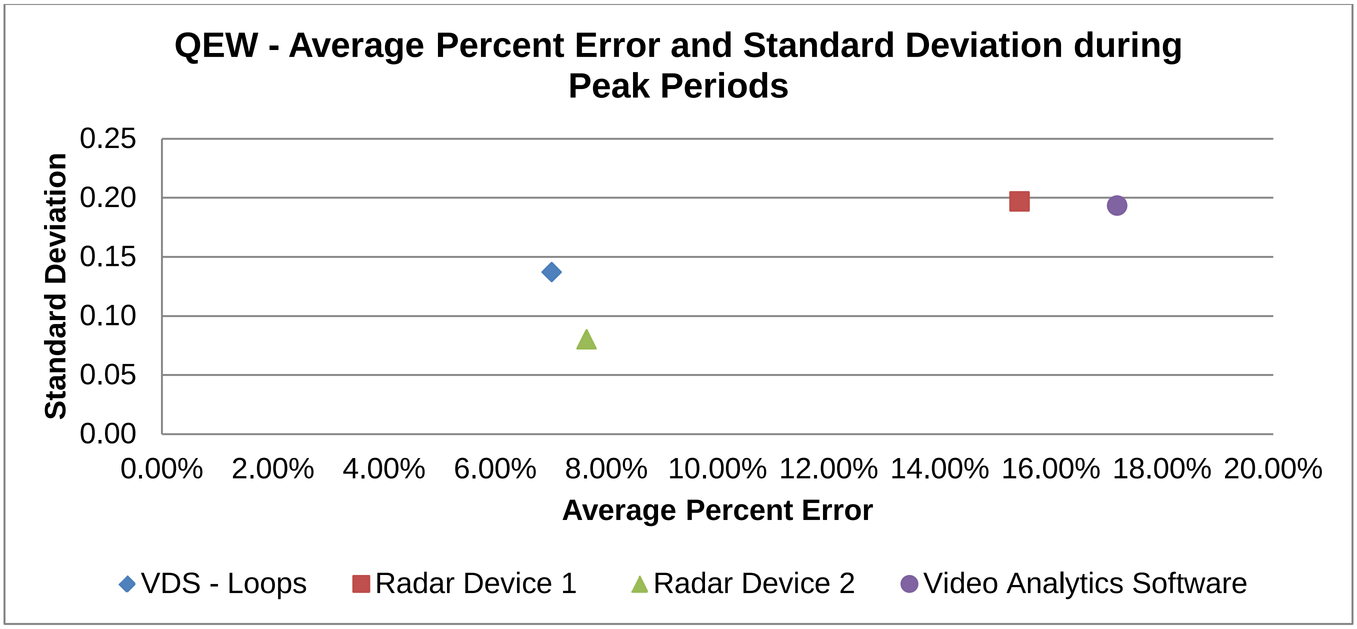


Figure 2 and Table 2 summarize the accuracy of each technology with ground truth data for Highway 401. It is evident that Radar Device 2 outperformed all other technologies. Loops achieved an Average Percent Error of 8.09% and a Standard Deviation of 0.11. Loops slightly outperformed Radar Device 2 based 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

