Traffic Flow Data Acquisition Using Magnetic-Loop Vehicle Detectors

STAN STERN, System Development Corporation, Santa Monica, Calif.

One means of acquiring validation data for digital computer simulation of traffic flow in a freeway diamond interchange will be through the use of magnetic-loop vehicle detectors. Actual interchange performance will be monitored by direct measurement of vehicle parameters (count, size, and velocity), leading eventually, through the validation process, to a realistic simulation model.

Techniques were developed to extend existing loop-detector capabilities, permitting direct measurement of vehicle parameters (measurements were available heretofore only on a statistical basis) and experiments were conducted to determine detector/sensor-loop response characteristics.

A practical sensor-loop configuration, which was developed for the validation runs and tested in controlled experiments, provided an accurate picture of the over-all traffic pattern.

Measurement accuracy was investigated, considering the effects of varying vehicle height and of closely following vehicles (tailgating), such as might be expected in heavy traffic. Measurement errors due to tailgating were attributable to recovery-time limitations inherent in the loop-detector circuit.

The techniques described in this paper can be used, employing commercial loop-detectors, for traffic applications in which it is desired to determine vehicle velocity and/or size directly in addition to vehicle counting.

•THIS PAPER discusses one aspect of a traffic flow study being conducted at the System Development Corporation: the development of a technique to obtain direct vehicle parameter measurements using magnetic-loop vehicle detectors.

The measurements will provide data to be used in validating the digital computer simulation of vehicular traffic flow in a diamond interchange between a freeway and an arterial street. The general aim of the research program, which also includes mathematical analysis of traffic models related to the diamond interchange problem, is to gain an understanding of the phenomena involved in traffic flow on surface arteries, freeways, and their interconnecting ramps.

In the validation process, data acquired by the loop-detectors and by synchronized motion pictures taken from a hovering helicopter will be compared in the laboratory with the computer simulation outputs and, if the computer model does not perform realistically, indicated changes will be incorporated into the model and the entire validation process repeated. This iterative procedure is expected eventually to result in a realistic simulation model. The techniques employed to utilize loop-detectors for validation data acquisition, and the results obtained, are the subjects of this paper.

The magnetic-loop vehicle detector was originally developed, and applied in practice, for traffic counting and signal control (1). This device operates in conjunction with an inductive wire loop placed in the traffic lane. The loop leads are brought out to the

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roadway and connected to the vehicle detector. The loop excitation signal, generated by an oscillator in the detector, induces a magnetic field surrounding the loop. The passage of a vehicle through the magnetic field is sensed and a relay is activated. The duration of relay closure (which ends when the vehicle leaves the magnetic field) varies directly with the length of the vehicle and inversely with its velocity. A detailed description of the loop-detector is given in Appendix A.

Vehicle velocity and size cannot be determined independently using a single loop-detector. Determination of traffic speed has been obtained in practice on a statistical basis, by assuming an average car length, with the duration of relay closure (pulse width) giving an indication of traffic speed.

To obtain the required computer validation data, it was necessary to develop a technique for applying the loop-detector to measure vehicle parameters directly. This objective was accomplished by employing the detectors in pairs and using a special (but simple) calibration procedure to provide the required velocity measurement accuracy using unmodified commercial detectors.

It is planned to operate loop-detector pairs taped to the roadway at various positions throughout the diamond interchange to measure vehicle count, length (vehicle classification), and velocity. The outputs of the detectors will be sampled periodically by a multiplexer whose output will be recorded by an instrumentation tape recorder. A timing track and synchronizing pulses will also be recorded in addition to a verbal annotation. The recorded data will be returned to the laboratory where it will be reduced from the tape recordings and entered into the Philco 2000 digital computer using an input channel of the RL101 Real Time Input-Output Transducer.

Development of a loop configuration for the freeway validation tests was based on theoretical considerations confirmed empirically by means of controlled experiments, and verified in actual traffic conditions. The loop configuration chosen is based on the dimensions of the diamond interchange lanes.

THEORY OF PARAMETER MEASUREMENTS

The technique we employed to measure vehicle length and velocity uses a basic sensor-unit consisting of a pair of loops, separated by a known distance (parallel to the direction of traffic), and connected each to its own detector. As a vehicle passes over

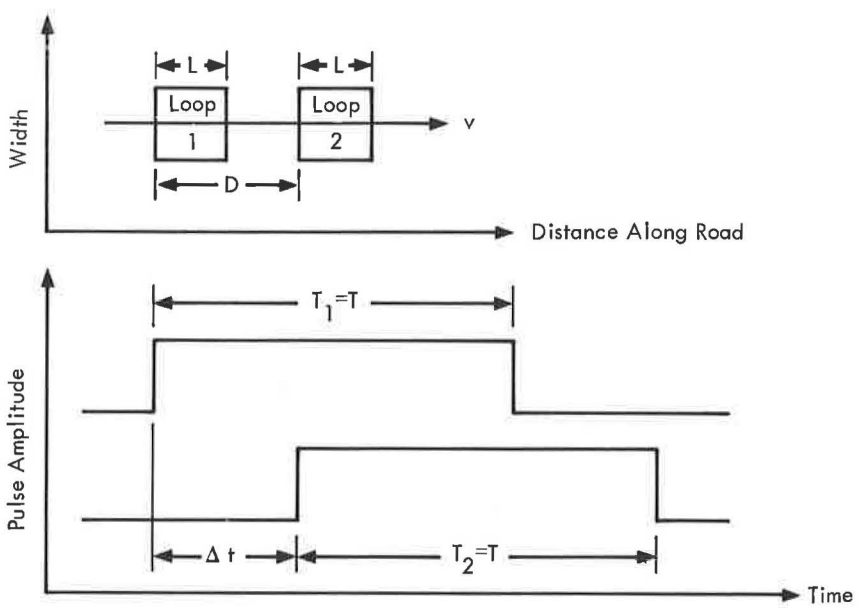

Figure 1. Loop-pair (ideal response).

