Application of Freeway-Corridor Assignment and Control Model

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An improved traffic assignment and control model—CORCON—has been applied to a real freeway corridor. This model is capable of predicting traffic behavior in a freeway corridor by assigning time-varying origin-destination demand to the freeway mainline and the surrounding network streets. The impact of queueing behavior on the selection of minimum-cost travel paths is incorporated by using a flexible traffic-diversion model. Because all or a portion of the traffic may be diverted from a particular queueing path, the effects of freeway-entrance-ramp control on adjacent roadway systems can be investigated. The model was calibrated and validated by using 15-min volume, travel time, and queueing data collected during the 2-h morning peak period on a section of the Queen Elizabeth Way freeway corridor for typical before-control and after-control periods. The calibration resulted in an overall correspondence of 3 to 5 percent, and the validation process predicted average traffic behavior within 5 to 10 percent of actual behavior. The testing was considered very successful because the model was shown to be capable of predicting with reasonable accuracy flows, queues, and travel times on a freeway and adjacent street network.

Over the past 10 to 15 years, freeway surveillance and control has evolved from being considered as a traffic engineer's toy to being recognized as a useful urban traffic management tool.

The inexorable growth of urban traffic demand forced investigators, as long as 10 years ago, to acknowledge that attention must be given to both the freeway and the adjacent street networks if the maximum utilization of existing facilities is to be attained for the entire freeway corridor. However, despite the efficacy of that acknowledgment, the analytic techniques available at that time were not capable of predicting and assessing traffic operations on the freeway and the street system simultaneously. Therefore, the impact of freeway control strategies on adjacent street networks (and vice versa) could not be easily forecast.

In the past several years, there has been considerable work in the development of the tools necessary to correct that problem. The methods proposed have tended to fall in three major categories:

1. Methods that deal with corridor operations and characteristics in a gross manner by ignoring detail in favor of analytic simplicity and efficiency,
2. More complex methods that treat the freeway and the street network in greater detail and thereby (presumably) achieve greater accuracy, and
3. Traditional transportation planning models capable of assigning traffic flows to network links.

Because the models representative of the third category are well known and have had little practical application in the freeway operations field, only the first two categories will be dealt with here. A method typical of the first category was presented by Allen and Newell (1, 2, 3) who suggested that operations on the entire freeway corridor network could be represented (for preliminary planning purposes) by only two routes—one route for the freeway and one route for all other streets. That work was further developed and applied to a real corridor by Liew and Allen (4, 5), who showed that the very simple model could be useful in preliminary development and planning of control strategies.

More extensive work on methods in the second category has been regularly reported by May and his co-workers (6, 7, 8). That work has focused mainly on developing an optimization package that treats the freeway and street network in considerable detail, in fact, in sufficient detail to permit reasonably comprehensive assessments of optimal design and control improvements to selected portions of the freeway corridor. The results of this work have received considerable attention and have been adopted for regular use by many operating agencies.

Parallel to the above methods, Yagar (9, 10, 11) has developed and tested a procedure that conceptually lies somewhere between them. This model uses a relatively conventional link-node configuration for network representation but includes considerably more corridor detail than models in the first category. The basic structure of this model has been improved by Easa and Allen (12, 13, 14, 15), who felt that it had great potential for evaluating the effect of control on freeway corridor operations and recommended that it be fully tested by application to a real corridor.

This evaluation was undertaken (16) on the recently established Queen Elizabeth Way (QEW) freeway surveillance and control system demonstration project study site (which is described by Case and Williams in the following paper in this Record). Data describing traffic volumes, link travel times, and queue lengths were collected for periods before and after implementation of freeway entrance-ramp control along a 9-km (5.5-mile) section of the QEW corridor. These data were used as the basis for a before-and-after test of the predictive capability of the model.

The results of the calibration and validation testing are presented in this paper. The basic model structure (including a brief description of its more novel features) is contained in the following section. The third section contains an introduction to the study site, examples of the data collected, and a brief discussion of the application procedures. Details of the results obtained from the calibration and validation process are reported in the fourth section. The final section contains a brief accounting of the major conclusions and recommendations stemming from the project.

MODEL

The freeway CORridor assignment and CONtrol model—CORCON—divides the peak period into equal lengths of homogeneous demand called time slices. The demand in each time slice and the queued demand of the previous time slice are assigned to the network by using the principle of minimizing individual travel cost (time). The flow versus travel time relationship for each link is an increasing function and is approximated by three linear components. Network features are represented by a simplified link-node method of representation. The model incorporates a procedure for turn prohibitions and overlapping minimum paths to avoid illogical paths within the corridor, a traffic diversion procedure, and a method for calculating turning volumes without the need to provide turning links.

During the development phase, particular attention was given to establishing a simple and efficient method of network representation, avoiding the occurrence of illogical paths in the minimum path assignment algorithm, minimizing the input data requirements, and considering traffic diversion and queueing characteristics. After a careful review of a first generation of the model (13), several improvements were made; a detailed description of the final version of operating characteristics and input-output formats is given elsewhere (14, 15). Therefore, only a brief summary of the key elements is presented here.

