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16. Abstract

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The study results revealed that the warning system is cost-effective. Both primary and secondary accidents were reduced. The system did not create any adverse traffic operational conditions. The results of the questionnaire study indicate the motorists believed the system to be useful, the warning sign was readily noticed, and the message was generally understood and appropriate to traffic conditions.

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EVALUATION OF A PROTOTYPE SAFETY WARNING SYSTEM ON THE GULF FREEWAY

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Development of Urban Traffic Management
and Control Systems

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ABSTRACT

This study is concerned with the evaluation of a prototype real-time system that warns approaching motorists of stoppages downstream of crest type vertical curves. Before and after studies were conducted to measure speed changes and 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 system did not create any adverse traffic operational conditions. The results of the questionnaire study indicate the motorists believed the system to be useful, the warning sign was readily noticed, and the message was generally understood and appropriate to traffic conditions.

SUMMARY

An experimental warning system has been in operation on the inbound control section of the Gulf Freeway in Houston since April 3, 1972. The purpose of the system is to assist the freeway driver approaching crest type vertical curves in formulating his expectations of the actual downstream traffic flow by alerting him of stoppage waves downstream of the crest. The warning system consists of two alternately flashing beacons and a static sign displaying the message, "CAUTION - SLOW TRAFFIC WHEN FLASHING". This study is concerned with the evaluation of the prototype warning system.

The primary measure of effectiveness selected was accidents. In addition, a questionnaire was administered to obtain motorist reactions to the system.

The results of the study suggest that the warning system on the inbound Gulf Freeway is a cost-effective system for alerting approaching motorists of stoppages on the freeway. The warning system significantly reduced the total and secondary accidents on the freeway. The following specific findings are 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. Since the warning system was integrated with the existing control system on the Gulf Freeway, there were considerable savings in the initial cost. An analysis of a new system, assuming no hardware were presently available, resulted in a benefit/cost ratio of 4.8.

3. Studies of accidents for nine-month periods before and after the warning system began operation revealed that the accidents reduced from 72 to 37 or 49 percent in the sections of the inbound Gulf Freeway influenced by the warning system, while accidents in comparable sections outbound reduced from 60 to 55 or only 5 percent. The greatest accident reduction inbound occurred during the a.m. 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, while essentially no change in secondary accidents occurred in the other inbound or outbound freeway sections.
4. The results of the questionnaire study indicate that the motorists observing the sign in operation believed the sign to be useful, to be readily noticed, and the message to be generally understood. The respondents reacted to it appropriately and confirmed that the message displayed was verified later by traffic observed. The sign was especially effective and accepted during off-peak conditions 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 traffic respondents. They reported seeing the sign in operation all or most of the time on 51 percent of the occasions as compared with 15 percent of the off-peak users. While both groups reported the sign useful, 9 percent more of the off-peak drivers said they would slow down gradually, while 18 percent more peak drivers said they would continue with caution upon seeing the sign--presumably due to not being able to slow down much. Twice as many peak drivers said they needed to do very little upon seeing the traffic, again suggesting no need for

action due to the prevailing traffic speed. Peak drivers also wrote in criticisms of the sign being on most of the time and presenting obvious information to stop-and-go drivers.

There was a dichotomy of results between the accident studies and questionnaire survey. Motorists complained that the sign was activated most of the time during the peak periods which was particularly true at the Griggs location, while the statistics show a large reduction of primary and secondary accidents during the peak periods. These results suggest that the warning system should be operated during the peak periods but measures should be taken to turn the sign off as quickly as possible when the shock wave passes over the overpass crest. This operational change would avert the display of obvious information and increase motorist acceptance of the message at other times. This can be accomplished by placing the upstream sensors as close to the structure as possible.

The results verify that the flashing beacons are effective and provide excellent target value. Also, although it may be desirable to state the distance ahead of the sign's applicability and the indicated safe speed, a sufficiently large percentage of drivers interpreted the distance to be a block to a half-mile with an implied speed of 15 to 35 mph which are safe assumptions except when the traffic was actually stopped immediately over the crest. The sign is useful within the constraints of a fixed message and has demonstrated its value in reducing accidents on the Gulf Freeway.

Implementation

The warning system has been shown to be cost-effective and can be implemented on other freeways with traffic volumes comparable to the Gulf Freeway. Although the warning system evaluated on the Gulf Freeway was installed at overpass structures, the system could be implemented at other geometric situations where traffic stoppages create hazards to approaching motorists.

Recommendations for Further Research

1. Research should be directed at developing incident detection algorithms and systems for low volume conditions so that the warning system can be made operational 24 hours per day.
2. Studies should be conducted to test the effectiveness of a warning system with the sign removed using only the flashing beacons.

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System Description

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 the freeway driver approaching crest type vertical curves in formulating his expectations of the actual downstream traffic flow by alerting him of stoppage waves downstream of the crest.

Three overpasses were selected as the sites for pilot installations to study the effectiveness of the warning system, to develop automatic control algorithms, and to further evaluate the design concepts. The system consists of a static sign with attached flashing beacons (Figure 1) located upstream of each overpass crest, and a flashing beacon mounted on the bridge rail on the top of each crest (Figure 2). The warning signs are controlled automatically by a digital computer. Double loop detectors are installed on each lane and located on both sides of the three overpasses. The primary function of the detectors downstream of the overpass is to sense stoppage waves in order 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 three warning signs are shown in Figure 3.

Objective

This study is concerned with the evaluation of the prototype warning system.

