EVALUATION OF A PROTOTYPE WARNING SYSTEM FOR URBAN FREEWAYS

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This paper evaluates a prototype real-time system that warns approaching motorists of stoppages downstream of cresting vertical curves. Before and after studies were conducted to measure primary and secondary accidents. A questionnaire survey was administered to obtain motorist reactions. The study results revealed that the warning system is cost effective. Both primary and secondary accidents were reduced. The results of the questionnaire study indicated that motorists believed that the system was useful, that the warning sign was readily noticed, and that the message was generally understandable and appropriate to traffic conditions.

•AN EXPERIMENTAL warning system has been in operation on the inbound control section of the Gulf Freeway in Houston since April 3, 1972 (1, 2). The purpose of the system is to assist freeway drivers approaching cresting vertical curves by giving them information on the downstream traffic flow and by alerting them to stoppage waves downstream of the crest.

Three overpasses were selected as the sites for pilot installations to study the effectiveness of the warning system, develop automatic-control algorithms, and further evaluate the design concepts. The system consisted of a static sign with attached flashing beacons (Fig. 1) located upstream of each overpass crest and a flashing beacon mounted on the bridge rail on the top of each crest (Fig. 2). The warning signs were controlled automatically by a digital computer. Double-loop detectors were installed on each lane and located on both sides of the 3 overpasses. The primary function of the detectors downstream of the overpass was to sense stoppage waves to activate the warning sign. The upstream detectors would indicate the time that the sign should be turned off. Installation sites and the freeway sections influenced by the 3 warning signs are shown in Figure 3.

This paper evaluates the prototype warning system.

METHOD OF STUDY

Measures of Effectiveness

The objective of the warning system is to alert approaching drivers of stoppages downstream of the overpass crest so that they can gradually reduce their speeds and avoid rear-end collisions. Therefore, accidents were selected as the primary measure of the system's effectiveness. In addition, a questionnaire was administered to obtain subjective reactions to the system.

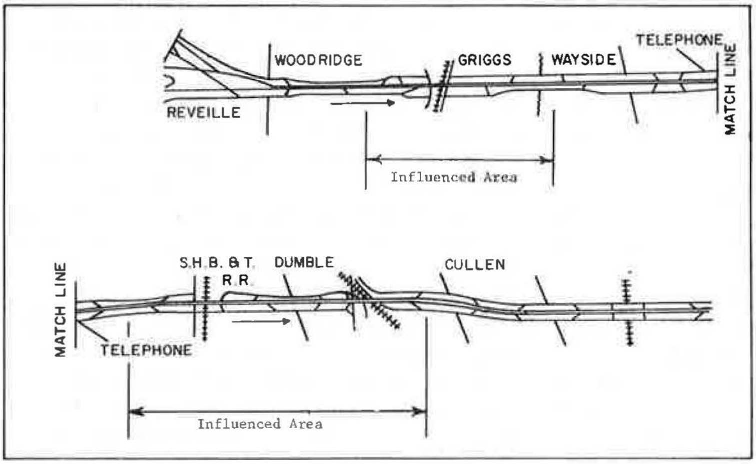
Accidents

The Houston Police Department furnished the Texas Transportation Institute daily logs of all reported accidents on the test section of the Gulf Freeway since August 12, 1971, to evaluate the use of the accident-investigation sites (3). These data provided the

Figure 1. Warning sign with flashers.

Figure 2. Flasher unit at overpass crest.

Figure 3. Freeway area influenced by warning system.



researchers with a data base to evaluate the effect of the warning system on accident experience. The warning system became operational April 3, 1972, and police accident records provided accident experience for approximately 9 months before the system was turned on. These data were compared to data from comparable dates and time periods during the first year of operation. Only accidents occurring during the operation periods (Monday through Friday from 6:30 a.m. to 6:30 p.m.) were included in the study.

Questionnaire

Studies were conducted at the 3 warning-sign sites during peak and off-peak periods. License plate numbers were recorded on hand-held tape recorders when the warning system was activated. After the tapes were transcribed, we obtained the names and addresses of the drivers within 24 hours after each field study by means of a remote terminal in the Texas Highway Department in Houston. The questionnaire sent to the drivers is shown in Figure 4.

ACCIDENTS

The number of inbound accidents before and after the warning system became operational is given in Table 1. The results show a statistically significant reduction at the 5 percent level of inbound freeway accidents. A total of 158 accidents occurred during the 9-month period before the warning system became operational, and 123 accidents occurred during the 9-month period after the system became operational. This represents a reduction of 35 accidents or 22 percent. The greatest reduction was during the morning peak period. Data for the outbound direction also are given in Table 1 and serve as a base to determine whether the changes in the inbound direction merely reflect a pattern consistent with the freeway as a whole. The results reveal that accidents in the outbound direction increased from 140 to 166 or 19 percent during the same period. The upward outbound accident trend places more significance on the inbound accident reduction.

