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MAXIMUM SPEED LIMITS

A Study for the Selection of Maximum Speed Limits

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ABSTRACT

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A STUDY FOR THE SELECTION OF

MAXIMUM SPEED LIMITS

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SUMMARY

This report documents work conducted by the Indiana University Institute for Research in Public Safety under sponsorship of the National Highway Safety Bureau of the U.S. Department of Transportation to recommend a method for establishing maximum speed limits that could be widely implemented utilizing existing technology and manpower resources.

The research plan includes an extensive review of existing research literature, an evaluation of identified methods, collection and analysis of data utilizing a Computer-Sensor System to validate existing methods, and the development of a programmed instruction text to implement the recommended method.

The literature review considered more than 300 documents relating to the history of speed limits; the relationship of speed and speed limits; driver speed behavior and variables, other than speed limits which influence it; the relationship of speed, speed limits, and accidents; and methods for establishing speed limits. The review revealed three major approaches to establishing speed limits, one based on measure of prevailing vehicle speeds, another based on characteristics of the speed distribution, and a third based on cost.

A national survey of practices used by states and cities to establish maximum speed limits was conducted to determine existing methods, technical resources, and the manpower involved in establishing speed limits. Questionnaires were sent to traffic engineers of all state highway departments, all cities over 100,000 in population (130), and 52 selected cities with populations under 100,000. The response (88%) indicated that the following items were most frequently considered in establishing speed limits:

* 85th percentile
* ball-bank indicator data
* accident experience
* length of zone and adjacent zone
* design speed
* pace
* spacing of intersections and driveways
* traffic volume
* presence and condition of shoulders
* average test run speed
* presence of pedestrians
* traffic signals and controls

The survey also showed the general availability of radar, vascar, ball-bank indicator, and vehicle counters to measure vehicle speed, traffic characteristics, and roadway features.

The various techniques for establishing speed limits identified as a result of the literature review and the survey of jurisdictions were subjected to a screening analysis to identify those methods worthy of further consideration

for full-scale implementation. The analysis revealed these such techniques:

* Taylor's theory of speed distribution skewness
* Oppenlander's cost-oriented approach
* The 85th percentile method

Data collected using the IRPS Computer-Sensor System were analyzed to provide a further basis for selecting a recommended technique from the three identified by the screening analysis. The analysis clearly showed the strong relationship between deviation of the speed of the accident-involved vehicle from the mean speed of the traffic stream. The analysis also showed that the cumulative accident involvement rates were acceptably flat (i.e., independent of speed) until the speed deviation reached a point corresponding to the 85th percentile speed plus rounding and enforcement tolerances, after which it started to rise at a precipitous rate.

The final result of the study effort was to recommend that maximum speed limits be established on the basis of the 85th percentile of travel speeds. Such a limit is:

1. Fundamentally fair in the context of the Traffic Law System.
2. Related to risk of dysfunction in the Surface Road Transportation System.
3. Accepted as reasonable by drivers.
4. Applicable to a wide range of highways.
5. Capable of being implemented with existing resources.

The recommendation of the 85th percentile is supported by a substantial portion of the technical literature as well as by the data and analyses of the present study.

The final project report is presented in four volumes. Volume I contains the technical portion of the report; Volume II presents an extensive review of the literature; Volume III provides an implementation program for the recommended method of establishing a speed limit; and, Volume IV contains a condensed explanation of the recommended method for the experienced traffic engineer.

1.0 INTRODUCTION

This is the final report of research on establishing speed limits conducted by the Indiana University Institute for Research in Public Safety (IRPS) under contract FH 11-7275 with the National Highway Safety Bureau of the U.S. Department of Transportation.

This report is presented in four volumes. Volume I contains the technical portion of the report including a summary review of relevant literature. Volume II presents an extensive review of the literature concerning speed and speed control. Volume III presents an implementation program for the recommended method of establishing an appropriate speed limit. Volume IV is a brief explanation of the recommended method to be used by the experienced traffic engineer.

This report documents research conducted during the period June 20, 1969 through August 31, 1970.

1.1 General Objective

The general objective of the study was to recommend a method for establishing maximum speed limits that could be widely implemented utilizing existing technology and manpower resources.

1.2 Specific Objectives

The specific objectives of the study were to:

1. Present a comprehensive summary of existing methodology relating to speed control and the establishment of speed limits.

2. Survey state and local jurisdictions to identify current practices in establishment of speed limits.

3. Identify the availability of technical resources (at state and local levels) that could be utilized in establishing speed limits.

4. Develop an operational explanation of the function and objectives of speed limits.

5. Select the best, real-world conceptual approach for the establishment of speed limits.

6. Conduct analytical investigations to validate such concepts.

7. Develop a statistically valid method of establishing speed limits that can be implemented utilizing existing technology and manpower resources.

8. Identify such research as may be necessary to further refine the "state of the art" of speed control and the establishment of speed limits.

1.3 Background

At present there appear to be three distinct methods of establishing speed limits. They are: arbitrary methods, political or constituent pressure methods, and traffic engineering methods.

Arbitrary methods are generally carried out by county highway departments or city street commissions that are handicapped by lack of funds and are generally unable to secure competent personnel. The result of this handicap takes the form of speed limits which are posted by judgment rather than traffic analysis.

Political pressures, such as driver complaints and accident publicity, often indicate that a speed limit should be changed. Such pressures, however, give no means for determining the amount of the change. Political pressures, furthermore, are highly irregular and do not necessarily meet the needs of the traffic.

Speed limits determined by utilizing traffic engineering theory take their impetus from the 85th percentile, pace, and average test run concepts. These methods are rather widely used and are documented in most traffic engineering texts. It should be noted that although these methods are widely accepted the selection of these methods is, in most cases, arbitrary.

Independent of the method used in determining the limit, there are three distinct types of speed limits used in conjunction with a basic speed rule. Every state has a statute covering what is known as the "basic speed rule." The substance of such laws is that a driver shall always operate his vehicle at a speed that is reasonable and prudent under existing conditions.

The three types of speed limits that are used to supplement the "basic speed law" are: absolute limits, *prima facie* speed limits, and advisory speed limits. Of these,

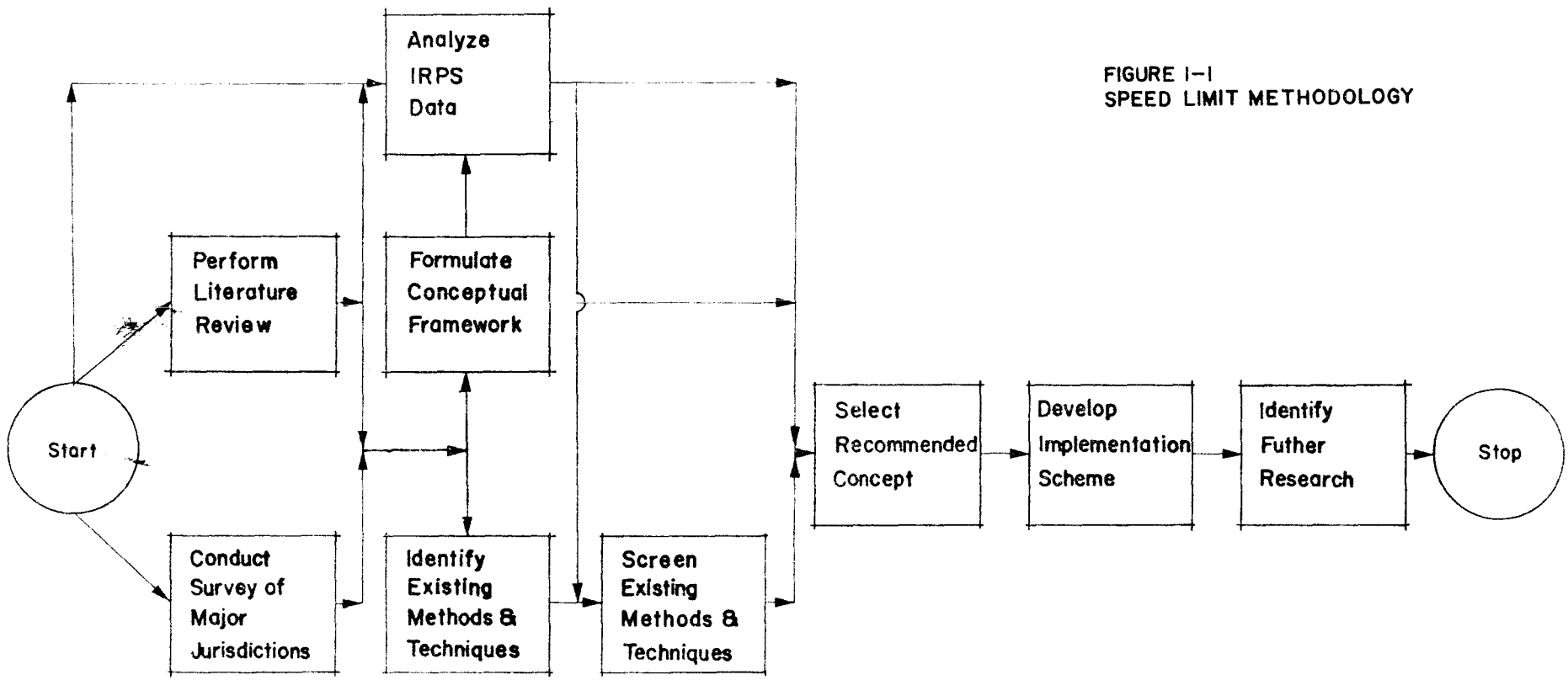

FIGURE I-1
SPEED LIMIT METHODOLOGY

sponsored study conducted by IRPS on "The Effects of Enforcement on Traffic Flow Behavior" were utilized in the analytical phases of this study.

Such data allowed detailed examination of existing speed limit concepts and validation of the recommended statistical method for implementation.

2.0 SUMMARY REVIEW OF THE LITERATURE

This section presents a summary review of selected literature dealing with the subject of speed and speed control in the context of highway safety.

In excess of three hundred publications were reviewed during the extensive literature search conducted for the Optimum Speed Limits study. Several facilities were used during this search, including the National Safety Council, Highway Research Board, and Northwestern University Transportation Center Library, in addition to the Indiana University Library System.

A number of aspects of speed control have been considered. Among these are: the history of speed control; the relationship of speed and speed limits; the variables which influence driving speeds; the relationship of speed, speed limits, and accidents; and methods for setting speed limits.

Detailed results of this extensive search can be found in *Maximum Speed Limits, Volume II, The Development of Speed Limits: A Review of the Literature.* A brief summarization of the body of literature in this area follows.

The following chronology of highlights in the history of speed control in America illustrates the progress that has been made in this area.

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The history of speed limits in the United States dates back to 1678 when speed restrictions were imposed on horses in Newport, Rhode Island (4) European speed control had its effect on American policy, and in 1901 the first speed limit for automobiles in the U.S. was enacted in Connecticut. (6)

Early speed control campaigns were colorful and dramatic. But in addition to the radical denunciations of speed and "speed mania" came more rational arguments supporting the adjustment of driving speed and speed regulations to existing conditions and condemning reckless driving rather than speed, per se.

Along with speed restriction legislation came technological developments for speed measurement. And by the 1920's a need had developed for minimum speed limits in addition to maximum limits.

"...By the 1930's efforts were begun to study speed control and take a more realistic approach to it..." (31) The organized traffic safety movement began in the mid-30's, causing both cities and states to institute rigid accident reduction campaigns, the most notable being Providence, Rhode Island. (63, 65) Already in the late 1930's western states such as Colorado had speed limits as high as 60 mph.

During World War II an effort to conserve gasoline and rubber brought the entire nation under a 35 mph limit. (74) And in 1948 radar became a part of the traffic control system. (80)

Tracing the development of the present day speed limit, it can be seen that many of the ideas which generate controversy today were proposed quite early in the history of automobile regulation.

A study conducted at the University of Illinois in 1947-1948 concluded that traffic ignored speed limits and ran at speeds which drivers considered safe and that most posted speed limits were ineffective because they were unreasonable. (79)

J. Edward Johnston suggested in 1956 that the 85th percentile was reasonable and encouraged uniform speeds. (85)

Since the 1950's several major concepts have prevailed in the controversy over the effects of speed limits on driving speeds. The first is that speed limits have little or no effect -- that drivers ignore them and drive at speeds which they consider reasonable and safe. (95, 96, 98, 104, 105, 109) An opposing view states that speed limits do have an effect (101, 107), however, different studies have shown varying effects, including decreased pace (97), reduction of

excessively fast or slow speeds causing vehicles to travel closer to the same speed (77, 114, 175), and a random effect. (99)

A 1955 book on *Traffic Engineering* explained:

> "For any given road there is an optimum speed limit which will have the greatest effect on spot speed. This value is usually between the 80 and 90 percentile of the free-flowing speed as plotted on a cumulative-frequency curve." (77)

Other articles seem to concur that the 85th or 90th percentile is a reasonable guide for setting speed limits. (81, 99, 113)

It has been stated that absolute speed limits receive the highest observance, while advisory limits are exceeded more often than either absolute or regulatory limits. (90) Urban limits appear to be violated more often than rural limits. (105, 109)

The study of driver speed behavior has illustrated a number of interesting findings.

A 1954 study found that about a third of all drivers exceeded the 85th percentile of the spot speed distribution. If a set of drivers was observed as many as seven times, more than half could be expected to exceed the 85th percentile speed at least once. (116)

A study to investigate drivers' speed perception involved the ability of eight subjects to halve or double their speed.

on command. In this study drivers seemed to underestimate their speed when decelerating and overestimate it when accelerating. (119)

A Los Angeles study to assess the effectiveness of written warnings as compared to citations involved the stopping of motorists who exceeded 40 mph in a 25 mph zone. By following these drivers after citations or warnings were issued, the study found that:

(1) Where a citation was issued, accompanied by no conversation between driver and officer, 32 of 100 cases recorded exceeded the limit again within five miles.

(2) Where a safety message accompanied the citation, 33 of 100 cases exceeded the posted speed within the next five miles.

(3) Where a written warning and safety message were issued in place of a citation, 43 of 100 motorists had exceeded the limit within two miles and 22 more within five miles, for a total of 65. (122)

Numerous publications discuss the factors which affect speeds. The following factors and relationships have been identified:

Studies of driver variables found that speed increased with trip distance (126, 136, 138); non-local vehicles traveled faster than local vehicles (138, 139, 143, 144, 145); male drivers drove slightly faster than female drivers (136, 137, 143, 145); and, drivers with passengers in the car drove slightly slower than those without passengers (137,

144, 145). Other driver variables which influenced speeds were expected arrival time (146), frequency of road use (1[illegible] opinion of the speed limit (146), and amount of driving connected with the driver's work (146).

Vehicle variables showed that vehicle type (137, 138, 139, 143, 145) and age affected speeds with newer cars traveling faster than older ones (126, 136).

Among the roadway variables cited were: functional classification of road type (137), surface type and condition (137, 138, 140, 142, 147), number of lanes and lane width (129, 137, 138, 140, 142), lane position (137), median type (139, 147), access control (137, 139, 142), frequency of intersections (137, 139, 140, 147), shoulder width and condition (140, 142, 147), and design speed (147). Other factors identified include geographic location (137), sight distance (137, 138, 139, 140, 142, 143), curvature (137, 138, 140), gradient (137), length of grade (137, 140), lateral clearance (137, 142), horizontal and vertical resistance (138, 143), marginal friction (138), vertical and horizontal alinement (142), traffic signals and control devices (140, 142, 147), parking (140, 147), and presence of pedestrians (140, 147).

Traffic variables shown to affect speeds were volume (129, 130, 138, 140, 142, 147), passing maneuvers (137).

opposing traffic (137), and percentage of commercial vehicles (137, 142, 147). A study also indicated that vehicles in each lane tended to adjust their speed to the speed of the slower parallel lane (107).

A study of environmental factors which affected speeds found that objects on the road shoulders had little affect on speeds unless the lane widths were less than 20 feet (132). Other environmental factors include weather (137, 142, 146), time (133, 137, 142), and roadside establishment (138, 139, 140, 142, 147).

It can be seen that a number of studies have been conducted to identify the above mentioned variables and that there is considerable agreement in this area.

Although discussions of the speed-accident relationship date back to the early use of the automobile, serious research in this area seems to have begun in the 1930's. From 1930 to 1939 the speed capability of the average vehicle sold rose from 55 mph to 84 mph. (126)

A number of the early studies in this area attributed the occurrence of accidents to speed (70, 151, 153) while others did not find a relationship between high driving speeds and accidents (126, 152). One author even went so far

as to say that all traffic problems were grounded in highway design. He wrote:

> "It is as essential to spend effort to improve the speed of transportation as it is to spend it to reduce accidents. The automobile was not manufactured to save lives, or the roadway built to prevent injuries." (154)

Since the 1950's several ideas have predominated the discussions of the speed-accident relationship.

One concept generally accepted by experts in this area is that accident severity increases with speed.

But opinions are polarized on the questions of speed as a cause of accident occurrence and speed limits as an effective means of accident reduction.

There are those who believe that speed is the prime cause of accidents (4) and others who indicate that accidents increase with increased speeds (157, 162).

M. Earl Campbell presents an interesting approach to speed-accident comparisons. A May 30, 1964 news release from the California Division of Highways stated that although only 19 persons have been killed at the Indianapolis 500 since 1911, this is a fatality rate of 3,930 per 100 million vehicle miles on California freeways. This 133,424% increase at 140 mph on the race track shows how accident frequency increases above 65 mph.

> "Traffic records and physics indicate that not only the hazard of severity but also the hazard of frequency of hitting another vehicle or

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fixed object increases with speed, and these hazards become specially notable in the higher ranges. Speed and accidents cannot be related to each other simply as a two-dimensional relationship: the relationship is always multi-dimensional and may include one hundred other factors...the third dimension of traffic density must always be included if any valid relationship is to come out of the analysis." (183)

"The hazard of frequency...is related to these conditions: (1) the speed of the subject car related to the density, frequency distribution of speeds of all the cars in the total traffic stream, and (2) fixed objects and other roadside hazards. There are other factors, but these appear to be most important. It appears also that the hazard rate above and below the average speed of traffic flow increases faster than the change in rate of speed." (183)

"One of the best confirmations of the increases in hazard of frequency of involvement with increase in speed is found in the 1959-61 records of the single-vehicle accident...This type of accident constitutes more than one-third of the accidents resulting in fatalities, and it is increasing at a rate significantly faster than the average rate of increase of fatal accidents, especially in urban areas." (183)

A 1956 study stated:

"[f]aster drivers have more accidents than slower drivers, especially when judged by their speeds in the afternoon. The individual speeds of the drivers with accident records are slightly higher than those for the drivers without accident records; while in the morning, it is the drivers without accident records whose speeds are slightly higher." (158)

Another idea having several proponents is that low-speed drivers are more likely to be involved in accidents

than high-speed drivers. (159, 165, 190) Chance of being involved in an accident is lowest about 65 mph, highest for low-speed drivers, and increases over 65 mph. (163)

> "...[O]nly eight percent of all fatal motor vehicle accidents are reported to have happened at speeds above 60 mph in 1962. On the other hand, more than half of all fatal accidents in urban areas reportedly occurred at speeds under 30 mph, that same year." (178)

A very rational stand taken by several authors is that speed is a causal factor in accidents, but it is one of a number of causes and not necessarily the most important. (156)

> "Speeding is outrageously overrated as a CAUSE of accidents. The fact is that it is inattentiveness or errors in judgment or lack of driving skill which contributes most heavily to the causes of accidents. Seldom does a single deficiency cause an accident." (178)

The *Proceedings of National Highway Safety Bureau Priorities Seminar* gives the following explanation.

> "Does speed cause accidents and produce casualties? Obviously, considering speed of itself, the answer is often no. As a matter of fact there are occasions when the capacity for speed may even aid in the avoidance of a crash or the mitigation of its results (The capacity to pass quickly in a suddenly developing tight situation and the minimizing of speed differentials in rear-end collisions, for example). On the other hand speed can very often compound the task of accident avoidance if not precipitate a crash. Further, and without question, speed aggravates the consequences of the crash.

"In discussing speed in relation to accidents it is well to delineate the several senses in which the term might be used. It is useful to think of speed in the following contexts:

"a) very [*sic*] high speed -- speeds approaching and exceeding 100 mph. Under these conditions, the speed factor dominates as a causative agent, since few if any of the elements of the overall vehicle-driver-highway system have been designed to accomodate travel at this speed.

"b) Excessive speed for conditions -- speeds ranging anywhere from zero to design speeds. This category of speeding encompasses many of the speeding citations issued in connection with accidents.

"c) Differential speed or speed gradients in the traffic stream -- in part, an overlapping set with excessive speed but also includes inadequate speed. Differential speed and the related variable "acceleration noise" figure prominently in the safe and efficient flow of traffic. Large speed differentials are seldom if ever cited as a contributing cause, the factor being implicit in other improper driving categories such as following too close and reckless driving.

"With these connotations of speed in mind it can be appreciated that speed is very often not a singular or an explicit variable in the accident equation. Thus, efforts to treat speed as an accident cause are often reduced to treating symptoms arising from the synergy of speed and many other system factors." (179)

There are differing views as to the effect of speed zoning on accidents. Some studies have shown that speed limits reduce accidents either in number or in severity. (114, 155, 164, 168, 170, 172, 174, 176)

In 1960 John Baerwald wrote: "No evidence exists to indicate that accidents are increased when speed zones are

raised and by the same token, there is no evidence that accidents are materially reduced by establishing zones, although a downward trend is indicated." (96)

Other studies have shown that speed limit practices were ineffective at reducing accidents of any type. (177)

One of the newer theories in the area of speed and accidents is that accidents are related to speed differences. (189, 191) Probably the most noted study to support this theory was conducted by David Solomon. He concluded:

1. "The accident-involvement, injury, and property-damage rates were highest at very low speeds, lowest at about the average speed of all traffic, and increased at the very high speeds, particularly at night. Thus, 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."

2. "The severity of accidents increased as speed increased, especially at speeds exceeding 60 miles per hour."

3. "The fatality rate was highest at very high speeds and lowest at about the average speed."

4. "Pairs of passenger car drivers involved in two-car, rear-end collisions were much more likely to be traveling at speed differences greatly in excess of those observed for pairs of cars in normal traffic..."

5. "Drivers of passenger cars having low horsepower had higher involvement rates than drivers of cars having higher horsepower,... This may be related to the relatively poor acceleration capability at highway speeds of cars having low horsepower."

6. "Nearly half of all accident involvements were either rear-end collision or same-direction sideswipes. However, the proportion of these accident involvements decreased as travel speed increased. Single vehicle, noncollision accident involvements contributed an increasingly greater proportion of all accident involvements as speed increased, particularly at speeds of more than 70 miles per hour. At speeds of 80 miles per hour, non-collision accidents constituted half of all involvements. Although angle collisions usually were less than 15 percent of the total, at speeds of less than 25 miles per hour they constituted more than one-third of all accident involvements. The proportion of head-on collisions or opposite-direction sideswipes increased as speed increased; but this type of accident involvement always was less than 20 percent of the total regardless of speed and day or night conditions." (167)

A recent study by RTI-IRPS indicated "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..."

The RTI-IRPS study also gave support to the use of the 85th percentile criterion stating:

"The standard deviation of the speed distribution is from 5 to 7 mph. Approximately 85% of the drivers drive below the mean plus one standard deviation. The drivers having speeds between the mean and one standard deviation above the

mean are definitely in a low involvement group. The region between one and two standard deviations above the mean speed encompasses approximately 10 percent of the drivers and does not have a significantly greater involvement rate than at mean speed. This region from the end of the first to the end of the second standard deviation is approximately the tolerance level allowed by police agencies." (191)

A 1966 article showed that on the five sections of freeway studied "...more than half of the violations contributing to accidents...were directly related to speed differential or to stream friction between vehicles moving in the same direction." (188)

As with the other areas of speed regulation and control a number of factors have been suggested as criteria upon which speed limits should be based. (193, 194, 195, 196, 198, 199) These factors are quite adequately summarized into four main categories in the article "An Informational Report on Speed Zoning." This article suggests that speed limits should be based on prevailing vehicle speeds, physical features, accident experience, and traffic characteristics and control. (197)

Again we find a great amount of support in the literature for the 85th percentile criterion. (85, 140, 191, 203, 205, 206, 208, 209)

Warren Kessler gives the following justification for the 85th percentile as a basis for setting speed limits:

"The 85th percentile speed is based upon the theory that the majority of motorists traveling upon a city street or highway are competent drivers and possess the ability to determine and judge the speed at which they may operate safely; further, that motorists are responsible and prudent persons who do not want to become involved in an accident and desire to reach their destinations in the shortest possible time." (204)

A 1969 "Resolution of the annual meeting of the American Association of State Highway Officials" states:

"The review of existing practice revealed that most of the member departments use, primarily, the 85th percentile speed. Some agencies use the 90th percentile speed, and of secondary consideration are such factors as design speed, geometric characteristics, accident experience, test run speed, pace, traffic volumes, development along the roadway, frequency of intersections, etc.

. . .

"On the basis of the foregoing review, the Subcommittee on Speed Zoning recommends to the AASHO Operating Committee on Traffic for consideration as an AASHO Policy on Speed Zoning that:

"The 85th percentile speed is to be given primary consideration in speed zones below 50 miles per hour, and the 90th percentile speed is to be given primary consideration in establishing speed zones of 50 miles per hour or above. To achieve the optimum in safety, it is desirable to secure a speed distribution with a skewness index approaching unity." (207)

A California publication "Speed Zoning -- Why and How" discusses the results that realistic speed zoning may produce.

"A. Reduce the speed differential in a traffic stream when there is a large variation of speeds. This makes driving easier, increases capacity and reduces the likelihood [*sic*] of accidents by encouraging most drivers to travel at about the same speed.

B. Give enforcement officials a good guide as to what a reasonable and prudent speed is under normal conditions and permits concentration of enforcement against real traffic violators.

C. Give motorists a speed limit which they can respect and obey. When drivers respect speed limits in areas with which they are familiar, they are more likely to pay attention to limits in unfamiliar areas.

D. Assist traffic courts by providing a realistic guide as to normal, reasonable and prudent speeds.

E. Give local residents a realistic picture of the actual speed of most traffic. There is no safety in blind reliance on a speed limit inconsistent with speeds actually traveled by traffic.

F. Insure that all speed zones satisfy the requirements of state law." (208)

More recently developed areas of discussion concern the uniformity of speeds or the speed distribution. (85, 214) William Taylor has said that assuming that variation of speed distribution and high accident rates on certain sections of highway are a result of drivers' inability to properly evaluate the driving situation, it seems that the speed distribution would be helpful in determining where speed zoning might be effective. Mean speed and 85th percentile may not be influenced by each driver's inability to

make a proper evaluation of conditions in the way that skewness and kurtosis of the speed distribution are. (210)

Taylor's theory states that a relationship exists between the rate of occurrence of accidents and the distribution of speeds on a section of rural highway, and that the effectiveness of speed zoning in reducing accidents depends on the speed distribution before and after zoning. (211) His study concluded:

> "1. There is a strong relationship between the rate of occurence of accidents and the speed distribution on rural state highways.
> 2. The best parameter to use in determining non-normality is the skewness of the distribution.
> 3. Changing the speed distribution from non-normal to normal results in an accident rate reduction which is about twice that found under any other set of before and after conditions.
> 4. Warrants for speed zoning should be established which include the speed distribution as a factor.
> 5. The 'Before' speed distribution alone is not adequate as a warrant for speed zoning." (177)

A Tennessee Department of Highways Study based on Taylor's theory concluded that speed limits below 50 mph are best represented by the 85th percentile, while limits of 50 mph and above are best represented by the 90th percentile. (212)

J. C. Oppenlander proposed a cost-based method of establishing speed controls. His theory entails:

1. The selection of an optimal speed that minimizes the cost of highway transportation, taking into consideration monetary, time, safety, and comfort factors.
2. An adjusted speed is derived from the optimal speed by subtracting the reduction in speed occasioned by driver, vehicle, roadway, traffic, and environmental variables that modify vehicular speeds.
3. Statistical relationships between upper and lower speed limits and adjusted speed produce the posted speed regulation. (200)

Jack C. Marcellis attempted to apply part of Oppenlander's theory, calculating the total cost of traffic movement as the sum of operation cost, time cost, and accident cost. The optimal speed for urban streets was scaled according to frequency of stops. For passenger cars, optimal urban speed ranged from 42 mph for 0 stops per mile to 27 mph for 16 stops per mile during the day. Night optimum is slightly lower. Commercial vehicles would move at an optimum speed of 37.5 mph at 0 stops per mile, and at 8 stops per mile the optimum would be 25 mph. (215)

Thus, it can be seen that there are three major approaches to establishing speed limits, one based on measures of prevailing vehicle speeds, another based on characteristics of the speed distribution, and a third based on cost.

In summarizing the body of literature concerning speed and speed control, the reader can probably be certain of only one thing -- the controversial nature of many of the

findings in this area. However, in considering the most rational and best supported approaches to various aspects of the speed problem, the following conclusions would seem reasonable.

1. Many of the basic premises concerning speed behavior and its control are not new; they appear early in the history of speed regulation and the automobile.

2. Numerous factors relating to the driver, the vehicle, the roadway, traffic, and the environment have a determining effect on driving speeds.

3. The main element in determining whether drivers observe a speed limit is their perception of the reasonableness of the limit.

4. Speed limits, taken as a whole, are beneficial, or at least appear to have no detrimental effect on accident occurrence.

5. Speed may play a large role in the severity of accidents, but is merely one of many factors in accident causation.

6. At present the most widely supported criterion on which to base a speed limit is the 85th percentile speed.

7. The theory that accidents increase as the value of the standard deviation increases, i.e., that speed differences play a causative role in accident occurrence, is a promising one, as evidenced by a high accident rate at both low and very high speeds and a lower accident rate around the average or normal driving speed.

3.0 SURVEY OF SPEED LIMIT PRACTICES

A survey of the practices used by states and cities to establish maximum speed limits was undertaken to determine existing methods, technical resources and the manpower involved in actually establishing speed limits throughout the nation.

Questionnaires (see Appendix C) were addressed to the Chief Traffic Engineer of the Highway Department of all states, of all cities over 100,000 in population (130) and of 52 selected cities with populations under 100,000.

It must be understood that the summary that follows represents a summary of responses and not necessarily a summary of actual practice. In general, the 85th percentile concept has apparent widespread acceptance and speed-measuring and volume-counting devices are available in nearly all jurisdictions surveyed.

3.1 Response Rates

An overall response rate of 88% was achieved. Of the questionnaires sent to each of the 50 states, 48 were returned as a result of either our initial request or follow-up letter. One hundred thirteen of the cities of over 100,000 population responded to the survey. All of the surveys from the states and the larger cities are thus included in the quantitative response analyses.

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The 45 surveys received from the cities of less than 100,000 population are included in a qualitative evaluation only. The responses from these cities were generally of questionable reliability, and they were thus excluded from the quantitative analysis.

3.2 Analysis

3.2.1 State Survey

Information from the state survey was analyzed in two ways. Tables of response breakdowns are presented in Appendix D. Table I shows the number of responses to each question. For example, on question I, no one selected response "1," three selected response "2," and 46 selected response "3." In cases where more than one response was permitted (questions I, II, III, IV, VI, VII, and VIII), responses to each alternative were tabulated separately. For example, if the responses to a particular question were 1, 6, 18, and 20, each was viewed as a separate response. The frequency with which each such combination occurred was not determined, due to the great number of possible combinations for each question.

Second, for questions in which multiple responses were allowed, the average number of responses was tabulated and the information presented in Table II. In the case of

question V, for example, this indicates that an average of 10.31 different factors out of a possible 21 are used by states in setting or altering speed limits.

3.2.2 General State Profile

In an overwhelming majority of states, numerical speed limits are set by state statute, with provisions for changing or setting speed limits by other agencies or jurisdictions. Nowhere, are numerical speed limits set by state statute without some such provisions allowing other agencies, primarily the state highway commission, county, or municipal administrative agencies, to change or set speed limits. Most states reported that any changing or setting of speed limits by local agencies had to be supported by an appropriate engineering or traffic study.

In 10 of the 12 driving locations listed under question VIII, the states reported that they relied heavily on traffic surveys and engineering methods as aids to setting speed limits. On residential streets, traffic surveys and engineering methods were used with the same frequency as local officials or an agency representing a local jurisdiction; in business districts local officials were most commonly used to set speed limits, with traffic surveys a close second choice. Though few states specified other locations where speed limits were set, in those cases where

such other locations were specified, traffic surveys and engineering methods were used by a slim majority as aids in establishing limits. In all types of driving locations, citizens' petitions were rarely used as aids in the establishing of speed limits.

All states but one reported that the 85th percentile is used in engineering or traffic studies prior to the alteration or establishing of a speed limit. Other factors considered were, in order of decreasing frequency: accident experience at that or similar locations, ball-bank indicator, length of zone and effect of adjacent zones, design speed, pace, and spacing of intersections and driveways. Percentage of commercial vehicles was considered least frequently.

Most states reported a differential speed limit for trucks and cars, primarily for reasons of safety. In states where cars and trucks had the same speed limit, facilitation of traffic flow was the primary consideration. In no case did any state report that trucking or other industries directly influenced truck speed limits.

All states reported the availability of radar in determining vehicle speeds, and all but one reported the availability of ball-bank indicators. In addition, most states

reported that vehicle counters were available to them. Very few states listed additional available devices which might aid them in setting speed limits. Where additional devices were listed, computers were most frequent, but by a very slight margin.

Most states did report making attempts to evaluate the effect of new speed limits. Answers as to how this effect was measured were quite varied, but most contained similar elements: before and after studies were used extensively, and were related to other factors such as accident experience, 85th percentile, radar checks, and speed checks. While reasons for not measuring the effects of new limits were not requested, one state did provide such an explanation, namely, that the beneficial effects of reasonable limits have been well established in numerous studies.

In summary, responses concerning speed limit practices at the state level may be summarized as follows:

1. State statutes set numerical speed limits and make provisions for changing or setting speed limits by other agencies or jurisdictions.

2. Authority to set or change limits is largely delegated to two agencies or authorities: the state highway commission and county or municipal administrative agencies.

3. When local agencies set or change speed limits, the change must be supported by an engineering or traffic study.

4. For residential streets, traffic surveys and local officials set speed limits; in business districts local officials set speed limits; at all other locations traffic surveys are used exclusively.

5. The ten elements most frequently considered in traffic or engineering studies of speed limits are, in order of frequency:

   - 85th percentile speed
   - accident experience at that or similar locations
   - ball-bank indicator data
   - length of zone and effect of adjacent zones
   - design speed
   - pace
   - spacing of intersections and driveways
   - traffic volume
   - presence and condition of shoulders
   - average test run speed.

6. For reasons of safety there is a speed limit differential for trucks and cars.

7. Four instruments; radar, vascar, ball-bank indicator, and computer, are generally available to measure vehicle speed, traffic characteristics, and roadway features.

8. Attempts to measure the effects of new or altered speed limits are made with the use of before-and-after studies.

3.2.3 Cities

Information about the cities with population over 100,000 is tabulated in Appendix D. Data for cities with populations less than 100,000 were not tabulated due to response size and response validity considerations. As for the states, the responses were counted to obtain the number

of responses to each question. Table III shows this information. The first two listings on this table show that there wery 90 "1" ("yes," in this case) and 15 "2" ("no," in this case) responses for question I. Again, each number in a combination response was counted individually.

Second, on questions where a combination response was possible (questions II, II, IV, V, VIII, and IX), the average number of responses was tabulated. Table IV shows that on question II, for example, the average number of responses was 1.02.

Third, all cities were classified into groups, based on the state in which they were located. A profile of each state's cities was then developed by counting the responses of the cities, and comparing the cities of each state among themselves to find similarities and differences.

Fourth, the general profile of each state's cities was then compared to that state to find similarities or dissimilarities in the answers.

3.2.4 General City Profile

A great majority of the cities reported that states delegate authority to them for establishing or setting speed limits in their jurisdictions. This authority, granted

by the state legislatures through statute, rests primarily with state highway commissions, county or municipal traffic engineers, and other agencies, such as the city council. Though each of these three agencies can set speed limits, most limits are actually established by county or municipal engineers.

Minimum speed limits are set in most, but certainly not all cities. Their use is largely confined to expressways and urban expressways.

All but three cities report using engineering studies to determine speed limits, and the 85th percentile is an important consideration in nearly every case. Other factors, including accident experience at that or similar locations, length of zone and effect of adjacent zones, presence of pedestrians, and traffic signals and other traffic controls, are considered much less often than the 85th percentile.

That traffic surveys and engineering studies are widely used again reveals itself in the cities' reports that at every location these methods are most often used to set or change a speed limit.

Radar was available to every city but one, and that city listed it as being helpful for future work. Vehicle counters and ball-bank indicators were also available to

many cities. While there was no extensive listing of desired but unavailable instruments helpful in dealing with speed limits, computers and road sensors were most requested.

Most cities did report attempting to learn the effects of new speed limits, relying heavily on before-and-after studies for work in this area.

In general, a typical city had the following characteristics:

1. Authority to set or change speed limits, as provided to the city by the state legislature through statute.

2. County or municipal traffic engineers having this authority and actually setting most of the speed limits within the jurisdiction.

3. Use of minimum speed limits, primarily on expressways.

4. Use of engineering studies in setting or changing speed limits.

5. Eight factors commonly used in such engineering studies are, in order of frequency:

    - 85th percentile
    - accident experience at that or similar locations
    - length of zone and effect of adjacent zones
    - presence of pedestrians
    - traffic signals or other traffic controls
    - traffic volume
    - design speed
    - spacing of intersections and driveways

6. At every location, traffic surveys and engineering methods are most commonly used to set speed limits.

7. Radar, vehicle counters, and ball-bank indicators are available for use in measuring vehicle speeds, traffic characteristics, and roadway features.

8. Effects of new speed limits are studied by before-and-after tests and surveys.

3.2.5 Comparisons of Cities to the States in Which They Are Located

Although specific questions on the state and city surveys vary slightly, the questionnaires request very similar kinds of information.

For purposes of this comparison, responses to the following questions are discussed:

State Question Number	Corresponding City Question Number
I	I
I	II
II	III
III	VI
III	VIII
IV	VIII
V	VII
VIII	IX
IX	X

For convenience in the remainder of this discussion, state questions are preceded by "s," and city questions by a "c."

When the cities of a state were compared to the state, agreement was found in the following cases:

sI cI	There was agreement when the state replied "1" (no delegation of authority to set speed limits), for all such cities replied "2" (no delegation of authority to set speed limits). There was also agreement when the state replied "2" or "3" (delegation of authority to set speed limits), for all such cities replied "1" (delegation of authority to set speed limits).
sI cII	There was agreement when the state replied "2" or "3" (delegation of authority to set speed limits), for all cities replied "1," "2," or "3" (specification of the agency which grants authority to set speed limits).
sII cIII	There was agreement when the state and all cities specified the same agencies to whom authority to set speed limits was delegated. (Since in sII, "1" is no delegation of authority, state response "2" matches city response "1," state response "3" matches city response "2," etc.).
sIII cVI	There was agreement when the state responded "5" (cities must use engineering methods to set speed limit), for all cities responded "1" (engineering studies are used). If the state responded "2," "3," or "4" (specification of other constraints on the cities) in addition to "5" and all cities responded "1," there was still agreement, for the other state constraints do not conflict with the requirement of an engineering study.
sIII cVIII	There was agreement when the state responded "5" (cities must use engineering methods to set speed limits), for the city responded "2" (use of engineering methods to set speed

limits) in every case a-m. If the state responded "2," "3," or "4" (specification of other constraints on the city) in addition to "5," and all cities responded "1," "3," "4," or "5" (other factors considered in setting speed limits) in addition to "2," there was still agreement, for the other constraints or methods do not conflict with the state requirement or the city use of engineering methods in setting speed limits.

sIV cVIII	There was agreement insofar as the state and all cities considered the same factors or used the same methods in setting speed limits (parts a-m were considered separately: state response "1" matches city response "1," state response "2" matches city response "2," etc.).
sV cVIII	There was agreement insofar as the state and all cities considered the same factors in setting speed limits. (State response "1" matches city response "1," state response "2" matches city response "2," etc.).
sVIII cIX	There was agreement insofar as the state and all cities used the same instruments to measure vehicle speeds, roadway characteristics, etc. (state response "1" matches city response "1," state response "2" matches city response "2," etc.).
sIX cX	There was agreement when the state responded "1" (study of the new speed limits is made), for all cities responded "1" (study of new speed limits is made). There was also agreement when the state responded "2" (no study of new limits), for all cities responded "2" (no study of new limits).

A comparison of sI (state question I) to cI (city question I) and cII shows general agreement between states and cities. A great majority of states report that authority to set or alter speed limits has been given to the cities by statute. The cities corroborate this information, for they report in appropriate cases that the states have, in fact, delegated this authority to them. Further, cities most commonly report that this authority has been statutorily granted.

In sII the states report that the authority for setting or changing speed limits is most often delegated to the state highway commission, and then to the county or municipal administrative agencies. Cities are in slight disagreement on this point, however, for they indicate in cIII that first, county or municipal traffic engineers, and second, the state highway commission, most often have this responsibility. Only one state selected county or municipal traffic engineers as having this authority; the cities indicated the authority of county or municipal administrative agencies with about medium frequency.

In sIII the states reported that the cities must support speed limit changes or alterations by engineering or traffic studies. Cities do, correspondingly, follow this constraint. In cVI all responding cities reported using engineering

studies in the determination of speed limits. Further, in cVIII, cities reported that at every location traffic and engineering methods were used more commonly than other methods of setting or changing speed limits. In addition, in cX most cities indicated that the effects of new limits were studied, usually by engineering or traffic study methods.

Answers from the states and cities on questions sIV and cVIII are virtually identical. As mentioned, cities prefer to do traffic surveys and engineering methods at every location. States preferred these methods in every case but two; of these two, engineering methods were used either as often as local officials and agencies or were a close second choice. Citizens' petitions were rarely utilized by states or cities. With the exception of engineering methods and citizens' petition, then, all other choices were selected with similar degrees of frequency.

With regard to factors included in engineering or traffic studies, states included an average of 10 factors and cities an average of 8. Using the information from sV and cVII, the factors in this question can be ranked. The factor selected the most frequently is assigned rank number 1, the factor selected next most frequently is rank number 2, etc. With a few exceptions, the rankings are <u>not</u> similar. States

and cities ranked 85th percentile and accident experience at the location, first and second, respectively. In both cases, factors least often considered were ranked identically. For example, slipperiness of pavement, roughness of pavement, percentage of commercial vehicles, and other factors were ranked 18, 19, 20, and 21, respectively. With these exceptions, the rankings vary widely, as Table V illustrates.

Responses to sVIII and cIX were similar in two ways. First, both states and cities indicated that an average of three of the instruments cited were available to them. Second, both selected the same kinds of instruments as being most commonly available. Radar was most frequently available to both states and cities. In order of availability, the states then selected ball-bank indicators and vehicle counters; for the cities the availability of these two was reversed. States and cities did not report that the remaining instruments were equally available, however.

In response to sIX and cX, most cities and states indicated that the effects of new speed limits were studied. Similar methods, such as before-and-after studies of accidents, 85th percentile, etc., were utilized in both cases.

In general, states and cities agreed in their responses to most of the survey questions.

4.0 SPEED LIMIT CONCEPTS

The following discussion of the objectives and functions of speed limits and the establishment of speed limits is intended to provide the reader with conceptual framework necessary for critically examining the literature and understanding the analytical objectives of this study.

4.1 General Concepts

Certain generalizations can be made that highlight the interplay of factors that constrain the development of a methodology for the establishment of speed limits:

1. Speed limits are established by the operation of the legal system. Such establishment must be consistent with the objectives of the Traffic Law System.

2. Speed limits are intended to reduce risk within the Surface Road Transportation System. Thus, the speed limit must be related to hazard.

3. Drivers tend to ignore limits that are perceived as unreasonable. Thus, an effective limit must be perceived by the majority of drivers as reasonable.

4. There are an almost unlimited range of variables arising from the man-machine-highway mix that impact on the determination of a reasonable speed limit.

5. Few jurisdictions have manpower resources or technology to permit implementation of a method for establishing speed limits requiring sophisticated data collection and analysis.

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The above-mentioned factors are discussed in more detail in the following sections. It is hoped that the reader will realize the complexity of issues presented, and will accept the inherent difficulty accompanying a short dissertation on a complex subject.

4.2 Speed Limits and the Traffic Law System

The establishment of speed limits may be regarded as an operational act of the Traffic Law System (TLS) consistent with the basic objective of the TLS -- risk management of the Surface Road Transportation System (SRT).

The TLS is the basic social control system applied to manage risks within the SRT system. The TLS operates in four basic functional components; Rule Making, Enforcement, Adjudication, and Sanctioning.

Thus, when the operation of a motor vehicle at a speed inappropriate for existing conditions is identified as a risk to the basic operation of the SRT System, the TLS is called upon to operate in risk management mode. In general, this is done by the establishment of a speed limit, the enforcement of such a rule with appropriate adjudication and sanctioning of offenders. Theoretically, sanctions act to correct the offender and serve as a deterrent to others similarly inclined.

If the TLS is to effectively function as a risk management system, the rule making component must precisely and correctly identify risk. If this is not done, the remainder of the system inefficiently allocates resources in dealing with individuals who technically violated a rule but in fact did not engage in hazardous activity.

An examination of enforcement activity indicates that the bulk of traffic citations are given for speeding offenses. Accordingly, the bulk of court activity is taken up with speeding offenses and the bulk of sanctions are imposed for speeding.

If it were clearly established that all speed zones were precisely established to define risk, the above-mentioned allocation of resources could be defended as appropriate for a risk management system. Regrettably, the opposite seems to be the case in many instances.

Speed limits which are improperly posted, particularly those which are set artificially low, tend to be ignored by the majority of drivers and thus have little effect on SRT risk. At the same time the limit makes technical violators of a high percentage of drivers. Frequently, the high number of violators draws enforcement presence and concurrent citations.

Such action violates the basic concepts of risk management inasmuch as resources are being diverted to deal with low risk behavior when they should be focused on high risk behavior as a priority. Not only are enforcement resources diverted but the resources of the courts and administrative agencies are also clogged.

Perhaps more important than the damage to the TLS system in a sheer cost sense is the damage to the TLS as a control mechanism. The TLS, as part of the Criminal Justice System of our society, is dependent upon public support and must maintain a position of fundamental fairness to operate effectively. Inappropriate rule making which creates fundamentally unfair enforcement, adjudication and sanctioning constitutes a detriment to society.

The impact of such improper setting of speed limits can be evaluated only when one recognizes that more citizens have contact with the Criminal Justice System and its constituent agencies through traffic violations than through any other single cause.

