Abridgment

Traffic Data-Collection Systems: Current Problems and Future Promise

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Evaluations were undertaken of off-the-shelf automatic traffic data-collection systems to examine their capabilities in two specific areas: data collection for speed compliance and vehicle classification by type. A prototype system developed by the United Kingdom's Transport and Road Research Laboratory (TRRL) was also briefly tested. System performances in the speed mode were not outstanding although several systems showed promise, whereas in the vehicle-classification mode, performance was not good and most systems experienced serious problems. Significant problems were also encountered in the use of pneumatic tubes as sensors. In the classification mode most systems also suffered from inadequate classification schemes (i.e., number and definition of categories). However, the TRRL system performed quite well; it uses a more sophisticated classification scheme (proposed as an alternative to current schemes) and incorporates inputs from both presence and axle sensors.

Transportation engineers deal continually with large amounts of traffic data generated in a variety of ways and for numerous purposes. Because many states are experiencing financial problems, data-collection activities are being reviewed from several perspectives: whether the data are really needed, what accuracy is required, and what the best ways are to collect them. Institution of the national maximum speed limit (NMSL) and the attention brought by the Federal Highway Administration (FHWA) to developing the Highway Performance Monitoring System (HPMS) have also focused attention on data-collection techniques.

Although several states have investigated and/or invested in a different automatic data-collection system, most data collection in the areas noted has been done manually. Not only is this a labor-intensive operation, but there are other problems that may be introduced, e.g., seasonal bias of data and unreliability of observers. In spite of the apparent need for labor- and cost-saving systems, until recently no organization had undertaken a comprehensive review of currently available systems or their performance. In light of this, FHWA contracted for an extensive evaluation of such systems with regard to how well they could satisfy data needs in two specific areas: collecting speed-compliance data (with regard to the NMSL) and classifying vehicles by type (e.g., on the basis of axle spacing and overall length).

Manufacturers' names will not be used with regard to which system was best or worst; rather, the discussion will be limited to comments about system capabilities in general. [The exception to this will be in the discussion of sensing devices (indirectly) and experimental systems developed in the public domain.] However, findings with regard to specific systems may be found in final reports to FHWA (1,2). Systems that were evaluated were produced by the following manufacturers: Leupold and Stevens, Inc.; Safetran Traffic Systems, Inc.; Streeter-Amet; Redland Automation, Inc. (Sarasota Division); and Golden River Corporation. A prototype unit from the United Kingdom's Transport and Road Research Laboratory (TRRL) was also tested as part of the program but will not be discussed directly.

GENERAL DESCRIPTION

The discussion that follows is directed to available off-the-shelf systems that are marketed for general purposes and does not necessarily apply to special-purpose systems used in a research context.

In general, systems used for speed monitoring or for vehicle classification have four basic components: sensing devices (sensors), which provide the essential indication, or signal, of a vehicle's presence and movement; detectors, which receive the signals from the sensors and amplify and/or interpret them; and the recorder and processor, which receive the signals from the detectors and calculate the speed or assign a category, record that information, and perform whatever manipulations of the basic data are necessary to present them in final form (e.g., individual vehicle speeds and frequency counts). Although these components essentially serve the functions indicated, most systems do not actually have separable components beyond the sensing device. In addition, all systems are currently limited to using only one type of sensing device in a given installation.

Most systems are capable of producing either speed or classification (by type) data but not both concurrently. However, it should be noted that when a system is operating in the classification mode, a speed calculation is made internally as a prerequisite to classification.

Sensors that are commonly used include inductance loops, pneumatic tubes, coaxial cables, and tape-switches, although the last is typically used only in research situations. Inductive loops are typically imbedded in the pavement and are thus permanent and hence most costly, whereas the tubes and cables are used on the road surface and have shorter lives. Although commonly used, easy to install, and fairly inexpensive, the tubes are most prone to damage: The inherent high visibility of the installation led to one of the most prevalent problems in recent testing in Maine--purposeful damage by truckers (i.e., locking their trailer brakes and skidding over the installation). Hence, life expectancy is unpredictable at best. It should also be noted that air leaks are often hard to find and intermittent operation of systems is possible. The latter is a serious problem since total volumes or populations of classification categories may be incorrectly estimated from data that appear to be good.

