NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT 6

MEANS OF LOCATING AND COMMUNICATING WITH DISABLED VEHICLES INTERIM REPORT

HIGHWAY RESEARCH BOARD NATIONAL ACADEMY OF SCIENCES - NATIONAL RESEARCH COUNCIL

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MEANS OF LOCATING AND COMMUNICATING WITH DISABLED VEHICLES INTERIM REPORT

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no. 6 NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by Highway Planning and Research funds from participating member states of the Association and it receives the full cooperation and support of the Bureau of Public Roads, United States Department of Commerce.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, non-profit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

This report is one of a series of reports issued from a continuing research program conducted under a three-way agreement entered into in June 1962 by and among the National Academy of Sciences-National Research Council, the American Association of State Highway Officials, and the U. S. Bureau of Public Roads. Individual fiscal agreements are executed annually by the Academy-Research Council, the Bureau of Public Roads, and participating state highway departments, members of the American Association of State Highway Officials.

This report was prepared by the contracting research agency. It has been reviewed by the appropriate Advisory Panel for clarity, documentation, and fulfillment of the contract. It has been accepted by the Highway Research Board and published in the interest of an effectual dissemination of findings and their application in the formulation of policies, procedures, and practices in the subject problem area.

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FOREWORD

By Staff

Highway Research Board

The purpose of this research was to investigate the problem of the disabled vehicle, particularly on limited-access highways, with emphasis on methods of detection and communication. Knowledge and application of the materials presented in the following pages will give state highway administrators and policy-makers in other agencies such as state highway patrols a better grasp of the factors involved in this problem and enable them to make objective decisions appropriate to their jurisdictional areas.

The extensive mileage of interstate highways now being completed, together with modern vehicles and better driver education, has made possible safer and more efficient transportation. However, certain problems remain. That of the disabled or stopped vehicle has actually grown because of the increasing number of miles driven on limited-access highways where the number of exits is greatly reduced. On these facilities in particular, the driver of a disabled vehicle may be miles from the nearest point from which he can summon assistance.

Formerly, assistance to motorists on limited-access highways was taken for granted as a responsibility of toll-way operators and other officials of similar facilities directly financed by users. As a consequence, many users of free highways have come to expect similar assistance. Agencies concerned with operation of free highway systems are giving increased consideration to this problem.

Although some research on the subject of the disabled or stopped vehicle had been conducted previously, information concerning the nature and extent of the problem was sketchy. Little had been published about the frequency and causes of stops and their relationship to highway types, or the kind of assistance desired, or how assistance could be rendered. Such basic information was considered vital to this growing problem. The subject study was designed to inquire into these questions.

Airborne Instruments Laboratory in the immediate study has thoroughly explored the problems involved in locating stopped vehicles and in establishing methods of communicating with a central location. Mathematical models have been devised to relate the available information and to bridge gaps in the data. Stops are categorized as emergency or leisure, and related to average daily traffic and trip length. Roadway patrol activities are analyzed and use of highway patrol techniques for detection purposes considered.

Existing detection techniques, including those involving surveillance by aircraft and passing motorists, are evaluated. Other detection techniques involving mechanical, pneumatic, visual, optical, acoustical, infrared, electrical, and magnetic principles are discussed. In addition, possibilities of several innovations in detection systems are investigated.

Included in the report are findings from four different road types: freeways, including the urban expressway; the urban bridge or tunnel; a limited-access rural highway; and a network of free-access roads consisting of a mix of major, secondary and local roads.

Analysis of the functional requirements of various communication systems indicates that the implementation needed for most appropriate utilization of these

detection and communication techniques should issue from management and policy-making personnel.

Although this study substantially increases our knowledge of the disabled vehicle problem, research on this subject is not yet complete.

A second stage of this work is now under way by Airborne Instruments Laboratory. It involves a detailed evaluation of the feasibility of using elevated detectors on the roadside to detect a modulated light source mounted on a vehicle. This research is expected to determine the system's characteristics and practicality.

CONTENTS

ACKNOWLEDGMENTS

In performing this work, the authors have been fortunate to have associated with and received assistance from a large number of individuals in all parts of the country. Although it is impossible to mention each individual by name, it is hoped that listing the name of his organization will serve as an expression of appreciation: American Automobile Association; Automobile Club of Southern California; Bureau of Public Roads; California Department of Public Works, Division of Highways; California Highway Patrol; City of Chicago; Cook County Highway Department; District of Columbia Department of Highways; Eisenhower Expressway Surveillance Project; General Motors Corporation, Research Laboratories; Greater New Orleans Expressway Commission; Bureau of Public Roads, Illinois Division; Illinois Department of Public Works and Buildings; Illinois State Toll Highway Commission; John C. Lodge Freeway, Traffic Surveillance Project; Los Angeles Department of Traffic; Los Angeles Police Department; Michigan Highway Department; Mississippi River Bridge Authority; New Jersey Turnpike Authority; New Jersey State Highway Department; New York State Department of Public Works; New York State Thruway Authority; New York Telephone Company; Oklahoma Turnpike Authority; Pennsylvania Department of Highways; Pennsylvania Turnpike Commission; Port of New York Authority; Richmond-Petersburg Turnpike Authority; San Francisco-Oakland Bay Bridge Authority; Texas Turnpike Authority; University of Illinois; Virginia Highway Department; and Yale Bureau of Highway Traffic.

MEANS OF LOCATING AND COMMUNICATING WITH DISABLED VEHICLES—INTERIM REPORT

SUMMARY The main subject of this study was the "Methods and Means of Communicating with Disabled Vehicles from a Central Location." The problem was approached in four reasonably distinct, but highly interrelated stages: (1) the problem of the disabled vehicle was defined in terms of its frequency of occurrence, reason for stop, traffic level, and road type; (2) the importance of defining an objective as a basis of system design was analyzed and some relationships of the objectives to the system concepts were developed; (3) the generic types of equipment applicable to the detection of and communication with disabled vehicles were examined and a number of novel approaches discussed; and (4) several representative roads or road complexes were hypothesized and a sequence of logical steps followed toward a workable solution of the disabled-vehicle problem.

Problems are defined by using data pertaining to stop distributions from whatever facilities such data could be obtained. Some of the pertinent variables, such as average daily traffic, average trip length, and the expected stop rate, are shown to be sufficiently related to allow a statistical prediction of the stop rate, given the other two variables. Distribution in stop types for the various types of facilities are found. An analysis of the patrol effort that forms the chief source of the stopped-vehicle data is made. Patrol characteristics must be known before reliance can be placed on the quantitative validity of the data collected by these patrols.

Also analyzed are the many possible objectives that may serve as the basis for the eventual solution of the disabled vehicle problem; for example, (1) to increase safety, (2) to maintain or increase the capacity of the facility, (3) to offer service to the motorist, and (4) to aid in law enforcement. The fact that the objective is dictated by road type, traffic volumes, and the desires of the cognizant authorities is discussed and the unsuitability of the same objective for different road types is shown.

The basic types of sensors are examined as to their capabilities and limitations, costs, and ease of maintenance. A number of novel ways of detection, communications, and servicing are discussed. Some that are considered worthy of further investigation are (1) specialized patrols, (2) signaling devices, (3) means for the distressed motorist to call for aid, and (4) devices to render services in a manner consistent with some specific objectives. It is concluded that only one basic communication from the driver is required—a request for aid.

Several representative problems are hypothesized and realistic objectives for each are formulated. A logical procedure is then followed in choosing elements of detection, communications, and service so that the objectives can be met. The cost of implementing the complete system is assessed in terms of dollars per assist.

The road types examined are (1) an urban expressway; (2) an urban bridge or tunnel; (3) a cross-country turnpike or toll facility; and (4) a network of unlimited access roads consisting of a mix of major, intermediate, and small

rural roads. The four examples are intended to serve as guides for dealing with most road types; they point out the close interrelationship between the elements of detection, communications, and service.

The first solution sought for the examples chosen was in systems achievable either immediately or in the future at reasonable costs. It is concluded that when police patrols are available, they should stand ready to render the basic services required by the disabled vehicles. It is cheaper to expand existing law-enforcement agencies than to form and equip new agencies devoted to detection or service exclusively.

In all cases, the manpower costs were greater than equipment costs; therefore, automatic devices should be used when they can perform as well as a man. However, the increased cost of automatic equipment without removing men is usually out of proportion with the improvement achieved in fulfilling the objectives.

Technically, communications to the motorist are much more easily achieved than communications from the motorist. However, it is shown that most problems can be solved without such complications. A solution that does not require a motorist to invest in equipment is believed superior to one that requires compulsory investment. The degree to which the system relies on the motorist to help actively in his detection should likewise be kept to a minimum, or altogether avoided.

CHAPTER ONE

VEHICLE STOP CHARACTERISTICS

INTRODUCTION

As the world becomes more dependent on reliable vehicular traffic and the complex of roads becomes greater, the problem of the stopped vehicle increases. Research has been undertaken by the National Cooperative Highway Research Program in an effort to learn more about the problem, its characteristics, extent, and possible solutions. The first phases of a continuing research program have been directed toward gathering and presenting a comprehensive summary of the disabled- and stopped-vehicle problem. Therefore, the nature of the problem, the quantitative evaluation of its occurrence, and the philosophical and technical considerations for its solution have been studied.

During this work, it was not necessary to perform new experiments because the analysis of existing data, experience, and opinion in the specific terms of this project was more important. Now that this analysis is complete, the direction of future experimentation has been indicated more clearly. Because of the diversity of highway situations and the wide range of unknowns, the number of experiments that can be developed to increase knowledge in this disabled-vehicle field is large. Several of these are pointed out in this report.

SHOULDER-USAGE STUDIES AND STOP CHARACTERISTICS

Rural Roads

The Billion report (*1*) concerned 33 sections of rural roads in upstate New York. Each section averaged 4.8 miles in length, and was patrolled from 8:00 AM to 8:00 PM on weekdays during the summer of 1958. These patrols stopped and interviewed all persons found on the shoulders. The roads observed were categorized as interstate and interregional, intercity, and feeder. The types of stops were categorized as leisure and emergency.

Tables 6 and 7 of Billion's report provided the basis for Figures 1 through 12. The curves matched to the data for Figures 2, 4, and 6 were estimated and drawn in. No special criterion other than apparent fit was used for matching. A computer program for fitting a polynomial curve to a set of data points was used for the curves in Figures 3, 5, and 7 through 12. This program uses a minimum-residue or square-error criterion.

The point of interest is in establishing the relative frequency of stopped vehicles, for both leisure and emergency stops. Intuition indicates that the characteristics of roads may depend on the purpose and use of the facility; thus, increased use or increased traffic levels should vary the nature of the stops.

Figure 1 plots all data points from the Billion report for vehicle-miles per stop versus the 12-hr traffic count during the observation period. Although there are no outstanding curves, some trends appear. The emergency points in general are higher than the leisure points and both appear to have somewhat of an upward slope.

As a better test of these assumptions, the data were refined by using only data gathered for 2-lane roads. Figures 2 and 3 show the characteristics of these leisure and emergency stops. Some points in Figure 3 had two or less observed stops. These points were assumed less reliable than the others and are consistently higher. Therefore, these points were removed in the machine calculation for Figure 3. The results indicate that, for 12-hr traffic counts lower than about 2,200 vehicles, the rate of stops is somewhat constant at about 1,500 vehicle-miles per stop. The vehicle-miles per stop increase as the traffic count increases above 2,200. The curves indicating the ± 1 standard error encompass the majority of the points.

Figure 2 shows a much more rapid increase in vehicle-miles per stop for emergency stops than leisure stops. It was not possible to eliminate all data points with two or

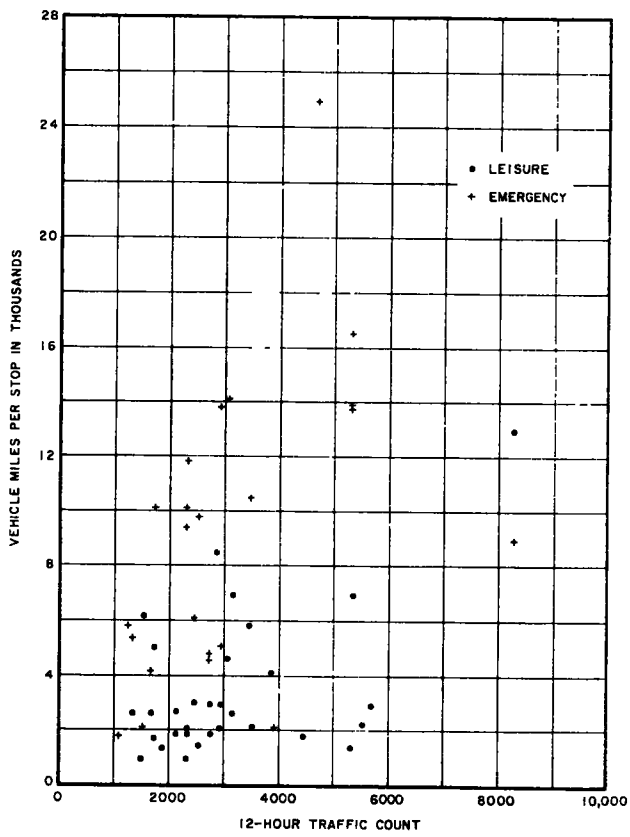

Figure 1. Vehicle-miles per stop vs traffic count for all roads.

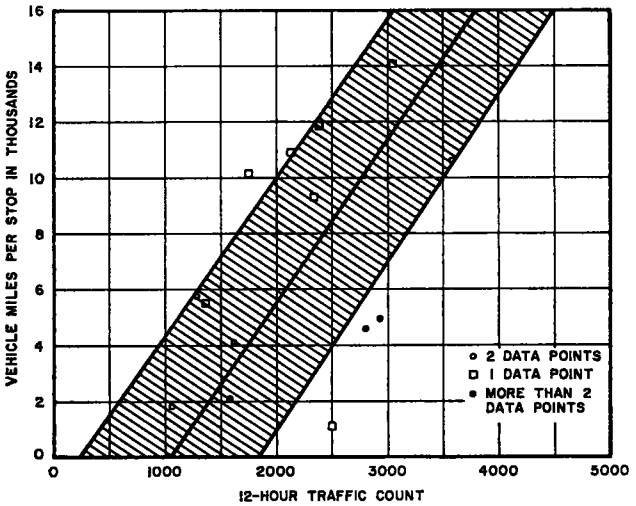

Figure 2. Vehicle-miles per emergency stop vs traffic count (2-lane roads only).

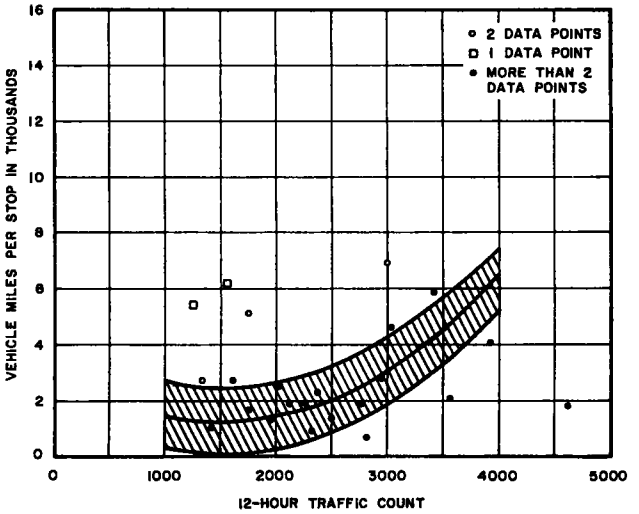

Figure 3. Vehicle-miles per leisure stop vs traffic count (2-lane roads only).

less observations. The trend is still obvious and the standard error does not remove the validity of the assumed form.

Because it was felt that the trucks in the sample may have an effect on the characteristics of the curves, the trucks were removed from the sample. Figures 4 and 5 are for stops made by passenger cars only. The results showed no significant difference. Also, there are no figures in Billion's report that show the relationship of truck volume to car volume. However, it cannot be concluded that there are no differences between trucks and cars. It can only be said that this refinement of data does not explain the sample spread.

It appears that the spread in data is due to some parameter that defines roads. To check this hypothesis, the roads were subdivided into three categories: interstate and interregional, intercity, and feeder. Figure 6 shows the results of this subdivision. Although there are not sufficient data to determine characteristics reliably, it seems that the reduced spread is more than coincidental. The gross characteristics and general range of parameters is the same as before; only the spread is reduced.

A second type of parameter that may enter the problem is more a function of the driver than the road. To test this, the vehicle-miles per stop were plotted as a function of the average trip length. Average trip length is used here in the same sense as it was used by Billion. It is assumed to be the total length of the trip taken by the driver and not just some segment taken on a specific facility. In this report, it becomes more of an origin-destination concept. It is therefore more closely associated with the driver than with the road. All data for car and truck stops combined are shown in Figure 7. There does not appear to be any correlation between the vehicle-miles per stop and the

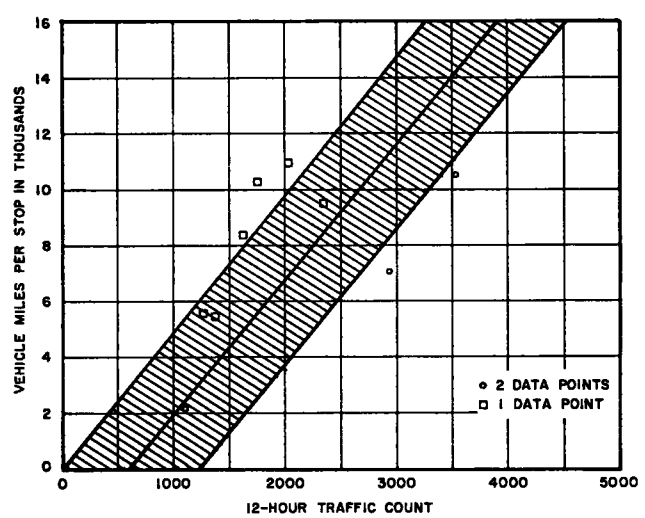

Figure 4. Vehicle-miles per emergency stop vs traffic count (2-lane roads, no trucks).

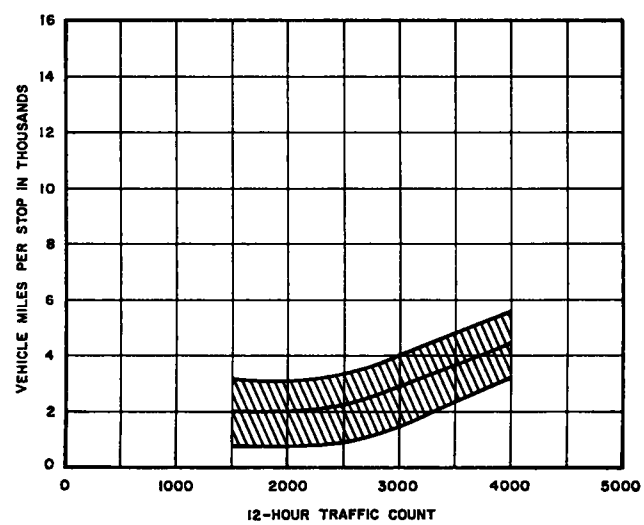

Figure 5. Vehicle-miles per leisure stop vs traffic count (2-lane roads, no trucks).

average trip length. The trucks were again removed (Fig. 8) to show an apparent downward slope.

The sample was further separated into out-of-state and New York passenger cars in Figures 9 and 10, respectively. Figure 9 again shows the downward slope of the curve; however spread has been somewhat reduced. No trend is apparent in Figure 10 and the spread is larger than before.

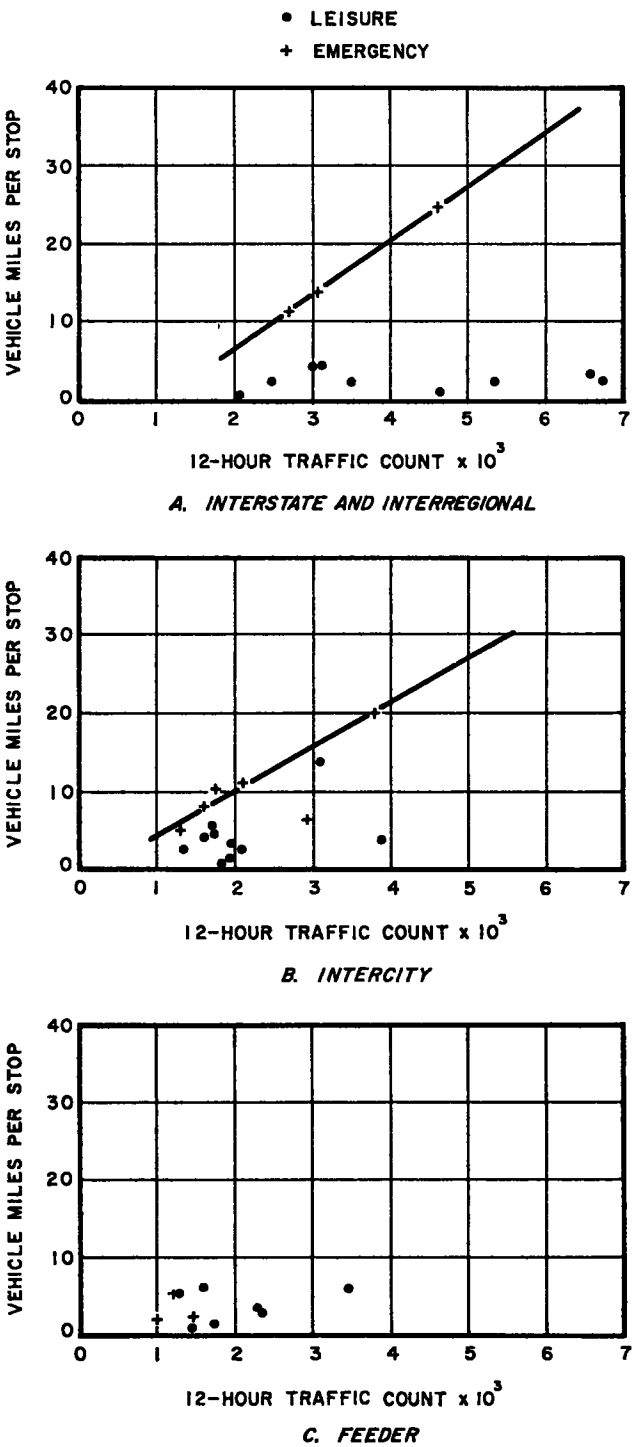

Figure 6. Interstate and interregional vehicle miles per stop vs traffic count.

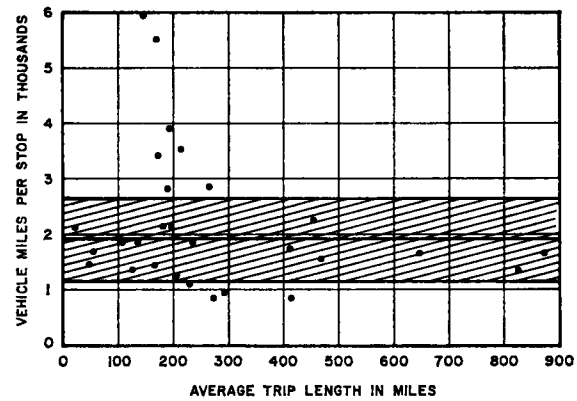

Figure 7. Vehicle-miles per stop vs average trip length (all roads).

The range of the average trip lengths is less for Figure 10 than Figure 9. Over the range of Figure 10, the curve of Figure 9 is not significantly different from that of Figure 10; only the spread varies. This would indicate that a vehicle many miles from its origin should not be assumed a function of the state that contains its origin but only of the distance it has traveled.

There is a motivational factor that can further refine the problem. Persons making shorter trips are more likely to be highly motivated to achieve their destination. Therefore, less stops per mile are made. As the trip length gets longer this motivation apparently decreases as does the number of vehicle-miles per stop. For drivers in the state, the trip lengths are shorter and apparently the motivation spread is greater, thereby giving a lower correlation as in Figure 10.

The relationship between average trip length and the leisure and emergency components of Figure 8 was tested in Figures 11 and 12. Figure 12 shows the same trend as Figure 8; however, Figure 11 has the opposite slope.

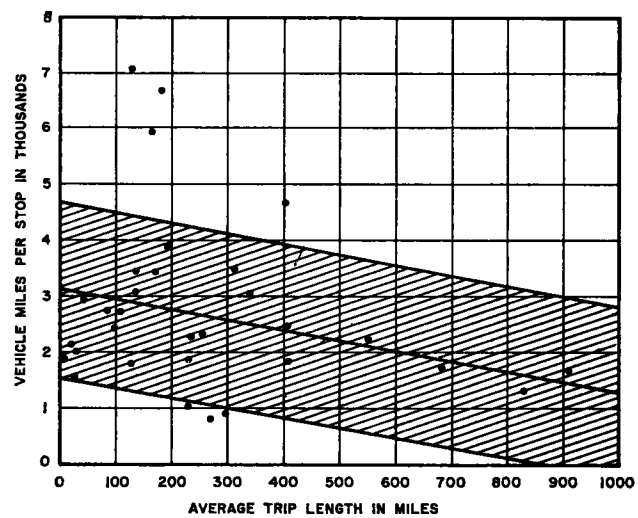

Figure 8. Vehicle-miles per stop vs average trip length (all roads, no trucks).

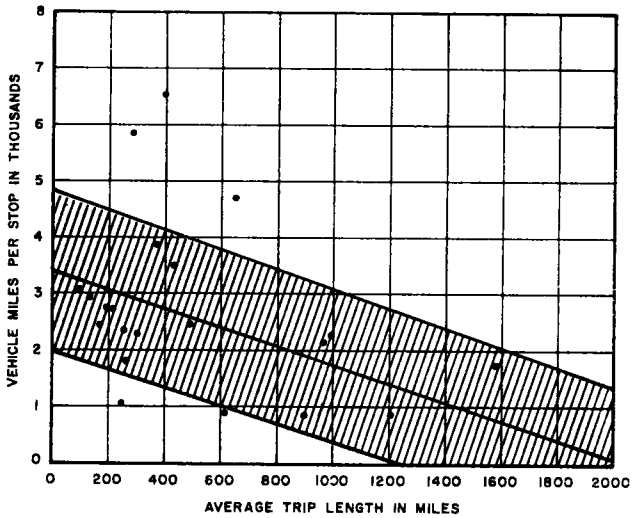

Figure 9. Vehicle-miles per stop vs average trip length (out-of-state drivers).

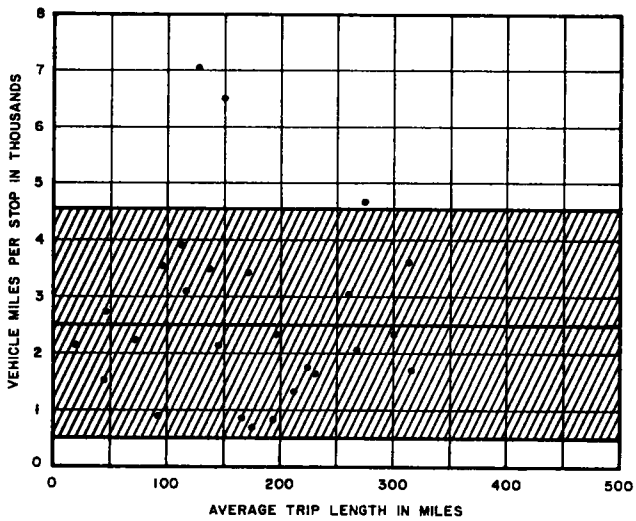

Figure 10. Vehicle-miles per stop vs average trip length (New York drivers).

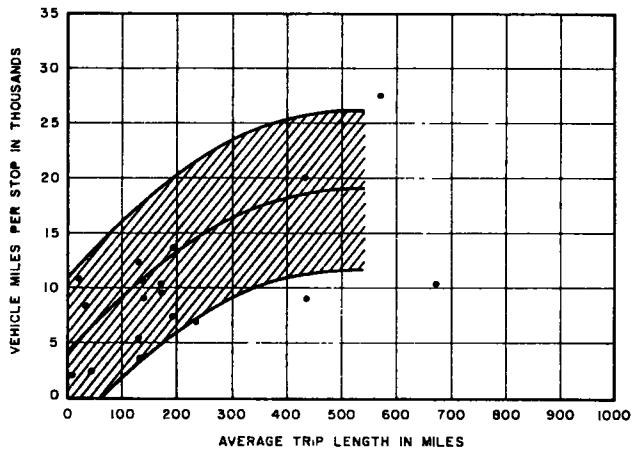

Figure 11. Vehicle-miles per emergency stop vs average trip length.

It is believed that the motivational factor of the road users enters into the relation of Figures 11 and 12 and Figure 8. Since the majority of the road users are not highly motivated to reach their destination, the road characteristics of Figure 8 would more closely resemble the leisure characteristics of Figure 12 than the emergency characteristics of Figure 11. This factor may also be important in defining the spread of data. If the roads could be better classified as to motivation, then possibly the standard error observed would be appreciably less.

Three parameters of the stopped-vehicle problem have now been isolated. The first is a measure of the road type; the second, trip length, is a measure of the user type; and the third, traffic count, is a measure of the effects of other users on the individual and the road system. The three parameters are necessary to define the rate of stopped vehicles.

High-Volume Facilities

In examining high-volume facilities, again the effort is to determine the frequency with which vehicles stop. Most major facilities maintain records of the aids or assists given to their patrons by their various patrols; therefore, this is a slightly different number from that in the Billion data. The stops recorded are those detected. The same is true of the Billion report; however, the probability of detection was much higher there because the length of road patrolled was much less.

The vehicle-miles per aid for various facilities is shown in Figure 13 as a function of year. The spread is huge. However, it is not possible to conclude that all major roads are alike merely because they have similar construction. It was felt that the differences might be attributed to the various levels of patrol activity, but this was not found to be valid. In many cases inverse relationships were found between patrol activity and the number of vehicles detected.