Any operational model of this type includes three principal steps:

1. The link-node representation,
2. The determination of the minimum paths, and
3. The traffic-demand assignment to those minimum paths subject to the corridor controls implemented.

These steps, as performed in CORCON, are outlined below.

Link-Node Representation

An essential task in the modeling process is to adequately represent the corridor network in terms of a set of links and nodes. It is obviously desirable to use the most efficient representation possible, either to reduce network coding effort or to permit investigation of larger networks. CORCON incorporates a new method of network representation that allows more than one directional roadway link to have common upstream and downstream nodes. This feature is particularly advantageous in simplifying the representation of complex merging, weaving, intersection, and interchange network sections (14, 15).

Determination of Minimum Paths

After representing the corridor by a complete set of links and nodes, the minimum paths from each origin in the corridor to all destinations are obtained. However, existing minimum-path algorithms are not capable of use with the simplified link-node representation adopted. Consequently, a completely new minimum-path algorithm that has provision for turn prohibitions was developed. The new algorithm allows the use of turn prohibitions without additional coding and simplifies the link-node representation by allowing more than one link in the same direction to have common upstream and downstream nodes. Unlike existing algorithms, the new algorithm also allows up to four costs to be reserved at each turn-prohibition node.

The new algorithm does not require direct input of network turn prohibitions because these are identified automatically by CORCON by using information regarding available upstream feeder links.

Traffic-Demand Assignment

Once the minimum paths have been determined, the traffic demand is assigned to those paths by using the principle of minimizing individual travel cost. A traffic-diversion procedure is incorporated in the assignment algorithm. This procedure first assigns demand to the minimum path. If this path contains any queueing links, a certain proportion of that demand is diverted to a non-queueing alternative minimum path, if such exists. The proportion (percentage) of traffic diverted is calculated according to the travel characteristics of those paths as follows:

$$P = 100/[1 + (\Delta T/Q)]^r \qquad (1)$$

where

- P = percentage of traffic diverted,
- ΔP = difference in travel cost (time) between non-queueing and queueing minimum paths respectively,
- Q = queueing cost (time) along queueing minimum path, and
- r = diversion parameter.

The diversion parameter (r) is used as a calibration control for the diversion characteristics. When $r = 0$, total diversion will occur. When $r = \infty$, no diversion will occur. A respective proportion of the traffic will divert when $0 < r < \infty$.

APPLICATION

The CORCON model was applied to an existing freeway corridor on which entrance-ramp metering was implemented in the summer of 1975. Specifically, CORCON was used to predict traffic operating characteristics in the corridor network for peak-period traffic demand before (1975) and after (1976) the implementation of the freeway-access control strategy.

Study Corridor

The study corridor is located southwest of Toronto in the city of Mississauga as shown in Figure 1. The more detailed view in Figure 2 shows that the major east-west routes in the corridor are the six-lane QEW and two arterial highways, Dundas Street (Highway 5) and Lakeshore Road (Highway 2). Traffic operations in the eastbound direction only were considered for these roadways. Major north-south crossing streets include Southdown Road-Erin Mills Parkway, Mississauga Road, Hurontario Street (Highway 10), and Cawthra Road. Traffic operations on these roadways were considered for both directions with the exception of Mississauga Road north (the northbound direction was not considered necessary because it is not used by the eastbound traffic under consideration). The corridor also included all freeway service roads within the study area.

The three-lane eastbound portion of QEW considered in this study extends approximately 9 km (5.5 miles) from the mainline origin west of Southdown Road to the mainline destination east of Cawthra Road and contains five entrance ramps and three exit ramps. This portion currently experiences congestion and queues during the morning peak period (7-9 a.m.) because of a bottleneck section immediately east of Highway 10. In addition, the corridor includes arterial and other street sections that have existing or potential operating problems because of the entrance-ramp control strategies implemented at the five QEW entrance ramps.

After the corridor configuration had been investigated, it was represented in traditional terms of links and nodes to form the necessary model input as shown in Figure 3. Each merging section on QEW was represented by two dummy links, e.g., 28-29, that had common upstream and downstream nodes. These links were used to regulate the merging capacities of both freeway and entrance-ramp approaches. The two links 35-40 represent exit ramps at the Highway 10 interchange. The two entrance ramps at this interchange required special treatment. As shown in Figure 4, the entrance ramps from northbound and southbound Highway 10 combine together to form one merging section with the freeway and each ramp has its own metering control system. Consequently, the two links 50-36 are used as dummy links to set the metering rates of these ramps and link 36-37 (lowest) is used to represent the merging section of the combined ramp traffic.

The corridor has 93 turn prohibitions; this includes U-turns located at intersections, interchanges, merging sections, and origin-destination nodes. (There are 17 turn prohibitions at the Highway 10 interchange alone.)

Data Collection and Reduction

After the boundaries and configuration of the study corridor had been established, the following data for model calibration and validation were collected:

1. Freeway-user origin-destination (O-D) demands (15-min basis),
2. Link volumes and queues (15-min basis), and
3. Network characteristics (physical and control).

