Demand Diversion for Vehicle Guidance, Simulation, and Control in Freeway Corridors

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Rapidly increasing traffic volume, congestion, and excessive delay are making the management, control, and guidance of traffic flow one of the most critical transportation problems in urban freeway corridors. Modeling demand diversion to less congested routes within a corridor is a necessary part of demand modeling efforts for improved simulation and control, as are guidance-navigation systems in real time. Models for describing diversion at the trip origin and diversion at freeway entrance ramps are discussed. Data collected in a major metropolitan area have shown that diversion at the origin is a function of trip time, route length, and the number of intersections along the trip. However, trip time is the dominant determining factor and can be employed to estimate the decision in the absence of additional information. Diversion at freeway entrance ramps depends on the perceived trip time on the freeway and arterial and the perceived waiting time at the ramp queue. The data confirm that socioeconomic indicators do not play a role in the diversion decision. The purpose of developing these models is for dynamic simulation, on-line freeway corridor control, and demand forecasting suitable for guidance and navigation.

Rapidly increasing traffic volume and the ensuing congestion and excessive delay are making the management and control (guidance) of traffic flow one of the most critical transportation problems on urban freeways. To remedy the problem, corridor management seeks to divert freeway drivers away from the congested segments of freeway corridors to alternative routes within a corridor, such as adjacent arterials. The diversion can occur at the beginning of the trip, before entering the freeway ramp, or on the freeway.

Demand diversion, generally caused by excessive delay and ramp queues, is a major problem (*1–3*) that has not been effectively considered in real-time control systems, although recently an effort has been made to address the problem (*4*). The major difficulty lies in the rapidly changing traffic flow conditions; furthermore, substantial instrumentation is required to collect data for modeling traffic diversion. Determination of realistic control policies and effective guidance-navigation schemes for the freeway corridor should include diversion as an integral part. Existing literature (*1,2*) suggests that there is a lack of an on-line demand predictor suitable for real-time control for interconnected ramps and arterials. However, existing demand diversion models are not suitable for effective real-time freeway control strategies. Current demand diversion models are based on assumptions that are considered unrealistic (*5*), such as user-optimized equilibrium flow patterns, perfect knowledge of traffic conditions ahead, and infinite storage capacity on surface streets. Diversion is only a part of the more general demand prediction problem.

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Modeling of demand diversion is addressed in this paper; this modeling was needed to develop a reliable prediction algorithm suitable for implementing real-time control policies (*6,7*) in freeway corridors. Within this context, diversion is an essential element necessary for proper estimation of traffic demand as well as for determination and simulation of the optimal control strategy or guidance plan. The diversion models presented here can be used with a demand predictor (*7*) to simultaneously determine ramp demands and diversion volume as part of an integrated corridor simulation-control-guidance process in real time.

The models should be appropriate for employment in guidance-navigation systems that use information on current traffic conditions for selecting optimal routing in real time. In such systems the models are needed to estimate the impact that the guidance-navigation information has on drivers. In particular, guidance-navigation systems are expected to respond to drivers' queries by providing information on freeway and arterial delays, freeway ramp queues, and the resulting ramp delays as freeway conditions and ramp metering rates change with time.

A critical review of the most widely accepted research on the diversion problem is presented first. This review includes a summary of model features that emphasize effectiveness and drawbacks of each approach from the limited tests found in the literature. Subsequently, two utility-based demand diversion models are developed, one for the diversion at the trip origin and one for the diversion at freeway ramps. The models are tested with data from the I-35W freeway corridor in the south area of the Twin Cities—Minneapolis and St. Paul, Minnesota.

Consistent with expectations, the model specifications indicate that trip time is the dominant factor determining diversion at the trip origin, whereas route length and the number of intersections along the trip also play significant roles. Diversion at freeway entrance ramps depends on the perceived trip time on the freeway and arterial and the perceived waiting time at the ramp queue. The data confirm that socioeconomic indicators do not play a role in the diversion decision. Further, for commuter trips shorter than 1 hour, freeway drivers consider only one diversion alternative, a preferred arterial, and do not divert to downstream ramps. The diversion models require only limited data for implementation.

BACKGROUND

Freeway corridor models have considered diversion within the context of control and assignment by determining the long-term equilibrium flow pattern that satisfies Wardrop's principle within a given time slice or by employing self-assignment (i.e., assuming that omniscient drivers can find the quickest route at each decision point of their trip). Although some researchers determined the flow pattern through a combination of models, others sought to increase computational efficiency and avoid potential modeling inconsistencies by developing a single modeling approach. Further, earlier methods (*8*) may, by assumption, limit diversion to occur only at the trip origin, whereas more recent methods offer the flexibility of allowing diversion at multiple points during the trip.