The same facilities as in Figure 13 were then plotted in Figure 14 as a function of average trip length. The

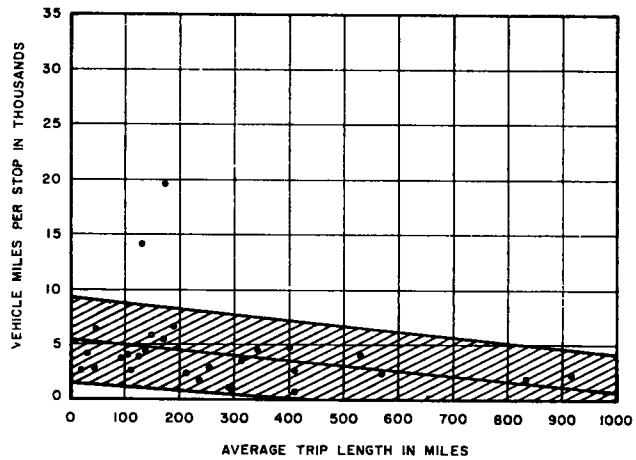

Figure 12. Vehicle-miles per leisure stop vs average trip length.

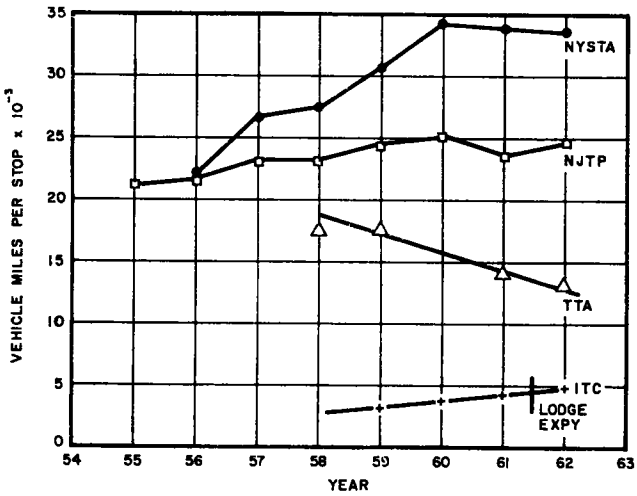

Figure 13. Vehicle-miles per stop vs year.

term "average trip length" also has somewhat of a different meaning here than in the Billion data. Here a facility measures the average length of trip on its road. In Billion's study, the average trip length was more of an origin-destination nature independent of the number of facilities used in the trip. Figure 14 attempts to convert from the facility figure to one more indicative of the origin-destination nature.

A much closer correlation is found between vehicle-miles per stop and average trip length in Figure 14 than in Figure 13. As the trip length increases, the vehicle-miles per stop also increase. The slope of this curve is the opposite of that found in Figure 8; however, this is not contradictory. When the data for Figure 8 are broken down into leisure and emergency components, as in Figures 9 and 10, the emergency component has the same characteristic as observed here.

Thus, two phenomena simultaneously yield the differences between Figures 8 and 14. The first is the manner of collection; that is, only emergency data are taken. The second is the nature of the users. The persons on the roads in Figure 14 are more highly motivated toward their destination and hence have a lower probability of making a leisure stop. Thus, it would be natural to assume that the users of roads of this class should have characteristics more like those of Figure 11 than Figure 12.

The predominantly positive slopes of the curves of Figure 13 are an important observation. This seems to indicate that the vehicles used on these roads are becoming more reliable. This may be due to the automobiles themselves as well as to drivers becoming more educated in highway travel and conscious of vehicle condition.

Another observation may be made of Figure 14; there is almost a factor-of-ten difference between the two extremes. If most of this difference is due to vehicle condition, then the owners of these vehicles are somewhat responsible for this phenomenon. Also, congestion, city streets, and general urban conditions may create a higher hazard to vehicle health.

Stop-Frequency Model

The following stop-frequency model is based on logical conclusions drawn from the previous results. The only objective has been to present a means by which all the previous data can be represented. The model uses the hypothesized general curves of Figure 15 for the relationship between the vehicle-miles per stop for emergency and leisure stops and the average daily traffic. These curves are composites of the previous curves and represent the arithmetic means of the various data.

Figure 16 shows the variation of vehicle-miles per stop for leisure and emergency stops with average trip length and introduces a motivation parameter (m). Both Figures 15 and 16 will be used to predict the rate at which vehicles stop on any arbitrary facility that can be characterized by an average daily traffic and an average trip length.

The character of the road is determined by the motivation of the road users. On highly motivated roads the drivers are not likely to make a leisure stop but to continue on to their destination. Therefore, the probability is high that a stop when made is an emergency stop. The level of motivation of such a road is called m.

The value of m is obtained from the curves in Figure 15.

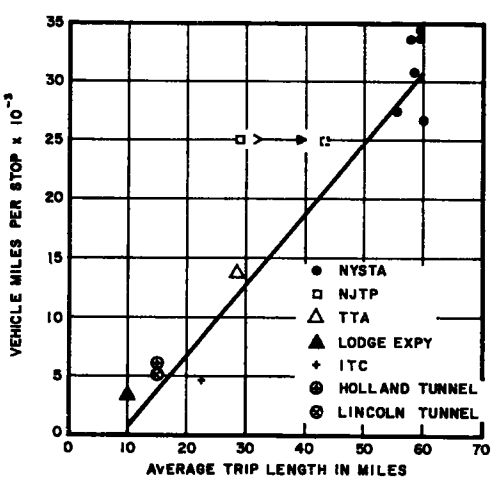

Figure 14. Vehicle-miles per stop vs average trip length.

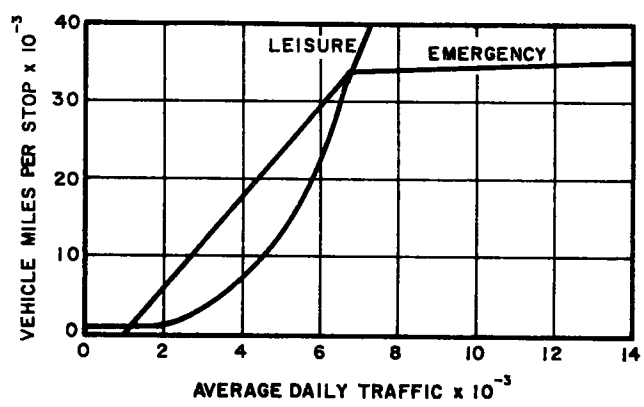

Figure 15. Vehicle-miles per stop vs average daily traffic.

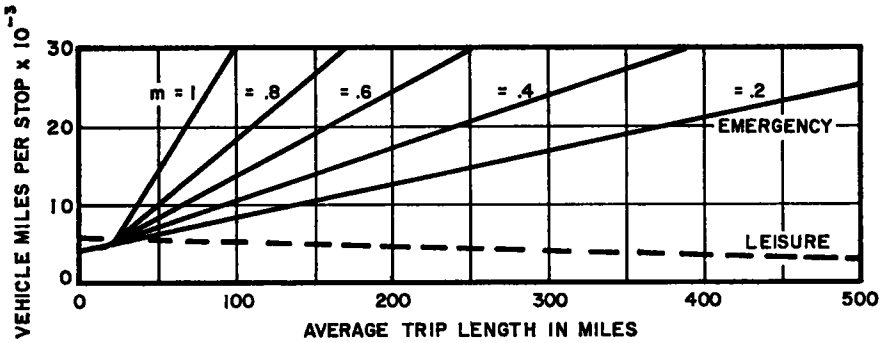

Figure 16. Vehicle-miles per stop vs average trip length (with m *as a parameter).*

The overall rate (R_T) at which vehicles stop can look either like the rate for emergency stops or like the rate for leisure stops depending on the motivation level. If the motivation is high, R_T looks like the emergency rate. If the motivation is low, then R_T looks like the leisure rate. Thus, if m is a number between 0 and 1, then it is logical to define R_T in the form

$$R_T = m R_E + (1 - m) R_L \qquad (1)$$

where R_E is the rate of emergency stops and R_L is the rate of leisure stops. If the average daily traffic is known, the relative rates at which the leisure and emergency stops occur can be determined from Figure 15. Defining r_L and r_E as the rates in vehicle-miles per stop of leisure and emergency stops obtained from Figure 15, respectively, then the number of stops per vehicle-mile would be

$$n_E = \frac{1}{r_E} \text{ and } n_L = \frac{1}{r_L} \qquad (2)$$

Therefore, m can be defined as

$$m = \frac{n_E}{n_E + n_L} = \frac{\frac{1}{r_E}}{\frac{1}{r_E} + \frac{1}{r_L}} = \frac{r_L}{r_L + r_E} \qquad (3)$$

Figure 17 is a plot of m obtained in this manner. Equivalently, m would be defined as the percentage of all stops that are emergency stops. The values R_E and R_L of Eq. 1 can be obtained from Figure 16. Thus, by defining the expected average daily traffic and average trip length of the users for a given facility, it is possible to find the split between leisure and emergency stops and their relative frequency.

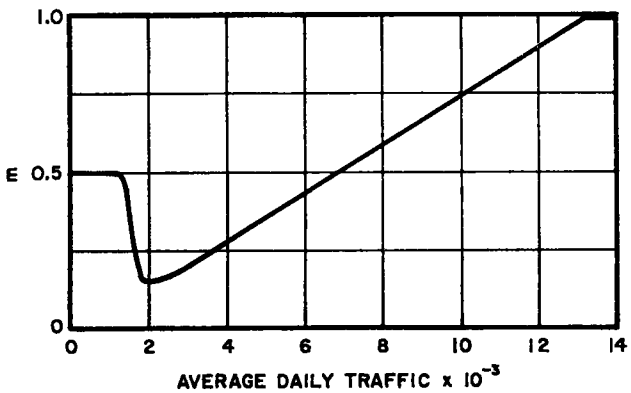

Figure 17. Motivation (m) *vs average daily traffic.*

To test this formula, the results of Figures 8 and 14 are reproduced. The traffic levels for the facilities in Figure 14 are so high that m is effectively one. Thus, the number of vehicle-miles per stop for these roads should follow the curve for emergency stops in Figure 16, which Figure 14 bears out.

The roads covered in the Billion report had average daily traffic rates of somewhat less than 3,000. From Figure 17, this would give m-values of about 0.2, indicating that Figure 8 should follow the leisure curve of Figure 16, which is precisely what it does.

As a further example of how to use the method, assume that a road has an average daily traffic of 8,000 vehicles and that the average trip length is 100 miles. From Figure 17, $m = 0.6$. With this value of m and an average trip length of 100, Figure 16 gives $R_L = 5 \times 10^3$, $R_E = 14 \times 10^3$. From Eq. 1, $R_T = 0.6 \times 14 \times 10^3 + 0.4 \times 5 \times 10^3 = 10.4 \times 10^3$ vehicle-miles per stop.

The stops will be split so that 60 percent are emergency and 40 percent are leisure stops.

Nature of Stops

The frequency of stopped vehicles and the parameters that affect frequency have been emphasized. The reasons for emergency stops will now be examined.

The annual reports of the New Jersey Turnpike give the number of assists made during the year in each of five categories: mechanical, tire, gas, heat, and other. These numbers were converted to percentages so that the annual variations of number of assists could be separated from the nature of the assists. These percentages are shown as a function of time in Figure 18, whose most salient feature is a decided learning procedure involved in the use of modern roads. The curves are erratic until 1958. From that point on they smooth out and become rather linear. A steady state has not been reached because the curves do not have a zero slope. Figure 18 shows that people have been learning to put gas in their cars and to be more conscious of their gas level. Therefore, the percentage of assists due to this cause has been decreasing.

A similar phenomenon appears to be present for the tire problem. The apparent rise in tire trouble for the years 1955 to 1958 is probably due to the rapid fall in out-of-gas cases.

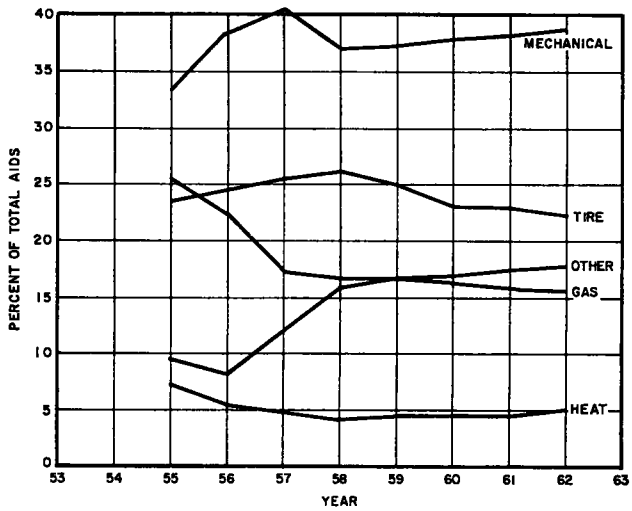

Figure 18. Distribution of stops by type for New Jersey Turnpike.

Heat appears to be a small part of the problem; however, a more seasonal or regional perspective may give an entirely different result.

The 1958 to 1962 data seem to indicate a continuing long-term trend that is different from the learning phenomenon shown by the data before 1958. This long-term trend indicates that the mechanical and other categories of stops are increasing in importance at the expense of tire and gas, whereas heat is remaining somewhat constant.

Figure 18 indicates types of motorists' needs. These data show a decided learning curve for such roads; all other data must be interpreted with this in mind. The time constant for such learning appears to be quite long. As such roads become more common, this learning curve will probably change.

It is also indicated that those stops that are most easily serviced are decreasing; therefore, the concept of on-the-spot service might be difficult to fulfill. The entire picture of needs is not seen here, however, because many of the stops made by patrols are not recorded, particularly if they require no police action.

A logical question is whether the mixture of stop causes varies from facility to facility. As previously stated, the methods of collecting and categorizing data vary greatly. Two categories that are hard to change are gas and tire and hence they appear rather universally. Figure 19 compares the gas and tire categories for various facilities. Remarkable similarities exist despite drastic differences in nature and vehicle-miles per stop. All of the characteristics of the data in Figure 18 apply here also. Hence, the nature of the emergency stop appears to be universal.

The nature of the stopped-vehicle problem appears to be solved at this point. The frequency and nature of stops has been investigated and an encompassing picture made. The credibility of the data that this work is built upon will now be investigated through various patrol techniques.

Patrol Analysis

Patrols are presently the primary means for surveillance of highways. Among the many types of patrols are police, service vehicle, and state or local authority vehicles. On many highways, more than one type of patrol exists simultaneously; however, one type is generally so much more intense than the others that the effects of the others can be ignored for the purposes of this study. Most of the information pertinent to this study is gathered by these patrols.

Two widely used patrol methods are analyzed in Appendices A and B. It is found that the probability of detection is a function of the stops distribution and the frequency of the patrol effort.

The stop duration distribution has been found to approximate a Gamma distribution, whereas the patrol passage generally follows a Poisson distribution. Both of these are based on observed data.

Figure 20 shows, for example, that for a stop distribu-

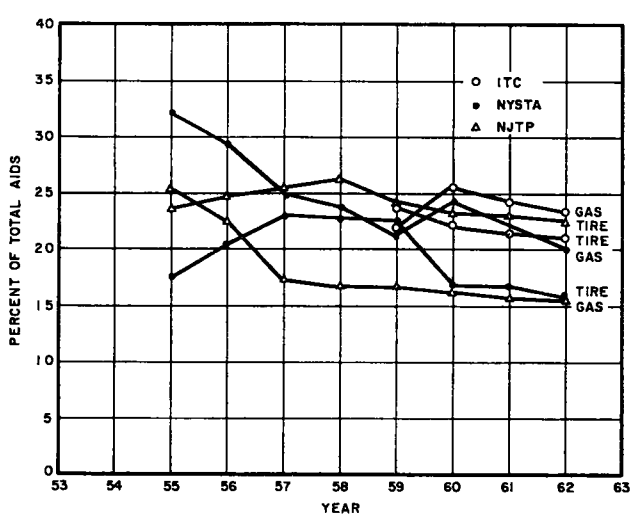

Figure 19. Comparison of tire and gas stop distribution for various facilities by year.

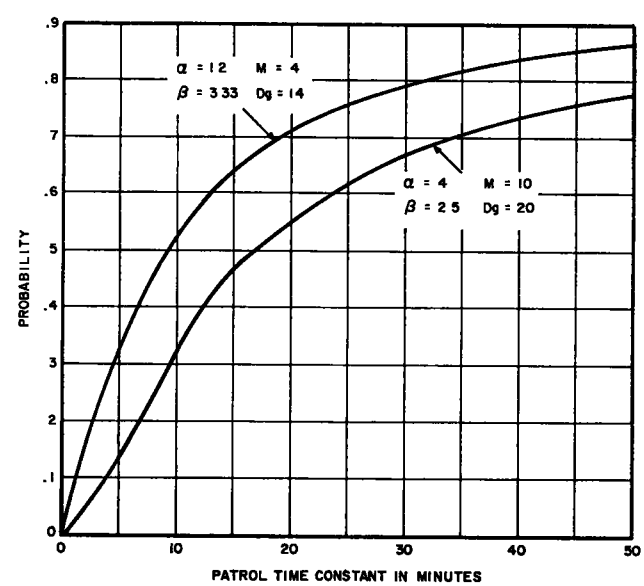

Figure 20. Probability of not detecting stopped vehicle vs patrol time constant.

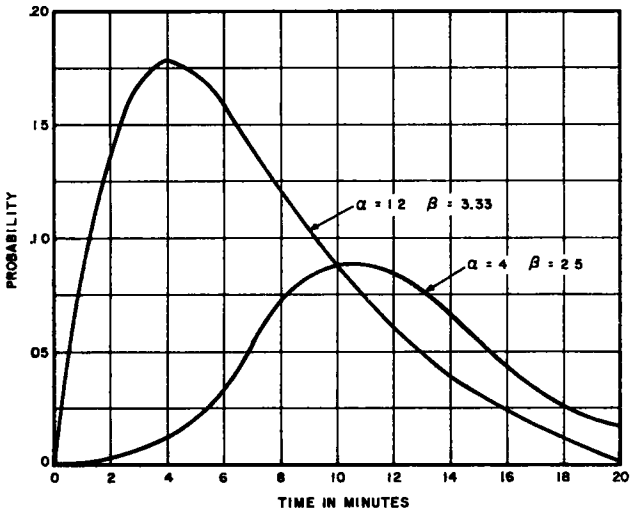

Figure 21. Stop time density function for two stopped types.

tion such as the short-term stops of Figure 21, the probability of missing a stop is somewhat higher than 0.7 for a patrol constant of 20 minutes.

Effect of Patrol on Stopped-Vehicle Data

One objective of the patrol analyses is to study a presently used method of detection and communication with stopped vehicles to determine the nature of the stopped-vehicle problem. Few facilities have the data necessary for this type of study. Many sources are available; however, they usually lack information about the number and types of stops and the patrol effort. Some sources do not want to release information about patrols. However, one source was extremely cooperative and provided well-documented statistics. Thus, data pertaining to the Richmond-Petersburg Turnpike will be used as an example (Figs. 22 and 23). The records contain all stops made by patrols. Therefore, this is one of the few sources of information on the number of stops made by persons in need of directions. The nature of the Richmond-Petersburg Turnpike makes it logical to assume that the percentage of tourists is quite high, thereby distorting the magnitude of this category somewhat. As will be shown later by the Lodge data, this distortion is probably not too great.

The data for the Richmond-Petersburg Turnpike for one month were analyzed. Table 1 gives the number of assists and percent of total stops in each category in the left-hand columns. In general, the relationships between gas, motor, heat, and tire are consistent with the relationships found on other roads. The percentages are somewhat lower because of the number of stops recorded for directions.

The next step is to apply the results of the previous patrol analyses and determine the effect on the stop mixture.

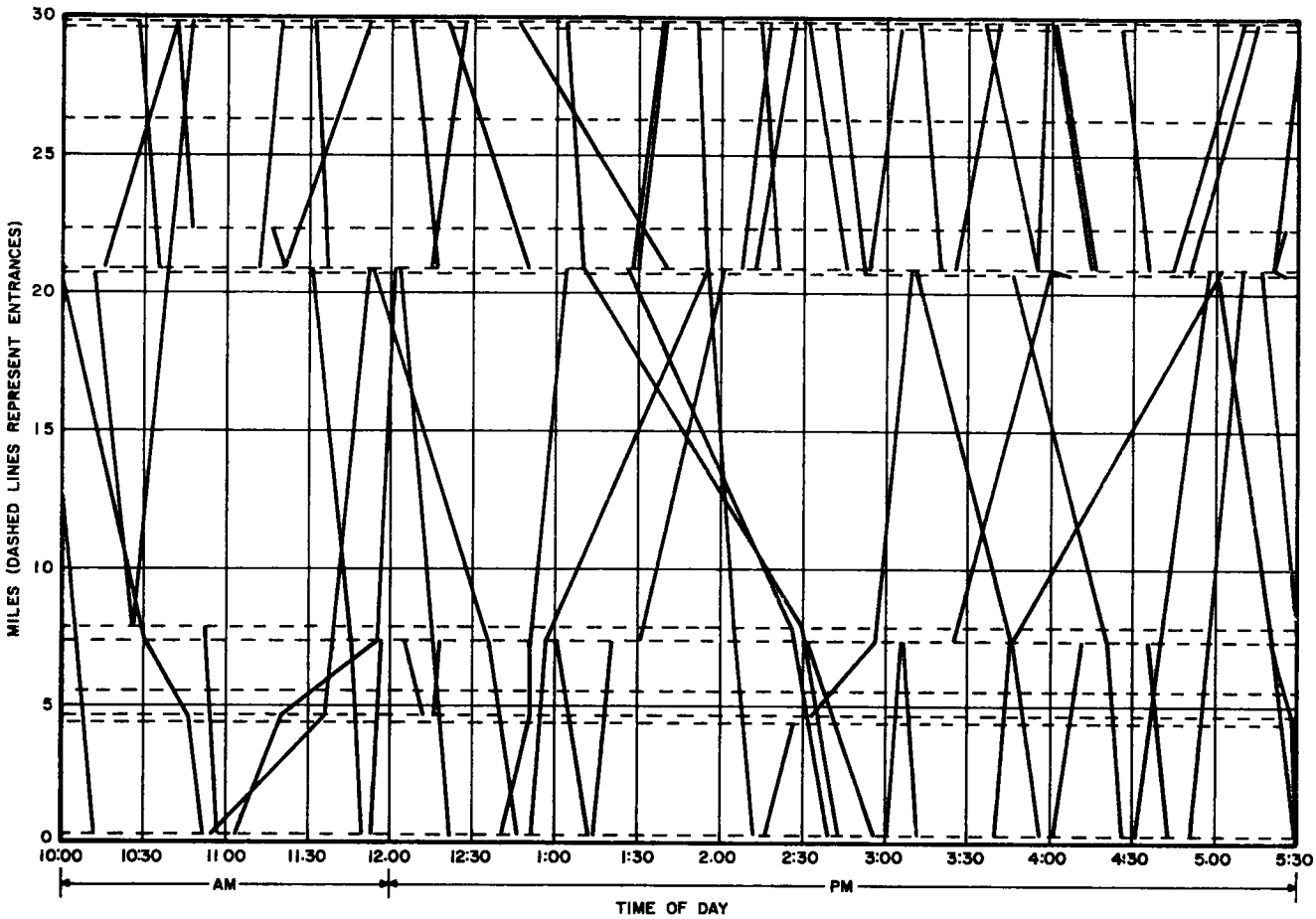

Figure 22. Patrol time.

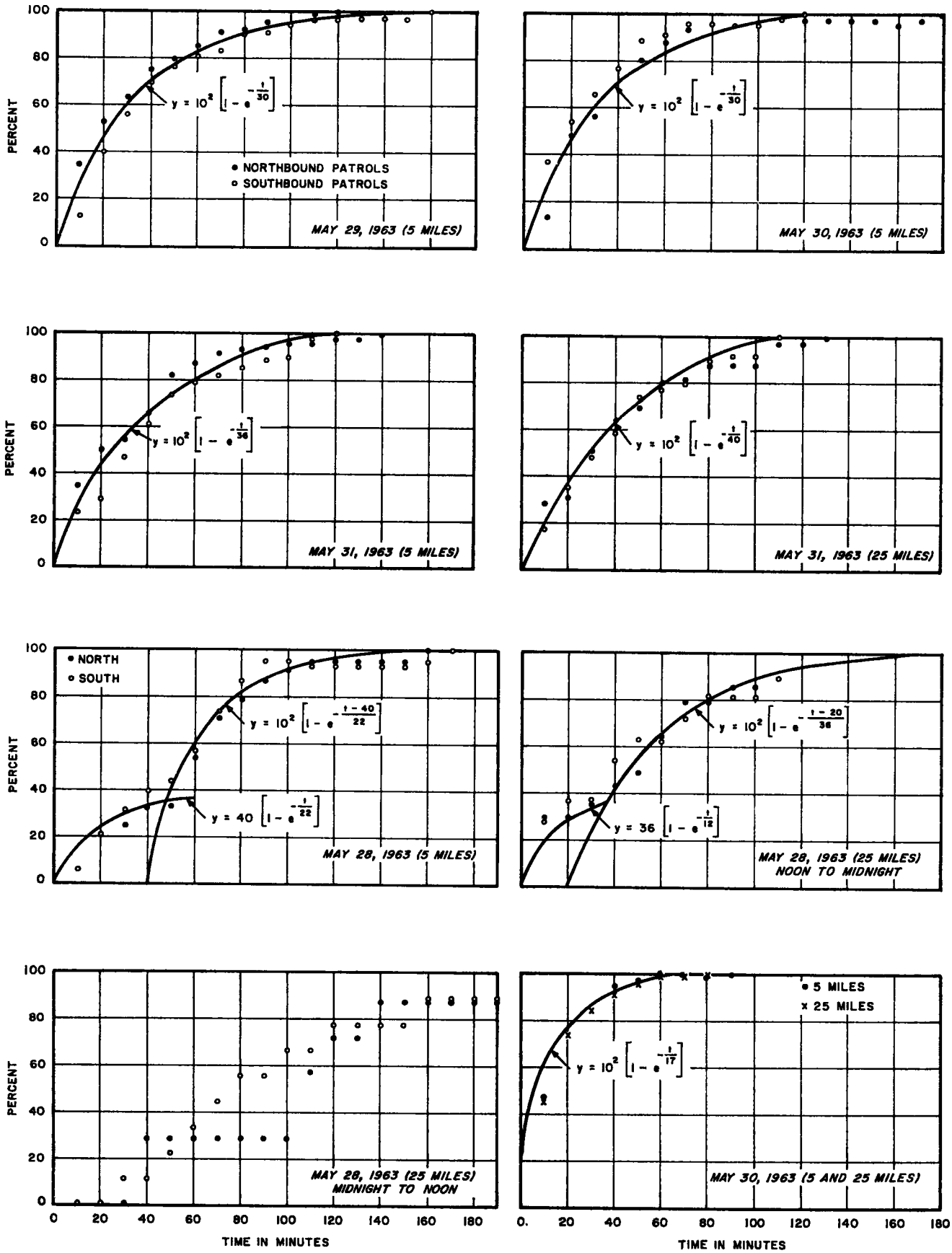

Figure 23. Distribution in time between successive patrols.

It is assumed that the probability of detection of short-term stops is about 1 to 5. Such categories as "directions" and "tires assisted" should be scaled up because they represent categories that were detected by chance. Other categories, such as gas, motor, heat and "tires sent help" are considered to be of such a nature that they would remain until detected. The new totals for the number of stops in each category and the associated percentages are given in the right-hand columns of Table 1.

The total number of stopped vehicles on the side of the road is now 2.74 times as many as were recorded. Most of these stops are made to ask directions and the frequency is at least three times as high as the second most frequent cause.

