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Number 272

Safety and Accident Research

5 Reports

Subject Area

51	Highway Safety
53	Traffic Control and Operations

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Foreword

The authors of the papers in this RECORD have performed research studies that broaden the field of knowledge in three areas of highway safety—the rail-highway grade crossing problem, research concerned with use of traffic accident data, and medical aid for the injured. The findings contribute specialized knowledge and give additional insight into these areas of concern.

The first paper, by two Texas researchers, describes the diagnostic team study approach to the field of rail-highway grade crossing safety evaluation. Indications were that the diagnostic team approach was a successful procedure in identifying and isolating factors that contribute to unsafe conditions at grade crossings, preparing priorities for crossing protection, recommending improvements in protective equipment, developing on-the-spot improvement programs, establishing an interdisciplinary approach to the solution of a common problem, and establishing a line of communication between groups and individuals responsible for the safe operation of rail-highway grade crossings.

The next paper tells how three Purdue University researchers studied rail-highway grade crossings in rural areas and evolved a mathematical model to predict relative hazard for the locations sampled. Warrants were developed for selection of the recommended type of protective device. Factors such as average daily highway and train traffic, roadway distractions, pavement width, and number of trucks were used in developing the model through regression analysis.

The third paper gives results of an Illinois Tollway study done by Northwestern University researchers on the subject of tire disablement and accidents. The research reports the amount of disablement actually occurring, resultant accidents, and statistical data concerning the problem.

The fourth paper describes the Maine system of locating highway accidents, beginning with a review of alternative methods available and ending with an evaluation of the initial results as applied to Maine's 4500 miles of federal-aid and state highways. The node-link method of accident location proved to be an economical and flexible tool that has greatly enhanced capability of utilizing factual data in Maine's safety program.

This RECORD concludes with a Pennsylvania Department of Highways study of helicopter ambulance service for traffic accident victims. The paper reviews the work under way and tells of the problems, responses, and reactions encountered.

Contents

The Diagnostic Team Approach to Rail-Highway Grade Crossing Safety Evaluation

HOY A. RICHARDS and NEILON J. ROWAN, Texas Transportation Institute; and
ERNEST W. KANAK, Texas Highway Department

Rail-highway grade crossing safety has received increasing emphasis since the creation of the Department of Transportation. As a part of an action program announced by the Secretary of Transportation in the fall of 1967, the Bureau of Public Roads has issued an instructional memorandum suggesting guidelines for the implementation of grade crossing safety programs within individual states. Included among the guidelines is a suggestion for the formation of diagnostic teams to conduct studies and recommend improvements for increasing safety at rail-highway grade crossings.

This paper describes the diagnostic study technique as it is applied by the medical profession and relates the applicability of this approach to rail-highway grade crossing safety evaluation. The results of the diagnostic team approach, as a research procedure, in the conduct of a Bureau of Public Roads-Texas Highway Department cooperative project is reported in the paper.

The role of the diagnostic team in safety evaluation is described by defining responsibility in areas such as (a) assignment of team members, (b) scheduling team activities, (c) preparation of diagnostic study support data, (d) development of diagnostic study procedures, (e) questionnaire design, and (f) results of the diagnostic team activities.

In general, the diagnostic team has proven to be a successful procedure in identifying and isolating factors that contribute to unsafe conditions at grade crossings, preparing of priorities for crossing protection, recommending improvements in protective equipment, developing on-the-spot improvement programs, establishing an interdisciplinary approach to the solution of a common problem, and establishing a line of communication between groups and individuals who are responsible for the safe operation of rail-highway grade crossings.

•INCLUDED among the Department of Transportation guidelines for the establishment of rail-highway grade crossing safety programs within individual states is a suggestion for the formation of diagnostic teams to conduct studies and recommend improvements for increasing safety at grade crossings. The Bureau of Public Roads memorandum issued to individual states in early 1968 suggested that the diagnostic teams be comprised of representatives of all groups having specific responsibility and interest in safety at rail-highway intersections.

At the time the guidelines were issued, the Texas Highway Department, in cooperation with the Bureau of Public Roads, was conducting a research project at the Texas

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Paper sponsored by Committee on Highway Safety and presented at the 48th Annual Meeting.

Transportation Institute that included among its research procedures the application of the diagnostic team approach to rail-highway grade crossing safety evaluation.

The purpose of this paper is to describe the results of the application of the diagnostic team techniques, as developed and implemented in the Texas study, as a research procedure. Hopefully, the results of this phase of the Texas study will be of benefit to sister states in the formation and implementation of diagnostic teams.

DIAGNOSTIC STUDY TECHNIQUES

In the medical profession the epidemiologist has the responsibility for describing patterns of diseases as they occur in groups of people. As a part of his professional training, the epidemiologist must come to know what diseases affect particular groups; their frequency of occurrence; the relative importance of different types of diseases—which are liable to sudden fluctuations in their frequency, which are fairly consistent within the group, which are widespread, and which are localized. In accident analysis the investigator may be faced with very similar, if not identical, questions. For example, the assumption that accidents are caused at rail-highway grade crossings rather than occur at random provides a logical framework in which to study factors which contribute to the cause of these accidents.

As in human illness, the cause of accidents at grade crossings may result from different types of diseases prevalent at a particular grade crossing. Often in the human population, only a small segment of the total group is included in the population at risk for various disease categories. The same may be true in grade crossing safety analysis. Therefore, the basic task of the safety epidemiologist, or in this instance the diagnostic team, is to determine which crossing or group of crossings is diseased and whether the disease is common to the entire group or prevalent in only a selected number of crossings. That is to say, the diagnostic team must know where the disease is to be found.

The medical doctor or team of doctors employs a series of clinical tests to systematically check all of the functions and response systems in the human body. When a malfunction is discovered an attempt is made to identify the cause of the malfunction by comparison with symptoms previously found to be associated with such illnesses. Although precise identity of the illness is not always possible, the probability of existence of various illnesses or malfunctions may be computed. From these computations, decisions are made to administer medicines and/or perform surgery in an attempt to correct the disorder. As a part of this clinical procedure the patients' response to the remedial action is observed. In the event an expected response does not occur, a re-evaluation of the probability of correct diagnosis is made. Since the procedure is based on an analysis of response to remedial treatment, changes in diagnoses are relatively frequent.

Employing the diagnostic procedure, known medical and surgical techniques are applied in a systematic manner to cure illnesses and correct body malfunctions. Many of the techniques developed in the medical application of the diagnostic technique to correct complex body systems may be useful to the proper identification of disease patterns among hazardous rail-highway grade crossings. From the knowledge gained through the application of the diagnostic techniques, the safety epidemiologist may postulate theories relating to the diseases that he has identified. For example, research in the field of rail-highway grade crossing safety has indicated that factors such as probability of conflict (between automobile and train traffic) and obstructions to the driver's view of trains approaching a grade crossing are contributors to accidents. It has also been determined that the contributions that these factors make to hazardous conditions at grade crossings can be expressed in statistical terms. With this information available, the diagnostic team made up of traffic engineers, railroad signal engineers, highway and railroad maintenance engineers, research and administrative personnel and other related professions are better able to put forth logical ideas for the control of the diseases (hazards) that have been identified and isolated.

ASSIGNING THE DIAGNOSTIC TEAM

The primary factors for consideration in the assignment of the diagnostic team members is first, that the team is interdisciplinary in nature, and second, that it is representative of all groups having responsibility for the safe operation of rail-highway grade crossings.

In order that each of the vital factors relating to the operational and physical characteristics of the crossing may be properly identified, it is necessary that individual team members be selected on the basis of their specific expertise and experience. Figure 1 illustrates the basic organization of the diagnostic team described in this paper. It is to be noted that the overall structure of the team is built on three desired areas of team responsibility. These areas include local responsibility, administrative responsibility and advisory capacity. All operational and physical characteristics of individual or groups of crossings may be classified in one of three areas: (a) traffic operations, (b) signal and communication, and (c) administration. In general, the responsibility of team members within each of these categories may be defined as follows.

Traffic Operation. This area includes both vehicular and train traffic operations. Responsibility of highway traffic engineers and railroad operating personnel chosen for team membership includes among other things specific knowledge of the vehicular and train volume, peak period characteristics, operating speeds, and type of vehicle, including information on train class and length, and automobile-truck-bus makeup of vehicular traffic.

Signal and Communication. The highway maintenance and signal control engineer along with the railroad signal and communication engineer, provides the best source for expertise in this area. Responsibility of these team members includes special knowledge of grade crossing warning and protective signal systems, train communication systems, interconnection of adjacent signalized highway intersections, warning and control devices for vehicle operation, highway signs and pavement markings.

Administration. Since many of the problems relating to rail-highway grade crossing safety involve the apportionment of administrative and financial responsibility, it is necessary to recognize this fact in the membership of the diagnostic team. Members of the team representing this area should be carefully selected from the upper echelon of both highway department and railroad company management. The primary responsibility of these representatives is to advise the team of specific policy and administrative rules applicable to any decision to modify or upgrade crossing protections.

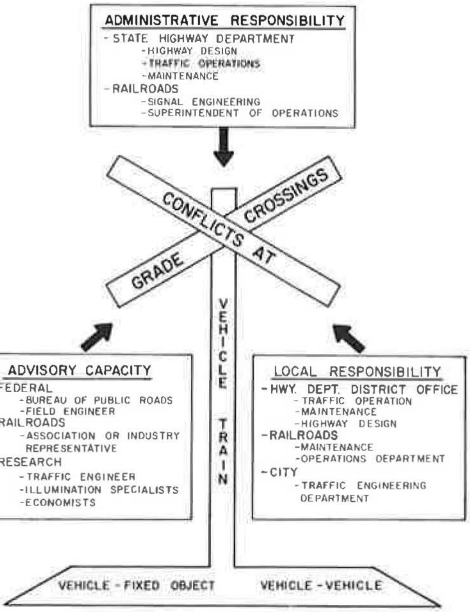

Figure 1. Diagnostic team structure.

In addition to this basic diagnostic team structure, local representatives of highway maintenance, railway signal maintenance, city and county traffic engineers (when applicable), are needed to complete the team membership. The addition of research-oriented advisory personnel to membership on the team provides a highly technical and workable combination of an 8- to 10-member diagnostic team.

Where diagnostic team activities may cover a rather large geographic area, therefore requiring considerable time and travel on the part of team members, it is suggested that the membership be rotated. This practice was employed in the Texas study not only to reduce time and travel requirements of individual members, but also to develop a rather large group of experienced people for future team membership. As a result of this approach, there are currently 65 experienced team members available for assignment to diagnostic teams.

It is suggested that if the rotating membership method is employed, there should be established some degree of continuity among the membership. The permanent membership should have representatives from each of the areas of local responsibility, administrative responsibility and advisory capacity.

SCHEDULING DIAGNOSTIC TEAM ACTIVITIES

The scheduling of team activities will depend primarily on the number of crossings to be studied, the geographic location of the study crossings, and the administrative responsibilities of the highway department, railroad company and cities or counties. Since the State of Texas has an inventory of approximately 2,500 rail-highway grade crossings under the administrative responsibility of the Highway Department, it was obvious that during one fiscal year all crossings could not be evaluated by the diagnostic team. Therefore, it was determined that a sample of 36 crossings would be selected for study. In order that the findings of the diagnostic team would be applicable to the total inventory, classes of crossings representative of all highway department crossing types were established. To be representative, the crossings were classified according to (a) their location in either rural or urban areas, (b) whether or not they had experienced accidents within the last three years, and (c) the type of crossing protective devices, either actuated or non-actuated. Three crossings within each of the twelve classes were selected for study. Another major objective of this phase of the research study was to evaluate the total concept of the diagnostic team approach to grade crossing safety evaluation; therefore, care was taken in the selection of study crossings to insure that as many highway district offices and railroad companies were involved in the study as was feasible.

It was found that once the study crossings had been selected, the scheduling of diagnostic team activities was greatly simplified. The technique used in the research project was to request the responsible and interested agencies to submit qualified personnel, as defined previously, for team membership. Names were submitted by the State Highway Department, Bureau of Public Roads, and the railroad companies. In addition to these, city traffic engineers were invited to participate as members of the team that studied grade crossings located within their respective cities.

The responsibility for scheduling the diagnostic team activities was given to the research project staff. Information relative to the location of each study crossing and the date and hour the team was to assemble to evaluate the crossing was prepared and made available to each diagnostic team participant. Approximately two hours was allocated to each study crossing. No more than six study crossings were to be visited during any one week with all diagnostic work to be accomplished in a period of three months. It is interesting to note that although the schedule was prepared at least a month in advance of the first assembly of the team and the last three crossings visited by the diagnostic team were scheduled some four months in advance, no requests for changes in the schedule were made during the entire study period. Only on three occasions was a team member absent. Since there were more than 65 different people involved in the membership of the various diagnostic teams, this fact speaks well of the interest that can be shown in diagnostic team participation.

DIAGNOSTIC STUDY SUPPORT DATA

The recovery of physical data to supplement and support the diagnostic study of rail-highway grade crossings may be classified by two categories, i. e., operational and environmental characteristics. Operational characteristics include such factors as (a) train and vehicle speed, volume and types; (b) accident records; (c) signalization and signing; and (d) adjacent roadway and railways vehicle and train operations. Environmental characteristics include among other factors (a) roadway geometrics; (b) location of buildings, trees and other structures near the crossing; (c) location of adjacent streets, roadways, and railways; (d) topography of immediate area of the crossing; and (e) population density.

The following data recovery procedures were developed for use in the collection of physical data:

1. Grade Crossing Inventory. From the Texas Highway Department inventory of rail-highway grade crossings compiled jointly by the railroad companies of Texas and the Texas Highway Department, basic information relating to train frequency, speed, etc., was obtained. The highway department and local traffic engineers supplied data relative to vehicle average daily traffic count, distribution by time period, and type of vehicles using the crossing.
2. Inventory of Physical Characteristics. Figure 2 is a reproduction of the data form that was designed to record data relating principally to environmental characteristics of the crossing.
3. Accident Records. The Texas Railroad Commission rail accident report form, Texas Department of Public Safety accident report, and local police accident reports were the primary sources of information necessary to compile these records. A summary of the reports of all accidents occurring at each accident crossing, during the three previous years, was available to the diagnostic team.
4. Aerial Photographs. The highway department provided several aerial views of the study crossings. These photographs were available to the diagnostic team during the crossing evaluations. Since the photographs were produced by photogrammetry methods, they are also suitable for additional analysis through the use of the stereoplotter.

DIAGNOSTIC STUDY PROCEDURE

The first objective of this phase of the study was to determine the manner in which individual member's evaluation of the crossing would be recorded. Previous research at the Texas Transportation Institute employing the diagnostic study technique had revealed that the study questionnaire is a feasible method of collecting these data. The technique of using the critique as a method of recovering each member's observations of the crossing was considered. However, this procedure was rejected because of the relatively large number of participants in the diagnostic study, the lack of adequate methods for noting or recording team member observations and the lack of facilities near the crossing for conducting the critique.

Recognizing that the diagnostic study questionnaire would require field testing and possible revisions, a draft of the questionnaire was prepared for initial diagnostic studies. Subsequent revision to the initial questionnaire design produced an opinion-oriented data recovery form that has satisfactorily met the objective of its intended design.

DIAGNOSTIC STUDY QUESTIONNAIRE[1]

As pointed out previously, the purpose of the diagnostic team study is to determine the conditions that affect safety at rail-highway grade crossings. Therefore, the objective of the questionnaire is to provide a record of the individual team member's evaluation of these conditions at each study crossing.

For organizational purposes the questionnaire is divided into three areas. Two sections are to be completed on each roadway approach and one on the crossing in general. Each of the areas that applies to the crossing approaches is further divided into sections in which driver requirements vary. This may be best explained by referring to Figure 3. Note the placement of traffic cones in the area of the approach illustrated by the drawing. Cone B is placed at the point where the driver must begin making his decision as to whether or not he may safely proceed over the crossing. Cone A is placed where the driver must begin applying his brakes if he is to stop short of the crossing. Both measurements are based on the maximum legal or practical vehicle speed and stopping distance on wet pavements.

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[1] Due to the length of the questionnaire developed for the Texas Study it has not been included as a part of this paper. Copies of the questionnaire may be obtained from the authors.

APPROACH DATA:

SPEED LIMIT ________

GRADIENT:

UP ☐ DOWN ☐ LEVEL ☐

CURVATURE:

RT. ☐ LEFT ☐ STRAIGHT ☐

NO. OF DRIVEWAYS WITHIN 200' ________

HIGHWAY NO. ________

RAILROAD CO. ________

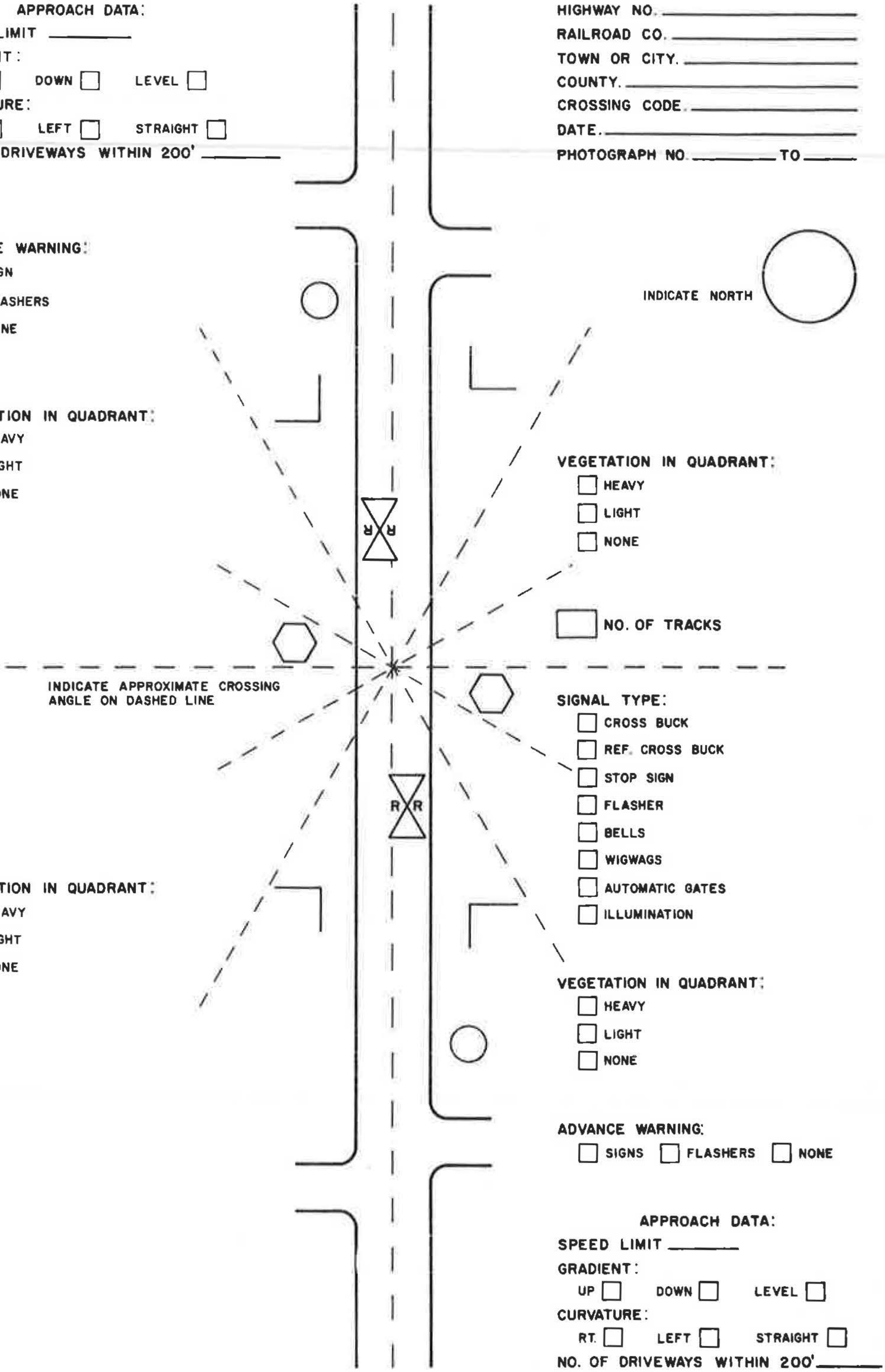
TOWN OR CITY. ________

COUNTY. ________

CROSSING CODE. ________

DATE. ________

PHOTOGRAPH NO. ________ TO ________



ADVANCE WARNING:

- ☐ SIGN
- ☐ FLASHERS
- ☐ NONE

INDICATE NORTH

VEGETATION IN QUADRANT:

- ☐ HEAVY
- ☐ LIGHT
- ☐ NONE

VEGETATION IN QUADRANT:

- ☐ HEAVY
- ☐ LIGHT
- ☐ NONE

☐ NO. OF TRACKS

INDICATE APPROXIMATE CROSSING ANGLE ON DASHED LINE

SIGNAL TYPE:

- ☐ CROSS BUCK
- ☐ REF. CROSS BUCK
- ☐ STOP SIGN
- ☐ FLASHER
- ☐ BELLS
- ☐ WIGWAGS
- ☐ AUTOMATIC GATES
- ☐ ILLUMINATION

VEGETATION IN QUADRANT:

- ☐ HEAVY
- ☐ LIGHT
- ☐ NONE

VEGETATION IN QUADRANT:

- ☐ HEAVY
- ☐ LIGHT
- ☐ NONE

ADVANCE WARNING:

☐ SIGNS ☐ FLASHERS ☐ NONE

APPROACH DATA:

SPEED LIMIT ________

GRADIENT:

UP ☐ DOWN ☐ LEVEL ☐

CURVATURE:

RT. ☐ LEFT ☐ STRAIGHT ☐

NO. OF DRIVEWAYS WITHIN 200' ________

Figure 2. Grade crossing facility inventory.

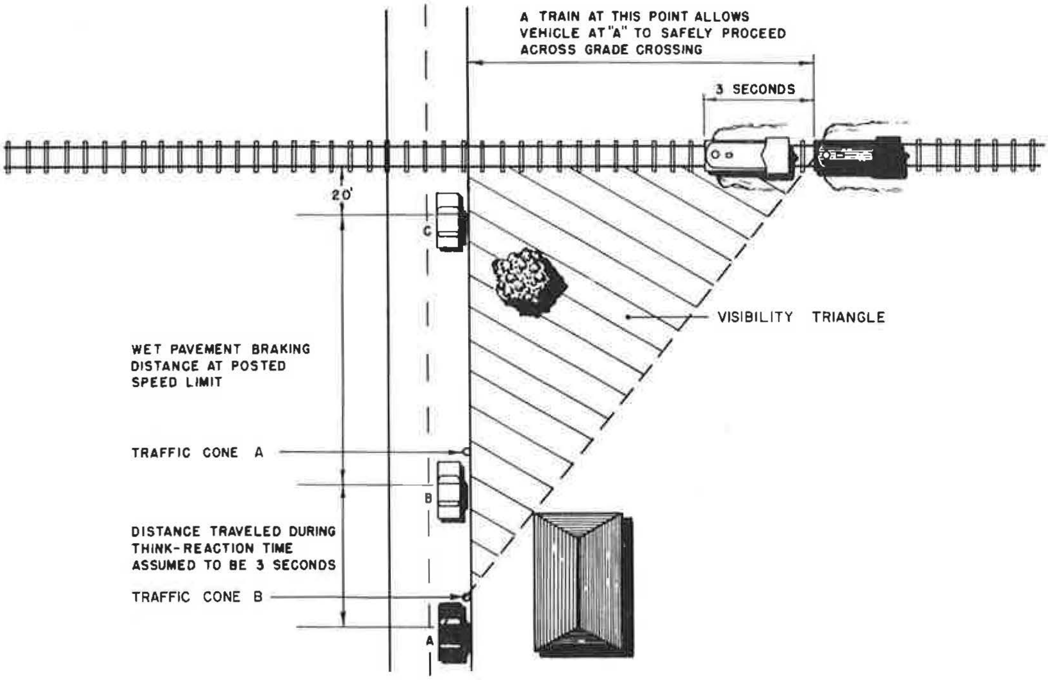


Figure 3. Sight clearance.