Diversion methods that are based on a combination of models are older. Lieberman (*9*) developed a freeway corridor simulation program, SCOT, by combining DAFT, a macroscopic corridor simulation model, with UTCS-1. Traffic flow on non-freeway links is treated as a collection of individual vehicles, each processed every second of simulated time; in contrast, the freeway flow is described macroscopically, which permits the grouping of vehicles into platoons and the use of a coarser time step. With the origin-destination (O-D) demand matrix or turning movements at each node specified by the user, traffic is routed following the minimum-time path, which the user recalculates successively by selecting the time interval.

Another composite model that incorporates diversion within a freeway corridor simulation, CORQ1C, was proposed by Orthlieb and May (*10*). CORQ1C allows diversion from the freeway to arterials only for the "flexible" users whose destinations are within the corridor boundaries, whereas other users have fixed O-D routes. The model combines FREQ3 and TRANSYT5 to simulate the diversion following a linear-programming decision process that selects the optimal ramp metering rates. The corridor assignment associated with the optimal rates maximizes the total trip time savings for the flexible users of the freeway. In each 15-min time slice, after all fixed-route demand has been distributed, the decision process incrementally assigns the optimal flexible-route demand subject to corridor capacity constraints. For each optimization increment, a constant value of time savings for the flexible users is estimated from simulating the previous traffic loadings in the corridor. After each optimization, the resulting optimized volume is assigned and the new value of time savings is found. This method assumes that diversion is possible only at the trip origin.

In contrast to the earlier methods, FREQ7PE (*11*) is based on a single program rather than a combination of programs. At each 15-min time slice the method calculates the optimal ramp metering rates for the given O-D ramp volumes that optimize freeway objectives. The resulting diversion is determined by estimating the equilibrium flow pattern in the corridor for each time slice. An iterative assignment procedure is performed until the travel time difference between any alternative routes for each O-D pair is within an acceptable range. Evidently this procedure allows for diversion at several alternative ramps.

The models in the CORQ (*12*) family use a form of microassignment corridor technique with the given O-D zone demand divided by 15-min time slices. For each time slice, a minimum-time path is constructed for all O-D pairs, and an incremental assignment is performed by iteratively updating the link cost. The remaining demand at each time slice is stored at the upstream node of a link where it is queued and assigned at the next time slice with the new demand and updated minimum-time path. CORCON (*13*) extended the minimum path assignment algorithm of CORQ by incorporating turn prohibitions and a traffic diversion procedure from the queueing link to the nonqueueing alternative on the basis of travel cost (time) difference. However, both models assume unlimited queue storage capacity of arterials and drivers' perfect knowledge of the existing traffic condition in the network. Although these assumptions are not realistic, the ability to determine and keep track of queues is an advantage over the previous methods.

INTEGRATION-1 (*14*) is a microscopic corridor simulation model, which, unlike previous methods, considers the behavior of traffic flow in terms of individual vehicles that have self-assignment capabilities. The model is not based on the time-slice approach; rather, it assigns individual vehicles sequentially to a network that is already loaded with any previous departures that have not reached their destination. The turning movement of each vehicle at each node and instant is dictated by the minimum-path tree table existing at that instant and is recalculated every 6 sec. The main difference between CORQ and INTEGRATION-1 is that CORQ considers vehicle flow rates for an entire time slice, whereas INTEGRATION-1 treats individual vehicles on a continuous basis. The departure times of all trip demands are given, and drivers are assumed to have full knowledge of the existing traffic conditions on the entire network.

In addition to the above methods, a number of models developed for network simulation implicitly consider diversion. Of these, TRAFLO (*15*) and SATURN (*16,17*) are worth mentioning because of their extensive use by government and private organizations. These composite models implicitly consider diversion in the larger context of simulation and assignment. In particular, TRAFLO combines an equilibrium assignment model with four different simulation models that estimate the expected performance of the assigned flows. However, the assignment model does not have the feedback function that can employ the refined travel time and queue size estimates to update and correct the initial traffic assignment assumptions. Although SATURN adopts an iterative procedure to correct and update the network parameters for the assignment, it currently uses all-or-nothing assignment; further, it assumes a cyclic flow profile, only suited for signalized arterials. Such assumptions limit its applicability for freeway corridor analysis.

