HIGHWAY RESEARCH RECORD

Number 450

Motorist Communications and Services

4 reports
prepared for the
52nd Annual Meeting

Subject Areas

51	Highway Safety
53	Traffic Control and Operations

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING
Washington, D.C. 1973

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ISBN 0-309-02182-0
Library of Congress Catalog Card No. 73-13459
Price: $2.00

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CONTENTS

FOREWORD

The four papers in this RECORD deal with the provision of a variety of services needed by users of the highway system. Individual papers discuss hardware systems, software systems, and alternative medical care systems. The material will be of interest to highway and enforcement administrators, traffic and operations engineers, and communications specialists.

The results of installation and usage tests of a two-wire emergency call system are reported by Reilly, Hollinger, and Santacroce of the New Jersey Department of Transportation. Detailed records of services needed and provided, response times, and system installation and maintenance costs were maintained. Similar costs for telephone and call box systems used elsewhere are included for comparison.

Woolman and Wisepart discuss motorist aid from a systems viewpoint, suggesting that the principal focus in the past has been on hardware, to the detriment of the overall systems approach. A plan for cooperation by the various agencies involved in motorist aid is suggested.

Using two simulation models, Chow and May studied a San Francisco area freeway to find the optimal locations for service facilities along the freeway. Best locations are defined as those that minimize the total freeway delay time caused by an accident or incident or by response of the service unit. Three discussions by Hess, Carter, and Wattleworth identify and raise questions about a number of the assumptions necessarily made by Chow and May, but they also are unanimous in their agreement that the work has good potential for future practical application.

Gochenour, Neumann, and Wegmann used a simulation model to test alternative delivery systems for providing emergency medical care to rural areas (not necessarily highway sites). The numbers and locations of ground ambulances, with and without helicopter support, were examined, and the authors suggest ways to improve medical service with fewer response vehicles by improving the location pattern.

TWO-WIRE EMERGENCY CALL SYSTEM

Eugene F. Reilly, Richard L. Hollinger, and Joseph Santacroce,
New Jersey Department of Transportation

The results of the installation and usage tests of the 2-wire emergency call system do not indicate any significant advantages of that system over other types of call systems. Before-installation and after-installation field surveys were conducted to determine the number of motorists needing aid along the roadway and the type of problems they had. Details of servicing times for the stopped motorists also were collected. Records were maintained for system installation and maintenance costs. The summaries of the field survey and system costs are included in the report. Costs for 2 other types of systems (telephone and call box) used in other states are included for comparison.

•MOST INTERSTATE HIGHWAYS have no means for motorists to summon aid in the event of a breakdown or emergency; Interstate highways are noted for their isolation from service facilities, even in urban and suburban areas, due to access control. The demand for improved communications between the motoring public and the highway system is steadily increasing. Several states have implemented emergency aid call systems, including voice (telephone), coded call box, and microwave systems.

The New Jersey Department of Transportation, in cooperation with the Federal Highway Administration, undertook the development of an emergency call system with the following primary objectives:

1. Closely spaced emergency call stations,
2. Low installation costs,
3. Low maintenance costs, and
4. Simplicity of system operation.

It was felt that an emergency call system utilizing a buried two-conductor cable with simple, momentary contact switches for signaling calls would best fulfill the objectives.

The system was designed to have call stations at 200-ft intervals, thus providing access to the system much more frequently than do other systems. The system design concept is basically of a resistance-measuring type. An emergency call is made when a switch is depressed (closed), which shorts the buried cable and decreases its resistance in an amount proportional to the distance from the resistance-measuring unit. This resistance can be converted to a specific location along the highway.

Because the system utilized common principles (shorting a wire and measuring its resistance) for which simple equipment already existed, it was felt that the objectives of the system would be met.

After installation of a test system, the system was operated and a field survey was conducted to determine whether the system would fulfill the objectives as planned.

SYSTEM DESCRIPTION

The section of I-287 chosen for the test site was 8.2 miles long, extending from Main Street, Metuchen, to River Road, Piscataway Township. A cable comprised of two 14-gauge copper wires insulated suitably for direct underground burial was trenched

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Publication of this paper sponsored by Committee on Communications.

along the shoulder of the highway, approximately 6 in. below the surface. Wherever bridges and ramps were encountered, the cable was run through conduits. At each of the 425 delineator posts located on the north and south lanes of the 8.2-mile section, loops were brought up to a height of 3 to 4 ft.

The call stations, which were reflective push-button switches in weatherproof protective enclosures, were connected to the cable and attached to each delineator post replacing the usual reflector (Fig. 1). Instructional signs were also attached to each delineator post to instruct motorists in the use of the system.

The 8.2-mile section of I-287, 16.4 miles in both directions, was divided into four separate segments consisting of approximately 4 miles per segment. With this arrangement, the cables from the four segments, two from the north lanes and two from the south lanes, were terminated at a central location. The central location contained the monitoring equipment as well as the required electrical and telephone utilities. The monitoring equipment consisted of four identical test panels, one for each segment of cable, housed in an equipment rack. Each panel had a meter for indicating an emergency call location, a table for converting the meter reading to the actual milepost value, two push buttons, and two indicator lamps mounted in the front and the associated electrical circuitry in the back. One indicator lamp would light when an emergency call had been made and was turned off by one of the push buttons after the necessary information was recorded. The other indicator lamp warned that a break in the two-wire cable had occurred, making the system inoperative. By use of a known terminating resistance at the end of each segment, a continuous low current flowed through the segment. Any break in the conductor would interrupt the current flow, causing the warning lamp to be actuated. The remaining push button was used for testing the electrical monitoring circuitry.

The electrical source for the system consisted of two 12-V automobile storage batteries under constant charge from a 110-V ac main. In the event of loss of ac power, the storage batteries were capable of supplying the necessary power to operate the system for up to 14 days.

Pressing one of the switches along the highway effected a change of potential in the current-carrying cable and caused a sensor to activate an audio and visual alarm. Simultaneously, a peak voltage memory voltmeter indicated the level of the change, corresponding to the location of the switch. After recording the reading, the attendant restored the line and checked the location chart for the exact location of the alarm.

Once the location of the emergency call was determined, it was necessary to dispatch a vehicle to the location to determine the type of assistance required (police action, fire, mechanical, and the like). State police were notified by telephone of each call and dispatched a patrol car if one was available. If a state police patrol car could not respond, a radio-equipped Department of Transportation vehicle was sent out. Upon determination of the type of assistance required, the information was radioed to the central monitoring station and relayed by telephone to the state police who made arrangements for the aid.

STUDY PROCEDURES

The base for developing an effective two-wire emergency call system rests on the ability to

1. Keep installation costs low;
2. Have a system where malfunctioning is a minor problem and damage caused by vehicles or vandals is minimized, easily detected, and quickly taken care of; and
3. Service the motorist in need of aid in a shorter time than if there were no emergency call system.

Measurement of these items is possible, but, unless another system is used for comparison, the cost and maintenance factors can only be subjectively evaluated. To avoid the possibility of misinterpreting the installation and maintenance costs of other emergency call systems we simply itemized these items (given in a later section of this report). The effectiveness of the system, using these costs, can then be weighed with other factors of policy, availability of funds, motorists' needs, and so forth.

Definite comparative measures are provided for the third item between summer of 1970 (when no emergency call system was in operation) and summer of 1971 (when the two-wire emergency call system was in operation). It is also possible to compare the service times for the drivers who chose to use the two-wire call system and those drivers who chose to service their own needs (either by themselves, through other drivers, or by walking off the road for service).

The field studies that provided this information, in the summers of 1970 and 1971, consisted of observers stationed along the roadside during the daylight hours and patrolling the road in vehicles during the nighttime hours.

Information about drivers who used the call system during the 1971 survey was determined by matching results of the field survey with records of calls kept in the central monitoring station and the state police barracks. From the 1970 and 1971 surveys, information about the time stopped, time from stop to first contact, time until aid arrived, type of assistance required, and other vehicles contacting the disabled motorist was obtained. Results of the surveys are presented later in this report.

Definition of Terms

1. Need aid—those motorists during the field survey who, in the observer's opinion, needed aid from another party in order to be on their way;
2. First contact—those motorists who stopped during the survey period because they needed aid and who were observed having contact with another motorist, state police, or Department personnel;
3. Serviced by system—motorists who pushed the emergency call switch during the period of operation, were contacted by state police or Department personnel, and obtained assistance through the contact made by means of the system; and
4. Gone on arrival—those calls that were responded to by the state police or Department personnel but that resulted in no contact, or, if contact was made, the motorist had left before the service vehicle arrived.

Daytime Studies (Stationary Observers)

When all survey positions were covered, 5.7 miles of the 8.2-mile system were observed with the aid of binoculars. For 14 days the observers were stationed from 5:30 a. m. to 1:00 p. m. and for 14 days from 12:30 p. m. to 8:30 p. m. They used the form shown in Figure 2. (The column for "time switch was pushed" was only used during operation of the emergency call system during the summer of 1971.)

Nighttime Studies (Patrolling Vehicles)

An observer and driver in each of four vehicles patrolled the entire route of the emergency call system for 7 successive nights from 8:00 p. m. through 5:30 a. m. The use of four patrolling vehicles resulted in an average spacing between vehicles of 7.5 min. To maintain this headway, each vehicle, in the course of a round trip, passed a specified point on the road at a specific time. A fifth vehicle was used to allow ½-hour breaks every 2½ hours for each of the four patrolling vehicles.

Volume Data

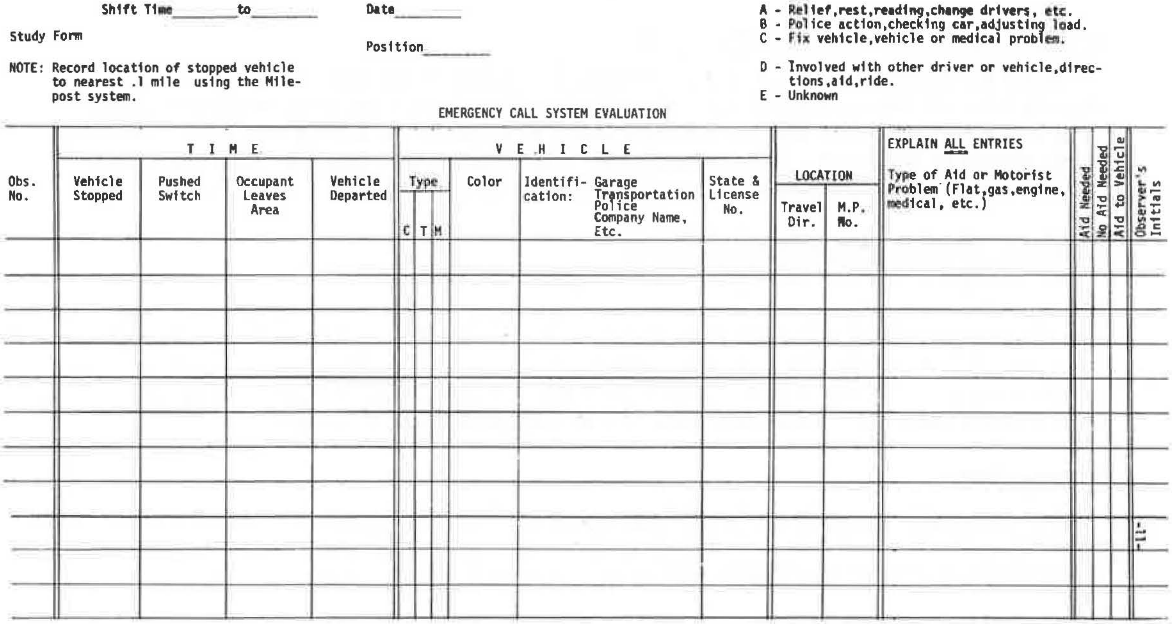
A permanent count station (with loop detectors) was located within the 8.2-mile study roadway. Counting at the station was continuous and was tabulated (by hour and day) for 3 weeks in the primary direction and 1 week in the other direction.

Central Monitoring Station

The monitoring station was located near an interchange in the center of the study section. The interchange afforded convenient access to the road for Department of Transportation personnel when they were required to answer an alarm. This was only necessary when the state police indicated they were unable to respond. It also permitted the call system to be easily divided into four segments, two to the north and two

Figure 1. Reflective push-button switch: call station.

Figure 2. Emergency call system reporting form.



Shift Time________to________ Date________

Study Form

Position________

NOTE: Record location of stopped vehicle to nearest .1 mile using the Mile-post system.

A - Relief,rest,reading,change drivers, etc.
B - Police action,checking car,adjusting load.
C - Fix vehicle,vehicle or medical problem.

D - Involved with other driver or vehicle,directions,aid,ride.
E - Unknown

EMERGENCY CALL SYSTEM EVALUATION

Obs. No.	TIME				VEHICLE						LOCATION		EXPLAIN ALL ENTRIES	Aid Needed	No Aid Needed	Aid to Vehicle	Observer's Initials
	Vehicle Stopped	Pushed Switch	Occupant Leaves Area	Vehicle Departed	Type			Color	Identification: Garage Transportation Police Company Name, Etc.	State & License No.	Travel Dir.	M.P. No.	Type of Aid or Motorist Problem (Flat,gas,engine, medical, etc.)				
					C	T	M										

to the south of the station. Two Department of Transportation personnel were monitoring the system at all times for the 57 days of operation.

When the central monitoring station records were matched with the state police log (described in the following section), information was obtained on total calls received, time and date of calls, nature of motorist's need, extent of misuse of system (gone on arrival), and response time to alarm.

State Police Log

Each alarm received at the central monitoring station was immediately relayed by telephone to the Somerville State Police barracks (located 12 miles west of the monitoring station). The desk sergeant on duty at the time made the appropriate entries into a log and advised Department of Transportation personnel at the monitoring station on whether a police patrol could respond to the alarm. If a state trooper responded, he then supplied the desk sergeant with vehicle description, type of service required, and time of arrival at the site. The desk sergeant then completed the log by entering the time and name of the service agency called to respond to the site.

If a state trooper did not respond but Department personnel did, the Department personnel then supplied the appropriate information to the sergeant at the Somerville barracks for entry into the log.

Motorist Information Signing

Motorists on I-287 were informed of the presence of the emergency call system by eleven 5- x 12-ft informational signs. The signs were placed prior to and throughout the system.

Smaller instructional signs (Fig. 1) were placed below each delineator switch. No reference was made on these signs regarding the type of aid that would arrive. The operation of the system necessitated the determination of the type of aid required prior to sending aid. Hence, the initial contact with the motorist was made through either the state police or Department of Transportation personnel.

RESULTS

1970 and 1971 Field Surveys

The following results reflect only those vehicles that were observed by field survey personnel and determined by them to need aid. The field surveys were conducted for 285 hours each summer during the 1970 and 1971 studies. The emergency call system was in operation for 1,368 consecutive hours during the summer of 1971.

The 1970 field survey results indicate that 62 motorists were observed to need aid for the 2.48 million vehicle-miles (MVM) traveled, yielding a rate of 25.0 motorists needing aid per MVM. During the 1970 survey period, approximately 3,250 motorists were seen to stop along the survey section for a stopping rate of 1,310 per MVM.

The 1971 field survey results indicate that 101 motorists were observed to need aid for the 3.77 MVM traveled, yielding a rate of 26.8 motorists needing aid per MVM. During the 1971 survey period, approximately 5,500 vehicles were seen to stop along the survey section for a rate of stopping of 1,460 per MVM. These rates include all motorists who stopped during the survey period, whether or not they left prior to the end of the survey period, because they were included in the vehicle-miles of travel given.

A summary of the types of aid needed and the average times required for first contact to be made and for aid to arrive (as well as the average total stopped time) is given in Tables 1 and 2. The data are for both the 1970 and 1971 field surveys and include only those vehicles that stopped within the time limits of the surveys. Figure 3 shows total stopped time for all vehicles needing aid during the surveys, and Figure 4 shows times until first contact and aid arrived and total stopped time for vehicles that needed aid and that were serviced by the system during the 1971 survey.

