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Queen Elizabeth Way Freeway Surveillance and Control System Demonstration Project

E. Ryerson Case and Kenneth M. Williams, Systems Research and Development Branch, Ontario Ministry of Transportation and Communications

The design, operation, and effects of a freeway surveillance and control system that became operational near Toronto, Ontario, in July 1975 are described. The system consists of a low-light-level closed-circuit television system, microprocessor-based ramp-metering controls, ramp and mainline loop-detector installations, a central traffic-control computer, and a cathode ray tube graphic display. A single broadband coaxial cable is used for both television and two-way data transmission. The system provides traffic-responsive control that is based on both mainline and ramp conditions, incident detection, hardware-status monitoring, and a performance evaluation and reporting capability. The control center is located in a local Ontario Provincial Police facility near the freeway. Operating experience is discussed in terms of the effect of adverse public reaction to ramp metering, driver behavior, and system reliability. Substantial improvements in travel time and freeway speeds have been achieved, even under poor operating conditions, and the accident rate appears to have decreased. The closed-circuit television system has proved to be a valuable tool for traffic and incident management, particularly because of the close interaction with the police. The incident-detection system has been operating satisfactorily but requires verification by using the television system to eliminate false alarms. Overall, the project is considered to be successful.

Freeway surveillance and control is used in many cities. Even so, its introduction in a new area can still be a noteworthy event. And, because of changes in technology and public attitudes, the design, operation, and results of a new system can still add to the general pool of knowledge about the subject.

The Queen Elizabeth Way freeway surveillance and control system demonstration project represents the first venture by the Ontario Ministry of Transportation and Communications into the field of freeway surveillance and control. The project was considered for the following reasons:

1. The continuous increase in traffic on the freeway system,
2. The appearance of congestion on the freeway system,
3. The high cost of constructing or reconstructing freeways,
4. Public aversion to more or bigger urban freeways, and
5. Favorable results from similar projects in the United States.

Two broad goals were established for the overall freeway surveillance and control program:

1. To operate the freeway system at a high volume rate and a reasonable level of service while maintaining the best quality of service possible on nearby arterial roads and
2. To minimize collisions on the freeway system by

(a) recognizing conditions likely to cause collisions and providing adequate warning and (b) rapidly recognizing and responding to collisions (thus reducing the risk of secondary collisions).

Within the framework of these goals, specific objectives were established for the QEW demonstration project:

1. To provide relief to a congested component of the freeway system,
2. To introduce to the public the freeway surveillance and control concept and to demonstrate its effectiveness,
3. To provide local data and experience in system operation to project personnel, and
4. To obtain and develop expertise in the technology of freeway surveillance and control.

A portion of the Queen Elizabeth Way (QEW) just west of Toronto was selected for the demonstration project. There was localized congestion and, because it is close to a metropolitan area, the area was felt to be consistent with the above objectives. There was an additional advantage in that space for a control center was available in a nearby Ontario Provincial Police detachment office.

This paper describes the QEW freeway surveillance and control system (FSCS) and outlines the operational experience and the results achieved since the system was implemented in July 1975.

CORRIDOR DESCRIPTION AND SYSTEM REQUIREMENTS

Physical Description

The QEW connects the Niagara peninsula and Buffalo with Toronto (see Figure 1). Near Toronto, it also serves as a major commuter access route from the nearby cities of Burlington, Oakville, and Mississauga. The QEW FSCS controls the heavy flow toward Toronto in the morning. The actual project site is in Mississauga between Southdown Road and Highway 10, a distance of 6.2 km (3.9 miles), as shown in Figure 2. This is the area of greatest congestion.

Figure 1. Site of Queen Elizabeth Way demonstration project.

The Credit River, which crosses the QEW just east of Mississauga Road is a barrier to the movement of east-west traffic. The nearest alternative routes that cross the river are located about 2 km (1.75 miles) away. Both of these, Highway 2 and Highway 5, are four-lane urban arterials that have traffic signals and are not attractive as alternative routes. There is also another east-west freeway (Highway 401) about 10 km (6 miles) to the north.

In the project area, the QEW has three lanes in each direction; there are four or more lanes closer to Toronto. There are right-side paved shoulders except on the 224-m (800-ft) Credit River Bridge. Southdown Road and Highway 10 are four-lane arterials, and Mississauga Road is a two-lane residential collector. The control center is at the Highway 10 interchange.

Traffic Conditions Before Metering

Traffic data collection was begun in 1973 for project justification and to provide a data base for before-and-after studies.

As expected, traffic volumes in the morning peak period increased from west to east; 15-min volumes reached a peak of 5900 vehicles/h between 7:15 a.m. and 7:30 a.m. and then dropped off rapidly even though there were still waiting vehicles. Seven percent of the traffic is trucks; therefore, the through lane capacity is 5580 vehicles/h (1). Congestion, as represented by low speeds, extended from west of Mississauga Road to Highway 10, and its extent increased by 1.5 km (0.9 mile) in 1 year. At the height of the peak period, there were extensive queues of vehicles on the Highway 10 ramps and shorter ones at Mississauga Road but none at Southdown Road. Concentrations of collisions were located at the Credit River and at Highway 10. Residential development was increasing to the west in the QEW corridor.

System Requirements

In compliance with the goals and objectives described above, the following broad functional requirements and specifications were identified:

1. Ramp metering that included provision for several metering rates and control modes was to be installed at each of the five entrance ramps.

Figure 2. Queen Elizabeth Way freeway corridor and locations of metered ramps.