To effectively control the traffic flow in a corridor, the estimation of the time-dependent flow pattern of the diverting traffic is of critical importance. As the above review indicates, existing diversion methods determine the equilibrium flow pattern satisfying Wardrop's principle at each time slice either macroscopically or by employing the self-assignment technique, thus assuming that drivers can find the quickest route at each decision point with perfect knowledge of traffic conditions ahead. However, it has been argued that Wardrop's principle is not applicable to the dynamically changing traffic environment mainly because of the human nature of drivers; that is, drivers are not well informed or are not sufficiently skilled to choose the best route (*5*).

Understanding commuter reactions to ramp control strategies and guidance-navigation information on freeway and arterial trip characteristics is essential in estimating and controlling corridor flow to decrease congestion. This paper proposes a utility-based approach for the dynamic diversion problem, which, when combined with an appropriate filter, will more realistically model the commuter diversion process for simulation, control, and guidance-navigation in congested freeway corridors.

For the purposes of this analysis we assume that diversion occurs at two points: the trip origin and the entrance to the freeway ramp. Although diversion can occur at any point during the trip, all intermediate decision points were included in the stated two because of time and data limitations and the need to immediately employ a diversion model that addresses the points where most drivers make a route diversion decision. The following sections summarize the model formulation and the parameter estimation results.

MODEL FORMULATION

The structure of the overall diversion-control-guidance modeling approach can be analyzed at several levels of detail. At the most general level, it may be pictured as a sequential process (Figure 1) with the freeway corridor performance sector acting as a link between traffic diversion and changes in freeway controls and guidance-navigation information. For instance, at the trip origin, trip makers select either the freeway or the arterial route, depending on their corresponding perceived trip times, which are functions of known variables such as volume and capacity. Their perception is enhanced with the updated information they receive from radio and TV and from guidance-navigation systems, if such are in operation.

Even though the initial route of choice may be the freeway, at the entrance ramp the freeway commuter can still decide