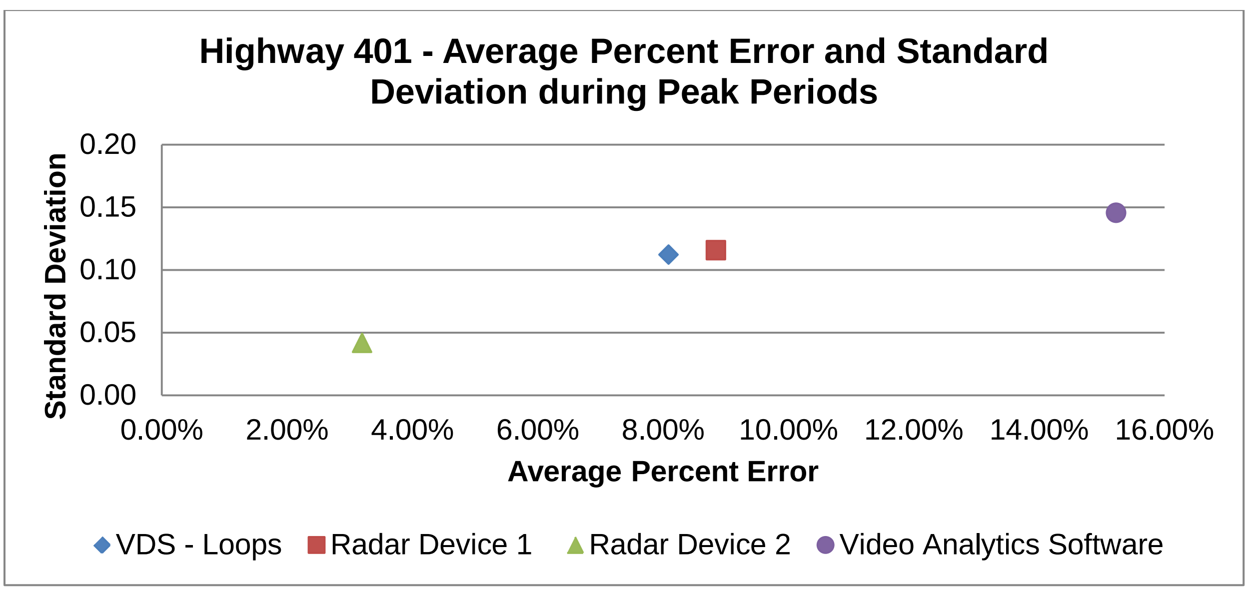


Table 2 – Highway 401's Percent Error, Standard Deviation and Range of Error during Peak Periods

	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 Free-flow Traffic Conditions

Figure 3 and Table 3 summarize the accuracy of each technology with ground truth data during free-flow traffic conditions. 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.

Figure 3– QEW's Average Percent Error and Standard Deviation during Free-flow Conditions

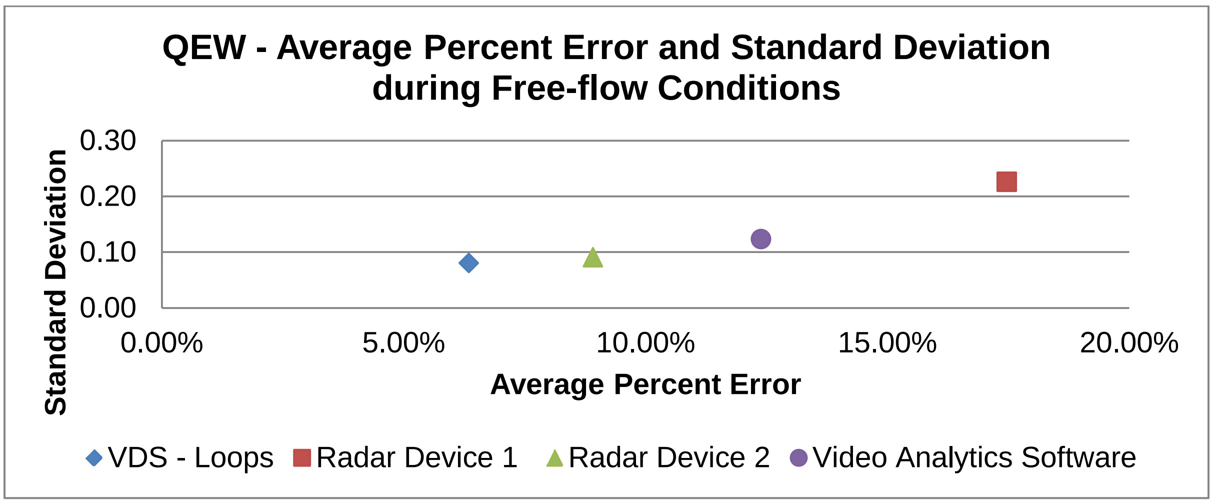


Table 3 – QEW's Percent Error, Standard Deviation and Range of Error during Free-flow Conditions

	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 4 and Table 4 summarize the accuracy of each technology with ground truth data during free-flow traffic conditions for Highway 401. All four technologies performed well under free-flow traffic conditions on Highway 401.

