Real-Time Freeway-to-Freeway Diversion: The San Antonio Experience

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Studies to evaluate the effectiveness of a low-cost changeable message sign motorist-information-diversion system in San Antonio, Texas, are documented. The system was implemented as a demonstration program by the Texas State Department of Highways and Public Transportation, working in cooperation with the San Antonio Corridor Management Team. Its purpose was to alleviate congestion and reduce accidents on Interstate 35 in San Antonio near the central business district. This paper describes the system, its effectiveness, the problems encountered, and recommendations to avoid or overcome the problems. The information should be useful to others who may be implementing and evaluating a similar system.

In 1977 the Texas State Department of Highways and Public Transportation (TSDHPT), working in cooperation with the San Antonio Corridor Management Team (CMT), initiated programs aimed at alleviating congestion and reducing accidents on Interstate 35 in San Antonio near the central business district (CBD). The programs were the development, implementation, and demonstration of a low-cost motorist-information-diversion system (MIDS), which included the following phases:

1. I-35 route change around the CBD,
2. Use of a low-cost changeable message sign (CMS) system for freeway diversion, and
3. Use of the CMS system for managing traffic during freeway maintenance.

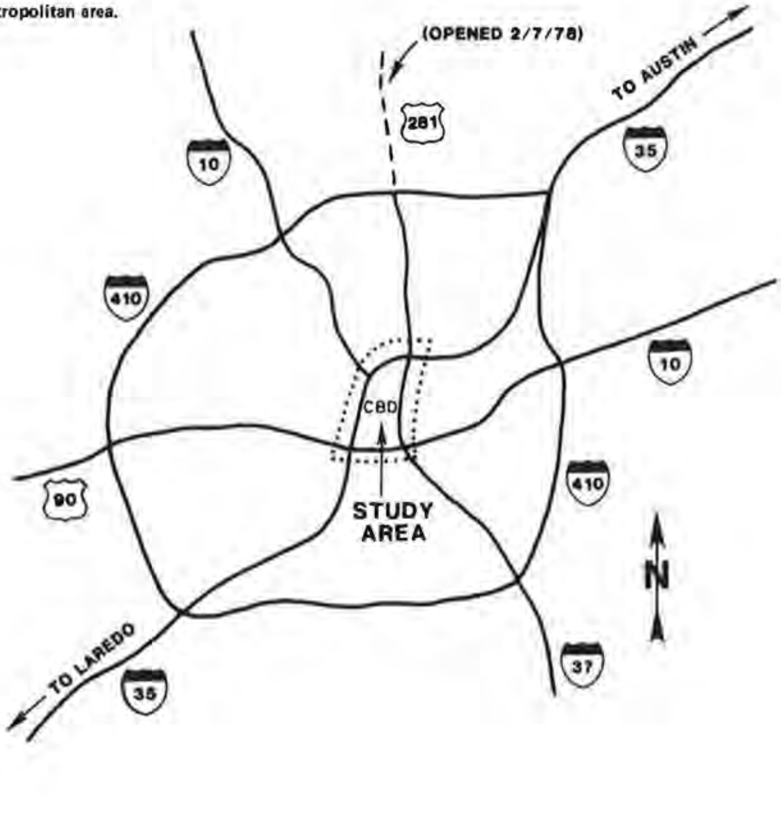
The Texas Transportation Institute (TTI) was contracted to evaluate the effectiveness of the above three programs as part of phase 2 of the Federal Highway Administration (FHWA) sponsored research entitled, Human Factors Requirements for Real-Time Motorist Information Displays. This provided an opportunity to not only evaluate the effectiveness of the specific traffic-management approaches but also to study the institutional and operational approaches used in San Antonio, and to develop hardware, operational, and evaluation guidelines for other cities in the United States that may implement and evaluate similar types of systems.

Results of the I-35 route change and the use of the CMS system for managing traffic during freeway maintenance are presented in other papers and reports (1,2). This paper discusses the use of a low-cost CMS system for freeway diversions of CBD-bound traffic.

The major freeway routes in the San Antonio metropolitan area are shown in Figure 1. I-35 is the primary facility in the Austin-Laredo corridor and is one of the oldest freeways in San Antonio. The four-lane section of I-35 that forms the north and west boundaries of the CBD was completed in 1957. Considerable congestion and relatively high accident rates are experienced on this partially elevated freeway section that has capacity restraints, such as relatively severe alignment and narrow right-of-way, particularly at the structures (3).

I-10 and I-37 are eight-lane freeways built in the late 1960s with higher design standards. As the southern and eastern boundaries, they form an alternate route around the downtown area. This route is approximately 0.8 mile (1.3 km) longer than the

Figure 1. Major highways in San Antonio metropolitan area.



primary route [5.6 miles (9.0 km) versus 4.8 miles (7.7 km)]. During off-peak periods, travel time is lower on the alternate route. The annual average daily traffic (AADT) on I-35 in 1977 was approximately 79 230 in contrast to 58 140 on I-37.

The effectiveness of the CMS diversion system was studied by assessing the change in traffic volumes on the freeway, interchange ramps, and the primary off-ramps that lead to the CBD. Effectiveness of the system as perceived by police patrols was evaluated by studying the willingness of the police to use the CMSs during incidents over a period of two years.

SUMMARY OF RESULTS

Analysis of seven incident case studies for which all relevant data were available revealed that, on average, diversion rates when the CMSs were used were higher than normal but were about the same as the natural diversion that occurred due to incident congestion when the CMSs were not used.

Two factors seemed to contribute to the less-than-acceptable results:

1. The diversion ramp was too close to the final destinations of divertable (CBD-bound) drivers. Thus, the amount of time saved by taking the diversion route was probably not sufficient to encourage diversion.
2. Drivers were using routes other than the diversion route when they saw messages on the CMSs. Diversion to these other routes was not evaluated as part of the point-diversion project.

Therefore, the results do not indicate failure of the MIDS but the fact that the advice came too late under the circumstances. In addition, some drivers know better routes (from their viewpoints).

LESSONS LEARNED

The program in San Antonio was successful from several standpoints. First, it gave the San Antonio CMT, particularly members of the San Antonio Police Department (SAPD), experience with operating a CMS system. It will be invaluable in the future when more elaborate systems are designed and implemented. Second, it illustrated how interagency teamwork can accomplish corridor-management objectives. Third, it allowed the research team to observe institutional hardware and operational conditions and limitations. These observations will assist other agencies that contemplate the installation of similar systems.

Although the amount of traffic diversion attributed to the CMSs may not be overly impressive, several lessons were learned from this low-cost MIDS demonstration project that will be beneficial to others. The problems encountered with the MIDS and recommendations for future systems are discussed later in the paper.

OPERATIONAL DEVELOPMENT

Development of the CMS operations plan evolved over a period of several months and included the following activities:

1. Identification of incident characteristics,
2. Selection of sites for matrix signs,
3. Determination of existing traffic patterns,
4. Development of diversion strategies,
5. Development of candidate messages,
6. Development of operational control procedures, and
7. Training of operating personnel.

Several meetings were held between TSDHPT, SAPD, and TTI in an attempt to develop a plan that was both acceptable to the operating and enforcement agencies and incorporated available inputs of recent CMS operational guidelines.

Matrix Sign Sites

Two trailer-mounted computerized bulb-matrix CMSs (Figure 2) were used to present diversion information to northbound I-35 drivers in San Antonio. The signs, available from previous TTI research studies, provided versatility in message length, display format, and rate of display.

Messages were presented on a 4-ft 10-in (174.3-cm) high and 15-ft 4-in (467-cm) wide display board. Each of the two lines was composed of an array of 33-W incandescent light bulbs, 7 rows by 64 columns, which formed a letter height of 18 in (46 cm) with a maximum capability of 13 characters. The bulbs were protected from sun glare by a glare screen attached to the front panel of the display. Previous research by TTI (4) has shown 650 ft (198 m) to be the 85th percentile legibility distance for these signs.