Referring again to the organization of the questionnaire, each section may be summarized in the following manner:

Section I. The questions in this section are concerned with whether or not the average driver will be aware of the presence of the crossings. This sense of awareness must be accomplished prior to reaching the first traffic cone so that the driver will be prepared to begin his decision-making process. To properly respond to questions in this section the crossing should be observed in an area of the roadway approaching traffic cone B. Questions in this section of the diagnostic study questionnaire are related to (a) driver awareness, (b) visibility, (c) effectiveness of advance warning signs and signals, (d) geometric feature of the roadway, and (e) repeat driver regard for the crossing.

Section II. The questions in this section are concerned with whether or not the driver has sufficient information to make correct decisions while traversing the crossing. Observations for responding to these questions should be made in the area between the two traffic cones. Where protective devices are installed, questions in this section assume that the devices have been actuated. Factors considered by these questions include (a) awareness of approaching trains, (b) driver dependence on crossing signals, (c) obstruction to view of train approach, (d) roadway geometrics diverting driver attention, (e) location of standing rail cars or trains, (f) removal of sight obstruction, and (g) availability of information for proper stop or go decisions on the part of the driver.

Section III. The questions in this category apply to observations in the section of roadway adjacent to the crossing. Traffic using any adjacent streets or driveways should be observed briefly to determine if traffic not passing over the crossing could affect traffic over the crossing. Questions in this section relate to (a) pavement markings, (b) conditions conducive to vehicle becoming stalled, (c) other traffic control devices contributing to vehicle stopping on the crossing, (d) hazards presented by vehicles required by law to stop at crossings, (e) signs and signals as fixed object hazards, and (f) opportunity for driver evasive action.

General Section. In this section the diagnostic team is given the opportunity to (a) list major features of the crossing that contribute to safety, (b) list features that reduce crossing safety, (c) suggest methods for improving safety at the crossing, (d) give an overall evaluation of the crossing, and (e) provide comments and suggestions relative to the questionnaire.

IMPLEMENTING THE DIAGNOSTIC TEAM STUDY

To describe the manner in which the diagnostic study is implemented, a discussion of the chronological order of events leading to the complete evaluation of a study site may be useful.

Event A—Briefing. As the diagnostic team assembles at the study crossing, informal introductions of team members with special emphasis on individual professional training and job responsibilities are encouraged. With introductions completed, a member of the project staff briefs the team as to purpose and objectives of the study. The questionnaire is then distributed to team members. Instructions are given for the completion of the questionnaire. The first page of the questionnaire has space available for vehicle and train operation data. As this information is made available to the team, appropriate agency respresentatives are asked to verify and update these data. The next step in the briefing is to summarize accident reports and ask for the personal experience of local team members who are familiar with circumstances surrounding the reported accidents. Aerial photographs are then reviewed to give team members a better perspective of the total environment of the crossing.

While the briefing is being conducted, a member of the project staff is locating traffic cones on both crossing approaches according to the criteria discussed previously.

Event B—Driving the Approaches. Team members are assigned to vehicles for the evaluation process. Normally, two vehicles are required for this event. Representatives of railroad, highway, and administrative interests are divided equally between the vehicles. This provides the opportunity for technical questions relating to the crossing operation to be answered in either vehicle. Team members then drive each approach several times in order to become familiar with all conditions that exist on or near the crossing. If the crossing is protected by a signal device, the railroad signal engineer is requested to activate the signals so that flashing light alignment, light intensity, awareness of light and audible signal, and traffic operating over the crossing may be observed. When the team members are satisfied with their familiarity of the driver's view of each approach, the signals are turned off and the evaluation is continued.

Event C—Completion of the Questionnaire. Positioning the vehicles according to the instruction provided by the questionnaire, individual team members answer questions within specific sections of the questionnaire. As each section is completed the vehicle is moved to the next required location until all questions have been answered.

Event D—Inventory of Physical Characteristics. Concurrent with event C, a member of the project staff is completing the physical characteristic inventory form shown in Figure 2. When this is completed, photographs are taken from specified locations. These data and photographs are for the purpose of reconstructing, at a later date, the crossing either with a model or by a drawing.

Event E—Critique. After the questionnaires have been completed, the team is reassembled for a short critique and discussion period. At this point the questionnaires have been collected; therefore, opinions expressed during this session do not bias individual team member questionnaire responses. The critique begins with a permanent member of the team summarizing his observations as to conditions that exist at the crossing. This generally leads to a discussion by team members of possible ways to improve the safety of the crossing. Other areas are open for discussion during this period including better means of communication and cooperation between agencies represented by the diagnostic team members.

RESULTS OF THE DIAGNOSTIC TEAM STUDY

The primary purpose of this paper has been to describe the diagnostic study technique as it applies in the medical profession and relate the applicability of this approach to rail-highway grade crossing safety evaluation. However, the results of the diagnostic team activities in the conduct of a Texas Highway Department-Bureau of Public Roads cooperative project should be of value in determining the effectiveness of the diagnostic team in Federal, state, county, and city grade crossing safety evaluation programs.

Based on conditions observed by the diagnostic team at each of the study crossings, 60 percent of the study crossings were considered to be fairly safe or safe, whereas the remaining 40 percent were rated as either unsafe or hazardous.

Table 1 gives the unsafe conditions observed and reported by the team in order of their frequency of mention. From Table 1 it may be seen that pavement markings were mentioned in the report of unsafe conditions at 72 percent of the study crossings. Also, 60 percent of the study crossings may experience unsafe conditions due to the requirement that certain vehicles must stop at all crossings. Approximately 50 percent of the study crossings were observed as having driver visibility obstructed due to heavy vegetation growth. Illumination, signing, signalization, and fixed-object hazards were mentioned with approximately the same frequency; whereas roadway geometrics, maintenance of railroad devices and traffic conditions on adjacent roadways were the least frequently observed unsafe conditions.

Following the listing of unsafe conditions at each study crossing, the diagnostic team was requested to make recommendations for the improvement of these conditions. Table 2 gives specific recommendations made for grade crossings included in this study. For purposes of this analysis the recommendations have been grouped into three

TABLE 1

UNSAFE CONDITIONS OBSERVED BY DIAGNOSTIC TEAM AT STUDY RAIL-HIGHWAY GRADE CROSSINGS

Conditions Observed	Percent of Crossings at Which Conditions Observed
1. Pavement markings missing, improperly located or in need of maintenance	72
2. Vehicles required by law to stop at all crossings would present a hazard to other vehicles by blocking traffic lanes and obstructing view of protective device	60
3. Driver's visibility of railroad approach obstructed by growth of vegetation	52
4. Under nighttime conditions lack of illumination presents additional hazards at grade crossing	44
5. Conflicts for driver's attention due to traffic conditions and the location of traffic control devices on adjacent roadways	40
6. Advanced warning signs missing, improperly located or in need of maintenance	40
7. Absence of area immediately adjacent to grade crossing for the driver to take evasive action	36
8. Highway signs and fixed objects obstructing driver's view of protective and warning devices	32
9. Fixed mount protective devices or barriers presenting fixed object hazard to vehicles	32
10. Legally parked vehicle would block driver's view of protective and warning devices	28
11. Geometrics of roadway design contribute to unsafe conditions at the crossing	20
12. Railroad protective device not properly located or maintained	12
13. Traffic conditions on adjacent roadway conducive to vehicles becoming stalled or stopped on railroad tracks.	8

TABLE 2

DIAGNOSTIC TEAM RECOMMENDATIONS FOR THE IMPROVEMENT OF SAFETY AT STUDY RAIL-HIGHWAY GRADE CROSSINGS

I. Maintenance and Relocation of Protective Devices, Signs and Pavement Markings.

1. The addition of vehicle stop lines on approach to crossing.[a]
2. Advance warning sign pavement markings be added or relocated to conform with vehicle approach speed.[a]
3. The removal of vegetation to provide adequate sight distance on the approach to the crossing.
4. A safety zone be provided in the area immediately adjacent to the crossing to provide the driver with an opportunity to take evasive action.
5. Protective device be located away from edge of roadway or be replaced with breakaway design.
6. Eliminate parking on all approaches to the crossing to insure driver visibility at the crossing.
7. Protective devices be maintained on a continuing basis.
8. Removal of fixed objects to provide an unobstructed view of the crossing.
9. Relocation of traffic sign obstructing view of protective and warning devices.

II. Installation of Actuated Protective and Warning Devices

1. Addition or relocation of advanced warning signs to conform with vehicle approach speed.
2. Illumination be installed to increase nighttime safety at the crossing.
3. The installation of flashing lights at crossings protected only with crossbucks.
4. Installation of larger diameter advance warning sign.
5. Installation of actuated advanced warning sign.
6. Installation of cantilever-type actuated signals.
7. Interconnect traffic signal with actuated flashing device.
8. Install control signs at cross streets intersecting crossing approach.

III. Widen Existing Roadway or Add Traffic Lanes to Crossing Approach

1. Addition of traffic lanes at the crossing approach for vehicles required by law to stop at all crossings.
2. Widen roadway in area adjacent to the crossing.
3. Realign roadway approach to crossing.

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[a] Proper maintenance of pavement markings be accomplished on a continuing basis was included in these recommendations.

categories. Listings of the recommendations within each group are according to their frequency of mention by the diagnostic team.

An analysis of the recommendations indicates that more than 60 percent were directed specifically to the maintenance of signals, signs, and pavement markings. Although approximately 50 percent of the study crossings were protected only with crossbuck signs, less than 30 percent of the diagnostic team recommendations were concerned with or involved the installation of actuated protective and warning devices. Recommendations for widening existing roadway or the addition of traffic lanes at the approach to the crossing made up the remaining 10 percent of the team's suggestion for safety improvement.

SUMMARY AND CONCLUSIONS

The results of the Texas Study suggest that the diagnostic team study technique, applied to the evaluation of rail-highway grade crossing safety, contributed to a safety program in the following manner:

1. The diagnostic team approach provides a highly reliable method for identifying, isolating, and measuring factors that contribute to unsafe conditions that exist at rail-highway grade crossings.
2. The diagnostic team provides a basis for determining not only which crossings should be protected, but more importantly what type of protection should be employed in order to achieve acceptable levels of safety among all crossings.
3. The diagnostic team provides recommendations for improving and upgrading existing protective equipment, roadway, and railway with minimum expense to responsible agencies.

4. The diagnostic team develops recommendations for on-the-spot safety measures such as the relocation of signals and signs, alignment of flashing lights, replacement of broken or worn signs or signal apparatus, upgrading pavement markings, relocation of public or railroad property, and other measures to reduce accident potential at specific crossings.

5. The diagnostic team provides an interdisciplinary approach to the solution of a common problem by utilizing technology acquired by each of the professions represented in its membership.

6. The diagnostic team develops a line of communication between groups and individuals who are responsible for the safe operation of rail-highway grade crossings.

Discussion

B. M. STEPHENS, Southern Pacific Company —In the twelve or so decades that have elapsed since establishment of a system of transporting people and goods by rail, the problem of safety at rail-highway grade crossings has expanded to alarming proportions in spite of the efforts of dedicated and knowledgeable engineers and traffic analysts and the expenditures of monumental sums of money for improvements.

Rail-highway and highway-highway intersections at grade, in the real economic sense, exist for precisely the same reason: to permit two streams of land traffic, in meeting demands for transportation service, to move in intersecting directions to provide this service to land areas under settlement and development. The grade crossing problem is such that it can be credited, with complete justification, to the outstanding economic growth of the nation.

It would be a work of supererogation to catalog and outline the many formulas for evaluating and indexing hazards at rail-highway grade crossings. There are close to two dozen such formulas generally reliable for computing relative hazard and differing basically only in the degree of their analytical sophistication. Unhappily, these formulas deal with the grade crossing safety problem on the basis, essentially, of engineering applications without full recognition of the fact that the problem is a complexity consisting of at least six other equally important elements identified as administrative policies, political ramifications, economic considerations, legal aspects, public relations, and accident analyses. For those interested in details, eleven crossing evaluation formulas have been outlined (1, 2).

In too many instances, decisions to protect rail-highway intersections are the direct result of pressures brought about by emotional outcries of individuals or small groups. In this day of extensive communication systems, the news media, through editorials and television documentaries, provide an opportunity for the thoughts and demands of individuals and small groups to be exposed to a large segment of the citizenry on a daily basis. Without regard to or consideration of the relative hazardous conditions existing with respect to other crossings, action on the part of public officials and railroad companies is demanded immediately. To complicate the problem further, little or no effort is spent in determining what type of protection is best suited for the unique characteristic of the individual crossing to be protected. How often in this decision process are the traffic engineer, railroad signal enginner, design engineer, railroad operating personnel, local law enforcement agencies, and maintenance engineers asked to participate in the selection of which crossing is to be protected, when it is to be protected, and how it should be protected?

It is evident with respect to the gravity of the grade crossing safety problem, despite unnumbered investigations and analyses, the profusion of published and unpublished reports and papers, and existence of some two dozen or so hazard rating or hazard index formulas, that efforts expended and measures adopted are not resolving the problem with notable success nor, in truth, keeping pace with it. Therefore, distinguished analysts and engineers have set out to explore and to endeavor to develop every newly postulated and conceivable avenue of approach, far-fetched or not. Two particular avenues of approach appear to be promising: (a) the utilization of engineering-economic analysis in evaluating grade crossings, and (b) the diagnostic team approach to rail-highway grade crossing safety evaluation.

The diagnostic team technique is not new nor untried in the annals of science. For many years, medical science has applied such technique in the identification and treatment of illnesses and malfunctions in the complex living body systems of both man and beast. On the premise that rail-highway grade crossings induce a complex arrangement of many characteristics and variables (any one of which may contribute to a train-vehicle collision), practicality of employing the diagnostic technique in examining grade crossing safety problems was suggested in papers presented at the 1967 Grade Crossing Safety Symposium at Texas A&M University. That the diagnostic technique theory can be deemed meritorious is revealed by Federal Highway Administration Instructional Memorandum of January 5, 1968, supplemented on January 25, requesting State Highway Departments, among other things, "to form a diagnostic team comprised of representatives of appropriate State agencies, the railroad companies, the Bureau of Public Roads, and others as needed to consider on-the-scene improvements at grade crossings."

In the meanwhile, Texas Transportation Institute undertook to implement the diagnostic team technique in the manner and with results as outlined and described in detail by the authors of the paper under discussion. It was my privilege to take part in several on-site investigations as a member of the diagnostic team and I found that completing the questionnaire (comprised of some 65 questions and personal observations about conditions) that was presented to team members taxed the acumen and ingenuity of the members, all of whom were experienced engineers or analysts in the field of rail-highway grade crossings.

The paper will be of significant interest to those who are aware of the severity of the grade crossing safety problem and who wish to implement a program for the resolution of it. It is likely that some modification of team constituency and procedure and some rephrasing and reorganization of questionnaire content may be necessary to more completely achieve the purpose. To this end, effectual discussions and concise and probing questions should tend to enhance the effectiveness of the diagnostic team technique.

It would seem that the authors of the paper have attempted to describe a procedure by which emotional criteria may be replaced with technical criteria in development of a grade crossing protection program designed to give maximum return for each dollar invested and to weave into the pattern of deliberation not only the element of engineering application but also at the minimum, those elements of accident analyses, administration policies, economic considerations, and legal aspects.

Too often, much of the grade crossing protection work has been done without meaningful knowledge of the "illnesses" of the crossings protected with the consequence that desired results were frequently only partially obtained and sometimes not at all. The apparent success of the initial application of the diagnostic theory to evaluation of grade crossing safety problems, as outlined and described in the paper, would indicate that a remarkably useful tool is available for use in resolving such problems and that the diagnostic team approach should contribute substantially to achievement of better results in grade crossing safety evaluation programs.

References

1. Automotive Safety Foundation. Railroad Grade Crossings (rev. 1968) Chapter 1. ASF Publ. Series: Traffic Control and Roadway Elements—Their Relationship to Highway Safety.
2. American Railroad Engineering Association. Proc., Vol. 50, p. 244-252.

HOY A. RICHARDS, NEILON J. ROWAN, and ERNEST W. KANAK, Closure—Although the paper stresses the evaluation of the crossing site by experts in the field of highway-railway design, maintenance, and operations, attempts were made to determine driver reaction at the crossing by placing team members in the position of the driver during the evaluation process. No attempt was made to study human factors as related to driver performance at rail-highway grade crossing intersections. It is recognized in the paper that financial responsibility is a significant factor to the solution of the rail-highway grade crossing problem. It is the opinion of the authors that the upper echelon of both the highway department and railroad company management should determine policy as to apportionment of the administrative and financial responsibility. This does not necessitate participation in the on-the-site activities of the diagnostic team. However, diagnostic team reports should be prepared in such a manner that administrative decisions may be clearly drawn from these studies.

Most of the study crossings were inspected during both daytime and nighttime conditions. Due to the climactic conditions of the geographic regions in which this study was conducted, the only unfavorable weather conditions under which the studies were made occurred during rain storms and heavy cloud conditions.

At the suggestion of one of the discussants, the final draft of this paper included conditions observed at the study crossings along with specific recommendations for improving safety at these crossings.

Using a priority rating system for ranking all crossings within the responsibility of the state highway department, only those crossings that are indicated to be the most hazardous should be investigated by diagnostic teams. It was not the intention of this paper to suggest that all crossings should be evaluated by diagnostic teams. In the opinion of the authors, the expenditures of the diagnostic team activities are minor compared to the cost of annualized improvement and maintenance cost at grade crossings. It is apparent from the field work reported in this paper that the most significant contribution of the diagnostic team is its ability to recommend the best available protective equipment to meet the unique requirements of individual crossings.

It is the opinion of the authors that the diagnostic study questionnaire is only one method for recording the response of team members. Other techniques may be better suited for conditions that exist in future studies; therefore, only a summary of the questionnaire was included in the paper. In addition, the length of the questionnaire precluded its publication; however, copies are available from the authors.

Evaluation of Rail-Highway Grade Crossing Protection in Rural Areas

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The purposes of this research investigation were to analyze the effects of environment, geometric characteristics, and highway and railroad traffic patterns with respect to grade crossing accidents in rural areas, and to develop warrants for protective devices at rural grade crossings. Previous research efforts have been concerned with long period accident experience or with before-and-after studies of various protective devices. In this research, 289 grade crossings that had experienced one or more accidents were compared to 241 randomly selected non-accident grade crossings.

Regression analysis was used to develop a model for predicting relative hazard, the occurrence or absence of an accident, for the sample locations. Relative hazard was expressed as a function of average daily highway traffic, average daily train traffic, roadside distractions, pavement width, and number of tracks. Modification of the model permitted the development of warrants for selecting the recommended type of protective device for crossings in rural areas. These warrants are predicted on protection levels that are currently employed at rural rail-highway grade crossings in Indiana.

•THE ACCIDENTS between motor vehicles and trains, though infrequent, are the most severe in terms of fatalities, personal injuries and property damage per accident of all types experienced on highways in the United States. Because of the large number of crossings and the large expenditures involved, it is not economically feasible to eliminate all crossings or even to provide all crossings with the most effective types of protection. The most logical procedure is to develop rational warrants for grade crossing protective devices. The level of protection would then be based on an objective evaluation of the potential hazard at any given location.

This study constitutes a quantitative analysis of rural rail-highway grade crossing accidents with respect to the relative importance of environment, crossing geometry, highway and rail traffic patterns, and existing protective devices. Proper use of the mathematical model that was developed permits an estimation of hazard at rail-highway grade crossings in rural areas. In addition, the model may be utilized to determine recommended levels of protection and to establish priorities for improving grade crossing protection.

PROCEDURE

Because previous research investigations had achieved only a limited degree of success in predicting grade crossing accident rates, locations that experienced an accident during a two-year period were compared to non-accident locations in an attempt to develop realistic correlations between hazard and various grade crossing characteristics. The 289 accident locations, which included most of the rural crossings in Indiana with at least one accident in 1962 and 1963, were established by using the

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Paper sponsored by Committee on Traffic Control Devices.

traffic accident reports of the Indiana State Police. The 241 non-accident locations were randomly selected in the following manner:

1. The railroad lines were outlined on a map of Indiana;
2. Railroad mileage for each county was measured on the map;
3. By simple proportion based on railroad mileage, each county was allocated a number of the total non-accident locations to be investigated; and
4. The allocated number of railroad crossings in each county was selected from county maps.

To ascertain that each non-accident crossing represented an accident-free location, the nearest available residents to the crossing were asked about accidents at the proposed study location. If an accident had occurred at the location, the crossing was eliminated from the analysis. The railroad companies also checked their records for accidents at these non-accident locations.

Data Collection

All possible variables that could be realistically evaluated were investigated for this accident study. Many variables were evaluated subjectively by use of dichotomous values (0 or 1) that represent the absence or the presence of a situation. The information for the following 56 selected variables came primarily from police accident reports, field investigations, and railroad correspondence.

Accident Data (Accident Locations Only)—

1. Vehicle type (0 if car, 1 if truck).
2. Age of vehicle—years.
3. Out-of-county vehicles (0 if in-county, 1 if out-of-county).
4. Out-of-state vehicle (0 if in-state, 1 if out-of-state).
5. Number of occupants in vehicle—driver plus passengers. This variable was included because of the possible distraction caused by passengers.
6. Actual vehicle speed—miles per hour. The speed of the vehicle was not always listed on the accident report. The speed was then approximated by driving the approach to the crossing at the speed that the investigator considered a maximum safe speed for the highway and then subtracting 10 mph.
7. Actual train speed—miles per hour.
8. Vehicle defects (0 if no defects, 1 if defects were indicated). This variable indicated whether or not mechanical defects were a contributing factor to the accident.

9-11. Surface type—portland cement concrete, asphalt, or gravel, respectively (0 if absent, 1 if present for each type). These three variables were also applicable to the non-accident locations, and the data for them were obtained from field observations.