Figure 4 – Highway 401's Average Percent Error and Standard Deviation during Free-flow Conditions

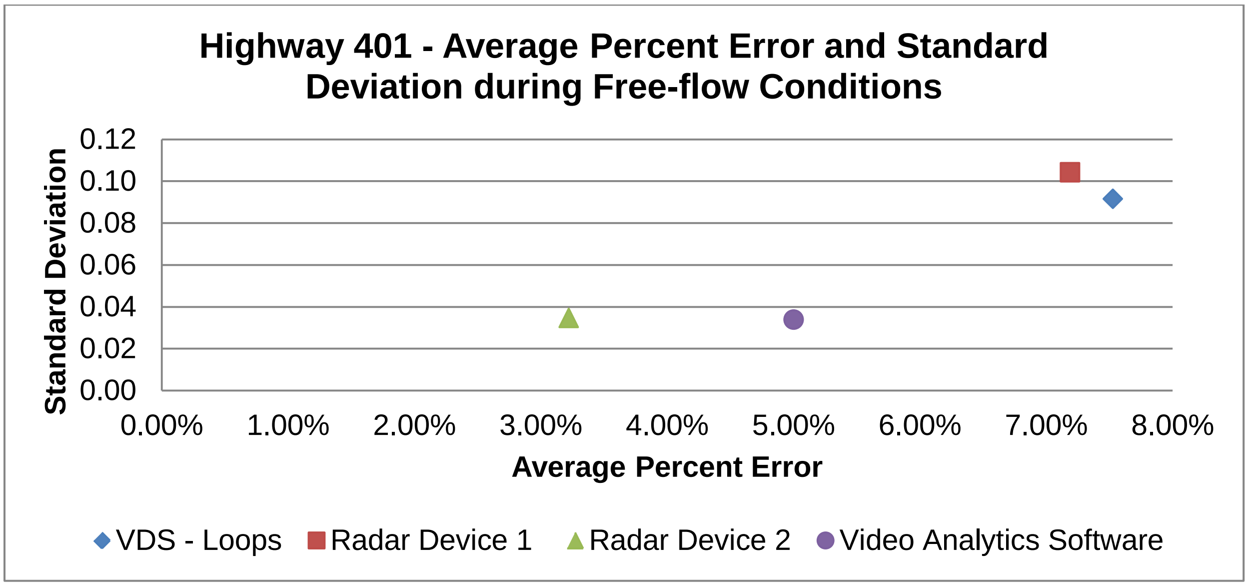


Table 4 – Highway 401's Percent Error, Standard Deviation and Range of Error during Free-flow Conditions

	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

5.3 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. On QEW loops and Radar Device 2 achieved the best accuracy when compared with the other two technologies.

Figure 5 – QEW's Average Percent Error and Standard Deviation during Weekend Traffic Conditions

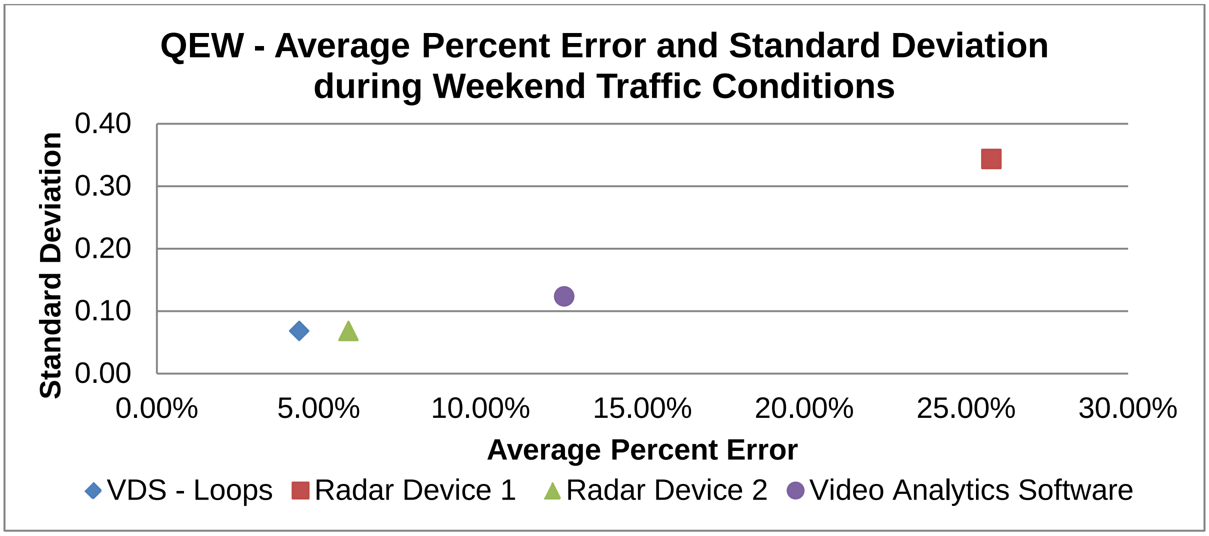


Table 5 – QEW's Percent Error, Standard Deviation and Range of Error during Weekend Traffic Conditions