Figure 1 - Warning Sign with Flashers

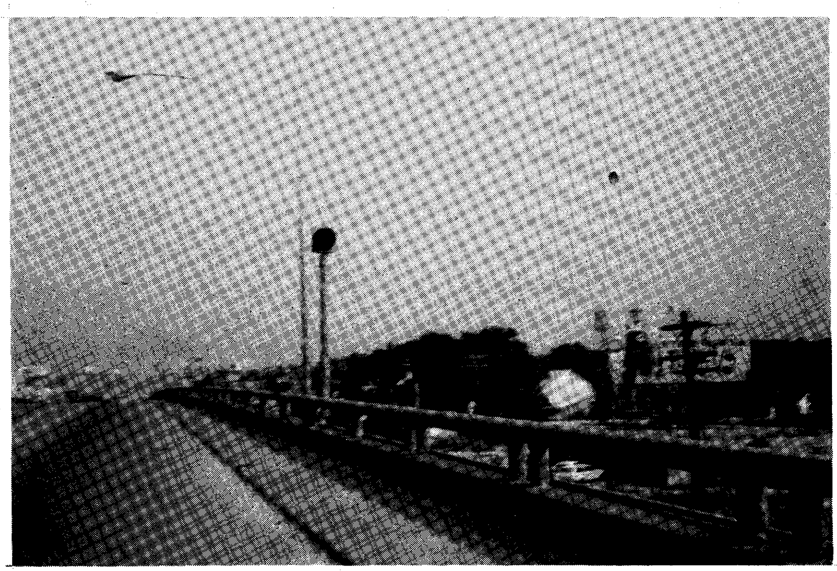

Figure 2 - Flasher Unit at Crest of Overpass

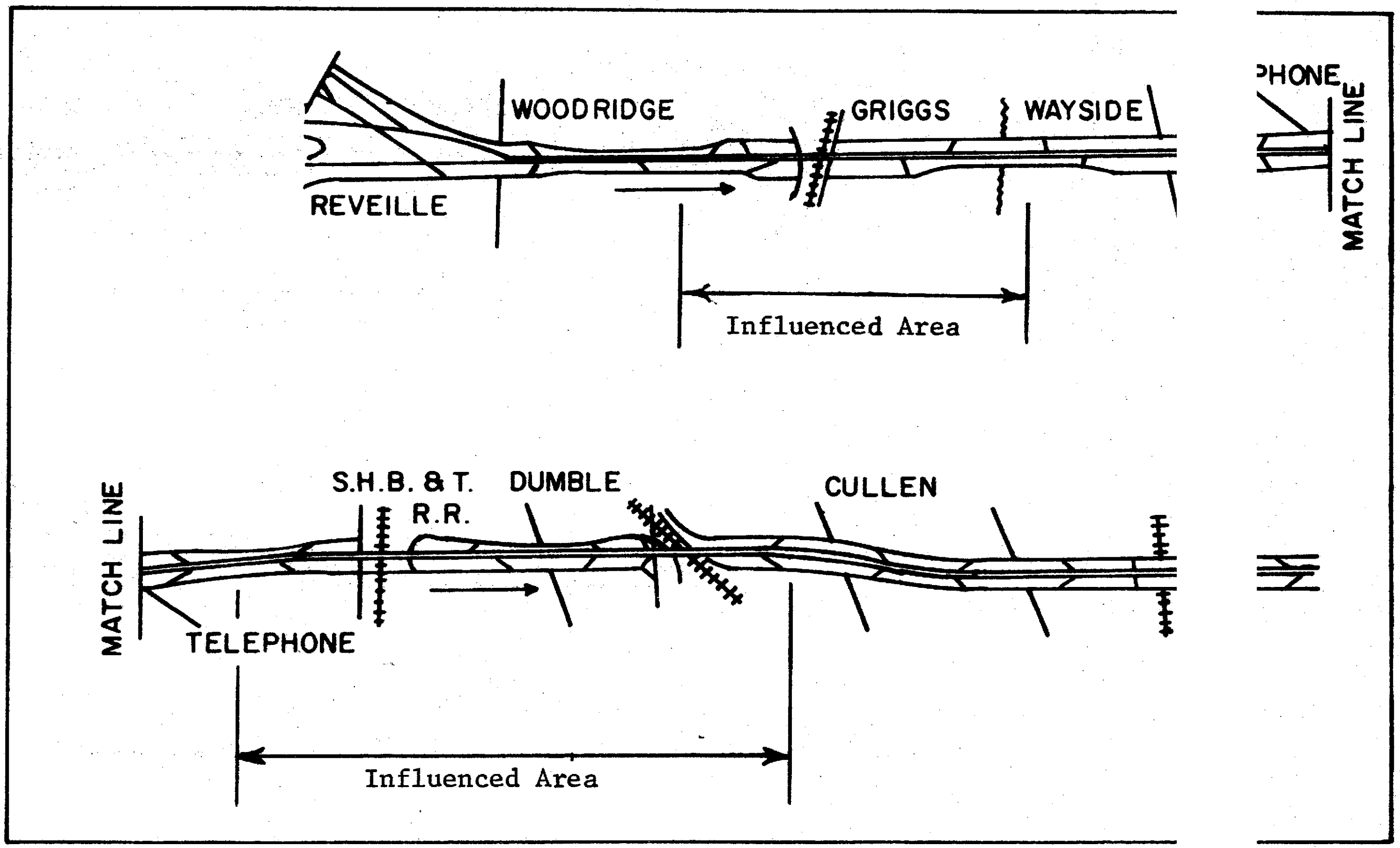

Figure 3 - Freeway Area Influenced by Warning System

METHOD OF STUDY

Measures of Effectiveness

The objective of the warning system is to alert approaching motorists of stoppages downstream of the overpass crest so that they might gradually reduce their speeds and thus avoid rear-end collisions.

Therefore, the primary measure of effectiveness selected was accidents. In addition, a questionnaire was administered to obtain subjective reactions to the system.

Accidents

The Houston Police Department has furnished the Texas Transportation Institute daily logs of all reported accidents on the test section of the Gulf Freeway since August 12, 1971, as part of the program to evaluate the utilization of the accident investigation sites (3). These data were also used by the researchers as a data base to evaluate the effect of the warning system on accident experience. Since the warning system became operational April 3, 1972, and since the above police records were the only available accident data, only nine months of accident experience were available prior to the turn-on date of the system. These data were then compared with accident data from comparable dates and time periods during the first year of operation. Accidents occurring only during the operation periods (Monday through Friday, 6:30 a.m. - 6:30 p.m.) were included in the study.

