Development and Evaluation of Congress Street Expressway Pilot Detection System

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•IN APRIL 1961, an expressway surveillance project was established as a part of the research program of the Illinois Division of Highways, under the supervision of the Bureau of Research and Planning. The project is being financed with Highway Planning Survey funds made available through the Federal-Aid Highway Acts with the State, Cook County, and the City of Chicago contributing the necessary matching funds. An advisory committee, consisting of representatives of the four cooperating agencies was appointed and meets frequently to review the progress of the experimental work of the staff and to review and advise on the steps recommended for future experimental work.

The project objective is to conduct operational studies, locate critical points, determine causes of congestion both qualitatively and quantitatively, investigate ways to improve flow, and measure resulting benefits to traffic. The activities of the project staff also include the investigation of electronic techniques for the surveillance of traffic behavior and the detection of stalled vehicles. The ultimate objective being to reduce congestion on expressways in the Chicago area by means of automatic traffic control and information measures.

This paper reports on the development and evaluation of a pilot detection system which has been installed on a 5-mi section of the westbound Congress Street Expressway between Cicero Avenue in Chicago and First Avenue in Maywood.

This system consists of traffic detectors on the ramps and on the expressway at selected locations along the study section, interconnection to the central office, and analog computers, map display, and various data recording devices including a paper punch tape output.

PRELIMINARY OPERATIONAL STUDIES

Study Techniques

The initial study was a machine-count program to measure the volumetric traffic flow characteristics of the Congress Street Expressway. These counts were summarized by the daily 24-hr total (Fig. 1), and the individual hourly totals (7 to 8 AM and 4 to 5 PM). The data collection consisted of machine counts at all the entrance and exit ramps and four mainline (expressway through lane) counts. The mainline counts at all remaining locations were derived by the addition and subtraction of ramp movements.

Another measurement made was the speed of vehicles at the points where volume counts were taken. Speeds were recorded at frequent intervals before, during, and after the peak-volume period of the outbound traffic. A moving vehicle technique was used whereby the speedometer reading was noted at each 0.2-mi increment of the odometer. This study was conducted using standard employee automobiles, and as a control check, the times and distances of passing each overpass were recorded. The distance between overpasses within the study section was accurately determined, and observations from

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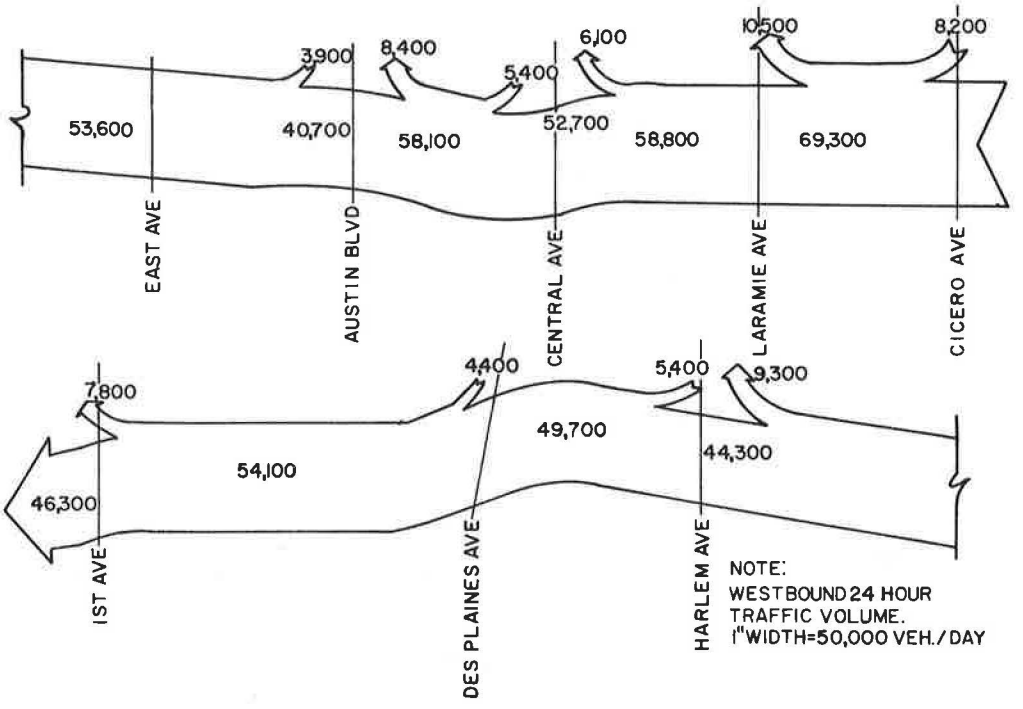

Figure 1. Traffic flow map.

individual runs were interpreted in this light. From the results of these speed runs, contour maps were prepared (Fig. 2) which showed the speed changes, by time and location, occurring along the expressway, as well as the duration of those speed changes. The speed contour maps showed the locations at which speed changes first occurred and also the manner in which those speed changes were reflected back along the expressway.

Aerial photographs recorded the density of traffic within the expressway section under study. A light aircraft flew over the expressway and took aerial photographs with a 50 percent overlap. From these photographs, technicians counted the number of vehicles present on the roadway between overpasses. These determinations yielded a measurement of density at a certain point in time. Similarly with speed, density contours were prepared (Fig. 3). Inasmuch as only one density reading was taken between structures, for each pass of the aircraft, the density contours, as compared to the speed contours, were less sensitive to small variations along the roadway.

From a review of the operating characteristics of the expressway shown in the volume flow map and the speed and density contour maps, it was decided to locate a more detailed ground photography study at eight locations at the western edge of the westbound congestion area. The choice of the westerly location provided that, with possible operational improvements through the study area, the downstream section would be adequate to handle the increased traffic flow.

At the eight stations selected, cameras were mounted on the overpasses, and time lapse photographs were taken at the rate of 60 frames per minute. On each frame the dial of a watch appeared in one corner and served as a time reference. The individual watches were in turn related to a master timing device and assured time comparisons for traffic at various locations.

From the time-lapse photographs individual speeds, density, and volumes were measured on a per-lane basis. Individual speeds were measured from the films by recording the distance traversed by a vehicle relative to markings on the shoulder, the time to travel such a distance being determined from the speed of the film. Average density was determined by counting the vehicles within a 400-ft trap and averaging five

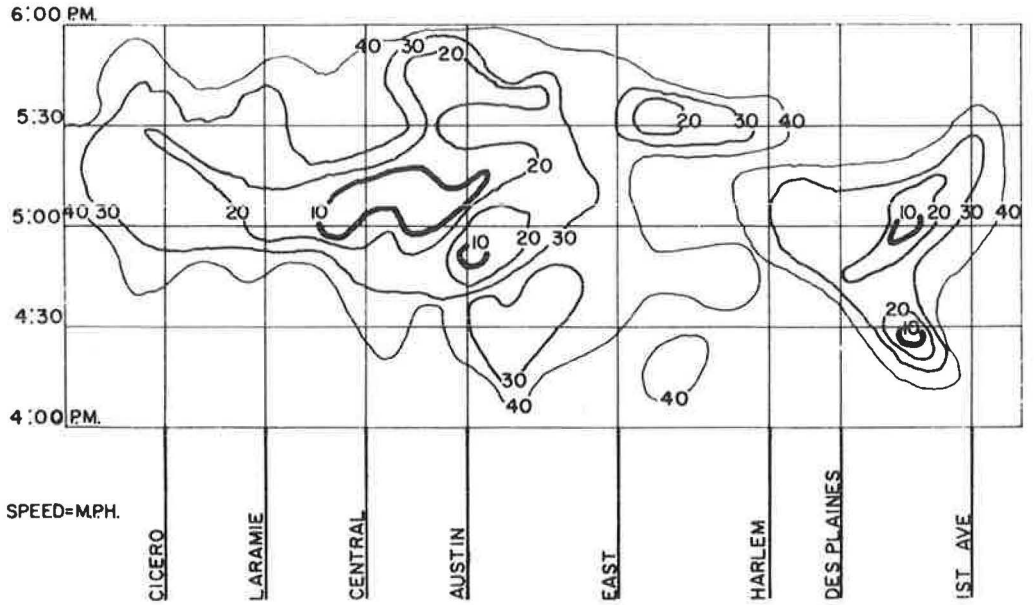

Figure 2. Speed contours.

