Vehicle Tracking and Speed Measurement at Intersections Using Video Detection Systems

MOST COMMERCIALLY AVAILABLE VIDEO DETECTION SYSTEMS ARE UNABLE TO DIFFERENTIATE TURNING MOVEMENTS AT INTERSECTIONS. THEREFORE, SPECIAL APPLICATIONS NEED TO BE DEVELOPED. USING THE BASIC TIME EVENTS RECORDED BY A VIDEO DETECTION SYSTEM, A VEHICLE-TRACKING ALGORITHM WAS DEVELOPED TO TRACK VEHICLES AND MEASURE SPEEDS AT TWO-WAY, STOP-CONTROLLED INTERSECTIONS.

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INTRODUCTION

Video detection systems provide a way to automate data collection and significantly reduce the efforts of many traffic data collection tasks. This feature describes a unique use of video detection systems to track main-street through vehicles and measure speeds at two-way, stop-controlled (TWSC) intersections.

The initial intent of this research was to find an automated method to measure main-street vehicle speeds and study driver gap acceptance characteristics at TWSC intersections. The first task was to identify whether or not commercially available video detection systems were capable of tracking main-street through vehicles and measuring their speeds at TWSC intersections. In the literature search, two commercial video detection systems with similar functions were available. Mobilizer and VideoTrak are designed to track vehicles along travel paths by matching a series of images.

Only a small portion of the vehicles (about 18 percent) were correctly tracked during tests of Mobilizer.[1,2] In testing VideoTrak, more than 20 percent of the errors were due to volume counts. While some errors were caused by vehicle occlusion (vehicles being obstructed from the field of view) and low-quality video images, the majority of the errors were due to lack of accuracy in vehicle tracking. Furthermore, the test results were based primarily on freeway segments, where there were no vehicle interferences among turning movements.[3]

Researchers in the area of general machine-vision technology have recognized the lack of vehicle tracking capabilities in most commercial video detection systems. Efforts have been made to develop advanced algorithms using machine-vision technology to address the limitations of those systems.[4–7] Most algorithms developed in these studies focus on addressing the occlusion issues while performing vehicle tracking along freeway sections.

For example, a segmentation algorithm was developed to track vehicles under severe occlusion conditions. This algorithm was based on videos collected from freeway segments and could lead to the next generation of video detection systems.[8] However, such advanced algorithms have not been adopted by any video detection system manufacturers.

Additional data collection problems occur when using video detection systems to track turning movements at TWSC intersections. Previous studies have attempted to solve this specific problem. One study developed a method of tracking vehicles at all-way, stop-controlled intersections based on the principle of flow conservation and data redundancy. This method used multiple detectors for each movement and established a matrix to relate each detector's counts to a specific turning movement.[9] While the method was theoretically correct, actual field trials illustrated the difficulties in obtaining quality detector counts to satisfy the volume count solution requirements. One such challenge was vehicle occlusion, where multiple detections resulted from a single vehicle movement.

BASIC AUTOSCOPE FEATURES AND LIMITATIONS

The specific system used in this study was AUTOSCOPE, a video detection system manufactured by Econolite Control Products Inc.[10,11] AUTOSCOPE provides basic point detection capabilities with two types of detectors: count and presence. Several detectors can be logically connected to provide combined detections.

However, these detectors do not associate counts with specific traffic movements.

AUTOSCOPE uses speed traps to measure vehicle speeds and estimate vehicle lengths. It has an internal algorithm for calibrating the field of view based on the geometric information provided by the user. Vehicles are tracked along a speed trap, then the vehicles' speeds are estimated from travel time and the length of the speed trap.

As part of this study, a test of the speed trap was conducted for its potential in measuring vehicle speeds at TWSC intersections. Based on the results of the test, the speed trap could not fulfill the requirements of this study. The specific problems identified included the following:

- The speed trap lacked the capability of differentiating turning movements. Speeds of all vehicles that passed the speed trap were reported.
- Large errors usually resulted when a turning vehicle traversed only a portion of the speed trap. The internal algorithm did not have a feature to detect and correct such errors.
- The measured speeds were sensitive to the length of the speed trap. Using a longer speed trap normally improved the accuracy of speed measurements under low-volume conditions but resulted in larger-volume errors when traffic volumes were high.