Questionnaire

Studies were conducted at the three warning sign sites during peak and off-peak periods. License plate numbers were recorded on hand-held magnetic tape recorders during times when the warning system was activated. After the tapes were transcribed, names and addresses of the motorists were obtained within 24 hours after each field study via a remote terminal located at District 12 Headquarters of the Texas Highway Department in Houston which was on-line to the Department of Public Safety computer data bank. The questionnaire is shown in Appendix A.

TRAFFIC VOLUMES

Table 1 illustrates the ADT for the before and after analysis periods. The ADT in the inbound direction increased from 64,600 to 69,200 or 7 percent while the ADT in the outbound direction decreased 2 percent from 63,100 to 61,700.

ACCIDENTS

The number of inbound accidents before and after the warning system became operational is shown in Table 2. The results show a statistically significant reduction at the 5 percent level of inbound freeway accidents. A total of 158 accidents occurred during the nine-month period before the warning system became operational, whereas 123 accidents occurred during a comparable period after--a reduction of 35 accidents, or 22 percent. The greatest reduction was during the morning peak period--thirty-two (53 percent) fewer accidents occurred after the warning system became operational.

Data for the outbound direction are also included in Table 2 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

Table 1

Average Daily Traffic

	Before	After	Total Change	Percent Change
Inbound	64,600	69,200	+4,600	+7
Outbound	63,100	61,700	-1,400	-2

Table 2

Total Accidents

Direction	Time Period	Before[a]	After[b]	Net Change	Percent Change
Inbound	6:30 - 9:00 a.m.	60	28	-32	-53
	9:00 - 4:30 p.m.	68	65	- 3	- 4
	4:00 - 6:30 p.m.	30	30	0	0
		158	123	-35	-22
Outbound	6:30 - 9:00 a.m.	23	29	+ 6	+26
	9:00 - 4:00 p.m.	68	85	+17	+25
	4:00 - 6:30 p.m.	49	52	+ 3	+ 6
		140	166	+26	+19

[a]July 12, 1971 - April 2, 1972

[b]July 12, 1972 - April 2, 1973

results reveal that the accidents in the outbound direction actually increased from 140 to 166 or 19 percent during the same period. The upward accident trend in the outbound direction places more significance on the accident reduction inbound.

One objective of the warning system is to reduce the frequency of secondary accidents. The frequency of accidents identified from the police records as being secondary is shown in Table 3. The results again reveal a statistically significant reduction at the 5 percent level of secondary collisions in the inbound direction while the secondary accidents in the outbound direction remained relatively constant. Nine secondary accidents occurred inbound before the system became operational, whereas one secondary accident occurred during a comparable period after the warning system was operational, a reduction of 89 percent.

Perhaps of greater significance are the "before" and "after" comparisons of total and secondary inbound accidents within and outside the freeway sections influenced by the warning system (see Figure 3) tabulated in Tables 4 and 5. The results show that the entire reduction in both total and secondary inbound accidents took place in the freeway sections influenced by the warning system. Accidents were reduced by 49 percent in the influenced sections, whereas secondary collisions were reduced by 100 percent. There were no changes in the accident statistics in the other sections of the inbound control section of the Gulf Freeway. The statistics in the outbound direction show only a slight reduction in total accidents in comparable sections of the freeway where the warning signs influence the inbound traffic. Secondary collisions remained constant in these outbound sections.

Table 3

Secondary Accidents

Direction	Time Period	Before[a]	After[b]	Net Change	Percent Change
Inbound	6:30 - 9:00 a.m.	4	0	-4	-100
	9:00 - 4:00 p.m.	5	0	-5	-100
	4:00 - 6:30 p.m.	0	1	+1	*
		9	1	-8	- 89
Outbound	6:30 - 9:00 a.m.	1	1	0	0
	9:00 - 4:00 p.m.	5	4	-1	- 20
	4:00 - 6:30 p.m.	1	3	+2	+200
		7	8	+1	+ 14

[a]July 12, 1971 - April 2, 1972

[b]July 12, 1972 - April 2, 1973

Table 4

Comparison of Accidents by Freeway Sections - Total Accidents

Direction	Freeway Section	Before[a]	After[b]	Net Change	Percent Change
Inbound	Section A - Influenced by Warning Signs	72	37	-35	-49
	Section B - Not Influenced by Warning Signs	86	86	0	0
		158	123	-35	-22
Outbound	Section A[c]	60	55	- 5	- 8
	Section B[c]	80	111	+31	+39
		140	160	+26	+19

[a]July 12, 1971 - April 2, 1972

[b]July 12, 1972 - April 2, 1973

[c]Comparable freeway sections to inbound direction; however, warning signs are in the inbound direction only.

Table 5

Comparison of Accidents by Freeway Section - Secondary Accidents

Direction	Freeway Section	Before[a]	After[b]	Net Change	Percent Change
Inbound	Section A - Influenced by Warning Signs	8	0	-8	-100
	Section B - Not Influenced by Warning Signs	1	1	0	0
		9	1	-8	- 89
Outbound	Section A[c]	4	4	0	0
	Section B[c]	3	4	+1	+ 33
		7	8	+1	+14

[a]July 12, 1971 - April 2, 1972

[b]July 12, 1972 - April 2, 1973

[c]Comparable freeway sections to inbound direction; however, warning signs are in the inbound direction only.

In summary, the warning system on the Gulf Freeway significantly reduced the total and secondary accidents. The fact that accidents in the outbound direction increased during the same time period places more significance on the utility of the warning system.

COST-EFFECTIVENESS ANALYSIS

Benefit Analysis

The anticipated benefits of the safety warning system were improvement in safety and convenience, and reduction in delay time. Convenience is difficult to quantify but is reflected in a higher level of service resulting from fewer accidents and from the assurance of conditions downstream while the motorist is traveling at a relatively high speed.

Reduction in Accidents - The results previously discussed showed that 35 fewer accidents occurred during a nine-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 twelve-month period. It may be argued whether all 35 incidents during the nine-month period were eliminated by the warning system. However, since the accidents actually 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 using the Chi-Square (χ^2) 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 sections, and the 100 percent reduction of secondary accidents occurring within the influenced sections are all statistically significant at the 5 percent level. In other words, the accident reduction was due to the treatment (safety warning system) rather than due to chance.