The warning system also aimed to reduce the frequency of secondary accidents. The frequency of secondary accidents is given in Table 2. The results again reveal a statistically significant reduction in secondary collisions at the 5 percent level in the inbound direction, and, again, the secondary accidents in the outbound direction remained relatively constant. Nine secondary accidents occurred inbound before the system became operational, whereas only 1 secondary accident occurred during the same time after the warning system was operational, which is a reduction of 89 percent.

Perhaps of greater significance are the before and after comparisons to total and secondary inbound accidents within and outside the freeway sections influenced by the warning system (Fig. 3) given in Tables 3 and 4. The results show that the entire reduction in both total and secondary inbound accidents took place in the freeway section influenced by the warning system. Total accidents were reduced by 49 percent in the influenced section, whereas secondary collisions were reduced by 100 percent. There were no changes in the accident statistics in the other section of the inbound control section of the Gulf Freeway. The statistics in the outbound direction show only a slight reduction in total accidents in the same section of the freeway where warning signs influenced inbound traffic. Secondary collisions remained constant in these outbound sections.

So the warning system on the Gulf Freeway significantly reduced total and secondary accidents. That accidents in the outbound direction increased during the same time period places more significance on the utility of the warning system.

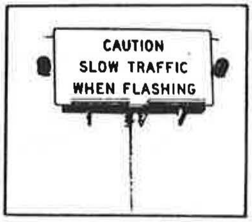
Figure 4. Questionnaire.

1. *Approximately how often do you use the inbound Gulf Freeway each week?*

   1 to 3 times per week____; 3 to 5____; 5 to 10____; over 10____

2. *Have you ever noticed the yellow sign, shown in the photograph, on the Gulf Freeway?*

   Yes____ No____



3. *Was the sign ever working when you saw it?*

   Yes____ No____

4. *About how many times have you passed it when it was working?* ____________

5. *What aspect of the sign called your attention to it?*

   ____

   ____

6. *The sign stated: "Caution Slow Traffic." How far ahead did you think it meant?*

   Over a mile____; a half-mile____; less than half mile____; less than 1 block____

7. *What speed did you think you should slow down to?*

   55____; 45____; 35____; 25____; 15____

8. *How useful was the sign to you in the actual traffic situation? (in avoiding an accident)*

   Very useful____ Moderately useful____ Limited use____ No use____

9. *Can you think of a better message that could have been on the sign?*

   Yes____ No____

   *If yes, what message?*______________________________________

10. *What did you do when you saw the sign in operation?*

    Began braking____; Slowed down gradually____; Continued at same speed, but with caution for slow traffic____; Waited until I could see the traffic ahead____

11. *To what extent was it necessary for you to slow down after you came over the overpass and saw the traffic?*

    Very little____; Moderate reduction in speed was required____; Needed to brake or change lanes____

12. *When you got over the overpass, what was the speed of the traffic ahead?*

    Same speed as before____; Moving slightly slower than before the overpass____; Moving very slowly____; Traffic was stopped in some lanes____

Table 1. Total accidents by time period.

Time Period	Before[a]	After[b]	Net Change	Percentage of Change
Inbound				
6:30 a.m. to 9:00 a.m.	60	28	-32	-53
9:00 a.m. to 4:00 p.m.	68	65	-3	-4
4:00 p.m. to 6:30 p.m.	30	30	0	0
Outbound				
6:30 a.m. to 9:00 a.m.	23	29	+6	+26
9:00 a.m. to 4:00 p.m.	68	85	+17	+25
4:00 p.m. to 6:30 p.m.	49	52	+3	+6

[a]July 12, 1971, to April 2, 1972. [b]July 12, 1972, to April 2, 1973.

Table 2. Secondary accidents by time period.

Time Period	Before[a]	After[b]	Net Change	Percentage of Change
Inbound				
6:30 a.m. to 9:00 a.m.	4	0	-4	-100
9:00 a.m. to 4:00 p.m.	5	0	-5	-100
4:00 p.m. to 6:30 p.m.	0	1	+1	
Outbound				
6:30 a.m. to 9:00 a.m.	1	1	0	0
9:00 a.m. to 4:00 p.m.	5	4	-1	-20
4:00 p.m. to 6:30 p.m.	1	3	+2	+200

[a]July 12, 1971, to April 2, 1972. [b]July 12, 1972, to April 2, 1973.

