Testing of the Tapeswitch System for Determining Vehicle Speed and Lateral Placement

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This research evaluated the use of a pressure-sensitive electrical strip switch, or tapeswitch detector, to record vehicle speed and lateral placement simultaneously. Tapeswitch can be cut to any length and used as a vehicle detector as a pneumatic tube is used. A series of tapeswitch detectors, with the appropriate electronics and recording equipment, determines the speed and lateral placement of a vehicle.

The tapeswitch system, used as part of the Bridge Shoulder Width Study at West Virginia University (WVU) (1), tested vehicle reactions (speed and lateral placement) to changes in bridge shoulder width and type of barrier.

As a part of the research, three smaller studies were undertaken to evaluate the precision and accuracy of the tapeswitch system. The first of these compared the tapeswitch system with time-lapse photography to determine lateral placement and with radar to determine speed. The second study used an instrumented vehicle equipped with a fifth wheel to determine speed when the vehicle passes over a tapeswitch and a fine powder to determine placement. The final study was a theoretical study involving error analysis.

The tapeswitch detectors are installed as a trap, consisting of three detectors: Two are installed perpendicular to the direction of travel 5.49 m (18 ft) apart, and one is installed in the middle at 45 deg to the direction of travel and extending 1.83 m (6 ft) into the roadway so that traffic in only one lane is recorded.

FORMULA FOR SPEED AND LATERAL PLACEMENT

Figure 1 shows the tapeswitch trap being used to measure vehicle speed and placement. The times at which vehicles cross tapeswitches 1, 2, and 3 are $t_1$, $t_2$, and $t_3$. The time to transverse is $t_L$ for distance $D$ and $t_0$ for distance $L$. These are related as follows:

$$t_0 = t_2 - t_1$$  \hspace{1cm} (1)

$$t_L = t_3 - t_1$$  \hspace{1cm} (2)

From these times the speed, $V$, and the placement, $P$, may be calculated.

$$V = L/t_L$$  \hspace{1cm} (3)

$$P = (Lt_0/t_L - R) \tan \theta$$  \hspace{1cm} (4)

The values for $L$, $D$, and $R$ as used in the study are $L = 5.49$ m (18 ft), $R = 1.83$ m (6 ft), and $\theta = 45$ deg.

COMPARISON WITH TIME-LAPSE PHOTOGRAPHY

The tapeswitch technique and time-lapse photography technique were evaluated simultaneously under three separate test conditions for determining vehicle lateral placement and speed:

1. WVU Coliseum parking lot ($L = 1.83$ m, $R = 0$ m, $\theta = 45$ deg);
2. WVU Coliseum parking lot ($L = 5.49$ m, $R = 1.83$ m, $\theta = 45$ deg); and
3. I-79 field test ($L = 5.49$ m, $R = 1.83$ m, $\theta = 45$ deg).

STATISTICAL ANALYSIS OF RESULTS

The data collected for the three study conditions were compared by statistical methods. The significance test used for the statistical analysis of the data collected for this research involves the Smith-Satterthwaite $t'$ statistic (2). The comparisons of the mean lateral placements for all cases show no significant differences at the 5 percent level. However, the comparison of means between vehicle speeds for all cases showed significant differences at the 5 percent level. Further, the data tended to indicate a systematic error in the radar speed measurements.
SECOND FIELD TEST OF THE TAPESWITCH SYSTEM

The second field test used an instrumented test vehicle with a towed fifth wheel in an isolated section of a large parking lot. Approximately 15 runs were made over the trip for each 16.1-km/h (10-mph) increment between 16.1 and 96.5 km/h (10 and 60 mph). Also, vehicle placement varied from as near the shoulder line as possible to the maximum limit of the tapeswitch. The speeds for each run were recorded both in the vehicle and at the tapeswitch printer. The stationary recorder also measured and recorded the vehicle placement on the pavement; a fine powder was sprinkled along the tapeswitch prior to each run, and thus distance from a reference point to the tire track was measured.