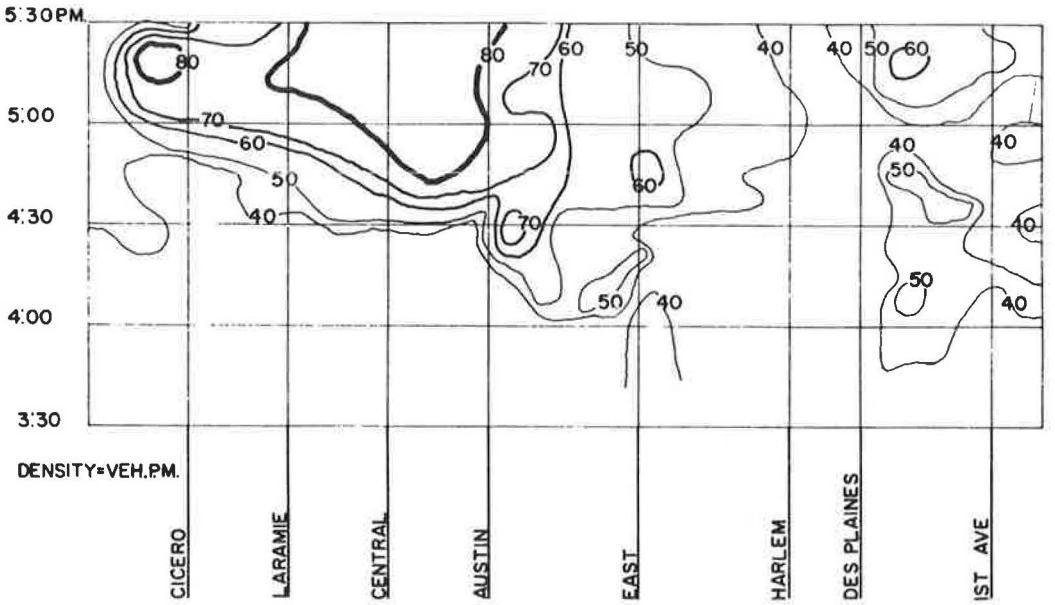

Figure 3. Density contours.

such determinations per minute. Volume was a straight forward count of vehicles passing a line. These measurements result in a space mean speed and a space mean density over a similar section, and also a point volume within the measuring section. In this analysis of the time-lapse filming, over 200,000 individual vehicles were analyzed from a selected total of 32 hr of filming free from technical faults in both exposure and timing.

Results

Selection of Study Section.—The study section chosen was the most westerly section experiencing lengthy and irritating traffic delays, and included a wide variety of geometric design features. The upstream limit of the study section occurs to the downstream side of an exit ramp, thus the traffic reaching the study section is reduced in an amount equal to the ramp volume. Detailed studies showed the downstream limit of the study section to be a location downstream from a constriction point and operated free of reflected congestion during detailed studies. With the limits of the study area defined by stations not causing operational difficulties, it is possible to isolate the extent of operational difficulty experiences within the study section.

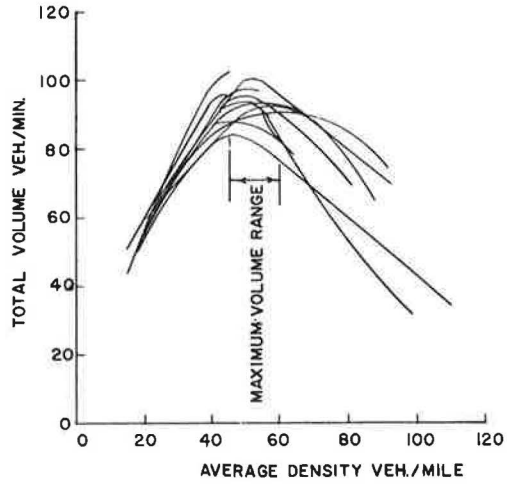

Figure 4. Average density related to total volume.

Selection of Measurements.—The selection of parameters to be measured was tempered by the limitations of the manufactured detection equipment available. Speed and volume detectors are available, from several manufacturers, though varying in accuracy. On the other hand, density as measured on a space mean basis is not available while the available point density system calculates density from measured speed and volume. Lane occupancy is an additional measurement which is presently available from manufacturers and is a point measurement of the percentage of time that a vehicle is present under the detector. Lane occupancy may be compared to calculated density, the unit "percentage occupancy" varies with the type of vehicle present in the traffic stream and is dependent on the length and corresponding speed of the individual vehicles.

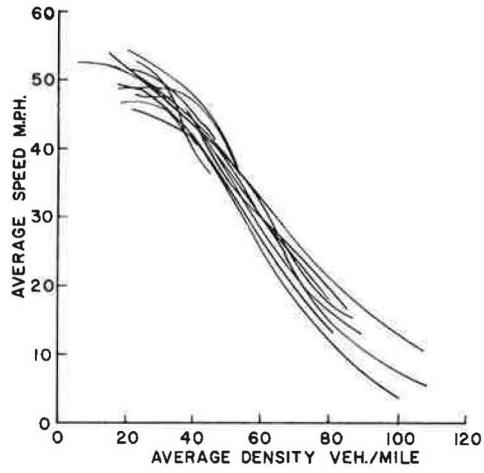

Figure 5. Average speed related to average density.

The selection of measurements was based on the results of the ground photography, and a comparison of the manufactured detection systems presently available. Observation of the speed and density profiles indicated that as operations deteriorated there appeared to be inverse relationship between these measurements—speed decreased as density increased.

The interrelationships between speed, density, and volume as measured from the film were examined on the basis of the minute averages; these were arithmetic averages of the individual data collected within the minute. Each of three pairs of these measurements was directly compared in Figures 4, 5, and 6. It was evident from the data that the interrelationships depended on the station location relative to a trouble spot. Downstream operations do not directly break down under observation, but reflections upstream often cause breakdown. The trouble spots themselves appear to cover an area of expressway and are not easily pinpointed. Along a section of highway, very often the downstream station for a trouble spot becomes the upstream station for another trouble

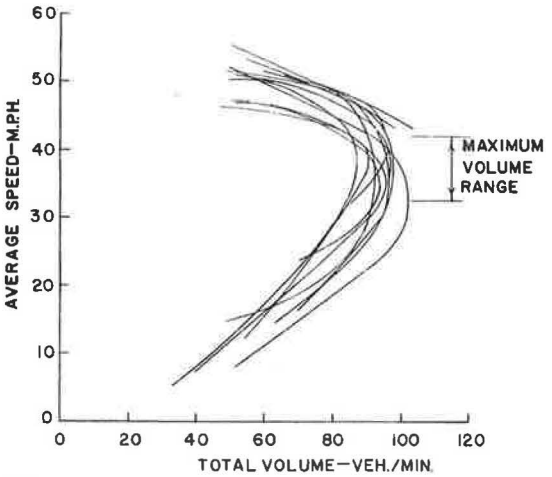

Figure 6. Average speed related to total volume.

spot and there is often considerable difficulty in isolating conditions. This is also the reason for individual stations changing their characteristics. The eight camera stations compared were at two downstream locations, three upstream locations, and three trouble spots.

From the summary graphs, the closest relationship appeared to exist between speed and density; linearity in this relationship yields a parabolic curve of volume-density. However, a concave relationship between speed and density was also noted, and this closely approximates a constant volume. Again, there was a dependence on the stream location of the station as to which characteristic predominated; upstream tended more closely towards the constant volume situation.

As a summary of average conditions at various locations along the stream of traffic, the generalized traffic flow diagram of Figure 7 was prepared. This generally divides traffic operations into three zones, which may be briefly described as constant speed, constant volume, and constant rate of change of volume with density. Interpreting the diagram, it may be stated that zone 1 (constant speed) is an operation in which the speed of vehicles is determined by the facility itself and that the volume matches the demand. Zone 2 represents impending poor operations; average speed drops but the volume rates may be sustained at a high level. In zone 3, both speed and volume rates decrease, and this in itself may serve as a definition of congestion.

The effectiveness of individual measurements to describe and predict traffic operations was noted as follows: Zone 1 shows the limitations of speed to indicate the proximity of traffic operation to zone 2. Small changes in speed may correspond to larger changes in traffic operations. Volume rates zones 1 and 3 may be of equal magnitude and cannot be differentiated; however, density appears indicative of traffic operations over the complete spectrum of traffic operations.

Manufacturers at present offer volume as a "free" measurement included with their speed occupancy or density detector systems. The systems to review, therefore, would be all three measurements (speed-occupancy-volume) or two measurements (occupancy and volume or speed and volume). Speed detection requires movement of traffic and is less reliable as operations approach stoppage. Measurements of occupancy tend to increase the stoppage, and their accuracy remains at about the same level as with free-flowing traffic.

The measurement proposed for the pilot detection system was a volume-occupancy system with an additional, limited number of speed detectors that afford the opportunity to verify the preliminary parameter selection and give added flexibility in designing future studies.

Placement of Detectors

Longitudinal.—The selection of detector stations was restricted to structures over the expressway upon which detector heads could be conveniently affixed. Within the limits of the study section defined, the detector stations were selected in the following manner. The limits of the study section fixed the locations of two stations, Cicero Avenue in the east and First Avenue in the west. The next station selected was at East Avenue which was chosen as a base, at a location away from ramps and situated at approximately the halfway point of the study section. The final selection of the remaining four stations was predicated on the location of trouble points associated with inferior traffic operations, pinpointed from the photographic study, and also from the moving vehicle studies.