This number of stops to ask directions seemed disproportionately high. To check this factor, the Lodge shoulder usage data (*2*) were employed. These data were gathered

TABLE 1

RICHMOND-PETERSBURG TURNPIKE SHOULDER STOPS

			PROBABILITY OF DETECTION = 1 TO 5	
CAUSE	NUMBER	PERCENT	NUMBER	PERCENT
Directions	146	35.9	730	65.5
Flat Tire:				
Assistance	31	7.6	155	13.9
Sent help	39	9.6	39	3.5
AAA	3	0.7	3	0.2
Gas	35	8.6	35	3.1
Motor	131	32.2	131	11.7
Heat	21	5.1	21	1.8
Total	406		1,114	

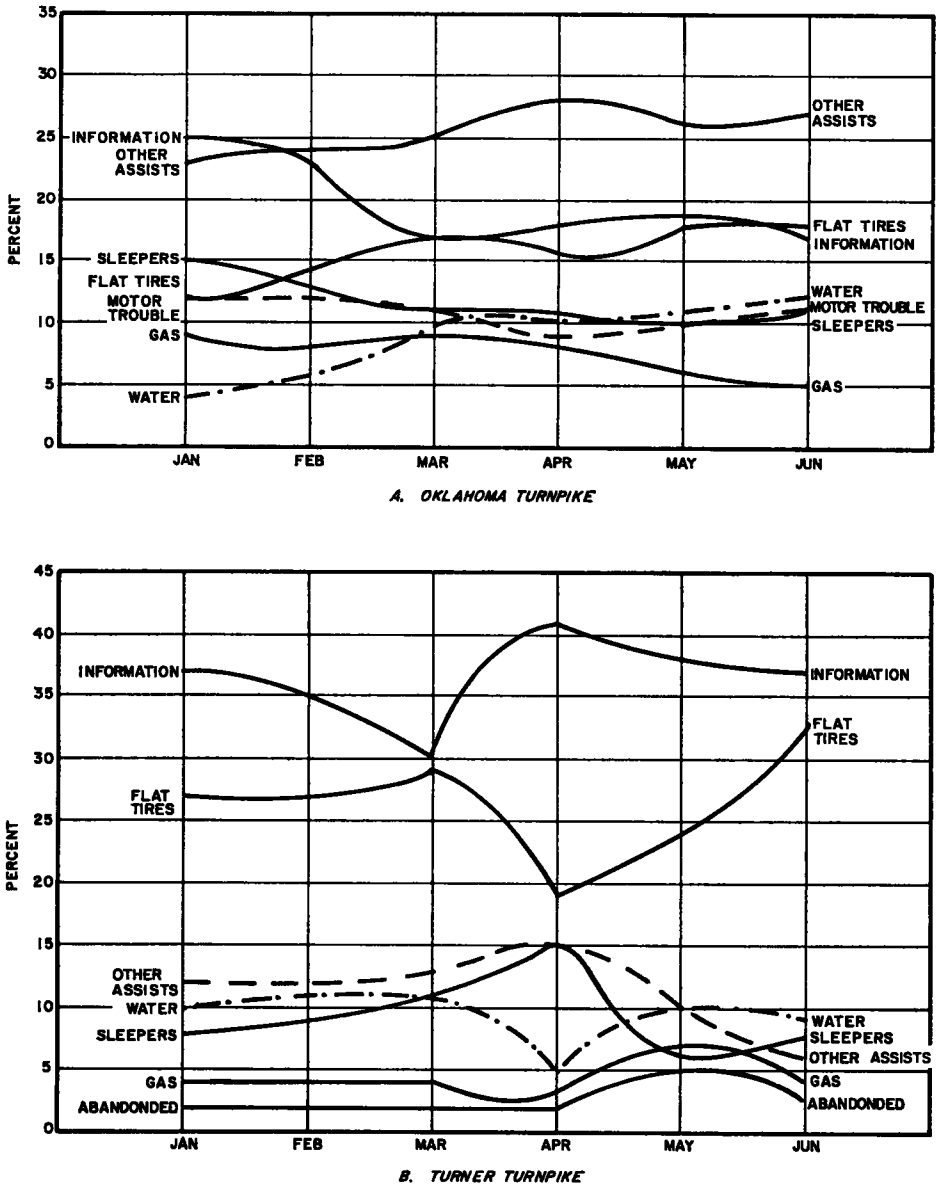

Figure 24. Distribution of stop causes.

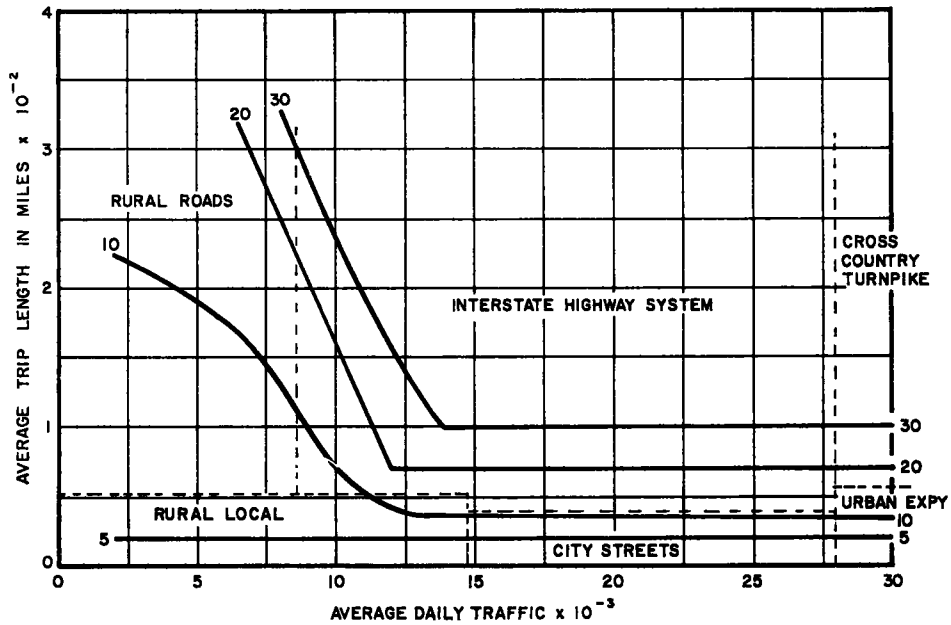

Figure 25. Stop rate vs average daily traffic and average trip length.

on the Lodge Freeway Traffic Surveillance Project by means of television cameras. For each stop, an observer recorded the time that the vehicles stopped and the time that they started. They also attempted to determine the cause of the stop.

In Table 7 of the Lodge report, 656 stops and their causes are listed. Of these stops, 186 or 28.3 percent are for undetermined reasons. Included in the total are 219 stops attributable to freeway maintenance, tickets, and to give aid. These are different stops from those studied in this report; therefore, they have been removed from the sample and the remaining 437 stops are used. The percentage of unknown stops is now 42.5 percent. Therefore, it is believed that to assume that about 50 percent of all stops on a shoulder are for unknown or informational purposes is not too unreasonable.

As further substantiation, Figure 24 gives plots of the distributions in stop causes for the Oklahoma and Turner Turnpikes, respectively. The relative frequencies of occurrence of each category and their relative importance are of interest. The curves are not constant, but there is little change in the order of importance of each category. A

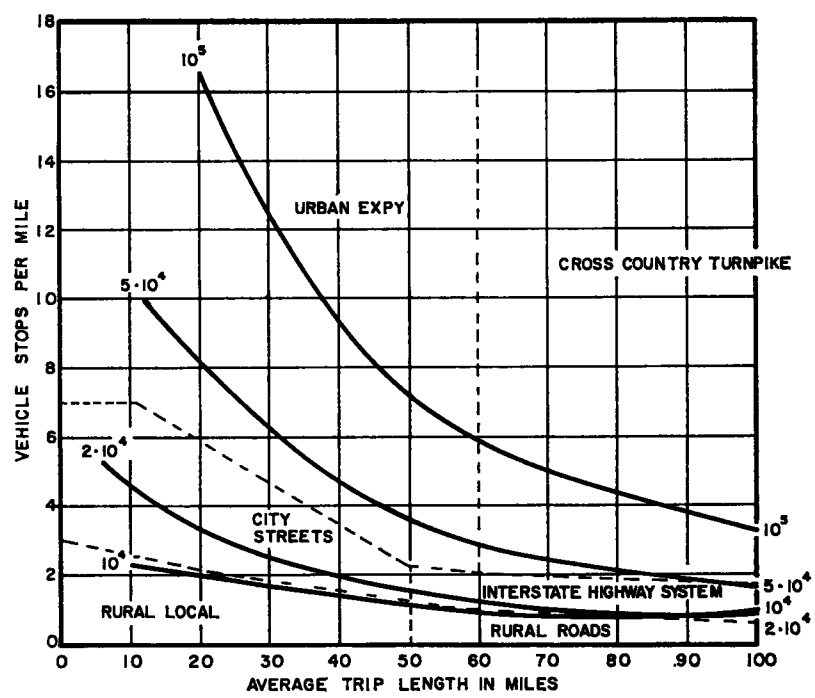

Figure 26. Number of stops per mile per day vs average trip length (with average daily traffic as parameter).

new category ("sleepers") is shown. This may be the result of a more complete reporting, an actual increase in frequency of occurrence, or the definition of the category. Nevertheless, it appears to warrant a position in the overall picture.

Further Development of Stop-Frequency Model

Assuming the fundamentals, the rates at which vehicles stop is less important than the total number that stop. Figures 15, 16, and 17 were previously used to present a computational algorithm for the rate of vehicle stops. This information can be plotted on a single graph (Fig. 25). The curves represent constant rates of stops as a function of the average daily traffic and average trip length.

Different road classes can be defined as regions in the average daily traffic/average trip length plane. An arbitrary selection is shown. It is realized that the entire Interstate System incorporates roads in just about all categories; however, there is one segment of the plane that appears to be unique; hence, it is so designated.

Figure 25 shows only the rate of stops; it does not tell the actual number of stops that one would expect to find. Figure 26 was constructed to show the expected number of stops per mile per day on a facility. Figure 26 is obtained from Figure 25 by dividing the average daily traffic by the rate of stops to determine the number of stops per mile. The sectors of Figure 25 that represent road classes can be transformed into Figure 26.

As a further example to explain the use of these curves and to validate their use, the Holland Tunnel has excellent statistics on the number of stops made in that facility. The average daily traffic for 1959 was about 113,000 vehicles per day. The average trip length of the tunnel users is estimated to be about 20 miles. Figure 26 would thus predict that there should be somewhere between 16 and 17 stops per mile. The actual number observed was 16.7 (see J. Greenberg, "Statistical Analysis of Disabled Vehicles in the Holland and Lincoln Tunnels," Port of New York Authority, Feb. 1961).

CHAPTER TWO

SYSTEM OBJECTIVES

The stopped-vehicle problem can be divided into two categories: in-lane stops, and stops off the traveled way. These two classes of stops cover all stops. This breakdown is advantageous because of the entirely different characteristics of each case and the completely different policies and techniques that can be associated with each.

The system description can be further broken down into active and passive categories. Active implies that the system requires some action on the part of the motorist; passive, on the other hand, requires no motorist action. This categorical description is also pertinent on a policy and technique basis.

OBJECTIVES OF A SYSTEM

Before an actual system can be designed, its purposes and objectives must be considered. A stopped-vehicle detection system can be used to:

1. Increase safety (a) to a vehicle stopped in a lane of travel, (b) to a vehicle stopped off the lane of travel, and (c) to the remainder of the vehicles on a facility,
2. Maintain capacity of road,
3. Increase capacity of road,
4. Decrease travel times,
5. Increase probability of survival in an accident,
6. Provide motorist service,
7. Aid law enforcement.

In addition, it is necessary to specify the level of service desired by defining the types of stops to service, the time response or service time, and the probability of detection.

In addition to these administrative policies, more specific characteristics exist for each type of system used. These include cost, maintenance reliability, channel reliability, effective noise, safety aspects such as structures introduced on road system, and ability to integrate with other equipment and other systems.

It is apparent that a researcher's problem in this field is to organize the multitude of existing ideas. It is not proposed to establish the administrator's policies, since these depend on specific situations and personal desires, but to elucidate some situations and to give the decision makers stronger and better grounds upon which to make the required policies.

ANALYSIS OF OBJECTIVES

Safety

The aspects of safety were divided into three categories for purposes of analysis and system evaluation.

A vehicle stopped in a driving lane is a safety hazard to the remaining traffic, to its driver, and to its occupants. Since about 5 percent of the stops occur in-lane, it is necessary to look further into their composition. The Lodge surveillance project indicates the following: (1) the average duration of a lane incident (incident means all stops, including accidents, stalls, etc.) is about 5¼ minutes, (2) in about 46 percent of the incidents the vehicle was moved by the motorist to the shoulder, or

continued on, (3) 43 percent required physical assistance, and (4) 11 percent waited for such assistance though they themselves could have moved their vehicles. Hence, 54 percent did not cease being lane stoppages until assisted. Logically, these stops can be expected to average considerably higher in duration than those dealt with by the drivers themselves, since assistance had to be summoned and arrive, or they had to be "found" by a patrol. On the basis of 16.5 stops per mile per day (the figure based on ATL of 20 miles and ADT of 100,000), this amounts to about 0.45 stop (occurring in the driving lanes) per mile per day that must be serviced. Statistics of the Pennsylvania Turnpike show that 80 percent of all their accidents take place on the main highway, the remainder being in service areas, exit/entrance lanes, and on shoulders. Hence, the stopped motorist's exposure to an accident is higher in the driving lanes than on the shoulder. Of course, other users of the highway are also endangered.

A vehicle that stops in a travel lane is in danger. This is indicated by the high percentage of accidents that are the rear-end type. These occur primarily at induced stops such as toll booths, stop signs, entrances, and exits. This indicates that a speed differential is dangerous, though it is difficult to determine exactly how dangerous. Accident data generally list only the fact that the accident was of the rear-end nature and sometimes that one of the vehicles was stopped. This does not imply that the accident was due to a disabled vehicle or one making an in-lane stop of the nature to be detected. The majority are stops made during the course of normal driving. A system of the type under discussion would not aid in solving this problem.

Even if accident statistics permitted determination of the number of accidents due directly to a specific type of stop, the relative hazard involved in stopping would not be truly indicated unless the number of stops made were also known. The number of accidents can be high either because every vehicle that stops is involved in an accident, or very few of those stopping are involved but the number stopping is very large. This gives widely different values to a problem that as yet has not been, and is not capable of being, documented.

Another safety aspect is that of vehicles entering and leaving a traffic stream. Here, a similar documentation problem exists. It is important, however, to isolate this category when analyzing the stopped-vehicle detection system with respect to safety because of the totally different characteristics from the preceding problem.

It is apparent that a stopped vehicle on the shoulder is hazardous, but it is difficult to assign a magnitude to this hazard. The Pennsylvania Turnpike Joint Safety Research Group issued a report on accident causation in which 3,118 accidents were studied during the 1952 to 1953 period. Of these accidents, 67 or 2.1 percent were attributed to vehicles parked on the highway.

Other data indicate that about 0.7 percent of the accidents involved pedestrians; about 3.4 percent involved legally parked vehicles, and 2 percent involved illegally parked vehicles. It was also found that about 13 percent of the accidents involved running off the road and about 7.4 percent were with fixed objects off the road. It was concluded that the frequency of accidents involving stopped, stopping, and parked vehicles was significantly higher than would be expected by chance.

The preceding statistics, although apparently quantitative, do not relate the values of present interest. They define the relationship between accidents involving stopped or parked vehicles and the total class of accidents; they do not say how dangerous it is to stop on the side of the road or what the accident rate is for stopped vehicles. In this respect, it is only said qualitatively that the frequency is "significantly higher than expected by chance." Appendix C shows that for a motorist spending an average of 1 hour per year on the shoulder, the probability of being involved in an accident is 10^{-5}.

If the average accident rate per year is 2×10^6 vehicle-miles per accident and the same person drives 2×10^3 miles per year, then the probability that this person will be involved in an accident is

$$P(A) = \frac{2 \times 10^3}{2 \times 10^6} = 10^{-3}$$

The probability of being involved in a shoulder accident is $10^{-5}/10^{-3} = 10^{-2}$ or 100 times less than the probability of being involved in a driving accident.

In the Billion report the accident rate and the shoulder accident rate are given for each site studied. The data were plotted in Figure 27 and curves matched to them by the machine process. Figure 27A and B show the relationship of the accident rate to traffic count and vehicle-miles per stop. There does not appear to be any correlation, indicating that neither of these parameters is predominant in accident causation on rural roads. It was expected that roads with low vehicle-miles per stop might cause disturbances of the normal traffic stream, thereby increasing the accident rate. This does not appear to be true from Figure 27B.

The shoulder-accident rates have a slight dependence on traffic count and vehicle stops; however, it is about an order of magnitude less than the accident rate. This seems to be in agreement with the Pennsylvania study and the safety model.

Since neither of these parameters appears to be singularly significant in accident rates, a measure of their joint effect was tried. Figure 28 was constructed wherein each site on a 2-lane road was plotted according to its traffic count and vehicle-miles per stop. The points were divided into four quadrants. Each dividing line was chosen so that about half the points were to either side of the line.

The points were then divided by accident rate and whether the rate was high or low. The arbitrary rate of 1 was chosen as the division point. Table 2 shows the number of points from each quadrant of Figure 28 that went into the category of high and low accident rates.

Again, the results were contrary to expectation. In quadrant I, the traffic count is low and the vehicle-miles per stop is high. It would be expected that the accident rate should be low. The results indicated thaat half the points went into each category. This seems to indicate either the complete lack of correlation of accident rate

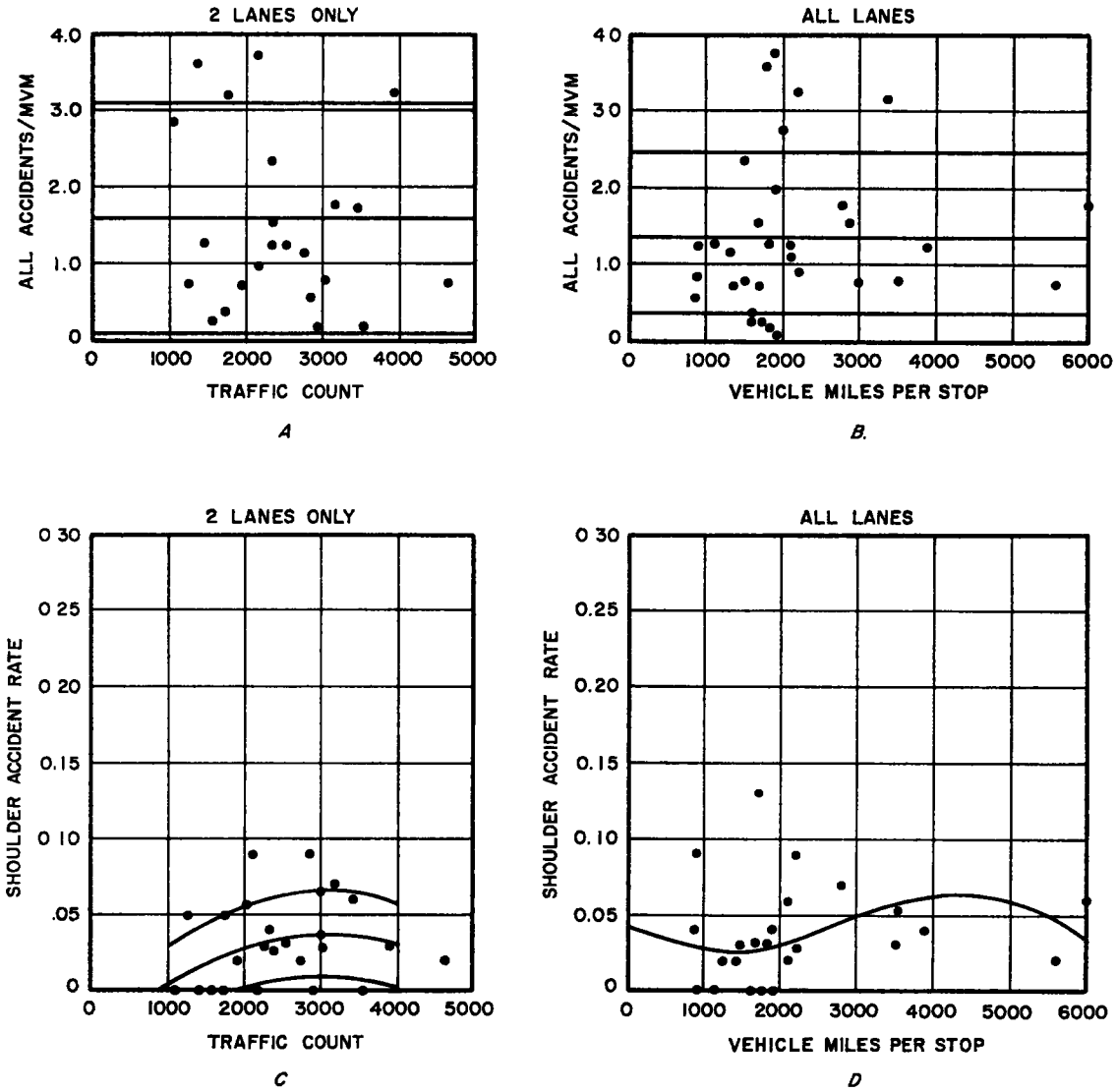

Figure 27.—Plot of data from Billion report.

with this condition or the fact that it is more dangerous than believed.

A similar contradiction is seen in quadrant IV. Here due to traffic congestion and frequent stops, it would be expected that the accident rate would be high. This is not indicated by the data.

One apparently hazardous condition is shown in quadrant III. Here many stops are made, but the traffic count is low. It is difficult to determine reasons for the indicated relationships with the present data. There must exist some parameters which are still unknown.

These results can be summarized as follows:

1. Accidents involving stopped or stopping vehicles appear to be a low percentage of all accidents.
2. The probability of an accident assuming that a stop is made on the shoulder does not appear to be excessively high.
3. The total accident rate on rural roads does not appear to be affected by stopped vehicles.
4. The shoulder accident rate appears to increase as the vehicle-miles per stop increases, until a maximum is obtained, after which it again decreases.
5. Stopped vehicles on low-traffic-count roads are apparently in a more dangerous situation.

TABLE 2

NUMBER OF POINTS[a] WITH HIGH (H) AND LOW (L) ACCIDENT RATE[b]

(Traffic Count: Vehicle-Miles/Stop)	
(Low; High)	(High; High)
(H) 4 (L) 4	(H) 4 (L) 3
(Low; Low)	(High; Low)
(H) 4 (L) 1	(H) 1 (L) 2

[a] See Figure 28.
[b] > 1 high; 0,1 low.

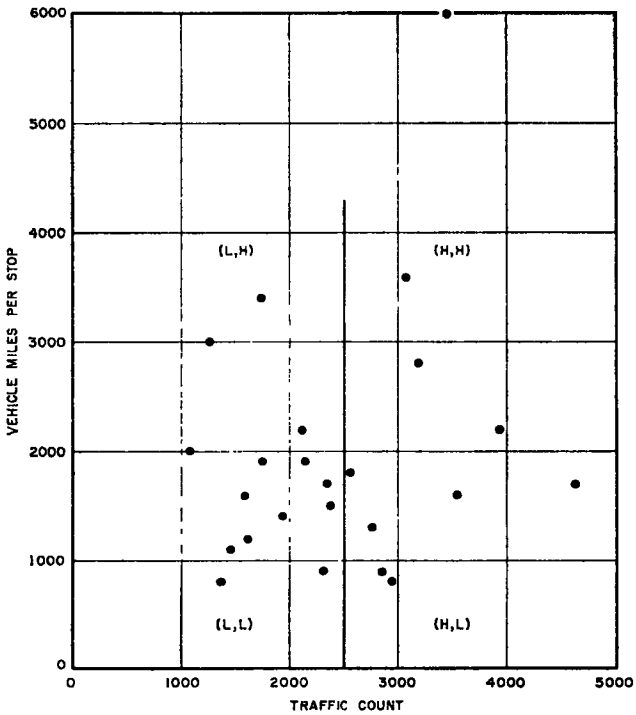

Figure 28. Safety calculation.

Capacity

The desire to increase or maintain road capacity is often expressed as a purpose for a stopped-vehicle detection system. This is generally expressed for facilities that are operating at or near their capacity and where improvements are expensive. Capacity has been thoroughly defined in the Highway Capacity Manual of the Bureau of Public Roads. However, herein reference is to a short-term capacity that is the result of a constriction caused by a stopped or disabled vehicle rather than to a steady-state capacity. It is therefore difficult to determine just what, or often which, "capacity" we are designing to improve. Many people maintain that any stopped vehicle reduces the "capacity" of the road. This statement has never been proved. In reality, the effect of the stopped vehicle on traffic depends on the nature of the stop and the attractiveness of the driver.

The capacity is reduced by "gawkers," lower quality of traffic flow, and induced constriction.

A means of alleviating the first cause is to reduce visibility. This has been achieved, as a by-product, by high dividers in some cases and antiglare screens in others. The purpose of the dividers and screens is not pertinent here; however, in situations where they were used, it was found that disturbances in one direction of travel did not affect the opposite direction of travel. Hence, the capacity was not reduced to the extent that it had been, and no detection or communication system was involved.

The second factor is reduced by the ability to remove a constriction as soon as possible. This indicates that to determine properly the value of a detection system it is necessary to know the proposed system for supplying the service required.

The third cause of the capacity problem can be reduced if the quality of the traffic stream is improved. This reduced quality can be expressed as a greater amount of stop and go action in the stream. Because of the human factor involved, the constriction must be removed to permit normal operation to be resumed. If it were possible to determine the optimum speed and to have all vehicles travel at this speed, then it would be possible to improve the quality of the traffic stream without removing the constriction. The present state of traffic theory and communications with drivers does not permit this course.

Travel Time

The improvement of travel time generally enters heavily into cost-benefit ratios. Travel time is increased by the congestion associated with a stopped vehicle. This implies that the magnitude of the disturbance and the traffic level must be sufficiently high so that congestion will develop. It is usually inevitable that some congestion will develop for some situations. In these cases, it would be helpful to have a road system that would adapt to the situation—that is, a means of directing traffic.

Increased Probability of Survival

Since no conclusive studies have been made that will show the probability of survival as a function of time, this objective is hard to substantiate. It cannot be stated, therefore, that improved detection time will increase the probability of survival by a certain percentage. Here again, the most important aspect is not the detection time, but the time required to get aid to the victims. If a graph depicting the probability of survival (assuming that aid is received in time τ) could be determined, then some measure of the system effectiveness could be obtained. Such a curve would be similar to Figure 29A.

The initial and final points of the curve indicate those who will not survive independent of the level of aid and those who will survive independent of aid. From such a curve, the value obtained by installing a detection system can be determined.

Figure 29B is the negative of the derivative of the curve in 29A. This figure shows the need for aid at time τ. There is some delay followed by a peak, after which the need for aid returns to zero. Thus, the time range over which aid is required can be derived from this figure.

The time τ is the time before aid is received. This time includes not only detection time but the transit time required to get the aid to the person needing it. In some cases, this is the time required to get to the scene; in other cases, it is the time required to get the victim to a hospital. It can be seen that as these travel times become excessively long, the need for a rapid detection system diminishes. If the travel time is short, then there is little need for instantaneous detection because the victims will live another few minutes.

Nothing definite can be said from this discussion because of the lack of data; however, a framework is estab-

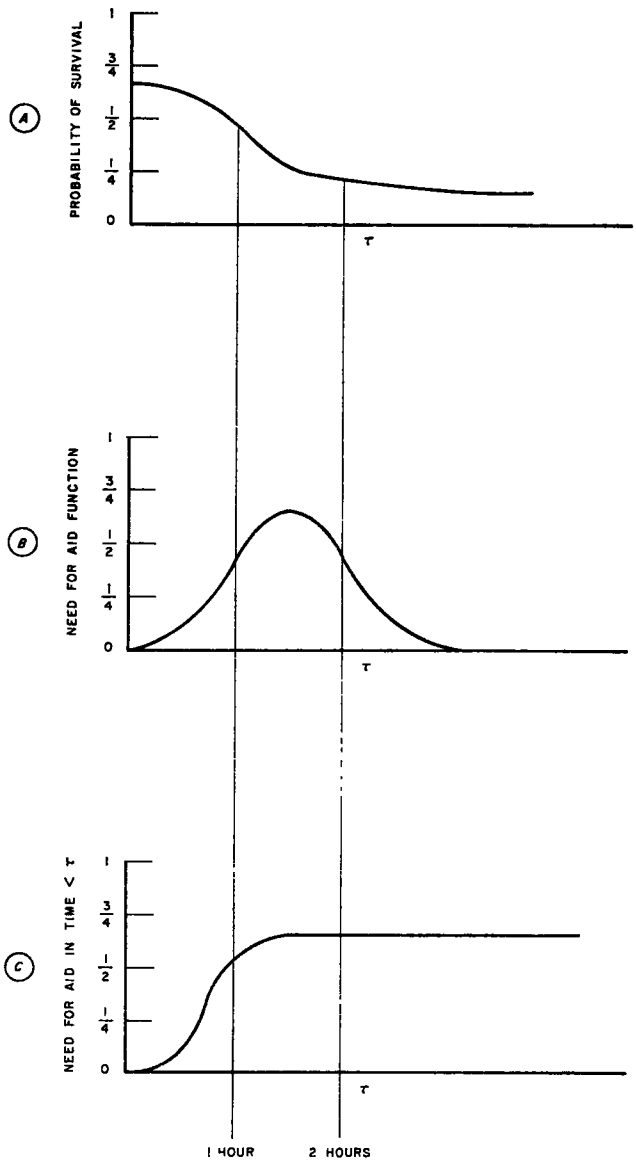

Figure 29. Emergency aid function.

lished wherein the problem can be evaluated and in many cases given a qualitative value. Here, probably more so than in any other situation, the detection aspect plays a subordinate role to travel time.

Motorist Service

To the afflicted motorist, the service derived from instrumentation or patrols can range from help in changing a tire to emergency first aid. To the nonafflicted motorist, removing the vehicle from the road or even away from the shoulder constitutes the elimination of a distraction and potential side-swipe hazard, and the restoration of smooth traffic flow. It is desirable to describe that service quantitatively.

Of the major stop categories, not all require aid; of those that do, all do not require aid with equal urgency. Thus, it can be subjectively estimated that a considerable percentage of motorists with tire problems can and will change their own tires. Someone who stops on the shoulder to rest certainly requires no aid. On the other hand, the motorist who runs out of fuel almost certainly requires aid, particularly on a limited-access highway. The matter of urgency is subjective, but no less important: fire will not wait to be extinguished, and medical aid, if needed, might be literally a matter of life and death. On the other hand, a person desiring information could wait without any potential worsening of his condition.

Table 3 summarizes these quantities for the 8 major stop types that are prevalent.

To determine the characteristics of each type of stop, the probability of such stops occurring, the probability that if such stops occur aid will be required, and the degree of urgency of aid being rendered have been considered. These factors are, respectively: (1) the frequency of occurrence of each type of stop (known), (2) the ratio of the conditional probability of aid being required (assuming that such a stop occurs) to the probability of the stop occurring—this ratio is equal to the probability that aid is required, and (3) an estimated "urgency index." From

TABLE 3

STOP-TYPE DISTRIBUTION

TYPE OF STOP	PROBABILITY OF OCCURRENCE	PROBABILITY THAT AID IS REQUIRED	URGENCY, OR RELATIVE NEED OF AID WEIGHTING FACTOR [a]	SERVICE REQUIREMENT PRODUCT	PERCENT OF TOTAL SERVICE
Rest	0.12	0	0	0	0
Nonemergency [b]	0.30	0.1	0.1	0.003	1.5
Tire	0.15	0.4	0.4	0.024	11.9
Information	0.16	0.5	0.5	0.040	19.9
Medical help	0.01	0.7	1.0	0.007	3.5
Fire	0.01	0.9	1.0	0.009	4.5
Mechanical	0.15	0.9	0.5	0.068	33.8
Gas, oil, water	0.10	1.0	0.5	0.050	24.9
Total service level required				0.201	100.00

[a] Time urgency.
[b] Probably no aid required.

this, the service demand and service requirement are formulated.

