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AN EVALUATION OF DRIVER BEHAVIOR AT SIGNALIZED INTERSECTIONS

Final Report

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16. Abstract

Time-lapse photography was used to study driver behavior associated with the traffic signal clearance interval at a total of six intersections in the Phoenix and Tucson metropolitan areas. In addition, nighttime studies were conducted at two of these intersections. An evaluation of the time-lapse film permitted the determination of the approach speeds of the vehicles, the average deceleration rates of the stopping vehicles, the perception-reaction times of the drivers of the stopping vehicles, and the distance that the vehicle was from the intersection at the onset of the yellow interval. The distance from the intersection was measured for both the stopping vehicles as well as those that proceeded through the intersection.

The results of the study indicated that the mean deceleration rates at the six sites ranged from 7.0 to 13.9 feet per second per second, and the mean value for all observations was 11.6 feet per second per second. The observed mean perception-reaction time was approximately 1.3 seconds while the 85-percentile times ranged from 1.5 to 2.1 seconds. Comparisons of intersections with yellow only versus yellow plus all-red intervals produced mixed results in terms of differences in observed behavior. Even for intersections with the same clearance interval design, there were cases where the observed deceleration rates were significantly different.

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AN EVALUATION OF DRIVER BEHAVIOR AT SIGNALIZED INTERSECTIONS

TABLE OF CONTENTS

AN EVALUATION OF DRIVER BEHAVIOR AT SIGNALIZED INTERSECTIONS

LIST OF FIGURES

AN EVALUATION OF DRIVER BEHAVIOR AT SIGNALIZED INTERSECTIONS

LIST OF TABLES

SI UNIT CONVERSION FACTORS

The material contained in this report is presented in terms of English units. The following factors may be used to convert the measures used in this report to the International System of Units (SI):

1 mile per hour (mph) = 1.6093 kilometer per hour (kph)

1 kph = 0.6214 mph

1 foot = 0.3048 meter

1 meter = 3.2808 feet

1 foot per second per second = 0.3048 meter per second per second

1 meter per second per second = 3.2808 feet per second per second

AN EVALUATION OF DRIVER BEHAVIOR AT SIGNALIZED INTERSECTIONS

INTRODUCTION

Accidents at signalized intersections continue to represent a major highway safety problem in Arizona even though the intersections comprise a small portion of the total highway system. The magnitude of the problem is reflected by the fact that approximately 20 percent of all reported accidents occur at intersections.

It can be anticipated that accident rates at intersections generally would be higher than elsewhere on the roadway because of increases in (a) opportunities for vehicle conflict, (b) the necessity for driver decisions, and (c) the complexity of the driving task. Because of the role of the driver, one of the key elements in the design and operation of signalized intersections is driver behavior. The failure to properly recognize and understand driver behavior in signalized intersection design can contribute to safety problems. A review of 1980 traffic accidents in Arizona reveals that approximately three percent of the reported accidents had disregard of a traffic signal listed as a contributing circumstance (1). This would indicate that there are certain aspects of driver behavior that are not fully understood.

The recognition of driver behavior is particularly critical in the design of the traffic signal clearance or change interval. The clearance interval has two recognized purposes. The first is to advise the motorist that the red interval is about to commence; and the second is to allow vehicles that have legally entered the intersection sufficient time to clear the point of conflict prior to the release of opposing pedestrians or vehicles.

The determination of the clearance interval considers driver perception-reaction time and vehicle deceleration rates; and the use of unrealistic values for these factors would potentially affect driver compliance, safety, and even possible intersection capacity.

The current edition of the Transportation and Traffic Engineering Handbook (2) contains the following description for the determination of the clearance interval which is based on their work:

> "A driver at distance x from the intersection is in the most critical position. This driver can proceed into the intersection if the clearance time is at least:
>
> $$T_{min} = \frac{x}{v} = t + \frac{v}{2a}$$
>
> or through the intersection if the clearance time is at least:
>
> $$T_{min} = \frac{x + w + L}{v} = t + \frac{v}{2a} + \frac{w + L}{v}$$
>
> where T_{min} = the minimum clearance interval (in s)
>
> w = the width of the intersection (in ft or m)
>
> L = the length of the vehicle (in ft or m)
>
> x = the distance required for stopping (in ft or m)
>
> t = the perception-reaction time (in s)
>
> v = approach speed (in ft/s or m/s)
>
> a = deceleration rate (in ft/s^2 or m/s^2)"

The Handbook assumes a perception-reaction time of one second and a deceleration rate of 10 feet per second per second. The latter value has been decreased in the recent edition of the Handbook from 15 feet per second per second which was used in practice for a number of years. In this determination of the duration of the clearance interval, it should be noted that there is no direct consideration of situations where the intersection approach is on a grade.

The current Arizona Department of Transportation policy (3) indicates that 8 and 12 feet per second per second are the upper and lower limits for deceleration rates which are used in establishing the clerance interval duration. This range provides some degree of latitude in applying engineering judgment to the determination of the change interval; however, the policy further states that 10 feet per second per second should normally be used.

In recent years, several studies have focused on driver behavior during the yellow signal interval. For example, Williams (4) reported that a study of an intersection in New Haven, Connecticut, revealed that the average maximum deceleration rate for stopping vehicles was 9.7 feet per second per second. Other studies (5, 6) have suggested that a reasonable deceleration rate would be in the magnitude of 10 feet per second per second.

Two previous studies included field measurements of driver reaction time. In an early study of the change interval problem, Gazis, Herman and Maradudin (7) found a mean reaction time of 1.14 seconds based on a sample of 87 observations. A study in 1966 by Jenkins (8) contained a sample of 21 observations of reaction time. An analysis of the data sample obtained by Jenkins reveals that the mean reaction time was approximately 1.4 seconds.

The Handbook (2) states that excessively short or long intervals are undesirable; thus, the common practice is to use yellow intervals of three to five seconds. If a longer duration is required for the nondilemma yellow interval, an all-red period can be used in addition to the selected yellow interval. The Arizona Department of Transportation policy (3) indicates that a yellow interval of up to six seconds may be used. If a longer clearance interval is required, then an all-red interval should be used.

With respect to the operation of a vehicle in Arizona during the clearance interval, it is legal for the vehicle to enter the intersection during the yellow signal indication. The current statutes address when the vehicle may enter the intersection; thus, it is not necessary for the vehicle to have cleared the intersection prior to the onset of the red signal indication.

An examination of the clearance interval raises a number of questions that are pertinent to the conditions and practices in Arizona. First, previous studies related to deceleration rates have been conducted in other parts of the United States. Certainly, one of the questions that should be addressed is whether driver behavior in Arizona is similar. Also, there is concern about potential variations in driver behavior for different intersection locations and driving environments in Arizona. A second general group of questions might be related to the actual design of the clearance interval. For example, one issue would be associated with possible differences in behavior given the yellow only and the yellow plus all-red clearance interval designs.

Study Scope and Objectives

In order to gain some degree of insight into these questions as they apply to conditions in Arizona, this study was initiated for the purpose of examining driver behavior that is related to the clearance interval. The intent was to document driver behavior parameters and possible variations in behavior that exist in Arizona. More specifically, the study objectives focused on the determination of:

(a) The actual deceleration rates and the range of deceleration rates that are used by drivers;

(b) Possible differences in driver behavior due to the intersection environment; and

(c) The effect of the all-red phase on driver behavior.

In addition, the study was designed to provide information about the perception-reaction times of drivers as well as measures of driver compliance in terms of the signal indications.

Driver behavior associated with the clearance interval is certainly a complex phenomena in that there are numerous facets to the overall problem. It was anticipated that this study would not necessarily answer all questions about such behavior. It was believed, however, that the study would provide a factual basis for assessing the current conditions in Arizona and evaluating future efforts regarding the necessary understanding of driver behavior. It was not the intent of this particular study to include an evaluation of the current practice used in the determination of clearance intervals.

METHOD OF STUDY

The approach that was utilized in this study was a detailed examination of driver behavior that is associated with the clearance interval at selected intersections. The intent was to select intersections that reflect variations in the clearance interval as well as the intersection environment.

Basically, the variations in the clearance interval involve the use of yellow only versus a yellow plus an all-red signal indication. As will be discussed in a later section, there was generally little variation in the durations of the clearance intervals. It should be noted that it was not feasible to conduct before-and-after studies of the effects of changes in the clearance interval design and duration at a particular intersection. The study was limited, therefore, to examining behavior at existing intersections with existing signal timing.

The intersection environment reflected the surrounding development and the geographic location of the intersection. Initially, it was anticipated that intersections would be selected which would represent a cross section of rural and urban conditions in Arizona. In reality, most of the signalized intersections in Arizona are situated in the Phoenix and Tucson metropolitan areas; thus, the study focused on these two geographic areas. An attempt was made to select three different types of intersection environments in each of the two metropolitan areas.

Given the variation in clearance interval design and intersection environment, the study was developed on the basis of a total of six intersections being examined. While a total of six intersections were selected, only one approach at each of those intersections was included in the study. In addition, there was a desire to study the influence of nighttime operations on driver behavior; therefore, two of the six intersections were also selected for observations during the nighttime period.

Time-lapse photography techniques were utilized to record the driver behavior associated with the clearance interval at each of the intersections. Vehicles were filmed prior to the onset of the yellow, during the clearance interval, and until the vehicle either stopped or cleared the intersection. The camera was located so that it was possible to record the intersection and the signal indication as well as the operation of approaching vehicles within 350 to 400 feet of the intersection. Given the onset of the yellow signal indication, the study focused on the first vehicle to stop and the last vehicle to pass through the intersection. Where multiple approach lanes were involved, this information was included for each lane.

It should be noted that the utilization of time-lapse photography techniques did not permit an analysis of variation in behavior by differing driver classifications. For example, it was not possible to determine information such as the age, sex, experience, and route familiarity of the driver.

The main advantage of the photographic technique is that it is possible to simultaneously record multiple items of information about the individual vehicles and the operation of the intersection. It is assumed that the study sample is a representative sample of the drivers using that route.

The filming of driver behavior at the various intersections was accomplished using two different types of movie camera equipment. The University of Arizona group employed a Minolta super 8mm movie camera with a zoom lens while the Arizona State University study team had a 16mm movie camera available. Because of the age of the 16mm equipment, it proved to be less reliable and more expensive to operate than the super 8mm unit; thus, it was used only on a limited basis. Also, higher speed film for the night observations was readily available for the super 8mm camera; therefore, that camera was used for all of the nighttime studies.

The cameras were operated at a frame speed of 18 frames per second. While time-lapse cameras can certainly operate at slower rates such as two frames per second, this faster speed was chosen in order to increase the accuracy of the time measurements.

The day filming was accomplished using a Kodak Kodachrome color film. This made it possible to easily distinguish the signal indications as well as when brake lights were illuminated on a vehicle. For the night filming, a Kodak Ektachrome color film was used. While it was not possible to see the entire vehicle at night, the lights on the vehicle and the traffic signals were recorded on the film.

If available, the intersection was filmed from a nearby building or structure. If such a facility were not available at a particular location, the Arizona Department of Transportation furnished a truck with an elevating platform which would extend to a height of approximately 30 feet. The camera was placed on a tripod which resulted in a total height of about 35 feet.

The truck was parked in a parking lot or vacant area approximately 400 to 450 feet from the intersection. Where the truck was employed for filming, it was located about 30 to 50 feet from the edge of the roadway. There was concern that the presence of the truck might influence the behavior of the drivers. Based on observations by the study teams at the sites, there was no evidence that the drivers were cognizant of the filming activities.

Distances from the intersection were noted using reference points on the roadway. Generally, strips of tape were placed at 50-foot intervals along the edge of the approach. In some cases, the dashed lane striping was measured and used as the reference for distance from the intersection.

DATA COLLECTION

While the previous section described the general approach and methodology that was used in the study, this section will provide specific details regarding the data collection phase of the effort. In addition, the work associated with the extraction and reduction of the data from the film is discussed.

Selection of Intersections

Major difficulties were encountered in the selection of intersections that were to be used for study observations. These difficulties served to severely limit the choice of intersections that could even be considered. The problems can be attributed to several reasons. First, the use of time-lapse photography techniques required the use of an elevated vantage point for the purpose of filming the intersection approach. For this study, there was an option of using a nearby building or a truck with an elevating platform. Even with these options, it was frequently difficult to find a suitable building or an acceptable place to locate the truck.

Second, a number of the intersections in the Phoenix and Tucson areas are operated as part of an areawide traffic control system. In many cases, the timing of the signal is such that approaching vehicles are seldom in proximity to the intersection at the onset of the yellow. When such a condition exists, the probability of obtaining a data sample is relatively small, and the time required for data collection is greatly increased. Jurisdictions are reluctant to temporarily isolate a signal from the control system because of liability questions.

Finally, signalized intersections in outlying areas generally have traffic actuated controllers and equipment installed. In most cases, the intersection control has advance detectors on the actuated approaches. If the advance detectors are properly designed and working effectively, the probability of observing a "sample" vehicle is reduced especially during periods of lower approach volumes. Again, the jurisdictions that are responsible for the intersections are reluctant to disconnect the advance detectors due to the liability issue.