Table 3. Total accidents by freeway section.

Freeway Section	Before[a]	After[b]	Net Change	Percentage of Change
Inbound				
A[c]	72	37	-35	-49
B[d]	86	86	0	0
Outbound				
A[e]	60	55	-5	-8
B[e]	80	111	+31	+39

[a]July 12, 1971, to April 2, 1972.
[b]July 12, 1972, to April 2, 1973.
[c]Influenced by warning signs.
[d]Not influenced by warning signs.
[e]No warning signs.

Table 4. Secondary accidents by freeway section.

Freeway Section	Before[a]	After[b]	Net Change	Percentage of Change
Inbound				
A[c]	8	0	-8	-100
B[d]	1	1	0	0
Outbound				
A[e]	4	4	0	0
B[e]	3	4	+1	+33

[a]July 12, 1971, to April 2, 1972.
[b]July 12, 1972, to April 2, 1973.
[c]Influenced by warning signs.
[d]Not influenced by warning signs.
[e]No warning signs.

COST-EFFECTIVENESS ANALYSIS

Benefit Analysis

The anticipated benefits of the safety warning system were improved safety and convenience and reduction in delay time. Convenience is difficult to quantify, but it is reflected in a higher level of service resulting from fewer accidents and from the driver's confidence in conditions downstream while he or she travels at a relatively high speed.

Reduction in Accidents

The results previously discussed showed that 35 fewer accidents occurred during a 9-month period after the warning system became operational. If the rate of reduction is assumed to be consistent throughout the year, then the total would be approximately 47 fewer accidents (43 fewer peak-period accidents) during a 12-month period. Whether all 35 incidents during the 9-month period were eliminated by the warning system may be argued. But, because the accidents increased by 20 percent in the outbound section of the Gulf Freeway, it can be assumed that the warning system contributed to the bulk of the accident reduction in the inbound direction.

A convenient method that uses the chi-square test is available to determine the statistical reliability of accident reductions resulting from a safety improvement (4). Based on the chi-square test, the 22 percent reduction in total accidents, the 49 percent reduction in total accidents occurring within the influenced section, and the 100 percent reduction in secondary accidents occurring within the influenced section are all statistically significant at the 5 percent level. In other words, the accident reduction was due to the treatment rather than chance.

Burke (5) in 1970 determined costs of accidents. If we assume a 5 percent per year compounded increase, the cost per vehicle in 1972 would be $308 for property damage accidents and $1,857 for injury accidents.

If we assume that all the accidents analyzed involved only 2 cars and that only property damage was incurred, then the annual savings due to reduction of 47 accidents would be $29,000.

Reduction in Delay

Goolsby (6) found that an average of 340 vehicle hours of delay results from an accident that occurs during the peak period on the Gulf Freeway; very little delay is experienced when accidents occur during the off-peak period unless the incident blocks more than 1 lane for a prolonged period of time. Pittman and Loutzenheiser (3) later estimated that use of the accident-investigation sites can reduce delay by 54 percent. Thus if the involved vehicles are removed from the freeway, estimated delay for an accident during the peak period would be 156 vehicle hours. Pittman also reported that approximately 70 percent of the accidents occurring in the study section of the Gulf Freeway are moved to accident-investigation sites or off-freeway sites for investigation and reporting. If we assume that 70 percent of the accidents that occurred during the study were removed from the freeway for investigation and reporting, then the following would reflect the estimated annual reduction in delay during the peak period due to the safety warning system:

$$43 \text{ accidents} \times 0.70 \text{ removed} \times 156 \text{ vehicle hours} = 4{,}696 \text{ vehicle hours}$$
$$43 \text{ accidents} \times 0.30 \text{ not removed} \times 340 \text{ vehicle hours} = \underline{4{,}386} \text{ vehicle hours}$$
$$\text{Total annual reduction in delay} = 9{,}082 \text{ vehicle hours}$$

If we assume that there are 1.2 persons per vehicle and that $4.50 per vehicle hour represents the value of time (3), then the annual monetary savings due to the reduction in delay would be $40,850.

Cost Analysis

Gulf Freeway System

The following summarizes the initial and annual maintenance costs for the Gulf Freeway warning system:

Item	Cost
Engineering, materials, and labor costs for 3 signs	$16,900
Estimated engineering costs for 26 detectors	2,000
Materials and labor costs for 26 detectors	21,200
Estimated annual maintenance costs	2,000

If we assume an interest rate of 7 percent for a 10-year system life expectancy, then the benefit-cost ratio (B/C) can be computed as follows:

$$B/C = \frac{AB}{(crf \times IC) + AMC}$$

where

- AB = annual benefits,
- crf = uniform series capital recovery factor for $i = 7$ percent, $n = 10$ years,
- IC = initial capital cost, and
- AMC = annual maintenance cost.