Table 1. Details of vehicles needing aid during survey periods.

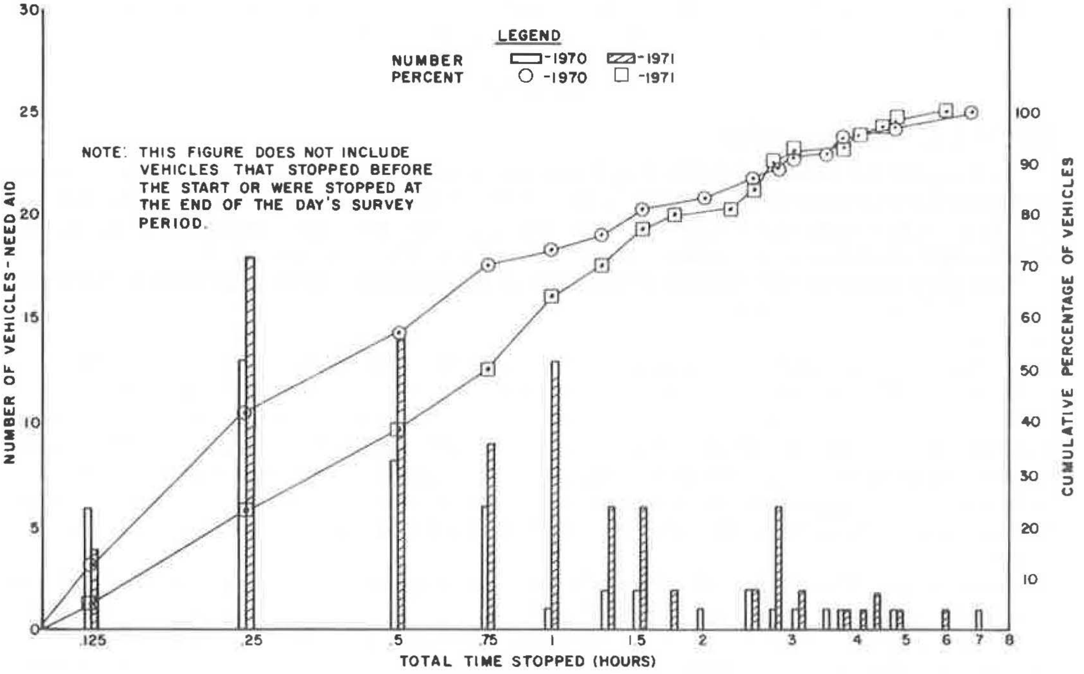
	1970 Field Survey		1971 Field Survey					
	All Vehicles		All Vehicles		Vehicles Not Serviced by System		Vehicles Serviced by System	
Reason for Stop	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Mechanical	28	45	50	50	35	47	15	58
Tire	13	21	25	24	20	27	5	19
Gas	9	14	5	5	4	5	1	4
Other[a]	12	20	21	21	16	21	5	19

[a] Includes motorists whose needs could not be determined by the field observers; also includes cases in which operating personnel failed to properly fill out the data log and one motorist who required water for his vehicle.

Table 2. Average time (in minutes) spent by vehicles needing aid during survey periods.

		1971 Field Survey		
Item	1970 Field Survey	All Vehicles	Vehicles Not Serviced by System	Vehicles Serviced by System
To first contact	42	30	28	38
Until aid arrived	44	48	44	60
Total time stopped	65	74	69	90

Figure 3. Total time stopped on test section.



Emergency Call System Use

During the 57 days of operation, 539 calls were received at the central monitoring station, of which 170 or 32 percent were classified as serviced by system. The remaining 369 calls, or 68 percent, were classified as gone on arrival. The 369 gone on arrivals can be divided into two groups. The first group includes those calls where the motorist had left before state police or Department personnel arrived, including the true false alarm calls and the ones where service was obtained from another source (e.g., passing motorist). This group includes 311, or 84 percent, of the 369 gone on arrival calls. The second group includes those motorists with whom contact was made by state police or Department personnel but who left prior to the arrival of the service vehicle. Because initial contact was made with state personnel, it is doubtful that many of these calls were true false alarms; instead, assistance was received from another source before the service vehicle arrived. These calls make up 58 or 16 percent of the gone on arrivals calls. Of the 539 calls received, the state police responded to 224 or 42 percent and Department of Transportation personnel responded to 315 or 58 percent.

The rate of vehicles serviced by the system for the 57 days of system operation (170 vehicles serviced by the system with 21.6 MVM of travel) was 7.9/MVM. During the field survey, 26 vehicles were serviced by the system per 3.77 MVM of travel, which yields a rate of 7.0 vehicles serviced by the system per MVM.

A summary of the types of aid needed by motorists who were serviced by the system is given in Table 3.

MAINTENANCE OF SYSTEM

A log of all maintenance required by the system was kept for a period of 7 months. The last 2 months were during operation of the system. A total of 45 maintenance calls were handled. Two major problems were encountered: failure of system due to electrical shorts to ground and destruction of posts and switches by vehicles and lawn mowers.

During the 2 months of operation, the system or part of the system was down for a total of 35 hours due to a variety of electrical and test equipment malfunctions.

The most serious problem was shorts to ground, traced to excessive moisture in the underground splices and cable or moisture and corrosion in the splices aboveground. This problem was the most difficult to trace and repair. Repair time averaged 5 hours for the major down periods.

The remaining down periods were due to component failure in the test station monitoring equipment. These down times were relatively short compared to the periods described above. After 1 month of operation, all audio and visual alarm sensor cards developed a malfunction and were removed from the test set and not replaced. However, this did not in any way inhibit operation of the system. One memory voltmeter card, three relays, two capacitors, and indicator lamps were also replaced during this period.

Although the moisture problems were corrected during the down times, this problem recurred every time there was a rainstorm or excessive humidity; the short would be relieved as the ground, cable, or switches dried.

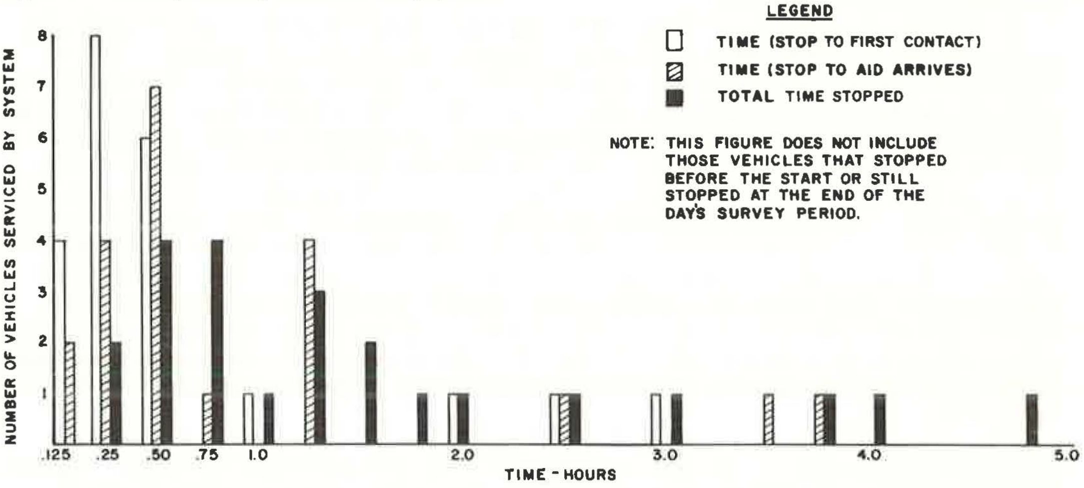
All maintenance calls were the responsibility of the Bureau of Instrumentation Services of the Department.

SYSTEM COST

Table 4 gives the costs incurred in the installation and operation of the two-wire emergency call system. The cost of installing this system reflects the expense of the materials and equipment used, along with the salaries of the personnel who installed and inspected the system. The cost also includes all operational and maintenance costs incurred for 57 days or 1.9 months of operation.

Operational costs include utilities, vehicle usage, and salaries for two men per shift for three 8-hour shifts per day who maintained the central monitoring station. All personnel used in the monitoring station were employed by the New Jersey Department of

Figure 4. Time expended by motorists using system.



NOTE: THIS FIGURE DOES NOT INCLUDE THOSE VEHICLES THAT STOPPED BEFORE THE START OR STILL STOPPED AT THE END OF THE DAY'S SURVEY PERIOD.

Table 3. Types of aid needed by motorists serviced by system.

Type of Need	Vehicles	
	Number	Percent
Mechanical	100	59
Tires	30	18
Gas	25	15
Other	15	8

Table 4. Breakdown of expenses for the two-wire call system.

Expense Item	Breakdown	Cost (dollars)
Installation		
Materials and equipment	Electrical installation contract	52,479
	Electrical equipment	3,500
	Vehicle expense	1,073
	Approximate cost of wire	9,000
	425 switches at $15.54/switch	6,605
	Housing for equipment	1,000
	Informational signs	1,500
Salaries[a]	Equipment installation (1 man-month)	1,000
	Delineator sign and switch installation (5 man-months)	5,000
	Inspection and testing of system (2½ man-months)	2,500
Subtotal		83,657
Maintenance	Delineator post and switch replacement	800
	Electrical equipment and cable	200
Subtotal		1,000
Operation	16 man-months[a]	16,000
	1 vehicle at $100/month	200
	Utilities	250
Subtotal		16,450
Total		101,107

[a] Salaries are based on $1,000 per man-month.

Transportation, and their salaries were computed at an average rate of $1,000 per man-month. However, it is important to note that the system may be intended to be operated by the state police. Thus, the operating costs of the system, if run as intended, would be quite negligible because of the use of normal police patrols to respond to the calls and the desk sergeant to monitor the operation in addition to his other duties.

Maintenance of the system was also performed by Department personnel. Maintenance costs involved materials and equipment needed to repair breakdowns in the system and personnel salaries for time involved in making the repairs. If the system, as intended, had been run by the state police, it might have been necessary to contract personnel for handling the maintenance of the system.

Table 5 gives a comparison of the expenditures of two other emergency call systems and the two-wire call box system. Both of these other systems provide the motorists with a means of summoning aid, as the two-wire emergency call system does, but differ in the mechanics of actual use. The two systems are the Michigan telephone system and the Texas call box system. The costs of the systems are broken down by installation, maintenance, and operation.

DISCUSSION OF TWO-WIRE SYSTEM

The results of the study indicate that not all of the primary objectives were acheived. The system, as designed, did provide the motorist with call switches spaced very close to each other and was simple to operate. However, the 2-month operating period did not indicate a low maintenance cost. Installation costs on a per-mile basis were high, but, because there were 50 switches per mile, the cost per unit switch was low. The largest portion of the installation cost was the contract to bury the wire. The cost of burying the wire may have been much less had it been performed by state forces instead of an outside contractor. This reduction in cost may have made the installation cost less than those of either of the other systems given in Table 4.

1970-1971 Field Study Comparison

When the 1970 and 1971 field results are compared, consideration must be given to the types of aid required. The comparisons given in Table 1 show that a slight increase in the percentage of the mechanical and tire needs was evidenced during 1971. However, the 1971 results indicate a much higher percentage of mechanical difficulties for those motorists using the system than for those motorists who chose not to use the system.

It may be assumed that many motorists who felt they had a serious problem (mechanical) were inclined toward using the emergency call system. The needs of the 1970 motorists and the 1971 motorists that were not serviced by the system were very similar.

Also, when the average total time stopped, average time to first contact, and average time until aid arrived between 1970 and 1971 are compared (Table 2), some interesting observations can be made. The average total time stopped and the average time until aid arrived for those who were serviced by the system were significantly higher than the corresponding times in 1970 and in 1971 of those who did not use the emergency call systems. Although no conclusive evidence is available, we may assume that many of those motorists who felt they had a serious problem utilized the system. Also, when a motorist used the system, he frequently refused aid from passing motorists, indicating that he had aid coming, but there were times when the aid was delayed. For those motorists who did not use the system (in 1970 and 1971), the first contact was frequently the source of aid, probably because the type of aid required was of a minor nature.

Emergency Call System Use

The fact that the system experienced a false alarm (gone on arrival) rate of 68 percent is difficult to explain. Although we have no absolute evidence except during the survey, not all of the gone on arrivals should be classified as no aid needed. It is shown that a number of them did need aid but serviced themselves or received aid from passing motorists prior to initial contact by the state police or Department personnel or, in some cases (16 percent), after initial contact but before the service vehicle arrived. Table 6 gives the reasons for gone on arrivals during the 1971 field survey period.

The operation of the emergency call system for 57 days showed that the majority of calls received and serviced were from those motorists having some form of mechanical problem (59 percent). The next largest group (18 percent) had a tire problem. The large variance between these two groups may be explained in that only those motorists that had potentially serious problems tended to use the system to summon aid.

A comparison of the field survey data for those who used the system (Table 1) and the log of the central monitoring station for system usage (Table 3) indicates a difference in percentages of two of the reasons for motorists' summoning aid: gas and other. The reasons for these differences can be attributed to the small time sample for the 1971 field survey, a lack of accurate identification on the part of field survey personnel, and failure to properly complete both the central monitoring station and the state police logs.

Without an emergency call system, it may be expected that some motorists will have to wait excessively long periods of time before first contact is made (another motorist stopping). In fact, this waiting period will add substantially to their total time stopped on the road. However, the operation of an emergency call system should show a reduction in the distribution of time until first contact (at least with the two-wire system). The explanation of why this was not true (Table 2) follows.

The distribution of times for motorists awaiting aid (utilizing the call system) is shown in Figure 4. If it is assumed that $\frac{1}{2}$ hour is a reasonable time for operating personnel to respond to a call and if the failuure of the operating personnel to respond to all calls within that time could be overcome, the average time to first contact could be reduced by 18 min. Similarly, if the aid that is requested by the motorist can arrive within 1 hour after being notified (a maximum of $1\frac{1}{2}$ hours after the time the motorist stopped), the average time stopped until aid arrives could be reduced by 15 min. It follows that a reduction of 15 min in the average time from stop until aid arrives would result in a similar reduction in the average total stopped time (Table 2 and Fig. 4). The increased number of serious problems (mechanical) in 1971 over 1970 (50 versus 28) at least partially explains the longer average stopped time for 1971.

The rate of motorists serviced by the system was 7.0/MVM during the survey periods and 7.9/MVM for the 57 days of system operation. The rate of drivers needing aid, 26.8/MVM, determined from the survey periods, is assumed to be constant for the 57 days of system operation. From these figures, it is determined that between one of three and one of four motorists needing aid utilized the emergency call system during the period of system operation.

SUMMARY AND CONCLUSIONS

With the rapidly increasing mileage of limited-access highways being built, the need for a means of summoning aid by stranded motorists is becoming of paramount importance. Emergency call systems are available that use land wires or radio propagation. However, because of the unit station cost, call stations are usually located between $\frac{1}{4}$ and 1 mile apart. In an attempt to place call stations closer together, a two-wire emergency call system was developed. This system provides call stations along the shoulder of a highway on each delineator post spaced an average of 200 ft apart. Because of the large number of call stations per mile, a low-cost call station was devised. The station only provided a switch that the motorist depresses to indicate a need. No provisions for type of aid needed or verification of a call being received were made. A vehicle is dispatched to the site of the call to collect the required information. Field surveys and system usage records were utilized to determine types of needs and servicing times.

The system was operated for 57 consecutive days during summer 1971. During this period, there were 21.6 MVM of travel in the system operation area. A total of 539 calls were received at the monitoring station: 170 were serviced by the system, and 369 were classified as gone on arrival.

Table 5. Comparison of costs for two-wire call system and two other emergency call systems.