To establish the demand characteristics of the entire corridor, the O-D demand at freeway entrance and exit ramps was obtained by conducting a license plate survey at each entrance and exit ramp in the corridor. For each 15-min time slice in the 2-h peak period, the license plate data were analyzed by first determining the origin location within the corridor for each vehicle surveyed and then establishing the number of vehicles from each origin area. The origin locations were ascertained from addresses in motor-vehicle registration files, each address was located within the study area, and the number of trips from each origin was computed to reflect the observed volume at each survey station. The destination locations of vehicles recorded at each entrance station and of those vehicles originating on the mainline were determined for each time slice by using a conventional license plate matching routine. Finally, the 15-min demand volumes emanating from a particular entrance station were assigned to the origin locations of that station in direct proportion to the total demand at each exit station. In addition, the observed link volumes and queue lengths were used to construct the O-D demand of freeway nonusers.

Data describing major corridor characteristics include principally the flow versus travel time relationships, capacity information, and network turn prohibitions. Standard travel time and delay runs were conducted for all corridor sections simultaneous with the volume counts. In this way, the correspondence between volumes and link travel times was obtained and the flow versus travel time relationship was constructed. Figure 5 shows a typical sample of the derived relationship for a particular corridor link. For use in CORCON, the relationship is approximated by three linear components of costs and capacities (15).

Capacities of corridor links and intersection approaches were calculated by using the Highway Capacity Manual procedure (17). The total merging capacity for each merging section was estimated from traffic volumes measured by the loop-detector surveillance system located along the freeway. Capacities of the controlled entrance ramps (i.e., metering rates) and queue lengths on both the freeway and the ramps were obtained from the Ontario Ministry of Transportation and Communications. Information on all turn prohibitions in the corridor network was also collected. Although much of the necessary data was collected for both the before-control (1975) and the after-control (1976) periods, the

Figure 1. Location of study corridor.

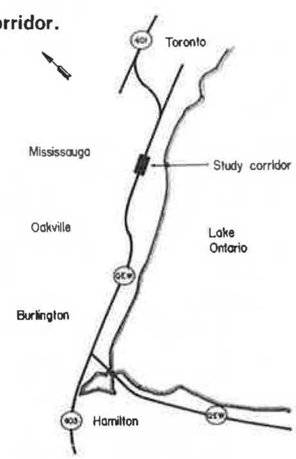
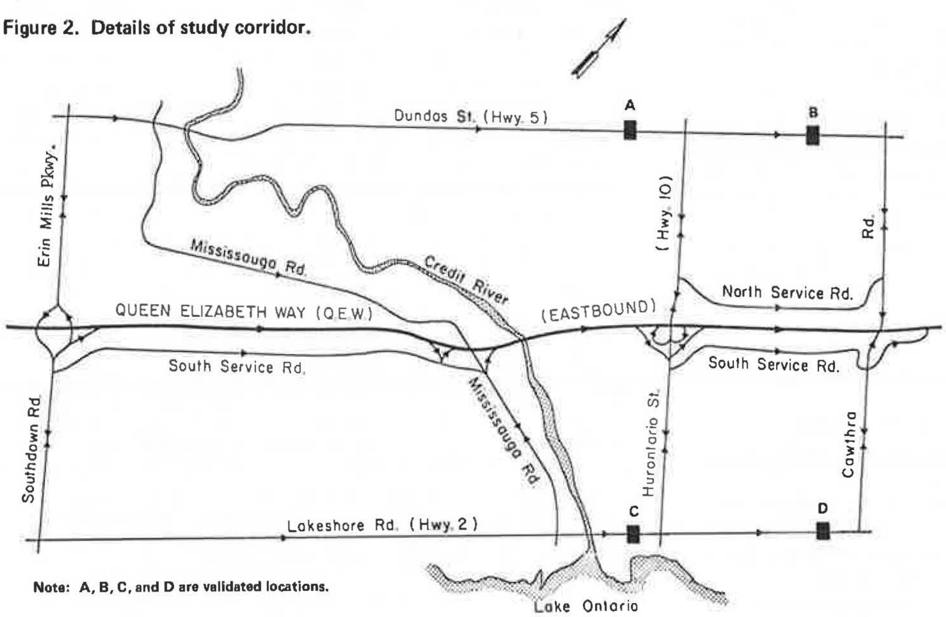


Figure 2. Details of study corridor.



after-control data were considerably more comprehensive. As a result, the CORCON model was first applied to the corridor and calibrated for the 1976 conditions.

CALIBRATION PROCEDURE AND VALIDATION RESULTS

The diversion parameter and the O-D demand patterns were calibrated for the after-control period, and the CORCON procedure was validated by comparing the predicted and the observed conditions for the before-control

Figure 3. Link-node representation of study corridor.