The ability of displaying a message on a sign was provided to the operator through the use of a digital computer located on the front side of the trailer in an environmental cabinet (Figure 2). Messages to and from the computer were transmitted and received through a teletypewriter (TTY) (see Figure 3). The coupler is located on the side of the TTY. The sign operator dialed the number of a telephone located in the CMS computer cabinet, placed the telephone ear and mouth pieces in the coupler, and then controlled the sign with the TTY. The process would then be repeated for the second sign. Automatic dial-up cards were used to reduce the time required to operate the signs.

The human factors design guide (5) emphasized the need to install CMSs far enough upstream from decision points to allow the driver time to take appropriate action. Site selection in San Antonio was constrained somewhat by horizontal and vertical curvature and narrow right-of-way widths. The sites chosen for the two CMSs are shown in Figure 4. The first sign seen by the driver was approximately 2.2 miles (3.5 km) from the diversion point. Sign 2 was approximately 1.0 mile (1.6 km) downstream from sign 1.

Diversion Strategies

Following a review of the origin-destination (O-D) patterns, a committee that consisted of SAPD, TSDHPT, and TTI representatives mutually agreed to address only traffic bound for downtown. It was agreed that messages would be displayed only during incident conditions. Diversion messages would be displayed based on criteria of incident and end-of-queue locations (relative to the diversion point) set forth by SAPD. Messages that warn drivers of incidents would be displayed when diversion was not warranted. Estimates by SAPD, based on previous experiences, indicated that the CMSs would probably be used for diversion about once every one to two months.

A total of 120 messages (2) was initially developed by TTI. The large number of message combinations was due primarily to the desire to display detailed incident-location information.

Operational Control Procedures

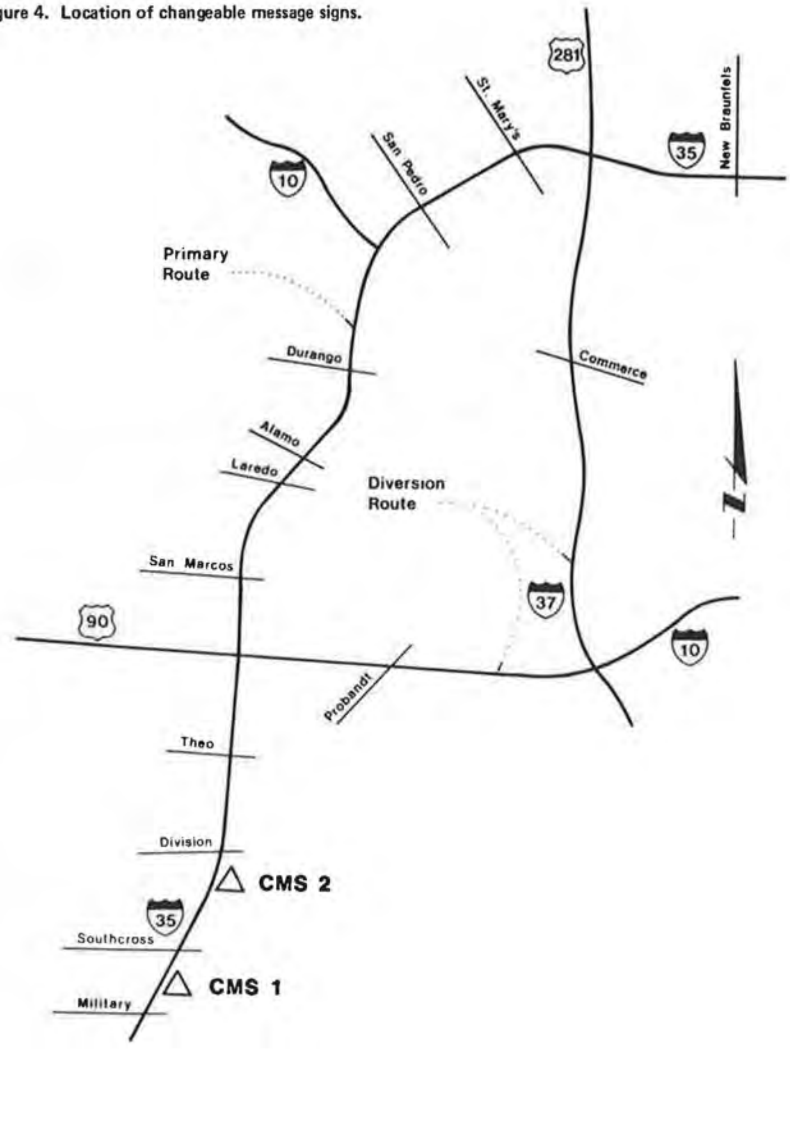
Freeway surveillance was accomplished by police freeway patrols, supplemented during peak periods with police helicopter patrols when weather permitted. Incident information and requests for sign messages were radioed to a single police dispatcher who not only dispatched police vehicles to accident scenes throughout San Antonio but also controlled the CMSs. No additional funds were available to SAPD for their participation in the CMS demonstration project. They operated the system with existing police funding and personnel constraints.

Recognizing the normally high demands placed on the dispatcher during an accident and the officers

Figure 2. Lamp matrix changeable message signs.

Figure 3. Teletypewriter with acoustical coupler.

Figure 4. Location of changeable message signs.



at an accident scene, it was necessary to develop a technique to streamline the effort involved in selecting and displaying messages. The approach developed was to assign a number to each message. Message matrices were developed for peak and off-peak periods and for complete and partial freeway blockages. The matrices allowed patrol officers and dispatchers to select numbers for the appropriate messages based on the locations of the accident and the end of queue.

A step-by-step dispatcher's procedure for operating the CMSs was also developed. The procedure listed 26 steps that were required to display a message on both signs and 26 steps to turn the signs off.

The planned scenario of operations was as follows. When a freeway patrol officer noticed unusual congestion, he or she would drive to the scene of the incident. (The helicopter pilot would fly to view the scene.) The patrol officer would either have some idea as to the location of the back of the queue or would obtain this information from another patrol officer or the helicopter pilot. The patrol officer would then look at the appropriate matrix and request that the dispatcher display the message that coincides with the message number.

By using the message chart the dispatcher would then identify the specific computer message number for each sign. He or she would dial sign 1 and display the appropriate message, and then dial sign 2 and display the message.

It is important to note that due to the software design and storage limitations of the CMS computers and the desire by TTI to use 120 messages, the message numbers and the computer storage numbers for the messages were different. For example, if an accident occurred at Alamo that blocked one lane during the morning peak period and the queue extended to I-10E, then message 32 would be displayed. The dispatcher would then look in the dispatcher's guide to find that in order to display message 32, a command must be sent to sign 1 to display message D-15 and to sign 2 to display message D-6. As the queue increased or dissipated, other patrol officers on their way to assist the officer now at the scene would notify the dispatcher of a new message number if required.

TRAFFIC DIVERSION

The primary objective of this phase of the research was to evaluate the effectiveness of the CMS system in diverting traffic to the diversion freeway route during incident conditions. A secondary objective was to develop a practical evaluation approach that can be implemented by city and state highway agencies in evaluating similar CMS systems, considering normal personnel and funding restraints.

Approach and Initial Observations

Collection of evaluation data posed several particularly difficult problems. License plate O-D surveys have been found to be a most accurate method of determining effectiveness of real-time displays. This type of study is particularly well-suited to predictable occurrences such as maintenance activities and special events (6,7). However, the random nature of incidents precludes keeping a license plate data-collection crew on standby. Therefore, a network of traffic-volume counters was employed to obtain data that could be used in the evaluation.

Analysis of data from previous TTI studies in Dallas (7) had indicated that for point diversion during special events, changes in ramp volume at the diversion point were directly related to total diversion. It was hoped that similar results could be obtained in San Antonio from strategically locating counters on primary and diversion routes. It was initially envisioned that volumes on the diversion freeway route would be expected to increase during intervals that the signs were on while volumes on the primary route would decrease.