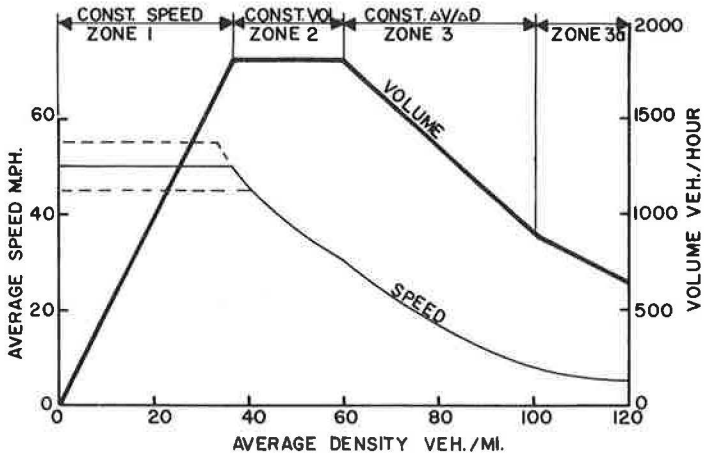

Figure 7. Generalized traffic operations.

In summary, the choices were as follows: the study limits of Cicero Avenue and First Avenue, the base station at East Avenue, and four trouble spot locations at Austin Boulevard, Central Avenue, Harlem Avenue, and Des Plaines Avenue.

Lateral.—The selection of the pilot detection system was in part based on the aim of the earliest possible prediction of congestion, defining congestion as both a lessening in speed of operation and the volume rate. The lateral placement of detectors was determined on the basis of traffic operations up to congestion. In this manner it was noted that the center lane of the three-lane sections, both before and up to congestion, gave the highest reading, or equal to the highest reading of occupancy across the pavement; exceptions may exist under extremely light traffic, but in such cases there would be no concern for impending congestion. For the four-lane section, both the center lanes appeared comparable and gave the highest occupancy readings before and at the commencement of congestion. In general, it was decided to locate the detector heads over the center lanes. To verify the choice of the center lane, one station was equipped with three complete detector systems and a second station was similarly adapted utilizing spare equipment. To pursue a comprehensive research study, detector heads were located over all remaining lanes, and switching units were installed at the roadside to facilitate detection on any one lane, as required by the different studies. As a result, detection is available on every lane; however, only one lane may be used at any one time, with the exception of the base station at East Avenue.

Roadside detectors were located on all entrance and exit ramps. Mainline volumes at individual stations may be calculated by the addition and subtraction of ramp volumes to the corresponding volumes recorded at the East Avenue base station. In addition, making use of the ramp detector chassis and spare equipment, any station may be activated to yield simultaneous reading of detectors on all the mainline lanes.

The overall system features reasonable economies in the quantity of equipment installed, and yet the built-in flexibility of the system permits more detailed studies and analysis as needed.

SURVEILLANCE EQUIPMENT EVALUATION

To have a basis for making a decision in the selection of vehicle detectors, interconnect methods, traffic flow computers, and data-collecting equipment suitable for use in an expressway surveillance system, the expressway surveillance project initiated an equipment evaluation study.

Invitations were sent to all manufacturers known to be interested in traffic surveillance or traffic-control equipment. Two manufacturers who had traffic flow computer systems replied and were willing to demonstrate their equipment to the project for test-

ing. Included with the demonstration equipment were graphic recorders and digital tape recorders.

Three types of traffic flow computers were tested, and are referred to as follows:

1. V.S. (measured volume and speed).
2. V.O.S. (measured volume and occupancy and computed speed, on line; that is, computation within the equipment's own computer).
3. V.S.D. (measured volume and speed and computed density on line).

Measurements

One week was devoted to data gathering with each manufacturer's equipment. The detectors were installed on the Paulina Street bridge over the westbound lane of the Congress Street Expressway. Interconnection between the detectors and computers was made by means of a voice grade telephone pair, used for both data transmission and voice communication.

To record accurately the volume, speed, and density of the traffic as it was being measured and recorded by the manufacturer's computer equipment, two types of film records were made. A Keystone 16-mm camera was set up on the Paulina Street overpass to film the westbound expressway traffic. The ground photography camera exposed one frame of film per second. At the same time, aerial photographs were taken from a helicopter flying at 2,500 ft over the test site. The 4 by 5 aerial camera exposed one frame per 12 sec.

During the period in which the equipment was undergoing tests, its outputs were recorded by graphic recorders and printed digital paper tape recorders furnished by the manufacturers. The data recorded were manually transferred to code sheets and then punched onto IBM cards. Actual traffic conditions which existed during the test period were determined by using a Perceptoscope (a single-frame projector) to view the time-lapsed films. Through the use of the Perceptoscope the staff technicians were able to take speed measurements and volume counts from the films with a high degree of accuracy.

Density measurements were made from the aerial photographs by viewing the negatives with a transparency projector and counting the vehicles in the test area. The volume, speed, and density data were then punched on IBM cards.

Although both manufacturers' equipment was tested at the same location and at the same time of day, it was not tested on the same dates; therefore, the data from the equipment cannot be compared directly. Furthermore, no attempt was made to interpolate the data to make them applicable to conditions different from those actually encountered.

Equipment

The V.O.S. computer gathered its data through an ultrasonic presence detector. The input to the V.O.S. computer was a pulse generated by the detector relay contact closure. The closure time is equal to the period that the pavement beneath the sensing head was occupied by a vehicle. The total count was displayed by means of a five-digit counter. The count data were integrated over a selected time base resulting in an analog volume display calibrated in vehicles per minute.

The input pulse length data were similarly integrated to provide an analog voltage, calibrated as percent of lane occupancy.

Speed was computed on line as a function of percent lane occupancy, volume, and assumed vehicle length. Two vehicle lengths were used: one for commercial vehicles and another for passenger vehicles as determined by the classification feature of the detector.

The V.S. computer gathered its data through an ultrasonic motion detector, using the doppler principle.

The detector output was a frequency proportional to the individual vehicle speed. The V.S. computer then transformed the doppler frequency into a voltage proportional to the individual vehicle speed. These individual voltages were integrated resulting in an averaged lane speed.

The V.S.D. computer gathered its data through a radar motion detector using the doppler principle. The detector output indicated the passage of each vehicle by producing a frequency proportional to that vehicle's speed. The doppler output was then fed into a speed and impulse translator which in turn produced two outputs, volume pulses and speed information. The volume computer and classifier received impulses from the speed and impulse translator which were then integrated and displayed on an analog meter calibrated in percentage of maximum vehicles per lane per hour.

The speed information was fed into two speed computers. The first computer displayed the speed of the last car on one meter and the root mean square lane speed on another meter. The second speed computer received its input from the first unit and displayed arithmetic average speed and the mean deviation on its meters. Means were included for adjusting the sample size and for connecting the meter current to graphic recorders on the volume and speed computers.

The output of the speed and impulse translator was also fed into a density computer. The computer integrated these inputs into two running averages and displayed the ratio as vehicles per miles. The output of the density computer was also recorded on an analog graph.

After completion of the data-gathering period the project staff manually transferred the data from the paper chart to graphs to code sheets. This information was punched onto IBM cards, and processed in a high-speed computer. The results yielded photographic data with the analog quantities of the equipment.

The laborious transfer of information from analog charts to a form acceptable to a data-processing system strongly indicated the need for a compatible data-gathering method. Therefore, the staff at this time began an investigation of data-collecting methods. Of the several methods investigated, punched paper tape seemed the most suitable, as three of the cooperating agencies were already using digital computers requiring this mode of input.

With the data-evaluation work completed, the task of determining which of the three systems would most closely meet the needs of the project was undertaken.

Summary

The three systems tested all showed a high degree of accuracy, although the system using the ultrasonic presence-type detector tested out slightly better than the other two.

This method of detecting traffic flow also gave promise to be more economical in a large surveillance system. The outputs of several detectors generating contact closures may be transmitted over one telephone pair using some form of tone equipment or telemetering, whereas the doppler detectors may not be combined in this manner. Doppler detectors may be combined for data transmission by the use of multiplexing. For each doppler detector handled by multiplexing, it is possible to substitute the number of contact closure systems carried by one pair of lines using telemetering or tone equipment. The ultrasonic detectors had another advantage over the radar detector demonstrated. The electronic chassis was separated from the inert sensing head mounted over the roadway which would permit normal servicing without necessitating the closure of an expressway lane and the switching of a single detector chassis between several sensing heads.

