

# HIGHWAY RESEARCH RECORD

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|--------|------------------------|
| Number | Communications         |
| 358    | and Emergency Services |
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Subject Area

53 Traffic Control and Operations

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## FOREWORD

The stranded motorist still represents a major area of concern to operating authorities of both rural and urban freeway systems. The four papers, 3 discussions, and 2 abridged papers in this RECORD reflect this concern and present research findings that engineers, administrators, and enforcement officials will find useful in dealing with this serious problem area.

Experience with a push-button call-box system in Houston, Texas, is described by Goolsby and McCasland in the first paper. Four types of assistance can be requested, and data for a 6-month period showed that two-thirds of the disabled motorists failed to use the system either because they were not aware of its existence or because they were fearful of the cost involved. One-third of the calling motorists were classed as being gone on arrival.

Roth presents the final report of a 2-year study of a rural freeway emergency communications system for stranded motorists in Michigan. The study was initiated to determine the level of need of such a communication system and the extent to which these needs were satisfied by the telephone system provided by the Michigan Department of State Highways. The conclusions will be of interest to any agency coping with the stranded-motorist problem.

Dudek studied the problem of communication to rather than from the motorist. He evaluated driver attitudes toward presentation of real-time freeway traffic information by commercial radio, and he concluded that it could play a vital role in an effective urban freeway communication system.

Sakashita, Lu, and May developed a simulation model of an emergency service system (police, mechanical, and communication services) for responding to freeway incidents in order to analyze 30 different candidate systems. Costs and effectiveness measures were developed and discussed, and conclusions were drawn regarding the most promising systems. The model can be expanded to include factors not studied in the paper and can be applied to other locations as well. Three thoughtful discussants comment on the authors' work and also pose questions whose answers will extend the usefulness of the study. These discussions, as well as the authors' closure, are included.

A helicopter system to serve both emergency and regional medical needs in a section of West Virginia was studied by Jordan, Wegmann, and Carter, the results of which are reported in this abridgment. Although conclusions were drawn concerning the use and effectiveness of the helicopter system, the need to assess this system in comparison with other alternative systems was noted.

In the final abridgment, Green and Bregman summarize the results of their study of the Northway Emergency Telephone System on I-87 in New York. Some very interesting and useful findings about system use are presented.



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# USE OF AN EMERGENCY CALL-BOX SYSTEM ON AN URBAN FREEWAY

Merrell E. Goolsby, Wilbur Smith and Associates; and  
William R. McCasland, Texas Transportation Institute, Texas A&M University

This is a report on experience with a push-button call-box system installed on an 11-mile section of I-45 in Houston. The system is composed of 65 master and 80 secondary boxes spaced at  $\frac{1}{4}$ -mile intervals on the freeway and a receiving console located at the Houston Police Department. Stranded motorists may send requests for 4 types of aid: police, ambulance, fire, and service. Use data for a 6-month period were available for this study. During this period, 1,025 calls were placed for a daily average of 5.6 calls and a use rate of 6.3 calls per million vehicle-miles. Rate of use of a given box was found to be a function of the distance to alternate assistance. One-third of the calling motorists had left the scene before service arrived. Use and driver interview data indicated that driver understanding and acceptance of the system were not complete. More than one-third of the disabled motorists were not aware of the system, while another one-third indicated that they did not use the system because of the costs (\$6.00 to \$18.50, depending on service required) involved when requesting service.

•AS urban freeway mileage and use increase, more attention is being focused on the operational efficiency of freeways. One of the greatest losses in efficiency on urban freeways results from disabled vehicles in moving-traffic lanes. During peak periods, a vehicle disability has far-reaching impact. The effect on traffic operations is merely 1 aspect of the problem. The presence of a disabled vehicle on the freeway also increases the accident potential both at the scene and in the traffic congestion upstream.

An emergency call-box (ECB) system is 1 means of addressing the disabled vehicle problem (1, 2). In addition to enhancing the safety and reducing the impact on traffic of disabled vehicles by expedient removal, it provides a convenience to motorists in need of assistance. An ECB system provides the stranded motorist with a communication link to needed assistance, with the net result of reducing the time required to obtain assistance and move from the freeway.

The Texas Highway Department designed and installed an experimental ECB system on Interstate 45 in Houston in 1969. The Texas Transportation Institute (TTI) was requested to evaluate the system (3). This report presents the use experience from the TTI study.

## SYSTEM DESCRIPTION

The system was installed on an 11-mile section of I-45 from Scott Street to Little York Road in Houston (Fig. 1). Call boxes are spaced at approximate  $\frac{1}{4}$ -mile intervals and are located so that a stranded motorist is not required to cross main-lane traffic to place a call. Thus, a typical location has 4 call boxes on each shoulder in each direction of travel.

The system, using battery-powered radio call boxes, consists of 65 master transmitter units and 80 secondary (slave) units. Slave units depend on an interconnected

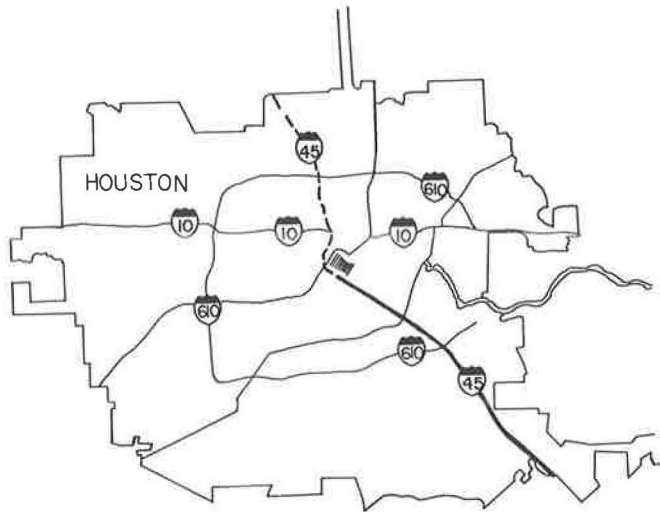


Figure 1. Location of emergency call-box system on I-45 in Houston.

master unit for signal transmission to the receiving unit located in the offices of the Houston Police Department. A master unit can support as many as 3 slave units. Each call-box installation (Fig. 2) has 4 buttons that are labeled "police," "ambulance," "fire," and "service" (tow truck). Provision is made for verification of calls through "message sent-message received" lights on the call-box face. These are activated when the radio message is transmitted and when acknowledgment is made from the receiving console. The boxes automatically place a check-in call once a day so that malfunctions can be located and corrected. Battery condition of the call box is indicated on the receiving console when any call is made. Tilting a call box causes the closure of a mercury switch in the box and a "tamper-knockdown" call is automatically placed.

The receiving console is located in the Houston Police Department headquarters where it is attended by a police dispatcher. The console unit decodes radio calls as well as records and displays the information received. Features of the console include



Figure 2. Typical call-box installation.

TABLE 1  
DISTRIBUTION OF CALLS FOR DAYS OF WEEK

| Day of Week | Number | Percent |
|-------------|--------|---------|
| Sunday      | 144    | 14.0    |
| Monday      | 122    | 11.9    |
| Tuesday     | 156    | 15.2    |
| Wednesday   | 151    | 14.7    |
| Thursday    | 183    | 17.9    |
| Friday      | 140    | 13.7    |
| Saturday    | 129    | 12.6    |

TABLE 2  
DISTRIBUTION OF CALLS FOR PERIODS OF DAY

| Period of Day | Number | Percent |
|---------------|--------|---------|
| 12 - 2 a.m.   | 56     | 5.6     |
| 2 - 4         | 21     | 2.1     |
| 4 - 6         | 20     | 1.9     |
| 6 - 8         | 108    | 10.8    |
| 8 - 10        | 94     | 9.3     |
| 10 - 12       | 79     | 7.8     |
| 12 - 2 p.m.   | 87     | 8.6     |
| 2 - 4         | 108    | 10.6    |
| 4 - 6         | 166    | 16.5    |
| 6 - 8         | 127    | 12.7    |
| 8 - 10        | 75     | 7.4     |
| 10 - 12       | 66     | 6.5     |

indicator lights that give a visual display of the call, printed tape record of calls, audible alarm actuated by a call, and signal wave form recorder for use by maintenance personnel.

### DATA COLLECTION

Data from 4 sources are used in this report: (a) police records of ECB use and accidents, (b) traffic volume counts, (c) stopped vehicle study, and (d) continuous surveillance study.

A call-box use log, maintained by the Houston Police Department and available for a 6-month period, contains the following information for each call placed: box number, service requested, time call was placed, time service arrived, and disposition of call. Police records of reported accidents were also used to correlate with ECB use.

A complete description of the traffic flow pattern in the call-box section was assembled from machine and manual traffic counts. From these data, it was possible to determine volume patterns and total travel (vehicle-miles) by sections on the freeway.

Stopped-vehicle studies were conducted for 1 week before and 1 week after installation of the call-box system. Data were collected by patrols on all vehicles stopped on the freeway main lanes and shoulders. The patrols operated on 15-min frequencies for 24 hours per day. Drivers of attended vehicles were asked questions relating to their stops and the call-box system.

A continuous surveillance study of an elevated section of the freeway was conducted to gain an understanding of driver actions. Observers were stationed in 2 buildings overlooking a 1.3-mile section of the freeway on weekdays between 7:00 a.m. and 7:00 p.m. for a 3-week period after installation of the ECB system.

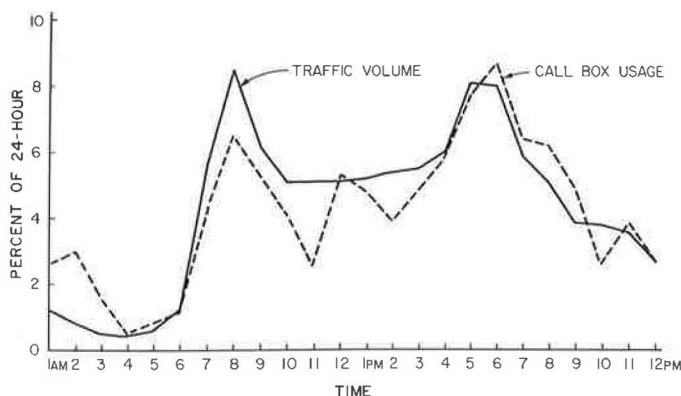


Figure 3. Weekday distribution of box usage and traffic.



### USE CHARACTERISTICS

During the 6 months of operation of the call-box system, 1,025 calls were placed for an average of 5.6 calls per day. Of the calls placed, 685 were classified as confirmed calls; that is, the person placing the call was at the scene when service arrived. The other 340 calls were classified as gone-on-arrival calls.

Distribution of all calls by day of week and hour of day is given in Tables 1 and 2. Figure 3 shows the hourly distribution of calls to the distribution of traffic. Types of calls placed are given in Table 3.

Stopped-vehicle studies determined the reasons for vehicle stops on the freeway. The reasons for stopping given by vehicle drivers, who could have used call-box, are given in Table 4. Not included are reasons for a significant number of miscellaneous, voluntary stops, such as checking vehicle, securing load, or reading map, which do not involve disabled vehicles. The nature of disability resulting in use of the call-box system is given in Table 5. A comparison of data given in Tables 4 and 5 gives an indication of relative use of the call box for categories of stops. Reporting of accidents accounted for the greatest use of the ECB.

### FACTORS INFLUENCING USE

Need for and use of the system are influenced by a number of factors such as accessibility of assistance, personal danger, convenience, degree of emergency, and exposure to the system (traffic volume). It was possible to quantify two of these factors in this study: accessibility of assistance and exposure to the system. The relationship of use to accessibility of assistance and exposure to the system are given in Table 6. The same data are shown in Figure 4 in terms of use rate (call per million vehicles) and distance to alternate aid. A least squares analysis resulted in the regression line shown. The correlation coefficient was 0.81, whereas the standard error of the estimate was 6.42 (hundred feet).

Because an ECB system is not designed as an isolated point installation but rather as a continuous system, the use data are more meaningful by sections than by individual box locations. Therefore, 3 essentially homogeneous sections of the freeway totaling 10.16 miles were selected. Total travel in the section served by the call-box system was 840,000 vehicle-miles on an average weekday. Expanding this for the 6-month study period yields 145 million vehicle-miles, for a call-box use rate of 6.3 calls per million vehicle-miles on the freeway main lanes. Use data for 6 months are expressed in terms of a rate (calls per million vehicle-miles) for the 3 sections given in Table 7.

The first section contains the downtown interchange and elevated freeway from Dowling Street to Quitman Street. It is difficult for a stranded motorist to reach alternate aid in this section, which has an average walking distance to assistance of 1,900 ft. The second section, called urban, includes the freeway from Quitman Street to the I-610 interchange and requires an average walk to assistance of 750 ft. The suburban sec-

TABLE 3

SERVICES REQUESTED BY SYSTEM USERS

| Service Requested | Confirmed |         | Gone on Arrival |         |
|-------------------|-----------|---------|-----------------|---------|
|                   | Number    | Percent | Number          | Percent |
| Service           | 401       | 58.5    | 190             | 55.9    |
| Police            | 237       | 34.6    | 123             | 36.2    |
| Ambulance         | 32        | 4.7     | 15              | 4.4     |
| Fire              | 15        | 2.2     | 12              | 3.5     |

TABLE 4

REASONS FOR STOPS AS OBSERVED IN PATROL STUDY

| Reason For Stop | Number | Percent |
|-----------------|--------|---------|
| Gas             | 131    | 19.0    |
| Tire            | 207    | 30.2    |
| Mechanical      | 299    | 43.5    |
| Accident        | 50     | 7.3     |
| Ambulance       | 0      | 0.0     |
| Fire            | 0      | 0.0     |

TABLE 5

NATURE OF TROUBLE FOR CALL-BOX USERS

| Nature of Trouble | Number | Percent |
|-------------------|--------|---------|
| Gas               | 155    | 25.1    |
| Tire              | 72     | 11.6    |
| Mechanical        | 177    | 28.6    |
| Accident          | 192    | 31.0    |
| Other             | 23     | 3.7     |

TABLE 6

MAIN-LANE CALL BOX USE RELATED TO DISTANCE TO ALTERNATE AID AND TRAFFIC VOLUME

| Box | Distance to Alternate Aid (ft) | 6-month Volume (millions) | Number of Calls (6 months) | Rate (calls/million vehicles) |
|-----|--------------------------------|---------------------------|----------------------------|-------------------------------|
| 10  | 200                            | 23.23                     | 19                         | 0.82                          |
| 11  | 300                            | 24.91                     | 20                         | 0.80                          |
| 12  | 300                            | 13.46                     | 14                         | 1.04                          |
| 13  | 1,700                          | 6.57                      | 21                         | 3.20                          |
| 14  | 1,700                          | 6.89                      | 24                         | 3.49                          |
| 15  | 3,100                          | 13.46                     | 51                         | 3.79                          |
| 16  | 3,000                          | 13.46                     | 59                         | 4.38                          |
| 17  | 1,700                          | 13.46                     | 49                         | 3.64                          |
| 18  | 800                            | 13.46                     | 45                         | 3.35                          |
| 19  | 1,000                          | 5.16                      | 9                          | 1.75                          |
| 20  | 1,000                          | 4.72                      | 4                          | 0.85                          |
| 21  | 1,700                          | 10.12                     | 29                         | 2.90                          |
| 22  | 1,700                          | 7.98                      | 36                         | 4.53                          |
| 23  | 1,200                          | 7.98                      | 33                         | 4.14                          |
| 24  | 1,700                          | 10.12                     | 21                         | 2.07                          |
| 25  | 1,100                          | 7.98                      | 22                         | 2.76                          |
| 26  | 900                            | 10.12                     | 49                         | 4.85                          |
| 27  | 2,600                          | 4.67                      | 23                         | 4.89                          |
| 28  | 2,000                          | 7.66                      | 32                         | 4.18                          |
| 29  | 4,000                          | 4.67                      | 28                         | 5.96                          |
| 30  | 3,300                          | 7.66                      | 26                         | 3.38                          |
| 31  | 2,200                          | 18.16                     | 47                         | 2.58                          |
| 32  | 400                            | 16.73                     | 18                         | 1.08                          |
| 33  | 200                            | 16.73                     | 15                         | 0.90                          |
| 34  | 200                            | 16.57                     | 13                         | 0.78                          |
| 35  | 500                            | 15.29                     | 11                         | 0.72                          |
| 36  | 900                            | 16.18                     | 30                         | 1.85                          |
| 37  | 1,100                          | 9.08                      | 21                         | 2.31                          |
| 38  | 1,100                          | 15.06                     | 43                         | 2.85                          |
| 39  | 1,200                          | 15.06                     | 18                         | 1.19                          |
| 40  | 100                            | 12.26                     | 7                          | 0.57                          |
| 41  | 500                            | 10.21                     | 7                          | 0.69                          |
| 42  | 800                            | 9.37                      | 6                          | 0.64                          |
| 43  | 500                            | 9.37                      | 8                          | 0.85                          |
| 44  | 600                            | 9.53                      | 10                         | 1.05                          |
| 45  | 700                            | 9.53                      | 9                          | 0.95                          |
| 46  | 200                            | 8.02                      | 2                          | 0.25                          |
| 47  | 200                            | 8.02                      | 10                         | 1.25                          |
| 48  | 300                            | 8.48                      | 10                         | 1.18                          |
| 49  | 400                            | 6.38                      | 9                          | 1.41                          |
| 50  | 100                            | 6.77                      | 3                          | 0.44                          |

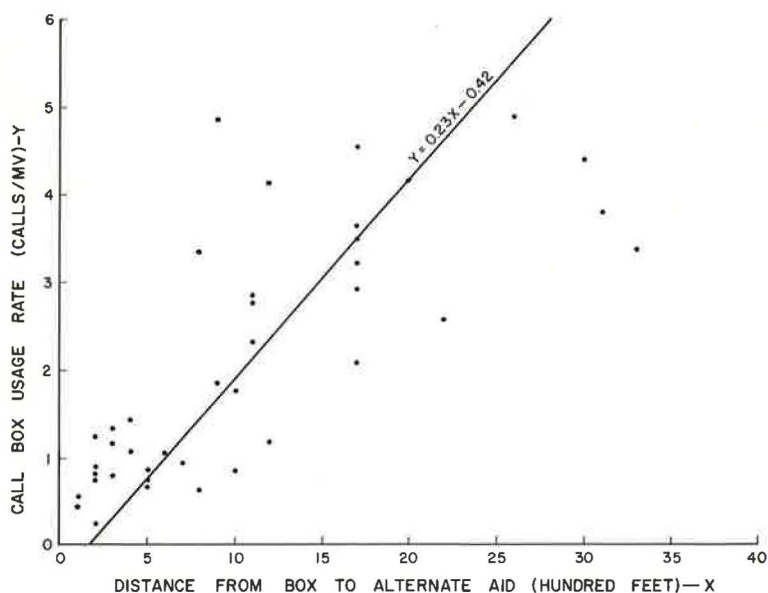


Figure 4. Relationship of call-box usage to distance to alternate aid.

TABLE 7  
COMPARISON OF BOX USE BY FREEWAY SECTIONS

| Section                                   | Length<br>(miles) | 6-month Travel<br>(million<br>vehicle-miles) | Number of<br>Calls<br>(6 months) | Rate<br>(calls/million<br>vehicle-miles) |
|---|-------------------|--|----------------------------------|--|
| Elevated and interchange<br>(boxes 13-30) | 3.34              | 48.3   | 561                              | 11.6                                     |
| Urban (boxes 31-36)                       | 2.20              | 34.6   | 134                              | 3.9                                      |
| Suburban (boxes 37-50)                    | 4.62              | 44.3   | 163                              | 3.7                                      |

tion includes the freeway from I-610 to the Houston city limits and requires an average walk to assistance of 560 ft. This comparison of use rates suggests that the need for a call-box system is 3 times greater in the elevated-interchange section than in the other sections.

### USER ACCEPTANCE AND UNDERSTANDING

The key person in the function of an emergency call-box system is the user. Therefore, it is important to investigate his understanding of the purpose of the system and how to use it. Questions were asked of stopped-vehicle drivers encountered in the patrol study, and driver actions were recorded during the continuous surveillance study in an attempt to determine driver understanding and acceptance of the call-box system.

