

A SPECIAL APPLICATION OF A VIDEO-IMAGE SYSTEM FOR VEHICLE TRACKING AND SPEED MEASUREMENT

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Abstract

This paper documents a special application of a video-image system (AUTOSCOPE) to track main-street through movement vehicles and measure their individual speeds at two-way stop-controlled intersections. The initial objective of this application was to find an automated means to collect vehicle speeds at unsignalized intersections for the purpose of analyzing a driver's gap-acceptance characteristics. To perform vehicle tracking for main-street through vehicles, a special application was developed which is beyond the basic system functions and features available in AUTOSCOPE. A vehicle-tracking program was developed that uses individual detector information and extracts the data associated with the main-street through vehicles. The study then addressed the issues that are related to speed measurement using video-image systems. Results from field tests indicated that the accuracy for tracking vehicle movements varies depending on the camera view. Under the worst-case scenario, the accuracy of vehicle tracking was about 87 percent. For speed measurements, the results were compared with those measured using a radar gun. The error was approximately ± 5 km/h while reporting individual speeds. Although the speed data obtained from AUTOSCOPE may still lack the precision required for studies such as gap acceptance characteristics at unsignalized intersections, the method developed through this study showed good potential to develop special applications beyond the basic features and functions of video-image systems.

Key Words: AUTOSCOPE, Video-Image Systems, Unsignalized Intersections, Vehicle Tracking, Speed Measurement

Introduction

Video-image systems provide a means of automated data collection, thus significantly reducing the efforts required for data collection and data reduction. This paper documents a special application of AUTOSCOPE, a video-image system manufactured by Econolite Inc. (1) for tracking main-street through vehicles and measuring their speeds at two-way stop-controlled (TWSC) intersections. This special application is beyond the basic functions and features available in AUTOSCOPE. The initial motive of the research was to find an automated means for measuring individual vehicle speeds for the main-street through vehicles and for studying their impacts on the minor-stream driver's gap acceptance characteristics at TWSC intersections (2). The authors feel that the methods developed and the issues discovered throughout this specific research may benefit other transportation researchers and professionals in seeking advanced applications of video image systems.

To achieve the initial objectives of vehicle tracking and speed measurement, an investigation was conducted to see which video-image systems are equipped with the capability of tracking major-street through vehicles and measuring their speeds at TWSC intersections. Among the video-image systems currently used in the U.S., the Mobilizer (3) developed by Condition Monitoring Systems is the only system that is equipped with vehicle tracking capability. However, the vehicle tracking feature within this system is designed to match vehicles along a through path with multiple images. Testing of the system indicated that only a small portion of the vehicles (about 18 percent) would be matched (3). While this system may be applicable to studies such as travel time estimation which can be based on a limited number of samples, it is not accurate enough for data collection tasks such as collecting turning movement counts at intersections, the main-street through vehicles in our case.

Although video-image systems have been used in various areas in transportation engineering, very limited research has been conducted to address the applications of video-image systems at intersection locations. Speed measurement at unsignalized intersection locations presents significant challenges due to vehicle interactions among different traffic movements. For our study, it requires that the main-street through vehicles be clearly identified from other traffic movements. AUTOSCOPE is one of the major

video-image systems used in the U.S. (4,5,6). While the system has the capabilities of providing volume counts and general speed measurements, it does not have the capability of directly tracking vehicle movements. However, several studies have demonstrated the possibilities of developing special applications beyond the basic detection functions provided by AUTOSCOPE. One such example is to automatically conduct vehicle turning movement counts at intersections. Tarko et al. (7) developed an application to track vehicles at an all-way-stop-controlled intersection based on the principle of flow conservation and data redundancy. Their method consists of using multiple detectors for each movement, and establishing a matrix to relate each detector counts to a specific turning movement. While the method is theoretically correct, actual field applications indicated the difficulties of obtaining quality detector counts to satisfy the requirements on obtaining a volume count solution. One such challenge is vehicle occlusion where multiple detections result from a single vehicle movement.

This paper is organized as follows. We first address the basic features of AUTOSCOPE and its limitations on vehicle tracking and speed measurement at intersections. We then discuss a method that was developed specifically for tracking major-street through vehicles and measuring their speeds at TWSC intersections. Finally, we present the results of field testing as well as findings and recommendations on future research.