4.3 Speed Limits and Risk

The basic objective of the Surface Road Transportation System is to facilitate the flow of goods and people from

point to point as safely as is possible. It might be more appropriate to think of the basic objective as having two components:

1. Maximize Flow
2. Maximize Safety

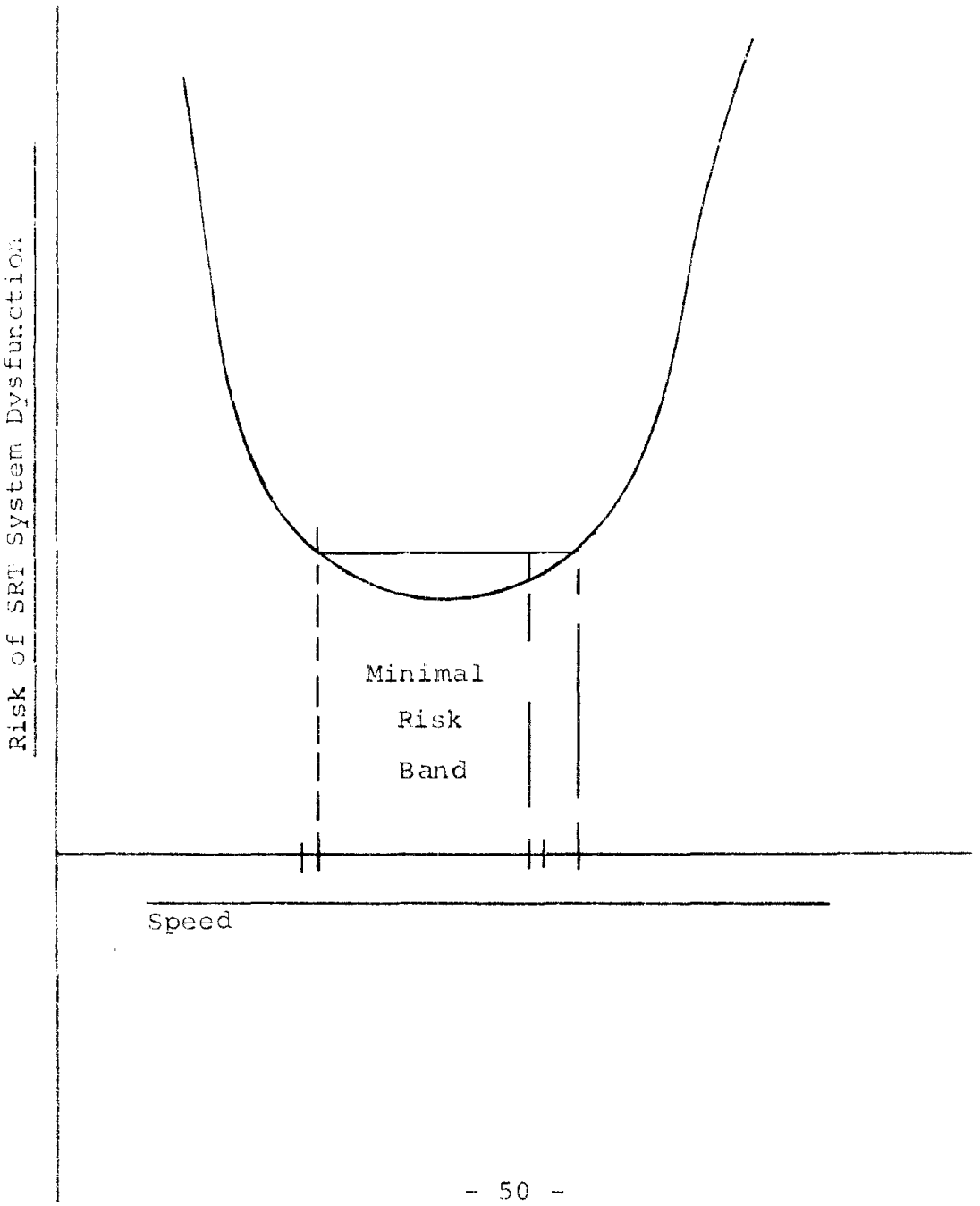
It should be obvious that some conflict exists in the concept of the two components. The flow rate would theoretically increase as speed increased. Similarly, it could be hypothesized that safety would decrease as speed increased.

Examination of the real world reflects that a trade-off has occurred as drivers have made heuristic judgments in arriving at the speed they travel. Thus, it appears that a discussion of the risk of flow disruption or the risk of an accident or other potential safety threat must consider such real-world activity. One could picture the concept of risk as a curve with a minimum point as shown in Figure 4-1. Available data indicates that the slope of the curve is quite flat near the minimum point indicating that there is a range of speeds with nearly the same risk value.

It would seem desirable to encourage drivers to operate their vehicles at speeds within the speed band with minimum risk.

Theoretically, maximum speed limits could be set at the upper end of the speed band, minimum speed limits at

FIGURE 4-1



the lower end of the speed band, and advisory speed limits at the middle of the speed band.

Establishment of enforceable maximum limits lower than the upper end of the minimum risk band would not act to reduce risk within the SRT system and would be inconsistent with the objectives of the TLS system.

Thus, it appears that a method for establishing a maximum speed limit should result in the selection of a value for the speed limit that would fall at or near the upper end of the minimum risk band.

4.4 Speed Limits and Driver Acceptance

There has been a tendency on the part of many individuals associated with rule-making and highway safety to assume that the correct method of dealing with a particular problem is to enact a law making the undesirable behavior illegal and it would cease. The illusory nature of this concept is perhaps nowhere better illustrated than in the case of speed limits.

While it is quite possible to compel response to unreasonably low speed limits by the presence of overwhelming enforcement resources, such a level of resources simply does not exist in the United States. The chances of a violator being detected and apprehended are so low that

travel speeds are selected by most drivers quite independent of considerations of the illegality of exceeding a speed limit. Studies have reflected that unreasonably low or high speed limits are ignored.

Unfortunately, all drivers do not ignore unreasonable speed limits. The net result of improperly selected speed limits appears to be a widely dispersed mix of speeds. Some drivers ignore the limits others obey them. The resulting speed distributions are often characterized by wide differences in travel speeds.

This result is inconsistent with the studies that indicate risk increases with deviations from a mean speed. It is also inconsistent with those studies which indicate that a normal distribution with a small standard deviation is desirable.

Thus, it appears that for a speed limit to minimize risk effectively, the speed limit must be accepted by the majority of drivers as reasonable and must be voluntarily obeyed.

4.5 Factors Affecting the Development of a General Method

The search for a general method to establish speed limits has occupied the attention of traffic specialists

since the wheel was invented. The literature is replete with discussions and methods.

Most discussions recognize the almost infinite set of variables arising from the man-machine-highway mix that interact to influence the choice of an appropriate speed limit for a particular highway. The type of drivers, the mix of vehicles, the geometry of the particular highway are just a few of the factors that could be considered.

While a method for establishing speed limits for a particular class of highways might be based on a complex evaluation of such variables such as number of intersections per road mile or nature of roadside development or any other number of physical characteristics, such an approach would be incapable of being widely generalized.

Researchers in the field of speed control have generally recognized the futility of attempting to base a general method on characteristics of a particular highway environment. Instead, they have recognized that the general behavior of the driver mix serves as an indicator of the influences of highway environment. Each driver considers, consciously or unconsciously, a range of factors and selects an appropriate travel speed for a particular highway. An examination of the distribution of travel speeds of a sample of safe

drivers appears to serve as the best indicator of an appropriate speed limit. The impact of the innumerable other variables are reflected in distribution of vehicle speeds.

The weight of expertise supports the concept of such a general approach and accepts that a value selected by such a method represents a best estimate. Such an estimate would then be judgmentally evaluated in light of local conditions and minor corrections made if warranted by factual data.

A general method has definite value for the overall highway safety field. It promotes consistency in a wide range of jurisdictions which in turn could be expected to produce better driver response or compliance.

While such an approach is accepted by the majority of researchers, the literature still contains references to "optimal methods" which are conceptually inconsistent with the approach of a general method. If one accepts the common scientific interpretation of the term "optimal" as the single best value, one must also conclude that it cannot be appropriately applied to a general method designed to select a value at or near the best value. Thus, this report focuses on a general method for the establishment of a "reasonable" or "appropriate" speed limit as opposed to an "optimal" speed limit.

4.6 Factors Affecting Implementation of a General Method

If the hypothesis that wide implementation of a general method of establishing speed limits is desirable to promote commonality and consistency within the SRT system is accepted, one must be concerned with the development of an implementation scheme that can be widely used.

Two basic considerations underlie implementation of any technique in the highway safety field. One, can it be implemented by existing manpower resources? Two, can it be implemented utilizing existing technology?

In general, the manpower available for the establishment of speed limits possesses limited scientific education and training. Major urban areas and state highway departments are usually staffed by competent traffic engineers. Smaller urban areas often assign traffic engineering duties to individuals without formal education or training.

The actual mechanical establishment of speed limits, even in the major jurisdictions, is often assigned to non-engineering personnel. The range of judgment exercised by such individuals is evident in the mix of speed zones on our highways. It is not uncommon to discover the function of speed zone establishment assigned to law enforcement officials. While there are noteworthy exceptions, in

general, such individuals are not familiar with traffic engineering practices and tend to rely on intuitive judgment. Such judgment is often conditioned by years of concern with speed as a primary perceived accident factor. Frequently, the result is a speed limit lower than appropriate for existing conditions.

The implementation of a general concept will be dependent upon its presentation in terms that can be easily understood by an individual without engineering or scientific training.

Speed measuring devices and traffic counters are almost universally available in most jurisdictions. The cost of such devices is relatively low so that acquisition or expansion of existing equipment could be accomplished with minimal difficulty. More sophisticated equipment is not generally available nor is the manpower available that could use such equipment.

The method developed for implementation must rely on data that can be collected by existing manpower utilizing presently available or easily acquired instrumentation.

4.7 Criteria for a General Method of Establishing Speed Limits

The discussions in the prior sections have indicated certain factors and constraints which structure the

development of a general method of establishing maximum speed limits.

A general method should meet the following criteria:

1. Be fundamentally fair in the context of the Traffic Law System.

2. Be related to risk of dysfunction in the Surface Road Transportation System.

3. Be accepted as reasonable by drivers.

4. Be capable of general use on a range of highways.

5. Be capable of being implemented by existing resources.

Such criteria have been considered in the analyses that led to the development of the recommended general method.

5.0 DISCUSSION OF METHODS FOR ESTABLISHING SPEED LIMITS

In previous sections of this report numerous techniques for establishing maximum speed limits have been described. The present section is concerned with:

1. Screening these techniques to eliminate those which clearly fail to meet the five criteria listed in section 4.7.

2. Further analysis of the techniques surviving the preliminary screening process.

5.1 Screening Analysis

A total of thirteen techniques for establishing maximum speed limits were identified in the literature review and the survey of jurisdictions. The screening analysis matched each of these techniques against the five criteria listed in section 4.7. Those techniques which clearly failed to meet any one of the five criteria were eliminated from further analysis. The results of the screening analysis are summarized in Table 5-1. Note that numbers 6, 7, 8, 9, 11, 12, and 13 in the matrix are only elements that may affect driving speeds, and thereby fail to meet all the necessary criteria.

In considering this presentation, the reader should bear in mind that the criterion "Be related to risk of dysfunction in the SRT system" means that a causal relationship between dysfunction and speed must be shown to

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METHOD	CRITERION: 1. Be Fundamentally Fair	2. Be Related to Risk of Dysfunction in the SRT	3. Be Accepted as Reasonable by Drivers	4. Be Capable of General Use on a Range of Highways	5. Be Capable of Implementation using Existing Resources
1. Speed Distribution Skewness	x	x	x	x	x
2. Cost Minimization	x	x	x	x	x
3. 85th Percentile	x	x	x	x	x
4. Pace	x	x	No	x	x
5. Average Test Run Speed	x	No	No	x	x
6. Accident Experience	x	No	No	x	x
7. Design Speed	x	x	No	No	No
8. Traffic Volume	x	No	No	x	x
9. Length of Zone & Adjacent Zone	x	No	No	x	x
10. Ball-Bank Indicator	x	No	No	No	x
11. Spacing of Intersections & Driveways	x	x	No	No	x
12. Presence & Condition of Shoulders	x	x	No	No	x
13. Presence of Pedestrians	x	x	No	No	x

Note: "x" indicates method could meet criterion; "No" indicates method does not meet criterion.

SPEED LIMIT METHOD -- CRITERION MATRIX

Table 5-1

exist by the present body of evidence. Further, the criterion "Be accepted as reasonable by drivers" is intended to imply acceptance by a large majority of drivers.

The table shows that, based on elementary considerations, only three of the techniques can be considered to be generally in consonance with all five criteria:

* Taylor's theory of speed distribution skewness
* Opperlander's cost-oriented approach
* The 85th percentile method

It is noted that criteria 2 and 3 are the ones most commonly not met by the various techniques.

The pace speed failed the screening test by the narrowest margin. It was rejected because, by definition, it is accepted as reasonable only by more drivers than any other speed increment. Thus, the drivers traveling within the pace speed do not necessarily comprise a large majority of the drivers, and criterion 3 is not met.

5.2 Analysis of Selected Methods for Establishing Speed Limits

The three approaches for establishing speeds limits which survived the initial screening process are subjected to further analysis in this section.

5.2.1 Taylor's Theory of Speed Distribution Skewness

Taylor's theory (177) states that accident frequency increases with increasing deviation of the speed distribution from normality, where the deviation is increased by the non-symmetry of the speed distribution. Thus, a speed limit may be said to be "effective" if the skewness of the resulting speed distribution is small.

The Tennessee Department of Highways has applied this theory in a study which undertook to define a method for determining speed limits and to present proof that the recommended speed leads to a speed limit which serves its stated purpose, namely the reduction of accident rates. To do this, speed data were collected at many speed zones. Those zones with a small value of skewness (i.e., non-symmetry) were selected as having effective speed limits.

Next, the Tennessee study attempted to determine which characteristics of the speed distribution (i.e., 85th percentile, 90th percentile, mean speed, or median speed) was most clearly represented by the posted speed limit. The result of this investigation, based on 384 locations, 189 of which showed normally distributed speeds, was that speed limits below 50 mph are best represented by the 85th percentile, and those above 50 mph are best represented by the

90th percentile. From this result the conclusion was drawn that the 85th or 90th percentile should be recommended where the appropriate conditions prevail.

Several questions arise regarding Taylor's theory and its application by the Tennessee group. The first is a basic one regarding the nature of speed distributions. Taylor states that:

> In a situation where all drivers are able to determine and evaluate the conditions that exist at that time and at that location, the resulting speed distribution is normal with no skewness and no kurtosis. (177)

Unfortunately, no data supporting this statement can be found nor has there been any analysis of how the probability distribution is influenced by speed, traffic obstacles, roadway obstacles, and other factors. For example, there is evidence that speed distributions may be bimodal in the vicinity of intersection. This effect is shown most vividly by the IRPS data collected in Monroe County, Indiana. Figure 5-1 represents data collected on SR 37 over a two-hour period. The sensor site was located within 50 feet of an intersection. A distinct bimodality is noted with peaks occurring at 24 and 40 mph. Figure 5-2 indicates bimodality may occur also at locations where there are other types of traffic flow impediments. The sensor site was located near a bridge under repair where traffic was being slowed by a flagman.

LOOP NUMBER 0

PLOT OF TRAFFIC FROM 16000 TO 18000 ON 2/26/70

COUNT	980	AVE. VEL.	35.43	ST. DEV.	8.32
85TH PERCENTILE	43	90TH PERCENTILE	45	PASSING COUNT	0
ZERO COUNT	2	MAXIMUM VEL.	57	MINIMUM VEL.	13
RANGE	44	MODE	39	MEDIAN	36

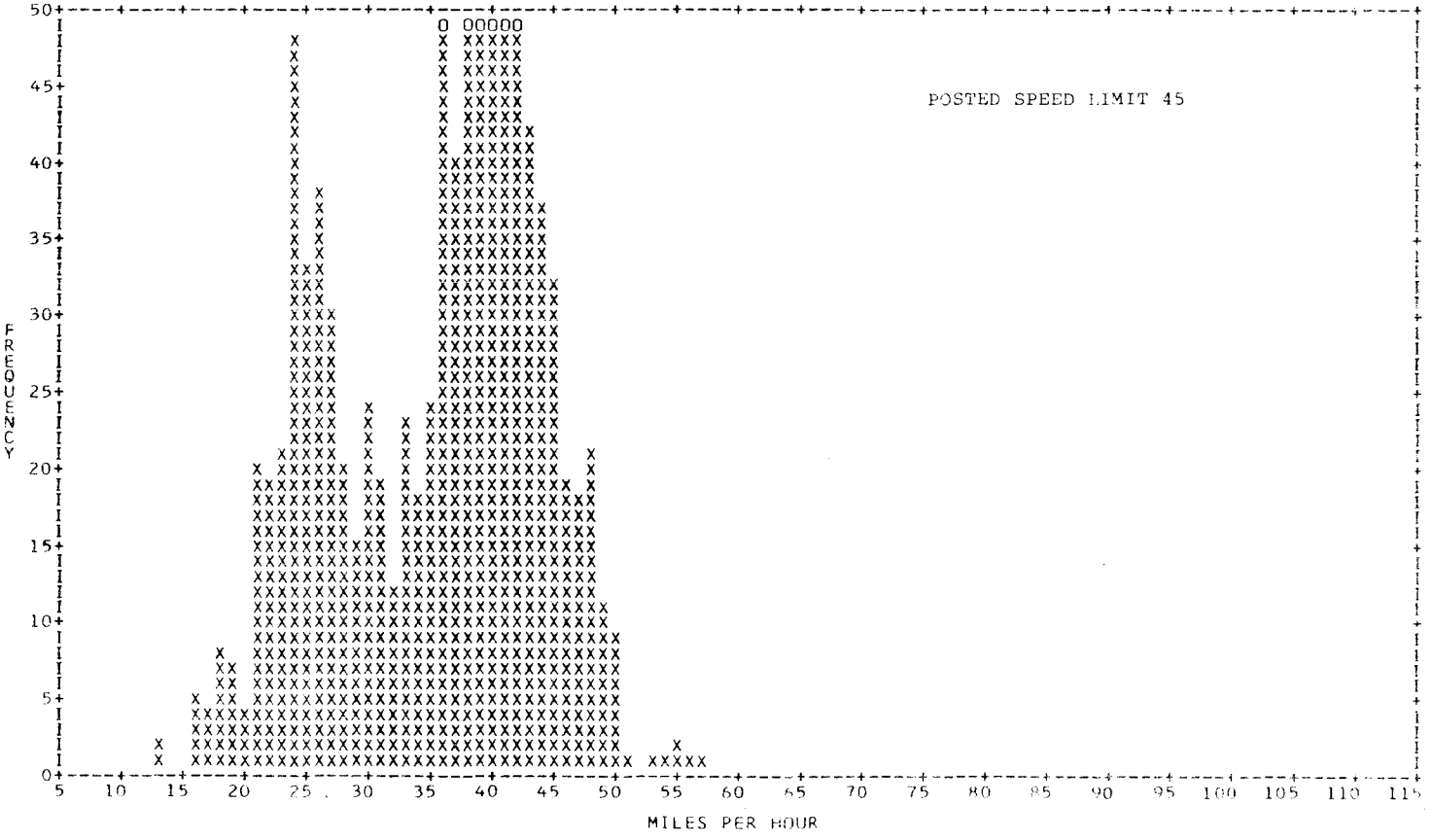

Figure 5 - 1

LOOP NUMBER 25

PLOT OF TRAFFIC FROM 8380 TO 9360 ON 8/27/70

COUNT	249	AVE. VEL.	48.82	ST. DEV.	7.01
85TH PERCENTILE	55	90TH PERCENTILE	59	PASSING COUNT	0
ZERO COUNT	5	MAXIMUM VEL.	65	MINIMUM VEL.	33
RANGE	32	MODE	53	MEDIAN	48

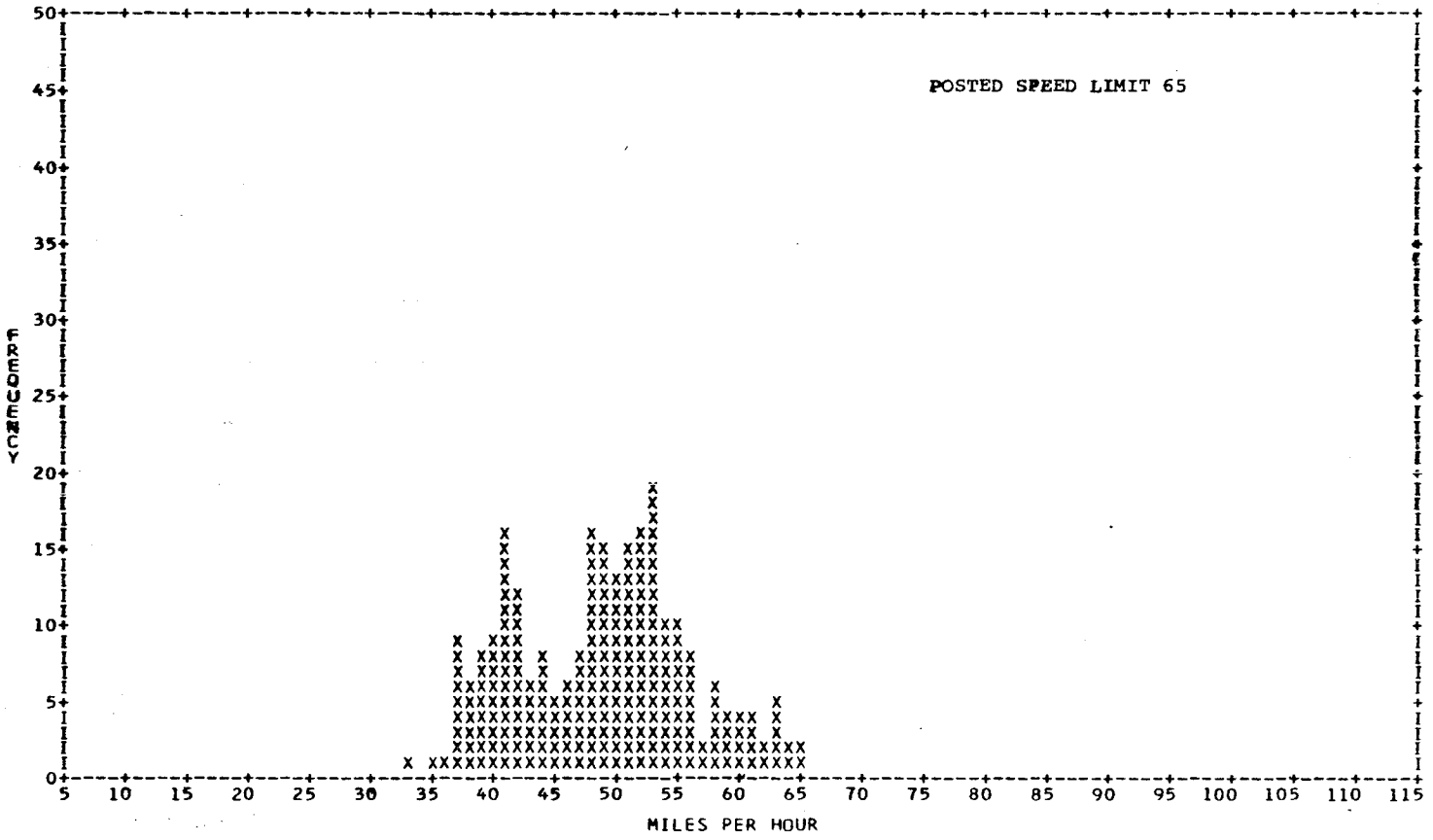

Figure 5 - 2

It is apparent, then, that before Taylor's assumptions regarding normality, skewness, and kurtosis can be accepted, we will need more data describing the probability distribution.

The application of the theory by the Tennessee group also raises a question. The Tennessee study used as the measure of normality the skewness index S.I., where S.I. is defined as

$$S.I. = \frac{2(P93 - P50)}{P93 - P7} \quad \text{and}$$

P7 = 7th percentile speed
P50 = 50th percentile speed
P93 = 93rd percentile speed

This index provides a measure of symmetry, not normality. For example, applying the skewness index to a normal distribution will result in a skewness index of 1.00, but the same result will also be obtained for any other symmetric probability distribution.

It is also important to note that Taylor's theory does not provide a measure for distinguishing the effects of left skewness from the effects of right skewness. A curve skewed to the right (i.e., with most of the probability distribution to the right of the peak of the distribution) will have more cars going faster than will one skewed to the left, and it would seem that the severity, if not the

frequency, of accidents would be greater for a right skew than for a left skew. It is believed that this factor should be considered in any theory of speed distribution.

Thus, considerable work needs to be done before Taylor's theory can be accepted as a basis for a methodology for determining speed limits. One believes that considerable insight could be gained by analysis of those 195 Tennessee locations which showed non-normal distributions. The Tennessee study does support the concept that for symmetric speed distributions, speed limits below 50 mph are best represented by the 85th percentile, those of 50 mph and higher, by the 90th percentile.

5.2.2 Oppenlander's Cost-oriented Approach

A major criterion of a speed limit is the degree to which it results in a reduction in accident rate. Oppenlander's approach takes this factor into account, along with several others, all of which are reduced to a common denominator, cost. He seeks the speed limit which minimizes total cost, where the cost components are the operation cost, the time cost, the accident cost, and the cost of comfort and convenience. Operation cost is assumed to be a decreasing function of speed; accident cost is assumed to be very small relative to the other two and is assumed

to be nearly constant; and the cost of comfort and convenience is assumed to be non-quantifiable. With these assumptions, Oppenlander creates a total cost function and finds its minimum at some "optimum speed." He then selects upper and lower speed limits "in such a manner that the average speed of travel on the roadway section being speed-zoned coincides with the adjusted (for roadway environment conditions) speed."

The advantage to Oppenlander's approach is that it makes the problem of determining optimum speed limits a problem of public choice, with the cost function being the cost to the public as a whole. In such a context it is possible to analyze such questions as the trade-offs between costs of increased law enforcement and benefits of increased traffic flow, if increased traffic flow is shown to be the result of more stringent law enforcement. It is also possible to analyze the costs and benefits of conducting speed surveys in order to determine the speed limit which most facilitates traffic flow, if such a speed limit does indeed exist.

Thus, Oppenlander's approach is regarded as having considerable interest conceptually and one deserving of future study. Such future efforts must place a heavy emphasis on the determination of the cost components. The cost of the political and emotional impact of high accident rates,

as well as ways of assessing more accurately the relatively concrete cost components (e.g., vehicle, loss of earnings, insurance) must be treated.

We must, nevertheless, conclude that Oppenlander's approach is not sufficiently developed to serve as a basis for present implementation. Future research may change this conclusion.

5.2.3 The 85th Percentile Method

The 85th percentile speed is mentioned in most of the literature dealing with the establishment of speed limits. It is a speed which uses the speed data usually collected by traffic specialists; it is a speed easily calculated once data has been obtained; and it is a number which reflects the judgment shown by most drivers in their reactions to the environmental conditions of the roadway. Further, a substantial body of data has been collected which indicates that the method may be consistent with the objective of low accident involvement rate (number of accidents per 100 million vehicle-miles).

A study by Solomon (167) shows that 85th percentile speed is in the speed range where the accident involvement rate (number of accidents per 100 million vehicle-miles) is lowest. This conclusion has been given added weight by a

more recent study performed by the Research Triangle Institute and supported by IRPS. This study concludes:

> There was not sufficient data available to allow a full analysis but it appears that this study reinforces the setting of speeds [*sic*] limits at the 85th percentile speed. The standard deviation of the speed distribution is from 5 to 7 mph. Approximately 85% of the drivers drive below the mean plus one standard deviation. The drivers having speeds between the mean and one standard deviation above the mean are definitely in a low-involvement group. The region between one and two standard deviations above the mean speed encompasses approximately 10 percent of the drivers and does not have a significantly greater involvement rate than at mean speed. This region from the end of the first to the end of the second standard deviation is approximately the tolerance level allowed by police agencies.
>
> If minimum speed limits are set a similar argument would lead to the conjecture that the limit should be placed at about the 15th percentile speed with enforcement at about the 5th percentile. (191)

Hence, current literature indicates that the 85th percentile speed limit is one falling in the speed interval within which few accidents occur.

The 85th percentile, by definition, also reflects the judgment of most drivers. This fact is brought out in "Speed Zoning -- Why and How":

> This [the 85th percentile speed] is the speed at or below which 85 percent of the traffic

> is moving. Experience has shown that this is the one characteristic of traffic speeds which most nearly conforms to a reasonable limit. Speed limits set higher than the critical speed will make very few additional drivers "legal" for each five mile per hour increment of speed increased. Speed limits set lower than the critical speed will make a large number of reasonable drivers "illegal" for each five mile per hour increment by which the speed is reduced. (208)

It seems remarkable that the speed range which 85% of the drivers do not exceed is also the safest. Apparently the public's perception of hazard is a valid one.

The arguments, then, for the use of the 85th percentile speed as a speed limit are that, first, the 85th percentile speed is a speed below which the probability of occurrence of an accident is low; second, the 85th percentile reflects the safe speed for given environmental and traffic conditions as reflected by the judgment of most drivers. The 85th percentile has the additional advantage that it is easily obtained with present equipment and with a minimum of computation.

6.0 ANALYSIS OF IRPS DATA RELATING SPEED AND ACCIDENTS

6.1 Introduction

This section of the report introduces data collected by the IRPS Computer-Sensor System. Analyses of the data are presented in order to provide a further basis for choosing a method for establishing maximum speed limits. The three methods discussed in the previous section will then be re-examined in light of these analyses, and a recommended method will be presented.

Since May of 1969, IRPS has been collecting extensive speed and accident data in the vicinity of the Indiana University in Monroe County, Indiana. The speed data were collected automatically by sensor loops installed at seven locations on Highway SR 37, near Bloomington, Indiana, and at four locations within Bloomington. The sensor loops are connected with an IBM 1800 computer. The arrival time and speed of each car which crosses a sensor loop are stored on magnetic tapes. These data are available beginning in May, 1969, up to the present time. A detailed description of the sensor loop system is given in Appendix B.

In addition to these speed data, there are accident files for SR 37 as well as for the areas surrounding two of

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the four locations within Bloomington. These files have been kept since the beginning of 1968. Among other information, the exact positions of the accidents are listed.

6.2 Approach

The analytical investigations were conducted in two parts. First, the interrelationship between the parameters which define speed distribution and accident frequency were studied from the viewpoint of sensor location. For each of the seven sensor sites on SR 37, these parameters were computed, and statistical comparisons were made. Thus, for each pair of parameters studied (e.g., mean speed and accident frequency), seven data points were available.

The other approach taken was to lump the data from all sensor sites and examine the parameters derived from the aggregate. In this approach, it was possible to study the accident rate distribution as a function of speed.

6.3 Results

6.3.1 The Effect of Location

For each of the seven sensor sites on SR 37, six characteristics describing vehicle speed distribution were computed using standard statistical techniques. These parameters are defined as follows:

$\bar{v}$ = Average speed

σ_v = Standard deviation of speed

V = Coefficient of variation

V_{85} = 85th percentile speed

V_{85-15} = Difference between 85th percentile and 15th percentile speeds

S_k = Pearsonian coefficient of skewness

The results of these calculations, plus the number of accidents occurring within 0.4 miles of each sensor site are summarized in Table 6-1. Statistical analyses of these data led to the following conclusions:

TABLE 6-1

SPEED DISTRIBUTION CHARACTERISTICS AT DIFFERENT LOCATIONS
(MEAN VALUES OF LOOPS OPPOSITE TO EACH OTHER)

Loop Number	$\bar{v}$	σ_v	V_{85-15}	V_{85}	V	S_k	N_A	$\tilde{N}_A$
10/14	58.3	8.3	16.0	66.4	0.14	-0.12	13	9.80
9/13	55.4	9.1	17.4	64.2	0.16	-0.13	21	17.09
8/12	53.9	7.6	13.1	60.8	0.14	-0.25	12	9.02
0/4	40.7	8.7	17.8	48.7	0.18	-0.50	16	10.57
1/5	46.0	6.9	13.4	52.9	0.15	-0.02	9	10.97
2/6	50.9	7.9	15.7	58.7	0.17	0.05	4	4.19
3/7	54.9	7.6	14.3	62.2	0.17	-0.07	6	7.13

Notes: 1. N_A = Total number of accidents within 0.4 miles of a sensor site during 1968 and 1969.

2. $\tilde{N}_A = \frac{N_A}{N_v} \times 100$

where: N_v = Total number of vehicles passing sensor site during 1968 and 1969.

1. Parameters which measure speed spread (e.g., σ) tend to increase with increasing number of accidents.
2. There is no apparent relationship between traffic mean speed and number of accidents.
3. The speed distributions at all of the sensor sites are nearly normal.
4. A large increase was noted in numbers of accidents with increasing absolute value of speed distribution skewness. This increase was observed even though the maximum skewness that occurred was only 0.5. These findings are consistent with Taylor's theory. (177)

Thus, it seems clear that speed distributions containing a large spread of speeds may be associated with high accident rates. An analysis of the fine structure of accident-speed distributions was conducted next to determine the amounts of spread that may be tolerated as relatively "safe," and that which the traffic law system should seek to eliminate by the implementation of suitable speed limits.

6.3.2 Accident Frequency Distribution Studies

This analysis considered how accident involvement rate varies with the deviation of the speed of the accident-

involved vehicle (AIV) from the mean speed of the traffic stream. The rationale followed was that in order to achieve a high level of traffic flow, the highest possible speed limit would be sought consistent with acceptably low accident rates. Thus, the speed limit would not necessarily have to occur at the speed which resulted in absolute minimum accident involvement but could be higher, if the accident involvement did not increase more than a few percent. Speed limits occurring in regions of rapidly increasing accident involvement were not permitted.

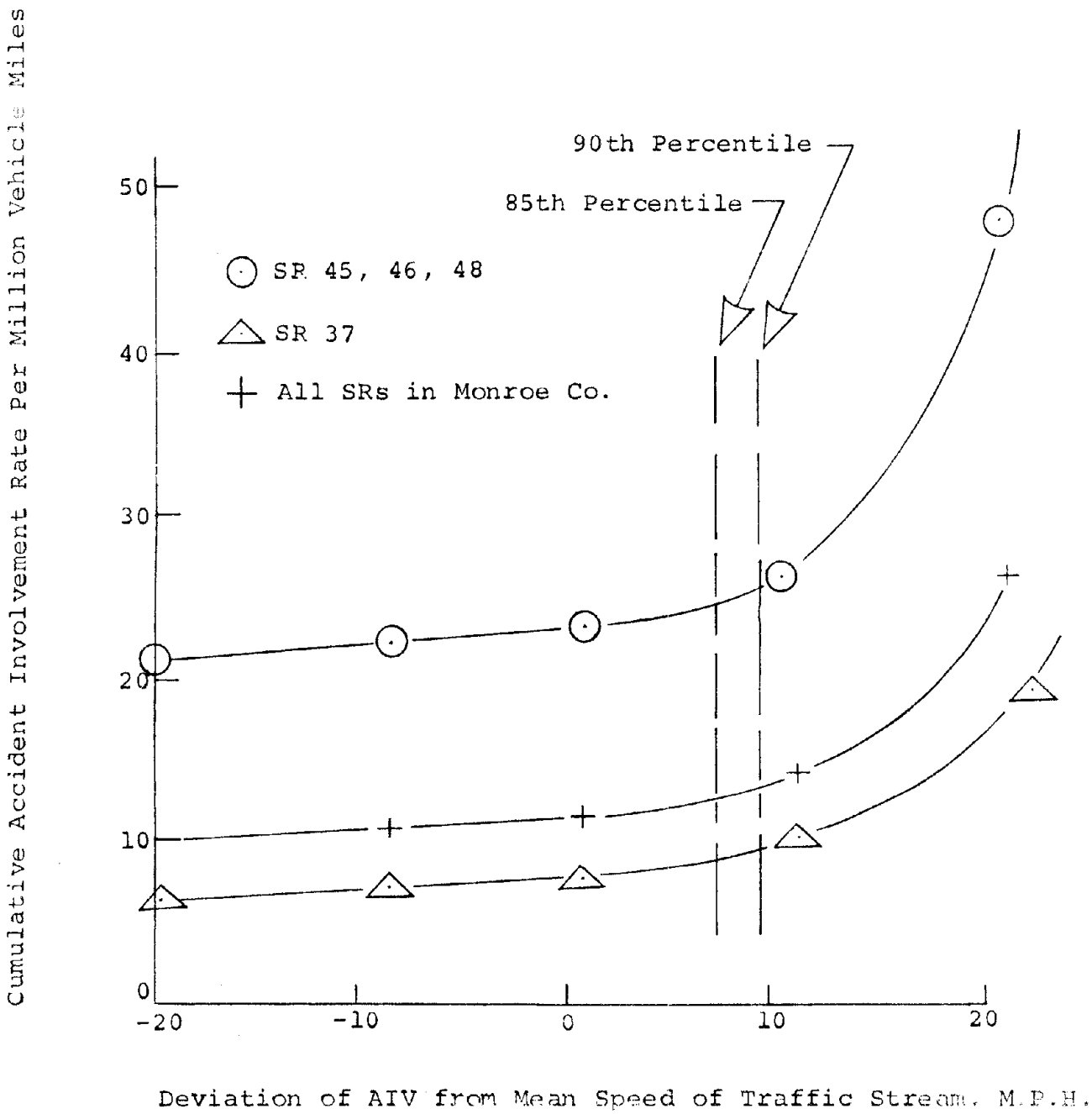
The basic data used were those collected by IRPS in Monroe County, Indiana, and reduced and presented by RTI in reference 191. Since we were seeking a maximum speed limit rather than a minimum limit, a cumulative distribution was used which showed accident involvement rates at all AIV speed deviations <u>less than</u> a given value.

The data are presented in Figure 6-1. Curves are shown for SR 37; SR's 45, 46, 48 (total); and all SR's in Monroe County. Turning vehicles have been excluded to make the data applicable to our purpose. Note that regardless of which roads are being considered, the slopes of the curves are nearly constant and reasonably low for AIV speed deviations of less than 10 mph from the mean speed of the traffic stream. A precipitous rise is noted in accident-involvement rate in

EFFECT OF AIV SPEED DEVIATION ON ACCIDENT INVOLVEMENT RATE FOR VARIOUS STATE ROUTES IN MONROE COUNTY, INDIANA

FIGURE 6-1

(non-turning vehicles)



the speed deviation region $10 \leq \nabla v_{AIV} < 20$ such that, for example, vehicles traveling at speeds up to 20 mph greater than the mean have an accident-involvement rate nearly twice that of vehicles traveling at speeds up to 10 mph greater than the mean!

It is therefore clearly important that maximum speed limits be set to reduce the likelihood of travel at speeds much greater than 10 mph from the mean speed of the traffic stream.

Consideration of a method to implement this concept must take into account two real world practices. First, speed limits are almost universally established in five-mile increments. Thus, the impact of rounding values is a consideration.

Second, enforcement practices allow a tolerance, that is a range above the posted limit before enforcement action is taken. This is justified partially on the basis of possible measurement error either by the officer or the driver. The fact that actual travel speeds vary so that a well-intentioned driver may slightly exceed an absolute limit is also considered.

Thus, any value selected as a function of speed distributions is likely to be altered in implementation. While the impact of a lower implemented value may not have great

risk significance due to the relatively flat slope of the risk curve, the opposite is true of a higher value.

The 85th percentile speed (85, 77, 98, 99, 113, 140, 203, 204, 205, 206, 208, 209) appears ideally suited for such a speed limit. First of all, it is a speed which, by definition, 85% of all drivers do not exceed, so that enforcement action need be targeted at a maximum of 15% of the drivers. If, however, enforcement is set at the 85th percentile plus 5 mph (i.e., mean speed plus 12 mph), only about 4% of the drivers will be enforcement targets. Further, the resultant accident-involvement rate will still be acceptably close to the region of lowest accident involvement.

The case for a 90th percentile speed limit is not as persuasive. It is, to begin with, uncomfortably close to the high accident involvement region, which is also a region of great sensitivity to small changes in speed deviation. Additionally, even a small enforcement margin places one too high up on the accident involvement curve.

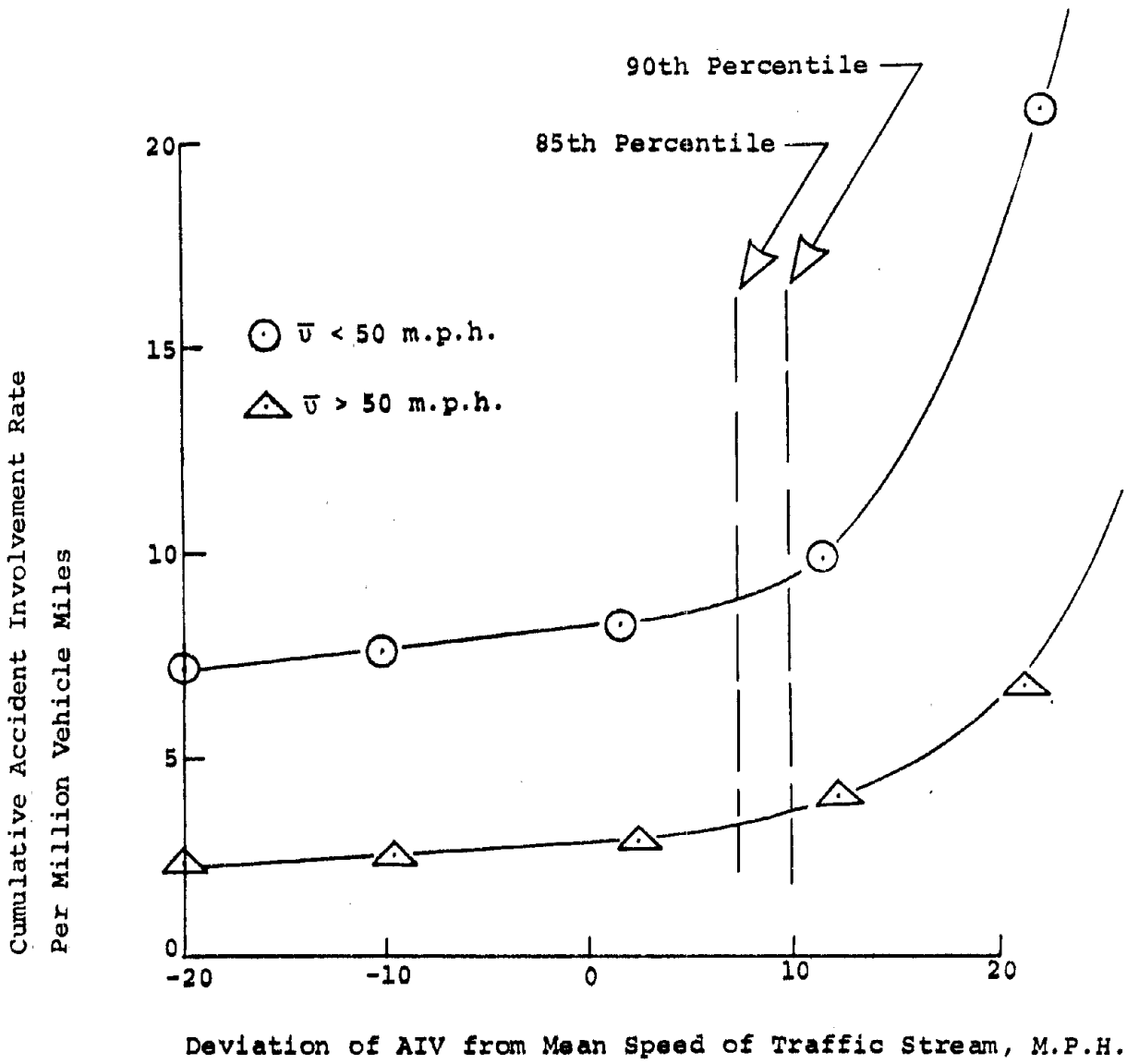
Some researchers have stated that a 90th percentile limit may be more attractive in situations where the mean speed of the traffic stream is greater than or equal to 50 mph (207). At first glance, the Monroe County data seem

to confirm this (figure 6-2). However, if percentage increase in accident-involvement rate is the criterion, then the 90th percentile limit fares no better for mean speeds over 50 mph than it does for those less than 50 mph. Consider, for example, the percentage increase in accident-involvement rates obtained from increasing the enforcement speed from 85th percentile plus 5 mph to 90th percentile plus 5 mph. For mean speeds of less than 50 mph, there is an 11% increase in accident-involvement rate, while at mean speeds of greater than 50 mph, a practically identical 10% increase is noted. Thus, the 90th percentile limit would appear to be preferable for speeds over 50 mph only if absolute accident-involvement rate is the criterion and accident-involvement rate, rather than accident-involvement disutility, is to be minimized.

Actually, in any real world application, the effect of setting a speed limit at the 90th percentile rather than the 85th percentile would be difficult to detect. In the first place, IRPS data indicate that the speeds associated with these points will not in all likelihood differ by more than 2 to 3 mph (see appendix E). Secondly, the practice of rounding speed limits upward to the nearest 5 mph provides a band of tolerance which, if the limit were set at the 85th percentile, would include the 90th percentile.

EFFECT OF AIV SPEED DEVIATION
ON ACCIDENT INVOLVEMENT RATE
FOR TWO RANGES OF TRAFFIC
MEAN SPEED
(non-turning vehicles)

FIGURE 6-2



7.0 CONCLUSIONS

The concept of establishing a maximum speed limit on the basis of the 85th percentile of travel speeds on a highway is recommended. Such a maximum speed limit meets the risk management objectives of a speed law and can be widely implemented utilizing existing manpower resources and technology.

Such a limit is:

1. Fundamentally fair in the context of the Traffic Law System.
2. Related to risk of dysfunction in the Surface Road Transportation System.
3. Accepted as reasonable by drivers.
4. Applicable to a wide range of highways.
5. Capable of implementation with existing resources.

The recommendation of the 85th percentile speed limit concept is supported by a substantial portion of the technical literature as well as the data and analyses of the present study.

A method for implementation of the 85th percentile concept is explained in the next chapter and presented in detail in Volume III of this report.

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8.0 THE RECOMMENDED METHOD

This section discusses in detail the recommended implementation method for setting a speed limit and the rationale behind various aspects of the method.

8.1 Background

In order that the findings of this study might be translated into a usable form, it was decided that an implementation manual would be structured to apply to any level of traffic personnel involved in the setting of speed limits, but primarily it would be directed toward those people without a college engineering background who are responsible for setting speed limits in smaller communities and jurisdictions. As was stated in section 3.0, the survey results indicated that often an enforcement or public works official is responsible for determining speed limits in such jurisdictions.

Since the findings of this study indicate that at present the best speed limit is a "reasonable" one, this manual is an implementation of the 85th percentile method. According to the conclusions of this research, the 85th percentile criterion produces an appropriate speed limit value in terms of the objectives of a speed limit defined in section 4.0. Also the literature and the survey indicate

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that the 85th percentile criterion is not only reasonable but is also familiar and acceptable to numerous people in the traffic field. Among those who responded to the questionnaire survey, awareness of the 85th percentile criterion was nearly universal.

Because the 85th percentile is familiar to many traffic specialists, it is undoubtedly put to use in various ways throughout the country. The purpose of this manual, then, is twofold. First, it is to teach traffic specialists how to correctly derive a speed limit from the 85th percentile criterion using statistically valid procedures. Secondly, it is to promote uniformity throughout the country in the setting of speed limits.

Before discussing the implementation method, itself, it is important to understand how the method will be presented to the individual traffic specialists. Since one of the primary objectives of the implementation package is to promote uniformity throughout the country, it is obvious that the implementation method must be distributed to a widely dispersed audience. It is also desirable that the presentation be relatively simple and understandable, as well as low in cost. Because of these three qualities, ease of distribution, ease of understanding, and low cost, a self-instructional

educational method -- programed learning -- was chosen. It was decided that the educational tool would be most effective if presented in two parts. Thus, the manual consists of first, a programed educational text which teaches the traffic specialist the 85th percentile method, and second, a field workguide for him to use as a checklist while actually setting a speed limit. This package has the additional advantages that no special instructors are needed and that the educational program can be worked at the convenience of the individual traffic specialist. The programed implementation text can be found in Volume III of the report.

In addition, a brief presentation of the recommended method can be found in Volume IV of the report. This manual was designed for the experienced traffic engineer, and contains a short discussion of the recommended implementation of the 85th percentile method, plus the field workguide that is presented in Volume III.

8.2 Sampling Method

The recommended method of setting a speed limit is based on a statistical procedure known as systematic sampling. The choice of a sample data method is based on a real-world constraint of utilizing existing instrumentation to collect speed data. Devices available to local jurisdictions are normally radar, VASCAR, or switch-actuated timing devices. The use of these instruments makes it literally impossible to measure the speed of every vehicle under many traffic conditions.

The systematic sampling technique best meets our requirements for a sampling method for determining the 85th percentile speed, namely, that it be feasible, accurate, easy to use, and easy to understand. The data for use in systematic sampling is a speed sample the traffic specialist can collect in a reasonable time interval using readily available instruments. The accuracy of systematic sampling in yielding an 85th percentile speed which closely approximates the 85th percentile speed of the population is shown elsewhere in this report. Systematic sampling is easy to use -- only simple hand calculations are required. Finally, the method of systematic sampling is easily understood -- it is, if any method can make that claim, the natural way to take a sample.

To take a systematic sample from a list it is necessary to determine the number of units to be skipped. This number is usually determined by the desired size of the resulting sample. For example, if a sample of size ten is desired from a list of one hundred speeds, a logical skip size would be ten, i.e., after the first speed in the list is chosen, every tenth speed thereafter is also chosen, the sample of speeds being made up of all such selected speeds. Such a sample will have ten speeds, as desired. The position in the list of the first speed chosen can be determined arbitrarily or with the use of a random number table, so long as that position is in the first ten at the beginning of the list. In this example, the first speed in the sample might be the seventh speed in the list. Then the other speeds chosen would be those occupying positions 17, 27, 37,. . . , 97 in the list. Choosing the speeds in this way gives a "systematic" sample.