Interviewed drivers were asked why they did not use the ECB. These responses are given in Table 8. Over one-third said that they either were not aware of or had forgotten about the call-box system. Another one-third indicated that they did not use the system because of the cost involved. A list of service charges is posted on each box (Table 9).

The continuous surveillance study, a summary of which is given in Table 10, found that only 20 percent of the disabled motorists requiring assistance even looked at a call box at close range. There are 3 possible reasons why a motorist would not even look at the call boxes: (a) He already knew about the system and rejected the alternative of using it because of cost or his ability to correct the problem; (b) he did not know of its existence; or (c) he did not know the call box could be used for obtaining gas or wrecker service. It was not feasible in this study to determine which of the 3 reasons was predominant.

The manner in which calls were placed is given in Table 11. The average number of times a button was pressed for a single call was 3.5 with 21 callers passing the button more than 15 times. There are 2 possible reasons for this repeated placing of calls. The police dispatcher may have been delayed in actuating the "message received" signal to the user, or the user merely wanted to make certain of his call for help by placing repeated calls.

The use log shows that some users of the system make a request for the wrong assistance. Of the 685 confirmed calls, 77 needed a different service than that requested. Thus, 11 percent of the users apparently did not understand how to request aid properly. The greatest number of er-

TABLE 8  
REASONS DRIVERS DID NOT USE CALL BOX

| Reason                                  | Number | Percent |
|---|--------|---------|
| Not aware                               | 21     | 31.8    |
| Forgot about it                         | 4      | 6.1     |
| Costs too much                          | 23     | 34.9    |
| No chance                               | 14     | 21.2    |
| Unable or unwilling<br>to leave vehicle | 4      | 6.0     |

TABLE 9  
SERVICE CHARGES POSTED ON CALL BOXES

| Service  | Charge                     |
|--|----------------------------|
| Remove vehicle from freeway  | \$ 6.00                    |
| Gasoline service after removal<br>from freeway   | 6.00 (plus cost<br>of gas) |
| Tire change after removal<br>from freeway  | 8.50                       |
| Remove vehicle to area <sup>a</sup> des-<br>ignated by owner                                       | 12.50                      |
| Move vehicle to area <sup>a</sup> designated<br>by owner after removal from<br>freeway and release | 18.50                      |

<sup>a</sup>Area within Houston city limits.

TABLE 10

INITIAL ACTIONS OF DRIVERS NEEDING ASSISTANCE

| Initial Action                     | Number | Percent |
|------------------------------------|--------|---------|
| Used call box                      | 7      | 13.5    |
| Looked at call box but did not use | 4      | 7.7     |
| Walked to help                     | 11     | 21.1    |
| Caught ride                        | 4      | 7.7     |
| Assisted by passing motorist       | 26     | 50.0    |
| Total                              | 52     | 100.0   |

TABLE 11

DISTRIBUTION OF NUMBER OF TIMES CALL PLACED FOR SAME INCIDENT

| Number of Calls | Frequency | Percent |
|-----------------|-----------|---------|
| 1 to 2          | 353       | 52.3    |
| 3 to 4          | 170       | 25.3    |
| 5 to 6          | 71        | 10.6    |
| 7 to 8          | 29        | 4.2     |
| 9 to 10         | 12        | 1.8     |
| Greater than 10 | 39        | 5.8     |

aneous calls was made for police when service was the aid needed.

It is difficult to determine whether the driving population understands the purpose and operation of the ECB system, because a comparison of those needing a particular service and those requesting it via the ECB system is not readily obtainable. The best means available for comparing actual needs to system use was through an analysis of accident records. Texas law requires that accidents resulting in damage greater than \$25 be reported to the police. Documentation of all accidents occurring in the call-box section is available in police accident files, while the use log reveals how many of them were reported on the system.

During the 6-month study period, 470 accidents occurred in the call-box section, of which 192 (41 percent) were reported on call boxes. Because there is no user charge for reporting an accident, it is suspected that those electing not to use it did not know of the system or had a more convenient means of reporting the accident.

#### SUMMARY OF FINDINGS

1. Approximately 5.6 calls per day were placed on the system for a use rate of 6.3 calls per million vehicle-miles of travel.
2. Use was 3 times greater in the elevated interchange section than in the urban or suburban sections.
3. Thirty-eight percent of interviewed stopped motorists were unaware of the call-box system on the facility where their vehicles were disabled.
4. Use of individual boxes was influenced by the distance to alternate assistance.
5. Eleven percent of the system users placed a call for the wrong assistance.

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# RURAL FREEWAY EMERGENCY COMMUNICATIONS FOR STRANDED MOTORISTS: FINAL PHASE REPORT

Walter J. Roth, Michigan Department of State Highways, Lansing

Various studies were conducted over a 2-year period directed toward determining the level of need for any motorist-aid system and the extent to which these needs were met by the system installed. This system proceeded from a research plan to system design and then to installation and operation. Many requirements and desirable aspects were detailed in the process for use in other system developments. Data of this nature have already been valuable to other states in their approaches to the stranded-motorist problem. This, of course, was one of the prime reasons that prompted the Federal Highway Administration to participate in this type of project and to create a data base in an area of conjecture in which realistic planning for the future would be possible. The studies show a vehicle stopping rate (over 12 min) of 0.825 stops per mile per day in the summer and 1 stop per 2 miles per day in the winter. It is possibly coincidental, but the stopping rates increased exactly the same as the increase in winter-to-summer average daily traffic volumes. On the basis of present knowledge of operating motorist-aid systems, we would recommend a telephone communication system. This approach, coupled with some patrol activity and ready reference to the appropriate commercial agency, seems to provide the most desirable elements of a system of aid for stranded motorists.

•THIS paper is a final phase report on a 2½-year experiment with a motorist-aid telephone system in Michigan. This project was a cooperative effort by the Michigan Department of State Highways and the Federal Highway Administration, which funded 90 percent of installation costs and, through the Highway Planning and Research Program, aided in the various research phases.

The study was designed to determine the usefulness of a roadside motorist-aid telephone system for stranded motorists on a rural freeway and to observe and record the needs of motorists who stop on the facility. A description of the system and its operation and maintenance was given in an earlier report (17).

The construction and operating costs are as follows:

| <u>Category</u>   | <u>Cost</u> |
|---|-------------|
| Total construction costs  | \$290,171   |
| 2-year maintenance  | 7,200       |
| Approximate vehicle damage and vandalism in 2 years (about \$1,800 recoverable) | 5,000       |
| Michigan Bell Telephone Company (6 pairs leased lines per year)                 | 3,414       |
| Consumers Power Company (power per year)  | 1,620       |

The contractor incurred costs that were considerably more than the \$7,200 maintenance cost bid in the original contract. The 1 big cost factor was the result of the complete encoder-decoder change, and the remainder of the cost was from system repair as a result of leased line problems, lightning, and water damage.

#### DISTRIBUTION OF AID PHONE CALLS AND STOPS OF 12 MINUTES OR MORE

The reasons for requesting aid (Table 1) show a great similarity to those reported on most motorist-aid systems. The number of calls for accident aid seems rather high for this type of need. These percentages, of course, are based on only the number of motorists who called for aid. The distribution of reasons given by drivers of stopped vehicles, as determined in our summer and winter interviews, are also given in Table 1. The differences in the tire failure percentages for the 2 groups confirm the fact that about half of the motorists change their own tires when they have this problem.

#### RATES OF CALLS AND STOPS RELATED TO VEHICLE-MILES AND ADT

The following rates for cars stopped 12 min or more were developed from data obtained during the winter and summer surveys on I-94:

| <u>Survey</u> | <u>Stop Rate</u>  | <u>Call Rate</u>   |
|---------------|---|--|
| Summer 1968   | 1 per 33,000 vehicle-miles<br>0.825 per mile per day,<br>17,960 ADT | 1 per 117,000 vehicle-miles<br>0.231 per mile per day<br>208 per month |
| Winter 1969   | 1 per 38,000 vehicle-miles<br>0.48 per mile per day,<br>10,445 ADT  | 1 per 85,000 vehicle-miles<br>0.208 per mile per day<br>187 per month  |

It could be a coincidence that the winter-to-summer stopping rates and the winter-to-summer ADT's both increased by 72 percent.

In the relationship between stops and calls, it is notable that, although the per-mile call rates are very close for winter and summer, the winter ADT is 42 percent less than the summer ADT. It is evident, therefore, that cold weather produces a much greater desire to call for aid. The number of motorists using the aid phone is given in Table 2.

#### RELATIONSHIP BETWEEN STRANDED MOTORISTS AND ALL MOTORISTS

Table 3 gives trip characteristics of all motorists and of stranded motorists according to 4 categories: trip length, frequency of road use, trip purpose, and location of vehicle registry. The percentage by category for the total number of vehicles and the stranded vehicles are similar. This seems to indicate that stranded motorists as a group may, in fact, be representative of all motorists in the traffic stream. The only noticeable variations occur in the summer survey data for trip length where the percentage of stranded motorists is less than the percentage of total motorists in the 0- to 100-mile trip category and is more in the 100- to 250-mile trip category. In addition, the percentage of stranded vehicles is less than that of total vehicles for the in-county reg-

TABLE 1  
REASONS FOR STOPS OR CALLS ON AID PHONE

| Reason             | Calls <sup>a</sup><br>(percent) | Stops <sup>b</sup><br>(percent) |
|--------------------|---------------------------------|---------------------------------|
| Tire failure       | 22.0                            | 40.9                            |
| Gas, water, or oil | 27.4                            | 14.9                            |
| Mechanical, tow    | 19.2                            | 16.3                            |
| Mechanical, no tow | 16.8                            | 21.1                            |
| Accident           | 7.3                             | 2.4                             |
| Fire               | 1.3                             | 1.0                             |
| Miscellaneous      | 6.0                             | 3.4                             |

<sup>a</sup>Derived from calls recorded by State Police dispatcher.

<sup>b</sup>From summer and winter surveys that include callers for aid, noncallers, and others.

TABLE 2  
USE OF AID PHONES BY MOTORISTS IN SUMMER AND WINTER

| Survey      | Number<br>Interviewed | Used Aid Phones |         | Not Aware of<br>Aid Phones |         |
|-------------|-----------------------|-----------------|---------|----------------------------|---------|
|             |                       | Number          | Percent | Number                     | Percent |
| Summer 1968 | 172                   | 48              | 28      | 40                         | 23      |
| Winter 1969 | 36                    | 16              | 44      | 4                          | 11      |

TABLE 3  
TRIP CHARACTERISTICS OF ALL MOTORISTS AND OF STRANDED MOTORISTS

| Characteristic          | Summer                        |                                    | Winter                        |                                    |
|-------------------------|-------------------------------|------------------------------------|-------------------------------|------------------------------------|
|                         | All<br>Motorists<br>(percent) | Stranded<br>Motorists<br>(percent) | All<br>Motorists<br>(percent) | Stranded<br>Motorists<br>(percent) |
| Trip length, miles      |                               |                                    |                               |                                    |
| 0 to 100                | 28.6                          | 20.0                               | 36.3                          | 47.1                               |
| 100 to 250              | 32.4                          | 44.4                               | 36.5                          | 29.4                               |
| 250 to 300              | 22.2                          | 23.1                               | 22.4                          | 23.5                               |
| Over 500                | 16.7                          | 12.5                               | 4.8                           | 0                                  |
| Frequency of road use   |                               |                                    |                               |                                    |
| Almost every day        | 12.4                          | 12.4                               | 17.7                          | 18.1                               |
| Almost every week       | 17.4                          | 17.8                               | 27.4                          | 36.4                               |
| Almost every month      | 22.6                          | 20.7                               | 33.1                          | 30.3                               |
| Once or twice a year    | 30.8                          | 26.0                               | 18.0                          | 15.1                               |
| Less than once a year   | 16.9                          | 23.1                               | 3.8                           | 0                                  |
| Trip purpose            |                               |                                    |                               |                                    |
| Social and recreational | 45.7                          | 53.2                               | 14.1                          | 27.3                               |
| School                  | 2.0                           | 0.6                                | 4.5                           | 3.0                                |
| Shopping                | 2.3                           | 0.6                                | 1.3                           | 3.0                                |
| Business                | 35.3                          | 41.4                               | 67.9                          | 57.6                               |
| Miscellaneous           | 14.7                          | 4.1                                | 12.2                          | 9.1                                |
| Vehicle registration    |                               |                                    |                               |                                    |
| In county               | 20.3                          | 12.8                               | 25.5                          | 23.1                               |
| In state, out of county | 47.8                          | 47.1                               | 56.2                          | 48.7                               |
| Out of state            | 31.9                          | 40.1                               | 18.3                          | 28.2                               |

istration category and more for the out-of-state category.

The winter survey data are very similar to the summer data except that the percentage of stranded short-trip drivers (0 to 100 miles) was greater than the percentage of total drivers. Only 14.1 percent of total motorists and more than 27 percent of the stranded motorists, nearly twice as many, were in the social and recreational trip category.

#### TRIP-LENGTH DISTRIBUTIONS FROM INTERVIEWS OF STRANDED MOTORISTS

Table 4 gives the relationship of trip length of use of aid phones by stranded motorists. The percentage of motorists stranded in the summer appears only to reflect the increased number of longer trips during this season, with the 100- to 250-mile trips having the highest percentage of stranded motorists. The percentage of motorists stranded in the winter also seems to follow the seasonal trend with more short trips; however, twice the percentage of stranded motorists taking short trips used the phones in the winter. Stranded motorists taking long trips in the winter are too few to be meaningful.

#### DISTANCE FROM STOPPING POINT TO NEAREST AID PHONE

The data given in Table 5 show that, on the average, stranded motorists could reach an aid phone by walking less than 2,000 ft. However, in order to reach a phone, a

TABLE 4  
USE OF AID PHONE RELATED TO TRIP LENGTH

| Trip Length<br>(miles) | Summer Survey                     |  |                                  | Winter Survey                     |  |                                  |
|------------------------|-----------------------------------|--|----------------------------------|-----------------------------------|--|----------------------------------|
|                        | Used<br>Aid<br>Phone<br>(percent) | Did Not<br>Use Aid<br>Phone<br>(percent) | Stopped<br>Vehicles<br>(percent) | Used<br>Aid<br>Phone<br>(percent) | Did Not<br>Use Aid<br>Phone<br>(percent) | Stopped<br>Vehicles<br>(percent) |
| 0 to 100               | 27                                | 21                                       | 23                               | 56                                | 29                                       | 41                               |
| 100 to 250             | 40                                | 35                                       | 36                               | 38                                | 33                                       | 35                               |
| 250 to 500             | 23                                | 33                                       | 30                               | 0                                 | 19                                       | 11                               |
| 500 and over           | 8                                 | 9  | 9                                | 6                                 | 0  | 3                                |
| (missing data)         | 2                                 | 2  | 2                                | 0                                 | 19                                       | 10                               |

TABLE 5  
DISTANCE FROM STRANDED VEHICLE STOPPING POINT TO NEAREST AID PHONE

| Survey                        | Number<br>Interviewed | Distance<br>Range<br>(ft) | Mean<br>Distance<br>(ft) | Standard<br>Deviation |
|-------------------------------|-----------------------|---------------------------|--------------------------|-----------------------|
| Summer                        |                       |                           |                          |                       |
| Total motorists               | 172                   | 0 to 4,390                | 1,240                    | 994                   |
| Motorists who used aid phones | 48                    |                           | 1,071                    | 1,223                 |
| Winter                        |                       |                           |                          |                       |
| Total motorists               | 36                    | 0 to 4,970                | 1,523                    | 1,013                 |
| Motorists who used aid phones | 16                    |                           | 1,234                    | 1,228                 |

stranded motorist has to leave his automobile and become a pedestrian on the freeway, which some drivers are reluctant to do.

Indications are that those stranded motorists who used the phones walked a slightly shorter distance than those who did not use the phone, which would indicate that the walking distance to reach a phone is not a main reason for not using a phone within the study area.

### FREQUENCY OF USE OF AID PHONES

Data accumulated during approximately 1½ years were analyzed to log the number of times phones were used. These data represent calls almost solely from stranded motorists as opposed to other informational calls. Of the 730 calls recorded, the analysis shows a mean of 11.77 calls per phone, a variance of 4.95, a minimum of 3, and a maximum of 25. Use appears to be rather uniform with some slightly greater use near each end of the highway section where the phones are installed.

The following is a listing of use of each of the phones for the group analyzed:

| Phone Site | Calls | Phone Site | Calls | Phone Site | Calls |
|------------|-------|------------|-------|------------|-------|
| 1          | 23    | 14         | 15    | 27         | 8     |
| 2          | 22    | 15         | 12    | 28         | 8     |
| 3          | 17    | 16         | 10    | 29         | 6     |
| 4          | 10    | 17         | 8     | 30         | 3     |
| 5          | 14    | 18         | 8     | 31         | 11    |
| 6          | 8     | 19         | 12    | 32         | 11    |
| 7          | 10    | 20         | 19    | 33         | 13    |
| 8          | 4     | 21         | 7     | 34         | 22    |
| 9          | 5     | 22         | 10    | 35         | 21    |
| 10         | 9     | 23         | 14    | 36         | 11    |
| 11         | 8     | 24         | 6     | 37         | 8     |
| 12         | 7     | 25         | 13    | 38         | 13    |
| 13         | 12    | 26         | 13    | 39         | 8     |

| Phone Site | Calls | Phone Site | Calls | Phone Site | Calls |
|------------|-------|------------|-------|------------|-------|
| 40         | 14    | 48         | 9     | 56         | 12    |
| 41         | 12    | 49         | 6     | 57         | 18    |
| 42         | 7     | 50         | 11    | 58         | 19    |
| 43         | 18    | 51         | 11    | 59         | 25    |
| 44         | 7     | 52         | 8     | 60         | 14    |
| 45         | 6     | 53         | 12    | 61         | 19    |
| 46         | 9     | 54         | 16    | 62         | 13    |
| 47         | 11    | 55         | 14    |            |       |

#### SUMMARY OF TAPE RECORDER DATA

For approximately 6 months, tape recorders were activated whenever the State Police answered an incoming call from an aid phone. Table 6 gives a summary of the recorded data. The distributions given are perhaps not as reliable as data from the summer and winter surveys inasmuch as the needs could not be determined from all conversations; also, more than 1 call per accident would often be received.

#### TIME NEEDED FOR STRANDED MOTORIST TO REACH PHONE

Of the 48 stranded motorists interviewed in the summer, 30 had records of time needed to reach the phones. Based on these data, we found that most of the stranded motorists spent fewer than 10 min, but not more than 24 min, to reach the phones (Fig. 1). Ten out of 16 interviewed stranded motorists who used the phones in the winter had the records of time needed to reach the phone. This analysis, again, showed that in winter conditions motorists reached phones in about 12 min. Apparently, the phone system provided a fast way for the stranded motorists to report their troubles and ask for help. Those who were aware of the telephone system and could use the phones to excellent advantage but did not use them were probably afraid of unreasonable charges.

#### TIME NEEDED TO SECURE AID

Figure 2 shows the time from the vehicle stop to the time of aid arrival from January 1, 1968, to May 1, 1969. About 90 percent of the stranded motorists who used aid phones waited fewer than 45 min before the aid arrived; 85 percent of them waited only 30 min or less. Most of the service stations provided effective emergency aid to motorists stranded on the highway. Those stations that took more than 100 min to respond to a call were delayed probably because of a busy wrecker schedule in the winter.

TABLE 6  
CALL INFORMATION TAPE-RECORDED DURING  
6-MONTH PERIOD

| Item   | Number | Percent         |
|--|--------|-----------------|
| Reason for call                                    |        |                 |
| Request aid for themselves                         | 595    | 70 <sup>a</sup> |
| Request aid for others                             | 137    | 16              |
| Obtain or give information<br>or satisfy curiosity | 120    | 14              |
| Test system  | 110    | —               |
| Total  | 962    | 100             |
| Aid requested                                      |        |                 |
| Tire   |        | 16.6            |
| Gas  |        | 18.2            |
| Water or oil                                       |        | 2.9             |
| Mechanical   |        | 24.6            |
| Accident   |        | 27.9            |
| Medical  |        | 2.2             |
| Directional information                            |        | 7.6             |
| Total  |        | 100.0           |

<sup>a</sup>Test calls not included.

