Traffic Sensing System for Houston High-Occupancy Vehicle Lanes

CLYDE E. LEE AND LIREN HUANG

The typical high-occupancy vehicle (HOV) facility in Houston, Texas, is a single, 22-ft-wide, reverse-flow lane situated in a freeway median and separated from the adjacent freeway main lanes on each side by a concrete median barrier. Arrays of inductance-loop vehicle detectors in the pavement, along with remotely controlled television cameras on high poles, are used routinely for surveillance and traffic monitoring activities. As part of a research study designed to identify and evaluate traffic sensors that feasibly can be used in lieu of the loop detectors, especially on bridges, the Center for Transportation Research, the University of Texas at Austin, designed, installed, and evaluated a traffic data acquisition (TDA) system that features a pair of infrared light beam sensors and a microprocessor. Evaluation of the system showed errorless detection of the direction of travel—critical information for managing a reverse-flow HOV lane—and perfect counting of vehicles, even during a period of heavy rainfall. The TDA system also produces speed, headway, and vehicle-length data. Digital data to and from the system can be transmitted over conventional communication links. The sensors have been operational for the past 13 months without adjustment or maintenance. The TDA system potentially has traffic-monitoring applications other than on the Houston HOV lanes.

A planned 154-km (96-mi) system of high-occupancy vehicle (HOV) lanes is being implemented in Houston, Texas, jointly by the Texas Department of Transportation and the Metropolitan Transit Authority of Harris County (METRO) (*1*). More than half the system is now operational. Typically, the single reverse-flow HOV lane 6.7 m (22 ft) wide is situated in a freeway median and is separated from the adjacent freeway main lanes on each side by a New Jersey–shape concrete median barrier 0.8 m (32 in.) high. Access to the lane is provided either by grade-separated interchanges with ramps connecting to surface streets or terminal facilities or by slip ramps through openings in the concrete median barrier. Manually operated gates across the openings are used along with official traffic control signs and signals to direct traffic in the proper direction of flow. Buses, vans, and other vehicles with two or more (three or more at certain sites and times) persons are allowed to use the HOV lanes during specific periods, but trucks, vehicles towing trailers, and motorcycles are prohibited at all times.

METRO has responsibility for enforcement and operation of Houston's HOV lane system. Routine surveillance and traffic sensing activities include the use of remotely controlled television cameras on high poles overlooking selected sections of the lanes along with arrays of inductance loop vehicle detectors embedded in the pavement and connected via hard-wire links to a communication center. Work is currently under way to expand and improve these activities with color television equipment and fiber-optics communication links.

Over the years, the inductance loop detectors have provided the primary sensor elements for traffic sensing and control, but an inherent characteristic of this type of sensor, which requires sawing grooves in the roadway structure to install the wire loop, has limited its applicability, particularly on bridges. The reliability and durability of the loops and the communication system along with the time and expense of installing and maintaining the loops under traffic also have been matters of concern.

As part of a research study conducted by the Texas Transportation Institute (TTI), Texas A&M University, to identify and evaluate feasible alternative traffic sensing systems for the Houston HOV lanes, the Center for Transportation Research (CTR), the University of Texas at Austin, designed, installed, and evaluated a traffic sensing system that uses a pair of infrared light beam sensors and a microprocessor. This traffic data acquisition system is described.

TRAFFIC SENSING REQUIREMENTS

The principal reason for continuous sensing of vehicular traffic in the HOV lane is to detect wrong-way movements so that warning procedures, which might prevent accidents and minimize disruption to normal traffic operations, can be implemented quickly. Additionally, it is desirable to collect statistical data about the number of vehicles of various types that use the lane, speed, and time headway between successive vehicles. These data are important for planning new facilities or modifying the existing ones, developing various operating strategies, monitoring bus activities, evaluating HOV lane efficiency and safety, possibly detecting traffic incidents, and providing warnings to speeding vehicles at critical locations. All these functions require a sensing system and an associated information-processing system that is easy to install, reliable, durable, inconspicuous, inexpensive, and capable of producing the desired types of data.