From Table 3, the service demand for "mechanical," "gas, oil, water," and "tire" account for 70.6 percent of the service demand. If information is included, over 90 percent of the service demand is satisfied.

Thus, a patrol that can satisfy these four service demands would satisfy the majority of the total demand. It is not inconceivable for a truck equipped with gas, oil, water stores, miscellaneous spare parts, and staffed by a competent auto mechanic who is informed about local road conditions to render just such service. The remaining two categories (medical and fire fighting) are specialized services. Limited fire-fighting apparatus could be a part of the patrol truck. With the five categories, 95 percent of the service demand could be satisfied, and possibly even 96.5 percent, leaving only the medical aid to specialized help.

A patrol of this sort does not exist today, though it may be worthwhile to consider the patrols of the New York State Thruway Authority. Each car is equipped with a supply of gasoline and water, first-aid kits and fire extinguishers; personnel manning these cars are ready to use their knowledge or any of the means at their disposal to help a stranded motorist. They are equipped with radio equipment and can call for specialized help or a tow truck if necessary. This effort appears close to the ideal patrol effort.

The category of motorist services appeals to humane instincts, but it is difficult to evaluate properly. It should be kept in mind however, that this category is a service. For this reason, this objective generally appeals to toll facilities more than to others. Persons paying for the use of a facility usually feel that they deserve the service. If this is true, the increased availability of such services is a competitive advantage of one facility over others. For this reason, many facilities in a competitive position look to such attractions for increased revenues. There is also the case of toll facilities such as bridges and tunnels that operate at or near their capacity. If this is the case, then these people look primarily at the increased capacity advantages of services rendered.

It is necessary to choose the desired level of service. For example, should only the basic services such as gas, oil, water, and tow be provided, or should additional services be offered?

The economic justification for a stopped-vehicle system is difficult to define. It can be approached from many points of view: benefit-cost ratio, rate of return, and savings-cost ratio. Appendix D shows the benefits of a stopped-vehicle detection system and the means of determining them. Weighting the various factors will have to be determined by the administrative authority; however, the analysis is objective.

Appendix D shows that the major portion of the benefit derived by the individual motorist is due to the use of other people's special equipment rather than to his own. It also shows that the value of the system to a motorist on an urban expressway can be as much as 10 times that on a country road; specifically, $4 to $5 versus about $50 per year.

Aids to Law Enforcement

If stops along the shoulder of a road are illegal then presence on the shoulder indicates either a need for aid or an infraction of the law. It is possible to direct the motion of patrols to points where they are needed, thereby decreasing the reaction time of the patrol and permitting a greater productivity from present equipment.

It is possible to obtain benefits for law enforcement and crime prevention from a stopped-vehicle detection system. Again, it is necessary to determine the type of system and the manner in which it is to be used before its value can be determined.

INTERRELATIONSHIPS OF OBJECTIVES AND SYSTEM CONCEPT

A detection system that only detects stopped vehicles is of little value. To be of significant value, the system must have means of alleviating the problem. If the system cannot perform all phases of its objective, it is worthless.

The best way to visualize the problem is to look at a few examples of the interrelationships of factors. After these hypothetical cases have been reviewed, the process of systematic analysis of objectives and systems will begin.

First, assume that the system used on a rural road senses shoulder presence only. Also assume some system objectives to see how well these objectives are achieved.

If the objective is to aid all persons in trouble, the data presented on rural roads indicate that the majority of persons using the shoulder do not want aid. Therefore, the false-alarm rate would be high.

If the objective is to maintain safety, it could be directed either toward the safety of those on the shoulder or the safety of those in the driving lanes. If the latter is assumed, their safety is maintained by a smooth flow of traffic. This smooth flow can be disrupted by vehicles entering and leaving the shoulder. Detection of these vehicles has done nothing toward the cause of the problem, the overt action of the vehicle.

If the other safety objective is paramount, the use of shoulders except for emergencies is essentially outlawed because shoulder usage is considered a hazard. It is doubtful that this could easily be enforced because of the low probability of detection by conventional patrols.

It may be that the prime interest is to service all persons on the shoulder. If this is the objective and the location is a rural road, the service would primarily consist of pillows, film, and sandwiches. The detection system achieves its objective fairly well.

The effectiveness of a system is determined primarily by the ability to reduce the amount of time spent by the motorist at the side of the road. A major factor, therefore, is the ability to get to this vehicle. This is not part of the detection system; but to be able to determine whether the expenditure for the detection system is worthwhile, this factor must be known. Hence, no meaningful value can be assigned to this situation at this point.

In considering an urban situation, it is necessary to talk more generally of system capability, not just shoulder presence alone. The objective is to give aid to distressed motorists. Assume that those who need assistance can be distinguished from those who stopped for an undetermined cause. Perfect indication of a desire for help is only a portion of the problem. Again, it is necessary to get aid to the vehicle. Hence, properly to evaluate the system with this objective demands that the other factors also be included. To spend the required amount of money for a detector system and not to be able to give assistance is wasteful. To spend the same money but be able to give this service, improve traffic flow, volume, and safety is not wasteful.

Another type of objective now is that of minimum time delay. This minimum delay can be either to the vehicle that is stopped or to the rest of the vehicles on the road. It is unlikely that the same practical system will optimize both simultaneously.

What can be done to reduce the time delay to the stopped vehicle? If the cause of the stop is of the nature of the undetermined causes of the Lodge Expressway, the system must act rapidly because the average time spent on the side of the road is only about 10 minutes. Those who stop appear to need information only. A direct communication channel into the vehicle is required. It may be more advantageous to supply the information before they enter the road so as to eliminate the stop completely.

Another major cause of shoulder stops is mechanical trouble, which causes inherently long delay. If the failure requires an hour to repair, a saving of 5 minutes is hardly sufficient to warrant the expense of a rapid-detection system.

Concerning the objective of minimum delay to the other vehicles, suppose that the vehicle has a mechanical failure and is on the shoulder of an urban expressway during a rush hour. Sending a tow truck to the scene to remove the disabled vehicle would probably create greater congestion and increase the time delay to the other users of the expressway. A better solution would be to leave the vehicle until traffic decreases. This is a case of a forced choice of system objective. Is the tow truck going to be dispatched immediately in order to minimize the delay to one stopped vehicle, or will the dispatch be delayed to satisfy the remainder of the road users?

The system designer has an objective to achieve and limited resources with which to achieve it. He must design to meet these objectives using a minimum of available resources.

Considering an urban expressway situation, it is known from the Lodge data that there are many short-duration stops for unknown reasons. What can the designer do? If the objective is to serve the people on the road and not those on the shoulder, the designer knows that the tow truck should not be dispatched immediately. This information will help to reduce the complexity and cost of the system. A simple shoulder-presence detector would probably suffice. Because most vehicles not requiring aid will be off in 10 minutes, aid will not be dispatched immediately. If the vehicle remains longer, it probably needs help which will be sent as soon as possible. This is a simple system, but it has done everything that a very complex system could have done.

If the objective is to service and/or remove the vehicle from the road as soon as possible, obviously the previously mentioned system is not satisfactory. More information is needed immediately. This requires a more complex system—possibly television, telephone, radio communication, or perhaps dense patrols by tow trucks. The last of these may be necessary in situations where there are excessive time lapses between the receipt of a call at a central location, the dispatch of the vehicle to the scene, and its arrival at the scene.

The previous discussion has shown that there are many systems at the designer's disposal. The choice of the best system requires that he be given the specific reason why the system is to be used.

CHAPTER THREE

EQUIPMENT AND TECHNIQUES

Very little equipment has been designed specifically for detecting stopped vehicles. The following discussion deals mainly with the characteristics and potentiality of equipment.

MECHANICAL

A device that depends on mechanical displacement, such as a treadle through direct or indirect contact with the passing vehicle, is likely to be cumbersome and relatively difficult to calibrate and maintain. Direct sensing may require the vehicle to depress a plate; indirect sensing could conceivably be performed by seismically sensing the passage of a vehicle nearby. Because of the complex nature of wave motion, the effects from different media (concrete, blacktop, loose or packed soil, wet, dry or frozen strata, reinforcing), and the anticipated presence of noise from railroads and industrial plants, these techniques are believed to be beyond the scope of practicability

at the present time. Conventional treadles are used widely for demand-signal control on primary-secondary road crossings; however, it is estimated that installation of such devices for the purposes of instrumenting roadway shoulders would be prohibitive in cost. Another disadvantage is the problem introduced by road resurfacing and snow removal.

It is suggested that mechanical devices might be useful in some singular cases, such as counts at an intersection; however, it is believed that currently available mechanical devices will find little use in the detection of stopped vehicles.

PNEUMATIC

Pneumatic sensors share some of the disadvantages of the mechanical. The basic difference is that the working medium or sensing device is a pneumatic tube, in which the pressure is changed by the passage of a vehicle's wheels. Thus, except for the sensing tube, the rest of the equipment (pressure transducer, counting devices, etc.) is located off the traffic lanes, and possibly even off the shoulders. Thus, installation and service are simplified; however, tubes are vulnerable to damage. They cannot supply any more information than the fact that a wheel, or possibly an axle, has passed. The pneumatic tube must be considered basically equivalent to a mechanical device. Its principal use is presently for establishing traffic counts, and occasionally for "speed traps."

USUAL

One of the most effective instruments in the perception of a situation is the human eye. The human observer is probably the most versatile (though perhaps not the most accurate or the fastest) sensor/computer combination in existence. Because the human monitor is not the least expensive "system," efforts have been made to enable each observer to monitor a greater length of a thoroughfare. By means of television, one person can survey a relatively long stretch of roadway in comfort and within reach of suitable communications/control equipment with which to initiate action.

Thus, by properly locating a series of cameras to survey successive segments of a thoroughfare, a single observer can detect stopped vehicles by scanning a series of monitors. Such instrumentation exists on the John C. Lodge Expressway in Detroit; it consists of 14 monitors that cover about a 3-mi length of the expressway (*3*).

The Lodge Expressway established that on an urban expressway about 30 percent of all stops are of an undetermined nature. The observer can see a stopped vehicle; however, except in the more obvious cases, he cannot determine with certainty why the vehicle is stopped and whether it is in need of aid. The observer's inability to determine the cause of the stop is a serious weak point of the system. This weakness is inherent to any passive "crystal ball" system.

It is seriously doubtful that it would be feasible to instrument all of the highways for visual (via television) surveillance, because the number of monitors that a single observer can observe is limited. There is also the cost of the cameras, monitors, surveillance centers, and personnel. It is suggested, however, that television surveillance of specific troublesome areas, such as traffic circles or tunnels, might be the simplest way of detecting stopped vehicles.

Another way to extend the human's field of view is by patrolling the road. Every part of the road is surveyed at time intervals. Continuous surveillance is not available. The basic drawback lies in this low frequency and the patrol costs incurred. A considerable percentage of all stops would not be detected. However, the patrol can give direct aid to the afflicted motorist when he is spotted. This contrasts sharply with television surveillance, where the monitor may see the motorist but have no idea whether he requires a tow truck, gasoline, an ambulance, or nothing at all.

The observer of a number of monitors is faced with a formidable task. He must continually be aware of all the monitors, but in time his attention tends to deteriorate and his ability to perceive a significant single item decreases. It has been determined by experiments that vigilance tends to drop off by about 20 percent during the first 30 minutes (*4*). This is known as the vigilance decrement. It was also found that if the observer were engaged in an active task together with the monitoring task, the vigilance decrement would be reduced somewhat.

Another aspect of human engineering states that a minimum of nonessential detail should be presented to the observer. Hence, the human observer could be considered the weakest and least understood component of a system using television surveillance.

If a way could be found to process video information before display, the observer's task would be somewhat easier. Thus, MTI radar presents only moving targets. In this situation, only unusual targets, such as stationary cars, should be of interest. No adequate methods of processing video information in this manner are known at this time.

OPTICAL

Optical devices can sense the presence (or passing) of a vehicle in many ways. Most use some kind of photo-sensitive device and a source of light. The passing of a vehicle interrupts or changes the intensity of the light beam impinging on the photo-sensitive cell; the result is a change in the electrical properties of the cell.

The photo-sensitive device itself may be one that generates a small current as a result of the incident light (photo-voltaic cells); it may also be one whose impedance changes drastically as the light intensity is changed (photo-resistive). The latter type is more common and inexpensive.

The light source could be a conventional bulb, natural light, or ambient lighting such as that found in some tunnels.

The more obvious advantages of photo-sensitive devices are low cost and the fact there is no requirement for physical contact between the sensing element and the vehicle. Since the cells are generally quite small, installation should not be difficult. A disadvantage is that the cell must be located so that traffic passes between it and

the light source. On a multilane roadway with no overhead structure a problems exists because horizontal sensing across multiple lanes does not allow the device to distinguish vehicles passing simultaneously. In fact, in three lanes of heavy suburban expressway traffic (assuming average lane occupancies of 40 percent), the beam would be interrupted about 78 percent of the time on the average. The average occupancy for the three lanes could be calculated but there would be no indication of individual lane conditions.

The response of the photo-resistive cell is generally about 1 millisecond and requires little external power. Photo-voltaic cells, on the other hand, have a much better response time (1 microsecond or less) and do not require an external power supply. Their cost is generally higher and they are less durable in many cases. Both types of cells can be made to operate in desired portions of the light spectrum; thus, there is no limitation in this respect.

The chief requirement for successful operation of photo-sensitive devices, therefore, is considered to be the contrast in illumination on the cell produced by a vehicle's passage. In view of the sensor's low cost and simplicity, such devices could be useful in many places.

A major disadvantage is that dust and grime accumulate on the face of the cell or light source and will, in time, adversely affect the cell's operation. This could be partially offset by careful placement, shielding, and periodic cleaning as a part of the routine maintenance.

ACOUSTICAL

Acoustical principles can be used in two ways: passive ("listen only") and active (sonar). The first method has not been explored adequately. It would depend on the vehicle as a source of noise. A highly directional microphone would be capable of hearing the noise within a relatively narrow cone across the roadway. Tire scrub, engine noise, exhaust noise, and air turbulence around the passing vehicle would mark its passage with a distinct noise spectrum. This spectrum is characterized by its increasing, then decreasing, amplitude, the doppler shift in the band limits of the noise spectrum, and its average value.

Since there is a limited number of broad vehicle classifications, a spectrum analysis of the noise from these vehicles (or vehicle types) should produce a number of distinct noise "signatures." Once established, these could serve as standards. Although spectrum analyzers would not provide an economically feasible vehicle detector system for extensive road coverage at this time, this should not preclude the possibility that in a few years a small, perhaps single module solid-state spectrum analyzer will be developed and become feasible. A potential use might be to determine the traffic mix in terms of the percentage of trucks, speed distribution, etc., all of which would be useful in achieving effective traffic control.

The possibility of spurious signals resulting from the use of horns, passage of aircraft, or nearby train or industrial noises certainly exists and would have to be examined for each installation.

An active method of vehicle detection relies on transmitting a sound wave of known frequency and duration, and listening for an echo. In the case of overhead-mounted sensing units currently in use, the "listen" gate is usually such that the receiver will shut off before the return from the pavement below is received. If there is a vehicle directly underneath, the echo is received before the receiver is gated closed, thus sensing the vehicle's presence. A series of "vehicle present" signals are received while the vehicle is passing underneath the detector. Knowing the vehicle's length, it is easy to calculate its velocity; conversely, knowing its velocity, it is easy to calculate its length. Obviously, both cannot be calculated from the output of the single sensor alone. Ultrasonic presence detectors such as these are used for traffic surveillance on the Congress Expressway in Chicago, and for vehicle counting purposes on the John C. Lodge Expressway in Detroit. One disadvantage to such a system is the required resetting of the gates when the surface distance changes such as in resurfacing. Most circuits adapt to snow conditions.

INFRARED

The possibility of passively sensing the temperature differences associated with a vehicle and its surroundings by means of an infrared sensor has been considered and some experimental work was undertaken. It is not presently believed that such sensors should be used. Infrared is somewhat parallel to normal optical techniques. The only advantage of infrared comes when the source tries to be uncooperative by obscuring its visible spectrum. Since the opposite is generally true of vehicular traffic there is no advantage to infrared. However, such units might find application in some specialized instances in the future. Units that have been developed are mounted overhead or side fire. They cost about $500 each, exclusive of mounting and data-processing equipment. The sensor consists of a transmitter and a receiver and operates on the beam returned from the pavement or the vehicle.

ELECTROMAGNETIC

Although electromagnetic sensors form a large category which may grow rapidly in the future, the following discussion is confined to existing working systems.

Radar is often used in speed measurements and traffic studies. Its chief advantage is that it gives velocity, as well as detecting presence. Its high cost (an installation of a single unit with minimum electronics can be expected to cost more than $1000) at this time precludes its wide use for detection of stopped vehicles exclusively. It is claimed that existing units present few maintenance problems. The projected life of the transmitting tube, the most critical component of the system, is 20,000 hours.

There are also magnetic traffic detectors or electromagnetic detectors which operate on somewhat diverse principles. Some rely on changes in the local magnetic field as introduced by the passage of the metallic mass of a vehicle (on the principle of the magnetic anomaly detector or MAD). Others use a single- or multiple-turn coil of

wire as the sensing element. The vehicle in proximity changes the electrical characteristics of the coil, which is then sensed by the associated circuitry. Some of the magnetic vehicle detectors depend on the vehicle's motion and will not detect a stationary vehicle. Others will be affected by a vehicle within the coil's range of influence because of the change in the inductance of the coil; thus, they will be sensitive to stationary and moving vehicles. These magnetic loops have the advantages of durability, low power consumption, no obstruction to street cleaning, and little effect due to resurfacing.

PASSING MOTORIST

One of the simplest detection "systems" consists of the good-will of passing motorists. In one facility with toll gates at both ends, this method, though not the primary detection medium, is found to be the first notification of a stopped vehicle in more than 30 percent of all stops. This facility, incidentally, has call boxes installed and is patrolled with great frequency.

On the New York State Thruway, a printed message on the back of the revenue card instructs motorists to report at a toll booth any stopped vehicle displaying a white cloth on the aerial or door handle. He must, in effect, leave the facility temporarily, unless he is leaving the facility at the exit nearest the afflicted motorist, and then re-enter to continue his trip. This is an inconvenience, of course, but motorists have done this.

If the motorist could convey information without leaving the facility and if his cooperation was solicited, he would probably cooperate. This could be done quite simply. For example, at designated spots, ask the passing motorist to blow his horn, or flash his lights. This signal could be sensed by a microphone, or photoelectric cell, and displayed as an alarm at the central location. To insure the veracity of the report, the central authority might wait to receive two, three, or more consecutive alarms from the same location before sending out a service vehicle.

A special and very simple device that might work well would be an ordinary sealed-beam light mounted in the side of the car. It would not blind either oncoming or following traffic, and would illuminate an area several feet square in the vertical plane adjoining the highway. If sensors were placed at regular intervals, with an appropriate sign requesting any driver who had spotted a stopped vehicle to turn on his "message light" just before reaching the sensor, then the passing motorist could signal with no more effort than that required for flipping a toggle switch, or pushing a button. To prevent the message light from being inadvertently left "on" it could easily be made to shut off automatically after 20 or 30 seconds. The question of false alarms due to reflections of sunlight from shiny bumpers, for example, is solved by noting the duration of passage of such a reflection. At highway speed, this is likely to be quite short, as it is the reflection of light from a compound curved surface. The beam from the message light has some finite width and, hence, a considerably longer duration illumination of the sensing element. Thus, as a part of the detection logic, it might be required that the "pulse" be considered an alarm only if it were greater than some predetermined fraction of a second—depending on the prevailing speeds, the probable distance of the passing car from the sensor, and the standardized beam angle. False alarms due to vandalism might be minimized by requiring that two or more signals be received by the same sensor within a prescribed period of time.

AIRCRAFT

Surveillance that could be conducted visually or by means of television can be conducted from the air by fixed-wing or rotary-wing aircraft. In New York, Los Angeles, and Chicago, helicopters are used to advise motorists during the rush hours of tie-ups or unusually dense traffic. Advisories to this effect are then broadcast by commercial stations at regular intervals.

Fixed-wing patrols are currently used by the California Highway Patrol over rural roads (*5*). The aircraft work with ground units with whom they communicate; the aircraft pilot acts as "eyes" for the ground unit. By means of a public-address system, he can issue brief instructions to the driver on the ground, issue a warning, or even instruct a stopped motorist to indicate whether help is needed.

The advantage of fixed-wing patrol lies in its ability to cover long stretches of road quickly, and in the unparalleled view. However, the aircraft pilot can do little to help the stopped motorist. He must have a ground unit (or several) working with him, and the weather may restrict flight operations partially or completely or render ground visibility inadequate. In areas where the weather seldom restricts flying, aircraft patrol may be the best presently available means of traffic surveillance and stopped-vehicle detection on networks of rural roads.

Statistical evaluation of Crittenden's report (*5*) gives a good indication of the costs involved, and to some extent the effectiveness.

The patrol activity was limited to daylight hours but not continuously, on the basis of the "selective enforcement principle." From the hours flown, it appears that the patrol effort extended over about 65 to 75 percent of the daylight hours. The operating costs for the aircraft (exclusive of pilot salary and special equipment) which were leased, amounted to more than $10 per hour, per aircraft. Of course, this figure may vary considerably for aircraft with more performance or equipment; if the aircraft were purchased, it would also include depreciation, insurance, operating cost, etc. The longest road sector covered by one aircraft was about 22 miles. From the total hours flown during the test periods and the known average cruise of the aircraft, it is estimated that the average time of passage while flying on that road segment is about 15 minutes. Thus, for all of the daylight hours, the expected patrol frequency would be about 20 minutes.

In areas other than California, area patrol covering a network of roads and intersections rather than a single road segment may be more advantageous. In effect, each aircraft would be patrolling many miles of roads simultaneously. Of course, this is predicated on good visibility,

but the advantages in rolling or hilly terrain are obvious.

In terms of detection of disabled vehicles, the California experiment indicated that the aircraft could be effective. During one 6-month test period, about 23 percent of the incidents observed constituted disabled vehicles, and a further 16 percent parked or abandoned vehicles.

Operationally, it was found that the pilot observer can fly for up to six hours per day in 2 or 3 installments without undue fatigue.

A further potentially useful feature of the aircraft patrol is its ability to act as a communications link or relay between ground units and central locations.

Helicopters are used on some occasions by the police departments of several of the largest urban centers. For the moment, however, their hourly operating cost is considerably higher (3 to 5 fold) than that of fixed-wing aircraft. They do offer a unique means of surveillance of singular events, and can land in almost any average-sized parking lot, provided that the wind is not too strong (15 to 20 knots). However, the immediate thought that they could offer service to a disabled motorist is tempered by the probable effect that a helicopter landing immediately adjacent to, or hovering only a few feet over, an urban expressway would have on the traffic stream. Furthermore, adequate and safe landing areas are generally not available next to major thoroughfares, particularly in densely populated urban or suburban areas.

Again, it is possible that as helicopters become more common, sophisticated, automated, and capable of all-weather operation, and as operating costs become more competitive with those of fixed-wing aircraft, wider application for the purposes of traffic monitoring and law enforcement will become practicable.

NEW DETECTION METHODS

Although the previously mentioned detection systems were shown to work, their primary purpose was to solve problems different from those under consideration. Some exotic methods for detecting a stopped vehicle, communicating with it, or both, are described in the following.

The cost of instrumenting the hundreds of thousands of miles of lightly traveled country roads with present systems would be staggering. Even if the roads were instrumented, the cost of rendering services would also be extremely high.

Disregarding highways that traverse deserts, a rural area showing at least occasional signs of inhabitation is considered. Reliance on a fellow motorist to act as a communication channel has been previously discussed. However, if fellow motorists can act as communication channels, the same may be true for the entire population, although it appears that people in rural areas are more likely to respond to a call for aid than those in urban areas. Thus, a way for the stranded motorist to "send a distress signal" that could be detected for several miles is sought.

A simple device that could probably be commercially produced at a nominal cost would consist of a balloon, inflatable from a (helium) cartridge and with a smoke-producing flare suspended beneath. In emergencies, the motorist would extract a safety pin or break a seal to drive a spring-loaded plunger into the gas cartridge, thus inflating the balloon and igniting the flare. The balloon would ascend so that the light from the flare (at night) or the smoke (in daylight) would be visible for several miles. Anyone seeing the signal could notify the appropriate authorities about the sighting. The airborne life of the balloon could be made relatively short, since it presents a hazard to light aircraft. At the same time, however, the brightly colored balloon, flare, and smoke should attract the pilot's attention. Also, since most light aircraft are radio equipped, the pilot could easily call in his sighting.

There should be safeguards against premature descent of the burning flare to minimize the possibility of fires. Use in densely populated areas should also be restricted since it would not be needed. Finally, since misuse by irresponsible persons is possible, severe punishment for misuse should be imposed.

Other methods that do not rely on visual detection are feasible, though probably more complex and expensive to implement. One possibility is an electronic beacon that transmits a signal at regular intervals, preferably at a frequency that would permit detection by electronic equipment in the area. Since most AM receivers have intermediate frequencies tuned to about 450 kc, this may be acceptable. Once again, however, reliance must be on someone to indicate the presence of the distress signal (and, of course, the approval of the FCC).

A much more complex system could consist of a beacon operating on its own unique frequency. A network of receiving stations would detect the signal and determine its location. Inasmuch as telephone poles and lines follow many country roads, a small solar-battery-powered receiver could be placed on selected telephone poles. When a distress signal is received, it would impose a signal on the telephone line, coded with its location. The location of the vehicle would be determined by the codes of all the receivers that detect the distress beacon.

The acceptance of a system that costs a motorist money is questionable, especially since he may never need it. For example, a motorist who seldom travels on country roads is not likely to invest money in such a system. Also, the cost of the fixed receiving equipment must be justified and paid for by taxes. The aspect of cost/benefit must be considered in any scheme of detection or communication. Today, the citizen band transceivers in use are so numerous that the frequencies allocated are frequently jammed. Prices for mobile citizen band transceivers range from $70 to $300; they are generally adequate for ranges of up to 5 miles. Small, hand-held "walkie-talkies" operating in the citizen band have ranges from 1 to 3 miles, are battery powered, and cost about $20. A feature of these is that they do not require power from the automobile's battery.

Because of the limited range of citizen band transceivers and walkie-talkies, the FCC allows their use without licensing or special examinations for operators. To use higher powered mobile units, an operator must have an amateur radio license; the equipment costs are also much more than the citizen band equipment.

Thus, at the present time and for the near future,

adoption of individual transmitters/receivers in cars solely for use in the event of an emergency is not economically feasible; however, the use of radio-telephones may gain popularity with advancing technology, though it is presently limited by its high subscriber cost and limited range.

Another possibility exists in the use of a car's radio. If adopted on a mass produced basis, a relatively simple modification to the average car radio could be designed and built at reasonable cost—presumably at a fraction of the radio's cost. This modification would permit the radio to be used as an emergency transmitter. Obviously, this scheme can work only if the disabled vehicle has an operative, properly modified radio, and there is no battery failure.

Although the approximate proportions of stops due to battery failure are known, the first premise is of more consequence. Figure 30 shows the percentage of cars sold in the United States, factory equipped with radios. Because some post-factory installations are made by the owners, it is estimated that about 70 percent of the cars in the United States are radio equipped, with a much smaller percentage of other motor vehicles being similarly equipped.

It must be reiterated that the adoption of any detection/communications scheme must be accompanied by the availability of service, because the psychological effect of an unheeded call is probably worse than no call at all.

The major problem to be found on urban expressways is the task of restoring normal traffic flow disrupted by an incident. The nature of the incident is generally of less consequence than its strangling effect on the expressway's capacity. The problem is not detection but service.

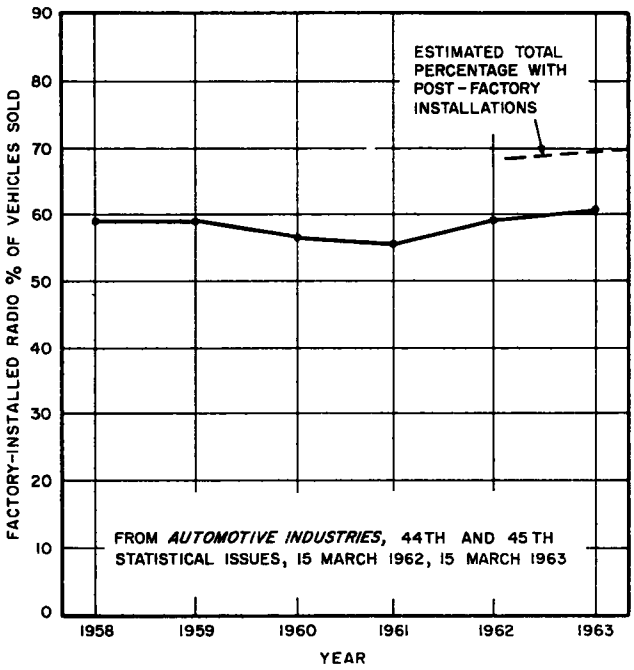

Figure 30. U.S. passenger cars by model year, factory equipped with radio.

There are occasions when the tow vehicle would have a difficult time reaching the scene of an accident. The operation of raising and pulling the disabled vehicle off the driving lanes in itself creates a disturbance.

Thus, perhaps there is need for a special vehicle that would be capable of reaching the scene of the incident regardless of traffic conditions. The first possibility is a heavy helicopter that could lift the disabled vehicle out of the traffic and deposit it where it could be serviced. This helicopter would be equipped with chains, hoists, hooks, and platforms. It might not need to land to perform this task. It would also serve as an excellent surveillance platform. It would have to be "on station" principally during the rush hours.