A good discussion of systematic sampling is given in Hansen, Hurwitz, and Madow, *Sample Survey Methods and Theory*, (John Wiley & Sons, Inc.: New York, 1953) Vol. 1, pp. 503-505. There it is pointed out that systematic sampling is a simple and proven technique when periodicities do not exist in the data or when no multiple of the interval between samples is a multiple of the period of the data. In the data

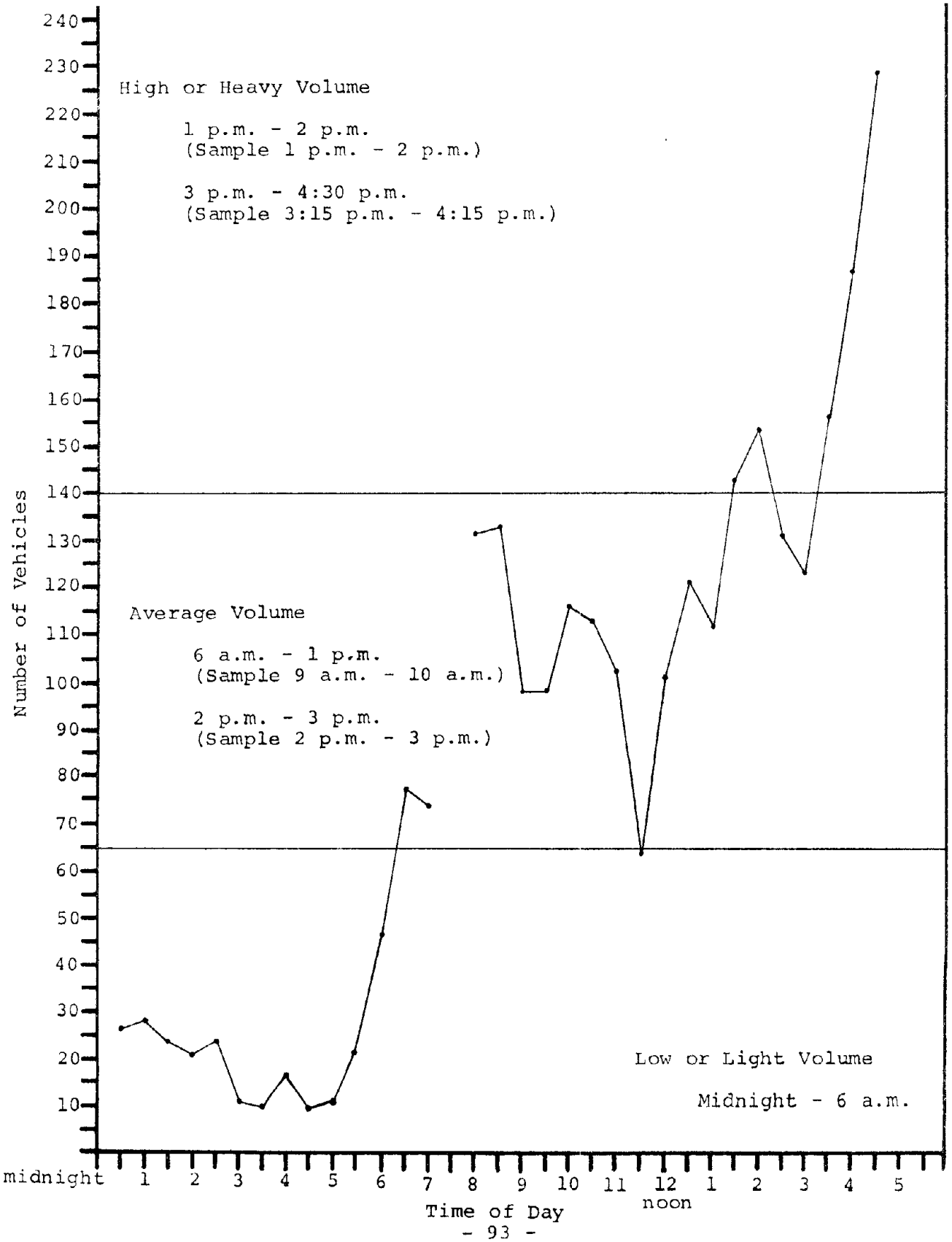
collected in this study, no problems arose with such periodicities.

To use systematic sampling is determining the 85th percentile, it is first necessary to determine when the sample speeds should be taken. It is recommended that this decision be based on a plot of traffic volume versus time, a plot of data easily obtained through the use of a traffic counter. With this plot, the traffic specialist can determine which time intervals correspond to the traffic volumes of interest. Such a plot is given in Figure 8-1. The traffic specialist must use his own judgment to classify the traffic flow into high, average, and low volume.

From each of the time intervals corresponding to the desired volume of traffic, the traffic specialist measures speeds in the hour falling in the middle of the period or, if the period is less than an hour long, for the entire period. Data from each time interval with the same volume are kept separately. The traffic specialist counts the number of speeds measured during each interval. He then divides the number of speeds of each interval either by 100 or by the smallest number of speeds in any interval if that number is less than 100, and rounds the result of his division down to the next integer. This integer is the "skip

VOLUME PLOT LOOP 26

FIGURE 8-1



size" referred to above. With this skip size, the traffic specialist takes a systematic sample from the speeds he has collected and calculates the 85th percentile speed. Figure 8-2 and Figure 8-3 give tabulations of both sample and population speeds and the resulting 85th percentile speeds. Figure 8-2 is for the average volume part of Figure 8-1; Figure 8-3 is for the high volume part of Figure 8-1.

In Figures 8-2 and 8-3 the difference between the 85th percentile speed when calculated using systematic sampling and when calculated using the entire speed population (as gathered with the computer sensor system described in Appendix B) differ by only one mile per hour.

The Institute has applied the technique just described to data from loops in traffic zones with speed limits of 20, 40, and 55 mph, for high and average traffic volumes. In addition, a variety of different roadways have been examined. In every case, the 85th percentile speed calculated from systematic sampling differed by no more than two miles per hour from that calculated from the entire population; for high and medium volumes the difference was never more than one mile per hour.

In summary, the 85th percentile speed is a good indicator of an appropriate speed limit, and the method of systematic sampling as presented above has been shown to be

	Speeds	6am-1pm	2pm-3pm	Total c.f.
	1-39	26	6	32
	40-54	330	59	421
	55	63	15	499
A	56	76	17	592
V	57	72	13	677
E	58	73	22	772
R	59	99	24	895
A	60	102	10	1007
G	61	58	6	1071
E	62	70	15	1156
	63	50	12	1218
V	64	69	9	1296
O	65	43	14	1353
L	66	32	5	1390
U	67	29	2	1421
M	68	31	7	1459
E	69	25	6	1490
	70-79	76	12	1578
	80-89	8	0	1586
	90+	1	0	1587
				x .85
				1349

Speeds	9am-10am	2pm-3pm	Total c.f.
1-39	1	3	4
40-54	32	29	65
55	9	7	81
56	1	8	90
57	5	4	99
58	4	7	110
59	5	9	124
60	4	6	134
61	3	1	138
62	3	4	145
63	2	5	152
64	6	2	160
65	5	4	169
66	3	3	175
67	2	1	178
68	4	3	185
69	2	0	187
70-79	8	4	199
80-89	1	0	200
90+	0	0	200
			x .85
			170

FIGURE 8-2

population ↑ ↓ sample ↑ ↓

	Speeds	1pm-2pm	3pm-4:30pm	Total c.f.
	1-39	10	16	26
	40-54	83	142	251
	55	14	42	307
	56	19	42	368
H	57	18	47	433
I	58	16	34	483
G	59	23	42	548
H	60	11	38	597
	61	17	25	639
V	62	17	31	687
O	63	9	20	716
L	64	11	21	748
U	65	9	19	776
M	66	4	15	795
E	67	5	8	808
	68	7	3	818
	69	8	8	834
	70-79	15	19	868
	80-89	1	0	869
	90+	0	0	869
				x .85
				739

Speeds	1pm-2pm	3:15pm-4:15pm	Total c.f.
1-39	3	7	10
40-54	26	29	65
55	5	8	78
56	7	4	89
57	7	8	104
58	7	1	112
59	8	7	127
60	6	4	137
61	6	8	151
62	5	6	162
63	3	5	170
64	2	2	174
65	2	5	181
66	1	2	184
67	1	0	185
68	3	1	189
69	3	1	193
70-79	5	2	200
80-89	0	0	200
90+	0	0	200
			x .85
			170

FIGURE 8-3

a statistically sound and accurate method for determining the 85th percentile speed.

8.3 General Comments

Several additional points included in the recommended method must be discussed.

No specific equipment is recommended for measuring speeds, however, it is critical that the measurements be taken in a manner that is not obvious to the drivers on the roadway. It should be noted that the survey results of this study indicated that nearly all jurisdictions have access to radar units. It was also shown that most jurisdictions had traffic counters, and, of course, if in any case such counters are not available, a manual vehicle count is possible.

It is recommended that in most cases speeds be measured during clear, dry weather and average volume conditions. Generally the traffic specialist will want to set a speed limit to deal with the driving situation most conducive to the faster speeds that could be expected on the road. Most drivers will automatically be slowed down by poor weather conditions and by increasing traffic volume. As volume increases on a road, the driver tends to flow with the traffic stream rather than obey the speed limit. It is, of

course, stated in the educational manual that predominant weather conditions and specific problem volumes may be used when appropriate.

After the 85th percentile speed has been computed, the speed limit is determined by rounding to the next higher 5-mph. The purpose of this is to include as many vehicle speeds as possible under the speed limit consistent with the discussion in section 6.0 of risk.

In its application the method put forth in the implementation package is not to be viewed as rigid. Much of the substance of the programed unit consists of common sense and good judgment. There are no hard, fast rules for such activities as selecting a representative measurement site; however, the purpose of the text is to alert the traffic specialist to the factors which should be taken into consideration. Thus, the entire method should be employed with careful judgment and good sense. The speed limit resulting from the application of this method should be subject to evaluation in terms of the traffic situation with which the limit was to deal. If, for example, the new limit creates an entirely new traffic speed pattern or increases the accident picture, additional studies must be conducted and a more appropriate speed limit reached. It must be

clearly understood that traffic behavior is dynamic, not static, and that a new speed limit may change traffic patterns enough to require additional changes in the limit. In any case, the speed limit must meet the need created by the individual traffic situation.

9.0 COMMENTS ON SPEED LIMITS AND SPEED CONTROL

Prior sections of this report have presented recommendations and conclusions that the authors believe are supported by data, the analyses, and the literature. In this chapter certain concepts and recommendations are discussed which the authors deem appropriate for consideration but are not supported by sufficient emperical data to warrant advocacy as proven. In essence such commentary represents the authors' insight into the problems of speed limits and speed control.

9.1 Special Speed Limits for Trucks and other Vehicles

Particular interest was expressed by the Sponsor in the rationale for separate maximum speed limits for trucks and other vehicles.

The survey conducted of various jurisdictions and reported in section 3.0 contained questions focused on this issue. In general jurisdictions with the same maximum limit for all vehicles responded that this was done to avoid impeding the flow of traffic. Those jurisdictions with lower maximum speed limits for trucks, buses etc., responded that this was done in the interests of safety. No jurisdiction gave any indication that any empirical data were available to support any position.

Conceptually, an argument can be made against a separate speed limit on the grounds that it would produce a separate

speed distribution which might result in the low end of the distribution heavily represented in the high risk area of the overall traffic distribution. In the same sense it might be said that the lower limit would produce platooning on two lane highways which would impede flow and generate passing activity which in turn might increase the potential for accidents.

An argument can be made for a lower limit if it can be established that trucks and other like vehicles can not travel safely at or near normal maximum limits. This is in effect stating that the risk curve for trucks rises more sharply for speeds above a mean speed than does the curve for cars and like vehicles.

The data collected in this study do not provide an answer to these issues. Examination of truck speeds at those points where free flow was possible does not indicate a significant difference between truck speeds and that of other vehicles.

Lower speeds are noted on grades. It should be noted that speed limits would have little impact on such behavior as it stems from vehicle limitations not driver choice.

One is led to suspect that concern over maximum limits for trucks, buses, etc., may be a misallocation of "worry". Our data, and other studies (159, 165, 190) indicate the slow moving vehicle to be of high risk. It would appear more satisfactory to consider

the problem of the slow moving truck. Pragmatically road geometry may provide the basic speed control mechanisms. Thus, some response is required to identify the slow moving truck on grades. New York and some eastern states have required vehicles traveling on limited access roads at speeds lower than 25 mph below the speed limit to flash both rear blinkers. It would seem this simple practice could be widely implemented with probable risk reduction.

At the same time it would appear relatively simple to gather basic data on speed behavior of trucks on highways (1) with the same maximum limit (2) with different maximum limits for trucks and cars. The distribution of speeds of trucks and all traffic should be compared for both sets of highways.

If it were apparent that the result of a lower maximum limit were to cause a significant number of trucks to travel at a lower speed so that the overall distribution of traffic was skewed or the standard deviation significantly larger, one would conclude that the lower limit was inappropriate.

It is perhaps more probable that the distribution of truck speeds would be more narrow and fall within the minimum risk range of general traffic. It is also possible that one would find that the lower maximum limit did not fall at the actual 85th percentile of truck speeds.

In absence of sound emperical data we would neither support nor deny the reasonability of lower limits for trucks and buses but would require those seeking to impose a lower limit to present clear evidence that risk management is served by such action. Imposition of the limit without such persuasive evidence can only be regarded as an inappropriate act that will cause misallocation of Traffic law system resources.

9.2 Minimum and Advisory Speed Limits

The establishment of minimum and advisory speed limits was not included within the scope of the study. However, it was impossible not to review the literature on such limits or to consider them in the context of the theoretical hierarchy of speed control. Adequate data collection elements were not included within the research design to allow the formulation of supportable emperical conclusions concerning such limits.

Certain insights are suggested by both the literature and theoretical considerations. First, if one accepts the concept that it is desirable to have as many vehicles as possible travel at or near the speed which is associated with the minimum risk, it would appear logical to set advisory speed limits at that value. The best evidence available suggests that the minimum risk value is the mean speed of traffic. Accordingly, it would seem that advisory speed limits should be established at the mean speed of traffic.

Secondly, the literature and the RTI-IRPS study clearly indicate the danger created by slow moving vehicles. In fact there is some evidence to indicate such vehicles constitute as much or more risk than do those traveling faster than the maximum speed limit. Examination of the risk curves indicate that the risk starts to rise at about one standard deviation below the mean speed and rises sharply at two standard deviations below mean speed. It would seem logical to place minimum speed limits at the value associated with two standard deviations below the mean speed.

9.3 Enforcement Tolerance

The practice of allowing some range of speeds above the posted speed limit before enforcement action is initiated is well known in law enforcement circles and equally well perceived by most drivers.

Unfortunately, the precise nature of the reasoning which governs the formulation of police on tolerances is not well established or widely known. Attempts to encourage law enforcement policy makers to write or speak on the subject have not met with much success. The precise tolerance allowed in a particular jurisdiction is a function of many factors not the least being the mood of the particular enforcement officer observing the violation.

It appears quite clear that the basic concept underlying the decision not to make an arrest in every possible instance when a speed limit is exceeded is sound. The problem lies in developing a general rule that can be consistently and widely applied.

If once accepts the fact that enforcement resources are quite scarce and should be selectively assigned against highest risk some of the data takes on particular significance. Examination of the risk curves indicates that while the risk starts to increase at approximately the 85th percentile (which is approximately one standard deviation from the mean speed) it increases even more sharply at two standard deviations from the mean speed. Thus, drivers traveling at a speed two standard deviations from the mean speed are a clear risk and should be subject to enforcement response. In the cases examined the standard deviation had a value of about 7 mph. Thus, a typical distribution would have a mean speed of about 58 mph, a speed limit at the 85th percentile of 65 mph, and the second standard deviation would fall at about 72. The risk curves would suggest 72 mph as a resonable point to initiate enforcement action.

What is of perhaps more interest is the fact that the use of the two standard deviation concept gives a rule that can be applied as traffic flow behavior on a particular roadway

changes. Traffic at 8 am or 5 pm will have a different mean speed than will traffic at 3 am. Examination of mean speeds might result in the decision to enforce at or close to the posted limit during times when the mean speed dropped and to allow a much wider tolerance during low volume hours when mean speeds are higher.

The data are not sufficient to allow a precise conclusion that the tolerance should be established at the value associated with two standard deviations from mean speed. What should be understood is that for a particular highway the risk does vary as a function of mean speed. A single tolerance does not satisfy the concept of risk management and selective assignment of scarce law enforcement resources.

9.4 Measuring the Effectiveness of Speed Limits

A great deal has been written and said about the impact of speed limits but almost no empirical data exists that can be used to quantitatively establish the precise effect of a speed limit. In the absence of such knowledge it becomes equally impossible to state quantitatively a method to measure the effectiveness of a speed limit.

If one thinks of the objective of a speed limit as regulating traffic in the risk management sense to achieve the objectives of the traffic law system and the SRT system, two measures of effectiveness are suggested. One, has the flow rate increased? Two, has the accident rate increased?

The measurement of flow if thought of in terms of throughput may be evaluated in terms of increase in average or mean speed. Readings of speed distributions before and after alteration or establishment of the speed limit may be expected to give some insight. However, the issue of accident reduction is much more complex. Accidents are infrequent events no matter how numerous they may seem. Further, the factors involved in accident causation are numerous and many variables are at play that cannot be influenced by a speed limit. The accident experience might actually rise following a change to precisely the best speed limit due to the action of intervening variables. Thus, dependency upon accidents for an evaluation of the effectiveness of a speed limit on a particular highway is at

best a lengthy process of uncertain reliability.

Obviously, some interim measure must be identified. The work of Taylor and the Tennessee Department of Highways is most promising in this regard. Consideration of the shape of the resultant distribution and accompanying parameters holds perhaps the best clue for a measure of effectiveness.

Conceptually, it would be ideal if all vehicles traveled at or near the same speed. This would minimize the potential for conflict of traffic traveling in the same direction. This concept is limited in the real world by differences in the capabilities of vehicles and drivers as well as the speed differentials that are created by entering and leaving the highway.

For a given highway there exists some set of vehicles at any instant of time that must travel at a speed lower than the mean speed of traffic simply because of vehicle condition or driver destination. Thus every distribution of speeds will have a definite set of vehicles to the left of the mean. The extent of the distribution to the right of the mean is more difficult to identify. The decision to travel faster than the average speed is a function of individual driver judgment and includes a mix of risk perception, time pressure, individual driving confidence, vehicle confidence, familiarity with highway, etc. Such decision-making process may be more susceptible to influence by speed limits but the extent, mode or manner is not now clear.

It would seem generally desirable to reduce the number of

drivers traveling at speeds different than the mean speeds. Thus, a speed limit which produced a distribution that was more nearly normal with a smaller standard deviation would seem more desireable or more effective. Unfortunately, data are not available to clearly support this position no matter how logical we may perceive it.

We believe that considerable effort should be made by the leaders in the field of Traffic Safety to encourage the implementation of the 85th percentile concept. Such implementation should be accompanied by post-implementation evaluation to determine the change in the parameters of the speed distributions. Such changes should be correlated against throughput and accident experience over a lengthy period of time with every effort made to identify the impact of intervening variables. Accident experience may be regarded as a poor indicator for a single highway, but should be useful for evaluation over a broad highway set over an extended period of time. Local jurisdictions should be required to collect post-implementation data at periodic intervals in a common manner to allow cross-correlative evaluation.

9.5 Recommendations for further Research:

It is a characteristic of every research report that it concludes with a recommendation for further research which is needed to solve the question the project was originally funded to answer. It would indeed be difficult to fly in the face of tradition and hope to maintain any status as a researcher.

However, we are constrained to question the wisdom or feasibility of conducting relatively small scale research projects on the subject of speed limits or speed control. The research to date has pointed quite conclusively to a method that can be broadly implemented and may be expected to have desirable results. It seems pointless to engage in further research unless it can clearly advance the state of the art.

The "state of the Art" stops at the point one asks the question "what is the effect of a speed limit". Such a question can not be answered by a small scale research project. One must either alter the speed limits on a fantastically large set of highways while measuring the effects or settle for a smaller set of highways and engage in continuous variation of the speed limit. The first prospect staggers the imagination when one considers the real world problems inherent in implementation.

The second prospect which would involve instrumenting a set of representative highways and measuring the response to variable speed limits is not an impossibility but the cost

factors associated with it are staggering as they would certainly be within the million dollar range.

One would question the value of such an expenditure which at best could be expected to add only slightly greater precision to the 85th percentile method. If the cost could be justified it would likely to be in terms of increased flow and in such case would be relevant to only a minimal set of the highway system, primarily urban expressways or feeder highways where maximizing volume is a critical issue.

The issue can probably be better met in terms of the need for a general information system for the nations highways. The use and value of process control computer systems has been adequately demonstrated in the private sector: Initial efforts in the utilization of computer systems for signalization have been successful but have represented relatively trivial demands on the inherent capability of computer technology.

It would be far more logical to think in terms of development of a comprehensive computer based information system for a highway set. Such a system would collect basic data, evaluate it, provide information to highway users, and those responsible for highway safety, traffic control etc. Such a system would logically include internal measures of effectiveness that would evaluate driver response to a range of stimuli merely one of which would be speed limits.

The cost of such a system would not greatly exceed that required for evaluation of a single variable such as speed limits and holds considerable promise for overall traffic safety management.

It is also believed that cost-oriented methodologies offer promise as a longer range approach to determining optimal speed limits. Properly directed, this techniques could place a large complement of highly developed and widely applied analytical tools in the hands of highway analysts, planners, and operational personnel. These tools could be of great value not only to the establishment of speed limits, but could also be applied to a host of other highway problems. Perhaps even more importantly, the approach could provide a means for determining SRT priorities and of allocating resources among them. Certainly, such a model would be most useful in structuring and designing a highway information system such as that described above. A considerable research effort will be required, however, to develop the cost-oriented approach to the point of practical utility.

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APPENDICES

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APPENDIX A

GLOSSARY OF TERMS

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absolute speed limit: "a speed above which it is always illegal to drive." Also known as a maximum lawful limit. (I, p. 538)

advisory speed limit: the maximum safe speed that is posted below a warning sign. "In most states, the advisory speeds are not legally enforceable, but in some courts violation of the advisory speeds is admissible as evidence that the driver was operating in a reckless manner." (I, p. 541)

average overall speed: "The average of the overall speeds of all vehicles on a given roadway during a specified period of time." (II, p. 12)

average overall travel speed: "The sum of distances divided by the sum of overall travel times (a space-mean speed)." (I, p. 159)

average spot speed: "The arithmetic mean of the speeds of all traffic, or component thereof, at a specified point." (I, p. 159)

critical approach speed: "At an intersection, that speed above which a vehicle does not have sufficient distance to stop in time to avoid collision with another

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vehicle approaching the intersection on the cross street ." (II, p. 39)

critical speed (on curve): "The speed above which a vehicle will slide off the curve rather than follow around it." (II, p. 40)

design speed: (of highway): "A speed selected for purposes of design and correlation of those features of a highway, such as curvature, superelevation, and sight distance, upon which the safe operation of vehicles is dependent. It is the highest continuous speed at which individual vehicles can travel with safety upon a highway when weather conditions are favorable, traffic density is low, and the design features of the highway are the governing conditions for safety." (II, p. 48)

85th-percentile speed: "That speed at or below which 85 percent of vehicles travel." (II, p. 68) [The xth percentile would also have a corresponding definition.]

free-moving vehicle: "One in which the driver is not restricted in selecting his speed by other vehicles...Some observers classify a free-moving vehicle as one which has not less than 6 - 9 sec. headway from the vehicle ahead of it and is making no apparent effort to overtake and pass the vehicle ahead of it." (I, p. 539)

headway: "The time interval between passages of consecutive vehicles measured from head to head, moving in the same direction as they pass a given point." (II, p. 91) or "The distance, measured front to front, between consecutive vehicles." (II, p. 92)

maximum lawful limit: "a speed above which it is always illegal to drive." Also known as an absolute speed limit. (I, p. 538)

median speed (of traffic): "That speed below which 50 percent and above which 50 percent of the speeds occurred." (II, p. 128) [the 50th percentile]

modal average: "that speed at which the greatest number of vehicles travel." (III, p. 51)

nominal speed (of traffic): "A running speed at which driver's operate on a given section of highway in the absence of traffic interference." (II, p. 140)

operating speed: "The highest overall speed exclusive of stops at which a driver can travel on a given highway under prevailing conditions without at any time exceeding the design speed." (II, p. 151)

optimum speed: "The average speed at which traffic must move when the volume is at a maximum on a given roadway. An average speed either appreciably higher or lower than the optimum will result in a reduction in volume." (II, p. 152)

overall travel speed: "The speed over a specified section of highway, being the distance divided by overall travel time..." (I, p. 159)

overall travel time: "The total time of travel, including stops and delays, except those off the traveled way..." (I, p. 159)

pace of traffic: "the range of speed which includes the greatest number of vehicles for some nominal increment in speed, usually 10 mph." (III, p. 51)

prima facie speed limit: "a speed above which the driver is presumed to be driving unlawfully but if charged with exceeding it, a driver may show cause to prove that his speed was safe for conditions and, therefore, that he was not guilty of a speed violation." (I, p. 538)

running speed: "The speed over a specified section of highway, being the distance divided by running time ..." (I, pp. 159, 161)

running time: "The time the vehicle is in motion..." (I, p. 159)

skew distribution: "A non-symmetrical distribution. A distribution is skewed to the left (right) if the longer tail is on the left (right) - also called negative (positive) skewness..." (IV, p. 126)

space-mean speed: "The speed corresponding to the average of overall travel times or running times over a specified section of highway." (I, p. 161)

spot speed: "The speed of a vehicle as it passes a spot or point on a street or highway." (I, p. 159)

ten-mile-per-hour pace: "The 10-mph speed range containing the largest percentage of vehicles in a sample of spot speeds." (I, p. 159)

time-mean speed: "The average of spot speeds of individual overall travel speed values." (I, p. 161)

APPENDIX B

SENSOR SYSTEM DESCRIPTION

One of the difficulties with the traffic measuring devices in common use is the influence the device exerts on the very thing it is measuring. Obtrusive methods such as radar and speed tapes tend to interject bias into the data because of their visibility to the driver.

As an integral portion of the present study, the Institute for Research in Public Safety undertook the development of an unobtrusive traffic measuring system in which loop detectors were connected via telephone lines to a process control computer.

Eight locations along State Route 37, North and South of the City of Bloomington, Indiana, were monitored 24 hours a day during Phase I of the study. This number was expanded to fourteen during Phase II.

The unobtrusive instrumentation at each site relayed two signals which were interpreted by the IBM 1800 computer to yield the vehicle's speed, length, location, lane of travel, direction, headway (the time differential between the preceeding vehicle and the vehicle being monitored), and time of transit.

One of the chief attributes of the computer-sensor system is its ability to collect, array, and store data without outside intervention. No human judgment (or error) became a factor in the data assimilated by the system. Other than the weekly calibration and a replacement of magnetic tape on a five day cycle, no personnel are involved in the system operation.

1.0 The Computer

The computer system developed for the present project has as its core an IBM 1800 system. An IBM traffic control system program was modified by project personnel to the special needs called for when measuring vehicle velocities data. The requirements of the project contemplated the use of the computer as a portion of an information system which would provide data for decision-making purposes.

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The decision-making process contemplated in these projects was more analytical in nature; however, the system could also be adapted for tactical decision-making.

Hardware

During Phase I, the IBM 1800 system was composed of the following components:

(1) 1802 Central Processing Unit (16K, 4mics.)

(2) 2401 Magnetic Tape Unit

(3) 1442 Card Read Punch

(4) 1810 Disk Storage (250,000 words)

(5) 1826 Data Adaptor

(6) 1816 Printer Keyboard

(7) 1802 Process Controller.

Twelve interrupt levels are necessary for a minimal system. The system also has a 1053 character printer which is used for data retrieval, while the other printer (1816) maintains a printed record of system status. In order to receive the vehicle information from the highway, four digital input strips with sixteen points each are mounted in the computer interfacing.

System Software

The basic system software used in the system design is IBM's 1800 O.S. Time Sharing Executive (TSX), Version 3, Modification Level 7. Through a series of programmed interrupts, queued programs and non-process programs, as well as optimizing alterations in the systems director, the facility has been adapted to the specific requirements of traffic study. Non-process programs can be run during low traffic volume periods without disturbing data collection.

Program PILOP, an incore subroutine, scans the digital input points every 5 milliseconds to check the status of each vehicle detector. A shift in voltage caused by a vehicle passing over a magnetic loop detector will be recorded along with the time as indicated on a 30.000 second clock. This, and the return to normalcy which accompanies the passage of the vehicle, are recorded for two wire

Program NC007 writes all the disk files onto magnetic tape. In this fashion, the disk unit may continue to collect and store vehicle data for a period of three to four hours (depending on traffic density) before requiring a tape backup. During this time, previously completed tapes may be re-examined for retrieval of old data (Program NC012), analysis or any other task which may require the assistance of a magnetic tape unit.

Program NC011 replaces the tape removed by NC007. To regain the computer for any analysis requiring the tape unit, the NC007-NC011 sequence may be rerun as often as necessary, up until midnight when Program ENDDAY computes the daily totals and reinintializes the system with the new date.

From the signals received from each loop set, vehicle speed, length, direction and lane of travel are calculated. Also recorded is the time of day and the time between the vehicle in the set and the previous vehicle. In this manner, the system yields lane usage information as well as speed relationship data.

2.0 Sensor System and Interface Equipment

The sensor consists of an RCA Vehicle Detector Unit which is connected to a loop of wire placed into the roadway. The vehicle detector senses the presence of a vehicle in the loop and closes a relay in the detector amplifier. The relay is connected to a phone line which terminates in an interface system specially developed for this project by Indiana University Institute for Research in Public Safety personnel. The interface system interrogates the relay by means of an electrical signal and reports the relay state to the computer in digital input form.

By combining the sensors in groups of four, it is possible to monitor traffic in two directions and to determine the speed and length of each vehicle passing through the loop set. Inasmuch as the events are time related, traffic densities as well as information on traffic flow composition may also be determined.

loops, as both are necessary to calculate the vehicle's velocity, length, direction, headway and time of passage. PILOP senses these times, and stores them in the appropriate buffer in INSKEL COMMON.

Program IR001, an interrupt core load, checks the INSKEL COMMON buffers for each loop set and dumps any full buffers to the appropriate disk files. Two 25 vehicle buffers are allotted for each loop set, so that one may be storing data while the other is being written to disk. If IR001 senses that a disk file is full, it queues up PC002.

Program PC002, a queued program, checks the disk files and dumps the full files to magnetic tape. The disk files are then reset, and the magnetic tape is checked to see if it is almost full. In this fashion, the system monitors traffic 24 hours a day without operator intervention.

Many non-process operations may be conducted utilizing the collected data, and other computer analysis functions may be performed while the system is monitoring traffic. A series of non-process programs have been developed to allow the users to care for the collection activity while engaged in other activity. Many of these programs provide for the maintenance of the computer-sensor system files and its calibration. The time-sharing capability of the IBM 1800 TSX provides for seemingly coincidental data collection and analysis activity.

Program NC003 establishes the disk files, initializes the tape and allows for parameter entry. When the loop sets are calibrated (by radar), adjustments in velocity and length are accomplished by means of modification in one of the conversion factors within the program which calculated these items from the four times provided by PILOP.

Programs NC004, NC005, and NC006 allow the operator to turn the loop sets on and off, and to enter the Data Input (interface) time sense base, day of week, weather and special conditions. The traffic at a given site may be examined on a real time basis if desired.

Description of Loop Installation

At each site, four loop detectors are installed in the configuration shown in Figure B-1. The cuts are 1/8 inch wide, and originally 2 inches deep for the loop wires. The wire depth, and the loop dimensions have been subject to some minor variance in order to optimize response. After the cutting operation, the wire (19 strand, 14 gauge TW) is placed in the cuts, making three turns per loop, and all leads are brought out to the edge of the road. When the wire installation is completed, the cuts are filled with a quick-setting hydraulic cement.

At the edge of the roadway, each pair of loop wires is spliced to a pre-twisted shielded cable, which is buried up to a service pole.

The Service Pole

Mounted on each telephone pole is an equipment cabinet and an electric power meter. The cables from the loops come up the pole in a piece of conduit and into the equipment cabinet, where they terminate on a terminal strip. On this strip the loops are connected to the detector amplifiers and the detector output (relay closure) is connected to the telephone lines, which in turn run to the computer room of the Institute (FigureB-2). 115V service is provided to the pole by Public Service of Indiana for the operation of the Vehicle Detectors.

The Vehicle Detector

The RCA Multi-Pak Vehicle Detector was designed primarily as an intersection traffic control device. Its solid state circuitry detects a phase shift in the loop impedance whenever a metallic vehicle crosses the wire loops embedded in the roadway. Since each loop at the site requires its own circuitry and relay, the standard package contains a power supply and four detector modules, grouped together in a 4-Pak configuration.

To adapt the Ve-Det to the special usages demanded by the research activity, several modifications were required. The original relays were replaced by faster mercury wetted relays, and at some sites, the tuning board gain has been increased by changing two resistors. This may become necessary where the cuts are deep or

the roadway has steel reinforcing. At some installations, the loop inductance was so great as to require the addition of external capacitance (0.012 mf, in parallel with the loop) to achieve a tuning peak within the range of the Ve-Det's variable capacitance. Occasional tuning is required, as the loop sensitivity experiences minor fluctuations with time and weather.

The Computer Interface Circuit

An IBM 1800 Computer with digital voltage input has two input conditions:

Voltage at input	Computer reads
-1 to +30 volts	1
-6 to -30 volts	0
-1 to - 6 volts	indeterminant .

The Detector returns a -25 volts signal (sent to the site via one telephone wire) to the computer digital input point when no car is in the loop. When a vehicle enters the loops, the relay change at the Detector causes the digital input point to be connected to the computer ground (zero volts). With this information the computer is able to compute vehicle speed, length, number of vehicles per hour, and so forth.

The interface connections system used is of nominal cost ($200) and replaces a system now in general use, which requires mechanical relays and costs in excess of $2,500.

Sensor Sites: Phase I

Each sensor site has two loop "sets" - so called because a set of two wire loops is required in each lane to gather the necessary information. Two lanes are monitored at each site, and this configuration is named a loop "pair". During Phase I, sixteen loop sets were being monitored on North and South State Route 37, for a total of eight locations, i.e., two lanes of travel at eight spots. For reasons of programming, these sets are numbered from zero through fifteen. The additional sites created for Phase II will be discussed in the following section.

Loop sets 0-7 are located on State Route 37 South, with sets zero through three monitoring southbound traffic, and sets four through seven monitoring northbound traffic. The sequence of numbering is such that ascending numbers move away from Bloomington.

Pair 0-4 is located in a 45 mph zone, on a blacktop section of Highway 37. It is approximately 75 feet North of an intersection with a stop street. For southbound traffic, there is a negative slope of -5.2%. This is a main artery leading into Bloomington, and some rather high rush hour traffic may be experienced (rate of 900+/hour). Loop set zero monitors southbound traffic, and loop set four monitors northbound traffic.

Pair 1-5 is located in a 55 mph zone, enough South of the speed change from 45 mph to 55 mph to be unaffected by the former speed limit. The site is in the middle of a short straight stretch which acts as the connector for two curves in a general "S" configuration. The road is 22' blacktop, and the site is in a no passing zone. Set one monitors southbound; five monitors northbound.

Pair 2-6 is located in a 55 mph zone, in a 22' blacktop section of Highway 37. Traffic from the North has good visibility to the site, and its path is straight and effectively level. 130' South of the site, traffic experiences a gradual curve to the right. Set two monitors southbound traffic; six monitors northbound traffic.

Pair 3-7, the southernmost site, is located just beyond the bottom of a long hill, with good straight visibility in both directions. The road is 22' blacktop, and the speed limit is 55 mph. Set three monitors southbound and set seven monitors northbound traffic.

Loop sets eight through fifteen were installed on State Route 37 North, with sets of eight through eleven monitoring southbound traffic, and sets twelve through fifteen monitoring northbound traffic.

Pair 8-12 is located in a 65 mph zone, approximately 0.2 miles North of a flat curve with a speed limit of 55 mph. The geometry is such that speed would be

expected to have normalized to the 65 mph zone by the time northbound vehicles arrive at the site. Southbound vehicles have been in a 65 mph zone for over 15 miles. The road is concrete, 24' wide. Set eight monitors southbound traffic, and set twelve monitors northbound traffic.

Pair 9-13 is located at the northern end of the straight-away from Pair 8-12, in a long flat curve. The full expanse of the South straight-away is not fully visible at this site. The speed limit on this concrete, 24' wide portion of the roadway is 65 mph. Seven hundred feet to the North lies a small bridge on the same curve. Set nine monitors southbound traffic; set thirteen monitors northbound traffic.

Pair 10-14 borders the northern end of a long straight uphill section (for northbound traffic) which contains a passing zone for northbound traffic. It lies midway through a long curve which terminated in the hill section just mentioned. The road is 24' concrete, and the speed limit is 65 mph. Set ten monitors southbound traffic; set 14 monitors northbound traffic.

Pair 11-15 borders the northern end of a long level straight-away, and the southern end of a long level curve. The road is concrete, and the speed limit is 65 mph. Set eleven monitors southbound traffic and set fifteen monitors northbound traffic.

Roadway Diagrams - Sensor Sites: Phase I

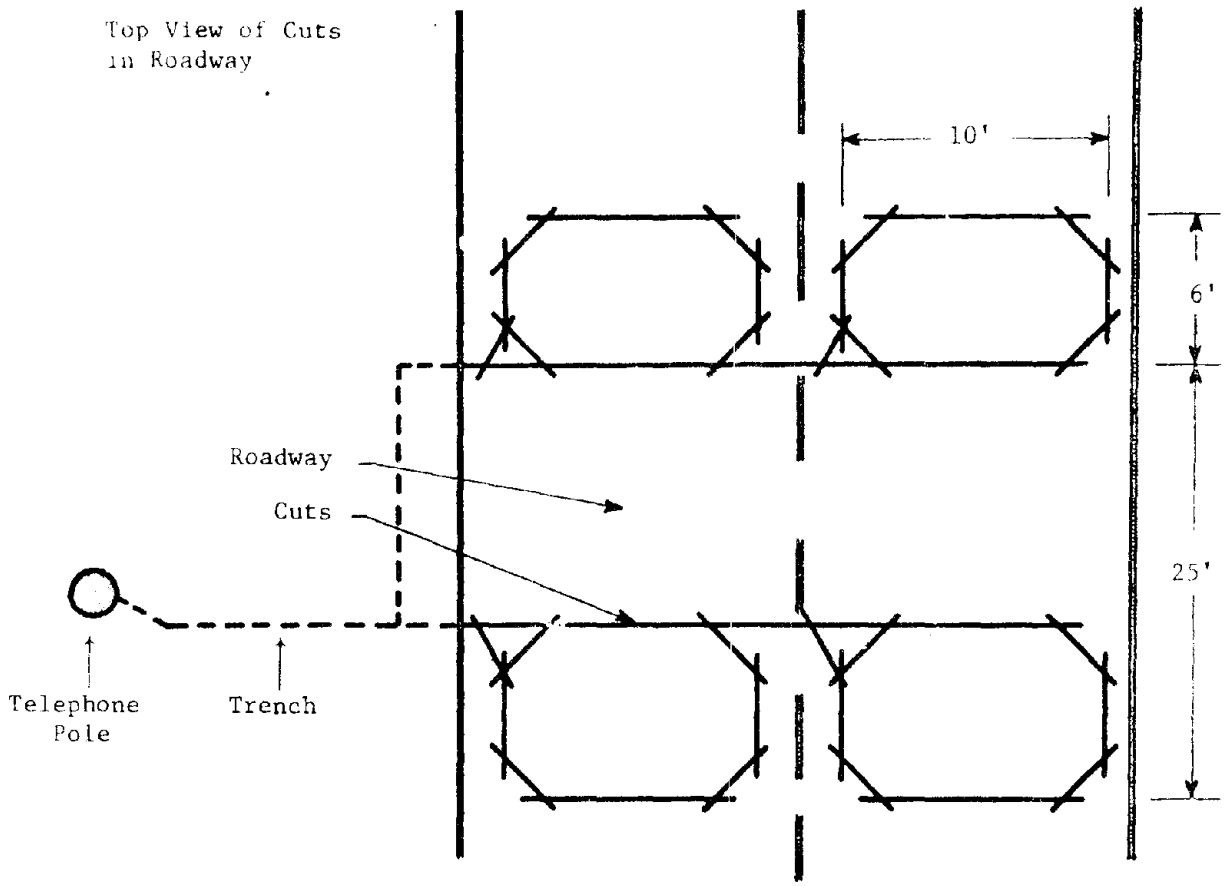
Figure C.3 shows the location of the sensor sites on State Highway 37. Figures C.4 through C.11 show plan views of the roadway along Route 37 North and South which contain the above described sensor sites. Included in these sketches are vertical profiles and curvature information as indicated.

System Expansion: Phase II

In late July, 1969, a meeting of project officials, including those from the National Highway Safety Bureau, the Research Triangle Institute, and the Institute for Research in Public Safety, reviewed the system's capability as an instrument of traffic data collection. At that time, the system had a demonstrated capability of speed measurements to within ±1.0 mph and length measurements to within ±2.0 feet.

Figure B-1

Top View of Cuts in Roadway



Cross-sectional View of Roadway

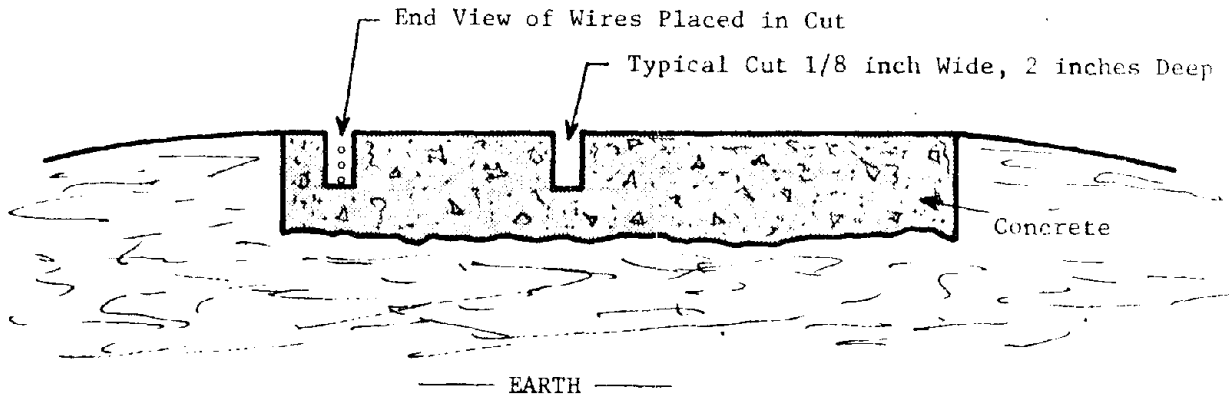
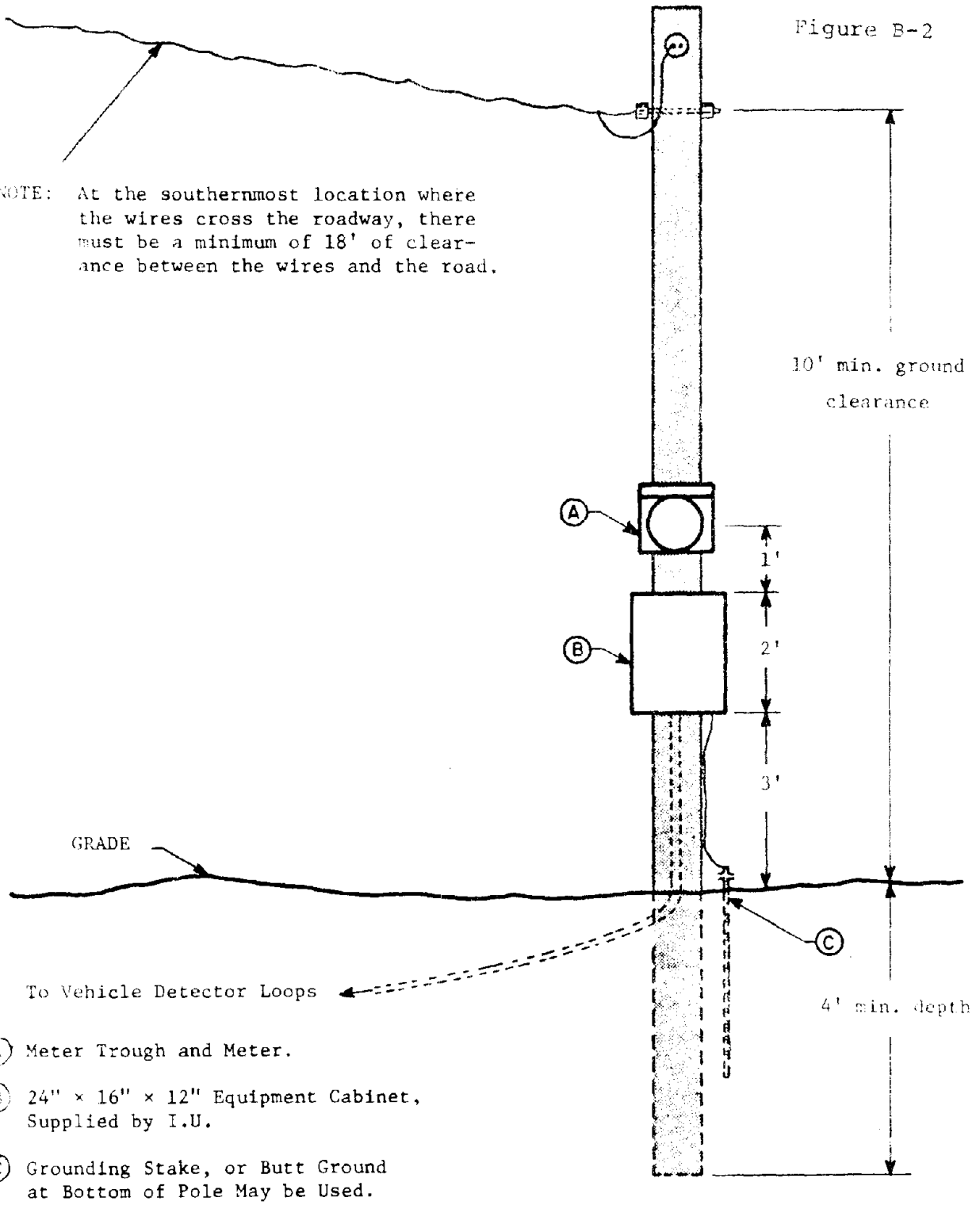


Figure B-2



(A) Meter Trough and Meter.

(B) 24" × 16" × 12" Equipment Cabinet, Supplied by I.U.

(C) Grounding Stake, or Butt Ground at Bottom of Pole May be Used.

