Comparison of Automated and HCM Delay Measurement Techniques

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Abstract

Delay is an important Measures of Effectiveness *(MOE)* that is used in optimizing and evaluating the signalized intersection operation. Traffic engineers use different data collection methods and measurements to obtain the delay. Most data collection methods rely on manual traffic counts and observation with recorded signal display data and vehicle detection data. It is expensive and time intensive to collect and compile these field data; furthermore, it is difficult to convert these data to delay results. In this paper, the authors present a delay measuring procedure proposed by Kebab et al. *(1)* for measuring delay with a point data collection approach. This delay measurement is more effective to measure and evaluate the delay of isolated actuated signalized intersections than the queue delay method proposed in the *Highway Capacity Manual (HCM)*. The proposed method also provides system operators with an automated and reliable approach to measure field delay at signalized intersections. The proposed method is advantageous over other field delay measurement techniques.

Introduction

Delay is an important Measures of Effectiveness *(MOE)* used by traffic engineers to evaluate traffic operations at signalized intersections. *Highway Capacity Manual* (*HCM*) *(2)* uses delay to define the level of service for different movements at signalized intersections. However, delay data is hard to be generated. Traffic engineers use different data collection methods and measurements to obtain the delay. Most data collection methods rely on manual traffic counts and observation with recorded signal display data and vehicle detection data. It is expensive and time intensive to collect and compile these field data. Therefore, in this paper, the proposed delay measurement method with three major objectives: 1) Using video detection to collect field delay data, 2) Increasing delay measurement details, and 3) Decreasing the labor efforts and time consumptions, is presented. The proposed delay measurement method is based on the point detection of vehicle events at different locations on the intersection approach. The proposed delay measurement results are comparing to *HCM* delay measurement results. Statistic analyses are used to evaluate the similarity of the two methods' delay results. For consistent comparison, the *HCM* queue delay measures are adjusted to approach delay. The times required for implementation the two delay measurements are also included.

2. Delay Measurements

2.1 The Automated (Proposed) Delay Measurement and Data Collection Methods

The automated delay measurement method presented in this paper followed the approach delay measurement methodology proposed by Kebab et al. *(1)*. Three data collection points, Event X, Event 1, and Event 3, were placed on each approach to collect the individual vehicle's timestamps starting when the vehicle enters the intersection approach until it completely exits the stop bar, Figure 1. Assuming no lane change between these two points, Event 1 and Event 3, allows the adoption of a first-in first-out (FIFO) queue discipline for each given lane. Because of FIFO discipline, the n^{th} vehicle to cross Event 1 will cross Event 3 in a sequential order. As a result, the travel time for the n^{th} vehicle is the difference between the n^{th} time stamps at Event 3 and Event 1.

Depending on the locations for these three events, the travel time for each individual vehicle can be calculated by comparing the timestamps at each event. (i.e. Event X to Event 1 and Event 1 to Event 3) Travel time measurements are then converted to delays by subtracting the corresponding average free flow travel times observed from the field. The average approach delay measurement can be estimated by adding the average delay between Event X & Event 1 and the average delay between Event 1 & Event.