12. Dry pavement (0 if dry, 1 if wet or covered with ice or snow).
13. Ice or snow (0 if dry, 1 if covered with ice or snow).
14. Clear weather (0 if clear, 1 if cloudy).
15. Darkness (0 if daytime, 1 if nighttime). This variable was defined as darkness if the accident occurred between 6:00 p. m. and 6:00 a. m.
16. Window position (0 if window down, 1 if window up). The investigating officers often reported that the windows were up (and/or radio playing), and the driver possibly could not hear either the warning bell or train whistle. If the accident report did not indicate this information, the time of day, time of year, and reported weather conditions were used as guides.
17. Drinking driver (0 if not drinking, 1 if drinking).
18. Male or female driver (0 if female, 1 if male).
19. Driver age—years.
20. Personal injury (0 if no personal injury, 1 if personal injury). A fatality was considered a personal injury for this variable.
21. Fatality (0 if no fatality, 1 if fatality).

22-28. Day of the week—Sunday through Saturday, respectively (0 if not on a certain day, 1 if on the day).

Field Data (All Locations)—The following field data were recorded for the approach quadrant where an accident occurred at accident locations and for one randomly selected quadrant at non-accident locations. Variables 29 to 35 were coded as 0 if not existing, 1 if existing.

29. Painted crossbuck.
30. Reflectorized crossbuck.
31. Flasher.
32. Gate.
33. No protection.
34. Stop sign.
35. White edge line.
36. Highway gradient—percent.
37. Railroad gradient—percent.
38. Highway curvature—degrees.
39. Railway curvature—degrees.
40. Number of tracks.
41. Pavement width—feet.
42. Advance warning sign (0 if not existing, 1 if existing).
43. Pavement crossing markings (0 if not existing, 1 if existing).

44. Number of businesses. This variable represents the number of business establishments located a distance of one-half mile along the approach to the railroad crossing on both sides of the roadway.

45. Number of advertising signs—measured similarly to variable No. 44.

46. Presence of minor obstructions (0 if not obstructed, 1 if partially obstructed). This variable considered such things as brush or trees which would partially obstruct the view of an approaching train.

47. Number of houses—measured similarly to variable No. 44.

48. Line of sight. This variable represents the angle at which a motorist could first view an approaching train when the vehicle is at a distance from the crossing equal to the stopping sight distance as determined either by the speed limit or maximum safe speed of the highway. The sine of the angle included between the highway and the first view of an approaching train was recorded to three decimal places.

49. Angle of intersection—degrees.

Railroad Data (All Locations)—

50. Average number of passenger trains per day.
51. Average number of freight trains per day.
52. Average freight train speed—miles per hour.
53. Average passenger train speed—miles per hour.
54. Average number of trains per day—TPD.

Vehicular Traffic Data (All Locations)—

55. Average daily traffic—ADT.

56. Average vehicle speed—miles per hour. Determined as described in discussion of variable No. 6.

Statistical Analyses

Summary statistics were developed for all study variables. Regression analysis was then performed on the 28 variables common to both accident and non-accident locations. Three other common variables—railway gradient, stop sign, and no protection—were not included due to insufficient data. The dependent variable was accident occurrence, a dichotomous variable representing occurrence or non-occurrence of an accident (0 if a non-accident location, 1 if an accident location). Relative hazard was defined as the functional relationship between the dependent variable and the independent variables.

The regression analysis that was utilized is often referred to as "buildup" or "stepwise" regression. The independent variables are selected in order of their ability to predict the dependent variable. However, the program allows the ordering of the variables and thus permits the development of a practical model. During the analysis, train and highway traffic volumes were ordered to permit their inclusion in the multiple regression expressions.

The regression model was then used to develop warrants for selecting the type of protection device recommended at rural grade crossings, as based on current levels of protection in Indiana.

RESULTS

Summary Statistics

Descriptive statistics of grade crossings located throughout the State of Indiana were developed from the results of both this investigation and a similar study of urban grade crossings in Indiana (5, 11). Several predominant patterns were observed when urban and rural grade crossing accidents were analyzed with respect to the statistics given in Table 1. Male drivers were involved in most of the grade crossing accidents, while the percentage of female drivers who had accidents was greater in urban areas than in rural areas. Most grade crossing accidents occurred within the city or county in which a motorist resided. Each of these facts can be attributed to driver exposure; that is, most drivers in both urban and rural areas are male, and the percentage of female motorists is greater in urban areas than in rural locations. In addition, most vehicle trips are made within close proximity to the driver's place of residence.

Drinking drivers were more frequently involved in motor-vehicle-train accidents in urban areas than in rural areas. This finding may be explained by the greater number of taverns and bars in urban areas.

In approximately 65 percent of the urban accidents, drivers apparently were unaware of the presence of a train or willfully disregarded an automatic warning device. The high severity of all grade crossing accidents was shown by the fact that a fatality

TABLE 1

CHARACTERISTICS OF SAMPLED RAIL-HIGHWAY GRADE CROSSING ACCIDENTS

Variable	Urban Locations[a]	Rural Locations
Driver:		
Average driver age, yr	37	36
Drivers who were male, %	78	86
Drivers who resided in the city in which the accident occurred, %	65	—
Drivers who resided in the county in which the accident occurred, %	85	72
Drivers who resided in the State of Indiana, %	96	94
Accident reports that indicated the driver had been drinking, %	11	6
Accidents in which the driver apparently was unaware of the train or an automatic warning signal, %	38	—
Accidents in which the driver apparently disregarded an automatic warning signal or a flagman, %	27	—
Accidents that resulted in at least one personal injury, %	39	48
Driver: (continued)		
Accidents that resulted in at least one fatality, %	10	14
Average property damage loss, $	871	—
Vehicle:		
Trucks, %	12	27
Average vehicle age, yr	5.1	5.2
Accidents in which the vehicle skidded or was out of control, %	21	—
Vehicle that evidenced contributing mechanical defect, %	3	17
Environmental:		
Accidents that occurred during clear weather, %	76	74
Accidents that occurred during the hours of darkness, %	45	36
Pavement surface condition:		
Dry, %	60	57
Wet, %	20	16
Covered with ice or snow, %	20	27

[a] This sample consisted of 295 accidents that occurred during 1963 and 1964 in urban portions of Indiana.

or personal injury occurred in 62 percent of the rural accidents and 49 percent of the urban accidents. This difference in severity was probably due to higher train and vehicle speeds in the rural areas.

The percentage of trucks involved in grade crossing accidents was more than twice as high in rural areas than in urban centers. This result can be attributed to the higher percentage of trucks traveling on rural highways. Contributing mechanical defects in a motor vehicle were more frequent in rural accidents, although the average vehicle age was almost identical for each group.

The importance of environmental conditions was quite apparent from the descriptive statistics. Although about 25 percent of the accidents occurred during some form of precipitation, about 40 percent took place on pavements that were wet or covered with ice or snow. Also, there was a high frequency of grade crossing accidents during the period from dusk till dawn when vehicle and train volumes are usually low. These facts indicate the influence of poor visibility on the occurrence of accidents at rail-highway grade crossings.

The data in Table 2 represent a summary of the physical features and characteristics of the accident and non-accident grade crossings investigated in both the rural and the urban studies. The frequency of an occurrence is represented by a percentage, and all other measures represent mean values.

Regression Analysis

Regression analyses were performed on the 28 variables measured at both accident and non-accident locations. The dependent variable for each equation was accident occurrence; that is, whether or not an accident had occurred at the study location.

An equation was developed to account for the various protective devices, train and highway volumes, and those additional variables that significantly influenced accident occurrence. This analysis produced the following prediction equation:

$$IH = +\ 0.149 - 0.376X_{29} - 0.300X_{30} - 0.383X_{31} - 0.331X_{32} + 0.082X_{40} + 0.0223X_{41} + 0.011X_{54} + 0.0142X_{55} + 0.024X_{57} \qquad (1)$$

where

IH = index of hazard (accident occurrence),
X_{29} = presence of a painted crossbuck (0 if absent, 1 if present),
X_{30} = presence of a reflectorized crossbuck (0 if absent, 1 if present),
X_{31} = presence of a flasher (0 if absent, 1 if present),
X_{32} = presence of a gate (0 if absent, 1 if present),
X_{40} = number of tracks,
X_{41} = pavement width in feet,
X_{54} = trains per day—TPD,
X_{55} = average daily traffic per 1000—ADT/1000, and
X_{57} = sum of distractions.

In addition to the protection variables, Eq. 1 also includes variables that are measures of train and highway volumes. The type of rail and highway operations are represented by the variables designated as number of tracks and pavement width. The number of roadside distractions (houses, businesses and advertising signs) also proved statistically significant in the regression analysis. The multiple coefficient of determination, R^2, for Eq. 1 was 19.3 percent.

The regression coefficients of the four protective devices were remarkably similar. To ascertain the statistical significance of the coefficients for the protection variables, a second multiple regression equation was developed that excluded the four types of crossing protection and included the remaining variables. The coefficient of determination for Eq. 2 was 18.3 percent.

$$IH = -0.185 + 0.079X_{40} + 0.021X_{41} + 0.011X_{54} + 0.013X_{55} + 0.024X_{57} \qquad (2)$$

TABLE 2

COMPARISON OF SAMPLED RAIL-HIGHWAY GRADE CROSSING CHARACTERISTICS

Variable	Urban Locations[a]		Rural Locations	
	Accident	Non-Accident	Accident	Non-Accident
Protective device:				
Painted crossbuck, %	20	19	53	69
Reflectorized crossbuck, %	11	11	23	20
Flasher, %	48	44	18	9
Gate, %	8	15	4	1
Roadway characteristic:				
Speed limit, mph	27	26	—	—
Railroad advance warning sign, %	21	21	69	72
Railroad pavement marking, %	5	6	10	4
Number of lanes	2.3	2.1	—	—
Painted centerline, %	47	24	—	—
Curb and gutter, %	58	47	—	—
Curb parking, %	56	67	—	—
Traffic signal within 200 ft of crossing, %	7	1	—	—
Illuminated roadway, %	19	7	—	—
Pavement width, ft	32	27	20	17
Pavement type:				
Portland cement concrete, %	14	9	7	1
Asphalt, %	83	86	75	43
Brick, %	1	3	—	—
Gravel, %	2	2	18	56
Local classification, %	31	60	—	—
Collector classification, %	43	28	—	—
Arterial classification, %	26	12	—	—
Roadside characteristic:				
Residential locality, %	30	57	—	—
Commercial locality, %	36	28	—	—
Industrial locality, %	34	15	—	—
Minor obstruction, %	49	41	70	77
Adjacent high-volume intersection, %	10	3	—	—
Number of businesses	5.0[b]	3.1[b]	1.6	0.8
Number of advertising signs	4.8[b]	2.5[b]	0.6	0.1
Number of dwellings	5.5[b]	7.9[b]	3.1	1.9
Roadside characteristic: (cont'd)				
Number of access points	8.5[b]	8.6[b]	—	—
Number of intersections	2.2[b]	2.6[b]	—	—
Number of loading zones	0.8[b]	0.6[b]	—	—
Railroad crossing characteristic:				
Number of tracks	2.4	2.0	1.4	1.2
Number of mainline tracks	1.4	1.3	—	—
Rough crossing, %	58	67	—	—
Railroad yards, %	16	4	—	—
Passenger station, %	4	4	—	—
Illuminated crossing, %	3	2	—	—
Tracks located parallel to center line and within the pavement of a roadway, %	5	5	—	—
Grade, %	—	—	1.0	1.0
Angle of intersection, deg	93	89	94	90
Line of sight	—	—	0.58	0.58
Traffic characteristic:				
Average daily traffic	4,861	2,299	1,185	342
Average passenger train speed, mph	18	16	44	41
Average freight train speed, mph	23	25	40	39
Average switching movement speed, mph	6	5	—	—
Average passenger trains per day	3.4	2.6	2.9	1.8
Average freight trains per day	11.0	8.0	9.8	7.0
Average switching movements per day	10.0	2.9	—	—
Average train speed, mph	21	24	41	39
Average trains per day	24.3	13.4	12.7	8.8
Average speed of fastest trains, mph	27	28	—	—
Percentage of non-scheduled trains per day, %	35	26	—	—
Exposure rate	132.7	28.0	—	—

[a] This sample consists of 576 grade crossings in urban portions of Indiana, 281 of which did not experience an accident during the 5-yr period from 1961 to 1965.

[b] Measured on both sides of the roadway along a section extending 500 ft from the crossing to 200 ft beyond the crossing, for one approach direction.

where

IH = index of hazard,
X_{40} = number of tracks,
X_{41} = pavement width in feet,
X_{54} = trains per day—TPD,
X_{55} = average daily traffic per 1000—ADT/1000, and
X_{57} = sum of distractions.

An F-test was used to test the hypothesis that the inclusion of the four protective devices in Eq. 1 did not significantly improve the prediction equation. The calculated F-value was 1.61 as compared to a critical value of 2.39 for the 95 percent level of confidence. Because the calculated value is less than the critical value, the hypothesis that the protection coefficients are equal to zero was not rejected. This analysis did not show that protective devices had a significant influence on the prediction of the occurrence of an accident at the sample grade crossings. Although the protective device variables can be eliminated from the prediction equation, the result of this significance test does not warrant the conclusion that protective devices have no influence on reducing hazard. This lack of significance probably resulted from a combination of several factors that were inherent in the study procedure. In reviewing the procedure, it was decided that although the accident locations provided a broad representation of all types of rural grade crossings, the non-accident locations were not as well distributed. Specifically, each type of protective device tended to be clustered within a group of grade crossings having similar physical and traffic characteristics. Therefore, the protective-device variables probably did not function as statistically independent variables.

Regarding the predictive ability of the models, it should be noted that the dependent variable, occurrence or non-occurrence of an accident at a study location, is a dichotomous rather than a continuous variable. Therefore, the index of hazard should not be interpreted as an accident rate, and the relatively low multiple coefficient of determination for the hazard prediction models might readily be expected.

Warrants for Protection Devices

Because the inclusion of the protection variables in the hazard model did not materially improve the estimation of hazard and because the types of protective devices were almost equally weighted, the nomograph shown as Figure 1 was developed from Eq. 2. In an attempt to correlate the index of hazard with the present standards of installing protective devices at rural grade crossings, the mean indices of hazard were calculated for the study crossings protected with reflectorized crossbucks, flashers, and gates. These mean values were, respectively, 0.523, 0.774, and 0.828. A suggested warrant for the selection of rural grade crossing protection was established by computing the average value between the mean index of hazard for the various protective devices. Thus, flashers would be recommended if the index of hazard is greater than 0.65, and gates would be recommended for indices greater than 0.80. The values suggested for these warrants are based on current levels of protection in Indiana. Painted crossbucks were not included in the nomograph because all crossbucks are required to be reflectorized by state law. Although many painted crossbucks are presently in service in Indiana, these devices are to be replaced with reflectorized crossbucks.

When the nomograph is used to evaluate a grade crossing, each approach direction to the crossing must be considered. The approach requiring the highest type of protective device, as indicated by the suggested warrants, establishes the protection recommended for that rail-highway grade crossing.

To check the adequacy of Eq. 2 and the appropriateness of the suggested warrants, the average calculated indices of hazard for the crossings studied were compared to the actual hazard as defined by the number of accident locations, A, per number of

$$IH = -0.185 + 0.079\, X_{40} + 0.021\, X_{41} + 0.011\, X_{54} + 0.013\, X_{55} + 0.024\, X_{57}$$

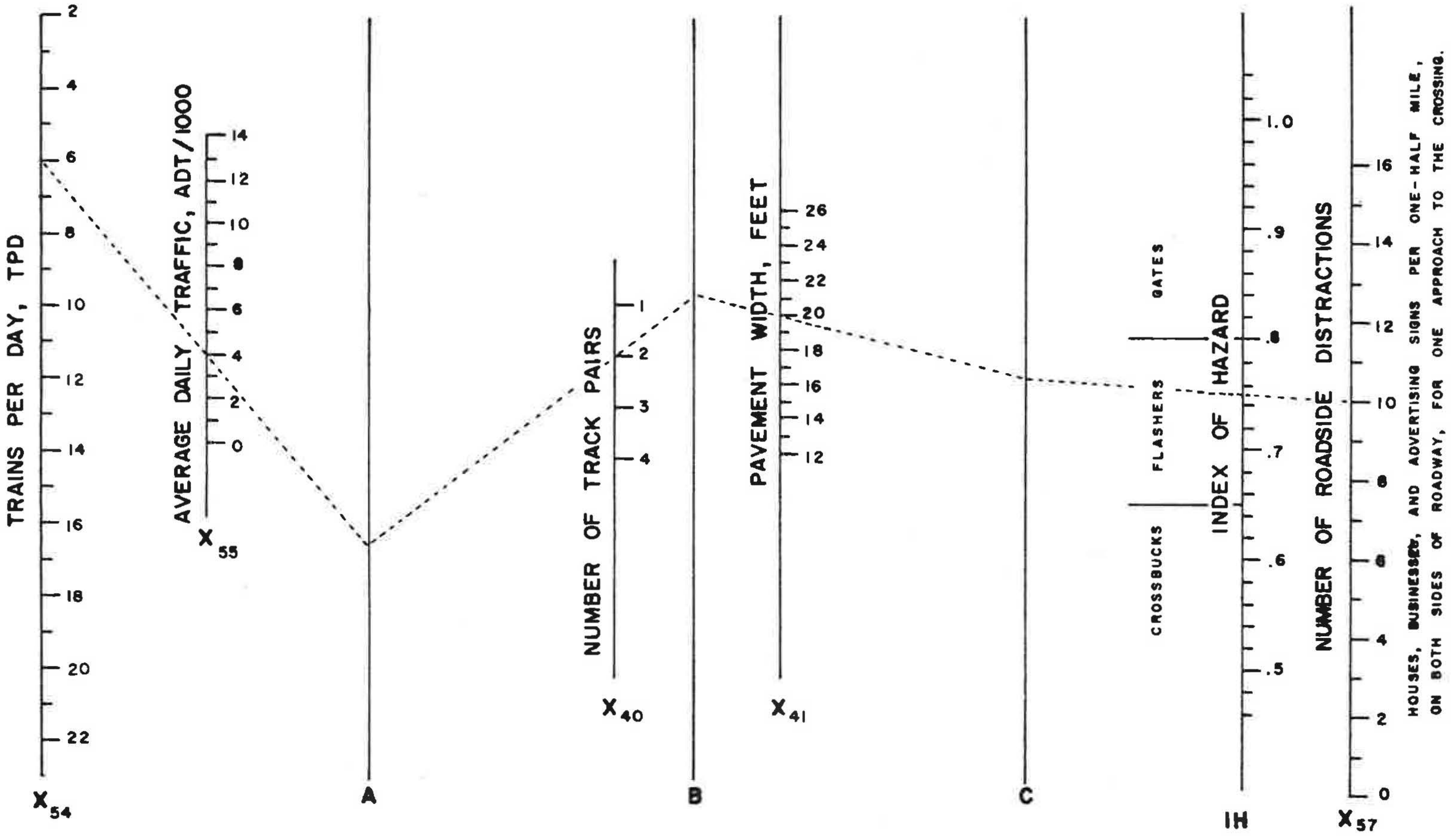

Figure 1. Protection nomograph-grade crossings located in rural areas of Indiana.

locations investigated, N, for each type of protection. The comparison is given below:

Type of Protection	Calculated Average IH	A/N	Actual IH	Difference	Percent Variation
Painted crossbuck	0.502	155/320	0.484	0.018	3
Reflectorized crossbuck	0.523	66/115	0.574	0.051	9
Flasher	0.774	51/73	0.699	0.075	11
Gate	0.828	12/14	0.857	0.029	3

The percentage of variation represents the difference between the calculated and the actual indices of hazard divided by the actual index of hazard. The average variation for all crossings investigated amounted to approximately 5.5 percent. The low variations indicated that those crossings with the greater hazard also had, on the average, the higher types of protective devices. Therefore, the suggested warrants may be used to determine whether or not a given location is underprotected in accordance with the current average levels of protection in Indiana.

Priorities for rural grade crossing protection improvements may be established by ordering underprotected crossings according to their calculated indices of hazard. Priorities may be determined for all deficient grade crossings as a group or for grade crossings that are categorized according to their recommended type of protective device.

CONCLUSIONS

The following conclusions concerning hazard at rural rail-highway grade crossings summarize the findings of this research investigation.

1. The accident victims are predominantly young male drivers residing in the county in which the accident occurred. These drivers are usually not under the influence of alcohol. More than one-half of them are injured, and about one out of seven is killed.
2. Trucks account for more than one-quarter of the accident vehicles. Seventeen percent of all vehicles involved in accidents have evidence of mechanical defects. The majority of accidents occur at moderate train speeds.
3. Most accidents occur during the favorable driving conditions of clear weather, daylight hours, and dry pavements. However, the number of accidents per unit time and per unit exposure is probably greater for ice and snow conditions and for wet pavements than for dry pavement conditions.
4. The hazard model developed by multiple linear regression (Eq. 2) identifies number of tracks, highway pavement width, train volume, average daily traffic volume, and the sum of distractions (number of houses, businesses, and advertising signs) as important variables for the prediction of relative hazard. Type of protection was not a statistically significant variable.
5. Warrants for the installation of protective devices at rural rail-highway grade crossings, based on the current standard of protection for Indiana, are indices of hazard of below 0.65 for reflectorized crossbucks, 0.65 to 0.80 for flashers, and above 0.80 for gates. The indices of hazard may also be used as priority ratings for scheduling the improvement of protection at rail-highway grade crossings in rural areas.

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Tire Disablements and Accidents On High-Speed Roads

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•THE study of tire disablements and accidents on high-speed roads was undertaken to give, for the first time, reasonably trustworthy numerical answers to questions that have long been bothersome. For example, in what percent of accidents are tire disablements a contributing factor?

The project was a cooperative undertaking of the Traffic Institute of Northwestern University, the Illinois State Toll Highway Commission, the Illinois State Police (Tollway Battalion), and the Rubber Manufacturers Association. No federal funds were involved.

The study was made on a toll road for the following reasons:

1. Toll collections give a very precise measurement of vehicle mileage.
2. Continuous high speed is acknowledged to be severe tire service and it certainly increases accident severity. Hence, tire disablements and associated accidents would probably be maximum rather than minimum on such a road.
3. Accidents are very completely reported on a toll road.
4. Uniform speeds minimize speed as a variable in the study.

To further reduce the number of variables, only four-tired vehicles were included, mainly passenger cars.

Four associated projects were required: Tire Study 1—frequency of tire disablements, Tire Study 2—use and condition of tires, Tire Study 3—tire disablements not followed by accidents, and Tire Study 4—tire disablements followed by accidents.

Data were collected between September 1, 1966, and August 31, 1967. The limited-access Illinois Tollway is 190 miles long and is mostly Interstate, around Chicago (Fig. 1). Use-and-condition studies were made at five service areas; frequency-of-disablement studies were made at two toll plazas.

In this abbreviated report, results rather than methodology are emphasized.

TIRE STUDY 1: FREQUENCY OF TIRE DISABLEMENTS

Three surveys were conducted at two exit toll plazas. Two were made at South Beloit where cars left Illinois to enter Wisconsin. These gave maximum Tollway trip length. One was made where cars left the Tollway to enter Chicago. These were mainly commuter trips giving minimum average trip mileage.