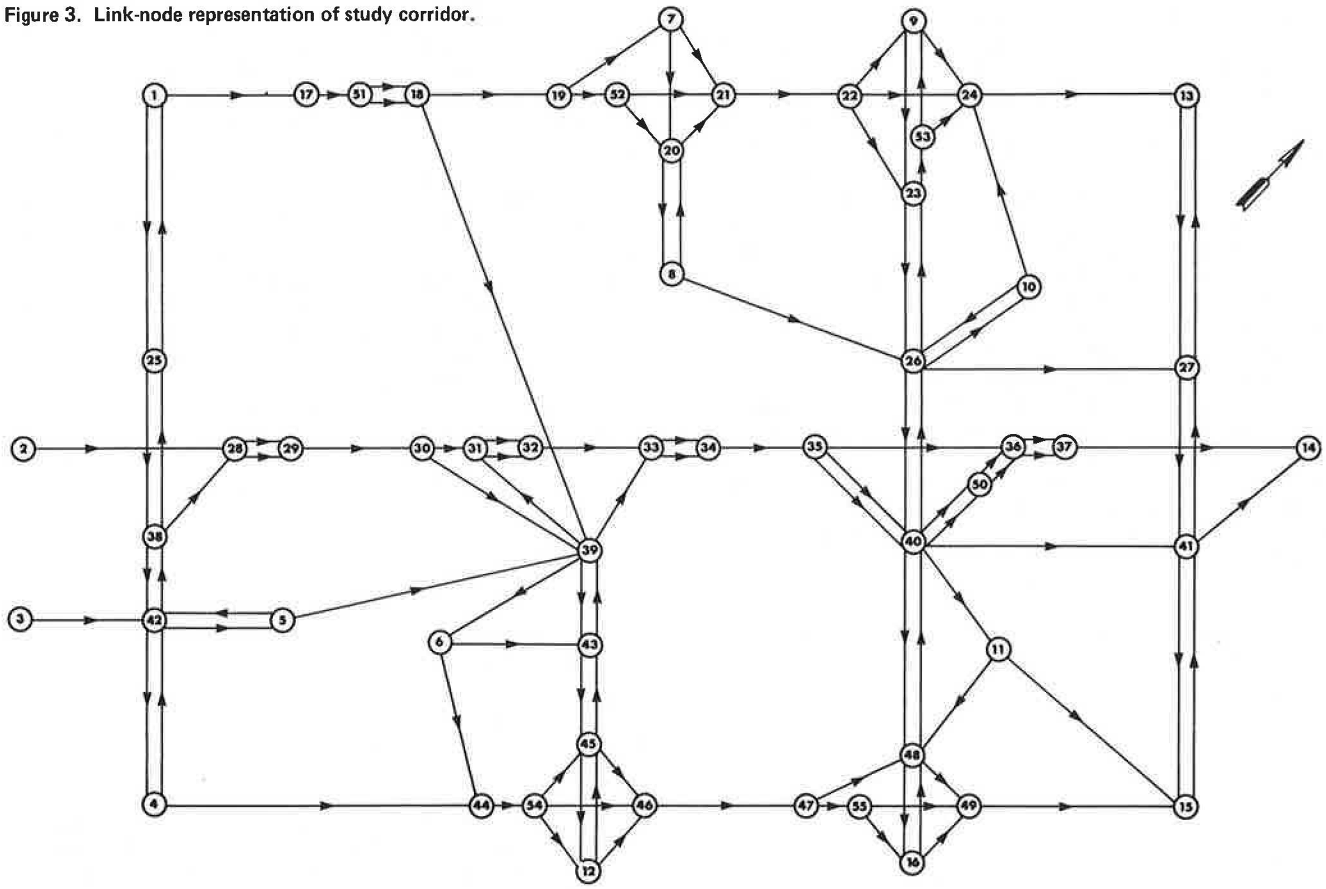
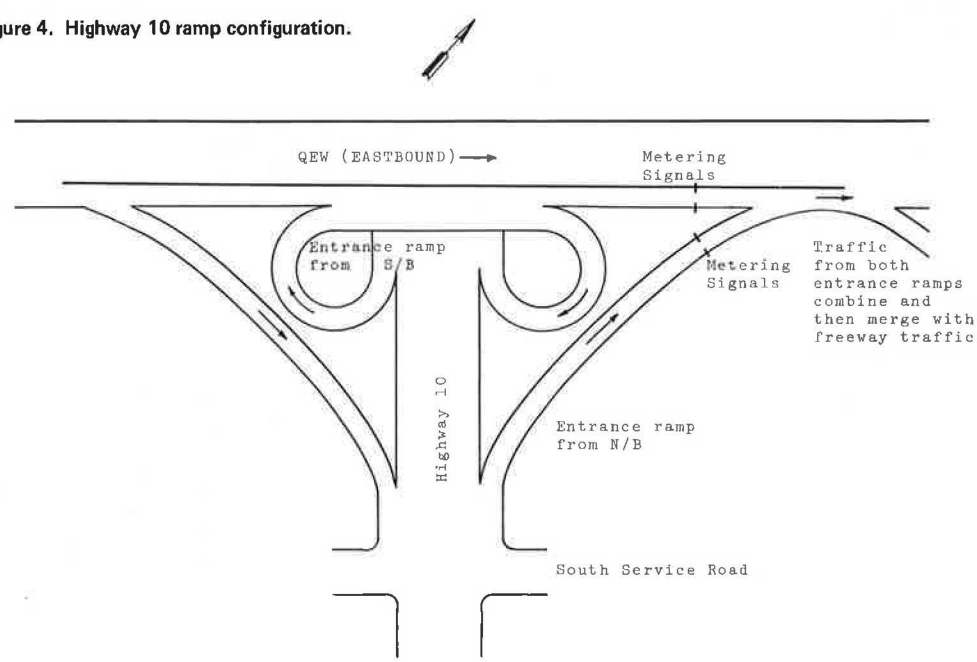


Figure 4. Highway 10 ramp configuration.



period. The calibration therefore included the preparation of a trip table that combined both freeway users and freeway nonusers and the determination of the best diversion-parameter value. It was assumed that identical O-D distribution patterns would be experienced for both study periods and the validation was evaluated on that basis.