Figure B-3

Location of Sensor Sites on State Highway 37

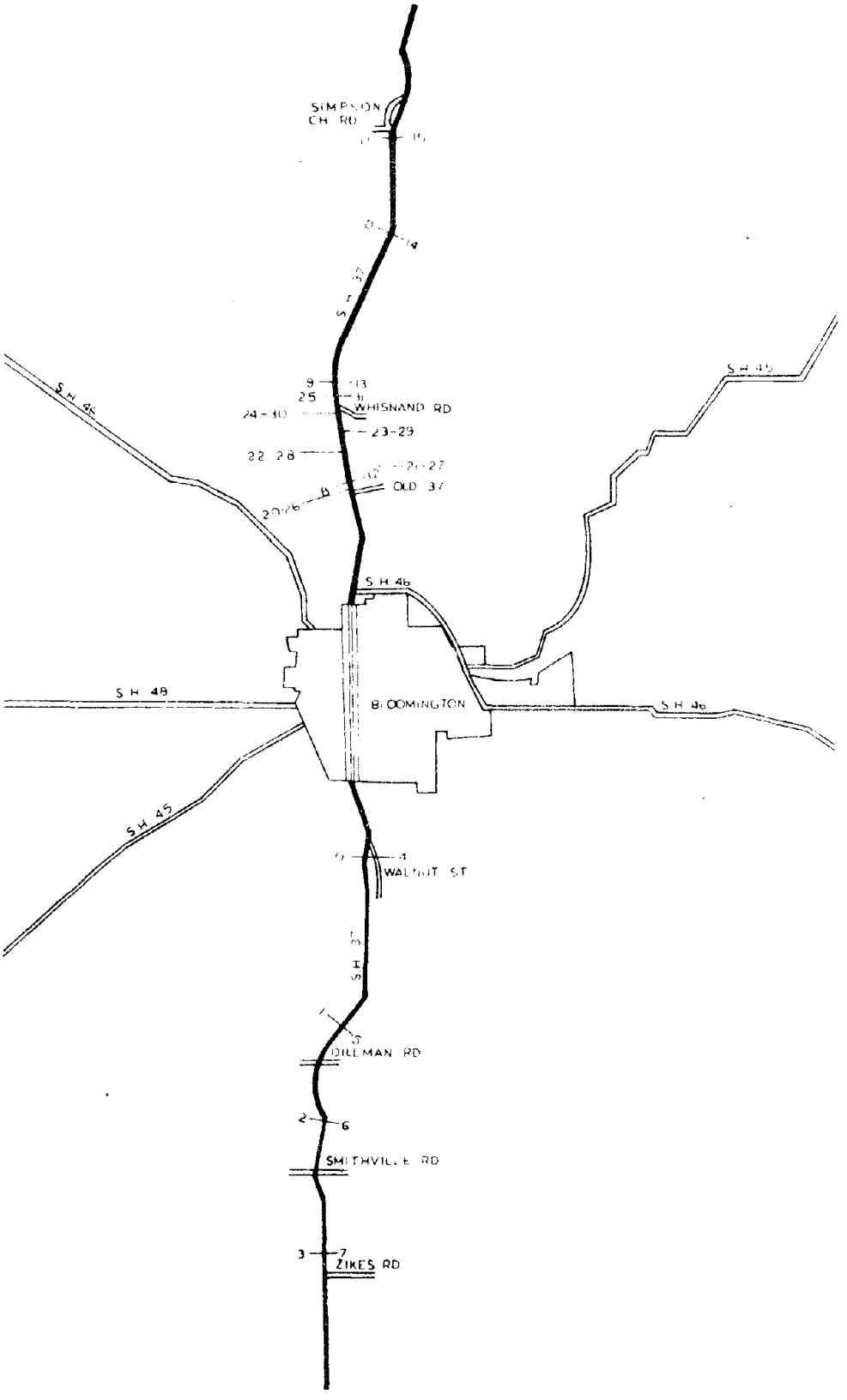
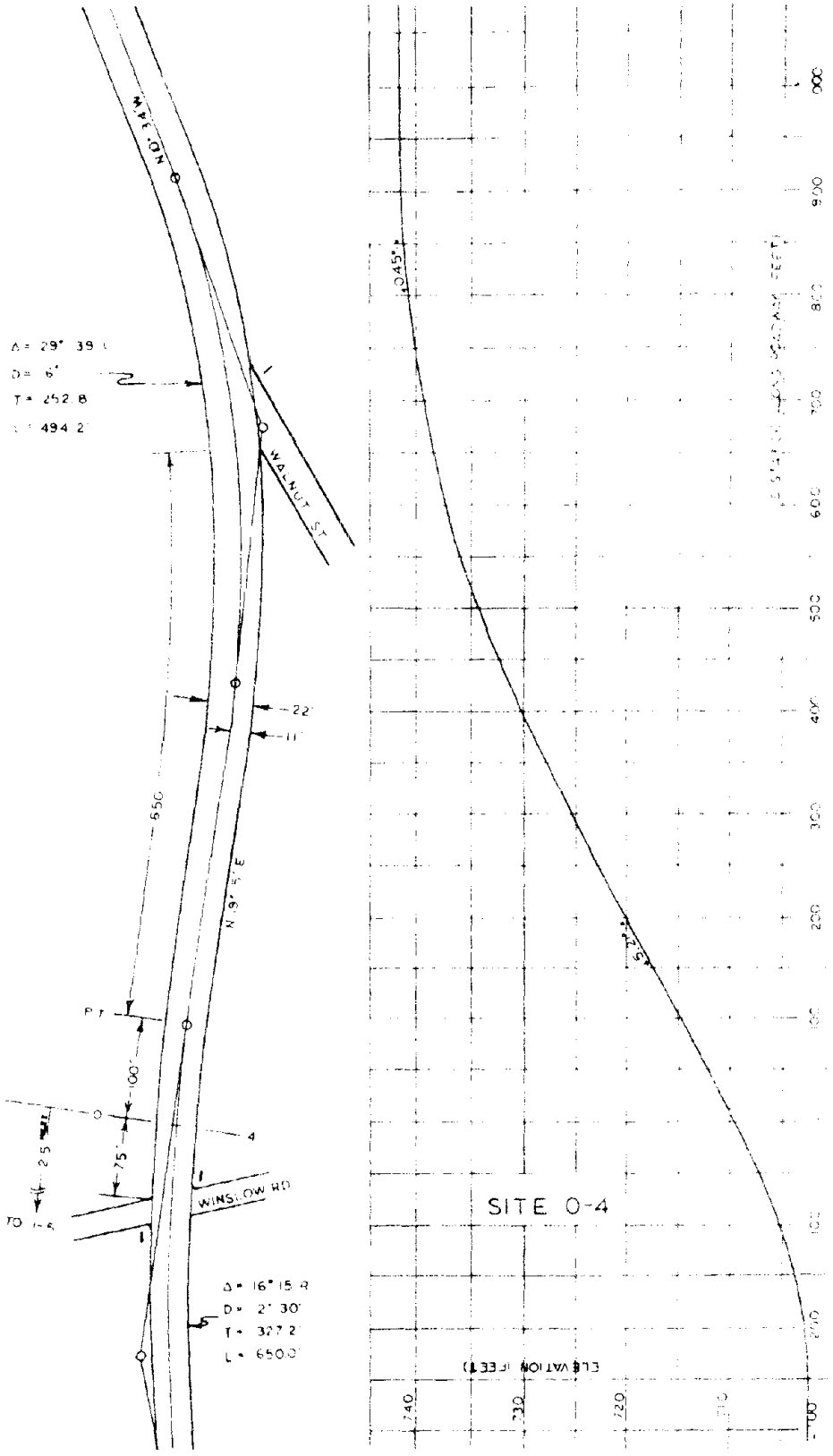


Figure B-4

Plan View of Roadway Section for Site 0-4



NOT REPRODUCIBLE

Figure B-5

Plan View of Roadway Section for Site 1-5

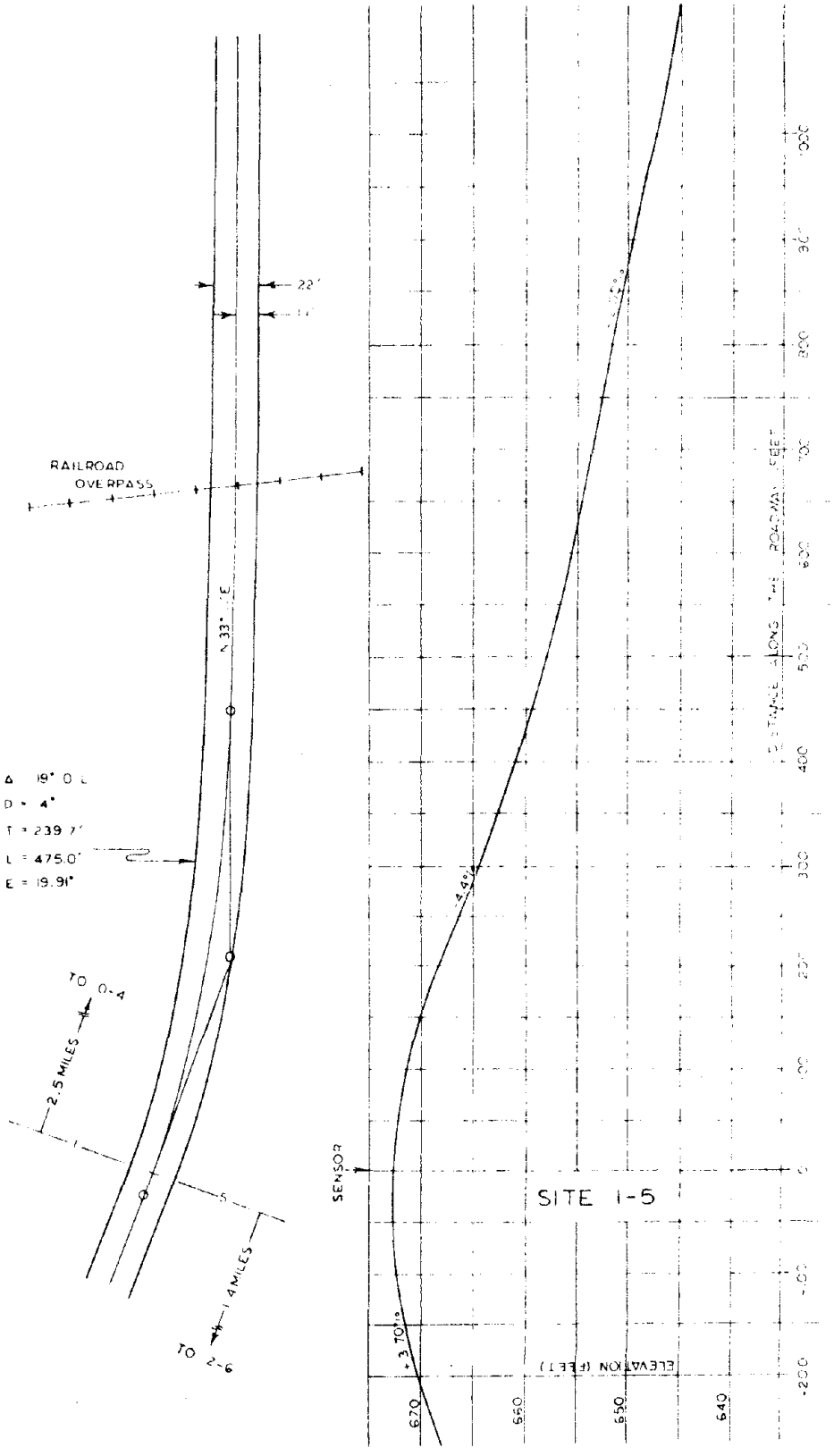


Figure B-6
Plan View of Roadway Section for Site 2-6

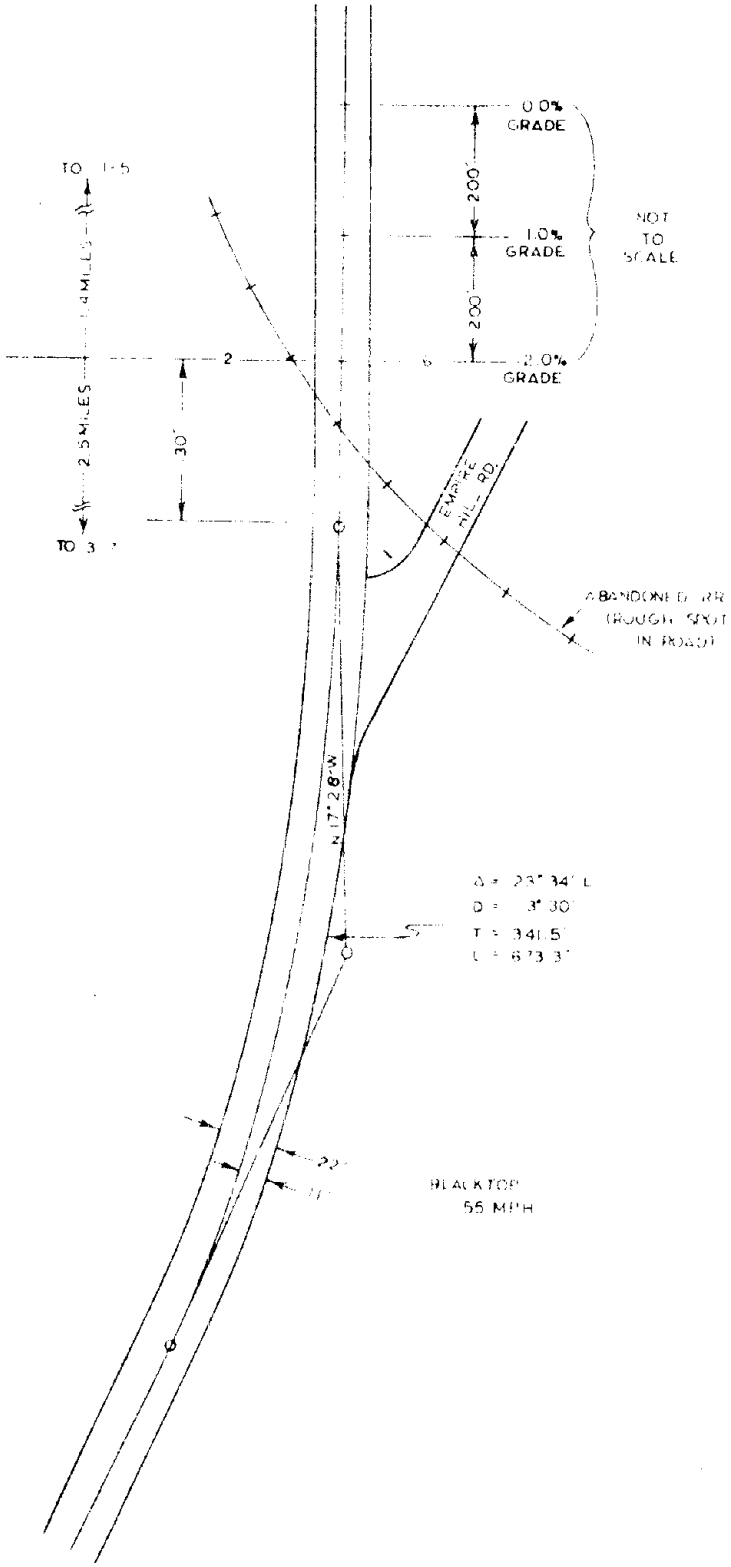


Figure B-7

Plan View of Roadway Section for Site 3-7

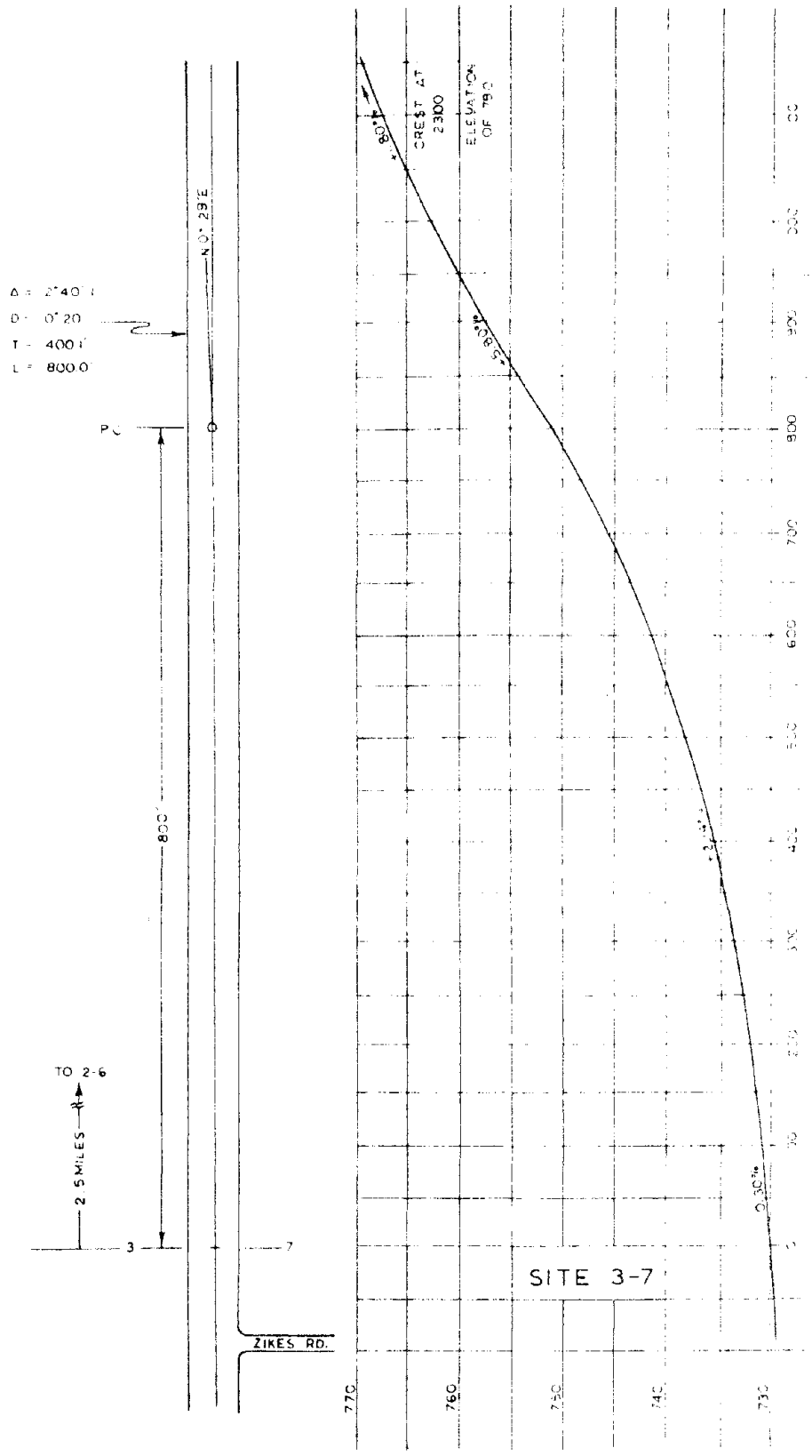


Figure B-8
Plan View of Roadway Section for Site 8-12

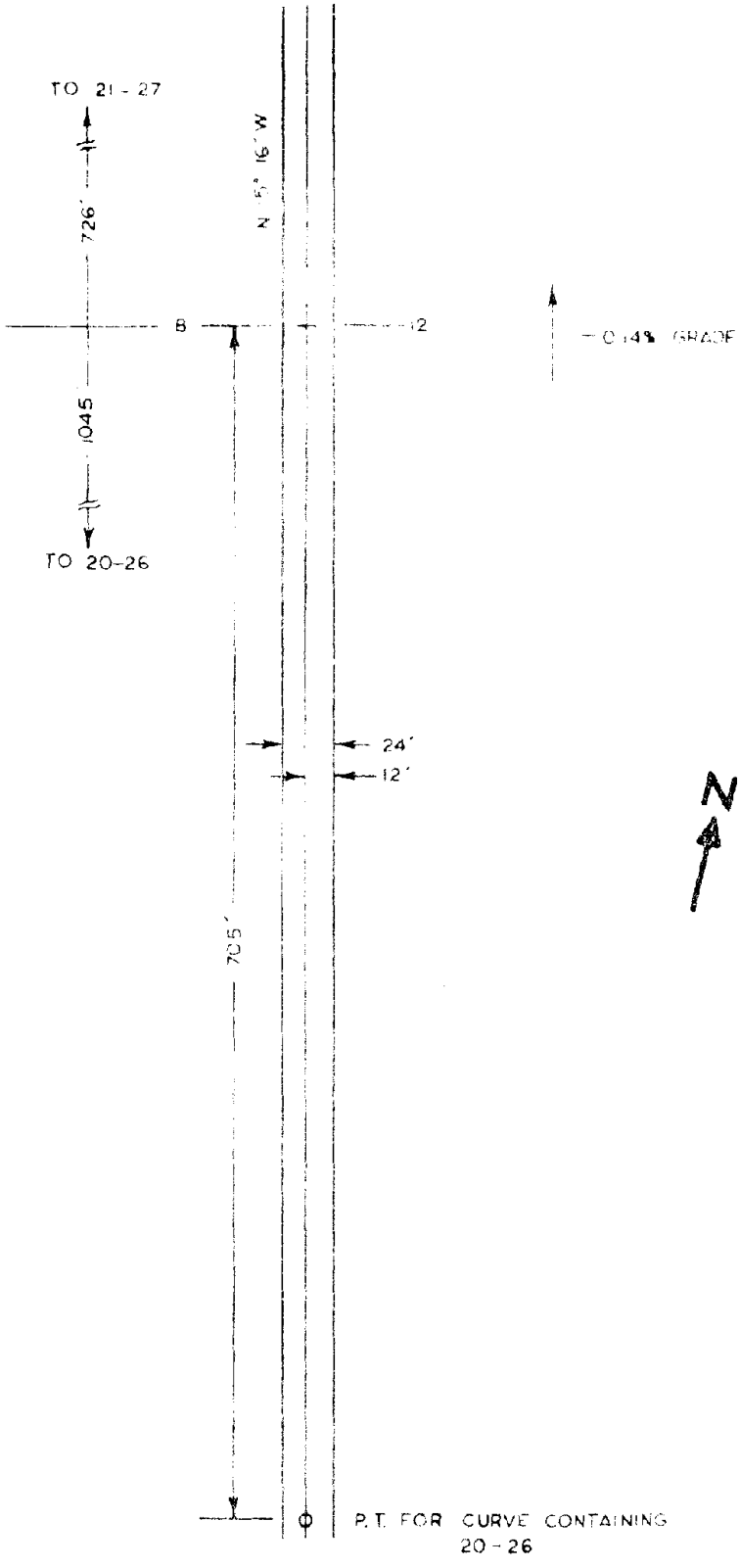


Figure B-10

Plan View of Roadway Section for Site 10-14

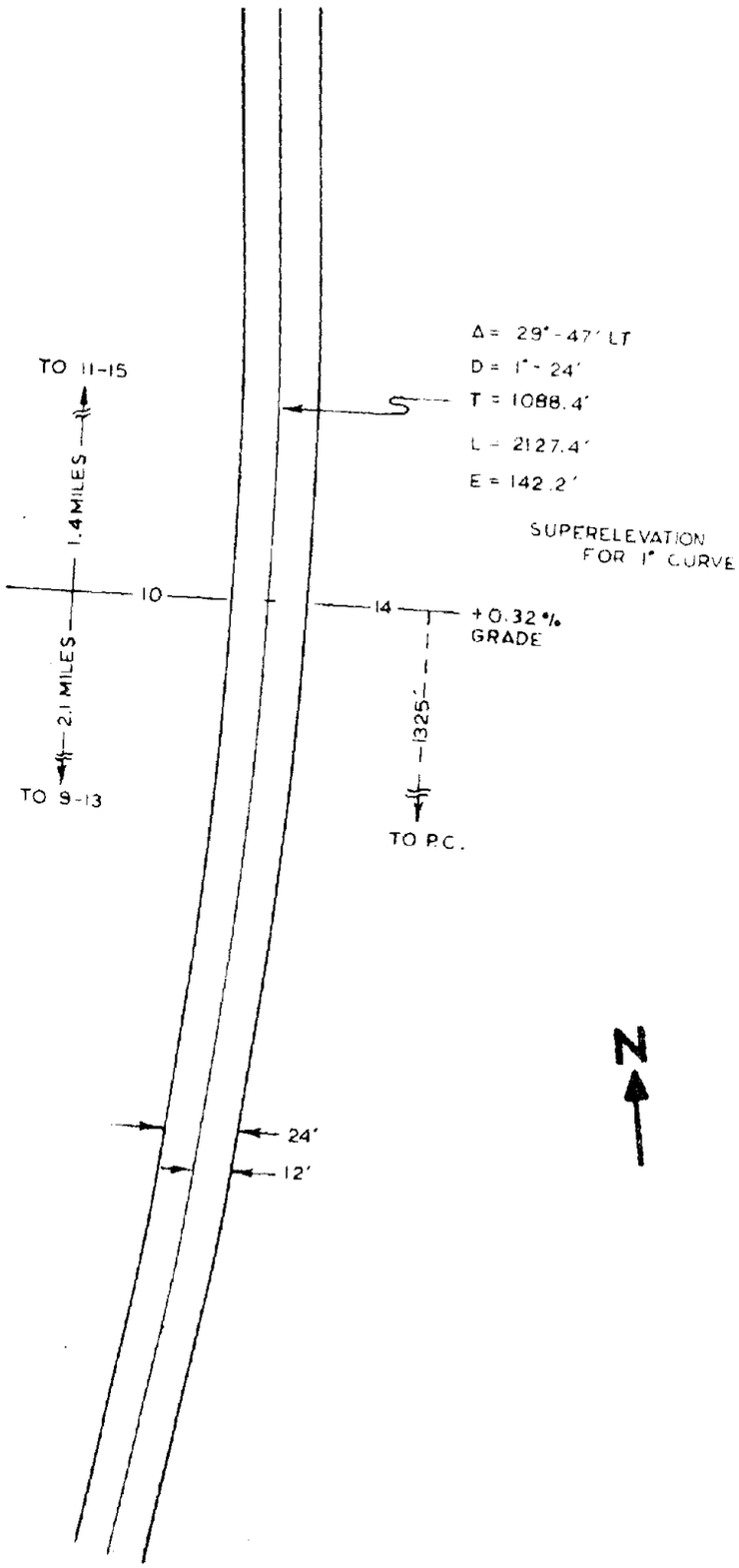


Figure B-9
Plan View of Roadway Section for Site 9-13

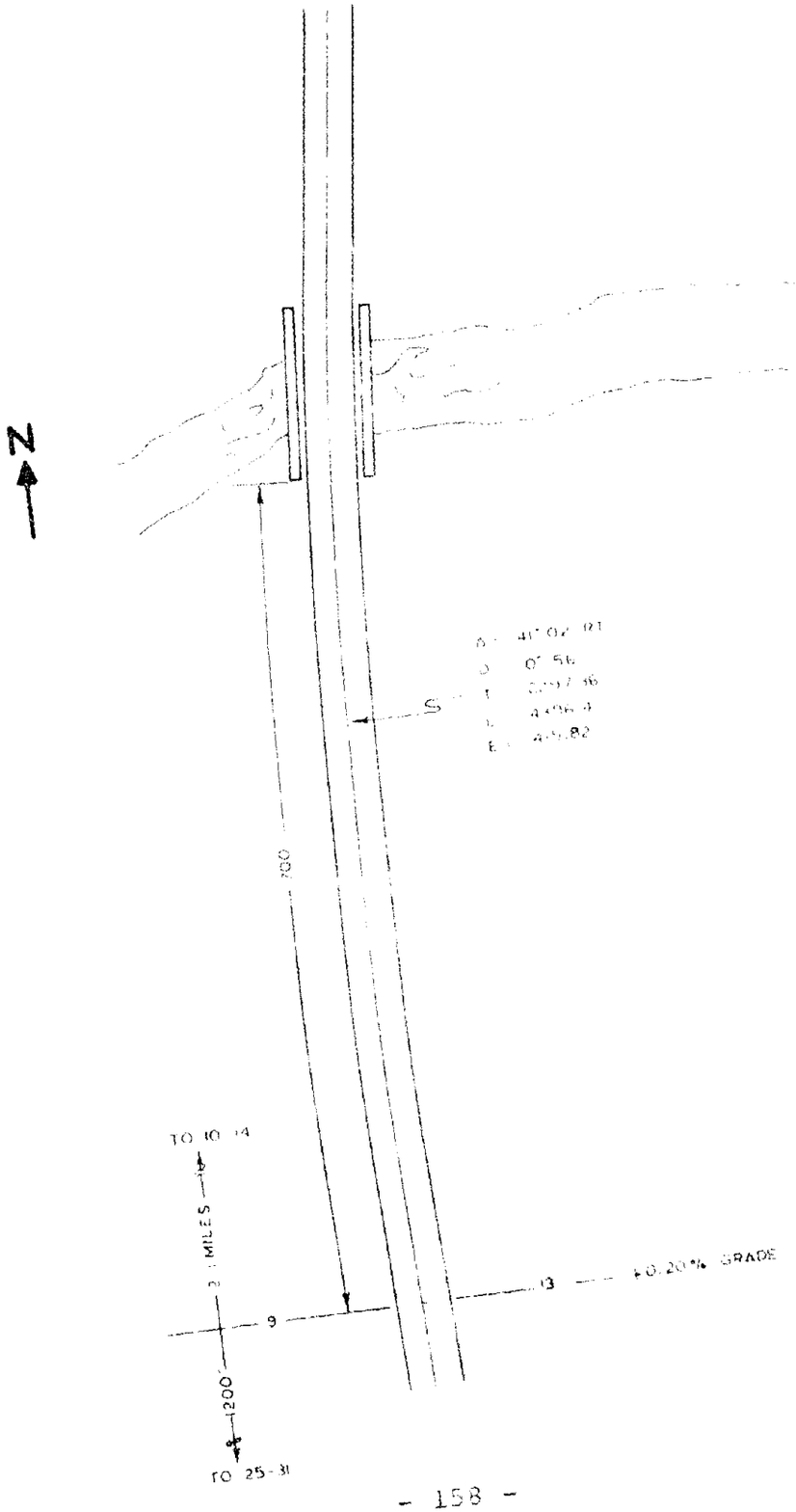
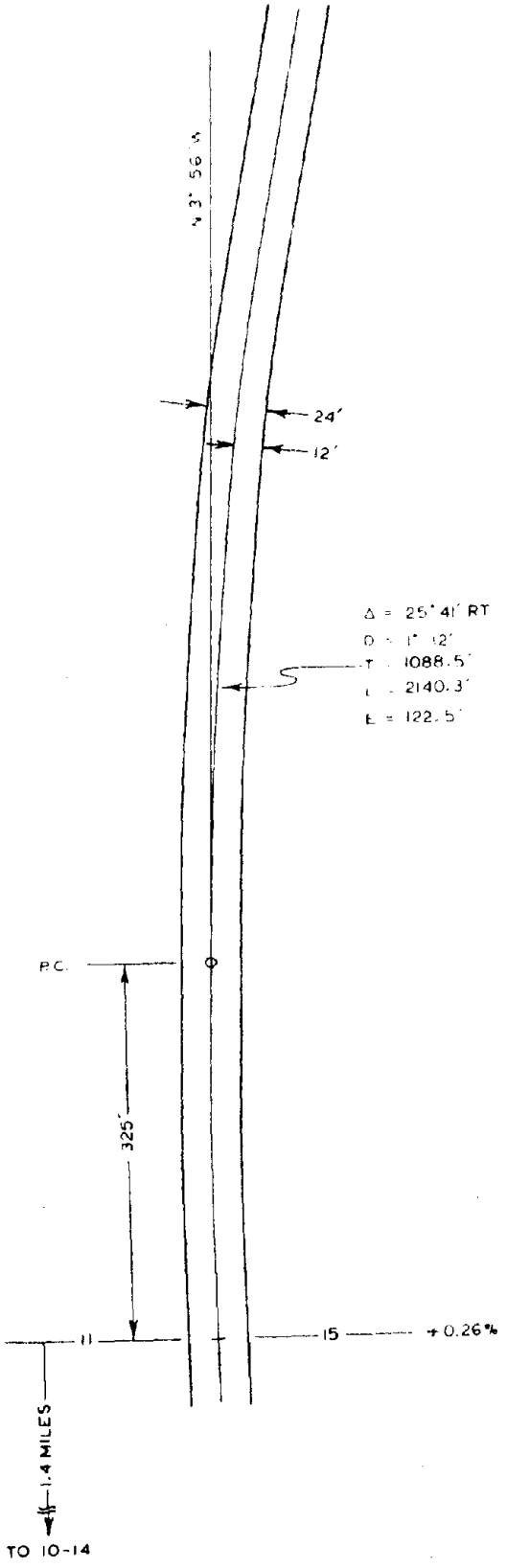


Figure B-11
Plan View of Roadway Section for Site 11-15



Phase II called for post-accident follow-up and the use of the system as the accident data collection approach. To aid in this data collection and system evaluation, the system was expanded. Six additional sensor sites were located on State Route 37 North, with the computer software being rewritten to monitor these new sites. The installation and the computer software were completed November 4, 1969. These changes are discussed below.

Six loop pairs were added; five were placed in between Loops Pairs 8-12, and 9-13 and one (Set 20-26) was placed 0.2 miles South of 8-12. Sets 20 through 25 are monitoring southbound traffic, and Sets 26-31 are monitoring northbound traffic. (See diagrams at the end of this section for spacing and locations of these new sites.)

The same basic computer hardware which monitored 16 loop sets was utilized for the expanded system. The only addition came in the interfacing, with four digital input strips being utilized, instead of two. The 16K of core did prove to be sufficient after modification of the system software. Also, while the overall logic remained the same, interrupt levels and core allocations were reduced to accomodate the load levied on the system by the additional input. IBM-furnished TSX up-dates arrived out of sequence, causing some delay until the system could be built up under Version 3, Modification level 7, but the expanded system came on-line on November 4, 1969.

In order that the 1800 could monitor the almost twice as many loops as before, core work areas were preserved. Whereas in Phase I each loop set had two 50-vehicle in-core buffers to store vehicle data until it could be written to disk, in Phase II each was reassigned to two 25-vehicle buffers. Addresses, previously stored in core, in Phase II were calculated by program PILOP. Also, without requiring a rewiring operation, all unnecessary interrupt levels were stripped of their in-core work areas, saving 100 words for each of the four deleted levels. The retained interrupt levels were pared down to their absolute minimum necessary work areas. Some of these core-saving measures resulted in longer execution times, but the basic five millisecond interrupt was undisturbed. All fifty-six digital input points were still scanned every five milliseconds.

Figure B-12

Location of Additional Sensor Sites on State Highway 37 North

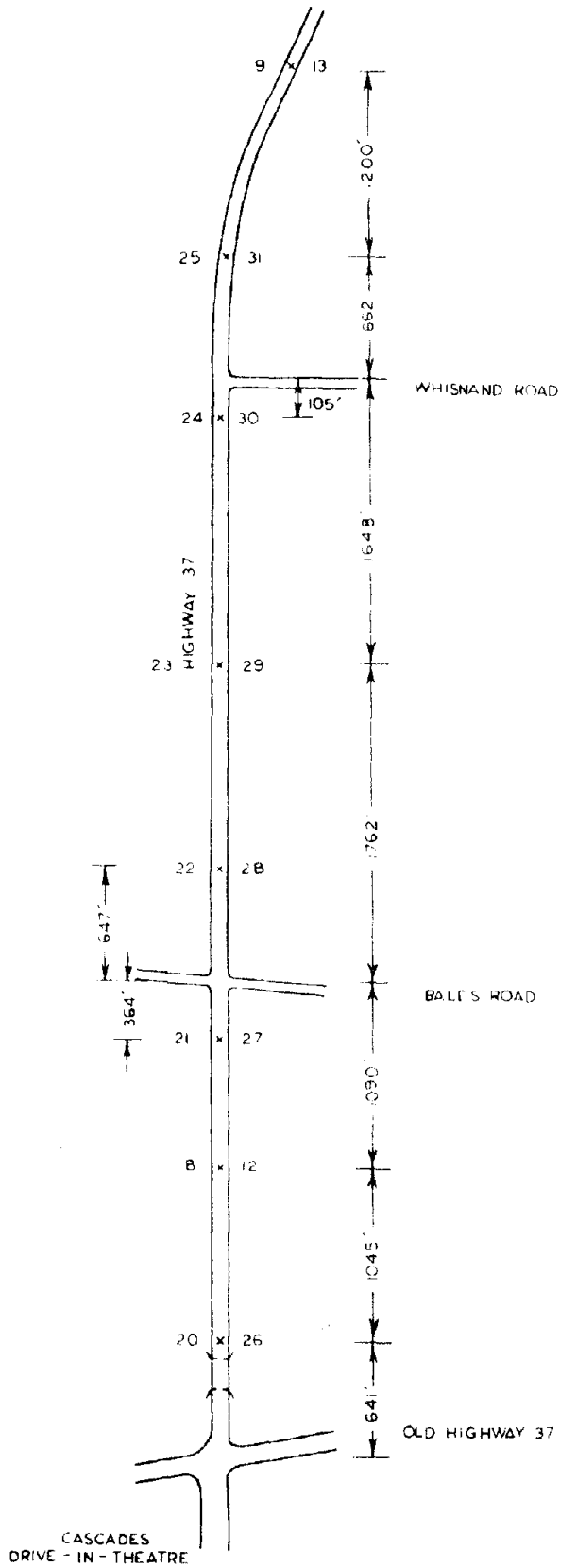


Figure B-13

Plan View of Roadway Section for Site 20-26

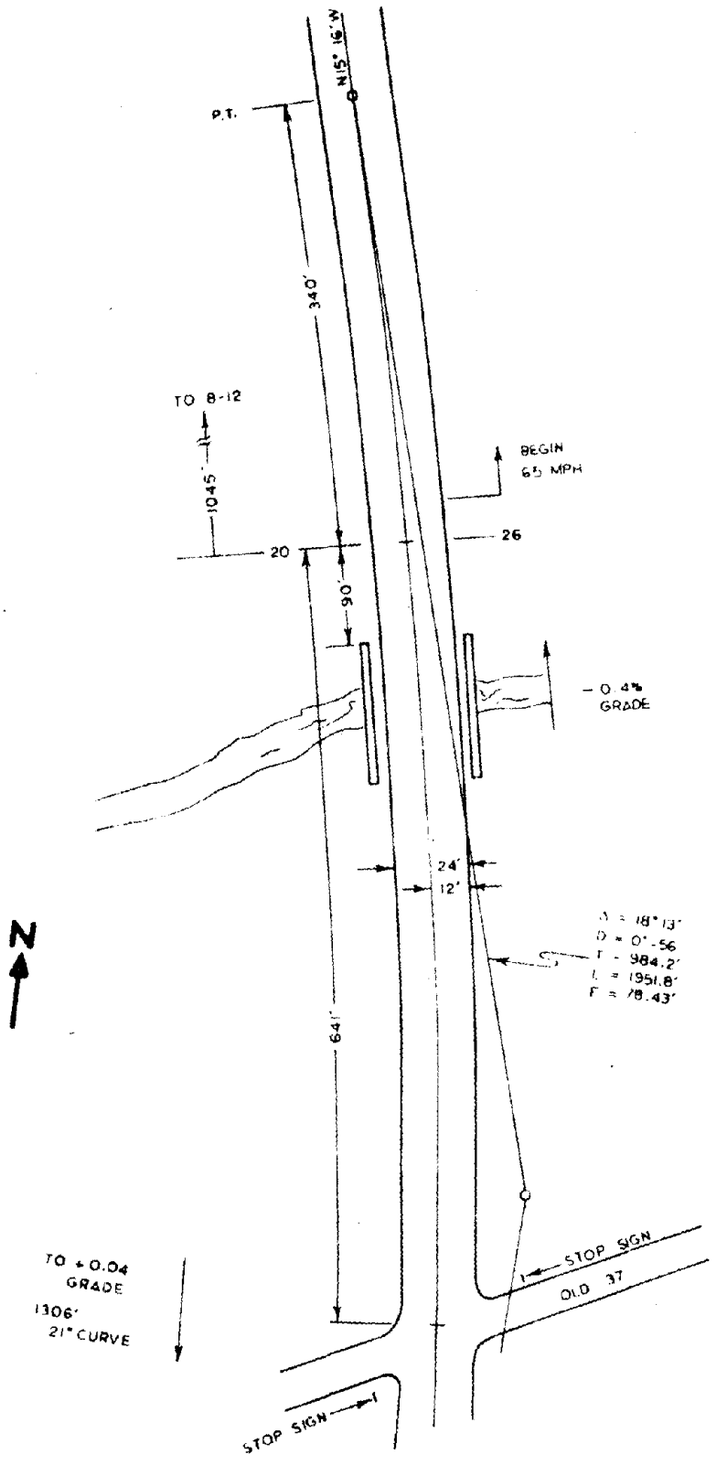


Figure B-16

Plan View of Roadway Section for Site 23-29

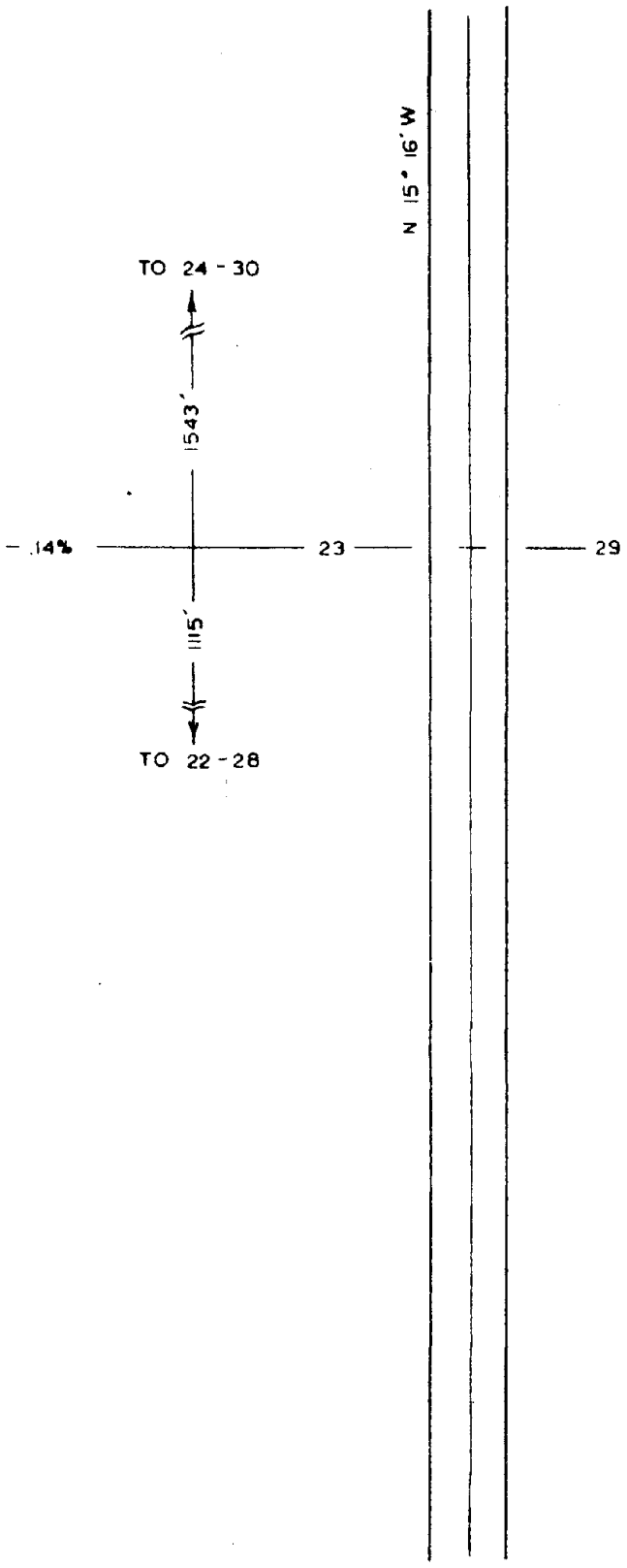


Figure B-15

Plan View of Roadway Section for Site 22-28

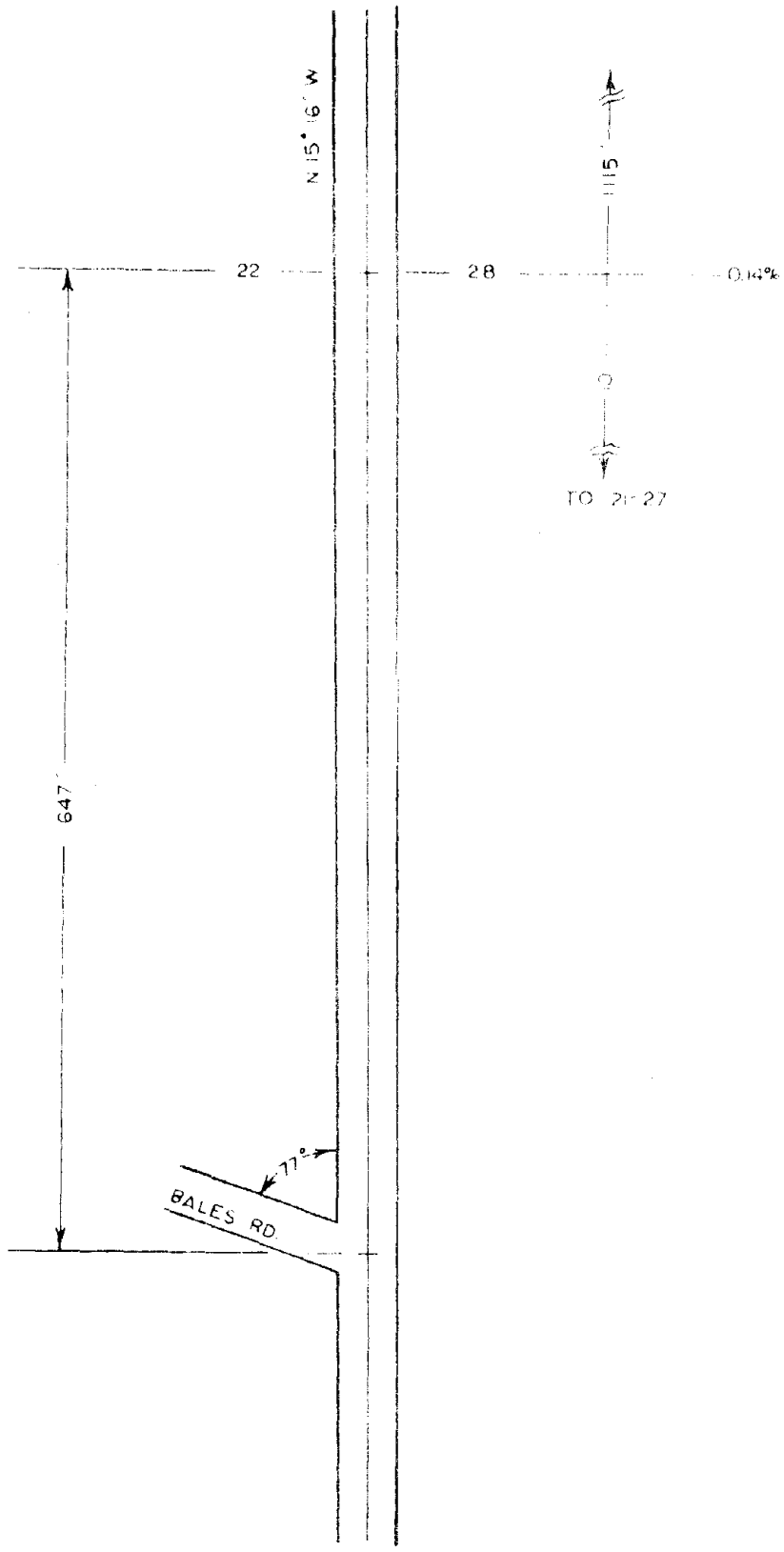


Figure B-18

Plan View of Roadway Section for Site 25-31

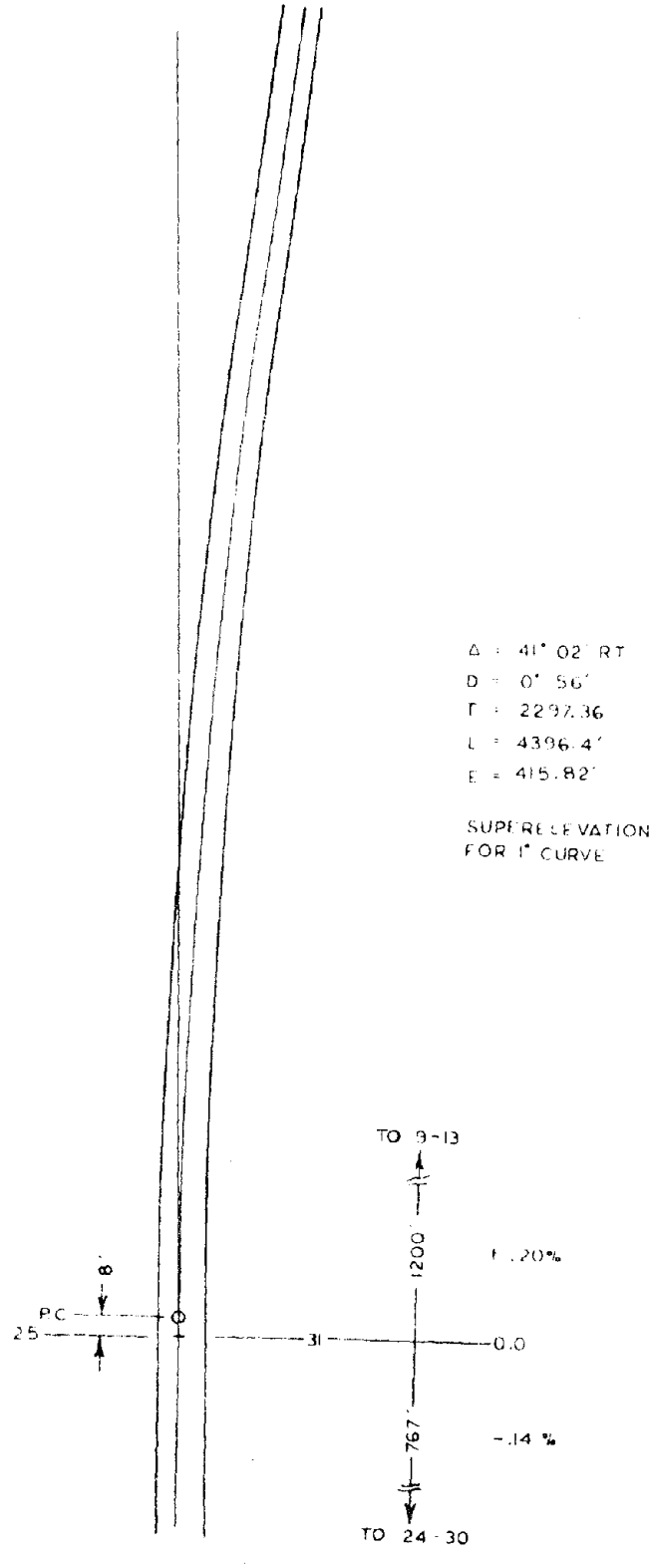
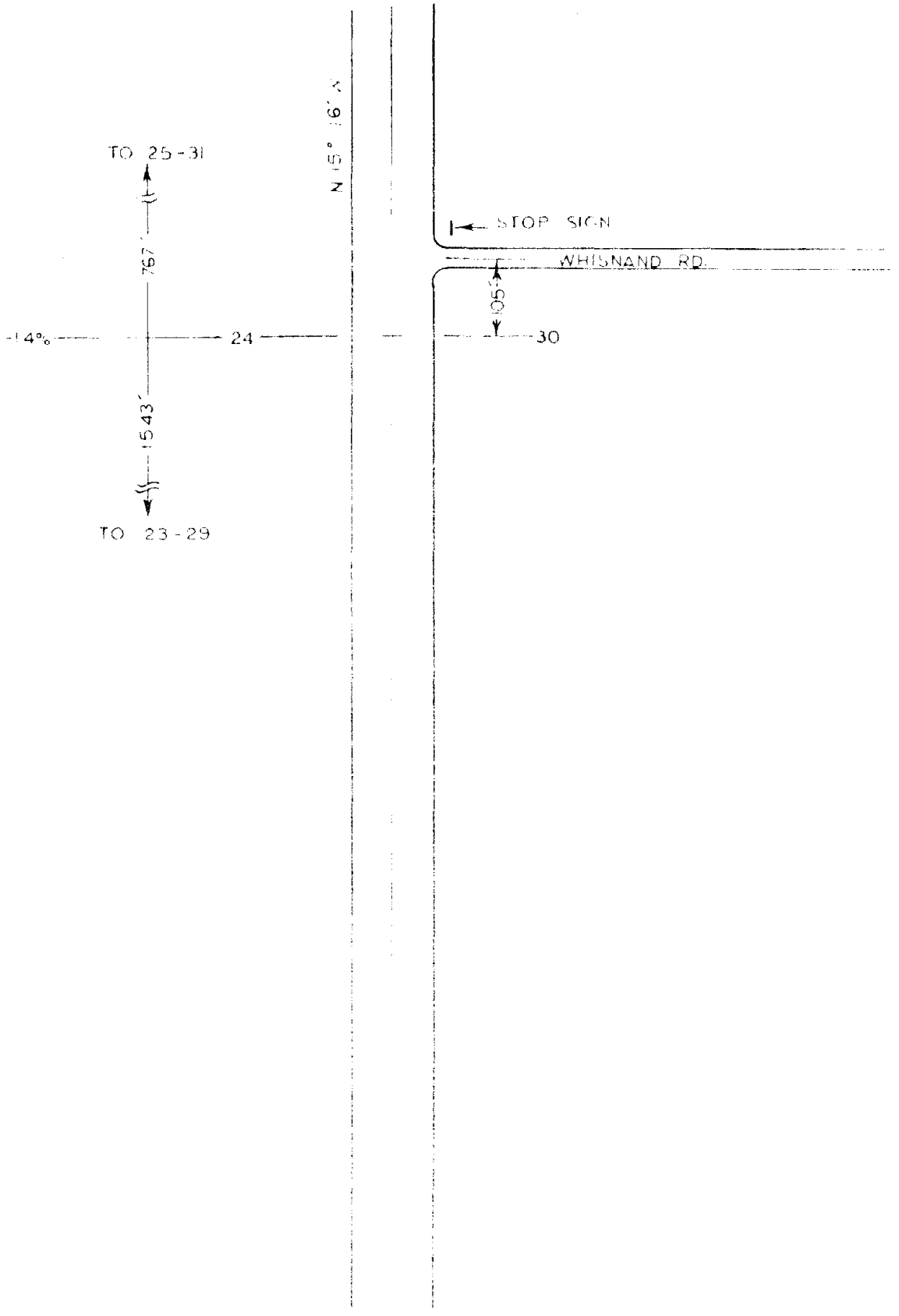


Figure B-17
Plan View of Roadway Section for Site 24-30



APPENDIX C

SPEED LIMIT PRACTICES

SURVEY QUESTIONNAIRES

SPEED LIMIT PRACTICES

PLEASE CHECK THE ANSWER OR ANSWERS TO THE FOLLOWING QUESTIONS WHICH ARE APPROPRIATE TO YOUR STATE.