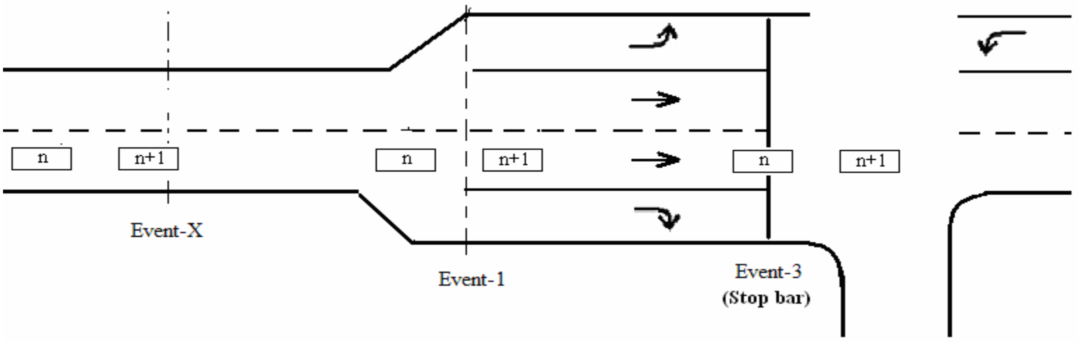

Figure 1. Event Locations for Automated Delay Measurement

While several data collection methods can be used to collect vehicle event data for the proposed delay measurement method, this paper focuses on the video-based data collection approach for testing the automated delay measurement. The video detection device, AUTOSCOPE Rack Vision 8.3, which produced by ECONOLITE Inc, was used for applying the video-based traffic data collection. The field data were recorded simultaneously for each approach at the intersections during different time periods representing different traffic flow conditions. Due to the limitations of recorded field-of-views, only data recorded from five approaches were selected for the analysis. Twenty 15-minute time intervals covering both non-peak and peak hour periods were used in this analysis.

2.2 Automated Error Checking

Raw data collected through video detection were processed to obtain approach delay values by turning movements. Data processing involved the following four steps:

1) Error checking and data filtering,
2) Measuring delay from Event X to Event 1,
3) Measuring delay from Event 1 to Event 3, and
4) Calculating approach delay by turning movements.

Steps 2 through 4 have been described in previous section. Therefore, the error checking is described in the following paragraph.

Error checking was accomplished by plotting the cumulative vehicles at upstream and downstream detector locations (i.e. Event X to Event 1) versus time as shown in Figure 2. This procedure identified vehicle event errors that may have occurred during data recording or processing. Errors were identified at one or more points where the two curves intersected. If data from a certain time period showed errors, further investigations were mandated to identify the source and the extent of the error. For data collected by video-based equipment, each approach was analyzed an average of two to three times under low flow conditions. Under moderate and high flow conditions, however, a minimum of five times is recommended because of the higher probability of recording detection errors. Data with minimum recorded errors was used to generate approach delays.

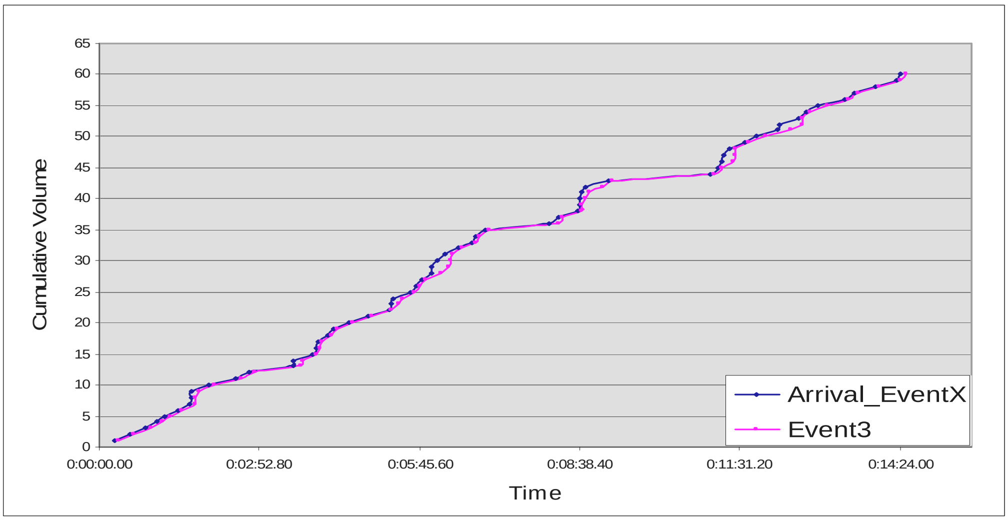

Figure 2. Cumulative Vehicles Versus Time

2.3 *HCM* Field Delay Measurement Procedures

Average queue delay for each approach was determined according to the procedures described in *HCM* 2000 Chapter 16 Appendix A. This method was based on direct observation of vehicle-in-queue counts in a pre-defined time interval. The delays were manually calculated by following a series of procedures recommended in *HCM*.