Basic AUTOSCOPE Features and Limitations

AUTOSCOPE provides basic point detection capabilities using two types of detectors: count detectors and presence detectors. More than one such detector can also be logically connected (e.g., AND, OR) to provide combined detections. Basically, these detectors only provide point detection and counts, but do not associate counts with specific traffic movements.

AUTOSCOPE uses *speed traps* to measure vehicle speed and estimate vehicle length. An established algorithm in the system is applied to calibrate the field of view based on the geometric information provided by the user. AUTOSCOPE tracks a vehicle along a speed trap and estimates the speed based on the travel time and the length of the speed trap.

Testing of the speed trap in AUTOSCOPE indicated that it could not fulfill the requirements for our study. The specific problems that were identified include:

- The speed trap lacks the capability of differentiating turning movements. Speeds of all the vehicles that pass the speed trap are reported.
- AUTOSCOPE reports unrealistic speeds when a turning vehicle traverses only a portion of the speed trap.
- The result of speed measurement is very sensitive to the length of the speed trap. Using a longer speed trap normally improves the accuracy from the count's perspective, but would also increase the errors in speed resulting from the speed trap being occupied by more than one vehicle. A rule of thumb in setting the speed trap is at least one vehicle length; longer speed traps run the risk of being occupied by more than one vehicle at the same time.

Due to the above limitations of AUTOSCOPE, a new application needs to be developed to achieve the objective of our study in tracking vehicles. The following section documents the details of the method as well as the results from a field test.

Method of Tracking Major-Street Through Vehicles

A special application was developed to overcome the limitations of AUTOSCOPE. The main principle of the application is based on the fact that each movement has its specific travel path along the roadway. Figure 1 illustrates some typical vehicle traveling paths at a TWSC intersection and the proposed detector layout for the application. A total of six count detectors were set up on the major street, three for each direction. Count detectors were used because they provide more accurate and reliable point counts than presence detectors. Taking the traveling direction from the left to the right as an example, a main-street through vehicle (V4) would normally travel through and activate all three detectors A, B, and C, while a main-street right turn vehicle (V3) would normally only activate detector A, and a minor-street left-turn vehicle (V1) would only activate detectors B and F. Although the camera view and vehicle occlusion may

trigger activation of additional detectors, only the main-street through vehicle would most likely activate detectors A, B, and C.

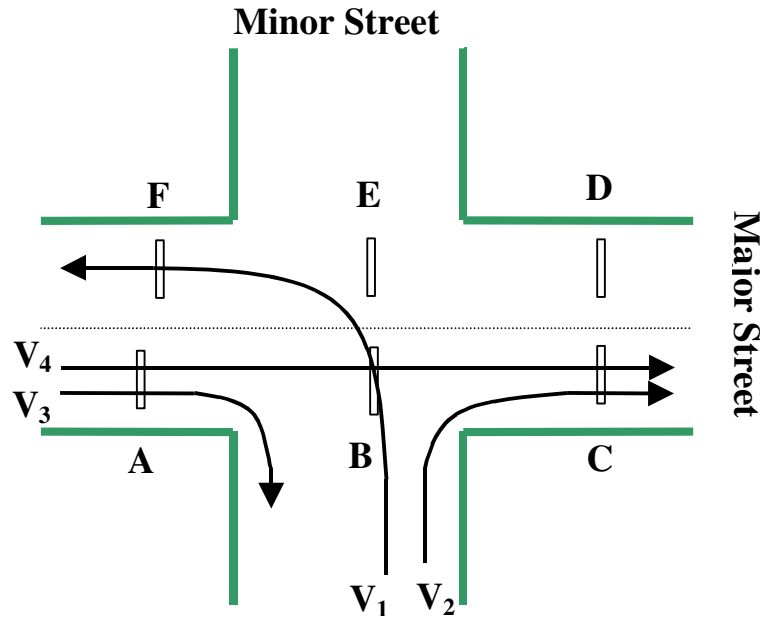


Figure 1 Example of Vehicle Traveling Path and Detector Set Up

One additional aspect is that the times a through vehicle (V4) passes the three detector locations would follow a logical sequence. By searching these logical time events, the main-street through vehicles and their associated time events can be identified. Equations (1) and (2) specify the conditions when a main-street through vehicle is detected.