		Length of System			Installation Expenses (dollars)			Maintenance Expenses (dollars)		Operation Expenses (dollars)	
Location	Type of System	Months	Miles	Call Station Spacing	Total	Per Mile	Per Call Station	Total	Per Mile per Month	Total	Per Month
Michigan	Telephone	42	30	1 mile	290,170	9,670	4,835	55,895	56	5,114[a]	426[b]
Texas	Call box	12	11	¼ mile	161,025	14,639	1,830	20,000[c]	151		
New Jersey	Call box	2	8.2	200 ft	83,657	10,202	197	1,000	60	16,450	8,660

[a] Annual. [b] For 12 months. [c] Estimated.

Table 6. Reasons for motorists who were gone on arrival during 1971 field survey period.

	Before First Contact		Before Service		Total	
Reason	Number	Percent	Number	Percent	Number	Percent
False alarm	24	73	0	0	24	55
Fixed self	1	3	2	20	3	7
Called own service	0	0	3	30	3	7
Assisted by other motorist	3	9	5	50	8	19
Unknown	5	15	0	0	5	12
Total	33	100	10	100	43	100

A sample of the stopped motorists, made by a field study, indicated that 37 percent of the total calls received were false alarms, and 31 percent serviced themselves or received aid from other motorists.

The 170 motorists serviced by the system yielded a rate of 7.9 vehicles serviced per MVM for the period of system operation. The rate of motorists needing aid, as determined from the field survey, was 26.8/MVM, showing that almost one in three motorists needing aid were serviced through the call system.

The study did not show the two-wire system to have a low maintenance or installation cost in comparison with other types of call systems on a per-mile basis. However, the two-wire system provided call boxes at 200-ft spacings instead of ¼- to 1-mile spacings, thus reducing the stranded motorist's exposure to traffic while walking to a call station.

For the emergency call system studied to be effective, the time for aid to arrive must be reduced. The long periods of time taken for aid to arrive can be partially explained by the failure in some cases of the operating and servicing personnel to respond in a short period of time. It must be noted that this is true with any type of call system and should not be considered a fault of the two-wire system alone. The total length of time stopped was much longer for motorists who used the call system than for other motorists needing aid. This can be explained by the fact that motorists with serious (mechanical) problems were more likely to use the call system than those with minor problems, thus increasing the time to effect repairs.

At the present stage of development, the two-wire emergency call system has not proved to have any significant advantages over other types of call systems now in use. If further research is conducted, two areas should be included. First, the equipment should be refined, and, second, procedures must be implemented to reduce the time required for servicing agencies to respond to motorists who need aid. One approach is to investigate the advantages of contracting with service agencies for the service.

ACKNOWLEDGMENT

The authors wish to express their appreciation for the assistance given them in this project by the Bureau of Instrumentation Services and the Bureau of Equipment, New Jersey Department of Transportation, and by the New Jersey State Police.

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A NEW APPROACH TO MOTORIST AID?

Stanley Woolman, Federal Highway Administration, Delmar, New York; and
Ivor S. Wisepart, Computran Systems Corporation, Hackensack, New Jersey

The paper focuses on the aid aspects of a highway motorist aid system and stresses that the attention in the past on hardware elements has precluded a systems approach to design criteria. The lack of guidelines and warrants for total system design and a lack of uniform reporting of motorist needs during breakdowns are two conditions that have prevailed. This paper suggests that a systems approach be used in implementing motorist aid systems and that a state agency be charged with statewide responsibility for motorist aid. This designation should be accompanied by a policy statement on the level of service to be rendered. The agency should develop plans for the implementation of motorist aid including means of detection, response, and service. The agency should have the authority to develop new public resources or to contract with local service organizations for the operation of the system. The suggested procedure is that (a) a task force of advisors with expertise in the various aspects of motorist aid be organized, (b) a sharper awareness among state officials regarding motorists' needs during breakdown be developed, and (c) technical resources and guidance during the design and implementation of an integrated statewide system be provided.

•THE PRIMARY PURPOSE of the highway system is safe and efficient movement of people and goods. Events leading to a disruption in this safe and efficient movement represent failures in the system. With the evolution of the motor vehicle as the prevalent mode of transportation, two major and related problems have emerged: highway accidents and disabled motorists (1). As catastrophic system failures, motor vehicle accidents are highly publicized; vehicle breakdowns and stranded motorists, though system failures of a lesser degree, are not. The question arises, "Why not?" Perhaps answers may be found among the following possibilities.

The lack of central interest in this system failure scatters information on individual case histories, complaint letters, and the like in a multitude of "miscellaneous files" nationwide. Thus, data on occurrence, severity, safety hazards, and related parameters are not readily available for research analyses and dissemination. Also, stranded motorists, being a very small fraction of the traveling public, exert little impact. They are merely someone's loss of time, comfort, or convenience, a minor hazard in today's highway transportation. Without national focus and concern, solution or remedial action for this nationwide problem of disabled motorists will continue to remain tomorrow's challenge instead of today's reality.

On several occasions in recent years, Arnold G. Fisch, Director of Operations, New York Thruway Authority, has pointed up this vacuum by stressing that "... just as in rail and air transportation systems, the safe, convenient, and efficient operation of expressway facilities must be a centralized responsibility and a coordinated function. Policing, maintenance and emergency services should be a responsibility of one—not several—operating official. This message, disseminated nationwide in the 1958-59 series of traffic operations seminars conducted by the Institute of Traffic Engineers, still remains largely unheeded. It is still a lesson to be learned; a practice to be adopted."

Publication of this paper sponsored by Committee on Communications.

In discussing operational responsibility for motorist aid systems, one research report (2) notes the following:

> It is desirable to tie together all of these operations; however, it is difficult to categorically award total systems management to any single organization except where the highway is operated by a toll authority....A single operational system manager goes a long way toward achieving the overall coordination that is necessary to realize optimal performance.

It is little wonder, then, that the stranded motorist and his system-failure problems, frustrations, and well-being as well as exposure of the vehicle and its occupants to unsafe or hazardous situations seldom appear in the media other than as individual local news of unusual situations. Without a national focus and source of statistics for study and research, it is most difficult to assess the full importance of this safety element in the highway environment.

It has been estimated, however, that 126 million emergency stops, other than accidents, occur annually on America's highways (3). The disabled motorist, in need of aid, thus remains a significant problem for local, state, and federal highway officials whether recognized or not. Douglas B. Fugate, in commenting on the Safety Service Patrol established on the Capital Beltway for the month of August and the Labor Day weekend 1972, stated that its purpose was to provide direct person-to-person contact for motorists whose vehicles become disabled. The service, an experiment conducted by the Virginia Department of Highways on major holiday weekends for several years, operated on an around-the-clock basis to provide radio communications for motorists seeking help. No doubt similar experimental adventures have been pioneered by other concerned officials.

Based on the preceding estimate, system failures are many and number far beyond the limited response resources currently available. Such resources as are available are primarily marshalled for motor vehicle accidents and, in some localities, are not generally available for aid to disabled motorists. This lack of adequate response facilities increases the likelihood of secondary accident involvements, such as chain reactions and shoulder accidents. In addition, it leads to traffic slowdowns caused by "rubbernecking" due to disabled vehicles remaining on the traveled way and other aspects of system failures. Given the present situation of limited and dispersed response resources, a great need exists to improve emergency aid services to disabled motorists as well as to accident victims.

To improve emergency services to stranded motorists requires that the characteristics of the stranded motorist problem be known. A uniform system of reporting such incidents must be developed and used nationwide as a basis for estimating the resources needed. As an example of the existing lack of uniformity, a comparison of data reported for four Interstate highways is given in Table 1.

It should be noted that the grouping of "stop categories" necessary to compile the available information from these four sources leaves many vacant cells and that the category items have unclear and ambiguous meanings. This absence of uniformity handicaps the highway community in taking steps toward an early definition of the problem and its solution nationwide.

The pressing nature of the problem is forcing some states to implement solutions based on fragmentary data. Highway administrators are beginning to recognize that the safety and emotional well-being of stranded motorists is a top-priority problem.

Morris Chorney, Director of the Rhode Island Department of Transportation, who for almost a decade has been a strong supporter of motorist aid, has recently been vocal in his emphasis that, first, "... highway officials have a duty and responsibility to provide the necessary motorist aid services" and that, second, "the greatest cost of any highway communication system must be borne by the State and Federal governments if it is to be uniformly accepted, used, and be available to all motorists."

In the 1930s, two decades before the "car population explosion," highway officials in metropolitan areas and toll authority operations, worldwide, recognized the need for roadside telephone systems. These covered relatively short segments of road facilities. With the growth of toll roads and turnpikes after World War II, around-the-clock police patrol with its mobile radio served as a motorist aid system.

Table 1. Percentage of disabled motorists on Interstate highways.

	Rural		Urban	
Stop Category	I-87, New York	I-94, Michigan	Harbor Freeway, Louisiana	Capital Beltway
Tire repair	19	22	17	26
Mechanical repair	43[a]	17	27	10
Fuel, oil, or water	21	27	13	11
Towing	—[b]	19	—[b]	8
Ambulance required	—[b]	7[c]	8	3
Fire truck required	—[b]	1	—[b]	1
Police required	12	—[b]	—[b]	—[b]
Information	5	5	29[d]	21
Police use	—[b]	2	6	—[b]
Gone on arrival	—[b]	—[b]	—[b]	20

[a] Includes 11 percent of "other" vehicle service.

[b] Not available separately.

[c] Medical and tow, 1 percent; tow only, 1 percent; no tow or medical, 5 percent.

[d] False alarms, 1 percent; miscellaneous, 28 percent.

The Interstate System, however, by virtue of its unprecedented mileage as a limited-access facility and the extremely wide range of its traffic volume spectrum, imposed conditions far beyond the available resources for police patrols as a proper response to the disabled motorist problem. However, as significant sections of Interstate mileage were placed in operation, highway administrators in the populous states recognized the need for roadside call systems.

Early installations were based on a 1962 AASHO informational report (4). This comprehensive guide has been validated by the test of time. It still stands as a tribute to the planning abilities, foresight, and scientific approach of AASHO and the committee members who prepared it. Several important insights in this report deserve our attention at this moment:

> Until more experience is acquired and meaningful data are available on the characteristics, usage, and operational value of roadside . . . communications devices . . . it will not be practicable to develop guides and clear-cut warrants to govern such installations.
>
> The sole purpose of an emergency communication system is to save time—that is, to reduce the time that a motorist in distress has to wait for assistance and . . . that other highway users might be subjected to accident hazards and delays to traffic movement.
>
> In analyzing the propriety of emergency communications devices along a given Interstate highway, the following are listed:
>
> 1. Characteristics of the freeway,
> 2. Surveillance,
> 3. Installation, maintenance, and operational costs, and
> 4. Safety to eliminate the often hazardous walk to a roadside call station.
>
> The installation of an emergency communications system places a considerable amount of responsibility and financial obligation on the agencies concerned—State, county, and municipal police and highway departments. Round-the-clock operation . . . must be assured, and provision must be made for immediate dispatching of help. This requires advance arrangements with suitable automotive service stations, fire companies and ambulance stations to respond to calls.

Where do we stand in relation to these goals? Ten years after the AASHO recommendation, guidelines and warrants have still not been developed. Should the responsibility rest with AASHO, FHWA, NHTSA, a new Department of Public Safety? Will it take another 10 years to decide?

The need is now. This the public has a right to expect, as it does other uniform highway safety features. Otherwise, continued proliferation and uncoordinated or "individual-insulated" state actions, with and without federal aid, taken in response to public demands, may soon preclude (by the very high cost of changeover) a planned, uniform, and coordinated nationwide operational motorist aid system.

In one report, 13 agencies are listed as potential users of electronic communications (5). Another report (2) states that "The challenge to highway agencies is first to learn exactly what the motorists' needs are and how best to provide for those needs. Then, agencies can provide aid systems that quickly detect stranded motorists, offer a means by which specific needs are communicated, and provide a timely and appropriate response." The summary in this same report presents the following conclusions:

1. Aid to motorists on the highways is an existing need,
2. Motorist aid and emergency communication systems should be coordinated with other statewide communications needs, and
3. Highway agencies should establish a function covering highway communication management.

It goes on to say, "There is a definite need for a coordinated effort to provide direction and to establish guidelines for planning, designing, and operating a motorist aid system." This coordinated effort should resolve the following issues and questions:

1. Among the safety features included in highway designs are wide shoulders, medians, protective systems, and aesthetic elements. Should not motorist aid systems be considered as essential safety elements in future designs for controlled-access highways?
2. Because motorist safety, comfort, and convenience are used to describe quality of service (6) and are basic to good highway design, construction, and operation, should not motorist aid systems be included in new construction and added to existing roads?
3. What is the relative benefit-cost of expenditures such as grass cutting, bare pavements, and aesthetics when compared to motorist aid as a safety feature?
4. What impact can we expect from present activities such as emergency medical services for motorists and statewide communications for law enforcement, health, pollution, and the like?
5. What do we know about the real life, real-time experiences of disabled motorists? Should not national statistics on stranded motorists be available to the media and others as readily as accident statistics?
6. Inasmuch as controlled-access highways are generally isolated and insulated from the areas they traverse, should not some form of motorist aid be provided for the physical and emotional safety of highway users who become stranded?

The thesis of this paper is that a design for a motorist aid system should start with a plan for organized, efficient, adequate, and prompt response resources, which we call software. It then proceeds with the call system or hardware. This is true whether we are considering a uniform nationwide policy or are planning an installation for a section of Interstate highway.

We emphasize that requirements or constraints, if any, derived from the software plan are requisite inputs to the design of a call system's hardware. Basic to system specifications for hardware is a need for a method for uniform comparative analyses of total costs (installation, operation, maintenance, etc.) over a specified time period (10 years, for example). This is an important element in selection of hardware from among available alternatives. Other elements include forecasts of future developments in equipment, public demand, engineering-executive judgment, and the like.

As system specifications or nationwide performance guidelines or warrants are evolved, we feel certain that our industrial and electronics associates will be able to supply the appropriate hardware systems with little difficulty. No doubt they would welcome a preliminary nationwide statement on guidelines and warrants. Possibly their representatives would aid in development of such guidelines or even system specifications for nationwide use.

The key criterion for the software design of a total motorist aid system is the "response-time" objective. On the average, what should be the maximum time that a motorist in distress should expect to wait for assistance? Should it be constant for all highway sections? Should it vary inversely with traffic volume? In a sense, this is a determinant of the quality of service to be provided to meet motorists' needs. Other facets to be considered include the following: What organization(s) will be designated to receive the call for aid on a round-the-clock basis? How will the requisite type of assistance be dispatched? How will reasonable service rates be set and enforced? How and by whom will system performance (service rendered the traveling public) be measured, reported, and evaluated to ensure conformance with established "response-time" and other criteria?

A basic aspect of software system effectiveness is inherent in a response to the question, Will the system distinguish between varying degrees of distress: on one hand, a salesman or a truck driver, and on the other, a young mother with two infants and a stalled station wagon? What are the effects of time of day (darkness versus daylight) and weather (winds, rain, snow, sleet)?

Can the system distinguish degrees of accident severity, e.g., fender benders, major property damage, injuries, fatalities, multiple-vehicle accidents? Should possible combinations of these parameters be postulated and a single weighted index of "response action" be evolved?

Acceptance of operations responsibility among highway and transportation departments is growing, though much too slowly. The experience encountered some time ago by a state traffic engineer when he attempted to apply his prior operating experience and toll road practices to highway department operations is a case in point. At an early staff meeting, he created a considerable reaction when he announced that he expected district traffic engineers to be present at the scene of serious accidents whenever they occurred, night or day, good weather or bad.

How often has the thought occurred, "What if a woman, while stranded on a rural section of a freeway, were robbed, raped, or murdered?" The May 19, 1972, slain librarian story is not the first newspaper account! When and where are the others? Are they buried in miscellaneous files of local governments or glossed over in the obituary columns?