The intersections that were ultimately selected for inclusion in the study were:

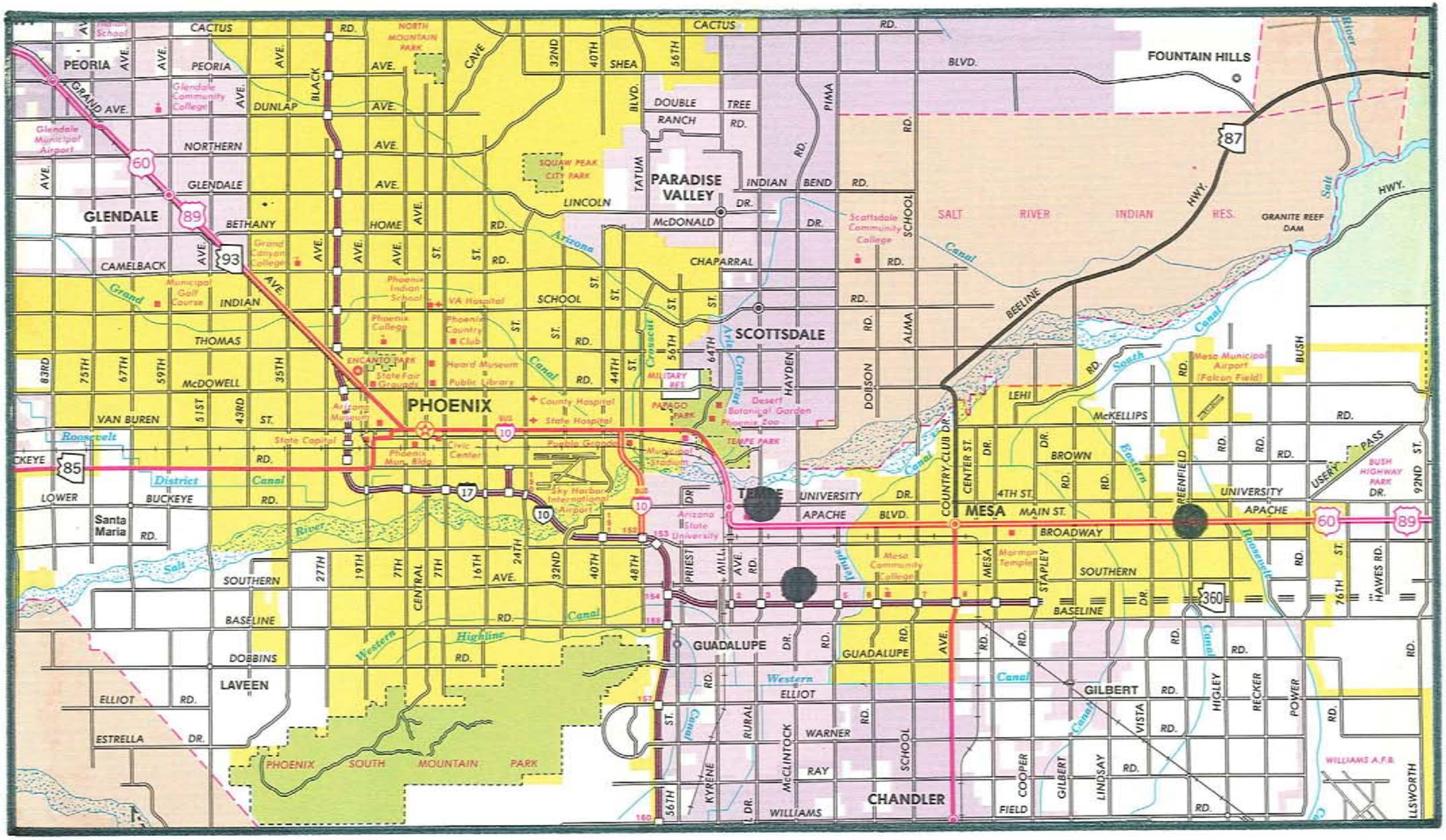
- Phoenix Metropolitan Area
  - University Drive and Rural Road (located in Tempe)
  - Southern Avenue and McClintock Drive (located in Tempe)
  - U. S. 60 and Greenfield Road (located in Mesa)
- Tucson Metropolitan Area
  - First Avenue and Roger Road
  - Sixth Street and Campbell Avenue
  - Broadway Boulevard and Columbus Boulevard

It should be noted that only one approach at each of the intersections was studied, and the study approach was located on the first street that is shown in the list of intersections. Figures 1 and 2 indicate the general locations of the intersections in their respective metropolitan areas.

As part of the planned research effort, two intersections were selected for night study. These intersections were:

- Southern Avenue and McClintock Drive
- Broadway Boulevard and Columbus Boulevard

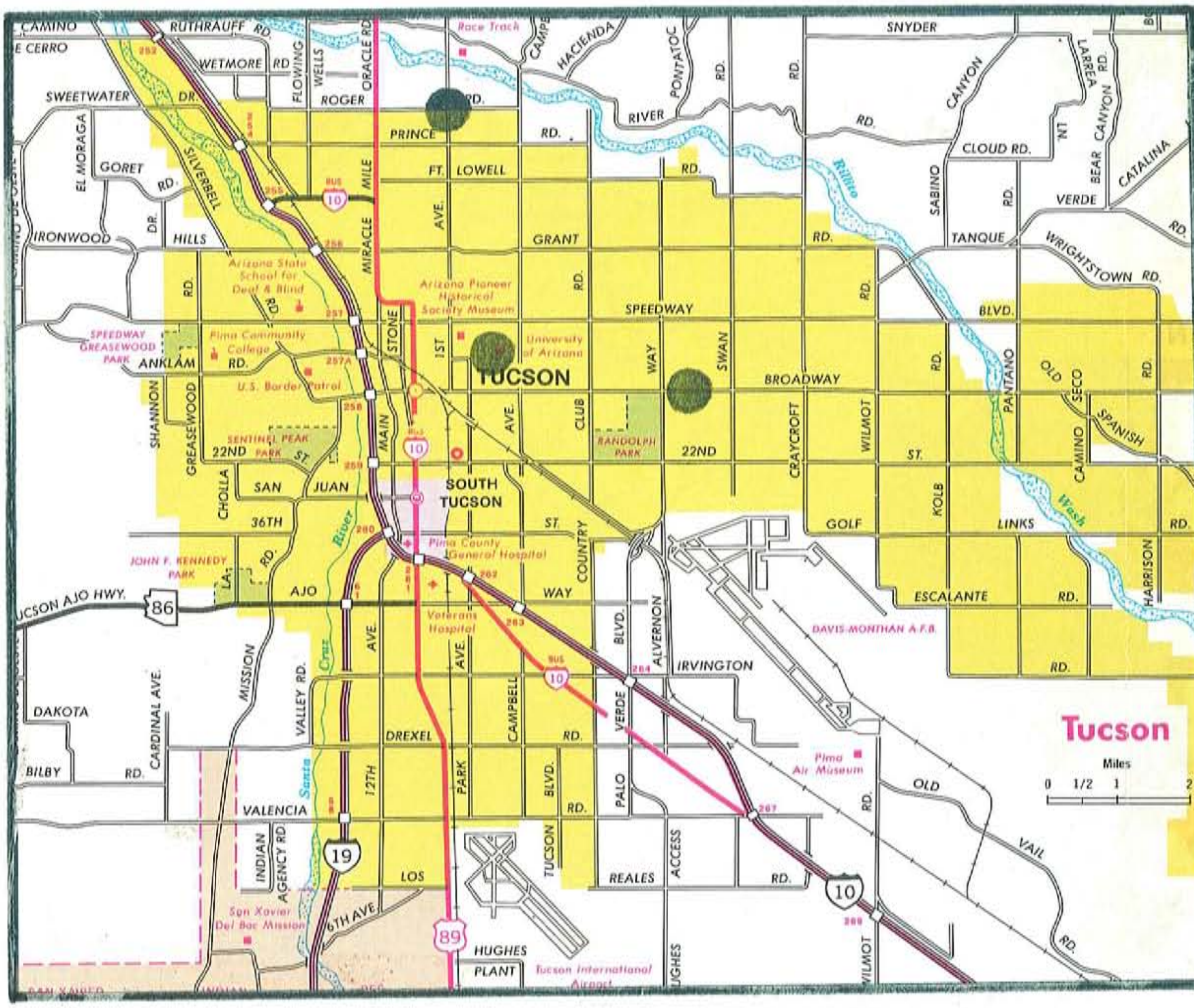
The same approaches were used for the night study as for the day observations.



● - indicates study site

FIGURE 1

LOCATION OF INTERSECTIONS IN THE PHOENIX AREA



● - indicates study site

FIGURE 2

LOCATION OF INTERSECTIONS IN THE TUCSON AREA

In addition to the six locations that have been listed, filming was undertaken at the intersection of Washington Street and Third Avenue in Phoenix. An analysis of the film revealed that the camera did not operate properly; thus, the observations were not usable. The signalization at this intersection operates as part of an areawide control system; therefore, it had been difficult to obtain data samples during the attempt to study the intersection. Subsequent efforts to restudy the intersection were not considered for this reason.

For each of the intersection approaches that were selected for the study, pertinent information relative to the operation and design of the intersection was compiled. The following summarizes this information;

- UNIVERSITY DRIVE AND RURAL ROAD (west approach)

  Clearance Interval: Five seconds of yellow.

  Approach Configuration: Two through lanes with an exclusive left-turn lane.

  Left-Turn Signalization: Turns permitted during an exclusive left-turn phase.

  Estimated ADT: 24,000 vpd

- SOUTHERN AVENUE AND McCLINTOCK DRIVE (east approach)

  Clearance Interval: Five seconds of yellow.

  Approach Configuration: Three through lanes with an exclusive left-turn lane.

  Left-Turn Signalization: Turns permitted during an exclusive left-turn phase.

  Estimated ADT: 22,100 vpd

• U. S. 60 AND GREENFIELD ROAD (east approach)

<u>Clearance Interval</u>: Five seconds of yellow plus three seconds of all-red.

<u>Approach Configuration</u>: Three through lanes with an exclusive left-turn lane.

<u>Left-Turn Signalization</u>: Turns permitted during an exclusive left-turn phase.

<u>Estimated ADT</u>: 24,200 vpd

• FIRST AVENUE AND ROGER ROAD (north approach)

<u>Clearance Interval</u>: Three seconds of yellow plus two seconds of all-red.

<u>Approach Configuration</u>: Two through lanes with an exclusive left-turn lane.

<u>Left-Turn Signalization</u>: Left turns permitted on a permissive basis during the through movement.

<u>Estimated ADT</u>: 21,400 vpd

• SIXTH STREET AND CAMPBELL AVENUE (west approach)

<u>Clearance Interval</u>: Three seconds of yellow plus two seconds of all-red.

<u>Approach Configuration</u>: Two through lanes with an exclusive left-turn lane and an exclusive right-turn lane except in the peak hours. During these hours, the left-turn lane is used as a reversible lane with left turns being prohibited. For the period from 4:00 to 6:00 p.m., the configuration would be three through lanes with an exclusive right-turn lane.

• SIXTH STREET AND CAMPBELL AVENUE (west approach) (Continued)

Left-Turn Signalization: Left turns permitted on a permissive basis during the through movement except during the reversible lane operation during the peak hour. Left turns are prohibited at that time.

Estimated ADT: 18,300 vpd

• BROADWAY BOULEVARD AND COLUMBUS BOULEVARD (east approach)

Clearance Interval: Three and six-tenths seconds of yellow plus two seconds of all-red.

Approach Configuration: Three through lanes with an exclusive left-turn lane and an exclusive right-turn lane. Transit vehicles are permitted to use the right-turn lane for through movements.

Left-Turn Signalization: Left turns are permitted during an exclusive turn phase and on a permissive basis during the through movement.

Estimated ADT: 35,800 vpd

All of the streets have two-way flow. The traffic volumes that are shown for each of the locations are the totals for both directions of flow.

Only one of the study approaches had a significant grade in terms of the vertical alignment. The approach at the intersection of Sixth Street and Campbell Avenue has an upgrade of approximately two percent.

In order to simplify the presentation of material relative to the study sites, reference to the intersections will be in terms of the street on which the approach is located. For example, the approach located at University Drive and Rural Road will be referred to as University Drive.

Filming of Intersection Approaches

Initially, a series of test filming sessions were undertaken to insure that methods associated with the use of the photographic techniques would yield the desired information and data. Following these series of tests, the formal filming of intersection approaches was initiated in July 1981. The filming efforts at all of the locations were completed in February 1982, with the exception of the Southern Avenue site. Because of a camera malfunction, this approach had to be filmed a second time. This was accomplished in early May 1982. All of the observations were made on weekdays.

Because of the arrangements that were necessary for access to buildings or to use a truck with a platform, filming activities were accomplished in periods of several hours duration. For example, a study team would frequently film an approach for a six- to eight-hour period. For the night observations, filming was undertaken during the months of December and January; thus, the data collection generally began about 6:00 p.m. and was terminated about 11:00 p.m.