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

$$T_{\min,B-C} \leq T_C^k - T_B^j \leq T_{\max,B-C} \tag{2}$$

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

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

Table 1 illustrates a sample data set where the time events associated with three main-street through vehicles are identified. These time events all satisfy the conditions as described in Equations (1) and (2). The time events shown in Table 1 were recorded using the count detectors in AUTOSCOPE as shown in Figure 1. The actual searching process was performed using a computer program named *Vehicle Tracking Program* (VTP) developed in this study. The searching process consists of a backward searching algorithm, i.e., from the last detector and the last event searching backward. It was found that a backward searching process usually can reach a solution faster and more accurately than a forward searching process. The steps to perform the backward searching 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 satisfies Equation (2). If such an event is found, go to Step 3, otherwise, go to Step 1.
3. Search time events, T_A^i , from Detector A that satisfies Equation (1). If such an event is found, go to Step 4, otherwise, go to Step 1.
4. One through vehicle is found and the times that the vehicle passes the three detectors are recorded for later speed calculations.

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	

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

The accuracy of vehicle tracking relies on two factors: 1) the accuracy of event detection by the count detectors, and 2) the travel time boundary values for $T_{min, A-B}$, $T_{max, A-B}$, $T_{min, B-C}$, and $T_{max, B-C}$. Essentially, all the time events which satisfy the conditions set by Equations (1) and (2) will be reported as main-street through vehicles. As a result, a false detection could result from events generated by vehicles other than a through vehicle, but satisfy Equations (1) and (2). Incorrect time events may also result in errors in speed calculation where the speed is determined based on the detector spacing and the times that a vehicles traverse through the detectors.

The travel-time boundary values can be determined based on observation of vehicle travel at the detection zone and an estimation of their travel times. Such travel time boundaries are better estimated based on the time stamps from a playback video by observing the faster and slower traveling vehicles. It is not necessary to obtain a very accurate travel time estimates to run VTP, however, discretionary selection of such boundary values would certainly improve the accuracy of vehicle tracking. The boundary values basically determine a range of speeds in which all the vehicles would fall, i.e., a vehicle traveling with

speed beyond such a range will not be detected. It is not recommended, however, to select the boundary values which try to cover the entire speed range (e.g., with a lower boundary of 0.0 km/hr, and a higher boundary of 200 km/hr). Selecting too broad a range would also increase the number of false detections. A false detection would occur if the time events not belonging to a through vehicle are recorded by all three detectors, and these time events satisfy the conditions of Equations (1) and (2). For example, when a minor-street right turn vehicle (V2) enters the intersection (see Figure 1), detector C will be activated. On the other hand, detector A could be activated by V3, and detectors B and F could be activated by V1. When the time events recorded by detectors A, B, and C satisfy the conditions in Equations (1) and (2), a false detection would be reported. However, when the travel time boundaries are properly selected, the chance of getting such a false detection is relatively small, because the minor-street vehicles generally have to wait for both the through and the right-turn vehicles on the main street. As a result, the time span as recorded by detectors A and B is generally large enough to exceed the upper boundary, $T_{max, A-B}$.

The proposed vehicle tracking method was tested using the recorded video tapes at five TWSC intersections collected for the NCHRP 3-46 project (2), and the results are shown in Table 2. Vehicle tracking was performed on both directions of the major street at each site. The true counts were obtained through manual counts from the recorded video tapes.

Table 2
Results of Vehicle Tracking by VTP

Intersection	Vehicles Detected		Error (%)
	VTP	True Count	
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	4127	3869	7.2

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

Table 2 indicates that VTP obtained reasonably accurate results. The error ranges between 2.1 percent and 9.1 percent, with an average error of about 7.2 percent. It is noted that VTP consistently counted fewer vehicles than were recorded manually. Two major sources for the missing detections were identified. The first source was due to the false and missed detections of the count detectors where the camera view was not ideal. Two examples can be noted here:: a largely skewed angle or the camera location too far from the intersection to have an adequate field of view. A 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 are normally observed at intersections where the main-street approach has a single lane, and a main-street through vehicle may have occasionally blocked by a left-turn or a right-turn vehicle.