TRAFFIC DATA ACQUISITION SYSTEM

The traffic-sensing system designed for application on the Houston HOV lanes consists of three functional components: (a) sensors, (b) a signal processor, and (c) a communication interface. It satisfies the traffic sensing requirements stated earlier. For convenience, the system will be referred to as the

Center for Transportation Research, University of Texas at Austin, Tex. 78712-1076.

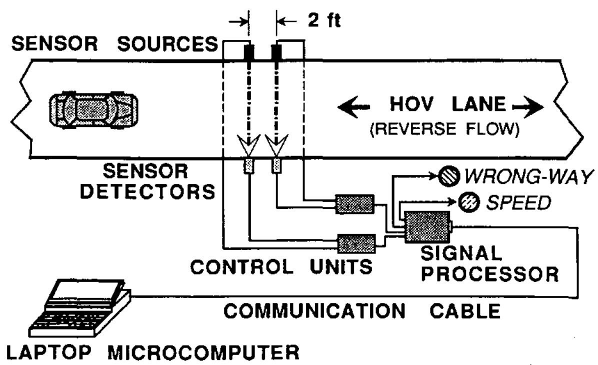

FIGURE 1 Configuration of TDA system.

traffic data acquisition (TDA) system. The overall configuration of the system is shown in Figure 1, and each component is described briefly.

Sensors

Sensors chosen for this application are through beam, modulated infrared (wavelength, 880 nm) photoelectric devices. The source unit emits a modulated (switched off and on) light beam through a glass lens in a 2-degree, full-conical radiation pattern, and the detector unit has a 2-degree, full-conical field of view. Depending on the type of control unit selected for use with the sensors, the rated maximum effective distance from source to detector is either 21 or 113 m (70 or 370 ft). In the Houston HOV installation, the actual distance between the source (mounted atop the concrete median barrier on one side of the lane) and the detector (mounted atop the concrete median barrier on the other side of the lane) is only 7 m (23 ft); therefore, ample reserve sensitivity is available even though the beam is partially obstructed by dust, grime, fog, smoke, or rain. The source and detector units are connected individually to a control unit via a two-wire, 22-gauge, shielded cable.

The control unit, supplied by 115 V of alternating current, provides modulated power to the light-emitting diode source and conditions the signal from the detector to produce a virtually instantaneous (about 1-msec response time) on-to-off indication when the light beam is blocked by an opaque object. Sensitivity to the proportion of blockage required for switching is adjustable. The output device of the control unit is an optically isolated transistor switch that is connected to the solid-state logic circuits of the signal processor.

Two infrared light beam source–detector pairs are used in the TDA system. The source units are contained in an aluminum box 0.1 m^2 (4 in.^{2}) $\times$ 0.7 m (28 in.) long cemented to the top of the concrete median barrier on one side of the HOV lane, and the detector units are mounted similarly on the opposite side. Thus, the two sensing light beams are 0.86 m (34 in.) above the road surface and 0.6 m (2 ft) apart in the direction of traffic movement. Anytime that an opaque object blocks a light beam, the transistor switch in the control unit provides a change-of-state (on to off) message to the signal processor.

Signal Processor

The TDA system signal processor unit is based on a Motorola MC68HC11E9 8-bit, single-chip microcontroller that is supplemented with other instrumentation circuits. This unit, which uses a general-purpose 12-V direct current power supply and hard-wire connections to the sensor controllers, receives the on and off signals from the infrared light beam sensor controllers along with signals from an auxiliary signal-sampling generator. These signals are converted to digital form, and programmed computations are performed to produce the desired traffic data. These data include the following:

- Sequential number of vehicle,
- Direction of travel,
- Speed [mph (km/h)],
- Length of vehicle [ft (m)],
- Headway [sec (time behind previous vehicle)], and
- Time of passage [hh,mm,ss].