One survey was begun as early in April as practical to give a low mean temperature, actually 39 F. Two were made in July to give a high mean temperature, 69 F.

In each survey, counts were made 16 hours per day, 7 days per week for at least 2 weeks.

Cars stopped to pay toll were asked where they entered the Tollway. This gave an accurate figure for their Tollway travel. They were also asked whether they had had tire or other car trouble on the Tollway. The size of each car and its State of regis-

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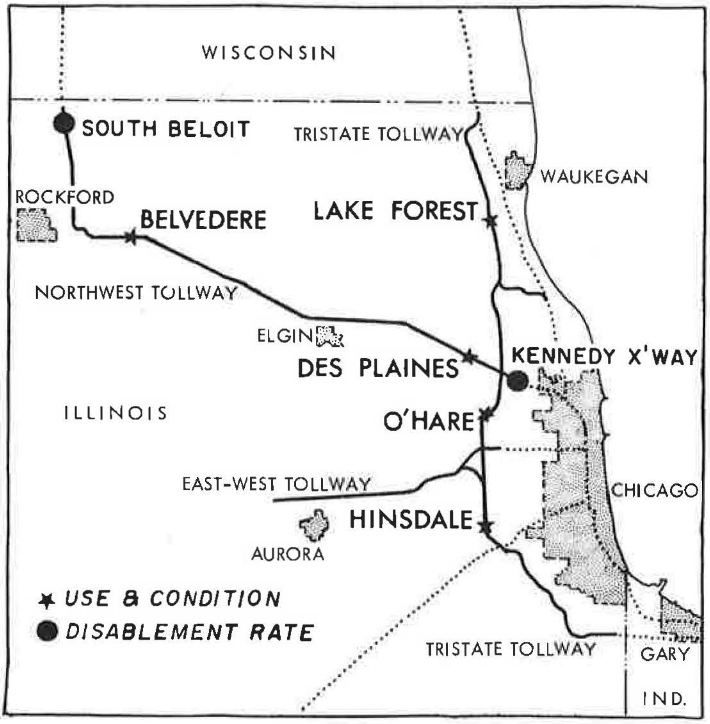

Figure 1. Study site.

tration was noted. If a driver said that he had experienced tire or other mechanical trouble, he was asked the following additional questions:

What kind of trouble?
Did you require assistance?
If so was it from police or service vehicles?
How long before help arrived?

If the trouble was a tire disablement, still more questions were asked:

Where on the Tollway did the tire fail?
At what time did it fail?
How long were you delayed?
Was the failure sudden or slow?
Did a patrolman make out a report on it?
If helped, was it by service truck, other motorist, or patrolman?
Did you have a usable spare tire?
Was the disabled tire repairable?

The sex and age of the driver were noted. If the motorist did not know whether the tire was repairable, he was given a return postcard to send in when he found out. About one-fourth of these were returned.

A simple method was used to determine adequacy of sample size. After each disablement reported, the miles per disablement to and including that one were computed and plotted (Fig. 2). When additional disablements had little effect on the rate, the sample size was sufficient. Figure 2 shows these plots and clear differences between the three surveys.

The three surveys (Table 1) gave disablement rates for three temperature-trip length combinations. Disablements per million car miles varied from 29 for low temperature and long trips to 71 for high temperature and short trips. It is reasonable to

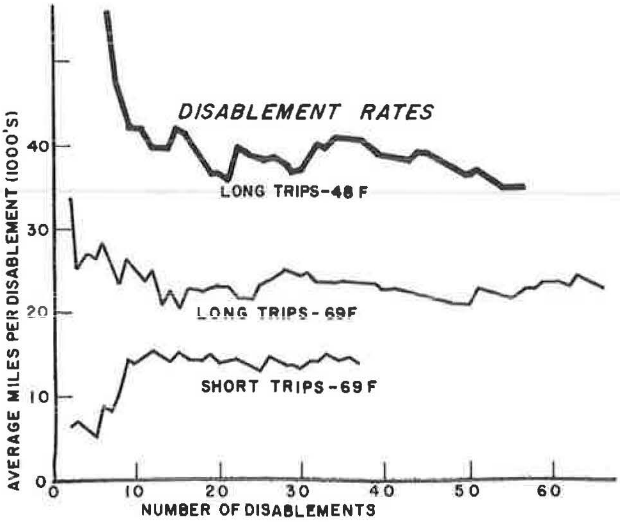

Figure 2. Miles per disablement.

believe that still lower temperatures would have given somewhat lower disablement rates and that higher temperatures might give substantially higher rates, but not much of the year would fall outside the 48 F to 69 F range obtained. From the three pairs of conditions represented, the disablement rate for low temperature short trips could be deduced: 46 disablements per million vehicle-miles.

Tollway travel was divided into groups according to approximate mean temperature and trip length. To these group totals were applied the appropriate disablement rates to obtain estimated totals for the entire tollway for 12 months. These estimates of tire disablements were as follows: 46 per 1,000,000 vehicle-miles, 1 per 22,000 vehicle-miles, 1 per 88,000 tire-miles, 1 per 340 hours of Tollway driving, 165 per day for entire Tollway, 7 per hour for entire Tollway, and 1 per mile per day.

Drivers reported whether tire disablement was slow or sudden. This was a subjective evaluation but it is believed useful to dichotomize an experience to which drivers must react: "slow leak," 48 percent; and "sudden blow," 52 percent.

Drivers also reported how tires were changed. The results are shown in Figure 3. About one-third of the drivers required help—many more women than men.

TABLE 1

SUMMARY OF TIRE DISABLEMENT FREQUENCY SURVEYS

	Surveys				
	1	2	3	Total	Avg.
Duration of survey, days	21	14	18	53	
Mean temperature, F	48	69	69	–	
Number of interviews	32,034	23,332	29,792	85,158	
Total miles represented	1,922,040	1,493,248	536,256	3,951,544	
Average trip length	60	64	18		46
Total disablements reported	56	67	38	161	
Per million car miles	29	45	71		41

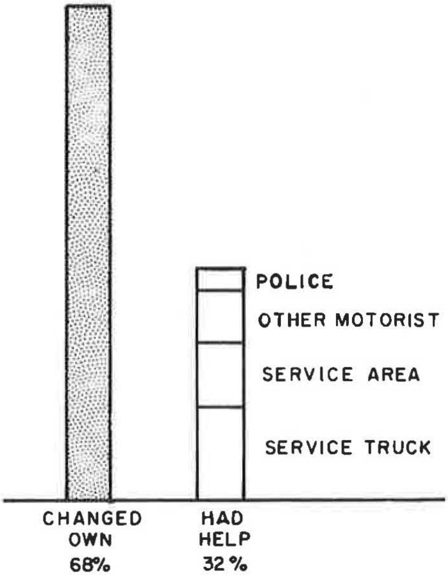

Figure 3. How tires were changed.

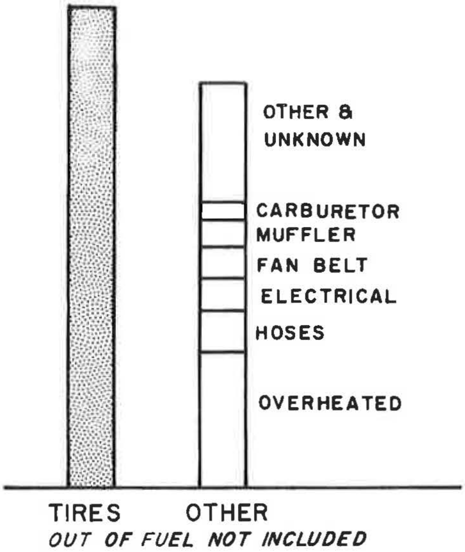

Figure 4. All disablements.

Only 3.7 percent of cars experiencing a tire disablement had no usable spare. The lack of a spare, therefore, accounted for only about 1 in 10 of the cases in which assistance was required.

Of the disabled tires, about 2 in 5 were reported to be repairable: reusable—52, not reusable—71, driver did not know—24, total—147.

Tire disablements were a little more common than all other mechanical disablements combined during the survey period. This might not have been true in midwinter. Engine overheating is the most common mechanical disablement; out-of-gas was not considered to be a disablement (Fig. 4).

TIRE STUDY 2: USE-AND-CONDITION SURVEYS

During October and November 1966, tires on 1746 four-tired vehicles were examined in the parking areas of the five service centers shown in Figure 1. This was to obtain a sample of condition of tires in use on the Tollway.

Drivers were persuaded to cooperate; they could not be compelled. Surveys were conducted 16 hours per day 7 days per week. More than 90 percent of those "invited" to have tires examined consented.

Pressure in each tire was measured and correction made to give equivalent cold pressure. Depth of each groove was measured where exposed. Load on each tire was weighed and tire was examined on visible tread and sidewalls for cracks and blisters.

Distribution of the 6984 tires examined according to amount of tread groove remaining in each is shown in Figure 5. Groove depths are represented by the tapering black bar across the bottom of the chart. The smaller percents of tires with great groove depth, shown at the left, result from the fact that few new tires have grooves deeper than $\frac{9}{32}$ in. The area under the curve represents the 6984 tires examined. The area under the curve in the shaded part represents tires that do not meet the inspection standard requiring more than $\frac{2}{32}$ in. of tread groove remaining. This is $4\frac{1}{4}$ percent of the total number of tires.

Load on each tire was compared to the rated or permissible load for that tire with the air pressure in it. Pressures measured were corrected to give equivalent cold

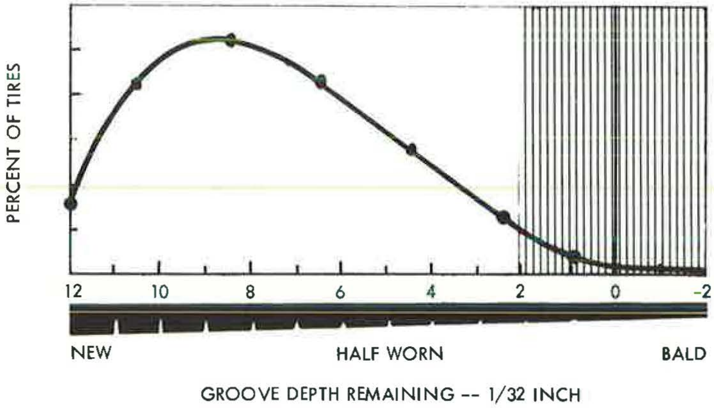

Figure 5. Amount of tread on tires.

pressure. Modal load was about 80 percent of rated load. The shaded area in Figure 6 under the curve at the right represents 5.9 percent of tires that were overloaded for the pressure in them but not exceeding the maximum allowable pressure. Although 5.9 percent of the tires were overloaded, only 1.8 percent carried more than a 10 percent overload.

The percent of tires that should have attention for various reasons is shown in Figure 7. Overload and worn treads, which were shown in Figures 4 and 5, are most common. Together they account for half of all tire deficiencies. Overloaded tires would not be discovered by usual inspection procedures, first because load is not weighed and second because loaded vehicles are rarely presented for inspection. Note in Figure 7 that more than half the tires with overload and almost all of the tires with too much pressure (usually more than 32 psi) could be corrected simply by adding or releasing air. The inflation condition of the tires may be summarized as follows: satisfactory for load 92.2 percent, underinflated (needs more air)—3.5 percent, overinflated (needs less air)—1.8 percent, and overloaded (needs less load or larger tires)—2.5 percent. The overloaded tires, could not be corrected by air pressure change. The load on the wheel should be reduced or a larger tire should be provided.

The distribution of station-wagon tires by percent of permissible load for actual air pressure was quite similar to that for all cars (including wagons) shown in Figure 6. For cars excluding wagons, the average actual load was 80.1 percent of permissible load at existing pressure, and for wagons alone the average was 80.4 percent. Therefore, in general, station-wagon tires were loaded about the same as those on other vehicles. Slightly fewer station-wagon tires (5.8 percent) had too much load for pressure in them than tires on other cars (6.0 percent). The difference is too small to be significant.

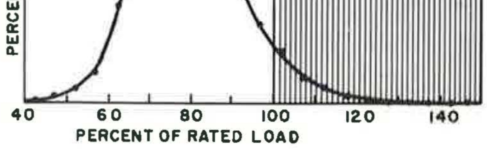

Figure 6. Percent of permissible load for actual pressure.

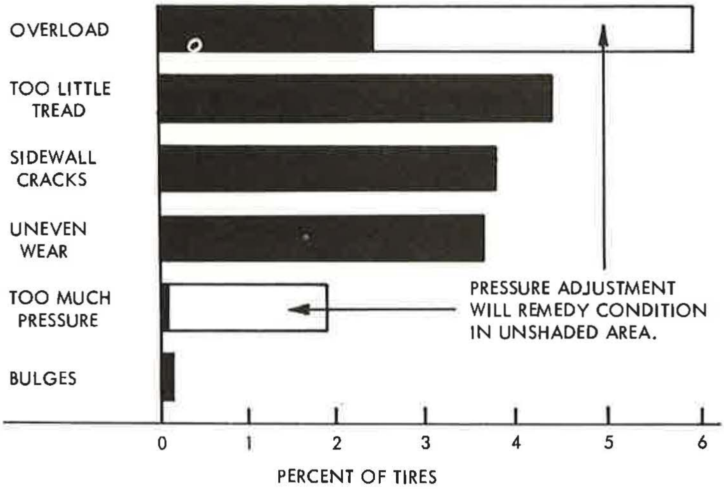

Figure 7. Percent of tires requiring attention.

A total of 1117 tire ailments was observed (not including uneven wear) on 1022 tires. In other words, few tires had more than one ailment. The 1022 tires with ailments represent 14.7 percent of all 6984 tires inspected.

These 1022 deficient tires were on 607 vehicles. This is an average of 1.68 ailing tires on the cars that had any deficient tires. If 607 cars have 1022 ailing tires among them, nearly 415 would have more than one deficient tire. Thus, approximately 2 out of 3 cars had more than one ailing tire.

Among 1746 cars surveyed, there were 1022 ailing tires. This would average 0.59 ailing tire per car. Among these cars, 607 (34.7 percent) had one or more tires about which something should be done. Thus, about 1 tire in 7 should have attention but 1 driver in 3 should do something about 1 or more tires.

TIRE STUDY 3: TIRE DISABLEMENTS NOT RESULTING IN ACCIDENTS

For the 12 months of the study, patrolmen on the Tollway were requested to make a special report when they encountered a car stopped on the roadside with a disabled tire. The report included the same data collected in the use-and-condition survey, except that the load on tires and air pressure in the disabled tire could not be measured. However, data were collected on the damage to the tire and the circumstances of its disablement.

The relationship of car age to tire disablements can be examined by comparing the percent of new, medium, and old cars in the general travel population with cars experiencing disablements. The comparison may be represented by "risk indexes" in which the risk of disablement of the average car is 1.00. Groups of cars with less than average risk will have indexes lower than 1.00; those with more than average risk greater than 1.00. Table 2 gives risk indexes by size of car for two comparisons: the cars with and without disablement in Tire Study 1 and all cars in Tire Studies 2 and 3. These show that old cars in Tire Study 1 were nearly three times as likely to experience disablements as new cars. In Tire Study 1 data were obtained for both disablements and nondisablements at the same time and place. Other indexes were computed from data

TABLE 2

DISABLEMENT RISK INDEXES BY AGE OF CAR

Age of Cars (yr)	Tire Study	
	1	2 and 3
1 and 2	0.6	0.5
3 through 8	1.2	2.1
9 or more	1.7	3.0
Average all cars	1.0	1.0

collected—for example, comparing Tire Study 1 and Tire Study 2. These gave greater range of risk indexes. It is logical that old cars would have old tires that would be more likely to give out.

Comparisons were made of a number of other circumstances of tire disablements. From these, the following circumstances seemed to have no effect on the likelihood of disablement: age of driver, sex of driver, 4-ply or 2-ply with 4-ply rating, power steering, and state of registration.

Comparing tread wear of disabled tires (Tire Study 3) with those in general use (Tire Study 2) permits calculation of disablement indexes for various remaining tread depths. Applying the disablement rates and mileage figures obtained in Tire Study 1 gives approximate disablements per 100,000 car miles for various degrees of tread wear. These are shown in Figure 8.

Note that the disablement rate curve rises sharply after wear reduces groove depth to less than $^{2}/_{32}$ in. This fact supports $^{2}/_{32}$ in. as an inspection standard requirement. Bald tires appear to be about 45 times as susceptible to disablement as new tires.

TIRE STUDY 4: TIRE DISABLEMENTS FOLLOWED BY ACCIDENTS

For this part of the program, police were asked to make a supplementary 4-page tire report whenever any tire on a 4-tired vehicle was disabled after an accident for any reason whatsoever. When applicable, the same form was used for disablements not followed by accidents and the use-and-condition survey. It was hoped to obtain the

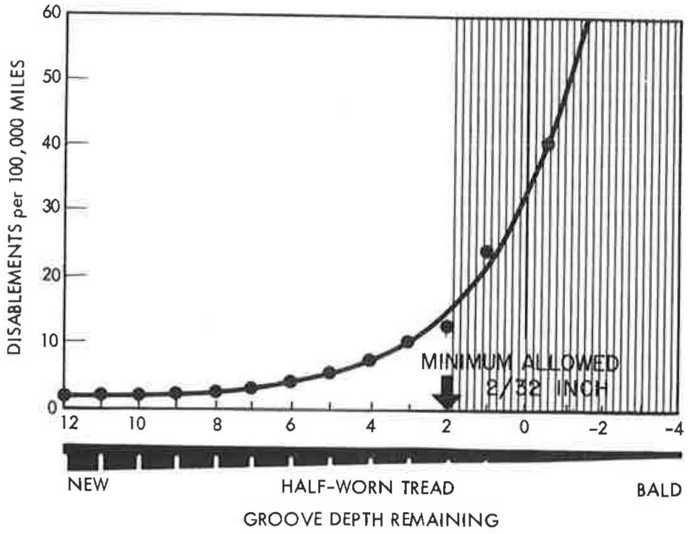

Figure 8. Tire disablement rate related to tire wear.

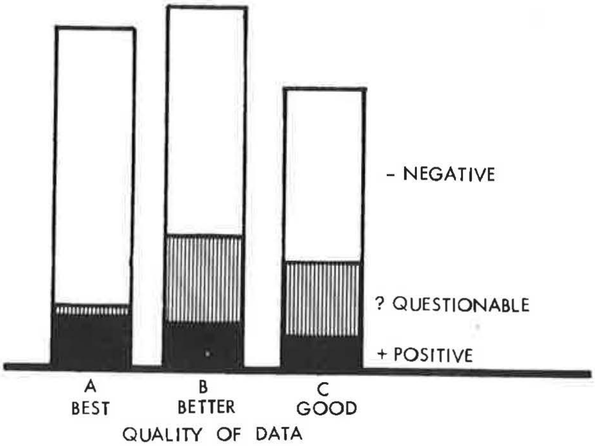

Figure 9. Disablements followed by accidents.

special reports on all such events, but it was realized that this would be impossible in practice. To estimate the number missed by police, all accident reports were examined to determine how many additional accident reports mentioned tire disablement in describing damage or explaining the accident. Then telephone calls were made to a random sample of drivers involved to inquire whether there had been unmentioned tire disablements. These resulted in the following 235 estimates of the number of accidents to 4-tired vehicles accompanied by tire disablements: supplementary police reports, tires obtained—39; supplementary police reports, tires not obtained—41; stated or inferred from official accident report—30; actually reported in phone survey—2; and estimated additional on basis of phone survey—123. This estimate is, if anything, high.

During 12 months there were 1566 motor-vehicle accidents (18 fatal to 21 people) reported on the Tollway involving 2582 vehicles, of which 2196 were four-tired. Of these, 112 (5.1 percent) were known to have had disabled tires afterward and there may have been as many as 235 (10.7 percent). Some cars had more than one disabled tire after the accident.

An Institute staff member tried to obtain for examination each disabled tire reported by police. Altogether 39 such tires were obtained.

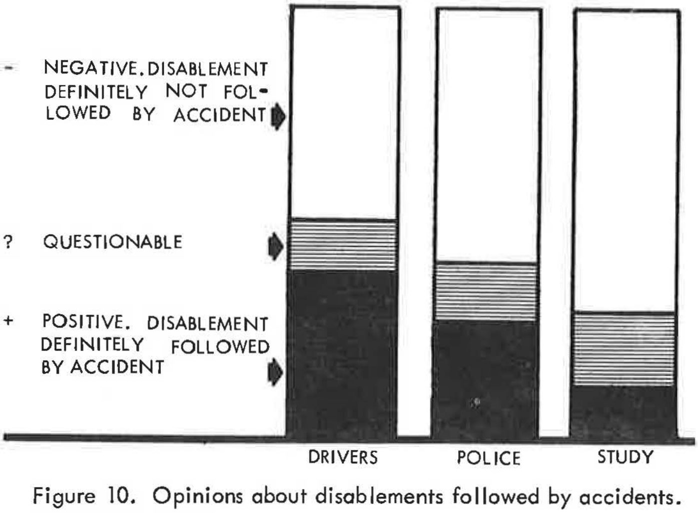

Figure 10. Opinions about disablements followed by accidents.

Circumstances of the accident, the supplementary tire report, and the tire (when available) were studied separately by at least two staff people independently to try to determine whether the tire was disabled before or as a result of the accident. The result was: unquestionably disabled before accident—5.5 percent, doubtful cases—9.8 percent, and unquestionably disabled by the accident—84.7 percent.

Equally good and complete data were not available for all accidents after which a tire was disabled. With the "best" data, the questionable cases were few; with "better" data questionable cases were much more numerous (Fig. 9). The minimum number of disablements preceding accidents is shown by the black areas in Figure 9; the maximum number by the shaded area plus the black area. The total area of all three bars represents 235 four-tired vehicles that had flat tires for any reason after the accident. This is 10.7 percent of all 4-tired vehicles in accidents on the Tollway during 12 months.