Traffic counters were installed on I-35 at one freeway location upstream from the diversion point, on three interchange ramps along the diversion route, and on the Durango Boulevard and Commerce Street exit ramps that lead to the CBD to supplement the existing four permanent TSDHPT counters located on the primary and diversion freeway routes. The six new counters were modified to record volumes on punched tape at 5-min intervals. The TSDHPT permanent counters provided hourly counts.

Initial plans were to evaluate the volume data collected from all six of the new automatic counters. It was expected that significantly high diversion rates would be reflected by lower volumes on the Durango ramp with corresponding increases on the diversion route interchange ramps (I-35/I-10E, I-10E/I-37, and I-37/I-35) and the Commerce ramp. Statistical analyses were to be performed on the data from each ramp to test whether there were differences during each incident period compared with periods immediately preceding and following it. Evaluations of data collected during selected incident cases coupled with a thorough assessment of available data resulted in changes to these plans. In addition to the counter problems, volume changes on the Durango, I-10E/I-37, I-37/I-35, and Commerce ramps were small in comparison to total ramp volumes. Thus, it was difficult to determine whether the changes were due to the CMSs or to random variations in traffic demands. Also, the counting scheme employed did not provide a closed system whereby all input and output points were counted. With small changes in volumes on the ramps under study, it was difficult to trace origins with any certainty. For example, volume increases on the I-10E/I-37 ramp could originate from northbound I-35, eastbound US-90, and eastbound I-10. The amount of traffic that originated from I-35 could not be determined.

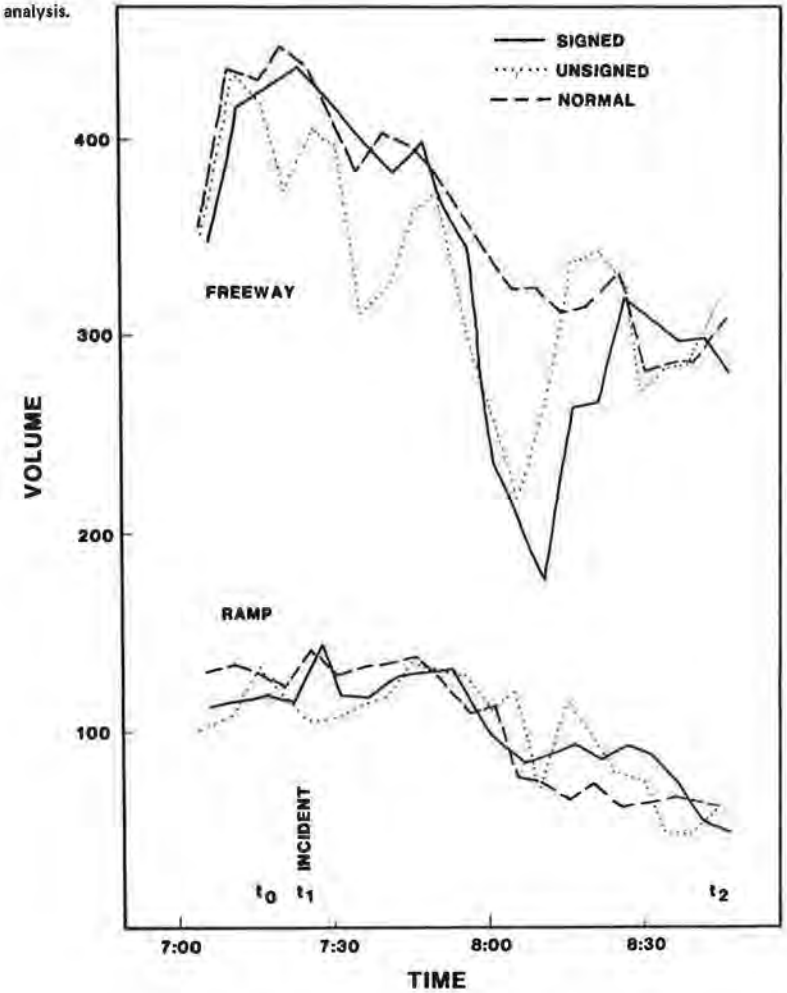
It was reasoned, however, that if there indeed was diversion due to the CMSs, the volumes on the I-35/I-10E diversion ramp would be the most sensitive to any changes and, coupled with the freeway counts made at I-35 at Theo Avenue, would at least provide some trends that indicated the effectiveness of the CMSs. Thus, efforts were then concentrated in analyzing the data from the diversion ramp and the freeway.

In contrast to the Dallas diversion studies (7) where congestion did not occur between the CMSs and the diversion ramp, queue buildup upstream from the diversion ramp due to incident bottlenecks and peak-period demand-capacity characteristics had to be considered.

The queue buildup had to be considered to accurately measure the diversion rate on the I-35/I-10E diversion ramp. It was important that motorists who read the CMSs and took the diversion route were accounted for even though they were trapped in the backup and their arrival to the diversion ramp was delayed. Therefore, the analysis period for each incident must begin prior to the time when there was a significant reduction in volumes upstream from the diversion ramp compared with normal days that indicated traffic backup from the incident. The analysis period extends to the time when congestion clears and the freeway volumes on the incident day return to normal.

Experience (6,8,9) has shown that there is a significant number of drivers who leave the freeway

Figure 5. Five-min volumes for diversion analysis.



(divert) upstream from their intended off-ramps whenever unusual congestion occurs, even though they do not know the cause of the problem. This type of diversion is often referred to as natural diversion and in many cases can be quite high. Therefore, the amount of natural diversion had to be considered in order to more accurately evaluate the true effects of the CMSs. The amount of natural diversion during incidents must be subtracted from the diversion that occurs when the CMSs were used to determine the added effects of the CMSs.

The available data were studied to obtain volumes for the following situations:

1. For the incident when the CMSs were used (signed incidents),
2. For an incident that occurred at approximately the same time of day and for which the CMSs were not used (unsigned incidents), and
3. Normal volumes for a comparable period that consisted of the average of two or three similar days (same day of week) within two or three weeks of the incident day.

A potential case-study incident was identified when volumes were available for all three situations. Certain criteria had to be met before the data from a signed incident day could be used in the analysis. These were as follows:

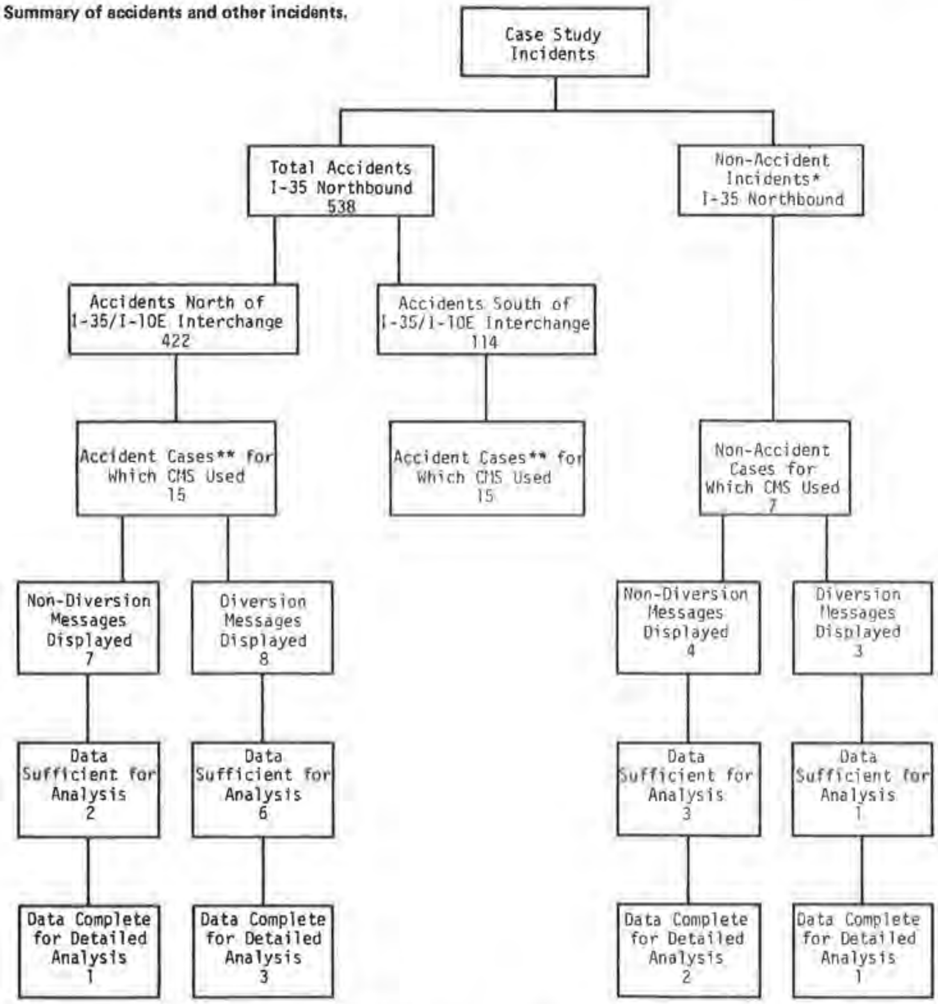
1. The incident must occur at or downstream from the diversion point,
2. The CMS must be activated, and
3. Information concerning incident time and location and the type and time of message must be available.