The output voltages of V.O. and V.O.S. computers were expressed in the same numerical value as the measured traffic flow values; that is, 48 volts equals 48 vehicles per minute, or 48 percent occupancy, or 48 mph. Also, the outputs of the meters were all calibrated the same (0-100) and were not affected by control adjustment knobs or range adjustments. These features are all most beneficial when the equipment is to be operated with a data-logging system. It was decided therefore to choose the presence-type detector and its associated computer as the prime measuring tool for the pilot detection system. There was however one major modification in the equipment purchased from that which was demonstrated. Only parameters directly measured are used in the system; therefore, the "on line" computed speed of the V.O.S. was not included in the purchased equipment.

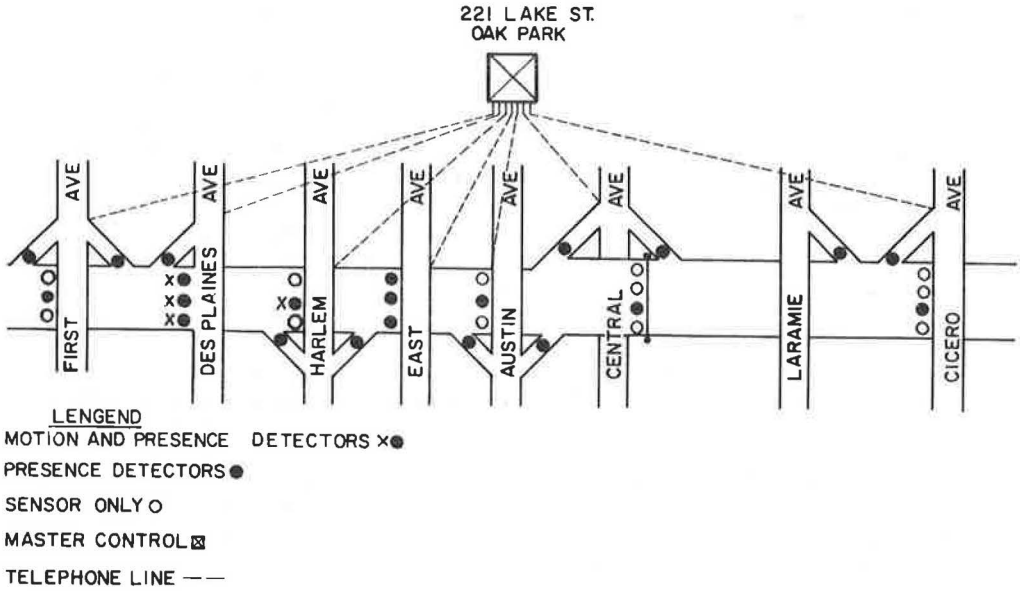

Figure 8. Proposed pilot detection system.

PILOT DETECTION SYSTEM DESIGN

Field Design

All field electronic equipment that was a part of the pilot detection system was installed along the right side of the expressway. Personnel performing routine maintenance, therefore, are not required to cross lanes when driving between sensing stations. Each detector chassis is housed in an individual roadside case; thus, any detector may be moved individually to a new location with a minimum of disturbance to other equipment.

Mainline.—There are seven mainline stations along the expressway where westbound through traffic is sensed for input to the pilot detection system (Fig. 8). Pavement-seeking sonic-type vehicle detectors were selected for this application. These detectors have a high resolution and, because of their pavement seeking feature, operation is not disturbed by the existence of other sonic equipment nearby.

The pavement-seeking sonic detectors consist of a transducer and an electronic chassis. The transducer (Fig. 9) is installed over the roadway and normally requires little or no maintenance. The electronic chassis is housed in a weathertight case on a pedestal located to the right of the paved shoulder for westbound expressway traffic.

The sensor heads (transducers) are mounted on existing structures; 19 are clamped to the flanges of beams at overpasses and 4 are attached to a sign bridge. There is a sensor head over each lane at each of the seven stations.

Ramp Detectors.—In addition to the detectors for through traffic, detectors are also located at each on-ramp and each off-ramp for westbound traffic within the 5-mi section of the pilot detection system. Because of the wide range of ramp traffic vehicle placement, side-fire sonic-type detectors were selected for this application. (Although it is possible for traffic to form two lanes on these ramps, this has never been observed at any of the ramp detector locations.)

The side-fire type of detector consists of a transducer and an electronic chassis. The transducers are installed on existing street light poles at all locations except four. Pedestals for supporting the side-fire detector transducers were installed at the four locations where street light poles are not used (Fig. 10). The electronic chassis for each side-fire detector is located in a roadside cabinet. The cabinet is attached to the same structure as the transducer, except at locations having left-side ramps. The cab-

Figure 9. Mainline detector station.

inets for detectors at left-side ramps are located remotely from the transducer on the right side of the expressway. At each of the eleven locations, the ramp traffic may be observed at the roadside case location.

Special Equipment.—In addition to the mainline and ramp equipment already mentioned, the following field equipment is also included.

Motion Detectors.—Direct speed-sensing capabilities are included in the pilot detection system at four locations. Sonic vehicle detectors employing a doppler principle provide the means for this feature. Each motion detector requires a transducer over the lane where speed is to be sensed. The transducer is connected to an electronic chassis located in a weathertight roadside case. The case is mounted on a pedestal installed to the right of the paved shoulder for westbound traffic.

Pavement Condition Detector.— A surface-mounted moisture and temperature sensor is included as part of the pilot detection system. The unit is installed in the right lane for westbound expressway traffic at the Des Plaines station. The sensor is connected to an electronic chassis which is located in a pedestal-mounted roadside case.

The pavement detector provides system capability for sensing wet or snow covered roadway and, at the same time, indicates when freezing temperature exists.

Chassis Switch.—All lanes for westbound traffic are sensed concurrently at the East Avenue detector station. Sensing at the six other mainline stations of the pilot detection system uses a sampling technique whereby only one lane is sensed at a time.

As previously mentioned, transducers are installed over each lane at each mainline station. The design of the East Avenue station requires that three electronic chassis be provided, one for each transducer. Only one electronic chassis, however, is provided at each of the six other stations, and by means of a remotely-operated switch the chassis may be connected to any one of the lane transducers provided at their assigned station.

Interconnect.—The interconnect system may be divided into two sections, that owned by the State of Illinois and that leased from the telephone company.

The State-owned interconnect is installed along the expressway connecting the ramp detectors at each station to the other equipment at the same station. The cabling consists of a service pair plus two pair of voice grade cables directly buried along the shoulder. The service cable usually is extended beyond the expressway right-of-way

Figure 10. Side-fire detector.

to the nearest service location where it is connected to 117 volts. The leased lines, depending on their use, are either voice or 0- to 15-cycle grade.

Telephone Lines (Data and Voice).— Low-grade (0- to 15-cycle) lines are used for all ramp detectors, the ice-rain detector, two of the East Avenue mainline detectors, and one detector at Des Plaines Avenue. All remaining interconnect lines are voice grade. Although the mainline detectors do not require voice grade line for the transmission of detector output, the voice grade lines are required for use with the special telephone equipment at the same locations. Whenever the telephone circuit feature of each mainline station is placed in operation, the mainline interconnect line is then used for voice communication, either between stations or between a station and the office, or both. Data are interrupted during voice interconnect.

Voice grade interconnect lines are also required for transmitting the doppler frequency output of the motion detectors located on the expressway to the V.S. computers located in the office.

Tone Equipment.— Special tone equipment is installed at the Des Plaines Station. The tone equipment provides system capability for transmitting the outputs of five separate detectors simultaneously over one voice grade telephone interconnect line. The unit is to be used during an extensive study for determining how accurately traffic data may be transmitted by tone equipment. If satisfactory results are found, the extensions of the pilot detection system will consider additional tone equipment.

Office Equipment Design

The office equipment for the pilot detection system is installed on the second floor at 221 Lake Street, Oak Park, Ill. The electronic components of the office equipment are mounted in a ten-bay relay rack (Fig. 11). Included in the racks are all averaging computers, level monitors, power supplies, printer, plotter, etc. Mounted above the racks is a 3- by 16-ft map panel.

Computers.—The design of the pilot detection system is such that practically all computing is performed by additional high-speed digital computers. Running averages, however, are computed on line by the system, and are obtained from basic analog circuits. There are two types of analog computing units in the system, volume-speed computers, and volume-occupancy computers.

The volume-speed computers obtain their input from the motion detectors. Individual speed on a per-car-per-lane basis is available from the output of this computer, as well as running average lane volume in vehicles per lane per minute and running average lane speeds in miles per hour. Four volume-speed computers are included in the system.

