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COMPUTERIZED ALLOCATION OF POLICE TRAFFIC SERVICES —

A Demonstration Study

Indiana University
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16. Abstract

A study was conducted to develop and implement a computerized highway traffic information system (CHTIS) for use in allocating police traffic services. The information system utilized a computer-sensor system to gather, process, store and display traffic flow information from 25 key highway locations in Monroe County, Indiana. The resulting information was provided to a local Indiana State Police post for use in conducting traffic law enforcement operations. It was concluded that the system is a highly useful operational tool for traffic law enforcement agencies. It was quickly and enthusiastically accepted by the police officials and was used regularly in assigning patrols so as to reduce traffic risks. The study recommends (1) the establishment of a continuing traffic resource allocation laboratory utilizing a CHTIS and (2) the initiation of a program to analyze the unique data base made available by the system.

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A DEMONSTRATION STUDY

COMPUTERIZED ALLOCATION OF POLICE TRAFFIC SERVICES

SUMMARY

This report documents work conducted by the Indiana University Institute for Research in Public Safety under sponsorship of the National Highway Traffic Safety Administration of the U. S. Department of Transportation to develop and demonstrate a computerized information system for use in allocating police traffic services.

The project plan included an investigation of certain operations research techniques for analyzing and improving resource allocation schemes for traffic law enforcement agencies, the development of computer-generated presentations of local accident statistics, and a study of the requirements for developing a public education program utilizing outputs from the information system. However, the main concern of the project was the provision of operationally useful county-wide, traffic flow information to traffic law enforcement, and over 90 percent of the project's resources were applied toward this end.

The heart of information system developed and implemented for this purpose was a computer-sensor system that had been used by IRPS since 1968 as a research tool to gather, process, store, and display traffic flow information from a number of key highway locations in Monroe County, Indiana. The information was collected by unobtrusive magnetic sensors at these locations and transmitted via rented telephone lines to a centrally located computer facility where it was processed and stored for use in the research projects. In the present project this system was expanded almost two-fold to provide county-wide coverage, and specific risk information outputs were developed to assist police decision-makers in determining more effective resource allocation procedures.

The information was provided to the police in the form of cathode ray tube (CRT) displays and computer-generated printouts. The CRT device was located at the headquarters building of a local Indiana State Police post and was capable of presenting both real-time

and historical traffic flow data collected at 25 sensor sites located throughout the county. The basic raw information available to the police user included vehicle speed, length, headway, direction, and number of cars passing a given site in a given time period. In addition, the system possessed the capability of performing certain analyses of these raw data (e.g., percentage speed limit violators at a given site) and presenting the results in both display and hard copy form.

The main conclusion of the study was that the information system thus developed and implemented is a highly useful operational tool for traffic law enforcement agencies. The system was not merely tolerated by the police, as is so often the case when testing experimental devices with user agencies, but was quickly incorporated into the regular police routine. It was extensively used by all levels of local police agency personnel for scheduling and assigning police personnel and in devising new traffic law enforcement tactics.

The hard copy printouts showing speed limit violations were found to be particularly useful to the police in identifying highway segments needing patrolling. Command officers would typically study the day's reports in the evening to determine where greater enforcement emphasis was needed for the following day. The CRT device was frequently used by officers before going on duty to determine violation rates and traffic counts on a particular loop site or highway to confirm predictions made by summary printouts from previous time periods. The CRT was also used by police to check headway conditions prior to deploying radar units and in identifying accident situations.

Two major recommendations were made as a result of the project. First, it was recommended that the system continue to be operated in a real-world environment over a multi-year period. Such an operation would, in effect, provide an advanced traffic resource allocation laboratory for use in investigating the nature of the police decision-making process; developing better information outputs for both the police and the public; and measuring the effectiveness of the information system itself, as well as other countermeasures, tactics, etc.

Second, it was recommended that a program be initiated to analyze the unique and extensive data base made available by the computer sensor system. The analysis would require the conversion of the present traffic flow data tapes to a more analytically suitable form and would utilize accident data from the Indiana State Police accident tapes and data from IRPS's multidisciplinary and tri-level crash studies to study relationships between traffic flow, accidents, and

environmental factors. The results of this study program would be of great value in identifying traffic accident risk in the detail required for developing acceptable quantitative solutions to the traffic resource allocation problem.

1.0 INTRODUCTION

This is the final report of a study to develop and demonstrate a computerized information system for use in allocating police traffic services. The study was performed by the Indiana University Institute for Research in Public Safety (IRPS) for the National Highway Traffic Safety Administration of the U. S. Department of Transportation under contract DOT-HS-034-1-039. The contract period was from December 1, 1970 through February 29, 1972.

1.1 General Objective

The objective of the study was to develop, implement, and evaluate an operationally useful Computerized Highway Traffic Information System (CHTIS) for law enforcement agencies in Monroe County, Indiana. The primary application of the information system was to be the identification of improved policies, strategies, and tactics for allocating police traffic services within Monroe County.

1.2 Specific Objectives

The specific objectives of the study were to:

1. Implement and evaluate a county-wide computerized system for real-time monitoring, storage, and dissemination of traffic flow information.

2. Develop techniques, methods, and procedures for disseminating detailed county-wide accident information to county law enforcement decision-makers.

3. Investigate the applicability of certain operations research techniques for analyzing and improving resource allocation schemes for traffic law enforcement agencies.

4. Specify guidelines for mounting large-scale traffic safety education campaigns based on information made available by a Computerized Highway Traffic Information System.

1.3 Background

The failure of many law enforcement agencies to utilize their resources effectively is well known. It is often stated that the police merely respond to the greatest immediate pressure and do not engage sufficiently in conscious management of their resources. Police are said to base their resource allocation decisions primarily on tradition and even folklore rather than on rational analysis of needs and capabilities. In fact, police administrators themselves have been among the strongest critics of police resource allocation procedures. Bruce Smith noted in 1940 that:

> ".. city police forces waste a part, and sometimes a considerable part, of their available manpower...distribution of uniform patrols...without regard to established needs... It is a matter of general observation that (patrols) are usually distributed on an equal, or nearly equal, basis throughout the twenty-four hours of the day, despite the fact that the crime curve shows a marked peak between 6 p.m. and 2 a.m. ..." (36).

Eleven years later (in 1951), V.A. Leonard observed that:

> "A small minority of professionally trained police executives in the United States are conscious of the administrative necessity for derivation of a formula that will serve as a basis for scientific distribution of the force. For the most part, however, the significance of this administrative problem is not widely recognized" (33).

Early attempts to develop better methods for allocating police resources were based almost entirely on the heuristic concept of proportional distribution of forces. This concept involves measuring the crime hazard at different places and times in terms of a crime variation index. Police patrol forces are then distributed proportionally to the values of the crime index calculated for the various locations. Thus, if a given patrol sector was found to contain 30 percent of a jurisdiction's "crime" for a given time of the day, the 30 percent of police patrol resources would be allocated to that sector during that time period. According to the President's Commission on Law Enforcement and Administration of Justice (29), the basic idea was conceived as early as 1909 when Chief August Vollmer of Berkeley, California, distributed his bicycle-mounted patrol force in accordance with expected calls for service in different parts of the city. O.W. Wilson later (1938) developed a specific methodology (published in 1941) for applying the proportional distribution concept which was stated in terms of the "relative need" for police services (40). In 1939, Frank M. Kreml of the Northwestern University Traffic Institute postulated the principle of selective enforcement for applying traffic law enforcement to the times, places and behavior patterns that proved the greatest threats to traffic safety.

No further schemes for allocating police resources were published until the 1960s when a series of papers utilizing the newly-developed techniques of operations research began to appear. Analytical models were developed to compute the probability of a "random" patrol unit interrupting a crime (8); to predict workloads for police departments (25); and to assist in determining, through queuing theory, improved police beat structures (27). In a recent report (1969), Larson developed a sophisticated multidimensional queuing model for patrol car dispatching and provided a description of a computer simulation of police patrol operations (22). Numerous other quantitative models and methods addressing almost every aspect of police operations are being generated at an ever-increasing rate.

However, none of these techniques (including the somewhat simplistic concept of proportional distribution) has found wide acceptance or use by police departments in this country. For the most part, departments continue to operate as they have always operated, allocating their resources according to tradition and intuition rather than by scientifically-derived formulas or procedures. It could be argued that a major reason for this situation is that most police administrators do not possess the necessary technical expertise to apply quantitative decision-making tools or, for that matter, to even understand them enough to want to apply them. While there is undoubtedly considerable truth in this reasoning, the real roots of the problem probably lie much deeper. First, even the most sophisticated models available today do not begin to incorporate the complexity of real-world police operations, and thus do not inspire the confidence of those who must cope with such problems nonetheless. Second, even the <u>basic</u> cause-and-effect relationships necessary to specify the expected result of a given resource allocation are not known well enough to state in mathematically precise terms: for example, one cannot in general write an equation stating the probable reduction in number of accidents as a function of law enforcement activity.

Thus, under the present state of knowledge, operations research alone cannot provide the police administrator with the tools he needs for better utilization of his resources. At this point in time, it should be more productive to provide decision-makers with relevant and timely <u>risk information</u> for use in their own informal decision-making process. Such an approach places less emphasis on the allocation process itself, relying more on the user's experience in dealing with the complexities and subtleties of real-world operations. Instead, it stresses the quality and availability of the information needed to make rational, if not mathematically optimal, decisions.

Since 1968, IRPS has been operating a computerized risk information system in Monroe County, Indiana. The system has been used as a research tool to investigate, under NHTSA sponsorship, the effects of speed on traffic accidents (contract FH-11-6965) and effects of moving and stationary enforcement symbols on traffic flow characteristics (contract FH-11-7476). Basically, the system was used to gather, process, store, and display traffic flow information from a number of key highway locations in Monroe County. The information was collected by magnetic sensors at these locations and transmitted via telephone lines to a centrally-located computer facility where it was processed and stored for use in the research projects. As the projects progressed, the system's potential as an operational risk information system for allocating police traffic services became apparent, and in the fall of 1970, the NHTSA decided to initiate the present project to demonstrate the system's feasibility as operationally useful management tool.

1.4 Scope and Approach

The main concern of the project was to provide operationally useful traffic flow information to traffic law enforcement agencies for their use in determining improved resource allocations for controlling traffic accidents. Secondary aims were to (1) provide a means for presenting selected operationally useful traffic accident information to traffic law enforcement agencies, (2) develop a limited capability for providing traffic flow information to the public, and (3) investigate the feasibility of developing decision making models for use by traffic law enforcement agencies in allocating their resources. Only a small fraction of the project's budget (<10 percent) was applied toward the secondary objectives.

The project was broken down into three phases for management purposes (see Figure 1-1). In Phase I, a detailed project plan was prepared, and a design philosophy for the risk information system was developed. The design philosophy embraced specified that the information system to be developed and operated (i.e., the computerized Highway Traffic Information System or CHTIS) would consist of three subsystems:

- Traffic Flow
- Traffic Accident
- Analysis

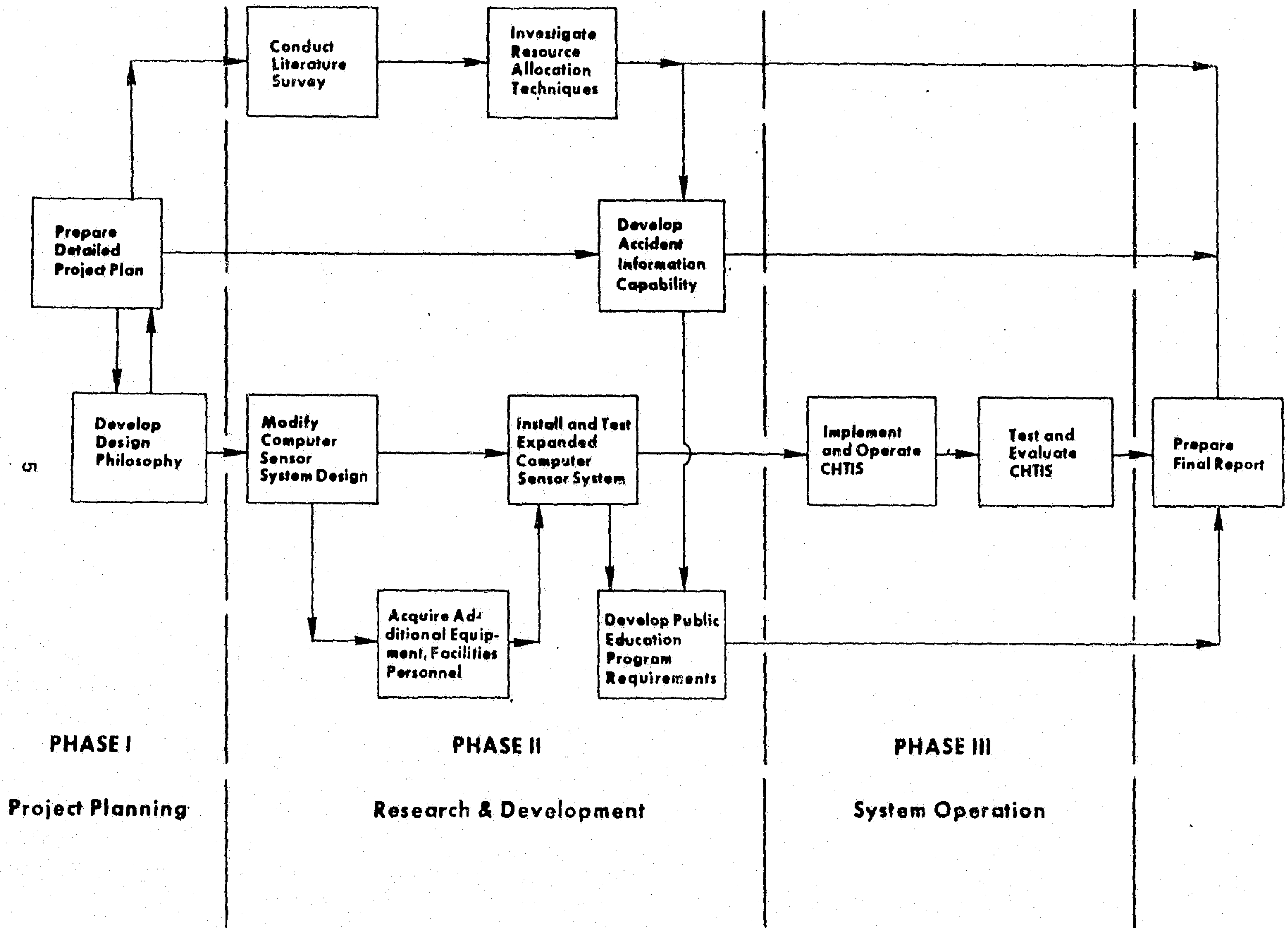


FIGURE 1-1: Project Technical Approach

The traffic flow subsystem would be an expanded and updated version of the existing Computer Sensor System and would be the heart of the CHTIS. This subsystem would be developed to full operational capability during the project. The traffic accident and analysis subsystems were to be concerned with accident information and resource allocation models, respectively. They would be developed to the extent permitted by project resources but would not be a part of the final operational system.

The first step of Phase II, Research and Development, was to modify the design of the existing computer sensor system to meet the requirements dictated by its intended operational use on a county-wide basis. Eleven new sensor sites were selected, and the necessary modifications to system hardware and software were specified. The necessary additional equipment, facilities, and personnel were then acquired, and the expanded computer sensor system (now known as the traffic flow subsystem) was installed and tested.

At the same time, a modest research effort investigating new resource allocation techniques and decision-making models was conducted, and methods for disseminating traffic accident information were developed. This work was supported by a comprehensive survey of the pertinent scientific and the technical literature. The research and development phase was completed with a study of the requirements for developing a public education program utilizing outputs from a CHTIS.

In Phase III, the traffic flow subsystem was placed into operation with the Indiana State Police post having jurisdiction on all state highways in Monroe County, Indiana. The impact of the information provided on this police agency's traffic law enforcement resource allocation process, as well as its impact on traffic safety as a whole, were then analyzed qualitatively and quantitatively.

The final project activity, was the preparation of the present final report. The report is presented in eight major sections:

- Introduction
- Conceptual Framework
- The Computerized Highway Traffic Information System (CHTIS)
- CHTIS Research and Development

- CHTIS Implementation and Evaluation
- Conclusions and Recommendations
- References

In addition, there are two reference volumes. Reference Volume I provides a detailed description of the computer sensor system which was used to provide information describing traffic flow, and Reference Volume II contains an Accident Data Handbook which presents basic information required for identifying traffic accident risk in the study jurisdiction.

2.0 CONCEPTUAL FRAMEWORK

The enforcement of traffic laws is not an isolated activity, but a part of an enormously complex process through which society attempts to control the negative benefits of its Highway Transportation System (HTS). The effectiveness of the enforcement function must ultimately be measured against its contribution to the achievement of the objectives of this larger social control system. Thus, enforcement resource allocations should be designed to enhance overall system effectiveness, and the nature of the information required for this purpose is dependent on the nature of the entire social control process.

This section presents a brief overview of a conceptual framework for describing this process and a more detailed discussion of its information requirements. The material is based on concepts developed in a recent IRPS study entitled A System Analysis of the Traffic Law System, performed for the National Highway Traffic Safety Administration under contract FH-11-7270. The reader is referred to the final report of that study (reference 18) for further details.

2.1 The Highway Transportation System and Risk Generation

The three basic elements of the Highway Transportation System are:

- Man.
- Vehicle.
- Highway Environment.

In simplest terms, the objective of the HTS is to provide fast, safe, road transportation via a private vehicle. The achievement of the objective will result in positive outputs (utility) in the form of:

- Individual mobility.
- Convenience and ready access.
- Distribution of goods.
- Employment.
- Demand for goods and services.

At the same, negative outputs (disutility) are produced as a result of dysfunctions in the HTS. Typical of these harmful effects are:

- Deaths.
- Personal injury.
- Property damage.
- Environmental pollution.
- Aesthetic damage.
- Breakdown of social institutions.

Thus, the HTS generates risk to the public, and there is created a need to control that risk so as to maintain an acceptable balance between the utility of the HTS and the disutility of its harmful effects.

2.2 The Traffic Law System and Risk Management

A number of systems have evolved to control or influence activity within the HTS. For example, the system of traffic rules known as "rules of the road" exerts a direct influence on man as an element of the HTS. Other less direct "systems" also operate, for example, automobile and driver insurance companies which assess higher premiums against drivers with records of many traffic accidents or traffic violations.

However, the primary control system for the HTS in the Traffic Law System (TLS). The TLS consists of four functional components within which the activities of the TLS agencies may be grouped:

- Law Generation.
- Enforcement.
- Adjudication.
- Sanctioning.

The TLS operates in these areas so as to manage the risk generated by the HTS. The first response of the TLS to a perceived risk is to generate a law or regulation aimed at removing or decreasing

the risk (Law Generation). The law then must be implemented, after which it is enforced by government personnel acting as agents of the law (Enforcement). If the enforcement action takes the form of a citation or arrest, then the TLS must formally prosecute the violator before an adjudicator who will determine his guilt or innocence (Adjudication). If the violator is found guilty, then the TLS must impose the penalty stated by law.

The larger aspects of the risk management process itself are depicted in Figure 2-1. The interaction of man, vehicle, and environment within the HTS results in both utility and disutility, and the latter is perceived by the public and the TLS as a risk requiring control. The TLS is charged with the responsibility of executing control forces (as indicated in the preceding paragraph) on those HTS components believed to be the primary risk generators. However, the TLS does not act against risk solely on the basis of its own perception, but is both directed and constrained by the public.

What is critically important to the present study is that both the public and the TLS base their risk management actions on their perceptions of risk as well as their perceptions of what should be and is being done about it. In a properly functioning risk management process, perceptions must closely approximate actuality, and this in turn requires a free transfer of relevant and accurate information between the HTS, the public, and the TLS.

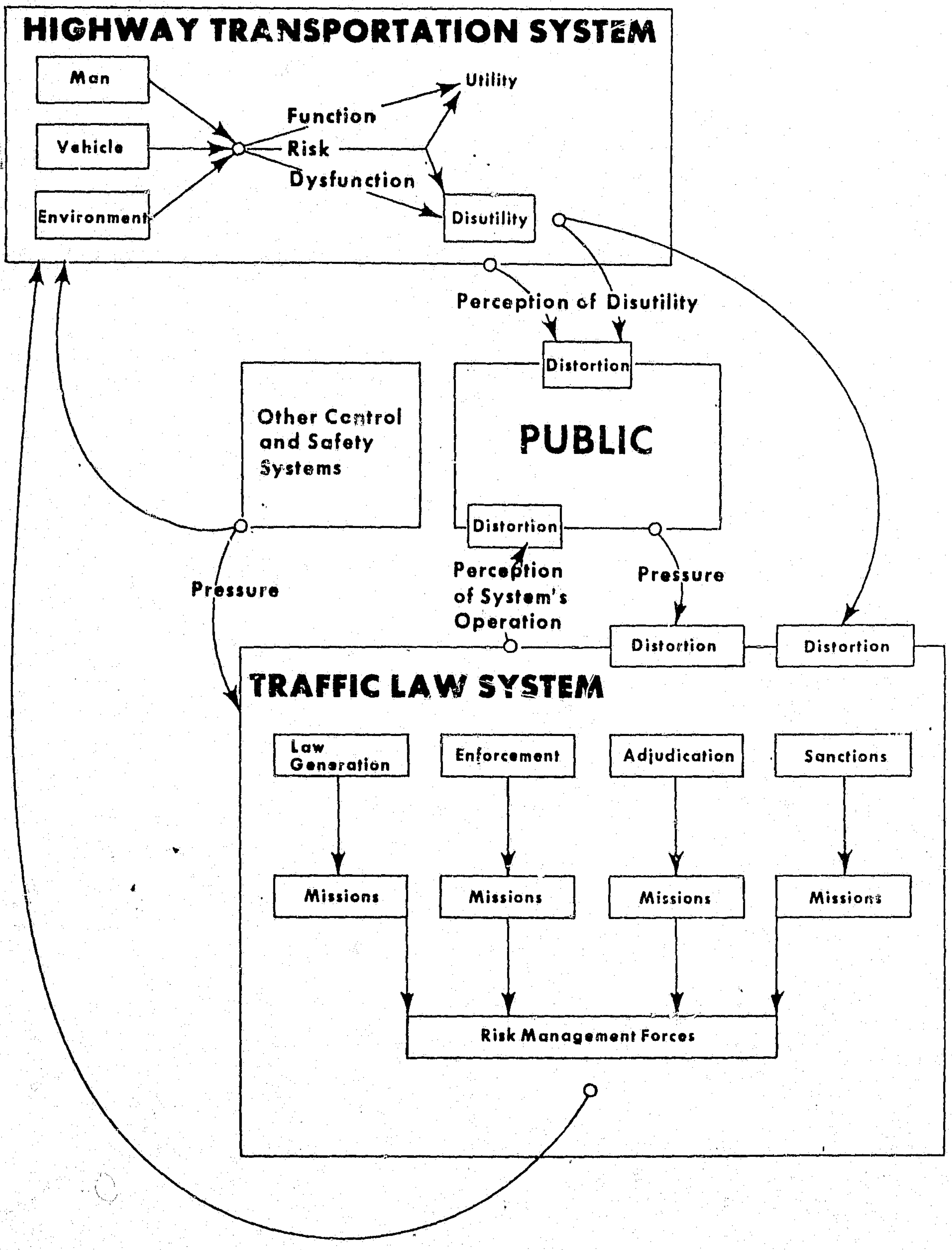
2.3 Functional Model of the Risk Management Process

The information needed for risk management is best considered from what is required to support the primary functions of the social control process itself. From the preceeding discussion these functions may be identified as follows:

- Identify Risk.
- Analyze Risk.
- Allocate Resources.
- Apply Risk Control Forces.

The flow diagram of Figure 2-1 may be re-drawn to depict this process as seen from a functional viewpoint. The resulting schematic is presented in Figure 2-2 and shows the most significant interfaces occurring in the process as well as the five primary functions. Here it can be seen even more clearly than before how the public and the

FIGURE 2-1: The Risk Management Process



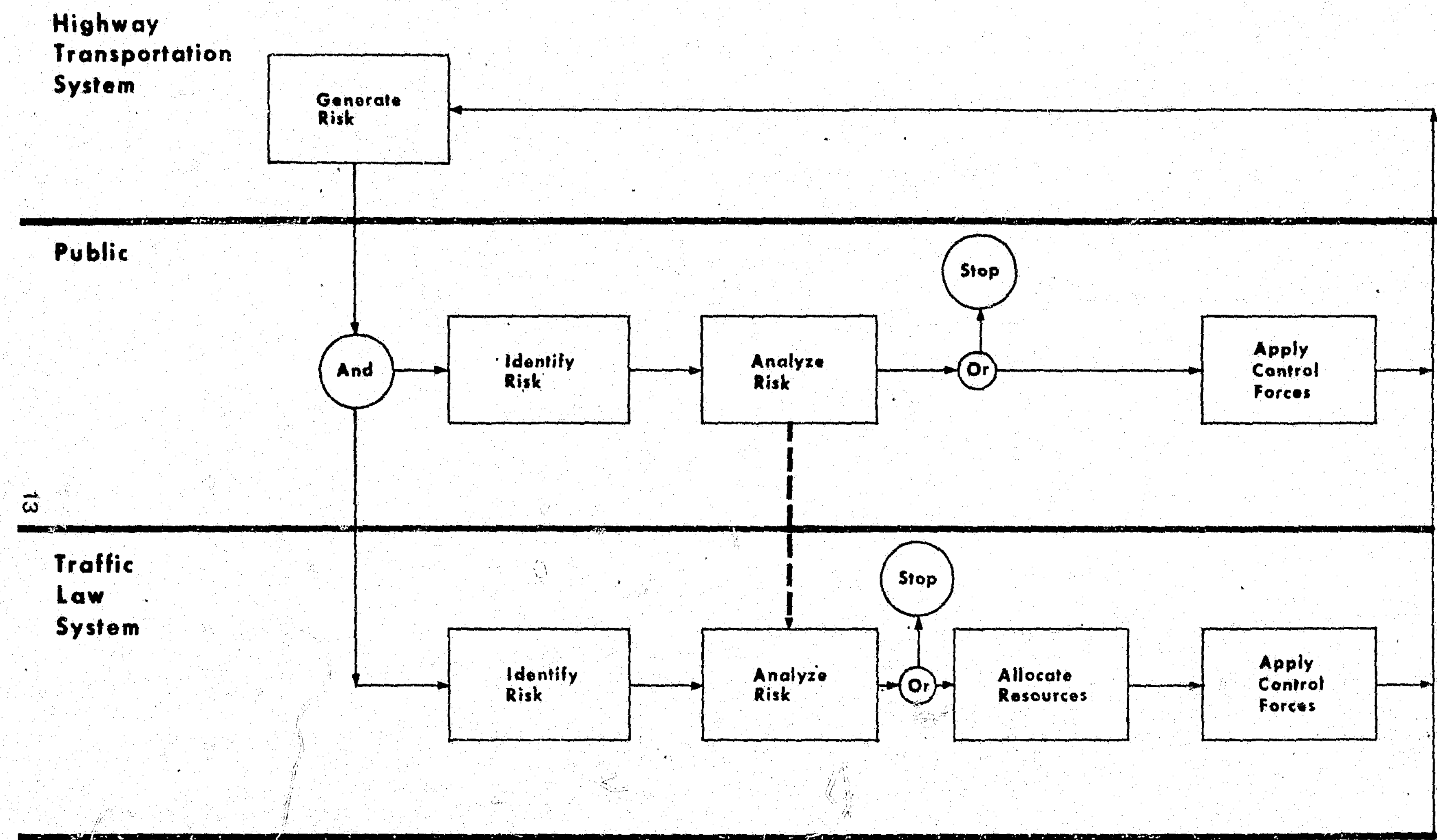


FIGURE 2-2

Functional Model of the Risk Management Process

TLS function together to control the risk generated by the HTS. However, it must be emphasized that while both the public and the TLS participate in the process, only the TLS functions so as to consciously manage risk, so that the concept of the TLS as the primary HTS risk management system is retained in this formulation.

Response to risk-generating HTS dysfunctions is initiated when the risk event or series of risk events is sensed by both the public and the TLS. At this point, the task is to identify the risk, and this requires the accurate determination of both the cause of the dysfunction and the degree of risk caused by the dysfunction. Next, it is necessary to analyze the risk to determine whether or not the magnitude of the risk is sufficient to warrant further action or concern. If not, the process stops for the particular dysfunction being considered. If the risk is considered to be both worthy of and amenable to corrective action, then the TLS must decide how best to allocate its resources to reduce the risk to an acceptable level. The allocation problem must be considered in light of the demands placed on the TLS by other HTS dysfunctions and requires, among other things, the establishment of priorities among invidivual risks so as to maintain the lowest possible total disutility within the HTS. A further consideration of the TLS in determining its allocation policy is the public's own assessment of risk. The resulting pressure on the TLS (indicated by the dotted arrow in the diagram) will be a major factor in determining risk priorities and in selecting measures for dealing with the risks.

The final primary function of the risk management process is to apply control forces against those HTS components believed to be primarily causes of the dysfunction. In the case of the public, these control forces consist of actions aimed at changing one's own driving behavior, as well as the driving behavior of one's relatives, acquaintences, and other social groups. Direct public control forces can also take the form of economic and other pressures exerted against HTS components and HTS support agencies (e.g., vehicle manufacturers, oil companies, and so forth) believed to be causing the dysfunction.

TLS - generated control forces will be of the kind described in the previous section, i.e., the generation and enforcement of laws prohibiting the behavior believed to be responsible for the dysfunction and the imposition of sanctions against those found to have violated those laws.

2.4 Information Requirements for Risk Management

The information requirements for risk management can now be identified in terms of the primary functions that are performed in

the risk management process. At this point, however, it will be more pertinent to depart from the more general treatment of the preceding sections and concentrate on the particular types of risks and the particular TLS component that are the subject of the present study. Specifically, the following discussion will be mainly concerned with traffic accident risk as related to driver behavior and with the enforcement component of the TLS.

Information requirements for supporting the four primary risk management functions and presented in Table 2-1. Risk identification requires information describing accident disutility in terms of such factors as numbers of accidents, cost of accidents, number of people injured in accidents, number of accident fatalities, number of accidents involving property damage only, number of non-total accidents involving one or more personal injuries, and number of accidents involving one or more fatalities. Further, it is required to know the where and when the various kinds of accident disutility are occurring and the conditions existing at the time and place of accidents. Typical measures of accident conditions will include information describing the involved driver, the involved vehicle and the nature of highway environment in terms of such factors as weather, highway geometry, highway surface, and traffic flow. Ideally, these measures of accident conditions would completely define the local state of the HTS for a given accident.

Risk analysis requires all the information required for risk identification, plus several additional types. However, enforcement information requirements and public information requirements will differ simply because each component analyzes risk differently. Enforcement will first need a clear definition of the kind of enforcement techniques that are available for use against the identified traffic accident risk. This requires not only a listing of the techniques (e.g., speed trap, stationary enforcement symbol, moving enforcement symbol, enforcement "campaigns"), but also a statement of their general applicability to the times, places, and conditions of risk occurrence. In this respect, it will also be necessary to state clearly the operational constraints under which any potential anti-risk activity would have to be conducted. The availability of resources for traffic law enforcement as a function of time and location would constitute a major category of such constraints.

The enforcement risk analyst also needs to know how his arsenal of enforcement techniques is likely to affect driver behavior and, hence, accidents that are related to driver behavior. He will, therefore, need the results of studies conducted in his own jurisdiction

TABLE 2-1:
Information Requirements to Support Primary Risk Management Functions

Type of Information	Function: Identify Risk	Analyze Risk	Allocate Resources	Apply Risk Control Forces
1. Accident Disutility	x √	x √	x	
2. Accident Locations	x √	x √	x	
3. Accident Times	x √	x √	x	
4. HTS Conditions ● Traffic Flow ● Other	x √	x √	x	x
5. Enforcement Techniques Definition		x	x	x
6. Enforcement Operational Constraints		x √	x	x
7. Enforcement Resource Deployment		x	x	x
8. Enforcement Techniques Effects (Driver Behavior)		x √	x	
9. Enforcement Techniques Effects (Accident Disutility)		x √	x	
10. Driver Behavior Effects on Accident Disutility		x √	x	
11. Enforcement Operations Support			x	x
12. Public Attitudes on Accident Disutility		x √	x	
13. Public Attitudes on Accident Priorities		x √	x	
14. Public Attitudes on Accident Control Forces		x √	x	x
15. Interactions with Other TLS Components	x	x	x	x

Note: x Enforcement Information Requirement
√ Public Information Requirement

to measure these interactions. Obviously, knowledge of resource deployment is essential to such studies.

If the enforcement agency is to be responsive to the desires of the public, it must be aware of public perceptions of risk and public attitudes about enforcement techniques employed in the application of risk control forces. If, for example, the public is aware that high-speed, high-density traffic is creating a risk on a certain highway segment but is willing to tolerate that risk as a result of its own cost-benefit trade-offs, then the enforcement agency should adjust its priorities accordingly. Similarily, if the public chooses to tolerate a risk in preference to the inconvenience caused by the enforcement technique known to be most effective against that risk, then the enforcement agency will have to select a technique of lesser effectiveness or, perhaps, take no anti-risk action at all.

The public will need most of the same types of risk identification and analysis information as enforcement agencies, but the information will have to be presented differently and will, in some cases, be less detailed. The data elements presented, the manner of presentation will all require considerable attention in designing an effective public education program (see Section 4.4 for a discussion of public education information requirements).

The resource allocation function will require the same types of information necessary for risk analysis. The main difference will be seen in degree of detail and specificity. The risk analysis function is essentially a screening operation to determine (1) whether or not an identified risk should receive enforcement action and (2) the general priority of that risk among other risks. Resource allocation, on the other hand, is concerned with the selection of a specific mix of well defined enforcement activities that are intended to be implemented. For example, a risk analysis problem might involve only a qualitative estimate of the effect of enforcement techniques on driving behavior to determine whether or not a particular risk location was amenable to enforcement action at all. The resource allocation problem would be concerned, in addition, with such matters as how long various enforcement techniques would continue to influence driver behavior and how that influence might vary over time.