Annual benefits of the system due to reduction in delay and accidents were

$$\$29{,}000 + \$40{,}850 = \$69{,}850$$

Thus

$$B/C = \frac{\$69{,}850}{(0.1424 \times \$40{,}100) + \$2{,}000}$$

$$= \frac{\$69{,}850}{\$7{,}710}$$

$$= 9.1$$

New System

Because the warning system was added to the existing control system on the Gulf Freeway, initial cost was reduced because communications and a computer were available. Table 5 gives the cost of the same warning system if new detectors and communications

Table 5. Warning system costs for new installation.

Item	Amount (dollars)
Engineering, materials, and labor costs for 3 signs	16,900
Estimated engineering costs for 48 detectors*	3,000
Estimated materials and labor costs for 48 detectors*	39,100
Estimated costs for 1 controller (minicomputer) and associated equipment	13,400
Estimated costs for communications (telephone lines)	8,700
Estimated annual maintenance costs	3,000

*Estimate is based on installing 48 detectors for the 3 signs on the Gulf Freeway, including 2 sensors on each lane at each detector station. This is a requirement for using the traffic-energy control variable. It is assumed that there are 2 downstream and 1 upstream detector stations. The number of detectors would be reduced by 50 percent if the lane-occupancy-control variable is used for shock-wave detection.

had to be installed and a computer purchased. The benefit-cost ratio for the new system is computed as follows:

$$B/C = \frac{\$69,850}{(0.1424 \times \$81,100) + \$3,000}$$

$$= \frac{\$69,850}{\$14,550}$$

$$= 4.8$$

QUESTIONNAIRE

Fifteen studies were conducted at the 3 study site locations. Seven were conducted at the Griggs overpass, 3 were conducted at the South Houston, Belt and Terminal (HB&T) overpass, and 5 were conducted at the Cullen overpass. Seven were during peak periods, and 8 were during off-peak periods. All off-peak-period studies and 2 peak-period studies were conducted when an accident occurred on the freeway. Weather was clear and dry except for 3 off-peak-period studies when it was damp, drizzling, or overcast. Table 6 gives these data and indicates (a) the number of questionnaires mailed, (b) the number who returned the questionnaire forms, and (c) the number who completed the forms.

A total of 278 forms (28 percent) of the 975 mailed were returned in the 15 studies. One hundred eighteen (43 percent) of the respondents were from the 8 off-peak-period studies, and 155 (57 percent) were from the 7 peak-period studies.

Frequency of Travel on Freeway

Table 7 gives the data on detection factors and frequency of traveling on the Gulf Freeway each week.

Combined Conditions

Table 7 indicates that 106 or approximately 40 percent of all respondents drove on the freeway 5 to 10 times per week, 8 percent traveled on it more often than this, 25 percent drove on it 3 to 5 times per week, and 27 percent drove on it 1 to 3 times per week.

Peak Versus Off-Peak Conditions

During off-peak periods we expected to sample the infrequent freeway user and during peak periods we expected to sample the regular commuter. These expectations were borne out in the reports of frequency of use. Eighty-two peak-period respondents (53 percent) said that they traveled daily (5-10 times a week); only 24 (21 percent) of the off-peak-period respondents traveled daily. Fifty-two (46 percent) of the off-peak-period respondents traveled only 1 to 3 times per week or less, and only 12 percent of the peak-period respondents reported traveling this infrequently.

Detection Factors

Two hundred sixty-five (98 percent) of the 273 respondents indicated that they had noticed the sign and 236 (89 percent) said that they had seen it in operation. Ninety-

Table 6. Summary of respondent data.

Location	Period	Incident	Number of Studies	Mailed	Returned	Completed	Response Percent
Griggs	Peak	Yes	1	35	15	14	43
	Peak	No	4	356	122	118	33
	Off-peak	Yes	2	71	27	27	38
South HB&T	Peak	Yes	1	48	10	10	21
	Off-peak	Yes	2	102	28	28	27
Cullen	Peak	No	1	94	13	13	14
	Off-peak	Yes	4	269	63	63	23

Table 7. Summary of detection factors.