Another specialized vehicle could be similar to a log transporter. It is a self-propelled vehicle that straddles the load to be picked up. It too, should be capable of removing a stopped vehicle quickly, particularly from portions of the urban expressways not bordered by sufficiently wide shoulders. Since this is where its chief use may be, it would have to be stationed close to these areas and proceed only when needed. It would have to be a large, slow moving vehicle. The problem of overhead structures reduces its use in most regions.

The Oakland Bay Bridge had a set of rails suspended under the upper level with full-width service platforms so that routine bridge maintenance can be conducted without interfering with the traffic below. If these rails and platforms were of sufficient strength and properly equipped with chains, hoists, etc., a stalled vehicle could be speedily pushed or pulled into one of those platforms lowered to the pavement and then raised back up. It could then proceed slowly to the end of the facility at which point the vehicle could be properly serviced. Alternately, it could remain suspended there until after the rush hour, and then be lowered to the pavement on arrival of a ground service vehicle.

Admittedly, this system would be applicable only where there is an overhead structure (with sufficient headroom) capable of handling the loads involved.

On facilities with limited room such as bridges and tunnels, it may be possible to mount a set of side or overhead rails. In fact, merely a catwalk might be sufficient. On these rails, a specially designed vehicle should be able to traverse the complete length of the facility in either direction. It should be manned, equipped with the necessary first-aid supplies, have communications system to the "outside" and the capability to handle most emergencies on that facility. Vehicles such as these are used currently in the New York City tunnels, but only to transport tunnel-surveillance personnel into the tube. The vehicle envisioned here would be one with sufficient power equipment to enable it to remove a stalled vehicle, untangle a wreck, and put out a fire—thus restoring normal traffic flow. It might be self powered or electrically powered by a third rail. It is realized that the incorporation of such a system would require very firm foundations for the rails, particularly if the vehicle were to lug a stalled truck uphill.

The capability of moving a large stalled commercial

vehicle on the roadway is not as formidable as it seems. The extended boom is one way, but places a considerable strain on the rail mounting. Another possible way is a self-powered dolly, with small wheels and jack. It might be lowered to the pavement just ahead of the stalled vehicle, pushed under it, and the front end raised via the jack. Applying power to the dolly's wheels via the boom from the patrol vehicle proper would move the disabled vehicle.

It is felt that in many situations the traffic stream can be used as a communications channel; that is, if a vehicle creates a disturbance at some point on the road this disturbance will be propagated along the traffic stream. This disturbance will be characterized by some variation in the traffic parameters. If a system can recognize this disturbance, then the traffic stream itself has transmitted the message.

As an example, suppose that the volume and density are being monitored and that 1-min averages are being plotted. This would be similar to the work reported by Ryan and Breuning in (*6*). Crittenden shows (Fig. 31) that for densities less than 55 vpm, the spread of the data is low. A disturbance occurred at about 38 vpm; since it lasted for less than 1 minute, it was not likely to have been a major accident or a vehicle stopped in a travel lane. It was probably caused by a vehicle leaving or entering the travel lanes. The feasibility of such a system appears quite good. Palmer, in his conclusions on the study of the development of traffic congestion, stated: ". . . and as an aid in locating and removing potential causes of bottlenecks (disabled vehicles), a traffic-monitoring device to sense the development of congestion would be very valuable."

There are, however, many questions: For what range of parameters is the system reliable? What are the characteristic patterns? What separation of detectors is required or what are the spatial characteristics of the disturbance? What is the time response of the system? To determine the answers to these questions, some concept of normal traffic flow should be known. This can be acquired by empirical means for a given facility or some general traffic theory can be used. The latter probably offers the greatest applicability and the most rewards.

Another possibility is to use the induction radio technique. It is possible for a low-power transmitter to induce a signal into a local cable such as a power or telephone cable. This signal will then propagate a considerable number of miles. Such low-power systems have been known to carry about 50 or 60 miles. A disadvantage is the difficulty in isolating segments of the road; for example, when a signal is induced, it will travel the entire distance.

Some persons are interested in establishing a national highway radio network. It may be possible that this network can be used not only for communications from the road to the vehicle, but also from the vehicle to the road.

Instrumentation of the shoulder is another possible technique for the detection of stopped vehicles. Loops can be installed in the shoulder for instance. These loops can be used for both presence detection and induction radio. Loops are not the only detection system that could be placed on the shoulder; there are also optical detectors such as photocells. These cells could pick up the tail lights of vehicles parked on the shoulder. This is of course not always unambiguous. The cell may see a vehicle that is on the roadway and think that it is on the shoulder. To prevent such confusion, the lights could be modulated with the speed of the vehicle. Only vehicles that are stopped would then be detected, whether they are on the road or on the shoulder. When the tail lights have been modulated with the speed of the vehicle, it is also possible for vehicles to communicate speed information between each other. It may also be possible to include a voice communication channel so that motorists can talk directly with a central location.

There are at this time, commercially available "wireless broadcasters," at a per-unit list price of under $10 for the AM and under $40 for the FM units. These units are limited in power and range since they operate in the commercial broadcast bands. The application of units

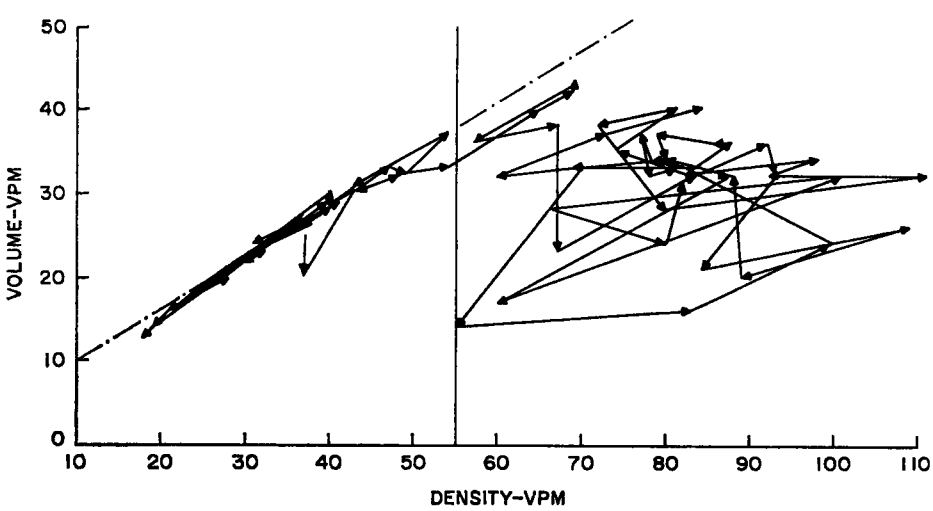

Figure 31. Chronological plot of data for Case 1, February 13, 1958.

similar to these in conjunction with a receiver network could be one solution.

Wire communication over long ranges is likely to exceed the cost of radio communications; nevertheless, it is worthwhile to consider a simple system that would require opening the line at the place where aid was needed. A relatively simple bridge-type measurement would permit the opening to be detected in a way similar to that used by power companies to locate breaks in power lines. This type of system might be applicable where there is one long road rather than an area network. A further refinement could be a device that would permit the motorist to tie into the line with his own voice transmitter. The possession of the hand set by the motorist is assumed instead of telephones located at regular intervals in order to give the afflicted motorist the opportunity to communicate from his stopped position, and because unattended telephone sets are often subjected to vandalism and easily broken. A simple clamp-on or inductive coupling would permit quick and easy tie-in.

COMMUNICATIONS

Communication can be either unidirectional or bidirectional. Signs and news broadcasts of traffic conditions are unidirectional from the authority to the driver. Handkerchiefs, raised hoods, and call boxes are examples of communications from the driver to the authority.

An important factor in evaluating a communication system is whether its action is initiated by the motorist. If the motorist is required to initiate the signal, it is possible that he either cannot or will not do so when an incident occurs. On the other hand, for systems that do not require motorist initiation, a problem exists with false alarms.

Studies performed on the Lodge Expressway show that even with perfect visual information obtained from television cameras it is impossible to determine the cause of 30 percent of all the stops on that facility. This strongly indicates that a higher degree of active participation on the part of the motorist is needed to clarify many situations. This is the only apparent need for direct driver-to-authority communications; however, under some circumstances, this can be an important factor.

If only emergency stops are permitted, the detection alone carries all the information that is necessary. In reality, however, there are numerous intermediate information levels that are necessary. The following analysis gives a better understanding for the amount and type of information that may have to be transmitted. As shown in the service requirement table, the product of the first two columns represents the "service needed" demand, that is, the distribution of occasions (according to cause of stop) for which help is required. Since the rest stop never needs aid, seven distinct stop types remain; listed in order of frequency of aid desired, they are mechanical trouble, 0.135—corresponding to 32.0 percent; gas, oil, water, 0.100—corresponding to 23.8 percent; information, 0.080—corresponding to 19.0 percent; tire trouble, 0.060—corresponding to 14.2 percent; miscellaneous stops, nonemergency, 0.030—corresponding to 7.1 percent; fire, 0.009—corresponding to 2.2 percent; and medical help, 0.007—corresponding to 1.7 percent.

If the "ideal" patrol described previously existed, it could respond to all but the last of these stop types; hence, only two distinct signals for help would be required and a single-digit binary channel would be sufficient, with no special coding required. If distinct services were offered in three or four categories, two digits of a binary information channel would be required, and all of the above could be coded using a maximum of three digits of straight binary coding. Considering the wide range of expected signals covering the categories, a coding scheme with more efficient use can be easily devised. An average message length of about 2.4 bits is attainable, on the basis of the above percentages (*7*). Of course, in the most likely case that several of the services (mechanical, tires, oil, gas, water) can be combined, the message requirements decrease.

The expected stop characteristics on a given road and the service types available must be considered in determining the type, complexity, and efficiency of the communications channel used.

CHAPTER FOUR

APPLICATIONS

Several methods for synthesizing a system are described. In general, the procedure will be to:

1. Define the problem—type of road and, hence, stop distribution;
2. Determine service requirement;
3. Choose suitable elements of the system—detection-communications-service (the latter assumed);
4. Consider alternate components such that the service requirement is matched as closely as possible by the service rendered; and
5. Attempt to gage the cost of implementing the complete system, in terms of dollars per incident.

Several distinct cases will be considered, each with unique problems and best applicable solutions. Since it is

almost impossible to investigate all of the possible combinations of the subsystem types involved, many can be discounted as unable to fulfill the required task or as having unwarranted redundancy or estimated costs excessively high compared with other combinations. The methods used are illustrative of the procedure that could be followed for any type of road for which a solution to the stopped-vehicle problem is sought. Table 4 lists the specific cases to be discussed and distinguishing characteristics that affect the ways in which a system can detect, communicate with, and aid motorists in distress. The similarities of case 1 to case 2 indicate that many methods applicable to case 1 are applicable to some facilities of case 2. There is a similarity in responsibility between the facilities of cases 2 and 3.

Case 4 roads share some of the problems, though not necessarily feasible solutions, of case 3 roads. The reason for the potential diversity of solutions lies in the division of responsibilities. The same can be said for case 5, with the added factors of unlimited access and environment. The predominant type of traffic for the different facilities will be somewhat different, thereby changing the expected stop distribution and thus the problem to be solved.

Case 6 presents the most formidable problem because of many miles of country roads, and low numbers of stops per mile require considerable cost per incident to implement any kind of system.

CASE 1: URBAN EXPRESSWAY

Problem Definition

Case 1 is distinguished by the highest traffic densities, high volumes, and highly motivated traffic. The latter limits the stop types to emergency stops plus information stops—that is, no leisure or rest stops. The effect of a stop is an impediment to smooth flow;[1] if the stop is in a driving lane, it causes an obstruction. It is dangerous for the afflicted motorist to leave his vehicle. There are generally frequent access and exit lanes, and "service roads" on either side.

The urban expressways are generally administered by the urban highway departments. Their prime concern is to maintain smooth, safe traffic flow with a minimum of delay and inconvenience to all motorists. With ADT's of 70,000 and up,[2] particularly during the peak hours, a stoppage in the driving lanes is almost catastrophic in terms of the effect on the remaining traffic. A stopped vehicle on the shoulder, on the other hand, has a more indirect effect of creating a change in velocity or lateral displacement away from the stopped vehicle in the stream adjacent to the shoulder. This disturbance tends to propagate, as a wave upstream. The act of an assisting vehicle pulling off the road is similarly disruptive.

Hence, the objectives of the system are essentially to reduce the number of stops to a minimum and to service unavoidable stops in a manner that minimizes interference with the remaining traffic.

Table 5 summarizes the distribution of the stop types column (1), the probabilities that each particular stop type requires assistance column (2), and the proportion of all stops requiring assistance column (3). Next, the assistance requirement of column (3) is normalized to show the distribution of the required assist types column (4).

[1] On the John C. Lodge Expressway it has been observed that a stopped vehicle, even though not in the driving lanes, has an effect on the passing traffic. This is further corroborated by a study by L. W. Cozan and R. M. Michaels: "Perceptual and Field Factors Causing Lateral Displacement," Traffic Systems Research Division, Bureau of Public Roads, *Public Roads*, Vol. 32, No. 11, p. 233-240, and verbally by Chief Sullivan of the Los Angeles Police Department.

[2] On the Long Island Expressway as high as 140,000, and on Los Angeles' freeways about 180,000 with peaks over 200,000 on the Harbor Freeway.

TABLE 4

DESCRIPTION OF STUDY CASES

CHARACTERISTIC	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6
Type	Urban expressway	Urban bridge or tunnel	Rural expressway (toll)	Interstate, major rural roads	Intercity, feeder roads	Rural roads
Area traversed	Completely urbanized	Completely urbanized	Principally rural	Densely settled with business establishments alternating with sparsely settled and rural	Same as case 4	Sparsely settled or completely rural
Service Organization	Service by urban highway department	Service by administrative authority	Same as case 2	Service by private enterprise or by state	Same as case 4	Same as case 4
Enforcement Organization	Enforcement by urban police department	Enforcement by administering authority, often with aid of local or state police	Enforcement by administering authority usually with the aid of state police	Enforcement by local administration interleaved with the state police by municipality borders	Same as case 4	Principally by state police
Administration	Responsibility with the city	Responsibility with the administering authority	Same as case 2	Responsibility with local administrations and by state —delineated by town, village, or incorporation limits	Same as case 4	Principally with the state

TABLE 5

STOP AND SERVICE DISTRIBUTIONS

STOP TYPES	(1)	(2)	(3)	(4)	(5)
Nonemergency, miscellaneous, unknown, check noise or load, etc.	0.34	0.1	0.034	0.072	0.56
Tire trouble	0.17	0.4	0.068	0.145	1.13
Information	0.18	0.5	0.090	0.192	1.50
Medical problem	0.01	0.7	0.007	0.015	0.12
Fire	0.01	0.9	0.009	0.019	0.15
Mechanical problem	0.17	0.9	0.153	0.324	2.53
Gas, oil, and water	0.11	1.0	0.110	0.233	1.82
			0.471		7.81

Since only 0.471 of all the stops require assistance [summation of column (3)], the rate at which stops occur must be considered. From Figure 16B, an ADT of 100,000 and an ATL of 20 miles, about 16.5 stops per mile per day can be expected; hence, the required assists will be about 7.8 per mile per day. These assists will, therefore, be distributed by type as indicated in column (5). Therefore, this column represents the service requirement for this road type and stop distribution, including the hypothesized proportion of each stop type serviced.

System Implementation

The next task is to choose a series of elements of a system that would permit the stated objectives to be fulfilled as well as possible. Having examined a number of possible systems (possible meaning achievable within the known state of the art) the costs of implementation will be considered.

Table 6 lists the elements of detection by type, with their respective "effectiveness" defined as the probability of detection. The first and last systems are strictly hypothetical and indicated only for control purposes. The "perfect" detection system is perfect in the sense that the probability of detecting a stop, irrespective of the stop's location or duration, is unity. The remaining probabilities of detection are shown in terms of the pertinent variables where applicable (time, distance).

The detector categories mentioned place no restriction on the specific equipment types that could be used. Care must be taken, however, when choosing a particular type to account for its range of effectiveness, reliability, etc. The number of a particular type of unit to cover a length of roadway may likewise be different from the number of some different detector, though the intent of both may be to accomplish exactly the same end.

In considering the communication aspect, clearly some of the detection schemes are in themselves communica-

TABLE 6

DETECTOR TYPES AND THEIR PROBABILITY OF DETECTION

GENERAL TYPE OF DETECTOR	BASIS FOR PROBABILITY OF DETECTION	PROBABILITY OF DETECTION
Perfect detector	Certainty of detecting all stops	1.0
Television or visual surveillance	All stops excluding those of very short duration and allowing for observer inattention	0.95 (est)
Continuous shoulder instrumentation (including median, if wide enough)	$\frac{\text{Expected No. of Stops on Shoulder}}{\text{Expected Total No. of Stops}} = \frac{593^*}{622} = R_d$	0.97
Intermittent shoulder instrumentation	(as above) $\times\, l_e \times n \times R_d = 0.953\ n\ l_e\ R_d$, where l_e = length of effectiveness of one detector, n = number of detectors per unit distance, R_d = detector reliability. Assuming $l_e = 0.025$ m, $n = 50$ per mile, $R_d = 0.99$	0.472
Traffic parameter sensing (volume or density)	Not effective for < 20 vpm/lane where lane changing is unrestricted. Effect as yet unknown for densities exceeding k_j	unknown
Traffic count (successive volume/density)	A simple sequential count of vehicles past successive locations and delayed comparison; or one of the traffic parameters such as density or volume. (Barker's radar scheme) subject to errors	unknown
Passing motorist	Based on "first call" data, Oakland Bay Bridge (Section III-D).**	0.20
Patrol	Based on patrol frequency and the duration of the stop-using distribution of Figure 11B, patrol constant of 20 minutes	0.29
Motorist actuated	Will not detect such stops where motorist not capable of acting or not willing	

* These values are from the Congress Street Expressway and as such can be considered as being representative. R_d is the detector's reliability.

** All stops are "in lane" stops; it is not certain that passing motorists would be as charitable if the stopped vehicle was on shoulder. Other facilities estimates range to 15 percent.

tion elements as well. For example, if the patrol effort is chosen as the detection medium, and if it can be assumed that patrol vehicles are equipped with communication equipment, both the detection and communication elements are present. On the other hand, the addition of another means of communication/detection would tend to improve the level of service significantly. Table 7 sums up the general communication media available.

The stated objective, "to reduce the number of stops to a minimum," has little to do with the scope of this study. The magnitude and texture of the problem is changed if an effort is made to achieve this objective. Thus, the solution begins with a public education campaign, supplemented by a concentrated effort to insure that the motorist is presented with sufficient, unequivocal information so that he would not have a need to stop for information purposes. Only emergency stops should be tolerated; concise instructions of what to do in an emergency must be clearly presented and the penalties for nonemergency stops indicated, and, if necessary, enforced.

Since urban expressways are mostly used by the same drivers over and over again, continuous and consistent education effort is certain to have its effect. A good example of this can be found on Los Angeles' freeways, as well as in the observance of the "no parking" regulations during specified hours on certain through streets. Emergency stops will not be completely eliminated through education; hence, service is necessary for such stops.

The second requirement was service of the unavoidable stops with a minimum of interference with the traffic flow. This calls for relatively "quick" detection and communication of the need for, and type of, aid required and rendering of that aid. It must be assumed that a stopped vehicle that is not detected and serviced might remain a stopped vehicle.

A detection scheme of low probability of detection based on detector spatial limitations is inherently bad; one with low probability of detection based on the stop duration distribution is equally undesirable.

Since the objective is to minimize interference, in-lane stops must be immediately detected and serviced to the extent of being removed from the main lanes. Unfortunately, the perfect detector does not exist.

TABLE 7

GENERAL COMMUNICATION MEDIA AVAILABLE

Visual	No special equipment required	Visual appearance makeshift signals common codes
	Equipment required:	Signs Lights, flashers, Flares
Call box Telephone	Code Voice Emergency Public } wire	
Radio	Code: limited range Code: long range Voice: limited range Voice: long range }	Frequent receivers to central location

Shoulder instrumentation will not indicate in-lane stops. Sensing of the traffic parameters may result in an indication that an unusual condition prevails (sharp increase in density, decrease in speed upstream of the stopped vehicle, and a decrease in density downstream). It must be realized that this effect is predicated on relatively high flow volumes [3] to start with. Because this is precisely when an in-lane stoppage has the most devastating consequences on traffic flow, this method of detecting in-lane stoppages is considered to be the most effective.

For sufficiently heavy flows, information pertaining to a vehicle entering or leaving the traffic stream may also be available. A disturbance is created whenever a vehicle slows and pulls off onto the shoulder. This disturbance is thought to be smaller, confined primarily to the right lane, and probably not nearly as well defined, though some experimentation may give more definite results.

A further advantage of the traffic-parameter sensing system is that it adapts to the severity of the situation (within the objective's framework). The denser the initial traffic, the greater the change in density across this suddenly developed "obstruction," which blocks (at least) one lane. The density buildup upstream will be rapid and the corresponding decrease downstream will be equally rapid. Hence, the difference will build up roughly two times as rapidly.

Thus, the rate of change of the difference density is indicative of the severity of the problem. If, for example, 3 of 4 lanes should be blocked, the flow that can pass the bottleneck is reduced to less than one-fourth of its former value. Assuming dispersal of the flow from the open lane to the remaining lanes downstream, the density difference should increase phenomenally and quickly as the upstream density builds up, since the upstream demand has not changed by diversion, or any other means.

Of the following categories, none are suitable in the face of the stated objective. Passing motorists must proceed downstream and initiate some action to inform the authorities, which may not be convenient, except on a short toll facility where they are obliged to stop anyway. An intensive patrol effort would be required even to approach the speed of detection of in-lane stops by the traffic-parameter sensing system. Motorist-actuated devices demand the motorist to leave his vehicle and walk to a call box/telephone, which may be exceedingly dangerous and time consuming to all road users.

Television and visual surveillance were also listed as possibilities. The disadvantages of both are their reliance on human vision and judgment; helplessness in case of reduced visibility or darkness; the high cost of television equipment, manpower, observation posts for the observer, camera housings, monitoring stations, etc.; and the phenomenon known as "vigilance decrement," which increases the probability of not seeing an incident.

[3] Until the magnitude of this difference plus its time history has been determined experimentally, one can only surmise that the difference will be much greater than the statistical variation for the two locations. It is further suspected that both its magnitude and time history will depend on the prevalent flow volumes at the time of the stop's occurrence.

Little mention has been made of the shoulder stops even though they comprise about 95 percent of all the stops. The reason for this lies in the principal objective—that is, least possible delay to the majority of the facility's users. The safety aspect of a shoulder stopped vehicle has been shown to be about 100 times better than that of the lane stoppage, and an attempt at immediate servicing of the stopped vehicle would tend to interfere with the normal traffic flow.

This does not imply that a motorist stopped on the shoulder should be forgotten, or left to help himself. It does imply that extreme speed in detection is not of prime importance because immediate service is most likely not available in any event. It further implies that communication from the driver to the service agency is desirable so that the appropriate service can be rendered to him with the least possible interference to the normal traffic.

A stopped vehicle on the shoulder with no activity around it attracts little attention from the passing motorists. Two vehicles, one of which is a police car or tow truck, result in considerably more "rubber-necking" leading to the attendant fluctuations in speed/density and increasing the probability of incidents.

To sum up, there is little need for shoulder instrumentation. There is however, a need for a communication device easily accessible to and operated by the distressed motorist, and a way to supply the needed service.

A fairly heavy patrol effort is adequate to detect shoulder vehicles. If each patrol vehicle (car-truck-motorcycle) is equipped with a UHF communication transceiver, the need for the call boxes is considerably diminished.

Because most urban authorities want to have some patrol activity for crime prevention and law enforcement, it remains only to determine the anticipated patrol frequency to see whether motorist-actuated devices would materially improve the position of the stopped motorist.

A further consideration is that of motorist cooperation. Experience in Los Angeles has shown that few stopped motorists use the call boxes. Admittedly, these boxes are available on a relatively short segment of only one freeway.[4]

Finally, the motorist in need of aid must look for and go to the call box; on the other hand, he can merely wait to be found by the police patrol.

The service to be rendered must also be considered in terms of the prime objectives. For example, if the patrol vehicle that is used to detect the stopped motorist calls for assistance and a special service vehicle is dispatched, a situation that seems far from optimum arises. The motorist might expect to stay there for quite some time waiting. Since this is usually acceptable (within the objectives' framework) for shoulder stops, it is not acceptable for in-lane stops. Furthermore, the rubber-necking effect is compounded not once but twice; first, when the stopped vehicle is joined by the police patrol, and second when the service vehicle arrives. Thus, the traffic stream is disturbed five times: (a) when the vehicle stops, (b) when the patrol arrives, (c) when the patrol leaves, (d) when the service vehicle arrives, and (e) when the service vehicle and the motorist leave.

There are two ways in which one of the two disturbance contributors might be eliminated. First, the service vehicle could be used for patrolling; alternatively, the police patrol could be used for servicing. The former does not eliminate the need for law enforcement and crime-prevention patrols that are the job of the police. The latter, however, even if not altogether agreeable to the police personnel, may be a better solution.

About 95 percent of the stops could be serviced by a competent mechanic patrolling in a vehicle equipped with gas, oil, water, an assortment of tools, a fire extinguisher, and assorted maps. Although the policeman may not be a competent mechanic, he could perform all of the other servicing if his vehicle were properly equipped and if such service did not interfere with his primary mission. This would account for more than 60 percent of all stops requiring assistance. In all of these cases, assistance could be rendered immediately following detection. Since this procedure would take some of the police patrolman's time, more frequent patrols would be indicated to keep up the desired level of law enforcement and crime prevention. The presence of more patrol units would also affect the traffic flow. It has been suggested that service patrol units be given the power of law enforcement; however, the training and experience of the police officer is much superior in this respect to that of a garage mechanic.

The mechanic and service vehicle is still required. However, it must now respond to only 35 percent of all stops requiring assistance, rather than to 95 percent. Hence, the number of service units and trained personnel can be reduced. The service truck is capable of the service only, whereas, the properly outfitted patrol vehicle is capable of patrol and service. This implies better equipment and manpower utilization.

The patrol/service vehicle must be capable of carrying personnel, emergency equipment, and communication equipment. It must be able to get through heavy traffic, and if necessary, to push or pull a stalled vehicle from the driving lanes to the shoulder. A standard American sedan is admirably suited for all of these except for "getting through," for which only the motorcycle appears to be suitable. The motorcycle's drawbacks are its limited equipment-carrying capability and lack of stability on wet pavement, in addition to being far from livable to its driver during inclement weather. Theoretically, it cannot push or pull another vehicle.

The Los Angeles Police Department uses motorcycles on their freeways all year. However, absolute necessity for the motorcycle, as dictated by very dense traffic, is not generally prevalent except during about 3 or 4 hours of

[4] It is speculated that people who use the freeways regularly have not learned to accept automatically the availability of these boxes in an emergency that can occur anywhere along the motorist's daily trip, a small part of which may be on the section of the Harbor Freeway where the boxes are available. Suppose that a commuter of 15 freeway miles uses that section of the Harbor Freeway. Logically, of the emergency stops he might encounter, no more than 1 in 3 are likely to occur on that section. Hence, the afflicted motorist is not likely to think of the boxes as a primary aid to help him out of his difficulties. This is compounded by his awareness of the frequent patrols that he observes during his commuting along the freeways. Therefore, if he should find himself in a predicament, he is more likely to think of, and wait for, the police patrol.

each weekday, and possibly at the beginning and end of a weekend, for a few hours each.

Hence, it appears that not one existing (or commonly used) vehicle will do the complete job. The alternatives are:

1. Choose a car or motorcycle, thereby sacrificing mobility during rush hours, or equipment-carrying capability and "all weather" operation.

2. Have a number of cars and motorcycles patrolling, assigning patrol posts in a manner such that motorcycles patrol primarily areas of the most frequent congestion and during the "rush hours," and cars elsewhere. This may result in occasional situations where the type of patrol at the scene where it is needed is of the "wrong" type, though undoubtedly any patrol is better than none.

3. Devise a special vehicle combining the desired characteristics of both the mobility of the motorcycle and the carrying capacity and stability of a 4-wheeled vehicle. This obviously would have to be a compromise, a very narrow 4-wheeler, or possibly a 3-wheeler similar to those used by urban police departments for parking meter checking/collection. The latter

TABLE 8

CASE 1 SOLUTIONS AND COSTS PER MILE PER YEAR

	SOLUTION			
COST FACTOR	TELEVISION	VISUAL	TRAFFIC PARAMETERS	PATROL
Units/mile				
Cost/mile/year over 10 years	At 1000 to 2500 per unit $ 750	3 stations	2 at 440 $ 88	1/3, at 3000 each 2 years life $ 500
Installation over 10 years	Assume equal cost of equipment 750	NA	Assume 3/4 of equipment 66	NA
Maintenance or operating cost	* 2500	NA	Est. $50/unit 100	90,000 m/veh/year at $0.4/mile 1200
Manpower	1/station 1 station/ 5 m 24 h at 6000	3 for 24 h 15 men/ mile at 6000	NA	2.7 men/mile at 7000 **
Cost	6000	$90,000		18,900
Auxiliary equipment	NA	Telephones 1/station Shelters over 10 years	Data-processing equipment *** at 3000 each, 2/mile over 10 years	Spare vehicles maintenance facilities Comm enter 1/5 veh, 1/20 maintenance and communication at 8000 2 years at 30,000 10 years
Cost		250	600	950
Auxiliary personnel	1/10 tech/mile 1/10 supervision, clerical, etc, at 6000	NA	Center personnel, 1 center/20 m 2 men/center 24 h, 1/2 man/mile at 6000	Maintenance and communication personnel assumed 2 per center 24 h day at 6000
Cost	1200		3000	3000
Remarks	Limited by low visibility, darkness, etc. monitor fatigue	Limited by low visibility	Will likely fail during periods of low densities (late at night)	
Total Cost/mile/year	$11,200	$90,250	$3854	$24,550

* Primarily vidicon replacement, from Lodge Expressway data.
** Based on patrol density as used on Los Angeles freeways
*** Based on cost of "VD" computer-traffic analyzer costing $2000. On-location logic, displays, alarms and ancillary equipment estimate may raise this to $3000.

is a motorcycle with 2 wheels in the back instead of 1 and considerable carrying capacity. The disadvantage of such a vehicle is that it cannot travel safely at high speeds for apprehending law breakers. This is offset by: (1) little high-speed chase activity is necessary or possible on the densely traveled urban expressways, and (2) its maneuverability, ability to carry communication equipment and rudimentary items to aid a stranded motorist, and stability during inclement weather is superior to a motorcycle. Furthermore, they might even be enclosed for the patrol personnel's comfort.