Burke (5) in 1970 determined costs of accidents. Assuming a 5 percent per year compounded increase, the cost per vehicle involved for the following types of accidents in 1972 would be:

1. Property Damage - $308
2. Injury - $1,857

Assuming that all the accidents analyzed involved only two cars and that only property damage was incurred, the annual savings due to reduction of 47 accidents is computed to 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 one lane for a prolonged period of time. Pittman (3) later estimated that the use of the accident investigation sites can reduce the delay by 54 percent. Thus, if the involved vehicles are removed from the freeway, the estimated delay for an accident during the peak period would be 156 vehicle-hours. Pittman also reported that approximately 70 percent of accidents occurring in the study section of the Gulf Freeway are moved to the accident investigation sites or off-freeway sites for investigation and reporting. If it is assumed that 70 percent of the accidents during the study reported herein were removed from the freeway for investigation and reporting, then the following reflects the estimated annual reduction in delay during the peak period due to the safety warning system:

a. 43 accidents x .70 removed x 156 vehicle-hours =		4,696 vehicle-hours
b. 43 accidents x .30 not removed x 340 vehicle-hours =		4,386 vehicle-hours
Total Annual Reduction in Delay	=	9,082 vehicle-hours

Assuming 1.2 persons per vehicle and $4.50 per vehicle-hour for the value of time (3), the annual monetary savings due to the reduction in delay is computed to be $40,850.

Cost Analysis

Gulf Freeway System - Table 6 summarizes the initial and annual maintenance costs for the Gulf Freeway warning system. The cost for adding the warning system to the existing surveillance, control, and communications capabilities was $40,100. Annual maintenance costs are estimated to be $2,000.

Assuming an interest rate of 7 percent for a life expectancy of 10 years for the system, the benefit/cost ratio (B/C) can be computed as follows:

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

where

AB = Annual benefits

crf = Uniform series capital recovery factor for i=7%, n=10 years

Table 6

Warning System Costs - Gulf Freeway Installation

3 Signs	
• Engineering, Materials, and Labor	$16,900
26 Detectors	
• Engineering (est.)	2,000
• Materials and Labor	21,200
TOTAL	$40,100
Annual Maintenance (est.)	$ 2,000

IC = Initial capital cost

AMC = Annual maintenance cost

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

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

Thus,

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

$$B/C = \frac{\$69,850}{\$7,710}$$

$$B/C = 9.1$$

New System - Since the warning system was added to the existing control system on the Gulf Freeway, the initial cost was naturally reduced because communications and a computer were available. Table 7 summarizes the cost of the same warning system if new detectors and communications had to be installed, and a computer purchased.

The cost estimate is based on the most economical of the three alternative hardware configurations analyzed in Appendix B. The total cost of a new system consisting of three sign installations is estimated to be \$81,100. Assuming an annual maintenance cost of \$3,000, the benefit/cost ratio for the system is computed to be:

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

$$B/C = \frac{\$69,850}{\$14,550}$$

$$B/C = 4.8$$

Table 7

Warning System Costs* - New Installation

3 Signs	
• Engineering, Materials, and Labor	$16,900
48 Detectors**	
• Engineering (est.)	3,000
• Materials and Labor (est.)	39,100
1 Controller (Minicomputer) and Associated Equipment (est)	13,400
Communications (Telephone Lines) (est.)	8,700
TOTAL	$81,100
Annual Maintenance (est.)	$ 3,000

*The costs assume that the system will be installed at a location where detectors, communications, and controllers are not presently available.

**Estimate is based on installing 48 detectors for the three signs on the Gulf Freeway. This includes two sensors on each lane at each detector station, a requirement for using the traffic energy control variable. Also, two downstream and one upstream detector stations are assumed. The number of detectors will reduce by 50 percent if lane occupancy control variable is used for shock wave detection.

QUESTIONNAIRE

Fifteen studies were conducted at the three study site locations--seven were conducted at Griggs, three at South HB&T, and five at Cullen. Seven were during peak periods and eight during off-peak periods. All off-peak studies and two peak period studies were conducted when an accident occurred on the freeway. Weather was clear and dry except for three off-peak studies when it was damp, drizzling or overcast.

Table 8 summarizes the above data and also indicates (a) the number of questionnaires mailed to those drivers whose license plates were sampled; (b) the number who returned the questionnaire forms, and (c) the number who completed the forms (excluding blanks only). Also, reported is the respondent rates (mailed/returned).

A total of 278 forms were returned in the 15 studies. One-hundred-eighteen (43 percent) of the respondents were from the eight off-peak studies and 155 (57 percent) from the seven peak studies.

Frequency of Travel on Freeway

Table 9 summarizes the data on detection factors and frequency of traveling the Gulf Freeway each week. In addition, the data are analyzed in terms of three study site locations.

Combined Conditions - Table 9 shows that 106 or approximately 40 percent of all respondents drove the freeway 5 to 10 times a week; 8 percent traveled it more often that this; 25 percent drove it 3 to 5 times per week and 27 percent, 1 to 3 times per week.

Peak Vs. Off-Peak Conditions - The off-peak conditions were expected to sample the infrequent freeway user and peak conditions, the regular

Table 8

Summary of Study Conditions and Respondent Data

Recording Location	Period	Incident	Number of Studies	Mailed	Returned	C ted	Respondent Percentage
Griggs	Peak	Yes	1	35	15		43
	Peak	No	4	356	122		33
	Off-Peak	Yes	2	71	27		38
South HB&T	Peak	Yes	1	48	10		21
	Off-Peak	Yes	2	102	28		27
Cullen	Peak	No	1	94	13		14
	Off-Peak	Yes	4	269	63		23
		TOTALS	15	975	278		28