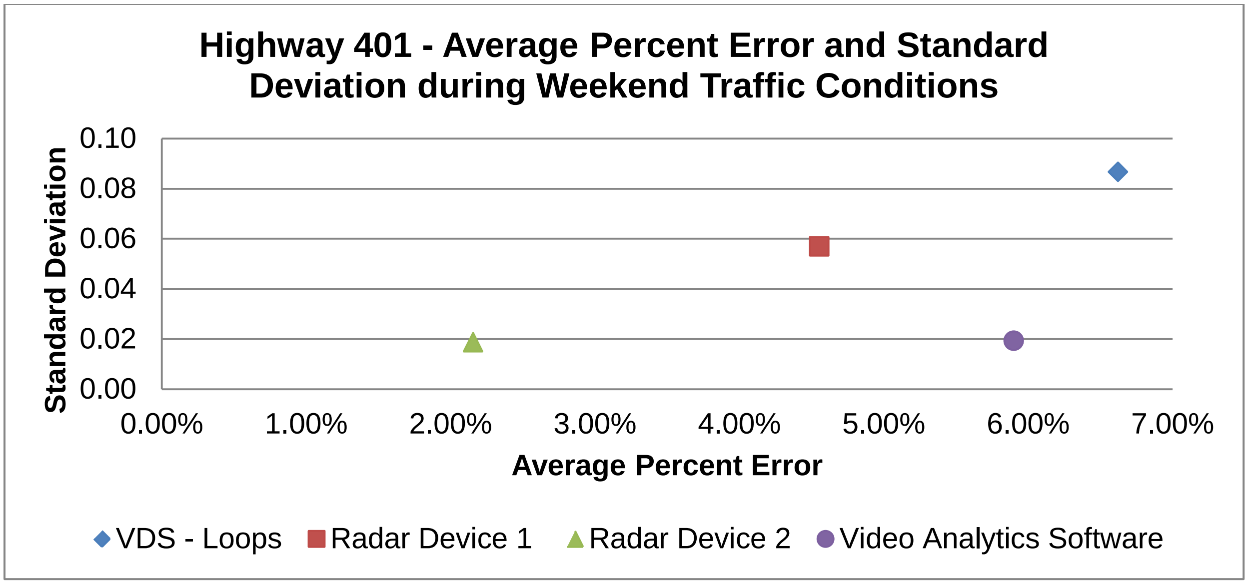
	Loops	Video Analytics Software	Radar Device 1	Radar Device 2
Average Percent Error	4.40%	12.59%	25.78%	5.93%
Standard Deviation	0.07	0.12	0.34	0.07
Range of Error	0.41	0.56	1.07	0.29

Figure 6 and Table 6 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.

Table 6 – 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

Figure 6 – Highway 401's Average Percent Error and Standard Deviation during Weekend Traffic Conditions



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

Video Analytics Software's performance was satisfactory, given the circumstances stated earlier.