the loop-pair each detector produces a pulse. Vehicle velocity is computed from the time delay between pulses and vehicle length from the pulse width.

Suppose a vehicle of length a traverses the loop-pair (Fig. 1) with constant velocity, v. The loop length is L and the loop-pair separation is D. The magnetic field extends slightly beyond the loop boundaries and the effective field length L' depends on the sensitivity of the detector. Each of the two detectors produces a pulse, and the time delay between pulses is denoted by Δt.

Vehicle velocity is determined by dividing the loop-pair separation by the time delay between pulses.

$$v = \frac{D}{\Delta t} \tag{1}$$

The pulse width, T, is the time required for the vehicle to traverse the field, L', along its entire length, a. Hence,

$$T = \frac{L' + a}{v} \tag{2}$$

Substituting Eq. 1 in Eq. 2

$$a = D \frac{T}{\Delta t} - L' \tag{3}$$

Equations 1 and 3 express vehicle velocity and length in terms of pulse width and the time delay between pulses. The effective length of field L' can be taken as equal to the loop length L with little penalty (for vehicles traversing the loop near its center)* since vehicle classification information does not require great precision.

INITIAL EXPERIMENTS

Initial experiments were conducted using a pair of RCA VeDet vehicle dectors with associated square loops, each consisting of three turns of No. 20 wire. The loop dimensions were 6 ft by 6 ft, as recommended by the equipment distributor.

A photoelectric system was employed as a velocity measurement standard. In operation, a pair of photosensors was placed in positions normal to the vehicle path and parallel to the leading edge of the inductive loops. The light-collimating tube of each of the sensors (which were mounted on tripods) was sighted along the loops' leading edges at a pair of light sources located on the other side of the traffic lane. Figure 2 shows the experimental setup. A vehicle passing over the loop-pair interrupted the light beams from the lamps, activating the photoelectric sensors. The photosensor output pulses were combined by connecting them to the differential inputs of one channel of a two-channel pen recorder, while the vehicle detector pulses were similarly connected to the other recorder channel. The permanent record was analyzed by comparing the two channels, using the optical data as a standard.

This measurement technique was then applied in vehicle velocity tests to determine detector accuracy, using a loop-pair separation of 10 ft and driving the test vehicle over the center of the loops. When each detector was calibrated according to the manufacturer's recommended procedure, the error in the velocity measurement was too great (typically 7 percent), with respect to the optical data.

Further tests conducted to determine the cause of this velocity measurement error revealed that it was due to unequal detector threshold levels, which caused the relative position between loop and vehicle at which the detector activates to be different for the two detectors. Hence, the loop-pair velocity measurement is in error by an amount that depends on the difference in the detector threshold levels. This effect is not sur-

*This is explained under the heading "Adjacent Loop-Pairs as a System."

Figure 2. Experimental setup.

prising considering that the detectors were designed for individual vehicle counting, and act independently of one another. No means is provided for detector calibration which uses the loop-pair as a system for velocity measurements. It became apparent, therefore, that a technique must be developed to calibrate a pair of detectors as a system by equalizing their sensitivities. In addition, it was recognized that such a scheme, to be practical, should not employ complex setup procedures.

CALIBRATION TECHNIQUE

The calibration method developed inserts an external capacitance directly in parallel with the inductive loop. When the capacitance is removed, the tuned circuit experiences a phase shift similar to that experienced when a vehicle enters the loop's magnetic field. The detector sensitivity is adjusted until the relay activates for a narrow range of capacitance values, but not outside that range. The procedure is then repeated for the other detector, similarly establishing its sensitivity setting. The calibration technique is described in Appendix B. This technique was applied in calibrating two pairs of TACDET vehicle detectors. The units tested during this study (RCA VeDet and Fischer and Porter TACDET) are only two of a number of commercially available vehicle detectors, which operate on the same principle. The two units were similar in their operation and circuit configurations. Although no attempt was made to test many different detectors, the techniques described herein should be generally applicable.

Additional velocity tests were conducted using the experimental setup previously described. Typical velocity measurement errors of 2 percent were obtained with respect to the optical standard, using a loop-pair separation of 10 ft. The accuracy of the velocity measurements suffered no observable deterioration during operation at ambient temperature for ½ hr (the time period over which it is planned to acquire validation data). No attempt was made to evaluate long-term accuracy or to test the detectors under a wide range of temperatures. Such testing would be required for applications involving continuous detector usage. These results confirmed the effectiveness of the calibration technique in reducing the velocity measurement error.