Recently, a first step was taken toward evolving a potential channel for attaining such information. The newly revised FHWA Instructional Memorandum 20-1-72 provides that "To be eligible for Federal aid funds, every proposed (motorist-aid) system shall have a complete operational response plan." FHWA's Highway Planning Program Manual (7) makes the statement:

> It is evident that there will be a continued and increased need for expanded and improved highway services. Population growth, the increasing number of vehicles, multiple-car families, and the steady upward trend of the Gross National Product all point to highway service demands far beyond the present level.
>
> It is, therefore, important that legislators and administrators not only be furnished with adequate data concerning the future physical needs of the highway, road, and street systems, but also be advised of the fiscal ability of the governmental units involved to meet such needs.

In line with this statement, we propose that the following actions be taken:

1. A joint meeting of appropriate highway, police, and emergency medical service agencies should be convened to discuss the problems of disabled motorists and action should be taken to

   a. Address a request to appropriate federal officials for allocation of funds to develop a uniform method (nationwide) for reporting the occurrence of disabled motorists and

   b. Suggest the issuance of periodic statistical reports using the preceding format and system, either separate or as part of FHWA's current statistical reporting.

2. A task force should be appointed to prepare a set of nationwide guidelines, formulate standard operating procedures for a series of "stopped vehicle" surveys to identify local needs, coordinate the conduct of these surveys, analyze the data, and disseminate the results and findings. Thereafter, an executive summary report and a film report should be prepared for presentation to congressional committees, federal and state agencies, and state legislators concerned.

3. Federal-aid funds should be provided for motorist aid software and hardware development.

4. Operations of the total motorist aid system should be monitored to ensure conformance with the prescribed level of service.

It is our firm conviction that highway users have a right to expect a facility that provides for their physical and emotional safety to ensure

1. Freedom from fear (of being stranded on a highway in daylight or darkness, in good weather or bad),
2. Freedom from pain (physical pain as well as mental anguish from being hurt in a crash or "lost" at the bottom of a highway slope or stranded with a child or infant in a disabled vehicle on a highway shoulder), and
3. Freedom from death (because no one saw the accident or a helpful motorist's rush for help took too long or because aid was late).

ACKNOWLEDGMENTS

The authors express their appreciation to Ms. James Ware, Ms. Frank Macarilla, and Ms. Saul Engel for assistance in the preparation of this paper.

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SEARCHING FOR THE BEST LOCATIONS FOR SERVICE FACILITIES ALONG A FREEWAY

We-Min Chow and Adolf D. May, Operations Research Center,
University of California, Berkeley

Two models were used to find the optimal locations for service facilities along a freeway. The first one is a simulation model called FREEQ. For a given accident or incident on the freeway, FREEQ can be employed to generate all necessary information, such as total travel time and individual average travel time on the freeway, provided that the demand pattern and the physical configuration of the freeway are known. Based on these results, an optimization model is used to search for the best locations for service facilities so that the total delay time caused by the accident or incident or the response time of the service unit is minimized. The Eastshore Freeway in the San Francisco Bay area was chosen to be the study area. Thus, a numerical problem is also given.

MAJOR PROBLEMS may develop due to the occurrence of accidents or incidents on freeways: Traffic flow will be interrupted because of reduced capacity, thereby causing traffic congestion and delays to passing motorists. Also, the waiting time for necessary service can possibly be vital to the survival of stranded motorists. Consequently, the objective should be to minimize total delay and response time (the time until service vehicles reach the accident location).

The purpose of this paper is to search for the best locations of service facilities along a freeway. Basically, two models are presented: a simulation model called FREEQ, which will be used to generate all necessary data such as average individual travel time and total travel time, and an optimization model employed to find the best locations of the service facilities based on the results generated from FREEQ. A schematic model is shown in Figure 1.

ASSUMPTIONS AND PROCEDURES OF SIMULATION MODEL

This simulation model was first developed by Y. Makigami, L. Woodie, and A. D. May in August 1970. A FORTRAN IV computer program written for a CDC 6400 is available.

The basic assumptions of the model are as follows:

1. Traffic is treated as a compressible fluid where an individual vehicle is regarded as an integral part of the flow and is considered individually;
2. Within a given time interval (usually 15 min), traffic demands remain constant and do not fluctuate over that time interval, and, for given subsections, traffic demands are expressed as a step function over the entire time period under consideration;
3. Once traffic demands are loaded onto the freeway, the demands propagate downstream instantaneously unless there are capacity constraints; and
4. Capacities of subsections, including weaving sections and merging points, are estimated by using Highway Capacity Manual methods (3).

If both the physical configuration of the freeway and the traffic demand pattern are known, then freeway performance can be evaluated by this model.

Publication of this paper sponsored by Committee on Motorist Services and Committee on Freeway Operations.

The stepwise procedure of the model is as follows:

1. Read input data, which consist of number of subsections, number of lanes in each subsection, capacity of each subsection, length of each subsection, truck factor in each subsection, type of ramps in each subsection (e.g., on, off, left, multilane), ramp capacity, and origin-destination demand pattern for each 15-min time slice.
2. Compute the demand.
3. Modify O-D distribution (ramp analysis).
4. Modify the freeway capacity (weaving analysis).
5. Compare the demand and the capacity (if demand > capacity, go to 6; if demand ≤ capacity, go to 7).
6. Go through queue increasing process; calculate the average speed, travel time, queue length, and travel distance. Then go to 9.
7. Check whether there is any queue remaining from the last 15-min time slice. If there is, go to 8. Otherwise, go through nonqueuing process, and go to 9.
8. Go through queue discharging process; calculate the same things as in step 6.
9. Print out the results.

This completes a whole cycle for each time slice. Some of the current results such as queue length and number of vehicles in the queue are used as the initial condition for the next computation cycle (the next time slice).

The basic idea used in the FREEQ model is to divide the freeway into subsections according to its physical configuration, so that each subsection can be treated as a uniform pipe and the capacity of every point in a specified subsection is always the same. Whenever an accident (inasmuch as there is no need to distinguish between accident and incident, the term accident will be used throughout this paper) occurs, the capacity is reduced until the disabled vehicle is removed. If the blockage time (during this time interval, the freeway may operate at reduced capacity) and the effective length (length of the freeway segment having reduced capacity) are both known, the modification can easily be made by subdividing the time slices and subsections into smaller intervals. Therefore, the uniformity property in each new subsection is preserved, and FREEQ can be used directly. Of course, in this situation some of the time slices may be less than 15 min in duration.

RESULTS AND ANALYSIS

The present application of this study is limited to the northbound Eastshore Freeway in the San Francisco Bay area. This freeway is composed of 30 subsections (in case of no accident). The time interval covers a $2\frac{1}{2}$-hour afternoon peak period from 3:45 to 6:15 p.m.; hence, there are a total of 10 time slices.

Normal Case: No Accident

Figure 2 shows the speed, density, and queue length in a time-distance space. The traffic volume in each subsection over each time interval can be computed by the relation $q = \mu k$; i.e., volume (vph) = speed (mph) × density (vpm).

Subsection 20 becomes a bottleneck at the beginning of the second time slice, and subsections 5 and 25 become bottlenecks at the beginning of time slices 4 and 6 respectively. The shock wave is recovered in time slice 7. The total travel time TTT = 5,017 passenger-hours.

Accident Case

In this report only the single-accident case has been considered, and 16 of the 30 subsections have been investigated for this example. These 16 subsections were chosen from the Gilman on-ramp to the San Pablo Dam Road off-ramp, inasmuch as this region covers all possible traffic situations such as forming and recovering of shock waves, bottlenecks, and congested flow and free-flow cases. Moreover, this region is far from the beginning of the main-line freeway, and, if an accident occurs, the chance that the queue backs up out of the upstream boundary of the freeway is small. The accident may occur in only 16 of the 30 subsections, but the total travel time over all 30 subsections is studied. It is assumed that

1. Only one accident can happen in the peak period,
2. When the accident occurs, one lane of capacity is lost,
3. The effective length of the accident is 100 ft, and
4. The accident spot is located at the midpoint of the subsection (and also at the midpoint of 100-ft section).

The last assumption will approximately give the average value of each measurement (total travel time, average individual travel time in each subsection, and so forth). In other words, when an accident occurs in a specified time slice and subsection, the average measurement is approximately equal to the computed measurement as if the accident took place at the midpoint of the subsection.

Because there are 16 subsections and 10 time slices, 160 accidents were generated. Each accident corresponds to an (s, t) pair if it occurs in subsection s during time slice t. The delay time of each accident is defined by

$$\Delta TTT(s,t) = TTT(s,t) - TTT$$

That is, delay = total travel time when an accident occurs in (s, t) - total travel time when there are no accidents.

In Figure 3, the number in each cell is the average delay in passenger-hours when an accident occurs in the corresponding subsection and time slice and blocks the traffic for half an hour. The blank cells show that the delay time due to the accident is less than 10 passenger-hours. Comparing this with 5,017 passenger-hours (TTT under normal condition) reveals that the increment is less than 0.2 percent and hence is considered to have no effect.

Clearly, it can be seen from this figure that, if an accident happens in time slice 9 or 10, it does not interrupt the traffic flow very much. According to Figure 2 in these two time slices, the freeway has low density and high speed. This implies that the traffic load is light. Consequently, if one lane of capacity is lost, the traveling speed will not be affected too much.

It is also interesting to note that an accident may have little effect if it occurs in the normal congestion area. In this case, the bottleneck is shifted upstream, and the traffic condition in the area downstream of the accident location is improved. Data shown in Figure 3 demonstrate that, if an accident takes place at the normal bottleneck, the delay time is significantly high, but, if it occurs in the congestion area (i.e., upstream of the bottleneck), the accident will cause little delay.

OPTIMIZATION MODEL

The best location for service facilities will minimize the maximal possible total delay time or minimize the maximal possible travel time of a service vehicle. In any case, a good emergency system should be able to clear off the accident promptly, that is, to minimize the blockage time. In general, the blockage time can be divided into three nonoverlapping parts: detection time, waiting time for service or, equivalently, the response time of a service vehicle, and on-site service time.

The detection time is dependent on the detection system, whether electronic detectors, call boxes, emergency telephones, patrolling vehicles, helicopters. The on-site service time, on the other hand, is contingent on the type of accident. The controllable variable in our problem is response time, and the investigation will be undertaken by assuming different values of the sum of detection time and on-site service time. The problems are solved by first selecting certain upper limits in total delay time or response time and then finding "admissible" locations for service facilities so that these limits will not be violated. By changing these upper limits, new problems can be formulated. Therefore, our work is to solve a sequence of parametric optimization problems, each of them corresponding to a specified upper limit value.

Figure 1. Schematic of FREEQ model.

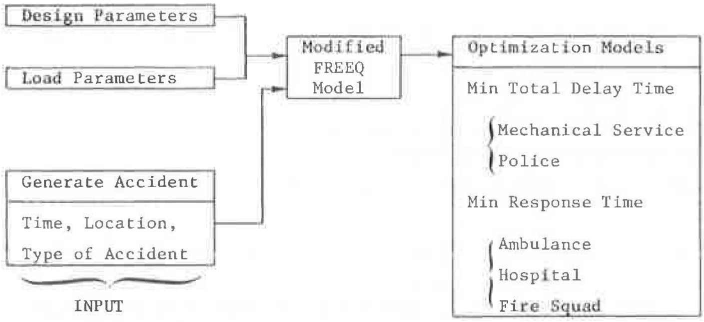


Figure 2. Speed, density, and shock wave diagram.

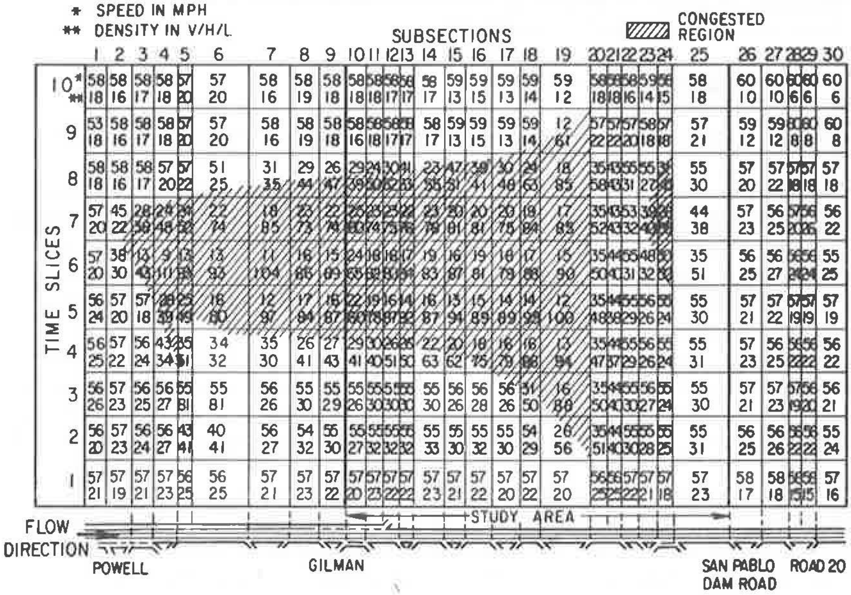
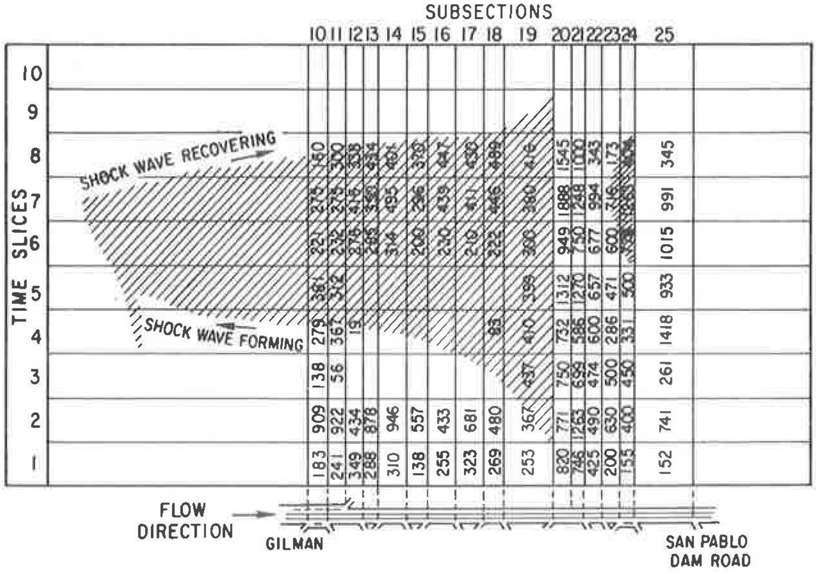


Figure 3. Delay in passenger-hours due to accident occurrence.



Mathematical Formulation

For each (s, t) pair, it is assumed that the total delay time to freeway users is a linear function of blockage time of the accident. Because the min-max criterion is employed, for each subsection s only the most critical time slice needs to be considered. (During this time slice, if an accident occurs, the delay time takes on its maximal value. For example, in Figure 3, for the last subsection, the most critical time slice is 4 where an accident causes a delay of 1,418 passenger-hours.) If the locations of service facilities have been found in this way, then the same solution will automatically satisfy the constraints for the other time slices.

Based on this assumption, the total delay due to the (s, t) accident is given by

$$\Delta TTT(s,t) = TTT(s,t) - 5{,}017 = B(s,t) \times DT$$

where

DT = blockage time of (s, t) accident and
$B(s,t)$ = rate of contribution of (s, t) accident.

For each s, the most critical time slice t^* will be one in which

$$\bar{B}(s) = B(s,t^*) = \max_t B(s,t)$$

or, equivalently,

$$TTT(s,t^*) = \max_t [TTT(s,t)]$$

Now, the problem is to investigate a number of potential locations and to find the best ones. Let

$$x_i = \begin{cases} 1, & \text{if a service facility is needed at location i} \\ 0, & \text{otherwise} \end{cases}$$

Then the problem is given by

$$\text{Minimize } Z = \sum_{i=1}^{n} c_i x_i$$

subject to $TTT(s,t^*) \leq SL$, for all s, and $x_i = 0$ or 1, for $i = 1, \ldots, n$, where

c_i = the cost incurred if a service facility is established at the i th candidate location and
SL = preselected upper limit (or service level).