Due to these limitations, a special algorithm was needed to achieve the study objective—tracking main-street vehicles and measuring their speeds at TWSC intersections. The following section documents the details of the tracking method as well as the results from field tests.

TRACKING MAIN-STREET THROUGH VEHICLES

The vehicle-tracking algorithm was based on the fact that the movements of vehicles follow specific travel paths at intersections. In Figure 1, four typical vehicle travel paths are illustrated. A total of six count detectors, indicated as A through F, were located on the major street to track the main-street through vehicles. Count detectors were used because they provide more accurate and reliable point detection than presence detectors.[12]

Table 1. Extracting major-street through vehicles.

Recorded Time Events		
Detector A ***(T_A)***	***Detector B*** ***(T_B)***	***Detector C*** ***(T_C)***
00:30:28.2	00:30:41.1	00:30:53.2[3]
00:30:50.1[3]	00:30:52.2[3]	00:31:15.3[2]
00:30:53.8	00:30:54.7	00:39:57.2
00:31:11.5[2]	00:31:14.0[2]	00:40:04.7
00:37:57.3	00:31:15.9	00:40:06.4
00:43:16.6[1]	00:35:47.6	00:43:11.9
00:43:31.0	00:36:05.4	00:43:17.0
00:43:35.1	00:36:42.1	00:43:19.3[1]
	00:43:18.8[1]	00:43:29.2
	00:43:20.0	

Note: 0.5 seconds was used for both $T_{min, A-B}$ and $T_{min, B-C}$; 3.0 seconds was used for both $T_{max,A-B}$ and $T_{max, B-C}$.

A main-street through vehicle (V4) traveling from the left to the right passes through and activates three detectors (A, B and C). A main-street right-turn vehicle (V3) activates only detector A and a minor-street left-turn vehicle (V1) activates detectors B and F. Although the camera view and vehicle occlusion could trigger activations of additional detectors, only the main-street through vehicle activates detectors A, B and C and the activation times recorded by the three detectors fall within a certain range. By searching these sequential time events, the major-street through vehicles were identified for this study.

As an example, Equations 1 and 2 represent the conditions when the time events recorded by the three detectors belong to a main-street through vehicle:

$$T_{min,A-B} \leq T_B^{\,j} - T_A^{\,i} \leq T_{max,A-B} \qquad (1)$$

$$T_{max,B-C} \leq T_C^{\,k} - T_B^{\,j} \leq T_{max,B-C} \qquad (2)$$

where:

$T_A^{\,i}$, $T_B^{\,j}$, $T_C^{\,k}$ = time events recorded by detectors A, B and C, respectively

$i, j, k = i^{th}, j^{th}$ and k^{th} = time events recorded by detectors A, B and C, respectively

$T_{min,A-B}$, $T_{max,A-B}$ = the lower and upper travel time boundaries between two successive detectors, A and B

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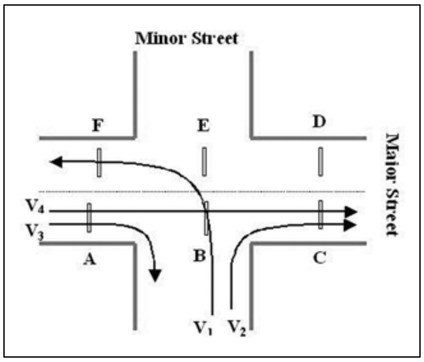

Figure 1. Example of vehicle's travel path and detector set-up.