DEPENDENCE OF MEASUREMENTS ON VEHICLE VELOCITY

Experiments were conducted to determine the effects on velocity and pulse-width measurements of varying vehicle velocity. The experiments used a pair of 4-ft square

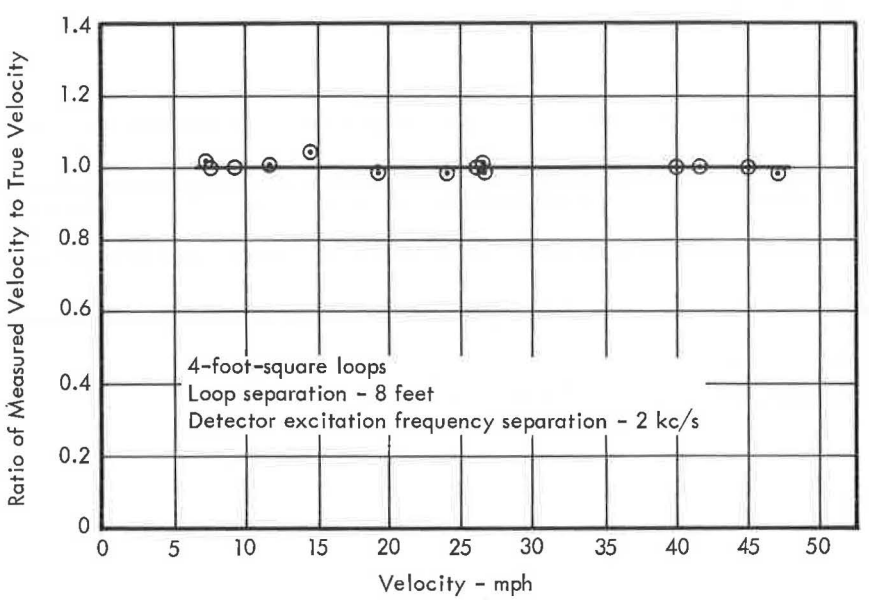

Figure 3. Accuracy of velocity measurement vs velocity.

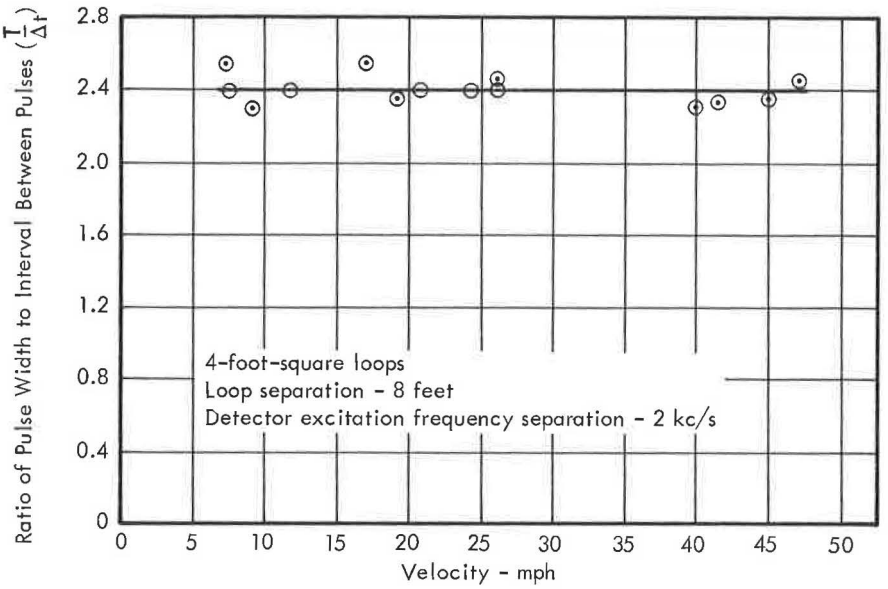

Figure 4. Normalized pulse width vs velocity.

loops separated by 8 ft (from leading edge to leading edge). The vehicle detectors were calibrated and a test vehicle was driven over the center of the loops at various speeds. The photosensor data were used to calculate true vehicle velocity.

Figure 3 plots the ratio of measured velocity to true velocity as a function of true velocity; the accuracy of the velocity measurements is independent of vehicle velocity.

Figure 4 plots the ratio of measured pulse width to the interval between pulses $T/\Delta t$ as a function of vehicle velocity. It is apparent that the ratio $T/\Delta t$ does not vary with velocity. This is consistent with the theory, as can be seen by solving Eq. 3 for $T/\Delta t$.

$$\frac{T}{\Delta t} = \frac{a + L'}{D} \tag{4}$$

Substituting $L' = L = 4$ ft, a (the overall length of the experimental vehicle as given in the manufacturer's specifications) = 15.3 ft, and D = 8 ft gives $T/\Delta t = 2.4$, which, it is evident, provides a nice fit for the data points. Hence the measured pulse width agreed with the expected value at all velocities. Christensen and Hewton (1) tested two different vehicle detectors and found that the actual pulse width differed from the calculated (expected) value by a factor that depends on vehicle velocity. The calibration curves they plot (ratio of measured to calculated pulse width vs velocity) for each detector have appreciable slopes. A plot of measured to expected pulse width ratio vs velocity for the vehicle detector tested at SDC would be a horizontal line at ratio unity, permitting the direct determination of vehicle length without correction of the measured data.