2.5 Risk Information Systems

Figure 2-3 shows the risk management process as it relates to those "systems" which collect, process, and disseminate risk information. These activities are performed by a wide variety of largely

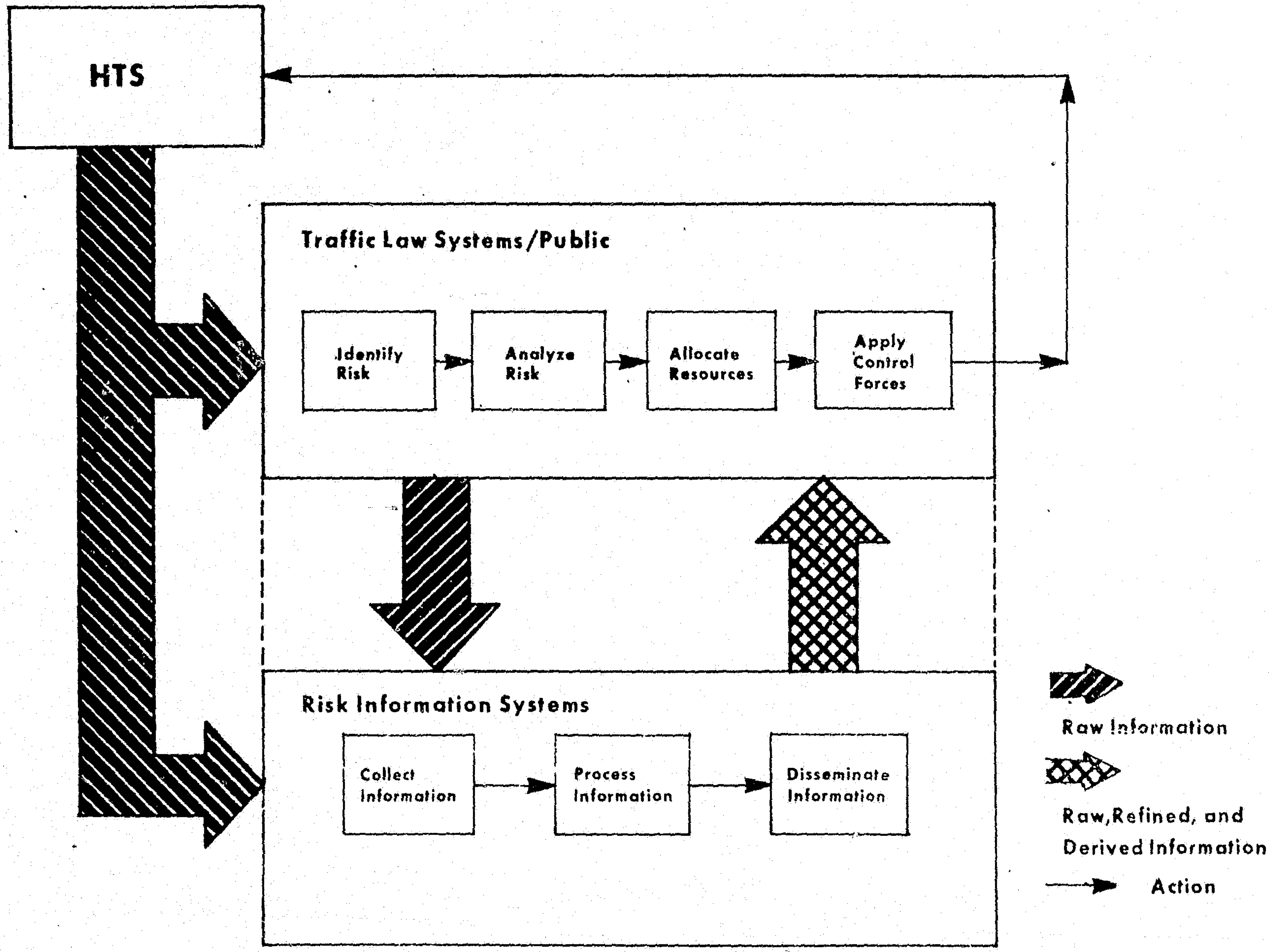


FIGURE 2-3: Risk Information Systems and the

uncoordinated mechanisms ranging from the direct observations of individuals to highly sophisticated computerized record systems maintained by large organizations. Public agencies on all levels of government are involved, for example, the National Highway Traffic Safety Administration, state divisions of motor vehicles, and local law enforcement agencies. Thus, a risk information system is not necessarily external to the TLS but, is often an important support component of a specific TLS agency. Private agencies such as the National Safety Council, organs of the mass communications industry, and organizations sponsored by the insurance industry are also highly active in various aspects of information development and dissemination.

Risk information systems operational today are of limited scope and are directed at supporting a single (or perhaps as few) operational or support functions of a specific TLS subsystem. No integrated risk information system exists at the present time nor, for that matter, is there any system which can provide all of the data needed to support any given primary risk function performed by a single TLS subsystem. Specifically, there is no risk information system operational today which provides <u>all</u> the types of information (listed in Table 2-1) needed to perform <u>any</u> of the primary enforcement functions involved in managing traffic accident risk.

All risk information systems perform the same general functions: the collection, processing, and dissemination of risk information. Information is collected from the HTS, the TLS, and the public in a form usually not suitable for immediate use. Examples of this <u>raw risk information</u> are data contained on police accident reports, traffic flow data gathered by traffic engineers, and response to public attitude surveys.

The risk information systems must therefore process the raw information for presentation in some meaningful format. In its simplest form, this processed information appears as tabulations or charts of the raw information presented in an orderly and methodical way, for example, a summary of accident statistics for a given jurisdiction. This kind of processed information is called <u>refined risk information</u> in the present report.

Further levels of information processing may also occur, resulting in entirely new interpretations of the original information. This <u>derived risk information</u> will relate various elements of raw and refined risk information to more meaningful, problem-oriented variables. For example, a statistical analysis of refined accident information may result in a single measure of accident disutility at a given location; a mathematical analysis of the enforcement resource allocation process may result in guide lines for allocating patrol units over various sectors of a jurisdiction, and so forth.

The last major function of risk information systems is to disseminate its output to the various user elements. The form of the information output will vary according to the nature of information output and will also depend heavily on its intended use. In general, however, all three categories of information (raw, refined, and derived) will be disseminated in the form of hard copy (e.g., printed reports, letters, computer printouts), images formed on viewing screens (e.g., cathode ray tubes, microfilm viewers) and by word of mouth. The outputs may be produced periodically, on an exception basis, or as called for by the user.

3.0 THE COMPUTERIZED HIGHWAY TRAFFIC INFORMATION SYSTEM

This section of the report describes the particular risk information system that was developed and utilized in the present project: the Computerized Highway Traffic Information System (CHTIS). The material presented is intended to provide the reader with a general understanding of:

- How the CHTIS functions within the framework described in the previous section.
- The system's information input requirements and its information output capability.
- The CHTIS configuration in terms of the equipment and facilities required for its operation.

The discussion is intended for the general reader with no specialized knowledge of information systems and the many related technical disciplines. Further, technical details will be found in the reference volumes, and a detailed discussion of the system's information requirements and information outputs is contained in Section 4.0 of the present volume.

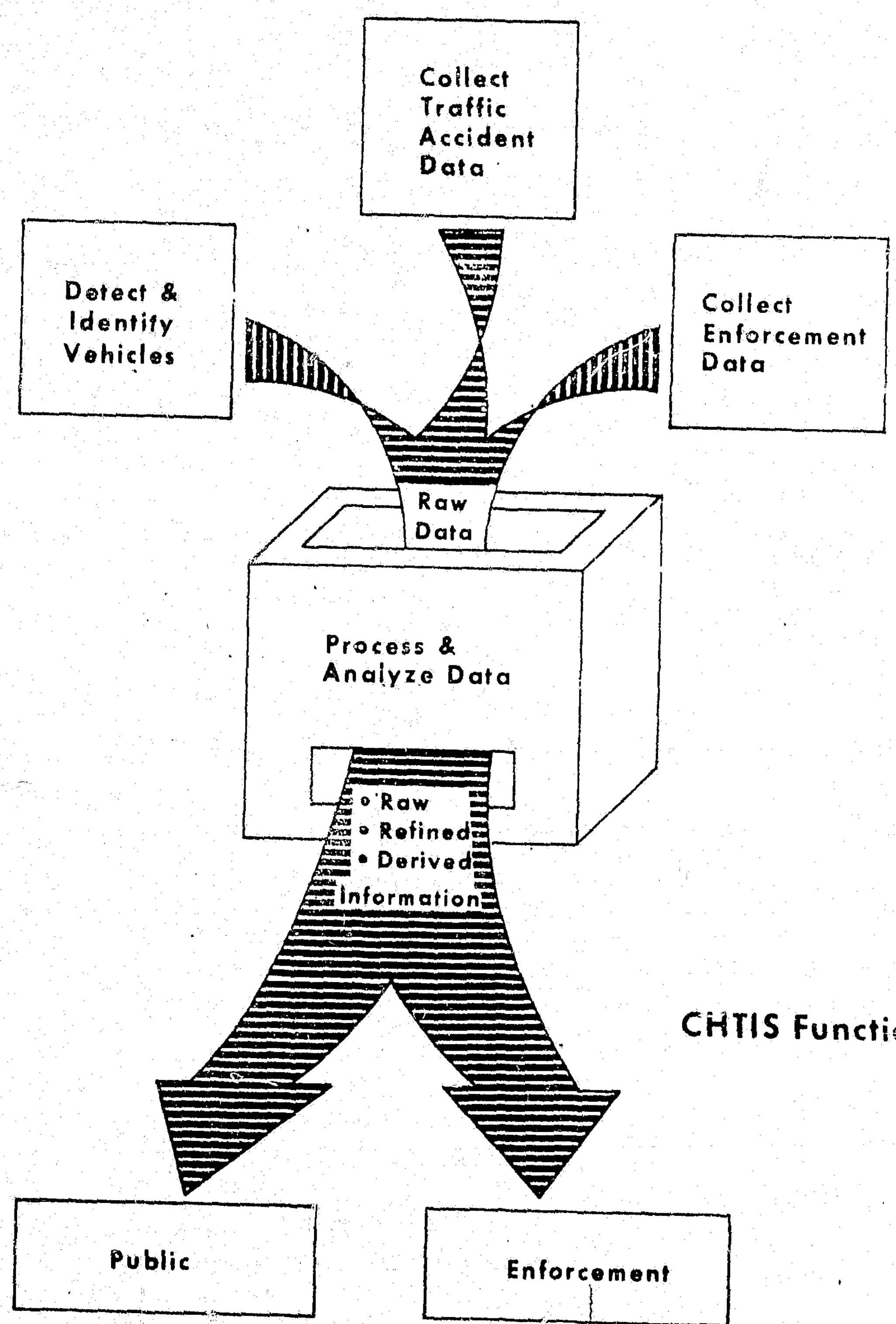
3.1 Overview of the System

The CHTIS is designed to support traffic accident risk management by local traffic law enforcement agencies and to provide certain risk identification information to the public. Its basic functions are shown schematically in Figure 3-1. The system collects three kinds of data:

- Vehicle detection and identification data.
- Traffic accident data.
- Enforcement data.

Vehicle detection and identification data are obtained in the form of electrical signals transmitted from magnetic sensors located on major highways in Monroe County, Indiana. The signals are received at the IRPS data operations facility where they are processed by a digital computer and translated into raw and refined information describing traffic flow for any given time period. The processed information is then disseminated to the local press, and to the local Indiana State Police (ISP) post.

Figure 3-1



CHTIS Functions

Traffic accident data are collected in the form of computer tapes which contain accident data obtained from police reports on Monroe County, Indiana, accidents. The CHTIS compiles and summarizes these tapes on specially created files which are used to produce statistical reports for county law enforcement agencies.

Enforcement data are collected from county law enforcement agencies for use in developing derived information. The data describes police patrol unit deployment, traffic law enforcement tactics, operational constraints, and so forth, and are used in conjunction with flow and accident data to devise accident indexes, enforcement indexes, and resource allocation guidelines.

Table 3-1 shows the CHTIS present capability to produce the 15 basic types of information needed for the management of traffic accident risks. It is seen that in its present state of development, the system functions primarily in a risk identification mode: that is, it has, at least, a moderate capability to produce information used directly for risk identification. Some capability exists for developing derived risk analysis and resource allocation information for enforcement agencies, but there is no present capability in the areas of enforcement operation support, public attitudes, or interactions with other TLS components. It is also apparent from Table 3-1 that the CHTIS is, at present, essentially an enforcement information system with a moderate capability for providing the public with traffic flow information. However, little additional effort would be needed to make all of the risk identification information available to the public.

The system's greatest capability by far is the area of traffic flow information, where what must be described as a full capability exists for describing the state of a traffic stream at selected locations. Further, the system is capable of providing this information to local law enforcement agencies on a periodic, exception, or real-time basis.

The primary components of the CHTIS are depicted in Figure 3-2. The heart of the system is an IBM 1800 digital computer and associated peripheral equipment. The computer constantly monitors vehicle sensors at 25 key locations in Monroe County, Indiana, and stores, processes, and produces the resulting traffic flow information for dissemination in the form of computer reports and real-time cathode ray tube (CRT) displays. The display units are located at the ISP Bloomington post and at the IRPS data operation facility.

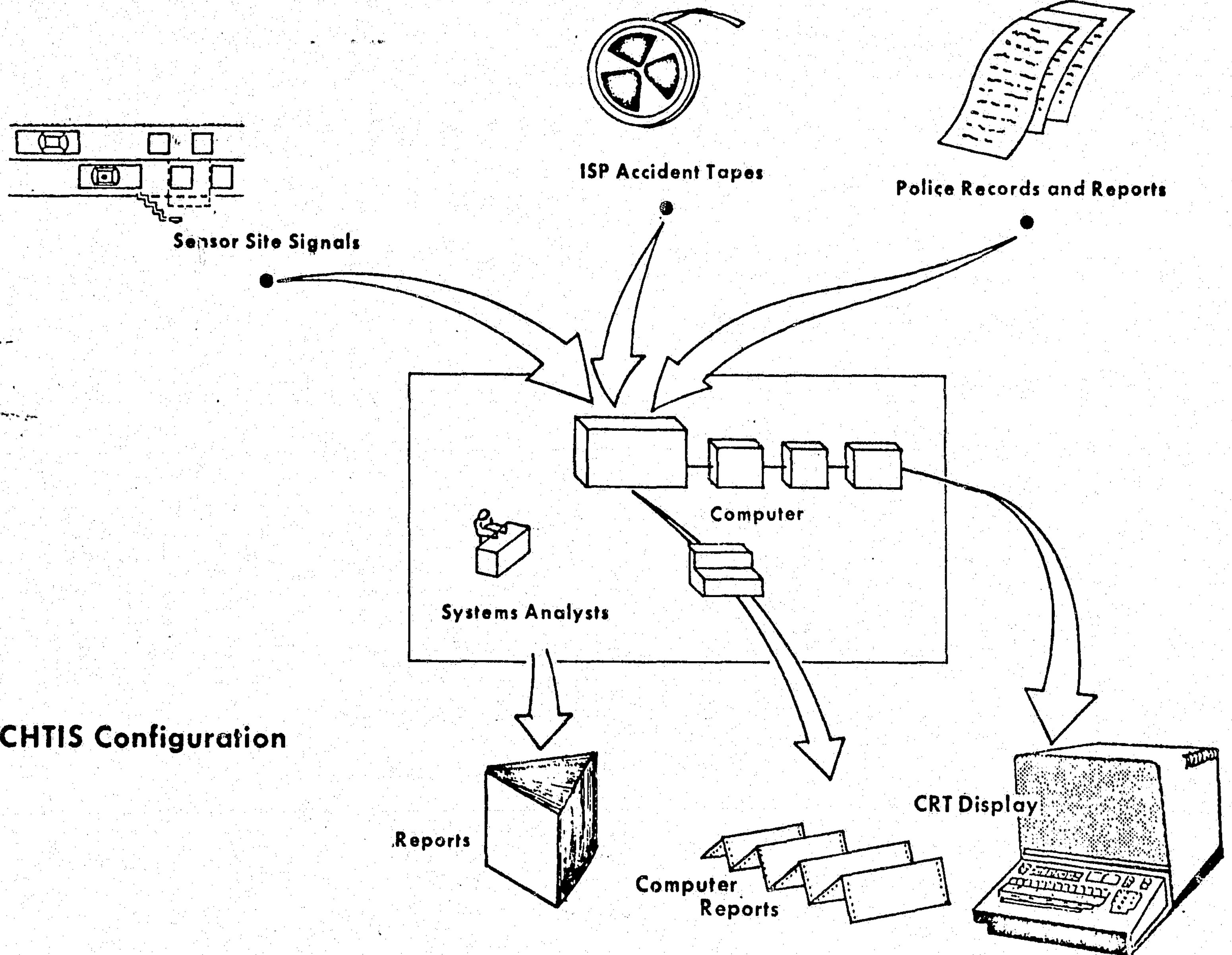
The computer also has the capability of accepting and processing the ISP accident tapes to produce tabulations and graphical displays

TABLE 3-1:
Present Information Output Capability of the CHTIS

Type of Information	Capability			
	Full	Moderate	Some	None
1. Accident Disutility		x	✓	
2. Accident Locations		x	✓	
3. Accident Times		x	✓	
4. HTS Conditions				
● Traffic Flow	x	✓		
● Other			x ✓	
5. Enforcement Techniques Definition			x	✓
6. Enforcement Operational Constraints			x	✓
7. Enforcement Resource Deployment		x		✓
8. Enforcement Techniques Effects (Driver Behavior)			x	✓
9. Enforcement Techniques Effects (Accident Disutility)			x	✓
10. Driver Behavior Effects on Accident Disutility			x	✓
11. Enforcement Operations Support				x ✓
12. Public Attitudes on Accident Disutility				x ✓
13. Public Attitudes on Accident Priorities				x ✓
14. Public Attitudes on Accident Control Forces				x ✓
15. Interactions with Other TLS Components				x ✓

x Enforcement Information Capability

✓ Public Information Capability



CHTIS Configuration

Figure 3-2

of accident disutility measures as a function of location, time and highway environmental factors. Using the traffic flow information, accident information, and enforcement information as inputs, CHTIS analysts also utilize the computer in statistical and mathematical studies of accident causation, enforcement effects on traffic flow, and enforcement resource allocation techniques.

In summary, the CHTIS collects, processes, and disseminates traffic accident related information in Monroe County, Indiana (see Figure 3-3). The major subsystems which perform these functions have been identified as:

- Traffic Flow Subsystem.
- Traffic Accident Subsystem.
- Analysis Subsystem.

Of the three, the Traffic Flow Subsystem is by far the most complex and highly-developed, and is, in fact, the heart of the present CHTIS configuration. Additional details on its mode of operation and major components are provided below.

3.2 The Traffic Flow Subsystem

This CHTIS subsystem performs all activities involved in collecting, processing, and disseminating traffic flow information generated at the vehicle sensor sites. These activities are most conveniently grouped into the following four functional categories:

- Detect and Identify Vehicles.
- Transmit Signals.
- Process, Store, and Display Information.
- Perform Maintenance.

The four functions and their major interfaces are shown schematically in Figure 3-4 and are discussed separately below.

3.2.1 Detect and Identify Vehicle

Vehicle detection is accomplished through magnetic sensors located at 25 selected sites on four Monroe County, Indiana, highways (see Figure 3-5). The site locations were selected to provide

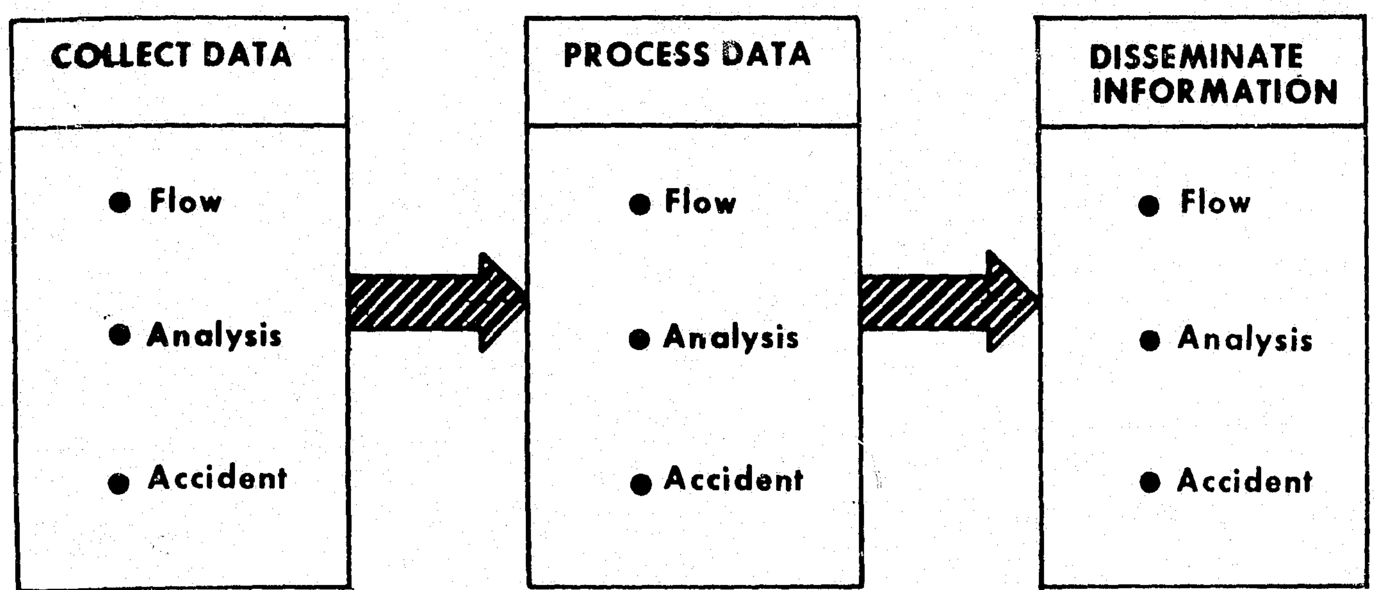


FIGURE 3-3
CHTIS Functions and Subsystems

FIGURE 3-4
Traffic Flow Subsystem Functions

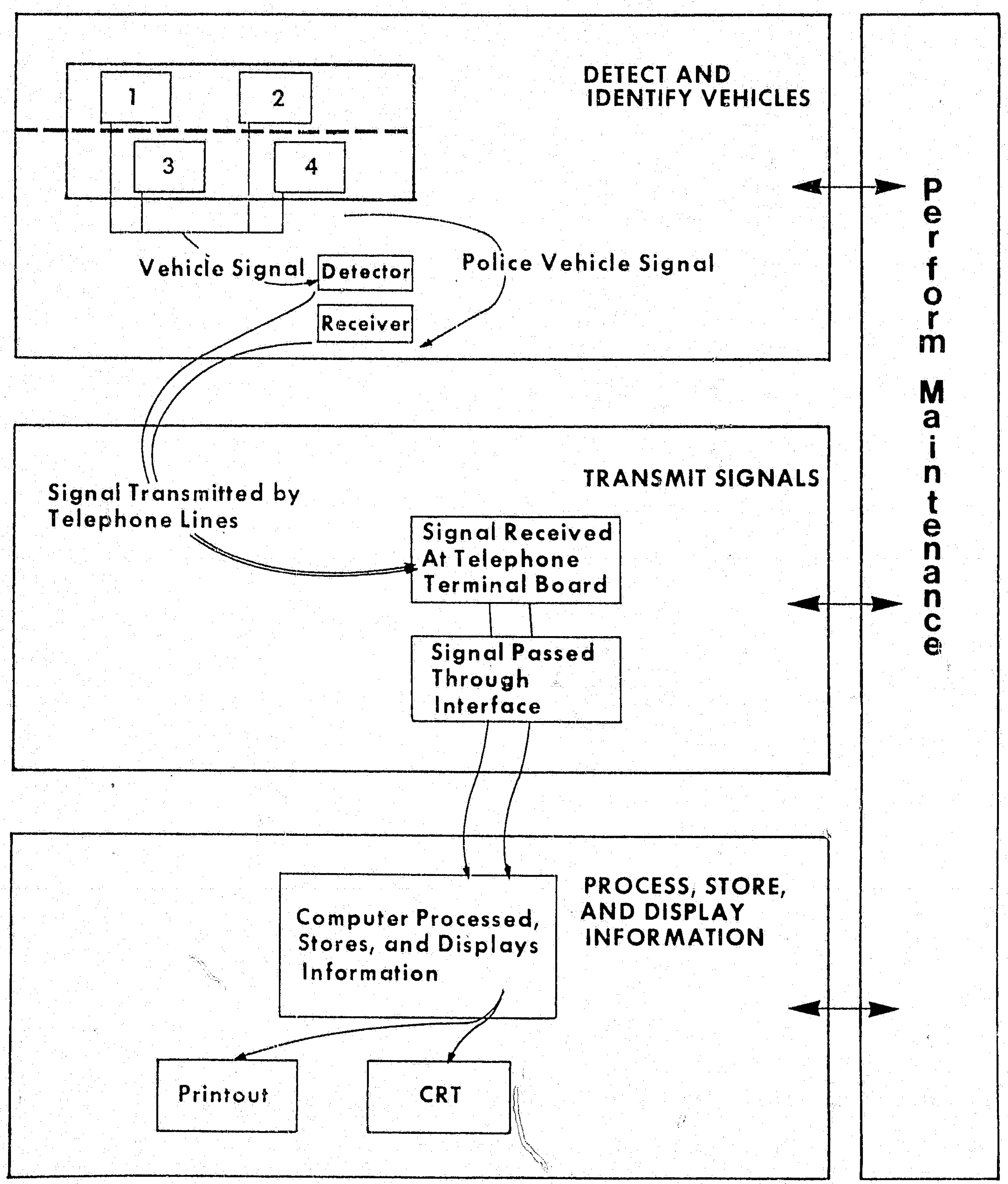
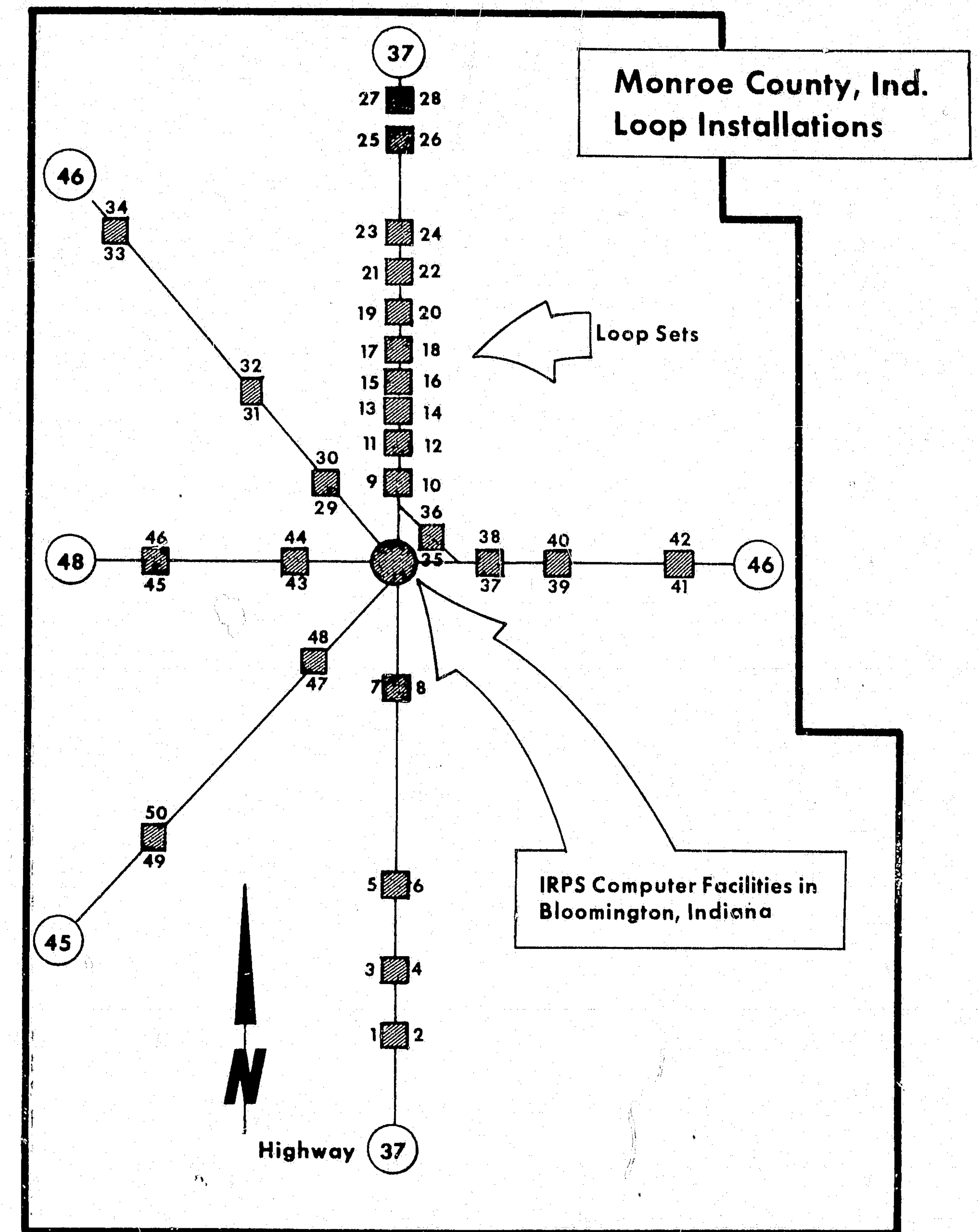


FIGURE 3-5



maximum coverage of the major highways leading in and out of Bloomington, Indiana, the home of Indiana University.

Each sensor site has two rectangular loops of coiled wire embedded in each lane of highway (see Figure 3-6). When an electrical current is passed through a loop, an inductance is created. A vehicle passing over the loop causes a change in this inductance which is utilized by the vehicle detection circuitry in confirming the vehicle's presence.

A vehicle travelling over a loop set will generate two signals, the first indicating the presence of the vehicle over the first loop circuit and the second indicating the presence of the vehicle over the second loop circuit. These two signals and their time phasing form the basis for later computation of the traffic flow variables at a given location.

The traffic flow subsystem also possesses a limited capability for identifying vehicles passing a sensor site. Indiana State Police (ISP) and Monroe County Sheriff's Department (MCSD) vehicles are equipped with short wave radio transmitters whose signals are received by radio receivers located in the sensor site equipment cabinets (see Figure 3-7). Each agency transmits on its own unique frequency which provides the basis for agency identification. Non-police vehicles are identified by an absence of a transmitted radio signal.

3.2.2 Transmit Signals

The signals generated at the sensor sites are transmitted over telephone lines to the IRPS computer facility at Indiana University. The signals are received at a test panel at the facility, and are then passed through an interface circuit which converts them to a form suitable for inputting into the computer. At the same time, the signals are sent to a demonstration map (resembling Figure 3-5) which has small light bulbs placed at points representing loop set locations. The lights flash on when vehicles cross the loop sets.

3.2.3 Process, Store and Display Information

The basic function of the computer is to convert the sensor site signals to raw information describing traffic flow throughout the county. In performing this function, the computer operates as a sophisticated timing device solving the familiar equation:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

the "distance" term is the spacing between the loops in a loop set, and the "time" term is the time required for a vehicle to traverse that distance. "Distance" is a known fixed value for all loop sets (i.e., 25 feet) and "time" is determined as the time difference between the signals generated by vehicle crossings of the loops in a loop set.

The computer is also able to calculate the approximate length of the vehicle passing over a loop by solving the equation:

$$\text{length} = \text{speed} \times \text{time},$$

where "time" is now the time required for the vehicle to cross <u>one</u> of the loops in a loop set.

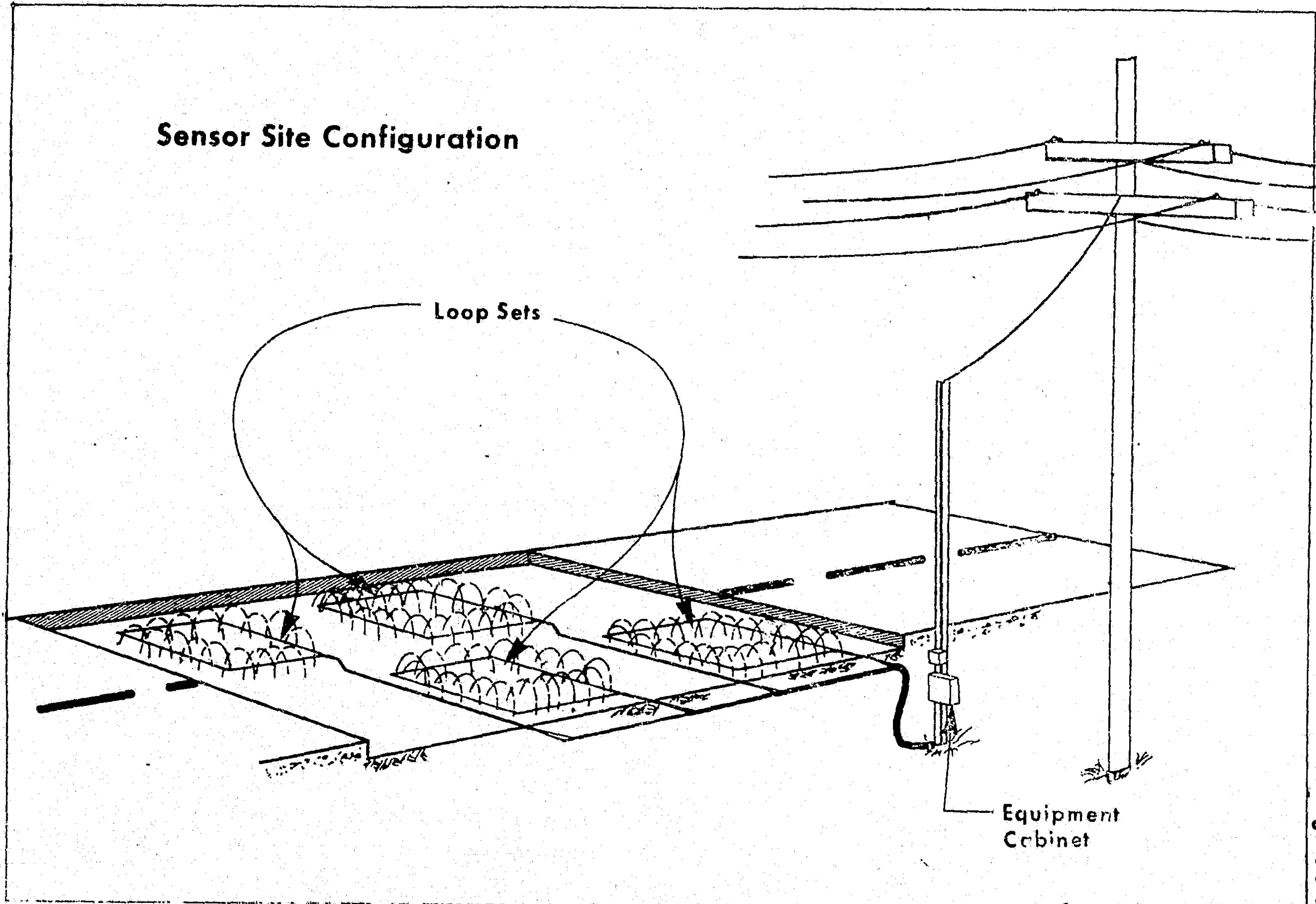
Numerous other functions are performed by the computer in processing the sensor site signals. It must, for example, store the speeds and lengths of the vehicles, the times at which vehicles pass the sensor sites, and the identities of the vehicles. It must retrieve the stored information and prepare it for display on print outs or on the Cathode Ray Tube (CRT). It must assist the operator in calibrating the subsystem (see Section 3.2.4), and it performs so-called non-process computations in support of the accident and analysis subsystems.

The computer operates in a time-sharing mode in performing these activities. The management of the various computational tasks is accomplished through a program provided by the computer manufacturer. This program, called the Time Sharing Executive or TSX, is stored in the computer core and allocates the computer's time according to specified priorities. Six such priorities have been established.

The computer's first priority is the acceptance and processing of data from the sensor sites. Since these data are produced discretely rather than continuously, it is not necessary to monitor the loops continuously, but only to scan them periodically to see if data requiring processing has been generated. If no data has been generated during a given scan, then the computer is free to perform other functions (in order of priority) until the next scan.

The second priority is the sensing of change of calendar date and preparing the computer storage to accept data collected during the new day.