To develop a data base for the amount of natural diversion for each case-study incident, attempts were made to find a day when the CMSs were not used during an incident that occurred at approximately the same time of day, weekday, and within two or three weeks from the case-study incident. As would be expected, there was some difficulty in finding such data for all case-study incidents. However, as a minimum, data were found for incidents that occurred during the same year and month and reasonably close to the same time of day. In most cases, data for unsigned incidents were available on the same weekday as the case study incidents.

A normal traffic-volume data base was developed for each case-study incident by averaging data from two or three days obtained from the same time period, weekday, month, and year as the case-study incident. Care was exercised to ensure that nonincident days were selected.

The analysis process used in this project to evaluate the diversion influenced by the CMSs is illustrated in Figure 5. Freeway volumes (in 5-min increments), obtained from the automatic traffic counters located on I-35 at Theo (just upstream from the I-35/I-10E diversion ramp) and on the diversion ramp, are plotted for one of the case-study incidents.

Figure 6. Summary of accidents and other incidents.



*Spilled load, high water, stalled vehicle, etc. Total number of such incidents are not available.

**In some cases two accidents occurred.

An examination of the freeway volumes in Figure 5 shows that at time t_0 the volumes are approximately the same for all three situations. After the incident at time t_1, traffic was stored due to the demands that exceeded the incident bottleneck capacity. As the queue propagated upstream and passed through the I-35/I-10E interchange and then over the freeway detectors at Theo, the volumes significantly decreased. The drop in volumes represents the queue buildup on the freeway. When this occurred, drivers destined for the I-35/I-10E diversion ramp (both those who normally use the ramp and those who intended to use it because of the congestion and CMS messages) were delayed in both time and space. When the incident vehicles were removed from the freeway the capacity increased and the buildup dissipated. This is illustrated by the volume increase at the freeway counter station. Once the queue dissipated from the interchange area, the volumes returned to those normally expected for the particular time of day. The volumes for all three situations are approximately equal at time t_2. In order to account for traffic volume by using the I-35/I-10 diversion ramp for all three situations, the analysis included the time period from t_0 to t_2.

Because traffic demands are likely to be different for each of three situations due to normal traffic variations, a direct comparison of volume changes on the diversion ramp for each of three situations is inappropriate. To account for normal traffic variations, volumes on the I-35/I-10E ramp were converted to percentages of the I-35 freeway demand volumes for further analysis. A basic assumption underlying this approach is that the percentage of I-35 drivers who would normally use the I-35/I-10E ramp between times t_0 and t_2 is the same each nonincident day. Increases in traffic percentages on the diversion ramp would be attributed to the incident and the CMSs.

Results

Figure 6 is a summary of the accidents and other incidents, CMS use, and resulting case-study incidents that were available for study. Details of CMS use are discussed in a later section.

As shown in Figure 6, 538 accidents occurred on northbound I-35 in the study area during the two-year study period; 422 accidents occurred at or downstream of the diversion point. The CMSs were used during 15 of these accidents. Diversion messages were displayed eight times and warning messages during seven incidents. Further analysis revealed that the necessary data for more detailed

Table 1. Results of case-study incidents.

Incident				Message Type	Analysis Period	Northbound I-35 Drivers Using Diversion Ramp		Test of Significance[a]
No.	Date	Time	Location			Condition	Percent	
1	8/17/78	8:45 a.m.	I-35 at I-35/I-10E interchange	Diversion	8:50-9:50 a.m.	Normal	19	
						Unsigned incident	22	a
						Signed incident	32	a,b
2	10/10/78	6:45 a.m.	I-10W at Colorado	Diversion	7:30-9:30 a.m.	Normal	24	
		8:00 a.m.	I-35 at I-35/I-10 interchange	Diversion	7:30-9:30 a.m.	Unsigned incident	27	a
						Signed incident	29	a,b
3	9/29/78	5:25 p.m.	I-35 at Commerce	Diversion	5:25-7:00 p.m.	Normal	25	
						Unsigned incident	24	
						Signed incident	25	
4	10/21/78	2:25 a.m.	I-35 at Alamo	Diversion	2:20-3:30 p.m.	Normal	22	
						Unsigned incident	22	
						Signed incident	22	
5	10/2/78	8:00 a.m.	I-35 at Alamo	Warning	7:50-8:50 a.m.	Normal	24	
						Unsigned incident	29	a
						Signed incident	30	a
6	10/25/78	7:35 a.m.	I-35 at Durango	Warning	7:30-8:30 a.m.	Normal	27	
						Unsigned incident	32	a,c
						Signed incident	29	a
7	11/2/78	7:35 a.m.	I-35 at Stockyards	Warning	7:25-8:30 a.m.	Normal	28	
						Unsigned incident	31	a,c
						Signed incident	28	
All incidents combined						Normal	25	
						Unsigned incident	27	a
						Signed incident	28	a,b
All incidents excluding no. 1						Normal	25	
						Unsigned incident	27	a
						Signed incident	27	a

[a]a = significantly greater than normal conditions, b = significantly greater than unsigned incident conditions, and c = significantly greater than signed incident conditions.

analysis were available for only four case-study incidents. Diversion messages were used during three of these cases and a warning message during the remaining one case.

The CMSs were also used during seven nonaccident incidents (e.g., spilled load, high water, stalled vehicles, etc.). The data sets were complete for three of these cases. Therefore, data sufficient for detailed analysis of diversion rates were available for only seven case-study incidents--four accident cases and three nonaccident cases.

Results of the seven case-study incidents are summarized in Table 1. Included in the table is the percentage of northbound I-35 drivers (counted at Theo) that used the diversion ramp (a) during normal conditions, (b) during an incident when the CMSs were not used (unsigned incident), and (c) during the incident when the CMSs were used (signed incident). Also shown are the results of the Z-test of proportions analyses (10), which tested differences between each of the three situations.

The results reveal that for five of the seven cases (numbers 1, 2, 5, 6, and 7), the percentage of traffic that used the diversion ramp during the unsigned incidents (natural diversion) was significantly higher ($p < 0.05$) than normal (on days when incidents did not occur). In four of these cases (numbers 1, 2, 5, and 6), the diversion rate during the signed incident was also significantly higher ($p < 0.05$) than normal. Of the five incident cases in which either the unsigned or signed incidents yielded greater diversion rates than what would normally be expected, only two of the cases had significantly higher diversion rates for the signed incident than the unsigned incident; in two other cases the unsigned incident yielded higher diversion rates than the signed incident. In the remaining case the diversion rates were the same for both the signed and unsigned incidents.