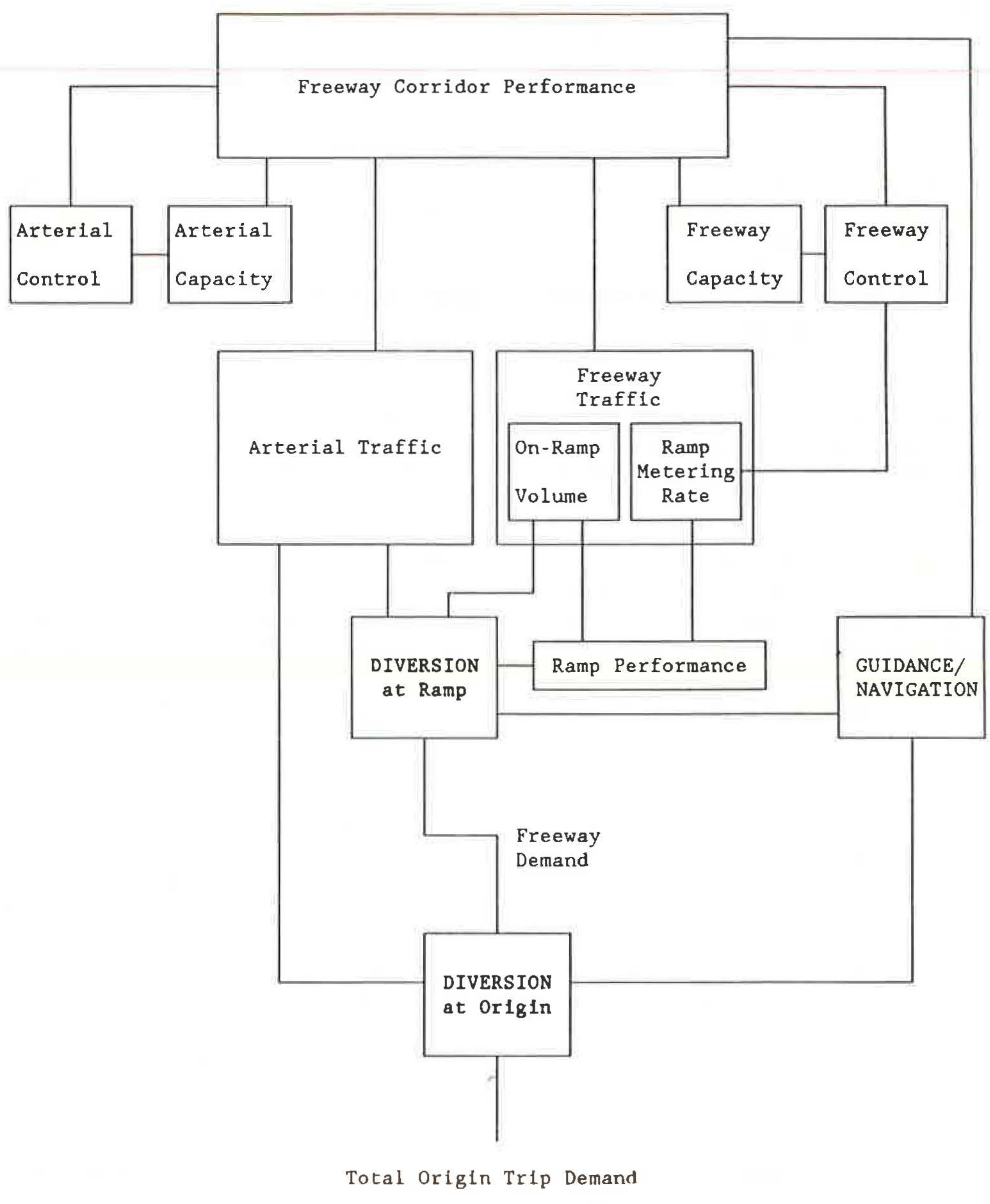

FIGURE 1 Demand diversion, control, and guidance-navigation.

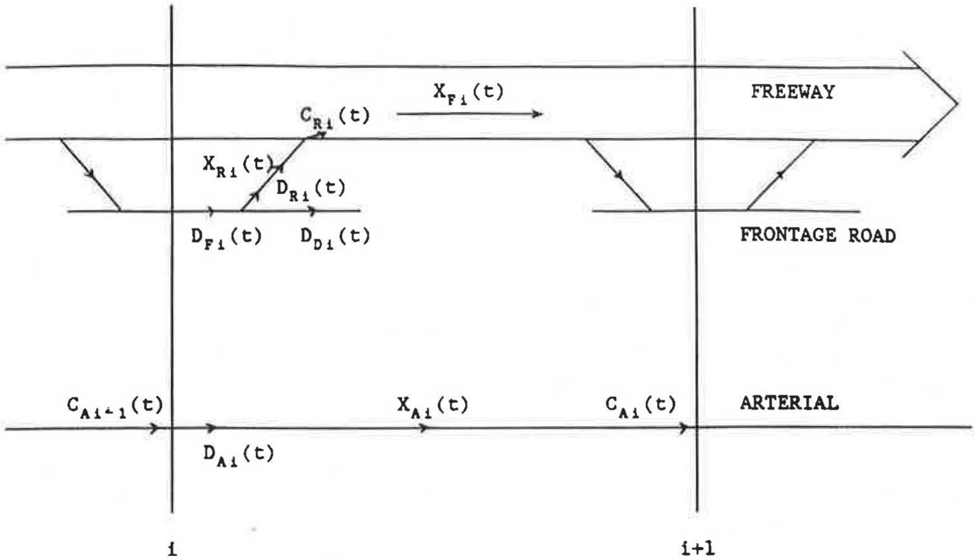

FIGURE 2 Sample freeway corridor.

not to enter; rather, the vehicle can divert to an arterial street depending on the ramp traffic situation. This decision is again enhanced by any additional information the driver has been receiving from guidance-navigation or other communication systems. The diversion decision of each driver affects the overall volume on the freeway and arterial(s) and, thus, the performance of the freeway corridor. In turn, the corridor performance is used as a basis for setting the control in the corridor, such as ramp metering rate and arterial signals, further affecting the corridor performance.

Communications and guidance-navigation systems pick up the current performance information and transmit it to the drivers, who can update their diversion decisions, and the process continues full circle. Therefore, the traffic diversion process reflects the short-term reaction of traffic flow to the control and guidance schemes, and the resulting congestion patterns in the dynamically changing traffic environment.

Tracing the diversion, control, and guidance-navigation interactions through time is done on the basis of component equations that are used to model the diversion, filter the traffic flow measurements, and set the desired control and guidance strategy. In this paper, we focus on the development of the diversion equations.

Because of the limitations of the existing models, dynamic freeway diversion equations were developed that fulfill the requirements of the time-sensitive approach followed in this work. Assuming for the purposes of this discussion that the freeway model and all other component equations are complete, the diversion equations apply the conservation principle to the freeway ramp and adjacent arterial(s) to determine the traffic volume as a function of known inputs and outputs and the state of the system. As a reference to the diversion equations, Figure 2 shows an example corridor system consisting of a freeway with an entrance ramp, a frontage road, a parallel one-way arterial street, and cross streets connecting the arterial with the freeway entrance ramp. For simplicity, the frontage road is used only for the diversion from the ramp, and the diverted traffic volume directly joins the arterial flow.