#### TOTAL ELAPSED TIME FOR STRANDED MOTORISTS

A mathematical model was derived that equated total elapsed time from the time the vehicle stopped until it departed to the various means of obtaining aid during the summer survey. Gamma distribution by maximum likelihood estimate (4) was chosen, and a computer program was run for the density functions on the categories of methods of obtaining aid.

For the various methods of obtaining aid, the following equations list these predicted gamma density func-



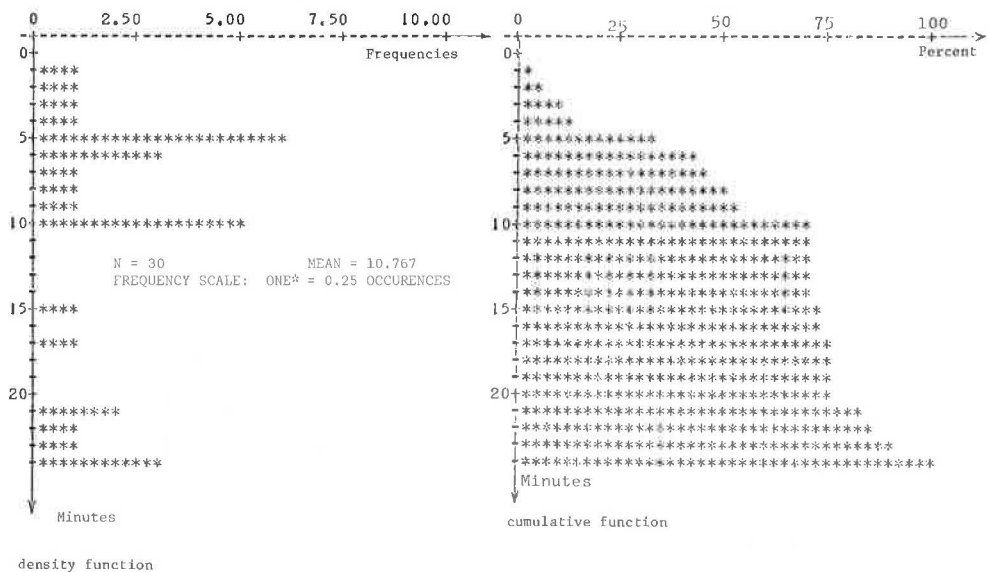


Figure 1. Time for motorists to reach aid phones in summer.

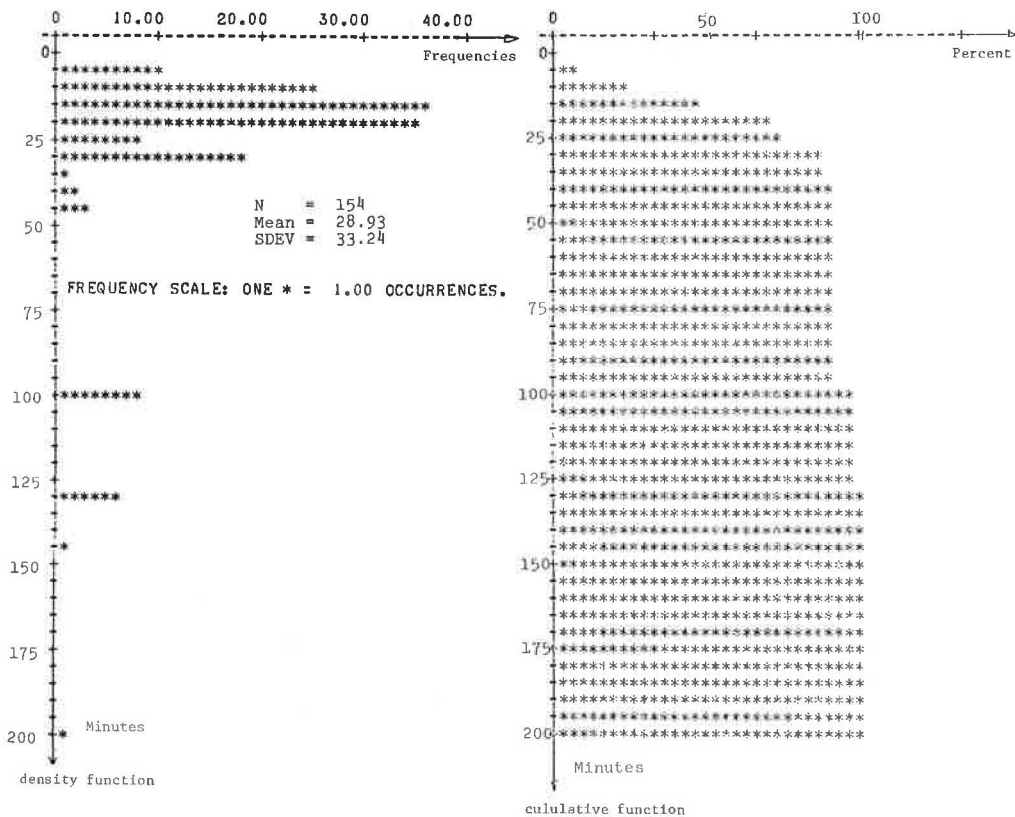


Figure 2. Time for aid to reach motorists who used aid phones.

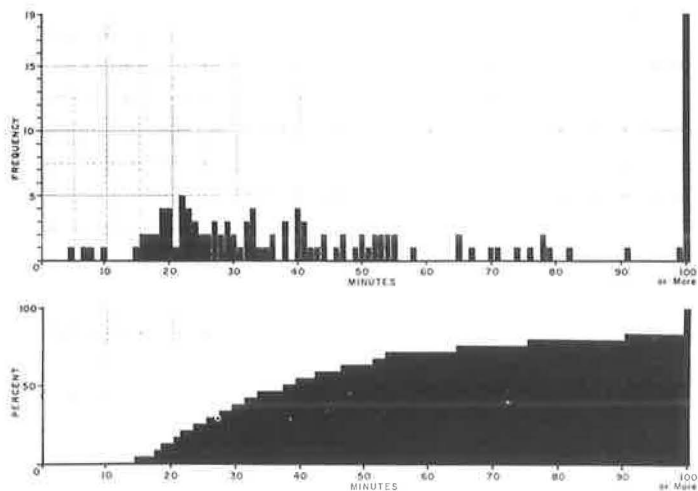


Figure 3. Total elapsed time for motorists who did not use phones in summer.

tions, where  $x$  is the elapsed time in minutes:

- 1. Aid phone used, no patrol aid,  $f(x) = 0.0092456 x^{0.108} \exp[-(x/86.803)]$ ;
- 2. Aid phone used, with patrol aid,  $f(x) = 0.0006792 x^{0.951} \exp[-(x/45.386)]$ ;
- 3. Public phone used, no patrol aid,  $f(x) = 0.0000139 x^{1.60375} \exp[-(x/36.486)]$ ;
- 4. Walked, no patrol aid,  $f(x) = 0.0018055 x^{0.9284} \exp[-(x/29.305)]$ ;
- 5. Hitchhiked, no patrol aid,  $f(x) = 0.0022847 x^{0.75329} \exp[-(x/43.69)]$ ;
- 6. Miscellaneous, no patrol aid,  $f(x) = 0.003074 x^{0.0870} \exp[-(x/25.775)]$ ; and
- 7. Miscellaneous, with patrol aid,  $f(x) = 0.0052012 x^{0.455} \exp[-(x/59.109)]$ .

Figures 3 and 4 show the relationship of total elapsed stranded time for users and nonusers of aid phones during the summer. When all needs are considered, no signifi-

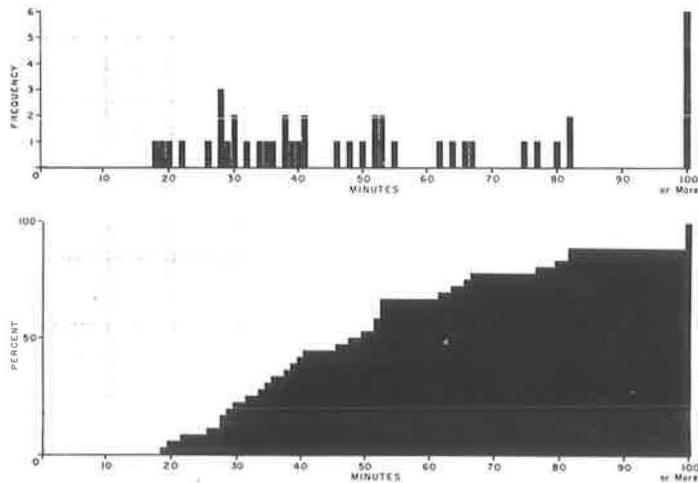


Figure 4. Total elapsed time for motorists who did use phones in summer.

cant differences occur between total stranded times of users and nonusers of phones. However, as stated earlier, times for specific needs will vary greatly for use or non-use of phones. Elapsed times during the winter were very similar except that waiting times for aid for both users and nonusers were increased for more people.

## CONCLUSIONS AND RECOMMENDATIONS

These studies have provided an intensive review of the stranded motorist problem at 2 relatively short rural locations on Michigan's freeway system. This look into the problem has provided much more information than was previously available.

The instrumented 30-mile section on I-94 has been generating 150 to 250 calls per month to the State Police posts. Many more stops occur because only 30 to 50 percent of all drivers in need of help call for assistance. Many factors of the system concerning motorist needs and benefits, telephone use, costs, and operation have been outlined. If the average rural stopping rate is expanded to cover the state's 1,400 miles of freeway, then on the average day, approximately 840 vehicles in the state will be stopped on the shoulders for 12 min or more. The stopping rates from Michigan studies varied directly with traffic volumes.

Many of the early telephone system operational problems have been resolved; however, some false ringing still occurs. At least part of the problem is caused by leased-line operating difficulties. Approximately 1 of every 6 phone sites has been struck by out-of-control vehicles, and some vandalism occurs sporadically.

Relative use of the system with and without area illumination was not a part of the study; however, the system would have cost 40 to 50 percent less had power needs for lights at the phone sites been eliminated. A study of the 135-mile system being installed on I-80 in Illinois should answer part of the question concerning the need for lights at each site. The Illinois study should also define whether operational problems may be avoided by not using leased telephone lines. It was recently found that the Michigan system has been operating for 2½ years without the leased lines connecting the system to each State Police post being shown on the telephone company's engineering charts. Periodically these lines were used as test circuits by the phone company, and extraneous signals would trigger the system equipment.

It appears that further investigations of operating characteristics and costs are merited to determine the efficacy of a leased telephone system operation as opposed to one that is wholly state owned. Information from a Battelle Memorial Institute report for the Ohio Department of Highways (11) indicates that some leased telephone systems without lighting are costing as much or more during a 10-year period as Michigan's test system. Also, some cost projections for regular official patrols appear to be several times more costly than a voice-by-wire communications system.

The studies have shown that a high percentage of freeway drivers desire some system that will provide positive communication for aid for stranded motorists, and drivers seem to favor the Michigan type of telephone system.

This study shows that a number of freeway drivers have problems that cause them to stop their vehicles and that the magnitude of these problems can now be estimated. The criticality of the problems is based on variables such as individual physical ability, nature of need, geographic location, weather, and even time of day.

A telephone system, combined with partial State Police patrol activity plus referral to a commercial agency, is recommended for servicing the stranded motorist. It should be noted that we do not believe that any system can necessarily be shown to be cost-effective in monetary terms. It should be considered as a necessary public service with system selection judged on the basis of operation and cost factors of other candidate systems. Based on a 10-year operation of this system, 150 calls per month, and \$15,000 annual costs, each call would average \$25.00.

If a statewide telephone network were to be constructed, certain economies in addition to those of this experimental system could be accomplished through selective grouping and intermediate terminations of circuits, possibly at rest areas or information centers, and then transmitting by direct wire to a nearby State Police post. In a large network, other design economies would be possible.



As a means of comparison, if a motorist-aid telephone system without lighting were extended to the state's rural freeways, it could be installed for an estimated cost of about \$3 million. This \$3 million would buy approximately 1,000 ft of urban freeway.

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# EVALUATION OF COMMERCIAL RADIO FOR REAL-TIME DRIVER COMMUNICATIONS ON URBAN FREEWAYS

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Driver preferences were measured through a questionnaire survey to evaluate the potential of commercial radio for providing real-time freeway traffic information to drivers in urban areas. In addition, traffic reports given by 3 radio stations in the Houston area were monitored to evaluate the reliability, accuracy, and timeliness of current traffic broadcasts. The results of the study suggest that commercial radio could play an important role as part of an effective real-time traffic information system for urban freeway drivers. However, traffic reports as currently broadcast by the 3 radio stations monitored in Houston would not be completely satisfactory for the system being considered. Improvements in the reliability and timeliness of the traffic information provided would be necessary.

•THE Texas Transportation Institute and the Texas Highway Department, in cooperation with the U.S. Department of Transportation, are conducting a research project on freeway control and information systems. This project is an outgrowth of previous research on the Gulf Freeway in Houston that culminated in an operational freeway ramp-control system (1). One objective of the project is to develop a real-time traffic information system for an urban freeway corridor. Several designs will be evaluated for the development of an effective system.

One method of transmitting real-time traffic information is through the use of commercial radio. To obtain a better understanding of the use of commercial radio for real-time driver communications on urban freeways, driver use of and attitudes toward radio broadcasts were evaluated. In addition, the procedures used by 3 Houston radio stations in broadcasting freeway traffic information and the reliability, accuracy, and timeliness of traffic information currently being broadcast were evaluated.

## PROJECT APPROACH

A comprehensive questionnaire designed by a multidisciplinary team was administered to 505 employees of several organizations in Houston and Dallas to obtain data for the design of a driver-information system. A portion of the questionnaire was designed to provide specific inputs for the study of the application of commercial radio to freeway communications. Specific details of the questionnaire survey have been documented in the literature (2, 3).

The Gulf Freeway in Houston was selected as the study site to evaluate traffic information currently being broadcast because of the existing research and surveillance facilities. The Gulf Freeway surveillance and control system includes entrance ramp signals, a digital process control computer, and a 14-camera closed-circuit television surveillance system. Since the installation of the television system, the Houston Police Department has maintained a patrolman and a base station police radio in the control center to detect and report traffic incidents that occur on the study section of the freeway. Information relating to the occurrence of incidents is also recorded on log



sheets. This surveillance provided the opportunity to evaluate the responses of radio stations in the Houston area to the incidents on the freeway.

For the purposes of this study, the broadcasts of 3 local radio stations that provided peak-period traffic bulletins were monitored with magnetic voice recorders. The tapes were later transcribed, and traffic information relating to the Gulf Freeway study section was recorded on prepared data forms. The following information was noted:

1. The station that broadcast information about the incident;
2. The extent of the information broadcast;
3. The time of the broadcast (or broadcasts) relating to the specific incident; and
4. The station that broadcast information when the incident had been cleared or removed.

The data forms were then compared to the raw data recorded by the television monitors.

To evaluate the provision of traffic information to motorists, personnel from the 3 radio stations were interviewed by representatives of the Texas Transportation Institute and the Texas Highway Department. A basic set of questions was prepared to make the interviews as consistent as possible. In addition, an interview was held with law enforcement personnel in the dispatcher's office of the Houston Police Department.

## RESULTS OF SURVEY

The results of the comprehensive questionnaire survey relevant to this study and those reported elsewhere (2, 3) have shown that a large majority of the participants indicated that they would use accurate real-time freeway traffic information to plan their trips. The respondents also indicated that they would react to real-time information about freeway conditions by rerouting to a suitable alternate route when it is known to be available. The majority prefer to use the alternate route only to bypass congested areas on the freeway and to return to the freeway as soon as possible. In addition, they would be more inclined to divert to an alternate route before reaching the freeway than to change when on the freeway.

### Current Use of Commercial Radio for Route Selection

The results of the part of the questionnaire used to evaluate the current use of commercial radio to provide real-time driver information are given in Table 1. The results show that 57 percent of the participants surveyed indicated that they normally use the traffic and accident reports that are given over the radio stations during the peak periods to plan their trips within the city.

Those who did not use the radio for these reports were asked to give reasons why they did not. A summary of these comments is given in Table 2. It is interesting to note that, although 43 percent of the sampled participants gave a negative response, about 7 percent would not have the opportunity to use the reports. This percentage includes those respondents who do not have car radios (3.7 percent) and those who do not travel on the city streets (3.0 percent) or ride buses during the peak periods (0.6 percent). If this 7 percent were eliminated from the sample, the results show that 62

TABLE 1  
DRIVER USE OF CAR RADIO

| Question  | Response | Respondents<br>(percent) |
|---|----------|--------------------------|
| Do you normally use radio traffic and accident reports for trip planning during peak periods?             |          |                          |
| All respondents   | Yes      | 57                       |
|   | No       | 43                       |
| Respondents excluded who do not have car radios, who do not drive during rush hours, and who ride the bus | Yes      | 62                       |
|   | No       | 38                       |
| Do you normally listen to car radio?  | Yes      | 89                       |
|   | No       | 11                       |

TABLE 2

COMMENTS OF THOSE WHO INDICATED THAT THEY DO NOT USE  
TRAFFIC AND ACCIDENT REPORTS GIVEN ON RADIO STATIONS

| Comment  | Respondents |         |
|--|-------------|---------|
|  | Number      | Percent |
| Dissatisfied with accuracy and timeliness of reports | 55          | 10.9    |
| Do not listen to or hear the reports                 | 30          | 5.9     |
| Take only one route to and from work                 | 26          | 5.2     |
| Do not have a radio                                  | 19          | 3.7     |
| Do not travel freeways during peak flows             | 15          | 3.0     |
| Live a short distance from place of work             | 7           | 1.4     |
| Have no congestion on route                          | 7           | 1.4     |
| Travel route not involved in reports                 | 5           | 1.0     |
| Ride bus to and from work                            | 3           | 0.6     |
| Other  | 8           | 1.5     |
| Total  | 175         | 34.6    |

percent of the participants who have radios and who could benefit from radio reports on freeway conditions currently use the information for trip planning (Table 1). There is indication, based on the comments given in Table 2, that this percentage would increase if the information were more accurate and timely.

#### Potential of Commercial Radio for Effective Systems Design

The data were analyzed to determine the potential of commercial radio as part of an integrated real-time driver communication system. Data given in Table 1 show that 89 percent of the participants normally listen to the car radio. Such a high majority indicates that this mode would seem to have great potential for providing real-time traffic information to the driver.

Analysis of the drivers' priorities for methods of communication revealed that there was a definite preference for receiving real-time freeway information by means of commercial radio and changeable message signs as opposed to a telephone service or television. The preference for the mode of communication was evenly divided between commercial radio and changeable message signs. Forty-five percent of the respondents selected changeable message signs. Telephone and television were not preferred, each having received only 5 percent of the first-choice votes. A summary of the driver priorities is given in Table 3.

The data were further analyzed to determine whether there was consistency in the manner in which the participants ranked these modes. Kendall's coefficient of concordance,  $W$ , which detects the consistency (or lack of consistency) in the ranking of ordinal data, was computed (4). The significance of the coefficient was then tested by using the  $\chi^2$  statistic. The test does not reveal the degree of preference, but it does determine whether the ranking was consistent among the participants and provides a

TABLE 3

DRIVER PRIORITIES OF MODES FOR RECEIVING REAL-TIME  
FREEWAY INFORMATION

| Mode       | First<br>Choice<br>(percent) | Second<br>Choice<br>(percent) | Third<br>Choice<br>(percent) | Fourth<br>Choice<br>(percent) | Average<br>Ranking <sup>a</sup><br>Points | Standard<br>Deviation |
|------------|------------------------------|-------------------------------|------------------------------|-------------------------------|---|-----------------------|
| Radio      | 45                           | 46                            | 7                            | 2                             | 3.4                                       | 0.6                   |
| Signs      | 45                           | 36                            | 13                           | 4                             | 3.3                                       | 0.8                   |
| Telephone  | 5                            | 11                            | 31                           | 53                            | 1.7                                       | 0.8                   |
| Television | 5                            | 7                             | 49                           | 39                            | 1.8                                       | 0.7                   |

<sup>a</sup>Based on assigning 4 points for each first choice, 3 points for each second choice, 2 points for each third choice, and 1 point for each fourth choice. Minimum mean = 1.0; maximum mean = 4.0.