Table 9

Summary of Detection Factors

	N	Freq. of Travel on Gulf Frwy. (Weekly)					Notice Sign			Sign Operating			Freq. Observed Operating					Aspect of Sign						ting Attention					
	N	1-3	3-5	5-10	>10	Blank	Yes	No	Blank	Yes	No	Blank	Always	Many (>20)	Some (<20)	None	Blank	Flashing Light	Yellow/Colored Lights	Lights	Not Flashing	Message	[illegible]	Slow Traffic	Vague	Newness	Colored Paint	Other	Blank
Peak Total	155	19	44	82	9	1	152	2	1	144	9	2	25	39	59	4	28	91	19	12	4	11		2	8	3	2	1	21
% of Total	57	12		53			99			94			29	31	47	2	--	81% (126)											
•Griggs	132	15	37	72	8	0	131	0	1	125	6	1	22	35	48	1	26	76	15	12	4	6		2	7	3	0	1	19
•South HB&T	10	4	3	1	1	1	9	1	0	7	3	0	1	0	6	3	0	5	0	0	0	2		0	1	0	2	0	1
•Cullen	13	0	4	9	0	0	12	1	0	12	0	1	2	4	5	0	2	10	4	0	0	3		0	0	0	0	0	1
Off-Peak Total	118	52	24	24	13	5	113	3	2	92	21	5	6	9	70	16	17	59	29	3	1	12	1	4	2	1	0	2	13
% of Total	43	46		21			97			81			6	9	69	16	--	78% (92)											
•Griggs	27	10	8	5	4	0	26	1	0	22	3	2	2	3	12	1	9	14	9	0	0	4		0	0	0	0	0	6
•South HB&T	28	13	4	6	3	2	26	1	1	25	2	1	1	4	17	1	5	18	6	1	0	2		2	1	1	0	0	4
•Cullen	63	29	12	13	6	3	61	1	1	45	16	2	3	2	41	14	3	27	14	2	1	6		2	1	0	0	0	3
Peak & Off-Peak Total	273	71	68	106	22	6	265	5	3	236	30	7	31	48	129	20	45	150	48	15	5	23	1	6	10	4	2	3	34
% of Total	-	27	25	40	8	-	98			89					57			80% (218)				8							
•Griggs	159	25	45	77	12	0	157	1	1	147	9	3	24	38	60	2		90	24	12	4	10		2	7	3	0	1	25
•South HB&T	38	17	7	7	4	3	35	2	1	32	5	1	2	4	23	4	5	23	6	1	0	4		2	2	1	2	0	5
•Cullen	76	29	16	22	6	3	73	2	1	57	16	3	5	6	46	14	5	37	18	22	1	9		2	1	0	0	2	4

commuter. These expectations were borne out in their reports of frequency of use. Eighty-two peak respondents (53 percent) said they traveled daily (5-10 times a week) while only 24 (21 percent) of the off-peak traveled daily. Fifty-two (46 percent) of the off-peak respondents traveled only 1 to 3 times per week or less often, while only 12 percent of the peak respondents reported traveling this infrequently.

Detection Factors - Two-hundred sixty-five of the 273 respondents (98 percent) indicated they had noticed the sign and 236 (89 percent) said they had seen it in operation. However, 94 percent of the peak respondents had seen it in operation, whereas only 81 percent of the off-peak respondents would admit the same. Since the sign was operating at the time the drivers passed, the negative responses could be due to not wishing to complete the questionnaire or not detecting it.

Responses to Question #5 relative to how often they had seen the sign in operation were highly variable--some giving numerical estimates, some reporting in terms of percentage of the time, and still others giving a response in verbal terms of "always" or "never". Responses were classified into 5 categories as follows:

(1) Always or nearly always

(2) Most of the time, 50% or more of the time; many times, or 20 or more instances

(3) Some of the time or numerical estimates less than 20

(4) None or never

(5) No responses

One-hundred twenty-nine or 57 percent of all respondents stated that they had seen it in operation "some" of the time. However, a peak vs.

off-peak comparison indicates significant differences: 51 percent of the peak respondents said it was on all or most of the time while only 15 percent of the off-peak reported the same. Sixty-nine percent of the off-peak said it was on "some" (usually giving a value from 1 to 5) while only 47 percent of the peak respondents reported seeing it working only occasionally.

Twenty-eight of the peak respondents and 17 of the off-peak respondents left the question blank, and thus was, by far, the most frequently omitted response to any question.

When asked what aspect of the sign attracted their attention, 218 respondents (80 percent) answered either flashing/blinking lights, yellow/colored lights, lights only, or lights not flashing. All of these write-in responses were judged to be indications that the alternatively flashing beacons had attracted the drivers' attention to the signs.

Of the peak respondents, 81 percent noted the lights and of the off-peak respondents, 78 percent noted them. The next most frequently mentioned aspects were the CAUTION message, (8 percent) and the size of the sign (6 percent). Other comments included vague reference 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 and off-peak respondents or between various sign location.

Interpreting the Message

Table 10 summarizes the respondents' answers regarding interpretation of the meaning of the message displayed, overall evaluation of its usefulness, actions taken in response to the sign, and relevance of the