Combining the data for all seven incidents, the results revealed that, on average, 25 percent of the northbound I-35 traffic used the diversion ramp during the normal periods whereas 27 percent and 28 percent of the traffic used the ramp during the unsigned and signed incidents. Statistical analyses indicated that the diversion during the unsigned incidents was significantly higher ($p < 0.05$) than normal and the diversion during the signed incidents was significantly higher than both the normal periods and the unsigned incidents.

An examination of Table 1 shows that in only one of the case-study incidents did the amount of the percentage increase in diversion appear to be high numerically. During incident case 1, when the CMSs were operating, 32 percent of the traffic used the diversion ramp. This was significantly higher than both the 22 percent diversion during the unsigned incident and 19 percent during the normal period. The incident, however, was different from the others. The accident occurred on the median lane just upstream from the diversion ramp. Blockage of the lane at that point may have indirectly caused several drivers in the right lane to be trapped because of the lane drop and forced onto the diversion ramp. This may have resulted in the relatively high percentage of traffic that used the ramp in comparison to the unsigned and normal periods.

An analysis of the six incident cases excluding number 1 revealed diversion percentages of 25 percent, 27 percent, and 27 percent for the normal, unsigned, and signed incidents, respectively. The 2 percent increase in diversion during the signed and unsigned incidents was significantly higher than normal ($p < 0.05$). However, as the data show, there was no difference in the diversion rate between the signed and unsigned incidents. Therefore, on average, use of the CMSs during the incidents did not result in greater use of the diversion route than the amount of natural diversion that occurred without the signs. In addition, although the 2 percent increase is statistically significant, it is insignificant from a freeway operations standpoint.

Table 2. Case-study incidents summarized by time period.

Incident Number	Period	Northbound I-35 Drivers Using Diversion Ramp		Test of Significance[a]
		Condition	Percent	
1,2,5,6,7	Peak	Normal	25	
		Unsigned incident	28	a
		Signed incident	29	a,b
2,5,6,7[b]	Peak	Normal	26	
		Unsigned incident	29	a
		Signed incident	29	a
3,4	Off-peak	Normal	24	
		Unsigned incident	23	
		Signed incident	24	

[a]a = significantly greater than normal conditions and b = significantly greater than unsigned incident conditions.
[b]Excludes incident 1.

The data were further analyzed to determine whether diversion rates were affected by the period of day when the incidents occurred. Table 2 is a summary of the case-study incidents grouped by peak and off-peak periods.

The results reveal that diversion rates were significantly higher during the unsigned and signed peak-period incidents in comparison to what would normally be expected. However, no differences were found in the diversion rates during the off-peak periods.

A review of Table 2 also reveals that when incident case 1 is excluded from the peak-period incident analysis, the diversion during the signed incidents was higher than normal but was no different than the natural diversion that takes place during unsigned incidents.

Discussion of Results

Analysis of the effectiveness of the CMSs was based solely on a freeway-to-freeway point-diversion concept. Funds were not available and no attempts were made to evaluate traffic diversion to other arterial routes induced by the CMS messages. During conversations with a few local drivers who commute to work on northbound I-35, the drivers stated that when accident messages were displayed on the CMSs they oftentimes left the freeway via one of the off-ramps upstream from the I-35/I-10E interchange (diversion ramp) and took another route to work. These alternate routes were more convenient than the diversion route recommended by the CMSs. Diversion to other arterial routes was also frequently noticed by freeway patrol officers. Thus, there was more diversion within the system than the data indicated. These observations suggest that, in contrast to diversion of special-event traffic when drivers are willing to use the recommended alternate route (7,11), point diversion during accidents in an urban area may be a misnomer.

Special-event traffic generally is destined to the same place and, in many cases, to the same parking facility. In contrast, the destinations of commuters going to the CBD are scattered throughout the downtown area. Thus, the route recommended by the CMSs may be the most logical one but may not necessarily be the most convenient one for many drivers. They may elect to choose their own routes based on the time of day, location of the accident, the degree of freeway congestion, etc., or they may decide to remain on the freeway for one reason or another, which includes simply a reluctance to use another route.

Driver response to real-time information in San Antonio appeared to be similar to that experienced in Dallas (6), Los Angeles (8), and Minneapolis (12). Rather than diverting via one major ramp when they were notified of an incident or when they encountered unusual congestion, drivers who diverted tended to use exit ramps that lead to routes most convenient to them. In retrospect, analyzing the San Antonio CMS installation as an incident-management system rather than a point-diversion system would have most likely resulted in a more complete description of traffic diversion. The limited scope of the study focused attention on the freeway-to-freeway diversion. The results strongly indicate that agencies evaluating similar systems should monitor all off-ramps that are likely to be used. Agencies should not be misled and restricted in their evaluation approach because of terminology; they should develop an evaluation approach that will assess the full impact of the CMS system if they can afford to do so.

PERCEIVED EFFECTIVENESS OF CMS SYSTEM

Background

During the first year of operation, two problems arose that had an impact on the CMS evaluation studies. First, there were numerous problems with the automatic counters, which limited the amount of useful data for estimating the amount of freeway-to-freeway diversion attributable to the CMSs. Second, the police patrol officers and the police dispatchers who operated the CMSs encountered difficulty in using the operational control procedures (i.e., selection of sign messages based on the location of accident and length of backup) developed by TTI, TSDHPT, and SAPD. As a result of discussions with SAPD, the 120 messages in the original CMS library were reduced to 7.

The potential of a small sample size due to counter malfunctions prompted the research team and the San Antonio CMT to seek alternative measures of effectiveness. It was the feeling of police administrators and some patrol officers that the CMSs were effective in improving safety in the accident area where the officers and involved motorists were located. They believed that by keeping drivers informed of freeway conditions, the CMSs help to relieve driver frustration and anxiety. As a result, drivers are less hostile when passing an officer directing traffic. It was their opinion that regardless of whether or not the CMSs divert a considerable amount of traffic, these intangible effects are realized.

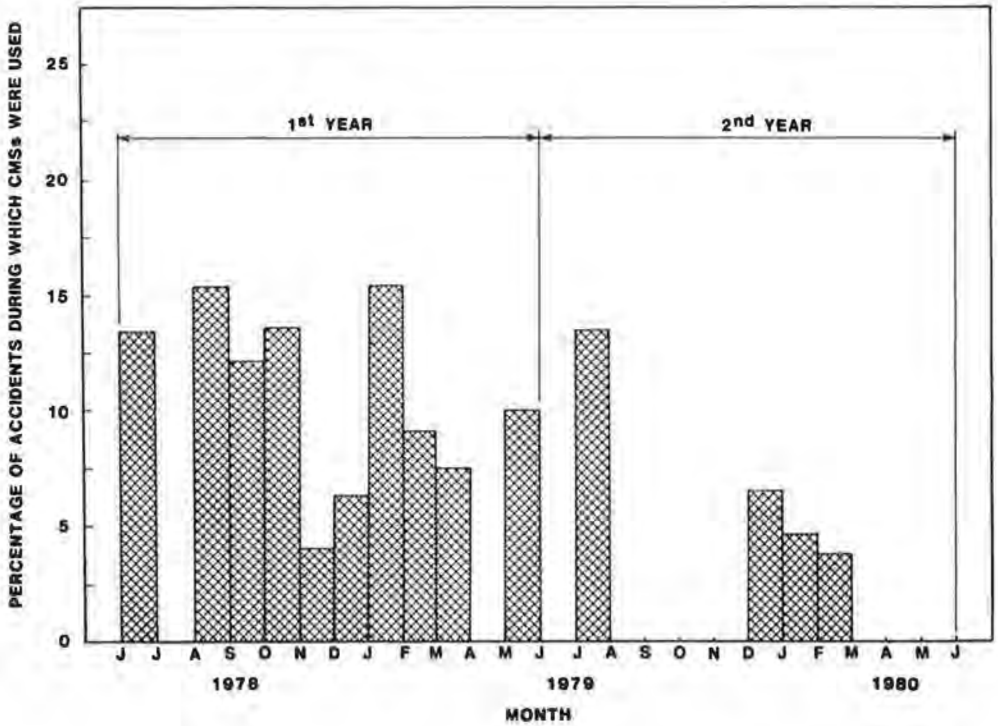
Administrators from SAPD stated that field patrol officers would use the CMSs if they felt the signs were helpful in controlling traffic on the freeway. Although the intangible benefits of less driver frustration and anxiety cannot be measured directly, it was speculated that perceived benefits can be assessed by measuring police use of the CMSs. Increased use during the second year would indicate positive feelings about the system by the police officers. As previously mentioned, operation of the system was simplified by TTI at the beginning of the second year of operation by reducing the number of messages and improving the operation control procedure.