A total of 118 test runs were performed. The measured field values obtained for speed and placement were designated "actual," and the values obtained from the tapeswitch system "theoretical." A linear-regression equation was thus developed to relate the actual speed and placement to the theoretical speed and placement by using a linear model, which was indicated from a graphical analysis of the data. The models developed for the theoretical speed and placement using regression analysis are

\[ V_t = 0.6148 + 1.0056 V_A \quad R_t^2 = 0.99901 \quad (5) \]

and

\[ P_t = 0.04308 + 0.99161 P_A \quad R_t^2 = 0.99647 \quad (6) \]

where

- \( V_t \) = theoretical speed,
- \( V_A \) = actual speed,
- \( P_t \) = theoretical placement,
- \( P_A \) = actual placement, and
- \( R^2 \) = coefficient of simple determination.

The \( R^2 \) values of 0.999 and 0.995 for calculated speed and placement respectively indicate a good fit of the data. Tests to determine whether the coefficients \( b_1 \) and \( b_2 \) differ significantly from zero and one respectively indicated that the constant term for both equations is significantly different from zero at the 5 percent level and that the regression coefficients on the actual values is not significantly different from one. If there were perfect agreement between the two methods of determining speed and placement, the constant term would be zero and the regression coefficient on the actual values would be one. It is highly likely that the difference is due to a calibration constant term in the placement equation and a constant error introduced by the fifth wheel.

ERROR ANALYSIS

The error in velocity measurement and lateral placement is found by using the formulas developed for the tapeswitch trap.

\[ \Delta V = -L(\Delta t/t_0^2) = -(\Delta V_t^2)/L \quad \text{if } \Delta t << t_0 \quad (7) \]

and

\[ \Delta P = L \tan \theta \left[ (t_0 + t_L)/t_1 \right] = (1 + D/L) V \tan \theta \Delta t \quad (8) \]

where

- \( \Delta T \) = error in time,
- \( \Delta V \) = error in speed,
- \( \Delta P \) = error in placement,
- \( \Delta L \) = error in end tapeswitch location,
- \( \Delta \delta \) = error in middle tapeswitch angle, and
- \( \Delta R \) = error in middle tapeswitch location.

The accuracy of the timing equipment was tested by using a switch-tripping mechanism with relays. Twenty-five comparisons were made by using the testing device. The difference was either 0 or -0.1 ms. Therefore, the error associated with the field equipment was assumed to be ±0.1 ms.

Two sources of errors resulting from errors in tapeswitch placement are considered: The errors in the distances \( L \) and \( R \) and the errors in the angle \( \theta \). The effect of the errors in \( L \) can be determined by considering an error of \( \Delta L \) and examining its effect on speed and placement. In this case:

\[ \Delta V = (\Delta L/L) V \quad (9) \]

The errors in placement can occur in two ways: errors in lateral distance between tapeswitches and errors in the angle of the diagonal tapeswitch.

\[ \Delta P = \Delta R \tan \theta \quad (10) \]

for errors in \( R \), \( \Delta R \), and

\[ \Delta P = \Delta L(D/L) \tan \theta \quad (11) \]

for errors in \( L \), \( \Delta L \).

In considerations of speed, the maximum errors to be expected under the most adverse circumstances are less than 0.8 km/h (0.5 mph). Similarly, the maximum error in placement is (60 mm) 0.2 ft. These calculations are for the most adverse combination of circumstances and rarely occur. The probable error, which is much lower, shows what can be expected. This is less than 0.4 km/h (0.25 mph) for speed and less than 15 mm (0.05 ft) for placement. The minimum level shows what can be obtained if circumstances are fortunate or if a conscientious effort at error reduction is undertaken.

CONCLUSIONS

Three different tests were run on the tapeswitch system that simultaneously records vehicle speed and lateral placement. In the first test, the tapeswitch system was compared with time-lapse photography for recording vehicle placement and a radar meter for recording speed. The tapeswitch system results are more precise for both vehicle speed and lateral placement. In the second test, the tapeswitch system was compared with vehicle speed recorded by a towed fifth
wheel. Placement was compared by using the tapeswitch system and a fine powder spread on the ground. Again, compatibility in both cases was obtained. The third test consisted of a theoretical error analysis that determined that the maximum likely error in speed was less than 0.8 km/h (0.5 mph) and error in placement was less than (61 mm) 0.2 ft. Both of these results are well within acceptable limits. Therefore, the tapeswitch system has proved to be an accurate means for obtaining vehicle speed and lateral placement simultaneously.

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REFERENCES