TABLE 4  
KENDALL'S TEST FOR RANKING MODES OF COMMUNICATION

| Rank  | Radio  |        | Signs  |        | Telephone |        | Television |        | Total  |        |
|-------|--------|--------|--------|--------|-----------|--------|------------|--------|--------|--------|
|       | Number | Points | Number | Points | Number    | Points | Number     | Points | Number | Points |
| 1     | 195    | 780    | 198    | 792    | 20        | 800    | 20         | 80     | 433    | 1,732  |
| 2     | 199    | 597    | 157    | 471    | 47        | 141    | 30         | 90     | 433    | 1,299  |
| 3     | 32     | 64     | 55     | 110    | 133       | 266    | 213        | 426    | 433    | 866    |
| 4     | 7      | 7      | 23     | 23     | 233       | 233    | 170        | 170    | 433    | 433    |
| $R_j$ |        | 1,448  |        | 1,396  |           | 720    |            | 766    |        | 4,330  |

Note:  $\bar{R} = \sum R_j / N = 1,082.5$ ;  $S = \sum (R_j - \bar{R})^2 = 463,451$ ;  $W = (12S) / [k^2 (N^3 - N)] = 0.4944$ ;  $\chi^2 = k(N - 1) W = 642.2$  (significant at 0.01 level); and degrees of freedom = 3.

basis for determining the best estimate of the true ranking based on the  $R_j$  values. The results are given in Table 4.

The analysis revealed that  $W$  was computed to be 0.4944. In addition, the  $\chi^2$  value of 642.2 was highly significant at the 0.01 level. Therefore, it can be concluded that there was consistency in the ranking of the communication modes among the participants and that the selection of the modes was not random. Based on the values of  $R_j$  given in Table 4, the order of preference is as follows: choice 1, radio; choice 2, signs; choice 3, television; and choice 4, telephone.

It must be emphasized that the statistical test does not allow one to measure the relative differences among the choice of modes. The final ordering of preferences was based solely on the  $R_j$  values of Kendall's test. An examination of these values for radio and signs showed that the differences between them were relatively small. In addition, from the data given in Table 3, it is evident that the computed average ranking points for these modes are approximately equal. The results indicate that there does not appear to be any appreciable difference between the preference for radio and the preference for changeable message signs.

To further evaluate the role of commercial radio in the design of a real-time freeway information system, analysis was made to determine the location, relative to the freeway, where information would be most helpful to the motorists. The results of the respondents' ranking of alternate locations are given in Table 5. Statistical analyses of the data are given in Table 6.

The computed value of  $W$  (0.1332) was shown to be highly significant at the 0.01 level, which indicated consistency in the rankings among respondents. Based on Kendall's test, the following is the order of preference for the following locations: choice 1, on the major street; choice 2, at the entrance ramp; choice 3, at the beginning of the trip; and choice 4, on the freeway.

The results indicate that motorists prefer to receive information about freeway traffic conditions before they enter the freeway and at locations where decisions can be made with respect to the selection of alternate routes. The preceding ordering is an

TABLE 5  
DRIVER PRIORITIES OF LOCATIONS FOR RECEIVING REAL-TIME FREEWAY INFORMATION

| Location             | First Choice (percent) | Second Choice (percent) | Third Choice (percent) | Fourth Choice (percent) | Average Ranking Points <sup>a</sup> | Standard Deviation |
|----------------------|------------------------|-------------------------|------------------------|-------------------------|-------------------------------------|--------------------|
| On freeway           | 8                      | 14                      | 34                     | 44                      | 1.9                                 | 0.9                |
| On major street      | 34                     | 39                      | 18                     | 9                       | 3.0                                 | 0.9                |
| At entrance ramps    | 16                     | 36                      | 41                     | 7                       | 2.7                                 | 0.8                |
| At beginning of trip | 42                     | 11                      | 7                      | 40                      | 2.6                                 | 1.3                |

<sup>a</sup>Based on assigning 4 points for each first choice, 3 points for each second choice, 2 points for each third choice, and 1 point for each fourth choice. Minimum mean = 1.0; maximum mean = 4.0.



TABLE 6  
KENDALL'S TEST FOR RANKING LOCATIONS OF COMMUNICATION

| Rank  | On Freeway |        | On Major Streets |        | At Entrance Ramps |        | At Beginning of Trip |        | Total  |        |
|-------|------------|--------|------------------|--------|-------------------|--------|----------------------|--------|--------|--------|
|       | Number     | Points | Number           | Points | Number            | Points | Number               | Points | Number | Points |
| 1     | 38         | 152    | 156              | 624    | 71                | 284    | 189                  | 756    | 454    | 1,816  |
| 2     | 62         | 186    | 177              | 531    | 165               | 495    | 50                   | 150    | 454    | 1,362  |
| 3     | 152        | 304    | 82               | 164    | 188               | 376    | 32                   | 64     | 454    | 908    |
| 4     | 202        | 202    | 39               | 39     | 30                | 30     | 183                  | 183    | 454    | 454    |
| $R_j$ |            | 844    |                  | 1,358  |                   | 1,185  |                      | 1,153  |        | 4,540  |

Note:  $\bar{R} = \sum R_j / N = 1,135$ ;  $S = \sum (R_j - \bar{R})^2 = 137,234$ ;  $W = (12S) / [k^2 (N^3 - N)] = 0.1332$ ;  $\chi^2 = k(N - 1) W = 181.4$  (significant at 0.01 level); and degrees of freedom = 3.

indication of the relative preference of the 4 alternatives. It does not indicate any lack of need for information at any of the locations. The ordering strongly suggests that drivers would prefer to receive freeway traffic information before they enter the freeway so that appropriate diversion at critical decision points can be made.

Although the preceding listing represents the ordering of locations based on averages, the first choice selections were somewhat different. Forty-two percent of the participants felt that the beginning of the trip was the most desirable location in relation to the other alternatives. Thirty-four percent chose to receive information on the major street as their first choice, 16 percent selected the entrance ramp, and 8 percent preferred information on the freeway.

The distribution of the sample relative to preference for receiving information at the beginning of the trip was of considerable interest. Forty-two percent selected this alternative as their first choice, whereas 40 percent indicated that this alternative was least preferred. These results indicate that approximately half of the freeway drivers prefer to know the freeway traffic condition before beginning their trips, while the other half find it unnecessary.

This contrast was evaluated by analyzing the data from these 2 groups. In addition, data of the groups that selected either radio or signs as the preferred mode of communication were analyzed to establish any relationships between the selection of location and the mode of communication. The results are given in Tables 7 and 8. The results show that the participants who preferred to receive freeway traffic information at the beginning of their trips ranked radio as their first choice of communication. Those who considered the provision of information at the beginning of the trip to be of least value selected signs as their first choice of communication.

Analysis of the communication modes revealed that the participants who selected radio as their preferred mode indicated that they considered information at the beginning of the trip and on the major streets to be of greatest value. The analysis also revealed that those who chose signs as the preferred mode of communication placed a

TABLE 7  
PRIORITIES OF LOCATIONS FOR RECEIVING REAL-TIME INFORMATION

| Participant  | Location             | First Choice (percent) | Second Choice (percent) | Third Choice (percent) | Fourth Choice (percent) | Average Ranking Points <sup>a</sup> | Standard Deviation |
|--------------|----------------------|------------------------|-------------------------|------------------------|-------------------------|-------------------------------------|--------------------|
| Prefer radio | On freeway           | 6                      | 11                      | 33                     | 50                      | 1.8                                 | 0.8                |
|              | On major street      | 32                     | 41                      | 16                     | 11                      | 3.0                                 | 0.9                |
|              | At entrance ramp     | 10                     | 35                      | 46                     | 9                       | 2.5                                 | 0.7                |
|              | At beginning of trip | 52                     | 13                      | 5                      | 30                      | 3.0                                 | 1.3                |
| Prefer signs | On freeway           | 12                     | 16                      | 37                     | 35                      | 2.1                                 | 0.9                |
|              | On major street      | 39                     | 33                      | 22                     | 6                       | 3.1                                 | 0.9                |
|              | At entrance ramp     | 23                     | 42                      | 32                     | 3                       | 2.9                                 | 0.8                |
|              | At beginning of trip | 26                     | 9                       | 9                      | 56                      | 2.1                                 | 1.3                |

<sup>a</sup>Based on assigning 4 points for each first choice, 3 points for each second choice, 2 points for each third choice, and 1 point for each fourth choice. Minimum mean = 1.0; maximum mean = 4.0.

TABLE 8  
PRIORITIES FOR MODES OF RECEIVING REAL-TIME INFORMATION

| Participant                                    | Mode       | First Choice (percent) | Second Choice (percent) | Third Choice (percent) | Fourth Choice (percent) | Average Ranking Points <sup>a</sup> | Standard Deviation |
|--|------------|------------------------|-------------------------|------------------------|-------------------------|-------------------------------------|--------------------|
| Prefer information at beginning of trip        | Radio      | 56                     | 34                      | 9                      | 1                       | 3.5                                 | 0.7                |
|  | Signs      | 28                     | 44                      | 20                     | 8                       | 3.0                                 | 0.9                |
|  | Telephone  | 9                      | 14                      | 28                     | 49                      | 1.9                                 | 0.9                |
|  | Television | 7                      | 8                       | 43                     | 42                      | 1.9                                 | 0.8                |
| Do not prefer information at beginning of trip | Radio      | 34                     | 60                      | 4                      | 2                       | 3.3                                 | 0.6                |
|  | Signs      | 64                     | 28                      | 6                      | 2                       | 3.6                                 | 0.6                |
|  | Telephone  | 1                      | 7                       | 32                     | 60                      | 1.5                                 | 0.6                |
|  | Television | 1                      | 5                       | 58                     | 36                      | 1.8                                 | 0.6                |

<sup>a</sup>Based on assigning 4 points for each first choice, 3 points for each second choice, 2 points for each third choice, and 1 point for each fourth choice. Minimum mean = 1.0; maximum mean = 4.0.

high emphasis for information on the major streets and at the entrance ramps. Information at the beginning of the trip and information on the freeway were least preferred.

The results of the study show an expected relationship between the selection of mode and the selection of location. If one were to analyze the locations where the participants live or work in relationship to the freeway, there undoubtedly would be a wide variance in the opportunities to divert, and the selection of communication mode would be influenced by these opportunities. In addition, some people plan their trips for work based on information received while listening to their radios at their homes. The results suggest that the combination of radio and signing would be desirable for an effective real-time freeway information system.

#### Houston Versus Dallas Participants

The data were analyzed to determine whether there were any differences between the responses of the Houston participants and those from the Dallas participants. There was some speculation that traffic reports given by the radio stations may have been better in one of the cities; thus, the responses by the participants may have been different. The results revealed that there were no appreciable differences in the responses from participants in the 2 cities.

#### **BROADCAST PROCEDURES**

Basically, all 3 stations that were monitored in Houston rely on traffic information provided by the Houston Police Department, although there are slight variations as to how the information is placed on the air. Telephone calls requesting the services of the police and calls from other police officers in the field are directed to the dispatch office. Those calls received relating to traffic accidents or other situations that cause traffic congestion during the peak periods are noted, and the information is given to an officer who has the responsibility of relaying this to the radio stations. It is important to note that information received by the police dispatcher is the only information that is relayed to the radio stations by the police. Consequently, traffic incidents not requiring police aid or investigation would not normally be available for broadcast by the radio stations.

A schematic of the normal broadcast process is shown in Figure 1. Two basic methods of obtaining traffic information are utilized by the radio stations in Houston. One method involves telephoning the officer who has the responsibility of relaying traffic information that he has received. The radio station personnel generally telephone whenever the station is ready to broadcast the information.

In the second method, the police officer takes the initiative. When the officer has recorded a sufficient number of incidents, he signals the radio stations by pressing a button located at the base of a microphone. Exactly 1 min from this signal, the officer broadcasts the available information to the radio station. Information is given at approximately 1/2-hour intervals. However, when a major incident occurs, the reports



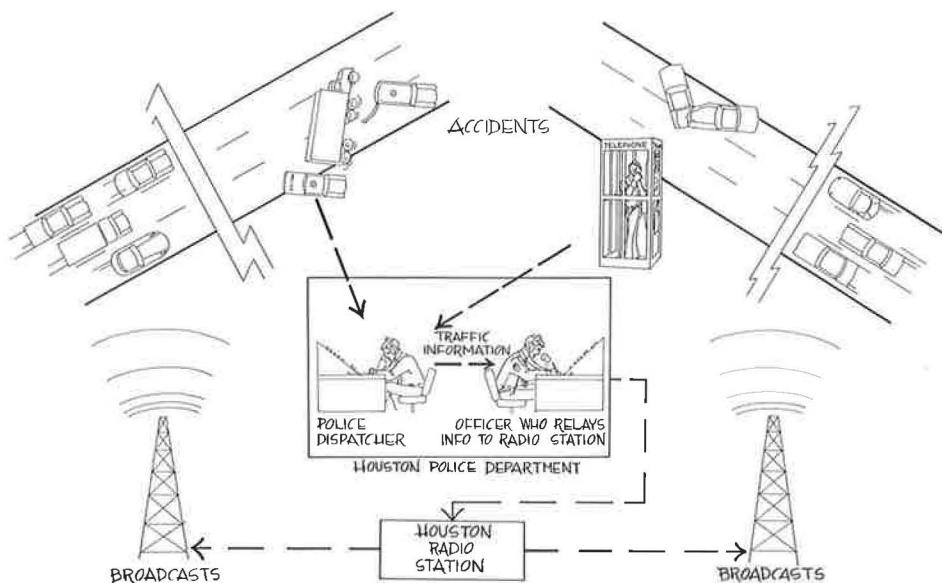


Figure 1. Schematic of traffic information transfer.

may be given at more frequent intervals. Four radio stations in Houston use this method, whereas the other stations telephone the officer directly.

The radio stations then take 1 of 3 actions. Some stations broadcast the information live as it is being received. Others record the information and then play the recorded tape on the air as soon as a convenient opportunity arises. Other stations utilize the traffic information that they receive, but the radio announcer himself makes the broadcast. The 3 radio stations that were monitored use the following procedures:

1. Station A calls the officer when it is ready to broadcast traffic information. The information is taped and played on the air as soon as possible.
2. Station B calls the officer when it is ready to broadcast but uses its own personnel to broadcast on the air.
3. Station C uses procedures comparable to station A.

### Traffic Broadcasts

A summary of the traffic reports by the 3 radio stations is given in Table 9. A total of 214 incidents were observed within the Gulf Freeway surveillance area during the study period and included 110 accidents and 104 stalls. The analysis revealed that a relatively low percentage of the observed accidents was actually broadcast. Analysis revealed that 52 percent of the accidents were not reported by any of the stations, 24 percent of the accidents were reported by only 1 station, 17 percent of the accidents were reported by 2 stations, and 7 percent of the accidents were reported by 3 stations.

TABLE 9  
TRAFFIC REPORTS OF INCIDENTS

| Station | Accidents Reported |                      | Stalls Reported |                      |
|---------|--------------------|----------------------|-----------------|----------------------|
|         | Number             | Percent <sup>a</sup> | Number          | Percent <sup>b</sup> |
| A       | 21                 | 19                   | 3               | 3                    |
| B       | 29                 | 26                   | 0               | 0                    |
| C       | 38                 | 35                   | 0               | 0                    |

<sup>a</sup>Number of accidents observed = 110.

<sup>b</sup>Number of stalls observed = 104.

Although the effects of stalled vehicles during the peak periods could be as adverse as some of the accidents, stalled vehicles were very rarely reported by the monitored radio stations (only 3 reports of 104 stalls). The average duration of a stall was about 10 min, which can be compared to the 13-min duration of an accident on the roadway.



### Relative Time of Radio Reports

In addition to the probability of incident reports by the radio stations, it was also important to determine the time of the reports relative to the occurrence of the incidents. The ideal situation would be that the radio stations report the incident immediately after it occurs. If the motorist is informed as early as possible, he is afforded more decision time in which to respond to the information and to choose an alternate route if necessary.

A summary of the reports by the 3 radio stations is given in Table 10. The earliest report time was 1 min, whereas the latest time of the initial broadcast was 98 min. The average number of broadcasts by the stations per reported accident was about 1.3.

Results of the accident reports, with respect to the duration of accidents on the roadway for stations A, B, and C, are given in Table 11. The results indicate that there is no relationship between the duration of accidents and the response time of the radio stations to broadcast the information. There was a wide variability in the response time of each radio station.

The delay by the radio stations to report freeway traffic accidents appears to be due to 2 major reasons. The first is the delay involved between the time the police dispatcher's office receives the information and the time this information is relayed to the radio stations. Based on the interviews with the radio stations and the Police Department personnel, it appears that a delay of  $\frac{1}{2}$  hour is not uncommon. The other major reason is that a station transmits reports when its normal scheduling permits, and often this increases the delay.

### Accuracy and Reliability of Radio Reports

An analysis of the locations of incidents reported by the radio stations and the locations observed by the surveillance center revealed the following: Radio reports of traffic incidents were generally correct as to location; little information was broadcast that indicated the length of freeway affected by an incident; and no radio reports were monitored that indicate whether an accident that was previously reported had been cleared.

TABLE 10

SUMMARY OF REPORTS OF ACCIDENTS BY STATIONS

| Station | Percent of Accidents Reported | Average Time to Report Accident (min) | Range of Report Times (min) | Average Number of Broadcasts per Accident Reported |
|---------|-------------------------------|---------------------------------------|-----------------------------|--|
| A       | 19                            | 21.3                                  | 8 to 44                     | 1.3  |
| B       | 26                            | 24.5                                  | 1 to 98                     | 1.2  |
| C       | 35                            | 26.9                                  | 3 to 58                     | 1.3  |

TABLE 11

REPORTS OF ACCIDENTS BY STATIONS A, B, AND C

| Station | Duration of Accidents on Roadway (min) | Number of Accidents | Number of Accidents Reported by Station | Average Time to Report Accident (min) | Standard Deviation (min) | Range of Report Times (min) | Average Number of Reports for Same Accident | Average Time Between Additional Reports (min) |
|---------|--|---------------------|---|---------------------------------------|--------------------------|-----------------------------|---|---|
| A       | ≤4                                     | 29                  | 4                                       | 23                                    | 7.6                      | 15 to 30                    | 2.0   | 18  |
|         | 5 to 8                                 | 24                  | 4                                       | 26                                    | 16.6                     | 10 to 44                    | 1.7   | 16  |
|         | 9 to 12                                | 12                  | 4                                       | 19                                    | 9.3                      | 11 to 31                    | 1.0   | —   |
|         | 13 to 16                               | 12                  | 2                                       | 15                                    | 9.9                      | 8 to 22                     | 1.5   | 33  |
|         | 17 to 55                               | 33                  | 7                                       | 21                                    | 9.7                      | 9 to 33                     | 1.3   | 38  |
| B       | ≤4                                     | 29                  | 4                                       | 15                                    | 7.4                      | 9 to 26                     | 1.0   | —   |
|         | 5 to 8                                 | 24                  | 4                                       | 25                                    | 10.1                     | 17 to 40                    | 1.0   | —   |
|         | 9 to 12                                | 12                  | 4                                       | 31                                    | 14.3                     | 13 to 48                    | 1.0   | —   |
|         | 13 to 16                               | 12                  | 7                                       | 22                                    | 12.2                     | 6 to 45                     | 1.0   | —   |
|         | 17 to 55                               | 33                  | 10                                      | 27                                    | 26.9                     | 1 to 98                     | 1.2   | 38  |
| C       | ≤4                                     | 29                  | 5                                       | 23                                    | 9.7                      | 10 to 34                    | 1.4   | 13  |
|         | 5 to 8                                 | 24                  | 8                                       | 29                                    | 16.8                     | 9 to 58                     | 1.3   | 45  |
|         | 9 to 12                                | 12                  | 6                                       | 21                                    | 10.4                     | 3 to 34                     | 1.0   | —   |
|         | 13 to 16                               | 12                  | 5                                       | 31                                    | 14.3                     | 13 to 49                    | 1.4   | 26  |
|         | 17 to 55                               | 33                  | 14                                      | 28                                    | 13.4                     | 8 to 40                     | 1.4   | 17  |

## SUMMARY OF FINDINGS

The results of this study suggest that commercial radio could play an important role as part of an effective real-time traffic information system for urban freeway drivers. However, traffic reports as currently broadcast by the 3 radio stations in Houston would not be completely satisfactory for the system being considered. Improvements in the reliability and timeliness of the traffic information provided would be necessary. More specifically, the following findings may be drawn from the study:

1. Sixty-two percent of the survey participants, who have car radios and who could benefit from radio reports of freeway conditions, currently use radio traffic bulletins for trip planning during the peak period. There were indications that this percentage would increase if the information were more accurate and timely.