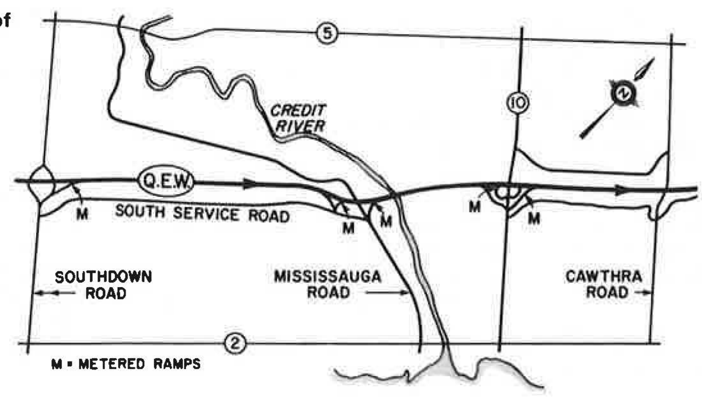
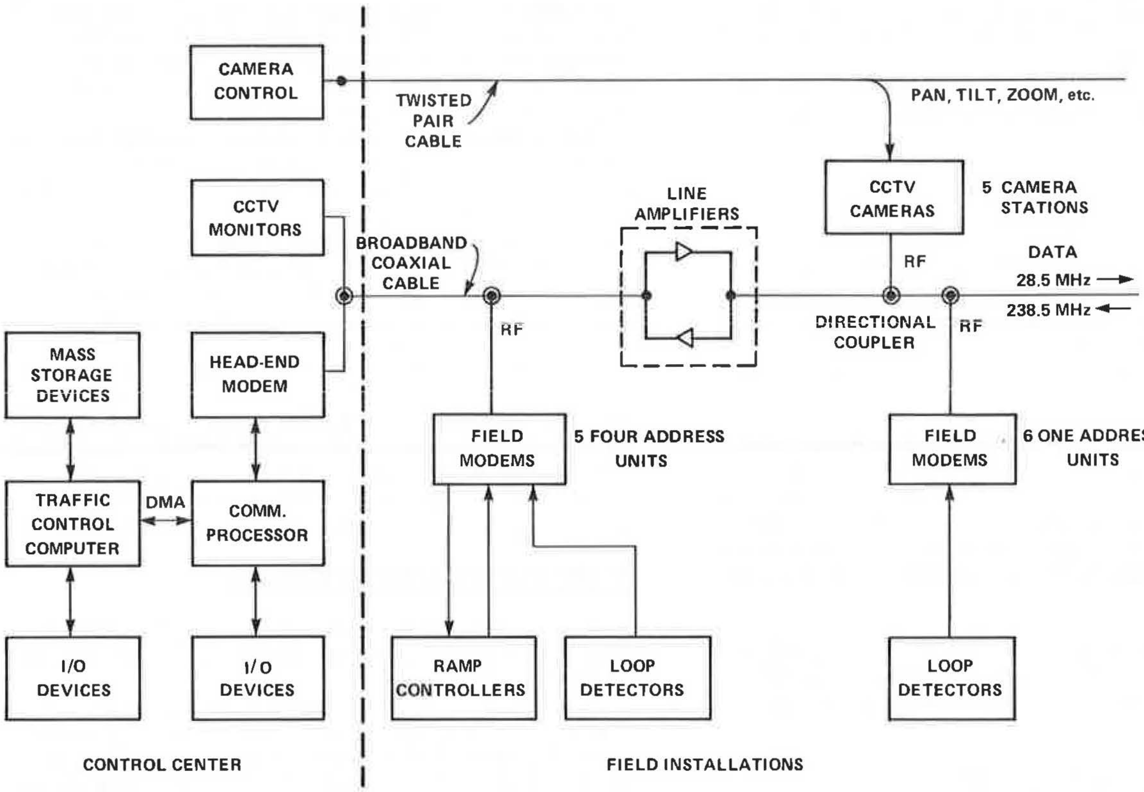


Figure 3. Functional block diagram of freeway surveillance and control system.



2. Closed-circuit television (CCTV) was to be installed to provide visual surveillance of the complete project area.

3. A central traffic control computer was to be installed at the control center to provide ramp-metering control, data collection, recording and analysis, incident detection, and hardware monitoring.

4. The feasibility of using a coaxial cable for broadband data communications was to be examined.

5. The project was to be carried out in-house to the greatest extent possible to give ministry staff in-depth expertise in the technology of freeway surveillance and control.

6. Sufficient instrumentation was to be provided to allow a comprehensive evaluation of system effectiveness.

SYSTEM DESCRIPTION

The six basic systems that compose the QEW FSCS (see Figure 3) are as follows:

1. Broadband coaxial cable system,
2. CCTV system,
3. Broadband data-communication system (BDCS),
4. Field installations,
5. Traffic-control computer (TCC) system, and
6. Application software for the TCC system.

The final configuration of the FSCS for the demonstration project was determined to some extent by the chronological order in which the various parts of the system were implemented. For example, the CCTV and coaxial cable systems, as well as the local ramp-metering controllers, were specified well in advance of the data-communication and TCC systems. This led to the installation of a 12-pair cable along with the coaxial cable to provide for voice-band data communications in the event that broadband data communications could not be used. As it turned out, the twisted-pair cable was used for CCTV camera control and central manual control of the ramp-metering controllers before the central traffic-control system was operational.

Broadband Coaxial Cable System

The broadband coaxial cable system is the main communication link between the control center and the remote field installations for both data and video transmission. It is essentially a high-quality coaxial television trunk line and uses a 1.91-cm (0.75-in) diameter aluminum-jacketed cable and bidirectional repeater amplifiers spaced about every 0.75 km (2200 ft) along its 7-km (4-mile) length. As shown in Figure 4, both the cable and the amplifiers are strung overhead on a pole-mounted, steel messenger cable. The system uses a subsplit configuration in which the central-to-remote bandwidth is 5 to 30 MHz and the remote-to-central bandwidth is 50 to 300 MHz. It can accommodate up to 30 television channels and several duplex data channels.