		Frequency of Travel on Gulf Freeway (times per week)					Number Noticing Sign			Number Noticing Sign Operating			Observed Signs Operating (number of times)				
Location (1)	Questionnaires Returned (2)	1 to 3 (3)	3 to 5 (4)	5 to 10 (5)	>10 (6)	Blank (7)	Yes (8)	No (9)	Blank (10)	Yes (11)	No (12)	Blank (13)	Always (14)	>20 (15)	<20 (16)	Never (17)	Blank (18)
Peak Period																	
Griggs	132	15	37	72	8	0	131	0	1	125	6	1	22	35	48	1	26
South HB&T	10	4	3	1	1	1	9	1	0	7	3	0	1	0	6	3	0
Cullen	13	0	4	9	0	0	12	1	0	12	0	1	2	4	5	0	2
Total	155	19	44	82	9	1	152	2	1	144	9	2	25	39	59	4	28
Percentage of total	57	12		53			99			94			20	31	47	2	—
Off-Peak Period																	
Griggs	27	10	8	5	4	0	26	1	0	22	3	2	2	3	12	1	9
South HB&T	28	13	4	6	3	2	26	1	1	25	2	1	1	4	17	1	5
Cullen	63	29	12	13	6	3	61	1	1	45	16	2	3	2	41	14	3
Total	118	52	24	24	13	5	113	3	2	92	21	5	6	9	70	16	17
Percentage of total	43	46		21			97			81			6	9	69	16	—
Peak and Off-Peak Periods Combined																	
Griggs	159	25	45	77	12	0	157	1	1	147	9	3	24	38	60	2	35
South HB&T	38	17	7	7	4	3	35	2	1	32	5	1	2	4	23	4	5
Cullen	76	29	16	22	6	3	73	2	1	57	16	3	5	6	46	14	5
Total	273	71	68	106	22	6	265	5	3	236	30	7	31	48	129	20	45
Percentage of total	—	27	25	40	8	—	98			89					57		

	Aspect Attracting Attention												
Location (1)	Flashing Light (19)	Colored Lights (20)	Lights (21)	Not Flashing (22)	Message (23)	Size (24)	Location (25)	Slow Traffic (26)	Vague (27)	Newness (28)	Colored Paint (29)	Other (30)	Blank (31)
Peak Period													
Griggs	76	15	12	4	6	7	2	2	7	3	0	1	19
South HB&T	5	0	0	0	2	0	0	0	1	0	2	0	1
Cullen	10	4	0	0	3	0	0	0	0	0	0	0	1
Total	91	19	12	4	11	7	2	2	8	3	2	1	21
Percentage of total	—[a]	—[a]	—[a]	—[a]									
Off-Peak Period													
Griggs	14	9	0	0	4	2	1	0	0	0	0	0	6
South HB&T	18	6	1	0	2	1	0	2	1	1	0	0	4
Cullen	27	14	2	1	6	7	3	2	1	0	0	0	3
Total	59	29	3	1	12	10	4	4	2	1	0	0	13
Percentage of total	—[b]	—[b]	—[b]	—[b]									
Peak and Off-Peak Periods Combined													
Griggs	90	24	12	4	10	9	3	2	7	3	0	1	25
South HB&T	23	6	1	0	4	1	0	2	2	1	2	0	5
Cullen	37	18	22	1	9	7	3	2	1	0	0	2	4
Total	150	48	45	5	23	17	6	6	10	4	2	3	34
Percentage of total	—[c]	—[c]	—[c]	—[c]	8	6							

[a]One hundred twenty-six people (81 percent) noted the sign aspects in columns 19 through 22.
[b]Ninety-two people (78 percent) noted the sign aspects in columns 19 through 22.
[c]Two hundred eighteen (80 percent) noted the sign aspects in columns 19 through 22.

four percent of the peak-period respondents had seen it in operation, whereas only 81 percent of the off-peak-period respondents had seen it in operation. Because the sign was operating at the time the drivers passed it, the negative responses could be due either to their not wishing to complete the questionnaire or to their not detecting it.

Responses to the question that asked how often the sign had been seen in operation varied greatly. Some drivers gave numerical estimates, some reported percentages of the time, and still others responded in terms of "always" or "never." Responses were classified into 5 categories as follows:

1. Always or nearly always;
2. Most of the time, 50 percent or more of the time, many times, or 20 or more instances;
3. Some of the time or less than 20 instances;
4. Never; and
5. No response.

One hundred twenty-nine (57 percent) of the respondents stated that they had seen the sign in operation some of the time. However, a peak-period versus off-peak-period comparison showed significant differences. Fifty-one percent of the peak-period and only 15 percent of the off-peak-period respondents said that it was on all or most of the time. Sixty-nine percent of the off-peak-period respondents said that it was on some of the time. Only 47 percent of the peak-period respondents reported seeing it working only occasionally.

Twenty-eight of the peak-period respondents and 17 of the off-peak-period respondents left the question blank. This question was the one most frequently not answered.