2. Eighty-nine percent of the participants said they normally listen to car radios.

3. The participants ranked their preferences for 4 modes of communication as being radio, signs, television, and telephone. These rankings were based on the  $R_j$  values of Kendall's coefficient of concordance (4). Further evaluation of the results indicated that there did not appear to be any appreciable difference between the preference for radio and the preference for changeable message signs, in spite of the ranking resulting from Kendall's test.

4. Motorists expressed preferences for receiving information about freeway traffic conditions before entering the freeway and at locations where decisions can be made with respect to the selection of alternate routes. The following represents the consensus of preference based on Kendall's test: on the major street, at the entrance ramps, at the beginning of trip, and on the freeway.

5. The findings shown in item 4 are based on average values. Analysis of first choice preferences revealed that 42 percent of the participants considered information at the beginning of the trip to be their highest preference, 34 percent chose to receive information on the major street as their first preference, 16 percent chose the entrance ramps, and 8 percent preferred information on the freeway itself.

6. Of the 110 observed accidents on the study section of the Gulf Freeway, 52 percent were not reported by any of the stations. In addition, 24 percent were reported by 1 station, 17 percent by 2 stations, and 7 percent by all 3 stations.

7. Only 3 of the 104 stalled vehicles observed were reported by the radio stations. The average duration of the stalls was about 10 min, in comparison to 13 min for the vehicles involved in accidents.

8. The average time to report an accident after it was observed was 21.3 min for station A, 24.5 min for station B, and 26.9 min for station C.

9. No radio reports were monitored that indicated whether an accident, previously reported, had been cleared.

10. Little information was broadcast that indicated the length of freeway affected by an incident.

11. Radio reports of traffic incidents were generally correct as to location.

## ACKNOWLEDGMENT

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# EVALUATION OF FREEWAY EMERGENCY SERVICE SYSTEMS USING A SIMULATION MODEL

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The chronological sequence of events performed by the major components (police, mechanical, and communication service) of an emergency service system in responding to freeway incidents has been represented in a simulation model so that the performance of the system can be analyzed systematically. Thirty selected candidate systems, based on possible combinations of major detection and service subsystems, were simulated on the San Francisco-Oakland Bay Bridge by using a set of historical incident data. The performance of alternative systems was evaluated separately by a cost-effectiveness analysis and a total system cost procedure. The cost measure was expressed in dollars. The merit of various effectiveness measures was discussed, and their correlations were shown. The total delay to all motorists affected by the incident was selected as the representative effectiveness measure for the evaluation. Total system costs for different values of time ranging from \$0/hour to \$5/hour were presented. At a value of time of \$3/hour, both analyses resulted in the same best 5 systems in the same order. The most promising system of the 30 systems tested was the one with call-box units spaced at  $\frac{1}{4}$ -mile intervals, 2 stationary police units, and 3 stationary mechanical service units. The model has the potential to be extended to include other system components, such as medical service, and can be applied to different locations.

•THE Operations Research Center at the University of California, Berkeley, has been undertaking a research program since mid-1967 in system design and optimization under a National Science Foundation grant. One major research area of the program is the investigation of the economic and technical feasibility of systems for responding to freeway accidents and the optimal design and operation of such systems. Within the framework of this research objective, extensive research has been performed in several related fields (1 through 12). One part of the completed research is the development of a simulation model that can be applied to the performance of major components of a freeway emergency service system in responding to freeway incidents. Through the evaluation of system performance, elements that are crucial to system design and operation can be clearly identified, and possible ways of system improvement and optimization can be recommended. The simulation model was originally developed by Keller (5). Since then, work has continued on the documentation and validation of the computer simulation program, the model application to various freeway emergency service systems, and the analysis of model results. This paper summarizes the work done since the development of the original model and suggests areas of future research based on the experience with the model.

## OVERALL STRUCTURE OF THE COMPUTER PROGRAM

The chronological sequence of events performed by the major components of a freeway emergency service system in responding to freeway incidents has been programmed

into a simulation model so that (a) the time intervals between the occurrence of consecutive events, (b) the occurrence times of individual events in real-time scale (with the reference point at midnight of the day), and (c) the system effectiveness measures can be determined and the performance of the system analyzed on a digital computer.

The computer program DESERV is organized as a next event simulation routine where each major activity is represented as 1 or more subroutines. Consideration is given to each individual incident  $I$ , and the sequence of events after the incident occurrence is simulated until all service requirements are fulfilled and the detection and service units are in a stage of re-availability for the next incident  $I + 1$ . After each incident, the summations for the statistics, mean, and variance of the output values are updated. The same procedure is followed for the incidents  $I + 1$ ,  $I + 2$ , ..., unit  $I = NO$ , the total number of incidents (e.g., per day) analyzed. If all NO incidents are analyzed once, 1 iteration  $J$  of the simulation is completed. At the end of each iteration, the mean and variance are computed for the NO incidents. The entire process is repeated then for as many iterations  $JJ$  as needed. Finally, the mean and variance are computed for the output values after  $JJ$  iterations. If more than 1 day is studied, the daily statistics are stored and the program is started again by reading the input characteristics for the next day to be analyzed. After all days are analyzed, the statistics, mean, variance, and standard deviation are computed from the stored daily data. The program is written in FORTRAN IV language for a CDC 6400 computer. The program has about 5,000 statements, and it takes 60 sec to compile from the source deck and 5 sec to start from a binary deck. To run 100 iterations for 1 incident takes about 3 to 4 sec, depending on the type of incident and emergency service system studied. A flow chart of this computer program is shown in Figure 1.

A manual check was performed to validate the logic and the programming procedures of the computer program. Two selected candidate systems were simulated both by computer and by manual calculations. Computer and manual results were identical in both cases.

## MODEL APPLICATION AND SYSTEM EVALUATION

The simulation model was applied to 30 candidate systems by using the available data of 95 historical incidents in 5 days. In the first section, the design of experiment is presented where the structure of all candidate systems is shown. In the second section, correlation between measures of effectiveness is presented in which possible measures of effectiveness are discussed and representative measures for system evaluation are selected. Then correlation between those representative measures and other effectiveness measures are shown. The third section is devoted to economic evaluation of the candidate systems, in which technique of cost-effectiveness and total system cost minimization are incorporated by using the representative effectiveness measure that was selected in the second section. The results of evaluation analyses are given in this section.

### Design of Experiment

All of the possible combinations of detection and service subsystems that could be simulated by the model were considered, and these then were classified in a systematic way. First a classification by detection system was established, which produced 4 families: call-box family, emergency telephone family, detection patrol family, and no specific detection family. Then each of those families was classified into 4 sub-families by the combinations of types of police and mechanical service. As a result, 12 possible subfamilies were identified. Those subfamilies that are possible to exist in real life and that could be simulated by the model were selected as candidate systems. Thirty candidate systems were adopted for simulation. [Fifteen of these systems were tested by Keller (5). His results were used in this analysis.] The number of roadside apparatus and vehicles and the allocation of stations were standardized so that comparative analysis would become easier and more meaningful. The mechanical service system is emphasized more than the police service system in most of the systems. This is because all of the historical incidents used in simulation required mechanical service, but only a few of them required police service.

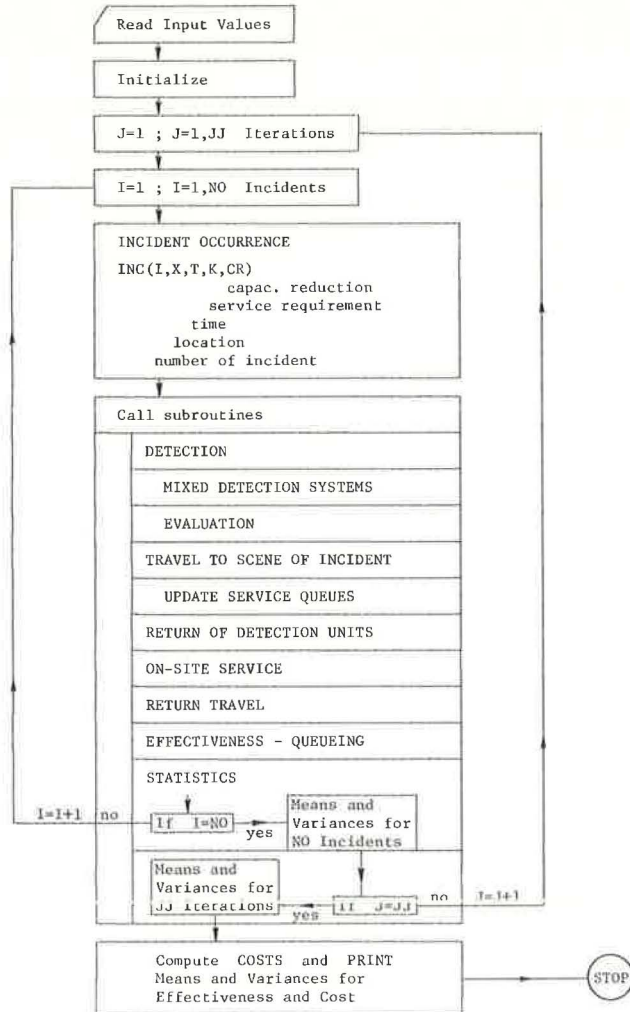


Figure 1. Flow chart for simulation program DESERV (5).

All systems are designated by 3 letters and 1 number. The first letter indicates family, the second letter indicates type of police service, the third letter indicates type of mechanical service, and the number in the fourth position indicates the candidate system number in a subfamily. For example, in the designation APS1, A indicates call-box family, P indicates patrol service, and S indicates stationary service.

Family A incorporates a call-box scheme as the detection subsystem as shown in Figure 2. It has 3 candidate systems in the PS subfamily (patrolling police and stationary mechanical service), 2 candidate systems in the SP subfamily (stationary police and mechanical service patrol), and 3 candidate systems in the SS subfamily (stationary police and stationary mechanical service). No system is analyzed in the PP subfamily (police patrol and mechanical service patrol) because it did not appear to be realistic to have no stationary vehicles when a call-box scheme is adopted as a detection subsystem. All of the candidate systems in family A have the same call-box spacing, 0.25 mile, and the same number of vehicles in the police service subsystem, although five of them use stationary vehicles and three of them use patrolling vehicles. The number of mechanical service vehicles is the main variable and varies from 2 to 4 in the stationary cases and from 2 to 3 in the patrolling cases.



| MECHANICAL SERVICE  |   |
|---|---|
| Patrol  | Stationary  |
| <div>Patrol</div>   | BPS1<br>Emergency Telephone: .25 mile spacing<br>Police Patrol: (1,1)<br>Stationary Mechanical Service: (1-1)       |
|   | BPS2<br>Emergency Telephone: .25 mile spacing<br>Police Patrol: (1,1)<br>Stationary Mechanical Service: (1-1-1)     |
| <div>POLICE SERVICE</div> <div>Stationary</div>   | BSP1<br>Emergency Telephone: .25 mile spacing<br>Stationary Police: (1-1)<br>Mechanical Service Patrol: (1,1)       |
|   | BSS1<br>Emergency Telephone: .25 mile spacing<br>Stationary Police: (1-1)<br>Stationary Mechanical Service: (1-1)   |
|   | BSP2<br>Emergency Telephone: .25 mile spacing<br>Stationary Police: (1-1)<br>Mechanical Service Patrol: (1,1,1)     |
|   | BSS2<br>Emergency Telephone: .25 mile spacing<br>Stationary Police: (1-1)<br>Stationary Mechanical Service: (1-1-1) |
| BSP3<br>Emergency Telephone: .25 mile spacing<br>Stationary Police: (1-1-1)<br>Mechanical Service Patrol: (1,1) | BSS3<br>Emergency Telephone: .25 mile spacing<br>Stationary Police: (1-1)<br>Stationary Mechanical Service: (1-2-1) |
|   | BSS4<br>Emergency Telephone: .25 mile spacing<br>Stationary Police: (1-1)<br>Stationary Mechanical Service: (2-2)   |

Figure 2. Candidate systems in family A (call box). Numbers in parentheses are patrol or stationary vehicles for each candidate system.

Family B uses an emergency telephone scheme as shown in Figure 3. Nine candidate systems were analyzed in this family. Spacing of emergency telephones is the same as in the call-box scheme, 0.25 mile for all candidate systems of this family. All of the candidate systems in this family, except for candidate system BSP3, have

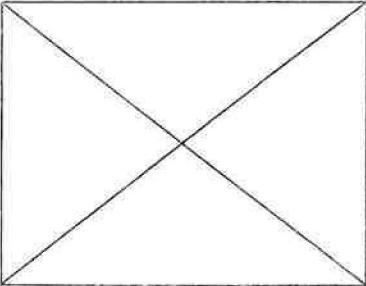
|                |        | MECHANICAL SERVICE   |  |
|----------------|--------|--|--|
|                |        | Patrol   | Stationary   |
| POLICE SERVICE | Patrol |                   | APS1<br>Call Box: .25 mile spacing<br>Police Patrol: (1,1)<br>Stationary Mechanical Service: (1-1)       |
|                |        |  | APS2<br>Call Box: .25 mile spacing<br>Police Patrol: (1,1)<br>Stationary Mechanical Service: (1-1-1)     |
|                |        |  | APS3<br>Call Box: .25 mile spacing<br>Police Patrol: (1,1)<br>Stationary Mechanical Service: (1-2-1)     |
| Stationary     |        | ASP1<br>Call Box: .25 mile spacing<br>Stationary Police: (1-1)<br>Mechanical Service Patrol: (1,1)   | ASS1<br>Call Box: .25 mile spacing<br>Stationary Police: (1-1)<br>Stationary Mechanical Service: (1-1)   |
|                |        | ASP2<br>Call Box: .25 mile spacing<br>Stationary Police: (1-1)<br>Mechanical Service Patrol: (1,1,1) | ASS2<br>Call Box: .25 mile spacing<br>Stationary Police: (1-1)<br>Stationary Mechanical Service: (1-1-1) |
|                |        |  | ASS3<br>Call Box: .25 mile spacing<br>Stationary Police: (1-1)<br>Stationary Mechanical Service: (1-2-1) |

Figure 3. Candidate systems in family B (emergency telephone). Numbers in parentheses are patrol or stationary vehicles for each candidate system.

|                |            | MECHANICAL SERVICE  |   |
|----------------|------------|---|---|
|                |            | Patrol  | Stationary  |
| POLICE SERVICE | Patrol     |   | <div>CPS1<br/>Detection Patrol: (1)<br/>Police Patrol: (1,1)<br/>Stationary Mechanical Service: (1-1)</div> <div>CPS2<br/>Detection Patrol: (1)<br/>Police Patrol: (1,1)<br/>Stationary Mechanical Service: (1-1-1)</div>             |
|                | Stationary | <div>CSP1<br/>Detection Patrol: (1)<br/>Stationary Police: (1-1)<br/>Mechanical Service Patrol: (1-1)</div> <div>CSP2<br/>Detection Patrol: (1)<br/>Stationary Police: (1-1)<br/>Mechanical Service Patrol: (1-1-1)</div> | <div>CSS1<br/>Detection Patrol: (1)<br/>Stationary Police: (1-1)<br/>Stationary Mechanical Service: (1-1-1)</div> <div>CSS2<br/>Detection Patrol: (1,1)<br/>Stationary Police: (1-1)<br/>Stationary Mechanical Service: (1-1-1)</div> |

Figure 4. Candidate systems in family C (detection patrol). Numbers in parentheses are patrol or stationary vehicles for each candidate system.

2 vehicles in the police service subsystem. The number of vehicles in mechanical service subsystem changes from 2 to 4 in stationary cases and 2 to 3 in patrolling cases. No system was proposed in the PP subfamily (police patrol and mechanical service patrol) for the same reason as in family A.

Family C incorporates a detection patrol scheme as shown in Figure 4. Six candidate systems were established in this family. The number of detection patrol vehicles is the same for all systems, except for candidate system CSS2. The police service subsystem has 2 vehicles for all candidate systems. The number of vehicles in mechanical service subsystem is a main variable in this family also and varies from 2 to 3 in all subfamilies. No system is proposed in the PP subfamily (police patrol and mechanical service patrol). This subfamily can exist in real life, but the present simulation model cannot analyze such a system.

Family D does not have any special type of detection subsystem, as shown in Figure 5. Therefore, either the police or the mechanical service vehicle has to be a patrol-

|                |            | MECHANICAL SERVICE  |   |
|----------------|------------|---|---|
|                |            | Patrol  | Stationary  |
| POLICE SERVICE | Patrol     | <div>DPP1<br/>Police Patrol: (1,1)<br/>Mechanical Service Patrol: (1,1)</div> <div>DPP2<br/>Police Patrol: (1,1)<br/>Mechanical Service Patrol: (1,1,1)</div>   | <div>DPS1<br/>Police Patrol: (1,1)<br/>Stationary Mechanical Service: (1-1)</div> <div>DPS2<br/>Police Patrol: (1,1)<br/>Stationary Mechanical Service: (1-1-1)</div> |
|                | Stationary | <div>DSP1<br/>Stationary Police: (1-1)<br/>Mechanical Service Patrol: (1,1)</div> <div>DSP2<br/>Stationary Police: (1-1)<br/>Mechanical Service Patrol: (1,1,1)</div> <div>DSP3<br/>Stationary Police: (1-1-1)<br/>Mechanical Service Patrol: (1,1)</div> |   |

Figure 5. Candidate system in family C (no specific detection system). Numbers in parentheses are patrol or stationary vehicles for each candidate system.

ling type. This family has 7 candidate systems. In this case, too, the main variable is the mechanical service configuration. The number of mechanical service vehicles varies from 2 to 3 in all subfamilies, although the number of police service vehicles is two, except for 1 candidate system.

### Correlation Between Measures of Effectiveness

Measures of Effectiveness—Nine measures of effectiveness were considered. These are as follows:

1. Detection time is the time period from incident occurrence to detection. Detection time is either the time when the existence of an incident is recognized at the scene by a patrolling vehicle or the time when necessary information of the incident is obtained at the central communication center. The output of the simulation program gives the average value for all 95 incidents, with each average value based on 100 iterations.
2. Police arrival time is the time period from incident occurrence to the arrival of a police service vehicle at the scene. Fourteen incidents out of 95 incidents required police service. An average value for those 14 incidents is given in the computer output.
3. Mechanical service arrival time is the time period from incident occurrence to the arrival of a mechanical service vehicle at the scene. All 95 incidents required mechanical service, and thus an average time for 95 incidents is given in the computer output.
4. First arrival time of service is the smaller of the arrival times of needed services, either the police service or the mechanical service. Average value for all 95 incidents is presented in the computer output.
5. Blockage time is the time period from incident occurrence to the removal of the disabled vehicle from the scene, or it is the time period from incident occurrence to the end of the longer one of the police or the mechanical service.
6. Average daily total delay is an average daily delay for the 5 weekdays studied. Delay was caused in 15 of the 95 incidents. The output of the program gives the average value of 5 sample days.
7. Number of vehicles delayed is the average number of vehicles stopped because of the incidents per day. The output of the program gives the average for 5 days, which is calculated from the same 15 incidents mentioned in item 6.
8. Individual delay affected by incidents is expressed as  $(\text{total delay per day})/(\text{total number of vehicles affected})$ . Computer output gives the value for each day.
9. Duration of queue is the duration of the queuing situation when the reduced capacity is below demand. The computer output gives average value for each day.

These measures of effectiveness are classified into 2 groups. One group of effectiveness measures is used to evaluate emergency service systems from the standpoint of individual stranded motorists. Measures of effectiveness of this group are called individual measures of effectiveness. Items 1 through 4 belong to this group. The other group of effectiveness measures is used to evaluate emergency service systems from a standpoint of all of the facility users. The measures that belong to this group are referred to as collective measures of effectiveness. Figure 6 shows the relationship of individual measures of effectiveness and collective measures of effectiveness. Blockage time is common to both groups of measures, and all of the measures of effectiveness are related to each other to some degree. Collective measures have deterministic relationships to one another in each incident as the queuing process is described by the deterministic queuing model in the simulation program.