Model Calibration

To fabricate the freeway nonusers O-D demand, a trial-and-error procedure was adopted. First, a preliminary O-D demand of freeway nonusers was established. The minimum paths that the freeway users would choose were hypothesized, and the freeway nonusers on each link were calculated (observed link volume minus freeway user volume). Although freeway nonusers have different origins and destinations, their route-selection processes are not likely to be particularly sensitive to varying control strategies. Knowledge of the actual origins and destinations was therefore not considered essential and the nonuser O-D demands were selected such that resultant link volumes matched observed values. Subsequently, demand volumes were established for a preliminary corridor O-D trip table.

To establish the value of the diversion parameter, it was assumed that diversion of freeway users from controlled ramps depends principally on the alternative-travel cost characteristics in the corridor. In CORCON, those characteristics are approximated by linear components that provide a range of flow within which the link cost remains constant (Figure 5). The exact nonuser link volume is therefore not necessary, and the preliminary nonuser O-D demand can be used in establishing the diversion-parameter value. Consequently, to estimate the value of the diversion parameter for the entire corridor, a representative link was selected on an alternative route for diverted traffic (the south service road east of Cawthra Road, shown as link 41-14 in Figure 3). The model was used to predict traffic volumes on that link for different values of the diversion parameter. These volumes were compared with observed volumes, and the best value of the diversion parameter was selected as that which minimized the discrepancy between the calibrated and the actual volumes.

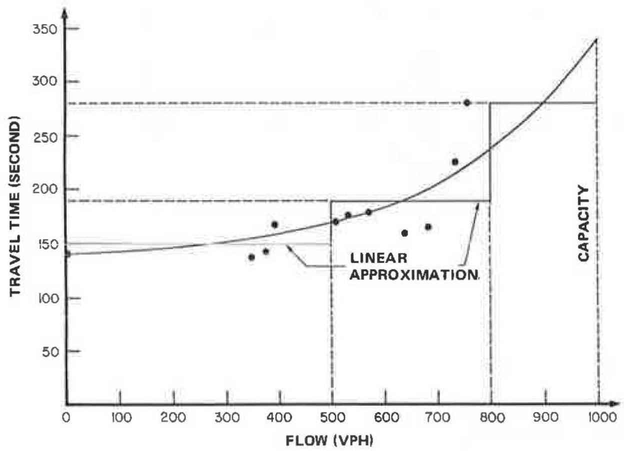
This value was found to be 4. (In other words, if the queueing time on a minimum path is equal to the difference in travel time between the nonqueueing and the queueing minimum paths, approximately 6 percent of the demand will divert to the nonqueueing alternative route.) That value was then used in CORCON, and the preliminary O-D table was adjusted by trial-and-error to minimize the difference between predicted and actual link volumes for the entire corridor by adjusting the freeway-nonuser demand patterns until an acceptable difference average was achieved. In Table 1, an example of the resultant O-D demand for an arbitrarily chosen time slice is shown.

A summary of the differences for each time slice on major arterial and freeway links is given below.

Time Slice (a.m.)	Average Difference (%) Link Volume	Unit Travel Time
7:00-7:15	3.0	4.9
7:15-7:30	2.7	5.6
7:30-7:45	3.0	5.9
7:45-8:00	2.1	4.1
8:00-8:15	2.9	5.3
8:15-8:30	4.0	4.5
8:30-8:45	1.0	4.5
8:45-9:00	2.3	4.9

The average differences for all time slices are approximately 3 percent for volumes and 5 percent for unit travel times. Results for a typical time slice are illustrated in Figures 6 and 7, which show respectively the calibrated and actual volumes, unit travel times, and queues.

Figure 5. Relationship between flow and travel time and its linear components.



Model Validation

After the corridor O-D demand and the best diversion-parameter value for after-control conditions were determined, the model was used to predict corridor operations for the before-control conditions. The validation

Table 1. Origin-destination demand table (8:00-8:15 a.m.).