Figure 7 – QEW's Average Percent Error and Standard Deviation during Rainfall

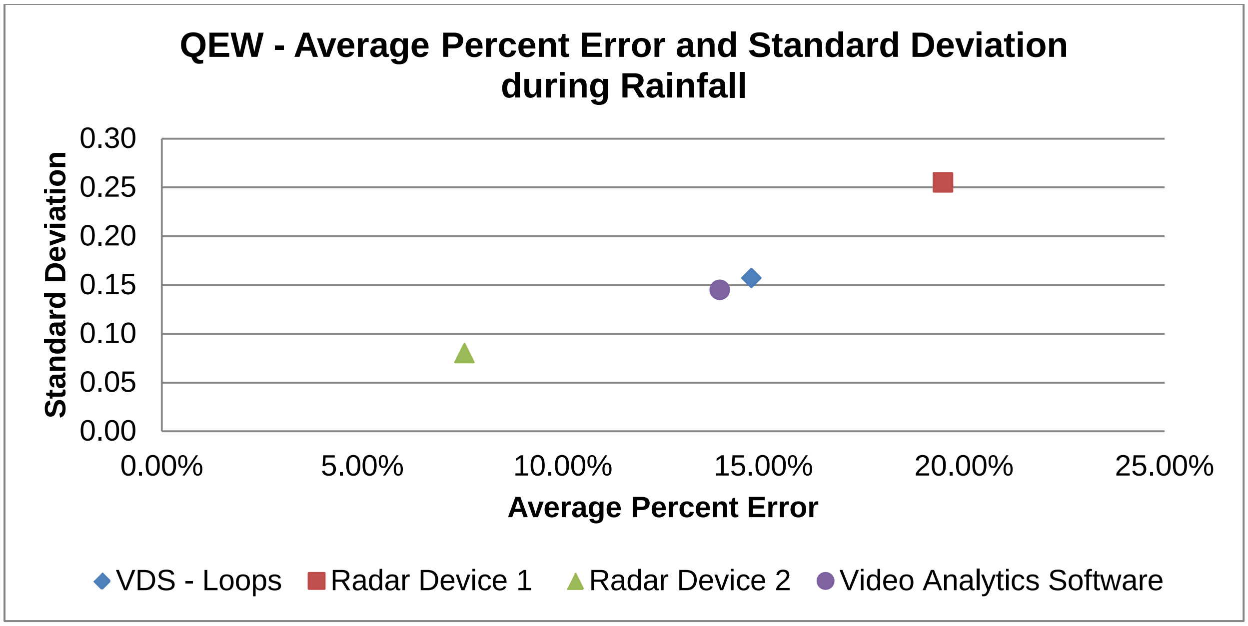


Table 7 – QEW's Average Percent Error, Standard Deviation and Range of Error during Rainfall

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

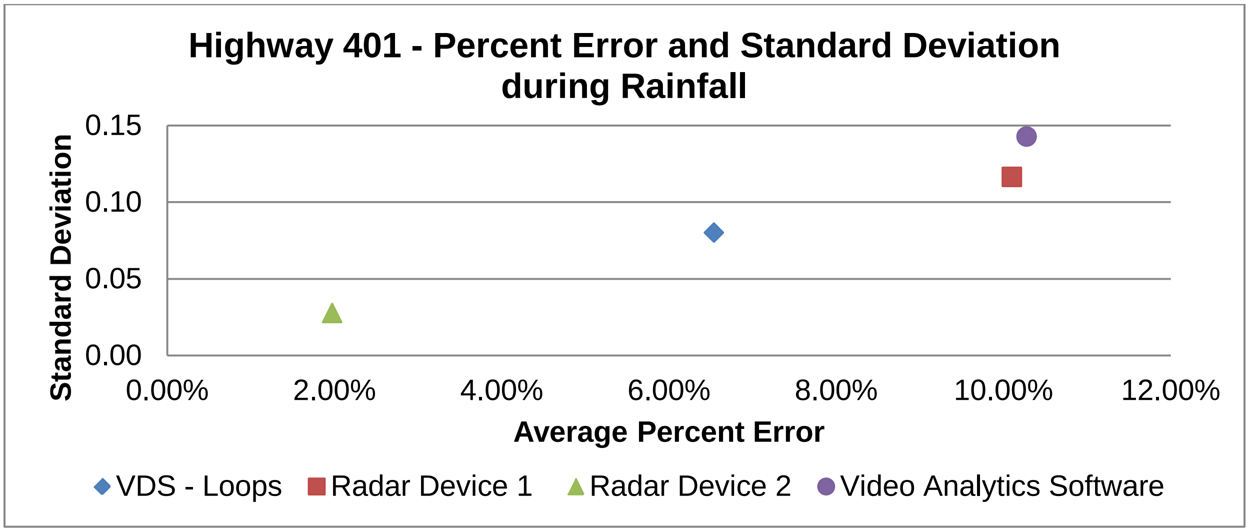


Table 8 – Highway 401's Average Percent Error, Standard Deviation and Range of Error during Rainfall

	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 9 and Table 9 summarize the accuracy of each technology with ground truth data during night conditions at QEW. It is evident that Range of Error is very high across all four devices. The Loops achieved the most accurate results.

Figure 9 – QEW's Average Percent Error and Standard Deviation during Night Conditions