These results (Figs. 3 and 4) demonstrate that vehicle velocity and length can be determined directly from the equations previously presented for a vehicle crossing the loops at their centers. The curves reveal no significant effects due to varying vehicle velocity for the velocity range investigated. No special calibration curves are required to provide for different vehicle velocities.

LOOP CONFIGURATION

Experiments were conducted using various loop sizes and loop-pair separations. The final configuration (Fig. 5) comprises a pair of 4-ft square loops, consisting of 4

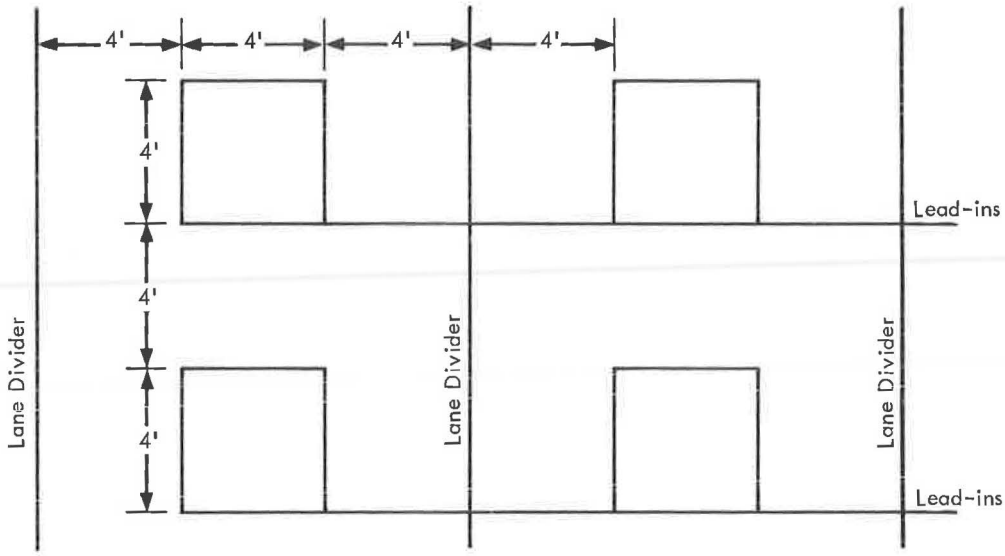

Figure 5. Loop configuration (adjacent 12-ft lanes).

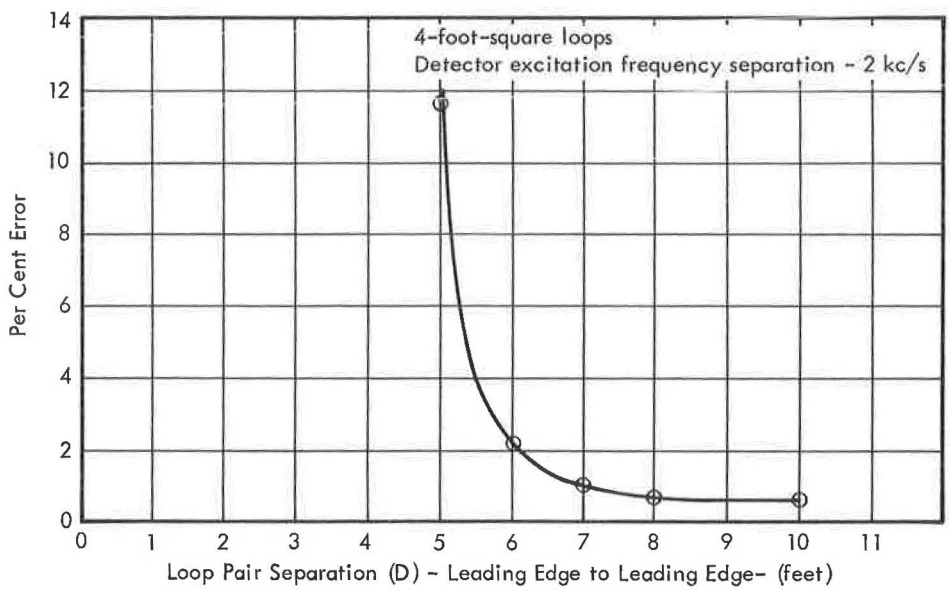

Figure 6. Accuracy of loop-pair velocity measurement vs loop separation.

turns of No. 20 wire, located in the center of each 12-ft lane and separated (leading edge to leading edge) by 8 ft.

The distance between loop-pairs in adjacent lanes (8 ft between adjacent conductors) was found to yield satisfactory results with respect to the numbers of missed counts (vehicles passing undetected between lanes) and double counts (vehicles being detected by adjacent loop-detector pairs as separate vehicles in each lane).

Loops were located at the lane center because parameter measurement is optimized when the vehicles cross the loops at their centers. It is expected that the great majority of vehicles will most often occupy the center of the freeway lanes. Therefore, placing the loops at the center of the lanes will yield the best measurements.

The width of the loops (4 ft) was dictated by the combination of lane-center location in the 12-ft wide freeway lanes and 8-ft adjacent loop spacing. Loop length should be no smaller than loop width to maintain the height of the magnetic field. If the height of the field (which depends on the smaller loop dimension) is too small, the reliability of counting high-slung vehicles (tractor-trailers, etc.) is impaired.