One measure of effectiveness in each group is chosen as the representative measure of those groups, so that we can evaluate systems by using those representative measures. The following are comments about the various measures of effectiveness that were discussed in the preceding:

1. Detection time is not a good measure of effectiveness because many situations are included depending on the detection subsystems. The following are all of the possible situations of detection time: (a) Call box—mechanical service vehicle is at the



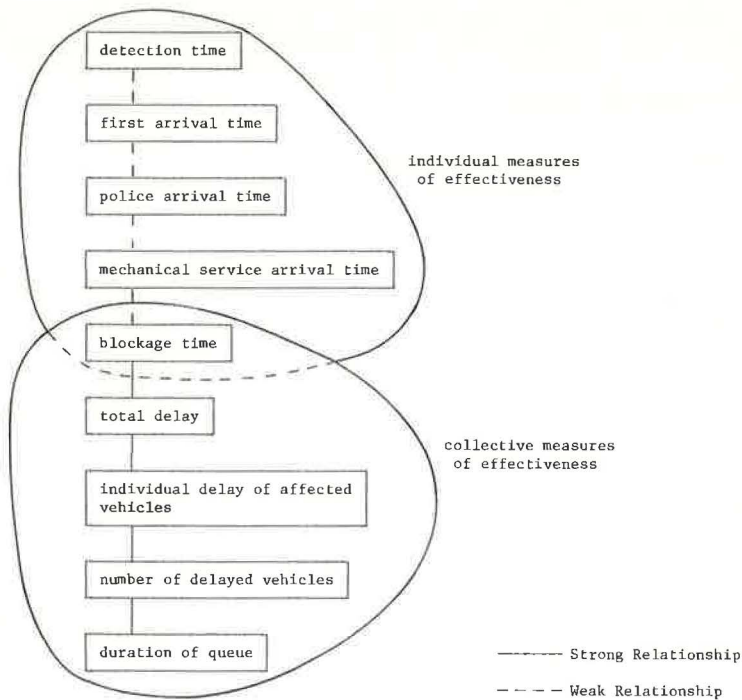


Figure 6. Grouping of measures of effectiveness.

scene and starts servicing immediately; (b) emergency telephone—communication center is informed of the incident, and needed service vehicle is dispatched from the nearest station at this time; (c) detection patrol—a motorcyclist is at the scene and informs the communication center or other patrolling vehicles of the incident, but he cannot give any kind of service; (d) police patrol—police service vehicle is at the scene, and occupants start police service immediately if police service is needed and, at the same time, report the incident to the mechanical service subsystems; and (e) mechanical service patrol—mechanical service vehicle is at the scene, and occupants start servicing immediately and, at the same time, provide information of the incident to the police service subsystems if police service is needed.

2. Police arrival time is not a good measure of effectiveness because only 15 out of 95 incidents required police service.

3. Mechanical service arrival time is a fairly good measure because all incidents required mechanical service.

4. First arrival time of service is a good measure because it was calculated for all 95 incidents and does not ignore police service, which is ignored in mechanical service arrival time.

5. Blockage time is classified into collective measures of effectiveness, but it could also be considered as a measure of individual effectiveness. In each incident, all of the other collective measures are expressed as functions of blockage time. Although blockage time has a strong relationship with other collective measures and is also a joint of collective measures and individual measures, it is not an adequate measure to evaluate systems because it is not as informative as either the collective measure or the individual measure.

6. Average daily total delay is most adequate as a representative measure of collective effectiveness. One of the direct objectives of an emergency system is to reduce delay caused by incidents. This measure has the advantage that it has implied in it a measure of time.

TABLE 1  
MEASURES OF EFFECTIVENESS AND COST OF CANDIDATE SYSTEMS

| System | Total Delay<br>(vehicle-hour) | Vehicles<br>Delayed | Detection Time |                                | First Arrival Time |                                | Blockage Time |                                | Dollars per<br>Mile per<br>16 Hours |
|--------|-------------------------------|---------------------|----------------|--------------------------------|--------------------|--------------------------------|---------------|--------------------------------|-------------------------------------|
|        |                               |                     | Mean<br>(min)  | Standard<br>Deviation<br>(min) | Mean<br>(min)      | Standard<br>Deviation<br>(min) | Mean<br>(min) | Standard<br>Deviation<br>(min) |                                     |
| APS1   | 273.35                        | 12,467.75           | 4.55           | 3.80                           | 4.55               | 3.80                           | 21.74         | 11.35                          | 121.6                               |
| PS2    | 207.70                        | 10,793.31           | 3.39           | 2.15                           | 3.39               | 2.15                           | 17.61         | 9.43                           | 133.8                               |
| PS3    | 198.69                        | 10,539.78           | 3.21           | 1.83                           | 3.21               | 1.83                           | 17.17         | 9.22                           | 148.1                               |
| SP1    | 279.79                        | 12,238.29           | 7.01           | 6.96                           | 7.01               | 6.96                           | 20.01         | 11.48                          | 134.4                               |
| SP1    | 220.88                        | 10,785.90           | 4.67           | 4.64                           | 4.67               | 4.64                           | 17.61         | 10.07                          | 165.0                               |
| SS1    | 290.06                        | 12,923.55           | 9.67           | 7.74                           | 9.67               | 7.74                           | 22.84         | 12.10                          | 105.4                               |
| SS2    | 212.62                        | 11,087.15           | 5.02           | 2.69                           | 5.02               | 2.69                           | 17.91         | 9.11                           | 117.9                               |
| SS3    | 202.47                        | 10,808.05           | 4.43           | 1.58                           | 4.48               | 1.58                           | 17.37         | 8.71                           | 131.9                               |
| BPS1   | 275.18                        | 12,738.23           | 2.83           | 1.30                           | 4.90               | 4.03                           | 22.06         | 10.97                          | 127.4                               |
| PS2    | 213.37                        | 11,086.74           | 2.85           | 1.29                           | 3.94               | 2.44                           | 17.88         | 8.84                           | 134.8                               |
| SP1    | 259.53                        | 12,018.19           | 2.84           | 1.29                           | 6.54               | 6.55                           | 19.34         | 10.54                          | 135.3                               |
| SP2    | 209.09                        | 10,652.67           | 2.55           | 1.36                           | 4.49               | 4.42                           | 17.23         | 9.50                           | 165.7                               |
| SP3    | 247.52                        | 11,824.15           | 2.84           | 1.29                           | 6.35               | 6.52                           | 18.92         | 10.19                          | 147.6                               |
| SS1    | 289.05                        | 13,252.88           | 3.59           | 0.69                           | 10.38              | 7.66                           | 22.84         | 10.93                          | 106.0                               |
| SS2    | 224.01                        | 11,563.28           | 3.59           | 0.69                           | 6.05               | 2.71                           | 18.68         | 8.70                           | 118.2                               |
| SS3    | 215.20                        | 11,326.95           | 3.59           | 0.69                           | 5.51               | 1.62                           | 18.23         | 8.50                           | 132.6                               |
| SS4    | 236.42                        | 11,908.16           | 3.59           | 0.69                           | 7.33               | 2.83                           | 19.72         | 8.59                           | 134.5                               |
| CPS1   | 296.39                        | 13,296.04           | 3.84           | 3.14                           | 5.43               | 4.59                           | 22.83         | 11.01                          | 134.3                               |
| PS2    | 230.36                        | 11,659.59           | 3.84           | 3.14                           | 4.65               | 3.59                           | 18.61         | 8.93                           | 155.6                               |
| SP1    | 273.60                        | 12,266.95           | 3.93           | 3.16                           | 6.84               | 6.87                           | 19.58         | 10.73                          | 156.2                               |
| SP2    | 210.07                        | 10,652.89           | 3.11           | 2.70                           | 4.50               | 4.46                           | 17.16         | 9.46                           | 186.8                               |
| SS1    | 296.20                        | 13,449.28           | 6.63           | 3.84                           | 9.04               | 4.34                           | 21.52         | 9.07                           | 139.8                               |
| SS2    | 220.88                        | 11,394.21           | 3.31           | 1.92                           | 5.71               | 3.06                           | 13.16         | 8.57                           | 163.6                               |
| DPP1   | 270.26                        | 12,203.03           | 3.64           | 3.61                           | 3.64               | 3.61                           | 19.61         | 10.80                          | 148.8                               |
| PP2    | 206.60                        | 10,581.61           | 2.79           | 2.75                           | 2.79               | 2.75                           | 17.24         | 9.61                           | 179.5                               |
| PS1    | 384.12                        | 15,025.82           | 7.33           | 7.40                           | 7.33               | 7.40                           | 26.12         | 12.34                          | 119.8                               |
| PS2    | 309.95                        | 13,318.37           | 7.33           | 7.40                           | 7.33               | 7.40                           | 21.67         | 10.55                          | 132.2                               |
| SP1    | 289.13                        | 12,429.72           | 7.28           | 7.25                           | 7.28               | 7.25                           | 20.06         | 11.43                          | 132.7                               |
| SP2    | 217.05                        | 10,731.23           | 4.67           | 4.64                           | 4.67               | 4.64                           | 17.40         | 9.85                           | 163.3                               |
| SP3    | 273.93                        | 12,209.67           | 7.28           | 7.25                           | 7.28               | 7.25                           | 19.56         | 10.99                          | 145.0                               |

|                        |     | Total<br>Cost<br>(\$/m/y) | Equipment<br>Cost<br>$c_{eq}$ (\$/u/y) | Installation<br>Cost<br>$c_{in}$ (\$/u/y) | Operating<br>Maintenance<br>Cost<br>$c_{op}$ (\$/u/y)<br>$c'_{op}$ (\$/u/m) | Manpower<br>Cost<br>$c_{ma}$ (\$/u/y) | Auxiliary<br>Equipment<br>Cost<br>$c_{ac}$ (\$/y)<br>$c'_{ac}$ (\$/u/y) | Auxiliary<br>Manpower<br>Cost<br>$c_{am}$ (\$/y) |
|------------------------|-----|---------------------------|--|---|---|---------------------------------------|---|--|
|                        |     | 1                         | 2                                      | 3   | 4   | 5                                     | 6   | 7  |
| Call Box               | (1) | $c_c =$                   | $30 \cdot n_c / L +$                   | $60 \cdot n_c / L +$                      | $20 \cdot n_c / L +$  | $--$                                  | $3000 / L +$  | $60000 / L$                                      |
| Emerg. Phone           | (2) | $c_e =$                   | $40 \cdot n_e / L +$                   | $80 \cdot n_e / L +$                      | $40 \cdot n_e / L +$  | $--$                                  | $3000 / L +$  | $60000 / L$                                      |
| Detect. Patrol         | (3) | $c_f =$                   | $3000 \cdot n_f / L +$                 | $--$                                      | $.08 \cdot n_f \cdot d_f / L +$   | $30000 \cdot n_f / L +$               | $3000 / L +$  | $60000 / L$                                      |
| Police Patrol<br>Post  | (4) | $c_a =$                   | $4000 \cdot n_a / L +$                 | $--$                                      | $.06 \cdot n_a \cdot d_a / L +$   | $30000 \cdot n_a / L +$               | $3000 / L +$  | $60000 / L$                                      |
| Service Patrol<br>Post | (5) | $c_b =$                   | $8000 \cdot n_b / L +$                 | $--$                                      | $.12 \cdot n_b \cdot d_b / L +$   | $30000 \cdot n_b / L +$               | $3000 / L +$  | $60000 / L$                                      |

u = unit, e.g., communication terminal, patrol or service vehicle

$n_q$  = number of units of type q = a, b, c, e, f, g, h per study section of length, L (miles)

$d_q$  = (miles/unit/year) distance travelled per unit per year.  $c_g = c_a$  for g = a

in (4)  $c_h = c_b$  for h = b. in (5)

Figure 7. Costs for individual detection and service systems (13).

- 7. Number of vehicles delayed is interpreted as a measure to indicate the degree of hazard created by incidents. It is a fairly good measure, but it is difficult to convert to dollars for economic analysis.
- 8. Individual delay affected by incidents is in proportion to total delay for 1 day. If we adopt total delay as a representative measure of collective effectiveness, it is also satisfied.
- 9. Duration of queuing is not an adequate measure of effectiveness because it is not informative as a measure to evaluate systems.

First arrival time was selected as a representative measure of individual effectiveness, and average daily total delay is selected as a representative measure of collective effectiveness. Table 1 gives model results for important measures of effectiveness and system cost for the 30 candidate systems. System costs are based on the results (Fig. 7) obtained in the work by Pogust, Kuprijanow, and Forster (13).

Collective Measures of Effectiveness—Blockage time, average daily total delay, and number of vehicles delayed are collective measures of effectiveness, which are obtained as computer output for a total of 5 days. For an individual incident, average

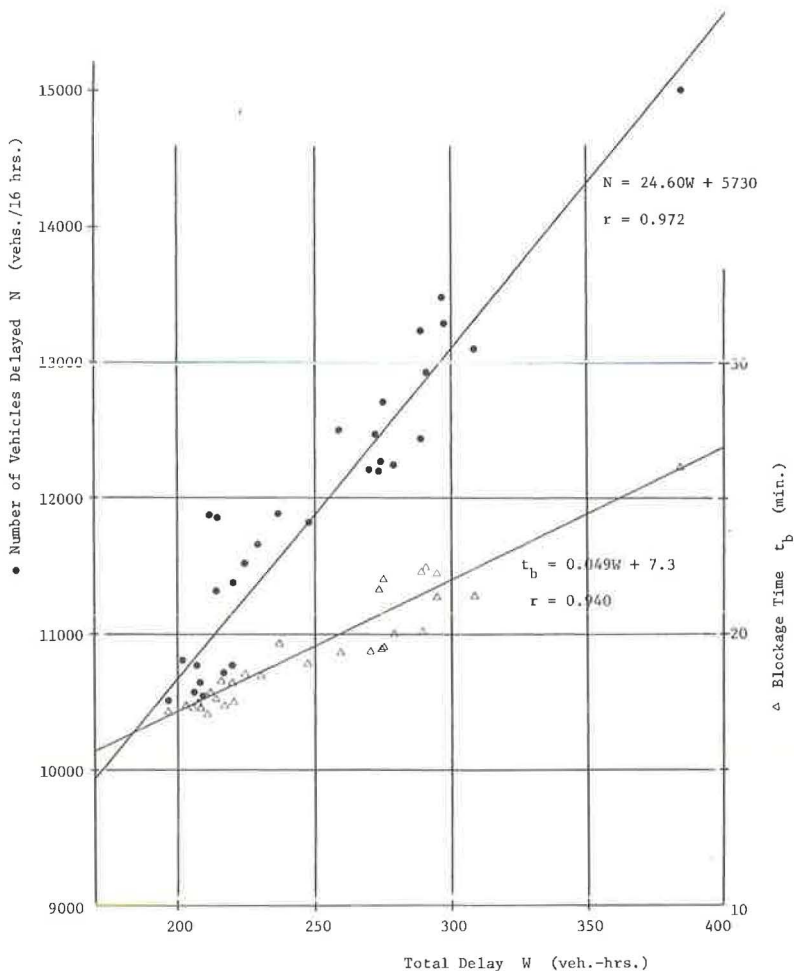


Figure 8. Correlation between total delay versus number of vehicles delayed and blockage time.

daily total delay and number of vehicles delayed are expressed as functions of blockage time, and both of these functions are not linear. Except for the reason that blockage time changes in each incident with large variance, correlation between those measures can no longer be expressed by the same equations as those used for each incident. The relationships of average daily total delay versus blockage time and average daily total delay versus number of vehicles delayed are shown in Figure 8. In spite of the fact that blockage time was computed as an average for 95 incidents and that total delay and number of vehicles delayed were computed for 15 incidents, those correlation coefficients are high and have a good linear relationship. Because these 3 collective measures of effectiveness have a strong correlation to one another, there is no question about taking average daily total delay as the representative measure of collective effectiveness.

Individual Measures of Effectiveness—First arrival time of service was selected as the representative measure of individual effectiveness because it is most informative and includes the arrival time of both services. We realized that it was biased in favor of the call-box family, family A, and no specific detection family, family D. For those families, first arrival time of service is also detection time, whereas detection time

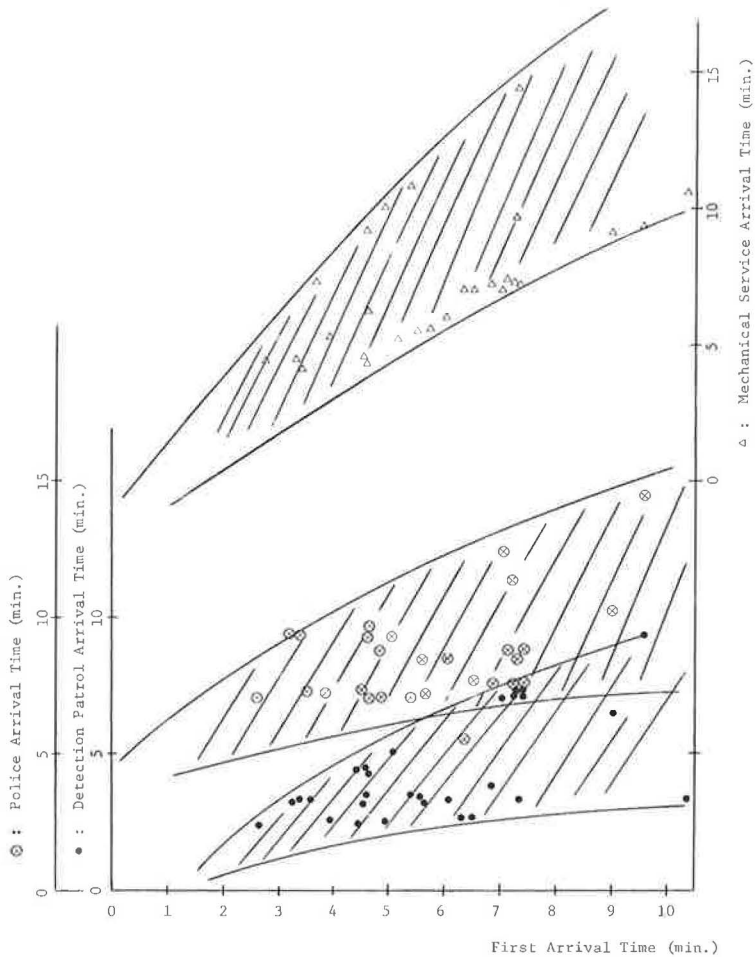


Figure 9. Correlation between first arrival time versus detection time, police arrival time, and mechanical service arrival time.



in other families—emergency telephone and detection patrol—is less than or equal to first arrival time. That is, the service suppliers know with high probability what type of service is needed before they arrive at the scene.

Four individual measures of effectiveness—detection time, first arrival time of service, arrival time of police, and arrival time of mechanical service—are shown in Figure 9. The correlation among those measures are weak as expected.

**Representative Measures of Collective Effectiveness and Individual Effectiveness—**Correlation of both representative measures—average daily delay and first arrival time of service—is shown in Figure 10. If the relationship between these 2 measures is assumed to be linear, the regression equation is expressed as

$$t_f = 0.028W - 1.357$$

with correlation coefficient  $r = 0.651$ , where  $t_f$  = first arrival time (min) and  $W$  = average daily total delay (vehicle-hour).

A general trend is recognized in the relationship of average daily total delay and first arrival time, although the correlation is not strong. Because there does appear to be some correlation between first arrival time and average daily total delay, and because average daily total delay is more conducive to economic analysis, average daily total delay was selected as the representative measure of effectiveness.

First arrival time of service is used to check the economic analysis based on total delay for a day, although it is biased to some families. It is also to be noted that first arrival time of service is computed as an average for 95 incidents, whereas total delay is computed from 15 incidents causing delay.