The third priority is the real-time display of the raw information being generated at a given sensor site. Because of the short

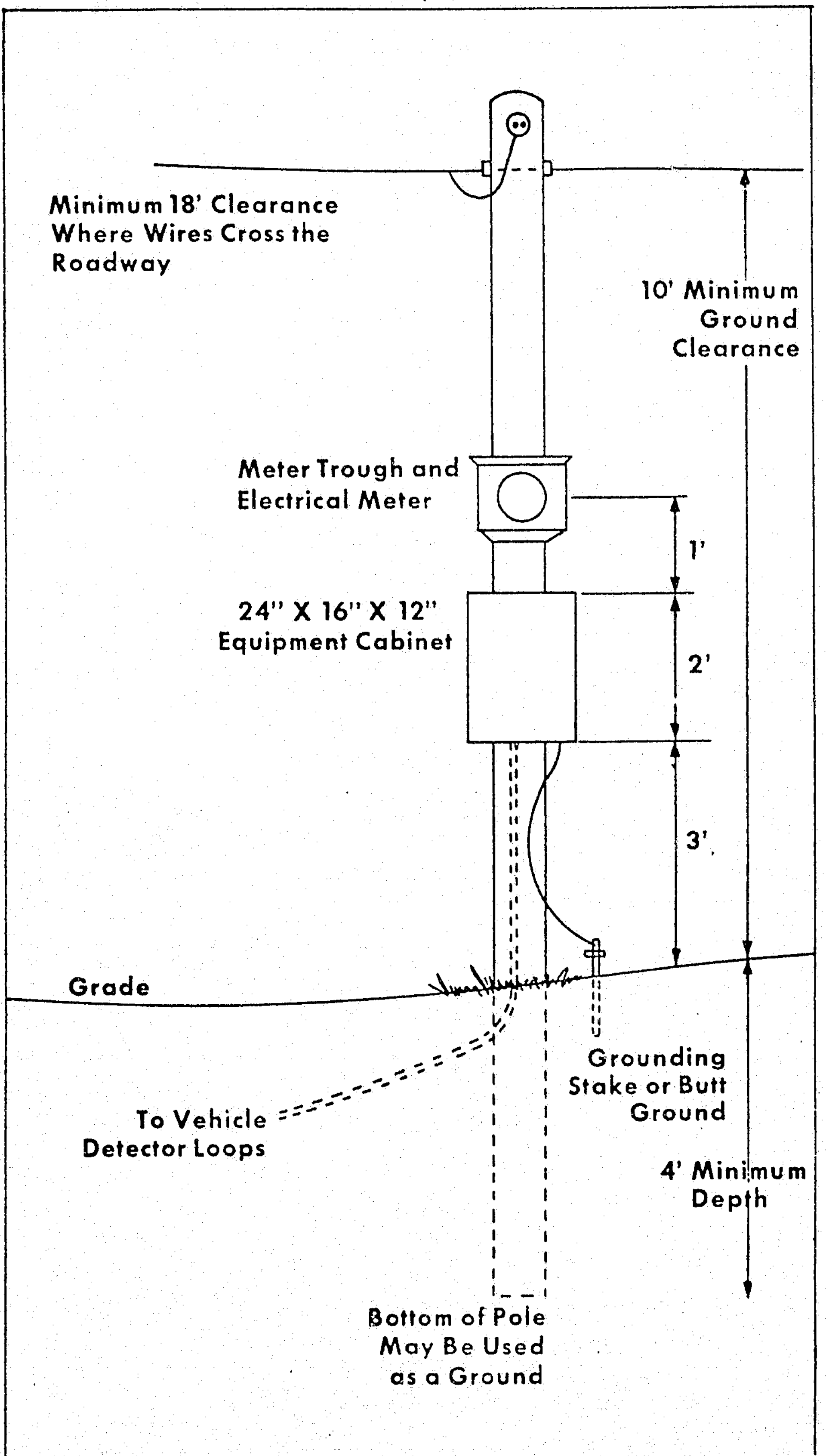


Sensor Site Configuration

Figure 3-6

Figure 3-7

Utility Pole and Equipment Cabinet



length of time required to scan the sites (less than .005 seconds), there is no perceptable interruption in the display.

The fourth priority is the performance of certain pre-determined computations at the discretion of the computer operator. Up to eleven such programs can be handled by the TSX.

The fifth priority is the presentation of data for calibrating the Traffic Flow Subsystem. This priority utilizes functions of the first priority (data collection) and the fourth priority (operator control).

The sixth and final computer priority is the performance of computations to support the Traffic Accident and Analysis subsystems. If, for example, a regression analysis is required to study the effect of average traffic speed on total number of accidents, then the related data processing activities would be performed only after the other five priorities have been satisfied. Computer operations related to this kind of activity have been termed "non-process" since they are external to the primary functions of the Traffic Flow Subsystem.

The major items of equipment employed in processing, storing, and display the traffic flow data are shown schematically in Figure 3-8. It is noted again that there are two CRT terminals, one located at the IRPS computer facility, and the other at the Indiana State Police Bloomington Post.

3.2.4 Perform Maintenance

The Traffic Flow Subsystem employs a wide variety of highly complex electronic and mechanical equipment which must be kept operating 24 hours a day to accomplish system design objectives. There is, therefore, a need for high levels of reliability and maintain ability for all critical components of the system. The system was designed and developed with this requirement firmly in mind, and particular emphasis was placed on developing and implementing operational procedures for performing both periodic and unscheduled maintenance.

Periodic maintenance schedules and procedures were developed from three logs which were kept throughout the developmental and operational phases of the project:

- Calibration log.

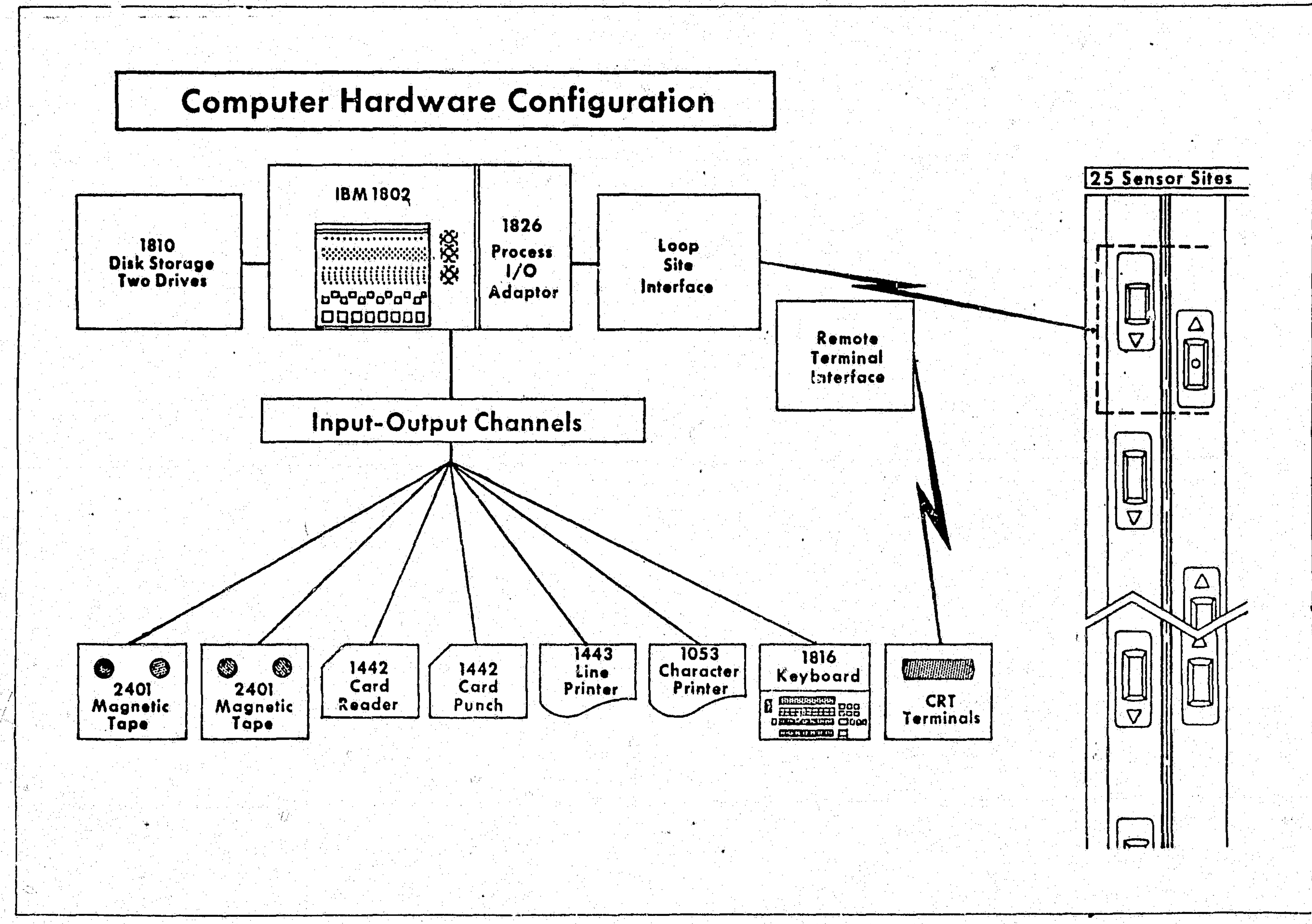

Computer Hardware Configuration
1810 Disk Storage Two Drives
IBM 1802
1826 Process I/O Adaptor
Loop Site Interface
25 Sensor Sites
Remote Terminal Interface
Input-Output Channels
2401 Magnetic Tape
2401 Magnetic Tape
1442 Card Reader
1442 Card Punch
1443 Line Printer
1053 Character Printer
1816 Keyboard
CRT Terminals

Figure 3-8

• Computer Status log.

• Repair Performed log.

Unscheduled maintenance procedures were based on recommendations from the equipment suppliers and experience gained in operating the equipment.

The success of the maintenance effort is indicated by the very high levels of system availability achieved during system operations: approximately 94 percent of the loop sets were available (i.e., generating acceptably accurate traffic flow data) during a five-month period in 1971. The computer operated properly during 95 percent of this period.

4.0 CHTIS RESEARCH AND DEVELOPMENT

This section of the report discusses the effort conducted under the present contract to develop an operational risk management information capability in Monroe County, Indiana. The research and development activities and results are described under the three primary risk management functions that the CTIS is designed to support: risk identification, risk analysis, and resources allocation. All three categories of risk information (i.e., raw, refined, and derived) are treated. In addition, this section presents a discussion of consideration applicable to the development of public education programs utilizing risk information generated by the CHTIS.

4.1 Risk Identification

Table 4-1 summarizes the six categories of risk identification information outputs that were sought during the research and development phases of the project. The raw and refined traffic flow information outputs consisted of the basic data generated by 50 CTIS loop sets and processed for dissemination to the local police agencies and local newspapers. The raw and refined accident information outputs consisted of accident statistics for Monroe County as contained on the Indiana State Police data tapes and a presentation of those statistics in the form of an Accident Data Handbook to be used by local police agencies. In addition, a limited research effort was conducted to identify possible theoretical or empirical expressions for providing derived information describing accident risk and its relationship to traffic flow variables.

Each of the outputs shown in the table is discussed in detail below.

4.1.1 Raw and Refined Information

4.1.1.1 Traffic Flow Information

The raw information describing traffic flow is generated by the CHTIS in response to vehicles passing over the magnetic vehicle detectors (i.e., loop sets). The nature of this information is completely determined by the times of interaction of a subject vehicle with the loop set geometry. It was noted in Section 3.0 that each of the 50 loop sets consists of two loop circuits embedded in a highway traffic lane a fixed distance apart. Thus, a vehicle travelling over a loop set will generate two signals, the first indicating the presence of the vehicle over the first loop circuit and the second indicating the presence of the vehicle over the second loop

TABLE 4-1: CHTIS Information Outputs for Risk Identification

Type Information	Information Output	
	Accidents	Flow
Raw	Indiana State Police Accident Statistics	Loop Set Data
Refined	Accident Data Handbook	Real-time and Summary Reports
Derived	Accident Indexes and Analyses	Traffic Flow Indexes and Analyses

circuit. The computer records the times at which both signals are initiated and terminated and uses this information plus information describing the loop set geometry to compute all vehicle parameters. Table 4-2 lists the resulting information.

Some commentary is required on the data elements in Table 4-2. First, vehicle headway is defined as the time difference in milliseconds between successive vehicle crossings of the loop sets. Obviously, one may obtain an estimate of the distance between vehicles through the expression:

SPACING (FT.) = .001467xMPHxHEADWAY(MSEC.),

where: MPH = speed in miles per hour of the n-1st vehicle

HEADWAY(MSEC.) = headway in milliseconds of the nth vehicle.

It is also clear that the sequence of vehicle passage over the loop circuits comprising a loop set will allow one to determine a vehicle's direction of travel, i.e., whether the vehicle is travelling in the intended direction of traffic flow for a given lane (normal) or opposite to it (passing). Finally, it should be noted again that Indiana State Police (ISP) patrol vehicles and Monroe County Sheriff's Department (MCSD) patrol vehicles were equipped with special shortwave transmitters whose unique signals were received at the time of passage over a loop set. A means was thus provided to identify a given vehicle as ISP, MCSD, or "other."

The raw traffic flow data described above are stored on seven-track, 556 bits per inch (BPI), magnetic tape. Each 64-word record contains values of these data elements for 25 vehicles at a given loop set. The records from a given loop set are sequential in time but are in general separated by records from other loop sets. Each tape contains on the order of 40,000 records, or data for about 1,000,000 vehicles. The data on a single tape cover a time period of about three days for the full 50-loop set system. The total data bank consists of 265 data tapes containing approximately 10,000,000 records for over 200,000,000 vehicles.

In addition to storing the raw traffic flow information for future use, a capability was developed to display the information on a real-time basis. Upon command by an operator, the information collected from a given loop set was presented on cathode ray tube (CRT) display units located at the computer facility and, later in the project, at Indiana State Police Post no. 33. Figure 4-1 presents a facsimile of a typical real-time display of raw traffic flow information.

TABLE 4-2

Raw Traffic Flow Information Generated by a CHTIS Loop Set

Data Element	Symbol	Units/Dimensions	Accuracy Carried
Time of loop crossing	TIME	Hours	-3.6 sec.
Vehicle Speed	MPH	Miles per hour	± 1 mph (truncated)
Vehicle Length	LEN	Feet	± 1 foot
Vehicle Headway	HEADWAY	Milliseconds	± 1 millisecond
Vehicle Direction	DIR	0 - Normal 1 - Passing	--
Vehicle Type	--	2 - ISP 3 - Sheriff 4 - Other	--

FIGURE 4-1
Format for Displaying Real Time Traffic Flow Information

Run 6

You are monitoring loop set 39

BCNT	TIME	DIR	MPH	LEN	HEADWAY	CARC	BADC
20	13780	0	51*	18	-19169	1147	16
21	13781	0	50*	18	-4965	1148	16
22	14005	0	51*	16	0	1149	16
23	14005	0	51*	15	-2941	1150	16
24	14006	0	62*	19	-3659	1151	16
25	14026	0	45	15	0	1152	16
26	14026	0	47*	15	-2951	1153	16
27	14041	0	49*	20	0	1154	16
28	14041	0	48*	12	-1270	1155	16
29	14042	0	49*	15	-2405	1156	16
30	14045	0	46*	16	-12445	1157	16
31	14052	0	61*	21	-25237	1158	16
32	14065	0	64*	19	0	1159	16
33	14069	0	53*	21	-16271	1160	16
34	14070	0	44	15	-4329	1161	16

*Speed limit violation

It was noted previously in this report that the CHTIS evolved over a period of about two and one-half years to its final level of capability (see Table 4-3). In its initial configuration, as developed under National Highway Safety Bureau Contract FH-11-6965, 16 loop sets were operational by January, 1969. In November, 1969, (under the same contract) another 12 loop sets became operational. All 28 sets were located along Indiana highways 37N and 37S at a total 14 sites where flow parameters were measured for both directions of travel. Data for 50 loop sets did not become available until March, 1971, when the additional 22 loop sets, installed under the present contract and located on Indiana Highways 45, 46, and 48, became operational. Thus, in its final configuration, the CHTIS possessed the capability to collect and store traffic flow data in both directions at 25 locations in Monroe County, Indiana. This capability was available for the time period March, 1971, through December, 1971. A more limited capability covering 14 locations was maintained from November, 1969, through December, 1971, and a total of eight locations were monitored over the entire three-year period from January, 1969, through December, 1971.

Of course, the information was not available 100 percent of the time during these time periods. From time to time various of the system components became either non-functional or did not function properly. This resulted in either the total system or parts of it being "down" or not available part of the time. Thus, a system user seeking raw traffic flow information for a given time increment during the above periods of operation could not expect, with certainty, such information to be available. The system availability is measured here by the expected fraction of loop sets producing acceptably accurate traffic flow information at a given time accuracy. Table 4-3 presents estimates system availability for two time factors calculated under the criterion that no more than five percent of the vehicles were counted incorrectly. The general conclusion is that system availability improved significantly over the three-year period of operation, rising to a value of nearly 90 percent for the full 50-loop set system.

The reasons for system unavailability are both varied and complex (see Table 4-4). In general, all subsystems must occupy unfailed states (according to specific failure criteria) and their ability to do so is a function of their reliability (mean time before failure) and maintainability (mean time to repair). Some component failures may require maintenance action while others, caused by environmental and other factors, may be self-correcting. Computer unavailability may be due to component, support, or human failures, or simply to an intentional shut down for revising software or updating hardware.

TABLE 4-3

Raw Traffic Flow Information Availability Summary

System Configuration	Number of Loop Sets	Date Operational	System Availability
1	16	Jan. 69	.73 (1)
2	28	Nov. 69	--- (2)
3	50	Mar. 71	.89 (3)

(1) Expected fraction of loop sets available in a given one hour period according to criteria:
(a) A summary report was printed, and
(b) Percent of bad car counts ≤ 5 percent.
(Source ref. 10)

(2) Availability was not computed for this configuration.

(3) Expected fraction of loop sets available in a given 24 hour period according to criteria:
(a) Vehicle count for a loop set > 200 vehicles a day,
(b) Percent bad car count ≤ 5 percent,
(c) Computer available.

Typical Causes of Raw Information Unavailability

Availability Criterion	Influencing Subsystems	Typical Causes of Failure to Meet Availability Criterion
Vehicle Count ≥200/day/loop set	Vehicle Detection, Signal Transmission	1. Component failure
BCC ≤5%/loop set	Vehicle Detection, Signal Transmission	1. Spurious failures in vehicle detector relays 2. Failure of a passing vehicle to cross both loops in a loop set 3. Imbalance in detection sensitivity causing one loop to detect while the other does not 4. Spurious failures in telephone or power line
Computer Operating	Computer	1. Component failure 2. Power/air conditioning failure 3. Operator error 4. Software revision 5. Hardward update

Table 4-5 shows a breakdown of availability by major subsystem for the months of May through September of 1971. It is seen that the computer and loop set availability are about the same (~.94). It is also clear that the total system is capable of achieving very high levels of availability: when computer availability was based on down time due to computer failures only (a reasonable operational criterion), a total system availability of .95 was achieved in September, 1971. The average total system availability for the six-month period was .89.

The utility of the raw traffic flow information is dependent not only on the nature and availability of the data, but on its reliability and accuracy as well. During the project, maintenance procedures were established to maintain maximum standards of data accuracy within limits inherent to component and system design.[1] The results achieved are summarized in Table 4-6 for key data elements. The vehicle speed error averaged ±3.6 mph (1σ) over all sensor sets at times of calibration. This amounts to about seven percent at a vehicle speed of 50 mph. Vehicle length errors were higher (σ = ±4.2 feet) due to inherent physical limitations of the measuring technique. Vehicle headway errors of only ±2 milliseconds were achieved. It was found that, on the average, about 4.5 percent of the vehicles were counted incorrectly (i.e., "bad car counts"). No relationship was found between time, between system calibrations, and the amount of error in vehicle speed, length, or headway. It is, therefore, concluded that errors due to timewise drift are probably negligible over time periods of the order of days.

In addition to storing and displaying the raw traffic flow information, a capability was developed to present summary and other special reports and displays from the raw information. One of the most basic presentations of this "refined" information was the summary report shown in Figure 4-2. This report presented a listing of the basic raw flow information for the last ten vehicles passing over a given loop set and provided, in addition, a summary of car count, a bad car count, and percent bad car count measured since the previous midnight. The report was displayed on the CRT device at the command of the operator.

A summary report listing the basic traffic flow parameters for vehicles crossing a given loop set in a given time period was available in hard copy at the request of the user (Figure 4-2A). The

1. A detailed discussion of periodic and unscheduled maintenance procedure is contained in Reference Volume I of this report.

TABLE 4-5

Raw Traffic Flow Information Availability Breakdown

Full 50-Loop Set System

Month	Computer		Loop Sets	Total System	
	Criterion 1	Criterion 2		Criterion 1	Criterion 2
May	.995	.996	.841	.836	.837
June	.905	.931	.955	.864	.889
July	.918	.936	.955	.876	.894
August	.899	.910	.944	.840	.860
September	.908	.991	.963	.874	.953
Average	.927	.953	.938	.858	.893

Notes: (1) Year 1971

(2) Criterion 1 includes all computer down time, regardless of cause.

(3) Criterion 2 includes computer down time due to computer failures only.

(4) Criteria for total system availability:
a) Vehicle count for a loop set > 200 vehicles/day
b) Vehicle bad count for a loop set ≤ 5%/day
c) Computer available

(5) Loop set availability calculated from computer availability and total system availability.

TABLE 4-6

Raw Traffic Flow Information Measuring Errors
Selected Data Elements

Data Element	Error (1σ)	% Error (1σ)
Vehicle Speed	±3.6 mph	±7.2 (1)
Vehicle Length	±4.2 ft.	±21.0 (2)
Vehicle Headway	±2.0 ms (1)	-
Vehicle Count	-	$\mu \approx 4.5$ (3)

Notes: (1) At 50 mph
(2) For a 20 ft. vehicle
(3) Average % of vehicles counted incorrectly during a given time period

FIGURE 4-2
Format for Displaying Real Time Summary Traffic Flow Information

Run 1

Date is December 17, 1971

Loop 1

CARC 1450 BADC 24 PERCENT BAD 1.65

TIME	DIR	MPH	LEN	HEADWAY
14201	0	58	20	3379
14211	0	69	24	0
14212	0	67	25	4721
14214	0	56	21	7789
14222	0	72	23	0
14225	0	59	20	12074
14227	0	62	22	8283
14230	0	66	23	9643
14234	0	59	21	13785
14239	0	77	22	19762

// JOB ,FRO ONE
.//.XEQ.NC012 ..FX1

TRAFFIC FLOW INFORMATION SUMMARY

FIGURE 4-2A

THIS LISTING IS FOR LOOPS 20 26 BETWEEN 16830 AND 17830 ON 11/ 6

LOOP 20						LOOP 26				
DIR	SPEED	LEN	HEADWAY	TIME		DIR	SPEED	LEN	HEADWAY	TIME
0	53	10	27677	16831	*	0	64	13	0	16835
0	54	5	7690	16833	*	0	56	17	4486	16836
0	45	12	0	16854	*	0	56	14	1234	16836
0	44	6	1828	16854	*	0	55	13	1112	16836
0	42	8	1285	16854	*	0	59	16	2776	16837
0	45	11	16065	16859	*	0	66	15	5847	16839
0	46	5	1547	16859	*	0	57	14	14715	16843
0	48	14	1665	16860	*	0	59	16	925	16843
0	49	12	1324	16860	*	0	60	14	965	16843
0	46	11	2421	16861	*	0	57	13	8592	16846
0	44	8	1406	16861	*	0	83	13	13943	16850
0	57	12	0	16871	*	0	60	16	16488	16854
0	57	13	2299	16871	*	0	60	16	11541	16857
0	51	11	23715	16879	*	0	59	14	0	16866
0	45	9	2569	16879	*	0	60	14	586	16866
0	46	7	0	16891	*	0	62	16	4960	16867
0	52	14	8551	16891	*	0	59	12	3052	16868
0	51	14	24 3	16892	*	0	55	16	486	16869
0	51	12	1228	16893	*	0	56	13	1291	16869
0	48	11	1648	16893	*	0	61	15	2747	16869
0	52	7	0	16905	*	0	64	17	23682	16876
0	51	13	2329	16905	*	0	65	17	946	16876
0	50	6	1446	16906	*	0	60	11	15137	16880
0	51	7	0	16925	*	0	59	14	14638	16884
0	51	12	3003	16926	*	0	72	8	767	16885
0	50	11	1034	16926	*	0	64	8	3795	16886
0	50	9	1540	16926	*	0	70	11	11593	16889
0	51	12	1958	16927	*	0	75	14	6946	16891
0	52	12	4957	16928	*	0	60	16	28373	16899
0	51	12	0	16940	*	0	60	16	1425	16899
0	51	12	22242	16946	*	0	70	15	8560	16901
0	51	12	1770	16946	*	0	67	14	1109	16902
0	49	11	1122	16946	*	0	69	8	4180	16903
0	50	6	1233	16947	*	0	67	10	2268	16904
0	52	11	1000	16947	*	0	70	9	15713	16908
0	52	12	1083	16949	*	0	63	16	19900	16913
0	47	12	21946	16954	*	0	64	15	2968	16914
0	47	9	1078	16954	*	0	66	15	4745	16916
0	53	14	8556	16957	*	0	67	13	7379	16918
0	52	13	1219	16957	*	0	67	14	16307	16923
0	52	11	945	16957	*	0	63	17	15365	16927
0	55	12	19723	16963	*	0	61	14	1534	16927
0	53	8	1709	16963	*	0	63	9	1527	16928
0	54	16	0	16973	*	0	67	17	5319	16930
0	52	10	4092	16974	*	0	70	13	5341	16932
0	53	6	0	16983	*	0	60	14	3171	16933
0	54	11	1465	16983	*	0	60	12	2877	16933
0	55	12	21300	16988	*	0	61	15	1006	16934
0	49	10	0	17005	*	0	61	15	[illegible]	16940
0	55	9	2329	17005	*	0	60	14	1260	16942
0	56	10	0	17016	*	0	65	5	8003	16942
0	54	13	4335	17017	*	0	73	12	0	16951
0	46	13	0	17025	*	0	62	14	10092	16953
0	47	12	1215	17025	*	0	64	9	12066	16957
0	53	13	16447	17030	*	0	63	8	1045	16957
0	46	11	12710	17033	*	0	64	12	21770	16963
0	52	7	[illegible]	17034	*	0	67	13	5359	16964
0	51	7	2012	17034	*	0	59	15	5662	16966
0	51	5	16274	17039	*	0	50	15	0	16976
0	53	11	3239	17040	*	0	51	9	1474	16976
0	53	15	15869	17044	*	0	65	14	17647	16981
0	51	13	1320	17045	*	0	61	14	18172	16986
0	49	14	5916	17046	*	0	59	11	22550	16992
0	45	[illegible]	1662	17047	*	0	56	10	8595	16994
0	[illegible]	12	1750	17047	*	0	59	14	2861	16995
0	54	11	[illegible]	17050	*	0	71	15	12934	16996

report presented vehicle direction, speed, length, headway, and time of loop crossing in each lane of traffic at the sensor site.

A summary of posted speed violations at the various loop sets for a 24 hour period was produced in hard copy (see Figure 4-3). The report lists both number and percentages of violations by loop for the day of concern. A more detailed speed violation report was also produced in hard copy (see Figure 4-4). The report listed hourly traffic volume and hourly number and percentage of speed violations at a given loop set for a given day. The report presented, in addition, hourly number and percentage of speed violations at a given loop set for a given day. The report presented, in addition, hourly number and percentage of vehicles travelling at or in excess of (1) the posted speed limit plus 5 mph and (2) the posted speed limit plus 10 mph. An hourly count of ISP or MCSD patrol vehicles passing the loop set was also shown. Both speed violation reports were made available to ISP personnel.

A daily traffic volume and speed report was prepared and distributed to the local press (see Figure 4-5). The report listed traffic volume and average speed both inbound and outgoing lanes for each of seven key highway segments in Monroe County. Data were presented for selected hours in the period 6 a.m. to 7 p.m. of the previous day.

A capability was developed to produce traffic speed histograms for use in analyzing traffic flow characteristics (see Figure 4-6). The histograms were based on raw information collected during any given time period and presented speed frequency distribution plus selected summary information.

4.1.1.2 Traffic Accident Information

The source of all traffic accident information managed by the CHTIS was the Indiana State Police (ISP) accident file. The information is stored on nine-track, 800 bytes per inch magnetic tapes, one tape for each quarter of the calendar year or four tapes per year. Each tape contains information describing some accidents stored roughly in the chronological order of occurrence of the accidents.

All information on the ISP tapes is taken from Indiana accident report forms which must be completed for motor vehicle accidents involving property damage of at least $100 or one or more personal injuries. Provisions have been made to record on the tapes the values of 55 variables describing a given accident involving up to nine

FIGURE 4-3

Speed Limit Violation Summary Report *

Date is xx/xx/xx

Percent Violators by Loop

Loop	Viol	% Viol	Loop	Viol	% Viol	Loop	Viol	% Viol
1	----	----	2	----	----	3	----	----
4	----	----	5	----	----	6	----	----
7	----	----	8	----	----	9	----	----
10	----	----	11	----	----	12	----	----
13	----	----	14			15	----	----
16			17			18		
19			20			21		
22			23			24		
25			26			27		
28			29			30		
31			32			33		
34			35			36		
37			38			39		
40			41			42		
43			44			45		
46			47			48	----	----
49	----	----	50	----	----			

*A facsimile.

FIGURE 4-4: Speed Limit Violation Detailed Report

INSTITUTE FOR RESEARCH IN PUBLIC SAFETY (CAPTS) AND
INDIANA STATE POLICE
TOTAL VOLUME, TOTAL VIOLATORS, AND PERCENT VIOLATORS FOR 11/29/71

HIGHWAY AREA - SOUTH 37
IN TOWN TRAFFIC

LOOP NUMBER 2

HOUR OF THE DAY

	1	2	3	4	5	6	7	8	9	10	11	12
TOTAL NUMBER	16	16	6	13	40	103	612	427	217	212	178	167
TOTAL VIOLATORS	4	10	3	7	24	43	47	53	53	74	76	61
PERT VIO(PL)	25.00	62.50	50.00	53.84	60.00	41.74	7.67	12.41	24.42	34.90	42.69	36.52
TOT VIO(PL+5)	1	4	1	5	13	19	14	10	28	35	37	25
PERT VIO(PL+5)	6.25	25.00	16.66	38.46	32.50	18.44	2.28	2.34	12.90	16.50	20.78	14.97
TOT VIO(PL+10)	0	3	1	3	6	7	2	3	9	8	13	10
PERT VIO(PL+10)	0.00	18.75	16.66	23.07	15.00	6.79	0.32	0.70	4.14	3.77	7.30	5.98
TOTAL POLICE	0	0	0	0	0	0	0	0	1	0	0	1

LOOP NUMBER 2

HOUR OF THE DAY

	13	14	15	16	17	18	19	20	21	22	23	24
TOTAL NUMBER	154	173	175	208	226	144	156	73	60	55	48	72
TOTAL VIOLATORS	52	64	71	74	101	58	66	29	24	22	25	24
PERT VIO(PL)	33.76	36.99	40.57	35.57	44.69	40.27	42.30	39.72	40.00	40.00	52.08	33.33
TOT VIO(PL+5)	22	29	24	32	51	28	30	8	12	13	19	13
PERT VIO(PL+5)	14.28	16.76	13.71	15.38	22.56	19.44	19.23	10.95	20.00	23.63	39.58	18.05
TOT VIO(PL+10)	4	10	11	13	18	14	7	2	4	6	9	9
PERT VIO(PL+10)	2.59	5.78	6.28	6.25	7.96	9.72	4.48	2.73	6.66	10.90	18.75	12.50
TOTAL POLICE	0	0	0	1	0	0	0	0	0	0	0	0

LOOP NUMBER 4

HOUR OF THE DAY

	1	2	3	4	5	6	7	8	9	10	11	12
TOTAL NUMBER	37	12	7	14	37	110	610	510	260	229	201	203
TOTAL VIOLATORS	20	4	2	6	11	17	10	6	18	18	24	32
PERT VIO(PL)	54.05	33.33	28.57	42.85	29.72	15.45	1.63	1.17	6.92	7.86	11.94	15.76
TOT VIO(PL+5)	18	1	1	4	4	12	3	2	7	8	11	13
PERT VIO(PL+5)	48.64	8.33	14.28	28.57	10.81	10.90	0.49	0.39	2.69	3.49	5.47	6.40
TOT VIO(PL+10)	18	0	1	1	1	3	0	1	1	2	5	5
PERT VIO(PL+10)	48.64	0.00	14.28	7.14	2.70	2.72	0.00	0.19	0.38	0.87	2.48	2.46
TOTAL POLICE	0	0	0	0	0	0	0	1	2	0	0	0

LOOP NUMBER 4

HOUR OF THE DAY

	13	14	15	16	17	18	19	20	21	22	23	24
TOTAL NUMBER	162	183	194	229	250	148	171	82	56	61	54	57
TOTAL VIOLATORS	21	17	20	27	28	23	19	10	6	5	13	6
PERT VIO(PL)	12.96	9.28	10.30	11.79	11.20	15.54	11.11	12.19	10.71	8.19	24.07	10.52
TOT VIO(PL+5)	8	6	8	15	13	9	5	5	5	3	12	3
PERT VIO(PL+5)	4.93	3.27	4.12	6.55	5.20	6.08	2.92	6.09	8.92	4.91	22.22	5.26
TOT VIO(PL+10)	0	1	2	3	3	5	1	2	2	0	5	1
PERT VIO(PL+10)	0.00	0.54	1.03	1.31	1.20	3.37	0.58	2.43	3.57	0.00	9.25	1.75
TOTAL POLICE	0	0	0	0	0	0	0	0	0	0	0	0

FIGURE 4-5: Daily Traffic Volume and Speed Report

INSTITUTE FOR RESEARCH IN PUBLIC SAFETY
DAILY NEWS PRINTOUT

DATE 11/24

VOLUME BY HOUR OF DAY (TODAY: 6A–7A; YESTERDAY: 8A–7P)

HIGHWAY	DIRECTION	6A	7A	8A	NOON	1P	2P	3P	4P	5P	6P	7P
US37 S	INBOUND	78	561	388	208	171	215	209	246	275	182	152
	OUTGOING	26	59	127	177	225	208	244	360	714	359	196
US37 N	INBOUND	36	251	246	323	298	330	335	321	404	319	235
	OUTGOING	71	169	258	481	692	893	860	832	961	609	363
US45 W	INBOUND	24	217	163	59	62	75	85	89	140	52	55
	OUTGOING	19	138	115	164	207	214	251	373	688	402	203
US46 E	INBOUND	13	88	112	141	166	163	182	175	165	140	117
	OUTGOING	22	67	86	178	229	254	262	264	310	280	133
US46 W	INBOUND	65	535	586	228	291	268	270	287	370	277	253
	OUTGOING	28	78	209	256	296	279	329	463	736	625	316
US46 BP	INBOUND	16	40	77	179	213	196	167	154	183	265	192
	OUTGOING	9	51	119	206	250	258	282	273	237	324	256
US48 W	INBOUND	31	191	223	81	96	100	78	81	101	83	80
	OUTGOING	5	18	30	93	99	116	89	129	268	195	97

AVERAGE VELOCITY BY HOUR OF DAY (TODAY: 6A–7A; YESTERDAY: 8A–7P)

HIGHWAY	DIRECTION	6A	7A	8A	NOON	1P	2P	3P	4P	5P	6P	7P
US37 S	INBOUND	47.6	39.5	41.6	51.3	51.1	51.8	50.1	45.7	44.7	42.7	35.6
	OUTGOING	50.6	43.8	46.0	52.9	51.8	50.9	49.8	46.3	44.0	43.7	34.4
US37 N	INBOUND	51.0	47.5	43.5	58.3	57.0	56.3	54.7	49.4	46.9	40.9	36.9
	OUTGOING	53.8	49.3	43.6	58.3	55.5	52.6	52.5	45.7	44.4	27.5	37.1
US45 W	INBOUND	48.1	39.2	43.0	58.7	55.8	59.4	53.3	50.0	45.7	40.1	46.4
	OUTGOING	49.5	43.3	42.6	53.4	53.7	55.0	51.4	46.9	43.5	41.7	36.6
US46 E	INBOUND	43.7	44.7	43.9	53.0	52.9	50.0	49.9	46.8	44.9	40.5	34.1
	OUTGOING	46.6	46.4	44.5	54.1	52.4	51.2	49.6	47.3	47.3	40.2	34.9
US46 W	INBOUND	44.0	37.7	37.0	47.4	46.5	47.1	45.4	40.4	37.8	38.6	34.7
	OUTGOING	43.5	39.6	35.1	47.6	47.9	48.8	46.7	41.1	38.3	39.3	36.3
US46 BP	INBOUND	41.6	38.3	36.3	42.5	42.0	42.2	41.2	39.3	40.5	36.4	33.3
	OUTGOING	43.2	42.3	38.4	45.0	45.9	46.0	46.0	43.6	43.5	37.9	37.6
US48 W	INBOUND	43.2	40.2	36.7	42.1	40.7	40.8	42.3	36.8	40.7	36.3	34.1
	OUTGOING	37.9	34.5	35.8	43.3	44.9	43.8	42.3	42.3	42.7	38.6	33.8

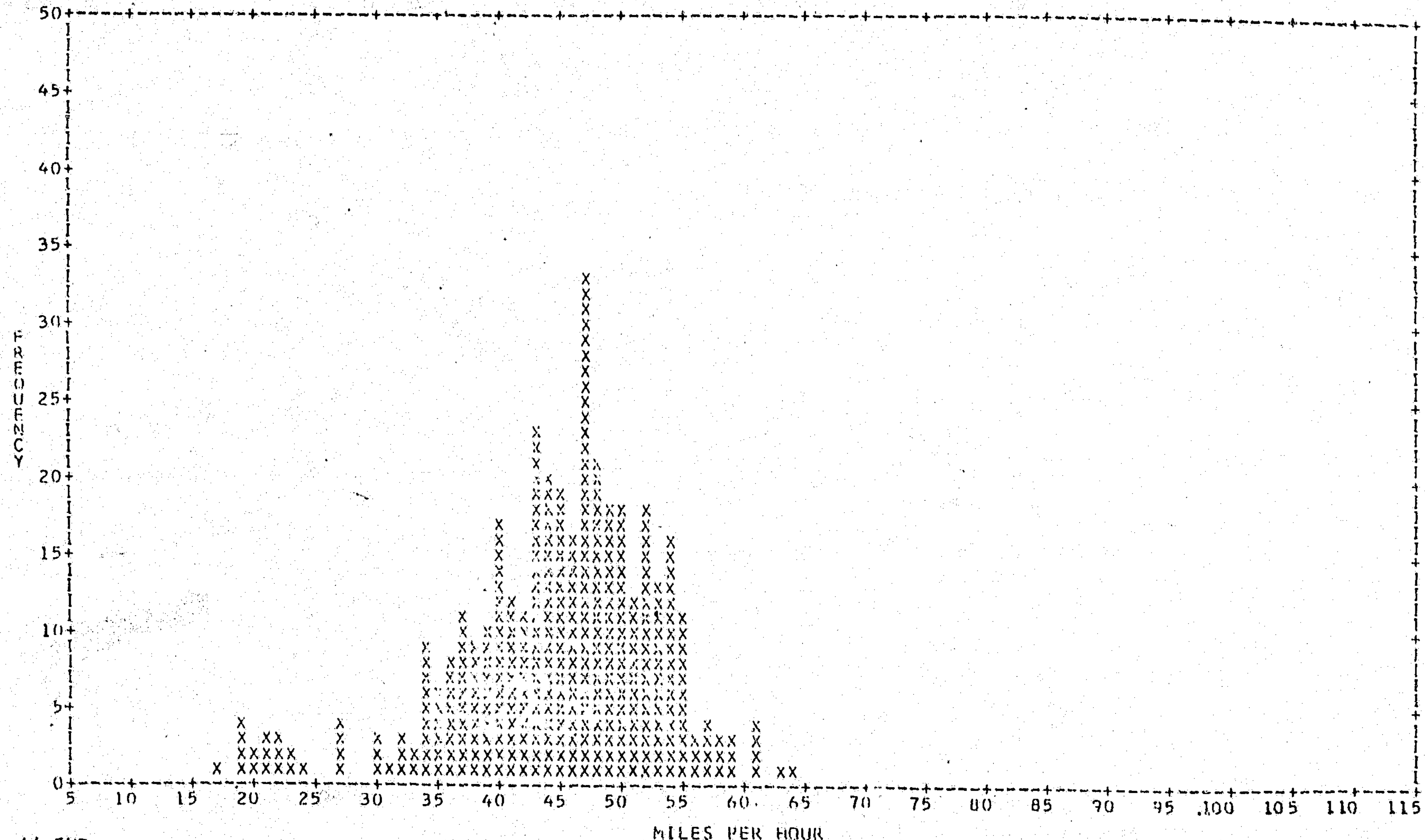
// END

Figure 4-6: Traffic Speed Histogram

LOOP NUMBER 6

PLOT OF TRAFFIC FROM 14500 TO 16000 ON 5/26/71

COUNT	379	AVE. VEL.	44.65	ST. DEV.	8.34
85TH PERCENTILE	52	90TH PERCENTILE	54	PASSING COUNT	0
ZERO COUNT	1	MAXIMUM VEL.	64	MINIMUM VEL.	17
RANGE	47	MODE	47	MEDIAN	45



// END

vehicles (see Table 4-7). The variables describe the nature of the accident, losses incurred, time and location of the accident, age and sex of drivers and injured persons; geometry and dynamics of the accident, opinions of accident causal factors, road condition, weather, and visibility.