It took about 12 to 16 hours of filming at each site to obtain a sample size of approximately 100 stopping vehicles. Even with this filming period, there were some intersection approaches which yielded less than 100 samples when the film was analyzed. It might seem that this duration of filming is somewhat excessive for such a sample size; however, there are two explanations. First, cycle lengths were sometimes as high as 120 seconds. Second, there were numerous cases for which there were no vehicles in the proximity of the approach at the onset of the yellow interval. Because of the duration of filming activities, it was not possible to focus on particular periods of time during the day. The observations that were made, therefore, represent a cross section of the traffic conditions at an intersection.

A truck was utilized in connection with the filming efforts at the Southern Avenue, U. S. 60, and First Avenue sites. The camera was located in nearby buildings when filming the approaches on University Drive and Broadway Boulevard. The Sixth Street intersection approach was filmed from the University of Arizona Stadium.

Data Reduction

Using the distance reference points that were established on each of the study approaches, a grid was developed so that the location of a vehicle could be determined when the film was projected on a screen. The grid indicated the distance from the intersection. In all cases, this distance was measured from the crosswalk.

The films were analyzed using specially equipped projectors that would permit an analysis of the film on a frame-by-frame basis. The elapsed time could be determined by counting the number of frames associated with a particular event.

For each of the vehicles that were the first to stop after the beginning of the yellow interval, the following information was extracted from the film record:

(a) The distance from the intersection at the beginning of the yellow interval,

(b) The location of the vehicle when the brakes were applied (as indicated by the brake lights),

(c) The location of the vehicle when it stopped,

(d) The time required for the vehicle to stop,

(e) The perception-reaction time (determined as the time between the beginning of the yellow interval and the application of the brakes), and

(f) Type of vehicle if other than a passenger car or light truck.

Based on this information, the approach speed and average deceleration rate were computed for each vehicle.

In addition, the behavior of the last vehicle to pass through the intersection after the beginning of the yellow was determined by making the following observations:

(a) The location of the vehicle at the beginning of yellow interval,

(b) The time elapsed from the onset of the yellow interval until the vehicle entered the intersection,

(c) The type of vehicle if other than a passenger car or light truck, and

(d) If the vehicle entered the intersection on the red signal indication.

For the vehicles that did not stop, the approach speed was also computed. In this case, the determination of speed was accomplished using the elapsed time and the distance traveled.

ANALYSIS OF DATA

The basic intent of the project was to determine the behavior of drivers during the period associated with the clearance interval as well as to examine the influence of signal timing practices and intersection environments on the driver behavior. The analysis of the data, therefore, was broken into these two broad categories of effort. The study sample contained few vehicles other than passenger cars and light trucks; thus, the analysis was limited to this group of vehicles.

Description of Observed Driver Behavior

For each of the observed intersection approaches, descriptive statistics were computed for the following parameters:

(a) Approach speeds,

(b) Distance from the intersection at the beginning of the yellow interval,

(c) Perception-reaction time,

(d) Deceleration rate, and

(e) Vehicles entering the intersection on the red signal indication.

Table 1 indicates the speed characteristics for each of the study sites. These values are presented for the last vehicle through the intersection as well as the first vehicle to stop after the onset of the yellow interval. The cumulative frequency distribution of the approach speeds for the first vehicle to stop at each location is shown in Appendix A. Similar information for the last vehicle through the intersection may be found in Appendix E.

At all six study locations, the mean approach speeds of the last vehicle through the intersection were higher than the first vehicle to stop. It should

TABLE 1

APPROACH SPEEDS

Intersection Approach	Posted Speed Limit (MPH)	Last Vehicle Through the Intersection			First Vehicle To Stop		
		Mean Speed (MPH)	Standard Deviation	85% (MPH)	Mean Speed (MPH)	Standard Deviation	85% (MPH)
University Drive	35	35.46	7.49	45.8	33.69	8.81	43.4
Southern Ave. (Day)	45	36.31	5.25	42.4	34.97	7.08	40.9
Southern Ave. (Night)	45	40.58	6.30	47.7	35.77	7.17	41.8
U. S. 60	50	39.66	7.52	48.0	35.88	7.90	44.8
First Avenue	45	39.84	6.42	46.5	39.04	7.27	46.9
Sixth Street	30	35.24	5.50	40.5	31.63	6.05	37.7
Broadway Blvd. (Day)	45	41.16	5.47	47.0	37.41	6.47	43.5
Broadway Blvd. (Night)	45	37.27	5.54	44.0	36.32	5.43	42.3
All Approaches		38.91	6.38	45.8	36.13	7.30	43.5

the intersection was considerably less for the last vehicle through the intersection. In fact, the mean distance ranged from approximately 100 to 150 for the study approaches. Figure 3 depicts the comparison of the cumulative frequency distributions for the last vehicle through the intersection and the first vehicle to stop. This plot uses the combined data for all sites.

A summary of the observed perception-reaction times is presented in Table 3, and Figure 4 depicts the cumulative frequency distribution based on all observed perception-reaction times. As indicated previously, the perception-reaction time was determined by measuring the time between the onset of the yellow interval and the application of the brakes. These times are for the stopping vehicles only. Generally, the study team was unable to determine the perception-reaction time for the drivers who chose to proceed through the intersection. There were a few cases during the night studies where it was possible to detect that drivers began to apply the brakes but then proceeded through the intersection. In these cases, a brief flickering of the brake-lights was recorded on the film. The cumulative frequency distribution curves for these data are shown in Appendix B.

In all cases the mean observed time was greater than the 1.0 second value that is used in the current practice. In fact, the 85-percentile of the observed times was approximately two seconds at most of the intersections.

It was theorized that the perception-reaction time is related to such factors as the location of the vehicle at the beginning of the yellow interval, the approach speed, or even possibly the deceleration rate that was used by the driver. These hypotheses were tested using correlation and regression

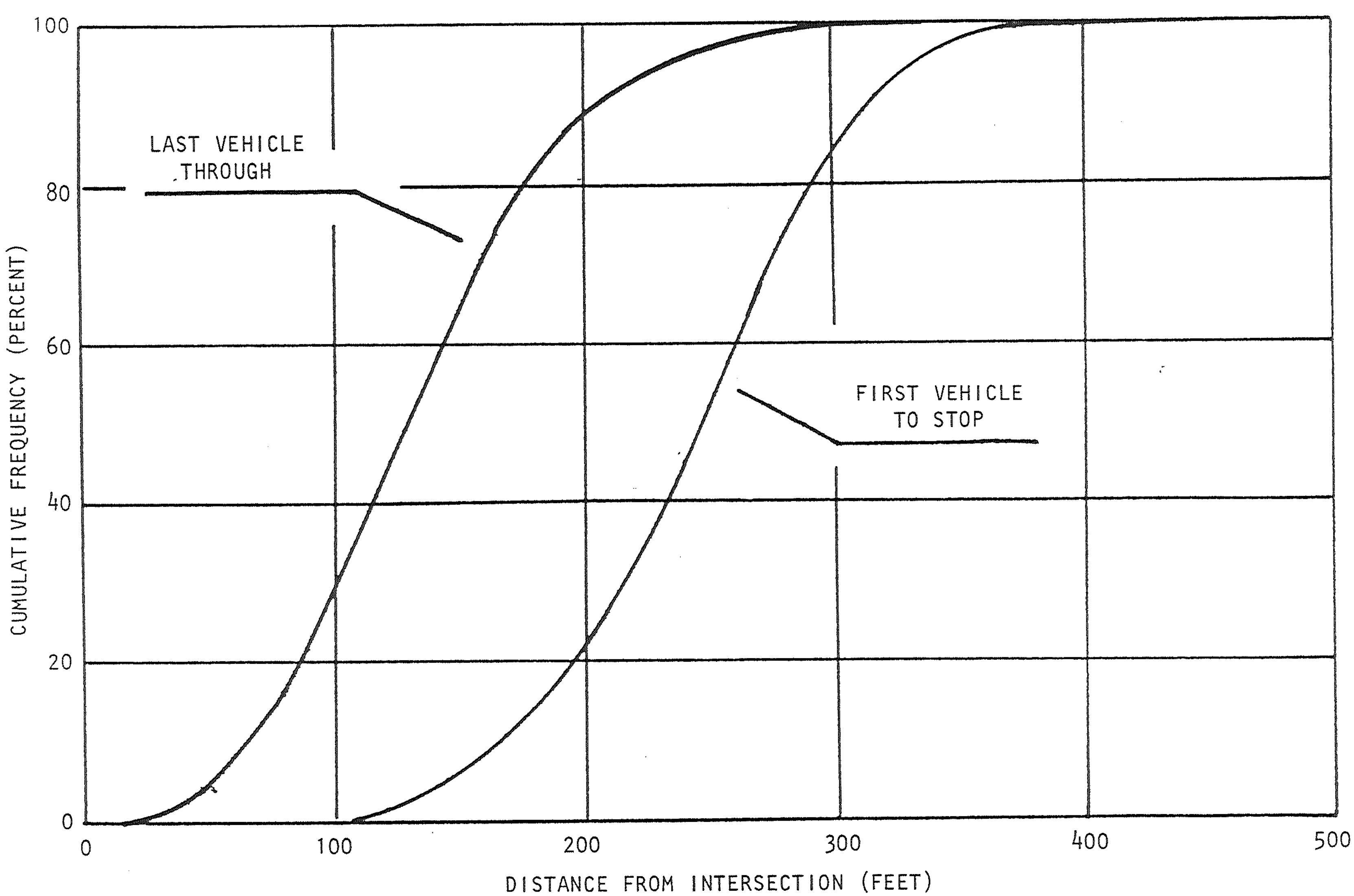


FIGURE 3

CUMULATIVE FREQUENCY DISTRIBUTION OF VEHICLE LOCATION AT THE ONSET OF THE YELLOW INTERVAL

TABLE 3

PERCEPTION-REACTION TIMES

Intersection Approach	Mean Time (sec)	Standard Deviation	85% Time (sec)
University Drive	1.28	0.82	2.0
Southern Ave. (Day)	1.49	0.62	1.9
Southern Ave. (Night)	1.43	0.73	2.0
U. S. 60	1.38	0.60	2.1
First Avenue	1.24	0.51	1.8
Sixth Street	1.55	0.70	2.0
Broadway Blvd. (Day)	1.16	0.48	1.5
Broadway Blvd. (Night)	1.09	0.44	1.5
All Approaches	1.30	0.60	1.8

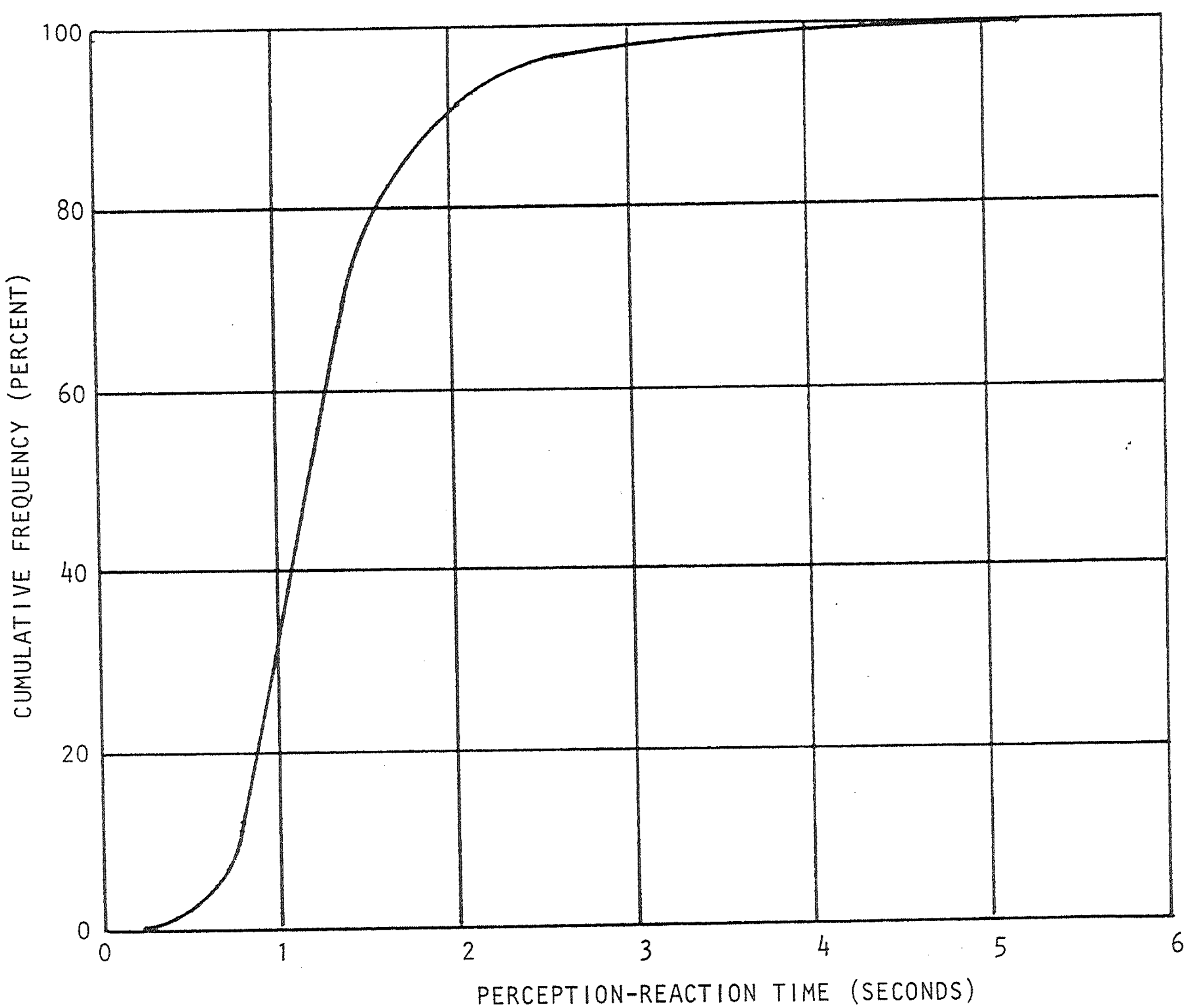


FIGURE 4

CUMULATIVE FREQUENCY DISTRIBUTION OF
OBSERVED PERCEPTION-REACTION TIMES

analyses and computing the coefficient of determination (r^2). The coefficient of determination is the proportion of variation in one variable that is accounted for by the variation in another variable. When these variables were analyzed in terms of the relationship with the length of the perception-reaction time, the following "r^2" values were obtained:

Variable	r^2
Distance from Intersection	0.08
Approach Speed	0.09
Deceleration Rate	0.01

These results would serve to indicate that there was little relationship between the perception-reaction time and these variables.