The visibility of cables is apparently considerably less than that of tubes (comparative tests showed that the tubes were always seen and damaged by truckers, whereas no attempts were made on cable sensor installations). Easy to install, the cables are longer lasting than tubes and will resist purposeful damage but will eventually succumb to snowplows, studded tires, and sharp dragging objects that breach their protective rubber coating. Variations of the cables (T-shaped cross sections imbedded in pavement) have been developed and used by TRRL with considerable long-term success.

There are several other sensing devices that have at least some potential for collection of vehicle-classification and/or speed data, including the self-powered vehicle detector (3,4), the magnetic-gradient vehicle detector (5,6), optical sensing (7), audio signals (8), and electronic timers (9). Radar can also be used for speed data collection although it is generally conceded that for large-scale collection programs it is cost-inefficient; it has limitations in high-volume situations in being able to record the speeds of specific vehicles in queues and in introducing bias toward lower speeds given the proliferation of citizen-band radios and radar detectors. Although potential use of other such sensors is not barred, their use in the near future in automatic systems seems unlikely.

PROBLEMS WITH EXISTING SYSTEMS

The existing data-collection systems were subjected to a series of tests to evaluate their performance in field situations, i.e., how well they performed in general and whether they did what they were purported to do. The systems were tested on separate occasions in the speed mode and in the vehicle-classification mode.

Results in Speed Mode

Results in the speed mode were as follows:

1. Primary problems were missed vehicles and inaccurate speeds.
2. Inaccurate speeds adversely affected speed-compliance percentages; there was a general high skew that was especially noticeable in the tails of the speed distribution (e.g., percentage over 55, 65).
3. There was variation in accuracy from unit to unit (same manufacturer) or from site to site (same unit).
4. When test system was compared with base system(s) such as radar, fifth wheel, and/or optical timer, average speeds of samples of vehicles were typically within 1 mph.

Results in Vehicle-Classification Mode

The following results were found for the vehicle-classification mode:

1. Classification schemes were based only on either overall length (loop based) or number of axles and spacing (axle sensor based, e.g., pneumatic tubes).
2. Sensitivity of loop detectors caused significant errors.
3. Minimum length error: 5-8 percent of vehicles were not measured within ±5 ft.
4. Maximum length error: 82 percent of vehicles were not measured within ±5 ft (loop detector out of tune).
5. Minimum percentage of axle-based classifications: 15-20 percent of vehicles were misclassified.
6. Maximum percentage of axle-based classifications: two-thirds of vehicles were misclassified.

Sensor Problems

The sensor problems included the following:

1. Axle-sensor-based units were limited to the number of axles and axle spacings.
2. Loop-based units were limited to overall length only.
3. Nature of axle sensors was nonpermanent.
4. Undetected intermittent failure of axle sensors (especially tubes) is possible.
5. Tubes are highly visible and often purposefully damaged.

Problems with Other System Components

The following are problems with other system components:

1. System-loop detector adjustments can be critical (and are variable by site).
2. There are numerous minor breakdowns.
3. Missed or misclassified vehicles are not obviously due (in some instances) to sensor failures.
4. Classification schemes are typically simplistic.

Positive Aspects of Systems

The existing systems are not without positive aspects. For example, it is clear that the technology exists to process information from either axle or presence sensors. In addition, some fairly sophisticated differentiations among vehicles were incorporated into the different systems' classification schemes.

CURRENT AND PROPOSED VEHICLE-CLASSIFICATION SCHEMES

As part of the larger question of what data are really needed, there is some debate over what constitutes an adequate vehicle-classification (by type) scheme (10). For currently available systems, the number of available categories varies from four, based entirely on overall length (raw data from loops), to eight, based on the number of axles and axle spacings (raw data from axle sensors). Users of vehicle-classification data, however, appear to desire more detail than is currently being provided. For example, FHWA has examined schemes with from 7 to 32 categories and currently suggests 13 in the Highway Performance Monitoring System (HPMS) program (11). At this point, then, there appears to be a significant gap between what available systems can deliver and what users desire.