Note that, first, $TTT(s,t^*) \leq SL$, for all s, implies that $TTT(s,t) \leq SL$ for all s and t and, second, $TTT(s,t^*)$ is a function of x_i's. This value can be evaluated based on the result from the simulation model.

To solve the problem, two things must be predetermined: the desirable service level SL and the sum of the detection time and on-site service time TT. If a service vehicle is dispatched from the i th service facility to an (s,t^*) accident location, the travel time of this vehicle $Tx_i(s)$ will be evaluated, based on the result from our simulation model. The duration of the accident DT is simply the sum of TT and $Tx_i(s)$; therefore,

$$\begin{aligned} TTT(s, t^*) &= DT \times \bar{B}(s) + 5{,}017 \\ &= [TT + Tx_i(s)]\bar{B}(s) + 5{,}017 \end{aligned}$$

and the problem can be reformularized as

$$\text{Minimize } Z = \sum_{i=1}^{n} c_i x_i$$

subject to $Tx_i(s) \leq \frac{SL - 5{,}017}{\bar{B}(s)} - TT$ for all s and x_i, and $x_i = 0$ or 1, for $i = 1, \ldots, n$.

This type of problem can be solved in several ways, such as integer programming, dynamic programming, and branch and bound procedure. However, only the following method will be used in this paper.

Algorithm

A minimal set solution (MSS) is a set that is a solution but no proper subset of it can be a solution. For instance, if there exist set solutions {1, 2}, {1, 3, 4}, {1, 2, 3}, and {1, 2, 3, 4}, then only {1, 2} and {1, 3, 4} are MSSs because $\{1, 2\} \subset \{1, 2, 3\} \subset \{1, 2, 3, 4\}$.

The algorithm used here is to search for a sequence of MSSs. If {i, j, k} is the MSS, it indicates that, when the service facilities are established at the candidate locations i, j, and k, the desirable service level can be attained.

Initially, the problem is formularized as a matrix. In the following example, a 1 is put into the cell (i, j) if location i can provide the service for a (j, t^*) accident without violating the preselected SL limit. Then the problem is solved by searching for all MSSs from the incident matrix, and only one column is considered at a time. The stepwise procedure of the algorithm is given as follows:

1. Find all MSSs for column one and treat these solutions as the current partial solution. In the example, they are {1} and {2}.
2. Find all MSSs for the next column.
3. Combine the partial solution and the solution just obtained to find all MSSs again. Treat the result as the current partial solutions.
4. Repeat steps 2 and 3 until all columns have been considered. At this moment the completed solutions are determined, which are the desirable MSSs for the whole matrix.

Example

Subsections j

Candidate Locations i	1	2	3	4	5	6
1	1	1	1			
2	1	1	1	1	1	
3		1	1	1		
4			1		1	1

Stage 1—Initial partial solution (from column 1): {1} and {2}.

Stage 2—MSSs for column 2: {1}, {2}, and {3}. Combine stages 1 and 2; the admissible partial solution will be $\{1\} \cup \{1\}$, $\{1\} \cup \{2\}$, $\{1\} \cup \{3\}$, $\{2\} \cup \{1\}$, $\{2\} \cup \{2\}$, and $\{2\} \cup \{3\}$. Because $\{1\} \subset \{1, 2\}$, $\{1\} \subset \{1, 3\}$, and $\{2\} \subset \{2, 3\}$, the current partial solutions should be {1} and {2}, which are also the MSSs for columns 1 and 2.

Stage 3—MSSs for column 3: {1}, {2}, {3}, and {4}. Admissible partial solutions: {1}, {2}, {1, 3}, {1, 4}, {2, 3}, and {2, 4}. Current partial solutions: {1} and {2}.

Stage 4—MSSs for column 4: {2} and {3}. Admissible partial solutions: {1, 2}, {1, 3}, {2}, and {2, 3}. Current partial solutions: {1, 3} and {2}.

Stage 5—MSSs for column 5: {2} and {4}. Admissible partial solutions: {1, 2, 3}, {1, 3, 4}, {2}, and {2, 4}. Current partial solutions: {2} and {1, 3, 4}.

Stage 6—MSS for column 6: {4}. Admissible partial solutions: {2, 4} and {1, 3, 4}. Current partial solutions: {2, 4} and {1, 3, 4}.

Inasmuch as all the columns have been scanned, the MSSs for the matrix will be {2, 4} and {1, 3, 4}. This means that the service facilities should be established either at locations 1, 3, and 4 or at locations 2 and 4. If the incurring cost for each location is known, the decision can be made by simply comparing the total cost for each MSS.

Clearly this method can find all the alternative solutions. If the problem is to minimize the maximal possible response time of the service vehicle, the same method is still applicable. A 1 is put into cell (i, j) if station i can send a service vehicle to the accident location within the preselected time limit. In this case it is not necessary to know the detection time and on-site service time.

It is also clear that, because no calculation is needed, the chances of making errors are reduced. When the preselected limit is changed, the post-optimality problem is easy to handle. To see this, first the problem is solved by using a large preselected limit (the desirable SL on the freeway). As this limit is decreased, some of the columns will have a different structure; i.e., the number of 1's is reduced. Those columns can be treated as if they were the m + 1, m + 2, and so on (if initially there are m subsections), and a post-optimality problem will be solved with current partial solutions equal to the previous MSS. This procedure is legitimate because any MSS generated from the new columns can satisfy the corresponding columns in the original incident matrix. In the preceding example, if the 1 in cell (3, 4) is removed, then the new column generates MSS {2}. Combining this to previous solutions {2, 4} and {1, 3, 4}, the final MSS will be {2, 4} only (because $\{2, 4\} \cup \{2\} \subset \{1, 3, 4\} \cup \{2\}$).

Algorithm Refinement

When the problem size is increased, the effort of determining MSS may grow very rapidly. It is desirable to go through a certain elimination procedure to cut down the size of the problem. Some refinement is therefore given.

1. If for each 1 in a given column there is also a 1 at the corresponding position in another column, then the latter can be removed from the matrix and never needs to be considered because any solution of the first column is a solution of the second column.
2. If for each 1 in a given row another 1 can be found at the corresponding position in some row, then the latter dominates the former. Physically, it means that there is another service facility that can provide the same service as the given facility. Hence, the dominated one can be neglected unless it has a smaller incurring cost than the other does.
3. If there is a column that has a 1 in every row, any facility can render the necessary service to this subsection. Hence, this column can be eliminated from further consideration.
4. If a column contains a single 1 in the i th row, then the candidate location i must be in every MSS. Consequently, any other columns that have a 1 in the same position can be removed from further consideration.

In the previous example, it can be seen that

1. Column 1 is a subset of column 2, thus eliminating column 2;
2. Column 3 can be dropped, because any choice of the service facilities will be the solution with respect to this column; and
3. Column 6 contains a single 1; therefore candidate location 4 must be in the MSS, and columns 3 and 5 do not have to stay in the matrix.

The equivalent matrix is now

$$\begin{array}{c|c|ccc}
 & & & \text{Subsections } j & \\
 & & 1 & 4 & 6 \\
\hline
 & 1 & 1 & & \\
\text{Candidate} & 2 & 1 & 1 & \\
\text{Locations} & 3 & & 1 & \\
i & 4 & & & 1
\end{array}$$

The final MSSs are clearly {2, 4} and {1, 3, 4}, which is of course consistent with the previous result.

If the incurring cost $c_1 \geq c_2$, row 1 is a subset of row 2 and therefore can be eliminated from further consideration. The new equivalent matrix will be the same as the above one except that the first row is removed. Consequently, the only MSS is {2, 4}. Because $c_1 + c_3 + c_4 > c_2 + c_4$, the solution {2, 4} has the minimal cost.

For most of the practical problems, one would expect that the problem size can be significantly reduced by going through the elimination procedure.

SEARCHING FOR THE BEST LOCATIONS

Procedure Used to Minimize the Maximal Possible Delay

The following general procedures are given:

1. Obtain the input data for **FREEQ**.
2. Generate the accident systematically for each (s, t) pair.
3. Run modified **FREEQ** to get TTT(s, t) and the average travel time in each subsection for every (s, t) accident.
4. Find the most critical time slice for each subsection.

$$\mathrm{TTT}(s, t^*) = \max_t \,[\mathrm{TTT}(s, t)]$$

5. Calculate the rate of change of delay $\bar{B}(s)$ for each (s, t^*).

$$\bar{B}(s) = [\mathrm{TTT}(s, t^*) - \mathrm{TTT}]/\mathrm{DT}$$

6. Choose the potential locations for service facilities.
7. Compute the response time $T_x(s)$ of the service vehicle from each of these potential locations to the most critical accident locations.
8. Select the value of the sum of detection time and on-site service time TT, and compute the contribution of the blockage time to the total delay.

$$\mathrm{SL}_x(s) = [\mathrm{TT} + T_x(s)] \times \bar{B}(s)$$

9. Select the desirable SL, and construct the incident matrix. If $\mathrm{SL}_x(s) \leq \mathrm{SL}$, then put a 1 in the cell (i, j) where i = x and j = s.
10. Search for the MSSs from the incident matrix.
11. Change TT and SL. Find the corresponding minimal set solutions by solving the post-optimality problem.

Procedure Used to Minimize the Maximal Possible Response Time

The first three steps are exactly the same as in the previous procedure.

4. Calculate the response time $T_x(s, t)$ from location x to the (s, t) accident location for all x, s, and t.
5. Find $\bar{T}_x(s) = \max_t T_x(s, t)$ for all x and s.

6. Select the upper limit for the response time, called T.
7. Prepare the incident matrix. If $\bar{T}_x(s) \leq T$, then put a 1 in the cell (i, j) where i = x and j = s.
8. Search for the minimal set solutions from the incident matrix.
9. Change the value of T, and solve the post-optimality problem.

Numerical Solutions of Minimal Delay Time

The value of TTT(s, t) is evaluated by using **FREEQ** with the duration time DT equal to 30 min. The results are shown in **Figure** 3. Meanwhile the average individual travel time in each subsection is obtained for every (s, t) accident. The values of $\bar{B}(s)$ are as follows:

s	$\bar{B}(s)$	s	$\bar{B}(s)$
1	30.3	9	16.3
2	30.7	10	14.6
3	14.5	11	62.9
4	29.3	12	42.3
5	31.5	13	33.1
6	18.6	14	23.9
7	14.9	15	42.1
8	22.7	16	47.3

Six potential locations will be selected, each located near the on-ramp. The traveling speed in the opposite direction of traffic flow (i.e., from downstream to upstream) is assumed to be 35 mph; therefore, the response time of the service vehicle is ready to be evaluated. The travel time on the freeway is of course obtained from the result of **FREEQ**. (Recall that this travel time corresponds to the accident case in the most critical time slice.) The estimated values of response time of a service vehicle from location x to subsection s is given in Table 1. Table 2 gives all values of the contribution of response time to the freeway delay. For a given value of TT, the contribution of the blockage time to the delay on freeway can be computed as $\bar{B}(s)\ [T_x(s) + TT]$ for all x and s. Consequently, if the desirable service level is chosen, the incident matrix can be obtained. By using the method suggested previously, it is easy to find the best locations for the service facilities.

The optimal solution curve is shown in **Figure** 4, the horizontal scale is the value of the sum of detection time and on-site service time TT, whereas the vertical scale indicates the total delay time in passenger-hours. The lower right side of the curve is the infeasible region, and the upper left side of the curves is the feasible region. In the figure, four solution curves are shown that correspond to the solutions {1, 2, 5, 6}, {2, 5, 6}, {5, 6} and {5} respectively. Hence, for a given value of TT, the maximal possible delay of an accident can be found from the graph for each solution.

Numerical Solutions of Minimal Response Time

Because the computation procedure is almost the same as the preceding section, only the result will be given here.

Solutions	Maximal Possible Response Time (min)
{1, 2, 3, 4, 5, 6}	2.46
{1, 2, 4, 5, 6}	3.59
{2, 3, 5, 6} or {2, 4, 5, 6}	3.82
{2, 5, 6}	4.69
{5, 6}	5.21
{5}	8.29

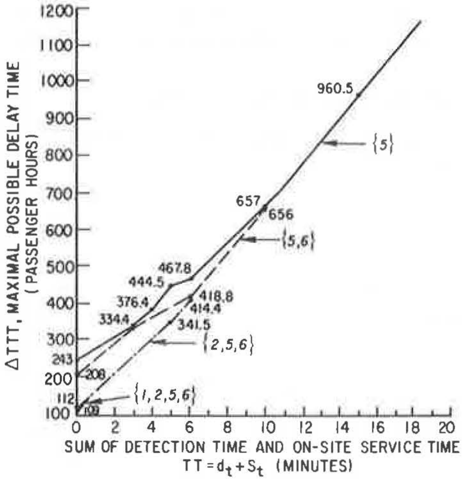
Table 1. Response time (in min) from service station to accident in subsection during the most critical time period.

	Service Station Location					
Subsection	1	2	3	4	5	6
16	23.56	16.94	13.71	8.22	3.89	2.31
15	25.58	21.84	18.01	12.90	4.95	0.24
14	16.85	14.07	10.52	7.18	2.32	3.85
13	18.32	15.25	11.96	7.79	1.74	3.27
12	28.40	22.92	17.83	12.06	1.10	2.63
11	27.58	23.45	17.44	10.71	0.43	1.96
10	5.42	4.57	3.70	2.38	4.09	5.62
9	9.64	7.03	3.82	0.65	2.36	3.89
8	6.15	4.69	2.23	3.59	5.31	6.84
7	7.13	4.27	0.76	2.12	3.84	5.37
6	3.67	2.04	3.43	4.79	6.51	8.04
5	3.64	1.00	2.39	3.75	5.47	7.00
4	2.46	3.82	5.21	6.57	8.29	9.82
3	1.71	3.07	4.46	5.82	6.54	8.07
2	1.02	2.38	3.77	5.13	6.85	8.38
1	0.38	1.74	3.13	4.49	6.21	7.74

Table 2. Contribution of response time to total delay time on freeway (in passenger-hours).

	Service Station Location					
Subsection	1	2	3	4	5	6
16	1,125	825	649	388	184	109
15	1,075	920	762	543	208	101
14	428	336	252	154	55	92
13	675	505	397	258	58	108
12	1,205	972	755	512	47	113
11	1,770	1,475	1,095	659	27	126
10	79	67	54	35	60	82
9	157	115	62	11	38	64
8	140	106	51	82	121	155
7	106	64	11	32	57	80
6	68	38	64	89	121	149
5	115	32	75	118	155	221
4	72	112	153	193	243	288
3	25	44	65	84	95	117
2	31	73	116	157	210	257
1	12	53	95	136	188	234

Figure 4. Optimal solution curve.



DISCUSSION OF MODEL

One assumption that has been made is the linear relationship between the duration time of the accident and the total delay to freeway users. This may not be always the case. If freeway operation is interpreted as a queuing system so that the demand is considered as arrivals to the system and freeway capacity as the service rate, then during the peak period this linear approximation usually will give a fairly good result. This assumption is made merely for simplifying the calculations. As a matter of fact, the problem can still be solved without using the assumption. The modified FREEQ model can be used to find the relationship between the duration time of the accident and the delay time to freeway users, and the rate of change of delay is then a function of time. For different values of TT and $T_x(s)$, the magnitude of $SL_x(s)$ can be determined as a function of $DT = [TT + T_x(s)]$. Consequently the incident matrix is capable of being constructed.