The information is available for the years 1967 through 1971 and, in general, lags the current data by about one quarter because of processing time requirements.

No attempt has been made to assess the accuracy, reliability, or completeness ISP accident information. In general, it has been found that values of variables describing the purely factual, (e.g., age and sex of drivers) are consistently reported, while values of variables based on opinion or hearsay (e.g., speed before accident) are often not provided.

In contrast to raw traffic flow information, the raw accident information as summarized above is of little or no direct use for risk identification. Considerable refinement is required in the form of classifying, summarizing, and presenting the raw information. Obviously, because of the sheer bulk and variety of the accident information, a comprehensive presentation was not feasible under the present contract. However, it was believed a limited presentation could be devised that would provide a much needed and useful tool for identifying risk in Monroe County, and, ultimately, allocating local police resources for risk control. The resulting document was called an Accident Data Handbook and is presented as Reference Volume II to the present report. A summary of its contents is shown in Table 4-8. The handbook presents data for calendar year 1970. Five dependent variables were used as measures of accident disutility: total number of accidents, number of property damage accidents, number of personal injury accidents, number of fatal accidents, and estimated direct cost of accidents. In deciding what information would be of primary interest, it was reasoned that the user would be most interested in seeing measures of accident disutility for the total county as a function of time, visibility, weather condition, and police jurisdiction of the accident location. Of secondary interest would be accident disutility for each of several key highway segments within the ISP jurisdiction as a function of the same independent variables. The former series of presentations would be most useful for determining overall allocation policy, while the latter would be more useful in devising allocation strategies and tactics. A third series of presentations was prepared to show how total accidents by day of week <u>and</u> time of day for a given month in order to illustrate the further refinements in presentation that are

Indiana State Police Accident File Description

Variable	Description	Number Possible Values
1. Accident Number	Accident report no.	999,999
2. Accident Type	First accident event	12 (e.g., collision with pedestrian, collision with other motor vehicle)
3. Source of Data	Shows whether or not accident was investigated and, if so, by what agency.	6 (e.g., was not investigated, state police investigated, sheriff investigated.)
4. Directional Analysis	Shows direction of accident involved vehicles relative to collision object	37 (e.g., car going straight collided with pedestrian, cars travelling same direction collided at intersection - one car stopped)
5. Cost of Property Damage	Estimated cost to repair or replace all damaged vehicles	5 (e.g., less than $15.00, $15.00-$24.00)
6. Character of Location	Significant feature of accident location	8 (e.g., street and/or highway intersection, culvert, underpass)
7. Month of Accident	Month when accident occurred	12 (01 - 12)
8. Date of Accident	Day of month when accident occurred	31 (01 - 31)
9. Year of Accident	Unit position of year when accident occurred	10 (0 - 9)

Variable	Description	Number Possible Values
10. Day of Week of Accident	Day of week when accident occurred.	7 (e.g., Monday, Tuesday, Wednesday)
11. Hour of Day of Accident	Hour of day when accident occurred.	25 (e.g., midnight to 12:59 a.m., not stated)
12. County	County where accident occurred. Toll roads are not counted	92 (e.g., Monroe, Morgan, Vigo)
13. Population group	Population grouping of city or town where accident occurred. Rural accidents are accounted for.	10 (e.g., rural accident, less than 1000, 1000 - 2500, 2500 - 5000, ---, 25,000 and over)
14. City or Township	Identification of city, town, or township where accident occurred. Toll roads are not identified.	8999 incorporated towns and cities, 29 townships
15. Highway Number	Identification of state or federal road where accident occurred. Toll roads are not identified.	999 state, 999 federal, 999 interstate
16. Additional Highway Information	Further identification of road where accident occurred.	9 (e.g., alternate, east, eastbound lane for toll road)
17. Highway Classification	The jurisdiction or classification of the road where the accident occurred.	5 (i.e., county road or city street, state road, federal road, interstate, toll)

TABLE 4-7 (cont.)

Variable	Description	Number Possible Values
18. Urban Interstate Indication	Whether or not the accident happened or on interstate highway within a city or town.	2
19. Intersecting Highway Number	The number of the intersecting highway, if any.	999
20. Vehicle Number	The number assigned to the subject vehicle.	9 (1 - 9)
21. Vehicle Type	The type of the subject vehicle.	21 (e.g., passenger car, truck, bus)
22. Special Vehicle Information	Whether the subject vehicle was emergency, military, or other public owned.	3
23. Age of Driver	Age of driver of the subject vehicle	Age to nearest year, if driver known or if age of driver known
24. Sex of Driver	Sex if stated and, if not stated, reason not stated.	8 (e.g., male, female, driverless moving vehicle, disabled vehicle, not stated)
25. Proximity of Residence	Approximate location of subject's residence.	4 (e.g., non-resident of state, residing in county where accident occurred)
26. Driver's License	Type of driver's license.	6 (e.g., Indiana operator or chauffer, etc.; Indiana beginner, school permit, etc.)

TABLE 4-7 (cont.)

Variable	Description	Number Possible Value
27. Deaths	Number of people killed as a result of accident.	10 (0 - 9)
28. Injured	Number of people injured, non-fatally.	10 (0 - 9)
29. Severity of Accident	Highest level of loss incurred in accident.	3 (fatal, non-fatal injury, property damage)
30. Age of injured or Killed	Age of person injured or killed in accident.	100 (99 years plus "not known")
31. Sex of Injured or Killed	Sex of person injured or killed in accident.	3 (2 plus "not stated")
32. Location of Injured or Killed	Location of injured or killed person at time of accident.	6 (e.g., driver, passenger, pedestrian, bicyclist)
33. Car Occupied by Injured or Killed	Number of vehicle occupied by person injured or killed in accident.	9 (1 - 9)
34. Severity of Injury	Most serious injury to subject person.	4 (e.g., died as a result of injury, visible regions of injury)
35. Test for Alcohol	Type alcohol test given, if any.	6 (e.g., no test offered, test offered by refused, breath test given)
36. Arrests	Whether or not driver was arrested.	4 (e.g., not arrested, arrested for DWI)

TABLE 4-7 (cont.)

Variable	Description	Number Possible Values
37. Speed Limit	Speed limit at accident location at time of accident.	12 (e.g., 20 mph, 25 mph, 30 mph, 35 mph)
38. Speed Before Accident	Investigating officer's estimate of speed of subject vehicle.	11 (e.g., stopped, less than 10 mph, 10-19 mph, 20-29 mph)
39. Contributing Circumstances	The one violation or circumstance believed to have contributed most to cause of accident (vehicle defects excluded).	12 (e.g., speed too fast, failed to yield right of way, drove left of center not in passing)
40. Vehicle Defects	Vehicle defects which could have contributed to cause of accident.	7 (e.g., no defects, brakes defective, lights defective, steering defective)
41. Vision Obscurement	Nature of any driver vision obscurement.	8 (e.g., not obscured, by buildings)
42. Driver's Actions, Miscellaneous	Action driver was performing just before accident.	10 (e.g., passing, turning, backing)
43. Pedestrian's Actions	Actions of the pedestrian just before accident.	12 (e.g., not in roadway, walking in roadway with traffic)
44. Condition of Driver Reference Drinking	Investigating officer's opinion of driver inpairment by alcohol.	6 (e.g., not drinking, had been drinking - obviously drunk)

TABLE 4-7 (cont.)

Variable	Description	Number Possible Values
45. Condition of Driver, Physical	Investigating officer's opinion of driver's physical condition.	11 (e.g., apparently normal, eyesight defective)
46. Condition of Pedestrian Reference Drinking	Investigating officer's opinion of pedestrian impairment by alcohol.	6 (e.g., not drinking, had been drinking - obviously drunk)
47. Condition of Pedestrian, Physical	Investigating officer's opinion of pedestrian's physical condition.	11 (e.g., apparently normal, eyesight defective)
48. Traffic Control	Type of traffic control at accident location.	10 (e.g., police officer, automatic signal)
49. Character of Road - Horizontal	Road curvature in horizontal plane.	3 (straight, curved, not stated)
50. Character of Road - Vertical	Road curvature in vertical plane.	4 (level, grade, hillcrest, not stated)
51. Type of Road Surface	Surface material of road	6 (e.g., concrete, blacktop, sand or dirt)
52. Condition of Road Surface	Road surface wetness or icyness.	5 (dry, wet, snowy/icy, other, not stated)
53. Weather Condition	Weather at time of accident.	6 (e.g., clear, raining, snowing, fog)
54. Light Condition	Ambient light intensity at time of accident.	4 (daylight, darkness, dawn or dusk, not stated)

TABLE 4-7 (cont.)

Variable	Description	Number Possible Value
55. Kind of Locality	Nature of surroundings in area within 300 feet of accident location.	5 (e.g., school or playground, industrial or business)
56. Road Defects	Type of road defects at accident location.	9 (e.g., foreign material on roadway surface)

CONTINUED

1 OF 2

TABLE 4-8

Summary of Accident Data Handbook Presentation

Series	Effects Shown	Dependent Variables (1)	No. of Plots
Total County	Month	1, 2, 3, 4, 5	5
	Day of Week	1, 2, 3, 4, 5	5
	Hour of Day	1, 2, 3, 4, 5	5
	Visibility	1, 2, 3, 4, 5	5
	Weather Condition	1, 2, 3, 4, 5	5
	Jurisdiction	1, 2, 3, 4	4
Highway Segment	Highway Segment	1, 5	2
	Month (2)	1, 2, 3, 4, 5	50
	Day of Week (2)	1, 2, 3, 4, 5	50
	Hour of Day (2)	1, 2, 3, 4, 5	50
	Visibility (2)	1, 2, 3, 4, 5	50
	Weather Condition (2)	1, 2, 3, 4, 5	50
Combined Effects	Day of Week and Hour of Day (3)	1	12
Total	--------	--------	293

Notes: (1) 1 = Total accidents, 2 = Property Damage acc., 3 = Personal injury acc., 4 = Fatal acc., 5 = direct cost of accident.
(2) For each of 10 highway segments.
(3) For each month of the year.

possible with additional resources. Examples of each series of presentations are provided in Figures 4-7, 4-8, and 4-9. All displays were produced by the IBM 1800 computer.

It should be mentioned that while the specific Accident Data Handbook developed here is for Monroe County, a similar handbook could easily be produced for any county or other suitably defined geographical region in the state of Indiana and that this capability could readily be extended to other states and geographical regions. The general procedures for preparing an Accident Data Handbook are described in Reference Volume II.

4.1.2 Derived Information

It has been noted previously in this report that the major thrust of the present project was toward providing timely and reliable county-wide accident and traffic flow information for use by local enforcement agencies in identifying and managing local highway transportation system accident risks. Such information was of a nature indicated by the present state of knowledge to be risk-related but for which no acceptably valid expression had been found for stating that relationship. In the case of risk identification, for example, there is evidence that such factors as location, hour of the day, and speed of the accident-involved vehicle relative to mean traffic stream speed may be related to certain measures of accident disutility. Yet, at the start of the project, the specific form of these relationships could not, in general, be stated so that it was not possible to present operationally useful "derived" information which would evaluate risk uniquely as a function of the relevant independent variables.

While the state of the art did not provide ready formulae for quantifying operationally useful risk indexes, it was also true that data of the type generated by the CHTIS had not previously been available to researchers engaged in developing such formulae. Therefore, a small amount of the project resources was devoted to an investigation of the data base made available by the CHTIS and the pertinent scientific literature to see if any progress could be made in devising meaningful risk indexes. The investigation was concerned primarily with the traffic flow parameters as the independent variables. The results are discussed below.

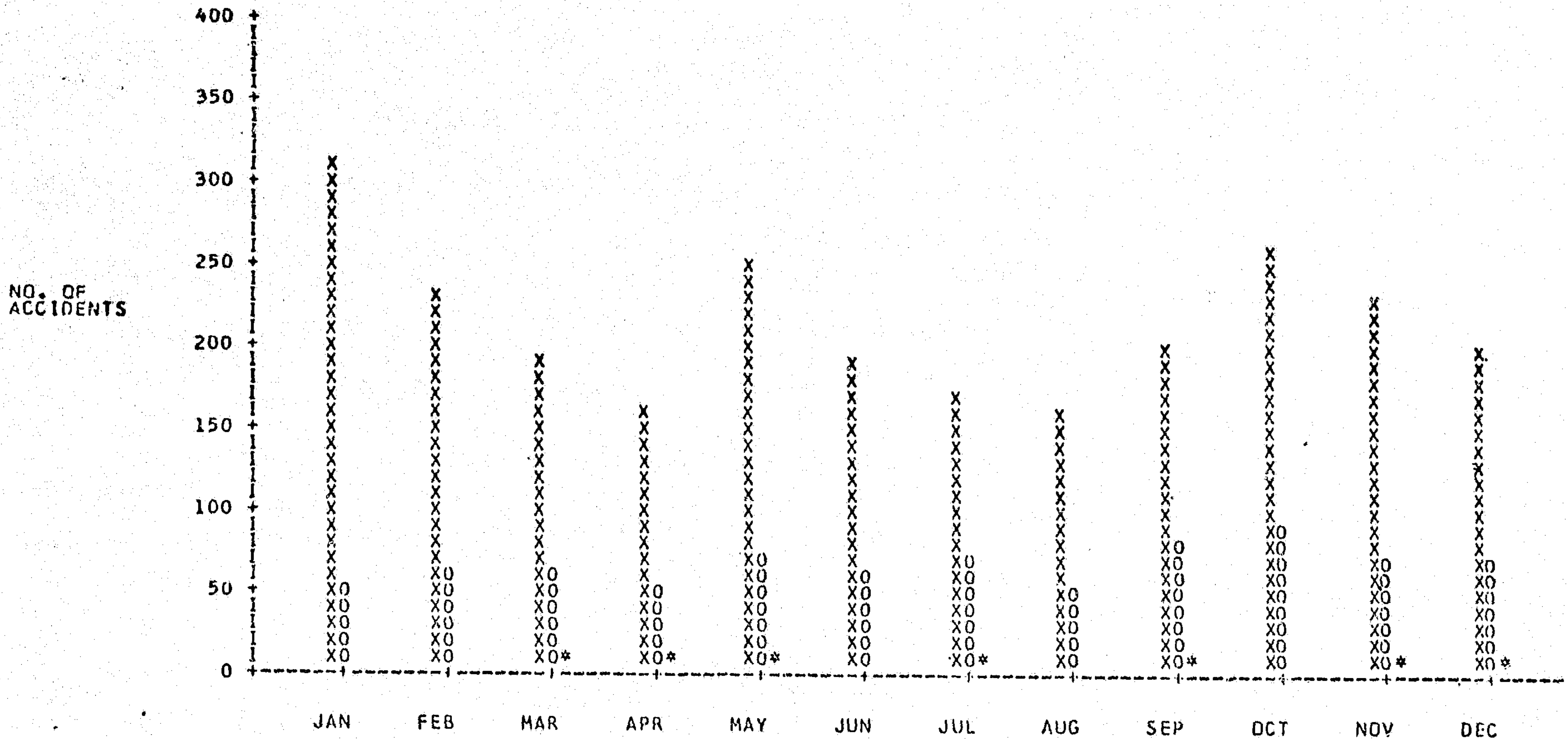
4.1.2.1 Theoretical Relationships

There is a considerable body of literature on the theory of traffic flow. Generally speaking, the theory is concerned with

TOTAL 1970 ACCIDENTS BY MONTH

FIGURE 4-7

X=PROPERTY DAMAGE
O=PERSONAL INJURY
Z=FATALS

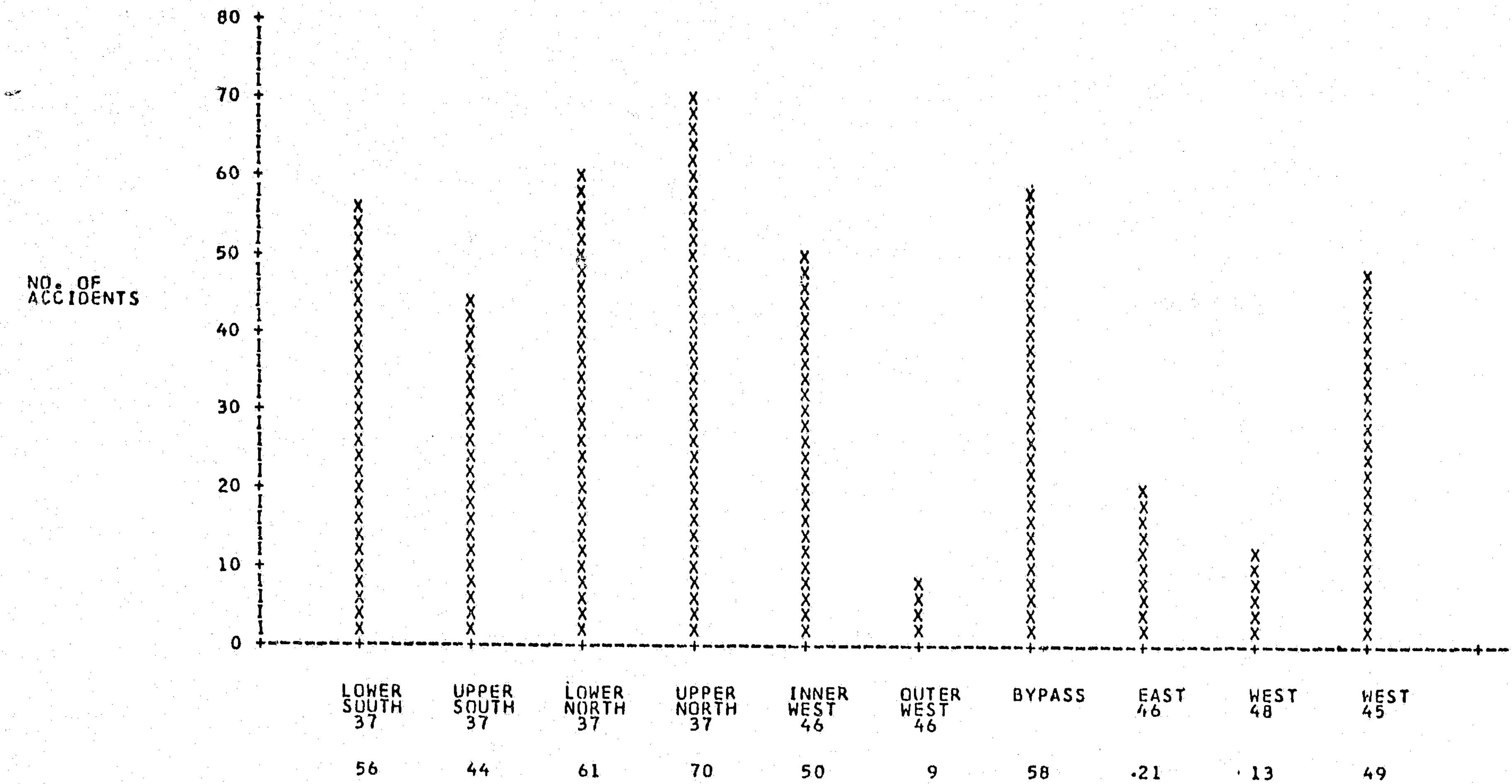


	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
X =	313	230	195	168	258	196	172	167	208	263	239	206
O =	56	61	69	58	75	60	79	50	86	90	72	71
Z =	0	0	1	1	1	0	5	0	2	0	3	4

* DENOTES A VALUE GREATER THAN 0, BUT LESS THAN 10

TOTAL 1970 ACCIDENTS BY HIGHWAY SEGMENT

FIGURE 4-8



TOTAL 1970 ACCIDENTS BY DAY OF WEEK AND HOUR OF DAY (ALL JURISDICTIONS)

OCTOBER

FIGURE 4-9

HOUR OF DAY

	00-02	02-04	04-06	06-08	08-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	TOTAL
MON	1	0	0	1	2	2	5	4	10	6	0	1	32
TUE	1	0	1	6	7	8	5	12	10	7	3	1	61
WED	1	1	0	0	1	5	2	6	11	2	7	2	38
THU	0	0	0	3	6	4	7	8	19	5	2	1	55
FRI	3	2	0	5	3	4	8	13	21	10	3	3	75
SAT	2	2	0	1	1	12	6	4	7	4	4	6	49
SUN	5	2	2	0	2	2	5	4	6	7	2	0	37
TOTAL	13	7	3	16	22	37	38	51	84	41	21	14	347

describing the characteristics of traffic flow in terms of (1) deterministic behavior patterns of individual drivers, (2) macroscopic properties of the traffic stream, or (3) statistical properties of the traffic stream.

The car-following theory developed by Gazis (11), Herman (12), and others is the prime example of attempts to develop flow models based on the behavior of individual drivers. In brief, the car-following approach assumes that a driver, in a single-lane traffic situation, reacts largely to a stimulus from his environment according to the relationship

$$(\text{reaction})_{t+T} = \lambda\ (\text{stimulus})_t$$

where λ is a sensitivity coefficient, t is the time, and T is a reaction time-lag.

The reaction is the acceleration of a vehicle, with the stimulus usually defined as the difference in velocity between the driver's car and the preceding car. The stimulus-reaction equation can be expressed in differential equation form as

$$\frac{dx_n^2(t+T)}{dt^2} = \lambda\left(\frac{dx_{n-1}(t)}{dt} - \frac{dx_n(t)}{dt}\right) \tag{1}$$

where n denotes the position of a car in a platoon of cars, x_n is the position of the n-th car on the roadway, and λ is either a constant, or a function of x_n and x_{n-1}. When λ is a constant, the differential equation is linear, and is the so-called <u>linear car-following model</u>. Various non-linear models for λ have also been considered for describing situations where larger fluctuations in speed and spacing are involved. Gazis, for example, has investigated models where λ is represented by:

$$\lambda = \frac{\lambda_0 \left[\frac{dx_n(t+T)}{dt}\right]^m}{[x_{n-1}(t) - x_n(t)]^\ell} \tag{2}$$

When λ is given by (2), one has a type of <u>non-linear car-following</u> model.

The linear car-following model has been used to derive a theoretical expression for the flow-concentration relationship. The steady state flow becomes:

$$q = \lambda_0\left(1 - \frac{c}{c_j}\right) \tag{2.1}$$

where: q = traffic flow (cars per unit time)
c = traffic concentration (cars per unit length of roadway
c_j = traffic concentration under "jammed" conditions (i.e., $q = 0$)

Various solutions to non-linear models have also been obtained.

Considerable data have been gathered in attempts to verify the car-following models. In situations where the underlying assumptions of the model are met, agreement between theory and experiment have been good (5). In most situations, non-linear models are required to account satisfactorily for flow versus concentration data.

The second general approach to traffic flow theory is based on the analogy of a traffic stream as a fluid flow. The entire theory is derived from the continuity equation

$$\frac{\partial c}{\partial t} + \frac{\partial(c\bar{v})}{\partial x} = 0, \tag{3}$$

where: x = time
t = distance along the roadway
$\bar{v}$ = average velocity of the traffic

Equation (3) results from the requirement that there be no removal or creation of cars on a given road. Since a functional relationship between flow and concentration is known to exist, equation (3) may be written as:

$$\frac{\partial c}{\partial t} + V\frac{\partial c}{\partial x} = 0 \tag{4}$$

where:

$$V = \frac{\partial(c\bar{v})}{\partial c}$$

Solutions to (4) take on the form

$$c = c(x - Vt), \tag{5}$$

leading, by analogy with fluid flow, to the concept of a traffic "wave" which propagates with the velocity V. Sometimes when the wave velocity decreases due to reduced concentration, the wave fronts may be overtaken by successive waves, leading to the formation of flow discontinuities analogous to the familiar shock waves that occur in fluid flow.

Recently, May and Keller (24) have attempted to unite the car-following and by hydrodynamic theories. While investigating non-integer values of ℓ and m in equation (2), they discovered that the fluid flow model discussed above is a special case of the non-linear car-following model. They state that:

> It has been shown that all reported macroscopic and microscopic traffic flow models can be reduced to the general car following equation [given above] by selection of appropriate exponents ℓ and m, representing the influence of the vehicle, respectively of the distance headway between vehicles on the sensitivity factor. The use of ℓ, m matrix gives the possibility of comparison of existing models due to given criteria.

and

> The combination of $\ell = .8$ and $m = 2.8$ fulfills all requirements of the assumed evaluation criteria, mean deviation, free speed, jam density, optimum speed, optimum density, and maximum flow. The evaluation indicates that the area around the line between $\ell = .5$, $m = 2.5$ and $\ell = 2.5$, $m = 3.5$ covers models of very good fit, but with a maximum flow rate of less than 1800 vehicles per hour. Models with a maximum flow rate greater than 1,800 v.p.h. appear in the area below this line... the speed-density relation tends to be bell-shaped in that area.

Both the car-following model and the fluid-flow model are deterministic. However, stochastic models have also been developed, an outstanding example being the kinetic theory of Prigogine (30). The technique involves modifications of the basic continuity equation,

which is now expressed in terms of the distribution function f(x,v,t) which is defined such that

$$dN = f(x, v, t)\, dx\, dv \tag{6}$$

where: dN = number of cars that, at a given time, are in the road interval between x and x + dx and in the velocity interval between v and v + dv.

The basic equation of kinetic traffic flow theory becomes:

$$\frac{\partial f}{\partial t} + v\frac{\partial f}{\partial x} = \left(\frac{\partial f}{\partial t}\right)_{rel} + \left(\frac{\partial f}{\partial t}\right)_{int}, \tag{7}$$

where the first term on the right hand side of is due to the existance of a desired velocity distribution, f_o, which in general differs from f, and the second term is due to interactions between vehicles. Solutions to this equation lead to relationships between flow and concentration, one for regions of low concentration, the other for regions of high concentration. In the latter case, two new parameters appear: T, the time required for $f \rightarrow f_o$, and P, the probability of being able to pass.

A different stochastic approach is that taken by Tanner (39), Miller (26), and Yeo (41). Tanner has derived the so-called Borel-Tanner distribution for the probability that a bunch of vehicles travelling at the same speed v has n vehicles. The probability mass function of this distribution is

$$P_n = e^{-nr}\,(nr)^{n-1}/n! \quad (n = 1,2,3....) \tag{8}$$

Miller has described the application of Tanner's models to two-lane road traffic in England and Sweden. Yeo had presented further results relating to the traffic density in vehicles per unit length of road.

The mathematical models discussed above are indicative of the present mainstream of traffic flow theory, but are in no sense exhaustive. For example, extensive work has been performed in the general area of queues, car spacing, and passing. Andrews has extended Prigogine's statistical theory to account for queuing and passing under special conditions (1). Erlander has applied the concept of desired speed distribution to developing and testing expressions for average speed in terms of passing distance, vehicle concentration, desired speed, and desired speed distribution (9). In an interesting paper, Kapur has shown how the basic car-following equation can be derived through a calculus of variations approach (20). Haight has presented numerous solutions to problems in traffic queuing, vehicle spacing, delay times, and so forth (13).

Thus, the literature provides ample evidence of considerable productive effort on the part of traffic flow theorists. Their work has led to several significant general theories which have been explored in depth and applied to a broad spectrum of specific problems by numerous highly competent investigators. <u>It seems remarkable, then, that no similar treatment of the relationship between traffic flow parameters and accidents was found in the literature search.</u> The reasons for this research gap are not entirely clear. Certainly, the problem is immensely complex and not at all amenable to instant answers. However, complexity <u>per se</u> has never been a viable deterrent to researchers, having <u>usually</u> tending to stimulate activity rather than to depress it. More likely, progress has not made because highway safety research in the U. S. has emphasized empirical and experimental approaches and has not given sufficient support to the purely theoretical.

At any rate, the reasons for this deficiency should be explored further and an attempt made to correct it. In this regard, it should be noted that the data base developed under the present contract could be of great value in providing insights for new accident theories and in furnishing the data to test their validity. More will be said on this subject in Section 7.0, Conclusions and Recommendations.

<u>4.1.2.2 Empirical Relationships</u>

The relationships between traffic flow parameters and accidents have been explored empirically in numerous studies. Recently in a study conducted for the Department of Transportation under contract FH-11-7275, IRPS performed an in-depth review of the literature to identify the nature of existing research on speed control and the establishment of speed limits (19). An important element of the effort was the review of all known empirical investigations which had attempted to relate traffic flow parameters (primarily speed, deviation from mean speed, and flow) to accidents. This work was up-dated and expanded under the present contract, and the significant findings are summarized in the following paragraphs.

One of the earliest attempts to develop empirical formulae for relating accident frequency to traffic flow parameters was reported by Belmont in 1953 (4). The study considered straight and level sections of two-lane roads under free-flow conditions (i.e., where traffic flow is proportional to traffic concentration) and developed the following expressions for average number of accidents per vehicle mile:

$$N'_A = k_1 v^{1.5} \quad \text{(single-car accidents)} \quad (9)$$

$$= k_2 q + k_3 qv + k_4 v^{1.5} \quad \text{(rear end accidents)} \quad (10)$$

$$= k_5 qv \quad \text{(head-on collisions),} \quad (11)$$

where

N'_A = average number of accidents per vehicle mile

q = average traffic flow in vehicles per hour

v = average traffic velocity in miles per hour

= empirically determined constants

No subsequent attempt to apply or verify these equations were found in the literature.

In recent years, empirical studies of traffic-related accidents have placed more and more attention on those parameters which measure dispersion within the traffic stream rather than average flow and concentration. The work of Solomon in this area is particularly noteworthy. He concluded that:

> "...the greater the variation in speed of any vehicle from the average speed of all traffic, the greater its chance of being involved in an accident" (37).

Cleveland arrived at similar conclusions in a comprehensive analysis of the effects of speed, deviation from mean speed, and flow on accidents. Specifically, he concluded that accident involvement rates are a U-shaped function of the deviation speed of the accident-involved vehicle (AIV) from the mean traffic speed, with the minimum involvement rate occurring at the mean speed. He states that:

"...the likelihood of involvement is estimated to be greater by a factor of about six to 21, depending on the type of road, for large speed deviations as opposed to small speed deviations and ignoring the accident involving the turning manuevers." (7)

The advent of the CHTIS and the subsequent availability of large quantities of accurate speed data made it possible to investigate Solomon's hypothesis in depth. The first such investigation was described in the final report of a joint Research Triangle Institute - IRPS project conducted under Department of Transportation Contract FH-11-6965 (32). The project analyzed data collected from early configurations of the CHTIS, utilizing, at first, eight sensor sites and later, 14 sites. In this study a technique was devised to estimate the speed of the AIV by "tracking" its trajectory through the sensor sites. The sensor site data was augmented by radar spot speed measurements, radar speed readings collected at each accident site, and accident analysis findings based on inputs from a number of sources. Again, it was concluded that there were indications of:

"...a U-shaped relationship between involvement rate and speed deviation...

"These results confirm the hypothesis that slow driving as well as fast driving increases the likelihood of being involved in an accident. However, the curvature of this U-shaped relationship is not as pronounced as that given by Solomon" (32).