Table 10

Summary of Interpretation, Evaluation, and Response Factors

Study Number and Location	N	Distance Meaning					Speed Meaning (mph)						Usefulness					Other Message Ideas	Action Taken					Post-		Credibility				
		1 mi.	1/2 mi.	< 1/2	< Block	Blank	55	45	35	25	15	Blank	Very	Medium	Limited	None	Blank		Brake	Slow	Cont. w Caut.	Wait to See	Blank	Little	Reduce Speed	Same Speed	Slightly Slower	Very Slow	Stopped	Blank
Peak Total	155	13	28	70	34	10	0	16	46	41	26	20	49	41	33	28	4	23	6	77	54	7	11	39	85	23	64	46	33	8
% of Total	57	9	19	48	24	--	0	11	33	37	19	--	32	27	22	19	-	--	4	53	38	5	--	27	59	14	39	27	20	-
•Griggs	132	11	24	58	32	7	0	14	40	47	22	13	41	32	31	25	3	17	5	55	48	5	7	35	70	19	54	38	27	5
•South HB&T	10	1	1	5	1	2	0	2	3	0	0	5	3	5	0	2	0	3	0	4	3	0	3	1	7	1	5	2	0	2
•Cullen	13	1	3	7	1	1	0	0	3	4	4	2	5	4	2	1	1	2	0	7	3	2	1	3	8	3	5	6	6	1
Off-Peak Total	118	14	19	50	22	13	0	18	43	33	11	14	46	39	10	10	13	21	14	63	20	4	21	14	62	7	46	25	24	19
% of Total	43	13	18	48	21	--	0	17	41	32	10	--	44	38	9	9	-	18	14	62	20	4	--	14	63	6	45	25	24	--
•Griggs	27	3	3	8	7	6	0	3	6	7	5	6	13	6	1	2	5	4	3	16	4	1	7	0	16	1	12	3	5	7
•South HB&T	28	3	2	19	1	3	0	3	11	10	2	3	9	14	1	1	3	4	4	18	2	1	3	4	16	1	10	7	7	4
•Cullen	63	8	14	23	14	4	0	12	26	16	4	5	24	19	8	7	5	13	7	29	14	2	11	10	30	5	24	15	12	8
Peak & Off-Peak	273	27	47	120	56	23	0	34	89	84	37	34	95	80	43	38	17	44	20	140	74	11	32	53	147	30	110	71	57	27
% of Total	-	11	19	48	22	--	0	14	36	35	15	--	37	31	17	15	--	16	8	57	30	5	--	22	61	11	41	27	21	--
•Griggs	159	14	27	66	39	13	0	17	46	54	27	19	54	38	32	27	8	22	9	82	52	6	14	35	86	20	66	41	32	12
•South HB&T	38	4	3	24	2	5	0	5	14	10	2	8	12	19	1	3	3	7	4	22	5	1	6	5	23	2	15	9	7	6
•Cullen	76	9	17	30	15	5	0	12	29	20	8	7	29	23	10	8	6	15	7	36	17	4	12	13	38	8	29	21	18	9

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 and 87 percent of the off-peak respondents) expected the slow-down to occur from a block to 1/2 mile away, whereas 11 percent expected the congestion to occur a mile or more ahead. Almost half the respondents felt the message, SLOW TRAFFIC AHEAD, referred to a distance of less than a half mile, but more than a block away. Very little difference between the peak and non-peak respondents was reported.

Speed Meaning - The message also implied that traffic should slow down to some safe speed. Slightly over a third of the respondents felt that this speed was 35 mph, and another third felt that it implied 25 mph. Those driving during peak conditions interpreted the meaning as slightly slower than those driving during off-peak conditions. Fifty-six percent of the peak group selected either 25 or 15 mph as compared with 42 percent of the off-peak group. Also, about 6 percent more of the off-peak respondents felt the message meant 45 miles per hour. This finding was anticipated based upon the higher traveling speeds during off-peak conditions.

No one selected 55 mph which was the speed limit itself and selecting it would imply traveling above the legal limit.

Usefulness

Sixty-eight percent stated the sign was either "very useful" or "moderately useful" to them. However, there were significant differences between the peak and off-peak drivers opinion of its usefulness. Eighty-two percent of the off-peak drivers who responded stated it was useful while only 59 percent of the peak drivers endorsed the sign. The higher percentage of negative response among the peak 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 two questions, the first relating to their immediate reaction upon seeing the sign and the second relating to their need for additional reduction in speed after they passed the crest and could see the actual traffic state.

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

A comparison between peak and off-peak respondents revealed that 62 percent of the off-peak respondents said they slowed down gradually while only 53 percent of peak respondents selected this response. These differences might be anticipated in terms of their vehicle speeds and opportunity to slow down further.

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

Post-Action - Sixty-one percent of respondents indicated they needed to reduce their speed moderately after they came over the overpass and saw the traffic. Peak and off-peak drivers responded to the same degree. Ideally, this would not have been necessary. The typical reactions were to slow down slightly to the sign, and to wait for some visual feedback from the traffic ahead before adjusting one's 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 anticipated.

Twenty-two percent of the respondents indicated that they had to do "very little" in the way of adjusting their speed after passing the crest. Twice as many peak as off-peak respondents indicated they did little adjusting. Again, this may be due to the comparative lack of opportunity to reduce speed.

Eighteen percent admitted a need to brake or change lanes--a frank admission that the sign was truthful, but that they had not responded appropriately to the message. However, this does not mean they would respond inappropriately in future encounters. More off-peak drivers needed to brake than did peak drivers as expected.

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 traffic state they encountered. A statement that traffic downstream was traveling at the same speed as upstream would be tantamount to stating that the system was not working. Only 11 percent of all respondents selected this extreme response--fourteen percent of the peak period respondents and 6 percent of the off-peak respondents. This would suggest that off-peak drivers, who were generally not exposed to the sign under stop-and-go conditions, found the message more credible.

Forty-one percent of all respondents said the traffic was slightly slower; 27 percent reported it very slow; and 21 percent reported stoppages. Peak and off-peak 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 of stoppages on the freeway. The warning system significantly reduced the total and secondary accidents on the freeway. The following specific findings are 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. Since the warning system was integrated with the existing control system on the Gulf Freeway, there were considerable savings in the initial cost. An analysis of a new system, assuming no hardware were presently available, resulted in a benefit/cost ratio of 4.8.
3. Studies of accidents for nine-month periods before and after the warning system began operation revealed that accidents reduced from 72 to 37 or 49 percent in the sections of the inbound Gulf Freeway influenced by the warning system while accidents in comparable sections outbound reduced from 60 to 55 or only 5

percent. The greatest accident reduction inbound occurred during the a.m. 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, while essentially no change in secondary accidents occurred in the other inbound or outbound freeway sections.

4. The results of the questionnaire study indicate that the motorists believed the sign to be useful, readily noticed, and the message generally understood. The respondents reacted to it appropriately and confirmed that the message displayed was verified later by traffic observed.

5. The greatest skepticism regarding the usefulness of the sign came from the peak traffic respondents. They reported seeing the sign in operation all or most of the time on 51 percent of the occasions as compared with 15 percent of the off-peak users. While both groups reported the sign useful, 9 percent more of the off-peak drivers said they would continue with caution upon seeing the traffic, again suggesting no need for action due to the prevailing traffic speed. Some peak drivers also wrote in criticisms of the sign being on most of the time and presenting obvious information to stop-and-go drivers.