The objective of this portion of the research was to measure the perceived benefits of the CMSs by evaluating CMS use during the first and second years of operation.

Approach

The approach used to assess the perceived effectiveness of the CMS system was to compare the use of the

Figure 7. Use of changeable message signs on I-35 in San Antonio.



CMSs during accidents and the attitudes of the police freeway patrols and dispatchers between the first and second year of operation. Accident records and CMS use information, discussed in detail later in the paper, were compiled during the two years. In addition, interviews were conducted with police patrol officers and dispatchers at the end of each year of operation.

Results

The table below lists the number of accidents and times the CMSs were used during each of the two study years:

Item	First Year	Second Year
No. of accidents	290	248
Frequency of sign use	26	6
Avg no. of accidents per month	24.2	20.7
Avg sign use per month	2.2	0.5
Accidents for which signs were used (%)	9.0	2.4

The data are also plotted in Figure 7 in terms of percentages by month during the two study years.

The results show that there was a significant reduction in the use of the CMSs during the second year of the study. The signs were used only 6 times (0.5 times/month) during the second year in comparison to 26 times (2.2 times/month) during the first year of operation. Considering the use per accident, the table shows that during the second year the signs were used for 2.4 percent of the accidents in comparison to 9.0 percent of the accidents the first year.

The results were disappointing considering the fact that the initial library of CMS messages was reduced from 120 to 7 to simplify operations following interviews with police patrol officers and dispatchers after the first year of operation. However, frequency of sign use during the second year (0.5 times/month) was not out of line with earlier estimates. SAPD administrators predicted prior to the CMS pilot program that, based on their experiences with the types of accidents on I-35, the signs would most likely be used an average of once every one or two months. The disappointment, therefore, stems from the indications of greater interest and desire to use the signs during the first year (even though the rate during the second year was in line with earlier SAPD predictions) and indications of reduced interest during the second year.

Interviews with SAPD administrators indicated the following reasons for reduced use:

1. Difficulties with existing hardware system,
2. Turnover and reassignment of SAPD personnel,
3. Shift rotations, and
4. Reduced direct contact between SAPD administrators and the dispatchers and patrol officers.

The CMS hardware system was primarily designed for research and is not ideally suited for operations by nontechnical personnel. This potential problem was recognized initially by TTI, TSDHPT, and SAPD, but it was hoped that some of the difficulties could be resolved.

Normal turnover and reassignments resulted in a situation where some police officers were not familiar with the objectives, design, and operation of the CMSs. In retrospect, the research project should have been funded to periodically furnish training to the newer officers.

The dispatchers and CMS operators were on rotating shifts. Use of the CMSs was highest during the morning peak periods. The dispatchers who became somewhat familiar with operating the CMSs would switch shifts and not return to the morning shift until two months later. The complexity of the hardware resulted in the operators being more reluctant to use the signs when they returned. CMS operating procedures were forgotten during the long periods away from operating the signs. Dispatchers switching from night to morning shifts seemed to forget the operating procedures because of the extended period between the training school and actual hands-on operations.

Probably the factor that had the greatest impact on the reduced use of the CMSs during the second year resulted indirectly from the energy situation. As was the case with other agencies, the City of San Antonio was hit by higher fuel costs. As a conservation measure, the city manager issued a directive in early June 1979 stating that official vehicles were no longer allowed to be driven to and from home. Radio communication between police administrators and supervisors with dispatchers and freeway patrol officers during the first year who requested the use of the CMSs was a positive indication and assurance of the importance of the system. The absence of radio communications between administrators, supervisors, and patrol officers was an influencing factor in the reduced use of the CMSs during the second year, according to SAPD officials.

CMS HARDWARE AND OPERATION PROBLEMS AND RECOMMENDATIONS

Operator's Control Console

The remote-control console used in San Antonio was a TTY. Although TTI researchers had no problems with the TTY while operating three trailer-mounted CMSs in Dallas (6), some police dispatchers seemed to be apprehensive about the equipment. The problem was compounded by the need to punch a "D" on the keyboard followed by a number. Some of the dispatchers lacked the confidence that the number they punched would display the desired message, even though they had a message number chart available.

There were also many occasions of dispatcher apprehension about whether the message requested was actually displayed. Although the message "D-number" was printed by the TTY printer when a message was displayed, the message content was not. This added to operational uncertainties.

The amount of operator action to display a sign message after a sign was contacted was excessive. As many as seven buttons on the keyboard had to be depressed merely to display one message and to have the D-number and computer clock time printed.

The number of CMSs that can be efficiently controlled with a TTY is also important to consider. TTI personnel had no problems operating three CMSs in the Dallas system. However, it is doubtful whether one technically trained individual could effectively and efficiently operate more than three signs in an urban area by using a TTY as a control console, even though he or she could devote full attention to sign control. Traffic conditions change too rapidly.

Thus, the following points are recommended. A TTY remote-control console can probably be effectively used in an urban area CMS system to control up to three CMSs by a technically oriented individual, provided he or she can devote full attention to operating the signs that need to be activated. A push-button console should be used when the system is operated by local or state police or nontechnical personnel, or the system has more than three CMSs. The push buttons should contain the specific CMS message that will be displayed when the buttons are depressed.

Positive visual-message verification should be provided. A message-display board should be available when either the signs are operated by nontechnical personnel or when there is a large number of signs to control. The message-display board must allow the operator to quickly identify the exact message content and the freeway locations where messages are displayed. Simultaneous display of the information is desirable. Technically oriented operators could get by with a cathode-ray tube (CRT) display, provided the number of signs is small.

Operator Considerations

Reports (5,8) have cited factors such as operator boredom as critical in the effective operation of CMS systems. Although incidents are random and there may be long intervals when the signs are not needed, the preparedness and alertness of the operator must not significantly diminish. Operator overload, rather than boredom, was a problem in San Antonio.

The CMS system operator in San Antonio time-shared responsibility with dispatching police and other emergency vehicles to locations throughout the city. Needless to say, during peak periods when the need for the CMSs was the greatest, the dispatcher was very busy responding to incidents. Overload in these critical situations required that the operator prioritize his or her tasks. Operation of the CMSs was of lower priority.

One major problem that arose in San Antonio was that because of the infrequent use of the signs by specific dispatchers due to shift rotations (signs are most frequently needed during peak periods) and other factors, the operators' self-confidence in the ability to operate the signs dwindled over time. This, in part, was a contributing factor to the decline in the use of the signs during the second year of operation. No provisions were made in the research project to retrain the operators.

Thus, the following points are recommended. The operator should be able to devote full attention to CMS operation during the peak-traffic periods when incidents are most likely to occur. During off-peak periods other related tasks are advisable, but the operator must be in a position to devote full attention to the signs when an incident occurs.

The operator should have a strong working knowledge of the freeway and streets in the corridor influenced by the CMSs. This knowledge will permit him or her to more efficiently and effectively select the appropriate information options for display.

The operator must be well-trained and confident about his or her ability to operate the system. Recognizing that sign use in smaller metropolitan or rural areas may be infrequent, provisions should be made to retrain the operators and to practice sign operation under simulated conditions. The CMS control console and associated hardware and software should be designed to allow operators to go through the actual motions of operating the system and seeing the messages appear on the confirmation panel without the messages actually being displayed on the signs in the field. These simulations should be conducted with a supervisor at least every six months. The operators should be encouraged to practice the simulated operations on their own at more frequent intervals.