Closed-Circuit Television System

Channels 4, 6, 10, 12, and 13 are used for the five television cameras, which are spaced approximately 1.6 km (1 mile) apart along the freeway. Each camera location uses a standard audiovisual modulator and is connected to the main trunk line by a directional coupler; the audio carrier of each channel is currently unmodulated. The cameras, which use a low-lag, low-bloom type of silicon-intensified-target tube for both nighttime and daytime operation, are enclosed in a weatherproof housing that has air filters, exhaust fans, and windshield wipers. They are mounted on

Figure 4. Coaxial cable and repeater-amplifier installation.

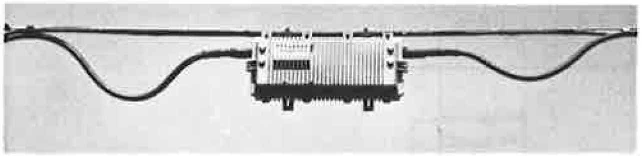
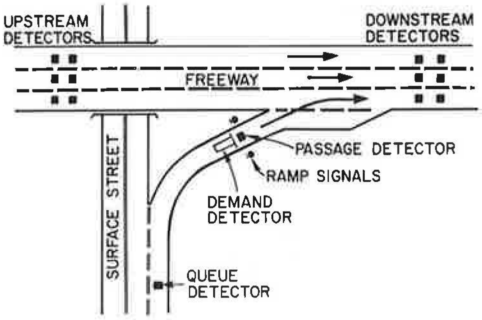


Figure 5. Basic ramp-metering installation.



15-m (50-ft) stressed concrete poles (which are used to minimize pole whip in high winds). All the usual remote-control functions are provided, such as pan, tilt, zoom, focus, iris opening, and windshield-wiper actuation. Five standard black-and-white television sets are used to separately monitor each camera. These are mounted in a console, which also includes a camera control panel, in the traffic-control center. The camera-control signals are carried over the twisted-pair cable shown in Figure 4.

Broadband Data-Communication System

Broadband data communications was a natural choice for the QEW FSCS because of the system requirement for CCTV. This type of system is cost-competitive with a voice-band system only when part of the cable cost can be apportioned to a CCTV system, but it has a number of advantages that make it an attractive choice from the technical point of view. These include high immunity to electric interference, large data-handling capacity, and ease of expansion.

The QEW BDCS (see Figure 3) interconnects the field loop detectors and the microprocessor ramp controllers with the central TCC by means of 11 field-data modulator-demodulator units (modems) located in 11 field cabinets. These field-data modems communicate with a head-end master-data modem through a duplex data channel by using a central-to-remote carrier frequency of 28.5 MHz and a remote-to-central carrier frequency of 238.5 MHz. The head-end master-data modem is connected to a communications processor (a 16K minicomputer) that serves as a front-end preprocessor to control the time sequencing of incoming and outgoing traffic data and to communicate with the central TCC. The communications processor has a teletype and a high-speed paper-tape reader for loading the communications-processor system software. Central-to-remote data communications is accomplished on a single time-share data channel that has a terminal addressing scheme. Remote-to-central data communications is accomplished by a time division multiplexing (TDM) system.

The maximum system data rate is 48 000 bits/s; this corresponds to a total of 64 terminal addresses that can be handled by the system, assuming a polling or sampling rate of 50/s. This sampling rate was chosen to limit the maximum absolute error of individual vehicle-speed-trap estimates to 10 percent at 100 km/h (60 mph), which corresponds to a 1-sigma sampling error of about 2.7 km/h (1.7 mph).

Field Installations

The field installations include five ramp-metering locations and 10 mainline detector stations. The specific configurations used (Figures 5 and 6) followed the recommendations given by Everall (2) wherever possible. Items worthy of comment are as follows:

1. Two signal heads are used on each ramp.
2. The right-side signal head is mounted 3.0 m (10 ft) above the roadway (Figure 7) to comply with legal requirements for traffic signals in Ontario.
3. An amber signal is included in each cycle, again to meet legal requirements. The amber time is 0.5 s. A 5.0-s amber is used during system turn-on.
4. The signal controller is a microprocessor-based device designed for ramp metering. The five cycle lengths can be selected on the basis of a fixed program, a remote device, mainline occupancy, or queue length.
5. The detector dimensions shown in Figure 6 will be adjusted in future installations because some motorists stop just before reaching the arrival detector and others stop just on the leading edge of the passage detector. In either case, the result is no green signal. The distance from the signal head to the leading edge of the passage detector will be increased from 2.4 m (8 ft) to 3.0 m (10 ft), and the length of the arrival detector will be increased to 6.1 m (20 feet) by moving the leading edge further away from the stop line.
6. The mainline detector stations are spaced approximately 800 m (0.5 mile) apart. Occupancy data are supplied to the local controllers, and occupancy, volume, and speed data are supplied to the central computer.

Traffic-Control Computer System

The TCC system consists of a 32 K-word minicomputer, a 1.25 million-word disk unit, a nine-track tape unit, a teletype terminal, and a cathode ray tube graphic display unit. The computer has a real-time clock, power-failure monitoring, and automatic-restart capability. The computer software runs under a real-time disk-operating system, which provides a real-time multitask environment and system-overlay facility. As shown in Figure 3, the TCC communicates with the communications processor through a duplex direct-memory-access (DMA) data channel. In addition to its normal communications task, the communications processor preprocesses freeway detector data before it is presented to the TCC. The graphic display unit uses a 48.3-cm (19-in) tube to plot graphic data on a 1024 × 781-dot matrix under computer control. An accompanying cathode ray tube hard-copy unit is also available.

Applications Software

The various software programs for real-time traffic-control-system applications are shown as a simplified functional block diagram in Figure 8. They are written in FORTRAN and assembly language and are under control of the master task program.

The purpose of the communications programs is to poll the communications-systems processor at 1-s intervals for the most recent traffic and field hardware-

Figure 6. Ramp detector configuration.