4. Conduct the patrols in a standard, fully equipped passenger vehicle, with each vehicle equipped with a scooter or light motorcycle, which would permit one of the two officers to proceed to the scene. No equipment could be carried on the scooter, except for a limited-range communication system such as a walkie-talkie. The officer's quick presence at the scene would be invaluable toward reducing the magnitude and duration of the jam-up upstream of the incident.

MOTORIST ACTUATED	PASSING MOTORIST: AUTO REPORTING	PASSING MOTORIST: NONE
8/mile 4 on each side 200-600 each $ 480	2/mile 1 on each side at 200-600 $120	NA
Assuming 1/3 cost 160	Assuming 1/3 cost 40	NA
Est $10/unit/year 80	Est $10/unit 20	NA
NA	NA	NA
Receiving and decoding center + installation 1/2 cost at 10,000 over 10 years 1500	Processing and alarm equipment 1/20 m at 2000 over 10 years 10	NA
Assumed same as traffic parameters. The two can be combined in one center 3000	None—Police dispatcher, etc.	NA
Can be telephone, RF, voice, or code		NA
$5220	$190	Free

Cost of Implementation

Table 8 presents some comparative costs of implementing detection in the various ways previously detailed. The costs shown are approximate and based on some assumptions. Specifically, the cost of any equipment and its installation is amortized over 10 years except for patrol cars, which are assumed to have a useful life of 2 years. Where no information on maintenance cost is available, a figure estimated to be high was chosen. In the case of the television cameras, it was learned from the Lodge Expressway that replacement of vidicons constituted the greatest maintenance expense.

Assignment of personnel to monitoring central stations is based on manning on a 24-hour day, 7-day week, 365-day-year basis. The salary levels assumed are those equal to a high-level technician, or low-level engineer; patrol personnel's salaries are assumed to be $7,000 per year. It is realized that this figure is considerably lower in some parts of the country. The patrol density assumed was that used on Los Angeles freeways, which is relatively high. Where a range of costs was found to be possible, such as for TV cameras or call boxes, the highest figure was used in obtaining the total cost.

In all categories, the major cost of the detection implementation is manpower. Detection by passing motorists with no special reporting devices should not be disregarded. On a short facility with toll booths at each end, this can be the solution. Naturally, it would have to be fostered by extensive education of the facility users. A sign just preceding the toll booths directing PLEASE REPORT ANY STOPPED VEHICLES might be sufficient. No single solution applies to all types of urban expressways.

Since patrols will always be available, they should aid in solving the in-lane stoppage problem. Call boxes may aid motorists stopped on the shoulder; therefore, the cost of implementation of the needed detection can be approximated by the sum of the total costs of columns 3, 4, and 5, or about $38,000 per mile per year. If call boxes were omitted, the cost would be about $31,000.

One class of stops requires additional communication: the case of the wreck or mechanical breakdown requiring specialized service or a wrecker. Aid can be summoned by means of call boxes, and the communication systems supplied to patrol vehicles. Hence, only the cost per mile of supplying these specialized services must be determined.

From the stop-type distribution, the patrol vehicles would be able to service 60 percent of all expected stops and special vehicles would be required for 35 percent. If one-third of the patrol's effort is directed toward service, one-third patrol car is assigned per mile, the required number of special purpose vehicles should then be about one-fifth per mile. For 24-hour, 7-day-week,

365-day-year manning, 5 men per vehicle are required, or effectively 1 man per mile per year.

Taking the average cost of the vehicle to be $10,000 and further assuming a vehicle's useful life of 5 years, then the special vehicle cost per mile per year is 10,000 ÷ 5 × ⅕ = $400 per mile per year. The manpower cost must be added: the mechanic's salary of $6,000 to $7,000, plus auxiliary personnel (one maintenance helper for two vehicles), or one-tenth man per mile per year for an additional $600 to $700.

Vehicle operating costs can be expected to average 10 cents per mile. Assuming an annual mileage of 50,000 miles (probably high), this amounts to $5,000. Therefore, the total cost is $400 + $7,000 + $700 + $5,000 = $13,100 per mile per year.

This value is about one-half that of the patrol. The major contributions are manpower and operating costs. Manpower costs cannot be reduced much, and operating costs should be watched carefully; this further supports the choice of the patrol vehicle as a service vehicle as well. Its operating cost and purchase price is less than one-half that of a service truck. It is also much more versatile, particularly if it is a standard American sedan.

The basic elements and their associated costs are patrol effort, ready to service, $25,000; traffic parameter sensing system, $6,000; special service, $13,100; and motorist-actuated devices, $7,000. The total anticipated cost is $51,100 per mile per year.

Inasmuch as the expected number of stops requiring assistance will be 7.8 per mile per day, or 2,847 stops per mile per year, the cost per assist is 51,000 ÷ 2,847 = $18 (approximately).

CASE 2: URBAN BRIDGE OR TUNNEL

Problem Definition

The urban bridge or tunnel has traffic characteristics similar to those of an urban expressway. The elimination of in-lane stops is compounded because most bridges and tunnels have no shoulders; thus, all stops are in-lane stops and must be assisted. The facility is often served by one or more urban expressways. Therefore, the objectives can be stated simply: prevent any stops from occurring and eliminate those that do occur as quickly as possible.

The urban bridge/tunnel stop distribution lacks information stops. Because of the generally short facilities, the motorist is able to ask the toll collectors at the end for information. Table 9 gives a representative stop-type distribution, all of which can be considered as emergency stops. The figures are based on one year's data from the Holland Tunnel in New York. The number of aids per mile required is significantly higher than that for the urban expressway because of the "no-self-help-permitted" rule that prevails in tunnels and on many bridges. The aid-type distribution is given in the last column. More than 97 percent of the aids are of a mechanical, tire trouble, or gas, oil, water nature. Mechanical also includes accidents, in the event of which medical would also be required concurrently.

For the urban expressway, shoulders and a certain amount of self-help on the part of the motorist was assumed. In this case almost no self-help is possible simply because it is difficult to accomplish safely. The ADT levels on such facilities are generally of the same order of magnitude as on urban expressways. The expected number of stops per mile per day is 17.1, all of which must be assisted because all are in-lane stops.

System Implementation

Since the same motorists generally use these facilities during the most critical periods, an educational effort is likely to be successful. The public should be informed that no stops other than truly emergency stops will be tolerated and that heavy fines will be imposed for emergency stops that are the result of driver's negligence. More than 97 percent of the emergency stops result from mechanical, tire, and gasoline problems.

Although short-term services can be performed on some bridges during off-peak hours, in tunnels such as the Holland, Lincoln, and Queens Midtown in New York, this is generally not done. Stopped vehicles are usually towed out of the tunnel without concern for the reason for the stop.

Since a bridge or tunnel is usually short, a few patrol units (and men) could patrol with great frequency. How-

TABLE 9

STOP AND AID DISTRIBUTIONS

STOP TYPE	PROBABLE OCCURRING	PROBABLE AID REQUIRED	PRODUCT	TIMES EXPECTED STOPS/MILE REQUIRING AID
Rest	0	—	—	× 17.1 = —
Nonemergency	0	0	—	= —
Tires	0.218	1	0.218	= 3.73
Information	0	—	—	= —
Medical [a]	0.016	1	0.016	= 0.27
Fire	0.01	1	0.010	= 0.17
Mechanical [a]	0.54	1	0.540	= 9.24
Gas, oil, water	0.216	1	0.216	= 3.71

[a] No detailed breakdown is available on these categories; medical is estimated on the basis of the percentage of total number of stops, and the fact that it would be a higher percentage of emergency stops only.

ever, because of its length the facility could be observed in other ways so that a patrol vehicle would be required only when an incident occurred.

The patrol vehicle should be equipped and staffed by personnel able to render the aid needed. From the expected stop types, the requirement for quick service, and records from existing facilities showing that more than 70 percent of their activity is assistance rather than law enforcement [5] it is concluded that service constitutes the larger part of the problem.

This is further compounded because little opportunity exists for flagrant traffic violations and if traffic is monitored in other ways, it may be possible to apprehend violators at the toll barriers. Nonetheless, most authorities administering such facilities will presumably want to have some patrol capability for off-peak hours. However, readiness of specialized service vehicles and their deployment in a manner that permits them to reach the scene of an incident are mandatory. This becomes crucial for tunnels and bridges where an incident quickly "plugs up" the facility upstream so that aid vehicles can reach the scene only by proceeding "the wrong way" from the downstream end of the facility, or "the right way" if there are provisions for the aid vehicle to cross over at regular intervals. Another possible solution is the provision of a single "emergency lane" in the middle separating the opposing streams of traffic and restricted to emergency vehicles and disabled vehicles only.

Other possibilities exist. One is the provision of islands or bays spaced at regular intervals into which a disabled vehicle could pull or be pushed to await help without constricting traffic. Equipped with emergency telephones, these bays would offer to the stranded motorist comparative safety and the ability to call for help.

Another possibility is a special vehicle capable of traversing the length of the facility on a special track or rails. This vehicle could be made narrow and afford protection to its personnel. It should be fully equipped to handle most emergencies likely to be encountered on the facility. It should have the capability of pulling or pushing a stalled vehicle toward either end of the facility. A vehicle of this nature would arrive quickly, unimpeded by traffic, and quickly remove the stopped vehicle from the facility or to the end where it could be serviced. This vehicle should be sufficiently enclosed and comfortable to permit regular patrols of the facility without interfering with traffic.

A vehicle somewhat related but of much more limited scope is being used in the Holland Tunnel in New York City, and more advanced versions are planned. However, their purpose is only to carry police personnel to and from posts along the tunnel and to investigate incidents when discovered by traffic sensing and TV-viewing, and not to render direct aid.

The number of such vehicles sufficient to survey the complete facility depends on length, alignment, number of lanes, etc. If these vehicles had the desirable capabilities, the facility would not require additional vehicles. If they were electrically powered, actual running costs would be relatively low, though installation costs would exceed those for a self-powered vehicle.

In summary, the patrol vehicle could also be the aid vehicle in most of the usual cases. The vehicle need not be particularly fast, but must be able to reach all parts of the facility. Its operating costs should also be kept as low as possible; this could be achieved with an electrically powered vehicle.

It is further suggested that traffic parameter sensing be used as the basic stopped-vehicle detection medium, and that the alarm be displayed at the offices of the facility's administrative authority and automatically transmitted to (or displayed concurrently in) the vehicles on the facility.

Thus, perhaps one standby service vehicle (heavy wreckers) and one or two standard patrol cars for inspection, administrative, and standby use would be sufficient for a typical facility. Of course, the number would depend on the size of the facility, accessibility, etc.

There are additional ways in which the motorist can communicate his need for help. The commonly used telephone call boxes are not practical on a facility without shoulders or islands because of the dangers involved. RF equipment is generally handicapped by the features of the facility types considered. A special light might be applicable at much more moderate cost to the user, but still at considerable cost to the facility. The cheapest solution is to rely on visual signals by the driver. The receptor must, of course, be provided by the facility in the form of observers stationed along the facility, television, or patrol. Finally, the passing motorist (if he can pass) undoubtedly will and should report the incident.

Since traffic on these facilities is generally the high ADT/low ATL class and since the facility comprises but a short portion of each trip (on the average), it is not likely that even a motorist residing in the area would be interested in investing in equipment usable only on that facility for emergency stops.

Costs

The facilities are usually fairly short; thus, in some cases, the per-mile cost is apparently quite high. In terms of central facilities such as monitoring centers, there is one complete center per facility, regardless of whether it is one-half mile or three miles long. The cost and manning of the center constitutes a considerable portion of the total cost. Therefore, an attempt to determine an approximate cost of implementation is made on the basis of a facility 2 miles long. Also, several factors can change the resulting values. For example, the alignment of tunnels determines the number of observers necessary to observe its full length. In the case of the urban expressway, the majority of the total cost is caused by the manpower required.

Columns 1, 2, or 3 in Table 10 are required for an adequate solution to the problem. Column 3 is superior in price, requires a minimum of the human element, and is more reliable though less versatile. Most importantly though, it quickly indicates in-lane stops. For a distinct

[5] Mississippi River Bridge: about 73 percent assists of various types. This facility includes the expressway-type approaches to the bridge for a total length in excess of the usual length for such facilities.

communications system, reliance can be solely on Column 7 and on Column 6 in places where it is safe to pull out of the main-line traffic. Column 6 can be dispensed with entirely, relying on speedy detection and arrival of a service vehicle instead. For the facility types considered, this is believed to be the most feasible solution. Finally, a choice between the service/patrol vehicles remains. Assuming the same manning for the two types considered, costs are comparable over a 10-year amortization. As in other systems, personnel comprises the major part of the costs. If the equipment costs alone are considered and if the special-purpose equipment is amortized over 20 years, the costs are almost identical. More important, though, on one-way, no-shoulder facilities it may be difficult for the conventional vehicle to do its job quickly. The downstream portion of the facility must be cleared first, then the vehicle would have to proceed upstream to the incident. All this time the upstream portion is at a standstill. The special-purpose vehicle described is not restricted and is therefore recommended as the preferred solution.

The total costs for the assumed 2-mile facility, with no shoulders or safety islands, are estimated to be the sum of the costs of implementing Columns 3 and 4. Column 7, with some reporting points for the passing motorist, may also be added at a small cost, amounting to about $200 per mile per year (over 10 years). Thus, the total cost would be about $115,000 per year (for the 2-mile facility). This is only slightly higher than the comparable per-mile cost for the urban expressway. In terms of incidents, the number expected for the 2-mile facility is 34.2, all of which have been stated to be stops that must be serviced. Hence, the cost per assist is 115,000 ÷ 34.2 × 365, or about $9.20.

This cost is only one-half of that of the urban expressway, because all stops are assisted; since there are more assists, the cost per assist is lower.

There might be a hybrid facility composed of 2 miles of bridge or tunnel and 3 miles of urban expressway (approaches, for example). Understandably, some overlapping of systems is possible from one section of the facility to the other. Thus, one center for all of the traffic

TABLE 10

CASE 2 SOLUTIONS AND COSTS PER MILE PER YEAR

COST FACTOR	SOLUTIONS: TELEVISION (1)	VISUAL (2)	TRAFFIC PARAMETERS (3)	PATROL-SPECIAL VEHICLES (4)
Units/mile or 2 mile facility cost	per mile 3-5 at 1000-2500 / 2 mile facility 6-10	3 stations/mile minimum	3/mile 6 for 2 mile facility at 300 each over 10 years	2/mile 4 for 2 mile facility at 25,000
	$1250 / $ 2500		$ 180	$ 10,000
Installation (10 years)	Assume equal to cost of eq—or lower	NA	Assume < cost of equipment over 10 years	Installation assumed included above
	1250 / 2500		150	
Maintenance per mile	Primarily vidicon replacement	NA	Est 50/unit	Est 250 per unit
	4000 / 8000		For 2 m 300	1000
Manpower men/facility	1 man for 24 hour monitoring ∴ 5 men for facility at 6000	3 men/mile 24 hours at 6000 ∴ 30 men for 2 mile fac	NA	1/vehicle 24 hours ∴ 20 men at 6000
Cost	30,000	180,000		120,000
Auxiliary equipment	NA	Simple comm eq est 250 for 3 stations	Data processing equipment for 5 pairs of detectors over 10 yrs	Backup vehicles over 10 years
		500	1500	1800
Auxiliary personnel	1 skilled tech for facility at 8000	NA	1 skilled tech for facility	1/facility 24 h at 6000
	8000		8000	30,000
For 2 mile facility Cost total per year	51,000	180,500	10,130	162,800

parameter sensors would suffice. The conventional vehicles used for patrol/service on the expressway portion could back up the special-purpose vehicles in the bridge/tunnel section; therefore,

Special-purpose vehicles (for 2 miles) manned around the clock	$103,000
Traffic parameter sensing (over 5 miles total)	30,000
Conventional vehicles manned around the clock	75,000
Motorist-actuated devices (over 3 miles)	21,000
Passing motorist reporting-automated	2,000
Total for facility	$231,000
Expected number of assists in 2-mile tunnel sector	12,483
Expected number of assists in 3-mile expressway	8,541
Total expected number of assists	21,024

Therefore, the cost per assist for the facility is 231,000 ÷ 21,024 = $11 (approximately).

PATROL-CONVERT. VEHICLES (5)	MOTORIST ACT. DEVICES (6)	PASSING MOTORIST (7)
2 mile 4 for facility at 3000, life 2 years $ 6000	4/mile 2 each side—on islands only, at 200-600 (10 years) for 2 m $ 480	Free
NA	Assume 1/3 cost 160	Free
Operating cost at $0.4 mile, 80,000 miles/veh/yr 12,800	Assume 10 per unit 80	Free
1/vehicle 24 hours ∴ 20 men at 6000 120,000	NA	Free
NA	Receiving-decoding facility (10 years) 1000	Free
1/facility 24 h at 6000 30,000	1/facility 24 h at 6000 30,000	Free
168,800	31,720	Free

CASE 3: LIMITED-ACCESS RURAL HIGHWAY

Problem Definition

One distinguishing feature of most toll facilities is the apparent desire on the part of the administering authorities to render services over and above that of keeping the road clear. Part of this aspect manifests itself in the generally available and conveniently spaced rest areas. In addition, the authorities apparently seek to secure the good will and continued patronage of the facility (and hence continued revenue) by aiding motorists who find themselves in distress.

The amount of aid offered varies between different facilities. One might look for a relationship between the length of the facility, its geographical location, or some other factor, to the amount of aid offered. However, examining the prevailing practices on some of the facilities in existence today, the amount of aid seems to vary inversely with the "urbanization" of the area served by the facility. On a facility that predominantly traverses rural areas, the services offered are extensive. All patrol vehicles on a major northeastern toll facility, for example, are supplied with gasoline, oil, water, first-aid equipment, fire extinguishers, and communication equipment.

Limited amounts of supplies such as are needed are given to the motorist free of charge so that he can reach the next service area; help in changing a tire is frequently offered. These facts substantiate one of the basic objectives: to offer service.

Another objective is to keep traffic moving smoothly. On rural segments of toll facilities, in-lane stops are dangerous to the motorist concerned; unless very high traffic densities are prevalent, it has a smaller effect on the traffic stream. Shoulder stops, on the other hand, have little effect on the traffic; hence, any measures taken concerning these stops are taken for the benefit of the stopped motorists themselves. A further task of the administering authority is to keep the road properly signed and free of debris, dropped objects, animals, and rocks.

For the predominantly rural toll highways (turnpikes, throughways, etc.), the emphasis is on providing for the needs of each driver on the facility rather than the traffic stream as a whole. Hence, the objectives could be stated as "to provide each motorist using the facility with any services that he might require for a safe and enjoyable passage on the facility."

The rural toll highway will generally have somewhat lower ADT's, but considerably longer ATL's than the urban expressway. For an assumed ADT of about 20,000 and an ATL of 60 miles, the expected number of stops per mile per day will be about 2. (Each facility must use ADT and ATL numbers applicable to it alone, to determine the expected number of stops.) Table 11 gives the percentage distribution of stops, the percentage of self-help expected, the number of stops of each type, and hence, the number by type of assists required on a per-mile per-day basis.

The corresponding value for the urban expressway was 7.81 aids per mile per day required. The last column shows the distribution of aid types (per 100) that can be

expected. It is similar to that on the urban expressway; the small difference is due to the absence of rest stops on the latter.

Implementation

This type of facility must be implemented differently from the facilities previously described since it has different objectves and stop-type distribution.

The average densities are sufficiently low so that build-up of density upstream of an incident and the concurrent decrease downstream may not be sufficient to give a positive indication of an in-lane stop. One reason is the general availability of at least two or more lanes. Another reason is the availability of conveniently wide shoulders, where statistics show that about 95 percent of the stops will eventually occur.

There is no operational requirement calling for immediate detection. There are several reasons for this: (a) the effect on the remainder of traffic is considerably less significant than that on the facility types considered thus far; (b) the distances involved are considerably larger, imposing a greater (average) time penalty in moving a service vehicle to the scene of an incident—hence detection in seconds will do little to detract from the total waiting time of many minutes; (c) the cost of such instrumentation for the total facility, assuming it could detect vehicles, would be high, particularly if viewed in terms of per incident.

Patrols, motorist-actuated devices, and passing-motorist reporting, are the basic methods for detecting stopped vehicles.

At the outset, patrols comprise a valuable detection medium. What should the patrol frequency be to insure sufficiently quick detection? For a probability of detection of 0.8 for stops with a mode of 4 minutes, a patrol time constant of about 3 minutes is required (Fig. 20). For the same probability of detection of 0.8 for stops with a mode at 10 minutes, the patrol time constant is about 7 minutes. Most turnpikes have center dividers that permit patrol vehicles to cross if necessary. It can be assumed that the patrol will be aware of a stopped vehicle both in its direction of travel and in the opposite direction. Hence, assuming an average patrol speed of about 40 mph in the former case, one patrol vehicle must be assigned per 2 miles; in the latter case, one vehicle per 5 miles.

Since the short-duration stop types constitute largely stops of the variety that do not absolutely require aid, the stops with the mode at 10 minutes are of more concern. With the patrol average at 7 minutes, the probability of detection of the short-term stops would be just under 0.6. From data taken on the Lodge Expressway, the short-term stops comprise about 0.7 of all the stops; of these, about 0.6 require assistance. If it is assumed that all long-term stops require assistance and the probabilities of detection are 0.6 and 0.8 for the two categories, the probability of detecting a stop requiring assistance is $0.7 \times 0.6 \times 0.6 + 0.3 \times 1 \times 0.8 = 0.5$ (approximately).

It is implied that all of the stops that are detected by the police patrol will not require assistance, only about one-half will. However, this does not mean that only 50 percent of those requiring assistance will be detected, these vehicles will wait until detected—and thus do not fit into the stop distribution as defined by either of the curves of Figure 21. The overall percentage of stops detected is of more interest. It is simply $0.7 \times 0.6 + 0.3 \times 0.8 = 0.66$. Of all stops, about two out of three would be detected.

The patrol vehicle must be able to perform much of the servicing, but for somewhat different reasons from those on the more heavily traveled urban facilities. The average stopped vehicle must wait 7 minutes to be detected by a patrol. If that patrol can do nothing except call for a service vehicle to come to the scene, a further wait becomes inevitable. The duration of this wait is closely related to the number and deployment of service vehicles along the facility. If each vehicle is assigned to a sector of the facility, of average length of x miles, then the number of service vehicles that the facility must furnish is its length divided by x; the average time for a service vehicle to reach the scene of an incident is the time it takes that vehicle to travel one-half its sector. Of course, such vehicles could well patrol their respective sectors, which would certainly increase the probability of detection of stops. More important, the waiting

TABLE 11

CASE 3 STOP AND AID DISTRIBUTIONS

STOP TYPE	PROBABILITY OF OCCURRENCE	PROBABILITY OF AID REQUIRED	PRODUCT	TIMES EXPECTED NO.	STOPS/MILE	REQUIRED AID
Rest	0.12	0	0	$\times 2 =$	0	0
Nonemergency	0.30	0.1	0.03	$\times 2 =$	0.06	7.1
Tires	0.15	0.4	0.06	$\times 2 =$	0.12	14.3
Information	0.16	0.5	0.08	$\times 2 =$	0.16	19.0
Medical	0.01	0.7	0.007	$\times 2 =$	0.014	1.7
Fire	0.01	0.9	0.009	$\times 2 =$	0.018	2.1
Mechanical	0.15	0.9	0.135	$\times 2 =$	0.27	32.1
Gas, oil, water	0.10	1.0	0.10	$\times 2 =$	0.20	23.8
Total aids required per mile per day					0.842	

time of the motorists detected by the service vehicles rather than police patrols would be limited to that of detection; hence, on the basis of the patrol figures used, it would average under 7 minutes.

This points out the benefit of the patrolling service vehicle. Since "service" to the motorist is the key word on the type of facility under consideration, it appears that the patrolling service vehicle is the best means of offering that service.

Traffic control, law enforcement, and crime prevention are also necessary services that cannot be performed well by vehicles that are specifically service vehicles, manned by personnel untrained in police work.

Referring to the expected distribution of stop types requiring aid, 52 percent of the stops could be serviced by the patrolmen with no more special equipment than a small supply of gas, oil, water, fire extinguisher, first-aid kit, and a supply of maps and other touring information.

Fire extinguishers and first-aid kits are already carried by police patrol cars. The objection that carrying gasoline is a potential danger can be overcome by the simple expedient of a small siphon-type (or mechanical) pump that could transfer a small quantity of gasoline from the patrol vehicle's tank to that of the disabled vehicle. A few cans of oil, several containers of water, touring information, some of which is usually printed by the facility, and maps, such as those published by gasoline companies, would complete the special equipment necessary to allow that patrol vehicle to render more than 50 percent of all the services required on the facility. About 46 percent of the assists consisting of mechanical and tire trouble require a service vehicle capable of towing the disabled vehicle. These vehicles could be equipped with a winch, jack, battery, jumper cables, spare sealed-beams and light bulbs, brake fluid, fan-generator belts in the most popular sizes, etc.; most important, they could be manned by a skilled serviceman, equipped with tools sufficient to perform emergency repairs.

But since both the patrol and service vehicles will patrol their respective sectors, the number of miles per patrol sector can now be increased about two-fold and still retain an average of about 7 minutes to detect.

Of course, this may not be as simple as it appears. Thus, the police patrol vehicle's speed of covering its sector will likely be higher and it can be assigned a longer sector, overlapping with other sectors. Furthermore, phasing (in time) the patrol passes between the police and service vehicles would likely be cumbersome, though not unachievable.

Since the service vehicle would also carry supplies of gasoline, oil, and water, it could service all stops, whereas, the patrol vehicle could service a little more than half those detected. Hence, if the time of passage for the police vehicle is 14 minutes, the probability that it will detect a stop is 0.38 for the short-term stops and 0.55 for the longer-term stops. The probability that it will detect all stops is 0.43. This is a joint probability of detection. The probability of detection of a short-term stop by either the police patrol or the service vehicle (or both) is $0.38 + 0.38 - (0.38)^2 = 0.616$. Likewise, for the long-term stops it is $0.55 + 0.55 - (0.55)^2 = 0.80$. Therefore, for all stops, the probability of detection will be $0.80 \times 0.3 + 0.616 \times 0.7 = 0.67$.

"Probability of detection" should be more correctly stated as "one minus the probability of no detection," or "the probability that the stop will not be missed." The true probability of detection for a stop involves a variable (time). Thus, what is the probability of detection in t minutes? The answer is somewhat more complex and is stated in Eqs. A-11 and A-12 (Appendix A). Solutions to these equations for specific values of t represent the probabilities of detection as seen by the motorist and those calculated above, as seen by the patrols.

Obviously, as t becomes large, any stop will be detected, at any patrol frequency greater than zero. This is not a practical solution, however. Conversely, the probability of detection as t approaches zero approaches zero.

A number of expected stops will not be detected sufficiently quickly; the measure of sufficiency here is the urgency of the need for aid and the individual motorist's desires. Since it is important to satisfy the patrons of the toll facility, an additional means to summon help is desirable such as roadside devices or equipment in the motorists' vehicles. Roadside devices could be voice-grade telephones or call boxes, wire transmission, or wireless transmission; the latter is less expensive over long distances. Power for these devices could be obtained from nearby power lines, from solar-cell batteries (in favorable climates) or motorist-generated via a (magneto) crank. Vehicle equipment may be the motorist's own or the facility's equipment on loan to the motorist for the duration of his transit of the facility. It may consist of a complete transceiver, an emergency transmitter only, or simply an emergency beacon; it would be the responsibility of the facility to devise and implement a suitable receiving network.

With good visibility, it is possible for fixed-wing aircraft to patrol long stretches of highway quickly; however, nighttime detection would be considerably more difficult. However, the motorist might be willing to invest a small amount of money in flares or a high-visibility cloth or sign that he might display on the roof of his vehicle. This would allow the aircraft to fly higher and survey a larger sector of highway at one time. Such emergency packets could be issued (free of charge) to the motorist as he enters the facility, and returned when he leaves.

Finally, there is the passing motorist. It has been found in the past that motorists generally will report having passed a stopped vehicle, particularly if the latter is in obvious need of help, or if a sign to that effect is displayed. On facilities where there are toll barriers, this presents no problem, but on facilities with toll booths at exits off the main road, speedy reporting at the very next exit may not be convenient. Hence, a reporting scheme similar to those for urban facilities may be necessary. Suitable sensors located on the main line lanes near each exit would permit the passing motorist to report without having to even slow down.

Cost of Implementation

As with other facilities, it must be pointed out that each has its own problems and optimum solutions based on the objectives adopted. For example, to estimate the costs of implementation, some salient characteristics of the road must be assumed. Thus, average distance between exits, for example, is assumed to be 10 miles. Necessity for special structures to house the receivers/decoders for the motorist-actuated devices may be necessary. A structure worth $20,000 is assumed, though the equipment could be installed in a police substation or an annex built to an existing building. As before, amortization of equipment is assumed over 10 years.