In 12 months, there were altogether 1486 accidents involving 2196 four-tired vehicles. Thirteen definitely and an additional 23 possibly had disablements before the accident. Thus, at least 0.9 but not more than 2.4 percent of all such accidents could be counted as contributed to by tire disablement. That would mean that 1 disablement

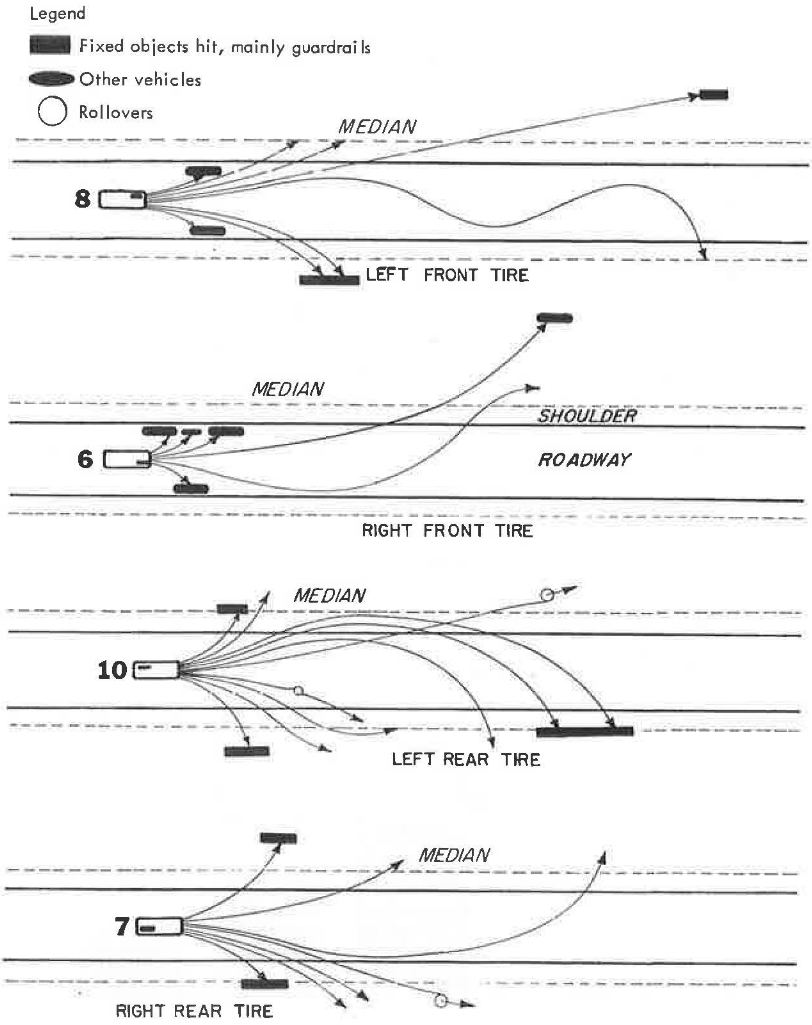

Figure 11. Response to tire disablement.

TABLE 3

INVOLVEMENT OF WOMEN IN DISABLEMENTS AND/OR ACCIDENTS

Tire Study	Title	Percent Women	No. of Drivers
2	Use and condition of tires (neither disablement nor accident)	8.8	1,746
1	Frequency of tire disablement (disablement but no accident)	10.9	147
3	Disablement not followed by accident (disablement but no accident)	29.7	383
4	Disablement followed by accident	42.0	33

in at least 4600 but not more than 1 in 1700 was followed by an accident. You might say that at least 99.94 percent of drivers successfully coped with tire disablements.

Accidents following tire disablements were compared to those with a number of other contributing circumstances. During the 12 months not more than 36 accidents followed tire disablements. However, in the same time, at least 75 accidents involved large animals, mainly deer. Remember that this is a well-fenced and mainly urban road.

Careful study of all available data showed that of an estimated 235 tires flat after accidents, not more than 18 percent were positively or possibly disabled before (Fig. 10, right column). But drivers (Fig. 10, left column) reported more than twice as many (37 percent) flat before. It appears to be easy to blame a flat tire for an accident. Police (Fig. 10, middle column) reported 27 percent. Note also that drivers are least in doubt and that the experts with the most complete data most in doubt.

Position of tires disabled before accidents for which special reports were available is as follows: left front—8, right front—6, left rear—10, and right rear—7. There are too few cases to make these differences very significant.

Most cars with a disabled left rear tire are supposed to veer in the same direction, but this is not necessarily so (Fig. 11). Therefore, we may infer that driver response to tire disablement, possibly overreaction, is usually also a contributing factor in these accidents.

The percent of Tollway drivers who were women is indicated by data from Tire Study 2. These were not involved in disablements or accidents. The percent of drivers experiencing disablements is indicated by data from Tire Study 1. Women in this study experienced disablements but not accidents. Tire Study 3 also gives the percent of drivers experiencing disablements but not accidents who were women. But Tire Study 4 gives the percentage of drivers who had accidents following disablements who were women (Table 3). The difference between Study 1 and Study 2 in percent of women drivers suggests that women are a little more likely to experience disablements but it is too small to be very significant. Theoretically the percent of women drivers experiencing disablements should be the same for Studies 1 and 3. The fact that the percent of women in Study 3 was nearly three times as great as in Study 1 may be explained by a circumstance of data collection: fewer women change tires than men, and women who do are likely to be delayed more than men. Women would then be much more likely to be encountered by a passing patrolman who would record data on a disablement not followed by an accident. Therefore, we cannot conclude that women are more likely than men to experience disablements.

But the fact that 42 percent of the drivers experiencing accidents after disablements were women cannot be overlooked and cannot be explained by an artifact of data collection.

By comparing data for the general driving population (Tire Study 2) with those for drivers having accidents after tire disablements (Tire Study 4), risk indexes were computed by age and sex for accidents following disablements (Fig. 12). The average driver would have an index of 1. Girls less than 20 years old had an index of about 22,

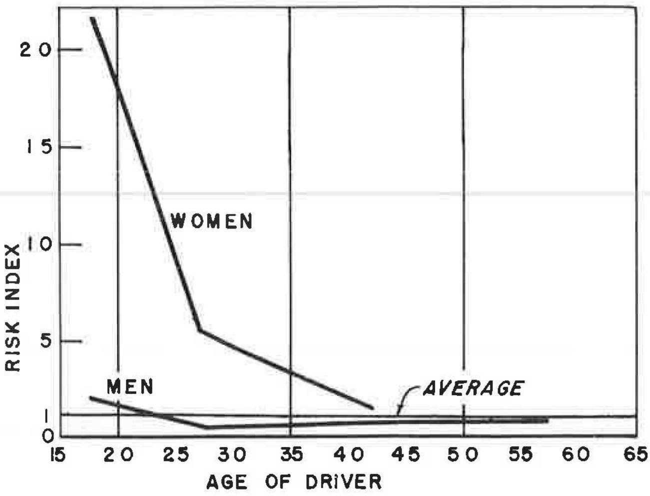

Figure 12. Accidents following disablement.

which means that they were about 22 times as likely as the average driver to have an accident after a tire disablement. All women and boys had indexes greater than 1.0. Although the number of cases is small (33), the difference between the average and all drivers less than 20 years old and all women drivers was so great that it is statistically significant at the 0.01 level.

APPLICABILITY OF RESULTS

People who pay to use a toll road are likely to afford better tires than other car owners. This suggests that toll road disablements and resulting accidents might be less than such events elsewhere.

On the other hand, high speeds are more likely to cause disablements and make coping with them more difficult. This suggests that toll road disablements and resulting accidents may be more prevalent than elsewhere.

To what extent these opposing considerations may offset one another would be difficult to guess. Hence, how much these data for a toll road apply to all traffic in the U. S. would be difficult to assess.

Discussion

M. PETER JURKAT, Stevens Institute of Technology—The authors have gone about finding the relationship between automobile accidents and a particular factor, tire disablements, in the correct manner. First they determined the role that tire disablements play in the accidents that occurred during the time and place of their investigations. They did this by intensive case studies. Second, they determined as best they could all the occurrences of tire disablements in which no accidents resulted. A step of this nature has not been given enough emphasis in previous accident research. It is only after completion of both of these steps for many factors thought to cause accidents that proper weights can be assigned to each factor in the total accident picture.

In several places the paper speculates that the tires used by cars that travel on toll roads are in better condition with regards to disablements and tread remaining than those in general use. The data collected during a tire-use study conducted by Stevens during the summer of 1967—east of the Mississippi River—confirm these speculations. This latter study was conducted at service stations on all kinds of roads—limited access, urban streets and rural highways. Concerning disablements, we found the rate to be 113 per MVM as opposed to the 46 per MVM as reported in the paper for tollway-like roads. I expect the figure reported in the paper to be more precise than the one found in our study since ours depended on driver memory concerning tire failures and annual mileage, and on sampling across many kinds of roads. However, I think it can be concluded that the general vehicle has more tire failures than the toll road vehicle. Concerning tread depth, the paper reported that 4.25 percent of the tires measured on the toll roads had less than 2/32 inch of tread left, whereas we found that more than twice as many, 11.8 percent, fell into this category. Our entire distribution of tread depth was more skewed toward the lower tread depth than that found by the authors. On the Tollway, only 1/4 of 1 percent of the tires were found to be retreads; we found nearly 5 percent. The load condition of these tires was almost identical: on the Tollway, 5.9 percent of the tires were overloaded for the pressure in them; the Stevens study found 6.2 percent.

I think the point is clear. Automobiles on toll roads, and by extrapolation, on divided, limited-access roads, exhibit better tires than those on all vehicles.

Concerning the curve presented in the paper showing the relationship between disablement rate and tread depth, the paper points out that the usual minimum tread depth allowed by inspection stations, namely 2/32 in., occurs at the point in that curve where the disablement rate begins to increase very rapidly. The curve shows that on tires with 2/32 in. of tread depth about 150 disablements per MVM will occur, and that for tread depth less than that standard, a rapidly increasing disablement rate will occur. Therefore, the first prerequisite for a standard, namely that conditions that break it are concomitant with undesirable results, is met by the 2/32-in. standard. Another prerequisite for standards concerns hardships felt by the population affected by the standard. The overall average for disablements found in this study, 46/MVM, and the one found by the Stevens study, 113/MVM, are well below the 150/MVM shown for tires with 2/32 in. driven on toll roads. This indicates that the public maintains its tires in sufficiently good condition so that the disablement rate is below that for tires, which are driven at high speeds for long distances, with 2/32 in. of tread. One aspect of maintaining this condition is keeping more than 2/32 in. of tread. A minimum of 2/32 in. of tread would then seem to be a good standard to avoid tire disablements.

HOWARD DUGOFF, University of Michigan—The current paper is a summary of the findings of four separate studies that have been described in greater detail elsewhere (1, 2, 3, 4). This discussion is based on a reading of not only the summary paper but also of the four source reports.

Tire Study 1 was an attempt to ascertain the frequency of tire disablement; i.e., disablements per mile of travel, under the driving conditions studied. From the standpoint of the highway safety researcher, the principal reason for seeking this information was to permit its utilization, in conjunction with independent data on the incidence of accident/disablement combinations, to estimate the probability that an accident will occur in the event of a tire disablement. Taken alone, however, the disablement rate data certainly constitute an impressive testament to the durability of the modern automotive tire. They also permit the authors to speculate as to some possible cause/effect relationships underlying various descriptive statistics, which they develop. The limitations of this approach are well known. They may be illustrated by discussing a particular example.

Trips averaging 18 miles had 1.57 times as many disablements per MVM as trips averaging 64 miles. The authors attribute this discrepancy to the fact that a greater percentage of the vehicles employed for the short trips were old; i.e., "that worn tires used on short trips rather than trip length accounts for the lower disablement rate for longer trips."

This certainly seems to be a reasonable explanation. It seems equally reasonable, however, that aside from those tire failures that are directly attributable to so-called road hazards, the likelihood of disablement in the first few miles of high-speed operation is much greater than in subsequent miles. This could also be the reason for the observed discrepancy between the "short trip rate" and the "long trip rate." This is not to say that it necessarily is, merely that the explanation hypothesized by the authors may not be either. Other possible explanations of the fact that the "short trip" and "long trip" data correspond to different road sections can also be readily hypothesized.

The objective of Tire Study 2 was to investigate the condition and use of tires in a particular vehicle population. The Office of Vehicle Systems Research of the National Bureau of Standards has supported extensive studies by Southwest Research Institute and Stevens Institute of Technology to make virtually identical measurements for other, more general, vehicle samples. It will certainly be of great interest to compare the results of the three large surveys when all are available. Taken in aggregate, they should provide a rich data base for (a) the vehicle dynamicist, who wishes to estimate variations in tire mechanical properties and, in turn, vehicle response characteristics associated with realistic ranges of tire service conditions; (b) the safety researcher, who needs control data for use in connection with data on the characteristics of vehicles involved in accidents; and (c) the standards setter, who wants to know under what ranges of conditions it is appropriate to try to protect the public.

Pending the release of the NBS data, a smaller, more limited sample of independent results is available for comparison purposes. These are values of tire tread depth measured on 1222 cars selected at random at gasoline stations in Ann Arbor, Michigan. that were collected as control data in connection with a study at the Highway Safety Research Institute.

The HSRI data are plotted, together with corresponding results of the authors, in Figure 13. It will be noted that there is a substantial discrepancy. In light of the

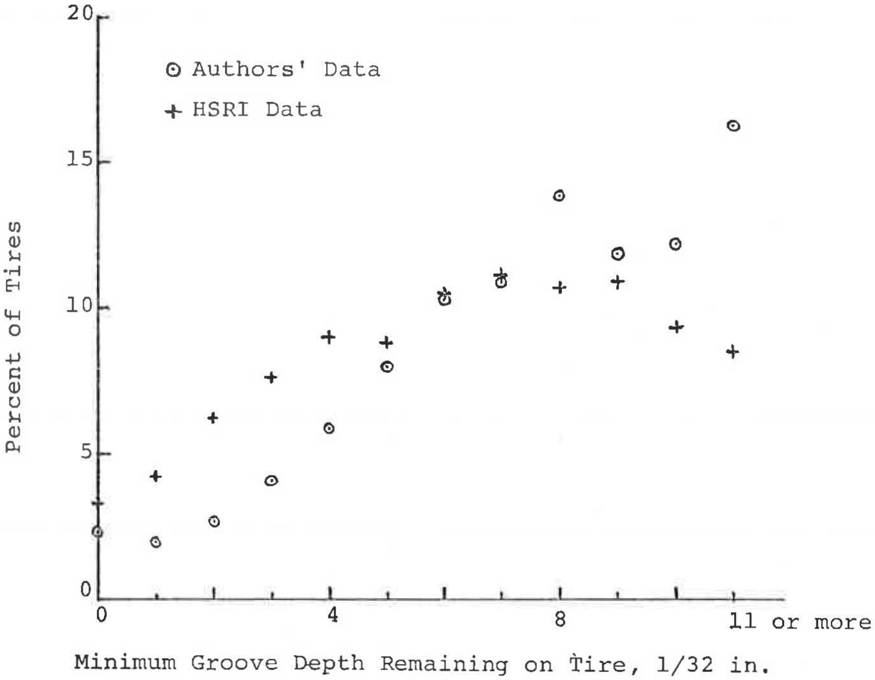

Figure 13. Comparison of tread depth data.

earlier discussion, it does not seem appropriate to attempt an after-the-fact explanation. The vehicle sample considered by the authors (i.e., cars people use on toll road trips) is one that "probably represents tires in better than usual condition," whereas the HSRI data were generated locally in Ann Arbor, an area characterized by a large population of students and professors—a group that might be expected to have tires in worse than usual condition.

Tire Study 3 was an investigation of the circumstances surrounding tire disablements. Its main result concerns the variation of disablement rate (flat tires per vehicle-mile) with tread depth. This result appears to provide one basis for an objective criterion for a tread/depth inspection standard; as such, it is virtually uniquely valuable.

Of the four studies summarized in the paper, the results of Tire Study 4 are potentially of the greatest relevance from the standpoint of the safety researcher. Here the authors have attempted to draw broad conclusions concerning the relationship between tire disablement and accident causation. Unfortunately, some of the conclusions reached appear to be founded on somewhat less than solid ground.

Of the total vehicle population studied, only 13 cases are considered by the authors to represent "definite" instances where an accident actually followed a disablement. Of these 13 definite instances, data on tire condition were available to the authors for 10. Data were also available for 7 other cases in which it was "questionable" whether or not the disablement preceded the accident. All of the conclusions reached by the authors concerning the condition of tires whose disablement preceded an accident are based on analysis of this sample of 17, 7 of which the authors qualify by the statement, "it is likely that most of these 7 were not actually disabled before the collision (4)."

The conclusions drawn concerning the characteristics of drivers involved in accidents following disablements are based on analysis of 33 cases in which the disablement either "definitely" or "possibly" preceded the accident. By the authors' classification, the probability that any particular case in this sample represents an instance where a disablement definitely preceded an accident is just about 1 in 3. In light of this, it appears clear that the various risk indexes presented in the paper should be interpreted with a considerable degree of discretion.

Since so many of the authors' results in Tire Study 4 depend on the evaluations that were made to determine exactly how many disablements occurred just prior to accidents, and since these evaluations contrasted so markedly with driver and police reports, it is of great interest to examine the methods used by the authors to make their evaluations. These are not described in the paper. However, they are discussed in the source report (4). Although the techniques are (inevitably) arbitrary and subjective, they do appear to provide a much better basis for making an accurate after-the-fact judgment than either the police or driver reports. On the other hand, it seems clear that such an authoritative statement as "at least 99.94 percent of the drivers are apparently able successfully to cope with a tire disablement," is not warranted by the accuracy of the analysis techniques employed.

The authors are to be commended and thanked for a complete and painstaking job of data collection. Although some criticism has been directed at certain interpretations and extrapolations of the statistical results, the results themselves must be recognized as having potentially great value to the highway safety research community. The authors have asserted a need for research directed to basic fact-finding on which safety program judgments can be more solidly based. Their findings certainly represent a significant step in that direction.

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J. STANNARD BAKER, Closure—It is gratifying to an author when discussants point out no important deficiencies in his work.

The small number of solid examples of accidents following disablements collected in a year is conceded to be a disappointing base for conclusions about how and why they occur. But until more prolonged studies give more cases, they must be considered at least as suggestive. The fact remains that tire disablements are not so great or inevitable a contributor to accidents as unsupported rumors might have one believe.

The data on condition of tires not in use on a toll road confirm the authors' suspicions that tires in the study were in better condition than normal, but it does not help solve the problem as to applicability of data from Tire Study 4 in estimating nationwide contribution of tires to auto accidents.

The two additional hypotheses offered by Dugoff for higher rates of short-trip toll road users had been considered but were not believed to be as cogent as the one offered. Roadway differences for the longer trips are scarely noticeable on a toll facility. That tires might be more likely to fail during the first few miles of toll road driving is a possibility. It could be that if heating were to disable the tire, temperature would rise enough in the shorter trips to do the damage; and if it did not, the tire would continue to function on a longer trip. Or it could be that puncturing objects picked up on less clean roads would be likely to give trouble soon after entering the toll road. But the fact that car age was less (50.0 percent new) for long trips than short ones (35.8 percent new) suggests that short-trip tires were more worn and therefore more likely to give out.

The Nodal Method of Collision Location

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The development of accurate and efficient accident location systems is of prime importance to the highway and traffic engineer. During the past two years the Maine State Highway Commission had developed a location system that is based on network principles widely used in the highway planning field. This paper describes the development of the systems, beginning with a review of alternative methods available and ending with an evaluation of the initial results as applied to the 4,600 miles of federal-aid and state highways. In brief, this initial experience with the node-link method of accident location suggests that it is an economical and flexible tool that has greatly enhanced the capability of the engineering staff to utilize factual data in the safety program.

•ACCURATE accident data, properly located and related to the highway environment, are essential to the work of the traffic engineer. Reviewing hazardous highway locations only after the accident problem has reached such proportions that the general public reacts is not a satisfactory operating procedure to the professional engineer. Therefore, current accident location data that enable the engineer to determine quickly those locations at which accidents are occurring or increasing must be made available as an everyday working tool. These data not only enable the engineer to determine high accident locations susceptible to correction, but also relate accident patterns to highway characteristics and thus provide the basis for corrective measures. Further, a properly established accident records system will provide the engineer with the basic data necessary to evaluate changes in highway design and operating policies that can lead to a reduction of accidents on a systemwide basis.

Accident location data are also of utmost importance to enforcement agencies. Selective enforcement programs, to be effective, must be aimed at those locations where changes in driving habits will lead to accident reduction. Accident rates and causes, when related to the type of enforcement activity, will allow evaluation of the enforcement program. Also, those involved in the public relations aspects of highway safety may make effective use of accident location and other data to provide a well-oriented service to the motoring public.

TABLE 1

HIGHWAY MILEAGES

Category	State (mi)	Includes	
		F. A. P. (mi)	F. A. S. (mi)
State highway	3,859	1,876	1,724
State-aid highway	7,628	–	779
Townways and miscellaneous	9,785	58	–
Total	21,272	1,934	2,503

The first step in the process of developing an accident location system was a review of the extent and nature of the highway systems in the state. As given in Table 1, there are slightly more than 21,000 miles of highways in Maine.

State systems are described as state highways and state-aid highways. The State Highway Commission is responsible for construction and maintenance activi-

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ties on the state highway system, whereas on the state-aid system these responsibilities are shared with the local municipality. More than 3,800 miles are designated as state highways, and some 7,600 miles are included as state-aid facilities. All but 259 miles of state highways are also designated on one of the federal systems, while only 779 miles of the 7,628-mile state-aid system are federally designated. A summary of the federal-aid and state highway system in miles is shown below:

System	F.A.I.	F.A.P.	F.A.S.	N.F.A.	Total
State highway	220	1,656	1,724	259	3,589
State-aid			779		779
					4,638

In total, there are some 4,600 miles of the more important federal-aid and state highways in Maine. Although this represents only 22 percent of the total mileage, 55 to 60 percent of the accidents are reported on these systems. In an effort to insure the rapid implementation of an effective system, a decision was made to initially limit the location system to the 4,600-mile federal-aid and state highway systems, while maintaining the flexibility for future additions.

With a total population of approximately one million and an average density of 31 persons per square mile, most of the highway system is distinctly rural in nature. Even though only 6 percent of the highway mileage is classified as urban, it was assumed that the absolute number of collisions occurring on these urban facilities was substantial, and thus flexibility of the location system to meet urban and rural needs became a design goal. Subsequent summaries of resulting data have shown that 40 to 50 percent of all the accidents reported occur in urban environments.

EVALUATION OF ALTERNATIVES

Objectives

There has been considerable discussion in recent years on the subject of collision location. Much of the published work has been concerned with the details of the physical portion of the location system—namely, the field reference markers. The decision by the Maine State Highway Commission to emphasize the improvement of the collision location process as a beginning step in improving the whole records system led to a review of previously used methods and a statement of the objectives for the accident location process.

Over the years various methods have been used to identify the locations of different design and operating characteristics and other events on state highway systems. Collisions, then, were only one item among many pieces of an inventory puzzle and were considered in that perspective. Although all of these programs present basically the same goal of inventorying a specific item on a massive highway network, the details of the inventory routine have not in the past been identical or even compatible. For this reason, the formulation of objectives for the collision location method assumed considerable importance. These objectives were summarized as follows:

1. The method should be sensitive enough to accurately identify high-frequency accident locations, and permit basic research on the relationship of design and operating elements to accident production.
2. The method should be simple enough to permit accurate use by the average policeman in the field.
3. The method should have maximum potential for use as a general road inventory procedure.
4. The method should have potential for uses other than collision (motorist information and guidance, traffic planning, etc.).

5. The cost of the system should be minimal.

The problem of inventorying collisions, design features, or any other descriptive element or event on a large highway system initially assumes substantial dimensions, but the use of high-speed computers with large storage capacities and easy access have reduced the problem considerably. The task of the state highway engineer in designing and carrying out this inventory may be compared to the inventory control problem frequently encountered in private industry.