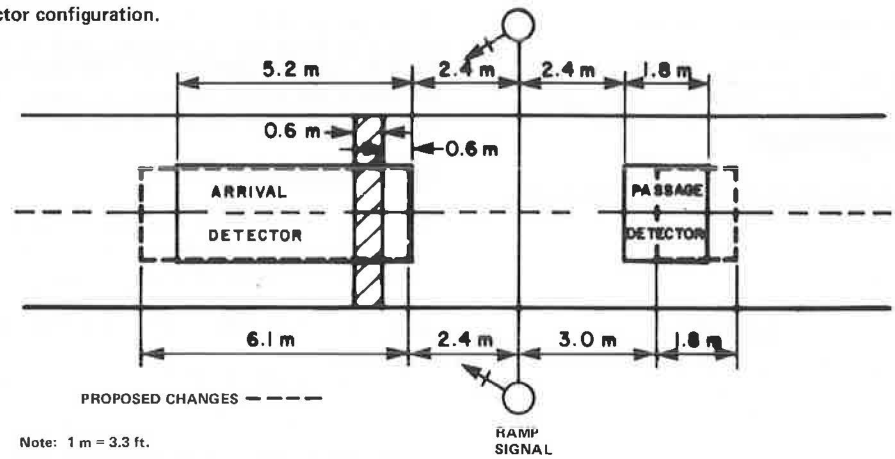


Figure 7. Typical ramp-metering installations.

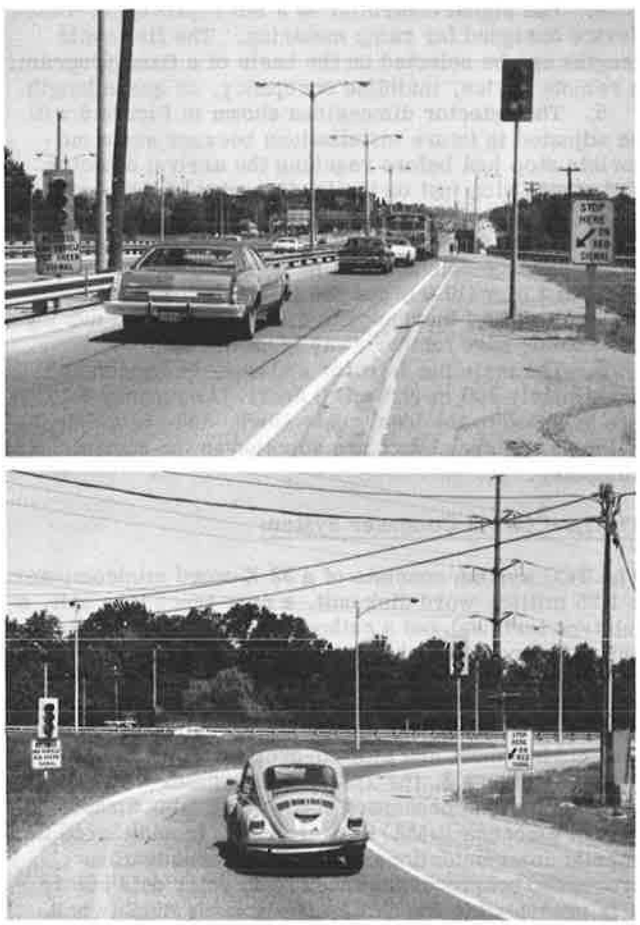
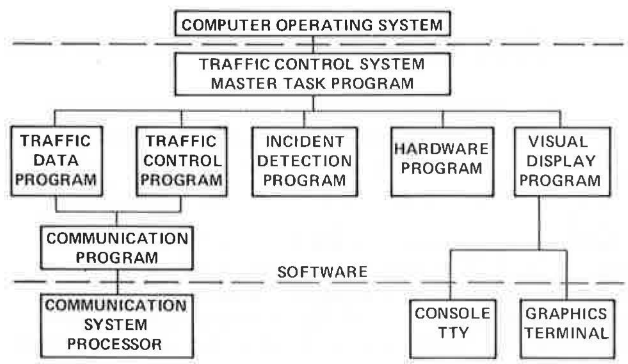


Figure 8. Software for real-time traffic-control system.



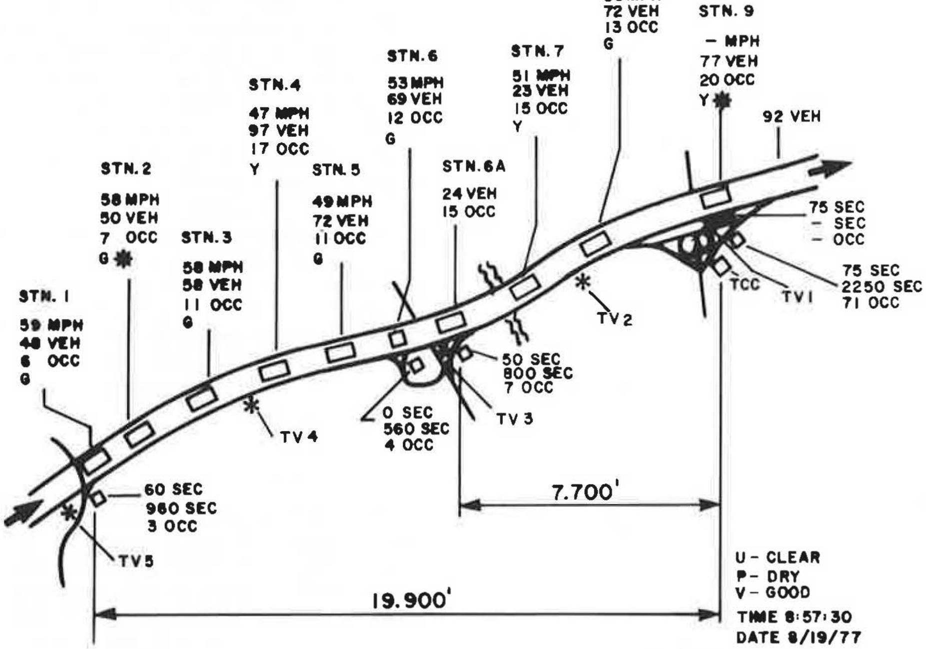
status data and to transmit the appropriate ramp-metering cycle-length commands to the communications-systems processor through the duplex DMA data channel. Data communication is accomplished through the execution of different protocols that are designed to accommodate different data transmission needs.