Applying the conservation principle to the ramp and arterial link, respectively, for a suitably small length of time slice t, the state evolution equations for the ramp and the arterial of corridor component $(i, i + 1)$ can be written:

$$X_{Ri}(t) = X_{Ri}(t - 1) + D_{Ri}(t) - C_{Ri}(t) \quad (1)$$

$$X_{Ai}(t) = X_{Ai}(t - 1) + I_{Ai}(t) - C_{Ai}(t) \quad (2)$$

where

$X_{Ri}(t)$ = number of vehicles on ramp i at time slice t,
$D_{Ri}(t)$ = vehicles entering ramp i at t,
$C_{Ri}(t)$ = vehicles exiting ramp i at t,
$X_{Ai}(t)$ = vehicles on arterial link $(i, i + 1)$ at t,
$I_{Ai}(t)$ = vehicles entering arterial link $(i, i + 1)$ at t, and
$C_{Ai}(t)$ = vehicles exiting arterial link $(i, i + 1)$ at t.

Then, on the basis of the concept of utility, the input volumes for the entrance ramp and the arterial link are

$$D_{Ri}(t) = D_{Fi}(t) * P_{Ri}(t) \quad (3)$$

$$I_{Ai}(t) = C_{Ai-1}(t) * Q_i(t) + D_{Ai}(t) + D_{Di}(t) \quad (4)$$

where

$D_{Fi}(t) = D(t) * \exp[V_F(t)]/\Sigma\exp[V'(t)]$
= freeway trip demand at trip origin at t, (5)

$P_{Ri}(t) = \exp[U_R(t)]/\Sigma\exp[U'(t)]$
= portion of $D_{Fi}(t)$ entering ramp i at t, (6)

$D_{Ai}(t) = D(t) * \exp[V_A(t)]/\Sigma\exp[V'(t)]$
= arterial trip demand diverted from origin at t, (7)

$D_{Di}(t) = D(t) * \exp[V_F(t)]/\Sigma\exp[V'(t)] * [1 - P_{Ri}(t)]$
= diverted volume at entrance ramp to arterial at t, (8)

$Q_i(t)$ = portion of $C_{Ai-1}(t)$ entering arterial link $(i, i + 1)$ at t,

$D(t)$ = total demand originating from this corridor section at t,

$V(t)$ = utility of freeway (V_F) or arterial (V_A) route for diversion at origin at t (see Table 2), and

$U(t)$ = utility of entering ramp (U_R) or diverting (U_D) to arterial at entrance of freeway ramp at t (see Table 4).

The above model assumes that the state evolution is first order, with the diverting volume estimated from disaggregate data collected in the study area. The exit volume $C(t)$ can be estimated as a function of the link volume and the physical characteristics of the link, or, in real-time application, the actual measured volume can be used to update the model parameters using filtering techniques (*18*). The model implicitly assumes that time slice t is suitably small or the link is relatively long.

Using the proposed model, the optimal control in the freeway corridor minimizing total system travel time for the given time period can be formulated as follows:

find optimal control policy $u(t)$ to minimize

$$\sum_{t=0}^{T} \left(\delta t * \{X_A[t, u(t)] + X_R[t, u(t)] + X_F[t, u(t)]\} \right) \qquad (9)$$

(subject to corridor flow standards and management constraints)

where

$X_F(t)$ = number of vehicles in freeway section at time slice t,
δt = size of time slice, and
T = number of time slices in optimization period.

We are now validating the proposed model using corridor traffic data. In this paper we report the estimation results of the utility functions for the diversion decisions. The comprehensive validation results will be presented in a forthcoming paper.

PARAMETER ESTIMATION

Route Diversion at Trip Origin

Before their departure, commuters make their initial decision on which route to take for their trip to work. In general, this decision considers two major determining factors—the set of alternative routes for the trip and the characteristics of each route. In this work we assume that the set of possible trip routes consists of a freeway and an arterial. Our extensive surveys indicate that very few commuters (less than 3 percent) seriously consider a third alternative and, even then, they select that alternative only in low-likelihood circumstances (e.g., in a severe snowstorm).

We estimated the route diversion at the origin by specifying a binary logit model for the freeway and arterial alternatives. For this model, we define the freeway alternative (and, similarly, the arterial) as a trip route that is at least 80 percent freeway. Model variables can be of two types—trip related and socioeconomic. The three trip-related variables are

- travel time (T) in minutes, the one-way trip time in the vehicle;
- route length (L) in miles, the one-way trip distance; and
- number of intersections (I), the number of intersections crossed by the vehicle along the one-way trip. (If the exact number is not available, a range of values can be used; e.g., suggested range is low at $I < 15$, medium at $15 < I < 45$, high at $45 < I$.)