I. Which of the following applies to your state regarding speed limits?

(1) ____ The state statute sets numerical speed limits but makes no provision for the setting or changing of limits by other agencies or jurisdictions.
(2) ____ The state statute does not set numerical speed limits but makes provisions for the setting of speed limits by other agencies.
(3) ____ The state statute sets numerical speed limits and makes provisions for changing or setting of speed limits by other agencies or jurisdictions.

II. To which of the following agencies is authority to set or change speed limits delegated? (You may check more than one.)

(1) ____ No delegation of authority
(2) ____ State Highway Commission
(3) ____ State Traffic Engineer
(4) ____ State Police, Highway Patrol, or other state enforcement agency
(5) ____ Other state administrative agency
(6) ____ County or municipal administrative agencies
(7) ____ County or municipal law enforcement agencies
(8) ____ County or municipal traffic engineers
(9) ____ Others (specify: _____)
(_____)

III. If in your state numerical limits are set by statute and local jurisdictions are allowed to set or change limits, which of the following constraints must they follow? (You may check more than one.)

(1) ____ Subject to no constraints
(2) ____ Must be above a specified minimum speed
(3) ____ Must not exceed a specified maximum speed
(4) ____ Must be reasonable and proper
(5) ____ Must be supported by engineering or traffic study
(6) ____ Others (specify: _____)
(_____)

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IV. Using answer choices (1), (2), (3), (4), and (5), which immediately follow this question, indicate how speed limits are set in your state at each of the locations (a through m) listed below. (You may use more than one answer choice.)

ANSWER CHOICES:
(1) BY LEGISLATIVE OR ADMINISTRATIVE DECISION WITHOUT A TRAFFIC OR ENGINEERING SURVEY
(2) BY TRAFFIC SURVEYS AND ENGINEERING METHODS
(3) BY CITIZENS' PETITION
(4) BY STATE OFFICIALS OR AGENCY REPRESENTING THE STATE
(5) BY LOCAL OFFICIALS OR AGENCY REPRESENTING A LOCAL JURISDICTION

a. _____ expressways
b. _____ rural two- and four-lane highways
c. _____ rural country roads
d. _____ urban expressways
e. _____ residential streets
f. _____ business districts
g. _____ school zones
h. _____ curves
i. _____ bridges
j. _____ exits and cloverleafs
k. _____ construction zones
l. _____ intersections
m. _____ Others (specify: _____)
(_____)

V. If engineering or traffic studies are used in setting or altering speed limits, check any of the following factors which are included in the study.

(1) ____ 85th percentile
(2) ____ pace
(3) ____ average test run speed
(4) ____ design speed
(5) ____ maximum comfortable speed on curves
(6) ____ ball-bank indicator
(7) ____ spacing of intersections and driveways
(8) ____ number of roadside businesses per mile
(9) ____ slipperiness of pavement
(10) ____ roughness of pavement
(11) ____ presence of transverse dips and bumps
(12) ____ presence and condition of shoulders
(13) ____ presence and width of median
(14) ____ accident experience at that or similar locations
(15) ____ traffic volume
(16) ____ parking and loading of vehicles
(17) ____ percentage of commercial vehicles
(18) ____ traffic signals and other traffic controls
(19) ____ presence of pedestrians
(20) ____ length of zone and effect of adjacent zones
(21) ____ Others (specify: _____)
(_____)

VI. Is the numerical speed limit for trucks in your state different from the speed limit for other motor vehicles?

(1) ____ YES
(2) ____ NO

VII. Check any of the following reasons which explain the difference or lack of difference between speed limits for trucks and other traffic in your state.

(1) ____ Safety factors (e.g., truck size or maneuverability)
(2) ____ Prevention of road wear
(3) ____ Influence of trucking or other industries
(4) ____ Facilitation of traffic flow
(5) ____ Others (specify: _____)
(_____)

VIII a. Which of the following devices and instruments are available to you for measuring vehicle speed, traffic characteristics, and roadway features?

(1) ____ Radar
(2) ____ Vascar
(3) ____ Road sensors
(4) ____ Aircraft
(5) ____ Speed timer
(6) ____ Ball-bank indicator
(7) ____ Computer
(8) ____ Vehicle counters
(9) ____ Others (specify: _____)
(_____)

b. List any of the above or any other devices which are presently unavailable to you but which you feel would aid you in your work.

_____
_____

IX a. After a speed limit is set or changed in your state, is an attempt made to determine the effect of the new limit?

(1) ____ YES
(2) ____ NO

b. If so, how? _____
_____
_____

X. Rank the following (1 = most important) according to what you think is the function of speed limits in your state. DRAW A LINE THROUGH ANY OF THE FUNCTIONS SPEED LIMITS DO NOT SERVE.

(1) ____ To reduce accidents
(2) ____ To slow traffic down
(3) ____ To make traffic flow more uniformly
(4) ____ To increase street and road capacities
(5) ____ To make streets safer for pedestrians
(6) ____ To decrease wear on streets and highways
(7) ____ Others (specify: _____)
(_____)

S P E E D L I M I T P R A C T I C E S

PLEASE CHECK THE ANSWER OR ANSWERS TO THE FOLLOWING QUESTIONS WHICH ARE APPROPRIATE TO YOUR JURISDICTION.

I. Has the state delegated any of its authority to establish or alter speed limits in your jurisdiction?

(1) ____ YES
(2) ____ NO

II. If so, what agency grants this authority?

(1) ____ State legislature through statute
(2) ____ State legislature by other means
(3) ____ State administrative agency
(4) ____ Don't know

III. Which of the following agencies or persons have authority to set speed limits in your jurisdiction? (You may check more than one.)

(1) ____ State Highway Commission
(2) ____ State Traffic Engineer
(3) ____ State Police, Highway Patrol, or other state enforcement agency
(4) ____ Other state administrative agency
(5) ____ County or municipal administrative agencies
(6) ____ County or municipal law enforcement agencies
(7) ____ County or municipal traffic engineers
(8) ____ Others (specify: _____)
(_____)

IV. Of the choices given in question III above, who actually sets most of the speed limits in your jurisdiction? (Use more than one only if necessary.) _____

V a. Are minimum speed limits used in your jurisdiction?

(1) ____ YES
(2) ____ NO

b. If so, check the types of roads they are used on.

(1) ____ expressways
(2) ____ rural two-lane roads
(3) ____ rural four-lane roads
(4) ____ urban expressways
(5) ____ Others (specify: _____)
(_____)

VI. Are engineering studies used to determine speed limits in your jurisdiction when they are set or altered?

(1) ____ YES
(2) ____ NO

VII. If engineering or traffic studies are used in setting or altering speed limits, check any of the following factors which are included in the study.

(1) ____ 85th percentile
(2) ____ pace
(3) ____ average test run speed
(4) ____ design speed
(5) ____ maximum comfortable speed on curves
(6) ____ ball-bank indicator
(7) ____ spacing of intersections and driveways
(8) ____ number of roadside businesses per mile
(9) ____ slipperiness of pavement
(10) ____ roughness of pavement
(11) ____ presence of transverse dips and bumps
(12) ____ presence and condition of shoulders
(13) ____ presence and width of median
(14) ____ accident experience at that or similar locations
(15) ____ traffic volume
(16) ____ parking and loading of vehicles
(17) ____ percentage of commercial vehicles
(18) ____ traffic signals and other traffic controls
(19) ____ presence of pedestrians
(20) ____ length of zone and effect of adjacent zones
(21) ____ Others (specify: _____)
(_____)

VIII. Using answer choices (1), (2), (3), (4), and (5), which immediately follow this question, indicate how speed limits are set in your jurisdiction at each of the locations (a through m) listed below. (You may use more than one choice.)

ANSWER CHOICES:
(1) BY LEGISLATIVE OR ADMINISTRATIVE DECISION WITHOUT A TRAFFIC OR ENGINEERING SURVEY
(2) BY TRAFFIC SURVEYS AND ENGINEERING METHODS
(3) BY CITIZENS' PETITION
(4) BY STATE OFFICIALS OR AGENCY REPRESENTING THE STATE
(5) BY LOCAL OFFICIALS OR AGENCY REPRESENTING A LOCAL JURISDICTION

a. _____ expressways
b. _____ rural two- and four-lane highways
c. _____ rural country roads
d. _____ urban expressways
e. _____ residential streets
f. _____ business districts
g. _____ school zones
h. _____ curves
i. _____ bridges
j. _____ exits and cloverleafs
k. _____ construction zones
l. _____ intersections
m. _____ Others (specify: _____)

IX a. Which of the following devices and instruments are available to you for measuring vehicle speeds, traffic characteristics, and roadway features?

(1) ____ Radar
(2) ____ Vascar
(3) ____ Road sensors
(4) ____ Aircraft
(5) ____ Speed timer
(6) ____ Ball-bank indicator
(7) ____ Computer
(8) ____ Vehicle counter
(9) ____ Others (specify: _____)
(_____)

b. List any of the above or any other devices which are presently unavailable to you but which you feel would aid you in your work.

_____

_____

X a. After a speed limit is set or changed in your jurisdiction, is an attempt made to determine the effect of the new limit?

(1) ____ YES
(2) ____ NO

b. If so, how? _____

_____

_____

XI. Rank the following (1 = most important) according to what you think is the function of speed limits in your jurisdiction. DRAW A LINE THROUGH ANY OF THE FUNCTIONS SPEED LIMITS DO NOT SERVE.

(1) ____ To reduce accidents
(2) ____ To slow traffic down
(3) ____ To make traffic flow more uniformly
(4) ____ To increase street and road capacities
(5) ____ To make streets safer for pedestrians
(6) ____ To decrease wear on streets and highways
(7) ____ Others (specify: _____)
(_____)

APPENDIX D

DATA TABLES FOR

SPEED LIMIT SURVEY RESPONSES

TABLE I: TOTAL NUMBER OF STATE RESPONSES (48 STATES)

I.	1)	0
	2)	3
	3)	46
	na)	0

na = no answer

II.	1)	0
	2)	38
	3)	8
	4)	6
	5)	3
	6)	34
	7)	1
	8)	4
	9)	13
	na)	0

III.	1)	2
	2)	8
	3)	17
	4)	6
	5)	37
	6)	13
	na)	2

IV a.	1)	23	b.	1)	22	c.	1)	15	d.	1)	20	e.	1)	17	f.	1)	16
	2)	42		2)	42		2)	34		2)	44		2)	29		2)	28
	3)	0		3)	1		3)	0		3)	0		3)	1		3)	0
	4)	18		4)	19		4)	11		4)	17		4)	10		4)	11
	5)	5		5)	7		5)	18		5)	10		5)	29		5)	30
	na)	0		na)	0		na)	1		na)	0		na)	1		na)	1

g.	1)	18	h.	1)	2	i.	1)	3	j.	1)	3	k.	1)	6	l.	1)	3
	2)	28		2)	40		2)	35		2)	38		2)	32		2)	34
	3)	1		3)	1		3)	0		3)	0		3)	0		3)	0
	4)	10		4)	10		4)	9		4)	11		4)	14		4)	11
	5)	20		5)	7		5)	8		5)	6		5)	9		5)	8
	na)	1		na)	5		na)	8		na)	6		na)	5		na)	9

m.	1)	1
	2)	4
	3)	0
	4)	1
	5)	1
	na)	44

V.	1)	47	6)	37	11)	20	16)	22	21)	10
	2)	30	7)	29	12)	25	17)	9	na)	1
	3)	23	8)	30	13)	18	18)	22		
	4)	31	9)	17	14)	39	19)	23		
	5)	20	10)	15	15)	27	20)	33		

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TABLE I : cont'd.

VI.	1)	30
	2)	17
	na)	0
	ca)	1

VII.		answered "1" on VI	answered "2" on VI
	1)	20	1
	2)	2	0
	3)	0	0
	4)	9	10
	5)	10	2
	na)	3	5
	ca)	1	0

VIII a.	1)	48	b.	1)	0
	2)	14		2)	2
	3)	8		3)	1
	4)	15		4)	1
	5)	4		5)	2
	6)	47		6)	1
	7)	18		7)	3
	8)	44		8)	1
	9)	4		9)	2
	na)	0		na)	

IX a.	1)	36
	2)	11
	na)	0
	ca)	1

TABLE II : TOTAL STATE AVERAGE NUMBER OF RESPONSES PER QUESTION

I. 1.20

II. 2.22

III. 1.72

IV.a. 1.83
b. 1.89
c. 1.62
d. 1.89
e. 1.79
f. 1.77
g. 1.60
h. 1.25
i. 1.14
j. 1.20
k. 1.27
l. 1.16
m. .14

V. 10.31

VII. for those who responded "1" in VI 1.36
for those who responded "2" in VI .76

VIII.a. 4.20
b. .27

All averages are based on a denominator of 48, unless otherwise indicated.

TABLE III: TOTAL NUMBER OF CITY RESPONSES (113 CITIES)

I.	1)	90
	2)	15
	na)	3
	ca)	5
II.	1)	75
	2)	5
	3)	11
	4)	1
	na)	18
	ca)	5
III.	1)	46
	2)	25
	3)	6
	4)	6
	5)	25
	6)	2
	7)	49
	8)	41
	na)	2
IV.	1)	10
	2)	9
	3)	1
	4)	0
	5)	8
	6)	1
	7)	49
	8)	46
	na)	5
V a.	1)	57
	2)	48
	na)	0
	ca)	5
b.	1)	34
	2)	2
	3)	4
	4)	30
	5)	15
	na)	48
	ca)	5
VI.	1)	110
	2)	0
	na)	2
	ca)	1

TABLE [illegible] c [illegible]

VII.	1)	105	6)	48	11)	40	16)	51	21)	17
	2)	45	7)	50	12)	35	17)	17	na)	1
	3)	33	8)	44	13)	37	18)	63		
	4)	56	9)	29	14)	76	19)	66		
	5)	46	10)	28	15)	57	20)	67		

VIII.	a.	1)	11	h.	1)	3
		2)	68		2)	82
		3)	0		3)	2
		4)	53		4)	12
		5)	12		5)	31
		na)	16		na)	16
	b.	1)	7	i.	1)	6
		2)	60		2)	72
		3)	1		3)	2
		4)	37		4)	17
		5)	23		5)	28
		na)	33		na	23
	c.	1)	8	j.	1)	4
		2)	54		2)	71
		3)	1		3)	0
		4)	20		4)	49
		5)	29		5)	11
		na)	36		na)	13
	d.	1)	9	k.	1)	13
		2)	74		2)	62
		3)	0		3)	1
		4)	49		4)	26
		5)	22		5)	37
		na)	10		na)	14
	e.	1)	31	l.	1)	10
		2)	73		2)	68
		3)	6		3)	1
		4)	12		4)	16
		5)	45		5)	25
		na)	6		na)	26
	f.	1)	27	m.	1)	1
		2)	81		2)	12
		3)	1		3)	0
		4)	17		4)	4
		5)	45		5)	5
		na)	5		na)	95
	g.	1)	35			
		2)	55			
		3)	2			
		4)	13			
		5)	29			
		na)	10			

IX	a.	1)	112	b. 1)	1
		2)	9	2)	2
		3)	24	3)	10
		4)	7	4)	4
		5)	20	5)	1
		6)	58	6)	6
		7)	14	7)	14
		8)	91	8)	1
		9)	14	9)	8
		na)	0	na)	81

X	a.	1)	88
		2)	16
		na)	8
		ca)	1

na = no answer

ca = contradictory answer

TABLE IV: TOTAL CITY AVERAGE NUMBER OF RESPONSES

PER QUESTION

II. for those who responded "1" in I 1.02

III. 1.76

IV. 1.09

V.b. for those who responded "1" in V.a. 149

VII. 8.93

VIII.a. 1.26
b. 1.12
c. .99
d. 1.35
e. 1.47
f. 1.50
g. 1.18
h. 1.14
i. 1.10
j. 1.18
k. 1.20
l. 1.06
m. .14

IX.a. 3.08
b. .41

All averages are based on a denominator of 113, unless otherwise indicated.

TABLE V: STATE AND CITY RANKING BY FREQUENCY OF SELECTION OF FACTORS IN sV AND cVIII

STATE RANK	CITY RANK	FACTOR
1	1	85th percentile
7	12	pace
11*	17	average test run speed
5	7	design speed
15*	11	maximum comfortable speed on curves
3	10	ball-bank indicator
8	9	spacing of intersections and driveways
6	12	number of roadside businesses per mile
18	18	slipperiness of pavement
19	19	roughness of pavement
15*	14	presence of transverse dips and bumps
10	16	presence and condition of shoulders
17	18	presence and width of median
2	2	accident experience at that or similar locations
9	6	traffic volume
14*	8	parking and loading of vehicles
20*	20	percentage of commercial vehicles
14*	5	traffic signals and other traffic controls
11*	4	presence of pedestrians
4	3	length of zones and effect of adjacent zones
20*	21	others

* two factors with the same rank.

APPENDIX E

SELECTED SPEED DISTRIBUTIONS FROM THE IRPS SENSOR SYSTEM

1.0 INTRODUCTION

The purpose of this appendix is to give the reader some insight into traffic flow behavior. As described in Appendix B, the computer sensor system records the speed, headway, length, and direction of every vehicle passing over a sensor loop. It is thus possible to obtain histograms showing the entire population of vehicle speeds for a given time interval. Each histogram in this appendix gives the speeds of the entire population of vehicles passing over one loop during one time interval; the loop and the time interval are shown at the top of the histogram.

The data are presented in three groupings. Section 2.0 shows how the speed distributions vary with time at a given sensor site. Section 3.0 demonstrates how the distributions vary with sensor site location over a single time period. Curves showing various other effects of interest are included in section 4.0.

2.0 TEMPORAL DISTRIBUTIONS

This section shows how speed distributions vary with time, first by time of day, then by day of week.

2.1 Distribution by time of day

The speed distributions of Figures E-1 through E-12 show the speeds in a series of sequential two-hour time intervals covering the day of November 6, 1969, at loop site 10. Loop 10 measures traffic in the southbound lane of Indiana

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State Highway No. 37, north of Bloomington. This loop is at the top of a long straight downhill section (for southbound traffic) which contains a passing zone for northbound traffic. It lies midway through a long curve which terminates in the hill section just mentioned. The road is 24' concrete, and the speed limit is 65 mph. Figure E-1 is from midnight to 2 a.m.: the others are sequentially numbered thereafter. Throughout November 6, the road surface was dry.

The effects of rush hour traffic show up clearly. It is also noteworthy that a larger percentage of traffic is within five mph of the mean speed at the high volume traffic conditions than at conditions of low volume traffic.

Rain occurred throughout the day on November 13. Figures E-13 and E-14 taken on November 13, in contrast to Figures E-5 and E-6 (the same time periods but on November 6) show a distinct drop (5mph) in mean speed as well as a distinct drop in volume (about 60 vehicles during this time period).

2.2 Distribution by Day of Week

The speed distributions of Figures E-15 through E-21 show how the speeds vary in an Indiana winter week. These distributions, again taken from sensor site 10, show the speeds between 0930 and 1130, starting with Sunday, November 9, 1969, and concluding with Saturday, November 15, 1969. The weather during this week was varied - the roads were dry from Sunday

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 0 TO 2000 ON 11/ 6/69

COUNT	72	AVE. VEL.	66.05	ST. DEV.	8.19
85TH PERCENTILE	72	90TH PERCENTILE	75	PASSING COUNT	2
ZERO COUNT	2	MAXIMUM VEL.	94	MINIMUM VEL.	49
RANGE	45	MODE	70	MEDIAN	65

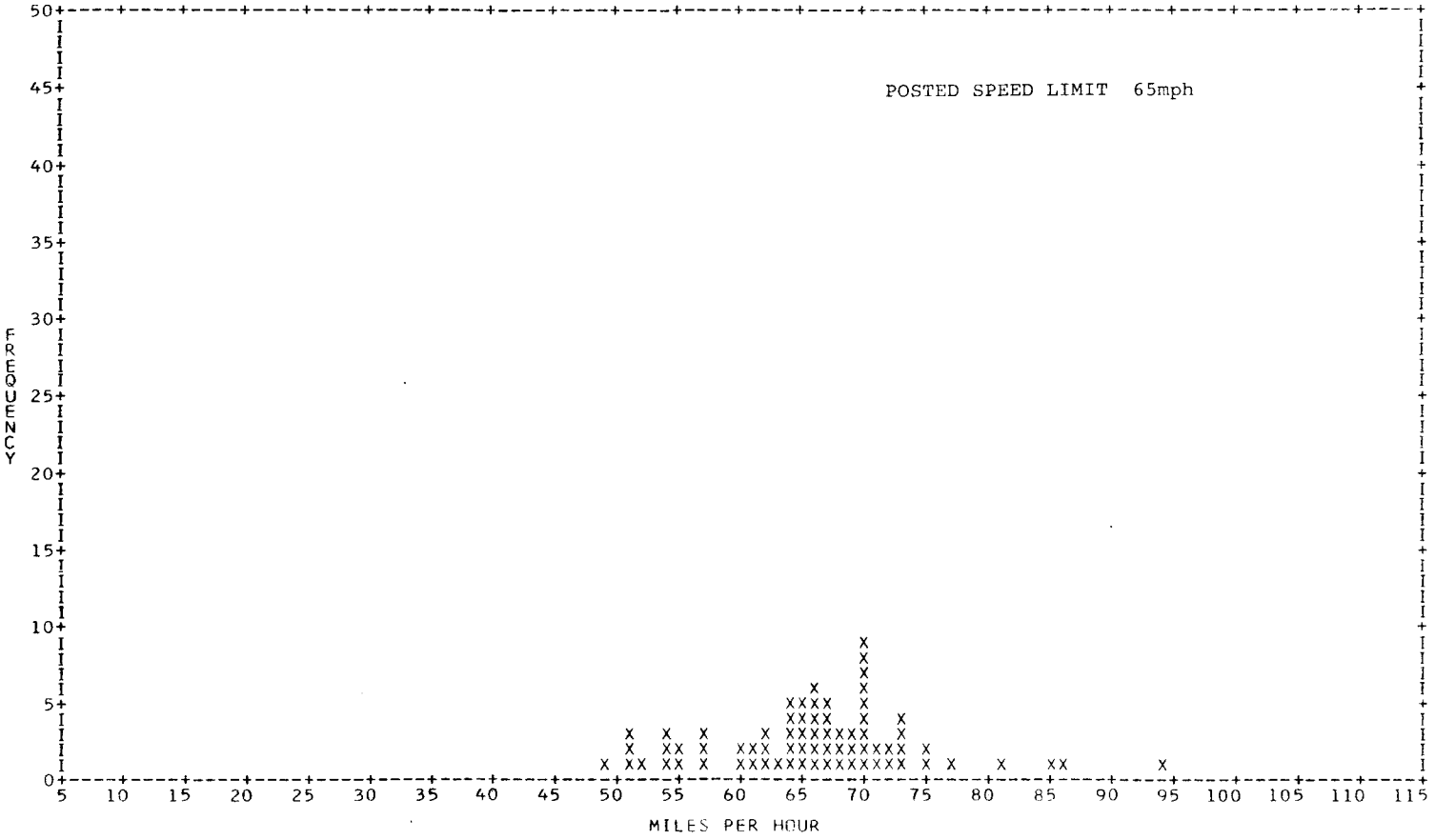


Figure E - 1

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 2000 TO 4000 ON 11/ 6/69

COUNT	33	AVE. VEL.	63.06	ST. DEV.	7.60
85TH PERCENTILE	71	90TH PERCENTILE	73	PASSING COUNT	1
ZERO COUNT	1	MAXIMUM VEL.	84	MINIMUM VEL.	52
RANGE	32	MODE	64	MEDIAN	61

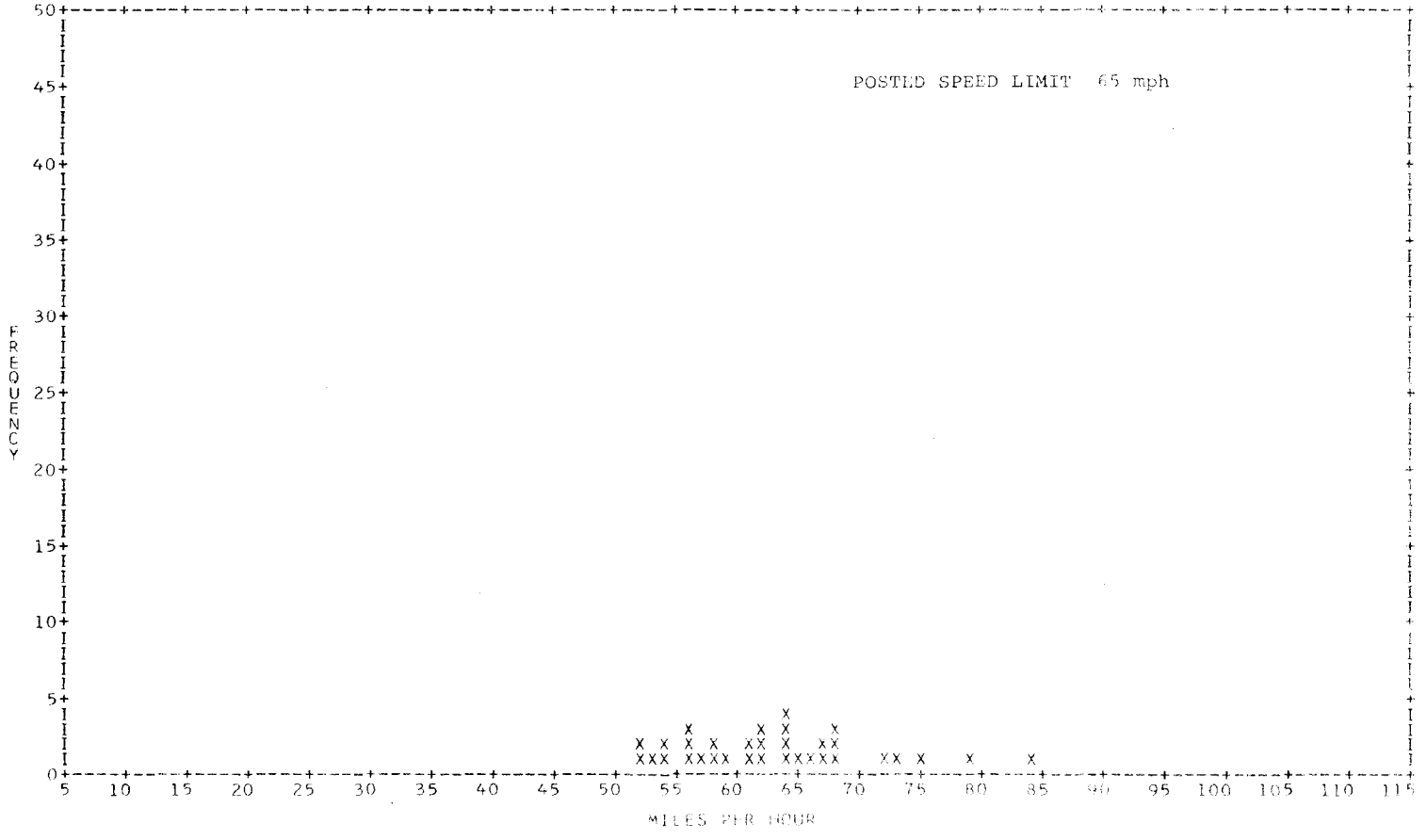


Figure E - 2

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 4000 TO 6000 ON 11/ 6/69

COUNT	52	AVE. VEL.	60.98	ST. DEV.	6.43
85TH PERCENTILE	67	90TH PERCENTILE	70	PASSING COUNT	0
ZERO COUNT	0	MAXIMUM VEL.	73	MINIMUM VEL.	44
RANGE	29	MODE	60	MEDIAN	60

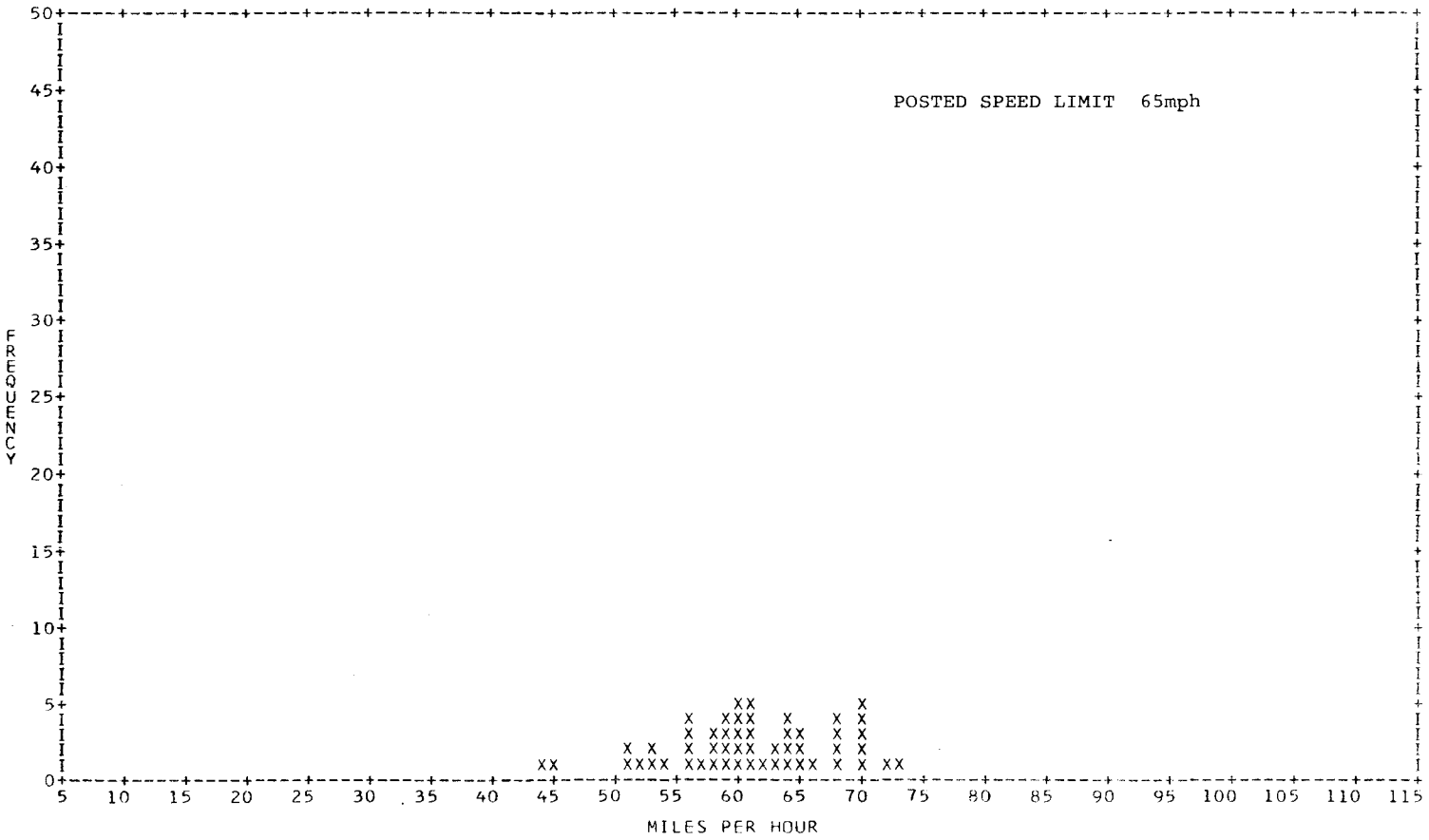


Figure E - 3

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 6000 TO 8000 ON 11/ 6/69

COUNT	443	AVE. VEL.	59.34	ST. DEV.	8.43
85TH PERCENTILE	66	90TH PERCENTILE	69	PASSING COUNT	8
ZERO COUNT	18	MAXIMUM VEL.	82	MINIMUM VEL.	19
RANGE	63	MODE	60	MEDIAN	59

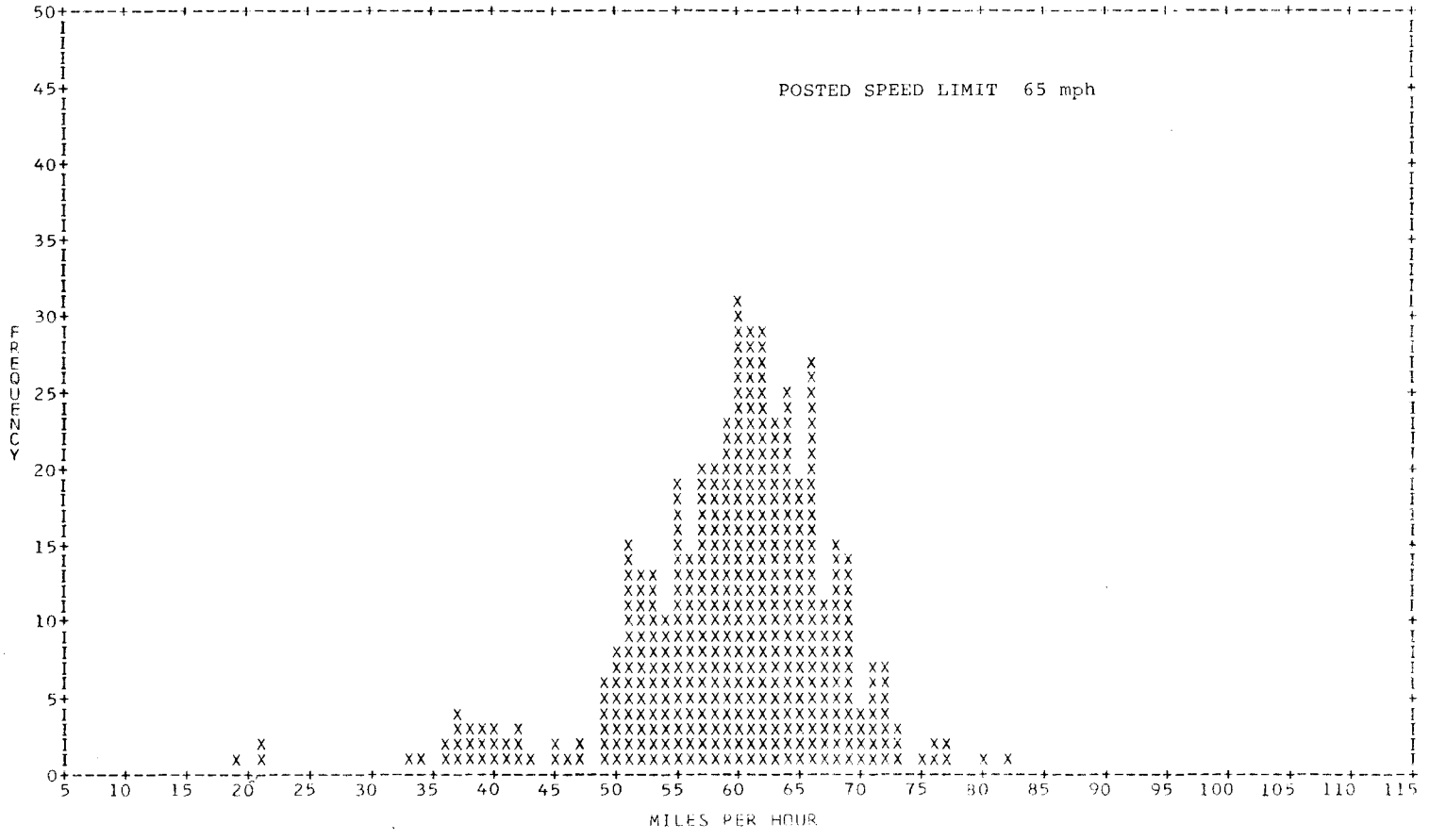


Figure E - 4

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 8000 TO 10600 ON 11/ 6/69

COUNT	519	AVE. VEL.	61.03	ST. DEV.	6.88
85TH PERCENTILE	67	90TH PERCENTILE	70	PASSING COUNT	2
ZERO COUNT	4	MAXIMUM VEL.	84	MINIMUM VEL.	24
RANGE	60	MODE	63	MEDIAN	60

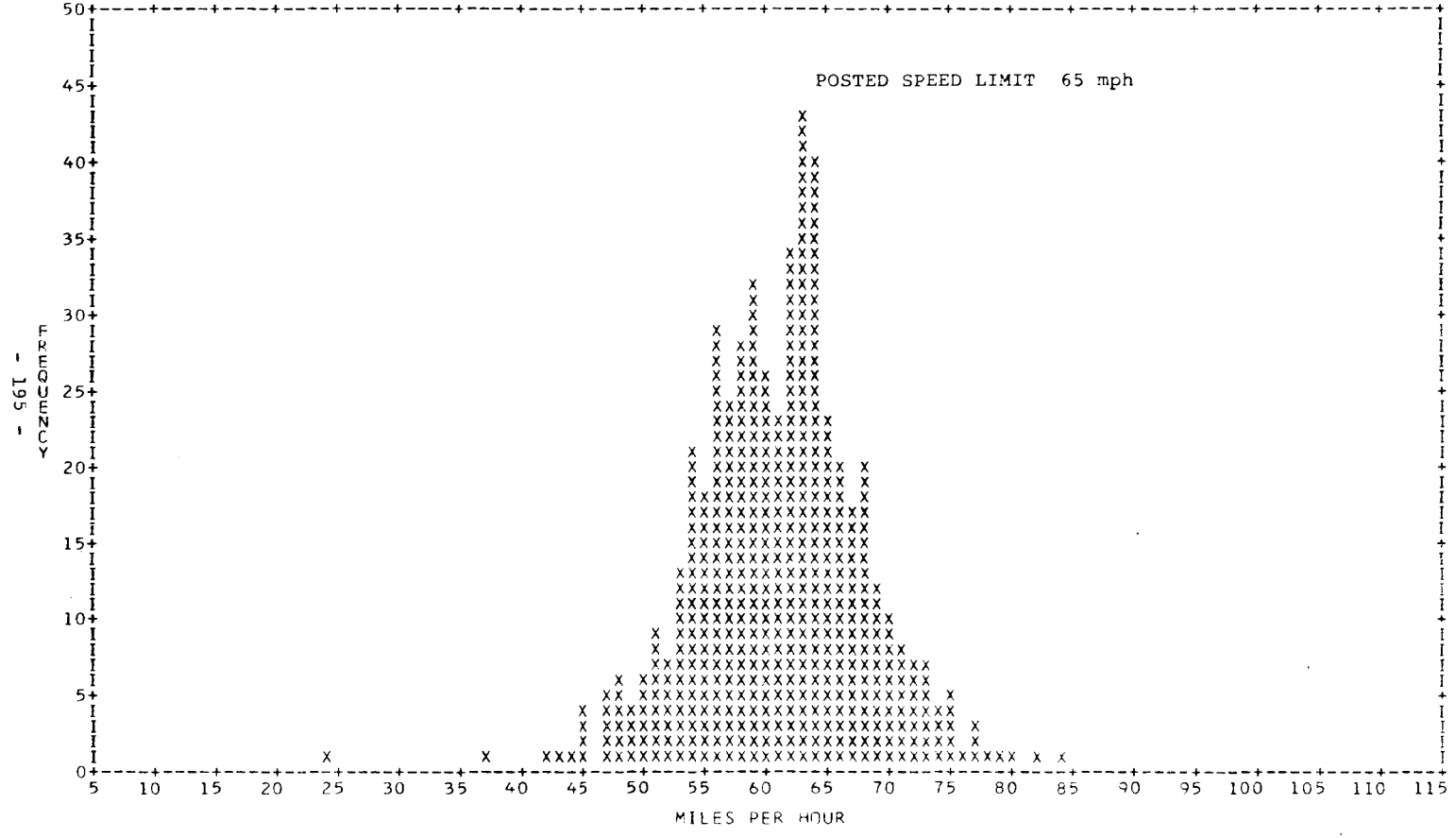


Figure E - 5

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 10000 TO 12000 ON 11/ 6/69

COUNT	419	AVE. VEL.	59.53	ST. DEV.	7.40
85TH PERCENTILE	66	90TH PERCENTILE	68	PASSING COUNT	1
ZERO COUNT	6	MAXIMUM VEL.	84	MINIMUM VEL.	18
RANGE	66	MODE	60	MEDIAN	59

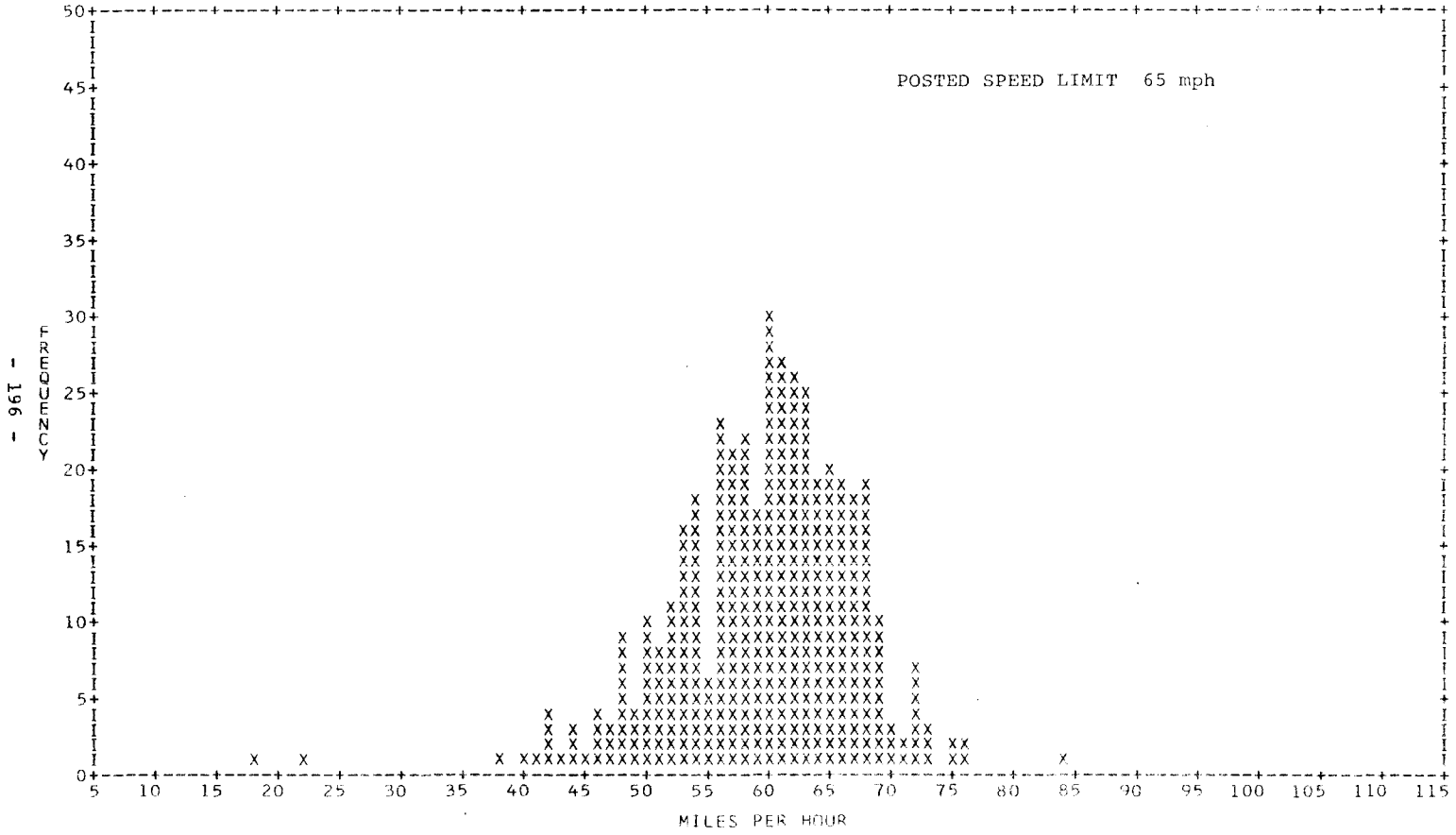


Figure E - 6

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 12000 TO 14000 ON 11/ 6/69

COUNT	437	AVE. VEL.	58.01	ST. DEV.	6.38
85TH PERCENTILE	63	90TH PERCENTILE	66	PASSING COUNT	1
ZERO COUNT	1	MAXIMUM VEL.	80	MINIMUM VEL.	32
RANGE	48	MODE	52	MEDIAN	57