The traffic-data program accumulates and computes the real-time traffic data and saves the data files on the system data-bank disk. The traffic data base created and managed by this program contains both lane and station values of volume, occupancy, speed, and vehicle-length distribution, each updated at 30-s, 1-min, and 5-min intervals. The continuity of the data files allows enquiry and reporting capabilities of data ranging from the most recent to historical data up to 1-d old. This traffic data base is available to the other programs.

The traffic-control program is based on a traffic-responsive plan-selection strategy in which ramp-signal cycle lengths are selected on the basis of mainline and on-ramp conditions. Mainline conditions are determined at mainline detector stations located upstream, downstream, and adjacent to each ramp. Ramp-queue-detector occupancy data provides a measure of ramp congestion and is used to activate a queue-override function when it exceeds a preset threshold value, at which point the metering rate is changed to the minimum cycle length until the queue-detector occupancy drops below a second preset threshold value. The difference between these two preset occupancy values is a hysteresis band that must be large enough to prevent hunting between the minimum cycle length and the cycle-length corresponding to mainline traffic conditions. This program also uses the ramp-queue-detector occupancy data to estimate ramp queue lengths empirically for each ramp. Waiting time, calculated by multiplying cycle length by ramp queue length, provides an optional queue-override control mode.

The incident-detection program is based on the automatic freeway incident-detection concepts developed by the state of California. The method of incident detection and clearance uses a series of tests based on comparing the current and the previous 30-s mainline-detector-station occupancy data. This program also provides the information for the visual display

Figure 9. Graphic map display of Queen Elizabeth Way.



program that displays incident detection on the freeway map display and sounds an audible alarm signal.

The primary function of the visual display program is to display real-time traffic data on a freeway map displayed on the cathode ray tube graphics terminal. The program provides the capability of displaying the whole freeway map as shown in Figure 9 or of zooming in on individual interchanges for more detailed information. (Because the operation of these programs required that the data be given in U.S. customary units, SI units are not given in Figure 9.) The freeway graphic displays show real-time traffic data, including occupancy, volume, speed, ramp-queue waiting time and ramp-metering cycle lengths, all updated every minute. The location of an incident is indicated by an "X" midway between the upstream and downstream detector stations on the map display (Figure 9). This type of display was chosen rather than the conventional wall map because of its inherent flexibility and because it is representative of the next generation of wall-map displays that use color-projection TV.

The hardware program is designed to identify and record malfunctions in the system hardware. A malfunction is indicated by an audible alarm generated on the teletypewriter, and a record is kept on disk for maintenance-analysis purposes. The data modems are checked every second for the proper response; a particular modem is declared to be in an error state if there is no response after five successive interrogations. The microprocessor ramp controllers and the ramp-metering signals are checked every 30 s for possible malfunction, and the loop detectors are checked every 5 min.

A number of off-line programs have been written for purposes of system-performance evaluation. The results obtained are reasonably precise because the high level of detectorization used for the demonstration system provides data on total system input and output as well as mainline speeds and volumes throughout the entire system. Typical of the plots produced by these programs is the travel-time plot shown in Figure 10, which illustrates the large difference in travel time between good and poor conditions. Other plots include ramp waiting times (Figure 11) and freeway-speed contour diagrams. These plots, as well as printouts of total freeway travel time and travel distance, are all provided on a daily basis. Also, to provide access for research and other purposes to the large amount of traffic data generated by the QEW FSCS, an historical traffic data base has been established in the ministry's large-scale time-sharing computer system.

OPERATING EXPERIENCES

The QEW FSCS is now fully operational and has met the requirements laid down at the beginning of the project. However, it has gone through several evolutionary stages (Figure 12) since it was first implemented and it has experienced numerous problems along the way. Public reaction to ramp metering was the most serious problem.

Operational History

The first operational stage began on July 3, 1975, when isolated ramp metering that used local percentage-occupancy control at the four ramps at Mississauga Road and Highway 10 was implemented. To meet the project objectives, it was planned to increase the freeway speed to about 56 km/h (35 mph), the condition for maximum throughput according to the traditional relationship between volume and speed. Although some queuing had been expected, the metering rates chosen proved to be much too restrictive, which resulted in very long queues, excessive waiting times, and considerable congestion on the ramps and intersecting streets. At this time, there was no interconnecting cable or CCTV system to give an overview of system operation. Adjustments to the signal timings made during the succeeding few days were not sufficient to reduce the large amount of adverse public reaction. As a result, the system was shut down for a week.

It took several days for traffic to return to the congested premetered state, and it then appeared to deteriorate further and become even worse than before the metering. Clearly, the first few days of metering

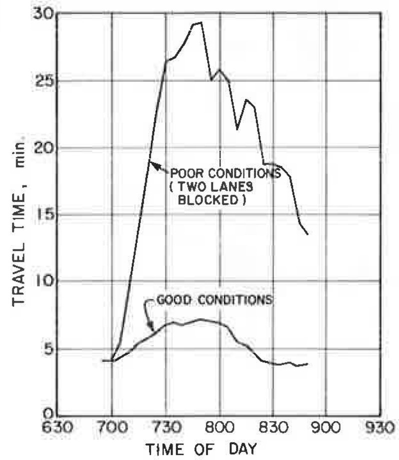


Figure 10. Typical travel-time plots.

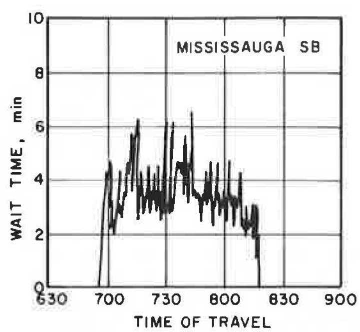


Figure 11. Typical plot of ramp waiting time.