Management and control policies can directly affect the above variables. For instance, for the same trip route, changes in ramp metering rates and in the number of freeway lanes available will affect the travel time. Similarly, ramp closings and construction detours will increase the route length. Reduced access at intersections will decrease the number of intersections experienced by the trip maker on the priority access road. Of course, changes that are of a more substantial nature, such as bridge reconstruction, a new bypass, or a new ramp, may develop new alternatives for a subset of drivers; in such cases, the new values for the above variables must be entered in the diversion specification.

Drivers are expected to know the value of each of the above variables for the two major commuting alternatives. Such values rarely change, but when they do, updated information is likely to become widely known to commuters because it is routinely communicated through newspapers, radio, and television. Up-to-the-minute information on changes resulting from unforeseen events, such as freeway incidents, is also commonly available through special radio or TV announcements and would be part of guidance-navigation systems in urban areas. Real-time information on incidents is smoothed by the departing driver depending on the planned trip departure time, a subject that we are currently analyzing.

In addition to the above trip-related variables, we tested annual household income, a socioeconomic variable proposed by Abu-Eisheh and Mannering (*19*) for the route choice process. However, we did not expect, and our tests did not indicate, this variable to play a role in the diversion.

A questionnaire survey of 500 households was conducted, and individual characteristics were recorded for the commuters with trips originating in the south I-35W corridor in November 1987 (see Figure 3 for an illustration of this freeway corridor crossing the Twin Cities in a north-south direction). Following data treatment, 105 employees having a common destination were selected as the sample commuters. All commuters in the sample had the choice of driving in a northerly direction using a predominantly freeway route or an adjacent, one-way arterial (Park Avenue, see Figure 3). Although the data treatment resulted in a decreased sample size, the improved quality of the treated sample contributed to an increased significance and robustness of the estimated model parameters.

Each employee was asked to draw his or her freeway and arterial routes on the map, indicating the initial choice and expected travel time for each route under normal conditions. From this information, the detailed trip characteristics including route length, number of intersections, and number of turns were obtained. Further, the socioeconomic characteristics of each driver were provided from the questionnaire (Table 1). Sample commuters were evenly distributed in the study area, and most sample characteristics were almost-Gaussian distributed (number of intersections was missing the left tail).

Three disaggregate models to estimate diversion at the trip origin were derived from the Twin Cities data (Table 2). Model M1 tests the hypothesis that trip time affects the diver-

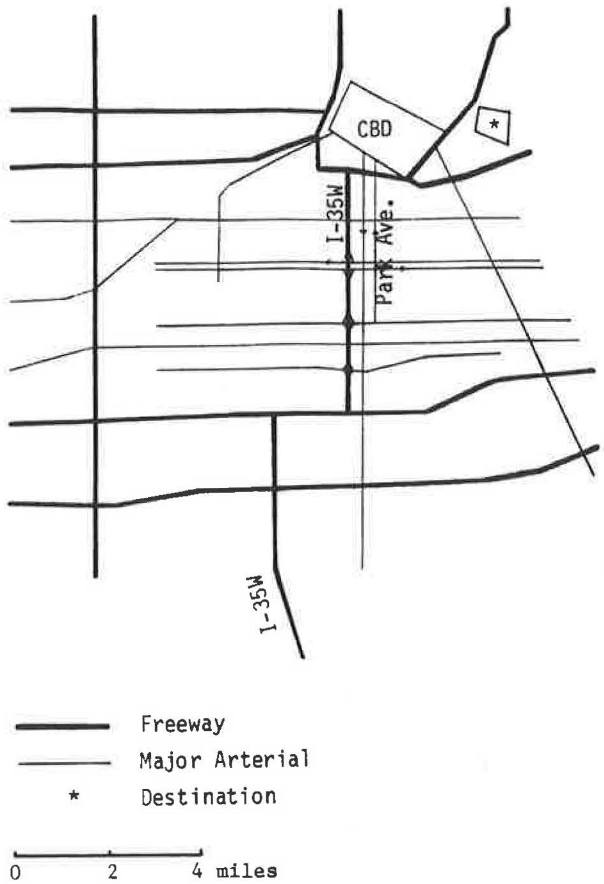

FIGURE 3 I-35W study area.

sion decision, and the estimation results indicate that it is, indeed, a significant factor (99 percent significance level). Model M2 indicates that, although travel time is a dominant factor in diversion, the number of intersections and route length also play a highly significant role. All coefficients have the expected sign; further, model M3 confirms our expectation that the socioeconomic indicator (income) does not influence the diversion.