There was a dichotomy of results between the accident studies and questionnaire survey. Motorists complained that the sign was activated most of the time during the peak periods, particularly at the Griggs location, while the statistics show a large reduction of primary and secondary accidents during the peak periods. These results suggest that the warning system should be operated during the peak period but measures should be taken to turn the sign off as quickly as possible when the shock wave passes over the overpass crest. This can be accomplished by placing the upstream sensors as close to the structure as possible.

The results verify that the flashing beacons are effective and provide excellent target value. Also, although it may be desirable to state the distance ahead of the sign's applicability and the indicated safe speed, a sufficiently large percentage of drivers interpreted the distance to be a half-mile or less with an implied speed of 15 to 35 mph except when the traffic was actually stopped immediately over the crest. The sign is useful within the constraints of a fixed message.

ACKNOWLEDGMENTS

The authors wish to acknowledge Mr. Richard Fullerton of the Texas Transportation Institute who coordinated the questionnaire studies.

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APPENDIX A

Letter and Questionnaire

COMMISSION

REAGAN HOUSTON, CHAIRMAN
DEWITT C. GREER
CHARLES E. SIMONS

TEXAS HIGHWAY DEPARTMENT

STATE HIGHWAY ENGINEER
B. L. DEBERRY

6333 Gulf Freeway
Houston, Texas 77023

IN REPLY REFER TO
FILE NO.

Dear Texas Motorist:

The Texas Highway Department is continuously developing methods for improving travel and safety on our highways. The Highway Department is evaluating a new sign which is located on the inbound Gulf Freeway. The sign displays the message: "Caution Slow Traffic" when traffic is being held up on the other side of freeway overpasses. We are asking a select group of Houston area motorists to help us evaluate the sign.

Your vehicle was observed traveling on the inbound Gulf Freeway on   at approximately   and we are asking your help in evaluating the sign. Would you please answer a few questions regarding your experience with the sign? Even if you have not noticed it, please check the first two questions. Please return the questionnaire in the enclosed pre-paid envelope as soon as possible.

If you were not the driver of the car, would you please ask the person who drove your car to complete the questionnaire.

Thank you for your cooperation.

Enclosure

<u>Note</u>: We obtained your address from a license plate survey conducted on the Gulf Freeway. It is possible that we may have misread the license. If so, please ignore this lettter.

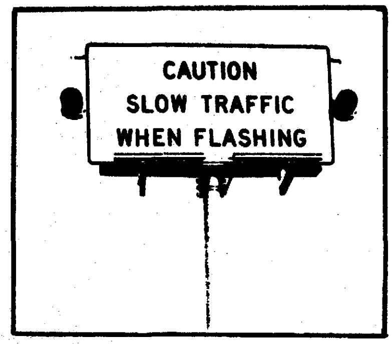
TEXAS HIGHWAY DEPARTMENT SIGN QUESTIONNAIRE

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_____

....

Thank you, sincerely. Please return this form to the Texas Highway Department using the enclosed envelope.