It should be noted that the speed deviation hypothesis discussed above was based on the speed deviation of the AIV which is often difficult to determine and which must, in any case, always be determined after the occurrance of an accident. An independent variable more relevant to accident predictions was needed. Such a variable would ideally be related to real-time or quasi real-time traffic stream state variables and could be monitored continuously by the CHTIS to identify a priori the build up of a potentially hazardous situation. Steps could then be taken to allocate the required enforcement resources to the hazardous locations and to reduce the local risk to an acceptable value. In the previously cited study of maximum speed limits (19), it was hypothesized that if the speed deviation of any single vehicle was a measure of accident risk, then the speed dispersion of all the vehicles in a given grouping would also be indicative of risk. Further, it was reasoned that the standard deviation of speeds of the vehicles in such a grouping would provide a useful measure of this dispersion and would, because of its ready availability from CHTIS data, closely fit the requirement (stated

above) for an ideal hazard predictor.

It was therefore decided to investigate the hypothesis chart the standard deviation of speeds, σ_V, is a meaningful predictor of accident frequency. This was done by computing σ_V for each of seven sensor sites along Indiana SR 37 and determining from accident files the number of accidents occurring within .4 miles of each site. The analysis was based on data collected in the years 1968 and 1969. The results of the analysis (shown in Figure 4-10) showed that sites having higher σ_V tend also to have a higher number of accidents. A similar trend is noted when the number of accidents at a site is normalized to the total number of vehicles passing that site during the time period of concern (Figure 4-10). It is observed from both Figures 4-10 and 4-11 that when the number of accidents or number of accidents per 100,000 vehicles gets very small (i.e., < ~10 during the period), the speed standard deviation starts to increase again. The reason for this apparent reversal in trend is not known, but it is clear that the statistical significance of the data starts to deteriorate rapidly in this region due to the very small number of accidents that were experienced. Obviously, a much larger accident population is needed for analysis of accident-speed deviation relationships at those sites where the reversal occurs.

It is also seen from both 4-10 and 4-11 that the accidents frequency is highly sensitive to speed deviation: as σ_V starts to approach 10 mph, the accident frequency increases precipitously. A similar effect was noted in the U-shaped curves investigated by Solomon, Cleveland, and RIT/IRPS.

In the present study it was decided to probe further into speed standard deviation effects, since this was the only traffic flow relationship identified by past studies as a really promising predictor of accident frequency. However the approach taken differed sharply from that in the study just described. Instead of determining accident frequency at given sites as a function of the characteristic speed standard deviation associated with those sites, speed standard deviation frequency distributions at the locations and times of known accidents were compared with speed standard deviation frequency distributions at the same locations during similar time periods when no accidents occurred. This provided a way of comparing the distributions of speed standard deviation on accident days with those on non-accident days.

A total of 45 accident days in 1970 were selected from ISP data tapes and the location, month, day, and hour of occurrence of each accident was noted. CHTIS magnetic tape records were then searched to determine the speed standard deviation at each accident location

FIGURE 4-10

Number of Accidents Vs. Speed Standard Deviation At Seven Locations Along SR 37

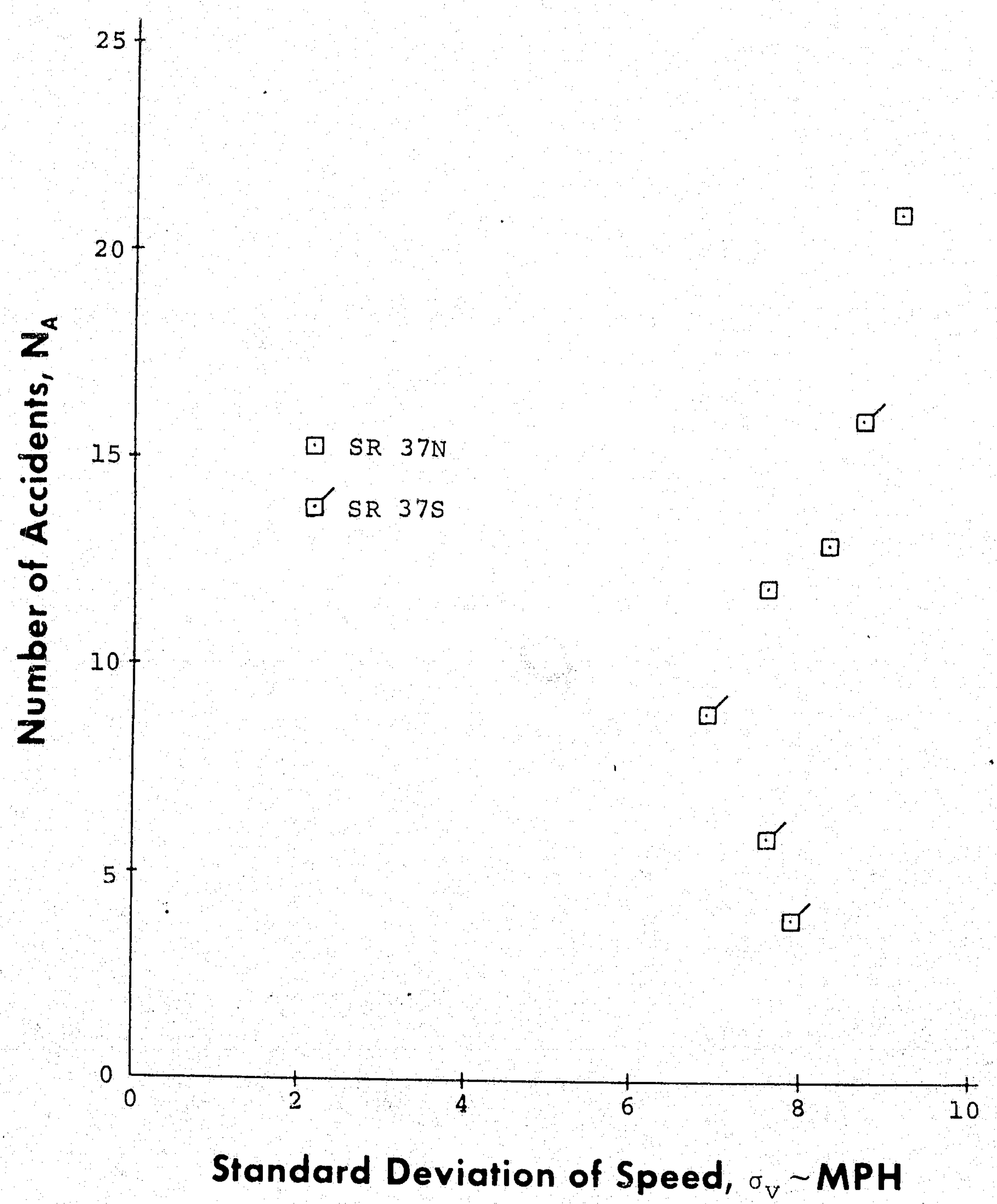
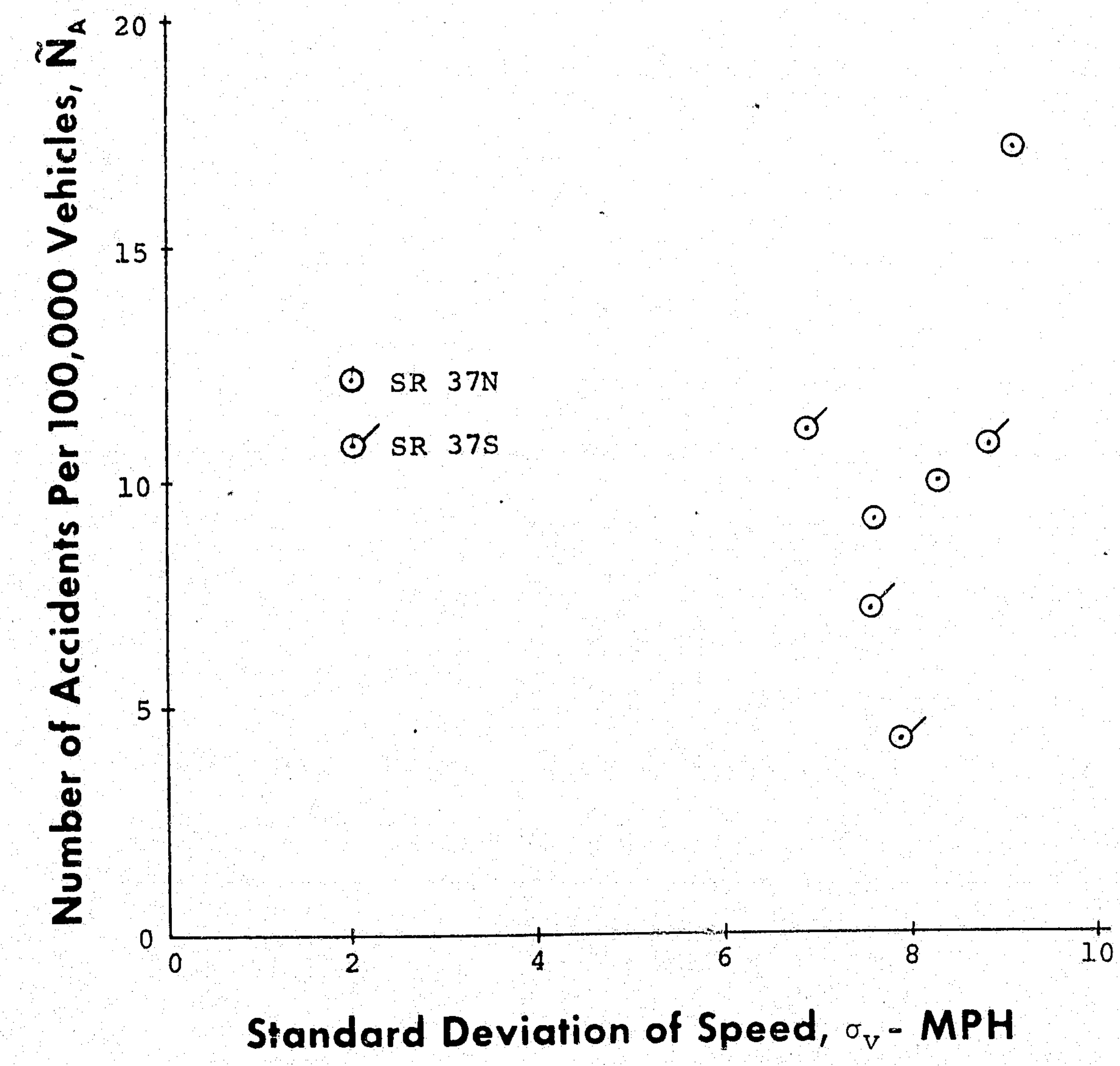


FIGURE 4-11

Number of Accidents Per 100,000 Vehicles Vs. Speed Standard Deviation At Seven Locations Along SR 37



for a time period of one hour previous to the time the accident occurred. Only accidents which happened along SR 37N and SR 37S were considered, because only those highways were being monitored by the CHTIS during 1970.

Thus, it was possible to determine the frequency distributions for the speed standard deviation on accident days such that:

$$\Pr\{\sigma_{v_{A_1}} \leq \sigma_{v_A} < \sigma_{v_{A_2}}\} = \int_{-\sigma_{v_{A_1}}}^{+\sigma_{v_{A_2}}} f_A(\sigma_{v_A})\, d\sigma_{v_A}, \qquad (12)$$

where:

$\Pr\{\sigma_{v_{A_1}} \leq \sigma_{v_A} < \sigma_{v_{A_2}}\}$ = Probability that the speed standard deviation on accident days lies between $\sigma_{v_{A_1}}$, and $\sigma_{v_{A_2}}$

σ_{v_A} = Absolute value of speed standard deviation on accident days

$f_A(\sigma_{v_A})$ = Frequency distribution of speed standard deviation on accident days

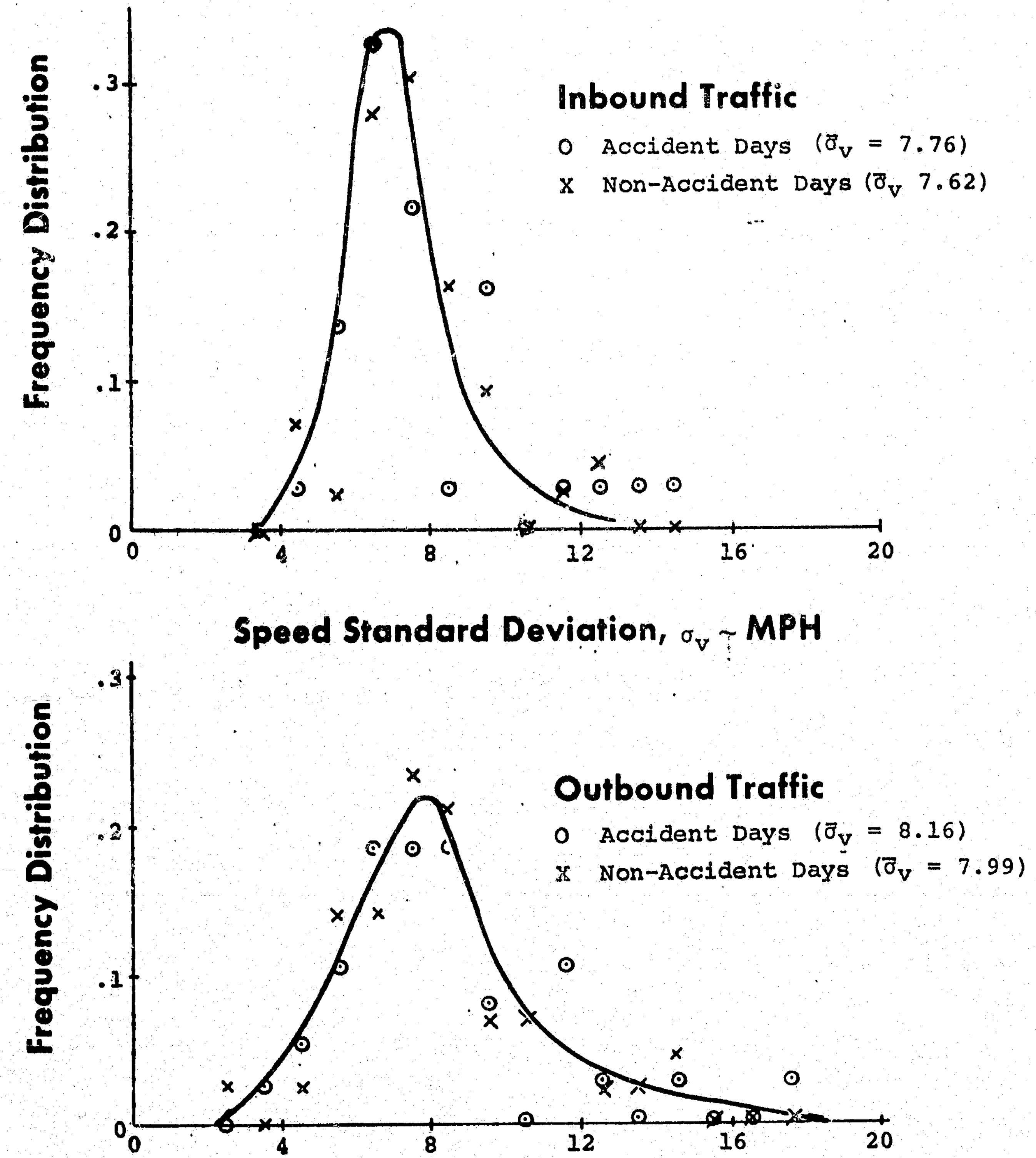
and

$$\int_0^{\infty} f_A(\sigma_{v_A})\, d\sigma_{v_A} = 1 \qquad (13)$$

Similarly, frequency distributions for speed standard deviation on comparable non-accident days were also prepared. The accident day and non-accident day frequency distributions were then graphed to provide a means for visual comparison. The results are presented in Figure 4-12. There is no discernable difference in the two frequency distributions, either for outbound traffic or for inbound traffic. The calculated means of the accident day and non-accident day speed standard deviations were, for all practical purposes, identical. Thus, it is concluded that, for the locations and time periods considered, speed standard deviation frequency distributions would not be useful in predicting traffic accidents.

FIGURE 4-12

Frequency Distributions of Speed Standard Deviation On Four Monroe Co., In., Highway Segments



97

FIGURE 4-13

Frequency Distribution of Traffic Mean Speed on Four Monroe Co., In., Highway Segments

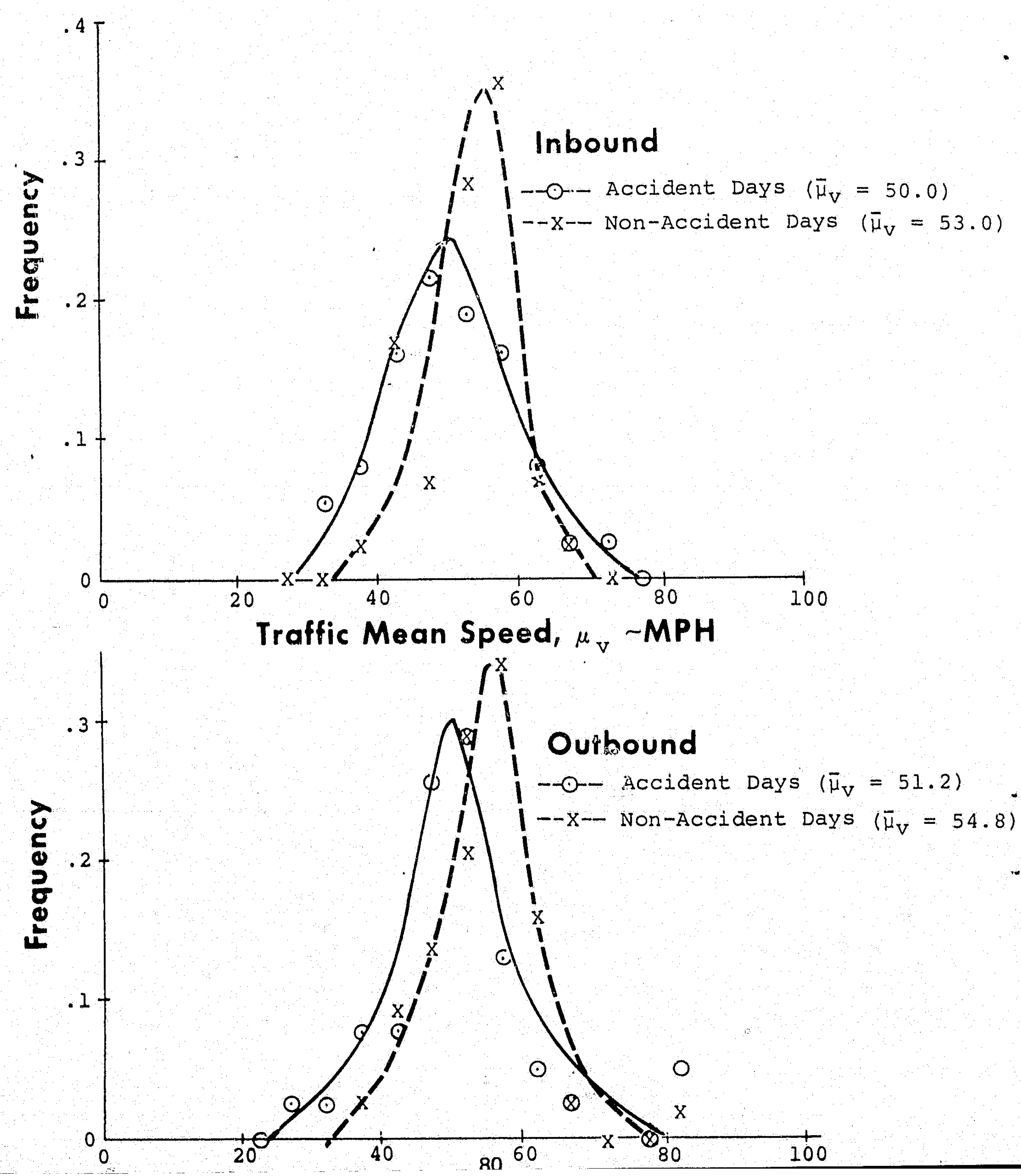
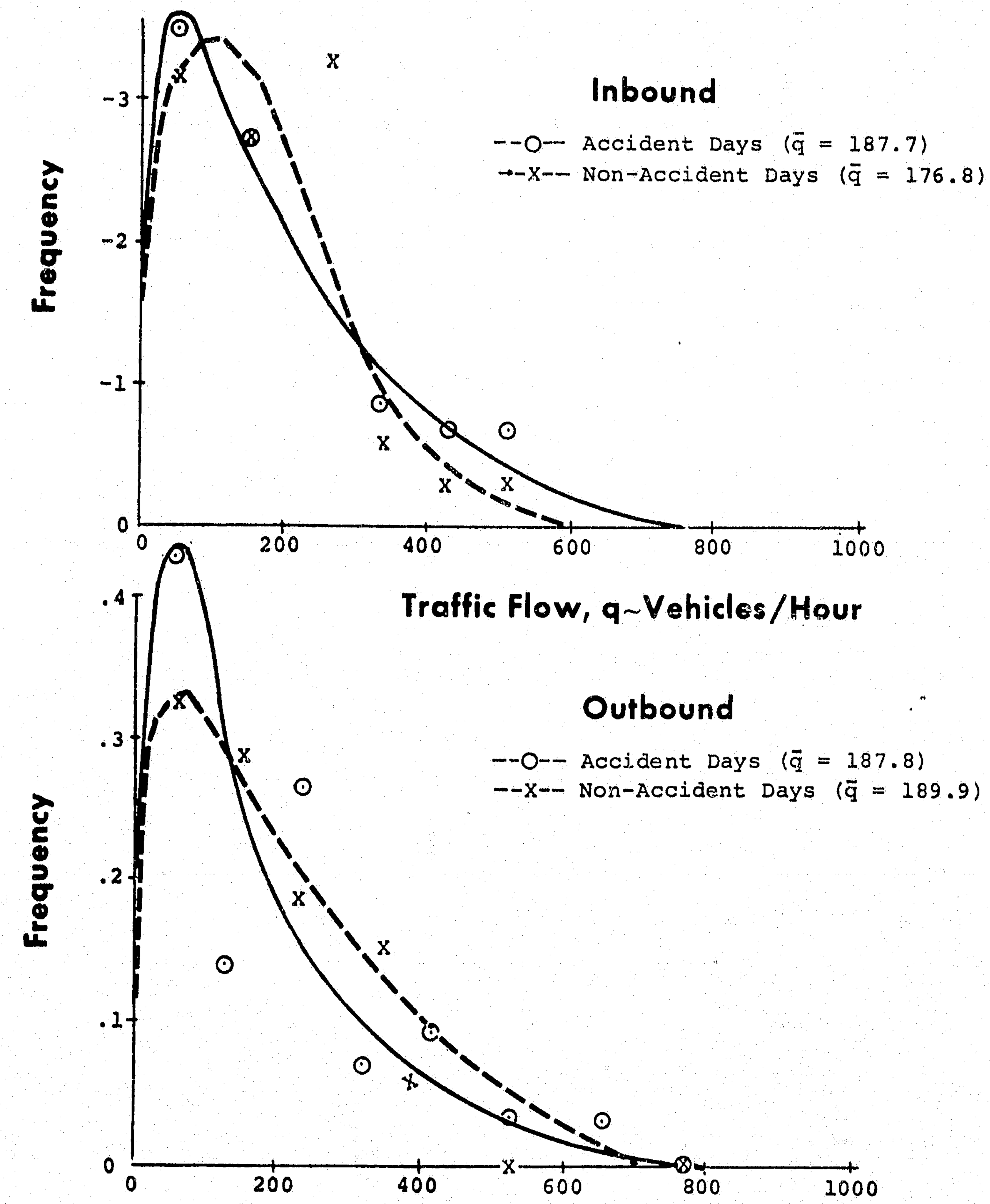


FIGURE 4-14

Frequency Distribution of Traffic Flow on Four Monroe Co., In. Highway Segments



The previous analysis also made available values of a number of other traffic flow parameters for the selected accident and non-accident days. In light of Belmont's study indicating a relationship between average number of accidents per vehicle mile and traffic flow and traffic mean speed, frequency distributions were also prepared for these variables. Figure 4-13 presents the results for traffic mean speed, μ_V. Here, one notes a definite difference in the accident day and the non-accident distributions: the non-accident day distributions are translated to the right of the accident day distributions and appear to have smaller variances. What is expected is that the mean of the traffic mean speed distribution is some three mph <u>greater</u> for non-accident days than for accident days! There is no obvious reason for this result; a careful statistical analysis of the data would be required to shed more light on the factors involved. Although such a study was beyond the scope of the present project, it would appear that in view of the implications of the finding, one ought to be conducted as soon as possible.

Figure 4-14 shows that the frequency distributions of traffic flow (i.e., volume in vehicles per hour) were highly skewed for both accident and non-accident days, a characteristic that is no doubt due to highway usage patterns at the locations considered. Any differences between accident and non-accident days were not pronounced enough for any operational application.

4.1.3 Conclusions

It is concluded that the CHTIS can provide decision makers with much potentially useful information for risk identification. Both the accident history information and the traffic flow information generated by the system seem relevant to the risk identification problem and can be presented in a variety of ways for use by operational personnel. Yet, the precise nature of such accident-traffic flow relationships cannot be delineated within today's state of knowledge. Although valuable clues are constantly being uncovered, no operationally suitable expressions exist today for relating traffic accident risk to traffic flow variables.

4.2 Risk Analysis

The second major step in the traffic risk management process involves the estimation of the amount of risk reduction that can be expected from available risk control forces. Rational risk management requires *a priori* knowledge of the expected impact of these forces on risk so that a preferred control force mix can be selected for application at indicated places and times. Ideally, the result

of this process would be the minimization of some measure of total risk over some specified geographical area, for a given amount of risk control resources. Thus, in the present application, one is interested in the effect of possible enforcement actions in reducing traffic accident disutility and the amount of resources required for such actions.

The role of the CHTIS in the analysis of risk control forces and their effects is to provide enforcement personnel with:

(1) Historical and real-time information on traffic flow.

(2) Historical information on accidents.

(3) Historical and real-time information on resource deployment (i.e., time-wise location of patrol vehicles).

(4) Special analyses of control force effects or (a) reducing traffic accident disutility and (b) reducing instances of risk-related driver behavior. Both types of analyses lie, by definition, in the derived data category.

Items (1), (2), and (3) serve the dual purpose of risk identification and of providing essential raw and refined input information for risk control force analysis. They have already been discussed in detail in Section 4.1. The present section is concerned with the application of this and other information to the development of derived information relating traffic accident disutility and hazardous driving behavior to the nature and magnitude of enforcement actions designed to reduce them. The discussion will consider the general state of the art of such analyses as well as more recent studies employing information made available by the CHTIS.

4.2.1 General State of the Art

In a comprehensive analysis of quantitative studies of police traffic activities and traffic safety reported in 1968, Joksch classified the studies as follows:

- Statistical analysis of historical data.
- Studies of increased police activity campaigns.
- Large-scale experiments.
- Small-scale experiments.

- Enforcement follow-up.
- Violation and arrests.
- Violation and accidents.
- Foreign studies (10).

Several of these categories are also applicable to the present study and are discussed below.

Recht (31) and Hooker (14) have performed extensive statistical analyses of historical data. Recht's analysis utilized data from the National Safety Council's 1960 State Motor Vehicle Inventory. He considered the effect of 285 dependent variables on various measures of accident disutility using the multiple regression technique (linear). Of the eight enforcement-related independent variables considered, only enforcement index (defined by Recht is "hazardous traffic violations with penalty per fatal accident") turned out to be associated consistently with any measure of accident disutility. Further, even this correlation is suspect because of a probable spuriou correlation that existed between the dependent variable (a so-called "death ratio" which included number of deaths as its numerator) and the enforcement index.

Hooker based his study on accident and traffic safety data taken from Wyoming records for the years 1951 to 1964. He also used the multiple regression approach, taking total number of accidents as the sole dependent variable. He found a significant linear relationship between "lagged" hours worked by the Highway Patrol and number of accidents, but a later analysis (10) indicated that nearly 80 percent of the variance could be explained by a trend alone and found no significant correlation between the two variables.

Numerous safety campaigns have been conducted in an attempt to reduce traffic accidents, and many papers have been written analyzing their results. A large number of the analyses have not been conducted objectively and are, therefore, not applicable to the concept of risk management. A paper by Kunz (21) is in many respects typical of safety campaign analyses. He reports the results of a rigid traffic control program conducted in Springfield, Mass., during the years 1944-47. Prosecuted violations were increased from ∿200 per month to ∿700 per month and total accidents decreased from ∿80 to ∿30 per month. A paper by Roche (33) relates an effort by the New York State Police to reduce accidents through a combination of special training in accident investigation and selective enforcement.

After attending a one much advanced accident investigation course, the men were sent to seven high-accident locations with instructions to concentrate their enforcement activities (i.e., arrests) on violations believed to have contributed to accidents rather than on those where no accident occurred. 13,000 "additional" man-hours resulting in 9,000 traffic arrests were recorded at the end of the 12-month period. During the same period, accidents decreased 17 percent from the preceding 12-month period (979 compared to 1177).

The so-called 101 study conducted by the California Highway Patrol in 1966 in an interesting recent example of a "saturation" enforcement campaign (6). The number of patrol vehicles were doubled on a 35.3 mile stretch of Highway 101 near San Diego for a one-year period. At the end of the period "significant" decreases fatal, injury, and total accidents were reported (along with a slight increase in property damage accidents) compared with the mean number of such accidents over the previous three years. The results were accompanied by a decrease in the number of actual violations. The increase on property damage accidents was attributed to the better reporting of these accidents because of the increased patrol activity.

Many attempts have been made to obtain statistically meaningful accident-enforcement relationships by conducting large-scale experiments. This approach usually compares the results of increased police activities at given times and places with data collected from "control" areas. Shumate was involved in three such experiments which typify the approach. The first was conducted by the Traffic Institute of Northwestern University, in cooperation with the Wisconsin State Highway Patrol and the Bureau of Public Roads in 1956-57 (34). Four test routes were selected for testing the effects of enforcement intensity (measured by the average number of patrol units that passed a driver per mile) on accident frequency. Different intensities of enforcement were applied to the test routes and accident frequencies were recorded and compared to those observed on similar control routes. The results of the experiment, while inconclusive, do tend to support the hypothesis that, in general, increased patrol activity tends to be associated with reduced accident frequencies.

The second Shumate experiment (28) was conducted in 1958 also in Wisconsin and involved a two-control group experiments wherein the effects of concentrated patrol activity on accidents on a 110 mile stretch of highway were compared with accident data collected from two "control" roads not subjected to the concentrated enforcement. It was found that the yearly fluctuation for both control groups were too large to allow any evaluation of the effect of the enforcement activity.

The third Shumate experiment investigated the effect of enforcement on driving speeds using a before and after approach (35). Speed distributions at each of five locations obtained before and after concentrated enforcement were interpreted by Shumate to mean that neither the average speed nor the number of speed limit violations decreased significantly after such enforcement, nor is the speed variance about its means significantly affected. His conclusions were disputed by Tamm (38) who took issue with his data collection procedures.

Small-scale experiments of short duration have been conducted to determine how driver behavior and, consequently, traffic flow variables are affected by enforcement symbols. For example, Baker performed a pilot study on a small number of vehicles to determine the effect of (1) a moving patrol unit on the speed of nearby vehicles and (2) increased enforcement on vehicle speeds (2). He concluded that there was a "halo" effect due to the enforcement symbol and that the effect was noticeable at distances of up to 1000 feet ahead and 2000 feet behind the patrol car. He also noted a decrease in average excess speed. No statistical significance could be attached to either finding because of the small sample sizes employed.

An IACP study also sought to quantify the relationship, if any, between enforcement symbol presence and vehicle speeds (15). Police vehicles (both marked and unmarked) engaged in various activities were placed at three sites and the average travel times over a given course were measured. These were then compared to average travel times obtained when no police vehicles were present at the same sites. The total number of measurements taken was 5,000. An analysis of covariance was performed on the resulting data with the result that is only significant single factor affecting average travel time was the presence of an enforcement symbol. However, the resulting reduction of mean speed corresponding to the increased travel times was only two miles per hour (from 58 mph to 56 mph)! No measure of the effect on speed standard deviation or on percent of drivers exceeding the speed limit was reported.

4.2.2 Analyses Based on CHTIS Data

More recently IRPS applied the CHTIS in conducting an in-depth analysis of the effects of both stationary and moving enforcement symbols on a number of traffic flow variables (16). Specific objectives of the project were to:

1. Review and summarize published research both on methods of measuring traffic flow and on the effects of enforcement on traffic flow.
2. Measure the effects of stationary marked police vehicles on traffic flow behavior.
3. Measure the effects of moving marked patrol vehicles on traffic flow behavior.
4. Measure the effects of enforcement by radar, Vascar, and other stationary speed-timing devices on traffic flow behavior.
5. Investigate the effect of various alternative enforcement methods on traffic flow behavior.
6. Collect and examine records of accidents occurring on the monitored highways in relation to measures of enforcement level.
7. Correlate information about accidents and concurrent variations in traffic flow caused by different methods of enforcement, with a view to identifying criteria for the selective assignment of police traffic units.

The approach taken in the study was described as follows:

> "The data gathered to measure the effects of enforcement were obtained by a computer-sensor system which was designed and developed -- and is maintained -- by Institute personnel. The computer monitors traffic at 14 separate locations on State Route 37 in Monroe County, Indiana. Eight such sites are located within a 1.4 mile section of highway where the stationary sampling activity was conducted."

> "To test the stationary vehicle effects on traffic flow behavior, four test locations were selected within the 1.4 mile segment mentioned in the preceding paragraph. The four sites were located so as to stimulate differing degrees of awareness in a driver as he overtakes stationary enforcement stimuli, with long or short periods of warning. The sites also provided for the varying capabilities

of the enforcement vehicle operator to observe traffic once it had passed by him. Four time slots within the 24 hour day were selected to represent flow, including moderate and heavy daytime traffic and light and moderate nighttime traffic. Finally, six different enforcement vehicle configurations were employed during the four different times at the four separate locations. The six vehicle types were:

1. Civilian

2. Unmarked State Police

3. Marked State Police

4. Marked State Police with Radar

5. Marked State Police in an Arrest Configuration with Lights, and Stopped Civilian Vehicle

6. Two Marked State Police, One with Radar

"The effects of moving enforcement vehicles were measured by a slightly different method. Nineteen Indiana State Police marked vehicles were equipped with low-power transmitters. Concomitantly, at 12 sensor sites, a receiver was installed to notify the computer of the presence of the police vehicle. Appropriate software was written to identify each police vehicle and label its data as they were placed into permanent storage. Since the computer-sensor system operates on a 24-hour-a-day basis, all varieties of traffic density and times of day were sampled.

"The effects of real enforcement on traffic flow behavior were included in the collection of data. A three-month program of verbal warning, written citations and written warnings was planned, but not implemented, because the closing for repairs of a bridge on the test highway caused a delay of six weeks. When the highway reopened, the necessary state police participants had been assigned to other areas where there were heavy manpower requirements.

"During the execution of Objectives #2 and #4 the stationary symbolic enforcement exercises, traffic on the test highway was exposed to varying numbers of police vehicles, from light to heavy levels. Accident data during these months were compared to those previous years, in an effort to relate the stationary enforcement activity to accident history."

The study concluded:

"The stationary police vehicles significantly affected both mean speed and percentage of violators, but no overall significant effects were observed for traffic headway or headway violators. In the vicinity of the stationary vehicles, the more "threatening" enforcement configurations (arrest, pack) produced greater actual decreases in mean speed and percentage of violators. These effects, however, died out more quickly than those produced by less threatening enforcement symbols.

Varying under different traffic density conditions, these decreases generally tapered off within 3.2 miles.

"Moving enforcement vehicles produced similar, but less pronounced, effects on traffic flow behavior. In the case of moving vehicles, the effects were observed to be the greatest ahead of the vehicle rather than adjacent to it. The effects of both stationary and moving enforcement symbols upon traffic speeds dissipated rapidly after these symbols were removed."