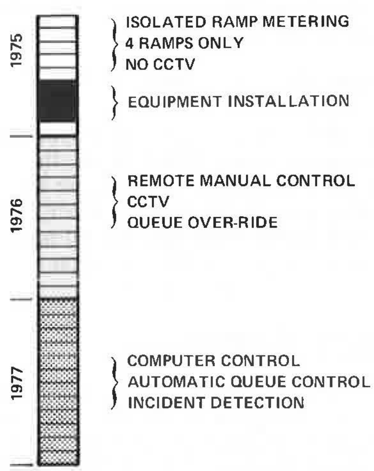


Figure 12. Operating history of freeway surveillance and control system.

had produced a radical change in the demand patterns on the entrance ramps and this had carried over into the nonmetered period.

During the shutdown period, it was decided that the only way the project could continue was to introduce a queue-override strategy. Maximum acceptable values of ramp queue length and waiting time were defined. When these values were exceeded, metering rates were increased even if this adversely affected mainline traffic. Combined with lower summer volumes, the queue-control strategy worked well until the end of August. But when volumes increased in September, adjustments could not be made quickly enough to prevent excessively long queues from forming and, after a few days, the system was shut down again—this time for 3 months. As before, conditions on the freeway deteriorated to premetering levels, but the merging interference with the mainline traffic returned more gradually.

During this second shutdown period, the communications cables and the CCTV system were installed and brought into operation. A remote, manual cycle-length selection system was also added by using spare wires in the 12-pair cable. When the system was started up again at the end of November, visual monitoring and manual adjustment of metering rates to maintain mainline flow while avoiding excessive ramp queues could be accomplished from the control center. This type of manual control constituted the second stage of ramp metering. There were no further shutdowns.

In January 1977, the third and final stage of ramp metering began when the data-communications system and TCC became operational. When necessary, the local controllers can still operate independently as a backup to the computer.

Public Relations

Public relations efforts included displays in local schools and a shopping center, a telephone survey, and distribution of leaflets explaining the project. The 3-day shopping center display was held a month before the start of ramp metering and included a ramp-metering signal, video tapes of traffic conditions on the QEW, charts and maps showing existing volumes and speeds, and handout leaflets. Many people visited the exhibit, and the staff were available to answer questions. The leaflets were also passed out on the ramps the day before ramp metering started.

During the 3-month shutdown, a similar display was set up for an evening in each of two local schools. A large and vocal turnout of people was expected in view of the adverse public reaction that had been generated. In fact, however, very few people came, although most of those who did attend were vehemently against the project. Their main argument was that it was inequitable to favor mainline users over Mississauga (ramp) users.

A telephone survey of Mississauga and Oakville residents was carried out by an independent consultant in the spring of 1976. At that time, the number of letters and telephone calls complaining about the project was diminishing and it was becoming more difficult to assess whether or not the public was still hostile. Of Mississauga residents who used the QEW in the morning peak period, 33 percent expressed some degree of satisfaction, 45 percent showed dissatisfaction, and 22 percent had no opinion. In Oakville, where a more favorable opinion would be expected because Oakville residents would not have experienced any ramp delays, the results were 70 percent satisfied, 16 percent dissatisfied, and 14 percent no opinion. About 60 percent of all motorists reported no change in travel time and of those who did report a change, 93 percent of Oakville residents reported a decrease and 65 percent of Mississauga residents reported an increase. Despite the publicity surrounding the project, only 30 percent of the users had noticed the television cameras. Only 6 percent had any objection to television surveillance. Two general conclusions obtained from the survey were that (a) there was not as much objection to the project as had been indicated earlier and (b) positive aspects of the project, such as motorist aid and incident management, should be publicized more fully.

Driver Behavior

It took only a few days for motorists approaching a ramp signal to adjust their driving habits. Stop-and-

go movement followed by rapid acceleration when the green signal was obtained soon was replaced by a gradual approach and less extreme starting and stopping. A few motorists continue to stop in the wrong place, but the revised detector placements discussed above should reduce that problem. At Southdown Road, the ramp tapers from two lanes to one at the signal location. At times of day that the ramp is metered, motorists form two lines but, during the rest of the day, only one lane operates at the signal. No problems have occurred, and the extra metering storage and 2 vehicles/green throughput have been beneficial on this high-volume, high-speed ramp. Red-signal violations, which are highest toward the end of the metering period when congestion is easing up, have generally been quite low and have not been a cause for concern. A few consistent violators have been cautioned by the police, but no convictions have been registered.

Ramp motorists appear to be less aggressive than they used to be when merging with mainline traffic. During times when queue control permits motorists to enter at a faster rate than they can merge, there does not appear to be as much interference with the mainline flow as previously.

System Reliability and Maintenance

The QEW FSCS failure statistics for the period between April 1976 and July 1977 are shown below (listed according to the major subsystems identified in Figure 3).

System	No. of Failures/No. of Units	Failures of Total System
Coaxial cable	0/1	0
CCTV		0
Cameras	Many/5	
Controls	Many/5	
Data-communication system		0
Processor	0/1	
Modems	8/13	
Field installation		0
Ramp controls	6/6	
Detector installations	36/77	
Computer system		1
Computer	0/1	
Disk drive	1/1	
Tape drive	1/1	
Input-output	0/1	

The coaxial cable system had no failures in its first year of operation and has required little maintenance except a periodic routine monitoring of signal levels. The life of a high-quality coaxial television trunk line of this type is estimated to be in excess of 15 years under normal conditions.

The original CCTV system was unreliable almost from the day of installation, and its performance deteriorated as time progressed. The problems appeared to be in both the cameras (electronics) and the control (particularly the zoom drive). Both cameras and lenses were completely replaced after the first year and have since operated satisfactorily. The picture reception during both daylight and darkness has been excellent.