In formulating the problem, the constraints are established by first selecting TT and the desirable SL and letting

$$SL_x(s) = [TT + T_x(s)] \times \bar{B}(s) \leq SL - 5{,}017 \tag{1}$$

where $\bar{B}(s) = \max_t B(s, t)$ for all s, and $T_x(s) = T_x(s, t^*)$ such that $B(s, t^*) = \bar{B}(s)$. But the actual constraints should be

$$[TT + T_x(s, t)]\, B(s, t) \leq SL - 5{,}017$$

for all s, t, and x where $T_x(s, t)$ is the travel time of the service vehicle from location x to an (s, t) accident location. This is equivalent to

$$\max_t \{[TT + T_x(s, t)]\, B(s, t)\} \leq SL - 5{,}017 \tag{2}$$

for all s and x. Clearly, the two sets of constraints (Eqs. 1 and 2) may not be the same, inasmuch as an accident that requires the longest response time may not delay the total travel time most. It is clear that

$$[TT + T_x(s)]\, \bar{B}(s) \leq \max_t \{[TT + T_x(s, t)]\, B(s, t)\}$$

for all s and x. If the blockage time DT is large enough, then

$$\bar{B}(s) \times DT \geq B(s, t) \times DT$$

for all t and

$$[TT + T_x(s)]\, \bar{B}(s) = \max_t [TT + T_x(s, t)]\, B(s, t)$$

for all x and s, and the constraints (Eqs. 1 and 2) are identical. In our problem, this is the case when

$$DT = TT + T_x(s) \geq 5 \text{ min}$$

and this is of course a relevant assumption for the realistic cases.

Although the present problem has been solved with Eq. 1, the same technique can be used if Eq. 2 is employed.

The present study is concerned with one-direction traffic flow; a more realistic result should be obtained by considering two-way traffic either along a given freeway or within a specified network of freeways. This is simply a generalization of the present work. The same procedures and techniques are still applicable.

FUTURE RESEARCH

Three major studies are considered as future research in this field.

Investigation of Multiaccident Case

It is not impossible that during a short time period there is more than one accident found on the same freeway. The problem will be to determine (a) the relationship between delay and duration time of the accidents and (b) the optimal locations for the service facilities.

Finding the Optimal Number of Service Vehicles

Two things are involved in this problem. First, the probability distribution of accident over the time space must be determined. Second, the type of accident and the duration of the service time including response time, on-site service time, and return of the service units should be determined. Perhaps the best that can be done for this type of problem is to find the confidence level for each preselected waiting time of stranded motorists for necessary service.

Finding the Best Locations for Service Facilities for the Future Time Period

From the present result, it can be seen that the traffic demand pattern does affect the solutions of the problem. If the demand is changed, the current solutions may not be optimal anymore. It would be interesting to know how the changes in demand pattern can affect the present result and what the optimal solutions should be for a given future period. To answer these questions, the very first study should be to investigate the stochastic property of traffic and future traffic demand.

ACKNOWLEDGMENT

This research has been supported by the National Science Foundation with the Operations Research Center, University of California, Berkeley.

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DISCUSSION

Robert L. Hess, University of Michigan

The paper presents a description of the modified FREEQ simulation model and an optimization model. The modified FREEQ simulation accepts all of the normal data associated with design and demand in terms of length segments and time slices with the special capability of being able to further subdivide length segments and to increase time slices according to the specifics of an assumed blockage. Flow in each original or modified subsection of length is taken as a compressible fluid in a uniform pipe. In the present study, two extremely important assumptions are made: that an accident is equivalent to loss of one lane's share of capacity and that the subsegment of length around the accident is fixed.

The output of FREEQ is apparently more influential on the final results than are the different choices of optimization procedure. The model chosen appears to have excellent clarity and benefits from being rather easily manipulated by hand operations by the user in simple cases to gain understanding, familiarity, and trust in the procedure.

The reviewer is prompted to question, however, the influence of the assumptions made in modified FREEQ on the final outcome of the optimization procedure. Basic to this question is the understanding that the freeway capacity submodel is not adequate for subsections where the number of lanes changes. If this is true, then is it admissible to simply cut a subsection with a blocked lane into three smaller subsections, the first and third of original capacity and the second being characterized by, say, $\frac{2}{3}$ capacity? The basic question is, What impedance is represented by the reduction or increase of one lane? Second, it would appear that an accident in one lane would introduce a weaving section that was not present before the accident and that its existence would have an effect on the capacity of a section of the subsegment prior to the accident location. Finally, the estimation of average speed from the relationship between the volume-capacity ratio and the operating speed shown in the Highway Capacity Manual appears questionable. Experience in fitting freeway capacity models to actual data seems to indicate that drivers, even under normal conditions, obtain actual speeds that differ from those estimated from the Manual. Furthermore, experience in accident investigation indicates that drivers, once perturbed in speed due to congestion, behave differently if the cause of the congestion is an accident than, say, if it were a maintenance operation.

It would seem that these questions do not speak to the real contribution of the current paper, i.e., a procedure for minimizing the maximal possible delay times of motorists or of response time of a service unit given an adequate flow model. Still, to the extent that modified FREEQ might not in fact adequately simulate the traffic situation, use of the minimization may suffer. To turn the questions around would be to ask, How sensitive is the result of the minimization process to variations in input? That is a question that was not addressed in the paper.

The paper concludes with suggestions for future research. Each of the projects mentioned would appear mathematically feasible but could potentially outstrip the ability of a field group to provide model validation. This discussant suggests that the authors might wish to frame a simpler problem that could have physical fruition sooner. The suggested project is to relate the optimal service station location to blocks of time suggesting that, by shifting the location during a 24-hour period, the system might achieve a lower maximum than expected. How would the maximums vary if a given station could have 2 or 3 possible different locations on a 12- or 8-hour shift basis?

Everett C. Carter, University of Maryland

The authors have presented the results of rather extensive modeling efforts at locating motorist service facilities for freeways. In general, what appears to be a very workable methodology for determining the location of motorist service stations has been developed and documented. As a result, a two-stage model evolved with two techniques presented for solving the second model. The first model, a simulation model, appears to operate well except that only a single incident (or accident) is generated for each run, whereas there is some probability of multiple incidents during a peak period for the average urban freeway. Although the assumption of a fixed demand pattern for a 15-min time slice is generally reasonable, short time (on the order of 5 min) fluctuations in demand may occur. It would be interesting to test the sensitivity of this assumption by running the simulation model for 5-min time slices.

The assumption made on the linear relationship between the duration of an incident and total delay on the freeway may not always hold. This is recognized by the authors later in the paper and in their proposed future research. It would seem that, for two incidents of equal duration, the demands might be substantially different, resulting in a significantly longer queue of delayed vehicles in one case. Hence it is expected that the total delay time required to discharge the queue on the freeway would be different for the two incidents of equal duration.

Also, proposed future research to consider the multiple-incident case should be encouraged. It would appear that the FREEQ simulation model could be modified to yield a time-space distribution of incident occurrence that is related to some actual observed probability distribution, reflecting geometrics and other characteristics. The total delay or TTT would likely be quite high in the case of multiple incidents in one time slice or in the case of a second incident occurring in the region affected by the first before the delay (queue) from the original incident had dissipated.

The total delay to freeway traffic due to an incident depends on a very complex set of factors, which is recognized by the authors. Such factors include

1. The type of detection;
2. Surveillance and/or motorist service (e.g., roadside communication system) system;
3. Detection time, which would be influenced by patrols, spacing of communication devices, and the like;
4. On-site service time, which could be described by a distribution that varies with the type of incident and the number and type of vehicles involved;
5. Time required for the service vehicle(s) to respond and reach the incident site, which varies with the traffic flow (or time of day) and travel distance; and
6. Physical factors such as geometrics and adequacy of shoulders.

The assumption by the authors of an average duration time of 30 min with an effective blockage length of 100 ft appears to be a reasonable value for representing this complex situation.

Because the paper does not contain an explanation of how the capacities of the subsections are estimated, it is not possible to judge the adequacy of the travel time estimates (obtained from the Highway Capacity Manual curve of speed versus volume-capacity ratio), which are the basis for the optimization model. Also, because the queue increasing and discharging processes, which are critical to estimating passenger hours of delay, are not explained, it can only be assumed that these steps in this simulation model adequately represent traffic flow on a freeway when an incident occurs.

A model that uses the results of the simulation model to simultaneously determine locations (and number of emergency vehicles) for motorist service stations and minimize the cost of providing such service would be desirable. Of course, constraints on level of service (in terms of total travel time) should be adhered to. In addition, constraints on response time should be employed, especially for emergency medical service needs. In fact, minimum response time will probably be attained by separate response vehicles for medical needs and mechanical needs, which probably involves two different sets of response times, one for each vehicle type. As indicated by the authors, the response time for mechanical needs may be directly reflected in delay or duration of the incident. However, it would be desirable to use an optimization model that included constraints on medical service response times. It is recognized that this will add complexity to the model.

The optimization model developed by the authors minimizes the cost of establishing and operating service stations and includes a constraint on maximum total travel time (service level). This model can be expanded to the broader concept expressed above by using cost functions that reflect the total cost per vehicle response for medical and mechanical responses. The objective function could take the following form:

$$\text{Min } Z = \sum_{i=1}^{n} \sum_{s=1}^{m} C_{is}^{1} X_{is}^{1} + \sum_{i=1}^{n} \sum_{s=1}^{m} C_{is}^{2} X_{is}^{2}$$

subject to TTT $(s, t^*) \leq SL$ and $T_x (s, t) \leq T^*$ for all X^1_{is} where

C^1_{is} = total cost per vehicle response for emergency medical needs from service station at i to section s,
C^2_{is} = total cost per vehicle response for mechanical demands from service station at i to section s,
X^1_{is} = number of medical responses from i to s,
X^2_{is} = number of mechanical responses from i to s, and
T^* = minimum emergency medical response time established for each freeway section or a standard throughout.

All other terms are the same as those used by the authors.

It is fully recognized that the model suggested may not be applicable to practical use for determining actual freeway service station locations. However, the authors are urged to explore the possible expansion of their model to include some of the above characteristics. With the tremendous emphasis on the attainment of high air quality standards by the mid-1970s, the authors are urged to modify their model to include, as a secondary output, measures of air pollution for alternative service facility systems.

In conclusion, the authors are to be congratulated for an excellent exploratory modeling effort that appears to have great potential for practical application.

Joseph A. Wattleworth, University of Florida

The authors have presented a very important step toward the development of an analytical tool to assist in the selection of an optimal system of facilities to provide emergency service to freeway motorists. The purpose of the service facilities is to respond to incidents, which reduce the freeway capacity, and to act to restore the capacity of the freeway as quickly as possible. The trade-offs involved in such an analysis are (a) the cost of the service facilities provided versus (b) the reduction in delay cost to the freeway motorists.

The analytical technique described is a combination of the freeway simulation model, which was previously developed by May and others, and a model of another type. The latter model can be one of a number of kinds, such as integer programming or dynamic programming models. The simulation model is used to determine the relationships between service level, accident location, and service location. In this way it is possible to determine which service locations would provide an adequate service level for any freeway section. When the feasible service station locations are determined for each freeway section, the second model is used to determine the optimal service station locations. This is done essentially by minimizing the number of these service stations.

Any mathematical model makes certain assumptions in describing a complex real-world situation. These assumptions are necessary to accomplish the abstraction desired. They must, however, be borne in mind when the results of the model are interpreted, when the use of the model is considered, or when further developmental work on the model is considered. Some of the assumptions made by the authors will be discussed in the following paragraphs. The importance of several of these assumptions is recognized by the authors, and they have suggested them as further research.

The first two assumptions are made in the simulation model. These are that there is only one accident per peak period and that there is a constant capacity loss for all accidents. These suggest an addition to the simulation process to add a Monte Carlo generation of the occurrence of accidents and the severity of the accidents. These data would then be input into the existing simulation program (with some modifications).

The model as currently formulated considers only one direction of flow. To be practical, of course, the model will have to optimize service facility locations with regard to both directions of the freeway. It would appear to be a rather straightforward extension of the model to make this change.

As formulated, the model uses maximal values of delay as a basis of the optimization. It is more traditional to use expected values for this purpose so that one can compare the annual cost and annual benefits of all candidate systems. The expected values of the delay time due to accidents could be obtained by use of the Monte Carlo accident generation routine with the existing models.

The assumptions examined so far can be relaxed by extensions or modifications to the existing models. These are some assumptions that do not appear to be so easily handled within the framework of the existing models. One of these is the assumption of stationary service facilities, e.g., garages that house service vehicles waiting to be dispatched to an accident scene. An alternate approach, such as is practiced on the freeway system in Chicago, is that of emergency patrol vehicles. These vehicles are not housed in fixed-location facilities but rather move in the traffic stream. They sometimes arrive at accidents that are unreported and are sometimes dispatched to the accident scene. In any case, it is doubtful whether this type of system could be considered by the reported models or their extensions.

The model also apparently assumes that the same service facilities are provided at each service station. This will probably not be the case in a real-world application. An examination of the case in which several accidents can occur in one peak period and the inclusion of less service incidents, such as disabled vehicles, will probably lead to the need for several patrol vehicles per service station. If the number of vehicles per service station is not constant, the cost of each service station will not be constant. If the variability of cost is quite high, the optimization routine will have to be changed because it minimizes the total cost by minimizing the number of service stations. If the cost per station varies, the total system cost cannot be determined by multiplying the number of units in the system by the unit cost.

The discussions have centered on several of the assumptions that were made in the reported models. As such, the discussions should not be construed to convey a negative evaluation of the paper or the models. The authors are to be congratulated for undertaking the analysis of the problem of optimizing freeway service facilities. This is an excellent example of a real-world problem being submitted to analysis rather than a mathematical model in search of an application. More such applications of analytical techniques to real problems are needed. The authors did not solve all of the problems associated with the optimal design of freeway service facilities but have made an important step toward such an optimization.

AUTHORS' CLOSURE

The authors are appreciative of the thoughtful and valuable reviews by Hess, Carter, and Wattleworth. The three discussions are mainly concerned with the simulation model (**FREEQ**) and the assumptions that were made throughout the paper. The writers agree that the initial assumptions are limiting and that further investigations are definitely desired in order to have more valid results.

As Carter pointed out, short time fluctuations in traffic demand may occur. One should carefully select the appropriate length of time slice such that the relative fluctuation is small.

In the paper, it has been mentioned that there are two types of problems: minimal total delay time and minimal response time. It then seems reasonable that the first type of problem is relevant to police or mechanical service, whereas the second type of problem is more important to ambulance or fire squad service. If these four services are considered to be independent of each other, the problems can be treated separately. (This has been illustrated in Figure 1, the schematic model.) Of course if one would not think in this way then two sets of constraints, one for the total delay and the other for the response time, might be included in one single problem.

The freeway capacity of each subsection is estimated, based on the method described in the Highway Capacity Manual (3). The capacity

$$C = 2{,}000 \times W \times N \times T$$

where

W = width factor,
N = number of lanes, and
T = truck and grade effect.

Detail of this was given elsewhere (4, pp. 29-32). The travel time of service vehicle in each time slice and subsection, on the other hand, was obtained directly from the simulation result.

The multi-incident case is much more complicated. One has to know the probability distribution of the incidents over the time-distance space first. There are a number of papers that discuss the probability model from a macroscopic aspect. However, it is more desirable to find a model that can be used to predict the secondary incident. On the other hand, the estimated service time of a dispatched service vehicle (including response time, on-site service time, and travel time to return to the station) must be found. Perhaps, for this problem the best one can do is to simulate the actual performance of the service vehicles under different systems and traffic conditions. Wattleworth suggested the use of the Monte Carlo approach to solve the problem. Usually simulation is a good method that can be used to analyze a complicated system whenever any analytical way seems helpless. A lot of effort, however, may be required to do this. If there exist 10 candidate locations, for instance, then a total of $2^{10} - 1$ feasible solutions must be considered, one for each simulation run. It then appears that the central problem for simulation technique is how to reduce the computation effort.

The reported models are established to deal with stationary service only. Certainly, it cannot be employed to analyze patrolling service systems. Simulation results (1, 2) based on the data from the San Francisco-Oakland Bay Bridge showed that stationary service systems were better than patrolling service systems because of higher benefit-cost ratio. However, this may not be the general case. An interesting study could be made by comparing these two systems under different traffic conditions.