It was also found through an analysis of variance that a stationary enforcement symbol was a significant main effect under 85th percentile speed (p=.001) but was <u>not a significant main effect under speed standard deviation</u> (see Table 4-9). <u>This tended to indicate that the enforcement</u> symbol tends to shift the entire speed frequency distribution toward the lower end of the speed regions but, at the same time, does not appreciably affect the shape of curve. This speculation is given further support by speed histograms prepared by the CHTIS before, during and after "treatment" (see Figures 4-15 and 4-16). Statistical analysis of the speed histograms confirmed that the distribution remained Gaussian throughout the displacement.

TABLE 4-9: Summary of Analysis of Variance Results for All Traffic Flow Measures (1)

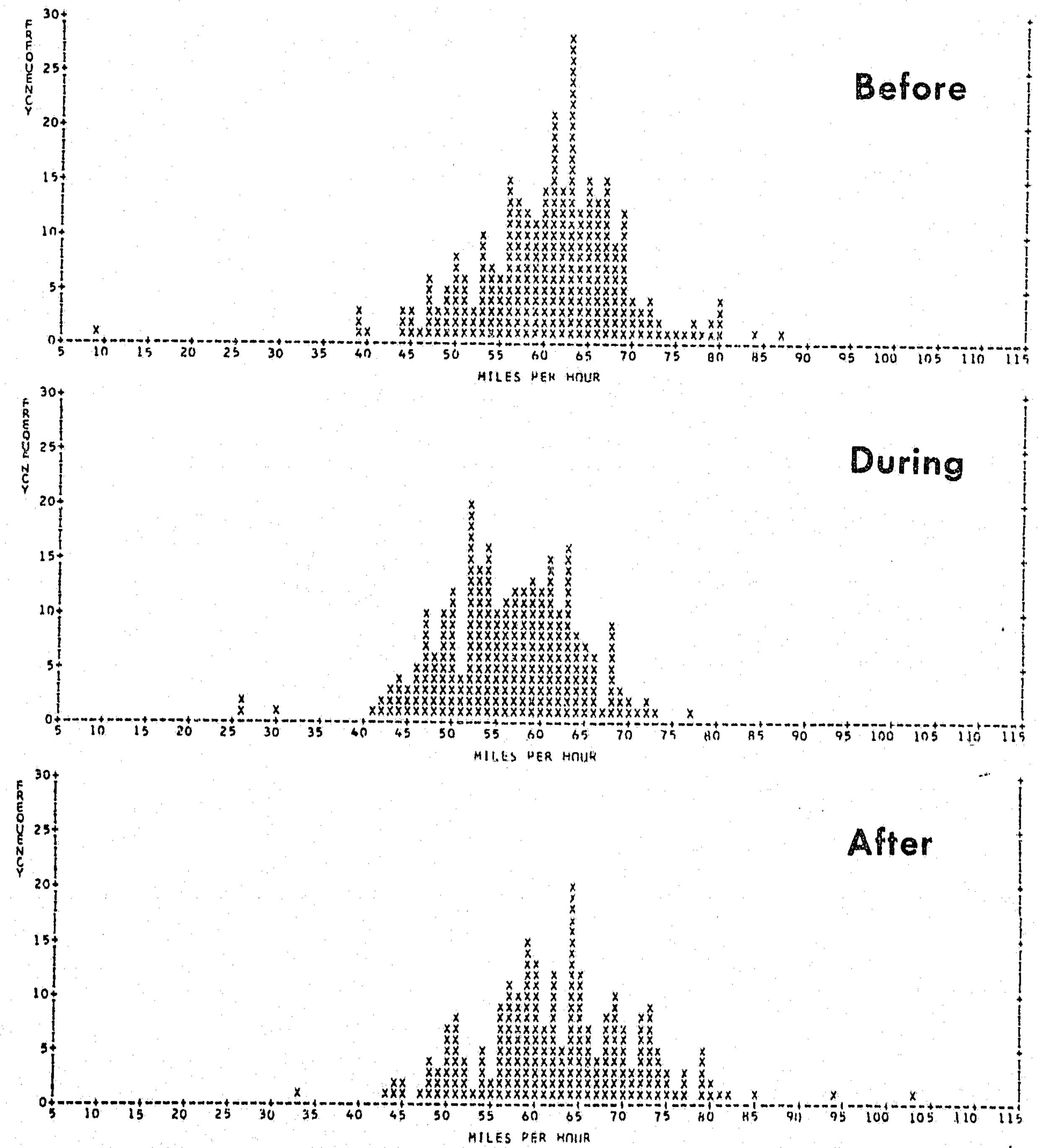
Traffic Flow Measure

Source of Variation	Speed	Speed Standard Deviation	85th Percentile Speed	Percent Speed Limit Violators	Headway	Percent Headway Violators (Tail-Gaters)
A (Stationary Symbol)	***		***	***		**
B (Time of Day)		***		**	**	***
C (Symbol Location)						
A x B	**		**	*		
A x C					*	
B X C						
A x B x C						

*p = .05
**p = .01
***p = .001

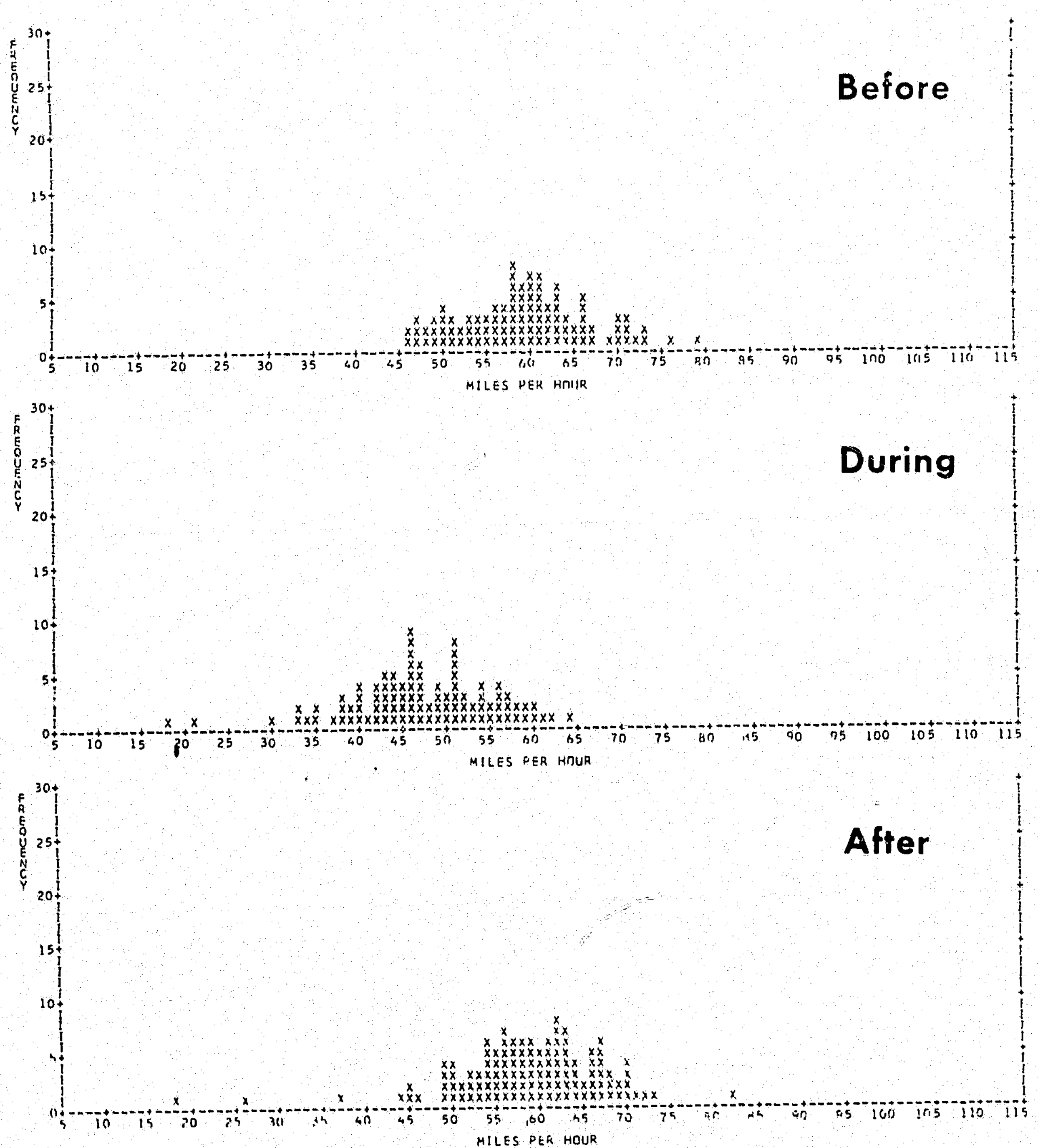
(1) Source: Reference 16

FIGURE 4-15: Distributions of Spot Speeds for Same- and Opposite-Sides of Road Combined, Before, During and After, Adjacent Application of A "Pack" Stationary Enforcement (1)



(1) Source: Reference 16

FIGURE 4-16: Distributions of Spot Speeds for Same- and Opposite-Sides of Road Combined, Before, During and After, Adjacent Application of An "Arrest" Stationary Enforcement[1]



(1) Source: Reference 16

It was noted in the previous study that it was not possible to implement a planned effort to estimate the affects of more conventional enforcement techniques on traffic flow variables because data collection problems brought on by repairs on the test highway. In the present study, the short-term effects of a concentrated warning-citation program in the vicinity of a CHTIS sensor site were measured.

The experiment provided data for comparing traffic flow characteristics at a given location over three 24-hour periods:

- The test day preceding the test day (before day).
- A day representative of the day preceding the test day (before day).
- The day following the test day (after day).

The test day selected was Tuesday, November 1, 1971. Five ISP patrol vehicles were stationed at loop sites 39 and 40 from 7:00 a.m. to 11.30 a.m They were instructed to apprehend vehicles exceeding the posted speed limit (i.e., 45 mph) by five mph or more. During the "treatment" period the officers issued 47 citations, 39 written warnings, and three notices to repair defective vehicles. No enforcement actions were taken on either the before day (Monday, October 25, 1971) or the after day (Wednesday, November 2, 1971).

The results are shown in Figures 4-17 through 4-26, which present various traffic flow variables as functions of time for the entire day of the experiment. Examination of the data indicates general reduction in percent speed violators during the treatment period from that observed during the same hours of the preceding day (i.e., 7:00 a.m. to 11:30 a.m.). On the day following the treatment, the percent speed violators had returned to about their original value. A similar result was noted for average speed, with reductions during treatment reaching approximately five mph. A possible reduction in speed standard deviation was noted in the inbound lane (loop set 40), but no reduction was apparent in the outbound lane (loop set 39). The other two flow variables considered (i.e., percent headway violators, speed distribution skewness) exhibited no obvious differences for the three days considered. Furthermore, no lasting effects of the increased enforcement activities were obvious: all three days exhibited similar traffic flow characteristics at times of the day corresponding to no treatment on the test day.

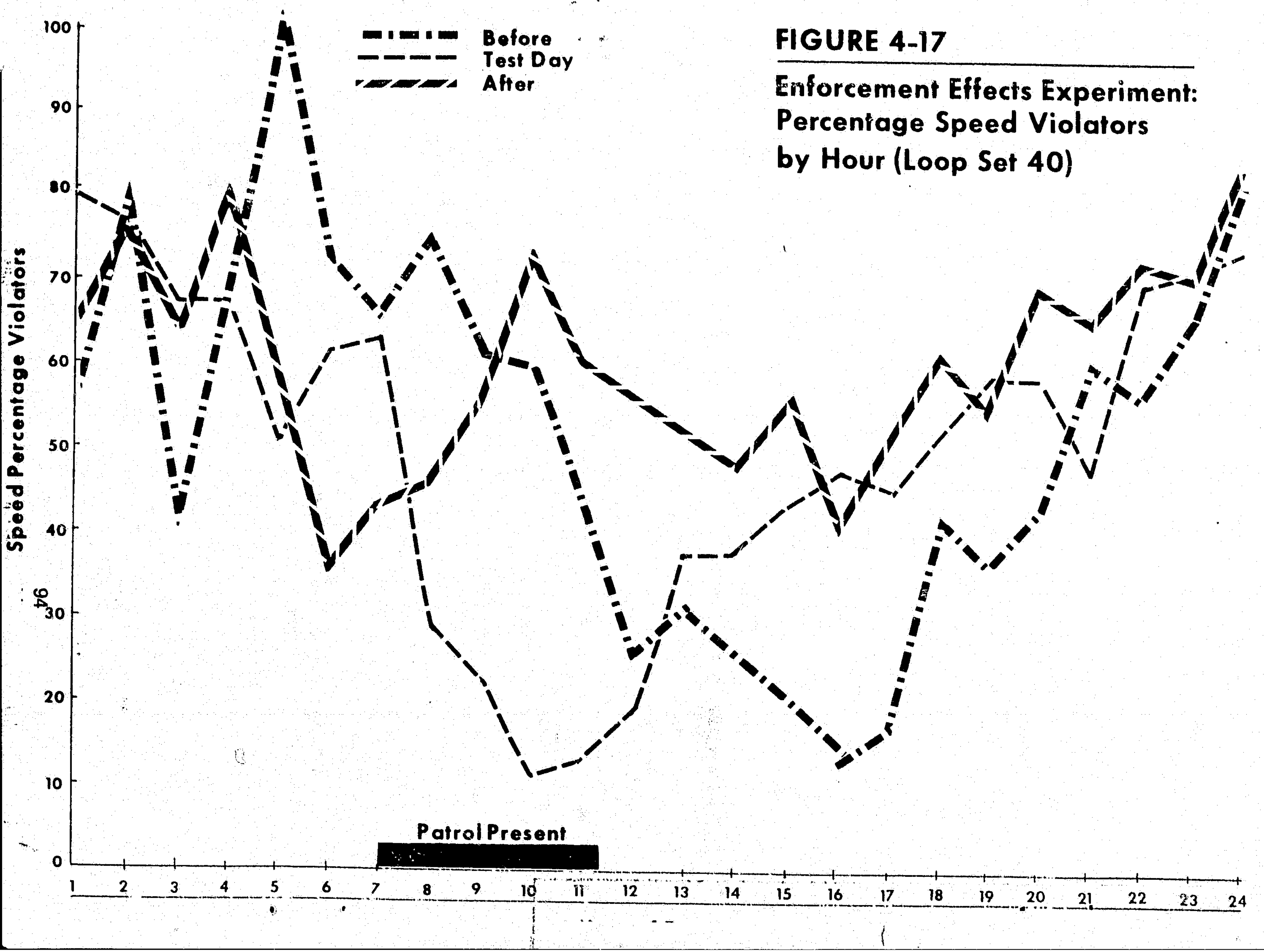


FIGURE 4-17

Enforcement Effects Experiment: Percentage Speed Violators by Hour (Loop Set 40)

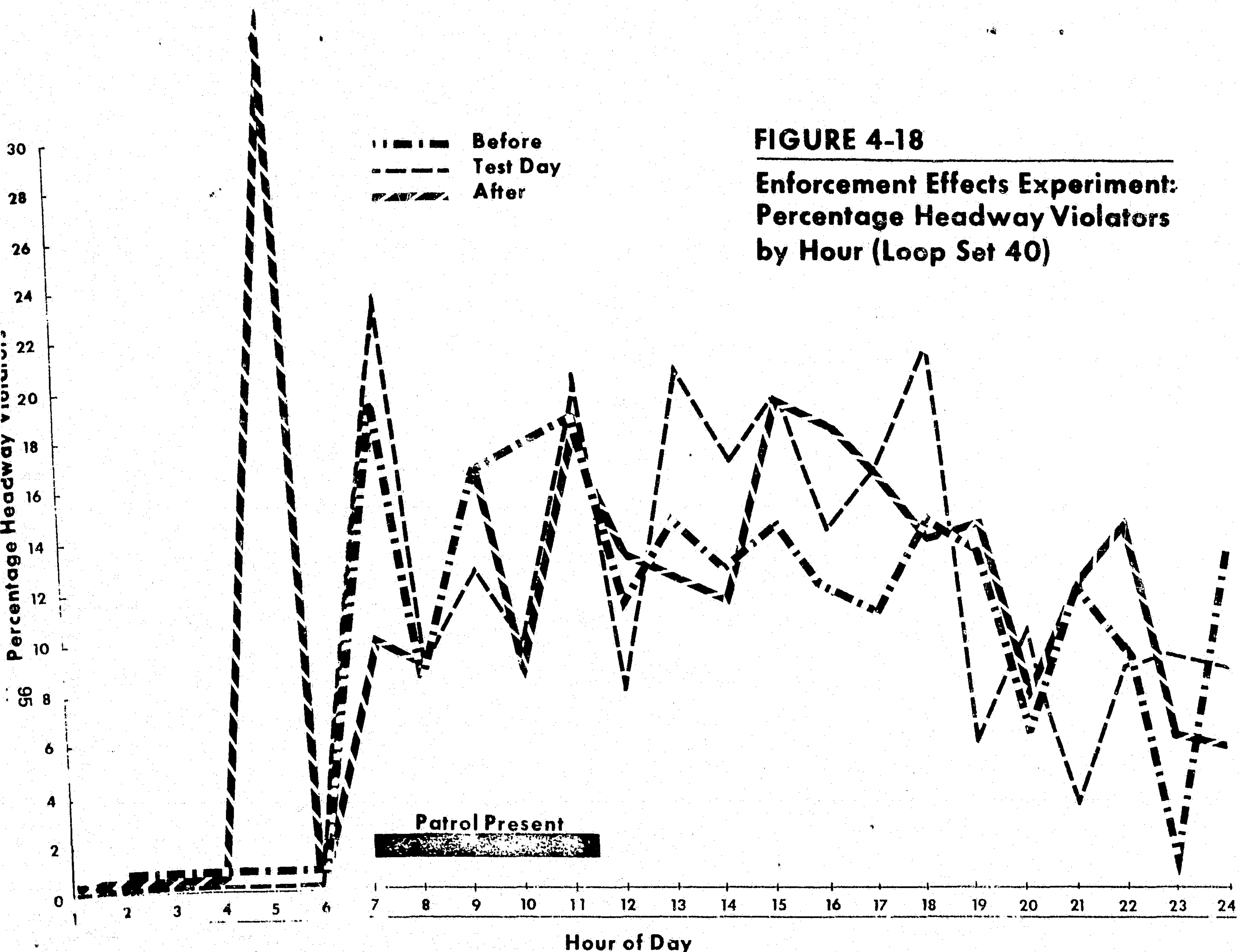


FIGURE 4-18

Enforcement Effects Experiment: Percentage Headway Violators by Hour (Loop Set 40)

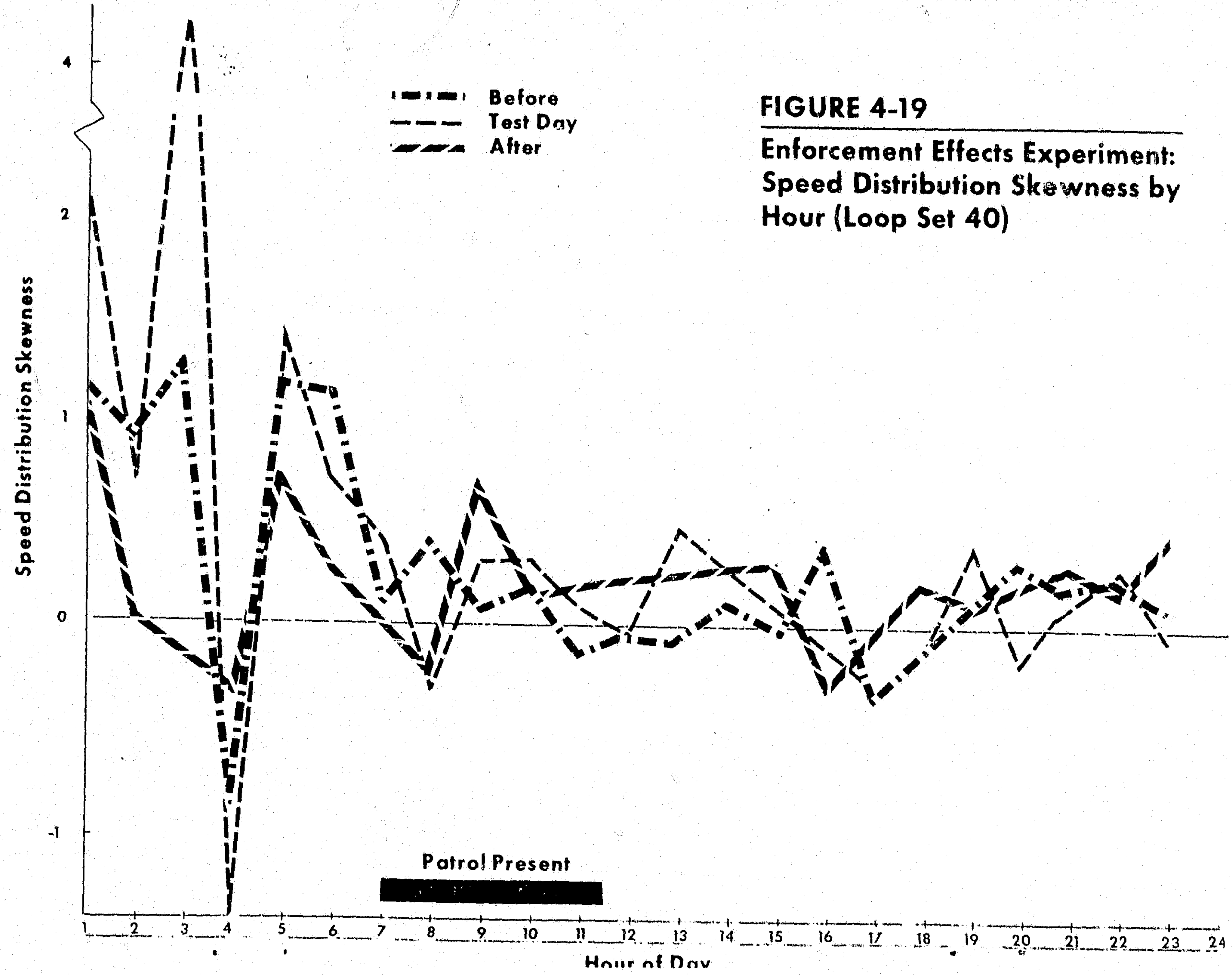
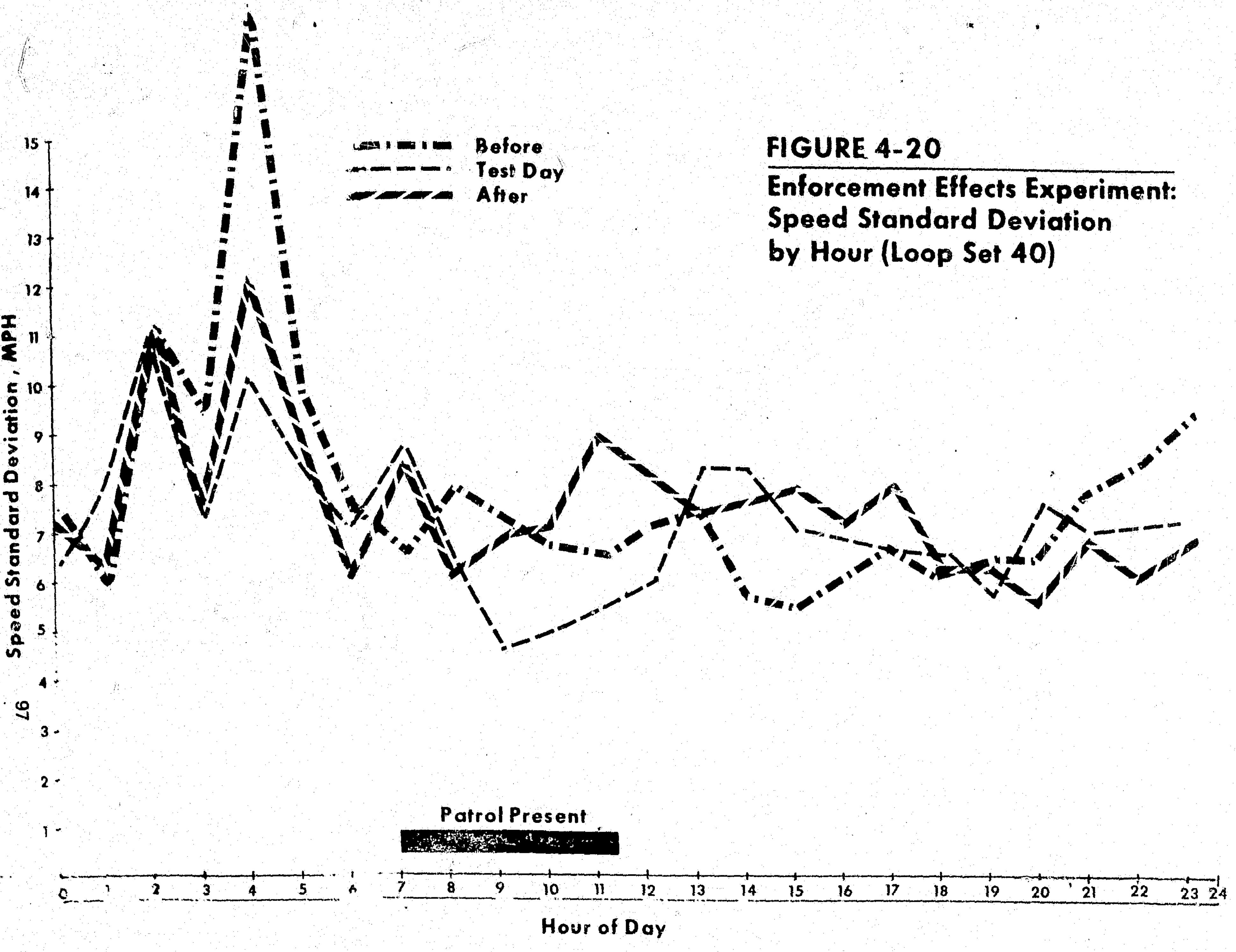


FIGURE 4-19

Enforcement Effects Experiment: Speed Distribution Skewness by Hour (Loop Set 40)


Before
Test Day
After
FIGURE 4-20
Enforcement Effects Experiment: Speed Standard Deviation by Hour (Loop Set 40)
Speed Standard Deviation, MPH
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
Patrol Present
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Hour of Day

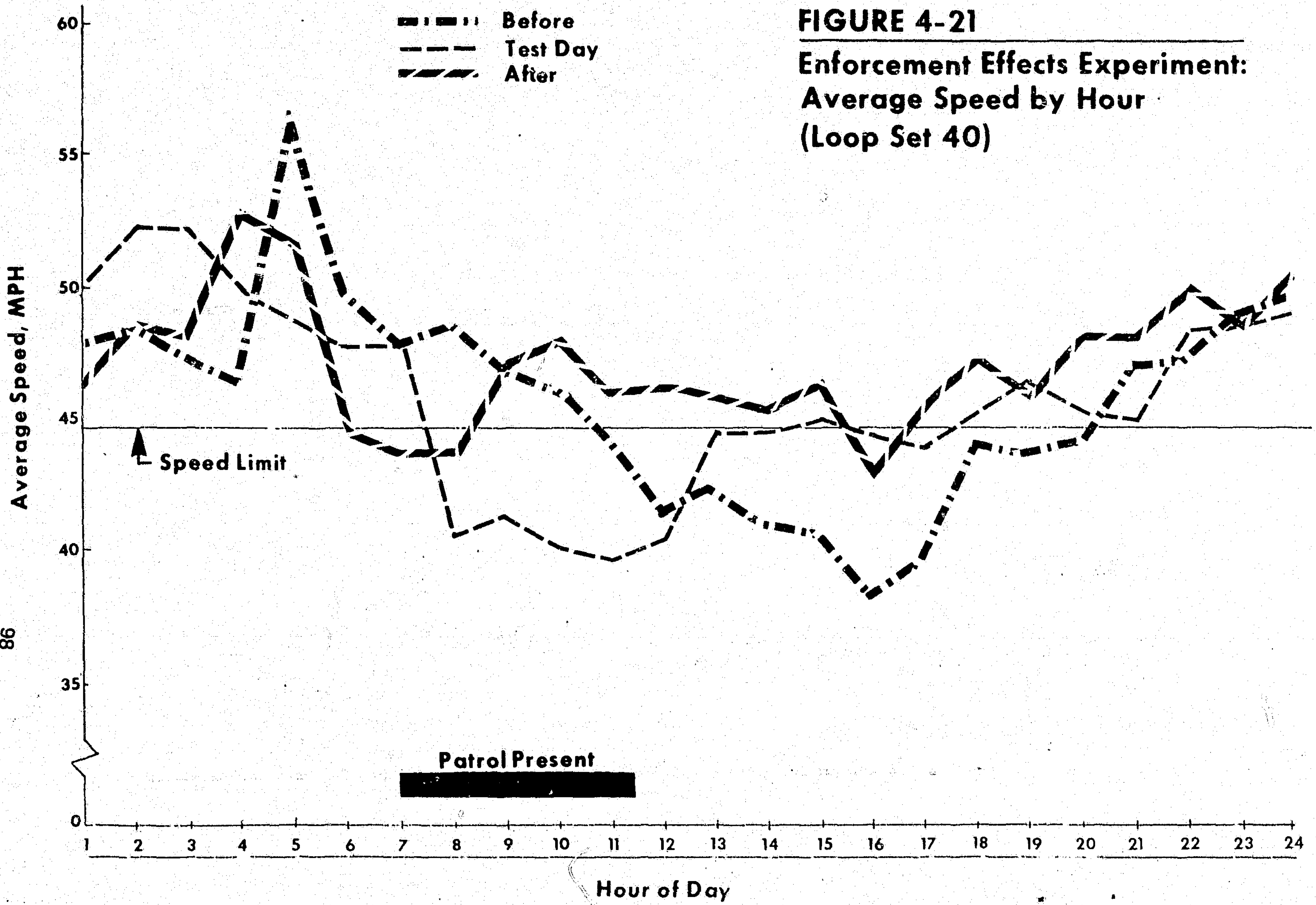


FIGURE 4-21

Enforcement Effects Experiment: Average Speed by Hour (Loop Set 40)

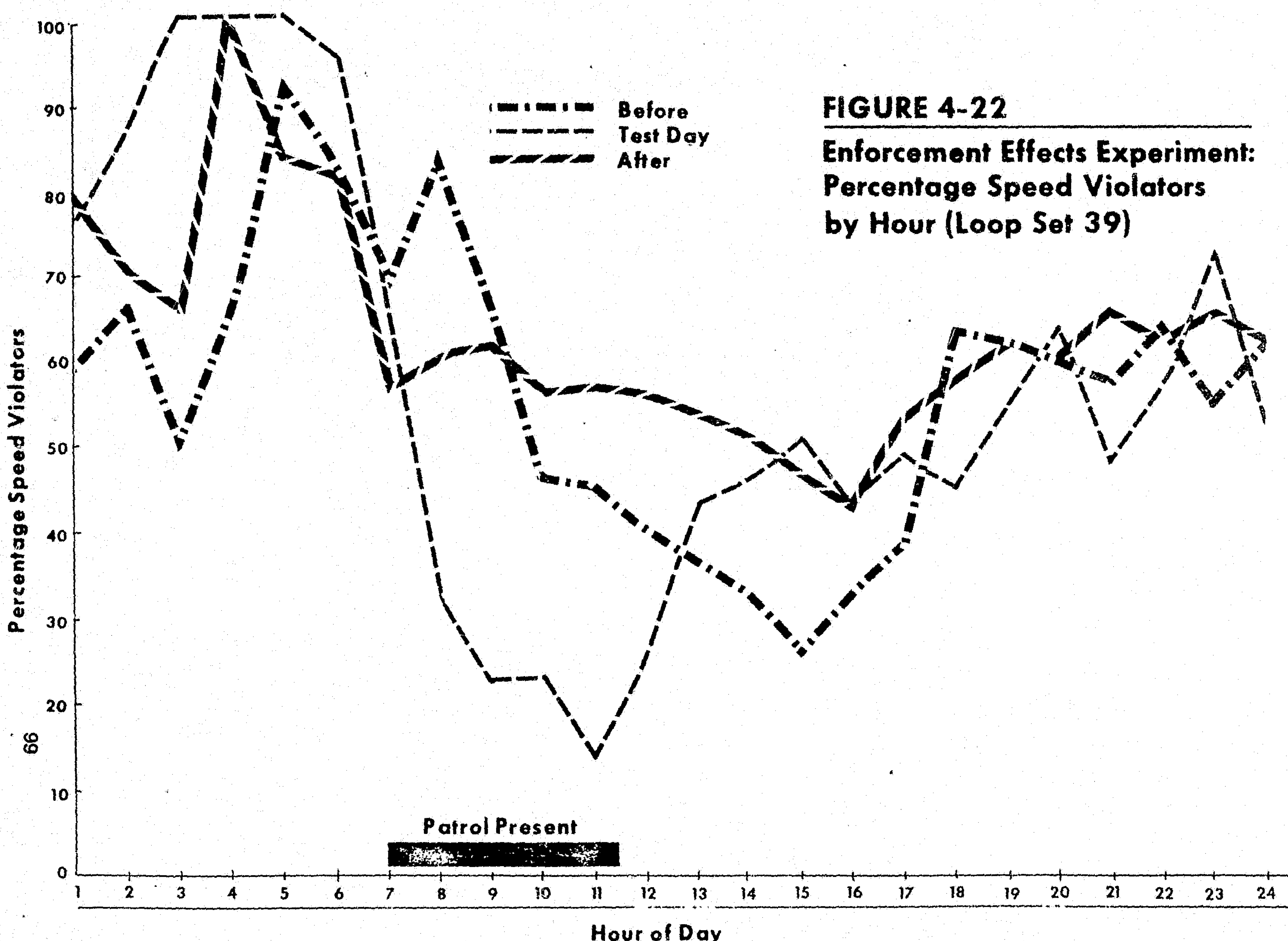


FIGURE 4-22

Enforcement Effects Experiment: Percentage Speed Violators by Hour (Loop Set 39)