A sample dataset is shown in Table 1 where the time events associated with three main-street through vehicles were identified. These time events satisfy all the conditions as described in Equations 1 and 2. The time events shown in Table 1 were recorded using the AUTOSCOPE count detectors in the situation illustrated in Figure 1. The actual searching process was performed using the vehicle-tracking program, a computer program developed as part of this study. The searching process consisted of a backward-searching algorithm from the last detector event to the earlier events. The steps of the vehicle-tracking program are summarized as follows:

1. Find the time event, $T_C^{\,k}$, from the last detector (detector C).
2. Search time events, $T_B^{\,j}$, from detector B that satisfied Equation 2. If such an event was found, go to step 3; otherwise, go to step 1.

Table 2. Results of vehicle tracking.			
Intersection	Vehicle Counts		Error (%)
	Tracking Algorithm	*True Counts*	
Site 1: Northbound	407	433	6.0
Site 1: Southbound	382	392	2.6
Site 2: Northbound	420	457	8.1
Site 2: Southbound	360	396	9.1
Site 3: Northbound	557	569	2.1
Site 3: Southbound	628	642	2.2
Site 4: Eastbound	333	345	3.5
Site 4: Westbound	534	571	6.5
Site 5: Eastbound	76	82	7.3
Site 5: Westbound	272	285	4.6
Overall	**4,127**	**3,869**	**7.2**

Note: Error is the difference between the counts divided by the true counts.

3. Search time events, T_A^i, from detector A that satisfied Equation 1. If such an event was found, go to step 4; otherwise, go to step 1.
4. One through vehicle was found. The times that the vehicle passed the three detectors were recorded for later speed calculations.

The accuracy of vehicle tracking relied on two factors: the accuracy of event detection by the count detectors and the selection of the travel time boundary values ($T_{min,A-B}$, $T_{max,A-B}$, $T_{min,B-C}$ and $T_{max,B-C}$). The travel time boundary values can be determined empirically by observing vehicles traveling in the detection zone and estimating their travel times. Such travel time boundaries were estimated on the time stamps from a playback video and by observing vehicles of different speed ranges. It was not necessary to obtain an accurate travel time estimate; however, careful selection of such boundary values would improve the accuracy of vehicle tracking.

The vehicle-tracking algorithm was tested with the recorded videos at five TWSC intersections collected for the National Cooperative Highway Research Program. The results are shown in Table 2.[13] Vehicle tracking was performed for both directions of the major street at each site. In the table, the true counts were obtained from manual counts of the recorded videos.

The proposed vehicle-tracking algorithm was able to achieve reasonably accurate results. The error ranged from 2 to 9 percent, with an average of 7.2 percent. The counts from the algorithm were consistently lower than the true counts. Two major sources for the difference were identified.

The first was due to false and missed detections of the count detectors where the camera view was not ideal. For example, camera views could result from a largely skewed angle or the placement of the camera too far away from the intersection. The second source was due to extremely slow or fast vehicles, where the time events detected exceeded the pre-defined travel time boundaries. Extremely slow vehicles were normally observed at intersections where the main-street approaches had a single lane and main-street through vehicles had been blocked by a left- or right-turning vehicle.

SPEED MEASUREMENT

The speeds of the individual vehicles were determined once the following items were obtained: the time events associated with the main-street through vehicles; the time difference between the two detectors; and the spacing of the two detectors. Calculation of a vehicle's speed was obtained from Equation 3:

$$V_i = 3.6 \frac{d_{m,n}}{t_{m,n}} \qquad (3)$$

where:

V_i = speed of vehicle i (km/hr.)

$t_{m,n}$ = travel time between detector m and n, obtained from the recorded time events (seconds)

$d_{m,n}$ = video image distance between detector m and n (meters)

One critical issue in the speed calculations was to determine $d_{m,n}$, a video image distance between detectors m and n. Video image distance is the distance perceived by the video system, which may be different from the actual detector distance in the field. The difference is caused by the parallax effect. In video detection systems, vehicle detection works by the recognition of background changes caused by the intervention of objects (such as a vehicle) between the camera and the detector. Because the camera usually has a limited mounting height and may also be offset to the vehicle travel path, detection may occur earlier than a vehicle actually reaches the detector location in the field. The actual distance that a vehicle travels in the field when the detection occurs is called the video image distance.[14,15]

One study indicated that the video image distance is different from the actual distance in the field only when the camera has a departing view (vehicles are moving away from the camera location).[16] As shown in Figure 2, the video image distance is generally shorter than the field distance under a departing view.