System Operation

The decision was made by local highway and police agencies that the San Antonio CMS system would be operated by SAPD. SAPD administrators and supervisors were enthusiastic supporters and lent considerable encouragement for this arrangement. Many institutional, personnel, and funding constraints limited the capability of the local police to staff the system to the levels needed to maintain an effective system during the two-year study. However, SAPD believes that the police should have operational responsibility.

Thus, the following point is recommended. Some local police departments are in a position to assume responsibility for operating MIDSs in urban areas. When the system is to be operated by local or state highway agencies, the police should be involved with the planning and design of the system and must be an involved partner when the system is operated.

Telecommunications

As previously discussed, the operator's console (TTY) in San Antonio communicated with each sign by way of a telephone dial-up system. This required that a sign be called before a message could be displayed, changed, or removed. Although the amount of time required would not be excessive and the efficiency of operation would not be seriously affected for a two-sign system with an experienced operator, problems could arise with larger urban area systems or when operators are not proficient in the use of the CMS system. Experiences with the telephone dial-up system in San Antonio indicated that it was quite inadequate for the occasional user who had a multitude of other simultaneous responsibilities.

Thus, the following point is recommended. It appears that the telephone dial-up system may be adequate for a small number of isolated CMSs in urban areas or for small CMS systems in rural areas. However, most urban systems should employ other telecommunications techniques to minimize the time required to change messages on the signs.

Surveillance

Surveillance is required for incident detection and an assessment of the operating conditions in the corridor. Detection of incidents, especially during peak periods, posed very little problem in this study. The thoroughness with which SAPD covered the freeway system with ground and air units reduced incident detection time to the lowest time possible without extensive freeway instrumentation. For maximum effectiveness, incidents should be detected rapidly enough to allow the initiation of diversion before the exits to alternate routes are blocked by the queue from the incident.

Accurate identification of the incident location is also critical. Selection of messages is highly dependent on the location of the incident. The more specific the description of the incident in the CMS messages, the more critical the identification of the incident location becomes. For example, ACCIDENT AT DURANGO requires a much more accurate location determination than does ACCIDENT NORTH OF US-90.

A second important function of surveillance is to provide information about conditions in the corridor. In San Antonio, the dispatcher-sign operator had to rely on those officers in the field to describe the conditions on the freeway. The patrol officers were in most cases so busy with investigating the incident and moving traffic that they were not able to provide this information to the operator. Thus, the operator was required to blindly operate the CMS without having the assurance and confidence that the messages displayed were the correct ones for the existing conditions. Eventually, some of the operators decided not to use the signs.

Thus, the following points are recommended. Use of police patrols is a good way to identify the occurrence and location of freeway incidents in small metropolitan areas. It is not adequate to provide detailed information that concerns the traffic conditions on the freeway so that the operator can make appropriate decisions about the messages. Electronic detector surveillance complemented by closed-circuit television are necessary parts of a CMS system in urban areas.

Discussion

Glen C. Carlson

Most, if not all, administrators of freeway traffic-management programs feel that motorist information services are an important system element. A design team that develops a MIDS must make a wide range of decisions on the type of hardware to be used, location of the field installations, surveillance techniques, telecommunications equipment, control equipment, and operational policies and strategies. Primary considerations in making these decisions include the following:

1. System effectiveness--Effectiveness in terms of reducing the number of secondary collisions that follow incidents, encouraging motorists to use alternate routes when appropriate, and reducing driver tension and anxiety. Accomplishing these objectives would obviously reduce fuel consumption and air pollutant emissions.
2. Reliability--The ability of the hardware to function properly without placing an inordinate burden on staff and financial resources.
3. Operations--Policies and strategies must be developed to permit efficient system operation without creating excessive demand on the operator's time.
4. Cost--Cost items include capital, operating, and maintenance costs relative to benefits derived.

Dudek, Stockton, and Hatcher did not provide information on system costs or maintenance experience for the San Antonio system, presumably because the CMS hardware consisted of trailer-mounted units available from previous studies. However, the study results relative to system effectiveness and operations experience were very interesting and should prove to be useful to other agencies. The primary evaluation item was the diversion of freeway traffic to an alternate freeway route, and a secondary evaluation item was the amount of MIDS use by the operating agency. They also presented recommendations on CMS hardware, system operations techniques, and evaluation efforts for future systems.

DIVERSION STUDIES

To evaluate the effectiveness of the MIDS in diverting traffic to the alternate freeway route, data from seven case-study incidents were studied. Analysis of the results indicated that use of the CMSs during incidents did not result in greater use of the diversion route than the amount of natural diversion that occurred without the signs. The authors conclude that this does not indicate failure of the MIDS but that the message came too late and some drivers apparently knew better alternate routes. This conclusion seems to be valid because informal discussions with local drivers and feedback from freeway patrol officers indicated that diversion to arterial street alternate routes may have been considerable.

The problems that the researchers had with the diversion studies illustrate the difficulties that can be encountered in evaluating diversion systems. A recommendation is made that agencies evaluating similar systems should monitor all exit ramps that are likely to be used. This is a good recommendation because a systemwide evaluation is desirable; however, since case studies are usually used to evaluate diversion systems, there are several potential problems that may arise, which include the following:

1. Incidents occur at unpredictable intervals and it may be necessary to extend the study over a lengthy time period to obtain an adequate sample.
2. To provide systemwide data collection over an extended time period, it is desirable to have the freeway and ramps heavily instrumented with permanent detectors. This type of instrumentation is often not available.
3. Even if permanent detectors are available, they will be subject to failure, and the exit-ramp detectors will probably have a lower maintenance priority than other detectors more critical to system operation.
4. If portable counting equipment is used it will have to be left in the field for lengthy periods of time and will require a great deal of staff time for collecting data, making adjustments, and recharging batteries.
5. Regardless of the type of detection used, it may be difficult to predict how far upstream the diversions start. For example, motorists learning of an incident via commercial radio stations or citizen band (CB) radio may stay off the freeway altogether.

PERCEIVED EFFECTIVENESS

The second evaluation item described was the effectiveness of the system as perceived by police freeway patrols and dispatchers. This was studied by collecting data on the willingness of the police to use the CMSs by comparing the first and second years of operation. Study results showed that there was a significant reduction in the use of the CMSs during the second year. The authors concluded that the reduced use was not caused by a perceived ineffectiveness of the system but rather was attributable primarily to a loss of radio communication between SAPD administrators and dispatchers.

A review of the data in Figure 7, which uses a slightly different perspective, seems to support the authors' conclusion. If system operators perceived that the CMSs were not effective, it probably would not take them an entire year to reach that perception. Yet the data in Figure 7 show that the CMSs were used fairly consistently over the first 14 months of operation. During the first seven months, for example, they were used during 9.1 percent of the accidents while during the next seven-month period they were used during 7.9 percent of the accidents. Over the final 10 months of the two-year study period, however, the CMSs were used during only 1.4 percent of the accidents. This seems to support the authors' conclusion that factors other than the perceived effectiveness of the system led to the reduced use.

CMS HARDWARE AND OPERATIONS RECOMMENDATIONS

The recommendations regarding the operator's control console, operator considerations, and system operation are well-grounded based on the study findings in San Antonio. Many of these findings have been affirmed by the experiences of other agencies, several of which are referenced in the paper. There seems to be general agreement that systems may be operated successfully by either police or transportation (highway) agencies and that the key factor is to develop teamwork between agencies. The success or failure of a system can depend on this teamwork because if CMSs are not operated efficiently they will lose credibility and effectiveness.

The recommendations regarding telecommunications are also valid based on the study results and experiences of other agencies. In most cases, the type of telecommunications techniques used will probably be determined by the data-transmission requirements of other traffic-management system elements such as surveillance and ramp control.