Ideally, the signal from a vehicle-presence sensor will consist of a single pulse corresponding to the length of the vehicle. The duration of the pulse multiplied by the speed of the vehicle gives the calculated length of the vehicle. This requires that some part of the vehicle be present in the sensing zone continuously as the vehicle passes. For the TDA system, the approximately conical effective sensing zone of the infrared light beam that is aimed perpendicularly across the HOV lane 0.86 m (34 in.) above the road surface is about 0.1 m (5 in.) in diameter at the center of the lane, and proportionally smaller as the blocking object is located closer to either lane edge. All buses and vans and most passenger cars break the beam continuously as they pass, but some low-profile cars do not. As these low vehicles pass, various objects such as roof posts, seats, and people interrupt the beam to produce a series of short-duration pulses. To make a logical approximation of the length of such vehicles, software in the TDA system signal processor applies a digital filter to the signals from the downstream sensor to group sequential pulses of 250 msec or shorter duration into a single pulse with effective duration from the beginning of the first pulse (begins after a 250-msec period with no pulse, i.e., the minimum gap between successive vehicles) to the end of the final short-duration pulse. Thus, the calculated vehicle length is the composite length of objects and the intervening spaces when there is less than a 250-msec time gap between successive objects. Vehicle-length data from the TDA system, will make low-profile vehicles appear shorter than their actual overall length, as only the portion of the vehicle higher than 0.86 m (34 in.) is sensed. This can be used in data analysis, however, to distinguish such vehicles from other types.

Direction of travel is determined by the order in which the two light beams are broken. Speed is calculated from the time required for the front of a vehicle to travel the 0.6-m (2-ft) distance between sensors. Headway is the interval between the arrival of the fronts of successive vehicles at the downstream sensor. The number of vehicles is counted as each vehicle leaves the sensing zone of the downstream sensor. The time of passage is determined from the internal clock in the microcontroller.

Communication Interface

In the TDA system, the communication interface between the signal processor software and external devices is implemented in software and passed through the RS232C communications port of the Motorola MC68HC11E9 microcontroller. Both signal-processing and communication software are retained in the electrically erasable programmable read-only memory (EEPROM) of the microcontroller. An IBM or compatible microcomputer has been programmed to communicate with the TDA system signal processor unit through its RS232C communications port for gathering and storing traffic data. The data are displayed in real time on the screen of the microcomputer. Control signals can also be sent via the RS232C communications port and modems to traffic warning devices on site or at remote locations. The programs stored on the microcontroller EEPROM are changeable from a remote location through the communication link.

Sample of Traffic Data

Table 1 presents a sample printout of traffic data collected on a laptop microcomputer. The TDA system was operating on the I-10 HOV lane west of downtown Houston near the interchange with I-610. Traffic was eastbound in the morning hours. Judging from the length and speed of vehicles, Vehicle 30 was a single-unit bus, and Vehicle 33 was an articulated bus-trailer vehicle. Actual measurements of buses in a nearby bus terminal have confirmed these length values within 0.3 m (1 ft). The two passenger cars (Vehicles 34 and 35) following the articulated bus were operating at short headways, but their speeds were matched to the headway condition, that is, the following vehicle was traveling at a speed lower than the vehicle ahead of it. Vehicle 38 appears to have been a low, small car that was traveling rather fast and at a relatively long distance behind the car ahead.

EVALUATION

The TDA system sensor hardware was installed and adjusted on July 18, 1991, in the HOV lane on I-10 near the Post Oak access gates (west of the interchange with I-610). Personnel worked in the elevated lane for about 1 hr during the early-afternoon period when the lane was cleared to reverse the direction of traffic flow. Cable installation beneath the surface to connect the sensors to the control units and signal processor in a cabinet at ground level required another 2 hr. The sensors have needed no further adjustment or maintenance; they have now been in service for 13 months.

On April 16, 1992, a signal processor unit was connected to the sensor controllers in the cabinet beneath the HOV lane. The RS232C port on the unit was connected via a communication cable to a similar port on an IBM-compatible microcomputer located in the METRO surveillance center building about 100 ft away. With assistance from TTI and METRO personnel in the center, a television surveillance camera, connected to a monitor and to a video recorder, was aimed at the HOV lane where the TDA system was installed. During the periods given in Table 2, traffic data from the TDA system and video images of the passing vehicles were recorded simultaneously. The periods encompassed morning, afternoon, and early-evening hours as well as a time when directional

TABLE 1 Sample of Traffic Data from TDA System for HOV Lane on I-10 at I-610 in Houston