Two observers are needed for applying the *HCM* delay measurement unless the volume is light. One observer keeps track of the number of vehicles in queue for each cycle in the survey period as well as the last vehicle in each lane that stops because of the traffic signal. The second observer records the counts of total vehicles arriving during the survey period and total vehicles arriving during the survey period that stop one or more times. Then, the second observer adjusts the error that may have occurred by applying the sampling technique as well as acceleration-deceleration correction factor. The *HCM* delay is computed by adding the delay for vehicle-in-queue and the acceleration/deceleration correction delay.

However, in order to compare the queue delay measured using *HCM* procedures, the queue delay was adjusted to approach delay in order to compare with proposed delay. Reilly (*3*) defined the approach delay as the delay upstream of the intersection. It consists of three delay components: 1) stopped (queue) delay, 2) acceleration delay, and 3) deceleration delay. The acceleration delay has two components: before and after the approach's stop bar. In comparison to the delay components of the approach delay, the queue delay in the *HCM* only consists of stop delay and acceleration delay. The queue delay can be adjusted to approach delay by adding the average deceleration delay to the corresponding queue delay. The deceleration delay is calculated using the recorded travel time form the Event X to the vehicle stopping point minus the FFTT from the Event X to the stopping point, *Equation* 1. The equation for adjusting the queue delay to approach delay can be found in *Equation* 2.

$$d_d = TT_{x \to stop} - FFTT_{x \to stop} , \qquad (1)$$

Where:

$TT_{x \to stop}$ = Travel time from the Event X location to the vehicle stopping point, and

$FFTT_{x \to stop}$ = FFTT from Event X to the vehicle stopping point.

$$d_{ap(n,m)}{}^{k} = d_{q(n,m)}{}^{k} + d_{d(n,m)}{}^{k} , \qquad (2)$$

Where:

$d_{ap(n,m)}{}^{k}$: Approach delay at time interval *k*, at intersection *n* and for *m* movement,

$d_{q(n,m)}{}^{k}$: Queue delay at time interval *k*, obtained from the *HCM* method, at intersection *n* and for *m* movement, and

$d_{d(n,m)}{}^{k}$: Deceleration delay at time interval *k* (obtained using the vehicle tracking method) at intersection *n* and for *m* movement

3. Analysis of Results

In this section, the automated delays are compared with the corresponding *HCM* delays to determine whether these two delay measurements can yield similar delays. If the delays obtained by these two measurements are similar, the comparison of data process time between two delay measurements was then used to verify that the proposed delay measurement can use less labor efforts and time consumptions.

3.1 Comparison between Automated Delay and *HCM* Delay Measurements

After applying automated delay measurements, it is necessary to draw a comparison between the automated delays and the *HCM* delays so as to analyze the correlation statistically. Using the statistical analyses, the automated method could be judged on its consistency with HCM delay results and be utilized in place of the manual data collection method for future research.

Figures 3-a through 3-d list the approach delay comparisons between two delay measurements and the R^2 values for the overall and each individual turning movements. Analysis of Variance (ANOVA) was used to test the null hypothesis indicating there is no difference between the mean delays for the automated and *HCM* delays at the 0.05 level of significance levels. The F-value was 0.25, smaller than the F-critical value of 4.1, which means the statistical result failed to reject the null hypothesis of equality of the mean values for the two delay measurements. Additionally, the value of the coefficient of determination (R^2) was 0.9757. The same results were obtained for the other two movements (LT and TH) except for some right turn movements.

It is because the *HCM* delay measurement has difficulty in measuring the delays for the shared through/right movement. Besides, the video detection results on the right turn lane are relatively more easily affected by its accuracies from some environmental or human factors, such as pedestrians waiting on the curb. For the reasons addressed here, the right turn movement is difficult to obtain accurate delay data for both the *HCM* and video-based methods. Thus, the R^2 of the right turn movement represents a relatively low value as compared with the other two movements. However, the statistical results still indicated that the automated delay measurement can yield similar delays as *HCM* for the majority of movements. The R^2 values for the TH, LT, and RT phases were 0.9255, 0.9407, and 0.6085 respectively.