Table 4 summarizes the deceleration rates that were observed at the study locations, and the combined cumulative frequency distribution curve for all of the sites is shown in Figure 5. The cumulative frequency curve for each individual site may be found in Appendix D. It should be emphasized that these observed values reflect the driver behavior under the set of conditions experienced at the study sites. Further analysis of the variation in the deceleration rates with respect to the study sites is discussed later.

The tabulation of the vehicles entering the intersection on the red signal indication is given in Table 5. Generally, the intersections with the shorter yellow interval and the all-red phase resulted in a higher percentage of vehicles entering on the red indication. This would be expected due to the shorter yellow duration. The First Avenue site had an extremely high percentage

TABLE 4

DECELERATION RATES

Intersection Approach	Mean Rate (fps^2)	Standard Deviation	85% Rate (fps^2)
University Drive	7.0	3.8	11.5
Southern Ave. (Day)	10.7	3.0	13.9
Southern Ave. (Night)	11.6	2.6	14.8
U. S. 60	11.8	3.4	15.8
First Avenue	12.4	3.5	16.1
Sixth Street	13.9	4.5	18.2
Broadway Blvd. (Day)	12.8	4.1	17.2
Broadway Blvd. (Night)	9.7	3.0	12.5
All Approaches	11.6		

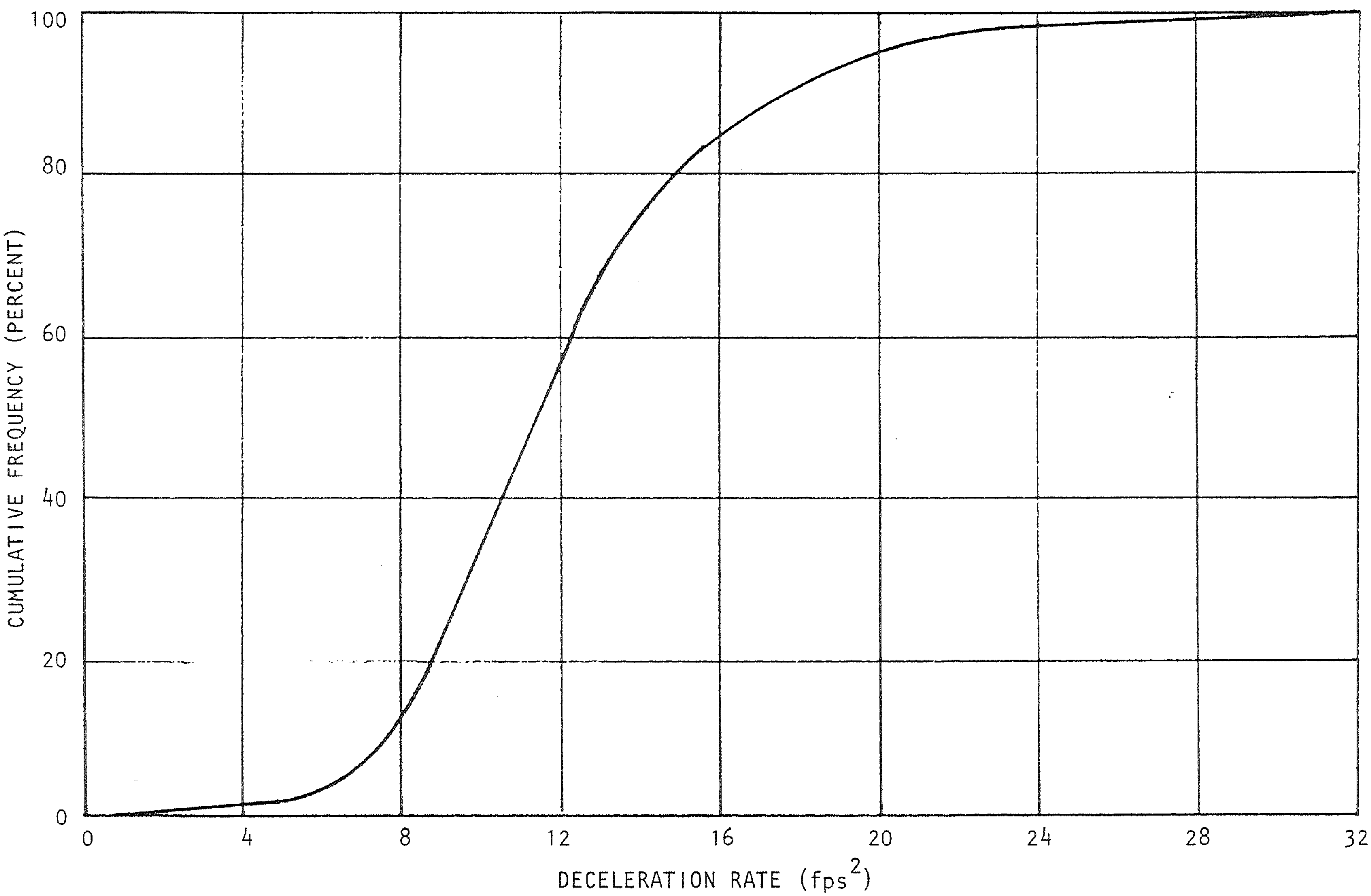


FIGURE 5

CUMULATIVE FREQUENCY DISTRIBUTION OF OBSERVED DECELERATION RATES

TABLE 5

PERCENT OF LAST VEHICLES THROUGH THE INTERSECTION ON THE RED INDICATION

Intersection Approach	Sample Size of Last Vehicles Through the Intersection	Percent Entering on Red Indication
University Drive	16	0
Southern Ave. (Day)	69	2.9
Southern Ave. (Night)	49	0
U. S. 60	87	2.3
First Avenue	152	29.6
Sixth Street	67	8.9
Broadway Blvd. (Day)	156	8.3
Broadway Blvd. (Night)	96	1.0

of vehicles entering on the red signal compared to the other locations. While this intersection is situated in a more outlying area than the other two study locations in Tucson, there is no clear explanation for this percentage being so much higher than the other sites.

It is interesting to note that the use of the longer yellow intervals did not increase the percentage of the vehicles entering on the red signal. Also, the behavior at the U. S. 60 site was similar to the other intersections with a five-second yellow duration even though that site had an additional three seconds of all-red in the clearance interval.

When comparing the variation between the day and night conditions, the percentage of entring vehicles was drastically reduced during the night conditions. This may be partially explained by the fact that there were less vehicle queues during the nighttime period. The deceleration rate at the Broadway Boulevard site also decreased during the nighttime period, and this site at night had the lowest mean deceleration rate value when compared to all other approaches.

Comparative Analysis of Study Sites

The second major portion of the analysis effort dealt with the comparison of observed behavior at the different study sites. Basically, these comparisons were intended to test the influence of the driving environment and signal timing practices.

The mean and standard deviation for each of the measured parameters were computed. Where data from intersections were combined for a particular analysis, these values were computed for the combined data. Potential differences in behavior were analyzed by examining differences in the means for specific groups or pairs. In all cases, the 95-percent confidence level was utilized for the purpose of assessing statistical significance.

Table 6 presents a summary of the results for a comparison of the sites in the Phoenix metropolitan area. For this analysis, a particular site was compared with each of the other sites in that metropolitan area. The U. S. 60 site had a five second yellow plus a three second all-red phase, and the other two sites in the Phoenix area had a five second yellow clearance interval. It can be noted that there was a statistically significant difference in the deceleration rate at the University Drive site even though there was no significant difference in the other parameters for the first vehicle to stop. For the last vehicle through the intersection after the beginning of the yellow interval, there were two cases where the differences in the approach speeds were significant.

A comparison of the sites in Tucson yielded a somewhat different set of results as shown in Table 7. For this group of intersections, the comparison revealed significant differences in a number of measures of behavior.

Table 8 presents the results of the comparison of the day-night studies at the two sites selected for that purpose. In this case, the observed day and the night behavior at each of the two sites were compared. Again, there were some differences between the two study sites. As was previously indicated, the observed deceleration rates were significantly lower at night for the Broadway Boulevard location. The Southern Avenue site revealed no

TABLE 6

COMPARISON OF PHOENIX AREA SITES

(DAY OBSERVATIONS)

	SITES COMPARED		
	U. S. 60 - University Drive	U. S. 60 - Southern Avenue	Southern Avenue - University Drive
FIRST VEHICLE TO STOP			
APPROACH SPEED	N*	N	N
PERCEPTION-REACTION TIME	N	N	N
DISTANCE FROM INTERSECTION	N	N	N
DECELERATION RATE	S	N	S
LAST VEHICLE THROUGH INTERSECTION			
APPROACH SPEED	S	S	N
DISTANCE FROM INTERSECTION	N	N	N

* N = Difference is Not Significant

S = Significant Difference

TABLE 7

COMPARISON OF TUCSON AREA SITES

(DAY OBSERVATIONS)

	SITES COMPARED		
	First Avenue - Broadway Boulevard	First Avenue - Sixth Street	Sixth Street - Broadway Boulevard
FIRST VEHICLE TO STOP			
APPROACH SPEED	S*	S	S
PERCEPTION-REACTION TIME	N	S	S
DISTANCE FROM INTERSECTION	S	S	S
DECELERATION RATE	N	S	N
LAST VEHICLE THROUGH INTERSECTION			
APPROACH SPEED	N	S	S
DISTANCE FROM INTERSECTION	N	S	S

* N = Difference Is Not Significant

S = Significant Difference

TABLE 8

COMPARISON OF DAY - NIGHT BEHAVIOR

	SITE	
	Southern Avenue	Broadway Boulevard
FIRST VEHICLE TO STOP		
APPROACH SPEED	N*	N
PERCEPTION-REACTION TIME	N	N
DISTANCE FROM INTERSECTION	N	N
DECLERATION RATE	N	S
LAST VEHICLE THROUGH INTERSECTION		
APPROACH SPEED	S	N
DISTANCE FROM INTERSECTION	N	N

* N = Difference Is Not Significant

S = Significant Difference

difference in the day-night comparison except the mean approach speed for the last vehicle through the intersection was significantly higher at night.

All three of the study locations in Tucson had clearance intervals with the all-red phase; thus, an analysis of the influence of the yellow only versus the yellow plus all-red intervals required a comparison of the Phoenix and Tucson area sites. For this analysis, the Southern Avenue and the University Drive study approaches in the Phoenix area were used. The data for these intersections were compared with the information for the three Tucson intersections. The results of this analysis are given in Table 9. The mean approach speeds for both the stopping and through vehicles were significantly higher in Tucson. In contrast, however, the distance from the intersection at the beginning of the yellow interval was significantly less and the deceleration rate was higher in Tucson.

TABLE 9

COMPARISON OF YELLOW ONLY VERSUS YELLOW PLUS ALL-RED INTERVALS

(DAY OBSERVATIONS)

<u>FIRST VEHICLE TO STOP</u>	
APPROACH SPEED	S*
PERCEPTION-REACTION TIME	N
DISTANCE FROM INTERSECTION	S
DECELERATION RATE	S
<u>LAST VEHICLE THROUGH INTERSECTION</u>	
APPROACH SPEED	S
DISTANCE FROM INTERSECTION	N

* N = Difference Is Not Significant
S = Significant Difference

CONCLUSIONS

This study did yield considerable information about driver behavior at signalized intersections in Arizona. Generally, a study of this type had not previously been conducted in this State; thus, the findings should establish a foundation for efforts to evaluate and develop clearance interval policies and practices. The results of this study reflect the behavior of drivers given the existing intersections and traffic signal timing. It is not possible to anticipate what the resulting driver behavior would be with a different set of conditions. Based on the observations and analyses that were made a part of this study, the following conclusions can be drawn:

(a) The observed mean decleration rates chosen by drivers at the various study sites ranged from 7.0 to 13.9 feet per second per second. The mean deceleration rate for all observation was 11.6 feet per second per second. The study site with the two-percent upgrade on the intersection approach had the highest mean deceleration rate.