APPENDIX B

Cost Estimates of Alternative System Designs

APPENDIX B

Cost Estimates of Alternative System Designs

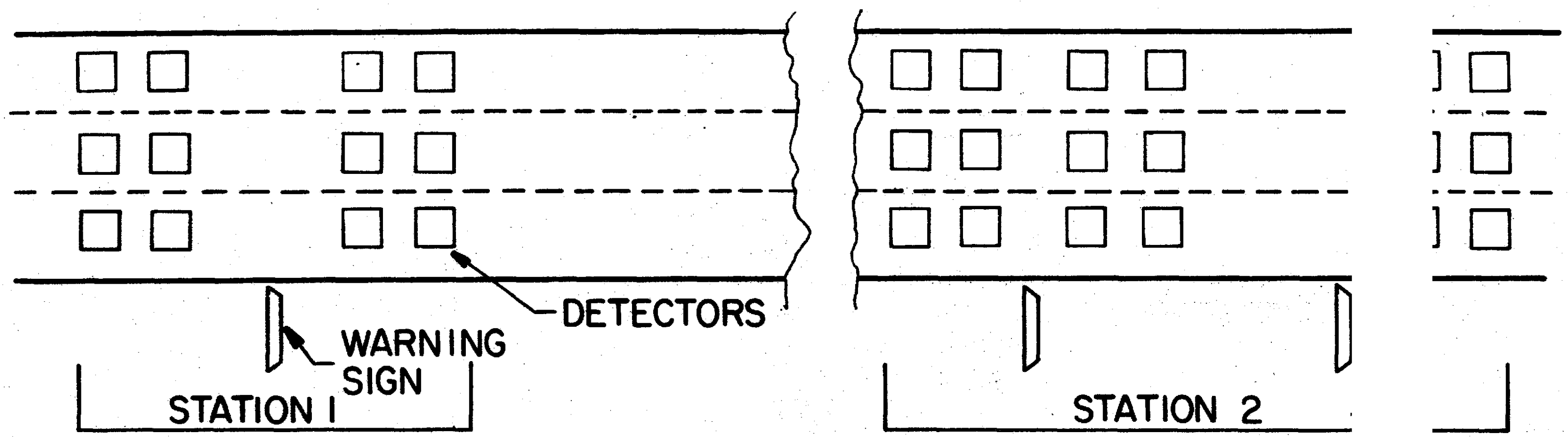


Figure B-1 - Study Plan

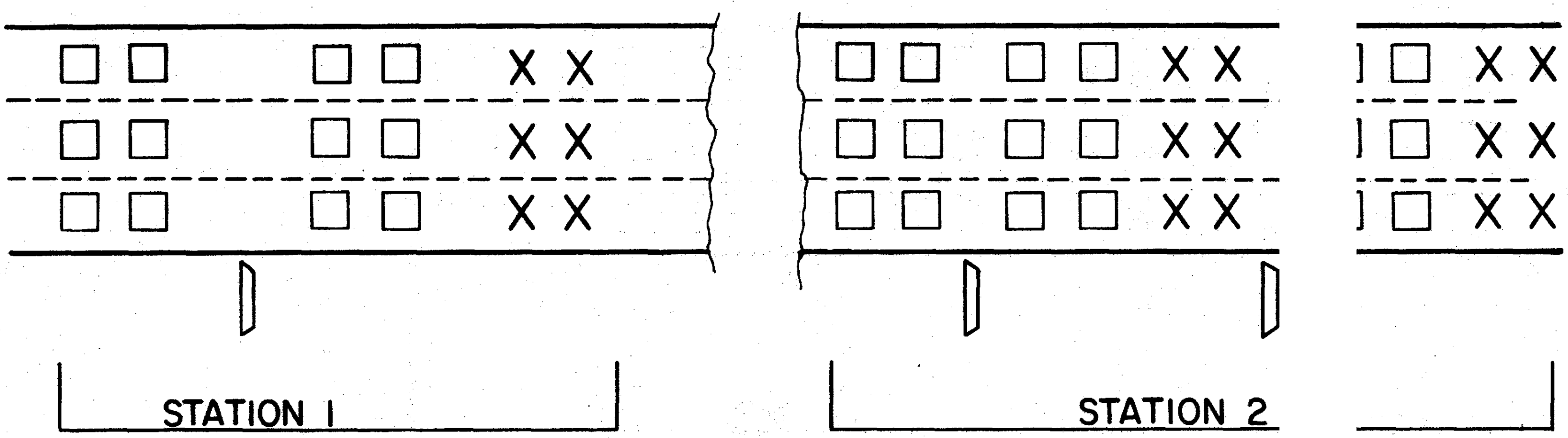


Figure B-2 - Expanded Study Plan

Table B-1

Computer Cost

ITEM	DESCRIPTION	UNIT COST	TOTA COST	MAINTENANCE COST/YEAR
1. Minicomputer	8 microsec, real time clock, power fail/auto restart, 4K core, TTY and paper tape I/O interface, power supply	$8,000	$8,00	$100
2. Digital I/O	1 input per detector. 1 output per sign. 16 inputs or outputs per module. 2 input and 1 output modules.	$ 800	$2,4	
3. Teletype	ASR-33 TTY with lu cps paper tape I/O	$1,500	$1,5	$200
4. Cabinet	Small 19" enclosed cabinet	$ 700	$ 7	

Table B-1a

Computer Costs for Expanded Detectors

ITEM	DESCRIPTION	UNIT COST	TOT COS	MAINTENANCE COST/YEAR
1. Minicomputer	No change	-	$8,00	$100
2. Digital I/O	1 additional input module	$ 800	$3,20	
3. Teletype	No change	$1,500	$1,50	$200
4. Cabinet	No change	$ 700	$ 70	

Table B-2

Communications Cost

ITEM	DESCRIPTION	UNIT COST	TOTAL COST	MAINTENANCE COST/YEAR
1. Direct Burial Cable	28 pair direct burial cable in 2" conduit for 10,000 feet	Cable $.25/ foot Installation $3/foot	$32,50	-
2. Telephone Lines				
a. Voice-grade	2 separate voice grade pairs at $5 first mile, $4 each extra mile $25 installation charge/pair	Station 1 - $4/month Station 2 - @ 4 miles $9/month	$ 5	$200
b. Tone Multi-plexors MODEMS	2 detectors per channel, 20 channels per voice pair			
	1. Cabinets (both ends)	Station 1 - $100 Station 2 - $100	$ 20	
	2. Power Supplies (both ends)	Station 1 - $200 Station 2 - $200	$ 40	$400
	3. Tone Channels	$300/channel	$ 5,10	
	Station 1 - 7 channels Station 2 - 10 channels			

Table B-2a

Communications Cost for Expanded Detectors

ITEM	DESCRIPTION	UNIT COST	T(C(	MAINTENANCE COST/YEAR
1. Direct Burial Cable	No change		$32	
2. Telephone pairs				
a. Voice-grade	One extra voice grade pair for station 2, $25 installation	$5 first mile $4 each mile thereafter	$	$300
b. Tone multi-plexors	In addition to Table B-2 cost 1 extra MODEM with power supplies for station 2			
	1. Cabinet	Station 1 - $100 Station 2 - $100	$	
	2. Power Supplies	Station 1 - $200 Station 2 - $400	$	$400
	3. Tone Channels Station 1 - 10 Station 2 - 16	$300/channel	$ 7,	

Table B-3

Communications Costs

ITEM		DESCRIPTION	UNIT COST	TOT COS	MAINTENANCE COST/YEAR
3. Coaxial cable					
a.	Direct burial	Wide-band direct burial coaxial cable for 10,000 ft in 1" conduit	Cable - $.20/ ft. Installation $2/ft.	$22,(	
b.	RF carrier	Low frequency RF carrier one Transmitter and Receiver per station	$1,500	$ 6,(	$200
c.	Tone multi-plexors	(Same as Item 2b in Table B-2)	-	$ 5,7	
			-		$400

Table B-3a

Communications Costs for Expanded Detectors

ITEM	DESCRIPTION	UNIT COST	TOTA COST	MAINTENANCE COST/YEAR
3. Coaxial cable	No change from Table B-3a	-	$22,0	
a. Direct burial				
b. RF carrier	"	-	$ 6,0	$200
c. Tone MODEMS	No change from Item 2b, Table B-2a	-	$ 2	
		-	$ 6	$400
		-	$ 7,8	

Table B-4

Cost Summaries

		COMPUTER		DIRECT BURIAL CABLE		TELEPHONE LIN		BURIED COAXIAL CABLE	
		Equip.	Maint.	Equip.	Maint.	Equip.	Mai	Equip.	Maint.
Study Plan	Equip.	$12,600	$300	$32,500	-	$ 5,750	$	$33,750	$600
	Total	-	-	$45,100	$300	$18,350	$	$46,450	$900
Expanded Study Plan	Equip.	$13,400	$300	$32,500	-	$ 8,700	$	$36,600	$600
	Total	-	-	$45,900	$300	$22,100	$1,	$50,000	$900