Two hundred eighteen respondents (80 percent) said that flashing lights, yellow lights, lights only, or lights not flashing attracted their attention. All of these write-in responses were judged to be indications that the flashing beacons had attracted drivers' attention to the signs. Of the peak-period respondents, 81 percent noted the lights; of the off-peak-period respondents, 78 percent noted them. The next most frequently mentioned aspects were the message, CAUTION (8 percent), and the size of the sign (6 percent). Other comments included references to the visibility or appearance of the sign, its location, slow traffic in the area, newness of the sign, and color of the sign. Twelve percent left the question blank. No appreciable differences were found between peak-period and off-peak-period respondents or among various sign locations.

Interpreting the Message

Table 8 gives the respondents' answers on interpreting the meaning of the displayed message, overall evaluation of the sign's usefulness, actions taken in response to the sign, and relevance of the message to what was later observed about traffic conditions downstream of the overpass.

Distance Meaning

Eighty-nine percent of the respondents (91 percent of the peak-period and 87 percent of the off-peak-period respondents) expected the slowdown to occur from 1 block to 0.5 mile (0.805 km) away, whereas 11 percent expected the congestion to occur 1 mile (1.609 km) or more ahead. Almost half the respondents felt that the message, SLOW TRAFFIC AHEAD, referred to a distance of less than 0.5 mile (0.805 km) but more than 1 block away. Very little difference between the peak-period and non-peak-period respondents was reported.

Table 8. Summary of interpretation, evaluation, and response factors.

Location	Questionnaires Returned	Distance Meaning: 1 Mile	0.5 Mile	<0.5 Mile	<Block	Blank	Speed Meaning: 55 mph	45 mph	35 mph	25 mph	15 mph	Blank	Amount of Usefulness: Great	Fair	Limited	None	Blank
Peak Period																	
Griggs	132	11	24	58	32	7	0	14	40	47	22	13	41	32	31	25	3
South HB&T	10	1	1	5	1	2	0	2	3	0	0	5	3	5	0	2	0
Cullen	13	1	3	7	1	1	0	0	3	4	4	2	5	4	2	1	1
Total	155	13	28	70	34	10	0	16	46	51	26	20	49	41	33	28	4
Percentage of total	57	9	19	48	24	–	0	11	33	37	19	–	32	27	22	19	–
Off-Peak Period																	
Griggs	27	3	3	8	7	6	0	3	6	7	5	6	13	6	1	2	5
South HB&T	28	3	2	19	1	3	0	3	11	10	2	3	9	14	1	1	3
Cullen	63	8	14	23	14	4	0	12	26	16	4	5	24	19	8	7	5
Total	118	14	19	50	22	13	0	18	43	33	11	14	46	39	10	10	13
Percentage of total	43	13	18	48	21	–	0	17	41	32	10	–	44	38	9	9	–
Peak and Off-Peak Periods Combined																	
Griggs	159	14	27	66	39	13	0	17	46	54	27	19	54	38	32	27	8
South HB&T	38	4	3	24	2	5	0	5	14	10	2	8	12	19	1	3	3
Cullen	76	9	17	30	15	5	0	12	29	20	8	7	29	23	10	8	6
Total	273	27	47	120	56	23	0	34	89	84	37	34	95	80	43	38	17
Percentage of total	–	11	19	48	22	–	0	14	36	35	15	–	37	31	17	15	–

Location	Other Message Ideas	First Action: Braked	Slowed	Continued With Caution	Waited	Blank	Secondary Action: Little	Reduced Speed	Braked	Blank	Credibility: Same Speed	Slightly Slower	Very Slow	Stopped	Blank
Peak Period															
Griggs	18	6	66	48	5	7	35	70	19	8	19	54	38	27	5
South HB&T	3	0	4	3	0	3	1	7	0	2	1	5	2	0	2
Cullen	2	0	7	3	2	1	3	8	2	0	3	5	6	6	1
Total	23	6	77	54	7	11	39	85	21	10	23	64	46	33	8
Percentage of total	–	4	53	38	5	–	27	59	14	–	14	39	27	20	–
Off-Peak Period															
Griggs	4	3	16	4	1	7	0	16	5	7	1	12	3	5	7
South HB&T	4	4	18	2	1	3	4	16	3	4	1	10	7	7	4
Cullen	13	7	29	14	2	11	10	30	14	10	5	24	15	12	8
Total	21	14	63	20	4	21	14	62	22	21	7	46	25	24	19
Percentage of total	18	14	62	20	4	–	14	63	23	–	6	45	25	24	–
Peak and Off-Peak Periods Combined															
Griggs	22	9	82	52	6	14	35	86	24	15	20	66	41	32	12
South HB&T	7	4	22	5	1	6	5	23	3	6	2	15	9	7	6
Cullen	15	7	36	17	4	12	13	38	16	10	8	29	21	18	9
Total	44	20	140	74	11	32	53	147	43	31	30	110	71	57	27
Percentage of total	16	8	57	30	5	–	22	61	18	–	11	41	27	21	–

Note: 1 mile = 1.609 km.