(b) The day-night comparison of driver behavior revealed mixed results in that the mean deceleration rate was not significantly different during the nighttime period at one site; however, there was a decrease in the mean rate from 12.9 to 9.7 feet per second per second at the Broadway Boulevard location.

(c) With respect to the perception-reaction times of drivers, the observed mean time for each of the sites ranged from 1.16 to 1.55 seconds. The mean for all approaches was 1.30 seconds. The 85-percentile value for the time measurement ranged from 1.5 to 2.1 seconds.

While the nighttime studies revealed mean times that were slightly less at both sites, these differences were not statistically significant. Factors such as approach speed, distance from the intersection at the beginning of the yellow interval, and the deceleration rate that is used by the driver had little or no influence on the perception-reaction time.

(d) The comparison of study sites in each of the metropolitan areas also provided mixed results. In the Phoenix area, the mean deceleration rate at the University Drive location was significantly less than at the other two sites even though most of the other measures showed no significant differences. Similar comparisons for the Tucson sites revealed differences in a number of the measured parameters.

(e) In terms of the comparison of the yellow only versus the yellow plus all-red change intervals, there were no significant differences in the perception-reaction times. This was true when the intersection with an all-red interval in the Phoenix area was compared to the other sites which had a yellow only interval. It was also true when the intersections in Tucson were compared with those in Phoenix.

(e) (Continued)

The analysis of the deceleration rates for the two types of clearance intervals did not yield consistent results. While the deceleration rates for the Tucson sites were higher than those observed in the Phoenix area, there was a variation in the significance of the differences between intersections with the same type of clearance interval.

In reviewing the comparisons of the observed behavior, the use of some degree of caution should be exercised. The indication of differences in behavior or sites is based on statistical analysis. Certainly, one must respect the results that are obtained by the application of scientific method. In many cases, however, the differences are relatively small even though they are statistically significant. In such cases, one should carefully evaluate the meaning of these differences in terms of the context of the actual driving situation and the effect on traffic operations and design. For example, small differences in deceleration rates may be statistically significant but may have no appreciable affect on the evaluation and solution of traffic problems.

In addition, the project staff spent considerable time observing the operations of these intersections during the course of the study. While the observed deceleration rates were lower and the perception-reaction times were higher than the values recommended by the current practice, it should be recognized that the intersections appeared to be operating reasonably well with respect to the clearance interval.

The results obtained from the conduct of this study do make a significant contribution to the rather limited documented information about driver behavior which is associated with the clearance interval. While this study of six intersections provides a major increase in the available data, a number of questions remain which are not fully answered about the causes in the variation in the observed driver behavior. The results obtained in this study do not justify a change in the current policies which pertain to clearance intervals. Further evaluation of the causes of the variation in driver behavior will be required prior to formulating modifications to the existing policies.

RECOMMENDATIONS FOR FURTHER STUDY

When this project was originally conceived, it was anticipated that the results of such a study would likely raise further questions about driver behavior which is related to signal clearance intervals. While the study does establish an initial data base for driver behavior given the conditions in Arizona, there are questions that remain unanswered and need to be addressed. The following discussion suggests several areas of effort that should be considered.

(a) The intersection approaches included in this study may have had differing driver populations. As was indicated previously, it was assumed that the samples represented the driver populations for those streets. For this study, however, it was not possible to determine if some of the measured variations were the result of differing driver populations. Future studies might consider an evaluation of the effect of changes in the clearance interval given the same driver population. This could potentially be accomplished by observing driver behavior using before-and-after studies at particular intersections. Such a study would require the cooperation of governmental jurisdictions who would be willing to modify the clearance interval at an intersection for the purpose of this study.

(b) As part of the current project, it was suggested that a study be undertaken in which a sample of drivers would be subjected to clearance interval situations at a controlled intersection. For this study, an existing intersection might be closed to public use during a low volume period, an abandoned intersection could be used, or even a simulated intersection could possibly be developed. This research effort was not included in the current contract; however such a project would offer the opportunity to gain information relative to the response of a particular driver given a variation in the clearance interval situations and design.

(c) In spite of the efforts to obtain some diversity in clearance interval design and duration as well as intersection environment, there were a number of similarities in the intersection approaches which were included in this study. Certainly, this sample of six locations does not represent the total spectrum of situations and conditions that exist in Arizona. It would be desirable to further expand the data base to include other types of conditions, particularly approaches which are on a downgrade.

(d) Finally, the scope of this project did not include an evaluation of the current practice used in the determination of the signal intervals. Given the information and the data base that has been developed by this study, there should be an examination of the influence of these findings on the current practice.

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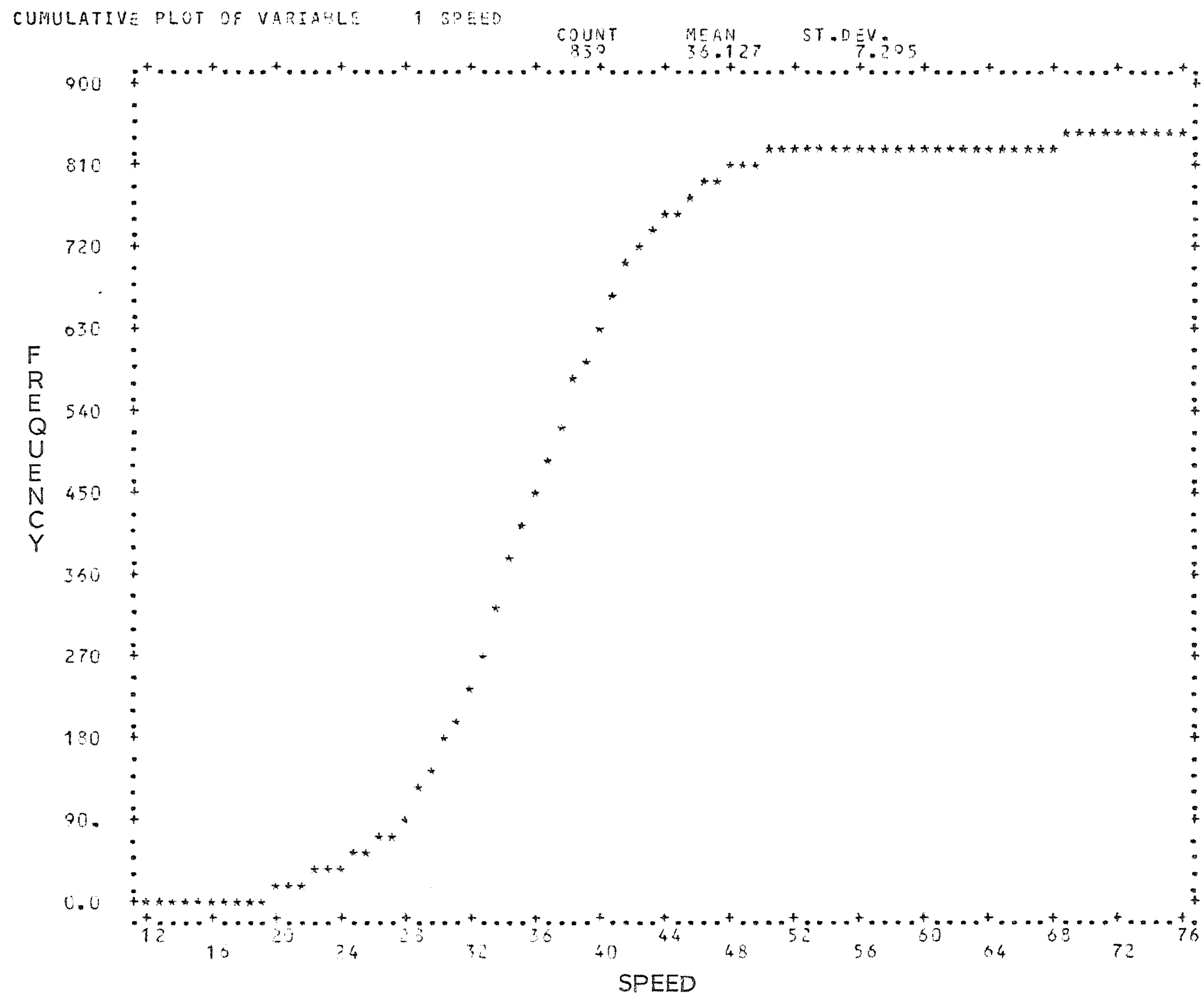
APPENDIX A