The currently proposed schemes themselves also have some problems since they do not necessarily reflect logical differentiations among vehicle types. Some of the problems with currently discussed schemes are summarized below (based on FHWA-supplied definitions and 1977 FHWA truck-weight study data):

1. There is substantial overlap in classifications of automobiles; with the trend in downsizing, current cutoffs (e.g., subcompact versus standard or compact) are inappropriate--for wheelbase, < 100 in; for overall length, < 180 in.
2. There is overlap between vans, light pickups, and standard sedans or station wagons.
3. There is overlap between light trucks and pickup trucks.
4. No system is accurate on motorcycle differentiation.
5. Bus categories overlap with some trucks; buses are seriously overestimated.

In an effort to provide a somewhat more reasonable departure point for further discussion of vehicle classification, the scheme in Table 1 is presented. It is characterized by the following: (a) it is based on information that can be obtained from axle sensors alone, (b) it recognizes some obvious problems with some differentiations and eliminates them, and (c) it considers the frequency of encountering certain types of vehicles (i.e., how important a specific category is). Three comments are pertinent. First, the scheme is based on data from FHWA and assumes that the shortcomings of those data do not seriously compromise the characteristics of different types of vehicles (e.g., some vehicle

Table 1. Vehicle-classification proposal (14 categories).

Vehicle Category	Description	Proposed Rule
E-1	Passenger cars, light trucks, vans	Axles = 2; wheelbase ≤ 10 ft
E-2	Heavy-duty pickups, delivery trucks, 2A6T's	Axles = 2; wheelbase > 10 ft
E-3	Cars and light trucks with one- or two-axle trailers	Axles = 3 or 4; 1,2 spacing ≤ 10 ft; 5.5 ft < 2,3 spacing < 22 ft
E-4	Three-axle single-unit trucks	Axles = 3 and not E-3
E-5	Trucks and semitrailers (2S2)	Axles = 4 and not E-3; 3 ft ≤ 3,4 spacing ≤ 10 ft
E-6	Four-axle single-unit trucks	Axles = 4 and not E-3; 3 ft ≤ 2,3 spacing ≤ 5 ft
E-7	Other four-axle combinations	Axles = 4 and not E-3, E-5, and E-6
E-8	Trucks and semitrailers (3S2)	Axles = 5; 2 ft ≤ 4,5 spacing ≤ 10 ft
E-9	Other five-axle combinations	Axles = 5 and not E-8; 3 ft ≤ 2,3 spacing ≤ 5 ft
E-10	Trucks and semitrailers plus full trailers (2S1-2)	Axles = 5 and not E-8 or E-9
E-11	Trucks and semitrailers plus full trailers (3S1-2)	Axles = 6 and 5,6 spacing > 7 ft
E-12	Trucks and semitrailers (3S3)	Axles = 6 and not E-11; 4,5 spacing ≤ 6 ft
E-13	Other six-axle combinations	Axles = 6 and not E-11 or E-12
E-14	Other seven-or-more-axle combinations	Axles = 7 or more

Note: An optional category would be for 2S1 truck and semitrailer combination.

types are underrepresented although it is assumed that recorded wheelbases, etc., would not differ from a scientifically drawn sample of the type). Second, the scheme does not attempt certain differentiations that could be made if overall length data were also considered (e.g., buses could probably be better differentiated). Third and last, the proposed scheme is presented only as a point of departure for discussion by data users and others and not as the ultimate scheme.

CONCLUDING REMARKS AND RESEARCH SUGGESTIONS

Speed calculation and vehicle classification by length, wheelbase, axle spacings, and number of axles are conceptually straightforward; e.g., the implicit decision rules for given categories are easily stated in terms of overall length and/or the information from axle sensors. While the currently marketed systems tested typically used only a limited number of categories, the more complex classification schemes do not necessarily imply the development of new technology but rather a refinement of that which exists. There are, however, several areas that would benefit from additional work and/or attention. These are outlined below:

1. A permanent, or at least longer-lived, axle sensor should be developed. At this point, it appears that some derivation of the coaxial cable would be the most likely candidate.
2. Prototype systems should be developed to examine the problems, if any, in interfacing coaxial cables with existing systems.
3. A single classification scheme should be developed for use by the states (for their own purposes) and FHWA. Such a scheme should recognize, for example, trends in vehicle sizes, especially in the passenger-car categories.
4. Systems need to be developed that can process inputs from a variety of sensing devices (e.g., from only coaxial cables or from a cable-and-loop combination).
5. System internal logic needs to be versatile enough to accommodate minor changes in the number and parameters of categories.
6. All systems should have at least the option of printing out hourly data (inherently useful) so that the time of potential breakdowns can be estimated.
7. All systems should have straightforward and fully documented diagnostics, calibrations, and adjustments that can be made by the user.
8. Systems that can simultaneously classify vehicles by type and collect speed data should be investigated.