	Begin Date:	04-17-1992	Begin Time:	07:48:05	
Vehicle No.	Direction	Speed (km/h)	Length (m)	Headway(s)	Time
30	WE	53	7.01	86.939	08:09:46
31	WE	74	5.18	4.730	08:09:51
32	WE	66	3.35	11.689	08:10:03
33	WE	50	17.07	11.102	08:10:14
34	WE	48	3.66	1.369	08:10:15
35	WE	42	5.18	1.490	08:10:17
36	WE	84	3.35	47.779	08:11:05
37	WE	66	3.66	3.961	08:11:09
38	WE	79	2.74	30.150	08:11:39
39	WE	60	4.27	7.410	08:11:46

TABLE 2 Comparison of Vehicles Counted by TDA System and by Observers Viewing Recorded Video Images

			Number of Vehicles	
Date	Time		TDA System	Video
4/16/1992	16:56:00-18:54:00		552	552
4/17/1992	07:48:05-09:49:18		192	192
4/17/1992	12:30:00-14:30:00		225	225
4/17/1992	14:30:00-15:48:00		255	255
		TOTAL	1224	1224

flow was changed from west to east to east to west, and a period (2:30 to 3:48 p.m.) with heavy rainfall.

Human observers subsequently viewed the recorded video images and counted all vehicles in the HOV lane, by direction of travel, during exactly the same periods when counts from the TDA system were recorded. It was possible to check the synchronization of the two counts by using easily recognized vehicles such as buses.

There was perfect agreement between the vehicle counts for all periods, as indicated by the data in Table 2. Likewise, there was no error in the direction of travel indicated by the TDA system. Although there were no quantitative measures against which to compare the other TDA system data, speed, vehicle length, and time headway values all appeared to be reasonable and consistent with the corresponding relative values that could be judged from the recorded video images. There was no degradation of performance during heavy rain.

It is appropriate to point out that this application of the TDA system was for a single traffic lane 6.7 m (22 ft) wide. The system also has potential use at other one-lane sites, such as freeway entrance or exit ramp terminals (e.g., to detect wrong-way movements, to count and classify vehicles by length, and to measure speed), interchange ramps (e.g., to activate speed-warning devices at curves), and automated toll gates through which vehicles move at a constant speed. When the infrared light beam is directed across two or more traffic lanes, the detrimental effects of simultaneous arrival of vehicles must be evaluated. In some instances, these effects may be considered to be insignificant. The system can also be used to detect over-height vehicles and to trigger warning devices.

The TDA system described in this paper was a first-generation development that has not yet been produced in quantity; therefore, costs that are comparable with those of other traffic sensing systems do not exist. It should be feasible to manufacture and install the system for less than about $3,000/site, excluding communication linkages. Installation can be made at many sites without blocking the traffic lane. At other sites, a shallow saw cut in the pavement might be necessary to accommodate a small cable that connects the source and receiver units of the sensors. The TDA system on the Houston HOV lane has operated for more than a year without maintenance or service.

SUMMARY

The traffic sensing system that has been developed especially for use on Houston's HOV lane network is easy to install, reliable, durable, inconspicuous, relatively inexpensive, and capable of producing certain essential data that are needed for managing and operating the extensive mileage of special-purpose lanes that are being implemented. A pair of infrared light beam sensors is teamed with a programmable micro-controller and associated communication links to comprise the basic TDA system. The sensors, mounted in small protective metal boxes atop the concrete median barriers on each side of the HOV lane, have been operational for more than a year without adjustment or maintenance. Installation time for personnel in the elevated traffic lane was about 1 hr, and no modification to the roadway structure or to the barriers was involved. Evaluation of the TDA system, by comparison with recorded video images of vehicles traveling in the HOV lane, indicated error-free performance in detecting the direction of travel for each vehicle and in counting vehicles in several time periods during 2 days. Heavy rainfall experienced in one period had no adverse effect on performance. TDA system data for speed, vehicle length, and time headway were all reasonable and consistent with a small sample of measurements made on test vehicles driven through the system and with qualitative judgments based on observing the video images. Data are produced in digital format and can be handled over long distances via conventional communication links. The TDA system should be considered as a feasible alternative to the part of the existing sensing system that depends on inductance loop detector vehicle sensors. Production costs for the system have not yet been determined, but installed cost, excluding communication links, is estimated at about $3,000/site. Although the TDA system was designed for the Houston HOV lane, other applications certainly are possible.

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