The first requirement—that the method be accurate enough to identify high-frequency locations—was, of course, the basic reason for the program, since the requirement has seldom been met. Some of the specific accuracy problems that had plagued Maine's Planning and Traffic Division are discussed in a later section.

Because the police investigator was to remain the principal source of data collection in the foreseeable future, the method chosen for improving the location process must be simple, concise, and not involve cumbersome or time-consuming procedures in the field. A stated goal of the entire records system improvement had been the reduction of effort on the part of the police investigator.

High-speed computers offer a good opportunity to improve the highway and traffic engineer's ability to recall descriptive information useful in his design and operations' tasks. At the same time, the unification of all inventory and descriptive procedures was identified as a major goal. Keeping road inventory information on one location basis, traffic volume information on another, and bridge inventories on a third was to be avoided if possible. It was initially felt that all these inventories should be placed on an identical location basis, rather than correlating different location procedures with lengthy computer routines.

The ability to use the accident location method for non-safety purposes could be considered a fringe benefit. Motorist information and guidance is frequently mentioned as another use for the accident location system with specific recognition of the reference markers in the field. This is possible at several different levels of sophistication. For example, the mere installation of an understandable series of signs along the road has obvious use to the motorist. In more sophisticated terms, there should be some consideration of the relationship between the future development of automated vehicle guidance and control systems and collision location procedures. Substantial research and development work has been undertaken in this area by the Bureau of Public Roads' Office of Research and Development. In the highway planning field there would be considerable advantage in a collision location method that would have some compatibility with existing traffic assignment procedures, since this could simplify areawide or statewide traffic assignments.

Although the ability to accurately locate collisions is of basic importance, it is only a tool to be used in reducing collisions, and the resources committed to developing the tool should be reasonable. The maintenance and operation of the whole location process in future years was considered an important part of the total cost, which had to be balanced with the initial investment. Thus, a procedure that might eliminate the need for reference markers in the field would be desirable only if the subsequent cost of the office coding of locations was less than the cost of the markers.

Existing Method of Collision Location

For several years in Maine, some excellent work in accident data collection has been accomplished, especially by the state enforcement agency, the Maine State Police. In this state, collisions are reportable if a personal injury results or if total property damage exceeds $100. The state statutes require that the police agencies investigating accidents file standard report forms with the State Police Headquarters and that drivers file similar reports. For the most part, driver reports are not used by the State Highway Commission. The Maine State Police have had the responsibility for processing the basic information. In 1966, a total of 21,000 accident reports were filed with State Police Headquarters. The level of reporting is considered to be reasonably good, although specific areas of underreporting have become clear as the accumulated data in the new system have become available.

Prior to the development of the new location procedures, the accident report form, which is standardized and used by all state and local police departments, contained the following location information: (a) city or town name, (b) county name, (c) name or number of street or highway, and (d) distance and direction in miles and tenths to a landmark.

Police were instructed to measure the distance from a landmark to the collision site using the vehicle odometer and also indicating the appropriate direction. They were encouraged to use intersections of US- and state-numbered highways as "landmarks." Experience in using the data had defined the following kinds of problems:

1. Locations based on the name of a business or residence.
2. Locations based on a street or highway name that does not appear on available maps.
3. Locations referenced by utility pole numbers.
4. Locations that were long distances from the reference landmark.
5. Errors in the direction from the landmark to the collision site.
6. Vague or incomplete data.
7. Estimates of distance rather than measurements.

In short, the location data, as available, did not provide the necessary accuracy or adaptability to machine processing to accommodate the expanding needs of the Maine State Highway Commission and other state agencies. For that reason, early in 1967 the State Highway Commission decided to establish an interim records system that would staisfy the needs of the Department until such time as proposed modifications to the existing records system were completed. As a beginning process, copies of all 1966 source documents (police reports only) were obtained, and those accidents that could be located on the federal-aid and state highway systems (approximately 4,600 miles) were processed onto punch cards for environmental analyses.

This work provided the opportunity to test some of the recommendations made in an earlier study of the entire accident records system, and these are described in a later section.

Comparison of Alternative Methods

The first step in selection of the accident location method was to review the procedures that have been developed in other states. A review of the literature and personal contacts with some of the state highway departments revealed four basic different methods of accident location then in use or under development, as follows: (a) route number and accumulated mileage (reference markers at regular intervals), (b) route number and accumulated mileage (reference markers at irregular intervals), (c) route number and accumulated mileage (no reference markers), and (d) coordinates.

The most commonly considered method of accident location was based on route numbers and accumulated mileage, with signs posted at specific intervals (usually one mile). In its usual form the signs showed the mileage for a particular route beginning at the state line and accumulating throughout its entire length within the state. To indicate the location of a collision, the police investigator must observe the mileage signs on either side of the site, or otherwise must be aware of their sequencing, and then measure the distance to one of these sign locations. He adds the distance measured (usually to the nearest one-tenth mile) to the lowest signpost number and records it in this fashion. Measurements are commonly done with vehicle odometers reading in one-tenth mile increments.

Several problems were apparent in the application of this procedure in Maine. The first of these concerns the difficulties that are encountered with overlapping route numbers. A considerable portion of the state highway system carries more than one route number. In order to retain the ability to easily recall data for a particular route, it would have been necessary to provide for considerable manipulative ability, which would have reduced the ease of data handling. Changes in the route locations would, of course, create some reporting problems on the local level, but the entire mileage of routed highways, which is changed from one location to another, is usually quite small in any particular year. Changes in the length of a particular route because of reconstruction or relocation would, however, have a significant effect on the procedure. It would require the repositioning of a substantial number of signs in the field to maintain the continuity of the system or as an alternate solution the use of additional equations. In urban areas, the reporting of accident locations on the basis of route number and accumulated mileage would be inadequate and further information would be required. It was realized that the accident problem is urban oriented to a significant degree, even in the rural State of Maine. The last and perhaps the most serious disadvantage of the regular mileposting procedure is that the locations that are referenced in the field have little or no significance in terms of changes in the environment. The locations are strictly controlled by the posting interval and are thus not the place where traffic volumes or highway design and operating elements change. Obviously, if the locations that are referenced by signs in the field have some significance in terms of a change in the environment, then the future data processing costs will be reduced. The best example of this is the problem of recalling a particular intersection or group of intersections. This is a task that Maine's Planning and Traffic Division is most frequently required to accomplish. Under the milepost procedures, efficient recall of accident data at specific intersections would require the preparation of a comprehensive listing that showed the mileage location of each and every intersection. The cost of this correlation would be significant, and it is not clear that adequate results could be obtained for complex intersection configurations. It would be necessary to search at least two, and possibly three, different route numbers and accumulative mileage figures to be sure that all accidents are recalled for the specific location.

The posting of route mileages at existing landmarks occurring at irregular intervals would eliminate some of the disadvantages of the regular interval posting. Several states, which are using this procedure, post accumulated route mileages on signs, bridges, utility poles, and at intersections. Thus, it is theoretically possible to choose the locations for the field reference markers that have environmental significance. The freedom of choice, however, is reduced considerably in rural locations. Considerable use has to be made of traffic signs as locations for field referencing. Since these signs tend to cluster rather than occur uniformly over a given stretch of highway, and since signs are not permanent in nature, it was felt that the method had serious drawbacks for use in the state, even though reference marker costs are lower. A complete sign inventory is not available to the Planning and Traffic Division, and thus design of the locations would have had to be accomplished in the field. Such a procedure would also be somewhat more difficult for the policeman to use in the field, but this was not a major consideration.

The third possibility for an accident location procedure was to use a route-number and accumulated-mileage system, which is based on very detailed straight-line diagrams of the entire highway system. Several states are using this procedure with apparent success. In one case, the accidents are coded in the field by the police officer, which requires distribution of maps to all accident investigators. In another case, the location coding is done in the office based on the usual data reported by the police authorities. In both instances reference markers in the field are not a part of the system. The procedures would have been difficult to apply in Maine, due to the lack of sufficiently detailed straight-line diagrams. In addition, the original problems of data handling with the mileposting procedure are still in evidence. From a long-term cost standpoint it was felt that the cost of installing and maintaining field reference markers would be less than the cost of coding all accident locations in the office.

The last concept, which was under consideration by several states, is based on the use of coordinates in stating collision locations. A major advantage of this procedure is that it is readily adaptable to mechanical plotting. Two basic possibilities exist for using the method. The first would involve preparation of a series of maps with coordinate grids superimposed on a considerable amount of topographic and cultural detail. These maps would then be distributed to the investigators who would determine and report the coordinates of the collision locations. An alternate procedure would involve the coding of the locations in the office using the same maps. The former approach was ruled out, since many problems had been encountered with the data on locations as currently reported by the police investigators, and it was felt that major innovations in the reporting process would be required. The first approach, involving the distribution of maps to the police investigators, was thought to be too cumbersome and complicated for the average investigator. In addition, the correlation of accidents with highway design and operating elements would require a complete digitizing of the highway system, a long and costly process. Development times for either of the two approaches were considerable and would have meant substantial delays in this portion of the traffic safety program.

In an effort to combine some of the advantages offered by the different alternates, the Planning and Traffic Division decided to evaluate a proposal that accidents be located on the highway system according to a simple nodal principle. The proposal called for numbering and posting in the field of all major intersections on the highway system, as well as city-town lines, urban lines, railroad grade crossings, and major bridge structures. The concept was adapted from the highway planning process that simulates highway networks on a nodal basis for traffic assignment purposes. Under the procedures proposed, the policeman would indicate the accident location by one of two processes, depending on the location. If the accident occurred at an intersection, then the number of the intersection is all that needs to be recorded. If the accident occurred between intersections, then the police officer is instructed to record the intersection numbers on either side of the location and measure the distance to one of the two intersections.

For the policeman, the concept of accident location as presented by this method is very similar to the concept now used; that is, he is locating the accident site by referencing it from a known landmark. However, since the frequency of these landmarks was to be greatly increased, the distance that has to be measured is considerably decreased, with more accurate results. The confusion concerning the direction from the landmark to the accident site is completely eliminated by the provision for recording intersection numbers on both sides of the accident site. The method is adaptable to rural and urban locations, and is particularly valuable on limited-access facilities, where individual ramps can be posted according to the same basic principles as other roads. The processing of the data using the method entails a minimum amount of work. In the first place, location of the accident is reported in numerical form, which is computer oriented. Only keypunching and a minimum amount of editing is required to put the data in computer format. Second, the ease in handling the data would be considerably enhanced. It becomes an easy matter, for example, to recall accidents at any particular intersection or group of similar intersections. By the same token, accidents can be easily recalled for routes, combinations of routes, areas, or highway systems. The adaptability of this accident location procedure to the highway planning process is evident. The procedure is also adaptable to some of the more sophisticated proposals for route identification and guidance. Work now in progress by the Federal Highway Administration indicates that such systems will be based on the identification of decision points (intersections) on the highway networks.

It is emphasized that the method of identifying intersections is adaptable to description by coordinates, and it is possible that the coordinates of each node will be established at a later date as the mechanical plotting process gains importance.

DESIGN OF THE ACCIDENT LOCATION SYSTEM

Map Numbering Sequence

The first element in the design of the node-link system was a careful review of the different possibilities available for numbering the field refrerence points. It was felt that the procedures developed should be readily adaptable to the entire street and highway mileage in the state, even though the first concern would be limited to the 4,600 miles of federal-aid and state highways. This decision, coupled with the desire to maintain four digits as the maximum on the field reference markers, meant that the numbering sequence would be unique on a county level. Thus, a total of 10,000 locations would be the capacity for each county. Final design and production of the necessary location maps showed that approximately 10,000 locations would be signed initially on the 4,600-mile federal-aid and state highway systems.

A total of six alternate numbering schemes were reviewed in some detail. Most of the schemes reviewed carried information identifying the highway system and the urban-rural classification. There were significant variations in the number ranges reserved in each group and the ordering of the number ranges. The scheme finally selected carries only the system designation as follows:

Highway System	Reference Marker Number Range
Maine Turnpike, non-Interstate	9700-9999
Interstate Highway System (state highway)	9000-9699
Federal-aid primary highway system (state highway)	7000-8999
Federal-aid secondary highway system (state highway)	6000-6999
Federal-aid secondary highway system (state-aid)	5000-5999
Non-federal-aid highway system (state highway)	4000-4999

The sequence as designed provides for (a) ease of sorting by highway system, (b) continuity of numbering along major routes in each county, and (c) expansion of system capacity by at least a factor of 2.

Numbering generally was done in ascending order from south to north and west to east along routed highways. The limited-access facilities have been treated as two

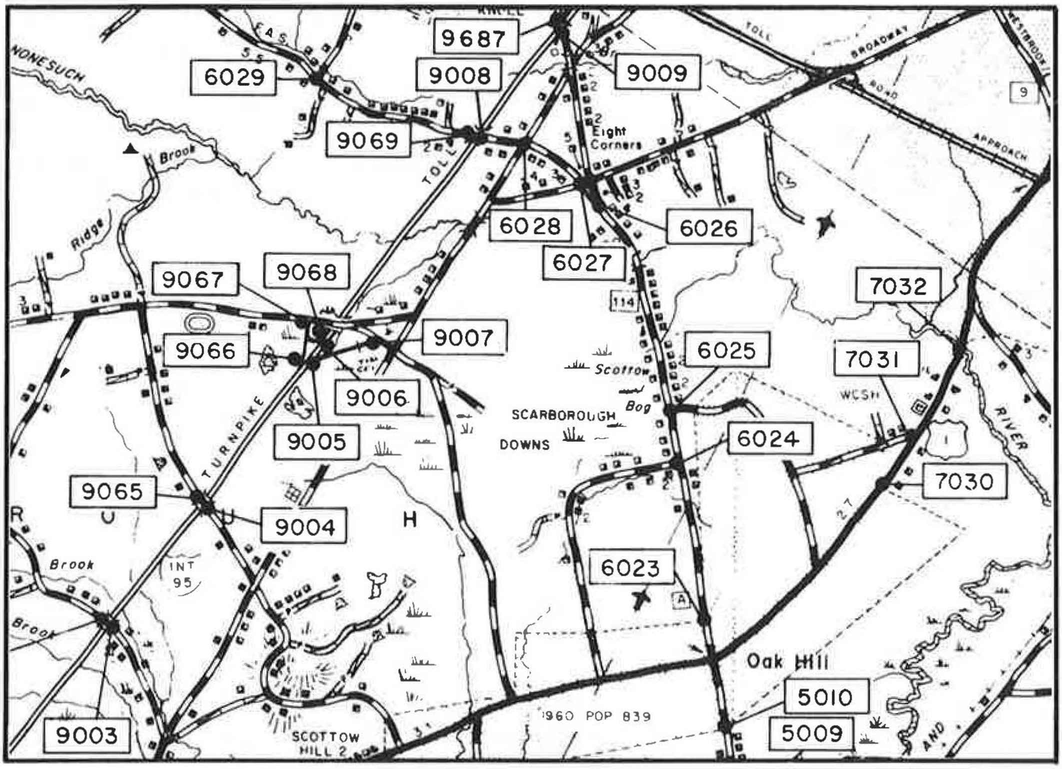

Figure 1. Typical accident location map.

separate roadways and numbered accordingly with reference markers also located at ramp terminals. Reference markers have also been located at the intersections of directional roadways within major channelized intersections.

TABLE 2

FREQUENCY OF REFERENCE MARKERS

County	Highway System Mileage	No. of Reference Marker Locations	Locations per Mile
Androscoggin	167	600	3.6
Aroostook	724	1,074	1.5
Cumberland	359	1,352	3.8
Franklin	243	320	2.8
Hancock	264	585	2.2
Kennebec	323	843	2.6
Knox	88	256	2.9
Lincoln	129	235	1.8
Oxford	342	493	1.4
Penobscot	453	1,190	2.6
Piscataquis	145	220	1.5
Sagadahoc	99	253	2.6
Somerset	364	622	1.7
Waldo	169	325	1.9
Washington	336	534	1.6
York	321	1,217	3.8
Total	4,526	10,119	Avg. 2.2

Preparation of Maps

Subsequent to defining the rules for numbering reference points on the highways, the Highway Commission prepared a series of 162 maps (Fig. 1) showing the location of each reference marker. These maps were produced to assist in the field installation phase, as well as to provide a test of the location process (without benefit of reference markers in the field). The base maps for this project were existing general highway maps prepared and maintained by the Highway Commission. The rural series (scale 1 inch = 1 mile) contains a considerable amount of culture, while the urban series (scale 1 inch = 600 feet) generally presents only street names, route numbers, rivers, railroads, and major public buildings.

Table 2 summarizes the total number of field reference marker locations in each of the 16 counties as compared with the miles of highway on all of the systems considered. The frequency of reference markers is directly related to the degree of urbanization, and this is clear from the data in Table 2. Androscoggin, Cumberland, and York counties are the most urbanized counties in the state and have the highest marker frequencies. In no case was the distance between reference markers allowed to exceed 1 mile in urban areas or 2 miles in rural areas. Where this would have occurred, due to the absence of an intersection, bridge, railroad grade crossing, or city line, a dummy location was established.

Table 3 summarizes the numbers and percentages of each type of location field referenced. It is noted that intersections account for approximately 80 percent of the total.

Test of the Location Process

The next step in the development of the records system was the creation of an accident records file for the federal-aid and state highway systems using the accident location process as previously described. It was recognized that the process itself should be subjected to a thorough test prior to an investment in field reference markers. In addition, there was a pressing need to create an accident records file of data for use in current programs. Obviously, the installation of the field reference markers,

TABLE 3

SUMMARY OF REFERENCE MARKER LOCATION TYPES

Type of Location	No. of Occurrences	Percent of Total
Intersections (and urban boundaries)	8,203	81.0
Railroad grade crossings at intersections	43	0.4
Railroad grade crossings between intersections	167	1.7
Bridges	572	5.7
City, town lines	764	7.5
Dummy nodes	370	3.7
Total	10,119	100.0

Figure 2. Reference marker installation.

the changing of the accident report forms, education of the police investigators, and the accumulation of several years of accident records would be a time-consuming process. To overcome these difficulties, a decision was made to establish a records file using existing accident reports (i.e., the previous year, 1966). Photocopies of all accident reports (police) for the calendar year 1966 were obtained and processed. Locations were fixed as accurately as possible with the existing data, and those collisions occurring on the federal-aid and state highway systems were recorded on punch cards for rapid analyses. The Highway Commission has continued to receive and process copies of the original source documents during 1967 and 1968.

In general, the coding project was a success, even though it was clear that the absence of field reference markers reduced the accuracy of the location process for the 1966 and 1967 data. The feasibility of the process has been established, and a workable file of accident records was then available. Prior to installation of the field reference markers, the location coding utilized business and city directories, commercial maps, and even telephone calls to local agencies, in addition to the routine data on the report form.

Installation of Reference Markers

Once the "map test" of the methodology was successfully completed, the Commission adopted the process and decided to install the field reference markers on the entire 4,600 miles of federal-aid and state highways. A total of 20,000 markers were fabricated in the state sign shop utilizing 3-inch numerals (silver) on a 5 by 10-inch sign blank (green). Each field installation consisted of two markers on a single support. Erection of the markers was accomplished during the winter months of 1967-68 by state crews attached to the Planning and Traffic Division (Fig. 2). Existing sign structures were utilized in approximately 60 to 70 percent of the installations. This phase of the program cost a total of $57,000 and was partially funded by the National Highway Safety Bureau.

TABLE 4

STATEWIDE ACCIDENT DISTRIBUTION, 1966

No. of Accidents	Number of Locations					
	Nodes			Links		
	Urban	Rural	All	Urban	Rural	All
1	717	369	1,086	991	1,571	2,262
2	249	112	361	309	563	872
3	119	34	153	104	235	339
4	73	18	91	55	124	179
5	45	4	49	27	55	82
6	26	2	28	12	22	34
7	21	1	22	10	12	22
8	14	–	14	5	6	11
9	9	–	9	1	3	4
10+	44	–	44	6	4	10

Initial Experience

During the period of field installation of the reference markers, the Maine State Police, which serves as the central records agency, modified the standard report form to provide for direct reporting of accident locations by node-link identification. At the same time, additional changes in the report form were made and a series of regional training sessions scheduled to instruct state and local police officers in the use of the new form. Initial results with the system have varied. Few problems have been noted where the system is used, but some of the local police agencies had not been consistently reporting locations using the node-link identification. The State Police, who account for approximately 50 percent of the accident reports, are using the system consistently and with no apparent problems. Additional training and orientation sessions with individual local police departments have been held to encourage use of the node-link system and thereby further reduce the office coding burden to a minimum. These efforts have been most encouraging. In addition to location-to-location data, 49 columns of other information are coded on the keypunch form. Of the total of 21,281 accidents reported to the central agency in 1966, 11,948 or 56 percent were located on the 4,600-mile federal-aid and state highway systems (22 percent of the total mileage). All coding, punching, and editing of the 12,000 reports that are processed by the Commission's Planning and Traffic Division consume $1\frac{1}{2}$ man-years of effort annually. Coding of the data makes up most of this total, and a significant part of the coding task involves the manual checking of location data and a comprehensive classification scheme. In summary, the initial experience with the process has been good, and the small cost of data processing suggests a high level of operational efficiency.

Use of Accident Data

Prior to the development of the data described, all principal accident studies done by the Commission's engineering staff required the use of the original report form document and involved large investments in searching and processing of the data. This problem, combined with the inaccuracies of the then existing location methods, severely limited the use of accident records. The availability of computerized accident information accurately located on a systemwide basis has effectively removed these restraints.

Early work with the collision data involved summaries of accident frequencies by highway system and type of environment. One of these summaries appears in Table 4 and consists of a distribution chart for urban and rural nodes and links for the year 1966. A total of 11,000 accidents are represented by these data, with 64 percent occurring on links and 36 percent at nodes. It is interesting to note that this preliminary information shows a much greater dispersion of link collisions as compared to those that occur at nodes. Approximately 18 percent of all nodes had one or more collisions in 1966, as opposed to 40 percent of all the links. It seems clear from these data that more than one year's information is necessary to satisfactorily identify high-frequency locations, particularly in the case of nonintersection locations.

In the short time since they became available, the data have been used for a wide variety of projects. The following represents a partial list of completed projects:

1. Comprehensive listing of high-accident links and nodes based on travel volumes followed by field reviews.

2. A study of bridge accidents.
3. A study of fixed-object collisions.
4. A study of collisions involving animals.
5. Analyses of specific locations initiated both internally within the Highway Commission and externally by other state and local agencies.

A recently completed project has established the framework for future data systems that will be used for the correlation of collision records and highway design and operating variables. Expansion of the data is now underway, as is a first step research project that includes an examination of at least the following relationships: (a) collision severity and collision type, (b) collision rate and intersection configuration, (c) collision rate and type of traffic control device, (d) collision rate and access control, and (e) collision rate and traffic volume.

Pennsylvania's Helicopter Ambulance Study

ROBERT R. COLEMAN, Study Director, Highway Safety Group,
Pennsylvania Department of Highways

The Pennsylvania Department of Highways is investigating the feasibility of using a helicopter as an ambulance, principally for traffic accident victims. The basic premise was that delay in bringing proper medical aid and the accident victim together could be caused by traffic congestion in urban areas and travel distance in rural areas. The study is being conducted in the Philadelphia suburban area for a period of one year.