The Automatic Vehicle Classification System (AVCS) developed by TRRL and tested in Maine (12-16) meets many of the above requirements, and the test results clearly demonstrated that reasonably sophisticated traffic data-collection systems can be developed and used successfully in the field and that the resulting data will have applicability in several areas of concern to engineers, planners, and policymakers.

There are, however, several questions that remain to be addressed by FHWA, the states, and other potential users of such systems and/or the resultant data:

1. Is the demand for such sophisticated data so widespread as to warrant the development of systems capable of delivering them?
2. Can sufficient consensus be achieved among the potential users on the form of required data so that basic parameters required for classification and minimum or maximum system capabilities can be defined?
3. Will the states and other local and nongovernment users pursue purchase of new systems if such data are not required and system acquisition is not supported by the federal government?

The last point to be made concerns the capabilities of systems that use more or less permanent sites (i.e., AVCS or AVCS-type system) versus those that might be truly portable (i.e., that use temporary road-surface sensors). Current sensor technology, and even that only available in prototype form, basically constrains sophisticated equipment to using permanent sensor arrays that require a large initial commitment of time and resources to implement any comprehensive data-collection program; more primitive systems can deliver lower-quality data much more cheaply. In this regard, it is not clear whether a truly portable system (including temporary sensors) can provide the same quality of data as an AVCS-type system in a permanent installation. It is apparent that large quantities of good data can be collected; are they worth the cost of acquisition?

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Analysis of TRANSYT Platoon-Dispersion Algorithm

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The development of an analytical solution to the recursive platoon-dispersion formula used in TRANSYT models of traffic flow is presented. Flow rates in the predicted platoon measured at the kth interval of the jth simulated cycle are expressed in terms of demand and capacity rates at the source intersection in addition to signal-control and travel-time parameters. It was found that the TRANSYT recursive formula implicitly contains a cycle factor that results in an underestimation of the toal flow rate simulated. An estimate of that error has been formulated, which can be applied as a constraint on the required simulation time in TRANSYT. The analytical solution also provided insight into the determination of critical intersection spacings below which signal coordination becomes feasible.

The proliferation of digital computer model applications in the areas of traffic flow and control in the past decade has led to the successful development of several widely used traffic signal operations models, such as Network Simulation Model (NETSIM), Signal Operations Analysis Package (SOAP), Traffic Network Study Tool (TRANSYT), and Traffic Signal Optimization Program (SIGOP) (1-4).

TRANSYT, a program for traffic signal timing and coordination initially developed in the United Kingdom by Robertson (5), has been successfully applied at many intersections in Europe and the United States. The TRANSYT-7F version, for example, has recently been used in the National Signal Timing Optimization Project (6), which encompassed 11 cities and approximately 500 signalized intersections in the United States.

The fundamental principle of traffic representation in TRANSYT-type models is platoon-dispersion behavior. Simply stated, as a queue of vehicles leaves the stopline on the green indication, its shape is altered along the downstream link in a manner reflective of the desire of individual drivers to maintain comfortable time headways. Thus, although the flow rate at the stopline is equivalent to the saturation rate in the presence of a queue and to the demand rate thereafter (assuming undersaturated operation), the flow patterns measured at an observation point t seconds downstream of the stopline would be considerably different.

Mathematically, platoon-dispersion behavior is expressed by the following recursive relationship:

$$IN(k + t) = F \times OUT(k) + (1 - F) \times IN(k + t - 1) \qquad (1)$$

where

IN(k + t) = flow rate in kth time interval of predicted platoon at observation point;
OUT(k) = flow rate in kth time interval of original platoon at stopline;
t = β times average platoon travel time from stopline to observation point [β is an empirical travel-time factor expressed as ratio between travel time of leading vehicle in platoon