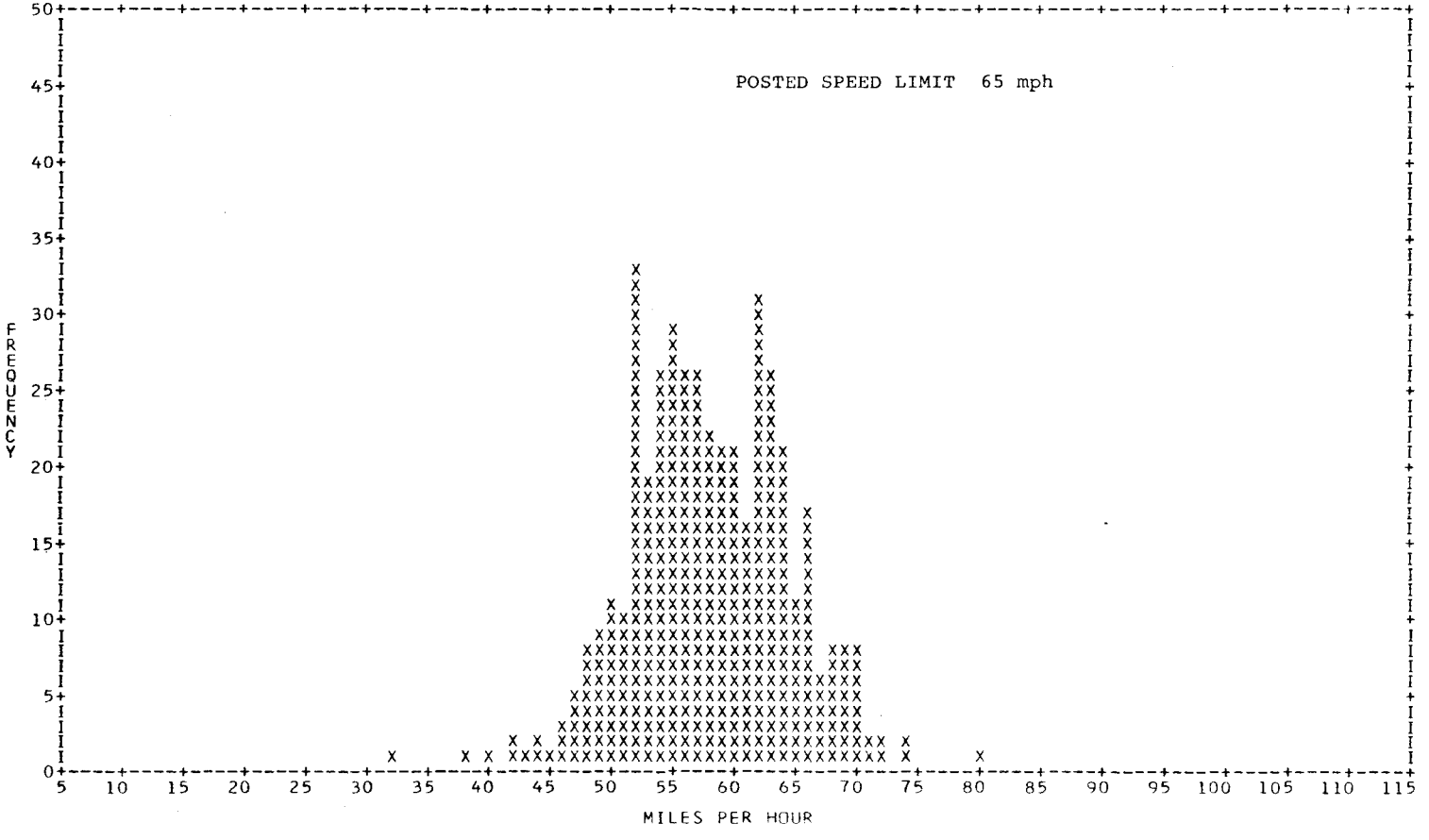


Figure E - 7

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 14000 TO 16000 ON 11/ 6/69

COUNT	438	AVE. VEL.	56.38	ST. DEV.	7.05
85TH PERCENTILE	63	90TH PERCENTILE	66	PASSING COUNT	6
ZERO COUNT	10	MAXIMUM VEL.	73	MINIMUM VEL.	34
RANGE	39	MODE	59	MEDIAN	56

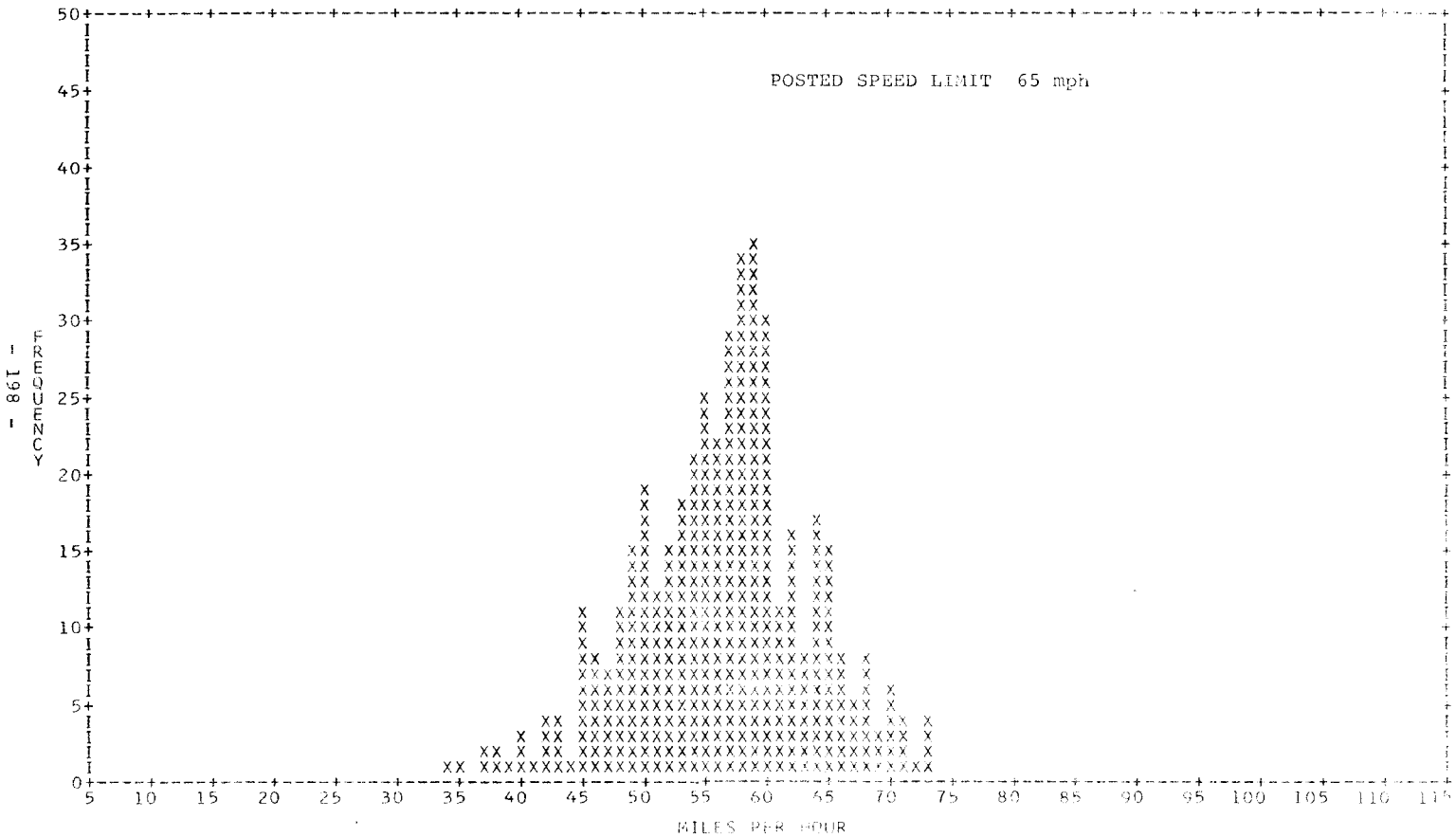


Figure 3

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 16000 TO 18000 ON 11/ 6/69

COUNT	602	AVE. VEL.	57.51	ST. DEV.	6.06
85TH PERCENTILE	62	90TH PERCENTILE	64	PASSING COUNT	3
ZERO COUNT	9	MAXIMUM VEL.	74	MINIMUM VEL.	17
RANGE	57	MODE	59	MEDIAN	57

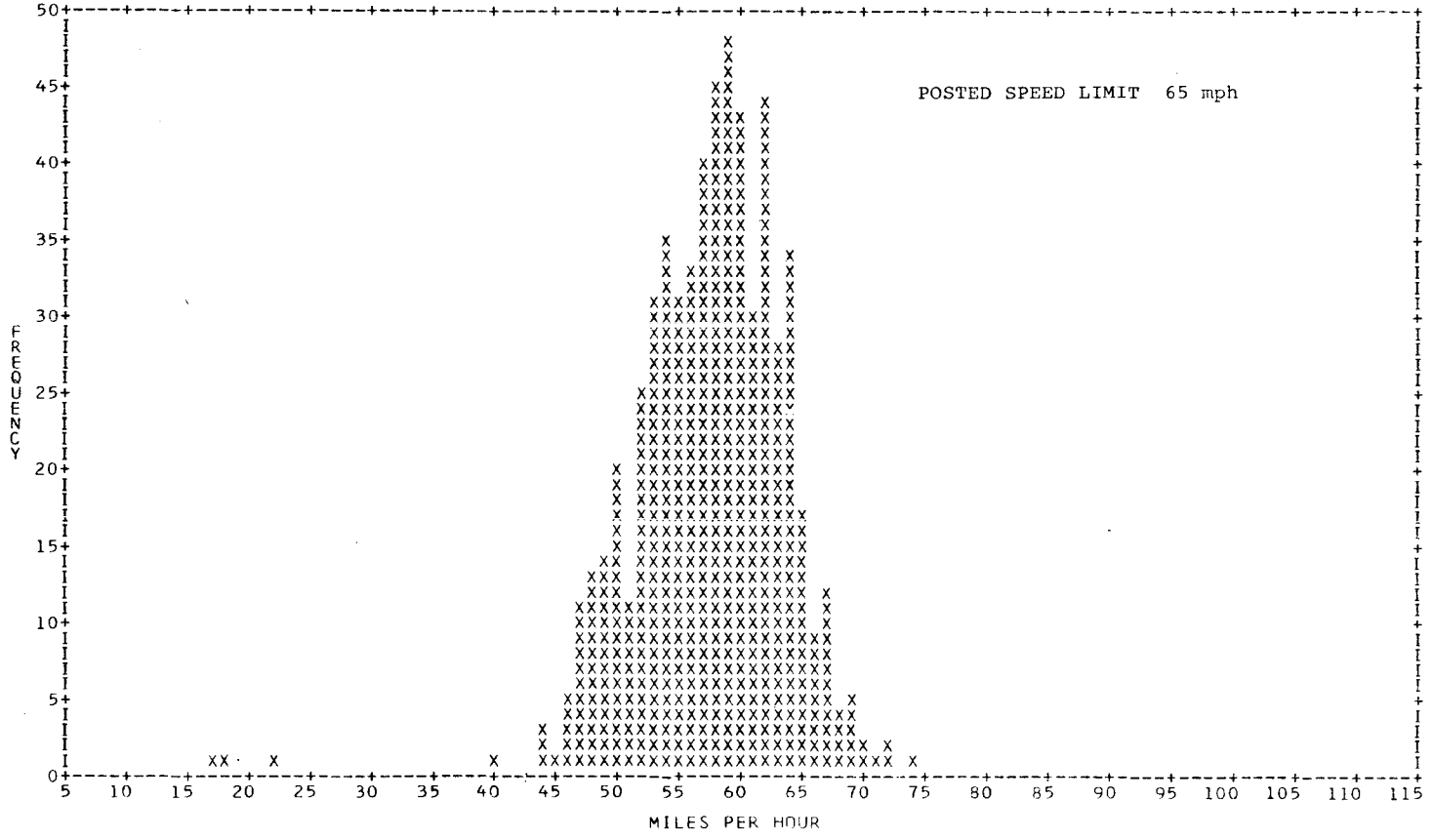


Figure E - 9

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 18000 TO 20000 ON 11/ 6/69

COUNT	424	AVE. VEL.	59.54	ST. DEV.	6.25
85TH PERCENTILE	65	90TH PERCENTILE	68	PASSING COUNT	1
ZERO COUNT	1	MAXIMUM VEL.	79	MINIMUM VEL.	33
RANGE	46	MODE	57	MEDIAN	58

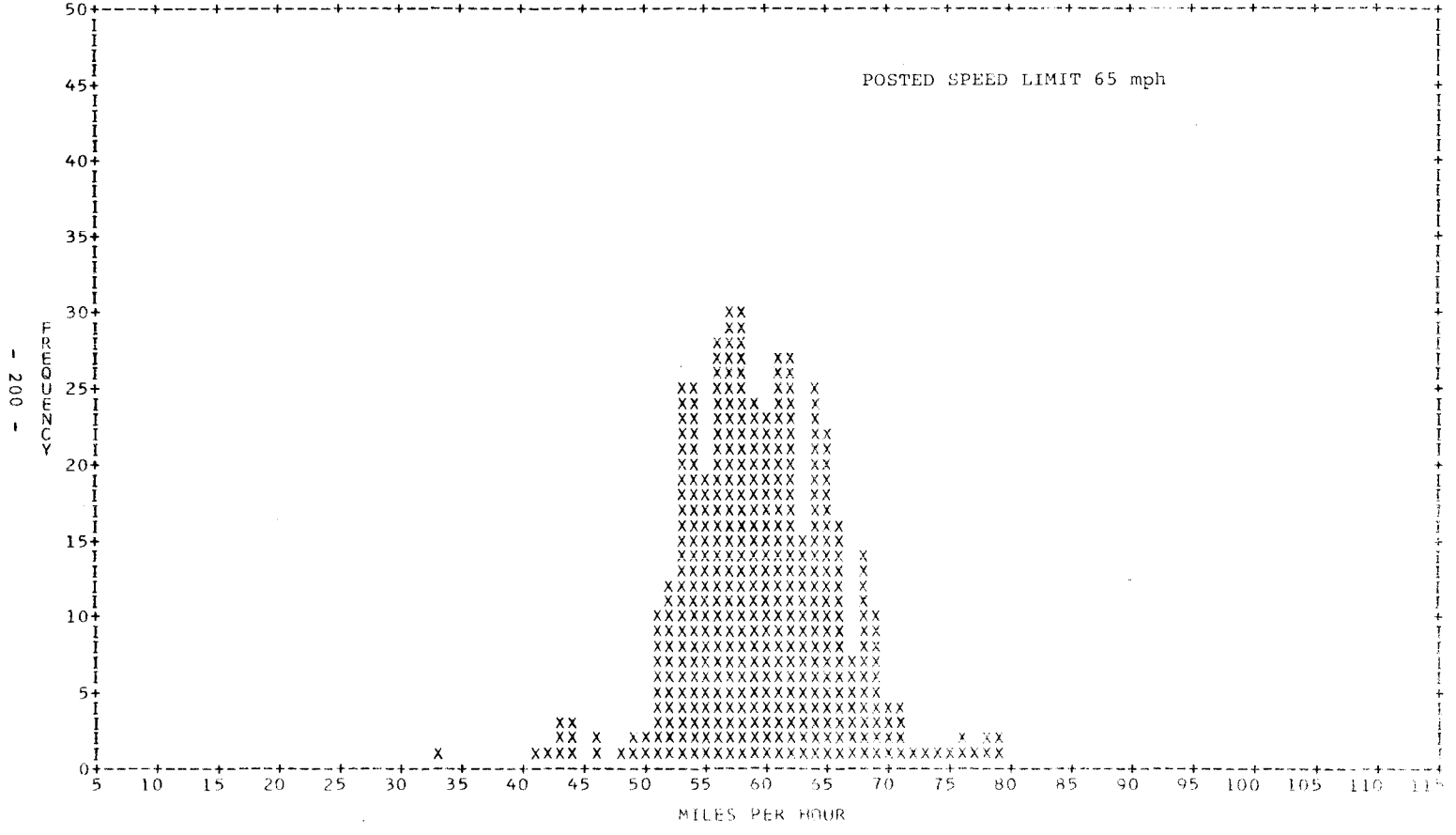


Figure E - 10

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 20000 TO 22000 ON 11/ 6/69

COUNT	256	AVE. VEL.	60.83	ST. DEV.	6.01
85TH PERCENTILE	66	90TH PERCENTILE	69	PASSING COUNT	1
ZERO COUNT	6	MAXIMUM VEL.	86	MINIMUM VEL.	46
RANGE	40	MODE	56	MEDIAN	60

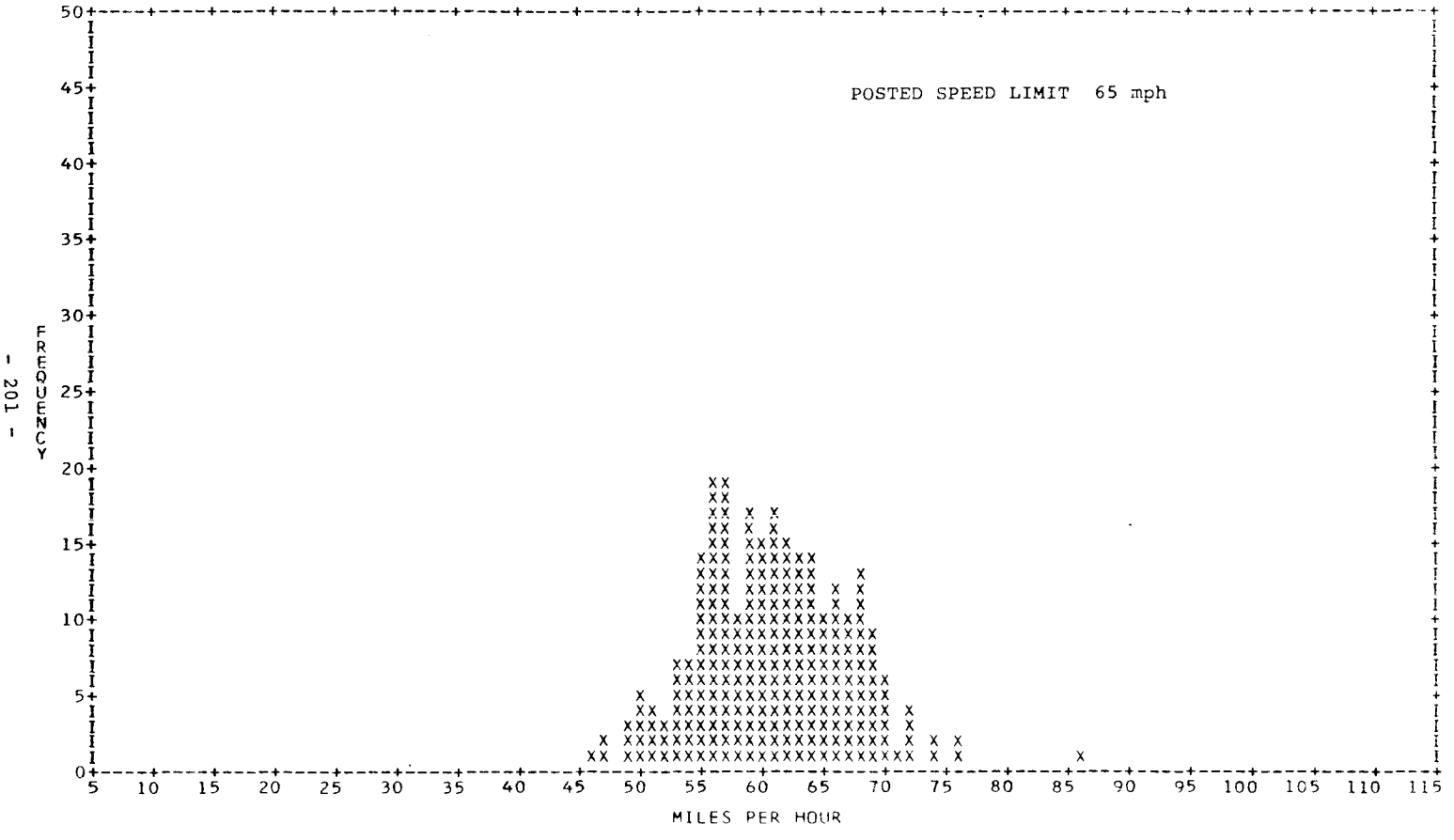


Figure E - 11

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 22000 TO 24000 ON 11/ 6/69

COUNT	210	AVE. VEL.	62.78	ST. DEV.	6.68
85TH PERCENTILE	68	90TH PERCENTILE	71	PASSING COUNT	2
ZERO COUNT	2	MAXIMUM VEL.	85	MINIMUM VEL.	39
RANGE	46	MODE	61	MEDIAN	62

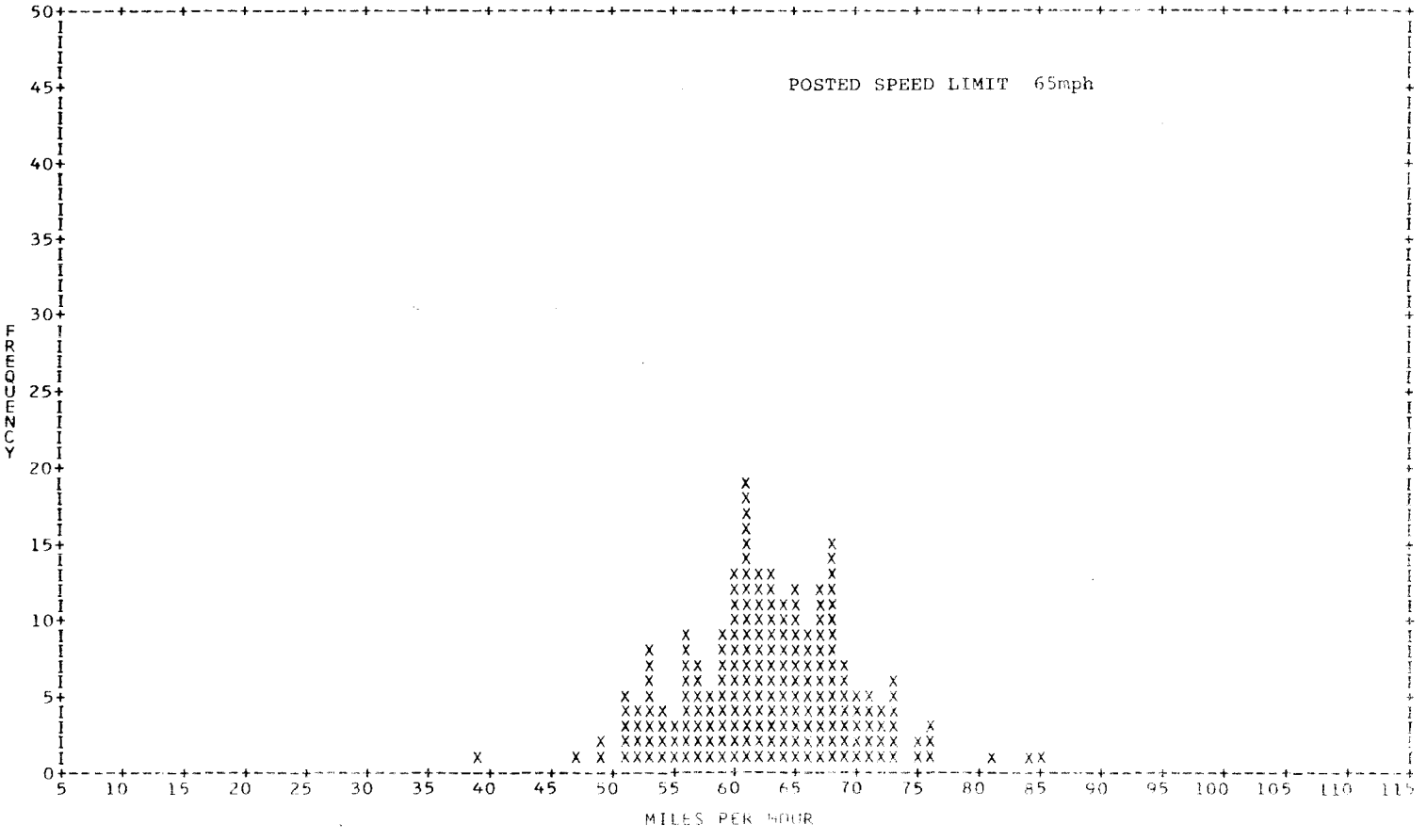


Figure E - 12

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 8000 TO 10000 ON 11/13/69

COUNT	454	AVE. VEL.	55.95	ST. DEV.	6.26
85TH PERCENTILE	61	90TH PERCENTILE	64	PASSING COUNT	2
ZERO COUNT	3	MAXIMUM VEL.	75	MINIMUM VEL.	40
RANGE	35	MODE	56	MEDIAN	55

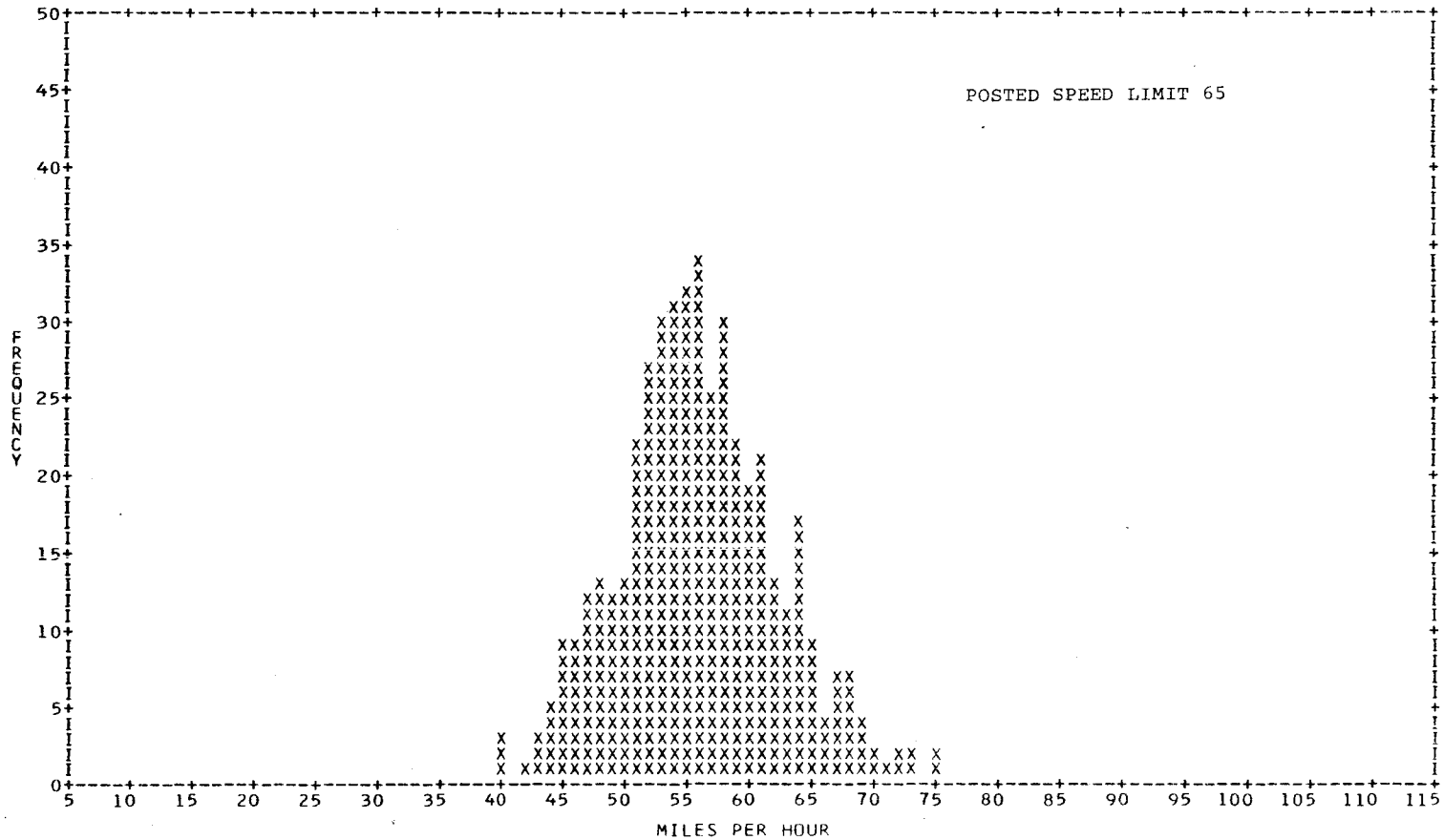


Figure E - 13

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 10000 TO 12000 ON 11/13/69

COUNT	457	AVE. VEL.	55.52	ST. DEV.	6.51
85TH PERCENTILE	61	90TH PERCENTILE	64	PASSING COUNT	3
ZERO COUNT	4	MAXIMUM VEL.	76	MINIMUM VEL.	39
RANGE	37	MODE	58	MEDIAN	55

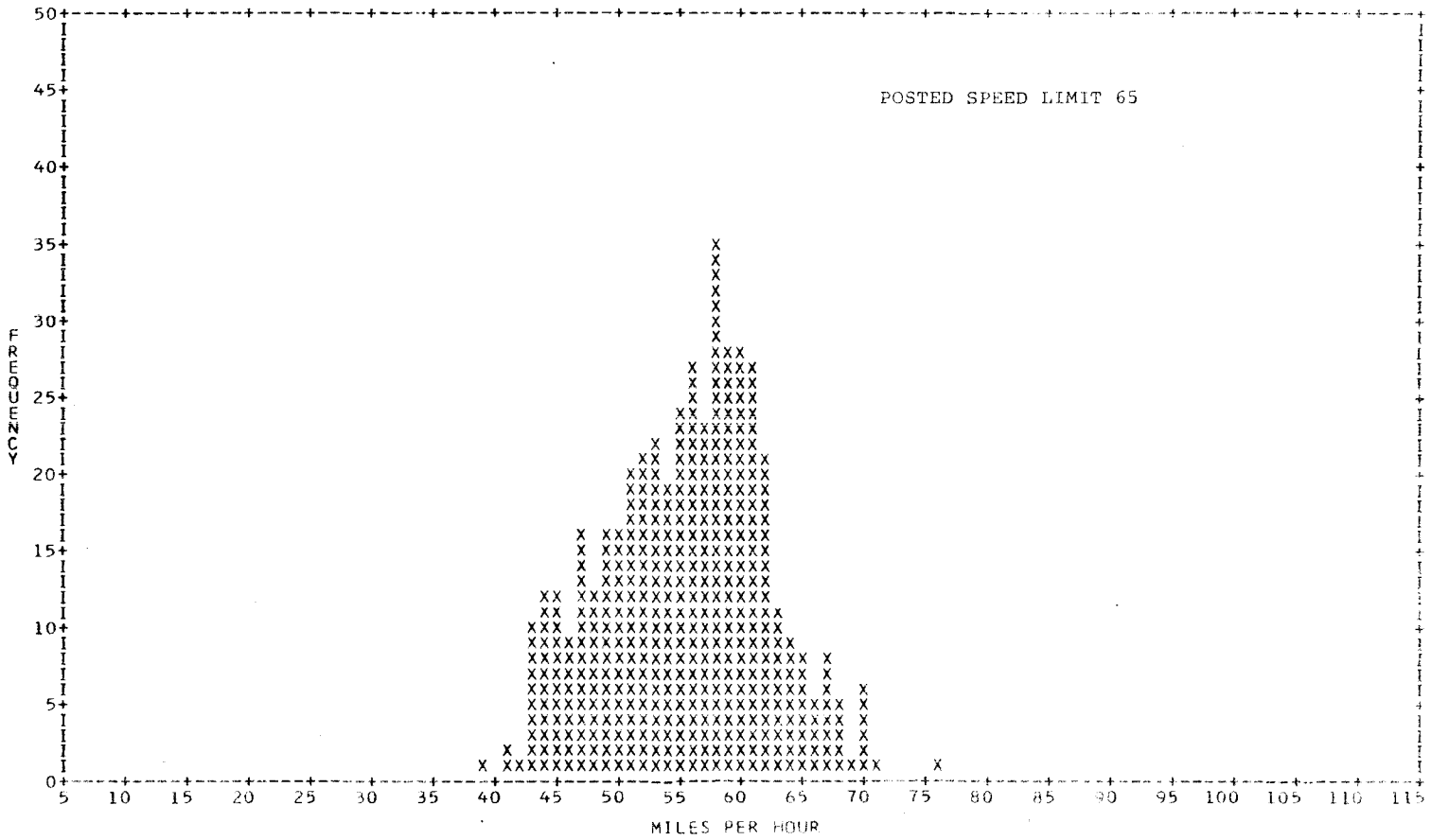


Figure E - 14

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 9500 TO 11500 ON 11/ 9/69

COUNT	541	AVE. VEL.	60.97	ST. DEV.	5.35
85TH PERCENTILE	65	90TH PERCENTILE	68	PASSING COUNT	1
ZERO COUNT	2	MAXIMUM VEL.	76	MINIMUM VEL.	35
RANGE	41	MODE	61	MEDIAN	60

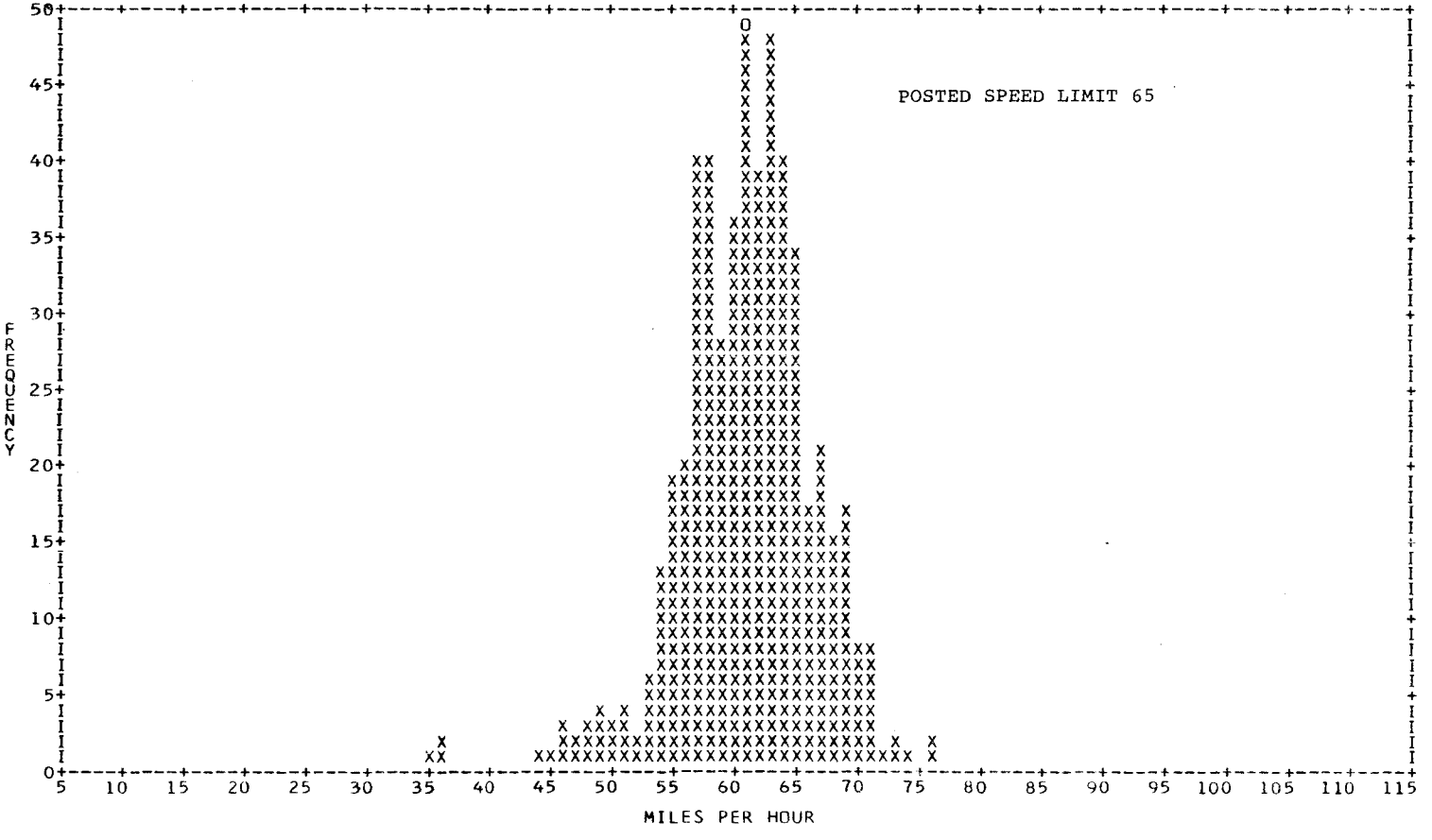


Figure E - 15 SUNDAY

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 9500 TO 11500 ON 11/10/69

COUNT	525	AVE. VEL.	60.28	ST. DEV.	6.98
85TH PERCENTILE	67	90TH PERCENTILE	69	PASSING COUNT	5
ZERO COUNT	8	MAXIMUM VEL.	83	MINIMUM VEL.	25
RANGE	58	MODE	63	MEDIAN	59

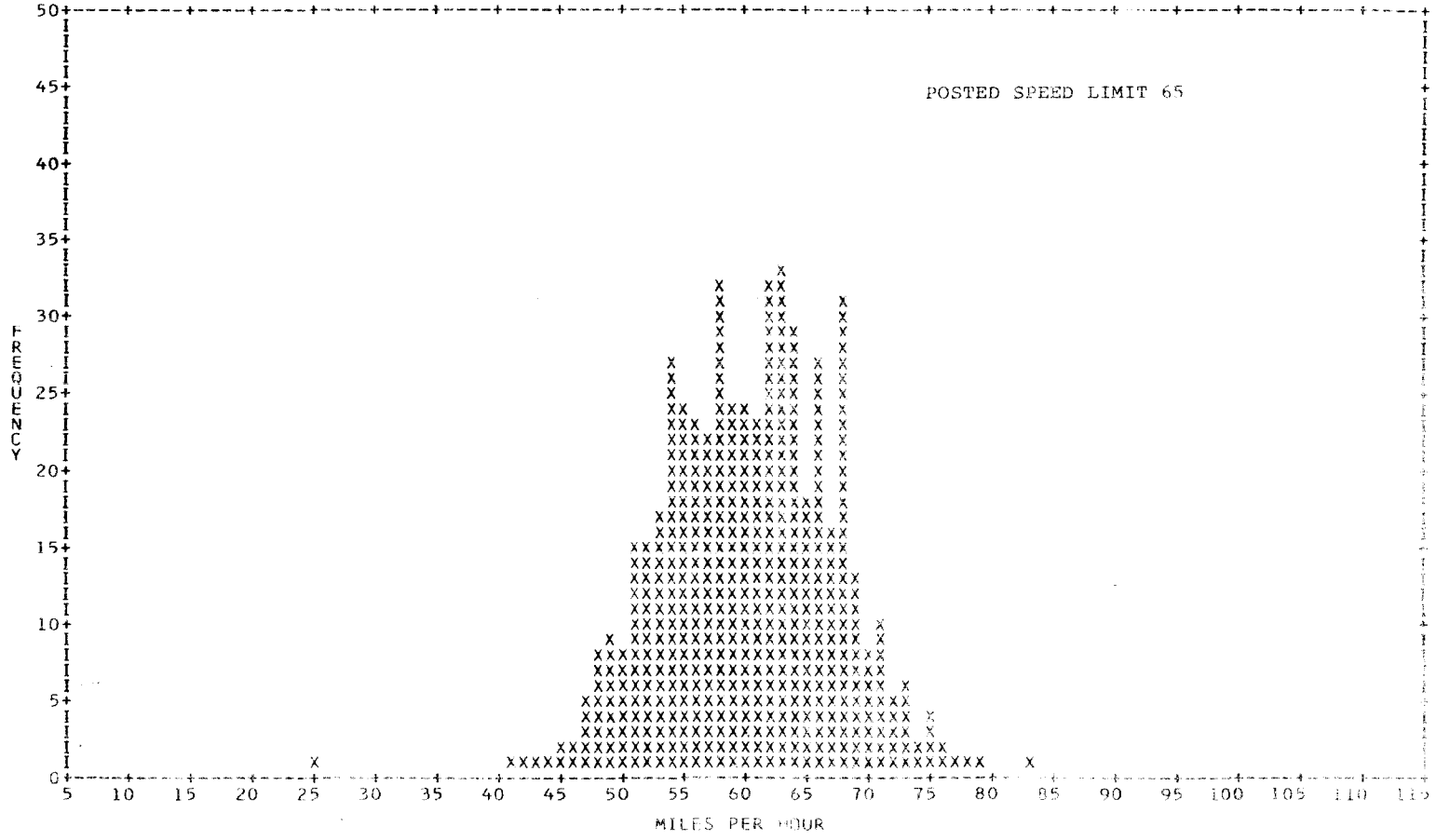


Figure B - 16

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 9500 TO 11500 ON 11/11/69

COUNT	485	AVE. VEL.	59.63	ST. DEV.	7.31
85TH PERCENTILE	65	90TH PERCENTILE	68	PASSING COUNT	1
ZERO COUNT	2	MAXIMUM VEL.	81	MINIMUM VEL.	23
RANGE	58	MODE	62	MEDIAN	60

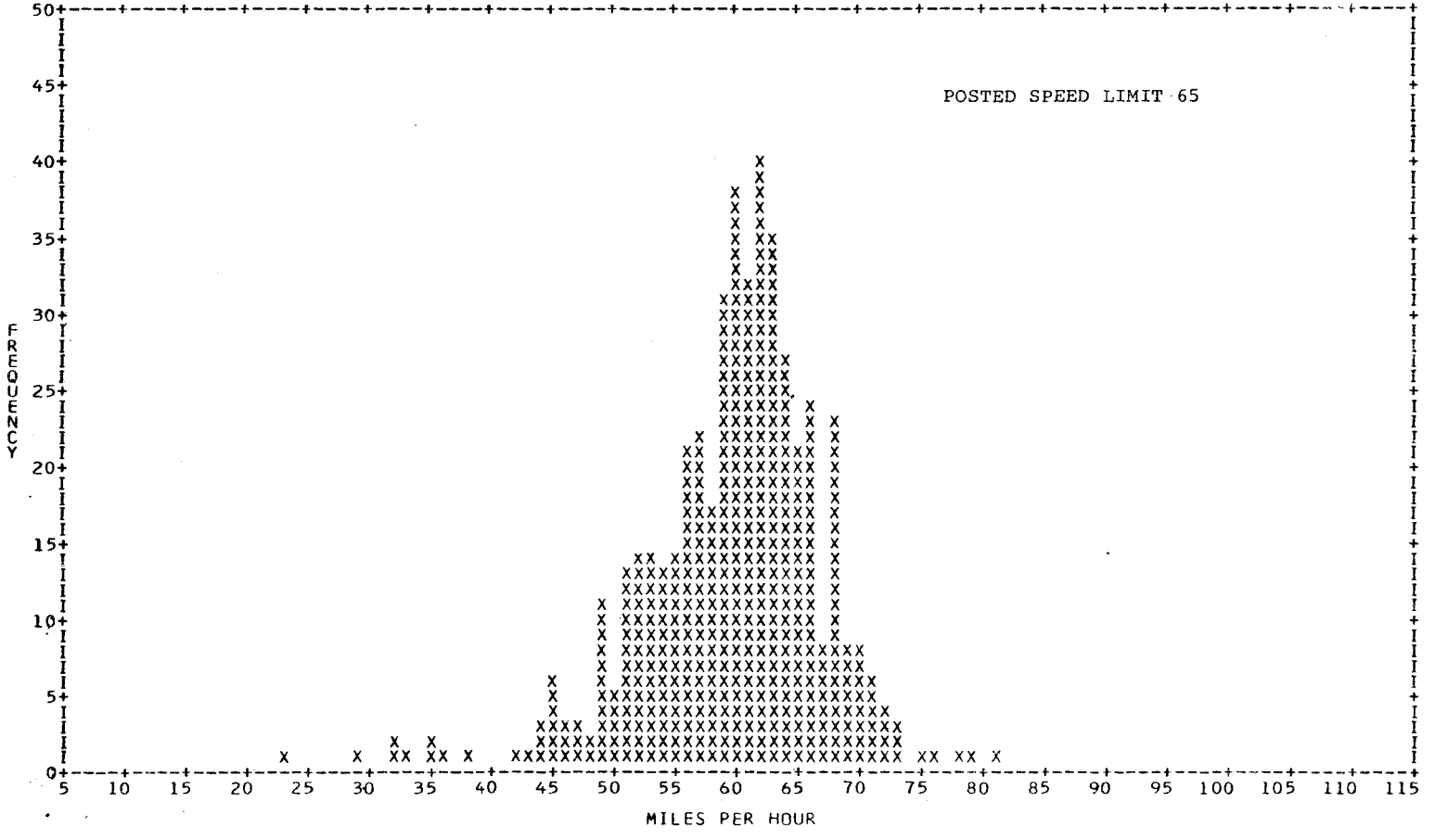


Figure E - 17 TUESDAY

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 9500 TO 11500 ON 11/12/69

COUNT	482	AVE. VEL.	58.83	ST. DEV.	6.74
85TH PERCENTILE	65	90TH PERCENTILE	68	PASSING COUNT	4
ZERO COUNT	8	MAXIMUM VEL.	81	MINIMUM VEL.	17
RANGE	64	MODE	60	MEDIAN	58

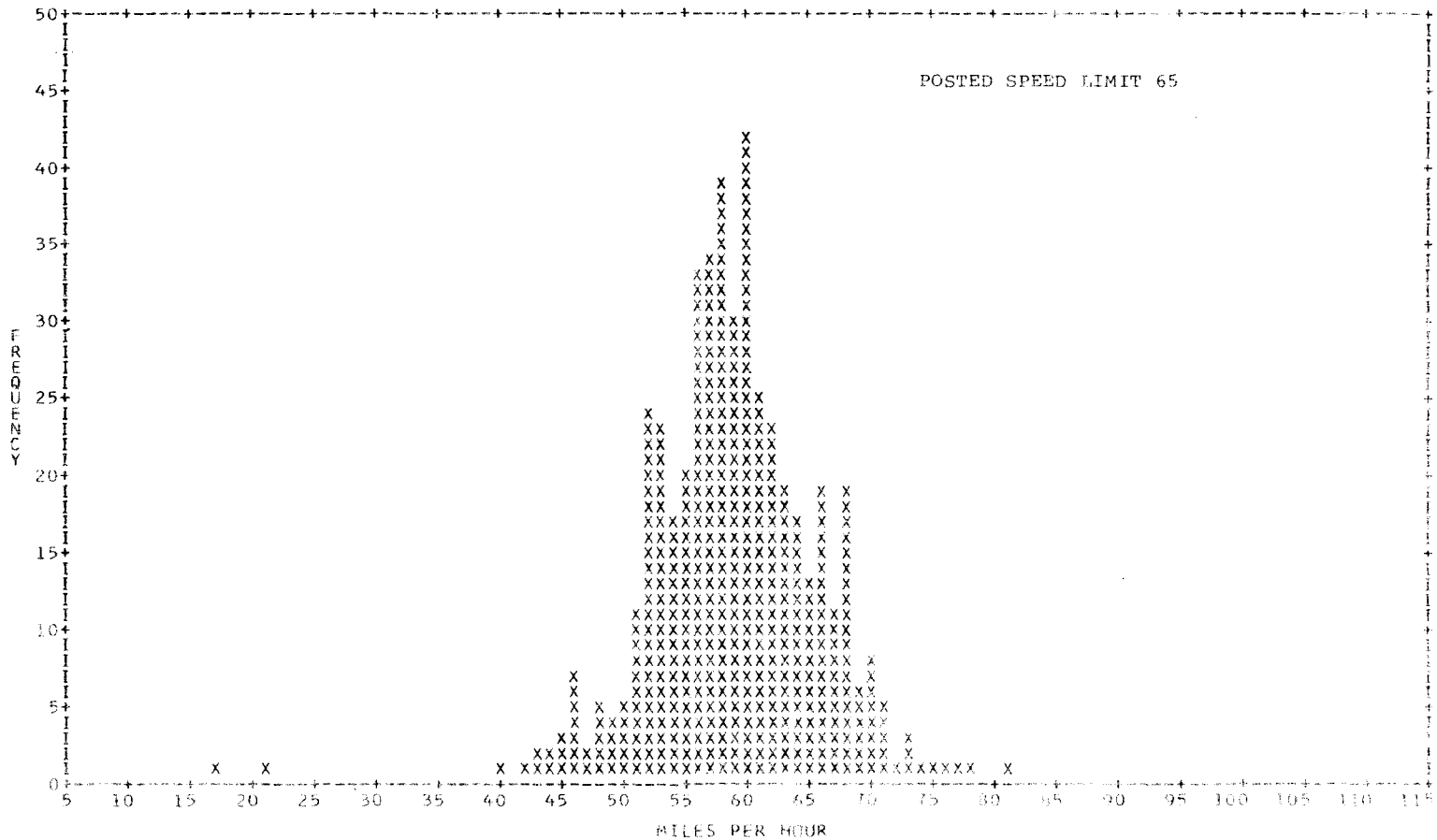


Figure E - 18 Model XX

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 9500 TO 11500 ON 11/13/69

COUNT	517	AVE. VEL.	55.28	ST. DEV.	6.44
85TH PERCENTILE	61	90TH PERCENTILE	63	PASSING COUNT	2
ZERO COUNT	3	MAXIMUM VEL.	75	MINIMUM VEL.	39
RANGE	36	MODE	56	MEDIAN	55