It is desirable that the loop-pair separation be small enough to detect lane-changing vehicles accurately. Close-spacing, furthermore, provides a more nearly instantaneous velocity indication (the vehicle has less time to change its speed in a shorter distance). However, when the loops become too closely spaced, the magnetic interaction between them degrades parameter measurements.

Figure 6 shows the variation in the velocity measurement error as a function of loop-pair separation. Nominal vehicle speed was 20 mph and detector excitation signal frequencies were 2 kc/sec apart. The error was relatively constant for large loop separations but when the separation was reduced to 5 ft (1 ft between adjacent conductors) the error increased to 11.7 percent. Additional data to observe the effect of frequency separation were obtained by operating the detectors 6 kc/sec apart in the 10-ft and 5-ft separation positions. In this case, the change in velocity measurement accuracy was less severe (2 percent error at 5-ft separation) because magnetic coupling was reduced as the circuits were operated farther apart in frequency. An 8-ft separation (leading edge to leading edge) was chosen as a compromise between loop proximity and error minimization.

ADJACENT LOOP-PAIRS AS A SYSTEM

Experiments were conducted considering adjacent loop-pairs as a system. All 4 lead-in wires for each couple of adjacent loops were run, in proximity, to their respective detectors. Care was taken that adjacent loops and the members of each loop-pair were operated with their detector excitation frequences at least 2 kc/sec apart to avoid interactions. The roadway was divided longitudinally into 1-ft strips and a test vehicle repeatedly driven along the strips, through the system. Figure 7 shows pulse width as a function of vehicle position for a single detector at a vehicle velocity of 25 mph. When the vehicle crossed directly over a loop the pulse width was relatively constant, but as

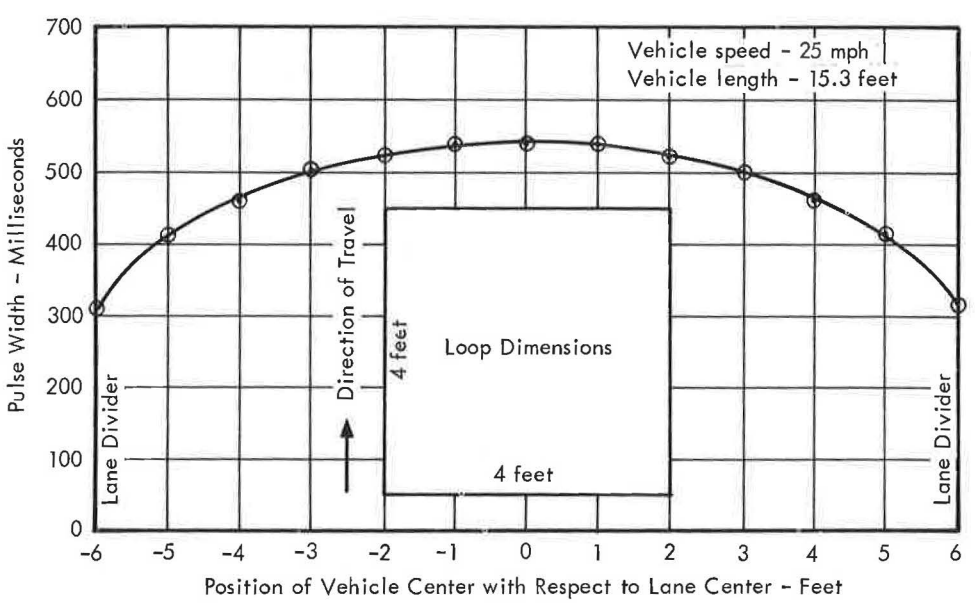

Figure 7. Variation of pulse width with vehicle position in the lane.

it passed farther off the lane-center to the sides of the loop, the magnetic field became narrower and pulse width decreased. (The effective length of field L' decreased as the vehicle traversed the loop farther off center.) The minimum pulse width occurred when traveling down the lane divider. The mid-lane value of pulse width was consistent with the theory, as can be seen by solving Eq. 2 with $L' = L = 4$ ft, a (the overall car length given in the manufacturer's specifications) = 15.3 ft, and $v = 36.65$ ft/sec (25 mph). The measured pulse width agreed with the calculated value (0.530 sec) within 2 percent. The velocity measurement error with respect to the measurement standard was relatively constant throughout the lane, even approaching the lane divider, because the detectors were so well matched during calibration that the pulses from each detector in the detector-pair remained accurately spaced even though the individual pulse widths varied with vehicle position in the lane. Beyond the lane divider, detector response ceased. Left-hand-lane traffic was not detected by right-hand-lane detectors and vice versa. There was no measurable effect due to magnetic interaction between the closely spaced lead-in wires.

There was a narrow region at the lane divider in which both pairs of adjacent detectors responded. In this region, the vehicle barely covered the adjacent magnetic fields, producing narrow pulses in each of the detectors (corresponding to the end points in Fig. 7). Such a condition will exist, however rarely, for vehicles that occupy a lane-straddling position.