Origin No.	Destination No. 1	4	6	7	9	10	11	12	13	14	15	16	25
1	0	171	0	176	180	0	0	20	0	0	0	0	67
2	0	0	8	0	36	0	8	0	0	738	0	0	0
3	118	0	0	0	0	0	0	0	0	32	0	0	0
4	63	0	0	0	0	0	0	36	0	50	94	0	0
5	118	0	0	0	0	16	0	0	0	61	0	0	0
6	0	0	0	0	0	16	0	0	0	213	214	0	0
7	0	0	0	0	0	0	0	0	98	50	0	0	0
8	0	0	0	0	21	0	0	0	60	50	0	31	0
9	0	0	0	0	0	27	0	0	60	45	0	180	0
10	0	0	0	0	127	0	0	0	203	44	0	0	0
11	0	0	0	0	20	40	0	0	71	60	0	0	0
12	0	0	0	0	0	0	0	0	0	50	9	15	0
13	0	0	0	0	0	0	0	0	0	141	43	0	0
16	0	0	0	0	20	24	0	0	0	36	46	0	0
18	0	0	0	0	0	0	0	0	0	51	0	0	0
25	0	75	0	86	0	0	0	0	0	40	0	0	0

process involved comparing predicted operating conditions with observed conditions at several locations on east-west arterials in the study corridor. (Only volume was used as a criterion for comparison because other criteria, such as travel time and queue length, were not available in sufficient detail for the before-control situation.) The four most important locations on Highway 5 and Highway 2 that were used for the final validation comparison are shown as blocks A, B, C, and D in Figure 2, and the measured and predicted volumes

Figure 6. Calibrated volumes, travel times, and queues (8:00-8:15 a.m.).

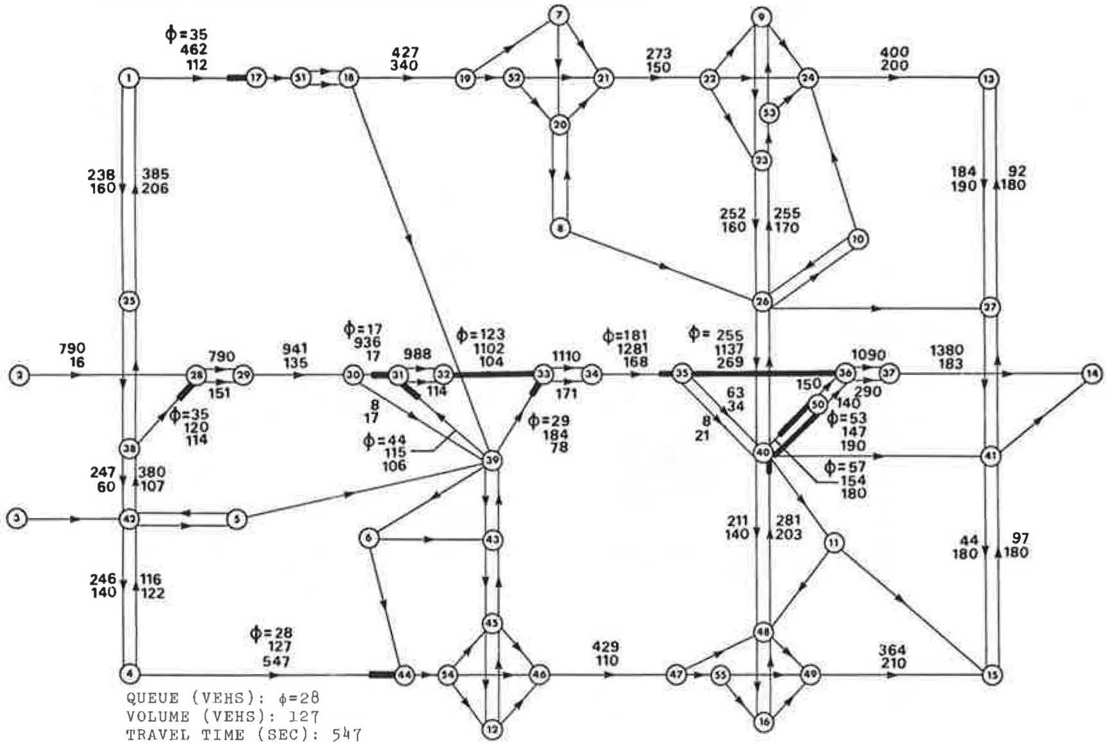


Figure 7. Measured volumes, travel times, and queues (8:00-8:15 a.m.).