In Table 12, the last column is pertinent, but only conditionally. If the radio equipment, beacon, or other communication or alarm equipment is loaned to the motorist merely for his passage of the facility, then the cost of the investment must be added to the overall implementation. If these units are motorist purchased, then the cost is limited to the facility's receiving/monitoring centers, substantially as for motorist-actuated (RF) devices.

The basic reasoning in choosing the components must

TABLE 12

CASE 3 SOLUTIONS AND COSTS PER MILE PER YEAR

	SOLUTIONS					
			MOTORIST-ACTUATED DEVICES			
				CALL BOXES		
COST FACTOR	POLICE PATROL	SERVICE PATROL	VOICE GRADE TELEPHONE	WIRE	RF	SELF-GENER.
Number of units/mile	1/10	1/10	4/mile—2 on each side			
Equipment cost/mile/year over 10 yrs or life of eq if 10 years	4000 ea life 1 yr	8000 ea life 1 yr	200-600 ea over 10 yrs	300 ea over 10 yrs	500 ea over 10 yrs	400 ea over 10 yrs
	$ 400	$ 800	$ 160	$ 120	$ 200	$ 160
Installation cost/mile/over 10 yrs	NA		2 × cost eq wire costs	2 × cos eq wire costs	1/3 cost of equip	1/3 cost of equip
			320	240	70	55
Maintenance/mile/year	Assume 100,000 miles at $0.6/m	at $0.12/m	Est $40/unit/ year incl light	Est $20/ year	Est $50/ year	Est $50/ year
	600	1200	160	80	200	200
Manpower cost/mile/year	1 man/vehicle 24 hours a day 1/2 at 6000		NA			
		3000				
Auxiliary equipment (if any)/mile/ year	1/50 vehicles—spares supervision, etc.		Center Receiving Emergency Calls 1/50 miles at 10,000		1/25 miles (range limitation) at 5000	
Cost	40	80		20		20
Auxiliary personnel	Maint. Administration etc. 1/4 men at 6000		2 operators 1 tech/50 m at 6000	1 monitor + 1 maint tech/50 m at 6000 24 hours/day		
Cost		1500	1800	1200		2400
Other	NA		Structures at 20,000 over 10 years			
				40		80
Total cost/mile/year	$5540	$6580	$2500	$1700	$2970	$2915
Motorist investment/car/year	—	—	—	—	—	—

not depend on cost alone. The following elements are necessary, and a facility cannot operate without them:

1. There will be police patrols.

2. Police patrols cannot perform all required service; hence, service vehicles will be required.

3. All additional services (detection or communications) at best improve the overall response of the total system; that is, they contribute to quicker service and therefore foster patron confidence, and presumably continued patronage.

The ultimate choice for any particular facility must, of course, be made by the facility's administration. Thus, to get an idea of the approximate cost of implementation, several combinations (all of which will contain columns 1 and 2) are considered.

Combination A—Columns 1, 2, 4, and 8 seem to comprise a complete system, relying on servicing patrols, callboxes, and passing motorist reports. The cost of implementation adds to $13,845 per mile per year.

Combination B—Substituting column 3 for column 4 in combination A, gives a slightly improved system, be-

	PASSING MOTORIST		VEHICLE EQUIPMENTS		
FIXED-WING AIRCRAFT PATROLS	WITH AUTO REPORTING	WITHOUT	RADIO/ TELEPHONE	LOW-POWER BEACON	FACILITY-ISSUED LOW-POWER BEACON
1/50	At ea exit assume 1 every 10 miles	NA	1/vehicle, motorist-owned and paid for		Assume veh on facility 2 h ave ADT 20,000 in 2 h 1660. For peaks, spares, assume 5000 units
20,000 ea life 5 yrs $ 80	1000 for all equipment, wire, alarm, etc. $10	NA	200-1000 per unit over 5 yrs $ 200	20 (est) over 3 yrs $ 7	If mass produced assume cost of $5/unit over 10 years $2500
NA	Assume equal to cost of eq 10	NA	Inst cost $100 20	None or negligible	NA
Assuming 10-12 hour operation 800	Assume 1/2 cost of eq 5	NA	Est $20/year 20	None—3 yr replacement	None—assume replacement of 10 percent 250
3 pilots/AC at 9000 540	NA	NA	NA	NA	NA
Back-up A/C sp patrols 1/50 m + oph 1/2 reg A/C 480	NA	NA	Rcvg sta 1/25 miles at 15,000 60	Rcvg stations along road with relays, coding, etc. As in RF call box with rcvr added. 1 per mile cost + inst + maint + center (1/25 miles)	160
2 pilots/A/C 5 mech etc./2 A/C at 8000 1100	NA	NA	Same as RF call box receiving centers		2400
Airstrip hangars, etc. 1/100 m at 50,000 50	NA	NA	Same as RF call box receiving centers		80
$3050 —	$25 —	Free —	$2540 240	$2640 7	$5390 —

cause the distressed motorist can ask for information and/or special services such as medical. The cost increases slightly to $14,685 per mile per year.

Combination C—Instead of motorist-actuated devices, the authority chose to invest in small "SOS" beacons and the associated receiver/transmitters, thus dispensing with motorist reporting. The total cost to the facility would then be the sum of columns 1, 2, and 12, or $17,510 per mile per year.

Combination D—A turnpike is assumed with clear weather, long stretches between exits, no convenient way to install wire call-boxes, long distances that prohibit the use of RF devices, and fairly frequent monitoring stations. It might be desirable to supplement the ground patrol's detection function with aircraft patrols. The sum of implementation will then be approximately the sum of columns 1, 2, and 7, or $15,176 per mile per year. The preceding modes of implementation could be carried further. Refinements can be introduced in terms of different patrol constants, resulting in different probabilities of detection, or all motorist's cars being equipped with a simple beacon device, perhaps as a factory-installed item. The latter may be worth consideration as to its cost of implementation.

Combination E—The sums of columns 1 and 2 and the lower portion of 11, gives $14,760 per mile per year.

As in the previous cases, these implementations can be examined in terms of the cost per assist. Since the expected number of assists was found to be 0.842 per mile per day, the expected number of assists per mile per year is about 307. Hence, for the above implementations, the costs run to approximately:

Combination A—patrols, call-boxes, motorist-reporting	$45 per assist
Combination B—patrols, telephones, motorist-reporting	$48 per assist
Combination C—patrols, facility-owned beacons	$57 per assist
Combination D—patrols, aircraft	$49 per assist
Combination E—patrols, motorist-owned beacons	$48 per assist

These figures are noticeably higher than those for the urban facilities, and the rapidity with which service is rendered is inferior. The problems are different and an attempt to equate the service would increase the costs greatly.

CASES 4, 5, AND 6

Problem Definition

In cases 4, 5, and 6, the responsible agency must be determined. A highway traversing a state frequently changes the agency responsible for maintenance and law enforcement. This change in authority places upon the motorist the burden of determining the proper authority to notify.

Cases 4, 5, and 6 differ substantially in the degree to which the road is under a unified jurisdiction. Interstate highways generally have numerous controlling agencies. In their physical characteristics they frequently resemble turnpikes and rural expressways; therefore, their implementation will closely resemble that of the turnpikes and rural expressways. This section deals primarily with these roads where they can be handled as an area of a network of roads.

Referring to the stop-type distribution for rural roads, a considerable percentage of such stops are classified as "leisure" stops. As long as the vehicle is on the shoulder, or otherwise out of the driving lanes, there is no need for detection or servicing of these vehicles.

Clearly, without the motorists' cooperation, no automatic stopped-vehicle detector, no matter how sophisticated, can distinguish between motorists in distress and those stopping of their own choice. Since the detector cannot read the driver's mind, the driver himself will have to cooperate and thus become part of the system; this is essential to avoid a high "false alarm rate" of a nondriver cooperative system.

Therefore, the objectives of the system are to detect stops in need of assistance on or off driving lanes (with or without the driver's cooperation) and to insure that needed service is supplied within a reasonable time period; that is, a time period commensurate with the urgency of the need for aid.

Who is to determine the degree of urgency? A desperate motorist can panic and completely overestimate the seriousness of his affliction; yet, he is the only one who really knows whether he needs help; hence, reliance must be on him.

From Figure 26, for ADT's of less than 10,000 and ATL's ranging from 10 to 100 miles, the expected number of stops is between 1 and 2 per mile per day. From Figure 17, the motivation factor (the ratio of emergency stops to all stops) for this type of road will range from a high of 0.75 to a low of about 0.2. To relate the numbers more closely to the three cases under consideration, assume an ADT of 10,000 and an ATL of 60 for case 4 ($m = 0.75$); an ADT of 8,000 and an ATL of 30 for case 5 ($m = 0.6$); and an ADT of 3,000 and an ATL of 50 for case 6 ($m = 0.2$). The expected numbers of stops per mile per day will be 1 (case 4), 1 (case 5) and an estimated 0.5 (case 6). Of these, however, only 0.75 (case 4); 0.6 (case 5), and 0.1 (case 6) will potentially require aid. With a stop-type distribution substantially such as that for the cross-country turnpike,[6] the expected number of assists per mile per day will be 0.64 for case 4, 0.51 for case 5, and 0.08 for case 6.

This illustrates part of the reason for lumped treatment of the 3 cases. Any road fitting anywhere within these three cases is likely to have ADT's slightly different from those used for illustrative purposes, and hence, slightly different motivation factors and expected number of required assists. However, the expected number of assists per mile per day on an urban expressway was two orders of magnitude larger than that of case 6.

Implementation

As an example, a network of roads of the case 5 and 6 type covering an area of about 50 by 50 miles (2,500 sq mi) is assumed. NS and EW roads are spaced an average

[6] Differences of several percentage points between stop categories will not materially alter the types of service needed, or their approximate relative frequency of occurrence.

of 5 miles apart, giving the network about 1,000 miles of road. If emergency telephones were installed about every quarter mile (as suggested for other facilities) the cost per mile per year would be $2,549. The cost of the telephone network for a case 5 road would be about $14 per call for assist; for a case 6 road it would be a staggering $87 per call for assist. The average for the network would be over $50 per call. The total cost for the network would be more than $2½ million per year, assuming 10 year equipment amortization. These prices do not include the cost of the service, which would probably cost more than twice the price of the telephone network.

This illustrates that conventional techniques of distressed-motorist detection cannot be applied without running into unrealistic costs; therefore we must look for different avenues of approach.

A basic difference in this case is that driver participation is almost a necessity; another is that motorists using these roads must make some investment. It is true, however, that the cost of the additional equipment may be hidden in the price of the vehicle if and when such devices become common.

Various methods of detection in sparsely populated areas have been discussed. Those that could be implemented immediately rely heavily on other motorists' humanitarian feelings. Almost without exception, they demand some action on the part of the driver to initiate action.

To increase the effectiveness of a system in which the casual passerby is a vital part, a widespread educational effort is necessary. The public must be made aware of the means of transmitting a distress signal and given the opportunity to report the observation quickly and conveniently. A step in this direction is one easily remembered telephone number: for example, HE 5-7xxx, which can be dialed H-E-L-P plus any other three digits, similar to California's current ZEnith 1-2000, which is statewide. (One cannot dial ZEnith 1-2000 directly since there is no Z on the dial; one must call Operator and ask for the ZEnith number.) The California educational campaign through the usual media, plus distribution of leaflets by the California Highway Patrol, took some 7 years before the public accepted it; thus, overnight success cannot be expected.

In built-up areas (case 4, and in lesser amounts, cases 5 and 6) the distressed motorist can walk to the nearest house or store and ask permission to use the telephone or that the homeowner or businessman place the call for him. Again, if this could be accomplished quickly and conveniently, rather than through a series of false starts, the owner of the telephone would be more certain to cooperate. Calls to that number should be toll-free so that a motorist or helpful citizen should not be penalized for a lack of dimes.

This method will work where a telephone is available or within easy walking distance; however, a greater percentage of the case 5, and most of case 6 type roads are quite rural. If the traffic level is sufficiently high and if all motorists can be relied on to stop and inquire, then passing motorist detection might work, but not until the educational effort has begun to show results.

How then, short of being seen by passersby or residents directly, can a motorist in need of help communicate that need? A wide variety of ways were discussed previously; basically, they range from visual means (balloons, flares, smoke, signs) to RF transmission. The information, to have an effect, must be received. The signs must be sighted or the signals intercepted by someone ready to render aid directly, or by "any citizen," who in turn is educated to relay the message.

It is a matter of conjecture and may warrant a study by competent human behavioral scientists how much reliance can be placed on humanitarian ways of the people inhabiting rural regions. If no reliance can be placed on them, this places the burden of implementing an adequate detection/communications system in cost, maintenance and operation on the state (through taxation or assessments levied upon all of the people of the state or upon the motorists only). If, on the other hand, considerable reliance can be placed on a citizen to react to the plight of another, then implementation of the detection system may become feasible, at reasonable cost to the state and possibly some limited cost to the user.

The state police has as its primary function law enforcement and crime prevention on the state's highways. The frequency of patrols is not generally sufficient to permit them to be the only detection medium, particularly on case 5 and 6 roads. However, patrols are equipped with communication equipment and in contact with their base of operations as well as each other (if terrain permits).

On the facilities considered thus far, service vehicles were assumed to be owned and operated by the cognizant authorities. Under such an arrangement, uniformity of services offered could probably not be achieved. Use of service units might be relatively low in view of the expected low stop rate.

In all cases, the cost per assist would be high because of the low expected stop rate per mile per day.

A working arrangement does exist, however, on some toll facilities by which privately owned and operated vehicles perform services on the facility as requested. In these cases, motorists are generally charged fees in accordance with a fixed schedule. Where the motorist is aware of the rates for services, and if the rates are relatively high, he is likely to try to obtain service in other ways or aid himself.

Unquestionably, there are areas with too many service stations just as there are many square miles with none. The chief problem in the latter case is time to service. A partial solution might be the stationing of service vehicles in areas where the distance between accredited service stations is greater than some predetermined number of miles, a nominal hourly fee being paid, with the services paid for at a regular rate. These vehicles (and men) would come from the nearest service station and be responsible for services on a limited network of otherwise unserviced roads, rather than a single stretch of one road. It is assumed that the service vehicles would be equipped with communication gear.

TABLE 13

CASES 4, 5, AND 6 SOLUTIONS AND COSTS PER MILE PER YEAR

	SOLUTIONS						
	DETECTION AND COMMUNICATION						
	ALL CITIZENS (INCLUDING PASSING MOTORIST)			STATE/AGENCY			
				VEHICULAR PATROL EFFORT			
COST FACTOR	PASSING MOTORIST VISUAL	SIGNAL SIGHTING VISUAL	SIGNAL RECEPTION AURAL	VISUAL	SIGNAL	PATROL A/C OR HELICOPTER SIGNAL	RECEIVER NETWORK
Equipment cost/ yr over 10 yr	NA	Motorist supplied "Attention getter" p.u. $10	Lim range beacon in BC band p.u. $10	Patrol vehicles + communication equipment at $3000, life 2 yr 25 veh $37,500	15 veh $22,500	Helicopter at $200,000 5 heli $100,000	1 rcvr/500 m² at 10,000 $5,000
Installation over 10 yr	NA	NA	Est = equip cost p.u. 10	NA	Special signal receiving equipment at $500 including installation 750	250	Assumed 1/2 of cost 2,500
Maintenance/yr operating cost	NA	5 yr repl ∴ cost to motorist 2	3 yr repl ∴ cost to motorist 7	Operating costs per year for area 250,000	Comm equip 1/5 cost 150 150,000	50 438,000	Assumed 1/5 of cost 1000 Negligible
Manpower cost/ yr	NA	NA	NA	2 men/veh, 24 hr a day at 6000 250 men 1,500,000	150 men 900,000	2 men/A/C at 8000 24 hr 400,000	1.2 men/ sta 24 hr at 6000 180,000
Auxiliary equipment cost	Public and private telephone at least at 5 m intervals. Simple emergency number. Driver education Negligible			NA	Motorist-supplied beacons		p.u. 10
Installation and maintenance	Call reimbursement at $0.10 per call based on unlikely assumption that all aids are called for. 13,300			NA	Assume = cost of equipment 3 yr replacement. Yearly cost to motorist		7
Auxiliary personnel cost/yr	Extra communicators during busy periods at telephone center 3 for 2 shift operation at 6000 18,000			Communicators, maintenance personnel, etc 2 men/area at 6000 24 hr a day ∴ 10 men	60,000	15 men 24 hr ∴ 25 men at 6000 150,000	0.3 men/sta at 6000 45,000
Remarks	For cases 4 & 5 road types only	For cases 4, 5, & 6 road types		Must cover all roads post assignment crucial	Sufficient to cover 1/2 of roads, others being in range of beacon	Ability to quickly serve serious accident victims	Strictly a unidirectional comm work
Other	Time to respond a function of traffic level, population density, citizen education			TTR about 30 min	TTR est at 20 min	TTR about 6-10 min after detection	Structures 20,000/sta 10,000
Total for 1000 m			$31,300	$1,847,500	$1,333,400	$1,088,300	$243,500
Approximate/ mile cost	$32	$32	$32	$1,848	$1,134	$1,089	$244
Motorist annual investment	—	$2	$7	—	$7	$7	$7

Note: All estimates based on 2500 square miles with 1000 miles of roads of classes 4, 5, and 6 in area of 2500 square miles.

	SERVICE					
MOTORIST-ACTUATED TELEPHONE/ CALL BOX EMERGENCY ONLY	STATE-OWNED VEHICLES		PRIVATELY-OWNED VEHICLES STATE REIMBURSED		SPECIAL VEHICLES HELICOPTER, VTOL STATE-OWNED AND OPERATED
	PATROLLING	ON CALL	PATROLLING	ON CALL	
	1/40 m	1/66 m	1/40 m	1/66 m	1/500 m² 5 aircraft at 200,000
1/mile average taking advantage of intersections etc, at 400	at 8000 over 5 yr		at 8000 over 5 yr, subsidized 50 percent		
	25 veh	15 veh	25 veh	15 veh	
$40,000	$40,000	$24,000	$20,000	$12,000	$100,000
Assume at most equal to cost	NA	NA	NA	NA	NA
40,000					
Assume 1/10 cost	$0.12/m 200,000 m each veh	$0.12/m 20 m/ assist 133,000 assists for all veh	$0.12/m 200,000 m + $10 per assist	$0.12/m, 20 m/ assist $10/assist for all veh	
4,000	600,000	319,200	600,000 1,330,000	319,200 1,330,000	
Maintenance personnel for area & center 10 men at 6000	2 men/veh for 24 hr ∴ 10 men/veh		Inspection, check pers 2/area at 6000		2 men per A/C for 24 hr ∴ 50 men at 8000
	250 men	150 men			
	at 6000				
60,000	1,500,000	900.000		12,000	400,000
Center, 1/area at 20,000	Structures etc. assumed 20,000 for area over 10 yr		NA		Structures 40,000 over 10 yr
2,000		2,000			4,000
Assume = cost 2,000 Assume 1/10 cost	Assume 1/10 cost		NA		Assume 1/10 cost
200		2,000			4,000
Center personnel 1.5 persons, 24 hr ∴ 7.5 men at 6000	Maintenance personnel, communications Assume 1/10 patrol personnel at 6000		NA		Maintenance personnel 1/A/C at 6000
	25 men	15 men			
45,000	150,000	90,000			30,000
Assumed separate from telephone co.	All stops requiring assistance are assumed serviced by these vehicles				
Structures 40,000/sta	TTR est 20 min	TTR est 30 min	TTR 20 min	TTR 30 min	Average TTR est 10 min or less
4,000					
$197,200	$2,294,000	$1,337,200	$1,950,000	$1,673,200	$538,000
$198	$2,294	$1,338	$1,950	$1,674	$538

In general, since the vehicles would not engage in regular patrolling, the operating expenses to the operators would be lower and the vehicles' useful life longer; hence, amortization could extend over a longer period of time (perhaps 5 years), and the overall cost per year would be lower than the costs to facilities using their own vehicles for patrol purposes.

The communication and the service aspects have been viewed largely in the light of present-day achievability. However, the ultimate development of the helicopter, for example, may be to the point where the service vehicle could be "on station" covering an area of many square miles and possibly containing its own distress signal receiving and location equipment. There is also great potential for fixed-wing VTOL or STOL aircraft for patrolling and servicing on long stretches of plains or desert road. Radio-telephony is slowly finding its way into the automobile. Presently, channel limitations, the lack of complete coverage by base/relay stations, and extremely high cost preclude universal adoption.

Implementation Cost Estimate

The cost estimate table is somewhat different for this group of road types, because of the prevailing element of motorist participation and the necessity of considering systems by area rather than linearly.

In addition to listing the more popular and currently used methods of detection and service, a number of new ways are considered and shown to be competitive. Most important, they can do the job better in terms of time response.

The detection and service functions have been separated because some feasible detection schemes are completely divorced from service, as well as to determine the best compromise of accomplishing the desired objectives in cost and response. This separation also points out the advantage of using servicing patrols if patrols are to be used.

Consider some of the specific costs in Table 13. The cheapest detection schemes are incapable of service and can be used only with one or more of the service methods. Of the latter, the service by privately owned but subsidized service vehicles (assumed subsidy level is 50 percent of equipment cost, 12 cents per mile, and $10 per assist) appears to be the most advantageous. The time to respond would average about 30 minutes plus an amount that depends on the detection method used. The fastest and probably most reliable method would be vehicle-mounted emergency beacons and a state-installed, maintained, and operated receiver network. The assumed density is one receiver per 500 square miles giving each receiver a range of 12 to 15 miles, and a control/communications center each 2,500 square miles. This requires an outlay on the part of each motorist of perhaps $20; that is, $10 for the equipment and the rest for installation. Such prices would prevail if the relatively simple beacons were mass produced and sold as vehicle equipment such as seat belts. The expected number of assists for the area can be calculated by assuming a realistic mix of road types. Assume that 400 miles are case 6 type roads, 400 miles are case 5, and 200 miles are case 4 type roads. Using their respective expected numbers of assists as calculated previously, $(400 \times 0.08 + 400 \times 0.51 + 200 \times 0.64)\ 365 = 132{,}860$ which is the expected number of stops per year requiring assistance for the area.

It is of interest to examine the assist load on the assumed service vehicles at 364 expected assists per day; 25 service vehicles would be forced to give about 15 assists per day each; 15 such vehicles would have to average 25 assists per day, or average less than one hour per assist. Finally, if helicopters were used, each of the 5 helicopters assumed would have to perform about 73 assists per day thus averaging 3.3 assists per hour and having 20 minutes to arrive and perform each assist.

Obviously, therefore, 5 helicopters are insufficient as is the number of privately owned but subsidized service vehicles, simply because they would be busy full time doing assist work for the state. They would not, therefore, want to participate unless the subsidy was sufficiently high to allow for profitable business; this would amount in effect to having state owned and operated vehicles. The numbers of vehicles were chosen on the basis of being able to render service or detect, in a reasonably short time. But the number of required assists causes potentially intolerable delays on distressed motorists. The costs are already high, since by adding more vehicles to reduce this delay, the costs are raised much higher.

Fortunately, the answer is the servicing patrol. As previously shown, only limited supplies and mainly the willingness of the patrolmen are required for them to perform routine, minor services. The police patrols undoubtedly will continue to patrol roads as long as laws and law enforcement exist. If properly equipped, they could dispose of 2 out of 3 required assists. The objection that this would detract from their law-enforcing and crime-preventing duties is easily solved. A slight increase of the police manpower and patrol effort will result in more intensive and more effective fulfillment of the police force's prime functions when and where necessary. The mere increased incidence of "police presence" would have precisely the effect desired.

Therefore, a system can be considered using the following:

1. Police patrols: occasional detection of stopped vehicles, basic assistance, but principally law enforcement;
2. Beacon + receiver network: primary detection of stopped vehicles in need of assistance; and
3. Subsidized service operators: performing all other services when called on to do so; reimbursed by the state at a fixed rate.

The implementation costs of this system are derived in Table 14. A slight change in the receiver network results from the assumption that five receiving stations are unattended and one central location receives all calls. The reason for this is the lower manpower cost. Even with better maintenance and a more expensive central plant, and maintenance vehicles, the overall cost is considerably lower.

This rearrangement shows once again that to reduce

costs man must be replaced by machine. The police strength is 210 men and the receiver network requires 15 men; the costs for the former are more than 10 times those for the latter.

In determining the number of subsidized service vehicles, their spatial distribution must be considered in determining the correct number required so that not more than a fixed percentage of the private operators' time is taken up with rendering emergency services. Since the police force will service about 60 percent of the required minor assists, 150 assists per day are to be handled by the private operators. Allowing an average of 5 assists per operator, and assuming that on the average each assist will require from one-half hour to an hour, about 15 such vehicles should be available for the area in question, or about 1 per 66 miles of lineal roadway. Since service operators usually locate at intersections, no point in a given area of responsibility need be much more than about 20 miles from his base location. Each service call is assumed to be a trip of 2×20 miles, which should be close to a maximum. Thus, the implementation cost with the system as described (including police activities) amounts to about $1,954 per mile per year.

Having previously determined the expected number of

TABLE 14

CASES[a] 4, 5, AND 6 SOLUTIONS AND COSTS PER MILE PER YEAR

COST FACTOR	SOLUTION: POLICE PATROL	BEACON EQUIPMENT	RECEIVER NETWORK	SUBSIDIZED SERVICE—ON CALL
Equipment	Patrol vehicles: 20 1/50 m, life 2 years at 4000 incl comm and service supplies		1 receiver/500 sq miles at 10,000 over 10 years, 5 for area	15 vehicles subsidized at 50 percent at 8000, life 5 years, incl comm equipment
Cost/year	$ 40,000		$ 5000	$ 12.000
Installation	NA		Assume 1/2 of cost 2500	NA
Operating cost or maintenance	App 10,000/vehicle 200,000	Motorist—supplied: assume $20 each with 3-yr replacement Cost to motorist, $7/yr	Assume 1/5 of cost 1000	Assist reimbursement 150 day at $10 each mileage 40 m/assist, $0.12/m 54,750 262,800
Manpower	2 men/vehicle, 24 h 200 men at 6000 1,200,000		Maintenance personnel 2/area 24 hours 10 men at 6000 60,000	NA
Auxiliary equipment installation and maintenance	Maintenance facilities 30,000 base comm eq 2000. Installation of comm equipment 1/2 cost maint 1/5 cost 3700		Central station eq 20,000 over 10 years Installation 1/2 cost maintenance 1/5 cost 3400	NA
Auxiliary personnel	Maintenance personnel 2/area 24 hours at 6000		1/station 24 hours 5 men at 6000	Compliance inspection and liaison personnel: 2/area at 6000
Cost	60,000		30,000	12,000
Other			Structures 30,000 (10 years) maint veh: 3 at 4000 each over 3 years 7000	
Total for 1000 miles	$1,503,700		$108,900	$341,550
Cost/mile/year	$1504		$109	$342

[a] Based on 2500 square miles ≈ 1000 miles of roads: case 4 (20 percent), 5 (40 percent), 6 (40 percent).

assists to be 132,860 per year for the 1,000-mile road network, the expected number of required assists per mile per year is about 133. Therefore, the cost per assist is about $1,954 ÷ 133 = $15.

This cost is not as high as that computed for the cross-country turnpike, and even lower than that for the urban expressway. One reason is that "time to respond" is considerably slower.

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APPENDIX A

SIMPLIFIED PATROL ANALYSIS

In this appendix a mathematical model for stopped-vehicle detection by patrols is developed. It is assumed that the only means of detection is a patrol effort.

A vehicle that stops at time t_0 will wait a time τ to be detected if no patrol passes in time τ and then one comes by in the period $d\tau$. The probability of this event is

$$p(d,\tau) = p_0(\tau)\, p(\tau)\, d\tau \qquad \text{(A-1)}$$

where

$p_0(\tau)$ = probability of no patrols in time τ,
$p(\tau)d\tau$ = probability that a patrol vehicle passes in the time element $d\tau$ at time τ.

For the sake of calculation and because of the resemblance in actual distribution functions, it is assumed that the patrols are Poisson distributed in time. With this assumption, Eq. A-1 becomes

$$p(d,\tau) = \exp(-\lambda\tau)\lambda d\tau \qquad \text{(A-2)}$$

The probability of a stop being detected by time τ is

$$P(d,t \leq \tau) = \int_0^\tau \lambda \exp(-\lambda\tau)\, d\tau = 1 - \exp(-\lambda\tau) \qquad \text{(A-3)}$$

This analysis assumes that a vehicle that stops will remain stopped until it is detected. This is probably true if there is a mechanical failure; however, it is not true for information stops, etc. There is some function $p(s, \geq \tau)$ that is the probability that the length of the stop is greater than or equal to τ. In such situations, the probability that a vehicle is detected at time τ is

$$p(d,\tau) = p_0(\tau)p(\tau)p(s, \geq \tau)\, d\tau \qquad \text{(A-4)}$$

The length of a stop is assumed to be a Gamma distribution. This distribution was chosen because it has a shape similar to that experienced; hence,

$$p(s,t) = \frac{t^\alpha \exp(-t/\beta)}{\beta^{(\alpha+1)}\,\Gamma(\alpha+1)} \qquad \text{(A-5)}$$

The distribution function for $p(s,\tau)$ is

$$P(s,\tau) = \int_0^\tau p(s,\tau)\, d\tau \qquad \text{(A-6)}$$

and

$$p(s, \geq \tau) = 1 - P(s,\tau) \qquad \text{(A-7)}$$

Eq. A-1 now becomes

$$p(d,\tau) = \exp(-\lambda\tau)\lambda\left[1 - \int_0^\tau \frac{t^\alpha \exp(-t/\beta)}{\beta^{(\alpha+1)}\,\Gamma(\alpha+1)}\, dt\right] d\tau$$

$$= \exp(-\lambda\tau)\lambda\left[1 - \frac{1}{\Gamma(\alpha+1)} \int_0^{\tau/\beta} v^\alpha \exp(-v)\, dv\right] d\tau \qquad \text{(A-8)}$$

The probability that the vehicle is detected by time τ is

$$P(d,t \leq \tau) = \int_0^\tau p(d,\tau)\, d\tau \qquad \text{(A-9)}$$

This analysis has been viewed from the stopped-vehicle perspective and is, in effect, the level of service offered to drivers and patrons of the road.