INTERPRETATION OF DATA

Referring to the previously derived equations, values of $D = 8$ ft and $L = 4$ ft give

$$v = \frac{8}{\Delta t} \tag{5}$$

and

$$a = 4\left[2\left(\frac{T}{\Delta t}\right) - 1\right] \tag{6}$$

as the two equations defining vehicle velocity and length. These parameters are determined by measuring the pulse width and the interval between pulses with standard instrumentation techniques and performing the necessary computations.

The first of the two pulses should be used for pulse-width determination, since it corresponds to the interval during which velocity is measured.

TRAFFIC TESTS

Adjacent loop-pairs were taped to the road surface in each of the 12-ft westbound lanes of Olympic Boulevard in Santa Monica, just outside the SDC facility. The four detectors were calibrated during a brief lull in traffic. Data, including narrative tape recordings, were recorded during several different traffic conditions. Figure 8 shows the test configuration; Figure 9 the vehicle detectors and recording equipment. The recorded data were then analyzed and it was determined that the loop detectors provided an accurate picture of the overall traffic-flow pattern. The following observations were noted.

Lane Changing

Vehicles changing lanes over the loop-pairs sometimes activated all four of the detectors, and sometimes only three of them. The detectors associated with an active loop-pair reflected the passage of lane-changers by generating pulses of unequal width. The unequal-width pulses corresponded to the different positions at which the two loop-pair members were traversed (e.g., the 5-ft and 4-ft points in Fig. 7). The pulse pattern created by a lane-changing vehicle (a pair of pulses with unequal widths from one detector-pair, accompanied by a single pulse or two likewise dissimilar pulses

Figure 8. Traffic test configuration.

Figure 9. Traffic test equipment.

from the detector-pair associated with the adjacent lane) is characteristic and can be used to recognize lane-changers.

Lane Straddling

An occasional vehicle traversed the loops riding the centerline too faithfully to be detected as a lane-changer. In this event, a pair of equal-width pulses resulted from the detector-pairs associated with each lane. As previously noted, the pulses resulting from lane-straddling vehicles are of relatively short duration. Furthermore, the right-hand-lane and left-hand-lane pulse-pairs differ from one another in their widths if the vehicle favors one or the other of the adjacent lanes (Fig. 7). Observation of a record of the detector pulses shows a pair of short pulses from one detector-pair accompanied by a pair of even shorter pulses from the adjacent lane's detector-pair. The shorter pulses begin later and end correspondingly earlier than the longer ones. In this case, the characteristic pulse pattern of a lane-straddling vehicle can be distinguished from separate vehicles simultaneously present in each lane.

Any tendency of the lane-straddling vehicle to move horizontally creates an imbalance in the pulse widths of each of the individual detectors, making it difficult to determine whether the vehicle is straddling, or changing, lanes.

Certain Trucks

The passage of multisection vehicles employing long booms yielded more than one pulse, as though they were separate vehicles following each other closely (tailgating).

Tailgating

When one vehicle closely followed another, the detector-pairs in all cases detected the presence of both vehicles. Analysis of the data, however, led to the suspicion that the measured lengths of the tailgating vehicles were too small.

TAILGATING EXPERIMENTS

Experiments were conducted to determine the effects of tailgating on measurements of vehicle length and velocity. Two cars were driven over the center of a loop-pair, both tailgating and individually, at 10-15 mph. A pair of 6-ft square loops separated by 10 ft (leading edge to leading edge) was used. The photoelectric system previously described provided a velocity measurement standard.

Table 1 gives the results of the experiments. The indicated vehicle length was obtained for each vehicle when driven separately over the loops. The vehicles were then

TABLE 1

RESULTS OF TAILGATING EXPERIMENTS

Run	Vehicle	Measured Vehicle Length (ft)	Length Measurement Error[a] (%)	Total Velocity Measurement Error (%)	Velocity Measurement Error Due to Tailgating (%)
1	A	16.62	0	-3.8	—
2	A	16.00	3.7	-2.7	—
1	B	13.60	10.6	+6.5	10.3
2	B	13.60	10.6	+5.6	8.3

[a]Indicated vehicle lengths without tailgating (vehicle A = 16.62 ft, vehicle B = 15.22 ft) used for tailgating measurement error comparison.

driven over the loops, car B tailgating car A, in each of two runs. In each run the measured length of the tailgating vehicle differed from its indicated length without tailgating by 10.6 percent.

The error in the velocity measurement for vehicle A (2.7 to 3.8 percent), was due to the slight mismatch in detector sensitivities remaining after calibration. The total velocity measurement error for vehicle B was equal to the algebraic sum of the first error (residual sensitivity mismatch) and the error due to tailgating. The error due to tailgating was then computed from the algebraic difference between the total velocity measurement error and the error due to sensitivity mismatch. The velocity measurement error due to tailgating was found to be 10.3 percent for the first run and 8.3 percent for the second run.

The measurement errors are attributable to recovery time delays in the vehicle detectors. The vehicle length measurement error occurs because the detectors do not have enough time to recover from the passage of the first vehicle before the entrance of the second vehicle. The detectors trigger late, producing shorter-than-normal pulses that are interpreted as a shorter vehicle. Detector recovery time delay is significant despite the fact that the minimum available detector time constant was selected (the so-called pulse mode of operation).