The volume-occupancy computers receive input from the presence-type sensors. Two outputs are provided from the volume-occupancy computers, a running average

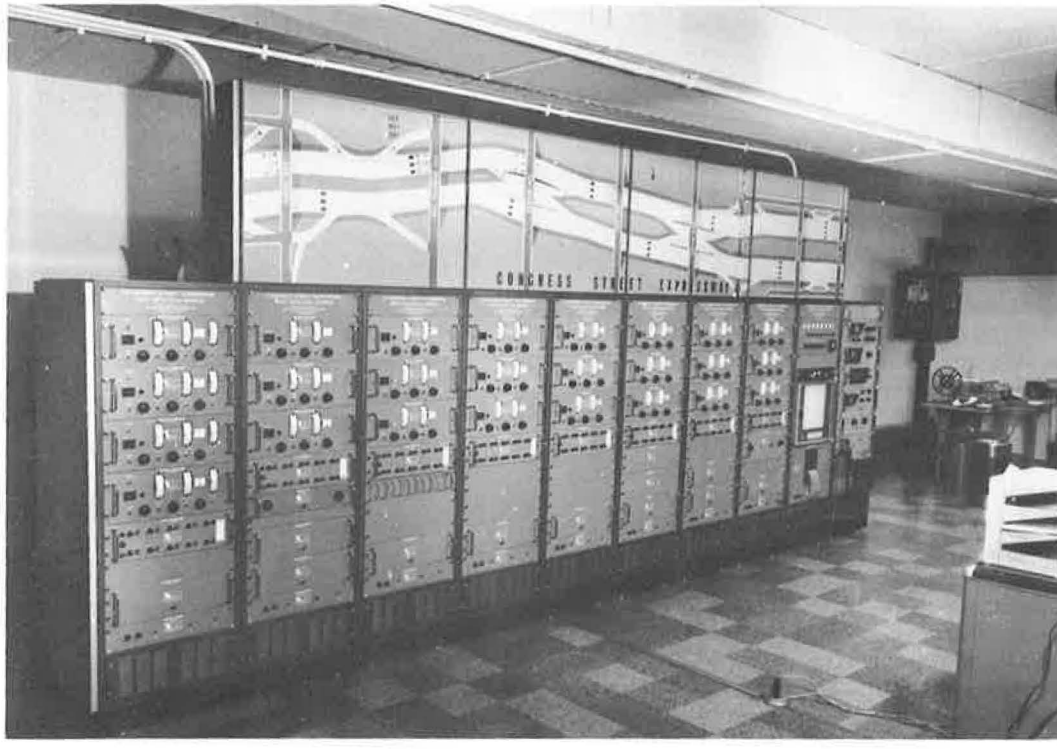

Figure 11. Ten racks of office equipment.

volume in vehicles per lane per minute and a running average occupancy in percentage of time a vehicle is present in a lane to total time. There are 21 volume-occupancy computers in the system.

Qualitative Output.—The outputs of the averaging computers may be fed to several components of the system, one of which is a level monitor. A level monitor might also be called a "comparator," in that the level monitor compares the output of the computer to the setting of one of its controls. Whenever the output of the computer is less than the setting of the level monitor, a contact in the level monitor will remain open; however, if the computer output equals or exceeds the setting of the level monitor, the contact will close. The level monitor may be used to separate data into class intervals, or to operate control devices or displays. Eighty level monitor channels are provided in the pilot detection system.

The five-mile section of the Congress Street Expressway, including the locations for the sensors for the pilot detection system, is displayed on a map panel. The map panel is mounted above the relay racks in the project's office. Indicator lamps on the map panel at the approximate location of each detector display the level of operation of the expressway for that location. Level monitor sections connected to computers are set to control the indications, causing a display of green, yellow, red, or flashing red for each detector location.

Data Logging.—The pilot detection system was designed principally for use in collecting traffic flow data. To this end, three different recording devices are provided: an X-Y recorder, a printed tape recorder, and a punched tape recorder (Fig. 12).

X-Y Recorder.—Any two analog values or any one analog value and time may be plotted on a 10 by 10 paper chart provided by the X-Y recorder. The analog value may be either an output of one of the computers, or it may be the difference between two computer outputs. The circuitry is such that other recorders may be operated concurrently with the X-Y, using the same analog voltages, without affecting the results.

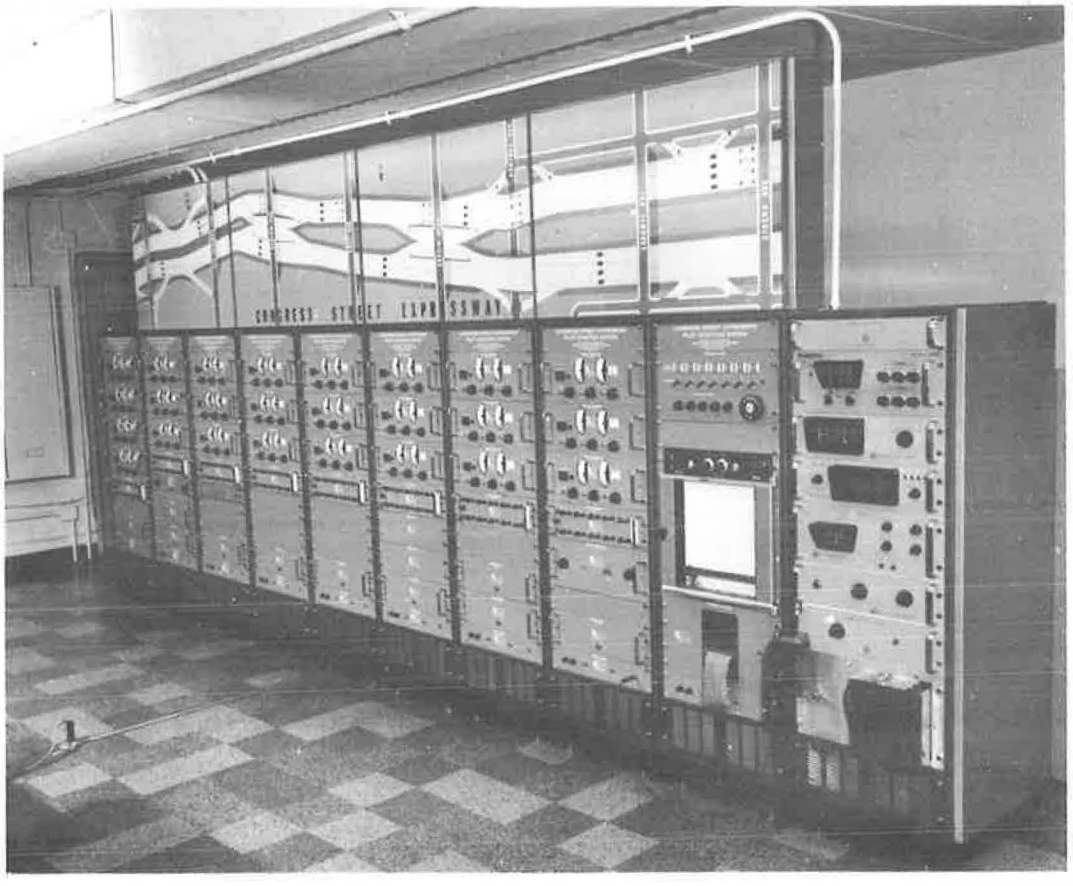

Figure 12. Racks showing data-logging equipment and X-Y plotter.

Printed Tape.—The output from as many as three detectors may be fed to the printer-counter at one time. Means are also provided by the printer-counter so that percentage occupancy may be recorded from one detector. A clock in the unit provides means for printing out accumulated totals for one, three, or six minutes. Print-out may also be initiated from the digital clock of the data-logging system, or manually.

Punched Tape.—Traffic flow data sensed by the pilot detection system may be recorded on punched paper tape by means of the data-logging system. The tapes are coded for input to a digital computer. The system consists of a digital clock, a scanner, a voltage-to-digital converter, a serializer, and a perforator. The clock provides time digits for recording on the tape as well as punch-out commands. The data-logging system may be operated in any of three modes.

During mode 1 operation, the clock will provide "repeat cycle" commands for initiating scanning cycles. These in turn will start the scanner through one scan with each command. The scanner will, during a scan, connect each output, one at a time, to the voltage-to-digital converter. The output of the voltage-to-digital converter will be fed through the serializer and punched out on the paper tape by means of the perforator. The perforator will punch out as many as five computer outputs per second.

During mode 2, the data logger may be set to record individual speed (or other individual input data) at one detector location. When operating in mode 2, the resulting punched tape will contain time in seconds and tenths of seconds, as well as, the individual speed for each vehicle as it is detected on the expressway. Thus, when using mode 2, speed distribution and time headway may be recorded.

Mode 3 is similar to mode 1 except that the scanner cycles continuously, rather than at fixed time intervals.

Flexowriter.—A Flexowriter is provided as part of the pilot detection system for printing out tapes made by the data logger, or for preparing tape for analysis on a digital computer.