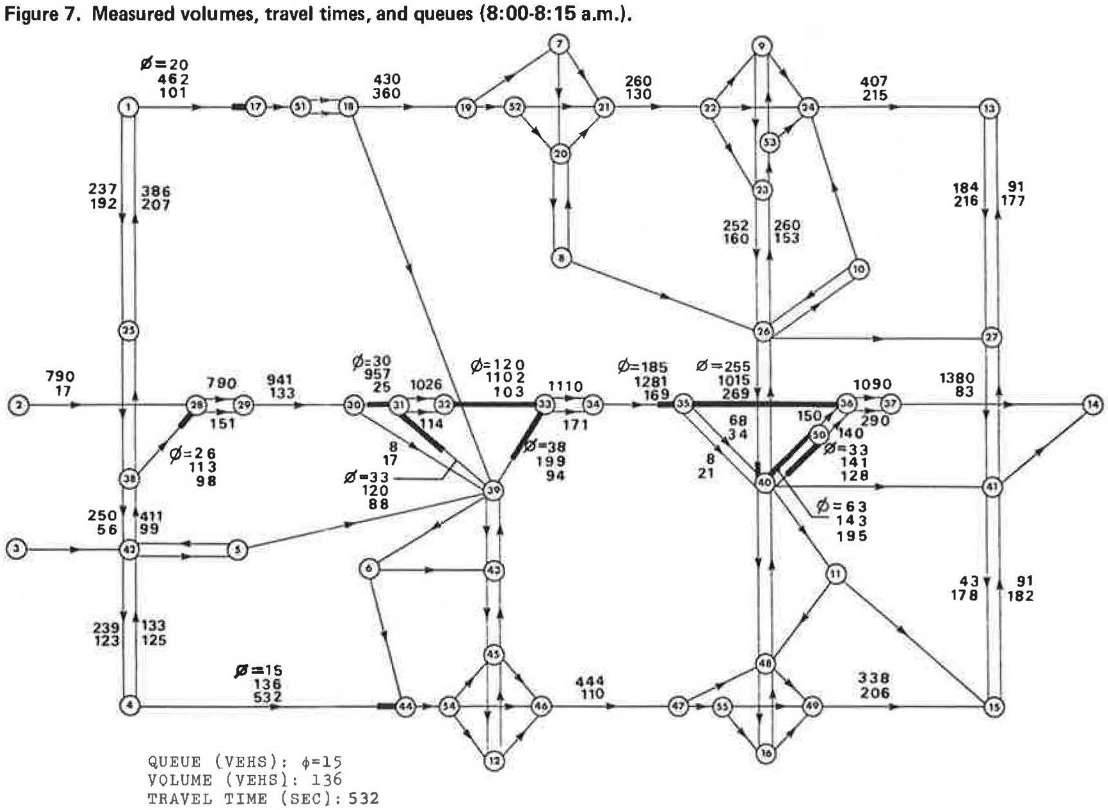
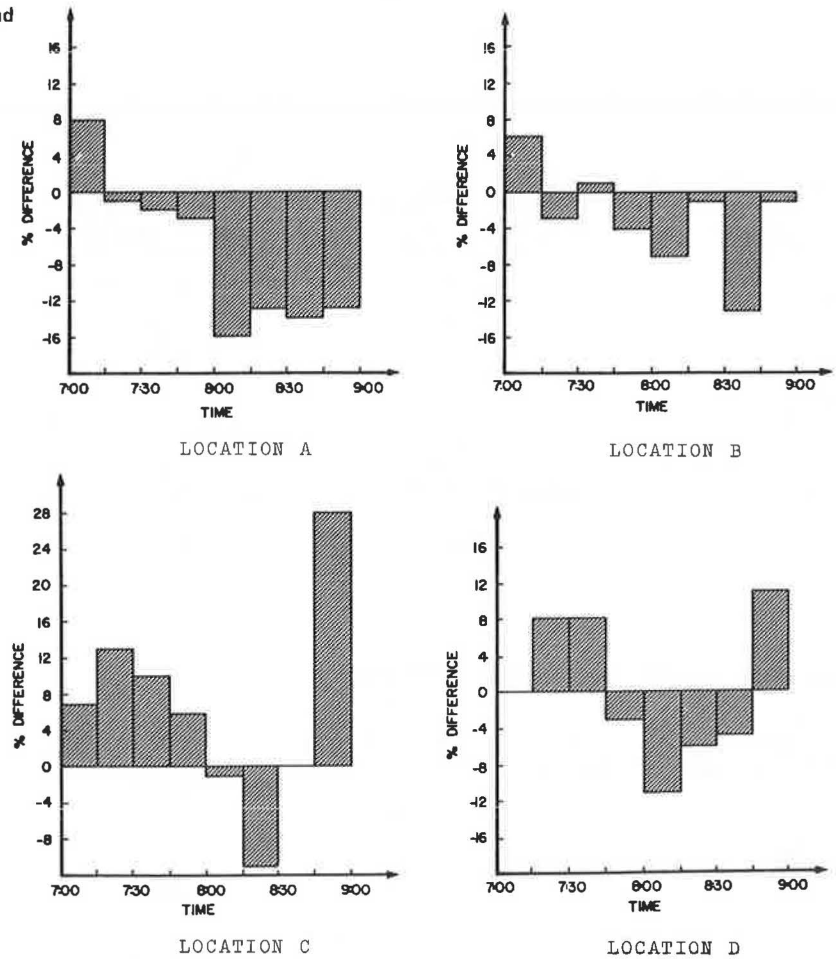


Table 2. Comparison between measured and predicted volumes.

Time Slice (a.m.)	Location A Predicted No. of Vehicles	Location A Actual No. of Vehicles	Location A Percent Difference	Location B Predicted No. of Vehicles	Location B Actual No. of Vehicles	Location B Percent Difference	Location C Predicted No. of Vehicles	Location C Actual No. of Vehicles	Location C Percent Difference	Location D Predicted No. of Vehicles	Location D Actual No. of Vehicles	Location D Percent Difference
7:00-7:15	212	196	+8	282	267	+6	138	129	+7	180	180	0
7:15-7:30	226	229	1	320	330	-3	270	239	+13	254	236	+8
7:30-7:45	256	260	-2	364	360	+1	357	324	+10	321	298	+8
7:45-8:00	243	251	-3	351	364	-4	381	358	+6	347	358	-3
8:00-8:15	268	319	-16	386	416	-7	404	410	-1	347	391	-11
8:15-8:30	277	317	-13	345	350	-1	370	415	-11	334	354	-6
8:30-8:45	239	278	-14	251	287	-13	301	300	0	250	263	-5
8:45-9:00	239	275	-13	240	242	-1	262	205	+28	184	166	+11

Figure 8. Differences between measured and predicted volumes.



for those locations are compared in Table 2.