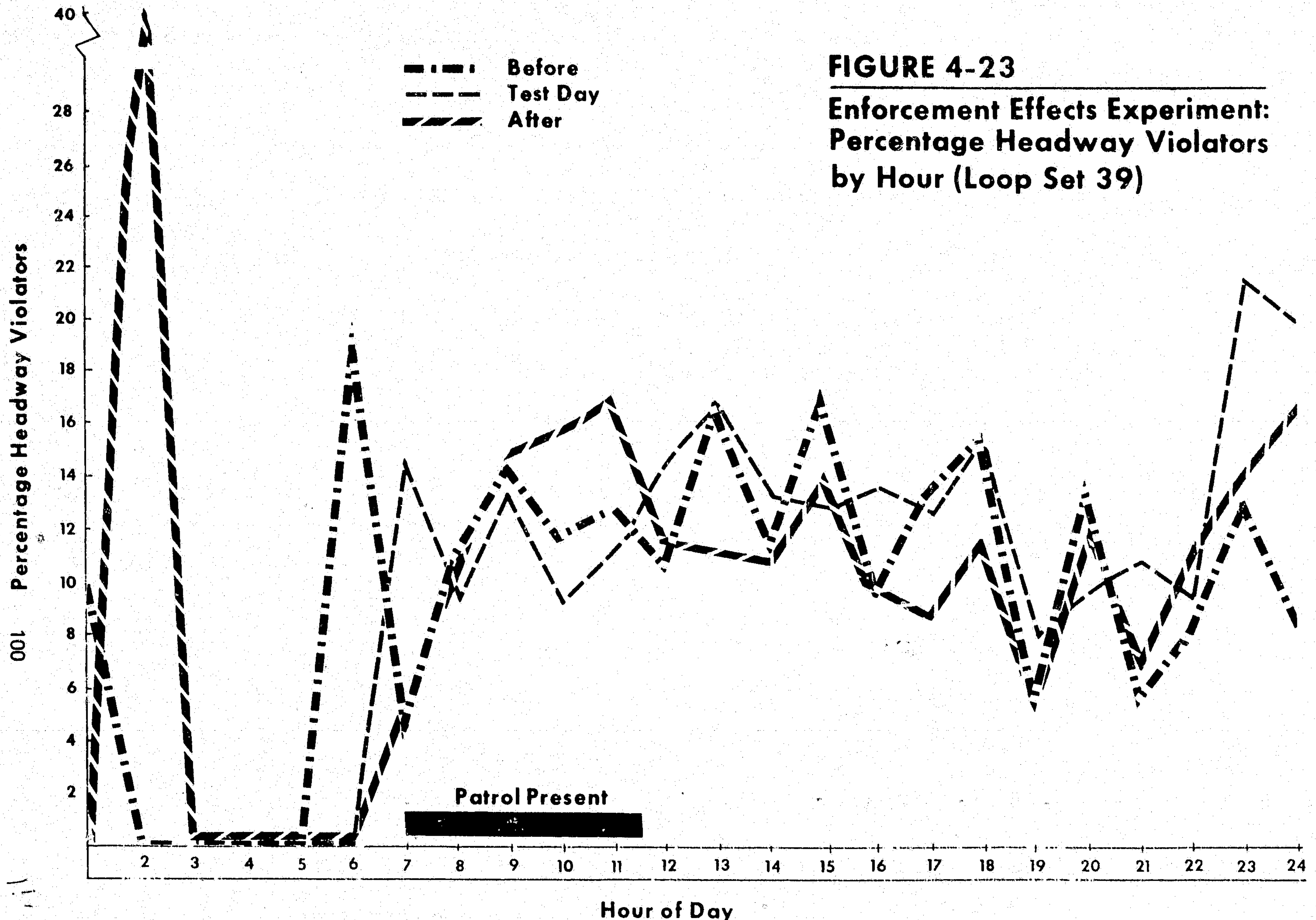


FIGURE 4-23

Enforcement Effects Experiment: Percentage Headway Violators by Hour (Loop Set 39)

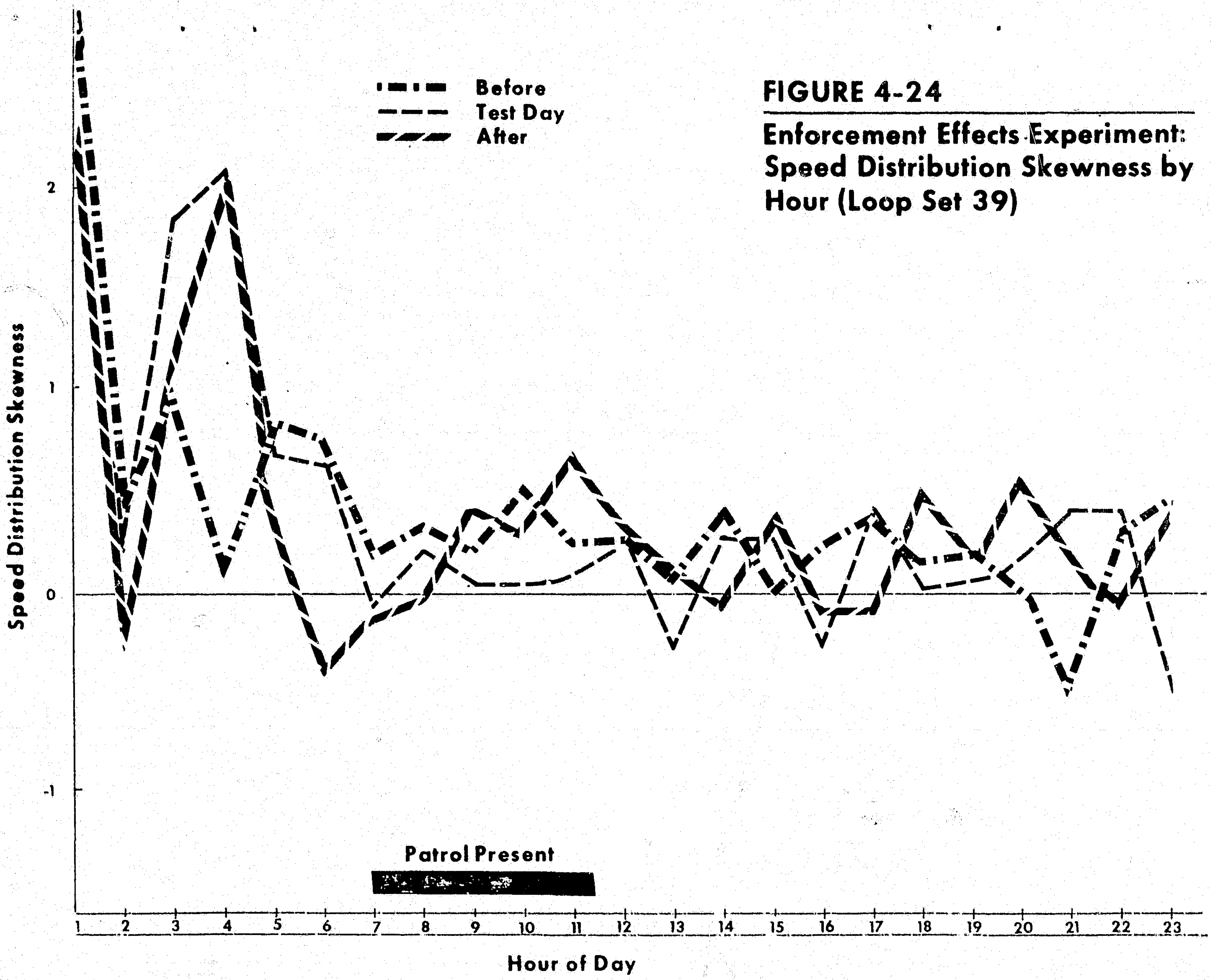


FIGURE 4-24

Enforcement Effects Experiment: Speed Distribution Skewness by Hour (Loop Set 39)

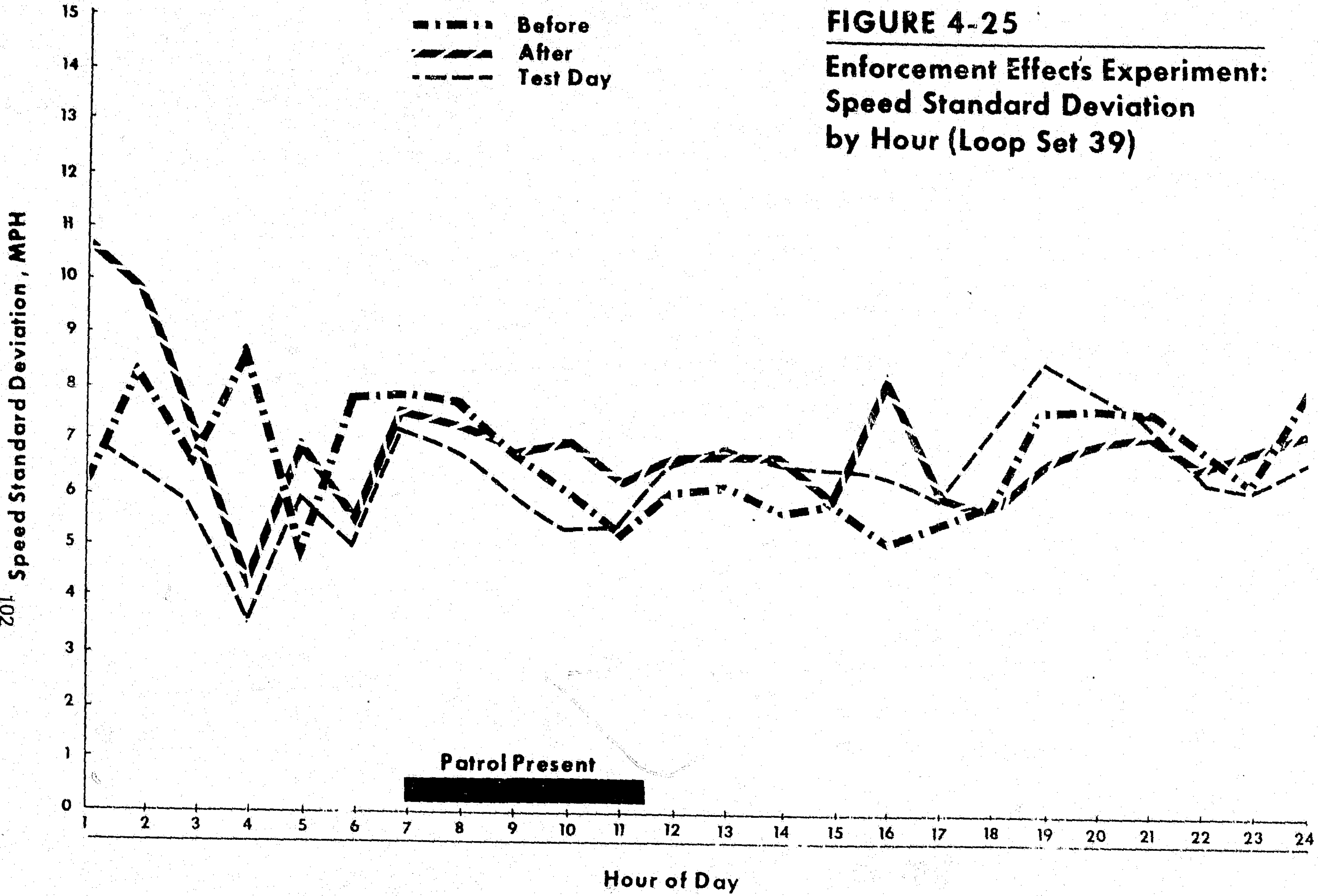
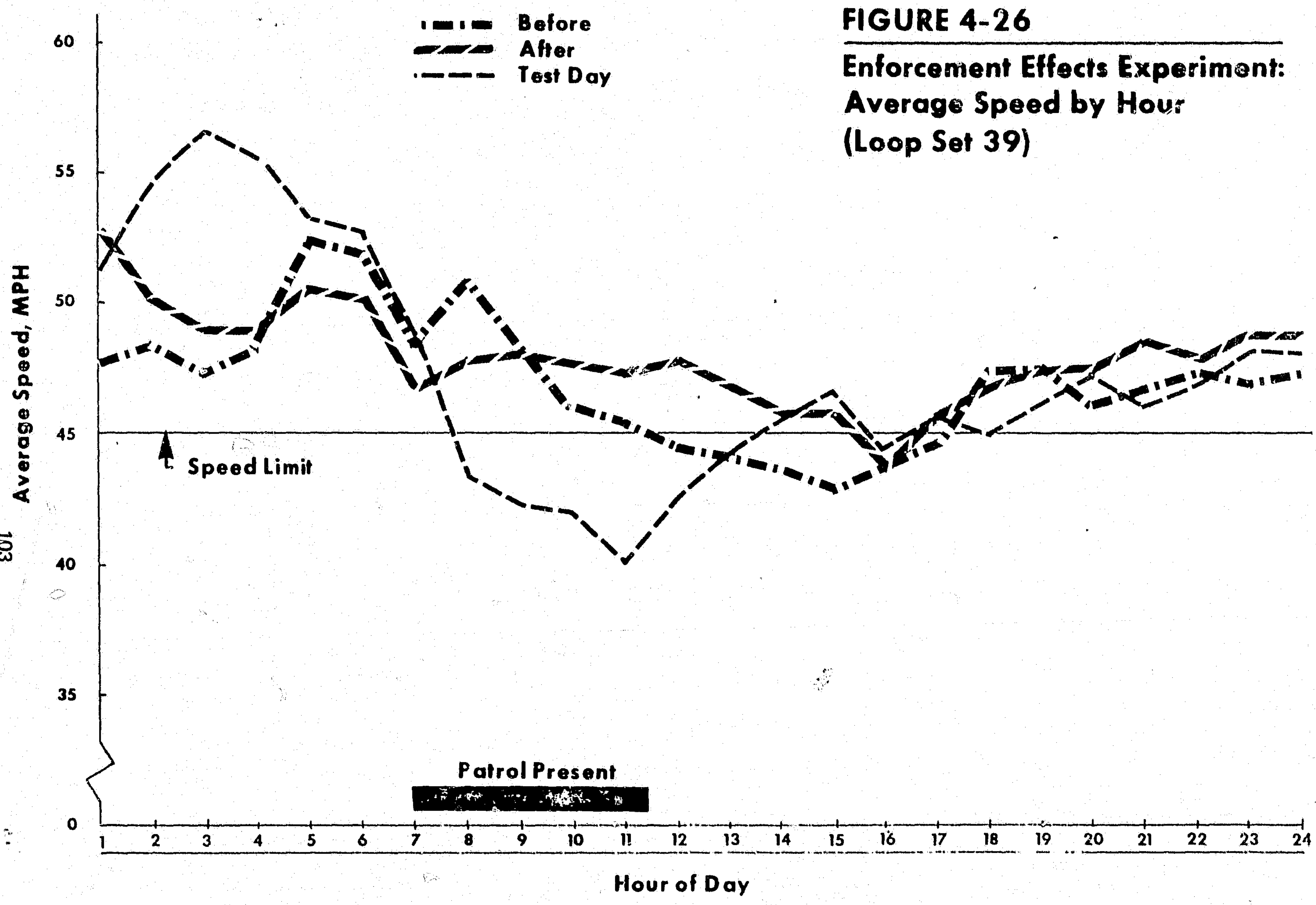


FIGURE 4-25

Enforcement Effects Experiment: Speed Standard Deviation by Hour (Loop Set 39)

FIGURE 4-26

Enforcement Effects Experiment: Average Speed by Hour (Loop Set 39)



Thus, the results obtained from data collected during the present study tend to indicate that increased conventional enforcement activity is associated with reductions in both average vehicle speeds and percent speed violators, but again failed to point to any real effect of enforcement on speed standard deviation. These results closely follow those cited previously in the investigation of the effects of stationary enforcement symbols on flow variables. This is not really surprising since that experiment had purposely sought to simulate police vehicles in various enforcement postures. To determine the effects on driver behavior of the actual arrests and subsequent further Traffic Law System actions, relative to those due to symbols alone would require a study of much longer duration. Such studies will eventually have to be done if rational traffic risk management is to progress beyond the superficial level.

4.2.3 Conclusions

Most past investigations of the effects of risk control forces on accidents have been concerned with the larger aspects of the problem rather than with its fine structure. Such studies tend to dump the myriad variables that describe traffic accidents and traffic law enforcement into a few all-encompassing factors and then attempt to relate them through simplistic expressions. Not surprisingly, the resulting conclusions tend also to be nonspecific and largely irrelevant to all but the broadest applications. Thus, for example, one can state that under some conditions, some kinds of enforcement actions appear to have a generally favorable affect on some kinds of accidents. The difficulty arises when one attempts to delve deeper into the nature of the conditions under which rigourously defined enforcement actions have a specific effect on particular kinds of accidents.

The picture with respect to enforcement traffic flow affects is much brighter. The CHTIS provides a tool for precise determination of both long-term and short-term effects of specific enforcement actions on the variables that describe the details of traffic flow. As yet, its applications have been limited so that no compendium of enforcement effects could be prepared even for Monroe County. Nevertheless, the potential has been clearly demonstrated and can be realized through a comprehensive and methodical analysis of all enforcement alternatives in given jurisdictions. The results of such an investigation would provide a means for selecting enforcement alternatives most appropriate to achieving desired traffic flow characteristics and would thus be of great benefit in determining more productive allocations of enforcement resources.

4.3 Resource Allocation

The next step in the traffic risk management process is the combination of knowledge of the nature of the risk with knowledge of the expected effects of alternative risk reduction actions to determine overall resource allocation policies, strategies, and tactics. The role of the CHTIS in this process is discussed below.

4.3.1 Nature and Relevancy of the Restricted Traffic Resource Allocation Problem

The general traffic resource allocation problem can be readily stated in succinct terms:

> The general traffic resource allocation problem in a given Traffic Law System (TLS) jurisdictions is to determine the operationally feasible mix of risk control forces and their point of application, both spatial and temporal, which minimize the total traffic risk in that jurisdiction.

Approaches to this problem, both qualitative and quantitative have been discussed at some length in reference (18). In the present study, however, we are interested only in the part of this overall problem which is concerned with the allocation of enforcement resources to the minimization of traffic accident risk. A solution to this more restricted problem can, of course, result only in a suboptimization which might not be consistent with a solution to the more general problem. Nevertheless, the bulk of TLS resources today are being applied to the enforcement subsystem (18) and the major concern is accident risk. Further, given the state of the art of the TLS resource allocation process, any solution at all, optimal, and suboptimal or otherwise, would be useful in providing insight and a point of departure toward more ambitious goals and would, therefore, be more than welcome.

At present, the attainment of optimal solutions to either the general or restricted resource allocation problem must, in fact, be regarded as a goal not likely to be reached in the forseeable future although progress toward it is now beginning to accelerate. While optimal overall TLS resource allocation policies resulting in minimum risk are an ultimate goal, better subsystem resource allocation policies resulting in less risk are also desirable. Therefore, the enforcement resource allocation problem being addressed in the present study is also relevant to the general TLS resource allocation problem and in deserving of attention. The major pitfall to be avoided in operational applications of any resulting solutions is the neglect of possible effects on the functioning of other components of the TLS. As was pointed out in reference (17, 18) any contemplated change in a TLS component should be preceded by a careful analysis of its impact on all other TLS components as well as to the system as a whole.

4.3.2 CHTIS Contribution to the Solution of the Enforcement Resource Allocation Problem

For the purpose of the present study, then, the resource allocation problem may be stated as follows:

> It is desired to determine the operationally feasible mix of enforcement control forces and their points of application both spatial and temporal, which minimize the total traffic risk in the enforcement agency's jurisdiction during a given time period.

Ideally to solve this problem, one needs to know.

- Traffic accident risk as a function of location within the jurisdiction, time, and enforcement control forces.
- Enforcement control forces as a function of enforcement resources.
- Total enforcement resources available in the jurisdiction as a function of time.
- Operational constraints in the jurisdiction.

One could formulate this problem in mathematical terms and set about obtaining an optimal solution through any one of a number of well-known and proven techniques. The solution could then be communicated to the enforcement manager as derived information and could be used in conjunction with other available knowledge, experience, considered opinion, and judgement to arrive at a decision. Unfortunately, difficulties start to arise almost immediately, and most of them stem directly from the first input requirement listed above. <u>One simply does not know how traffic accident risk varies with enforcement activity and without such knowledge there can be no optimal solution to even the restricted resource allocation problem</u>. For the present, only risk reduction is a reasonable objective, and the CHTIS can provide useful resource allocation information to

help achieve that objective.

Several kinds of such information can be made available. First, the raw and refined information described in Section 4.1.1 can be used directly by enforcement decision makers for risk identification and to thus assist in establishing enforcement priorities. Second, derived information resulting from risk control force analyses of the kind described in section 4.2 can be used to select preferred enforcement techniques (e.g., moving or stationary enforcement symbols, apprehension and arrest, and so forth). Third, simple resource allocation schemes can be devised to assist the enforcement decision-maker in applying the risk identification and risk control force information to the establishment of enforcement priorities and the selection of preferred enforcement techniques. Since the first two kinds of information have been discussed previously in this report, we will only be concerned here with the identification and discussion of possible decision-making models for providing derived resource allocation information to enforcement managers.

4.3.3 Decision Making Models for Enforcement Resource Allocation

Consider an enforcement jurisdiction interspersed with highways which have been divided into patrol sectors for the purpose of assigning enforcement resources (see Figure 4-27). Let the total number of patrol vehicles available during any given time period T be equal to M and the total number of patrol sectors be equal to N. Further, let the number of patrol hours spent during T in any sector, i, be represented by x_i and the enforcement technique employed in i be represented by ξ_i. Finally let the traffic accident disutility during T at i be given by u_i where u_i is a function of x_i and ξ_i. The resource allocation goal, then, is to choose x_i and ξ_i to minimize the total accident disutility during T over all patrol sectors in the jurisdiction. Stated mathematically,

$$\text{Min } u(x_1, \xi_1; x_2, \xi_2; \ldots; x_n, \xi_n) =$$

$$u_1(x_1, \xi_1) + u_2(x_2, \xi_2) + \ldots + u_n(x_n, \xi_n), \tag{14}$$

subject to

$$x_1 + x_2 + \ldots + x_n = x \equiv MT \tag{15}$$

(14) defines a two dimensional, N-stage optimization problem. However, the dimensions can easily be reduced to one by redefining the disutility function such that:

$$u_i(x_i) \equiv u_i[x_i, \xi_i^* (x_i)], \tag{16}$$

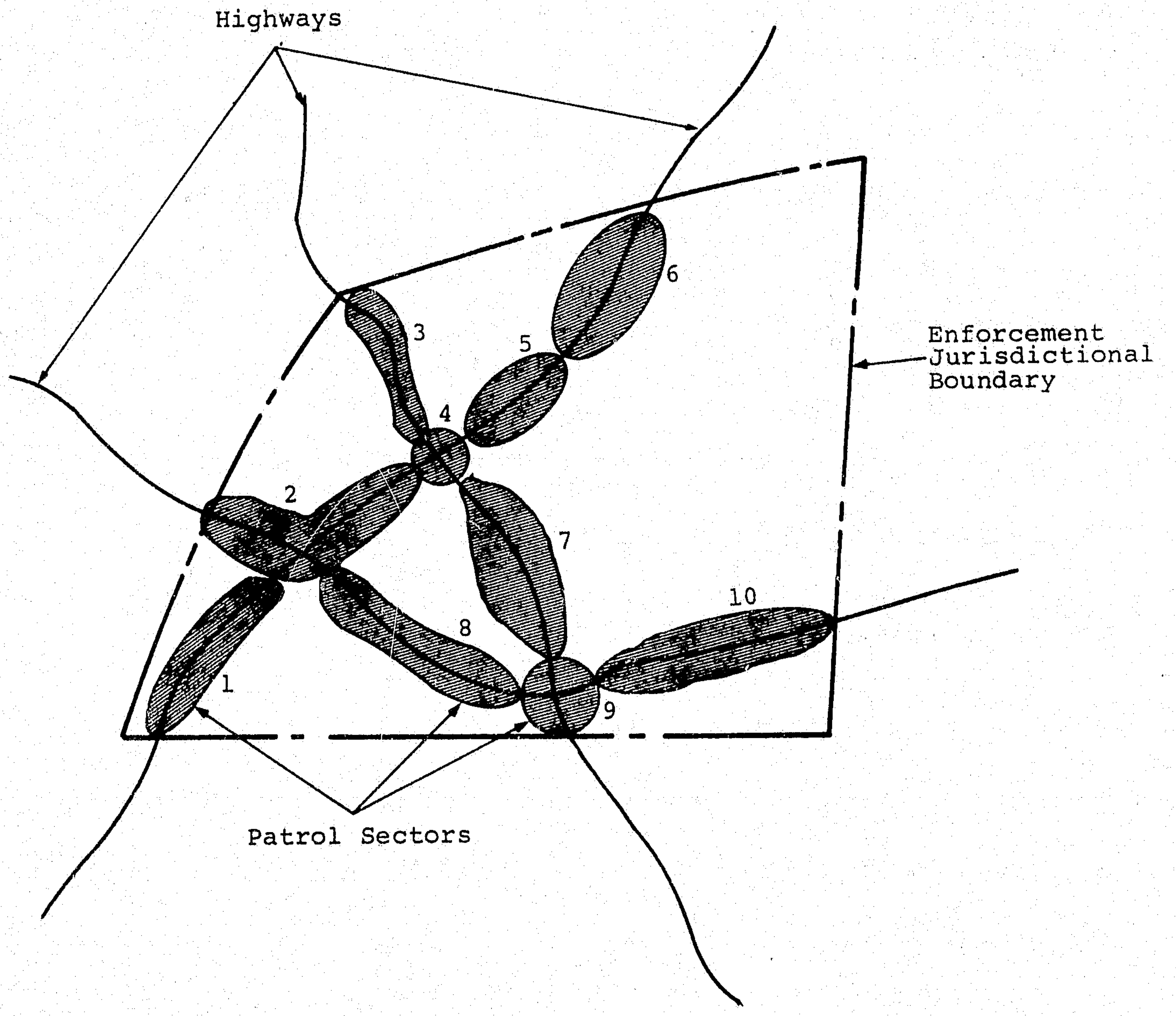


FIGURE 4-27

Enforcement Patrol Sectors In A Typical Jurisdiction

where $\xi_i^*(x_i)$ is the enforcement technique that minimizes u_i at x_i. Since ξ_i is a discrete variable, $u_i[x_i, \xi_i^*(x_i)]$ can be determined from the functions $u_i(x_i, \xi_i)$. Figure 4-28 shows how $u_i[x_i, \xi_i^*(x_i)]$ can be developed graphically.

The problem now becomes:

$$\text{Min } u(x_1, x_2, \ldots, x_n) = u_1(x_1) + u_2(x_2) + \ldots + u_n(x_n) \quad (17)$$

subject to

$$x_1 + x_2 + \ldots + x_n = x$$

If the $u_i(x_i)$'s are continuous and single-valued, then a necessary condition for (17) is

$$\frac{\partial z(x_1, x_2, \ldots, x_n)}{\partial x_i} = 0 \quad (18)$$

where

$$z(x_1, x_2, \ldots, x_n) = u(x_1, x_2, \ldots, x_n) - \lambda x, \quad (19)$$

and is a Lagrange multiplier. This means that

$$\frac{\partial u_i(x_i)}{\partial x_i} = \lambda, \quad (20)$$

Integrating (20) leads to

$$u_i(x_i^*) - u_i(0) = \lambda x_i^* \quad (21)$$

and

$$u^* - u(0) = \lambda x, \quad (22)$$

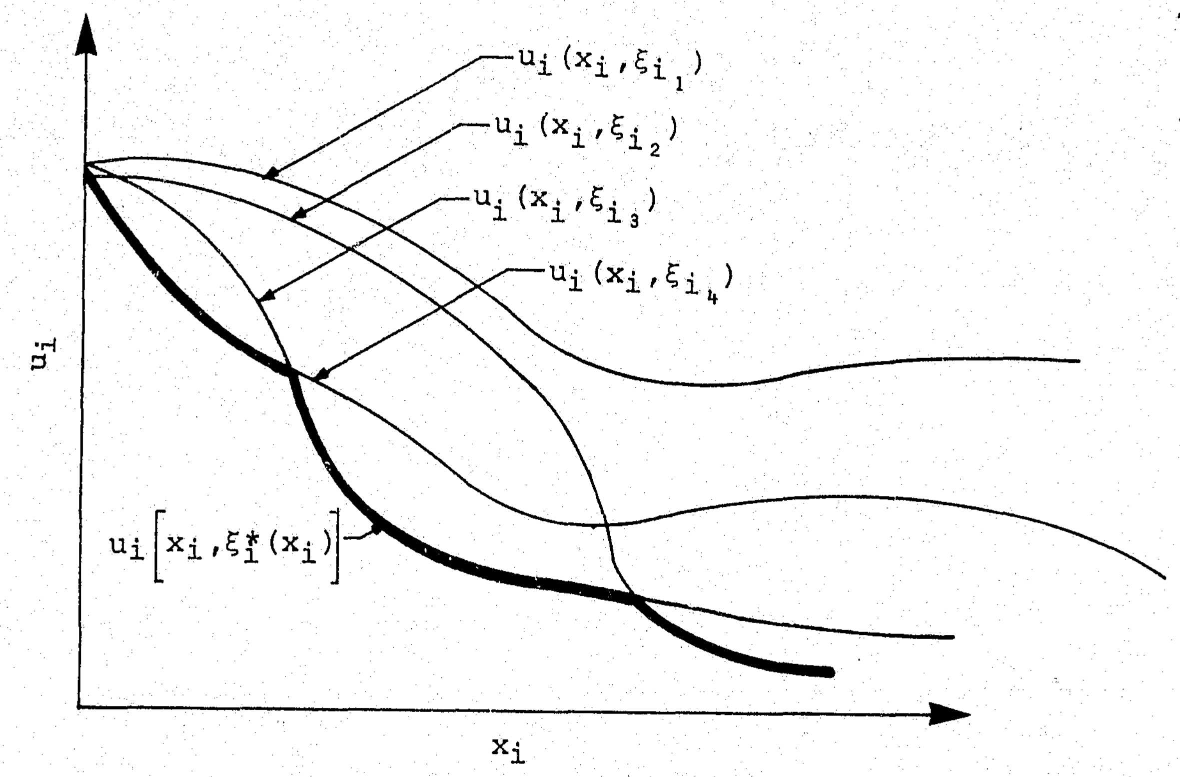


FIGURE 4-28

Graphical Development of Local One-Dimensional Disutility Function

where

$$u^* \equiv u(x_1^*, x_2^*, \ldots, x_n^*) = \text{Min } u(x_1, x_2, \ldots, x_n)$$

$$u(0) \equiv u(0, 0, \ldots, 0)$$

x_i^* = value of x_i used to minimize $u(x_1, x_2, \ldots, x_n)$

Dividing (21) by (22), we obtain

$$\frac{x_i^*}{x} = \frac{u_i(x_i^*) - u_i(0)}{u^* - u(0)} \tag{23}$$

(23) expresses the necessary conditions for an optimal solution to (17) and can be used to determine x_i^* when $u_i(x_i)$ is known ($i = 1, 2, \ldots, n$). However, as was noted earlier, $u_i(x_i)$ is not known, and the decision maker must be satisfied with allocations that approximate the condition (23).

A familiar allocation policy will result when the local disutility using an optimal policy is small compared to the local disutility using zero resources. In this case, we obtain

$$\frac{x_i^*}{x} \cong \frac{u_i(0)}{u(0)}, \tag{24}$$

or

$$x_i^* \cong k\, u_i(0), \tag{25}$$

where

$$k = \frac{x}{u(0)} \tag{26}$$

(24) and (25) state that, the available patrol hours in a given time period should be allocated such that number of patrol hours spent at a given patrol sector is proportional to the zero allocation disutility at that sector. Such a policy approximates an optimal policy only when large disutility decreases are possible in the vicinity of $x_i = 0$.

The above development demonstrates the mathematical justification for the well-known concept of proportional distribution or selective enforcement. This concept and its history have already been discussed briefly in this report (see Section 1.3). Proportional allocation would appear to be particularly useful in conjunction with the raw and refined accident and flow information provided by the CHTIS. It could be applied to policy making and strategic planning by using historical traffic accident disutility data of the kind presented in the Accident Data Handbook to approximate the zero allocation disutilities. One could then determine baseline allocations for a given year, months of year, days of the week, and hours of the day and the results could be used in both allocation planning and in allocation scheduling. Further, used in conjunction with the information provided by the CHTIS traffic flow subsystem, the approach could also be beneficial in making short range adjustment to the baseline allocations. In this case, disutility could be measured in terms of specified traffic violation believed to be indicative of local risk (e.g., number of vehicles exceeding speed limits by a specified amount).

Clearly, real world applications would have to be capable of incorporating operational constraints not specified in the above formulation. For example, patrol units nearly always have other non-traffic enforcement duties as well as non-enforcement traffic duties. Thus, an expected real world constraint would be the specification of both lower and uppper limits to the patrol hours that could be allocated to a given time period. Such constraints would take the form of

$$x_{i_{min}} \leq x_i \leq x_{i_{max}} \tag{27}$$

and could be easily worked into the computational procedure through a simple algorithm.

Of course, should future research make available reliable means for determining the functions $u_i(x_i)$, the proportional allocation approximation would no longer be necessary, and optimal alloca-policies could be determined. If, for example, it were found that

the disutility functions were exponential, one could obtain an analytic solution to the problem. Defining

$$u_i(x_i) \equiv c_{1_i} e^{-a_i x_i} + c_{2_i}, \tag{28}$$

the optimality conditions become

$$\frac{\partial u_i(x_i)}{\partial x_i} = - a_i c_{1_i} e^{-a_i x_i} = \lambda, \tag{29}$$

from which

$$x_i = \frac{1}{a_i} \ell n\left[-\frac{a_i c_{1_i}}{\lambda}\right] \tag{30}$$

Summing over all i's, we obtain

$$x = \sum_{i=1}^{n} \frac{1}{a_i} \ell n\left[-\frac{a_i c_{1_i}}{\lambda}\right] \tag{31}$$

Solving (30) and (31) for x_i yields

$$x_i = \frac{1}{\frac{n}{\sum_{i=1} a_i}} \left\{ \frac{a_i}{n} [x - \sum_{i=1}^{n} \frac{1}{a_i} \ell n\, a_i c_{1_i}] + \frac{1}{a_i} \ell n\, a_i c_{1_i} \right\} \tag{32}$$

The constants c_{1_i} may also be expressed in terms of the zero-allocation disutility and the study state disutility:

$$c_{1_i} = u_i(0) - u_i(\infty) \tag{33}$$

A more flexible way of solving problems of this type employs the technique of dynamic programming. This approach does not require continuous disutility functions and is far more suitable to obtaining solutions under constraints. Briefly, the approach involves obtaining solutions to a recursion equation of the form

$$f_n(x) = \max_{0 \leq x_n \leq x} [u_n(x_n) + f_{n-1}(x-x_n)] \qquad (34)$$

where

$$f_n(x) = \max_{\{x_i\}} u(x_1, x_2, \ldots, x_n) \qquad (35)$$

An algorithm for solving (34) is discussed in detail in reference 3.

It should also be mentioned in passing that the dynamic programming approach can be used in routing patrol units through highway networks from one patrol sector to another in minimum time (or distance). An expression for the recursion equation is also presented in **(reference 3)**:

$$f(\theta, \psi) = \min \begin{bmatrix} d(\theta, \psi; \theta+1, \psi+1) + f(\theta+1, \psi+1) \\ d(\theta, \psi; \theta+1, \psi-1) + f(\theta+1, \psi-1) \end{bmatrix}, \qquad (36)$$

where $d(\theta, y; \theta+1, \psi+1)$ represents the distance between the points (θ, ψ) and $(\theta + 1, \psi + 1)$. The authors (Bellman and Dregfus) also show how (36) can solved).

Equation (36) covers the case where there are two, one-way exit routes from a given mode. A more general expression may be written as

$$f_{N\to 1} = \min_{i=1,2,\ldots,N} [s_{n\to i} + f_{i\to 1}] \qquad (37)$$

$f_{N\to 1}$ = Distance from node N to node 1 using optimal route.

$s_{N\to 1}$ = Distance from node N to next adjoining node i.

$f_{i\to 1}$ = Distance from node i to node 1 using optimal route.

When the availability and cost of a patrol unit vary among the different patrol units, a classicial transportation problem approach may be applied. Table 4-10 illustrates the analogy, and allows one to write the conditions for optimal distribution of the units. We have

$$\text{Min } C = \sum_{i,j} c_{ij} x_{ij} \qquad (38)$$

subject to

$$\sum_{i=1}^{M} x_{ij} = a_i \quad \text{for each } j, \qquad (39)$$

$$\sum_{i=1}^{N} x_{ij} = b_j \quad \text{for each } i, \qquad (40)$$

and

$$\sum_{i=1}^{M} a_i = \sum_{j=1}^{N} b_j, \qquad (41)$$

C is the total cost of assigning M units to N sectors over a time period T; a_i and b_j are as defined in Table 4-10; and x_{ij} is the time spent by unit i in sector j. In terms of the present problem

$$\sum_{i=1}^{M} a_i = x, \qquad (42)$$

where

TABLE 4-10

Analogy Between the Classical Transportation Problem and the Patrol Unit Distribution Problem

Parameter	Parameter Description	
	Transportation Problem	Patrol Unit Distribution Problem
c_{ij}	Cost to ship from plant i to warehouse j	Cost per unit time for patrol unit i to service sector j
a_i	Production output of plant i (i.e., supply)	Patrol time available from patrol unit i
b_j	Number of units needed at warehouse j (i.e., demand)	Patrol time required at sector j

x = the total patrol time available over a given allocation period T.