One potential application of the vehicle tracking method developed in this study is to automate the process of traffic turning movement counts at intersections, which is one of the major routine tasks for traffic engineering studies. Because vehicle tracking is based on searching logical time events from a group of detectors, it can eliminate the errors associated with multiple detections resulted from occlusion in most video image systems. The shared-lane case, as the test site shown in this study, actually has the most challenges for differentiating turning movements. When an intersection has multiple lanes, the counts from exclusive lanes can be obtained directly from a single stop-bar detector, while the turning movement counts from the shared lane can be obtained using the proposed method.

Speed Measurement

Once the time events associated with main-street through vehicles are extracted, the speeds of individual vehicles can be obtained knowing the time difference between two detectors and their spacing.

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

where

V_i = speed of vehicle i , km/hr

$t_{m,n}$ = travel time between detector m and n , obtained from the time events detected, sec

$d_{m,n}$ = a video-image distance between detector m and n , meters

One critical issue found in speed calculation is to determine $d_{m,n}$, a video-image distance between detectors m and n . A video-image distance is the distance perceived by the video system, which may be different from the actual distance between the detector locations in the field. The difference is caused by the parallax effect as addressed both by McShane et al. (8) and Tian et al. (9). In video-image systems, the background pattern in pixels at the detector location is remembered by the system, and vehicle detection is achieved by recognizing the background changes due to the intervention of objects (e.g., a vehicle) between the camera and the detector. Because the camera has a limited mounting height and may also be offset to the vehicle travel path, detection may occur earlier before the vehicle actually reaches the detector location in the field. The actual distance that a vehicle traveled in the field when the detection occurred is called the video-image distance. For example, if a video detector is placed on the video image at a location that is 100 meters away from the camera (i.e., the detector is referencing to a field object that is 100 meters from the camera), a detection could occur while a vehicle only travels 80 meters from the camera. The 100 meters is the field distance, and the 80 meters is the video-image distance.

Tian et al. (9) indicated that the video-image distance is different from the actual distance in the field only when the camera has a departing view where vehicles are moving away from the camera location. While an approach view (i.e., vehicles moving toward the camera) is always desirable for speed measurement, it may not always be achievable due to physical constraints such as a proper location to place the camera or sometimes to avoid object obstructions. The same study also documented a model to calibrate the video-image distance as shown in the final form in Equation (4):

$$d_v = \alpha d_t \quad (4)$$

where

d_v = video-image distance between two detectors, meters

d_t = actual distance between two detector locations in the field, meters

α = a calibration term ranging between 0.5 and 1.0 based on normal camera set up and vehicle dimension

Field Testing

A TWSC intersection in Moscow, Idaho was selected as a testing site for our study. The main-street of the intersection runs north and south, with the speed limits of 40 km/h (25 m/h) and 48 km/hr (30 m/h) for the northbound and southbound respectively. Video taping lasted about 1.5 hours. During the same period, speeds were measured using a radar gun, and only the speed for the northbound direction was collected. The camera had to be set up with a departing view for the northbound direction due to physical constraints, which is less desirable. While recording speeds in the field, the time that each vehicle passed the intersection was also recorded. This allowed matching individual vehicles between the radar gun measurements and the measurements using the special applications developed for AUTOSCOPE. Similar to other speed measurement tools, both methods would involve errors in speed measurements, i.e., the true speed is unknown, therefore, the results presented in this paper tend to focus on investigating the correlation between the measurements. It should also be noted that a radar gun measures spot speeds while the application in AUTOSCOPE measures space mean speed. Efforts were made in the field to point the radar gun to the middle of the detectors so that the radar gun speed can best approximate the space mean speed. Figures 2 and 3 illustrate the results of the speeds measured using the special application in AUTOSCOPE (referred as AUTOSCOPE) and the radar gun, with Figure 2 illustrating the individual speeds, and Figure 3 illustrating the average speeds aggregated based on 5-minute intervals. The lines indicating ± 5 km/hr and ± 3 km/hr error ranges are also shown in the figures.