A 4-place Bell J-2A helicopter modified to carry one litter patient and a medical attendant was leased 14 hours daily from 7 a. m. to 9 p. m.—the period when the highest percentage of traffic accidents occur. It was equipped with a litter, first-aid kit, oxygen, splints, blankets and sheets, and PA system. The crew consisted of a state policeman and pilot, both of whom received special first-aid training. The helicopter ambulance, which carried a police radio, was based at state police substations and responded to requests for emergency service via state police radio or phone. Two patrols were normally made each day during peak traffic hours. The helicopter was also used extensively for police traffic surveillance and criminal work. The crew was dispatched to 128 traffic accidents in which they airlifted victims from 38. In addition, they transported two accident victims from non-traffic emergencies to the hospital. The total time from receipt of alert to delivery of victim to the hospital averaged 20.9 minutes for the 40 airlifts. Trip time from accident scene to hospital averaged 6.0 minutes. Hospital physicians are preparing special medical reports on each injured person airlifted to determine what effect or benefit, if any, he experienced as a result of the reduced response time. Victim's reactions to being transported by helicopter were highly favorable. In only one instance in 41 did an accident victim refuse to be flown.

•THE 16 Safety Standards developed under the provisions of the Highway Safety Act of 1966 are becoming well-known. These standards cover all phases of activities affecting highway travel. They set the goals and establish the levels of performance that each state or local government must attempt to reach over the next several years.

Standard 311, Emergency Medical Services, states that:

> Each State, in cooperation with its local political subdivisions, shall have a program to ensure that persons involved in highway accidents receive prompt emergency medical care under the range of emergency conditions encountered.

It was under this provision that the National Highway Safety Bureau and the Pennsylvania Department of Highways entered into a cost-share agreement to study the use of

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helicopter ambulances for traffic accident victims. Cooperating with the Department of Highways in this study were the Pennsylvania State Police, the Department of Health, the Pennsylvania Aeronautics Commission and several area hospitals.

It was the basic premise that delay in getting proper medical care to the injured is caused largely by traffic density in urban areas and travel distance in rural areas.

The suburban area adjacent to Philadelphia was chosen as the study site and a contract was entered into with the firm of Copters' Inc. to furnish a helicopter properly equipped for ambulance service, to be available 14 hours daily, 7 a. m. to 9 p. m., 7 days a week for a period of one year.

A Bell Model J-2A helicopter was modified to accommodate a pilot, a medical attendant and one litter passenger (Figs. 1 and 2). It operated over a semicircular area with approximately a 20-mile radius covering 900 square miles.

The principal objective of the study was to determine how effective a helicopter ambulance could be in increasing the chances of survival of traffic accident victims. Some of the questions for which answers are sought are as follows:

1. What is the time reduction possible in getting proper medical aid to the accident victim either at the accident scene or hospital as compared to normal ambulance transportation?
2. Is this time reduction significant in preventing death or permanent disability to a severely injured person?
3. What are reactions of the injured persons being transported by helicopter?
4. Are certain types of injuries likely to be aggravated by helicopter transport thereby limiting its usefulness?
5. Are specialized types of medical equipment necessary or desirable to optimize the helicopter mode of transport?
6. What communications are necessary between helicopter, local or state police, ambulance clubs and hospitals?
7. What are the minimum desirable characteristics for the helicopter, with respect to size, range, speed and equipment?
8. To what extent do adverse weather conditions, physical obstructions or other factors prevent the helicopter from performing its function as an ambulance?

Figure 1. Bell Model J-2A, 4-place helicopter modified to carry 1 litter patient, 1 attendant and pilot.

Figure 2. Interior arrangement showing litter drop and seat for attendant.

9. How large an area can one helicopter adequately service?
10. Can a helicopter reduce the number of ground ambulances required to properly service a given area?
11. What is the cost of maintaining helicopter ambulance service as compared to regular ambulance service?
12. Should the helicopter patrol certain areas at certain times or remain at the base awaiting calls?
13. Can helicopter be assigned other functions, such as police patrol or criminal work without adversely affecting its primary mission of an ambulance for traffic accidents or other emergencies?
14. How many deaths or permanent injuries can be prevented using helicopter over a given area and/or time span?
15. Does rapid removal of accident victims permit earlier resumption of normal traffic flow?

DESCRIPTION OF STUDY

Study Design

In recent years, with the growth of computer usage, much emphasis has been placed on the systems approach technique for developing solutions to difficult problems. This usually consists of identification of problems and system requirements, development of system components or subsystems, and finally testing alternatives independently and in combination to determine the effects on the total system.

This methodology is particularly applicable to studies involving many variables such as those encountered in development of emergency care systems. These systems are composed of many interrelated components including accident detection time, emergency room facilities, availability of physicians, jurisdictional boundaries, local habits and customs, to mention some that are in addition to the transportation mode variable.

Thus the "simple" task of evaluating one mode of transportation in relation to another mode could lead to a series of comprehensive studies reaching far beyond the original scope of this project, dissipating resources by utilizing specialists required to carry out such studies without necessarily finding the answer to the basic question, "Can a helicopter ambulance reduce deaths or effects of injuries in a civil environment as it does in a military environment?"

It was believed that answers could be found to most of the questions previously stated by practical testing. The method of approach, therefore, was to place a helicopter ambulance in service and develop, in general terms, only those studies required to find answers to those questions without the sophistication of rigorous systems analysis. These tasks included:

1. Measurement of helicopter capabilities in a civil environment through airlift of victims from both actual and simulated traffic accidents,
2. Medical evaluation of victims transported by helicopters,
3. Development of criteria of communication needs to permit optimum use of helicopter,
4. Survey and analysis of existing ambulance service within study area,
5. Analysis of accidents occurring during study year within study area,
6. Evaluation of other uses of helicopter (especially police),
7. Review of the legal status and responsibility of helicopter ambulance operating agency, and
8. Cost-effectiveness evaluation.

Location

It was hypothesized that a helicopter ambulance would be useful in reducing travel time under either of two common circumstances: (a) in heavily populated areas where

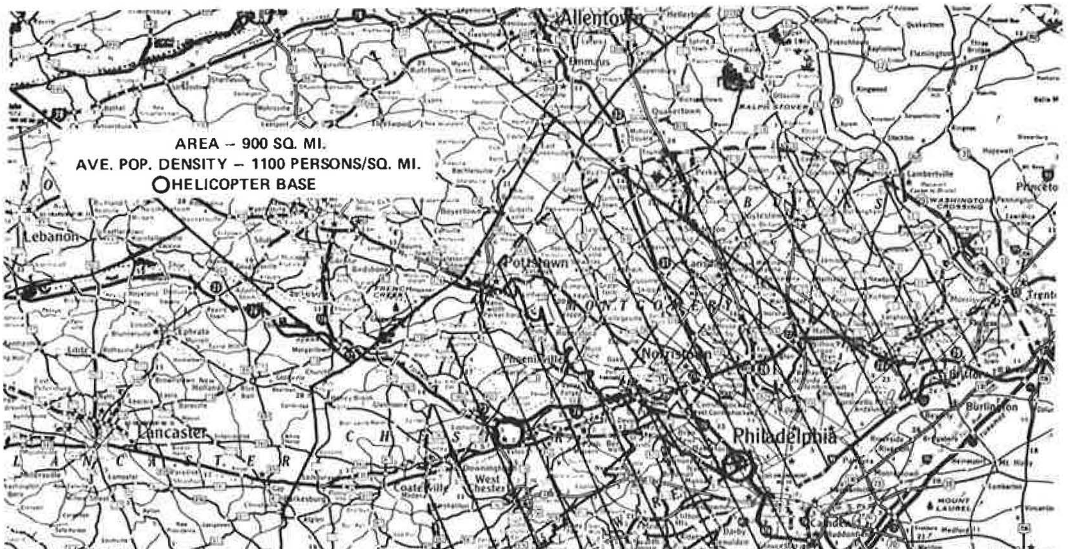


Figure 3. Southeastern Pennsylvania helicopter ambulance study area.

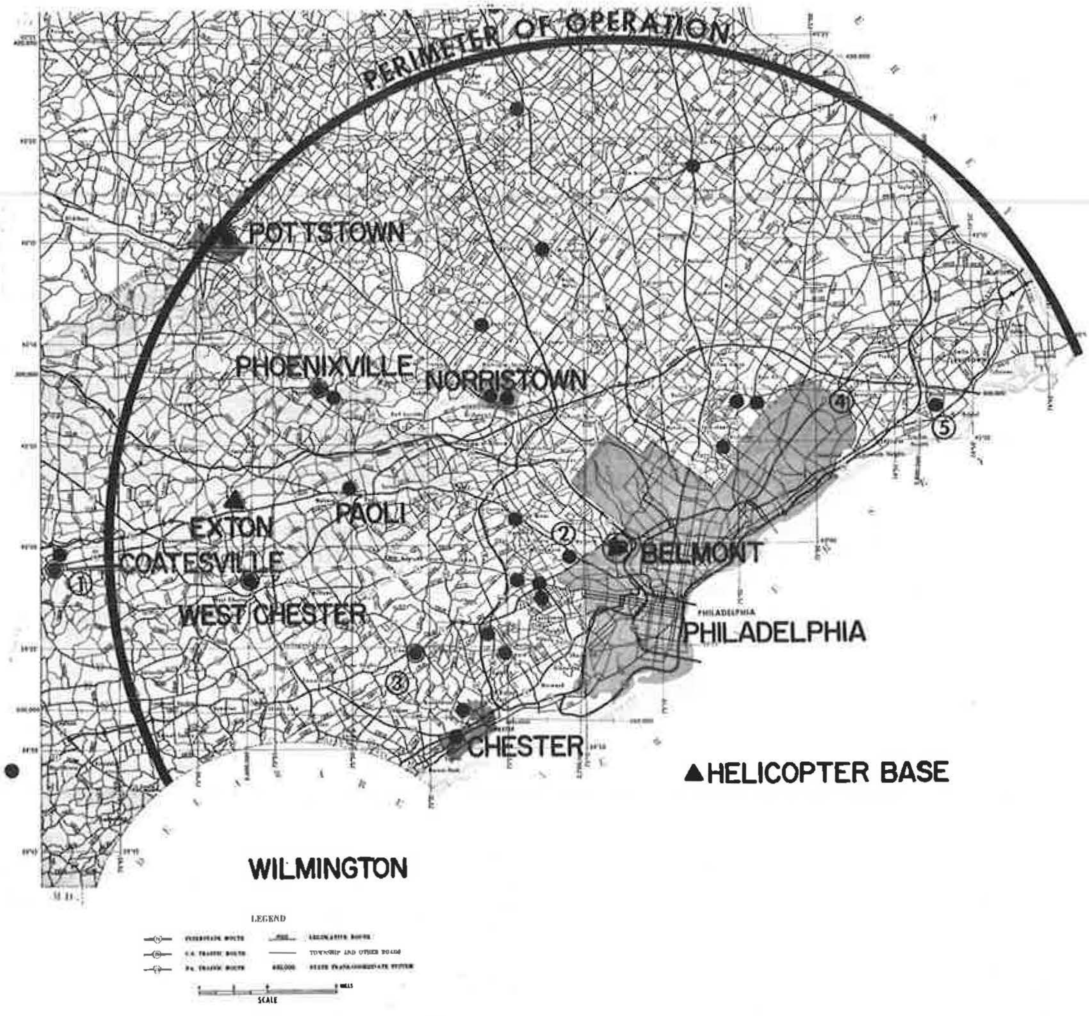


Figure 4. Locations of all hospitals in study area.

traffic density or unusual road network could delay normal ground ambulance operations, and (b) in remote rural areas where distance rather than traffic volumes prevented the ambulance from first reaching the victim and then the hospital quickly.

Since this study was to be conducted in an urban environment, the southeast corner of Pennsylvania (excluding City of Philadelphia) was selected as the study area (Fig. 3). This consists of 900 square miles encompassing the suburban Philadelphia region in Delaware, Chester, Montgomery and lower Bucks counties. This area, which has a population of just over one million persons, has an average density of 1100 persons per square mile. It includes 34,000 miles of highways and is presently serviced by 29 hospitals (Fig. 4), seven of which participated in this study (Fig. 5), and 93 ambulance companies (Fig. 6), the majority of which are volunteer.

Accident History

Approximately one-third of the 39,300 accidents that occurred in the study area during 1966 resulted in personal injuries. A cursory study of accidents occurring during December 1967, indicated an ambulance had been used in 25 percent of the injury-producing accidents. This would indicate that, on the average, 1 accident in 12 required

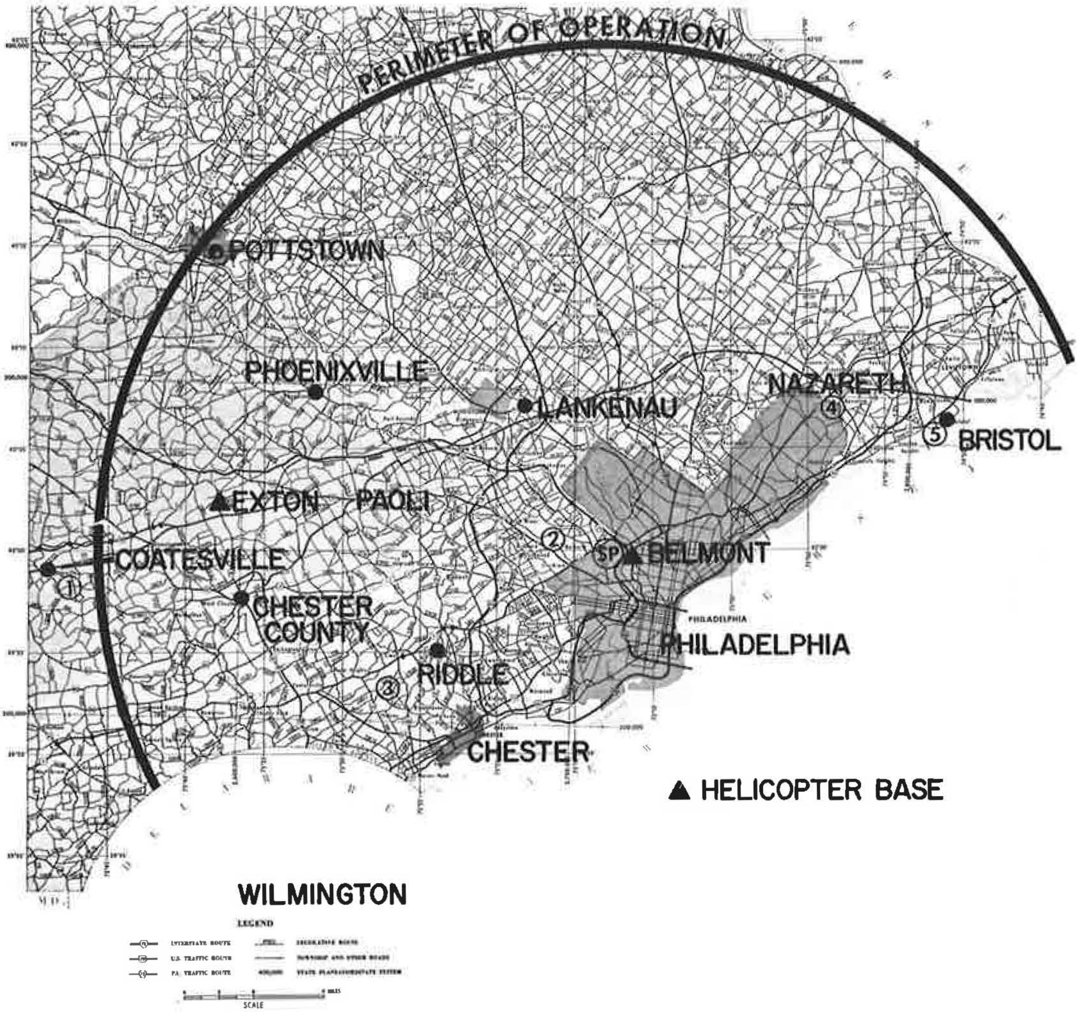


Figure 5. Locations of participating hospitals.

ambulance service. It also showed that approximately 60 percent of the accidents occurred during the 14-hr period in which the helicopter was available.

A 9-month study of accidents on 150 miles of high-volume routes in this area showed accidents occurred at rates varying between 232 and 1283 accidents per 100 million vehicle-miles. Expressed in terms of density, the rate varied between 20 and 89 accidents per highway mile. It was evident from this sampling that the accident frequency in this area was sufficient to test the helicopter ambulance (Fig. 7).

Orientation Meetings

A series of meetings was held with local police, ambulance clubs and participating hospitals to outline the objectives of the study, its relationship to the overall safety effort, and to enlist their support. Five hospitals originally were invited to participate. These were selected on the basis of their interest in the program, adequate emergency room facilities, adequate heliport, and geographical location within the study area.

A physician from the surgical staff at each participating hospital was asked to assume the responsibility for completing a medical evaluation of each accident victim admitted via helicopter. These physicians also served on a Medical Advisory Committee,

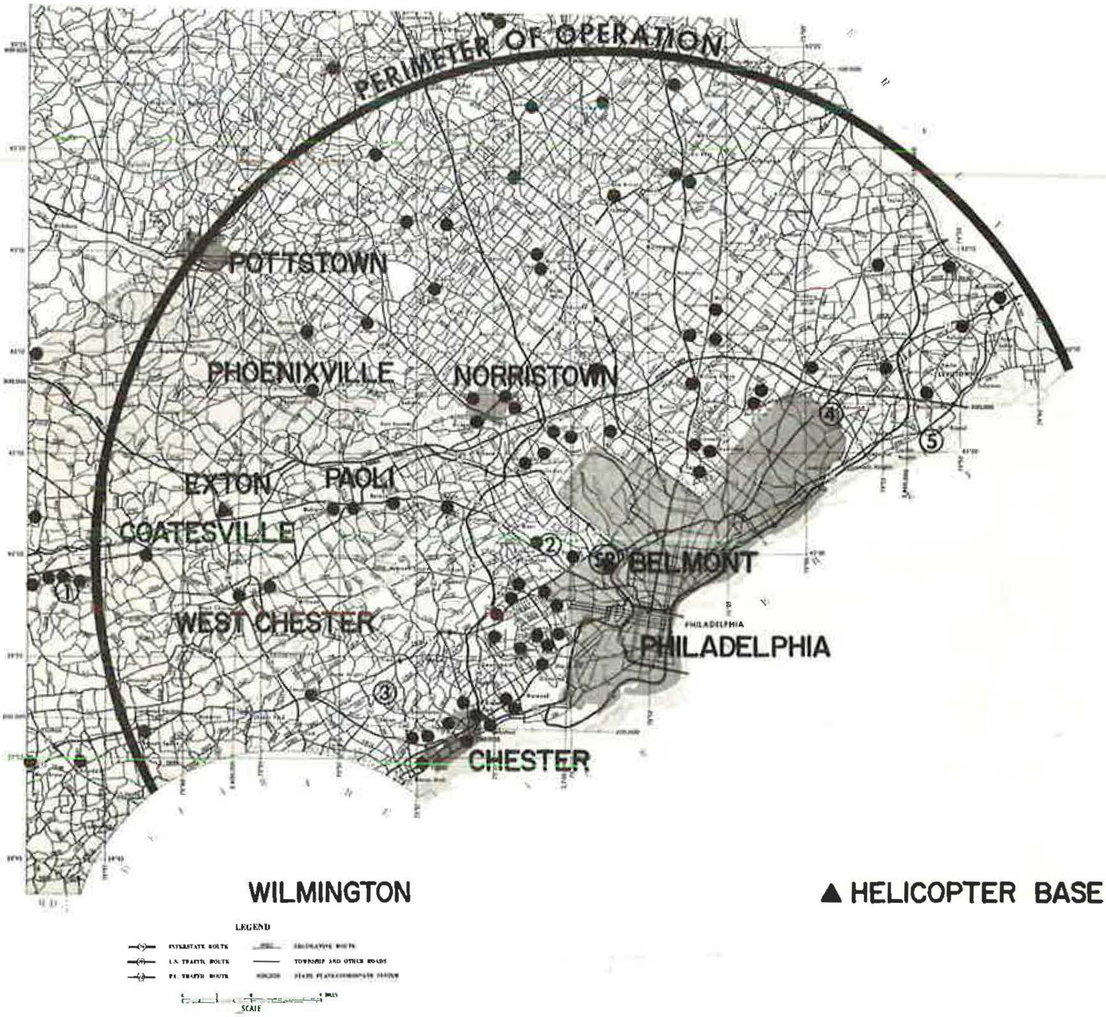


Figure 6. Existing ambulance service clubs in study area.

to provide the guidance by persons who understand the clinical needs of patients and who could suggest or evaluate equipment or procedures employed to best utilize the helicopter mode of transport in emergency situations.

Flight Crew

The helicopter was stationed initially at the western edge of Philadelphia at the Pennsylvania State Police barracks located on Belmont Avenue, between 7 a. m. and 9 p. m., 7 days a week. Seventeen troopers and three pilots were selected and given special first-aid training, which was equivalent to Advanced Red Cross and Ambulance Driver's Course. In addition, meetings were held with the troopers in which the objectives of the study were reviewed and suitable data forms developed for the recording and collecting of information required to evaluate the helicopter as a police patrol vehicle as well as an ambulance. Troopers were assigned on a rotating two-shift per day basis, 7 a. m. to 3 p. m. and 3 p. m. to 9 p. m. Flight crew consisted of a state policeman serving as a medic and a pilot with at least 3000 hours flight time.

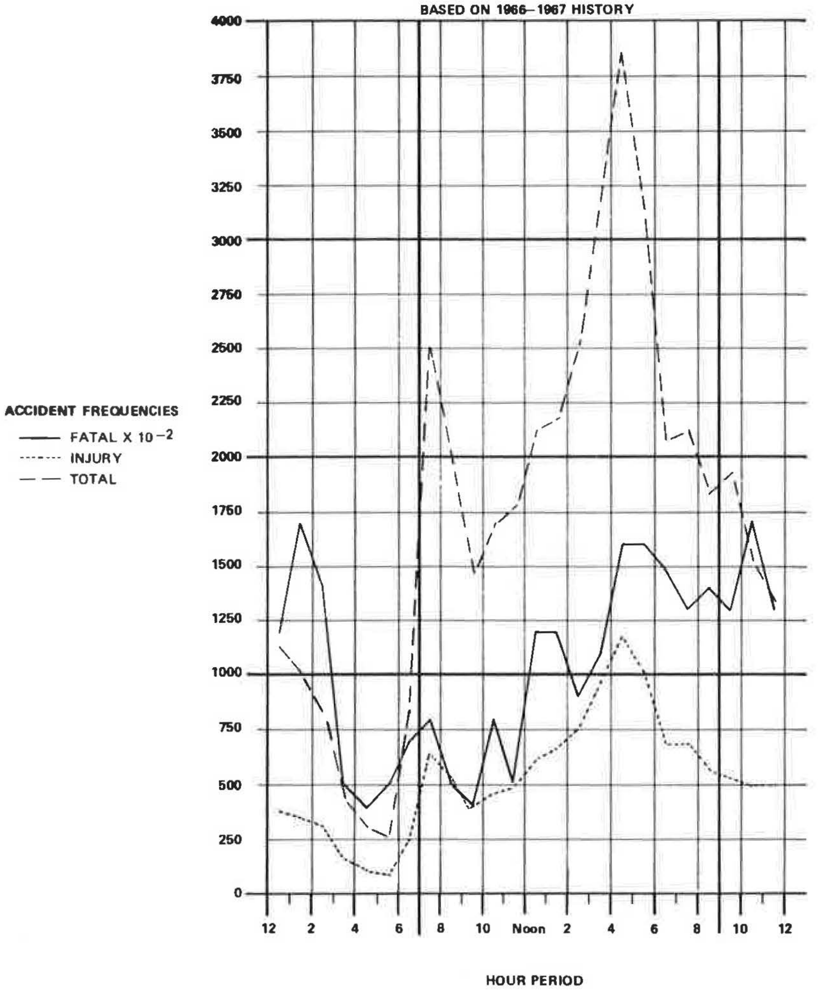


Figure 7. Average annual hourly accident frequencies Bucks, Chester, Montgomery and Delaware counties.