Further, if a proportional allocation policy is to be applied, then from (25),

$$b_j = k\, u_j(0), \qquad (43)$$

where

$$k = \frac{x}{u(0)} \qquad (44)$$

Substituting (42), (43), and (44) into (40), we obtain

$$x = \frac{x}{u(0)} \sum_{j=1}^{N} u_j(0) \qquad \text{or} \qquad (45)$$

$$x \equiv x,$$

Thus, the constraint of (41) is met, and we can set about solving (37) using classical transportation problem techniques or linear programming. A typical solution to this problem will provide, for example, a schedule for four patrol units and six patrol sectors is illustrated in Table 4-11.

If patrol unit demand were known in advance, an individual patrol unit schedule could be prepared in advance, as is shown in Table 4-12.

TABLE 4-11
Patrol Unit Assignment Schedule
Time Period 2300 Hours—2400 Hours
14 March 1972

Patrol Unit	Patrol Sector					
	1	2	3	4	5	6
1	2300[(1)] -2330				2330 -2345	2345 -2400
2		2300 -2400				
3		2300 -2400				
4			2300 -2400			

(1) Time period of assignment

TABLE 4-12

Assignment Schedule For

Patrol Unit Number 4 - 14 March 1972

Time Period	Highway Segment 1	2	3	4	5	6
0000 - 0030		x				
0030 - 0130				x		
0130 - 0230						x
. . .						
2230 - 2400			x			

The x's in the table indicate where unit four ought to be at the given times. Each unit would also have to be provided with its optimal path from its starting point to its destination as determined from equation (37). We note also that the above solution requires that the travel time must be small in comparison to the time spent by unit i at sector j.

Table 4-12 could be updated as required on a real time basis using the CHTIS. One could then account for changes in demand due to weather, emergencies, unforseen non-traffic demands, and so forth.

4.3.4 Conclusions

Under the present state of knowledge, the traffic accident-enforcement action relationships necessary for determining optimal resource allocations do not exist. It is, therefore, necessary to formulate the resource allocation problem such that one seeks only near-optimal allocations of fixed levels of enforcement resources rather than optimal allocations of all Traffic Law System resources. It is concluded that this restricted formulation of the general TLS resource allocation problem is relevant to the cause of traffic safety, provided care is taken to coordinate any resulting policies, strategies, and tactics with other TLS components.

It is further concluded that the CHTIS can be of considerable help in solving this problem by providing raw, refined, and derived resource allocation information to the decision maker. The raw and defined information would assist them in identifying risk and in setting up enforcement priorities, while the derived information could be used in selecting preferred enforcement techniques and in assigning patrol units to achieve lower levels of over all traffic accident disutility.

Several decision making models have been identified as useful in determining better ways of allocating enforcement resources. The familiar proportional allocation scheme could be used immediately in assigning patrol units. With appropriate extension, the technique can be used to devise patrol unit assignment schedules that utilize minimum time, distance, or cost routings between patrol sectors and that account for variation of availability and cost among patrol units. The CHTIS could provide essential input information to perform the necessary calculations and to maintain viable schedules.

4.4 Considerations in Developing Traffic Safety Public Education Programs

The preceding sections have discussed that part of the project effort that was devoted to developing a risk information capability for traffic law enforcement agencies. This section discusses the uses which the CHTIS might serve in educating the general driving public about matters related to increased highway safety. The data generated by the CHTIS, in conjunction with an organized educational effort, can provide a sound basis for the design of a functional public education program.

4.4.1 Public Education and Risk Management

Generally speaking, education is a means of creating behavior that meets predetermined standards and objectives. In the case of the Highway Transportation System (HTS), public education is a means of influencing driver behavior so as to increase highway safety and improve traffic flow, thus promoting the objectives of the Traffic Law System (TLS). Thus, public education, as was noted in Section 2.0, is an essential element of the HTS risk management process.

Three major objectives are suggested for such a public education program:

- Improve the public's perception of risk.

- Win the public's active engagement in managing risk through a change in their driving behavior.
- Encourage the public to pressure and to support the TLS and the HTS for changes which will reduce risks.

A public education program aimed toward the accomplishment of the objectives should emcompass the following five phases:

- Analysis of the public.
- Identification of desired behavioral changes.
- Preparation of the message.
- Determination of appropriate media.
- Evaluation.

Each of these five phases is discussed briefly below.

4.4.2 Analysis of the Public

An analysis of the driving public must be conducted in order to identify the groups that are responsible for the risks, are affected by the risks, and are able to reduce the risks.

The public can be identified on two levels of detail. At the first level such driver groups as commuters, students, tourists, drinkers, truckers, and so forth, can be identified through studies of their driving habits and motives. At the second level, one can develop within these large groups, more specific categorizations of driving habits. For example, within the student group are commuting college students, high school students driving around the local root beer stand, and so forth. Among the worker group are factory workers, university employees, businessmen, and so forth.

In Monroe County, the southbound traffic on highway 37 consists of local traffic, commuting traffic, and transients. A breakdown of the local traffic would identify such groups as residents, students, and businessmen in each town between Bloomington and Bedford. Analysis would undoubtedly show considerable consistency among these small groups from town to town and would probably indicate that the same educational information would be applicable to all of them. The transient traffic (e.g., tourists, truckers, and salesmen) would be expected to vary seasonally. In the summer, the total volume of traffic measured at the sensor sites increases significantly during holidays and vacation months so that educational information aimed at tourists would most likely be ineffective in a month such as January. On the other hand, survey data might indicate that most of the truckers are working for a few companies centered in Indianapolis and that they consistently utilize on south 37 the year round. Factory workers might be identified as commuters from local manufacturing firms, and so forth.

The analysis of the public can be as specific or general as is required for cost-effective identification of the targets of the education program. Whatever its extent, the analysis is essential, since it provides the educator with his first indications of the requirements for communicating with the target groups.

4.4.3 Identification of Desired Behavioral Changes

Once the actual sources of the risk-generating behavior are identified, specific behavioral changes must be initiated in order to reduce the risks. Generally, two kinds of changes are sought: first, the public must change its own driving behavior and, second, it must apply pressure to the TLS to reduce the risk-generating behavior of others.

For example, to influence favorably commuter traffic on Indiana State Route 37, some quite specific behavioral changes must be achieved. Public pressure on the TLS to reduce the risk of tailgate accidents during the rush hour and to increase the convenience of traveling home at that hour might be manifested in the following behavior:

- Individual drivers or groups of drivers asking their unions to negotiate with the industries for staggered schedules among the three industries.

- Lobbying done on the state level for a four lane highway from Bloomington to Bedford.

Direct behavioral changes in one's own driving habits might include:

- Forming car pools to reduce traffic volume.

- Driving alternate routes.

- Refusing to tailgate when traffic is heavy.

- A driver allowing a passenger to drive when the car owner is intimidated by the traffic.

Identification of these specific behaviors make possible the preparations of effective messages to inform the public of needed action for risk reduction and help to suggest specific actions for reducing risk.

4.4.4 Preparation of the Message

At this point, the educator has defined the nature of the risks, the source of the data describing the risk, and the necessary behavioral changes which must be stimulated in order to reduce the risks. He must now define the information that will generate these changes in the target group.

This information is provided by:

- The CHTIS (flow and accident data).

- Audience analysis.

- Analysis of interrelationships between flow, accidents and the audience.

For example, the educator may determine that a driver travelling highway south 37 on weekdays between 4:30 and 6:00 p.m. faces a high risk of tailgating accidents, and may find that the people primarily responsible for this risk are commuting workers from three Bloomington firms. He knows there will be no new highways built in five years, that the alternate routes south are inadequate for daily travel, and that the people generating the risks are not going to stop driving to work. The educator may, therefore, decide that his message should generate (1) group action that will lead to the rescheduling of work traffic until a better highway can be built, and (2) individual action to reduce the traffic volume by joining car pools to reduce risk by driving more safely in the existing traffic situation. The message designed to achieve these behavioral changes might inform the target group that (1) the risk is caused by tailgating and by inappropriate speeds; (2) group action could achieve rescheduling of working hours; (3) employers need specific kinds of pressure such as.....; and so forth.

The educator's message will always be determined by a careful identification of the nature of the risks, the sources of the risks, and the behavior changes which can reduce the risks. The educator necessarily must analyze data relating to all of these areas in order to design information which will achieve the desired results.

4.4.5 Determination of Appropriate Media

The means for delivering the educational information are of critical importance. If the media are inappropriate to the audience, the public will remain uninformed and unresponsive and will not be motivated to diminish the risks. If, for example, the target group is composed of teenagers, professional journals are obviously not going to reach them, but film at the local drive-in theaters might. In the case of workers who commute on highway 37, the most cost-effective medium might be the spoken word at union meetings, and in sessions with their employers. If the public needs evidence that the problem can be eliminated by their actions, film or graphs generated by the CHTIS could be used.

The media are frequently used inappropriately with little regard for the audience's needs. To be used effectively, CHTIS information would have to be made compatible with the media and translated into terms that are relevant and comprehensible to the public. Newspaper columns, for example, have little relevance if the raw computer data are printed with no explanations.

4.4.6 Evaluation

Evaluation allows one to determine whether or not the behavioral objectives have been accomplished, and if not, evaluation is the key to reorienting the education program so the objectives can be met. The two most important principles in public education evaluation are (1) that it be provided for in the initial planning stages of the program and (2) that the actual evaluation process be carefully specified. In terms of the present problem, this means deciding how to monitor risk generating behavior and how to interpret the monitoring information as an indication of the program's success or failure.

The data generated by the CHTIS are uniquely useful for evaluation because they provide a quantitative measure of driver behavior under actual operating conditions. The mathematical measurements of traffic flow data can be replicated in pre-test and post-test conditions, and traffic volume, vehicle velocity, and other factors related to driver behavior can be determined before and after the education program.

In the case of Monroe County, an educational program to reduce tailgating and traffic density on south 37 might be evaluated by

determining whether or not the traffic flow decreased in volume at the rush hour and whether vehicles traveled in close proximity to one another at high speeds. If the manufacturing firms staggered their shifts, the sensor site data could be used to indicate possible decreases in passenger car volume, and so forth.

When specific data (e.g., CHTIS data) are to be used to measure changes in behavior the evaluation effort must be planned in conjunction with the definition of education program objectives. Better overall education program results may be expected from a properly planned evaluation program.

4.4.7 Conclusions

The public education program for traffic safety should be designed in a systematic way according to well-established principles. With the CHTIS, public education becomes an extremely important tool for risk management. Proper utilization of that tool requires that one:

- Identify the risk--analyze the data.
- Identify the sources of risk--analyze the public.
- Identify the groups which are causing specific risks and groups that can reduce the risks.
- Determine what changes in the audience's behavior are necessary to eliminate the risks.
- Determine what media are cost-effective and appropriate for the selected audiences.
- Determine what evaluation can be achieved, how it can be accomplished, and how it can be used.

5.0 CHTIS IMPLEMENTATION AND EVALUATION

5.1 Introduction

This section of the report describes in summary form the CHTIS configuration that was implemented in Monroe County, Indiana, and presents a brief evaluation of the system's effectiveness in accomplishing the following objectives:

- Primary Objective - Provide, under operational conditions, useful traffic risk information to a local law enforcement agency.

- Secondary Objective - Reduce overall traffic accident risk in the jurisdiction covered by the operational CHTIS.

The operational phases are described first in terms of overall characteristics of the implemented CHTIS and the agencies serving simultaneously as users and components of the system. A general description is then provided of the sequence of events involved in implementing and testing the CHTIS. Evaluation procedures and findings are presented, assessing the extent to which both system objectives were attained. This is followed, finally, by a general discussion of evaluation findings regarding the impact of the CHTIS upon resource allocation procedures and upon traffic accident risk.

5.2 Summary Description of the Implemented System

The CHTIS traffic flow subsystem described in Section 3.0 above was fully implemented in the indicated locations, and involved the police and university agencies specified, in Monroe County, Indiana. Monroe County is located approximately 50 miles southwest of the City of Indianapolis in south-central Indiana. It is 410 square miles in area, and its population, according to the 1970 Census, is 83,908. The county seat is Bloomington, population 43,188, which is the home of the main campus of Indiana University. The area is physically composed of gentle, rolling hill land, for the most part. In terms of surface and geometry, its roadways are representative of all types, excepting Interstate highways, expressways or freeways. In 1969, some 2,227 accidents were reported by the law enforcement agencies of the City of Bloomington and Monroe County, and by the Indiana State Police. Within Monroe County, some 29,749 passenger vehicles and 7,207 trucks were registered in 1970 to County residents. In addition, some 12,501 vehicles were registered to University faculty and students, many of whom were non-residents.

Risk information generated by the CHTIS was fed to the Indiana State Police Post no. 33 serving Brown, Lawrence, Morgan, and Monroe Counties, and located in Bloomington, Indiana. This post employs 41 persons, 38 of whom are sworn law enforcement officers, and the remainder civilians. The sworn contingent is composed of four line commanders, specialists, two detectives, and 28 troopers.

Risk information generated by the CHTIS was provided to personnel at the State Police Post in the manner illustrated in Figures 4-1 through 4-4 in Section 4.1.1.1 above. Information was thus provided via cathode ray tube image and hard-copy computer printout, covering the following traffic flow/risk variables for each loop site continuously on a 24-hour basis:

- Direction, speed, length, headway, and time of loop crossing for all individual vehicles.
- Counts of total vehicle and of total police vehicles crossing loop.
- Totals and percentages of speed violators observed, within one, five, and 10 miles per hour above posted speed limit.

Thus, as described earlier, police personnel were able to use the implemented CHTIS to obtain on-line information concerning traffic behavior at any selected loop in either lane of traffic, and were provided daily summary reports on speeding violations and headways at all 50 loops.

5.3 Implementation Schedule

CHTIS implementation and testing activities were completed according to the following major milestone dates:

- Expanded computer sensor system installed and tested 3/71.
- CRT installed at State Police Post 9/71.
- Regular violation summary printouts provided State Police Post 11/71.

5.4 Evaluation Results

5.4.1 System Impact on Resource Allocation Procedures

In this section, evaluation findings are provided concerning the first objective of the CHTIS: "Provide, under operational conditions, useful traffic risk information to a local law enforcement agency."

Here observations and opinions gathered from Indiana State Police officers who used the Monroe County CHTIS are reported and summarized. As users of the traffic flow information generated by the system, these officers' subjective assessments of CHTIS effectiveness provide valuable insight into "real-world" aspects of using such a system to reduce accident risks and improve allocation efficiencies. Their reports are grouped according to five general categories of information: how the CHTIS was actually used to allocate State Police vehicles; cost/benefit considerations; attitudinal and morale factors; other impact considerations; and overall evaluation conclusions reported by these CHTIS users.

5.4.1.1 Description of Allocation Procedures Used

Prior to implementation of the CHTIS, patrol duty routes and schedules were assigned on a fairly arbitrary basis, with emphasis upon covering those highway stretches with previously-identified high accident rates. Without either real-time or summary data on speeding or headway violation rates, allocation was largely a "cut-and-dry" procedure; the general strategy was to cover as much territory as possible with the manpower and vehicles available, in hopes of creating a general appearance of police presence and availability.

Once traffic flow data became available through the CHTIS cathode ray display and regular hard-copy printout summary reports, State Police officers put this information to immediate use in allocating their vehicles and manpower where they felt they would have the greatest impact upon violators, and, consequently, they assumed, upon accidents.

In particular, it was found that the hard-copy printout summaries of loop data were the most useful in identifying highway stretches in need of patrolling. Command officers would typically take these daily summaries of speeding violation rates home in the evening for careful study. In the morning, they would identify locations with high violation rates, and let the patrol officers on duty select areas they particularly wished to patrol that day, during the hours violations were most likely to occur. Emphasis was placed upon areas where posted speed limits were exceeded by 10 mph or more, for officers felt these drivers were in greatest danger of accident involvement.

At times, definite assignments were made, when it was apparent that high-risk situations might not otherwise be patrolled. For example, when it was found that violation rates on a particular highway were high during lunch and dinner hours, officers in that area were requested to patrol during these hours and to defer their lunch or dinner until later.

The CRT on-line display was used to a lesser extent, and in slightly different ways, from the way summary printouts were used. Officers would frequently come into the State Police Post before going on duty or before changing shifts to query the CRT regarding violation rates and traffic counts on a particular loop site or highway to confirm predictions made by summary printouts from previous time periods. Also, headway data was checked more frequently on the CRT than on summary printouts, in determining whether or not to allocate radar cars to particular locations. When headways were small and cars closely packed, as on Sundays, radar cars could not effectively be used to arrest speeding violators, since it was more difficult to obtain radar speed readings and to identify particular vehicles under such conditions. Thus, when the CRT display indicated violations were up and headways down, the decision could easily be made to send radar cars elsewhere, and to send regular patrol vehicles instead to such locations. Finally, the CRT was used occasionally to identify accident situations. When traffic speed dropped severely at a particular location, it was assumed an obstruction of some sort was causing the slowdown, and a patrol vehicle might be dispatched to investigate the possibility of an accident, even before the accident was actually reported.

In making allocation decisions, State Police officers thus tended to depend more heavily upon speed and traffic volume data than upon headway data. It was noted that this was true in part because headway violations were difficult to enforce and prosecute in court, and partially because officers felt speeding violations under heavy traffic conditions created more accident risks than did headway violations. Regarding actual allocation strategies, the usual procedure of sending separate police units to separate patrol locations was followed during September, October and December of 1971. During November of that year, a new strategy was tried, involving the use of concentrated patrols or "wolf packs". These consisted of sending a number of police units to a particular patrol

location at particular times identified by the CHTIS to be associated with high speed violation rates. These runs would each last for a number of hours, and as many citations and warnings as possible were issued, in hopes of reducing accident risks at these sites.

5.4.1.2 Cost/Benefit Considerations

When asked subjectively to estimate possible savings the CHTIS could make possible for the State Police Post, officers emphasized that considerable savings were possible, and that their own effectiveness in reducing accident risk would certainly improve if a CHTIS were provided them on a permanent basis. In particular, officers felt the number of patrol cars used could be cut by 50 percent, provided the remaining units were allocated using a CHTIS at the Post. They also were certain that patrol effectiveness and arrest rates could be increased very significantly if a CHTIS were permanently available.

The CHTIS in its test configuration included 50 separate loops. Officers felt they really needed, and could effectively use only one loop for each major highway segment leading into or out of Bloomington, insofar as general allocation procedures were concerned. It was also noted, however, that having other loops nearby might be a help, in case a loop on one particular highway segment was temporarily out of commission, and a backup loop was needed.

Regarding particular police units, officers suggested that expensive radar units might be replaced by normal patrol cars equipped with mobile teleprinters. When tied into CHTIS, such teleprinters could provide instantaneous records of the speeds of vehicles passing over particular loops. When parked close to these monitored loops, patrol cars could accurately identify speed violators and make selective speeding arrests with a high degree of efficiency.

5.4.1.3 Attitudinal and Motivational Factors

It was in the area of attitudinal and motivational factors that State Police officers felt the CHTIS had especially marked, immediate impact. Troopers responded positively to being given the opportunity to pick their own patrol locations, based upon summary volume and violation reports provided them. They tended to see this as an opportunity to assume an active rather than a passive enforcement role, and as a chance to really be "where the action was," i.e., where violations were occurring, and where accident risk might effectively be lowered by their presence.

To the extent that trooper performance was equated with arrest and citation rates, officers got a boost out of seeing their on-duty performance improve. Supervisors, too, felt the CHTIS provided them a tool which could eventually be used to set meaningful performance standards, such as minimal "contact" rates expected of officers patrolling highways with known violations rates.

Since the CHTIS in its test configuration made it possible to identify police vehicles as they passed over loops, it became clear to officers on duty that their locations could be monitored, and that it would be possible for their supervisors to check to see that they were actually patrolling those locations. In short, supervisors felt this kept patrol units "on their toes," whereas it might have been difficult otherwise to monitor compliance with patrol assignments. Actually, no attempts were made to monitor patrol car compliance with assigned routes and schedules, since the number of patrol vehicles was small, and the effort and time required to track patrol vehicles in this fashion of dubious benefit.

5.4.1.4 Other Impact Considerations

It was noted that one advantage associated with the CHTIS in its current configuration was that of a high degree of system security. Loops in the road were almost invisible to traffic, and the relay equipment boxes mounted on telephone poles were unobtrusive. Officers felt that unless loop sites were identified publically, they would be likely to be safe from vandalism or sabotage attempts.

Regarding the accuracy and reliability of loop data provided by the CHTIS for allocation purposes, officers were highly pleased to find that when the system said violations of a certain kind and degree were present at a certain location, they were, indeed, present when they arrived at the scene; when the CHTIS said something was so, it was so.

5.4.1.5 Overall Evaluation of Impact on Police Activity

In summary, State Police officers interviewed praised the CHTIS to a high degree. One said it was the "best of all tools," another that it was the "best thing in 20 years of being a police officer."[1] They reported that during the test period they had come to depend upon the CHTIS for virtually all scheduling and allocation activities; and that they missed it sorely when it was dismantled at the termination of the present contract. The suggestion was raised that if a CHTIS was helpful to this degree in a county of the size of Monroe

(1) Appendix A contains a letter from Indiana State Police officials expressing this belief and other thoughts on the usefulness of the CHTIS.

County, Indiana, it might prove even more valuable if used to monitor and control accident risk through violation enforcement on large-city arteries, freeways, and so on. Officers suggested, finally, that enforcement personnel could appreciate the power and usefulness of a CHTIS only after having actually worked with one, and that only after one has been exposed to such a system could he see its immediate and long-range benefits.

5.4.2 System Impact on Traffic Accident Risk

In this section, evaluation findings were presented concerning the second objective of the CHTIS: "Reduce overall traffic accident risk in the jurisdiction covered by the operational CHTIS." Here, objective data on CHTIS effectiveness are intended to supplement subjective findings summarized in Section 5.4.1 above. In particular, data presented in this section are intended to reflect changes in accident statistics and police enforcement activity levels during the time the CHTIS was operational, as compared with the same months during the previous year.

Evaluation measures are thus examined in a before-and-after fashion for the months of September through December 1970 and 1971; the 1971 months represent test months, i.e., the period during which the CHTIS was implemented and used by the State Police Post in Monroe County. 1970 months were selected to serve as "control" months in order to nullify seasonal variations in accident rates.

Nine evaluation measures are examined, and are defined as indicated for the time periods involved:

- Total Accidents: Sum of all fatality, personal injury, and property damage accidents in Monroe County.
- Fatal Accidents: Total accidents in which at least one driver or passenger was killed.
- Personal Injury Accidents: Total accidents in which at least one driver or passenger was injured. (no fatalities)
- Property Damage Accidents: Total accidents in which at least one vehicle was reported damaged (no injuries or fatalities).

- <u>Dollar Cost of Accidents</u>: Total cost of total accidents computed according to the following formula:

  Cost = Fatality Accs. x $35,000
  + Personal Injury Accs. x $3,500
  + Property Damage Accs. x $300

- <u>Total Citations</u>: Total speeding tickets State Police officers gave drivers.

- <u>Total Warnings</u>: Total warning certificates State Police officers gave drivers.

- <u>Total Patrol Manhours Scheduled</u>: Total hours State Police officers were scheduled to be on patrol.

- <u>Average Citations Per Patrol Manhours</u>: Total citations divided by total patrol manhours scheduled.

5.4.2.1 Impact on Accident Rates and Costs

Accident rate and accident cost statistics for test (1971) and control (1970) months are presented in Table 5-1.

<u>Total accidents</u> were generally higher during 1971 than 1970 months, except for a slight drop in December of the test year, 1971. During the month of heaviest State Police use of the CHTIS, November of 1971, total accidents reached their highest level, making it difficult to attribute to the CHTIS any obvious effect on accidents <u>per se</u>. Monthly averages covering test and control periods also show higher total accidents averages during the test year.

<u>Fatal accidents</u>, however, showed a decrease during the test period, with a drop in average fatal accidents from 1.7 to 0.5 per month. Since the number of monthly fatal accidents in Monroe County is typically very low, this drop may be difficult to attribute to CHTIS influence. It is of interest to note, however, that during the two months of heaviest Police-CHTIS activity, November and December of 1971, no fatal accidents were reported.

<u>Personal injury accidents</u> also showed a slight average decrease; note, however, that breakouts of this type of accident were not

TABLE 5-1: Accident and Police Activity Statistics For Monroe County During Test (1971) And Control (1970) Months

Evaluation Statistic	Month					Average Per Month Examined
	Year	Sept.	Oct.	Nov.	Dec.	
Total Accidents	1970 1971	198 221	196 260	198 294	202 181	198.5 239.0
Fatal Accidents	1970 1971	2 1	0 1	3 0	4 0	1.7 .5
Personal Injury Accidents	1970 1971	67 50	53 74	60 32	66 (NA)	60.0 52.0
Property Damage Accidents	1970 1971	129 170	143 185	135 162	132 (NA)	134.7 172.3
Dollar Cost of Accidents (1)	1970 1971	342.2k 252.2k	228.4k 261.0k	335.5k 349.5k	410.6k (NA)	329.2k 287.6k
Total Citations	1970 1971	113 118	106 133	121 656	110 388	113.3 302.3
Total Warnings	1970 1971	(NA) 157	(NA) 177	(NA) 874	(NA) 267	(NA) 368.7
Total Patrol Manhours Scheduled	1970 1971	520 313	495 363	592 478	711 1,389	579.5 635.7
Av. Citations Per Patrol Manhour	1970 1971	.2 .5	.2 .6	.2 1.4	.2 .3	.2 .7

(1) See Text: Figures Are in Thousands of Dollars

(NA) = Not Available

available for December, 1971, at the time of publication. During November of 1971, roughly half as many personal injury accidents occurred as during the corresponding month in 1970.

Property damage accidents appeared untouched by CHTIS and State Police activity during test months, and were at uniformly higher levels for 1971. Insofar as these accidents tend to occur within the city limits of Bloomington, rather than on the State Highways monitored by the CHTIS, it is less likely that system activity would have affected accidents of this type.

Dollar cost of accidents, computed according to the formula cited in Section 5.4.2 above, showed an average decrease during test as compared with control months. This statistic is strongly affected by fatal accidents, however, and this should be taken into account in comparing differences between control and test months accident costs.

5.4.2.2 Impact on Citation and Warning Rates

Citation and warning rates are also presented in Table 5-1, comparing reported figures for test and control months of 1971.

Total citations went up markedly during the test months of 1971, reaching a peak in November, when the CHTIS was put to heaviest use in allocating police vehicles. The average citations per test month was almost three times that for control months, indicating the usefulness of the CHTIS in determining where speed violations are occurring, and in allowing police officers to make arrests at these locations at times of peak violations rates.

Total warnings also rose sharply from September through November of 1971, but 1970 statistics on warning rates were not available for purposes of comparison.

Total patrol manhours scheduled went down during the first three months of the test period, indicating what may have been more selective use of available manhour resources during these months of CHTIS operation. When normal allocation procedures were resumed in December of 1971, the manhours went up again.

Average citations per patrol manhour went up as expected during the test months, reaching a peak in November, where the seven times as many citations were given per manhour as were given during that month in 1970. On a cost/benefit basis, it may be that risk reduction through citation activity was considerably increased by the

CHTIS, even though overall accident rates may not have been as directly affected for the county.

5.5 Conclusions

It is clear that the CHTIS implemented in Monroe County had a considerable positive impact upon the activities of the State Police Post using the system. They felt the system was a valuable asset, both in determining where and how police units and manhours were to be allocated so as to increase arrests and warnings and to decrease accident risk, and in motivating officers to take an active, responsible and enthusiastic role in patrol and risk-reduction activities. To this extent, the first evaluation objective, that of developing and implementing an operationally useful risk information system for an enforcement agency, was successfully achieved. In particular, officers found hard-copy printouts summarizing volume and violation rates to be most useful in determining where police units should be allocated. On-line CRT readings of traffic characteristics were useful mainly in confirming predicted allocation needs.

Due to the shortness of the test period, i.e., the four months during which the CHTIS was fully operational and was available for use by the local State Police posts, it is more difficult to determine its impact upon accident and violation rates in the county. Available data indicate possible reductions in rates for certain types of accidents, but not for accidents taken as a whole, during these months. However, police efficiency in identifying and stopping speeding violators was, on the whole, greatly improved during the months of greatest CHTIS allocation activity. To the extent that speeding arrests and warnings may help reduce traffic accident risk, the second evaluation objective was achieved to some degree: the risk information system implemented may have made some impact upon overall levels of accident risk. Further evaluation data of this sort must be obtained if definite risk-abatement assessments are to be made.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The main conclusion of the project is that the Computerized Highway Traffic Information System implemented in Monroe County, Indiana, is a highly useful tool for law enforcement agencies in performing the primary functions of traffic risk management, i.e.:

- Risk identification.
- Risk analysis.
- Resource allocation.

In contrast to many decision-making aids developed in the past for the police, the CHTIS was readily and enthusiastically accepted for operational use and quickly became a part of police daily routine. A major reason for the highly favorable police response to the CHTIS as an operational tool, was that it provided the means to focus their attention on what they apparently perceive as their primary role in the Traffic Law System: i.e., enforcement of the existing laws which they believe to be the most risk-related. The CHTIS provided the police, for the first time, with a <u>direct</u> indication of where and when enforcement actions were needed and a <u>direct</u> means of evaluating their own performance as a component of the Traffic Law System. It was not necessary for them to base their actions and self-evaluations on abstract, incomplete, and operationally impractical concepts of the relationship between enforcement and accidents. Thus, they were better able to practice what they perceived to be meaningful law enforcement <u>per se</u>.

The CHTIS outputs found most useful to the police under actual operating conditions were the hard-copy reports showing the speed limit violations at the various sensor sites. Reports showing headway conditions were used, too, but less frequently. The use of the headway data was related mostly to speed limit enforcement: low values of headway were interpreted to be indicative of high-density traffic conditions not conducive to speed limit enforcement, and so forth. The cathode ray tube (CRT) displays were greatly in demand when first implemented, but were used less after the hard-copy reports became available.

Techniques and procedures were developed for disseminating detailed county-wide accident information to county law enforcement agencies. The information is presented in the form of an Accident

Data Handbook, since it was not provided to the user in the present project. It is believed, however, that accident data would not, in general, be as readily accepted as a law enforcement tool as would the CHTIS traffic flow data because of the more indirect relationships that exist between enforcement actions and accidents.

The investigation of the applicability of certain operations research techniques for analyzing and improving resources allocation schemes for traffic law enforcement agencies leads to the conclusion that optimal resource allocation procedures cannot be specified at present. The primary deterrent to obtaining optimal solutions to the police traffic resource allocation problem was found to be a lack of suitable analytic or empirical expressions relating traffic accident risk to traffic flow variables. However, it is believed that decision-making models can be used to assist traffic law enforcement managers in selecting preferred enforcement techniques and in assigning patrol units. Specifically, the techniques of dynamic programming and linear programming, used in conjunction with a CHTIS, appear particularly promising for determining better proportional allocation schemes.

6.2 Recommendations

While the present project clearly demonstrates the operational feasibility of a CHTIS as a traffic law enforcement tool, considerable work remains to be done to move the system to a fully operational status for a broad spectrum of applications. Two immediate steps in this direction are recommended. First, there is a need to continue operation of the system in a real-world environment over a multi-year period. Such an operation would provide, in effect, an advanced traffic resource allocation laboratory which would allow one to investigate such important factors as:

- The precise manner of functioning of the police decision-making process in allocating traffic services.
- Better information outputs for both police agencies and the public.
- The effectiveness of the CHTIS and its subsystems in promoting overall Traffic Law System risk reduction objectives.

A priority project of such a laboratory would be to develop, implement, and test a detailed, computerized resource allocation model based on proportional allocation theory and employing the techniques of dynamic programming and linear programming. The model would utilize information provided by the CHTIS traffic flow and accident subsystems and would establish, within the CHTIS, an operational analysis subsystem.

The laboratory could also be used to develop a compendium of law enforcement action effects on traffic flow in the model jurisdiction. The compendium would show how specific enforcement tactics would be expected to affect traffic flow spacially and temporally throughout the jurisdiction and would thus provide a basic input data to the resource allocation model.

Concurrently with the operation of the model CHTIS, studies should be undertaken to develop a methodology for determining the most cost-effective CHTIS configuration in a given jurisdiction. The results of these studies should be presented in manual form containing suitably detailed implementation guidelines for distribution to governor's highway safety representatives and should be made available, along with suitable technical data packages, to jurisdictions desiring to implement the system.

During its nearly three years of operation, the CHTIS (formerly known as the computer sensor system) has generated traffic flow data involving more than 200 million motor vehicles under an extremely wide variety of operating conditions. This unique data base offers almost endless possibilities for analysis of the nature of traffic flow. Combined with accident data available from the Indiana State Police accident ta;es and data from IRPS's multidisciplinary and tri-level crash studies, the data could be used to study in unprecedented detail relationships between traffic flow, accidents, and environmental factors.

It is therefore recommended that an extensive program to analyze the CHTIS traffic flow data be initiated. First, the present CHTIS data tapes must be converted to a form suitable for such analysis. This would be followed by statistical studies of environmental effects on the traffic flow and finally by analyses of interactions between the variables describing accidents, flow, and the environment. The results of these studies would make a significant contribution to strengthening the weakest link in the chain connecting enforcement to traffic accident risk, i.e., the specific identification and definition of risk generating behavior. Satisfactory completion of this task, coupled with a detailed statement of the effects of enforcement on risk-generating behavior, will allow the definition of really meaningful resource allocation procedures.

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APPENDIX A

LETTER FROM INDIANA STATE POLICE OFFICERS TO INSTITUTE FOR RESEARCH IN PUBLIC SAFETY

STATE OF INDIANA

INDIANA STATE POLICE

INDIANA STATE OFFICE BUILDING
100 NORTH SENATE AVENUE

INDIANAPOLIS, INDIANA 46204

April 10, 1972

Mr. Ralph K. Jones
Associate Director
Institute for Research in Public Safety
400 E. Seventh St.
Bloomington, Indiana 47401

Dear Mr. Jones:

Now that your computer-sensor system demonstration study is over, I believe it appropriate to offer a few comments on the system's usefulness in traffic law enforcement.

First, let me say outright that this is the best tool for conducting traffic operations that I have seen in 20 years of being a police officer. It allowed us to determine at a glance where the most dangerous locations were and to take appropriate actions to bring those situations under control. We found the level of detail provided by your system and the timeliness of the date to be particularly useful in this respect. In the past, we have had to rely pretty much on accident data summaries to help us determine where and when we ought to be concentrating our traffic law enforcement activities. Unfortunately, the accident data we receive lags the current date by several months and is not broken down fine enough (that is, by location and time) to be of much use in every day work. With the computer-sensor system, we were able to determine almost immediately where hazardous conditions were building up so that we could do something about them before they got out of hand.

Also, as a result of working with your system, we have begun to do some experimenting on our own to apply some new law enforcement tactics in our jurisdiction. Because of the limited resources we have available for traffic law enforcement, the concentrated patrol technique, applied selectively, has always appeared attractive to us. Our problem in applying this approach has been the precise identification of the places and times to assign our troopers. The computer-sensor system has allowed us to overcome this problem, and, as a result, we are now implementing an extensive concentrated patrol program in our jurisdiction.

Mr. Ralph K. Jones

Finally let me say that it has been a pleasure working with the IRPS team in this study. My only regret is that we no longer have access to the system now that we have come to rely on it so heavily. I feel that we have only scratched the surface in applying this system and that the real benefits are yet to come. Nevertheless, from what I have seen, I would heartily recommend it for any law enforcement agency interested in improving its traffic safety effort. Needless to say, our Post would welcome the opportunity to participate in any further applications of the system.

Sincerely,

Forrest V. Cooper

Forrest V. Cooper, Lieutenant
Commander, Bloomington District #33

James Graves

James Graves, First Sergeant
Bloomington District #33

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