The estimation results show that when freeway and arterial are the two alternatives, and collection of data on number of intersections and route length is exceedingly costly, model M1 can be employed to estimate diversion at the origin based only on travel time. Model users who wish to employ model M2, either to gain the additional predictive power or because it is necessary for policy purposes, do not have to know the exact number of intersections along the commuter trip. As indicated at the bottom of Table 2, an approximation of the value of this variable can be used to facilitate model implementation.

Ramp Diversion

Commuters approaching the freeway entrance ramp can opt to divert to an alternative route before entering the ramp. Their decision depends on the set of available alternatives and the traffic conditions at the ramp. Our surveys indicate that, for the corridor under study, only a small percentage (less than 4 percent) of drivers divert to a downstream ramp, while the vast majority of diverting drivers select the arterial option. Based on this finding, we have limited the set of route alternatives at the ramp entrance to two (freeway and arterial) and estimated the diversion by specifying a binary-choice logit model.

Model variables can be of two types—trip related and socioeconomic. However, based on our conclusions from modeling the diversion at the origin, and after confirming those conclusions with the data we collected for the ramp diversion, we eliminated all socioeconomic variables from the ramp diversion model. Our final hypothesis included four trip-related variables:

- Freeway travel time (FTT) in minutes, the one-way trip time from the point of entering the freeway proper to destination.
- Arterial travel time (ATT) in minutes, the one-way trip time from the point of diverting at the ramp entrance to destination.
- Waiting time (WT) in minutes, the one-way waiting time at the freeway ramp prior to entering the freeway proper.
- Total travel time (TTT) in minutes, equals $WT + FTT$ for the freeway alternative; if the driver diverts, $TTT = ATT$.

Freeway management and control strategies can directly affect the above variables. For example, ramp metering rates have an immediate effect on WT and an indirect effect on the main traffic stream on the freeway. Drivers approaching the ramp perceive changes in WT by considering the queue length but can only guess about any changes in FTT and ATT by considering the traffic situation (such as speed and density) in the vicinity of the ramp entrance. Lane closings and maintenance work can affect both FTT and ATT, but such information is either known to drivers at the origin or not known at all. Additional information on these conditions can be provided through other means of communication, including routine radio announcements and new guidance-navigation systems.

A return-mail questionnaire survey of 600 drivers actually commuting via the I-35W freeway corridor was conducted at three northbound freeway entrance ramps in November 1987. From the 195 usable responses, data were obtained on driver individual characteristics such as trip origin and destination, departure and arrival times, maximum tolerable waiting time and queue size before diverting to the arterial route, travel time of the alternate route from the diverting point, and socioeconomic information (Table 3).

Two disaggregate models of the diversion at the freeway ramp were derived from the data of the corridor sample (Table 4). Models D1 and D2 test the hypothesis that trip time affects the decision to divert at the ramp. Although the results from model D1 indicate that trip time is a significant factor (99 percent level), inspection of model D2 indicates that this variable should be treated as alternative specific rather than generic—a consideration that improves the estimation power of the model from 59 to 71 percent.

All estimated coefficients have the expected sign and a high statistical significance. The specifications reflect our belief that, for commuting trips of the nature encountered in the Twin Cities, the competition between freeway and arterial times should not follow a linear rule. In particular, the diversion should be highly sensitive to trip times that are very short

TABLE 1 SUMMARY STATISTICS OF SAMPLE COMMUTERS AT ORIGIN

		Group 1	Group 2
Sample size		74	31
Annual household income($)		39000	34000
Age		39.5	35.0
Years in area		7.8 yrs	6.0 yrs
Primary Route	Route type	Freeway	Arterial
	Route length	7.2 mi.	6.6 mi.
	Travel time	17.0 min.	20.1 min.
	# Intersections	18	40
	# Turns	5.4	7.4
Altern-ate Route	Route type	Arterial	Freeway
	Route length	8.8 mi.	7.8 mi.
	Travel time	23.3 min.	21.6 min.
	# Intersections	58	24
	# Turns	6.9	8.7