The other side of the situation is that seen by the patrol service. All readily available data come from records of detection; hence, for investigative purposes, a model from the patrol point of view is advisable.

Again, it will be assumed that the manner in which stopped vehicles occur is Poisson. In the analysis, time is taken as the basis for all rate parameters. In some situations, it may be more natural to use a mileage basis. The time distribution can be converted to a distance distribution using the speed parameter; hence, the following derivation is entirely general.

If one vehicle stops and the distribution in stops is Poisson, then the mean time to the next stopped vehicle is

$$< T > = \int_0^\infty t\,\mu \exp(-\mu t)\, dt = \frac{1}{\mu} \qquad \text{(A-10)}$$

For an example of the conversion of time-based parameters to distance-based parameters, let

$$x = vt \qquad \text{(A-11)}$$

where

x = distance,
v = velocity of vehicles, and
t = time.

Then,

$$< x > = \int_0^\infty \frac{x}{v^2}\mu \exp[-(\mu x)/v]\, dx = \frac{v}{\mu} \qquad \text{(A-12)}$$

Eqs. A-10 and A-12 say that if μ is the rate at which stops occur in time, then a new parameter

$$\mu' = \frac{\mu}{v} \qquad \text{(A-13)}$$

is the rate at which stops occur in distance.

Again, it must be noted that not all stopped vehicles are detected, as is assumed in the above equations. To determine the probability that a vehicle that stops is detected, the probability that it is not detected must first be found. It is again assumed that the distribution in patrols is Poisson and the distribution in stop time is Gamma. The probability that a vehicle stops for a time t and is not detected is

$$p(\bar{d},t) = \frac{t^\alpha \exp(-t/\beta)}{\beta^{(\alpha+1)}\,\Gamma(\alpha+1)} \exp(-\lambda_p t)\, dt \qquad \text{(A-14)}$$

The total probability of not being detected is

$$P(\bar{d}) = \int_0^\infty p(\bar{d},t)\, dt$$

$$= \frac{1}{\beta^{(\alpha+1)}\,\Gamma(\alpha+1)} \int_0^\infty t^\alpha \exp\left[-t\left(\lambda_p + \frac{1}{\beta}\right)\right] dt$$

$$= (\beta\lambda_p + 1)^{-(\alpha+1)} \qquad \text{(A-15)}$$

Eq. A-15 has been plotted in Figure 20 as a function of the patrol time constant (T_p), which is

$$T_p = \frac{1}{\lambda_p} \qquad \text{(A-16)}$$

Two curves are shown for different choices of a and β. The upper curve has $a = 1.2$ and $\beta = 3.33$, which gives a mode at 4 minutes and a ninth decile at 14 minutes. This indicates a short-term stop. The lower curve has an a of 4 and $\beta = 2.5$, giving a mode at 10 minutes and a ninth decile at 20 minutes. The actual density functions for stop time associated with the detection curves in Figure 20 are shown in Figure 21.

The stops are assumed to be Poisson distributed; therefore, the expected number of stops in time t is:

$$< S(t) > = \mu t \qquad \text{(A-17)}$$

The expected number of stops that are detected is

$$\begin{aligned} < N_d > &= \mu t[1 - p(\bar{d})] \\ &= \mu t[1 - (\beta\lambda_p + 1)^{-(a+1)}] \qquad \text{(A-18)} \end{aligned}$$

This equation uses many assumptions; primarily that multiple incidents do not interfere with each other. For the probable density of occurrences, this is most likely true.

Another assumption is that the distribution times between successive patrols is Poisson. This is true for some facilities. Revenue tickets were obtained from the Richmond-Petersburg Turnpike that gave the time direction and number of the officer as he went through a toll booth. From these slips, it was possible to reconstruct the paths of the patrol on the turnpike. An example of such a patrol plot is shown in Figure 22.

The time distribution between successive patrols can be determined from Figure 22. Some typical results for the time distribution between patrols going in the same direction are shown in the top four blocks of Figure 23. The solid lines show the assumed Poisson distribution with the parameter given in the accompanying equations. The time constant is in general about 30 minutes. This appears to be a very heavy patrol compared with other facilities.

If it is assumed that a stopped vehicle can be detected independently of the direction of the patrol, then the time constant for the patrol is reduced to 17 minutes as shown in the bottom four blocks of Figure 23.

The patrol frequency depends on the time of day shown in Figure 23. An anomaly that occurs occasionally is shown in the third pair of blocks of Figure 23—that is, the double exponential distribution. Another example is shown in the fourth pair of blocks of Figure 23. This type of distribution was not common.

It can be concluded that the data support a Poisson distribution. The reason that this assumption is valid for this facility is probably due to the patrol procedure. The vehicle that patrols the turnpike also patrols adjoining roads; therefore, the patrol is entering and leaving the turnpike somewhat at random. This would lead to the Poisson distribution. For facilities not using this procedure, the patrol post analysis in Appendix B is included.

The Gamma distribution is defined as

$$f(x,a,\beta) = \frac{x^a e^{-x/\beta}}{\beta^{(a+1)}\Gamma(a+1)}$$

$$(a > -1;\ \beta > 0;\ 0 \leq x \leq \infty)$$

The shape and nature of the Gamma distribution is highly dependent upon the two parameters a and β. The most familiar form of the Gamma distribution is the exponential distribution

$$f(x,a,\beta) = \frac{1}{B} e^{-x/\beta}$$

Some of the characteristics of the Gamma distribution are as follows:

1. The curve of $f(x,a,\beta)$ is J-shaped if $a \leq 0$ and unimodal if $a > 0$.
2. $f(x,a,\beta)$ is asymptotic to zero for large values of x.
3. If $-1 < a > 0$ then $f(x)$ is unbounded for small values of x.
4. If $a > 0$ then $f(0) = 0$ and the mode is at $x = a\beta$.
5. There are points of inflection at $\beta\sqrt{a}$ to either side of the mode if $a > 1$. If $0 < a \leq 1$ the only point of inflection is the one to the right of the mode.
6. $< f(x) > = \beta(a + 1) = M$.
7. $\sigma^2 = \beta^2(a + 1)$.

APPENDIX B

PATROL POST ANALYSIS

Many facilities assign men to patrol certain sections or posts. Therefore, the Poisson assumption for patrol effort is not always valid. It is assumed that the length of each post is L and that the patrol cruises at a speed v. The probability that a vehicle that stops will be detected by time T is

$$P(d,t \leq T) = \begin{cases} 0 & vT < 0 \\ \frac{vT}{2L} & 0 \leq vT \leq 2L \\ 1 & vT > 2L \end{cases} \qquad \text{(B-1)}$$

which is the probability that the patrol vehicle is in a segment of length vT behind the stopped vehicle when the length of the patrol route is $2L$. Variations in patrol speed (v_1) and the possibility of detection when the vehicle is at some other point in its patrol could be incorporated in a more complex model if it were warranted.

Using the model, the probability of detection of a stopped vehicle at time T becomes:

$$\begin{aligned} p(d,T) &= \left(1 - \frac{vT}{2L}\right)\frac{v}{2L}p(s \geq T)\,dT \\ &= \frac{v}{2L}\left(1 - \frac{vT}{2L}\right)[1 - P(s,T)]\,dT \qquad \text{(B-2)} \end{aligned}$$

Similarly, assuming a Gamma distribution in stop lengths, the probability that a vehicle stops for time t and is not detected is

$$P(\bar{d},t) = \frac{t^{\alpha}\exp(-t/\beta)}{\beta^{(\alpha+1)}\Gamma(\alpha+1)}\left(1 - \frac{vT}{2L}\right)dt \qquad \text{(B-3)}$$

Thus, the total probability of not detecting a stopped vehicle is

$$\begin{aligned} P(\bar{d}) &= 1 - \frac{v}{2L} < t > \\ &= 1 - \frac{v}{2L}\beta(\alpha+1) \qquad \text{(B-4)} \end{aligned}$$

Conversely, the probability of detection is

$$P(d) = \frac{v}{2L}\beta(\alpha+1) \qquad \text{(B-5)}$$

The form of Eq. B-4 is plausible when it is realized that $v < t >$ is the expected distance that the patrol will progress during the time the vehicle is stopped. Therefore, the probability that the vehicle is detected is simply the ratio of this expected travel distance to the total length of the patrol, or $2L$.

Assuming that a patrol is 30 miles long and that the vehicle patrols at 60 mph, the probability of detection is

$$\begin{aligned} P(d) &= 0.016\,\beta(\alpha+1) \\ &= 0.122 \text{ for } \alpha = 1.2,\ \beta = 3.33 \\ &= 0.208 \text{ for } \alpha = 4,\ \beta = 2.5 \qquad \text{(B-6)} \end{aligned}$$

These probabilities are not significantly different from those obtained with the Poisson model.

APPENDIX C

SAFETY ANALYSIS

The model developed is only useful as an indication of the approximate level of accident probability. This is again an area where very few statistics are kept. It is possible to assemble a model from some studies that have been made; however, not all of the parameters or their ranges are known.

Figure C-1 shows the model used in this analysis. The stopped vehicle is assumed to be of width W' and is a distance D' from the edge of the road. The vehicle that approaches on the median does so to a distance of D. The width of this vehicle is W. If the vehicle leaves the road at a point X down the road and remains off the road for a distance $\ell \geqq x$, then there is a possibility of a collision. It is also necessary that the vehicle be off the road a proper distance—that is, it must encroach at least D' and less than $D' + W' + W$. Mathematically, this is

$$P(a/D') = \int P(\text{off at } X)\, P(1 \geqq X)\, P(D' \leqq D \leqq D' + W' + W)\, dX \qquad \text{(C-1)}$$

where

$P(a/D')$ = probability of an accident given that a vehicle stops at D';

$P(\text{off at } X)$ = probability that encroaching vehicle leaves road at X;

$P(\ell \geqq X)$ = probability that encroaching vehicle travels a distance at least X down shoulder; and

$P(D' \leqq D \leqq D' + W' + W)$ = probability that encroaching vehicle penetrates shoulder at distance necessary to strike stopped vehicle.

This model was chosen primarily because of available information. Hutchinson in his study of median encroachments (*8*) has a distribution function for the length of travel in the median (Figure C-2). This distribution is taken as $P(\ell \geqq X)$. The probability function for distance traveled in the median is approximately normal. The mean and standard deviation of this distribution are μ and σ, respectively, which for Hutchinson's data take the values 300 and 130 feet.

If it is assumed that the probabilities other than $P(\ell \geqq X)$ are independent of X, then

$$\int_0^\infty P(\ell \geqq X) = \int_0^\infty \int_x^\infty P(\ell)\, d\ell\, dX = \sigma I(a) \qquad \text{(C-2)}$$

where $a = -\frac{\mu}{\sigma}$.

If the distribution function for the depth of encroachment (Figure C-3) is known, then

$$P(D' \leqq D \leqq D' + W' + W) = P(D \leqq D' + W' + W) - P(D \leqq D') = P_1(D') \qquad \text{(C-3)}$$

Here again, a normal distribution with mean m and standard deviation s is assumed. A change of variables can be defined as

$$\Delta' = \frac{D' - m}{s}$$

$$\delta = \frac{W' + W}{s} \qquad \text{(C-4)}$$

then Eq. C-3 becomes

$$P_1(D') = P_1(\Delta', \delta) \qquad \text{(C-5)}$$

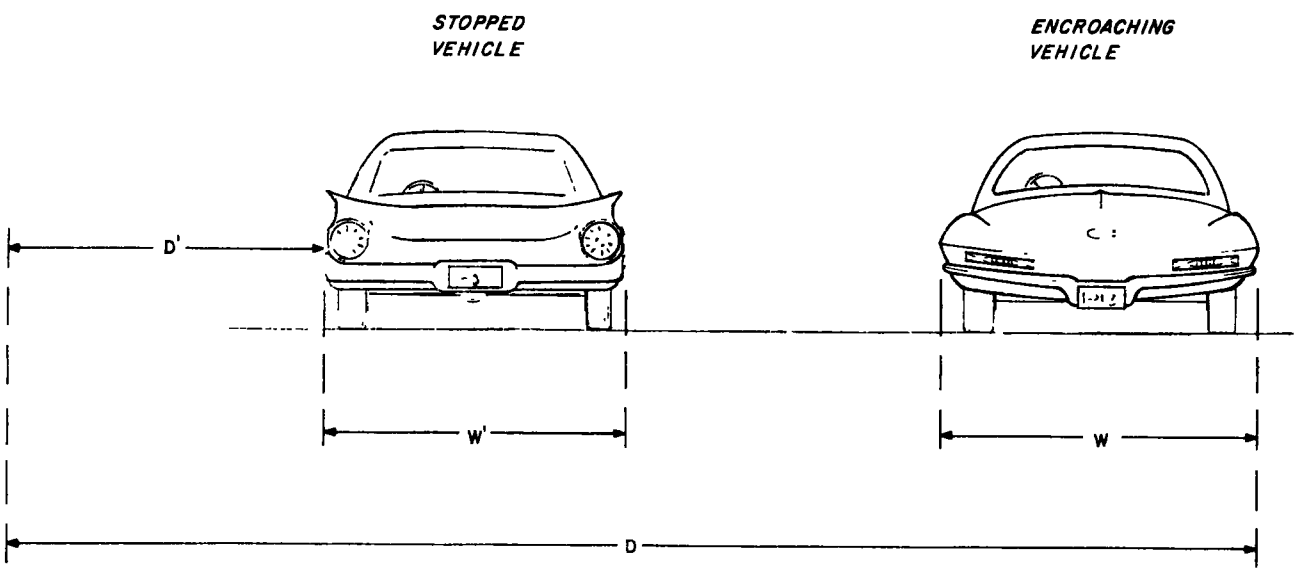

Figure C-1. Encroachment geometry.

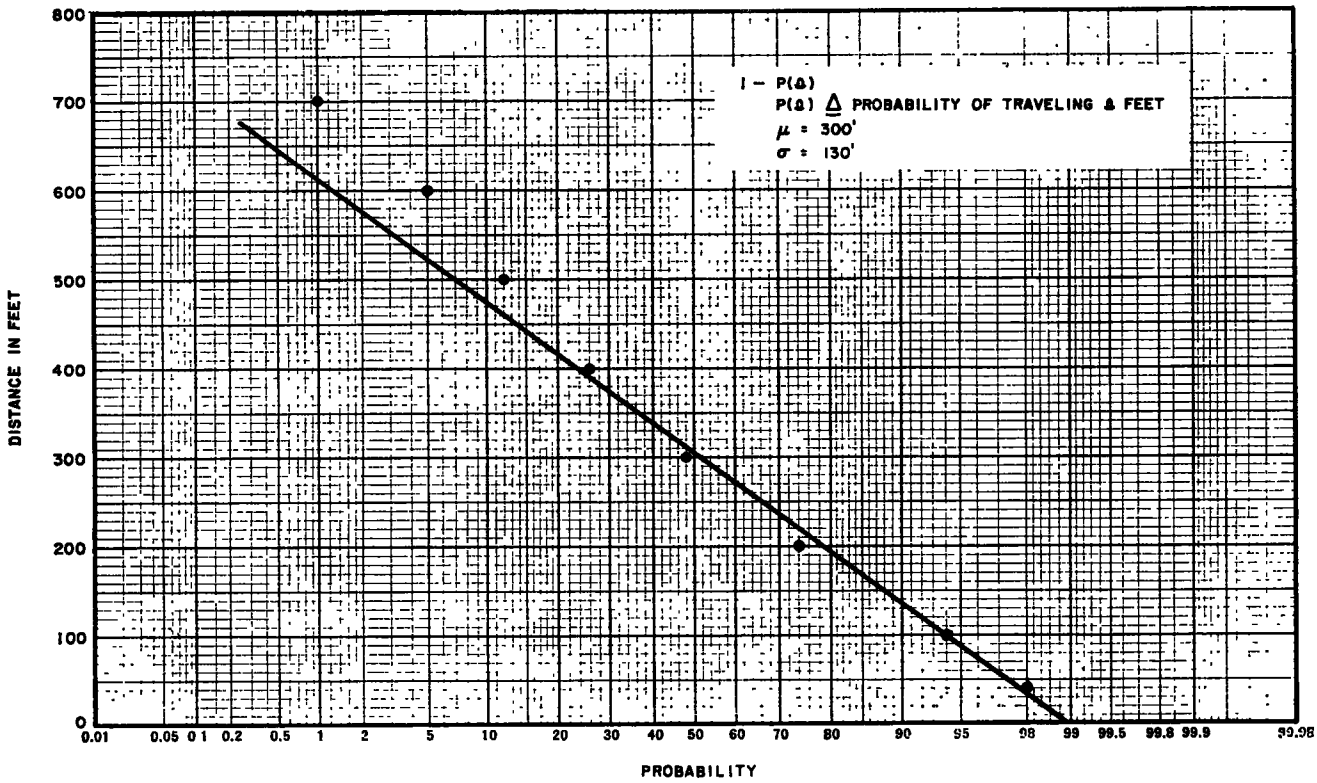

Figure C-2. Distribution of length of encroachment.

It is further assumed that $P(\text{off at } X)$ is a constant R_1, so that Eq. C-1 is now

$$P(a/D') = R\sigma l(\delta)\, P_1(\Delta', \delta) \qquad \text{(C-6)}$$

The constant R is derived from Hutchinson's report. Figure C-4 shows the basis for its determination. The number of encroachments made on a median per mile per year was determined by Hutchinson to be as shown in Figure C-4. There is again a dependence on traffic level. A value of 8 encroachments per year per mile is assumed although there are many factors that influence this number and these are discussed in Hutchinson's report.

If these encroachments are uniform in time and space, then the probability that a vehicle goes off the road at a point X in an hour is

$$R = \frac{8}{5280 \text{ ft} \times 24 \times 365}$$
$$= 1.73 \times 10^{-7} \frac{\text{encroachments}}{\text{ft per hour}} \qquad \text{(C-7)}$$

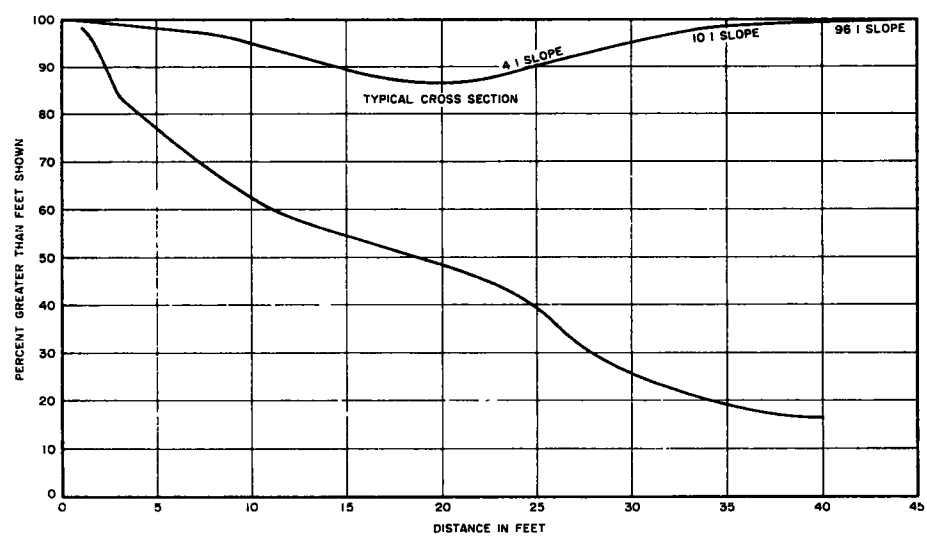

Figure C-3. Depth of encroachment.

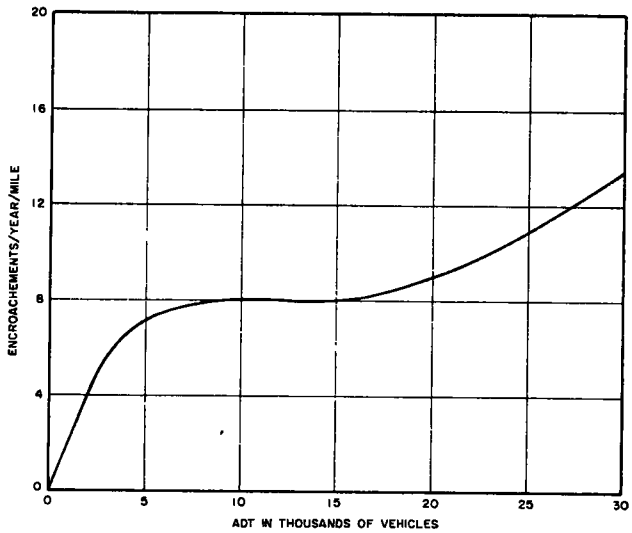

Figure C-4. Frequency of encroachment.

The probability of an accident on the shoulder if the distribution of D' is known can now be found.

$$P(a) = \int_0^\infty P_1(D')\, P\,(D')\, d\,D'$$

$$= R\sigma I(a) \int_0^\infty P_1(D')\, P(D')\, d\,D' \text{ per hour} \qquad \text{(C-8)}$$

Assuming that during a year a motorist spends one hour beside the road, if the parameters are such that

$$R = 1.7 \times 10^{-7} \qquad \sigma = 10^2$$

$$I(a) = 2.1 \qquad P(\Delta', \delta) = 1/4 \qquad \text{(C-9)}$$

then the probability of being involved in an accident is

$$P(a/D') = 1.7 \times 10^{-7} \times 10^2 \times 2.1 \times 1/4$$

$$= 10^{-5} \qquad \text{(C-10)}$$

Safety Model Calculations

In the safety model, many of the distribution functions were found to be nearly normal. For versatility reasons, the following general procedure for evaluating the necessary function from these normal populations has been used.

The first function to be evaluated is Eq. C-2. The integral of Eq. C-2 $\int_x^\infty P(\ell)d\ell$ is converted to a unit normal distribution by the variable change

$$t = \frac{x - \mu}{\sigma}$$

where

μ = mean of normal distribution, and
σ = standard deviation of normal distribution.

Using the new variable t, Eq. C-2 becomes:

$$\int_0^\infty P(\ell \geqq X)dx = \int_{-a}^\infty \sigma P(\ell \geqq t)dt = \sigma I(a)$$

where

$$a = -\frac{\mu}{\sigma}.$$

The remaining function to be calculated for Eq. C-1 is

$$P(D' \leqq D \leqq D' + W' + W) = P_1(D')$$

Figure C-3 shows a distribution function for the depth of median penetration found by Hutchinson. Assuming a normal approximation with mean m and standard deviation s, the variables are defined

$$\Delta' = \frac{D' - m}{s}$$

and

$$\delta = \frac{W' + W}{s}$$

Eq. C-3 can now be calculated as a function of Δ' and δ and

$$P_1\,(D') \Rightarrow P_1\,(\Delta', \delta)$$

APPENDIX D

VALUE ANALYSIS

This appendix attempts to determine the value of the stopped-vehicle detection system to the motorist.

The motorist will buy equipment if he feels that he "derives" enough from it. What he "derives" can be a decrease in operating costs, increased safety, service, or security.

Such a system will not increase tire life or decrease running costs since it does not apply to running vehicles but to stopped ones. Therefore, only costs incurred from stops are concerned. These costs can be caused by the individual himself stopping or someone else stopping. In the first case, the system does not help him pay the costs of any bills derived from the stop. Everything that it will do for him can be placed in the categories of service, safety, security, and time savings. The only interest here is time savings.

If the individual is not the one that stopped, then the only way that another person's stop can affect him is through delay. Here again, there is the problem of the value of time. This problem in itself is complex to analyze (*9, 10,* and *11*). Assume that the "cost" can be represented by a value C_t. Therefore, if a system will save a person t minutes with a probability $P(t)$, then the total expected cost savings, S_t, is

$$S_t = \int P(t) C_t dt \qquad \text{(D-1)}$$

This however is not complete. The savings may be large but the probability of obtaining that savings may be low. A proper weighting to such a figure then is the expected number of times, N, that an individual will be able to receive this savings. These numbers will not likely be the same for each of the above cases. S_{t1} and N_1 for when an individual will stop and S_{t2} and N_2 for when someone else stops may generally be different. Thus, the total expected savings S_{tT} to the individual is

$$S_{tT} = N_1 S_{t1} + N_2 S_{t2} \qquad \text{(D-2)}$$

The relationship of this system to safety is probably much less than that of seat belts and safety. Thus, the safety value of such a detection system is likely to be considerably underplayed in the individual's mind. The stops are divided into three cases: someone else stopped, you had an accident, and you stopped but did not have an accident.

For the case when someone else stopped, it is possible to perform a complete analysis of the costs for each category of accident and how frequently these accidents occur. However, only the results derived from insurance companies will be used. They conclude that they must charge a certain rate (R) to cover this risk. The assumption is that this rate varies directly as the accident rate. Thus, if the accident rate were to double then the premium rate would have to double. Suppose that instead of doubling, the rate goes up by a factor of k_2 when a person is in some congested traffic. This is essentially taken care of in the resultant rate set by the insurance company. Thus, saving a person t minutes saves him

$$\frac{(k_2 - 1)^t}{t_T} R \qquad \text{(D-3)}$$

where t_T is the total amount of time a person drives in a year. Again, there is the weighting factor of the number of times that one expects to be able to receive this benefit. This number will be N_2; therefore, the total savings S_1 is

$$S_1 = N_2 \int \frac{(k_2 - 1)^t}{t_T} R\, P(t)\, dt \qquad \text{(D-4)}$$

An earlier analysis showed that a vehicle that pulls onto the shoulder is safer than one that is in the traffic stream; therefore, it is doubtful that a similar "savings" is acquired in this case.

The last possible benefit is service. For the time being, carry this factor along as a parameter, S_s, and see how it affects the decision. This too should be weighted by N_1.

All the benefits can now be added to see what total has accrued. Eqs. D-1, D-2, and D-4 are combined to obtain the benefit to the individual, B_I,

$$\begin{aligned} B_I &= N_1 S_{t1} + N_2 \int P_2(t)\, C_t dt + N_2 \int \frac{(k_2 - 1)^t}{t_T} \\ &\quad R\, P_2(t)\, dt + N_1 S_s \\ &= N_1 S_{t1} + N_2 \int P_2(t) \left[C_t + \frac{(k_2 - 1)\, Rt}{t_T} \right] dt \\ &\quad + N_1 S_s \end{aligned} \qquad \text{(D-5)}$$

The foregoing is only a mathematical exercise until some numbers can be substituted. Assuming a conventional concept of cost of time (that lost time due to delay can be evaluated by a fixed rate, R_t),

$$C_t = R_t t \qquad \text{(D-6)}$$

The second term of Eq. D-5 becomes

$$N_2 \left[R_t + \frac{k_2 - 1}{t_T} R \right] \int P_2(t)\, t dt = N_2 K < t_2 > \qquad \text{(D-7)}$$

This assumption as to the value of time is subject to much controversy (*7*); however, it is an accepted procedure for benefit-cost ratios and on this basis acquires status. More information can be obtained from Eq. D-7 by examining K. If the average driver drives 250 hours a year and his average insurance premium is \$300, then

$$\frac{R}{T} = \frac{\$300}{250} = \$1.20/\text{hr}$$

Thus, the portion of his benefit due to increased safety is probably greater, though of the same order of magnitude, than his benefit from time savings. The major portion of the benefit derived by an individual from the system does not require his participation in the system, that is, if a scheme requires the installation of special equipment in a vehicle, the major portion of the benefit comes not when one's own equipment is being used, but when someone else's is being used. This raises the question of whether a

person will regard such a "benefit" as a true benefit worthy of the outlay of his own capital.

For simplicity, assume that $R(t) = P(t)$ and that $S_{t1} = R_t t$. Then, Eqs. D-5 and D-7 yield

$$B_I = < t > [N_2 K + N_1 R_t] + N_1 S_s \qquad \text{(D-9)}$$

If it is further assumed that the roads traveled have dense traffic such that the number of times you expect to be held up by other's stops, N_2, is about 100 times in a year and that you expect to stop once yourself, then

$$B_I = < t > [100 \times \$3.00 + 1 \times \$1.55] + 1S_s$$
$$= \$301.55 < t > + S_s$$
$$K = \$3/\text{hr} \quad R_t = \$1.55/\text{hr}$$

This value corresponds to an urban expressway situation. In such cases, if the system is capable of saving only 10 minutes on the average, then the expected value to the individual, ignoring his value for the service, is about $50.

As a comparison, assume that the individual travels on rural roads only. In this case, it is unlikely that a stopped vehicle will create the delay that it does in the more dense traffic situations. However, you expect to be held up by someone else's stop once during the year. In this case,

$$B_I = < t > [1 \times \$3.00/\text{hr} + 1 \times \$1.55/\text{hr}] + S_s$$
$$= < t > \$4.55 + S_s$$

Since $4.55 is much less than $300, the system is unlikely to be as valuable to a rural person as an urban person.

There is still the value of service, S_s. If a person wants to argue that this value increases in an urban situation, then the above mentioned difference decreases. It is doubtful, however, that S_s will increase by some $295.

The foregoing analysis indicates that a stopped-vehicle system has a substantially higher value to a person who travels a densely traveled road than to one who travels a rural road. In a rural situation, the expected value to the individual is probably less than $5.00, whereas in the city it is probably worth about $50. This gives the designer of a system some feel for the amount of cost the individual may be willing to absorb.

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