APPROACH SPEEDS
FIRST VEHICLE TO STOP

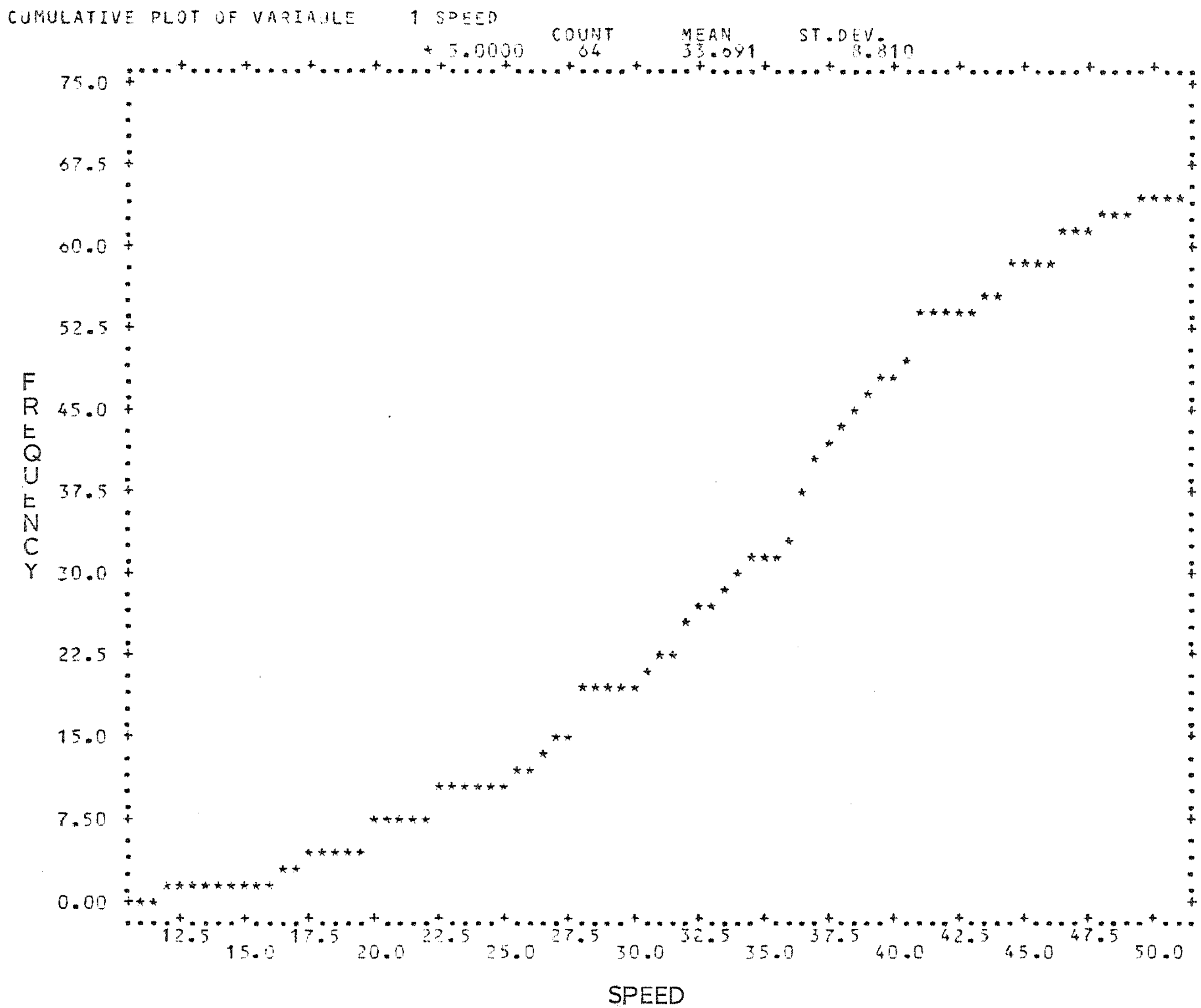


CUMULATIVE FREQUENCY DISTRIBUTION

APPROACH SPEEDS

FIRST VEHICLE TO STOP

ALL APPROACHES

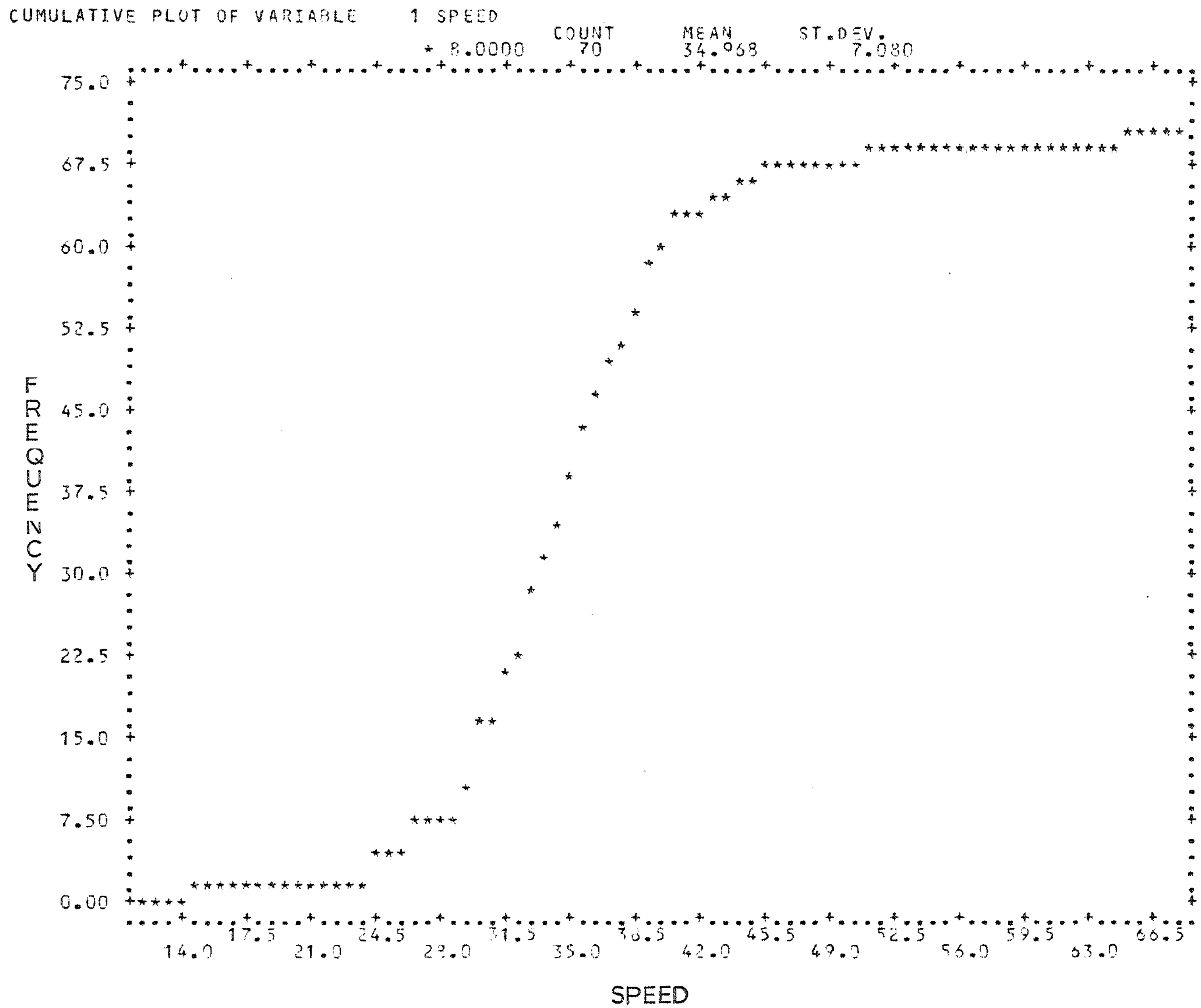


CUMULATIVE FREQUENCY DISTRIBUTION

APPROACH SPEEDS

FIRST VEHICLE TO STOP

UNIVERSITY DRIVE

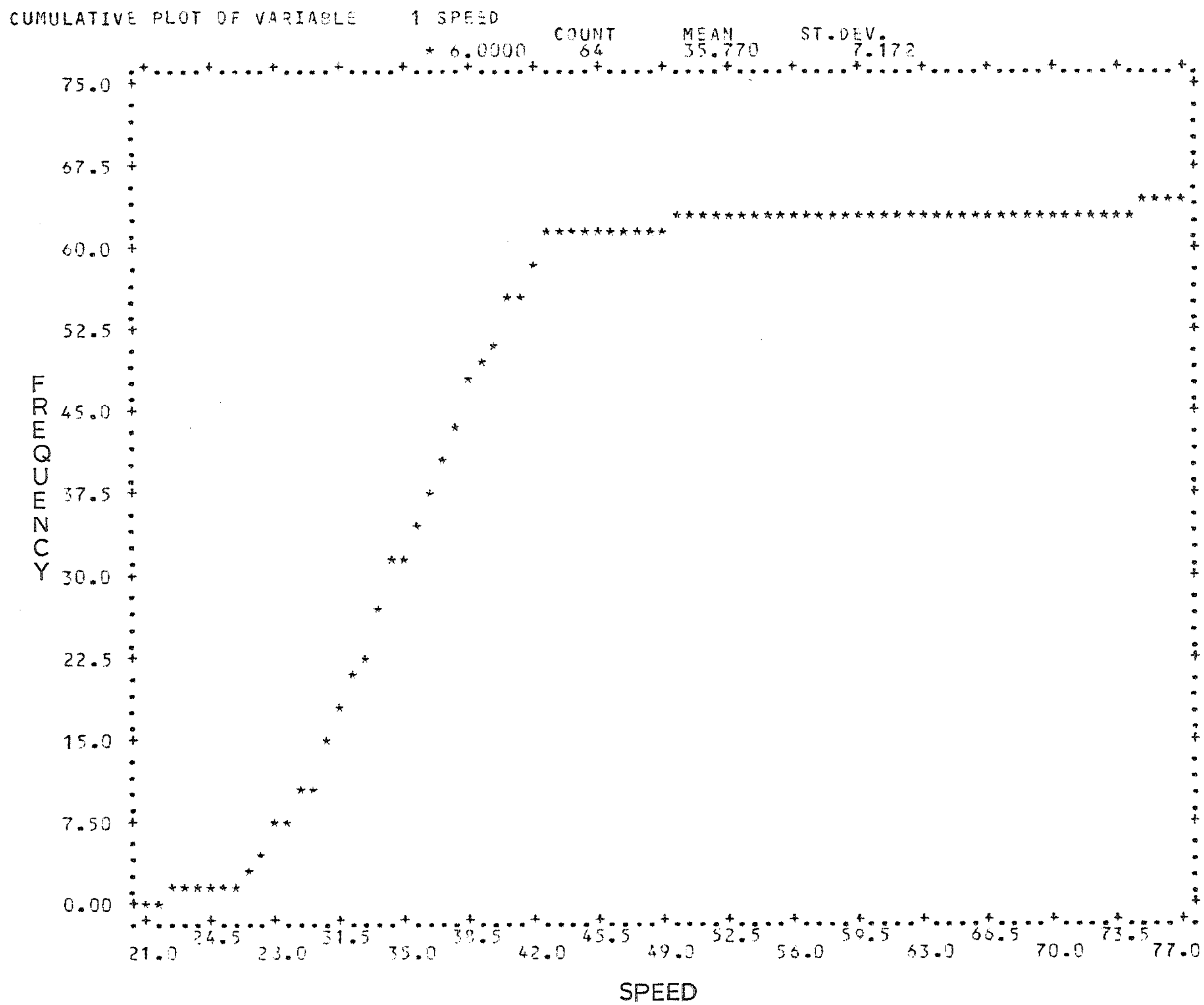


CUMULATIVE FREQUENCY DISTRIBUTION

APPROACH SPEEDS

FIRST VEHICLE TO STOP

SOUTHERN AVENUE (DAY)

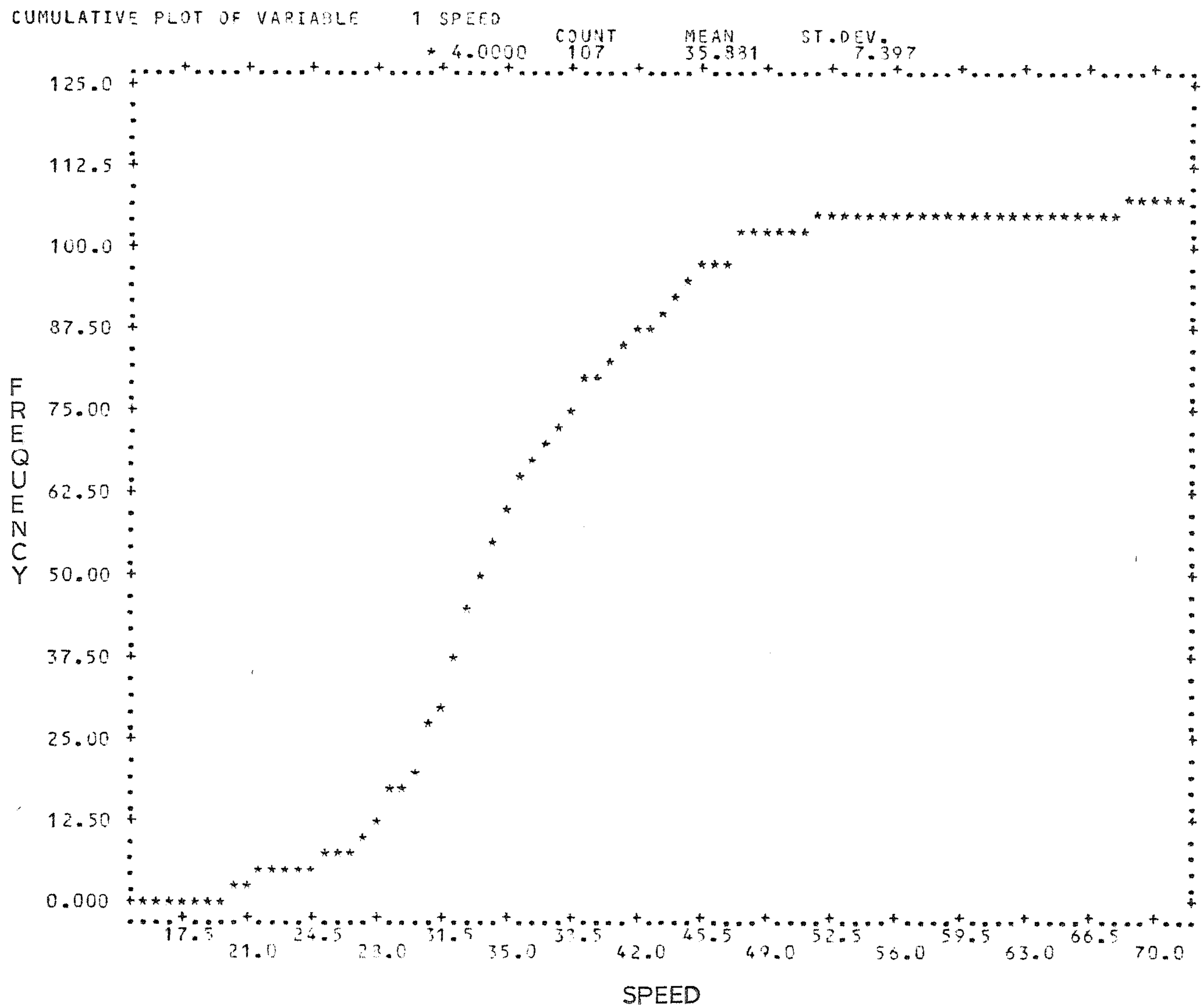


CUMULATIVE FREQUENCY DISTRIBUTION

APPROACH SPEEDS

FIRST VEHICLE TO STOP

SOUTHERN AVENUE (NIGHT)