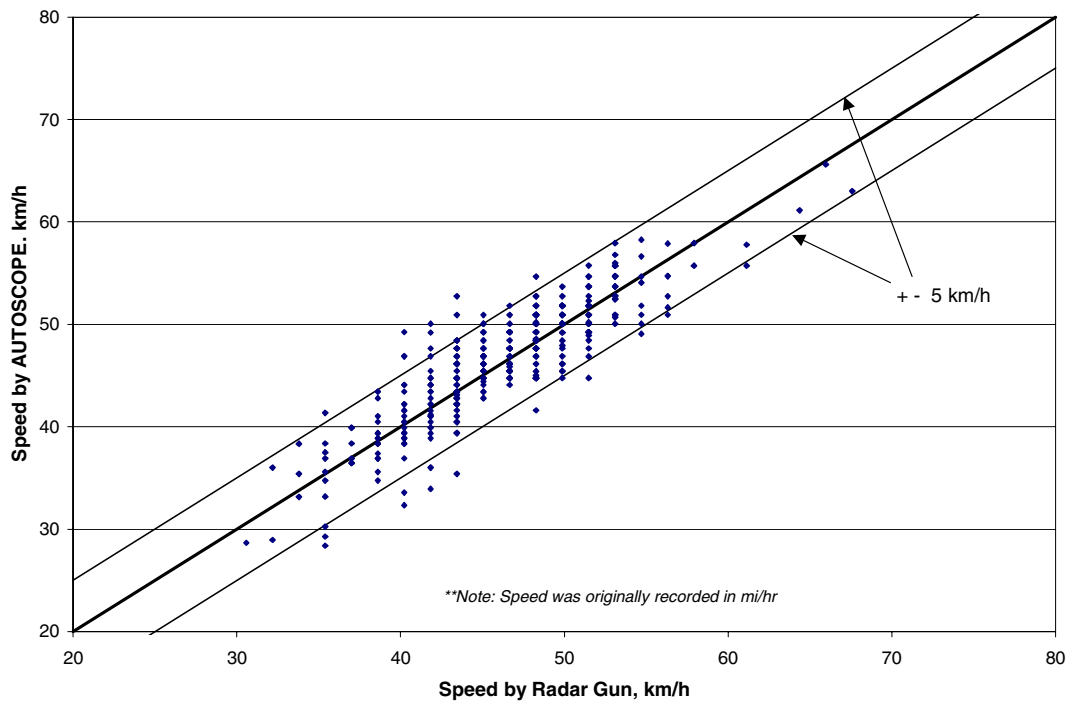


Figure 2 Individual Vehicle Speeds by AUTOSCOPE and Radar Gun

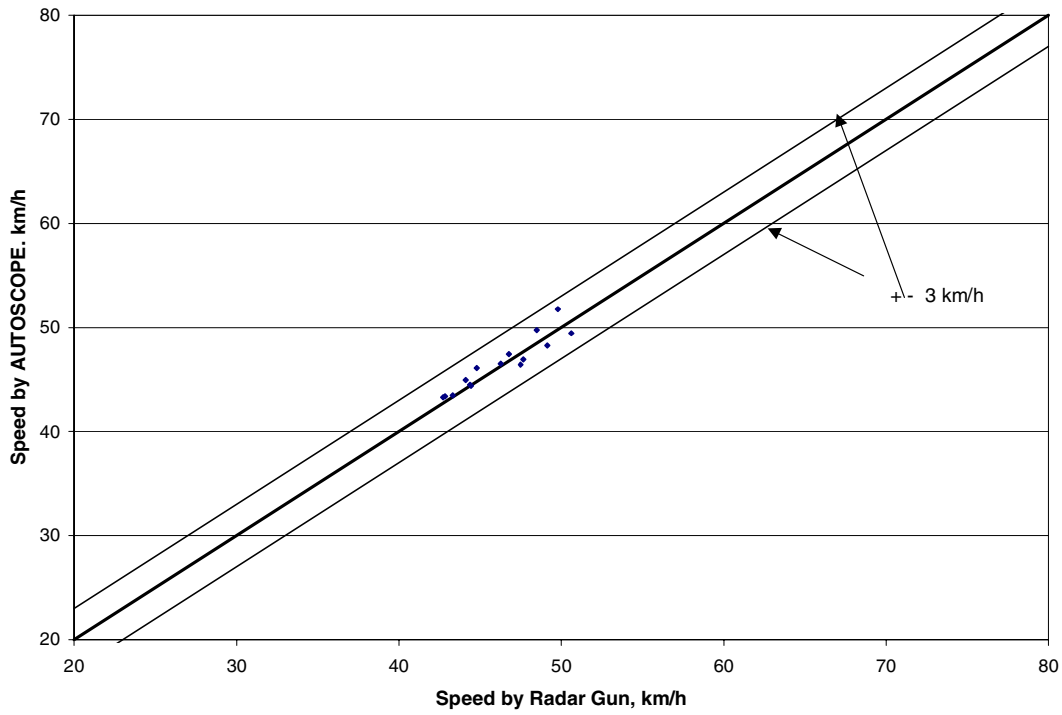


Figure 3 Average Speeds with 5-min Interval Aggregation

Figure 2 includes a total of 351 data points, each representing a pair of speed measurements using the radar gun and the proposed application of AUTOSCOPE. A total of 404 northbound through vehicles were observed in the field, which indicates that AUTOSCOPE resulted in an accuracy of about 87 percent under the case tested. Among the errors, there were 23 missed detections (vehicles that were not detected) and 30 false detections (AUTOSCOPE reported a vehicle which does not exist). Data presented in Figures 2 and 3 only include those that were matched between the two methods.

It can be seen from Figure 2 that the majority of the data points fall within the ± 5 km/hr error range. About 7 percent of the data (24 out of 350) fall outside this error range. The errors could have resulted from the following factors:

- the accuracy in detecting a vehicle passage which is affected by the detector's sensitivity
- human errors related to radar gun operations and measurements
- the difference between 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. Table 3 summarizes the paired t-test results for all the data points included in Figure 3. The statistical test indicates that the two methods yielded statistically different average speeds at the 95% confidence level ($\alpha = 0.05$), however, the difference (46.0 km/hr vs. 46.5 km/hr) may not be significant from the practical point of view. The two methods yielded statistically identical speeds when compared the average speeds aggregated based on 5-min intervals.

Table 3
Paired t-test for Sample Means

<i>Statistics</i>	<i>Radar Gun</i>	<i>AUTOSCOPE</i>
<i>Individual Speeds</i>		
Mean	46.0	46.5
Standard Deviation	5.7	6.0
Observations	351	351
t Stat	-2.92	
P	0.04	