If each detector in the pair had identical operating characteristics, the detectors' recovery time delays would be the same. The velocity measurement, which depends on the time interval between pulses, would then be unaffected. The existence of the additional velocity measurement error (due to tailgating) indicates that there is a mismatch between the detectors' recovery times. These recovery time delay problems are inherent in the circuit design of the vehicle detectors, which were originally intended merely for vehicle-counting applications. To reduce these effects it will be necessary to make circuit modifications.

The time lag between the passage of the rear bumper of car A and the front bumper of car B, the tailgating car, was approximately 0.35 sec in each run as determined by the photosensors. For a typically heavy traffic situation, in which the vehicles trail each other by approximately $1\frac{1}{2}$ to $2\frac{1}{2}$ sec, the measurement errors would be somewhat less, because the detectors would more nearly recover to the quiescent operating state.

The experimental results indicate that the accuracy of both length and velocity measurements will suffer under heavy traffic conditions because of the limited time available for the detectors to recover between the passage of successive vehicles. The measurements can be expected to be approximately 90 percent accurate in extremely heavy traffic, increasing in accuracy for lighter traffic. A higher degree of accuracy in heavy traffic can result only from the employment of improved vehicle detectors. If greater accuracy is required, a detector modification program should be undertaken.

EFFECTS ON MEASUREMENTS OF VARYING VEHICLE HEIGHT

A question was raised concerning how much the velocity measurement accuracy would be affected by varying vehicle height, such as might occur if a vehicle bounced as it passed over the loops.

Experiments were conducted in which a foreign-made, adjustable-body-height automobile was driven over the center of a loop-pair at a nominal speed of 15 mph with various pre-adjusted body heights. Table 2 gives the results of the experiment. Four different body-height positions were used. The first three are normal driving positions. Position 4, which is normally used only for tire-changing, provided an extreme operating height for the experiment. In each case the pulse width was normalized by multiplying Eq. 2 by the velocity to give the sum $L' + a$.

As the body height was raised, the vehicle entered each loop's magnetic field slightly later and left it slightly earlier, resulting in a decreasing pulse width. This effect was caused by the tapering contour of the loop's magnetic field (variation of L' with vehicle height). Subtracting the length of the loop (6 ft) from $L' + a$ for vehicle length determination shows that the measured vehicle length varies from 15.96 ft (a_o) to 14.56 ft, a variation of 8.8 percent in the indicated vehicle length, over the $3\frac{3}{4}$-in. range of body heights. This is indicative of the sort of variation in vehicle length measurement that would be caused by vehicles of differing body heights (i.e., high-slung vs low-slung).

TABLE 2

EFFECTS OF VARYING VEHICLE BODY HEIGHT

Preset Height Position	Relative Body Height (in.)	Pulse Width Expressed in Feet (L′ + a)	Indicated Vehicle Length, a (ft)	Assoc. Percent Velocity Measurement Error $\left[\frac{a_o - a}{2D}\right] \times 100$ Percent	
				10-Ft Loop Separation	8-Ft Loop Separation
1	0	$21.96\ (L' + a)_o$	$15.96\ (a_o)$	0	0
2	+ 3/8	21.63	15.63	1.65	2.05
3	+1	20.71	14.71	6.25	7.8
4	+3 3/4	20.56	14.56	7.0	8.75

The experimental velocity measurements were quite accurate since, of course, the vehicle crossed each loop with the same body height. The velocity measurement error that would have occurred if the body height had varied from its minimum value when crossing into the first loop to the new value when crossing into the second loop (or vice versa) approximates the effect that vehicle-bounce would have on the velocity measurement accuracy. The assumption made here is that the vehicle would move with a bounce-period equal to twice the loop-pair separation. The velocity measurement errors (with respect to the minimum-height velocity measurement) that would be associated with the varying pulse widths are calculated by extrapolation from the pulse-width data. The loop-pair used (10-ft separation) would, under the circumstances assumed, measure vehicle velocity with an error of 7 percent for a vehicle bouncing 3¾ in. Further extrapolation for an 8-ft loop-pair separation (chosen for the verification data runs) indicated that the velocity measurement would be in error by 8.75 percent for a 3¾-in. bounce. These are worst-case conditions. Even for a 3¾-in. bounce of the proper bounce-period, the error contribution due to bouncing would be something less than maximum, depending on the exact phase relationship between the bounce-cycle and the loops.

The foregoing represents a somewhat academic approach to the study of the effects of vehicle-bounce on velocity measurement. Important questions must be answered, i.e., how much bounce and what bounce-period can be expected at various speeds in a practical situation, etc., before measurement errors can be fully assessed. In any event, care should be exercised to locate the loops in smooth, flat sections of roadway to minimize vehicle-bounce.

CONCLUSION

The major advantage of the technique discussed in this paper is that it permits the application of commercially available magnetic-loop vehicle detectors to the measurement of individual vehicle velocity and length. It does so by operating a pair of detectors as a system. This is made practical by the application of a simple, convenient calibration procedure. The measurements are quite accurate in light traffic, but approach 90 percent accuracy when the vehicles follow one another closely (for an unmodified TACDET operating in the pulse mode).