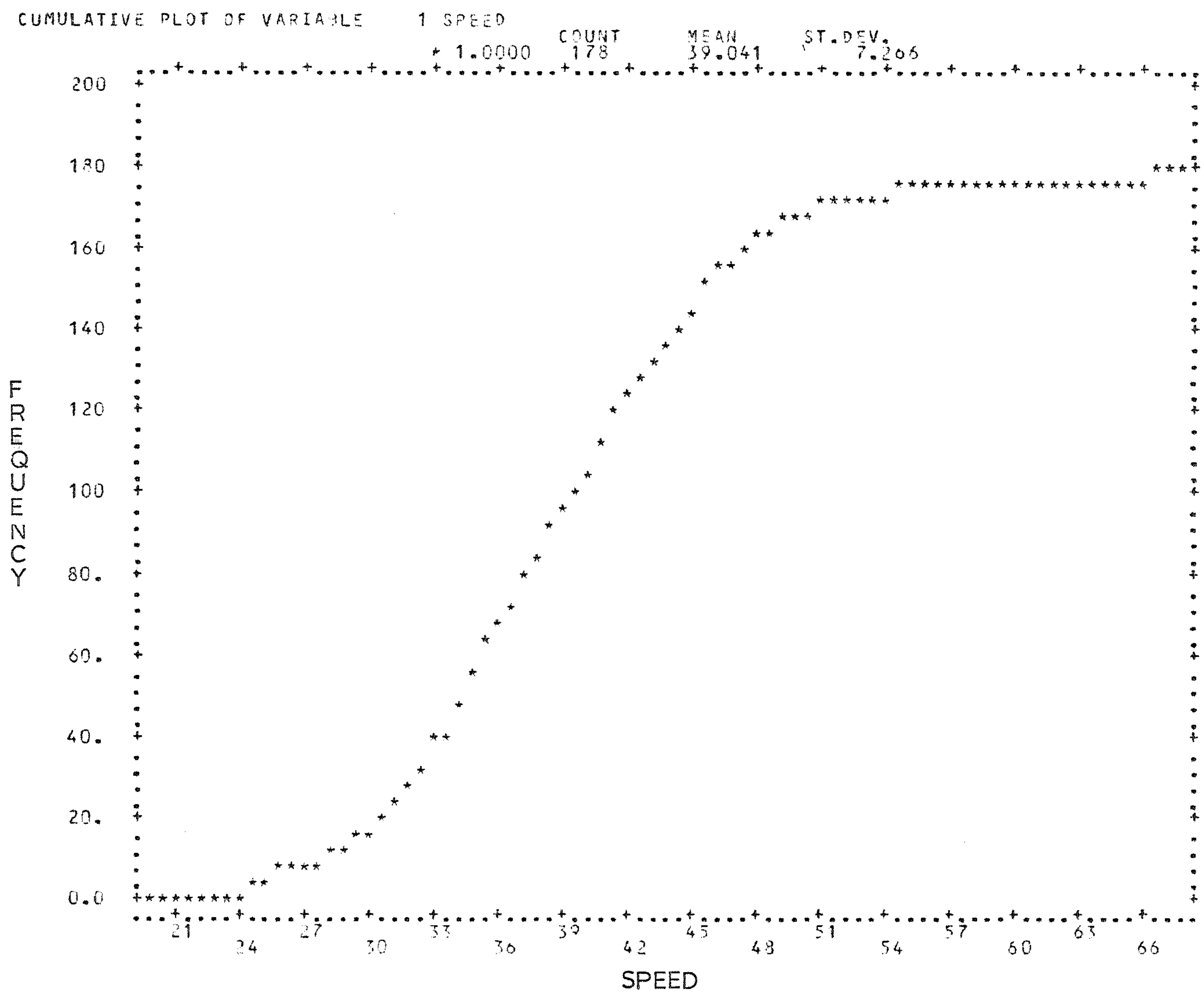


CUMULATIVE FREQUENCY DISTRIBUTION

APPROACH SPEEDS

FIRST VEHICLE TO STOP

U. S. 60

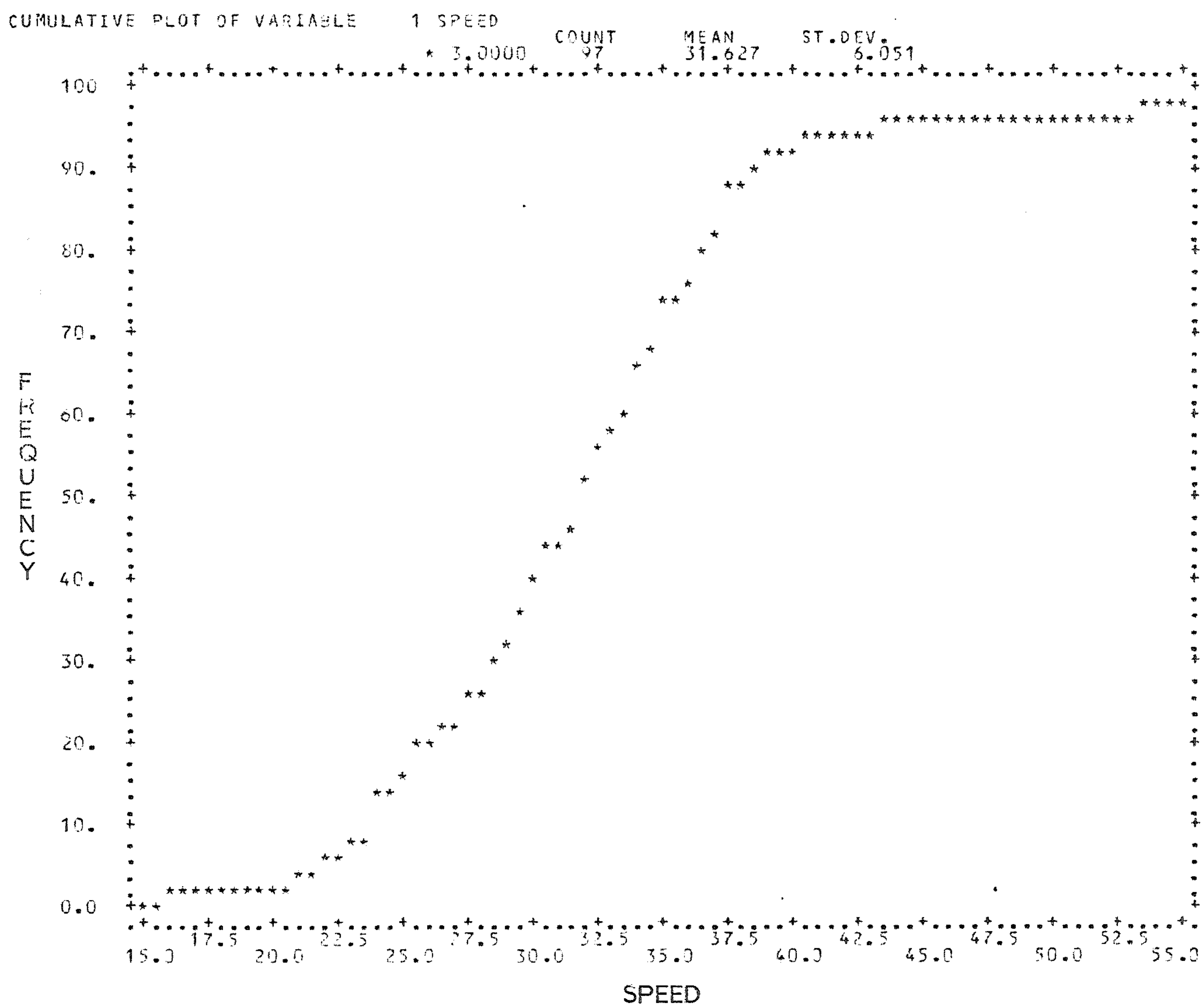


CUMULATIVE FREQUENCY DISTRIBUTION

APPROACH SPEEDS

FIRST VEHICLE TO STOP

FIRST AVENUE

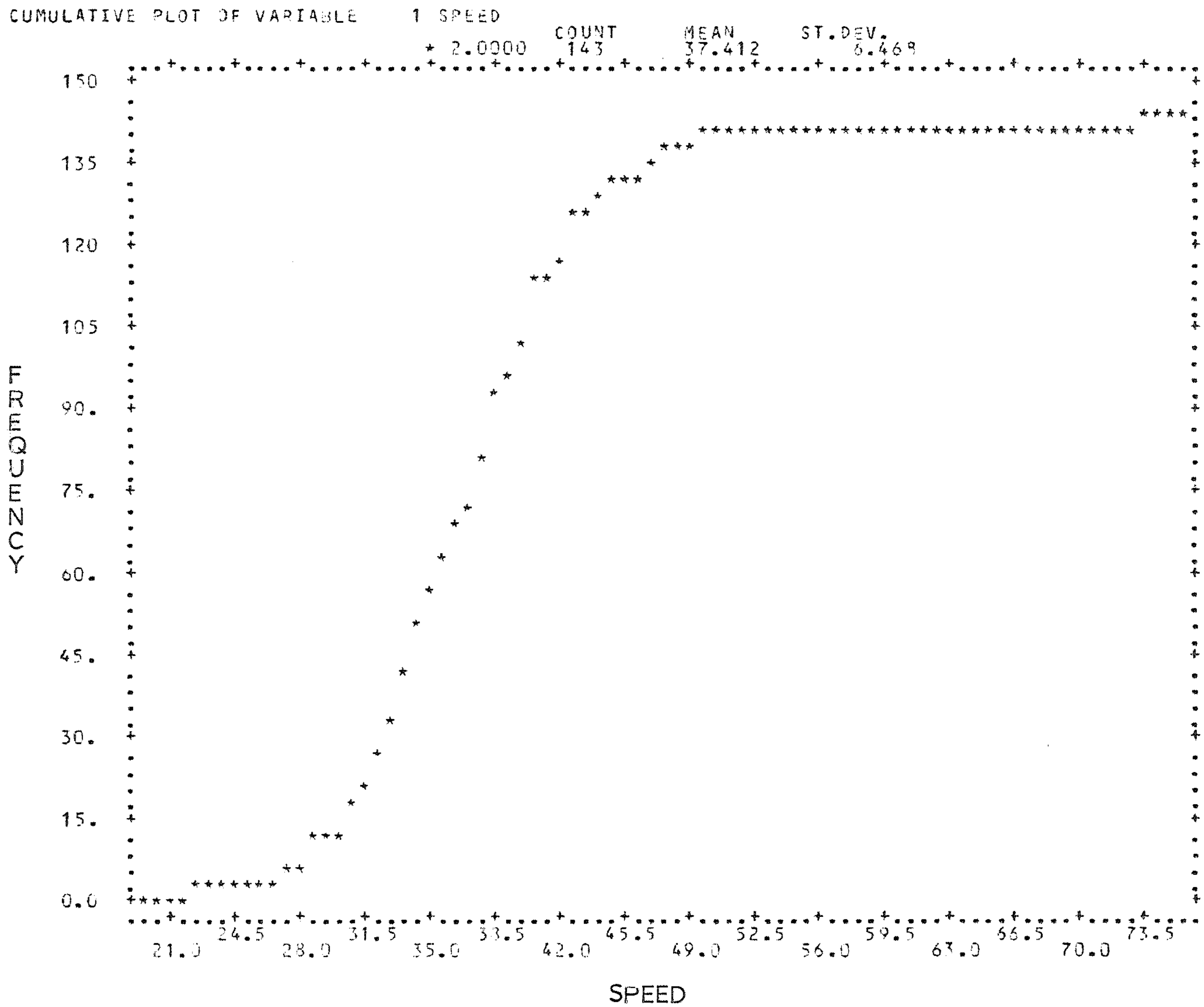


CUMULATIVE FREQUENCY DISTRIBUTION

APPROACH SPEEDS

FIRST VEHICLE TO STOP

SIXTH STREET

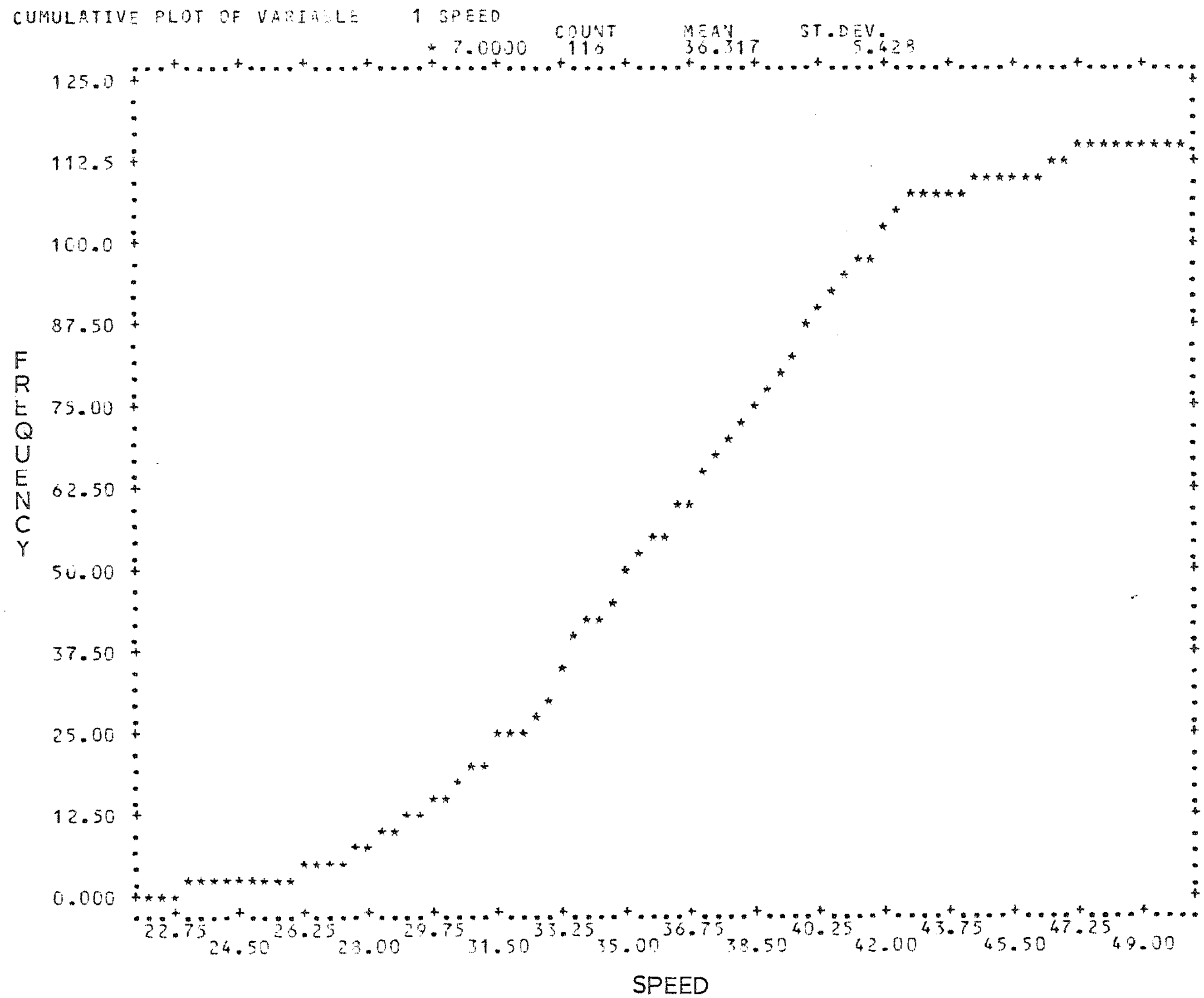


CUMULATIVE FREQUENCY DISTRIBUTION

APPROACH SPEEDS

FIRST VEHICLE TO STOP

BROADWAY BOULEVARD (DAY)