In general, the operation of the BDCS has been satisfactory. Proper heating, ventilation, and insulation are necessary to maintain the cabinet temperatures within the desired temperature range of operation of the data modems [0°C to 40°C(32°F to 105°F)]. The radio-frequency cards in the remote data modems required tuning every 6 months, and maintaining the integrity of the automatic gain-control system and the repeater amplifiers is an absolute necessity.

The only failures in the TCC system have been in the disk-drive and the magnetic-tape-drive units, both of which have been due to poor maintenance. Maintenenace is now carried out by ministry staff, and all repairs are performed by the manufacturer on an as-required basis.

In general, the modular design of the system has resulted in considerable ease in locating component failures and, as a result, there has been a minimum of disruption of system operation. It has been found that shipping and customs delays are very significant in determining the number of spares that should be kept on hand.

SYSTEM EFFECTIVENESS

An assessment of the effectiveness of the QEW FSCS during its first 2 years of operation has been carried out with reference to the original requirements for ramp metering, incident detection, and television surveillance.

Ramp Metering

As indicated above, ramp metering was implemented in three stages. The first, which used only local percentage-occupancy control, was short lived because of the unacceptably long queues generated. One can only speculate as to its ultimate effectiveness if it had been allowed to continue operating; perhaps the residual improvement shown in the immediate postmetering period gives some indication, but it is unlikely that the project could have continued if the ministry had tried to maintain mainline flow without sufficient regard for downstream ramp users.

The second stage of ramp metering involved centralized manual control in which cycle lengths were selected strictly on the basis of visual observation by CCTV of the mainline and ramp traffic conditions from 7:00 a.m. to 9:00 a.m. each weekday. The performance of the system during this period is summarized in Table 1. The operating statistics for the before condition were obtained from floating-automobile runs and extensive direct observations. The after statistics were derived almost entirely from data taken daily by direct television observations. Floating-automobile runs were made on occasion, but travel times and speeds were determined mainly by tracking an easily identified vehicle through the system. The other measures of effectiveness are similarly the result of direct television observations.

During this period, 49 collisions occurred in the eastbound lanes of the QEW on weekdays between the hours of 7:00 a.m. and 9:00 a.m. This compares with the 66 collisions that occurred under the same conditions a year earlier. The improvement is quite impressive, but the fact that the speed limit on freeways in Ontario was reduced from 112 to 100 km/h (70 to 60 mph) early in 1976 may be partially responsible.

The first-year operating statistics shown in Table 1 have been divided into two categories—good and poor—of conditions because of the different operating characteristics associated with the two categories. Poor conditions are defined as those that occur because of rain, snow, disabled vehicles, or collisions; good conditions are those that occur when poor conditions are not present. On good days, the system is operated to produce a downstream mainline volume of 5700 to 5800 vehicles/h, which is slightly over capacity. Under these conditions, there is obviously no reserve for unusual events that reduce the mainline capacity. On poor days, there are longer mainline queues, slower

Table 1. Operating statistics: December 1975 to December 1976.

Measure of Effectiveness	Good Conditions			Poor Conditions		
	Before	After	Percentage Gain	Before	After	Percentage Gain
Minimum speed, km/h	26.3	37.6	43	15.3	22.4	47
Avg speed, km/h	34.4	49.7	45	21.5	34.2	59
Congested period, min	105	85	20	131	113	14
Mainline queue length, km	4.7	3.1	34	6.3	4.9	24
Total travel time, vehicles/h	1308	1090	21	2020	1540	24

Note: 1 km = 0.62 mile.

speeds, longer or excessive ramp queues, and decreased ability to influence the overall operation of the system. Congestion is defined as the condition where the mainline density is greater than that which occurs at a speed of 64 to 72 km/h (40 to 45 mph), and mainline queue length is defined as the maximum extent of the congestion measured westerly from Highway 10. System travel time includes the waiting time on the ramps but does not include any allowance for vehicles that have sought alternative routes. Averages are taken over the 7:00 a.m. to 9:00 a.m. peak period.

Freeway traffic demand did not remain steady during this period, as can be seen from the average daily entering volumes before and after ramp metering was started given below.

Entrance	Before (1973-1974)	After 1975-1976	After May-June 1977
Highway 10 ramps			
Northbound	710	790	930
Southbound	1 335	1 260	1 120
Mississauga Road ramps			
Northbound	820	1 370	1 105
Southbound	1 055	1 000	965
Southdown Road ramp	1 820	1 880	1 270
Mainline	4 890	5 700	6 280
Total	10 630	12 000	11 670

Approximately 600 vehicles leave by the ramps at Mississauga Road and Highway 10; the remainder represents the downstream mainline volume. Thus, the entering volume was increasing steadily during the time that the project was being implemented and during its first year of operation.

From these results, it is apparent that a significant improvement in overall performance has been achieved by ramp metering, even under poor conditions. These results are even more impressive in view of the increase in demand. The system will operate at the capacity of the mainline on good days. The number of collisions has been reduced, and there have been substantial reductions in travel time, congestion time, and mainline queue length. There is no question that mainline traffic benefits from the system. Many people, however, have questioned whether the ramp users receive any benefits.

An early analysis of ramp delays compared with mainline benefits showed the following:

1. At Highway 10, which is at the downstream end of the system, it was assumed that there were no mainline benefits for the ramp users. However, it was found that the ramp delays had decreased after metering, so that there was an overall benefit.
2. At Mississauga Road, there was some benefit from improved mainline operation but there was also increased delay on the ramps. The result was a net loss.
3. At Southdown Road, there was considerable mainline benefit but, of course, some ramp delay where there had been none before. The result was a net gain.

Since then, attempts have been made to adjust the metering rates to reduce the loss to the Mississauga Road ramp users; the results have yet to be evaluated.