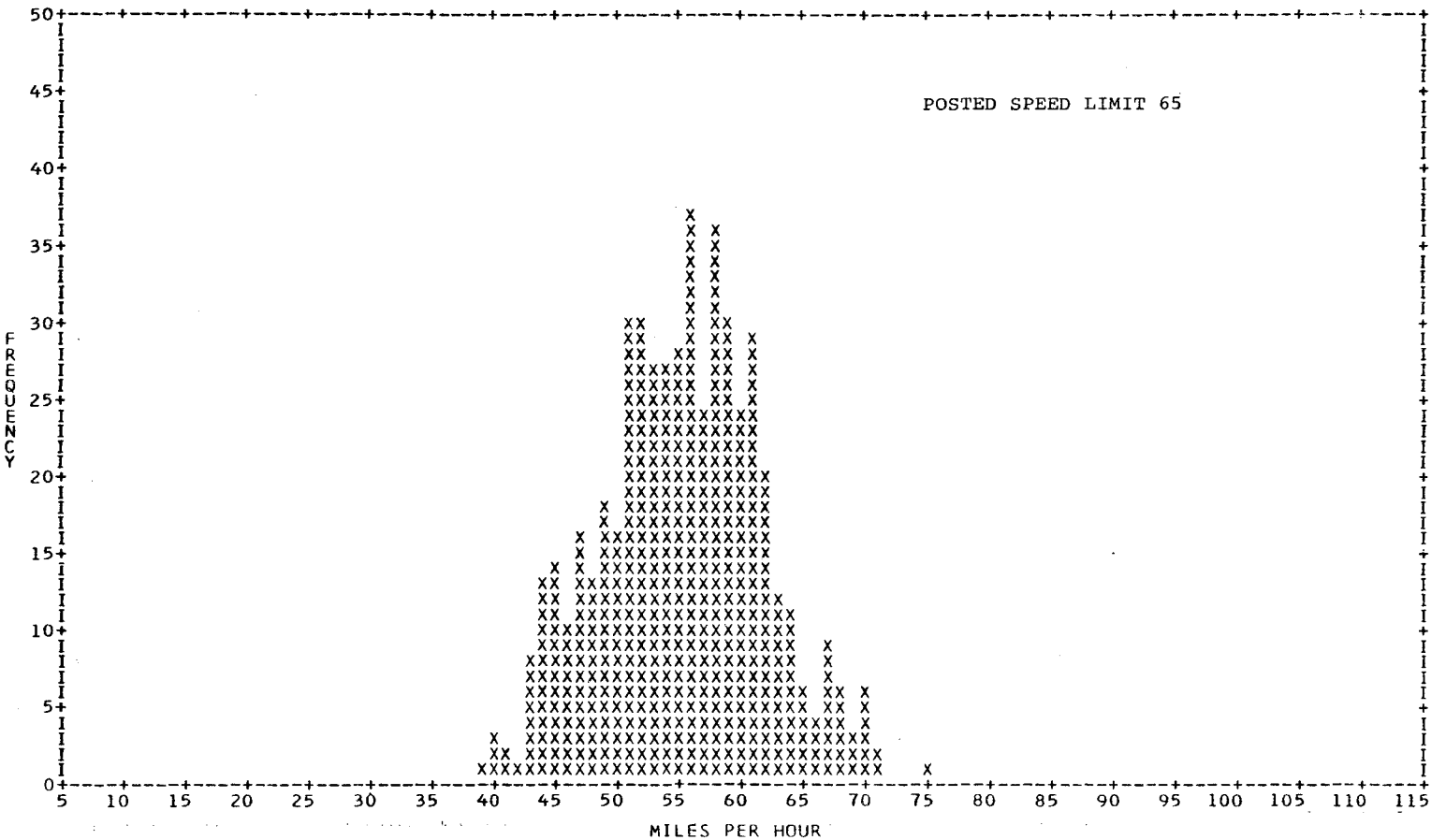


Figure E - 19 THURSDAY

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 9500 TO 11500 ON 11/14/69

COUNT	476	AVE. VEL.	58.54	ST. DEV.	8.51
85TH PERCENTILE	65	90TH PERCENTILE	68	PASSING COUNT	3
ZERO COUNT	9	MAXIMUM VEL.	82	MINIMUM VEL.	21
RANGE	61	MODE	58	MEDIAN	58

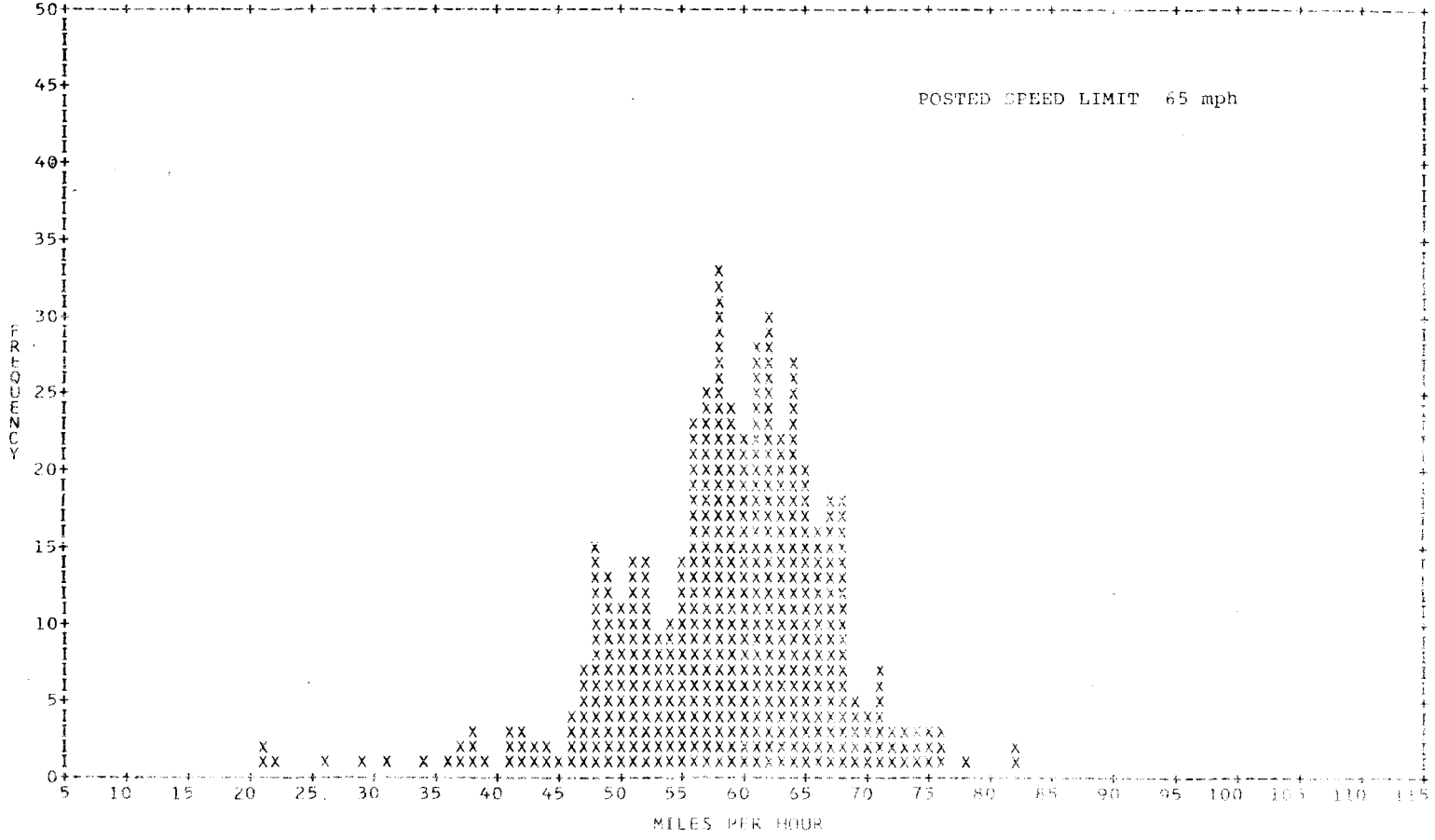


Figure B - 20 Page 87

LOOP NUMBER 10

PLOT OF TRAFFIC FROM 9500 TO 11500 ON 11/15/69

COUNT	493	AVE. VEL.	55.34	ST. DEV.	5.34
85TH PERCENTILE	60	90TH PERCENTILE	64	PASSING COUNT	5
ZERO COUNT	28	MAXIMUM VEL.	73	MINIMUM VEL.	40
RANGE	33	MODE	52	MEDIAN	54

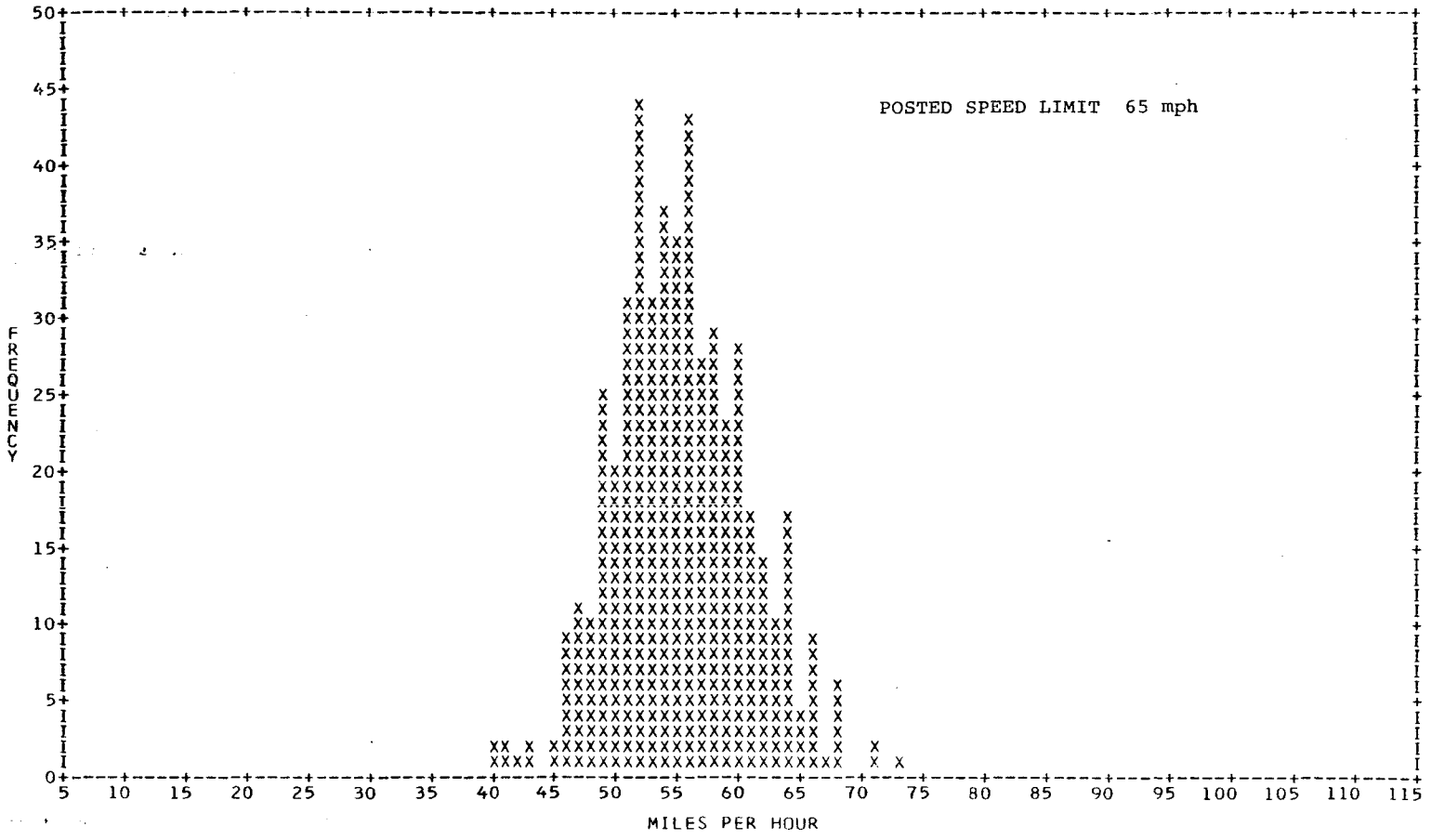


Figure E - 21 SATURDAY

morning until Monday night, when rain was recorded. Tuesday and Wednesday, the roads were dry; Thursday it rained all day. About 1300 on Friday, the rain turned to snow, and Saturday night some snow was still present.

Highway 37 is heavily travelled, and the roads dry rapidly once precipitation was stopped. Precipitation does not seem to have had much effect during this period. Note, however, on speeds that the mean speeds on Thursday and on Saturday are significantly less than on the other days. Note also that the volume of vehicles during this time period shows surprisingly little variation from 541 on Sunday to 47[illegible] on Friday.

3.0 SPATIAL DISTRIBUTIONS

Figures E-22 through E-34 demonstrate how speed distributions vary with location. The locations chosen are those in the northbound lanes of Indiana Highway 27 and include loops 7, 6, 5, 4, 26, 12, 27, 28, 29, 30, 13, 14, and 15. Loop 7 is the southernmost loop, and the rest are in their spatial order north of loop 7. These loops are described in more detail in Appendix B. The date chosen was November 6, 1969, a dry day, between 1600 and 1800.

The volume increases noticably from loop 7 through loop 4, as Bloomington is approached from the south, and decreases from loop 26 through loop 15, as Bloomington is left by vehicles going north. Loop 4 shows a distinct skew to the

LOOP NUMBER 7

PLOT OF TRAFFIC FROM 16000 TO 18000 ON 11/12/69

COUNT	402	AVE. VEL.	53.42	ST. DEV.	6.54
85TH PERCENTILE	59	90TH PERCENTILE	62	PASSING COUNT	12
ZERO COUNT	12	MAXIMUM VEL.	74	MINIMUM VEL.	29
RANGE	45	MODE	54	MEDIAN	53

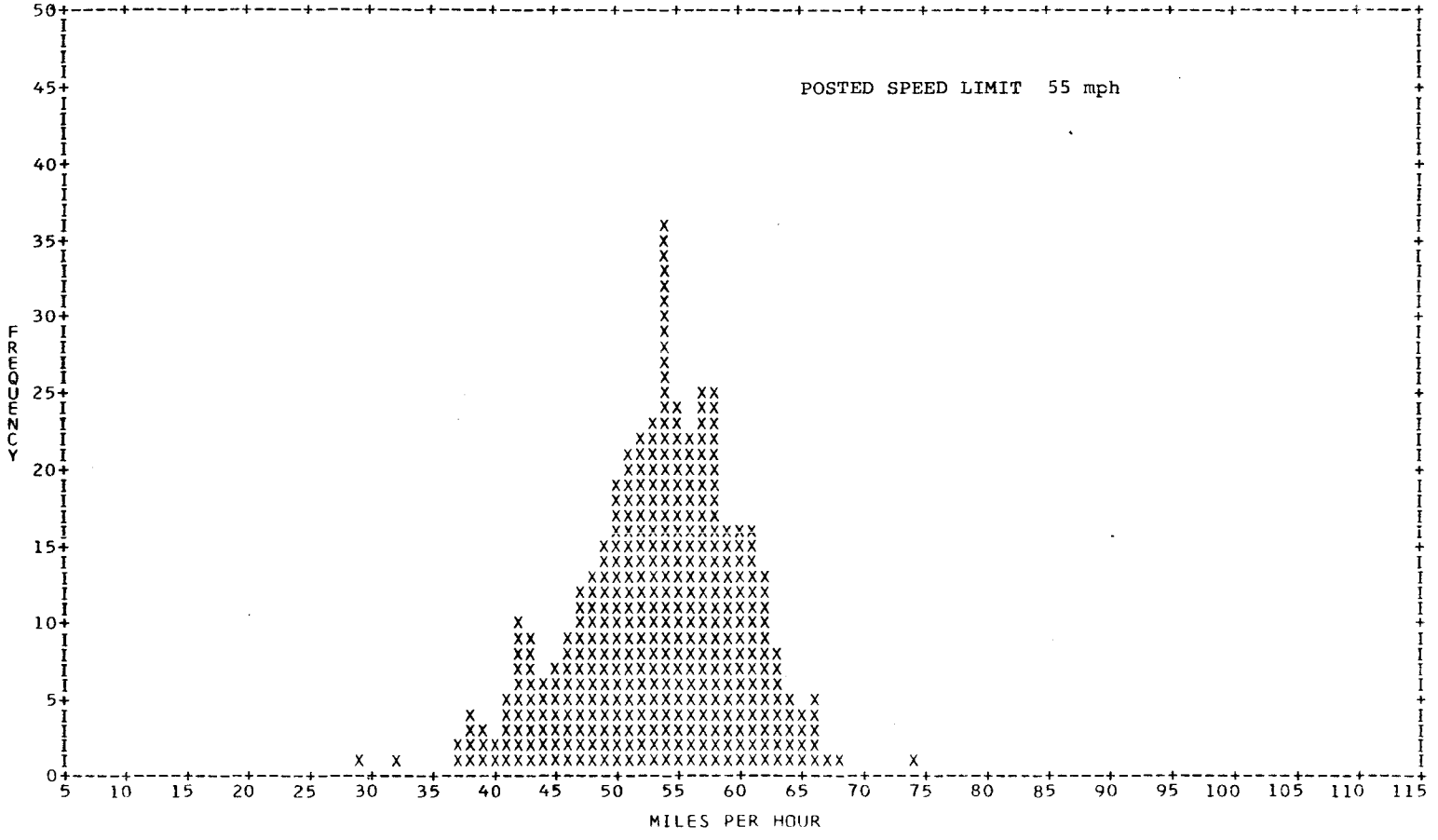


Figure E - 22

LOOP NUMBER 6

PLOT OF TRAFFIC FROM 16000 TO 18000 ON 11/12/69

COUNT	472	AVE. VEL.	52.04	ST. DEV.	7.87
85TH PERCENTILE	58	90TH PERCENTILE	61	PASSING COUNT	0
ZERO COUNT	0	MAXIMUM VEL.	81	MINIMUM VEL.	24
RANGE	57	MODE	56	MEDIAN	51

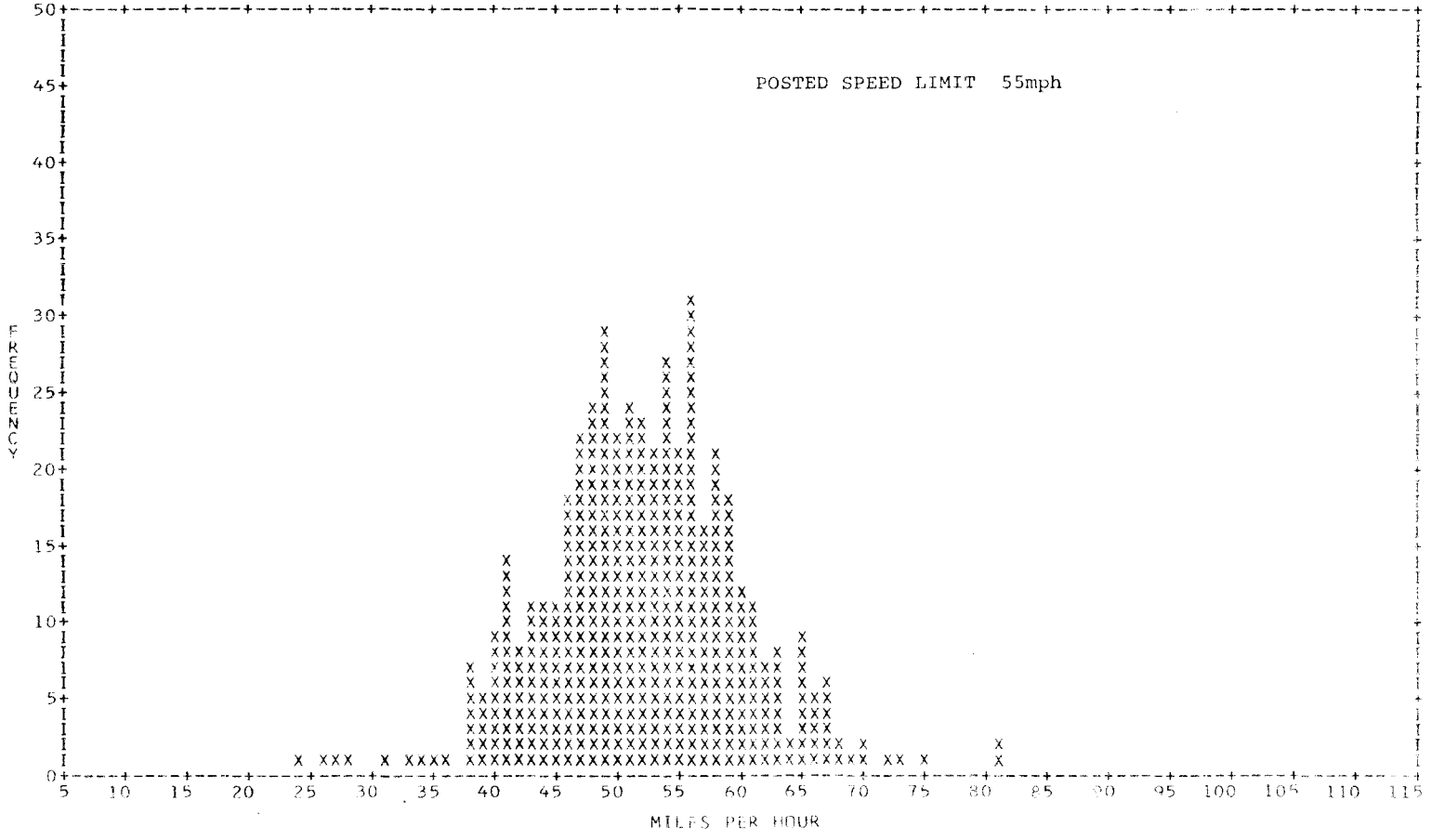


Figure E - 23

LOOP NUMBER 5

PLOT OF TRAFFIC FROM 16000 TO 18000 ON 11/12/69

COUNT	429	AVE. VEL.	46.89	ST. DEV.	6.51
85TH PERCENTILE	53	90TH PERCENTILE	55	PASSING COUNT	0
ZERO COUNT	1	MAXIMUM VEL.	65	MINIMUM VEL.	23
RANGE	42	MODE	50	MEDIAN	46

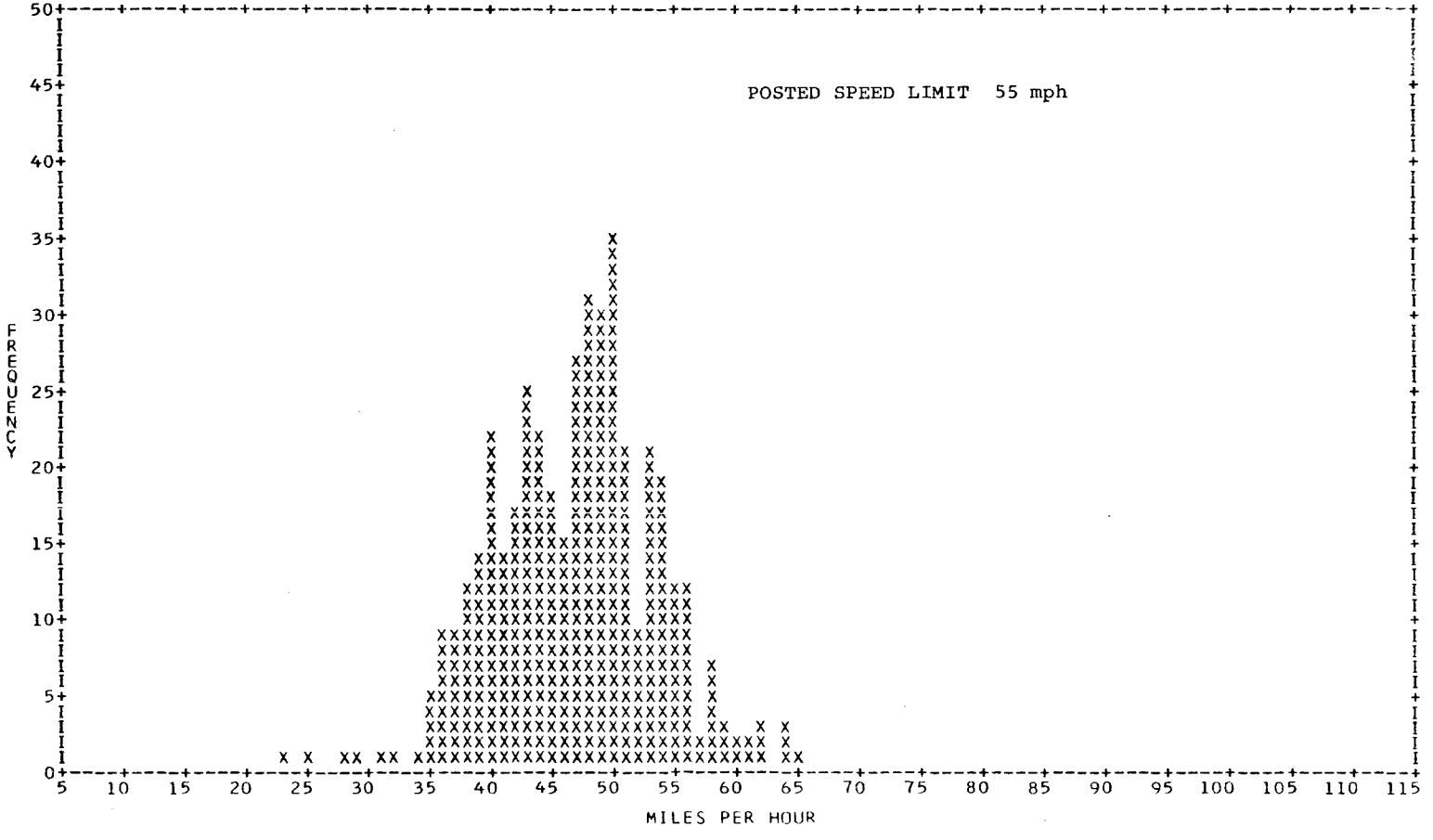


Figure E - 24

LOOP NUMBER 4

PLOT OF TRAFFIC FROM 16000 TO 18000 ON 11/12/69

COUNT	780	AVE. VEL.	38.42	ST. DEV.	8.19
85TH PERCENTILE	45	90TH PERCENTILE	47	PASSING COUNT	2
ZERO COUNT	8	MAXIMUM VEL.	55	MINIMUM VEL.	11
RANGE	44	MODE	41	MEDIAN	39

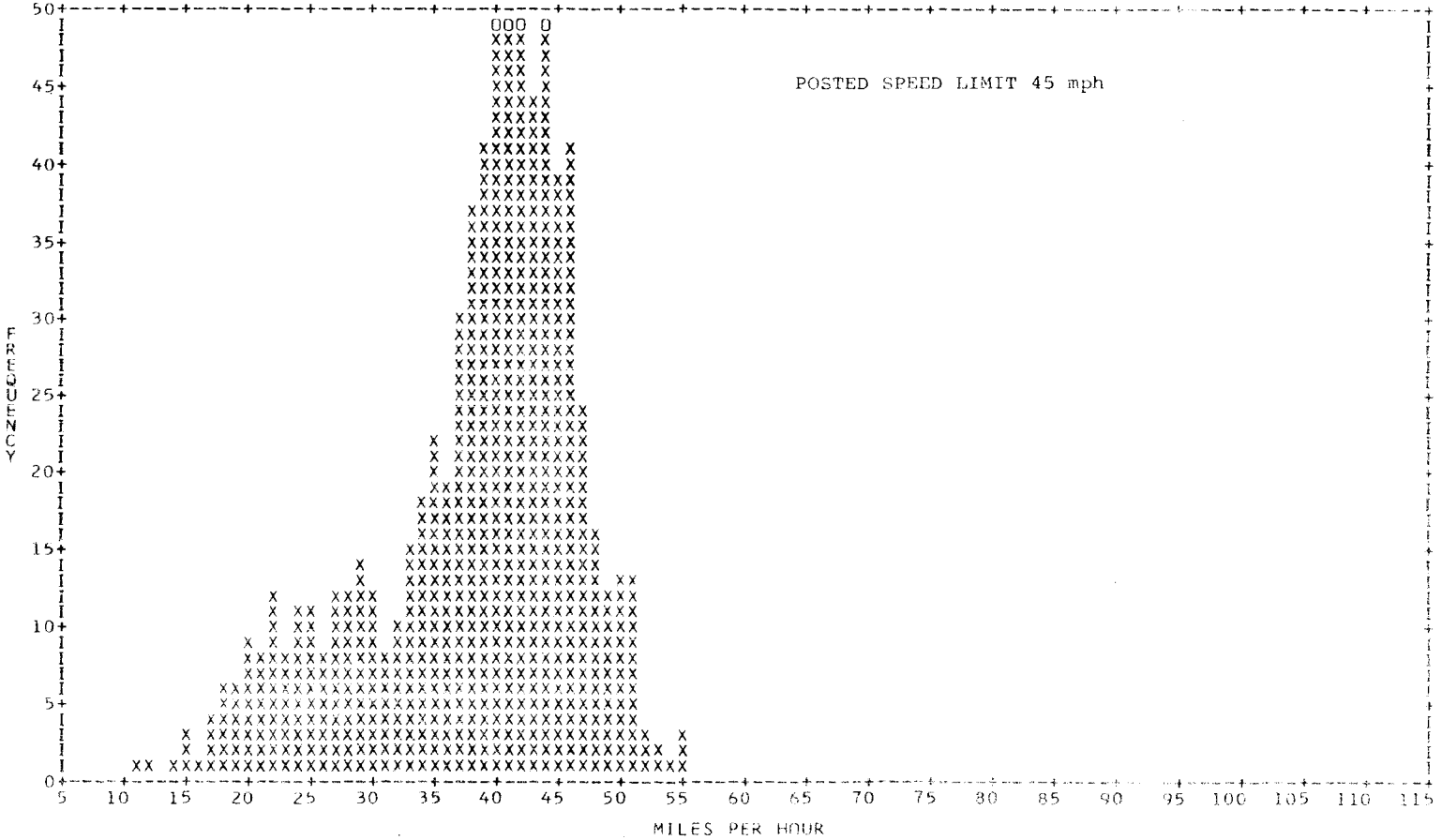


Figure F - 25

LOOP NUMBER 26

PLOT OF TRAFFIC FROM 16000 TO 18000 ON 11/12/69

COUNT	803	AVE. VEL.	58.00	ST. DEV.	5.91
85TH PERCENTILE	63	90TH PERCENTILE	65	PASSING COUNT	1
ZERO COUNT	10	MAXIMUM VEL.	97	MINIMUM VEL.	42
RANGE	55	MODE	58	MEDIAN	57

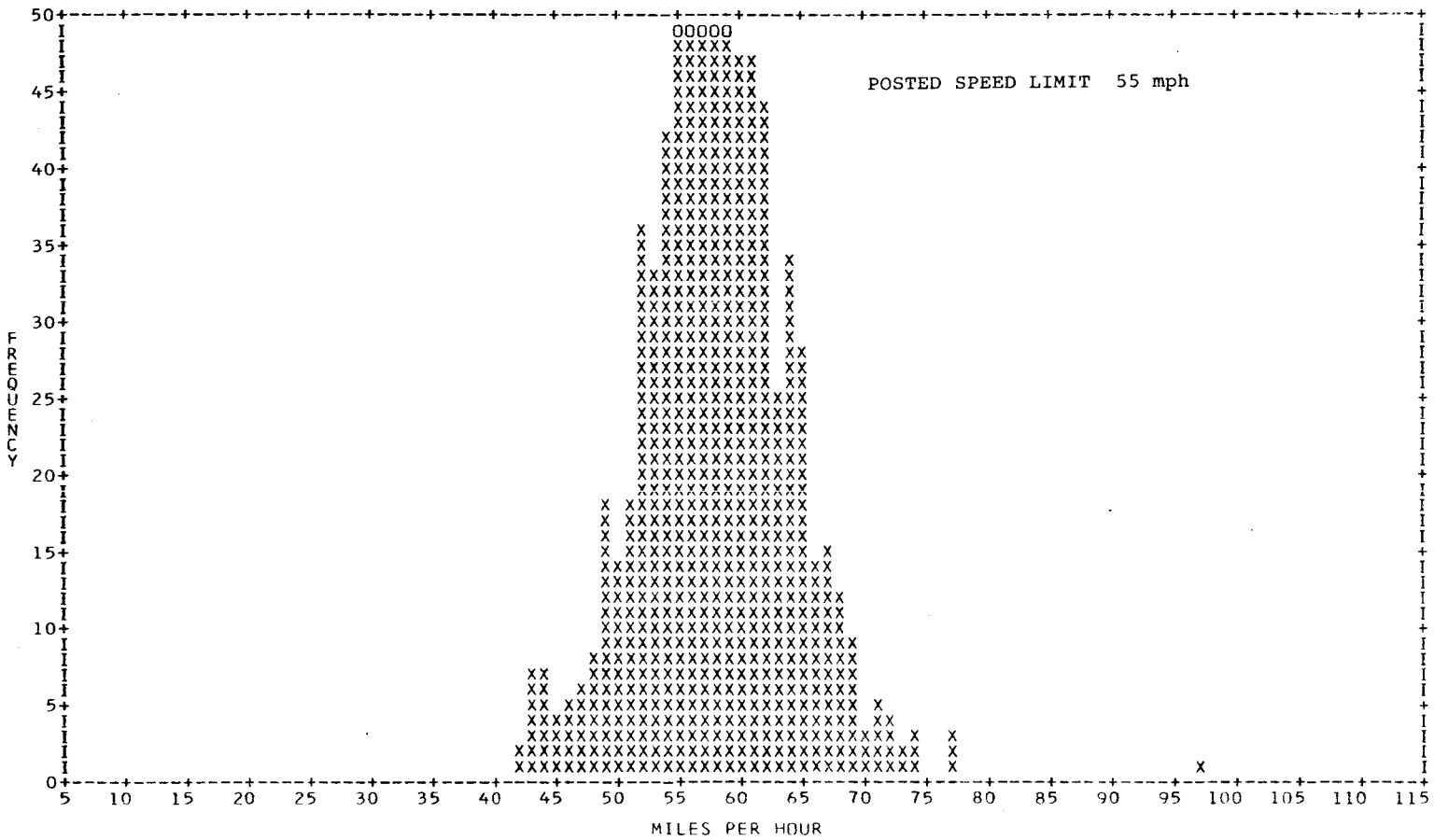
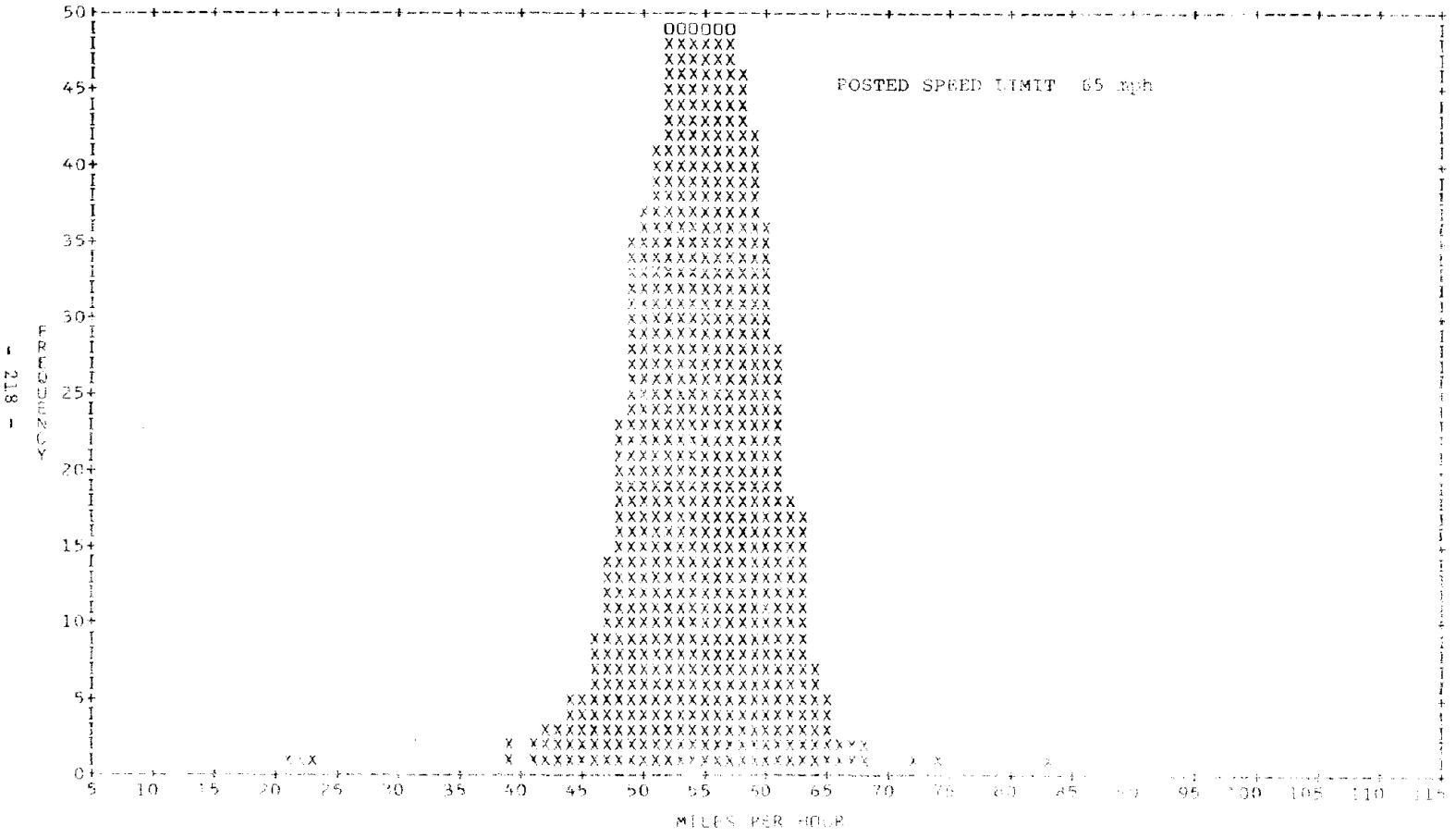


Figure E - 26

LOOP NUMBER 12

PLOT OF TRAFFIC FROM 16000 TO 18000 ON 11/12/69

COUNT	789	AVE. VEL.	54.70	ST. DEV.	5.18
85TH PERCENTILE	59	90TH PERCENTILE	61	PASSING COUNT	2
ZERO COUNT	6	MAXIMUM VEL.	83	MINIMUM VEL.	21
RANGE	62	MODE	56	MEDIAN	54



LOOP NUMBER 27

PLOT OF TRAFFIC FROM 16000 TO 18000 ON 11/12/69

COUNT	795	AVE. VEL.	66.12	ST. DEV.	7.91
85TH PERCENTILE	72	90TH PERCENTILE	76	PASSING COUNT	3
ZERO COUNT	18	MAXIMUM VEL.	114	MINIMUM VEL.	46
RANGE	68	MODE	68	MEDIAN	65

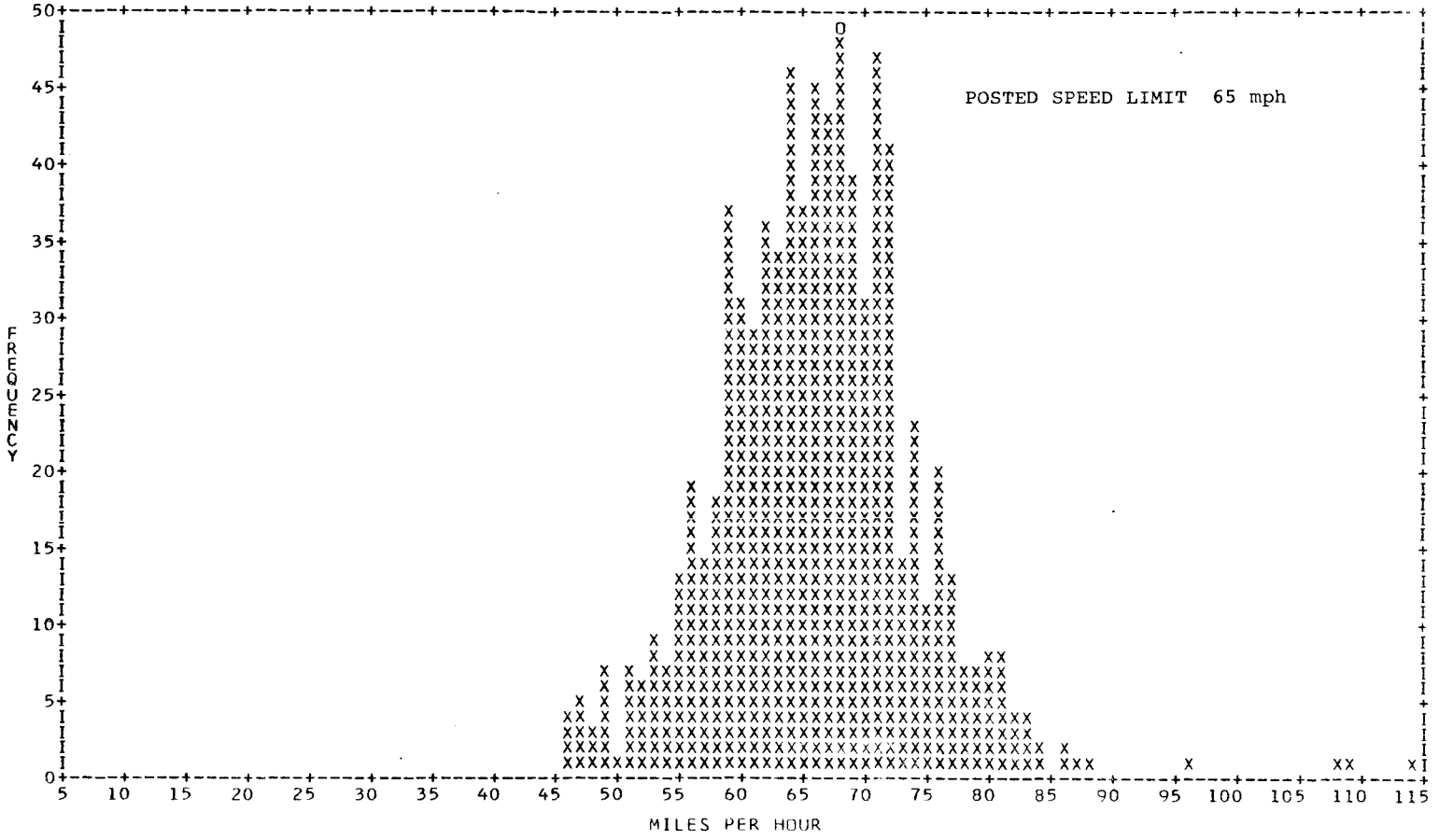


Figure E - 28

LOOP NUMBER 28

PLOT OF TRAFFIC FROM 16000 TO 18000 ON 11/12/69

COUNT	777	AVE. VEL.	58.76	ST. DEV.	7.56
85TH PERCENTILE	64	90TH PERCENTILE	68	PASSING COUNT	3
ZERO COUNT	15	MAXIMUM VEL.	108	MINIMUM VEL.	35
RANGE	73	MODE	59	MEDIAN	58

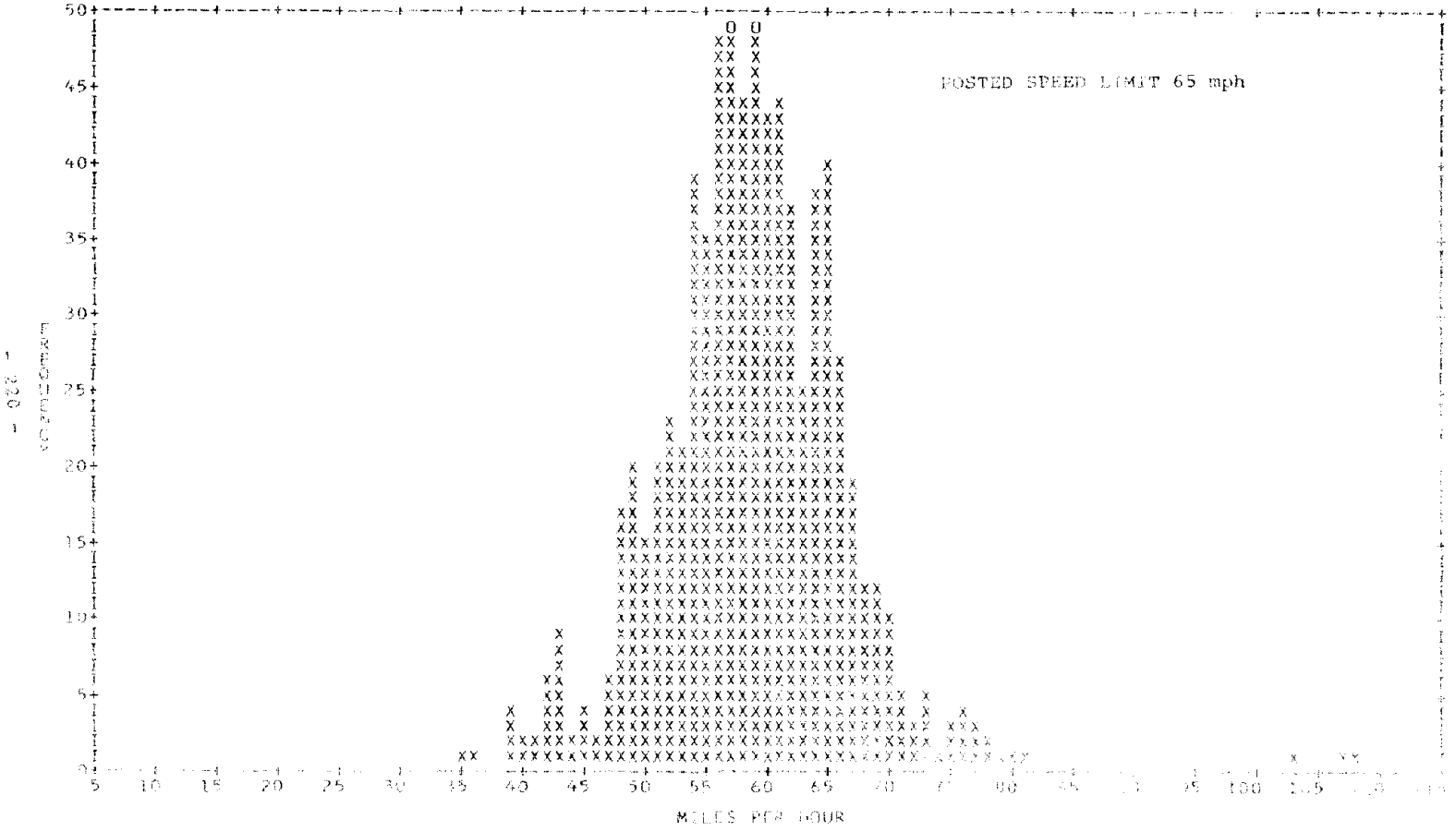


Figure [illegible]