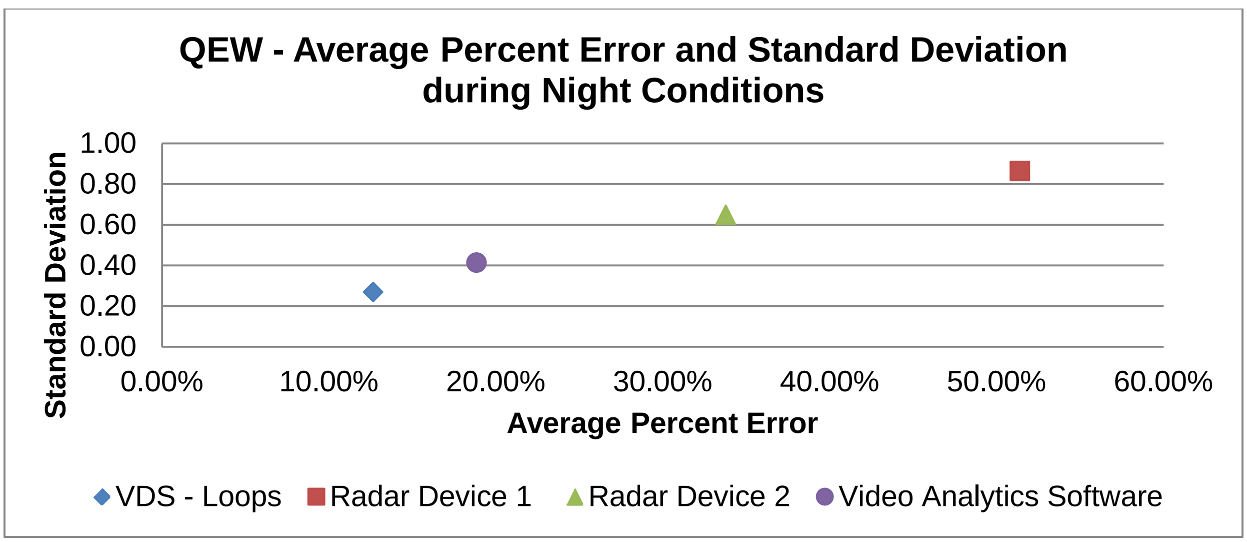


Table 9 – QEW's Percent Error, Standard Deviation and Range of Error during Night Conditions

	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

Figure 10 and Table 10 summarize the accuracy of each technology with ground truth data during traffic conditions at night at Highway 401.

Figure 10 – Highway 401's Average Percent Error and Standard Deviation during Traffic Conditions at Night

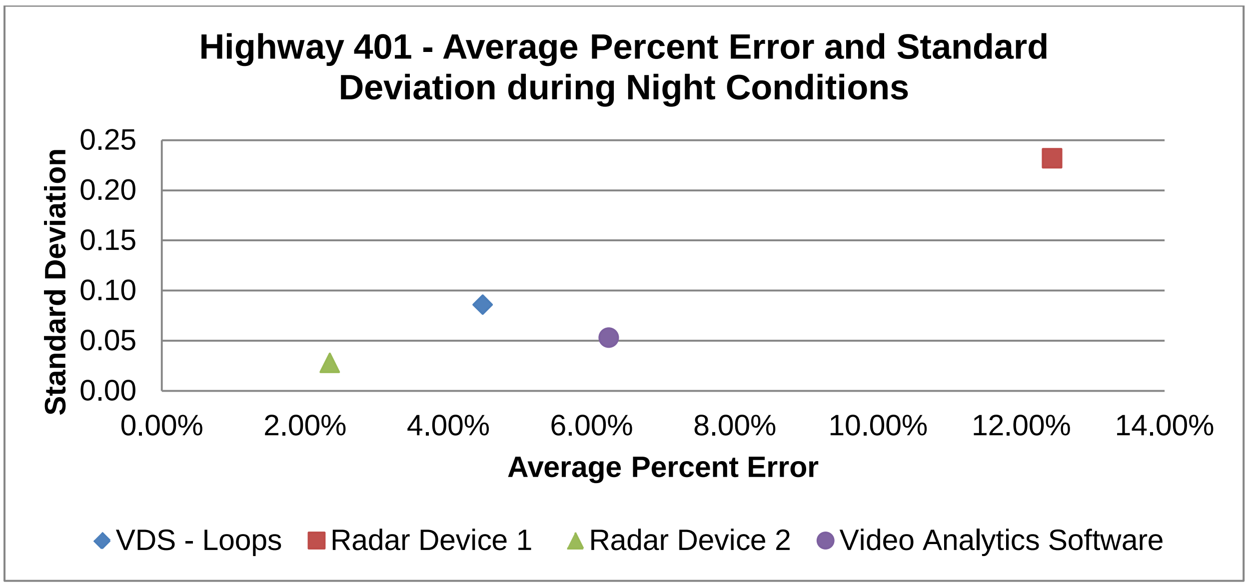


Table 10 – Highway 401's Percent Error, Standard Deviation and Range of Error during Traffic Conditions at Night

	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

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. 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.

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.

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.