Economic Evaluation of Systems

Average daily delay was adopted for the economic evaluation of 30 candidate systems. Two methods for evaluating freeway emergency systems were used. One of them fol-

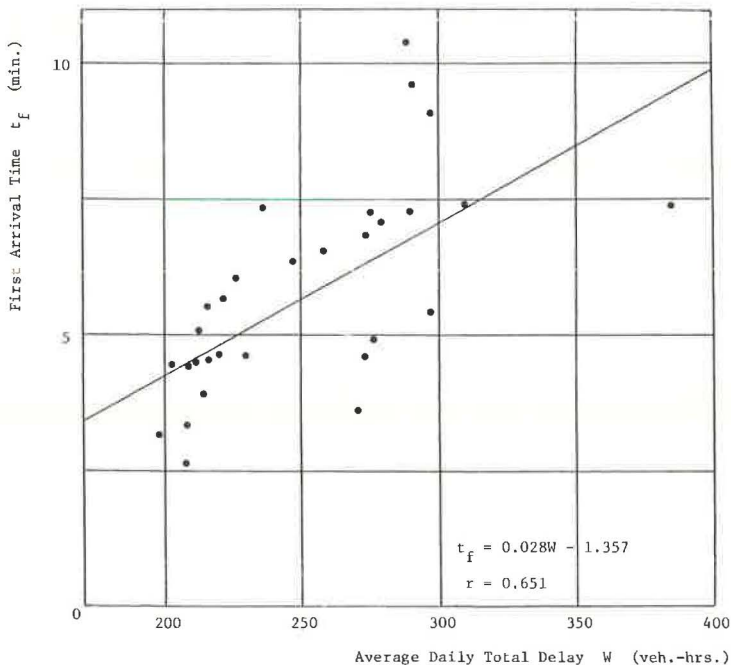


Figure 10. Correlation between average daily total delay and first arrival time.

lows the cost-effectiveness analysis technique, whereas the other follows the minimization of total cost procedure. In the former case, a basic system is selected, and the additional expenditure that is necessary to reduce unit delay for each alternative system is analyzed. In the latter case, delay is converted to cost according to some assumed value of time so that all of the candidate systems can be compared on the basis of total system cost. The objective of this latter analysis is to evaluate systems under different values of time.

**Cost-Effectiveness Analysis**—Candidate system ASS1 was selected as the basic system because its cost is the smallest of 30 candidate systems. All candidate systems are plotted in the cost-effectiveness diagram, as shown in Figure 11. The results are given in Table 2. In Figure 11, reduction of total delay is taken as the vertical axis, and additional cost is shown as the horizontal axis. Candidate systems of the same families are connected by lines so that visual comparison of subfamily systems is easier.

The cost-effectiveness diagram (Fig. 11) shows that candidate system ASS2 is the lowest, and candidate system BSS2 is the second lowest in cost-effectiveness. Only these 2 candidate systems are less than \$1/hour in cost-effectiveness. The \$3/hour line in the diagram divides all systems into 2 groups. Ten candidate systems, includ-

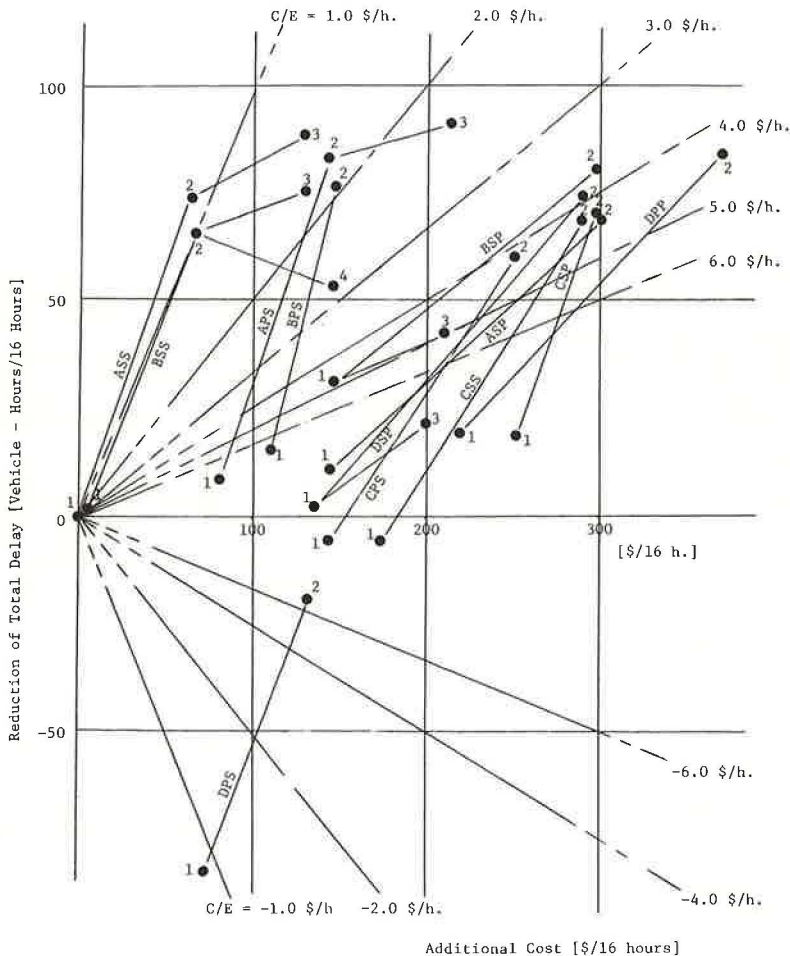


Figure 11. Cost-effectiveness for 30 candidate systems (basic system is ASS1).



TABLE 2  
COST-EFFECTIVENESS VALUES FOR 30 CANDIDATE SYSTEMS

| System | Additional<br>Cost Over<br>ASS1<br>(\$) | Additional<br>Effectiveness<br>Over ASS1<br>(vehicle-hour) | Cost-Effectiveness<br>(\$ per vehicle-<br>hour) | Ranking<br>for<br>10 Best<br>Systems |
|--------|---|--|---|--------------------------------------|
| APS1   | 81                                      | 17   | 4.78  |                                      |
| PS2    | 142                                     | 82   | 1.73  | 4                                    |
| PS3    | 213                                     | 91   | 2.34  | 7                                    |
| SP1    | 145                                     | 10   | 14.50   |                                      |
| SP2    | 298                                     | 69   | 4.32  |                                      |
| SS1    | —                                       | —  | —   | Basic                                |
| SS2    | 63                                      | 77   | 0.82  | 1                                    |
| SS3    | 133                                     | 88   | 1.51  | 3                                    |
| BPS1   | 110                                     | 15   | 7.33  |                                      |
| PS2    | 147                                     | 77   | 1.91  | 6                                    |
| SP1    | 149                                     | 30   | 4.97  |                                      |
| SP2    | 302                                     | 81   | 3.73  | 10                                   |
| SP3    | 211                                     | 42   | 5.02  |                                      |
| SS1    | 3                                       | 1  | 3.00  | 9                                    |
| SS2    | 63                                      | 66   | 0.95  | 2                                    |
| SS3    | 136                                     | 75   | 1.81  | 5                                    |
| SS4    | 145                                     | 54   | 2.69  | 8                                    |
| CPS1   | 145                                     | -6   | —   |                                      |
| PS2    | 251                                     | 60   | 4.18  |                                      |
| SP1    | 254                                     | 16   | 15.88   |                                      |
| SP2    | 317                                     | 80   | 3.96  |                                      |
| SS1    | 172                                     | -6   | —   |                                      |
| SS2    | 291                                     | 69   | 4.22  |                                      |
| DPP1   | 217                                     | 20   | 10.85   |                                      |
| PP2    | 371                                     | 83   | 4.47  |                                      |
| PS1    | 72                                      | -94  | —   |                                      |
| PS2    | 134                                     | -20  | —   |                                      |
| SP1    | 137                                     | 1  | 137.00  |                                      |
| SP2    | 290                                     | 73   | 3.97  |                                      |
| SP3    | 198                                     | 16   | 12.38   |                                      |

ing system ASS1, are less than \$3/hour in cost-effectiveness. All of those 10 systems belong to either the call-box family or emergency telephone family and have stationary mechanical service subfamilies.

The 5 most effective candidate systems from the standpoint of cost-effectiveness are ASS2, C-E = 0.82; BSS2, C-E = 0.95; ASS3, C-E = 1.51; APS2, C-E = 1.73; and BSS3, C-E = 1.81. The basic system ASS1 does not have a cost-effectiveness value, but it should be considered when system evaluation is made.

**Minimization of Total System Cost**—Although difficult, it is possible to place a monetary value on the driver's time. Then average daily total delay, the dimension of which is vehicle-hour, can be converted into dollars. Two measures, total delay and system cost, that are used in the cost-effectiveness analysis can be added to give the total system cost. For each system, let  $Y$  = total system cost (dollars),  $X$  = value of time (dollars per hour),  $a$  = average daily total delay (vehicle-hours), and  $b$  = system cost. Then, total system cost is a linear function of value of time.

$$Y = aX + b$$

Table 3 gives the actual total cost for various candidate systems for different values of time ranging from \$0/hour to \$5/hour. The 10 candidate systems were ranked on the basis of the minimum total system cost for each value of time selected. For example, if the value of time is selected to be \$3/hour, the candidate system that has the minimum total system cost is ASS2. Five candidate systems consistently resulted in minimum total system cost even when value of time varies from \$2/hour to \$5/hour.

Figure 12 shows the total system cost (as a function of time) for these 5 candidate systems and the system ASS1, which is the basic system in the cost-effectiveness study. There are no large cost differences among systems; however, when the value of time is less than \$0.84/hour, system ASS1 has the minimum total system cost. If the value of time is more than \$0.84/hour, system ASS2 has the minimum total system cost.

TABLE 3

VALUE OF TOTAL DELAY AND TOTAL SYSTEM COST FOR VARIOUS TIME VALUES

| System | Value of Total Delay |                 |                 |                 |                 | Total System Cost <sup>a</sup> |                   |                     |                     |                     |                     | Ranking<br>MTSC <sup>c</sup> |
|--------|----------------------|-----------------|-----------------|-----------------|-----------------|--------------------------------|-------------------|---------------------|---------------------|---------------------|---------------------|------------------------------|
|        | \$1 per<br>Hour      | \$2 per<br>Hour | \$3 per<br>Hour | \$4 per<br>Hour | \$5 per<br>Hour | \$0 per <sup>b</sup><br>Hour   | \$1 per<br>Hour   | \$2 per<br>Hour     | \$3 per<br>Hour     | \$4 per<br>Hour     | \$5 per<br>Hour     |                              |
| APS1   | 273                  | 546             | 819             | 1,092           | 1,365           | 602 <sup>5</sup>               | 875 <sup>6</sup>  | 1,148               | 1,421               | 1,694               | 1,967               | 4                            |
| PS2    | 208                  | 416             | 624             | 832             | 1,040           | 669 <sup>9</sup>               | 877 <sup>7</sup>  | 1,085 <sup>4</sup>  | 1,293 <sup>4</sup>  | 1,501 <sup>4</sup>  | 1,709 <sup>5</sup>  |                              |
| PS3    | 199                  | 398             | 597             | 796             | 995             | 745                            | 944               | 1,143 <sup>9</sup>  | 1,342               | 1,540 <sup>7</sup>  | 1,739 <sup>5</sup>  |                              |
| SP1    | 280                  | 560             | 840             | 1,120           | 1,400           | 672                            | 952               | 1,132               | 1,512               | 1,782               | 2,072               |                              |
| SP2    | 221                  | 442             | 663             | 884             | 1,105           | 825                            | 1,046             | 1,267               | 1,488               | 1,709               | 1,930               |                              |
| SS1    | 290                  | 580             | 870             | 1,160           | 1,450           | 527 <sup>1</sup>               | 817 <sup>3</sup>  | 1,107 <sup>7</sup>  | 1,397 <sup>8</sup>  | 1,687               | 1,977               |                              |
| SS2    | 213                  | 426             | 639             | 852             | 1,065           | 590 <sup>3</sup>               | 803 <sup>1</sup>  | 1,016 <sup>1</sup>  | 1,229 <sup>1</sup>  | 1,442 <sup>1</sup>  | 1,655 <sup>1</sup>  | 1                            |
| SS3    | 202                  | 404             | 606             | 808             | 1,010           | 660                            | 862 <sup>5</sup>  | 1,064 <sup>3</sup>  | 1,266 <sup>3</sup>  | 1,468 <sup>2</sup>  | 1,670 <sup>2</sup>  | 3                            |
| BPS1   | 275                  | 550             | 825             | 1,100           | 1,375           | 637 <sup>6</sup>               | 912               | 1,187               | 1,462               | 1,737               | 2,012               | 5                            |
| PS2    | 213                  | 426             | 639             | 852             | 1,065           | 674                            | 887 <sup>9</sup>  | 1,100 <sup>6</sup>  | 1,313 <sup>6</sup>  | 1,526 <sup>6</sup>  | 1,739 <sup>5</sup>  |                              |
| SP1    | 260                  | 520             | 780             | 1,040           | 1,300           | 677                            | 937               | 1,197               | 1,457               | 1,717               | 1,977               |                              |
| SP2    | 209                  | 418             | 627             | 836             | 1,045           | 829                            | 1,038             | 1,247               | 1,456               | 1,665 <sup>9</sup>  | 1,874 <sup>9</sup>  |                              |
| SP3    | 248                  | 496             | 744             | 992             | 1,240           | 738                            | 986               | 1,234               | 1,482               | 1,730               | 1,978               |                              |
| SS1    | 289                  | 578             | 867             | 1,156           | 1,445           | 530 <sup>2</sup>               | 819 <sup>4</sup>  | 1,108 <sup>6</sup>  | 1,397 <sup>8</sup>  | 1,686               | 1,975               |                              |
| SS2    | 224                  | 448             | 672             | 896             | 1,120           | 590 <sup>3</sup>               | 814 <sup>2</sup>  | 1,038 <sup>2</sup>  | 1,262 <sup>2</sup>  | 1,486 <sup>3</sup>  | 1,710 <sup>4</sup>  | 2                            |
| SS3    | 215                  | 430             | 645             | 860             | 1,075           | 663 <sup>9</sup>               | 878 <sup>8</sup>  | 1,093 <sup>5</sup>  | 1,308 <sup>5</sup>  | 1,523 <sup>5</sup>  | 1,738 <sup>5</sup>  | 5                            |
| SS4    | 236                  | 472             | 708             | 944             | 1,180           | 672 <sup>9</sup>               | 908               | 1,144 <sup>10</sup> | 1,380 <sup>10</sup> | 1,616 <sup>8</sup>  | 1,852 <sup>8</sup>  |                              |
| CPS1   | 296                  | 592             | 888             | 1,184           | 1,480           | 672 <sup>10</sup>              | 998 <sup>10</sup> | 1,214               | 1,510               | 1,806               | 2,102               | 5                            |
| PS2    | 230                  | 460             | 690             | 920             | 1,150           | 778                            | 1,008             | 1,238               | 1,468               | 1,698               | 1,928               |                              |
| SP1    | 274                  | 548             | 822             | 1,096           | 1,370           | 781                            | 1,055             | 1,329               | 1,603               | 1,877               | 2,151               |                              |
| SP2    | 210                  | 420             | 630             | 840             | 1,050           | 844                            | 1,057             | 1,267               | 1,477               | 1,687 <sup>10</sup> | 1,897               |                              |
| SS1    | 296                  | 592             | 888             | 1,184           | 1,480           | 699                            | 995               | 1,291               | 1,587               | 1,883               | 2,179               |                              |
| SS2    | 221                  | 442             | 663             | 884             | 1,105           | 818                            | 1,039             | 1,260               | 1,481               | 1,702               | 1,923               |                              |
| DPP1   | 270                  | 540             | 810             | 1,080           | 1,350           | 744                            | 1,014             | 1,284               | 1,554               | 1,824               | 2,094               | 5                            |
| PP2    | 207                  | 414             | 621             | 828             | 1,035           | 898                            | 1,105             | 1,312               | 1,519               | 1,726               | 1,933               |                              |
| PS1    | 384                  | 768             | 1,152           | 1,536           | 1,920           | 599 <sup>4</sup>               | 983               | 1,367               | 1,751               | 2,135               | 2,519               |                              |
| PS2    | 310                  | 620             | 930             | 1,240           | 1,550           | 661 <sup>7</sup>               | 971               | 1,281               | 1,591               | 1,901               | 2,211               |                              |
| SP1    | 289                  | 578             | 867             | 1,156           | 1,445           | 664                            | 953               | 1,242               | 1,531               | 1,820               | 2,109               |                              |
| SP2    | 217                  | 432             | 649             | 856             | 1,073           | 817                            | 1,034             | 1,249               | 1,466               | 1,673               | 1,890 <sup>10</sup> |                              |
| SP3    | 274                  | 548             | 822             | 1,096           | 1,370           | 725                            | 999               | 1,273               | 1,547               | 1,821               | 2,095               |                              |

<sup>a</sup>Superscripts in columns are system rankings for various value-of-time measures.<sup>b</sup>Based on system cost for 5 miles and 16 hours.<sup>c</sup>Minimization of total system cost.

For values of time from \$0 to \$5/hour, the best 5 systems from the standpoint of minimization of total system cost are ASS2, BSS2, ASS3, APS2, and BSS3.

**Comparison of 2 Economic Evaluation Results**—Table 4 gives the results obtained by the cost-effectiveness analysis technique and the minimization of total system cost

TABLE 4

SYSTEM STRUCTURES OF THE FIVE BEST SYSTEMS

| Rank | System | System Structure   | Cost-Effectiveness<br>(\$ per hour) | Total System<br>Cost <sup>a</sup><br>(\$) |
|------|--------|--|-------------------------------------|---|
| 1    | ASS2   | Call box, 0.25-mile spacing<br>Stationary police, 1-1<br>Stationary mechanical service, 1-1-1            | 0.82                                | 1,229                                     |
| 2    | BSS2   | Emergency telephone, 0.25-mile spacing<br>Stationary police, 1-1<br>Stationary mechanical service, 1-1-1 | 0.95                                | 1,262                                     |
| 3    | ASS3   | Call box, 0.25-mile spacing<br>Stationary police, 1-1<br>Stationary mechanical service, 1-2-1            | 1.51                                | 1,266                                     |
| 4    | APS2   | Call box, 0.25-mile spacing<br>Police patrol, 1,1<br>Stationary mechanical service, 1-1-1                | 1.73                                | 1,293                                     |
| 5    | BSS3   | Emergency telephone, 0.25-mile spacing<br>Stationary police, 1-1<br>Stationary mechanical service, 1-2-1 | 1.81                                | 1,308                                     |

<sup>a</sup>When the value of time is \$3 per hour.

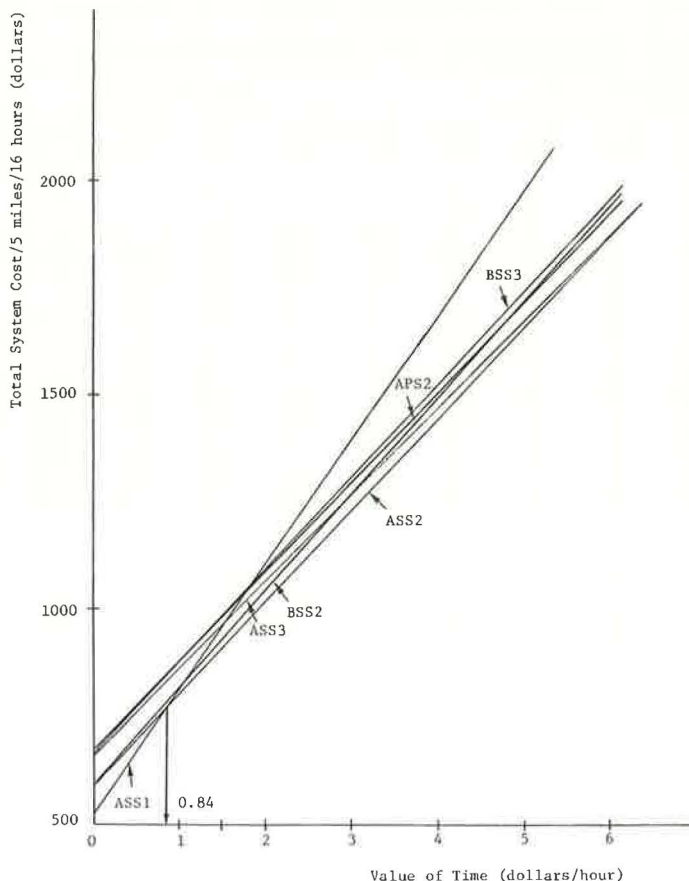


Figure 12. Relationship between value of time and total system cost.

procedure. The same candidate systems were selected as the 5 best candidate systems, and, in fact, they were selected in the same order.