TABLE 2 ESTIMATED LOGIT COEFFICIENTS FOR DIVERSION AT ORIGIN

Variable	Model M1	Model M2	Model M3
Constant (freeway only)	0.238 (0.83)*	-0.348 (-0.95)	-0.432 (-1.13)
Travel Time (min.)	-0.260 (-4.46)	-0.212 (-3.58)	-
Travel Time * Annual Household Income ($1000)	-	-	-0.00513 (-3.46)
Number of Intersections * Route Length	-	-0.00401** (-2.59)	-0.00462 (-2.86)
Sum of Chosen Probabilities	73.6	76.7	76.5
Sum Prob. Ratio	0.72	0.75	0.75
Initial Log Likelihood (L_o)	-70.7	-70.7	-70.7
Final Log Likelihood (L_θ)	-44.3	-39.5	-39.6
$\rho^2 = 1 - [\, L_\theta / L_o \,]$	0.37	0.44	0.44

* t-statistic

** For DI between 15 and 45,
if DI < 15 then -0.0232
if DI > 45 then -0.0362
where DI = Intersections in Arterial Route - Intersections in Freeway Route.

TABLE 3 SUMMARY STATISTICS OF SAMPLE COMMUTERS FOR RAMP DIVERSION

Location	Sample Size	Access Time to Ramp (min)	Freeway Travel Time (min)	Arterial Travel Time (min)	Max. Wait Time on Ramp (min)	Max. Queue Size on Ramp (no. of cars)
51st Street	64	5.4	18.8	26.3	7.5	13.0
46th Street	88	6.7	17.5	23.2	5.8	17.9
35th Street	43	7.1	17.2	23.7	8.3	16.9
Total or average	195	6.4	17.8	24.2	6.9	14.8

TABLE 4 ESTIMATED LOGIT COEFFICIENTS FOR RAMP DIVERSION

	Model D1	Model D2
Constant*	-0.751 (-4.03)***	-2.31 (-6.42)
TTT	-0.123 (-5.52)	-
DTT/FTT*	-	-4.71 (-5.29)
DTT/ATT**	-	-18.60 (-7.13)
Sum of Chosen Probabilities	76.7	92.3
Sum Prob. Ratio	0.59	0.71
Initial Log Likelihood L_o	-180.2	-180.2
Final Log Likelihood L_θ	-158.6	-115.3
$\rho^2 = 1 - [L_\theta / L_o]$	0.12	0.36

DTT = ATT - (WT+FTT)

* Freeway only, else 0.

** Arterial only, else 0.

*** t-statistic

but not as sensitive to those that are long. The improved estimation and statistical performance (in terms of t-statistic and ρ^2-value) of model D2 is not surprising because commuters are known to attach different values to their time, depending on whether they are traveling on a route where the speed is expected to be high (the freeway) or on one where no such expectation exists (the arterial).

Although implementation requires only limited data, an additional analytical step is needed before the above models become fully operational in a real-time traffic environment. In particular, relationships should be developed between the value of the model variables, which are perceived by drivers, and the value of variables that could be routinely measured by traffic engineers. For instance, a specification should be developed for the relationship between the length of the ramp queue (or the number of cars in queue) and the ramp waiting time perceived by approaching drivers. Such relationships are now under development.

SUMMARY OF THE RESULTS

The rapid increase in the volume of traffic, congestion, and excessive delays is making the management, control, and guidance of traffic flow one of the most critical transportation problems in urban freeway corridors. Modeling demand diversion to less congested routes within a corridor is part of demand modeling efforts for improved simulation and control as well as guidance-navigation systems in real time. In this paper two such diversion models were developed. The first model described the diversion at the trip origin, and the second, the diversion at freeway entrance ramps.

From a survey of approximately 1,100 commuters in the south I-35W corridor of the Twin Cities Metropolitan Area, two logit specifications were estimated. The data indicated that diversion at the origin is a function of trip time, route length, and the number of intersections along the trip. However, trip time is the dominant determining factor and can be employed to estimate the decision in the absence of additional information. Diversion at freeway entrance ramps depends on the perceived trip time on the freeway and arterial and the perceived waiting time at the ramp queue. Further, the data confirmed that socioeconomic indicators do not play a role in the diversion decision. It was also determined that, for commuter trips shorter than one hour, freeway drivers consider only one diversion alternative, that is, a preferred arterial, and do not divert to downstream ramps.

Although the models were based on data collected from only three freeway ramps in a specific metropolitan area and have not yet been transferred to other areas, it is expected that, for trips of a similar nature, the behavioral principles underlying the models generally would be applicable to other areas as well. Ongoing work seeks to validate the models and further extend them to make them operational in a real-time environment in conjunction with demand predictors under development. The purpose of developing these models is for dynamic simulation, on-line freeway corridor control, and demand forecasting suitable for guidance and navigation.

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