The optimization model is essentially to search for all the minimal set solutions. Different minimal set solutions may have a different number of elements (number of locations). If the incurred cost of each location is known, it is simple to compute the total cost for each minimal set of solutions. If there is a cost limitation, some of the solutions may be eliminated in the course of dynamic programming computation. Furthermore, different types of service facilities are not necessarily located at the same place. As was mentioned earlier, if each of the basic services is treated independently, then, for each type of service, one has to solve the problem once.

Hess made a critical comment about the assumptions used in the paper regarding capacity reduction due to incidents. Under normal conditions (in case of no incident), most of the freeway users, if necessary, would make a weaving movement far ahead of the place where the number of lanes is changed, provided that the passing motorists are familiar with the physical configuration of the freeway. On the other hand, if an incident occurs and blocks some of the lanes, a drastic reduction in the capacity will happen prior to the incident location, because of the weaving effect. Texas Transportation Institute made an interesting study that showed that, when an accident occurred in a three-lane freeway, the average flow was reduced by about 50 percent if one lane was blocked and 70 percent if two lanes were lost. This clearly demonstrated that the relation between reduction in capacities and lanes is not proportional. Certainly, more study on this is needed.

The speed-flow relationship suggested in the Highway Capacity Manual is not always applicable to a particular study area. The car-following theory has been studied for many years; there are a number of papers that investigate the relationship among flow, density, and speed. Unfortunately, none of them can be used as a general model. Probably, it is desirable to annex several subprograms in FREEQ, each corresponding to a specified car-following model, and to leave it as an option for the program users.

It is fully understood that the present report did not cover all the problems concerned with the optimal design of freeway service facilities. There exist a number of versions of the problem. This paper is only one phase of a broad research area. Some of the assumptions in the paper were used only to simplify the computation effort. Much detailed study and further work are needed.

APPLICATION OF A SIMULATION MODEL TO TEST ALTERNATIVE RURAL EMERGENCY MEDICAL CARE TRANSPORTATION SYSTEMS

Donald L. Gochenour, Jr., and Edward S. Neumann, West Virginia University; and Frederick J. Wegmann, University of Wisconsin at Milwaukee

The discrepancy of health care provided to rural and urban areas has centered on soaring costs, uneven quality, and limited availability. Due to economies of scale associated with the increasing sophistication, specialization, and cost of health services, people, money, research equipment, major medical centers, and ambulatory services are being concentrated in urban areas. However, it is just as important to the low population density rural areas to have an adequate level of medical care available to them. To improve the transportation facilities provided to rural areas, we developed a stochastic simulation model to test alternative systems for providing emergency medical care. These alternatives examined the impact of changing the number and location of ground ambulances within a rural area, introducing new technology (helicopters) to the medical care system, and utilizing the helicopter for supplemental functions to help off-set the costs of the system. For the Huntington, West Virginia, case study area, it was found that the addition of a helicopter to the emergency care system improved the performance characteristics of the system but increased system costs. Also, it was determined that fewer ground ambulances could provide at least the same level of service (with or without a helicopter) as that now being provided by an excessive number of ground ambulances. Relocating and reducing the number of ground ambulances within the study area resulted in a higher level of performance than simply reducing the number of ground ambulances while keeping vehicle base stations fixed. Finally, the individual vehicle utilization rates for both ground ambulance and helicopter were markedly improved when vehicles were relocated and when helicopters provided supplemental services other than purely emergency medical care to rural areas.

•IN RECENT YEARS much attention has been focused on the problem of improving the quality of ambulance care for the sudden illness or accident victim. With the number of highway fatalities exceeding 55,000 per year, questions are being raised on the quality and extent of the emergency medical system responsible for rushing life-saving aid to the highway accident victim. Although extensive programs have been developed to reduce the number and severity of highway accidents through education, enforcement, and engineering, it is estimated that the loss of life on the nation's highways, by present trends, could reach 100,000 deaths per year by 1980. Although the fatality rate has been reduced from 15+ per million vehicle-miles of travel during the 1920s and 1930s to approximately 5.3 per million vehicle-miles of travel in 1969, the absolute number of fatalities is still excessive and can be expected to increase as more vehicle-miles are driven (1).

Publication of this paper sponsored by Committee on Motorist Services.

In addition to fatalities, more than 4.6 million persons were injured in more than 20 million motor vehicle accidents in 1969. The resulting economic loss attributed to automobile accidents has been estimated to be as high as $16.2 billion per year. Beyond the need to respond to highway accident victims, an improved emergency medical system can also service the victims of accidental injury and sudden illness (1).

MEDICAL CARE TRANSPORTATION SUBSYSTEM

It is clear that a comprehensive attack on the emergency medical problem requires a systems viewpoint that considers not only the hospital or emergency room but also the transportation component. Transportation initially reduces the time between recognition of a need for emergency care and initiation of definitive medical aid and secondly dispatches the individual to the most appropriate hospital for treatment.

A recent study completed by a medical-engineering group concluded: "Ambulance services throughout the United States are inadequately performing their dual function of administering emergency treatment at the scene of the motor vehicle crash and other emergencies and of transporting victims without aggravating their injuries" (2). Further, Gerald Looney, physician-in-chief of the Kennedy Memorial Hospital in Boston, stated (3): "Once the injured are inside the majority of hospitals in this country, medical and surgical treatment is competent and capable of steadily reducing the fatal or disabling effects of accidental injury—the difficulties arise before reaching the hospital!"

The special importance of having an adequate transportation system for providing emergency medical services in rural areas becomes evident when the characteristics of such areas are considered. Within these areas, large distances usually separate rural communities from neighboring centers, and rural roads are often in poor physical shape. If the rural area is further characterized by mountainous terrain, as is most of West Virginia, the transportation problem becomes even more acute. Besides consideration of the physical characteristics of the roads, the transportation system has to be viewed in total, including organization, hardware, communications, documentation, and spatial separation (4).

As shown in Figure 1, the difficulties of delivering emergency medical aid by ground vehicles in rural areas are extensive. For one, extensive time delays are encountered on primary and secondary road systems because the speed of emergency vehicles is restricted by roadway alignment, inclement weather, and traffic congestion. The low population density precludes sufficient demand to adequately finance an ambulance system with the latest vehicles, equipment, and communications and trained personnel. Also, there are critical shortages of treatment facilities and paramedical personnel of any kind. The emergency care system is all too frequently associated with fragmentation of noncoordinated elements (5).

These noncoordinated elements are not the only factors complicating the issue of providing adequate emergency medical transportation to rural areas. Recently, increased stress has been placed on funeral home and private ambulance purveyors, who represent the predominant means of delivering emergency medical care in rural areas, by legislation that has (a) increased labor cost, (b) increased bookkeeping cost while reducing cash flows due to collection delays, and (c) imposed minimum standards for ambulance equipment and ambulance attendant training (2).

Now that groups such as the Regional Medical Program and the Comprehensive Health Planning Organization are emerging to consider the emergency medical system on a regional perspective and with interest in using the helicopter to provide emergency medical services, it is necessary to develop systematic procedures for evaluating the cost and effectiveness of alternative delivery systems (6, 7, 8). One method of implementing such a concept is through the development of a Monte Carlo simulation model, which can simultaneously examine the factors that influence the emergency medical transportation system. The model could then be used to economically and efficiently evaluate, on a regional level, alternative proposals for improving the emergency medical care delivery system.

Figure 1. Transportation problems encountered in providing emergency medical care to rural areas.

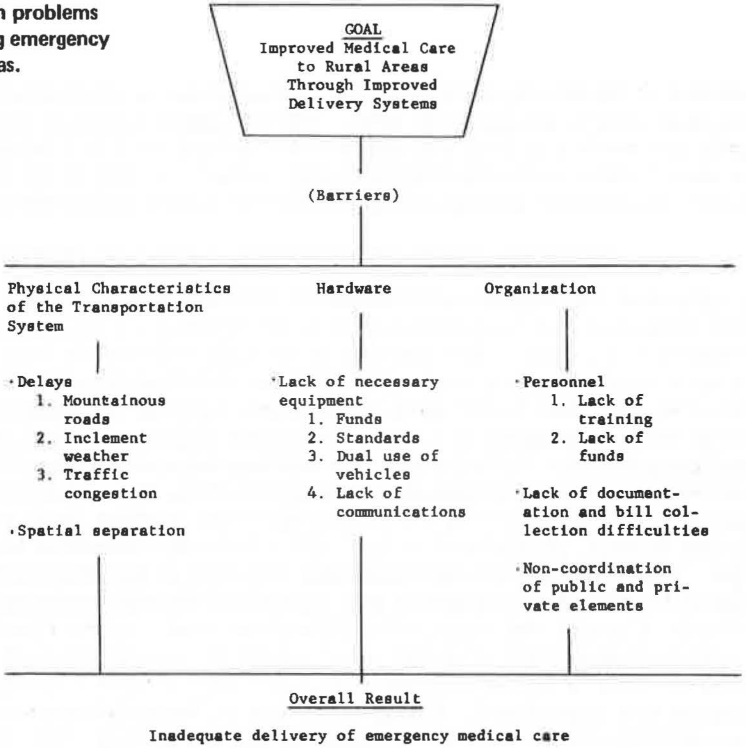
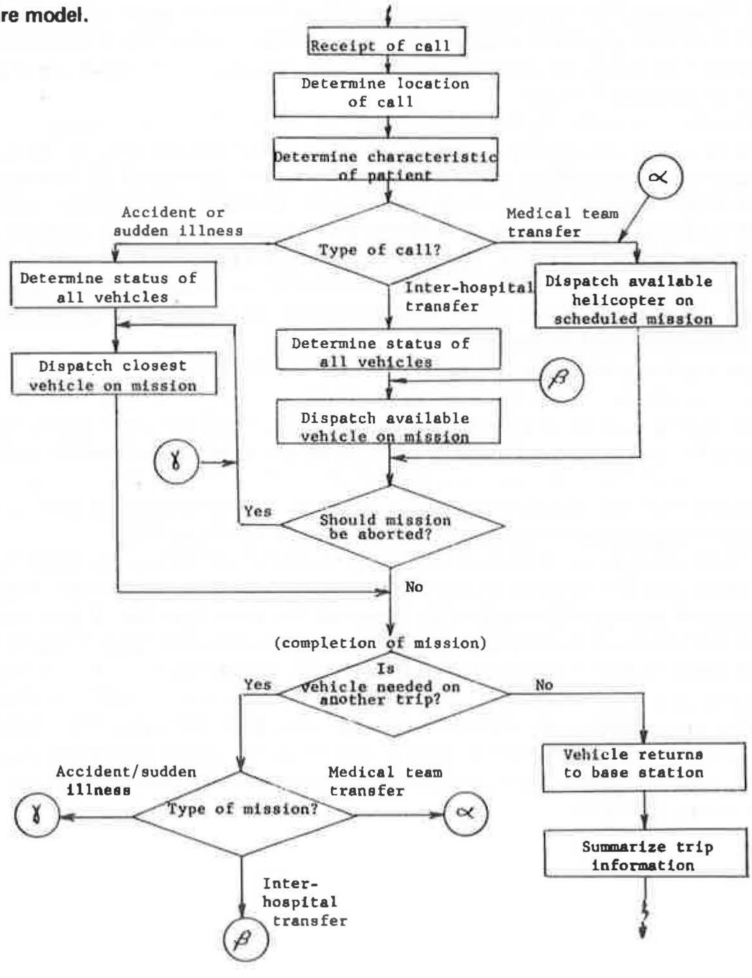


Figure 2. Emergency care model.



OBJECTIVE

The objective of this study was to develop and test a stochastic simulation model capable of examining alternative systems for providing emergency medical services to residents of rural areas. The model was designed to evaluate the use of a ground ambulance system to provide emergency services, specifically the effect of ambulance designs and operational procedures on response time, and the use of a helicopter system to provide these same emergency services. The simulation model could be used to aid a decision-maker in examining the effects of changes in the ground ambulance and helicopter systems, such as altering (a) operating hours, (b) location of the vehicle bases, (c) number and mix (air or ground) of vehicles located at each base, and (d) missions, such as transporting routine interhospital transfers or preventive care medical teams to rural clinic sites.

With these alternative delivery systems under study, it then became possible to determine the performance and cost differences between the alternatives. From this information, the effect of using helicopters as air ambulances and restructuring the ground ambulance system within rural areas could be evaluated. The ouput from the model included the following:

1. Response time for all helicopters and/or ground ambulances that respond to at least one call,
2. Helicopter and/or ground ambulance utilization rates,
3. Delays encountered on a mission per vehicle used,
4. Number of missions aborted or postponed, and
5. Overall travel time for all missions.

The model was tested for application to the Huntington, West Virginia, medical trade area. The inaccessibility of the Huntington metropolitan area, where the health facilities and personnel are located, to those in the remote rural areas surrounding it creates time and distance costs for persons seeking emergency medical assistance. In particular, the helicopter's maneuverability, speed, and flexibility appear attractive to link distant parts of the rural area with a greater spectrum of medical facilities. However, a key question became whether the helicopter could be justified over the existing or restructured ground ambulance system in terms of performance and cost.

SIMULATION MODEL—MACRO LOGIC

The logic used in the model to identify an accident or sudden illness call and dispatch the appropriate emergency vehicle to pick up the victim is shown in Figure 2. The logic starts at the point when a call is received by the system for an emergency vehicle. The next step is to determine the nature of the call. After it is decided that an emergency vehicle is needed, the specifics of the call are determined. This includes information necessary to pinpoint the location of the victim and the severity of the victim's condition. Once the location of the accident or sudden illness victim and the location of the ground ambulances and helicopter(s) are known, the model then assigns a vehicle that can arrive at the scene in the shortest period of time. If information on the nature of the incident is sufficiently detailed, the vehicle, air or ground, with the most appropriate medical equipment and personnel can be dispatched. Because the main concern is to get medical aid to the critically injured persons in the least response time, vehicles are aborted in their present mission when their future mission is deemed more critical.

After the vehicle is dispatched to pick up the accident or sudden illness victim, all times are updated within the model. It then is necessary to determine the time that another call is received on the system. These new and updated times, representing the times when calls are received for emergency vehicles, are then compared with the time at which one or more of the already dispatched vehicles completed a segment of its operation. Segments of the operation are defined as the vehicle arriving at the location of the accident or suddent illness scene, delivering the victim to the hospital, etc. With no other demands, the vehicle is routed to complete another segment of the operation. An example of this would be when the vehicle arrives at an accident scene and loads the patient; if no other priorities are established, the vehicle enters the "en route to hospital" operational segment. At this point the model determines the closest emergency room facility to the accident scene and routes the vehicle to it. Where information is available, the hospital designation can be determined as a function of spatial proximity and the unique capabilities of the hospital emergency room. Here patients are taken to the closest hospital able to treat their specific medical need.

Along with the logic necessary to dispatch vehicles to pick up and deliver accident or sudden illness victims to hospitals, the model performs the same functions for routine interhospital patient transfers and other supplemental uses, such as transferring medical teams to rural clinic sites. Only helicopters were dispatched on the supplemental mission of transferring medical teams to rural areas. These missions were dispatched on a preselected schedule, unless a higher priority emergency call was received.

STUDY REGION

The Huntington tri-state region was selected as a case study because it represents the diverse socioeconomic and topographic conditions encountered in Appalachia. The region's focal point is the Huntington-Ashland-Ironton metropolitan area, which had a total 1970 population of 253,742. Included in the study area are the industrial Big Sandy and Ohio River Valleys with linear urban development surrounded by rural nonfarm settlements. In total, the 1970 study area population contained 455,343 persons living in three states and 11 counties. The study area was defined as an approximation to the Huntington medical trade area with Cabell County at the core as identified by a recent hospital admission-patient flow survey (8).