Another statistic analysis, Analysis of Covariance (ANCOVA), was used to examine the correlations of overall movement between these two delay measurements. The purpose in applying this analysis was to test the null hypothesis indicating there is no difference between the slopes for the automated versus the *HCM* delays at the 0.05 level of significance levels. Based on the ANCOVA results for this comparison, the statistical result was lacking enough evidence and was failing to reject the null hypothesis of equality of the slopes for the two delay data of overall movement. From the slope and intercept of this comparison, the automated delay measurement yielded similar delays as the *HCM* delay measurement. (The slope was 0.99). Therefore, it can be concluded that the automated delay measurement can yield the similar delays as the *HCM* delay measurement. The relationships of the two delay data can be found in Figure 3-a.

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In summary, the results of the statistical analyses and R^2 values showed that the automated delays closely matched the *HCM* delays. The following section will compare the time requirement for these two delay measurements. The comparison result could be a basis for determining whether the automated delay measurement can substitute the *HCM* delay measurement for future researches.

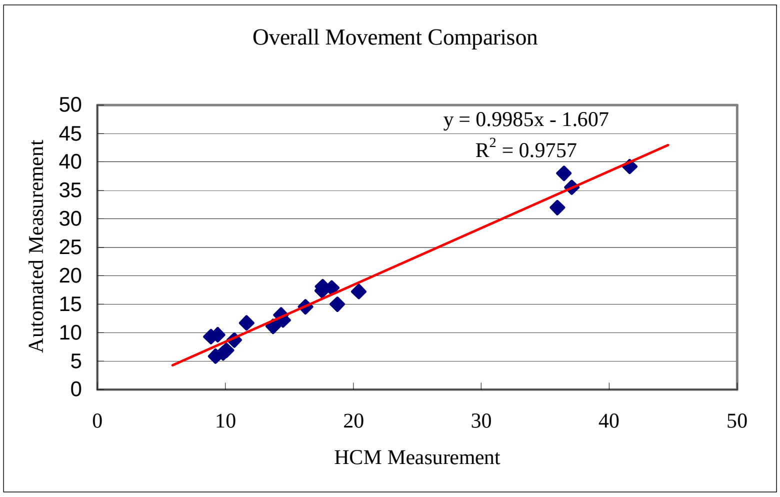

Figure 3-a. Approach Delay Comparisons-Overall Lanes

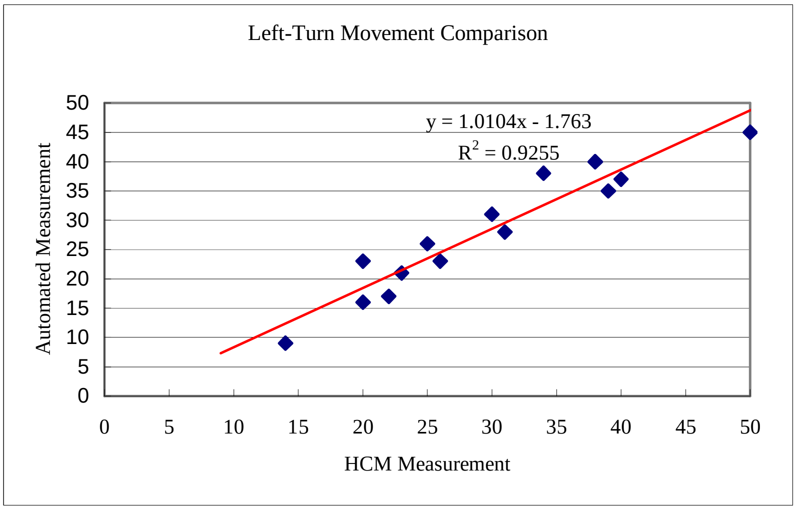

Figure 3-b. Approach Delay Comparisons-Left Turn Lane

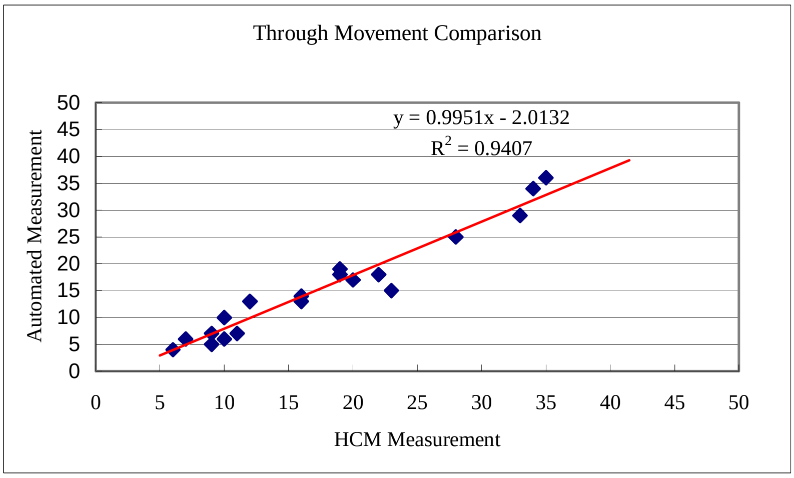

Figure 3-c. Approach Delay Comparisons-Through Lane

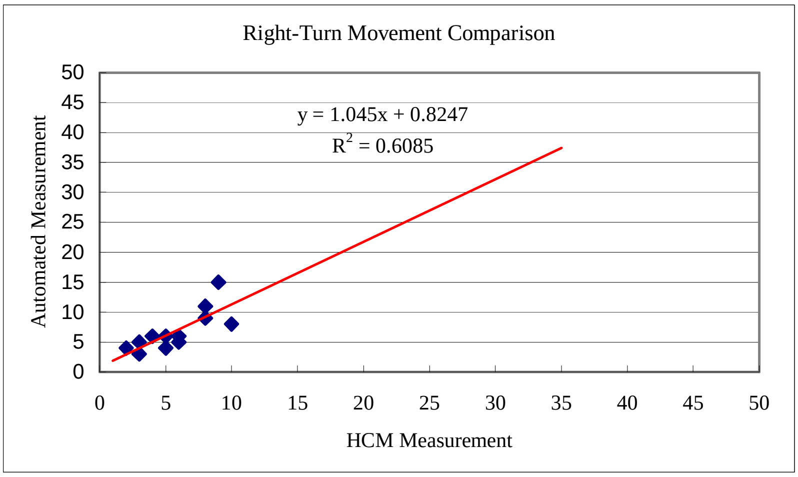

Figure 3-d. Approach Delay Comparisons-Right Turn Lane

3.2 Time Requirement Comparison

The times required for implementation varied between the two delay measurement methods. This is an important factor to select a delay measurement technique. The time required for implementation can be summarized as follows:

- The proposed method requires approximately fifteen minutes to perform the data recording and requires an additional fifteen minutes to extract the recorded data. Approximately, it requires thirty minutes per each 15-minute interval. Contrary to the *HCM* delay method, increasing volume will not directly affect the time required to extract the data. However, modest increases in data extraction time will occur with an increase in volume because of an increased likelihood for recorded detection errors caused by environmental or mechanical factors. A better video detector scheme can decrease the probability of recording error data.

- The *HCM* method requires relatively longer time than the proposed method under low and moderate congested conditions, approximately one hour per each 15-minute interval. However, this time will significantly increase with increased queuing. It is because additional vehicle-in-queue count zones will be required, increasing the number of vehicle counts.

4. Conclusion and Recommendations

The objective of this paper is to find a more efficient alternative data collection method and field delay measurement to improve the existing data collection and delay measurement methods. This paper presents an automated procedure for measuring approach delay, based on a video-based vehicle events data recording method at different locations along intersection approaches. In the analysis, vehicle event data was collected using video-based data collection systems and then used to estimate average delay for each movement. The automated delay measurement results were compared against the *HCM* delays obtained through manual recoding of individual vehicles throughout the intersection approach.

References

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(3) Reilly, W. R., Gardner, C. C., and Kell, J. H. (1976). *A Technique for Measurement of Delay at Intersections.* Federal Highway Administration, National Research Council, Washington, D.C.