While an approaching view (vehicles moving toward the camera) is always desirable for speed measurement, it may not always be achievable due to physical constraints such as finding a proper location to place the camera or attempting to avoid obstructions. A model is available that calibrates the video image distance.[17]

FIELD TESTING

A TWSC intersection in Moscow, ID, USA, was selected as a testing site. The main street of the intersection had speed limits of 25 miles per hour (mph), or 40 km/hr., and 30 mph (48 km/hr.) for the northbound and southbound directions, respectively. A 1.5-hour video was taken at the site and the experiment was conducted in the lab using a video detection system and the recorded video.

During the field videotaping, vehicle speeds for the northbound direction were collected with a radar gun. Because of physical constraints, the camera was set up to record a departing view for the northbound direction. The time that each vehicle passed the intersection was also recorded. This process provided the ability to match individual vehicles between the radar gun measurements and the video detection system.

It should be noted that the radar gun measured time-mean (spot speeds) while the video detection system (AUTOSCOPE) measured space-mean speeds. When there are no speed variations between the detectors, time-mean speeds are equal to space-mean speeds. Efforts were made in the field to point the radar gun to the middle of the detectors so that radar gun speeds could better represent the mean speeds between the detectors.

The results of the speeds measured using the video detection system and the radar gun are illustrated in Figures 3a and 3b. Figure 3a represents the individual speeds; Figure 3b represents the average speeds of 5-minute intervals. Lines indicating ±5 km/hr. and ±3 km/hr. error ranges are also shown.

A total of 351 data points, each representing a pair of speed measurements using the radar gun and the proposed application of AUTOSCOPE, are represented in Figure 3a. A total of 404 northbound through vehicles were observed in the field, for an accuracy of approximately 87 percent. Among the errors, there were 23 missed detections and 30 false detections. Data presented in Figures 3a and 3b only include those that were matched between the two methods.

The majority of data points fall within the ±5 km/hr. error range. Approximately 7 percent of the data (24 out of 350) fall outside this error range. The following items are contributing factors for the errors:

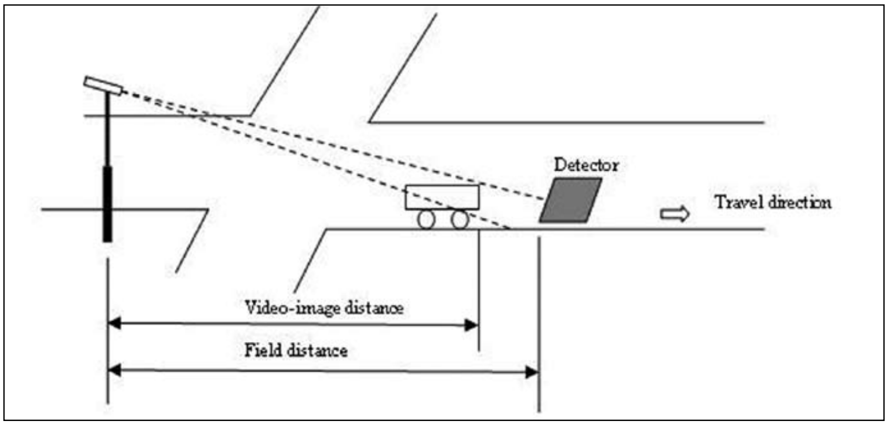

Figure 2. Video image distance and field distance under a departing view.

- the accuracy or inaccuracy of detecting a vehicle passage affected by the sensitivity of the detector;
- human errors related to radar gun operations and measurements; and
- the difference between the spot speed by the radar gun and space-mean speed by AUTOSCOPE.