<i>5-min Average</i>		
Mean	46.0	46.5
Standard Deviation	2.6	2.8
Observations	15	15
t Stat	-1.70	
P	0.110	

Summary and Conclusions

This paper documents a special application of AUTOSCOPE to track main-street through movement vehicles and measure their speeds at TWSC intersections. AUTOSCOPE itself does not have the capability of tracking vehicles with its basic functions and features. The special application developed in this study consists of a recommended detector layout and a vehicle tracking program. A field test was conducted and comparisons were made on the speed measurements using a radar gun and the application developed for AUTOSCOPE. The following conclusions can be reached based on the results of this study.

- The special application developed in this study overcomes the shortcomings of the available features in AUTOSCOPE in tracking vehicle movements and measuring speeds at intersections. The vehicle tracking methodology can be extended to other types of data collection, such as collecting turning movement counts at other types of intersections.

- Field testing of the application showed promising results. Under the worse case scenario with an un-ideal camera view, it reached an accuracy of about 87 percent in vehicle counts. The speeds were usually within 5 km/h error range between AUTOSCOPE and radar gun measurements when reporting individual speeds.
- Although the proposed AUTOSCOPE application may still lack the precision required for studies such as gap acceptance characteristics, it does present the potential to develop special applications and enhance the basic system features and functions of video-image systems.
- Further study is necessary to test the applications in a variety of intersection control, geometry and traffic flow conditions, such as automatic vehicle counts at all-way stop-controlled and signalized intersections.

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