The third stage of ramp metering started in January 1977, when the data communications and TCC systems became operational. Totally automatic operation under computer control did not start, however, until the end of March 1977. Preliminary evaluations have been carried out since that time by using the extensive performance-evaluation software that was developed for this purpose. The results are summarized in Figure 13, which shows a comparison of average travel times through the system with manual control (stage 2) and with computer control (stage 3). It is based on two samples of 36 good days chosen from travel-time data taken during the springs of 1976 and 1977 respectively. The improvement achieved by using computer control is apparent from the shape of the histograms; average travel times when computer control is used are less than those when manual control is used 72 percent of the time, and the mean value has decreased by almost 1 min. Some of this improvement may be due to a net decrease in total volume during the first half of 1977. The decrease occurred on some of the ramps, although the mainline volume beyond Southdown Road has continued to increase. Completion of the widening of Highway 401 a few kilometers to the north and the extension of a new east-west arterial has probably attracted some motorists away from the QEW ramps, which would account for some of the observed shift in demand.

Incident Detection

The QEW incident-detection system has been evaluated for the period from the time it became operational in early January 1977 to the end of May, a period corresponding to about 100 d of operation. CCTV was the main tool used to assess the accuracy of the system.

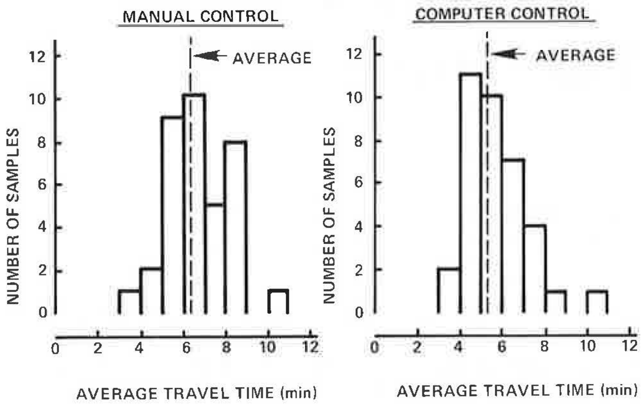
During this period, 45 incidents were recorded; 38 of these were detected by the system, which corresponds to a detection rate of about 84 percent. The total number of false alarms recorded was 142 but, of these, 50 were directly attributable to hardware failures; the false alarm rate was therefore 0.9/d.

It is interesting that, during this period, 49 percent of the false alarms had an alarm period of less than 2-min duration and 87 percent of the true incidents had an alarm period greater than 2-min duration. This would suggest that a persistence test should be added to the incident-detection algorithm; this feature is being added to the software and will be evaluated in the near future.

Television Surveillance

The CCTV system has been a useful tool for both the project staff and the Ontario Provincial Police. In con-

Figure 13. Comparison of manual and computer control.



junction with the computerized incident-detection system, it has been used to verify the occurrence of incidents and to locate them precisely between the mainline detectors, which is important for guiding police and emergency vehicles to the proper entrance ramp when the incident is located near an interchange. Incidents have also been detected independently by the CCTV by noting congestion in one or more lanes or an unusually low-volume condition. Even incidents in opposing lanes have been detected on occasion by noting slowdowns due to gawking motorists.

Proper camera placement at the interchange allows the use of the cameras to observe traffic on the ramps and the intersecting roadways. This becomes quite significant when queue control is used because the ramp queue detector provides information about the area at the detector but cannot indicate the extent of the queue in exceptional circumstances. In the event of detector failure, data can be gathered from the CCTV by direct observations. Mainline queues, undetected congestion, and the effects of increasing or decreasing ramp metering rates can likewise easily be observed by using the CCTV. In fact, the expression "a picture is worth a thousand words" is very apt for traffic management using CCTV.

The fact that the provincial police radio staff and the television monitors are in the same room has made the television even more effective in incident management. The incident can be precisely located, and its seriousness can be evaluated. The police will know how urgently they are needed at the scene. The television cameras are also used to verify and locate incidents reported by others. Major incidents can be quickly assessed by the police staff, who do not have to go out on the road and risk becoming delayed in the congestion.

The television cameras, together with very restrictive ramp metering, have been used to locate and clear a path for an ambulance on an emergency run. They are also used in inclement weather to give up-to-date traffic conditions to local radio stations. During complex lane-closing procedures, the cameras have been used to coordinate the procedure and keep vehicle delays to the minimum. The cameras have also been used to detect and send help to motorists in distress, possibly saving them from having to walk along the freeway. In one instance, help was quickly sent to a motorist whose car was dragging a mattress that appeared to have caught fire.

Although the other parts of the demonstration project operate only during the morning peak period, the television cameras operate 24 h/d and 7 d/week. The police radio staff operates and monitors the television system when the project staff are absent.

FUTURE PLANS

As its name implies, the QEW FSCS demonstration project was a limited-duration project to evaluate the effectiveness of freeway surveillance and control system technology in the Ontario context. In view of the favorable results obtained, it has been decided to add additional equipment and proceed with a local expansion program. In addition, an active research and development program has been undertaken to find ways to improve system operation and to explore the possibilities of applying this technology elsewhere in Ontario.

A changeable-message sign that uses two lines of 22 characters, each 45.8 cm (18 in) high, will be installed west of Southdown Road, facing the eastbound traffic. The sign will use reflective rotating magnetic disks to display up-to-date information obtained from the CCTV, incident-detection, and police radio facilities. Economy in operating costs is achieved because the sign requires power only for a message change. The coaxial cable will be extended to the sign site, and communication will be via a data modem.

Three new interchanges are to be constructed adjacent to the present control area, one downstream and two upstream. The QEW FSCS will be expanded to these areas, which will provide the opportunity for improved overall coordinated control. The television camera control signals will be sent via the coaxial cable, thus removing the need for the 12-pair data cable.

The research and development work under way includes the development of improved ramp-metering and incident-detection strategies, a study of the effect of the level of detectorization on the implementation of such strategies, the development of more refined performance-evaluation programs, and the development of a practical freeway-corridor model for use in systems analysis.

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