A paired t-test was conducted to investigate whether the two methods yielded statistically identical speed measurements. The paired t-test results for all the data points included in Figures 3a and 3b are summarized in Table 3. The two methods yielded statistically different average speeds at the 5-percent significance level, but identical speeds at the 4-percent significance level (P-value = 0.04). The difference (46.0 km/hr. vs. 46.5 km/hr.) is considered insignificant. When comparing the average speeds based on 5-minute intervals, no statistically significant difference was found between the two methods (P-value = 0.11).

SUMMARY AND CONCLUSIONS

A unique application of a video detection system was presented to track and count main-street through movement vehicles and measure their speeds at TWSC intersections. The vehicle-tracking program developed in this study consists of a recommended detector layout and a vehicle-tracking algorithm. Field tests were conducted to verify the accuracy of vehicle tracking and volume counts. Comparisons were made on speed measurements obtained using a radar gun and the video detection system application. The following conclusions were reached in this study:

- The vehicle-tracking application using a video detection system overcame the shortcomings of existing commercial video-detection systems in tracking vehicle movements and measuring speeds at TWSC intersections. This application could be extended to other types of data collection, such as

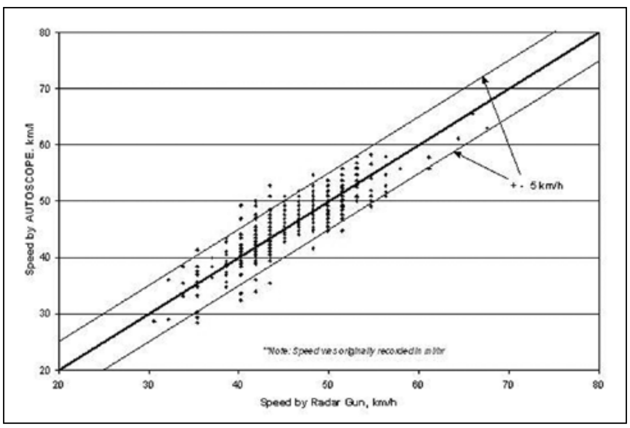

Figure 3a. Individual vehicle speeds by AUTOSCOPE and radar gun.

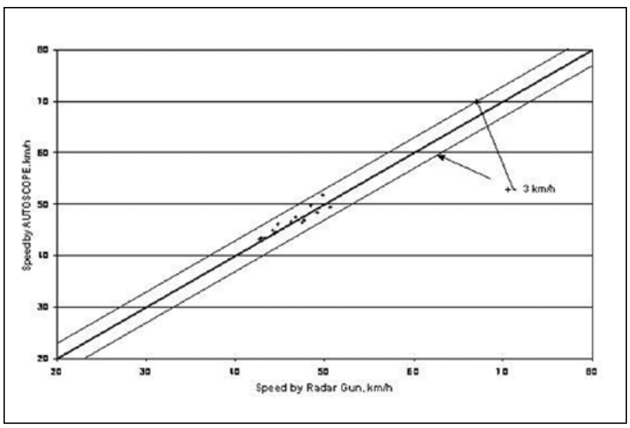

Figure 3b. Average speeds of 5-minute intervals.

Table 3. Paired t-test for sample means.

Statistics	Radar Gun	Vehicle Tracking Application
Individual Speeds		
Mean	46.0	46.5
Standard Deviation	5.7	6.0
Observations	351	351
t-Statistic	-2.92	
P-value	0.04	
5-Minute Average		
Mean	46.0	46.5
Standard Deviation	2.6	2.8
Observations	15	15
t-Statistic	-1.70	
P-value	0.11	

collecting turning movement counts at other types of intersections.

- Field testing of the application showed promising results. Under the worst-case scenario with an unfavorable departing view, the accuracy of vehicle tracking was about 87 percent. Nearly identical speeds were obtained between the video detection system and the radar gun. When reporting individual speeds, the speeds were usually within an error range of 5 km/hr. between the two types of measurements. ■

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