Mode of Operation

The following describes the operational procedures established for this study.

The need for the helicopter would be determined by the police first at the accident scene. If he were a state policeman he could communicate directly with the state police barracks by radio from his car; if he were a local policeman he would radio his headquarters who in turn would contact the state police barracks by radio or telephone. The state police would then dispatch the helicopter, which was equipped with both a state police FM radio and a VHF aircraft unit (Fig. 8). On reaching the accident scene, the helicopter would land on the highway or adjacent to it after the officer at the scene stopped traffic in both directions.

The decision would then be made whether the victim should be transported via helicopter or ground ambulance or whether the helicopter should bring a physician to the accident scene. In either event, the nearest hospital was notified by phone from the state or local police barracks of the situation after being advised by the officer at the scene. During the flight to the hospital the crew could maintain contact with the state police barracks.

Experience proved this was a sound procedure and it worked well throughout the study with few modifications.

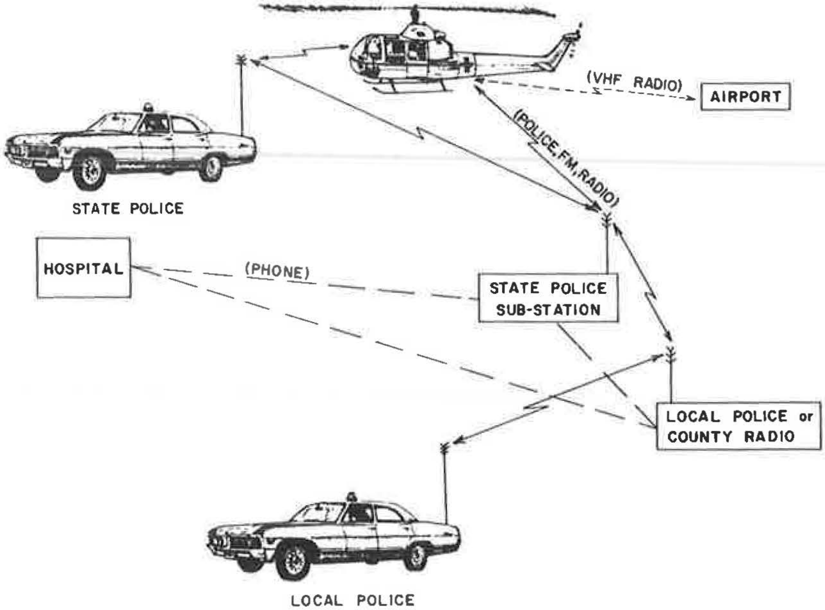


Figure 8. Communications network.

Phase I (Belmont)

The first weeks were spent principally in familiarizing the pilots and troopers with operational procedures, recognition of landmarks, physical obstructions and hospital landing sites. Patrols were flown during peak traffic periods, 7:30 to 9 in the morning and 4:30 to 6 in the afternoon. Flight schedules were not rigid, however, and some off-peak-hour patrols were also flown. The major service provided while on patrol consisted of dispatching assistance to disabled vehicles that were spotted, reporting minor accidents, and responding to varied emergencies. In one instance, a rare type of blood was rushed to an outlying hospital. In another, the helicopter served as an observation post, clearing a path and directing Highway Department salt trucks through hundreds of stalled vehicles on I-76 during a sudden icing condition.

Weather prevented flights 10 percent of the time during this study phase, which was significant because during this downtime three requests for ambulance service were received.

In view of the number of accidents that occurred, very few requests for helicopter service were received. Fourteen requests resulted in three actual airlifts, one of which was a heart attack victim. In each instance the landing, administration of first-aid, loading and transporting of the victim to the hospital were carried out smoothly and without incident. Response times were remarkably short; in one instance the total elapsed time from receipt of call at the police barracks to delivery of victim to hospital was just 9 minutes. Trip time from accident scene to hospital was 3 minutes. Normal trip time by ambulance at this hour to hospital from accident scene would have been 25 minutes.

Although 58 percent of the flights recorded a useful service of some type being performed, the lack of requests for ambulance service caused concern. Investigations indicated that 93 ambulance services were located throughout the study area, that competition between ambulance clubs in the area was high, that working arrangements between local police, ambulance clubs and hospitals had been in existence for many years, and that a general reluctance to call the helicopter prevailed unless the "spectacular" accident occurred. In the majority of instances, the police simply elected not to request the helicopter for the "normal" injury accidents that occurred so frequently. Thus, the study was suffering from a lack of necessary data required to evaluate the helicopter as an ambulance and it was a factor over which the project had little or no control.

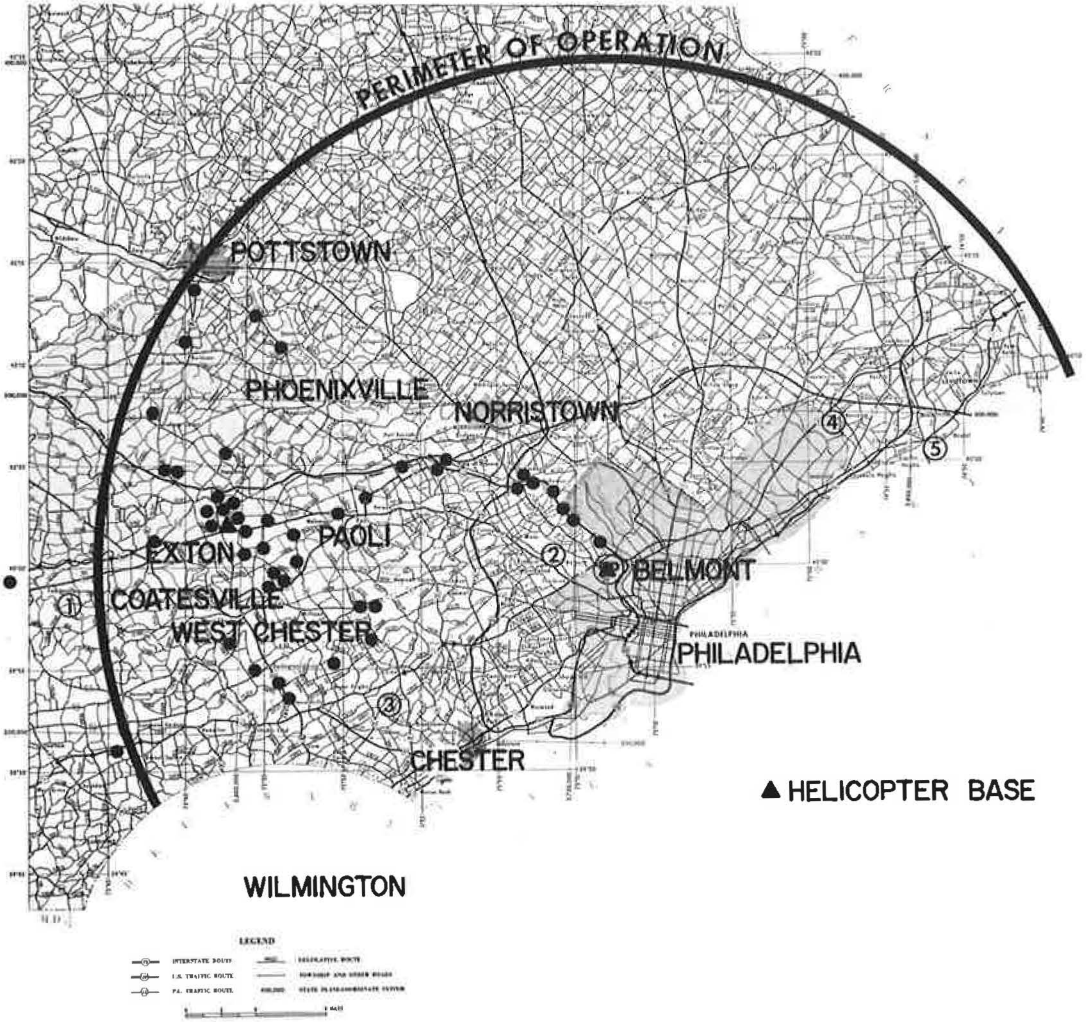


Figure 9. Locations of helicopter airlifts.

Phase II (Exton)

On March 1, the operation was transferred to the State Police Substation at Exton, which is located in the western section of the study area in a more rural environment. Four troopers were selected to fly as medics and received special first-aid training. The helicopter was identified as a police vehicle and was used more extensively in the day-to-day police operations although its primary mission continued to be an ambulance. The operation functioned in a similar manner as it did at Belmont with respect to time schedule and operating procedures, although the area of operations was generally limited to Chester County. Mutual monitoring between state police and Chester County radio network of local police radio systems resulted in more effective communications, and operation began to produce results that could be evaluated.

PRELIMINARY RESULTS

Although the flight operations for the helicopter ambulance were completed November 16, 1968, several of the study tasks are still in progress. It is possible at this time, therefore, to present a few of the results; however, they are considered preliminary.

1. During the 12 months of flight operations, the helicopter completed 622 or 85 percent of the scheduled patrols for a total of 983 flight hours.
2. The crew responded to 144 accidents (or emergencies), which resulted in completing 49 airlifts of injured or ill persons to a hospital (Fig. 9).
3. Disabled vehicles were observed on 83 patrols and investigation by the helicopter crew found that 55 percent of the vehicles required aid, which was summoned by the trooper aboard the helicopter.
4. As a police vehicle, it was dispatched to 55 criminal cases (many were bank holdups), 24 civil searches and 30 miscellaneous police activities.
5. It completed 244 (39 percent of the total) patrols in which no incidences were recorded.
6. In addition, it participated in 49 demonstrations at hospitals, schools, and ambulance club meetings.
7. It was used 9 times for engineering surveys and 15 times for airlifts at simulated accidents.

Response Time

The helicopter has proved its value in military operations in bringing the wounded to proper medical care quickly compared to ground transportation. This has also been found true in a civilian application although the environment, the operating procedures, and communications are substantially different.

For the actual airlifts completed, the total response time from initial alert to delivery of victim to the hospital averaged 20.9 minutes (Fig. 10). This is divided into four parts:

	Mean	Range (min.)
1. Alert to lift-off	2.0	1-5
2. Base to accident site	7.5	1-35
3. Time at accident site	5.4	1-48
4. Accident site to hospital	6.0	2-27

The range of times for parts 2 and 4 varied widely depending on the location of the accident with respect to the helicopter and hospital as well as wind conditions. On six occasions the helicopter was in flight at the time the alert was received.

Studies are being completed by several cooperating ambulance clubs to record their response and trip times, which will serve as a basis of comparison with the helicopter times.

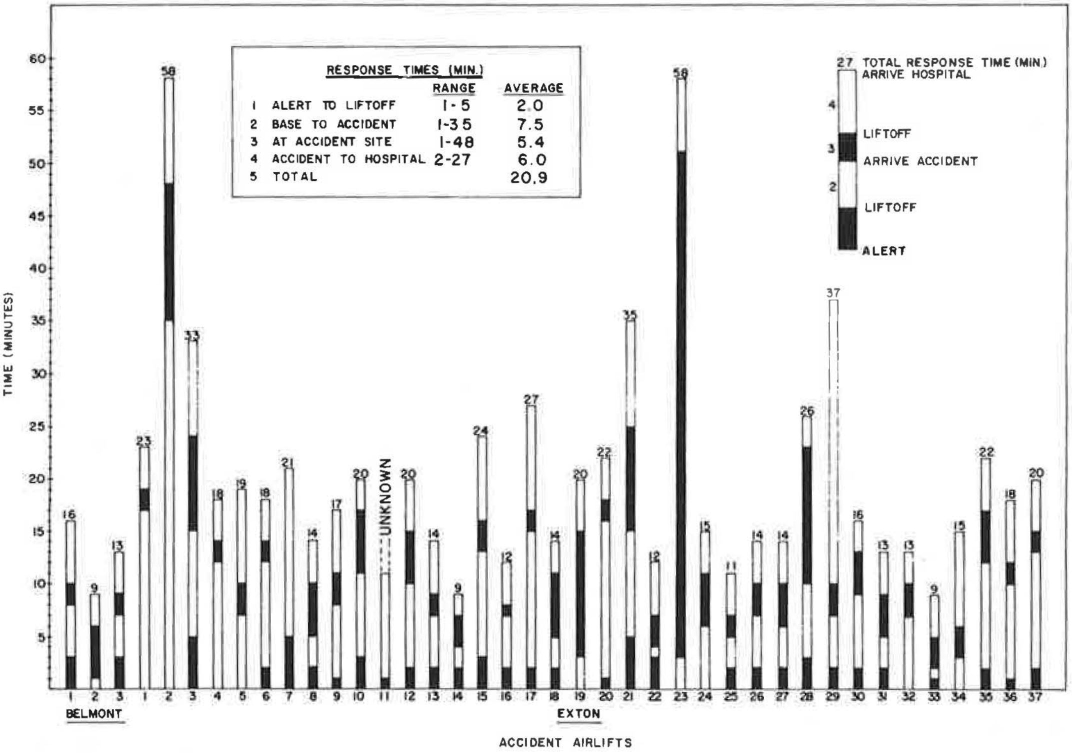
Medical Considerations

The first 40 airlifts included a variety of injury types. For simplicity they have been classified as follows:

Type Injury	No. of Victims
Lacerations (head, arms, legs)	23
Fractures	3
Chest, back and internal injuries	7
Other	7

In many of the accidents the time factor in getting the victim to the hospital was not critical. However, it is often not known at the accident site whether a head or internal injury is or is not critical. Of the 40 accident victims, three had injuries that were later classed as life-threatening.

Medical supplies and equipment carried by the helicopter are rather limited as compared to a modern ground ambulance because of weight and space limitations. Specially designed equipment for helicopter usage was not available. Care of the victim by the



RESPONSE TIMES (MIN.)	RANGE	AVERAGE
1 ALERT TO LIFTOFF	1-5	2.0
2 BASE TO ACCIDENT	1-35	7.5
3 AT ACCIDENT SITE	1-48	5.4
4 ACCIDENT TO HOSPITAL	2-27	6.0
5 TOTAL		20.9

Figure 10. Distribution of trip times for accident evacuations.

attendant is also limited because of space and seat belt restrictions. External bleeding could be treated and oxygen administered; however, other resuscitation methods such as clearing air passage or external heart massage and some common methods of treating shock were extremely difficult.

The shorter trip time made possible by the helicopter, may require a new appraisal of present emergency medical techniques. In many instances there would not be sufficient time to administer treatment during the flight as is done in the ambulance.

A basic question appears to be, therefore, whether stabilization of the victim at the scene followed by a slower trip to the hospital via ambulance is more (or less) beneficial than the use of minimum first aid at the scene followed by a rapid trip to the hospital via helicopter.

The physicians who are participating in this study are considering questions such as this in addition to determining the specific benefit of the helicopter flight to those injured persons who were airlifted to a hospital.

Victim Reaction

With two exceptions, the injured person's response to helicopter transportation was one of immediate acceptance. One victim who was a University Hospital staff physician and suffered a minor injury, expressed highly favorable reaction as well as amazement at the rapid trip (in his case 3 min) to the hospital.

Although many victims were not in a condition to comment at the time of their flight, they are presently being interviewed individually to determine if they experienced any fear, ill effects or other reactions from being transported by helicopter.

Relationship With Existing Ambulance Service

The majority of the 93 ambulance clubs are volunteer services supported by local citizens' membership dues and fixed fees for non-member users. Some services are operated as part of police or fire companies and some are completely independent of other service organizations.

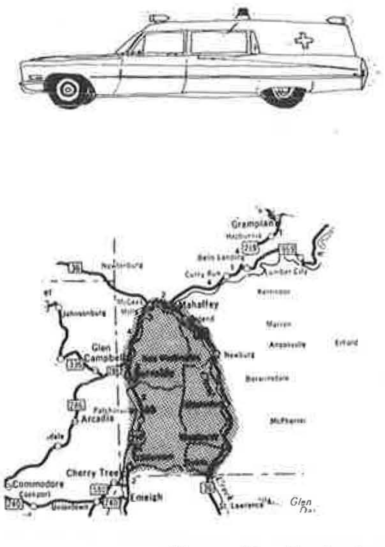
To better understand their functions and operations, a questionnaire was sent to 55 clubs requesting information concerning: number of units, geographical area of operation, personnel, training, number of calls of various classes, costs, etc. Approximately 60 percent of these questionnaires were returned and are being analyzed.

Based on the survey data received (Fig. 11), two-thirds of the clubs have one ambulance vehicle, while one-third has two or more vehicles. The typical ambulance club consists of 44 active members, all of whom are volunteer. Each vehicle, including emergency equipment, costs $10,000 after trade-in allowance for the old ambulance. It is driven 12,700 miles annually at an operating cost of $1,455. This typical club makes 630 trips each year of which 46 percent are emergencies. The average trip length is 16 miles.

Ambulances were called to 23 of the first 40 accidents in which injured persons were airlifted by the helicopter. In seven instances the ambulance arrived at the accident scene before the helicopter.

Although it was emphasized constantly that the helicopter was being used for study purposes only, and did not represent a new competitor to the existing service, there still developed the feeling with some ambulance groups that the helicopter was in fact a competitor, to be raced to the scene of the accident. In many other instances, however, the helicopter and ambulance crews cooperated closely using the helicopter where accessibility to the site, or speed, was essential, and the ambulance where medical facilities were needed en route that were not available on the helicopter. On one occasion, during the afternoon peak traffic period, the ambulance transported a victim who was critically burned at a rail siding ¼ mile to the helicopter, which transported him to the hospital within 3 minutes. It would have taken the ambulance 25 minutes to reach the hospital at that time of the day.

At one hospital, the ambulance regularly transfers severely injured victims from the helicopter to the emergency room—a distance of 375 feet.



VOLUNTEER – AFFILIATED WITH FIRE CO.

SERVICE AREA 50 SQ. MILES
POPULATION 55,000 PERSONS

ACTIVE MEMBERS – 44

NUMBER OF AMBULANCES – 2/3 HAVE ONE VEHICLE

1/3 HAVE 2 OR MORE

AMBULANCE COSTS – $10,000

NUMBER OF TRIPS (Annual)

SCHEDULED	342
EMERGENCY	288
TOTAL	630

MILES DRIVEN – 12,700

AVE TRIP LENGTH – 16 MILES

Figure 11. Typical ambulance service club.

For a 2-week period, the helicopter was based at a township building where it functioned as a unit in the Good Fellowship Ambulance Club. Both the helicopter and the ambulance were dispatched to accidents at the same time with a club member, in addition to the state trooper, accompanying the helicopter.

Communications under these conditions were excellent because both the township and the ambulance club were part of the county network through which all emergency calls were relayed.

During these 2 weeks the helicopter was called to 12 accidents in which seven persons were airlifted to the hospital. In addition, six simulated accident tests were conducted where both the helicopter and ambulance were dispatched at the same time. This provided an excellent means of evaluating the helicopter from the viewpoints of experienced ambulance attendants. It was possible to demonstrate the value of helicopter-ground ambulance teams working together to utilize the best capabilities of each to benefit the injured persons.

In general, the ambulance club members were highly impressed with the speed and accessibility of the helicopter; however, they regarded the space limitations, the litter arrangement and the emergency equipment carried by the helicopter as quite inferior to their ambulance vehicles.

Landing Sites at Hospitals

Although space was available at each of the seven hospitals used regularly by this study, only one had heliport facilities that had been planned previously for helicopter operation. The helicopter landing sites at the other six hospitals were usually located on reserved sections of parking lots, driveways, or lawn areas.

Each landing site, however, was checked and approved by the Pennsylvania Aeronautics Commission as having the minimum required approach clearance. Minimum standards require 8 feet horizontal clearance for each 1 foot of vertical height. Thus, an approach of 320 feet would be required to clear 40-ft trees such as existed at one hospital. The Aeronautics Commission recommends a pad of 200 feet in diameter as a desirable size for permanent heliports although none of the landing sites met this standard.

Ground delivery distance from the landing point to the emergency room entrance varied from 75 to 875 feet at the seven hospitals. Since the hospitals received prior notice of the helicopter's arrival with an injured person, they usually had personnel ready at the landing site with a wheeled litter. At Chester County Hospital, which received 23 airlifts, the local ambulance company met the helicopter and assisted taking the victims to the emergency room, 375 feet distant, using either a wheeled litter or an ambulance.

TENTATIVE CONCLUSIONS

Several areas of study vital to this project were either mentioned only briefly or were omitted entirely in this presentation because the analytic work is not complete. It will be necessary to relate the findings of this study with those of other studies (1, 2) recently completed by other agencies for the National Highway Safety Bureau.

The following general conclusions, therefore, are based on the information reviewed to date (December 15, 1968), and may be modified when the full analysis has been completed:

1. The helicopter can reduce the time required in transporting the accident victim to the hospital under conditions normally encountered on a day-to-day basis. Preliminary results show the trip may be completed in ½ to ⅙ the time required for the conventional ambulance depending on traffic flow and distances involved.
2. It has not been determined to what extent this time saving actually benefits the accident victim. Medical opinion must determine the value of time in relation to the rate of deterioration of an injured person's condition when adequate medical attention has not been provided.

3. The accident victims who were airlifted, as well as the general public, readily accepted the helicopter mode of transportation for traffic accident casualties.

4. Experienced ambulance attendants were initially skeptical about using a helicopter as an ambulance. As the study progressed, however, they gradually accepted it although it was considered by many as an auxiliary vehicle to be used only for those emergencies when a ground ambulance could not be used.

5. Adverse weather conditions prevented the helicopter from flying 15 percent of the time. After-dark usage of the helicopter is limited unless the pilot is familiar with the area being served. Thus, an effective emergency care system cannot exclude provisions for ground transportation.

6. The helicopter proved extremely useful for police activity both as a patrol vehicle in traffic surveillance and for criminal work.

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