The differences between predicted and actual volumes at all locations ranged from -16 to +13 percent, with the exception of one extreme value. The absolute difference was less than or equal to 13 percent in 91 percent of all results. The mean value of the absolute difference was 9, 5, 10, and 7 percent at the four validation locations respectively. A graphic view of the differences in each time slice for each of the four locations is shown in Figure 8. Results indicate that predicted volumes at locations A and B on Highway 5 tend to be underestimated and those at locations C and D on Highway 2 tend to be slightly overestimated.

Discussion of Results

Although the differences between measured and predicted volumes at the principal validation locations were as high as 16 percent and the mean difference was 10 percent, the correspondence was amazingly close when one considers how the O-D demands were established. Average growth rates in traffic demand for the entire corridor area were assumed for comparative purposes. In fact, however, considerably greater growth occurred in the northeast portion, contributing significantly to the underestimation of volumes on Highway 5, but the Highway 2 (southeast) area was overestimated. Closer correspondence would have obviously occurred had this change of growth pattern been reflected in the development of the O-D trip tables.

CONCLUDING REMARKS

As a consequence of the study results and experience gained during the conduct of this project, several observations are considered worthy of note.

It was shown that the new CORCON model was capable of predicting traffic volumes, travel times, and queueing characteristics on a freeway corridor; the maximum overall average difference between predicted and observed characteristics was 10 percent. Such a correspondence of predicted and actual traffic operating conditions is certainly sufficient to recommend CORCON for regular use as a planning tool for assessing alternative freeway-corridor control plans. (This is particularly apparent because fine tuning of the O-D demand table was not even attempted in this study; gross approximations are obviously sufficient.)

Furthermore, the new features of turn prohibitions (avoidance of illogical paths) and incorporation of a queue-diversion procedure operated extremely well and proved to be valuable additions to the corridor-assignment algorithm. By implication, the simplification of network link-node representation, the ability to simulate and introduce necessary turn-prohibition controls at critical network locations, and the ability to account for traffic diversion from entrance ramps where queues have formed are all useful and necessary elements of an acceptable model.

It should also be noted that CORCON, like many other models of this type, requires a complete matrix of O-D demand volumes for each time partition in the study period under investigation. The effort required to collect that information, either by postcard survey or by a comprehensive license plate survey, is not insubstantial. If the CORCON model is to be used regularly and relatively efficiently, O-D data could perhaps be best fabricated from more readily available data. (It is understood that a major effort to develop an O-D manufacturing process from volume counts is currently under way in New York. The results of that work could prove to be extremely useful to the operation of CORCON and other freeway-corridor assignment models. It is also important to note that the level of accuracy required is relatively low and that approximations of this type give perfectly acceptable results.)

Similar minor problems might be encountered in attempts to establish the value of the diversion parameter for use in CORCON. Although one would normally assume that diversion characteristics are similar at almost all entrance ramps, substantial amounts of data will be necessary to firmly establish the magnitude of the parameter. Should this prove difficult, one could calibrate to the best value by using representative alternative-route link volumes as the comparative baseline in a way similar to the procedure adopted in this study.

Because of dimensioning constraints in the currently available computer program, it may be difficult to apply CORCON to very large corridors [e.g., 8 × 40 km (5 × 25 miles)]. This can be accommodated by either increasing the dimension sizes, analyzing two or three smaller subsections of the corridors separately, reducing the amount of coded network detail, or some combination of the preceding. In any case, it should be possible to accommodate corridors of reasonable size without appreciable difficulty.

Despite these minor difficulties, the advantages of the model far outweigh its potential disadvantages. Consequently, we suggest that CORCON is the best available analytic procedure for reasonably predicting traffic-operating conditions on a complex urban freeway corridor. To this end, further work is currently under way using CORCON as the primary assessment tool for the investigation of the impact of proposed freeway-corridor traffic system management strategies on the Highway 401 bypass route in the metropolitan Toronto area. Preliminary indications are that the model is quite capable of handling the complex core-collector system of the freeway and the rather extensive network sections [which extend approximately 10 × 75 km (6 × 45 miles)].

The CORCON model can also be used very effectively for evaluating operating conditions in urban areas that may or may not have freeways. Furthermore, the model can be used not only to evaluate the effects of freeway ramp metering but also to evaluate the impact of a wide range of transportation system management strategies. A more detailed discussion of the use of CORCON for evaluating strategies in the fields of traffic demand management, traffic regulation, and traffic operations is given elsewhere (18).

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Queen Elizabeth Way Freeway Surveillance and Control System Demonstration Project

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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