INITIAL STUDIES

The installation of the pilot detection system began in May 1962, and detectors and associated computers for the first two stations (Des Plaines and First Avenue) went into operation during the latter part of June. During the remainder of the summer the other detectors and computers were placed in operation, as were the various data output units (printer-counter, X-Y plotter, map display, and punch tape). On September 12, 1962, the entire pilot detection system was officially turned on.

As individual components of the system became operational, they were adjusted and calibrated in preparation for the initial operational studies. Some of the results of these adjustments and initial studies are described next.

Traffic Analyzer Study

The Bureau of Public Roads' traffic analyzer was used to evaluate and calibrate the four motion detectors of the pilot detection system. At each of the four detector locations, a pair of hoses of the traffic analyzer was installed so that the motion detectors picked up the speed of individual vehicles within the traffic analyzer's 30-ft speed trap. The phone circuit of the pilot detection system was employed to inform observers of both sets of equipment the instant that an individual vehicle entered the measuring zone, and also was used to convey the individual speed readings of the traffic analyzer to the project office. In this manner, the comparison of individual vehicle speeds could be made and permitted the analyses of the speed data to be carried out concurrently with the data collection.

The tests were conducted during early morning low-volume high-speed traffic conditions so that individual vehicles could be recognized by both sets of equipment. Test vehicles were driven at low speeds to compare speed measurements in the low speed range.

A summary of the study results are given in Table 1. The final adjustments for the four motion detectors were 0.0, 1.8, 1.6, and 1.0 mph for Harlem - lane 2, Des Plaines - lane 3, Des Plaines - lane 2, and Des Plaines - lane 1, respectively. At low speeds, the detector speeds are higher than the traffic analyzer speeds (1 to 2 mph), whereas at high speeds the detectors' speeds are within 0.4 mph of the traffic analyzer speeds. The comparison between the speed detectors and traffic analyzer before and after calibration is shown in Figure 13.

Initial Studies with On-Line X-Y Plotter

The pilot detection system includes an X-Y plotter which permits the on-line plotting of one variable (volume, speed or occupancy) vs time or one variable vs another variable. A master panel board permits the use of any measured variable at any location to be plotted against any other measured variable at any location. Sample X-Y plots are shown in Figures 14, 15, and 16.

Initial Studies with Printer-Counter

Initial uses of the printer-counter included the evaluation of the 38 volume detectors and the recording of lane volumes for preliminary determination of volume variations and lane volume distributions.

Evaluation of Volume Detectors.—In testing each volume detector, the count obtained from the detector, the occupancy obtained from the detector, the manual lane count, and the time were printed on the printer-counter every three minutes until 1,000 counts were received. Counts were taken during moderate to heavy traffic flow. If the difference between the detector count and the manual count exceeded 4 percent, the per-

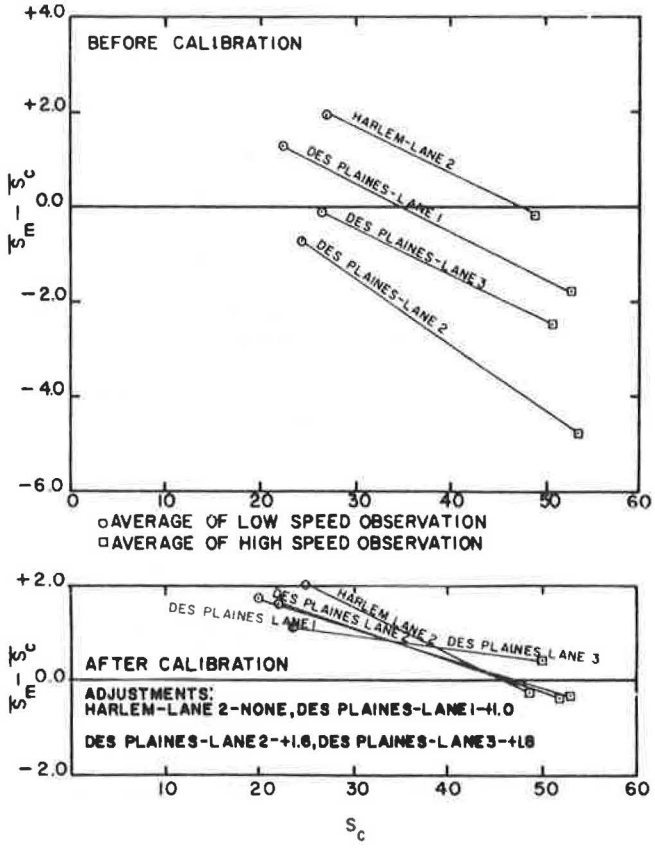

Figure 13. Calibration of speed detectors with traffic analyzer (Dec. 1962).

TABLE 1

SUMMARY OF STUDY RESULTS

Location	Lane[1]	Calibration[2]	Result Average								Percent of Individual Speeds Within Range[6]			
			Low-Speed				High-Speed				Low-Speed		High-Speed	
			Detector Speed	BPR Speed	Difference[3]	Sample Size[4]	Detector Speed	BPR Speed	Difference	Sample Size[5]	± 2 mph	± 5 mph	± 2 mph	± 5 mph
Harlem	2	None	28.6	26.6	+2.0	32	48.5	48.7	-0.2	100	97	100	46	94
Des Plaines	3	None	26.7	26.8	-0.1	33	48.5	51.0	-2.5	100	94	100	65	96
		+1.8	25.4	24.3	+1.1	37	50.5	50.1	+0.4	100	100	100	76	99
	2	None	23.7	24.4	-0.7	32	48.5	53.3	-4.8	100	88	100	27	78
		+3.0	25.6	24.8	+0.8	6	52.4	51.9	+0.5	100	50	100	35	79
		+3.0	26.5	24.1	+2.4	30	55.5	54.9	+0.8	100	83	97	40	79
		—[7]	25.4	23.8	+1.6	31	51.8	52.2	-0.4	106	97	100	46	89
	1	None	23.9	22.6	+1.3	30	50.4	52.2	-1.8	100	100	100	40	79
		+1.0	23.2	21.5	+1.7	31	52.0	52.4	-0.4	100	30	100	37	86

[1] Lanes 1, 2, and 3 are median, middle, and shoulder lane, respectively.
[2] None before calibration; + x.x = amount of calibration; underscore = final setting.
[3] + = detector speed BPR speed; - = detector speed BPR speed.
[4] Four test vehicles employed to obtain low speeds.
[5] Individual vehicles in traffic stream observed.
[6] For example, at Harlem lane 2, individual detector speed of 94 percent (94 out of 100 vehicles) was within ± 5 mph of the BPR individual speeds.
[7] Original adjustment + 3.0 and second adjustment -1.4, for net adjustment of + 1.6.

formance was not acceptable. The three types of volume detectors used in the pilot detection system are 11 side-fire detectors (used on ramps only), 4 motion detectors, and 23 presence detectors. Using the manual count as the standard, the performance

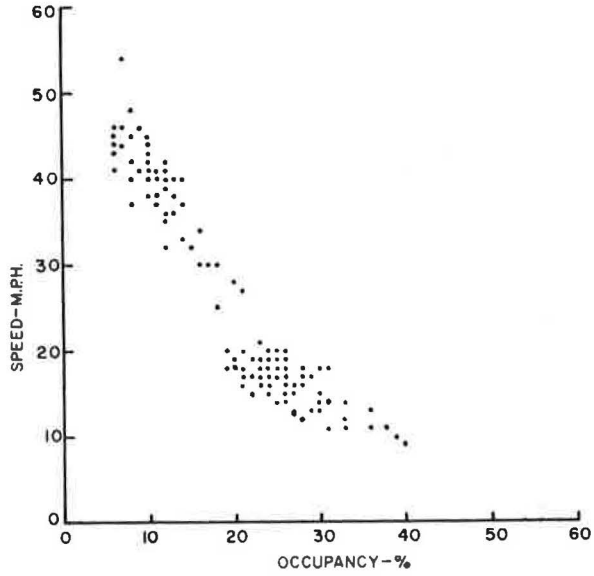

Figure 14. Off-line speed occupancy scatter diagram.

of the three types of detectors was evaluated, and a summary of the results is given in Table 2. The side-fire detectors ranged from -2.5 to 1.7 percent difference from the manual count, with five of the detectors undercounting and six of the detectors overcounting (average error of -0.3 percent). The motion detectors ranged from -1.7 to -0.5 percent difference from the manual count, with all four detectors undercounting (average error of -1.3 percent). The presence detectors ranged from -3.9 to 3.6 percent difference from the manual count with nineteen of the detectors undercounting and four of the detectors overcounting (average error of -1.7 percent).