LOOP NUMBER 29

PLOT OF TRAFFIC FROM 16000 TO 18000 ON 11/12/69

COUNT	786	AVE. VEL.	60.86	ST. DEV.	7.49
85TH PERCENTILE	66	90TH PERCENTILE	70	PASSING COUNT	3
ZERO COUNT	9	MAXIMUM VEL.	100	MINIMUM VEL.	40
RANGE	60	MODE	61	MEDIAN	60

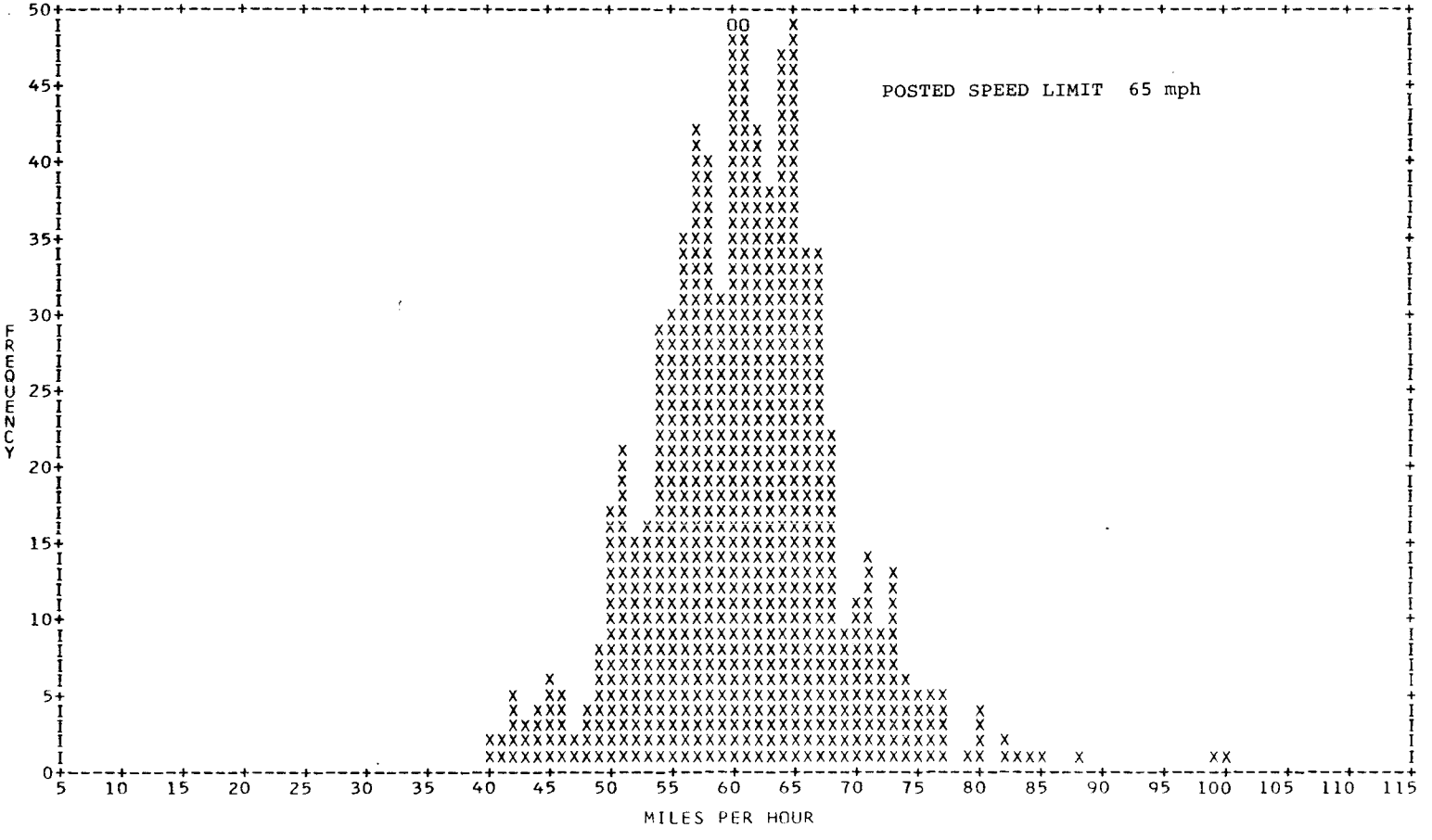


Figure E - 30

LOOP NUMBER 30

PLOT OF TRAFFIC FROM 16000 TO 18000 ON 11/12/69

COUNT	794	AVE. VEL.	61.78	ST. DEV.	6.86
85TH PERCENTILE	67	90TH PERCENTILE	70	PASSING COUNT	4
ZERO COUNT	10	MAXIMUM VEL.	89	MINIMUM VEL.	27
RANGE	62	MODE	64	MEDIAN	62

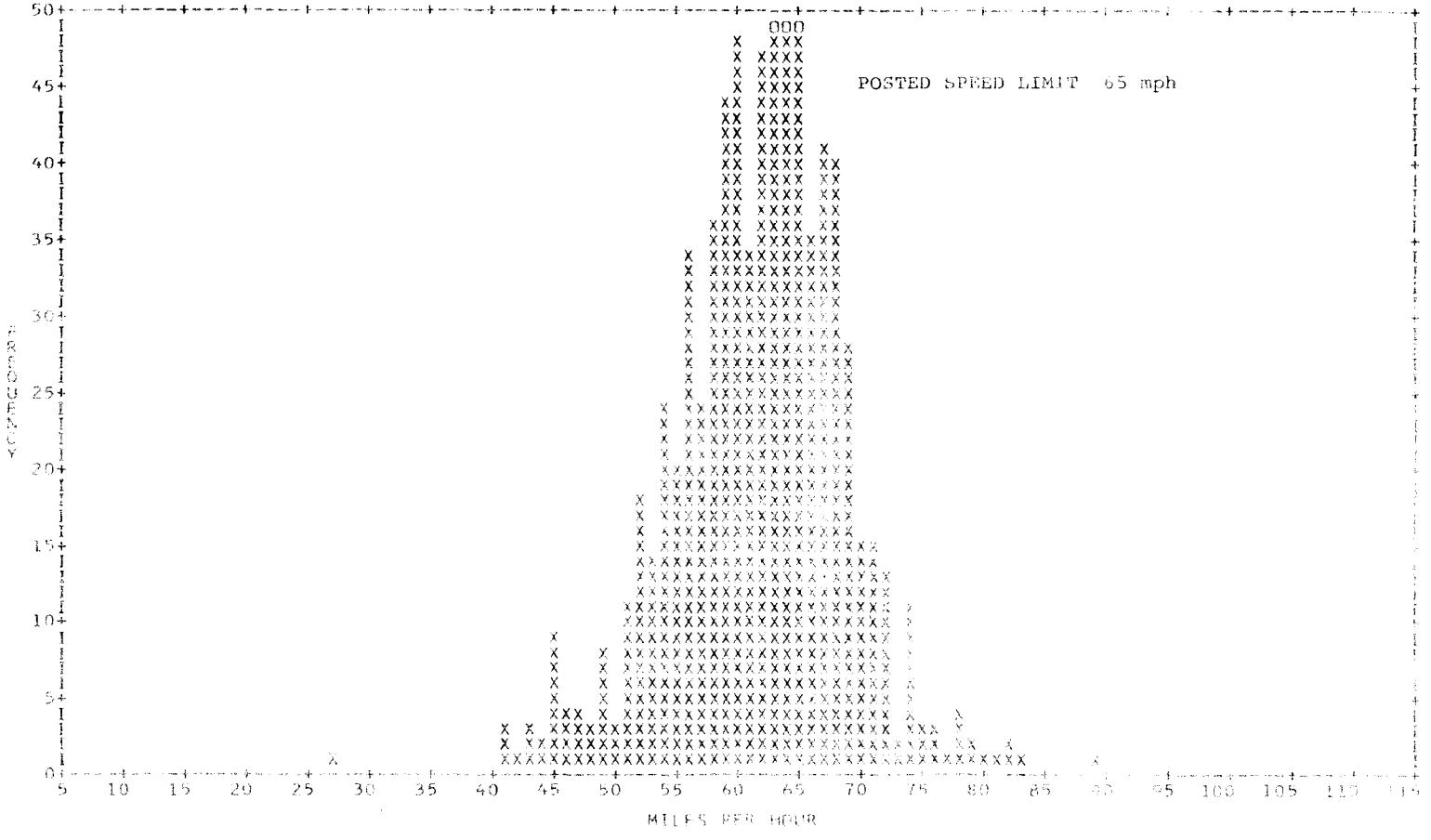
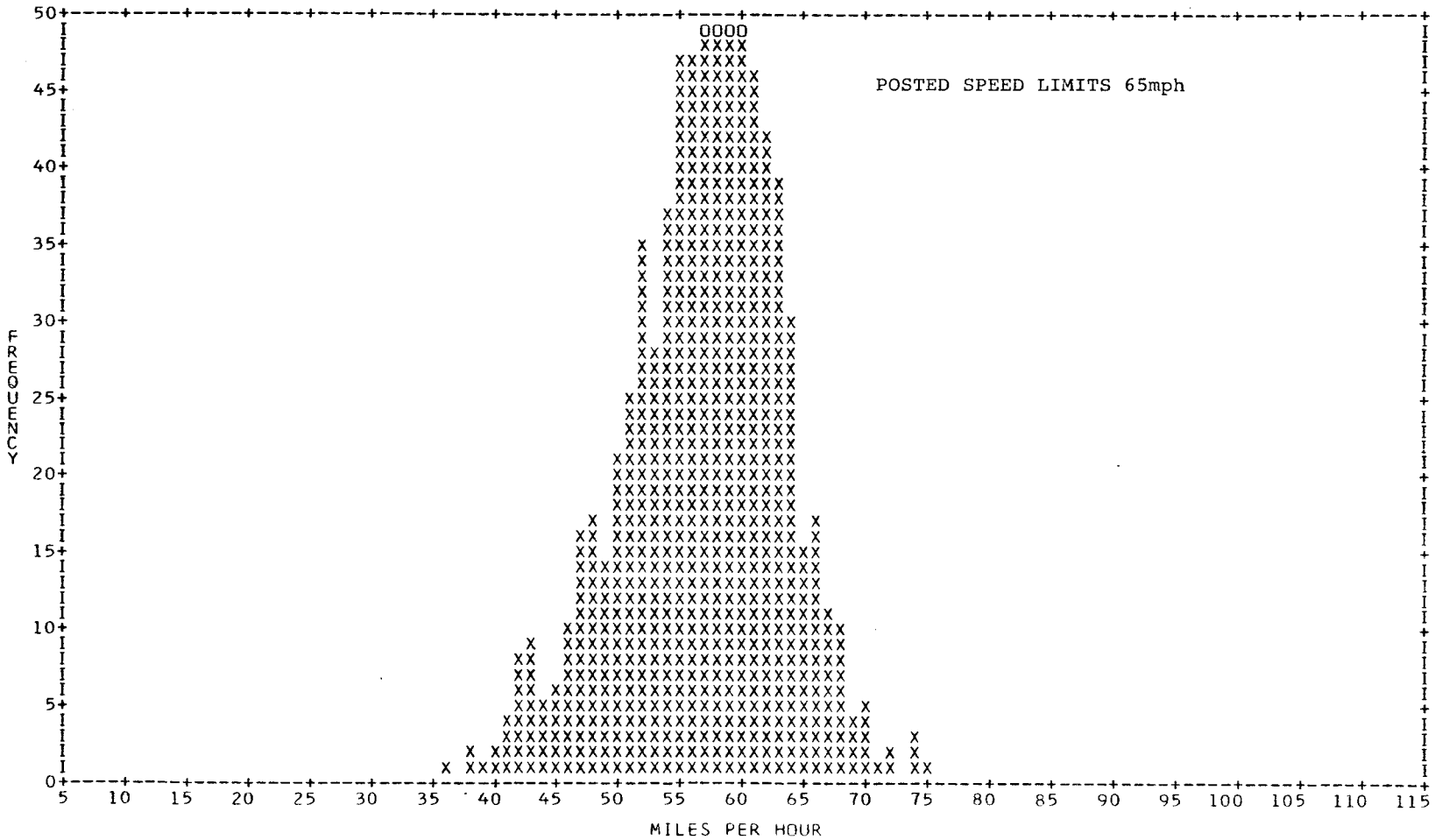


Figure E - 31

LOOP NUMBER 13

PLOT OF TRAFFIC FROM 16000 TO 18000 ON 11/12/69

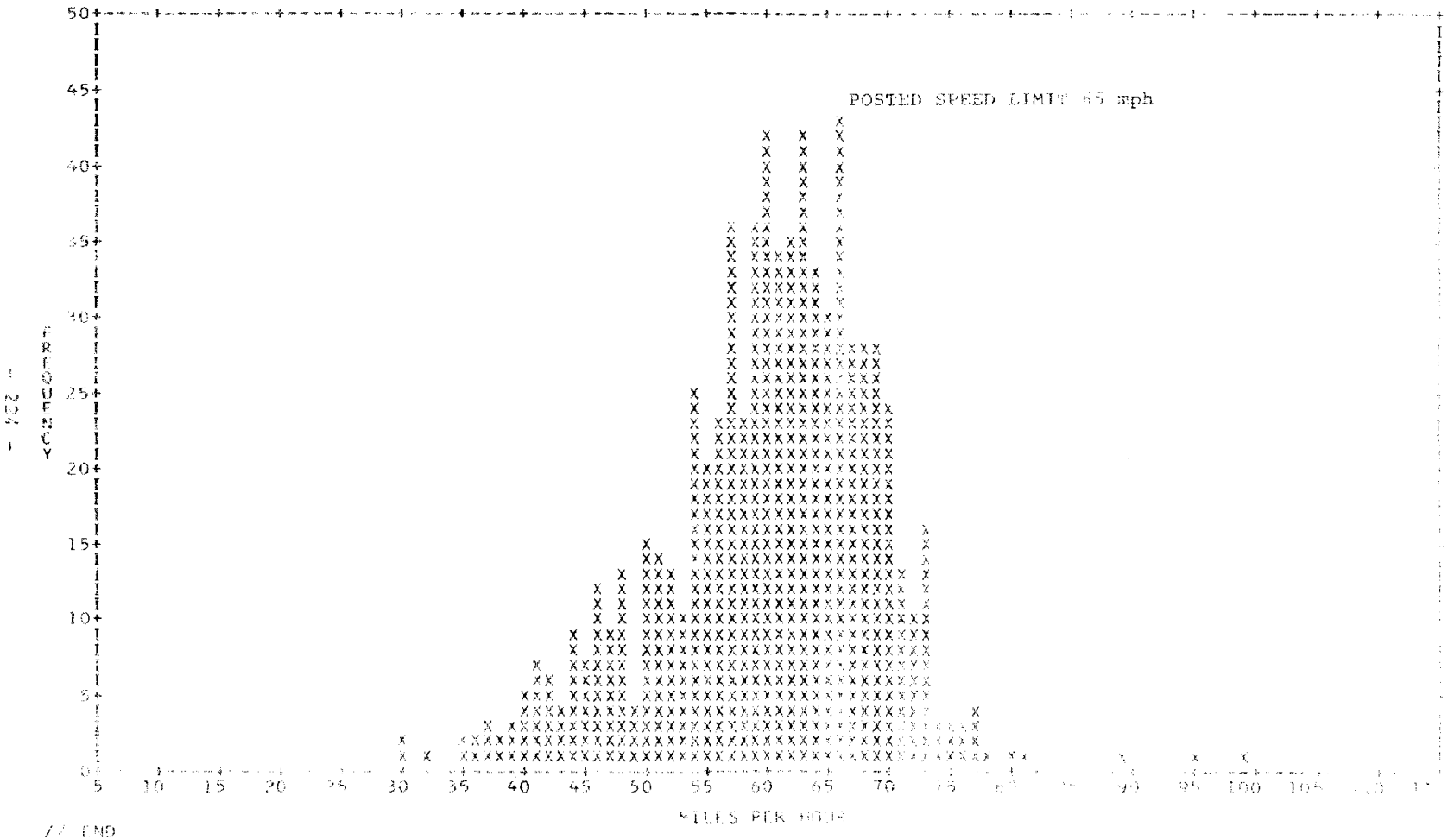
COUNT	803	AVE. VEL.	57.00	ST. DEV.	6.18
85TH PERCENTILE	62	90TH PERCENTILE	64	PASSING COUNT	0
ZERO COUNT	1	MAXIMUM VEL.	75	MINIMUM VEL.	36
RANGE	39	MODE	60	MEDIAN	57



LOOP NUMBER 14

PLOT OF TRAFFIC FROM 16000 TO 18000 ON 11/12/69

COUNT	731	AVE. VEL.	60.04	ST. DEV.	8.87
85TH PERCENTILE	68	90TH PERCENTILE	70	PASSING COUNT	0
ZERO COUNT	1	MAXIMUM VEL.	99	MINIMUM VEL.	30
RANGE	69	MODE	66	MEDIAN	60

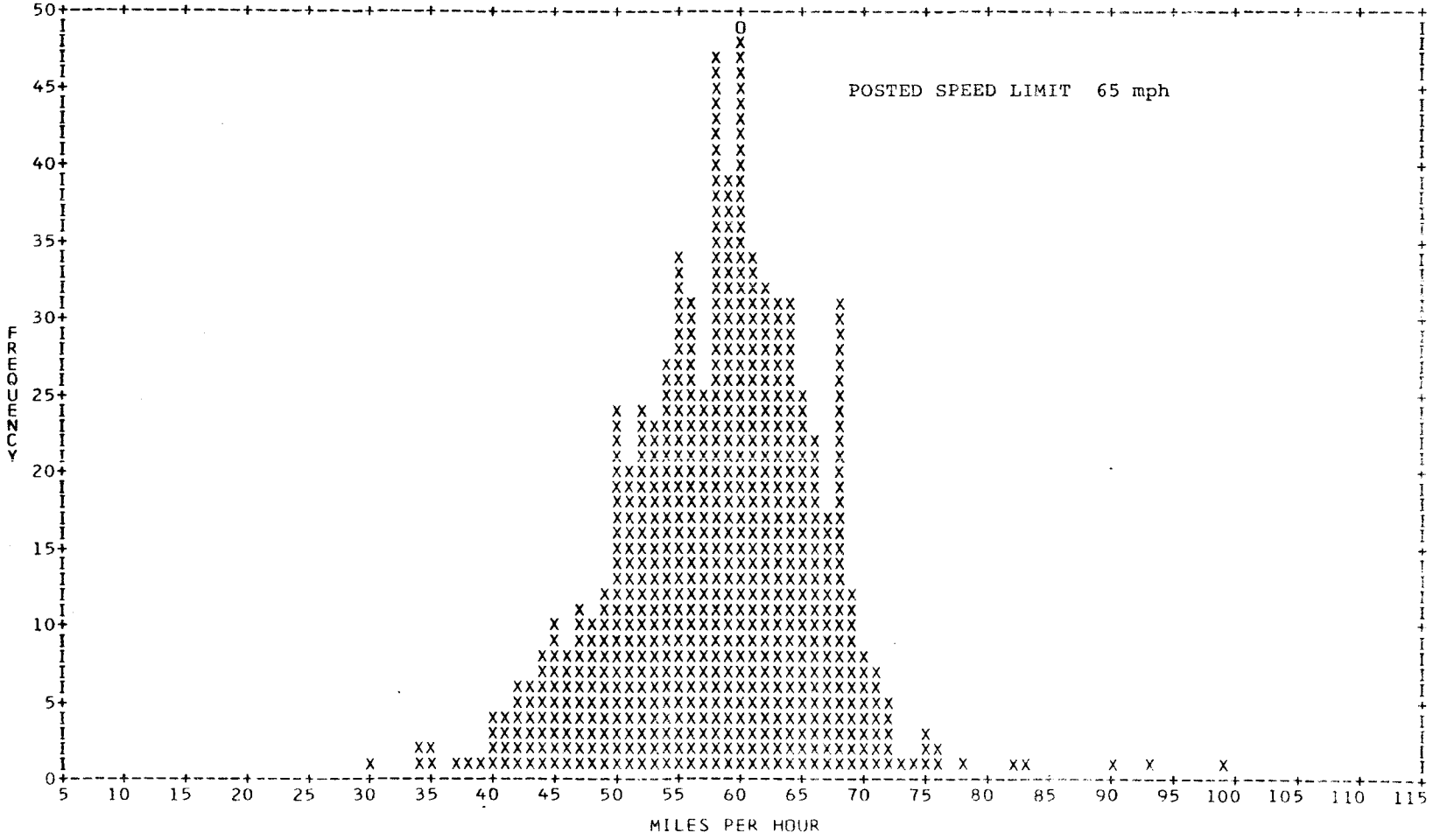


// END

LOOP NUMBER 15

PLOT OF TRAFFIC FROM 16000 TO 18000 ON 11/12/69

COUNT	709	AVE. VEL.	58.23	ST. DEV.	7.91
85TH PERCENTILE	65	90TH PERCENTILE	68	PASSING COUNT	5
ZERO COUNT	16	MAXIMUM VEL.	99	MINIMUM VEL.	30
RANGE	69	MODE	60	MEDIAN	58



left, due in part to an intersection fifty feet from loop 5. With the exception of loop 4, the distribution of traffic speeds conforms remarkably well to a normal distribution.

4.0 ADDITIONAL EFFECTS

The computer sensor system enables a detailed examination of the effects of many factors on the speed distributions. The specific effects demonstrated in Figures E-35 through E-40 are those of an intersection, some bridge repair, and a fatal accident.

4.1 Effect of an Intersection

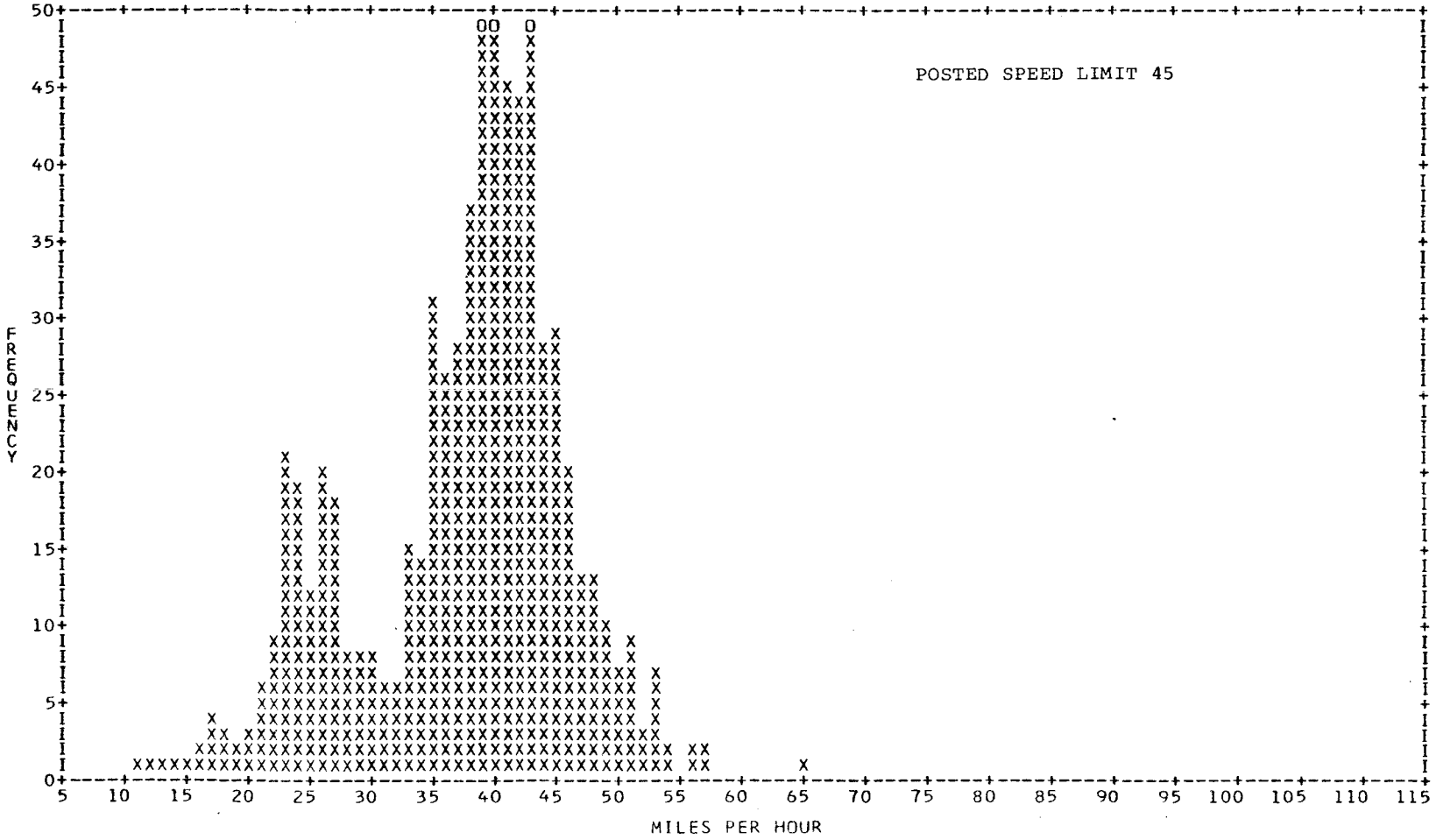
Figures E-35 and E-36 show the speed distributions on February 26, 1970 for loop sites 7 and 8. These loops are both located in a 45 mph zone, on a blacktop section of Highway 37 immediately south of Bloomington, with loop 7 measuring the southbound traffic and loop 8, the northbound traffic. This loop pair is approximately 50 feet north of an intersection with a heavily travelled stop street. For southbound traffic, there is a negative slope of -5.2%. This is a main artery leading into Bloomington, and some rather high rush hour traffic may be experienced (900+/hour).

Both figures show a bimodal speed distribution, the lower mode presumably corresponding to the speeds of those drivers who are turning or are behind those who are turning, the upper mode corresponding to the speeds of the other drivers.

LOOP NUMBER 0

PLOT OF TRAFFIC FROM 13500 TO 15500 ON 2/26/70

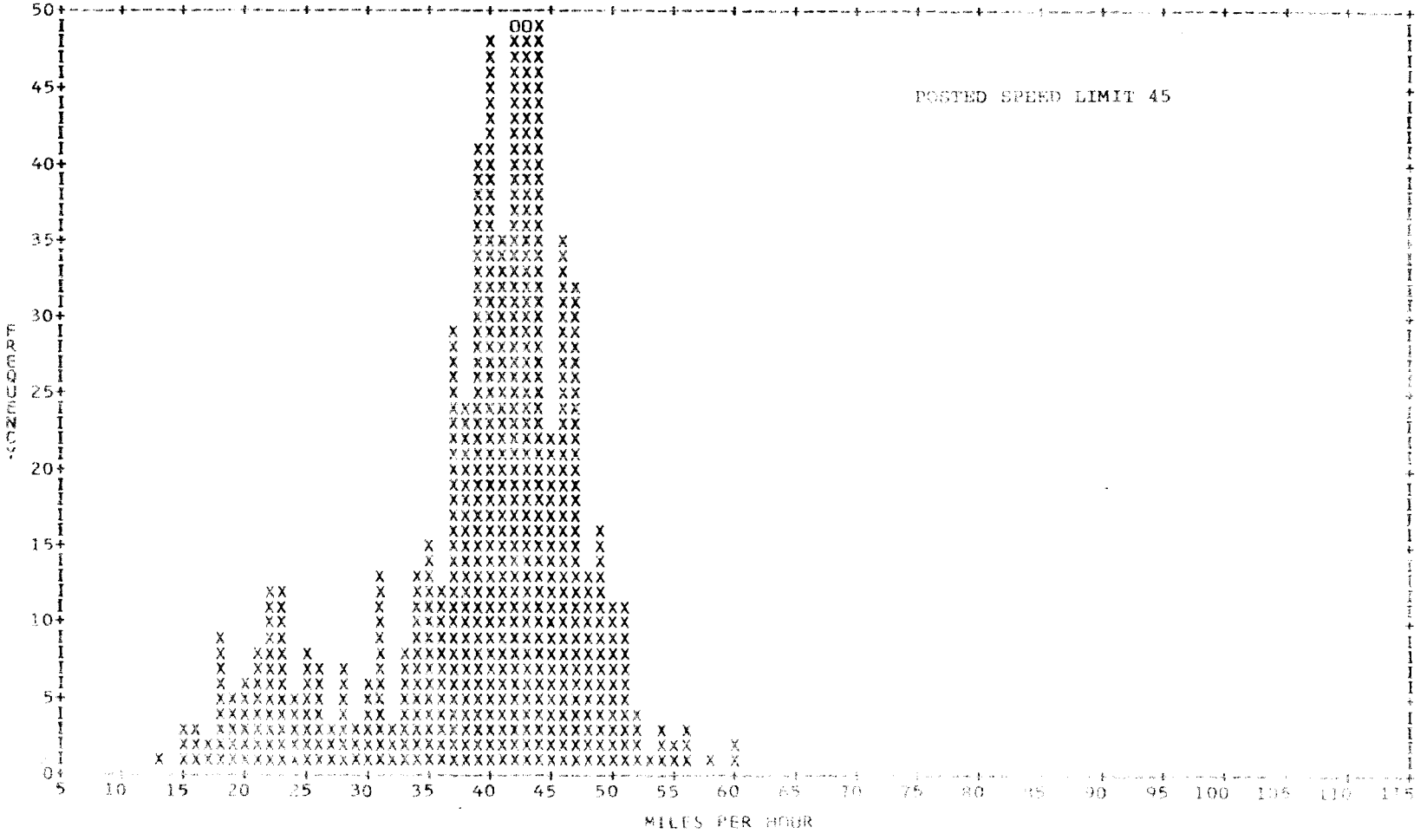
COUNT	702	AVE. VEL.	37.52	ST. DEV.	8.34
85TH PERCENTILE	44	90TH PERCENTILE	46	PASSING COUNT	2
ZERO COUNT	2	MAXIMUM VEL.	65	MINIMUM VEL.	11
RANGE	54	MODE	39	MEDIAN	38



LOOP NUMBER 4

PLOT OF TRAFFIC FROM 13500 TO 15500 ON 2/26/70

COUNT	653	AVE. VEL.	39.16	ST. DEV.	8.50
85TH PERCENTILE	46	90TH PERCENTILE	48	PASSING COUNT	4
ZERO COUNT	13	MAXIMUM VEL.	60	MINIMUM VEL.	13
RANGE	47	MODE	42	MEDIAN	40



4.2 Effect of an Accident

Figures E-39 and E-40 demonstrate the effect of a fatal accident on speed distributions. Figure E-39 shows the speed distribution at loop 12 on March 20, 1970, a rather normal Friday afternoon, for the time interval 1430-1530. At 1345 on March 27, 1970 an automobile accident occurred five miles north of this loop. One person was killed and nine injured, and there was a considerable traffic jam along the road. The effects of this accident are shown in Figure E-40. The time covered in Figure E-40 includes the time when traffic was stopped as well as that when the traffic was beginning to move more normally. The traffic jam and the subsequent speed increase both show up clearly.

4.3 Effect of Highway Maintenance

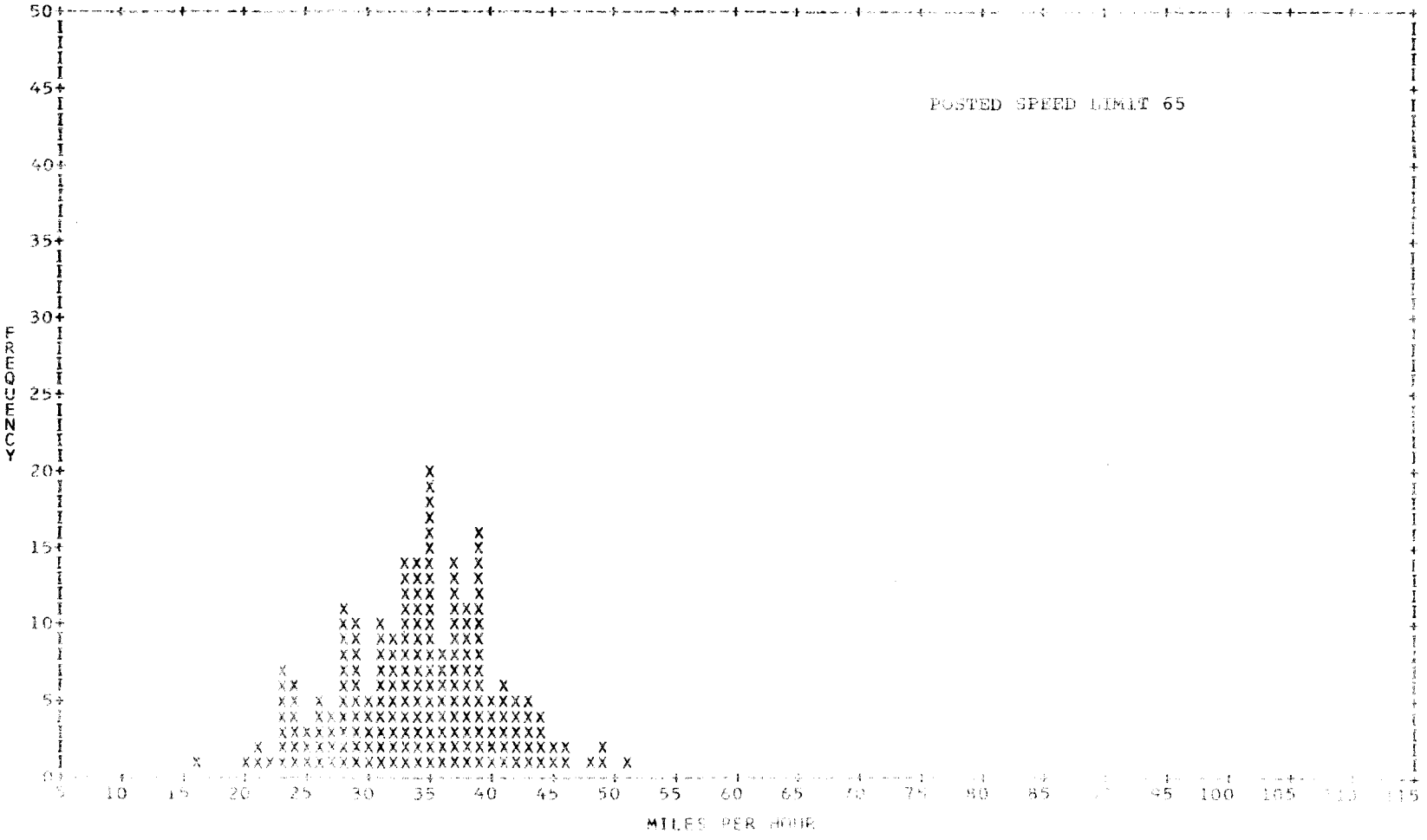
Figures E-37 and E-38 show the effects of a road obstruction - in this case painting on a bridge with a flagman present. Figure E-37 shows the distribution of speeds of southbound traffic immediately south of the bridge; figure E-38 shows the distribution of speeds of northbound traffic immediately south of the bridge.

As expected, the traffic coming off the bridge is going slowly (the speed limit here is 65mph) and somewhat irregularly, whereas that going northward shows two distinct peaks, one peak presumably corresponding to those vehicles who were slowed appreciably by the flagman, the other corresponding to those who were waved on through without much hesitation.

LOOP NUMBER 9

PLOT OF TRAFFIC FROM 8380 TO 9360 ON 8/27/70

COUNT	205	AVE. VEL.	34.02	ST. DEV.	6.20
85TH PERCENTILE	39	90TH PERCENTILE	128	PASSING COUNT	0
ZERO COUNT	56	MAXIMUM VEL.	51	MINIMUM VEL.	16
RANGE	35	MODE	35	MEDIAN	33

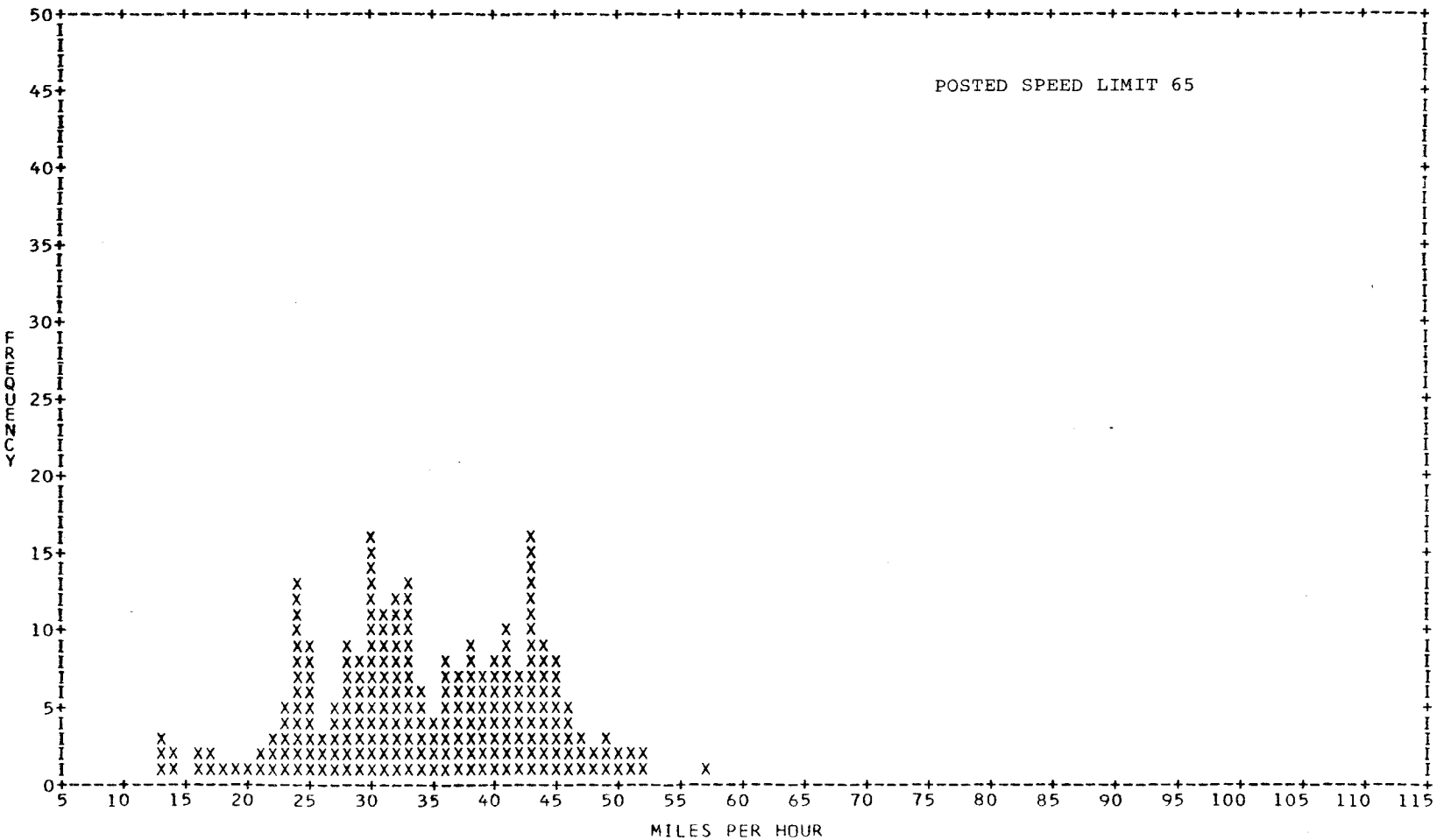


LOOP NUMBER 24

13

PLOT OF TRAFFIC FROM 8380 TO 9360 ON 8/27/70

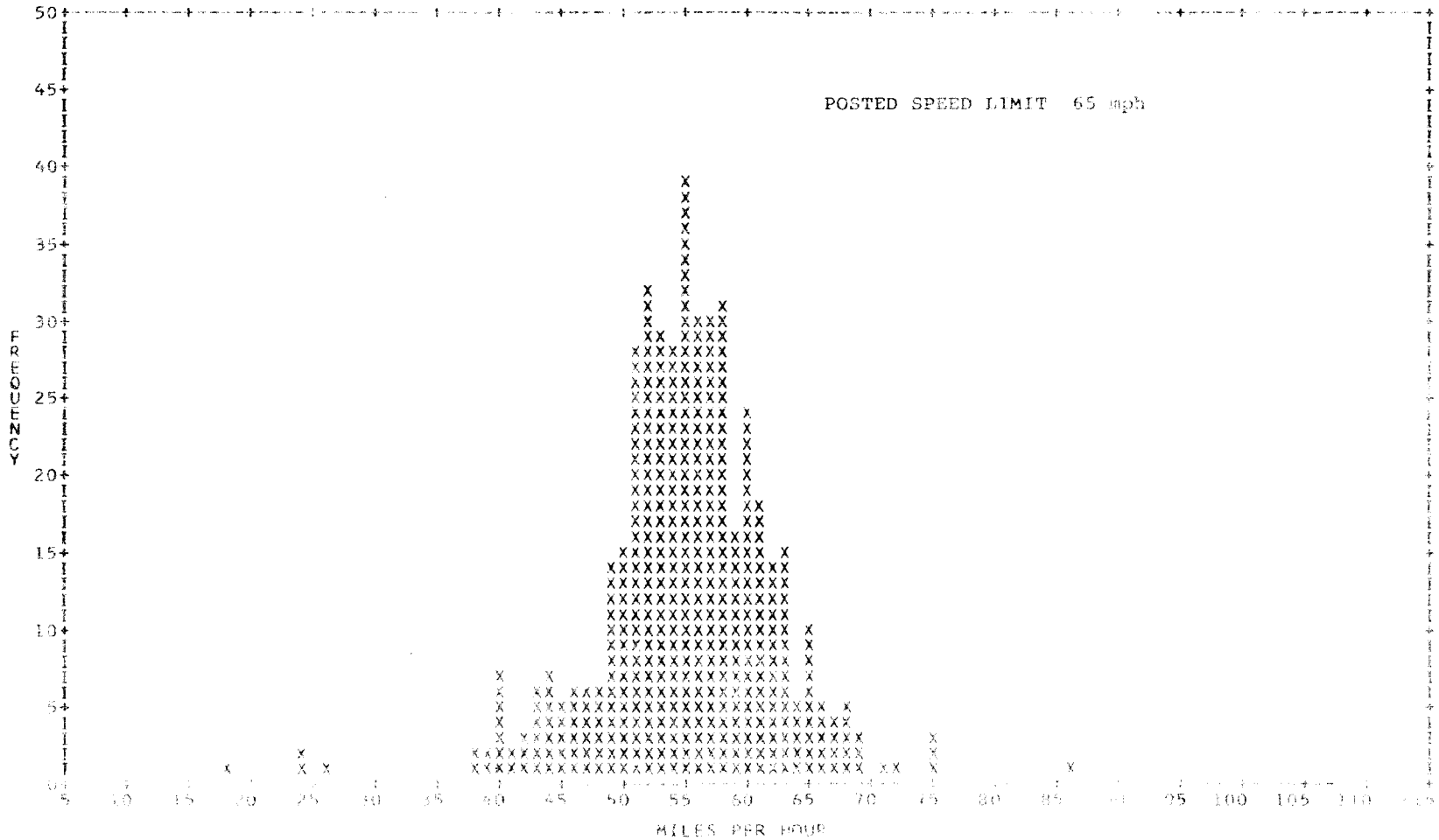
COUNT	240	AVE. VEL.	34.30	ST. DEV.	8.69
85TH PERCENTILE	43	90TH PERCENTILE	45	PASSING COUNT	0
ZERO COUNT	2	MAXIMUM VEL.	57	MINIMUM VEL.	13
RANGE	44	MODE	30	MEDIAN	32



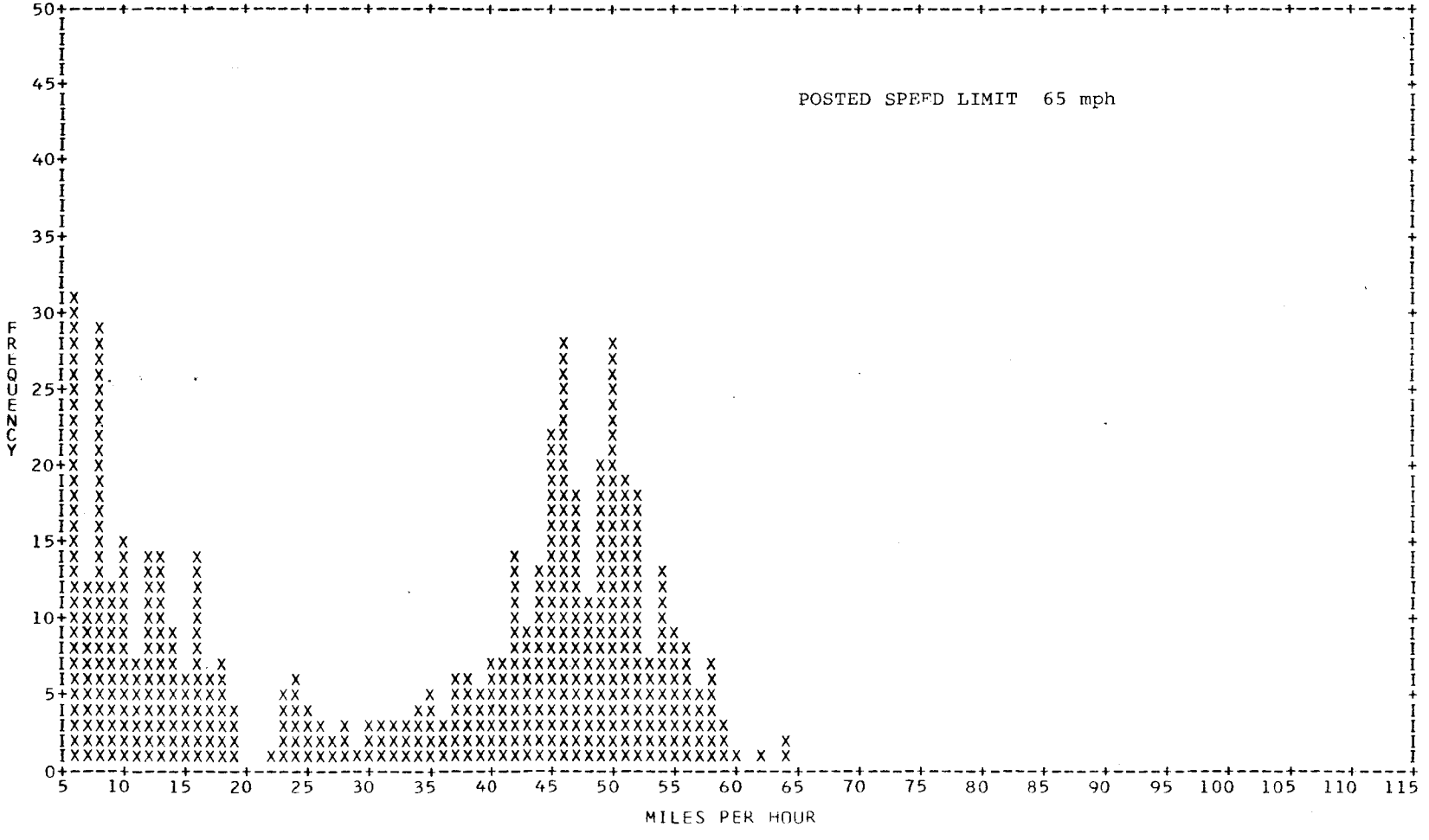
LOOP NUMBER 12

PLOT OF TRAFFIC FROM 14500 TO 15500 ON 3/20/70

COUNT	457	AVE. VEL.	55.02	ST. DEV.	7.11
85TH PERCENTILE	60	90TH PERCENTILE	63	PASSING COUNT	0
ZERO COUNT	3	MAXIMUM VEL.	86	MINIMUM VEL.	18
RANGE	68	MODE	55	MEDIAN	54



LOOP NUMBER 12

PLOT OF TRAFFIC FROM 14500 TO 15500 ON 3/27/70

COUNT	516	AVE. VEL.	33.24	ST. DEV.	18.14
85TH PERCENTILE	50	90TH PERCENTILE	54	PASSING COUNT	11
ZERO COUNT	40	MAXIMUM VEL.	64	MINIMUM VEL.	2
RANGE	62	MODE	6	MEDIAN	37