Speed Meaning

The message on the sign implied that traffic should slow down to some safe speed. Slightly over a third of the respondents felt that this speed was 35 mph (56.3 km/h), and another third felt that it was 25 mph (40.2 km/h). Those driving during the peak period felt that the sign meant a lower speed than did those driving during the off-peak period. Fifty-six percent of the peak-period group selected either 25 or 15 mph (40.2 or 24.1 km/h) compared to 42 percent of the off-peak-period group. Also about 6 percent more of the off-peak-period respondents felt that the message implied that 45 mph (72.4 km/h) was the safe speed. We anticipated this finding because of the higher traveling speeds during off-peak conditions.

No one selected 55 mph (88.5 km/h), which was the speed limit itself; selecting it would have implied that the driver was traveling faster than the legal limit.

Usefulness

Sixty-eight percent of the respondents stated that the sign was either very or moderately useful to them. However, there were significant differences of opinion between peak-period and off-peak-period drivers on its usefulness. Eighty-two percent of the off-peak-period drivers who responded stated it was useful, and only 59 percent of the peak-period drivers felt that it was useful. The higher percentage of negative responses in the peak-period group was borne out by write-in comments on the forms that the message was not informative when prevailing traffic conditions were already stop-and-go.

Responses to the Message

Respondents were asked 2 questions. The first related to their immediate reaction on seeing the sign, and the second related to their need for additional reduction in speed after they passed the crest and could see the actual state of traffic.

Immediate Reaction

Fifty-seven percent of the respondents reported that they slowed down gradually when they saw the sign; 30 percent stated that they would continue at the same speed with caution. Only 8 percent said that they would brake, and 5 percent said that they would brake, and 5 percent said that they would wait to see the traffic before doing anything.

A comparison between peak-period and off-peak-period respondents revealed that 62 percent of the off-peak-period respondents said that they slowed down gradually; only 53 percent of the peak-period respondents selected this response. This difference might be interpreted in terms of vehicle speeds and the opportunity to slow down further.

Thirty-eight percent of peak-period respondents said that they would continue with caution; only 20 percent of the off-peak-period respondents selected this response. Again, the off-peak-period drivers had greater opportunity to slow down so fewer drivers selected this response. Peak-period drivers were somewhat more compelled to drive at the prevailing traffic speed; hence more drivers continued cautiously at the same speed.

Secondary Action

Sixty-one percent of the respondents indicated that they needed to reduce their speed moderately after they came over the overpass and saw the traffic. Peak-period and off-peak-period drivers responded to the same degree. Ideally this would not have been necessary. The typical reaction was not only to slow down at the sign but also to wait for some visual feedback from the traffic ahead before adjusting the speed to the prevailing traffic flow. This response would be satisfactory except when the stoppage wave was immediately downstream of the crest—a possibility that only 22 percent of the drivers anticipated. Twenty-two percent of the respondents indicated that they had to do very little in adjusting their speed after passing the crest. Twice as many peak-period as off-peak-period respondents indicated that they did little adjusting. Again this may be due to the comparative lack of opportunity to reduce speed.

Eighteen percent of the respondents admitted that they had needed to brake or change lanes (an admission that the sign was truthful) but that they had not responded appropriately to the message. However, this does not mean that they would respond inappropriately in future encounters. As we expected, more off-peak-period drivers needed to brake than did peak-period drivers.

Message Credibility

The last question measured the respondents' interpretation of the validity of the system and the credibility of the message, SLOW TRAFFIC. Respondents were asked to select the actual state of traffic that they had encountered. A statement that traffic downstream was traveling at the same speed as it was upstream would be tantamount to stating that the system was not working. Only 11 percent of all respondents selected this response (14 percent of the peak-period and 6 percent of the off-peak-period respondents). This suggests that off-peak-period drivers, who generally were not exposed to the sign under stop-and-go conditions, found the message more credible.

Forty-one percent of all respondents said that the traffic was slightly slower; 27 percent reported that it was very slow; and 21 percent reported stoppages. Peak-period and off-peak-period percentages were similar.