The value of time, \$3/hour, was selected to make visual the differences of these 5 systems, where the rank of the 5 best systems by \$3/hour reflects the rank by overall values between \$0/hour and \$5/hour. Both of the analyses resulted in the same 5 best systems in the same order.

The best system of the 30 candidate systems is system ASS2 that has call boxes spaced at  $\frac{1}{4}$ -mile intervals, 2 stationary police vehicles, and 3 stationary mechanical service vehicles.

#### FUTURE RESEARCH

Three major studies are considered as future research in this field. First, a close field observation should be undertaken on the actual operation of existing freeway emergency service systems; this would help to validate model assumptions. Second, a medical service system that is not considered in the model should be studied. It is an important component of the emergency service system, especially to injured motorists. Third, other possible combinations of detection and service systems that have not been included should be investigated. These would involve more exotic detection systems, such as closed-circuit televisions, flow-monitoring devices, detectors, and vehicle emergency signaling devices.

## ACKNOWLEDGMENT

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## DISCUSSION

## A. C. Estep, California Division of Highways

The authors have provided a definite service to the profession by offering a systematic method for evaluating candidate systems for detection and servicing of incidents on freeways. The abbreviated version of the paper that was presented at the 1971 HRB meeting raises a number of questions. Some of the questions apparently are answered in a more extensive version that was published in July 1970 by the Operations Research Center of the University of California.

This paper would be considerably more useful if the authors had listed in tabular form the inputs required for the model and given a straightforward explanation of how these inputs can be estimated for any given system. That is, How does one estimate a frequency distribution of capacity reduction for incidents? Some incidents reduce capacity by 20 percent, some by 50 percent, and some by 100 percent, and so on.



Other questions that occurred to this reviewer were as follows:

1. The model is apparently good only for 1 link in a system of freeways. Presumably it could be expanded to be applicable to a larger network, but it is not clear from this paper whether this expansion would be an add-on to the existing work or whether it would be another major project. A potential user does not know from reading this paper whether he could use the model or not.

2. The assumptions that are made, e.g., with regard to the amount of reduced capacity caused by a given incident, are necessarily very broad. It appears that some discussion of the effect that varying assumptions would have on the results would be in order.

3. The abstract and the section on "Comparison of 2 Economic Evaluation Results" imply that a candidate system consisting of call-box units (and auxiliary services) was better than a system consisting of telephones at the same spacing with the same auxiliary services. This result is somewhat surprising in view of the fact that the telephone should obviate the need for a separate trip to the site to find out what kind of service is needed.

In summary, it appears that, although the work reported here is a first step toward the development of a model that would be useful in real life, it is a short step, and much work remains to be done before it can be utilized.

This is a new concept that may prove to be extremely valuable if it is not too hard to execute and if its validity can be proved. Inspection indicates that the model takes into consideration all factors that it should.

Donald E. Orne, Michigan Department of State Highways

At a time when a number of motorist-aid research projects are nearing completion and when actual facilities are being built and made operational, it becomes increasingly vital for the public administrator to have adequate information available for his major decisions in implementing systems and networks of aid for the stranded, disabled, or injured driver. He has to resolve several questions. Some of them are as follows: Does anything at all need to be done for the stranded driver? Does a motorist-aid system have to be cost-effective, or can it be considered a necessary public service? What are reasonable emergency aid response times? Should we have more telephones or more patrols?

The work presented here is an example of a rational approach to settling some of these issues relating to wise expenditure of public funds. The authors should be commended for their efforts to provide a means for the difficult transition from theory to practice.

For a number of practical reasons, we should approach the authors' findings with some caution. Perhaps of greatest concern to us is the danger of the conclusions being accepted and used without recognizing that they are only representative outputs of a technique and are not absolutes. It is apparent that the analysis excludes several important variables and holds others constant. We, therefore, do not have any assessment of such important matters as emergency medical service, call-box spacing, environmental effects, or alternate means of communication.

Parenthetically, we note a section of the paper entitled Model Validation that deals at length with some manual check-out procedures for the computer program. We question whether such material is germane to the major intent of the report.

The analysis on cost-effectiveness of the various candidate systems does not document the source of cost information, but we assume that this is derived from the larger work of which this report is a part. Also, we cannot determine whether system costs are included or whether only the assigned cost of time is used in the analysis. We only want to emphasize that there may be material differences among costs of prototype equipment, research equipment designed for life of the project, and equipment intended for continuing operational use.

In summary, it appears that the model is a simplified, limited-scope, idealistic approach of limited real-world use. Some important variables are neglected and others

are assigned constant values. In addition to ordinary real-world factors already mentioned, other factors such as vandalism, equipment malfunctions, public acceptance, system operation, and environment can have drastic effects on analyses sensitive to small changes in data inputs. The report has value as a contribution to furthering the science of modeling and simulation, but it cannot stand alone in support of decisions for field implementation of driver-aid technology.

C. F. Frey, University Hospital, Ann Arbor, Michigan

The authors of this paper are to be complimented for the effort expended to develop a technique for improving freeway emergency service that will be both economical and efficient.

My analysis of this paper is based not on any computer expertise but on examination of some of the assumptions of this study. I wonder whether the Oakland Bay Bridge is typical of our country's highways. The Mackinaw Bridge in Michigan, for instance, is said to be the safest freeway driving in the state. No fatal accident has been reported on the bridge or its approaches. Second, I wonder whether we should judge the effectiveness of a freeway emergency service system by the time of delay incurred by motorists. Other considerations such as human life or prevention of permanent disability should be considered. In Washtenaw County before the value of resuscitation of the injured was appreciated, a police officer threatened to arrest an ambulance attendant for delaying traffic while the attendant was taking time to apply a backboard before moving the patient because he suspected a cervical spine injury. An improper flexion of the head on the thorax in a cervical spine fracture could sever the spinal cord causing permanent paralysis. According to the criteria used by the authors of this paper, the policeman's actions would be justified; I happen to believe they were not.

The authors report they have developed a systems model that can simulate the major components of a freeway emergency service system in responding to freeway incidents. Exactly what these incidents include is not defined. It is stated that 14 of 95 incidents required police service. Does this mean that these 14 incidents were accidents, and the other 71 incidents represented vehicles disabled by having flat tires, running out of gas, or what not? The law varies from state to state as to what constitutes an accident, that is, one that must be reported to the police. In some states, if over \$200 damage is done to a vehicle, this is a police-reported accident. In other states, only injury-producing accidents are reported to the police. Therefore, we do not know whether the 14 incidents requiring police service in this simulation model were injury-producing accidents or simply an indication of vehicle damage. Data collected by the Highway Safety Research Institute of the University of Michigan show that, in Oakland County in 1968 (population 900,000), there was 25,000 accidents (over \$200 of vehicle damage) of which 10,406 (40 percent) were injury-producing and from which there were 137 deaths.

Not considered in this simulation model were the additional systems involved in providing emergency medical services. It would appear from the figures used in this simulation study that the incidence of injury-producing accidents based on the number of times the police were involved must have been either  $14/95$  (14.5 percent), depending on whether police were called only for injury-producing accidents, or 5.4 percent when cases were included in which over \$200 of vehicle damage was inflicted. Injury-producing accidents are likely to tie up traffic for longer periods than are disabled vehicles alone. Therefore, injury-producing accidents, even though they account for only 5.4 or 14.5 percent of accidents, will cause a disproportionately longer blockage and response time. The emergency medical response, an essential element of a freeway emergency system not examined in this simulation model, includes ambulances and helicopters. Ambulances or helicopters may have to be directed from distant locations during which time traffic may have to remain blocked. Even after ambulance arrival and mechanical service arrival at the scene of accident, traffic blockage may have to be continued while the injured are extricated from their vehicles or until resuscitation is completed. The traffic blockage time may be affected by more than the mechanical



factors involved in moving a wrecked or disabled vehicle if a patient had to be extricated from the wreckage or could not be moved from the scene until he received medical attention, such as application of a spine board that could be applied only by a trained ambulance attendant.

I feel, therefore, that the simulation model described in this paper is incomplete. Provision for emergency medical services essential to and inherent in injury-producing accidents (which are not at all uncommon) have not been incorporated in the model.

## AUTHORS' CLOSURE

The authors wish to thank Estep, Orne, and Frey for their valuable discussions. In view of the discussants' broad experience on the subject, their observations and comments certainly provide an added dimension to the paper.

The writers agree with Estep that a list of model inputs would add to the completeness of the paper. It was deleted from the paper after a consideration of the proper length for publication. It is true that the model, as presented, applies only to a 2-way freeway link. Because both demand and capacity were fixed in the model, further model expansion would be required for application to a larger network. Consideration has been given to restructuring the model so that it can be more flexible and applicable to more complex networks. Because historical incidents were used in the model, the amount of reduced capacity caused by a given incident was based on actual observation. However, in the case of generated incidents, the effect on capacity reduction depends on factors such as incident location, incident type, and level of traffic. This is truly an area needing more research. The analyses showed that a system consisting of call-box units was better than a system consisting of telephones at the same spacing. This can be explained as follows:

1. In a call-box system, it was assumed that a mechanical service vehicle was instantly dispatched to the scene to evaluate the service need of an incident, render service if mechanical service was needed, or call the police unit if police service was needed. In a telephone system, a 1-min delay in communication prior to the dispatch of the required service vehicle was assumed. Therefore, a required mechanical service vehicle was always dispatched earlier in a call-box system than it was in a telephone system, and the opposite was true for a required police vehicle.

2. All 95 incidents used in the model required mechanical service; only 15 of them also required police service. Therefore, the benefit of earlier dispatch of the required mechanical service of a call-box system outweighed the benefit of earlier dispatch of the required police service of a telephone system. It is important to note that model results are sensitive to incident service requirement; different incident data could lead to different conclusions. The authors agree that an overall validation of the model should be carried out to reinforce basic assumptions and parameter values of the model.

Frey offered a valuable discussion on the medical aspect of the freeway emergency service system. The delay to all motorists was chosen as a measure of system effectiveness because the model did not include a medical service system. The medical aspects of the survival of an individual are often contradictory to the desires of the collective passing motorists. Therefore, if the medical service system were included in the model, the effectiveness of a system would be evaluated on the basis of the efficient use of time instead of the delay alone. It is true that accidents will cause longer blockage and response time than will disabled vehicles. The types of incidents used in the model were not explicitly defined for the following reasons:

1. Real incidents were used, and the amount of capacity reduction identified for each incident implies the nature of the incident and the effect on response time.
2. The on-site service time generated by the model for each incident was based on the real service time of 716 accidents and nonaccidents, with the longer service time

required by an accident being accounted for even without explicit identification of the type of each incident.

The writers agree heartily with Frey and Orne that the medical service is an important element of the freeway emergency service system. In fact, in the process of model development, attempts have been made to construct the relationship between the probability of survival of a traffic victim and the delay in receiving medical treatment as a means of evaluating medical service systems (5). The emergency records of the Highland General Hospital in Oakland, California, were examined, and a qualified physician in charge of the emergency department was consulted. Among 238 hospitalized traffic victims, in only 5 cases (2.1 percent) was time really vital to the survival of the victim. Also, other factors, such as type of injury, victim's past health record, and type of medical treatment received, further complicated the investigation. Therefore, this effort has not led to any meaningful result. Future study in this area is definitely needed.

Orne pointed out that the conclusions drawn from the model outputs are only representative, not absolute. This is obviously true because the outputs will be different when the model is applied to different facilities with different traffic and incident patterns. The model was designed not to provide absolute conclusions about a system in general but to aid in selecting, from among several candidate systems, a system for a given situation. Conclusions should be made only on the basis of those systems that are inputs to the model. The assessment of the relative importance of model variables such as call-box spacing and alternative means of communication is a step toward system design and operation. The authors feel this is beyond what is intended in the paper and will be investigated in another phase of the continuing study. In the cost-effectiveness analysis, the cost measure was only the system cost that included the cost of equipment, manpower, vehicle operation, and maintenance. Both system cost and assigned cost of time delay were used in the analysis of minimum total system cost. As a result of Orne's discussion, the proper source of cost information used in the model will be incorporated in the final version of the paper. The authors realize that there are other factors such as vandalism, equipment malfunction, and public acceptance that may be sensitive to the cost and effectiveness of a system. Because the effect of such factors is not readily measurable and data are insufficient, they have not been included in the model. However, these factors should certainly be considered in the final phase of the evaluation process.

The authors wish to emphasize that the work presented in the paper is an important phase of a complex and continuing research project rather than a complete study. The authors realize that the model is incomplete in several respects and that much future work is needed. It is hoped that the paper will stimulate further thoughts and induce discussions from those who have similar interest in this research area.



# TESTING AN EMERGENCY AND REGIONAL MEDICAL HELICOPTER TRANSPORT SYSTEM

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## ABRIDGMENT

•THE OBJECTIVE of this study was to plan the organization of a helicopter delivery system to serve both emergency and regional medical needs in a specified section of West Virginia. Simulation techniques were used to examine alternative helicopter delivery systems for various levels of emergency evacuations, routine interhospital patient transfers, and preventive medical care demands. The geographic area selected for concentration was the region in which the West Virginia University Medical Center serves as the focal point for emergency and specialized medical services.

A coordinated pair of simulation models was constructed to describe the operational performance of a helicopter system assuming that 2 helicopters were based at the West Virginia University Medical Center. The helicopter system would perform a combination of the following functions:

1. The proposed system could keep helicopter units available for the prompt delivery of medical aid and the subsequent evacuation of emergency cases in critical need of extensive treatment;
2. The same network could efficiently transport medical teams to mobile clinic sites located in remote communities with periodic needs for preventive medical care; and
3. The helicopter system could also accelerate the flow of patients among hospitals.

The information inputs for the emergency evacuation model were based on analysis of patient arrivals at the emergency room of the West Virginia University Medical Center during a 2-week period. Patients who could be diverted to a helicopter system were identified by the patient's general diagnosis, the acceptance of a patient to particular advanced treatment stations, and the time before examination by a physician of a patient after arrival in the emergency room. Data for the preventive care model involved estimating the amount of preventive medical care needed by isolated communities. Under current conditions, persons living in 33 identified isolated localities must travel from 10 to 26 miles to reach the nearest physician. It was assumed that, by dispatching mobile trailer units in combination with medical teams commuting by helicopter, the availability of medical resources for rural residents could be efficiently increased. Criteria for scheduling the distribution of medical team units for such a hypothetical medical program were based on a recommended standard that 1 physician should be made available per 1,200 persons.

The basic hypothesis of this study was that regional medical services could be included in an emergency medical transport system by dispatching mobile trailer units in combination with medical teams commuting by helicopter. Through such an arrangement, the availability of medical resources for rural residents could be increased. The residents isolated from a nearby physician could then benefit from early diagnosis of conditions leading to such illnesses as cancer, strokes, or heart attacks.

The results indicate that it is possible to deploy a helicopter transport system to handle emergency medical functions along with routine transfers and regional medical ser-

vices. With this 3-pronged approach toward improving the delivery of medical services for a test region in West Virginia, only a few minor conflicts would have resulted. During the 15-day simulation period, 2 routine transfer requests would have incurred delays of 15 min each. None of these delays was serious enough to detract from the effectiveness of the helicopter system. Also, with the introduction of a 20 percent static level (1 false call after every 4 emergency calls), only 1 medical team transfer mission would have been delayed by 10 min; otherwise, static imposed no interference with the delivery of emergency transfers, routine transfers, and regional medical services. This study further showed that 2 medium-sized helicopters could save 9 hours over the existing ground ambulance system during the peak 72 hours of emergency calls. On an annual basis, the cost to operate 2 medium-sized helicopters would be \$250,000.

In addition, a helicopter utilization factor of 12 percent for emergency and routine transfer functions was expanded to 19 percent with the introduction of regional medical services during an 8-day period. For the peak 3 days, the utilization rate for a medium-sized helicopter was 27 percent with all 3 functions. However, expanding the helicopter system to transfer medical teams would only increase the annual cost over the basic emergency function by \$57,100 for 1 medical team (40 hours of service per week) and \$114,200 for 2 medical teams (80 hours of service per week). This respectively represents a 23.1 and 46.2 percent annual increase in cost over the basic emergency service for a medium-sized helicopter.

Use of helicopter medical system for the 3 functions outlined has the advantage of providing a complementary system that achieves a high helicopter utilization factor. Also, the system can be administered by 1 organization while upholding the respect of a "medical ship." Thus, multiple uses of the helicopter for related medical purposes appear to be attractive in serving a rural area with a dispersed population and do not detract from the dispatching of the helicopter on emergency medical missions.

# NORTHWAY EMERGENCY TELEPHONE SYSTEM

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## ABRIDGMENT

•THE NEED to provide for the safety and convenience of disabled motorists on limited-access highways is receiving considerable attention from state and federal highway agencies. The attention is certainly warranted because 85 percent of the planned 42,500-mile Interstate highway system lies in rural areas. Many of these areas are sparsely populated and completely lacking in motorist services, and service facilities are banned from the Interstate highways themselves by the U.S. Highway Code. In the event of accident, illness, or vehicle failure, the motorist is almost entirely dependent on assistance from a passing motorist or police vehicle. Quite often the delay while waiting for service is unreasonably long and may, in the event of a serious accident, result in a loss of life.

Many types of communication systems have been developed and tested, and some have even proved to be effective in an urban environment; however, their application to a rural area is very much in question. During the construction of the Adirondack Northway, which travels through urban, suburban, and remote rural areas, New York State realized the need to provide assistance to the motorist and, after considering the available systems, installed a 2-way voice communication system with telephones spaced at  $\frac{1}{2}$ -mile intervals on each side of the highway.

The monetary investment in this system plus the uniqueness of this application of telephones led to a research study to evaluate the effectiveness of the Northway Emergency Telephone System (NETS). The objectives of this study were to determine the following:

1. The need that Northway travelers have for an emergency communication system;
2. The use of the system by the motoring public;
3. The nature of the relations that are found between the use of the telephone system and parameters, such as traffic volume, trip purpose, trip length, vehicle type, sex and number of vehicle occupants, and time of day when the telephone is used, and that would indicate disproportionate needs for emergency telephones by particular travelers; and
4. The cost and effectiveness of this type of system both to motorists and to public agencies.

Several types of data were required to define the objectives. A survey of stopped motorists was conducted to determine their need for assistance, their knowledge of NETS, and their attitude about how to obtain assistance. A second survey of the general traffic stream defined the characteristics of the Northway travelers and was used to determine the knowledge of the system and the disproportionate needs for the NETS. The last major set of data was the actual calls received at the substations of the state police who were responsible for monitoring the system. Other data such as costs, traffic volumes, police patrol times, and accident records were also collected and used in the analysis of NETS.

The important results of the study are as follows:

1. Eighty-nine percent of the motorists know about the system;
2. Fifty percent of the stopped motorists need assistance;

3. Eighty-one percent of the people needing assistance would use NETS to obtain the assistance;

4. Approximately 10,000 calls a year are received over the 712 phones;

5. Truckers use NETS at a rate twice as much as their presence in the traffic stream would indicate;

6. Stranded vehicles with females as the only adult occupants have a greater need for assistance but use NETS at a lower rate than males;

7. NETS is used at a higher rate at night, on weekends, and during the winter;

8. The formula  $Y = -50.5 + 14.66X$  describes the expected phone use based on 2 years of call experience, where Y is the expected calls and X is the number of million vehicle-miles of travel that occur; and

9. NETS costs the public \$0.0125 per average trip (52 miles) on the Northway.

Based on these results, the following recommendations were made:

1. A more extensive educational program should be used to inform the people who were unaware that the system existed and to reinforce the knowledge of the people who forgot about NETS. This could be done through better signing, handing out of brochures at each terminal of the highway, and including information in travel guides.

2. The present name of the telephone system "Northway Emergency Telephone System" should be changed to "Northway Motorist Aid System."

3. A schedule of regulated changes should be established for the service stations that supply the support assistance to the police.

The small cost of the system to the public, in comparison to the many benefits provided to the stranded motorist and to the police agency that has jurisdiction on the Northway, as well as the benefit of security offered to each Northway traveler leads to the conclusion that NETS has proved to be an effective system.