In addition, the region had recognized difficulties with the delivery of emergency medical services, which is so often characteristic of mountainous rural areas. Funeral home operators were keenly interested in leaving the ambulance business because of existing and projected deficits. Of the 40 ambulance operators located in the study area, only one was publicly operated, one was a professional ambulance service, and the remaining 38 purveyors were operated in conjunction with funeral homes. Of the 52 designated ambulances and 62 backup hearses, only 17 vehicles were equipped with any form of radio communications, and personnel training in many cases was marginal.

To provide a data base for a model calibration, we made a survey of all hospital emergency room arrivals at nine of the 12 hospitals and 35 of the ambulance purveyors in the Huntington tri-state region for a representative 2-week period (November 9 to 22, 1970). The purpose of the survey was to identify regional utilization of hospital emergency rooms and to identify those individuals who were in need of rapid transportation to medical aid. Basically, the survey attempted to document regional emergency room flows on a macroscale.

A code system was devised to identify the general condition of each patient entering the emergency room and each patient being transported by a ground ambulance. In all cases the evaluations relied on personal observations and the experience of those individuals directly attending the patient. The emergency room study was cross-checked with the ambulance study, inasmuch as both were conducted simultaneously. Besides patient classification, the geographic location of the point where the patient was picked up was recorded as were all the event times for each transfer.

Over the 14-day period, 2,949 emergency room forms were completed and 95 patients were identified as in need of rapid transportation where time was highly critical. Out of the total number of 2,949 emergency room arrivals, only 404 patients were subsequently admitted to the hospital. Further, 84 percent of the total patient population arrived at the emergency room by private vehicles.

Information obtained from these sources yielded data used to obtain the distribution of time between calls for accident or sudden illness cases for the entire study area. Accidents and sudden illnesses represented calls for emergency care vehicles and were generated by the model through use of a coordinate system. It was assumed that sudden illness calls were a function of community population, whereas average daily traffic was assumed the critical factor in vehicle accidents. Thus, towns with larger populations and highways carrying greater numbers of vehicles would generate more frequent calls for emergency vehicles. Frequency distributions, based on 24-hour days, were obtained by plotting the emergency room arrival data from the 2-week period. From this information it was determined, by use of the Kolmogorov-Smirnov goodness of fit test, that the data representing times between arrivals at the emergency room were drawn from populations following exponential distributions.

In turn, verification checks were conducted to ensure that the model replicates the real world as observed during the 2-week test period.

ALTERNATIVE EMERGENCY CARE DELIVERY SYSTEMS

Nine alternatives were studied for improving the delivery of emergency medical services in the Huntington tri-state region. The output parameters obtained from simulating the operation of each alternative were then compared against each other and the existing case to determine whether significant differences were incurred by changing the "design" of the emergency medical care delivery system. The alternatives under analysis fell into the following three general classes of analysis:

1. Determining the effect of supplementing the existing ground ambulance system with helicopter capabilities while servicing the same level of demand as encountered during the 2-week data collection period,
2. Determining the effect of modifying the existing ground ambulance system by reducing the number of bases, relocating the bases to better coordinate demand, and then supplementing the ground service with helicopter capabilities, and
3. Determining the effect of modifying the ground ambulance system and supplementing it with helicopter capabilities while doubling the number of calls on the system.

Each class was represented by alternative "designs" reflecting some variation in terms of services provided, number of ground ambulances or helicopters deployed, and the like.

For the purpose of the Huntington example, a medium-sized, Fairchild Hiller 1100 helicopter was selected on the basis of a previous study (9) that determined its efficiency and suitability for emergency transfers in civilian use. This craft has also been deployed on demonstration emergency evacuation projects in Mississippi and Arizona (1, 7). The helicopter was assumed to be based at Huntington, which was the center of the roughly 60-mile-diameter study area.

The individual simulation runs given in Table 1 were designed to examine the existing medical care system and a series of proposed alterations to the existing system. Comparing the results from each simulation run then allows the analyst or user of the model to examine what effect, if any, the proposed alterations to the system have on measures of cost and effectiveness. It is then possible for an analyst to use the simulation model to test proposed changes rapidly and economically. Many other alternatives can be structured, but the ones presented represent one application in the form of an example.

The model was used first on a macrolevel to examine the effect of using different numbers and locations of ground ambulances and helicopters to provide medical care to rural areas. After the decision has been made that the emergency care system can be improved by reducing the number of ground ambulances, relocating ground ambulances, adding a helicopter to the medical care system, or any combination of these, then the model can again be used on a microlevel to pinpoint the best system design. The microanalysis would proceed with maximum local participation and should be part of a comprehensive planning methodology.

RESULTS FOR THE HUNTINGTON TRI-STATE STUDY REGION

Table 2 gives the system performance and total cost associated with each of the nine alternatives under analysis. In each case response time was taken as a representative measure of performance. Total system costs were viewed as the simulation analysis proceeded on a regional level. Consideration was not given to who incurred the cost and benefits. This approach is valid inasmuch as the emergency care delivery system in many areas of West Virginia is moving toward public responsibility. Alternative 1, the existing ground ambulance system with 114 primary and secondary ground vehicles,

Table 1. Description of alternatives.

		Function		Transportation			
Alternative	Title	Emergency and Routine Transfer	Medical Team Transfer	Ground Ambulance	Ground Ambulance Plus Helicopter	Demand[a]	Status of Ground Ambulance System
1	Base comparison	X		X(114)		Base level	Existing
2	Impact of supplementing ground ambulance with a helicopter	X		X(114)	X(1)	Base level	Existing
3	Impact of extending role of helicopter to include medical team transfers	X	X	X(114)	X(1)	Base level	Existing
4	Impact of modifying the ground ambulance system	X		X(19)		Base level	Relocate ground ambulances
5	Impact of modifying ground ambulance system and providing helicopter capabilities	X	X	X(45)	X(1)	Base level	Relocating ground ambulances via Missouri Guidelines[b]
6	Impact of further reducing the number of ground ambulances to increase utilization and providing helicopter capabilities	X	X	X(19)	X(1)	Base level	Improved utilization from alternative 5
7	Impact of doubling number of calls on modified ground ambulance system	X		X(45)		Number of calls doubled	Same as alternative 5
8	Impact of doubling number of calls on modified ground ambulance system	X	X	X(45)	X(1)	Number of calls doubled	Same as alternative 5
9	Impact of doubling number of calls on modified ground ambulance system with two helicopters provided	X	X	X(45)	X(2)	Number of calls doubled	Same as alternative 5 with two helicopters

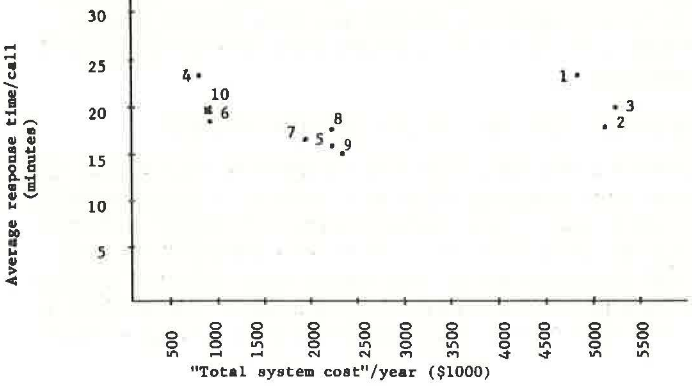
[a] Location of ground ambulances, operating hours, and time between calls are assumed to be identical to those encountered during survey conducted in November 1970.
[b] One ground ambulance provided for approximately every 20,000 individuals.

Table 2. Summary of results and costs for individual simulation runs.

	Ground Ambulances			Helicopters						
System Alternative	No. Available	No. Used	Utilization Rate (percent)	No. Available	No. Used	Utilization Rate (percent)	Average Response Time (min)	Standard Deviation	Emergency Transfers by Ground Ambulance (percent)	Total System Cost per Year[a] (dollars)
1	114	21	18.4	0	0		23.4	6.7	100	4,895,055
2	114	23	20.2	1	1	100	18.9	6.24	74	5,066,455
3	114	24	21.1	1	1	100	20.46	6.3	75	5,077,133
4	19	18	94.7	0	0		23.1	6.2	100	818,403
5	45	36	80.0	1	1	100	15.54	4.32	80	2,107,017
6	19	19	100	1	1	100	17.34	5.04	82	987,416
7	45	37	82.2	0	0		16.26	4.08	100	1,937,657
8	45	34	75.6	1	1	100	16.32	4.2	84	2,117,930
9	45	34	75.6	2	2	100	15.42	3.96	78	2,196,369

[a] Operating costs for ground ambulance = $0.60/hour; fixed cost per year for ground ambulance = $42,000. Operating costs for helicopter = $33/flight-hour; fixed cost per year for helicopter = $120,000.

Figure 3. Average response time and total system cost for each alternative.



costs approximately $4.8 million annually to operate (i.e., not considering potential revenues or shared costs with funeral home operations) and provides an average response time of 23.4 min. Supplementing this system with helicopter capabilities providing only emergency service (alternative 2) greatly expanded total system costs and cost per transfer but reduced response time to 18.9 min. Using the helicopter to perform supplemental services such as transferring medical teams to rural clinics on a scheduled basis increases helicopter flight time at a sacrifice in average response time (20.5 min) and increases total system cost by $181,000 (alternative 3). Although not included in this analysis, it was assumed that other agencies using the helicopter would share in the high initial cost of having a helicopter component available. Thus, helicopter cost would not be borne exclusively by the emergency care system. It then appears in response to the first analysis that a helicopter can reduce average response time but at a sizable increase in cost. Of particular interest were the consistently low utilization rate of the ground ambulance fleet (21 to 24 of the 114 available vehicles) and the potential cost savings associated with reducing the number of ground ambulances.

Alternative 4 represented a variation of the existing case with a reduction in the number (19 versus 114) and relocation of ground ambulances without the availability of a helicopter. For approximately the same response time as with 114 ground vehicles and no helicopter, the vehicle utilization rate was increased to 95 percent and total system cost was reduced by a factor of approximately six. Thus, it appeared that substantial economies could be initiated by simply reducing the number of and relocating ground ambulances on a regional level. Further, when the number of ground ambulances was reduced to 45 (alternative 5) and 19 (alternative 6) with the availability of a helicopter providing emergency and routine transfers along with medical team transfers, the average response times were reduced to 15.5 and 17.3 min respectively. This was accomplished at a reduction in total system cost of $2,789,038 annually for 45 ground vehicles and $3,908,639 annually for 19 ground vehicles. In response to the second analysis, relocation of ground ambulances on a regional level closer to the sources of demand made it possible to reduce both response time and total system costs. The reduction in response time was greater than that effected by simply introducing helicopter capabilities into an uncoordinated, unplanned ground ambulance system. In fact, it was possible to derive the same level of service, measured as response time, when just the number was reduced, the ground ambulances were relocated, and no helicopter capabilities were introduced. With the restructured ground system, it was less costly to introduce helicopter capabilities than to operate the existing system with no helicopter and 114 ground vehicles. Introduction of helicopter capabilities reduced the average response time by 5 to 7 min.

The third analysis tested the flexibility of the system to respond to increased demand. Alternative 5 was repeated with the number of calls on the system doubled and no helicopter capability (alternative 7), one helicopter provided (alternative 8), and, finally, two helicopters provided (alternative 9). With reference to Table 2 it can be noted that doubling the number of system calls increases total system costs slightly and also increases average response time by less than 1 min either with or without a helicopter. The introduction of two helicopters provided only a marginal reduction in average response time. This indicated that, even by doubling the number of calls, use of ground vehicles was not sufficient in the study region to suport two helicopters. Again, comparison with the existing case (alternative 1) indicated that even by doubling the calls on the system a 7-min reduction in average response time was achieved at less than half the cost with 45 ground vehicles.

With reference to the Huntington tri-state case study, Figure 3 shows the average response times and total system costs per year for each alternative. From this figure and the discussion presented previously, a decision-maker can initiate a detailed analysis at the macrolevel for determining the design of the emergency care system best able to service a rural area such as Huntington. In examining Figure 3, the decision-maker must realize that alternatives 7, 8, and 9 operate at a level of demand different from that currently experienced within the study area. Alternative 10 represents the relative system cost per year and average response time when a hypothetical system is formed by using 19 ground ambulances (as in alternative 4) along with several

National Guard helicopters. The helicopters would not be used full time as emergency care vehicles; rather, they would be used only on weekends. There is assumed to be no additional cost to the emergency care system for the helicopter component, inasmuch as they would be provided as a public service. The helicopter, which would be flown as part of the reserve training program, would be diverted to emergency care missions with no resulting charge for aircraft capital costs, aircraft maintenance costs, or personnel costs. This program is now being operated in a number of cities such as San Antonio, Seattle, and St. Louis as part of the Military Assistance to Safety and Traffic program undertaken in 1970 to explore the feasibility of utilizing military helicopters and service paramedical personnel to respond to civilian medical emergencies (10).

If all things are assumed to remain constant and response time is to be minimized, along with a specific restriction in cost, then alternative 7 would probably be recommended for further study. This alternative represents reduced costs over the existing systems with or without helicopter capabilities (alternatives 1 through 3). Even with fewer ground ambulances, it provided a level of service comparable to alternative 1 (response times of 23.4 min versus 23.1 min). In recommending this alternative for further study, the service level of the emergency medical care delivery system could be improved by utilizing National Guard helicopters on a part-time basis. Thus, the decision-maker has reduced the costs of the emergency medical care delivery system for a given level of service and has provided the flexibility of incorporating locally supported helicopters into the system at a later date if so desired. If sufficient funds were available for a high-quality emergency delivery system, then alternative 5 would be preferred because the level of service would be improved (response time reduced from 23.1 to 15.54 min over alternative 4). In either case, it appears that a ground ambulance system with 19 ground ambulances would be a good starting point to utilize the simulation model to initiate a microanalysis. With the introduction of a helicopter, average response time could be reduced with increased cost. However, this could be conducted on a stage basis with an introduction of National Guard reserve helicopters on weekends and perhaps eventual expansion to a full-time program. In either case, if a helicopter could not operate due to finances, maintenance needs, weather conditions, and the like, the system with 19 ground ambulances would provide the same level of service as the existing system is currently providing at substantially reduced costs.

In a microanalysis, the decision-maker would want to examine the influence of placement of vehicles at specific locations within a study area. At that point the decision-maker might supplement response time with other level-of-service measures, such as maximum response time, distribution of response times, distribution of distances the vehicles traveled from their base station to the accident or sudden illness patient, and distribution of distances the vehicles traveled from the accident or sudden illness site to the closest appropriate hospital. Using these parameters, the decision-maker would have to consider details such as institutional constraints, political ramifications, and cost constraints.

CONCLUSIONS

1. It is only practical to provide helicopter capabilities into the Huntington emergency medical care delivery system if the high costs associated with helicopters can be shared with other functions such as police surveillance, medical team transfers, and National Guard training. The helicopter utilization rate of 1.9 emergency calls per day was not sufficient to warrant full-time service because, with existing levels of calls, the region still has too many underutilized ground ambulances available for emergency care.

2. It is possible that, through planning of a regional ground ambulance system, inclusion of a helicopter would significantly reduce average response time at a cost substantially less than operating the present ground ambulance system. Even if the helicopter was removed temporarily, due to maintenance or weather, 19 ground ambulances could continue to provide emergency care without a significant decrease in average response time.

3. A sensitivity test indicated that doubling the number of calls on the Huntington emergency care system failed to fully utilize all of the available ground ambulances

with or without helicopter availability. A restructured ground ambulance system would have the ability to respond to future needs. Through use of a Monte Carlo simulation model the impact of altering the design of an emergency medical care delivery system can be assessed. The simulation model would be of value to a decision-maker concerned with improving the level of emergency care provided to accident and sudden illness victims in rural areas. The model permitted the testing of alternative system configurations more rapidly and more cheaply than was possible by influencing its real-world counterpart through demonstration projects.

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