FINDINGS AND RECOMMENDATIONS

The results of the study suggest that the warning system on the inbound Gulf Freeway is a cost-effective system for alerting approaching motorists to stoppages on the freeway. The warning system significantly reduced total and secondary accidents on the freeway. The following specific findings can be drawn from the results of this research:

1. The warning system on the Gulf Freeway resulted in an estimated annual reduction of approximately 47 accidents and 9,082 vehicle hours of delay. The benefit-cost ratio was estimated to be 9.1.
2. Because the warning system was integrated with the existing control system on the Gulf Freeway, considerable initial cost was avoided. (An analysis of a new system that assumed that there was no available hardware resulted in a benefit-cost ratio of 4.8.)
3. Studies of accidents for 9-month periods before and after the warning system began operation revealed that accidents were reduced from 72 to 37 or 49 percent in the sections of the inbound Gulf Freeway influenced by the warning system, and accidents in comparable outbound sections were reduced from 60 to only 55 or 5 percent. The greatest inbound accident reduction occurred during the morning peak period. There was a 100 percent reduction in secondary accidents (8 before, 0 after) in the inbound freeway section influenced by the warning system. Essentially no change in secondary accidents occurred in the other inbound or outbound freeway sections.
4. The results of the questionnaire study indicated that the motorists observing the sign in operation believed that the sign was useful and readily noticed and that the message was generally understandable. The respondents reacted to it appropriately and confirmed that the message displayed was verified later by traffic conditions. The sign was especially effective and accepted during the off-peak period when motorists were traveling at higher speeds and approached an incident not visible to them.
5. The greatest skepticism regarding the usefulness of the sign came from the

peak-period respondents. Fifty-one percent reported seeing the sign in operation all or most of the time compared to 15 percent of the off-peak-period respondents. Although both groups reported that the sign was useful, 9 percent more off-peak-period than peak-period drivers said that they would slow down gradually; 18 percent more peak-period than off-peak-period drivers said that they would continue with caution when they saw the sign, presumably because they were not able to slow down very much. Twice as many peak-period as off-peak-period drivers said that they needed to do very little when they saw the traffic; again this suggests that there was not need for action because of the prevailing traffic speed. Peak-period drivers also criticized the fact that the sign was on most of the time and presented information that was obvious to stop-and-go drivers.

There was a contradiction between the accident study results and questionnaire responses. Drivers, particularly those at the Griggs location, complained that the sign was activated most of the time during the peak periods. The statistics, however, showed a large reduction in total and secondary accidents during the peak periods. These results suggest that the warning system should be operated during the peak period but that the sign should be turned off as quickly as possible when the shock wave passes over the crest. This can be accomplished by placing the upstream sensors as close as possible to the structure.

The results verify that the flashing beacons were effective and provided excellent target value. And, although it may be desirable to state an indicated safe speed and the distance ahead to which the sign applies, a sufficiently large percentage of drivers interpreted the distance to be 0.5 mile (0.805 km) or less. They also felt that the sign implied a safe speed of 15 to 35 mph (24.1 to 56.3 km/h) except when the traffic was actually stopped immediately over the crest. The sign would be useful within the constraints of a fixed message.

ACKNOWLEDGMENTS

We wish to acknowledge the assistance of Richard Fullerton of the Texas Transportation Institute who coordinated the questionnaire studies.

This paper discusses 1 phase of a research project, Development of Urban Traffic Management and Control Systems, that is being conducted by the Texas Transportation Institute and the Texas Highway Department in cooperation with the Federal Highway Administration. The contents of this paper reflect the views of the authors who are responsible for the facts and the accuracy of the data presented. The contents do not reflect the official views or policies of the Federal Highway Administration.

REFERENCES

1. C. L. Dudek and R. G. Biggs. Design of a Safety Warning System Prototype for the Gulf Freeway. Texas Transportation Institute, Texas A&M Univ., Research Rept. 165-4, May 1972.
2. C. L. Dudek and C. J. Messer. Detecting Stoppage Waves for Freeway Control. Highway Research Record 469, 1973, pp. 1-15.
3. M. A. Pittman and R. C. Loutzenheiser. A Study of Accident Investigation Sites on the Gulf Freeway. Texas Transportation Institute, Texas A&M Univ., Research Rept. 165-1, Aug. 1972.
4. R. M. Michaels. Two Simple Techniques for Determining the Significance of Accident-Reducing Measures. Traffic Engineering, Vol. 36, Sept. 1966.
5. D. Burke. Highway Accident Costs and Rates in Texas. Texas Transportation Institute, Texas A&M Univ., Research Rept. 144-1F, 1970.
6. M. E. Goolsby. Accident Reporting and Clearance Procedures on the Gulf Freeway. Texas Transportation Institute, Texas A&M Univ., Research Rept. 139-1, Sept. 1969.