The loop configuration developed is consistent with the diamond interchange application, in which it is planned to use a large number of loop-pairs with their associated detectors to acquire the simulation validation data. For narrower lanes (less than 12 ft wide), the loops should be offset from lane-center to preserve the 8-ft adjacent conductor separation to minimize double counting.

The techniques described are usable for traffic applications in which it is desired to determine vehicle velocity and/or size directly in addition to counting. Some applications that come to mind are the following:

1. 85th percentile determination of speed for the establishment of speed limits.
2. Early warning speed indication for traffic approaching areas of limited distance visibility.
3. Speed limit enforcement.

ACKNOWLEDGMENT

We would like to express our appreciation to the California Division of Highways for their cooperation in making the traffic tests possible.

REFERENCE

1. Christensen, A., and Hewton, J. T. Developments in Conventional Ground-Based Detectors. Proc. of Highway Conf. on Future of Res. and Dev. in Traffic Surveillance Simulation and Control, U. S. Bur. of Public Roads, 1964.

Appendix A

VEHICLE DETECTOR DESCRIPTION

Figure 10 shows a block diagram of the vehicle detector. The sinusoidal signal from a crystal-controlled oscillator is connected, through an emitter follower, to the inductive loop. Variable capacitors are provided to tune the loop to the oscillator frequency. The voltage across the loop is applied to a phase detector, where its phase is compared with that of the reference oscillator signal. The filtered phase detector output voltage is amplified in a dc amplifier and connected to a two-transistor relay driver amplifier.

When a vehicle enters the loop's magnetic field, it produces a phase shift in the voltage across the loop, which raises the phase detector's output voltage. This voltage is amplified in the dc amplifier, activating the relay through the relay driver amplifier. The dc amplifier is capacitively coupled to the relay drivers to make the circuit insensitive to long-term dc voltage variations. A choice of time constants is provided. The maximum time constant provided permits the detector to continue monitoring the presence of a vehicle stalled in the field of influence, to the exclusion of all other passing vehicles. Minimum time constant should be selected to minimize detector recovery time.

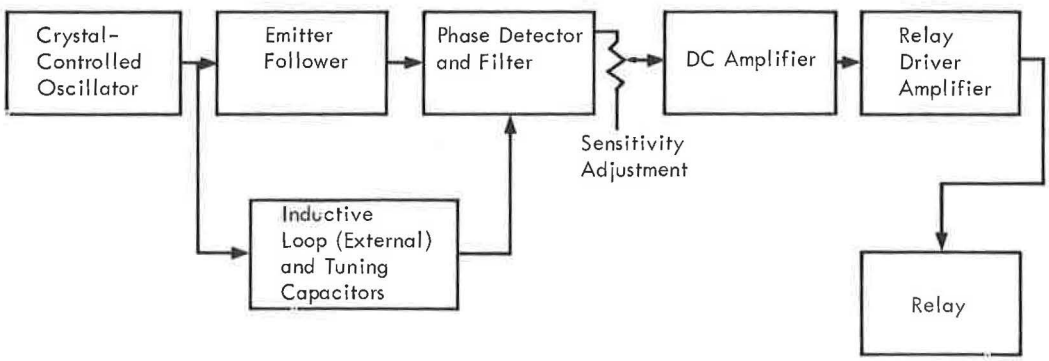

Figure 10. Vehicle detector block diagram.

Plug-in crystals are available in 2 kc/sec steps from 90 to 110 kc/sec.

A sensitivity adjustment provides a method of varying the relative position between loop and vehicle at which the relay activates.

Appendix B

VEHICLE DETECTOR CALIBRATION TECHNIQUE

The calibration circuit (Fig. 11) is connected to the vehicle detector's 'loop' terminals (the detectors usually provide monitor terminals, which can be used for this purpose). The state of the detector relay is monitored by means of a visual indicator circuit. If not already provided in the detector, a relay monitoring circuit can be constructed by connecting a 6-volt battery and a No. 47 indicator bulb in series with the normally open relay contact terminals. Two slightly different capacitance values (C1 = 25.2 picofarads, C2 = 28.2 picofarads) are used.

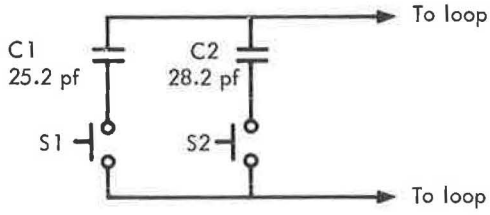

Figure 11. Vehicle detector calibration circuit.

The detector sensitivity is adjusted to a maximum. Pushbutton switch S1 is first depressed, connecting C1 across the loop, and then released, removing it. If the indicator lamp lights when C1 is removed (indicating that the relay has been activated) the detector sensitivity is decreased and the procedure repeated until a sensitivity position is reached for which the lamp does not light. Switch S2 is then operated in the same manner, introducing C2 and a slightly greater phase shift. The relay will now activate unless the detector sensitivity has been set too low. If this is the case, the sensitivity is increased slightly until the lamp lights when S2 is released after being depressed.

The detector is properly adjusted when a sensitivity setting has been found such that the relay activates when S2 is operated and fails to activate when S1 is operated.

When the sensitivity of the first detector is thus precisely set, the same procedure is repeated for the second.

Minimum detector time constant should be used during calibration to permit the detector to stabilize rapidly.