Volume Variations and Lane Volume Distributions.—The printer-counter was used to record hourly volumes in each of the three lanes at East Avenue, which is located in the center portion of the study section. These measurements were recorded 24 hr per day from Thursday, October 4, through Thursday, October 24, 1962. The purpose of this study was the preliminary determination of daily and hourly volume variations and the distribution of traffic volumes between lanes.

The average daily volume and the average weekday volume during the three-week study were 58,200 and 61,000 vehicles, respectively. The average daily factors and the average weekday factors are given in Table 3. The 24-hr average volumes are also given.

The weekday volumes increase as the week progresses (Monday to Tuesday to Wednesday, etc.) with Friday having the highest 24-hr volume. The hourly variations for the fifteen weekdays from October 4 to 24, 1962, are shown in Figure 17.

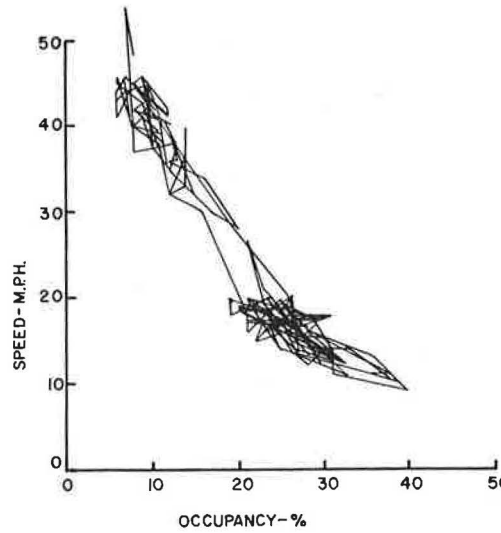

Figure 15. Off-line speed occupancy continuous diagram.

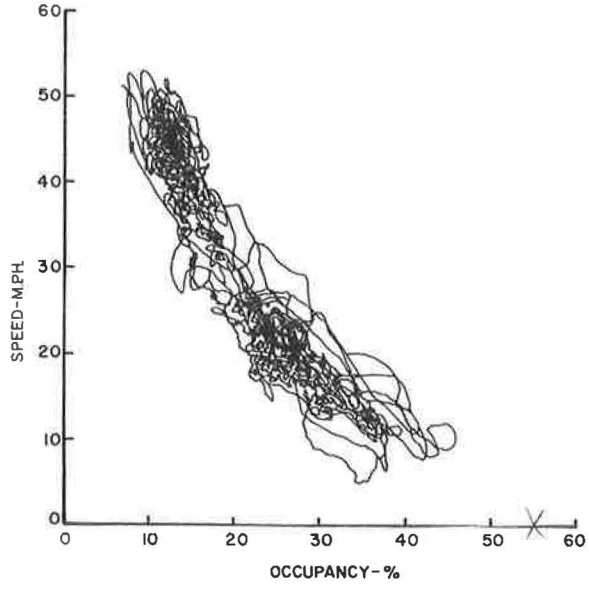

Figure 16. On-line speed occupancy continuous diagram.

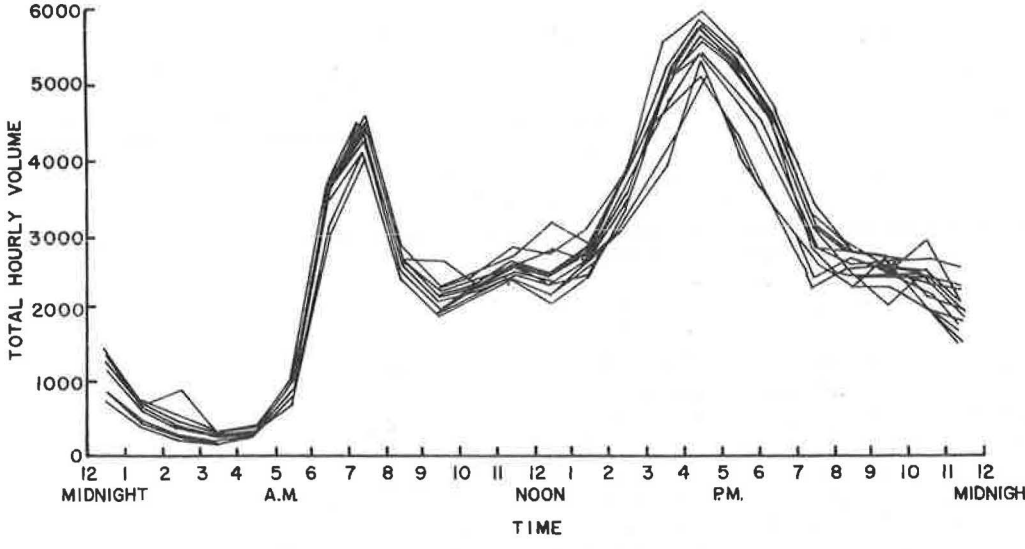

Figure 17. Hourly volume variations on westbound Congress Street Expressway (East Avenue, Oct. 4 to 24, 1962.

Figure 17 shows the hourly variations for the fifteen weekdays are very similar throughout the 24-hr period. The morning peak hour (7 to 8 AM) varies from 3,900 to 4,600 vehicles and the afternoon peak hour (4 to 5 PM) varies from 5,000 to 6,000 vehicles. The peak-hour factors (the ratio of the 4 to 5 PM hour volume to the 24-hr volume expressed as a percentage) for each of the fifteen weekdays are given in Table 4.

The distribution of hourly volumes between the median, middle, and shoulder lanes is shown in Figure 18. Lane 1 (the median lane) carried less traffic than lane 2 or 3 during light volume conditions (total volume of 0 to 1,000 vehicles per hour). As the total volume increases (3,000 to 4,000 vehicles per hour), the portion of traffic in lane

TABLE 2

VOLUME MEASUREMENT COMPARISON OF SIDE-FIRE, MOTION AND PRESENCE DETECTORS TO MANUAL COUNT

Location			Volume Measurement (%)		
Station	Avenue	Lane or Ramp	Side-Fire Detector	Motion Detector	Presence Detector
1	Cicero	Lane 1	—	—	-1.5[1]
		Lane 2	—	—	-1.7
		Lane 3	—	—	-1.8
		Lane 4	—	—	+0.7
		Entrance ramp	+0.9	—	—
		Exit ramp	-0.9	—	—
2	Central	Lane 1	—	—	-1.7
		Lane 2	—	—	-3.2
		Lane 3	—	—	-2.9
		Lane 4	—	—	-3.9
		Entrance ramp	-2.5	—	—
		Exit ramp	+0.1	—	—
3	Austin	Lane 1	—	—	-0.3
		Lane 2	—	—	-1.0
		Lane 3	—	—	+1.4
		Entrance ramp	+1.7	—	—
		Exit ramp	+0.3	—	—
4	East	Lane 1	—	—	-0.9
		Lane 2	—	—	-1.6
		Lane 3	—	—	-1.7
5	Harlem	Lane 1	—	—	+3.6
		Lane 2	—	-1.7	-2.0
		Lane 3	—	—	+0.8
		Entrance ramp	+0.4	—	—
6	Des Plaines	Lane 1	—	-1.5	-1.3
		Lane 2	—	-0.5	-3.6
		Lane 3	—	-1.4	-3.7
		Entrance ramp	-1.8	—	—
7	First	Lane 1	—	—	-1.7
		Lane 2	—	—	-3.6
		Lane 3	—	—	-0.8
		Entrance ramp	+0.2	—	—
		Exit ramp	-0.4	—	—
	Range		-2.5 to +1.7	-1.7 to -0.5	-3.9 to +3.6
	Undercounts (-)		5	4	19
	Overcounts (+)		6	0	4
	Avg. error		-0.3	-1.3	-1.7

[1]Figures obtained by $\% = \left(\frac{V_{detector} - V_{manual}}{V_{manual}} \right) 100.$

1 increases to 40 percent and equals the amount of traffic in lane 2. At the highest observed hourly volumes (5,000 to 6,000 vehicles), the volumes of lanes 1 and 2 are equal, and each carried 35 to 40 percent of the total volume. Except at total hourly volumes less than 1,000 vehicles per hour, lane 3 (shoulder lane) carries the smallest portion of the total volume and this portion is between 20 and 28 percent of the total volume.

TABLE 3

AVERAGE DAILY AND WEEKDAY VOLUMES

Day of Week	Average Daily Factors[1]	Average Weekday Factors[1]	Daily Volume
Sunday	0.81	—	46,900
Monday	1.01	0.95	58,500
Tuesday	1.02	0.96	59,300
Wednesday	1.06	1.00	61,600
Thursday	1.09	1.03	63,700
Friday	1.11	1.05	64,800
Saturday	0.91	—	53,100

[1] $\frac{\text{Day of week vol.}}{\text{Average daily vol.}}$.

[2] $\frac{\text{Day of week vol.}}{\text{Average weekday vol.}}$.