Regarding the discussion on surveillance, the authors made a very significant recommendation on the techniques used for incident detection and CMS operation. They reach the conclusion that "electronic detector surveillance complemented by closed-circuit television are necessary parts of a CMS system in urban areas." This type of surveillance is indeed necessary if CMSs are to be operated at maximum efficiency in large urban areas. Exceptions where this sophisticated electronic surveillance may not be needed include agencies that use monitoring via helicopter or a fleet of emergency service vehicles.

SUMMARY

Overall, this paper did an excellent job of describing the San Antonio MIDS evaluation, providing a frank discussion of the problems encountered and the adjustments made to compensate for them. The authors have made recommendations on system design, operations, and evaluation that should prove very useful to other agencies.

A final thought that warrants brief discussion regarding this research effort is the establishment of quantifiable goals for CMS systems. The authors did not approach the evaluation task with a set of quantifiable goals to be used in determining system effectiveness. There is often no valid basis to establish such goals for a CMS system, and this appears to have been the case with the San Antonio project. Setting arbitrary goals can lead to false expectations for a project and can also lead to misinterpretation of the study results if they are not met.

E.R. Case

Despite the fact that Dudek, Stockton, and Hatcher have concluded that the results of the diversion project described in their paper are less than acceptable, many important lessons were learned that will be invaluable to those involved in the planning and design of similar systems in the future. Probably the most important of these is that it is essential to use a systems approach in developing such systems. Incident management certainly does imply a much wider scope than simple single-point diversion, and this should be reflected in both system design and evaluation.

The paper has raised a number of important issues that are of critical interest to those contemplating the implementation of traffic-management systems that depend on the predictability of driver response to traffic-information systems such as CMSs. Although many of these have been addressed since this project was conceived in 1977, there are still a number of areas where more research and development are required. One is a human factors issue that relates to determining what could be called the motorists "marginal propensity to divert" under various conditions. Another relates to the use of traffic simulations to predict system performance. A variety of simulation models are available (13), which are increasingly being used for system design (and even real-time control). Data collection remains a problem, however.

In my view there are some important lessons to be learned from this project with respect to natural diversion. Natural diversion is a driver behavior pattern that has developed over a period of time in response to a variety of incident conditions. It can only really be measured accurately by an extensive survey that uses questionnaires and yet it is essential information for the development of a freeway corridor traffic-management system. Natural diversion patterns may well have to be modified to implement an optimal freeway corridor diversion strategy.

In the present case, the results indicate a relatively high degree of natural diversion that appears to be very responsive to the onset of congestion. It seems that a significant number of CBD-bound drivers were already receiving sufficient and timely traffic information--from whatever source--to enable them to make a decision to divert. This would certainly tend to reduce the effectiveness of the CMS messages, as was observed. No mention was made in the paper of commercial-radio traffic reports, but perhaps they played a role here.

The results obtained clearly support the authors' contention that single-point diversion is a myth in this particular case and indeed is probably generally so except in certain highly contained situations. But this does not necessarily mean that systems performance can only be evaluated by monitoring all possible diversion ramps. If the goal of diversion (or incident management) is to alleviate congestion and reduce accidents, then these could be used directly as system measures of effectiveness, regardless of where the diversion occurs. For example, the maximum length of the mainline queue due to an incident and the time it takes to dissipate are certainly valid measures of the degree of freeway congestion and are not too difficult to obtain. Also, the reduction in secondary accidents is a direct measure of overall system effectiveness.

Only 7 of the original 120 messages were used in the second year to simplify operations. No mention is made of which ones were chosen or the basis on which the choice was made. I am wondering, in view of the authors' extensive background in this area, if there were any human factors considerations involved that related to the perceived effectiveness of the messages?

Many of the problems experienced by the authors would not be experienced today where the trend is to implement CMS systems as an integrated part of a freeway corridor traffic-management system that may employ other strategies in addition to diversion. Such systems include extensive electronic detector surveillance as well as closed-circuit television (CCTV). Many employ automatic CMS message selection based on traffic information supplied by the electronic surveillance system to implement optimal incident-management diversion strategies. Nevertheless, there will still be frequent occasions where CMSs must be controlled manually, and the guidelines provided in the paper will be useful in defining acceptable operator work load levels.

In 1979, the Ontario Ministry of Transportation and Communications installed a CMS on the Queen Elizabeth Way (QEW) west of Toronto (14), with the dual purpose of evaluating its effectiveness in controlling traffic and obtaining experience in the installation, operations, and maintenance of this type of sign. The CMS system is integrated into the QEW Freeway Surveillance and Control System (FSCS) (15) and is manually controlled from the traffic control center about 3.7 miles (6 km) to the east.

Although the CMS is installed just upstream of a major interchange, the performance evaluation was limited to mainline control because the local political situation precluded any attempt to divert freeway traffic onto neighboring arteries (mainly residential). The results are therefore not entirely relevant to the subject of this paper, but they still may be of interest to those contemplating the use of CMSs for traffic control.

The QEW CMS is a magnetic disc matrix type with 2 lines of 22 characters each. It extends across all three lanes and replaces an existing static sign just upstream of a major interchange. Each of the character modules is 18 in (46 cm) high and is comprised of a 5x7 matrix of 2-in (5-cm) diameter fluorescent yellow discs. It is front lighted for visibility at night.

About 35 preprogrammed messages are available, although only about 7 are used routinely on a daily basis. Other messages can be typed in for special situations. The sign is available for use 24-h/day and is controlled through the QEW FSCS during the morning peak and by the Ontario Provincial Police at other times. CCTV is available to monitor the CMS messages and the resulting driver behavior.

The sign was evaluated under a variety of incident conditions. Typical of these is a study of the effectiveness of the CMS based on a lane-blocking incident located some 1.9 miles (3 km) downstream of the sign. A series of messages were used that advised that the lane was blocked and the resulting traffic changes were monitored by the FSCS detector station located 0.62 mile (1 km) downstream of the sign. The volume dropped more than 30 percent in the 10-min period during which the lane-closure message was shown. In other tests, it was observed that up to 50 percent of drivers followed the advisory messages on the sign.

Next year the Ministry plans to install a similar CMS at a major freeway-to-freeway diversion point on the QEW. The lessons learned in this paper will be of great value in the planning, design, and evaluation of this system.

Authors' Closure

We are appreciative of the thorough review and critique by Carlson and Case. Their comments, based on vast hands-on personal experiences, add significantly not only to the paper but also to freeway incident-management technology.

The establishment of goals for a CMS or other type of incident-management system is important. However, operating agencies are handicapped because of the difficulty in (a) predicting effects and (b) measuring effects.

It is difficult for operating agencies to quantify CMS system goals in terms of the percentage of anticipated reductions in accidents (both primary and secondary) and congestion and increases in diversion because there is a lack of available published data that can be used as a basis for estimating potential effects. Published field evaluations of CMS systems are very sparse and a data base sufficient for the agencies to use for their estimates is not available.

Two goals that most likely would be embraced by agencies are to alleviate congestion and reduce secondary accidents. Unfortunately, these are difficult to measure in a real-world setting for CMSs used for accidents. Congestion is often determined by measuring the length and duration of traffic queues that result from the incidents. Although the data would not be difficult to obtain for these to be valid measurements, all incidents must have the same characteristics in terms of location, type, degree, and duration. The wide variety in incident characteristics prevents the operating agencies from relying on congestion measurements as a basis for determining the effects of the CMSs. This is why we decided to use the amount of diversion during the specific study period as discussed in the paper. In addition, the number of known secondary accidents on a section of highway is normally too small to obtain statistically significant results.

The original set of 120 messages was reduced to 7 in the second year to simplify operations. Ideally, drivers should be told where the incident is. In San Antonio, incident location was initially referred to existing major street crossings, which accounted for most of the messages. After the first year, the I-35/I-10E interchange was used for referencing the incidents. Although the accident locations were not specific, we believe that the degree of response to the messages in terms of diversion was not adversely affected. The word ACCIDENT on a CMS has a profound effect on the driver's decision to divert. It is even more profound when MAJOR ACCIDENT is displayed.

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