TABLE 4

PEAK-HOUR FACTORS

Day	Peak-Hour Factor (%)[1]			
	Week One	Week Two	Week Three	Average
Thursday	8.5	9.0	8.9	8.8
Friday	8.9	8.6	8.9	8.8
Monday	9.8	9.5	9.1	9.5
Tuesday	9.0	9.4	9.2	9.2
Wednesday	9.0	9.4	9.2	9.2
Average	9.0	9.2	9.1	9.1

[1] Figures obtained by:

Peak-hour factor (%) = $\frac{\text{4 to 5 PM hr vol.}}{\text{24 hr vol.}}$.

Peak-hour factors vary from 8.5 to 9.5 percent with overall average peak-hour factor of 9.1 percent.

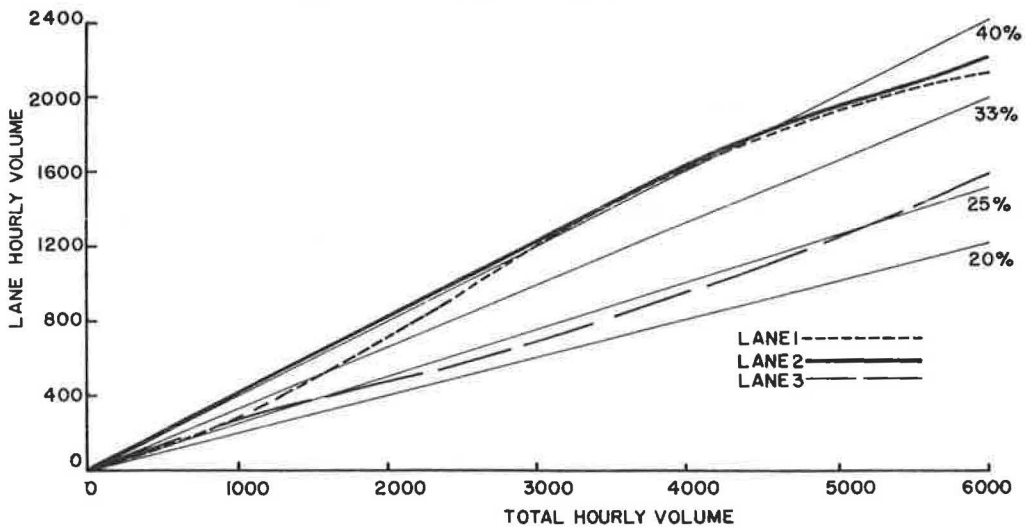

Figure 18. Lane distribution on westbound Congress Street Expressway (East Avenue).

Initial Studies with Map Display

At each mainline station of the five-mile study section, a light indicator is displayed on the map panel. The color of the light is selected based on the level occupancy measured at the mainline station. The four conditions denoted are given in Table 5.

During the afternoon peak traffic period (3 to 7 PM) the mainline light indicators were recorded each minute on Wednesday, October 10, 1962. Figure 19 shows how the map display presented the various levels of operation during a typical weekday afternoon peak period.

Free flow (zone 1) was maintained at the output station (First Avenue) during the entire afternoon peak period. Congestion, identified by zones 3 and 4, began at 4:23 PM

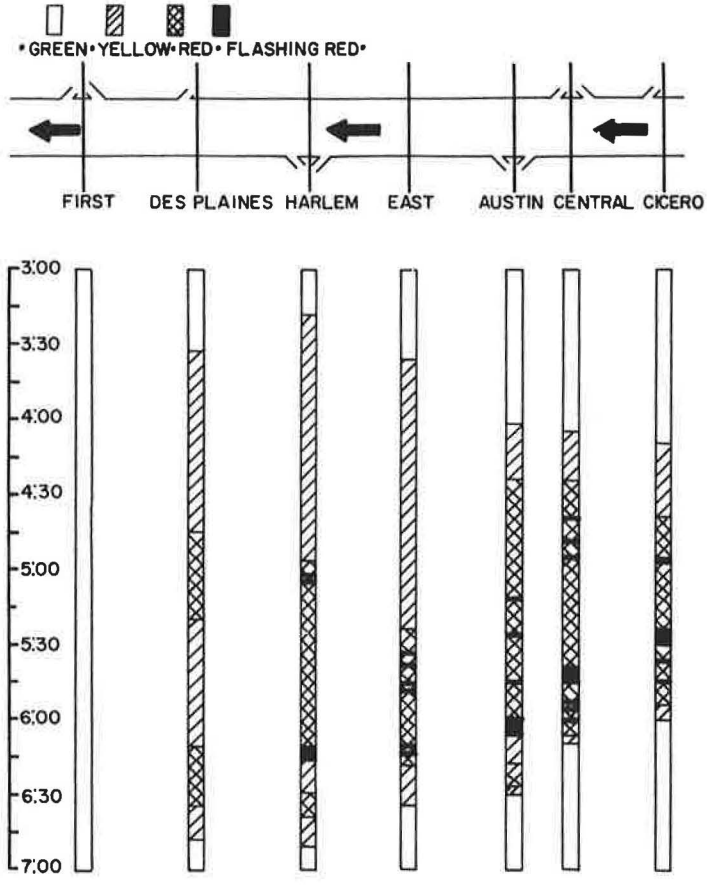

Figure 19. Map display indications during afternoon peak period (Oct. 10, 1962).

at Austin and at 4:42 PM at Des Plaines. By 5:10 PM congestion was evident from Des Plaines upstream through the study section. By 6:30 PM traffic began to move more freely, and by 6:50 PM free flow existed throughout the study section.

Initial Studies with Punch Tape Output

During a comprehensive three-week study, some 84 measurements from the pilot detection system were punched on paper tape for each minute for three consecutive weeks. The paper tape can be directly fed into a G-15 Bendix computer for analyses and a number of studies are now being undertaken in this fashion. In addition, the paper tape can be converted to a printed tape by the use of a Flexowriter, and a sample portion of the tape for four consecutive scans is given in Table 6.

TABLE 5

LIGHT COLOR SELECTION

Zone	Indicator	Occupancy Level (%)	Freeway Conditions[1]
1	Green	0-15	Volume demand speed 40 mph
2	Yellow	15-25	Volume = demand speed 30-40 mph
3	Red	25-40	Demand volume speed 10-30 mph
4	Flashing red	40	Demand volume speed 10 mph

[1]Approximate.

TABLE 6

PRINTED RESULTS OF PUNCHED TAPE SAMPLE OUTPUT

Channel	Description	Traffic Data for Minute Ending			
		4:39 PM	4:40 PM	4:41 PM	4:42 PM
001	Temperature	2	2	2	2
002	Degree of precipitation	0	0	0	0
003	Sky cover condition	0	0	0	0
004	Persons on duty	8	8	8	8
005	Special traffic events	0	0	0	0
006	Pavement condition	1	1	1	1
007	Des Plaines Lane 1 - volume	30	32	34	32
008	Des Plaines Lane 1 - speed	40	37	22	23
009	Des Plaines Lane 2 - volume	34	33	34	34
010	Des Plaines Lane 2 - speed	38	35	29	24
011	Des Plaines Lane 3 - volume	21	25	29	28
012	Des Plaines Lane 3 - speed	39	37	31	25
013					
014					
075	Des Plaines Lane 2 - volume	34	33	33	33
076	Des Plaines Lane 2 - occupancy	18	19	21	26
077	Des Plaines On-ramp - volume	17	14	14	14
078	Des Plaines On-ramp - occupancy	10	8	10	9
084					

The first six channels are used to record non-traffic measurements, and the data entries of 2, 0, 0, 8, 0, and 1, respectively, indicate temperatures between 70-85 F, no precipitation, clear skies, persons on duty, no special traffic events, and pavement dry and above freezing. Channels 007 through 084 are used to record traffic measurements at some 25 lane locations. The opportunity of analyzing such traffic data is almost unlimited, and Table 6 gives some of the initial traffic studies that are being made from the punched tape output:

1. Interrelationships between volume, occupancy, and speed.
2. Comparison of measured speed and speed calculated from volume and occupancy.
3. Comparison of measured occupancy and density calculated from volume and speed.
4. Comparison of lane traffic characteristics.
5. Comparison of traffic characteristics between mainline stations.
6. Changes in traffic characteristics just before congestion.
7. Combination of shoulder lane volume and ramp volume resulting in maximum flow and satisfactory operation.
8. Measurement of the effect of congestion on traffic flow and travel time.

In summary, the pilot detection system is providing the expressway surveillance project staff with a comprehensive library of measurements over an expressway section and for periods of time which permit microscopic and macroscopic investigations both qualitative and quantitative, and the data-logging subsystem is recording the measurements in a manner that makes full use of data-processing equipment with minimum of time and without loss of accuracy.