CUMULATIVE FREQUENCY DISTRIBUTION

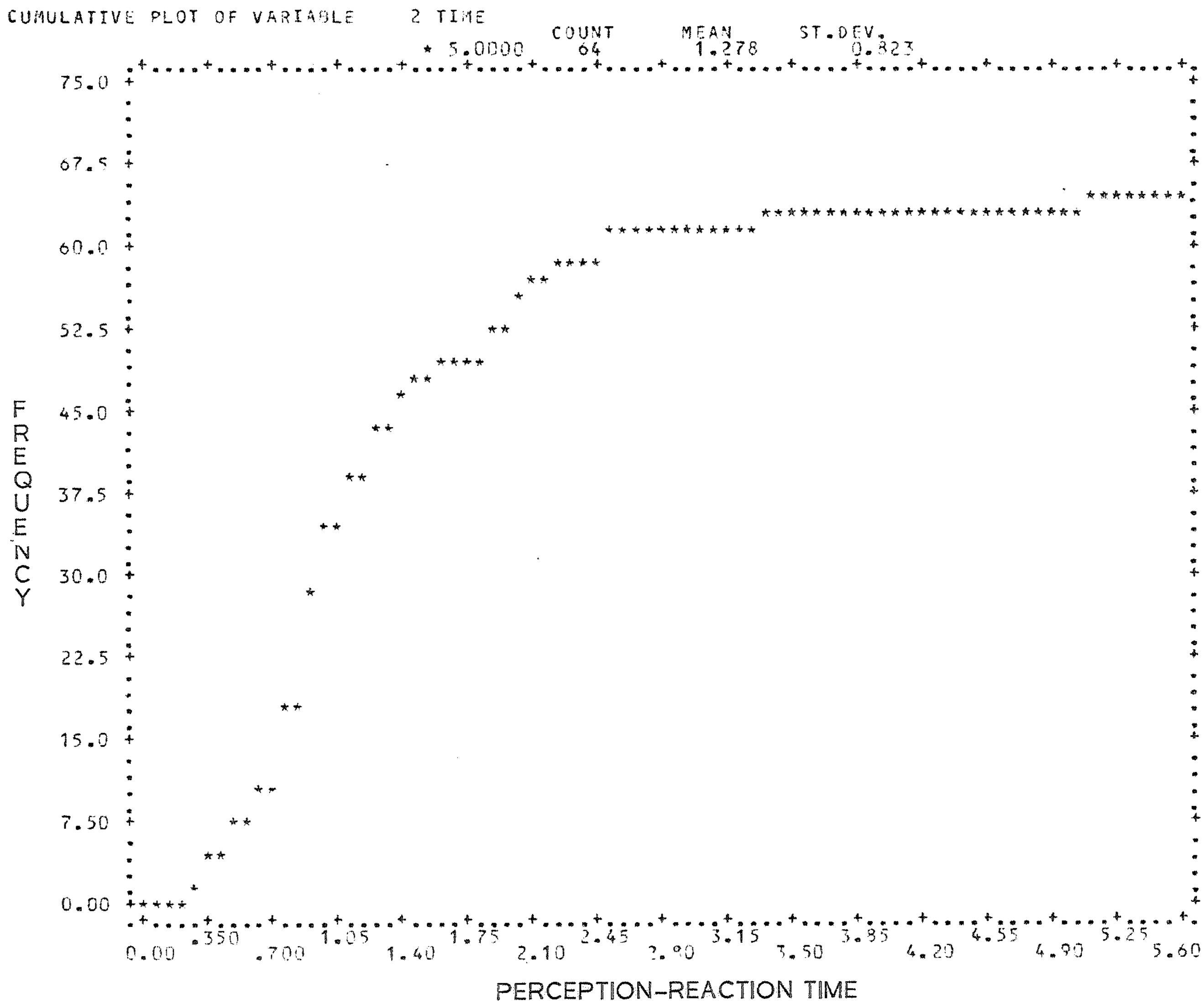
APPROACH SPEEDS

FIRST VEHICLE TO STOP

BROADWAY BOULEVARD (NIGHT)

APPENDIX B

PERCEPTION-REACTION TIMES
FIRST VEHICLE TO STOP

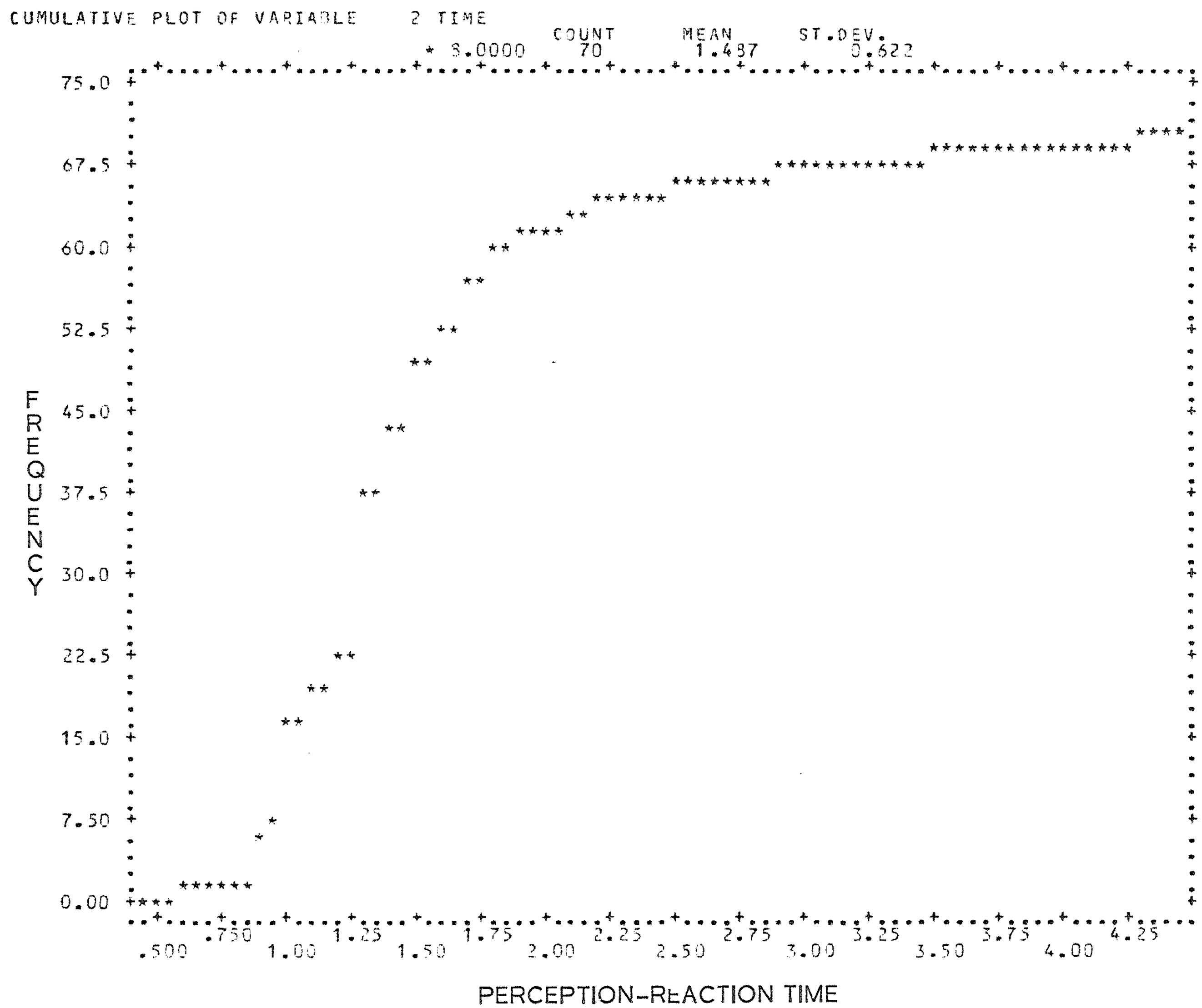


CUMULATIVE FREQUENCY DISTRIBUTION

PERCEPTION-REACTION TIMES

FIRST VEHICLE TO STOP

UNIVERSITY DRIVE

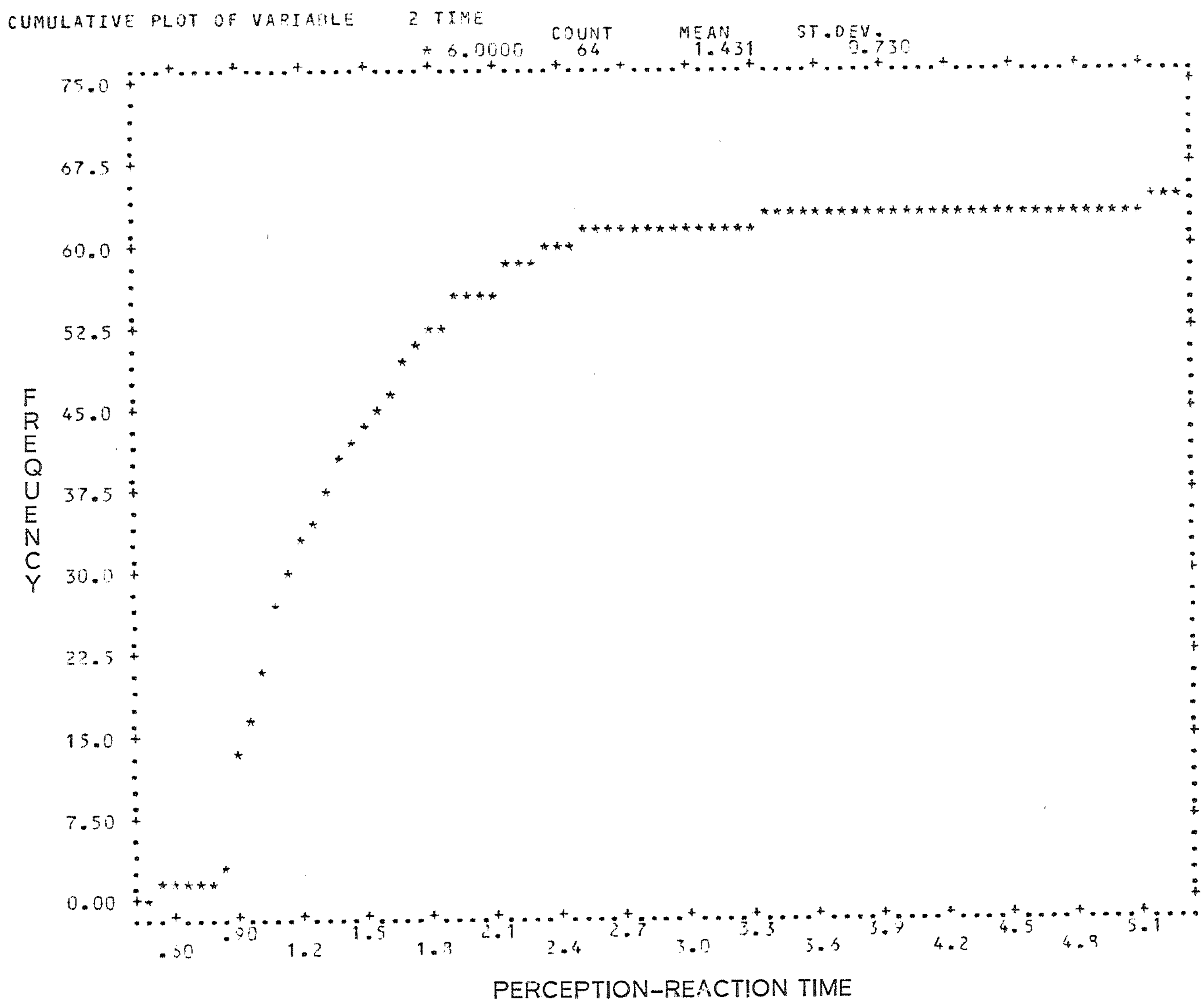


CUMULATIVE FREQUENCY DISTRIBUTION

PERCEPTION-REACTION TIMES

FIRST VEHICLE TO STOP

SOUTHERN AVENUE (DAY)

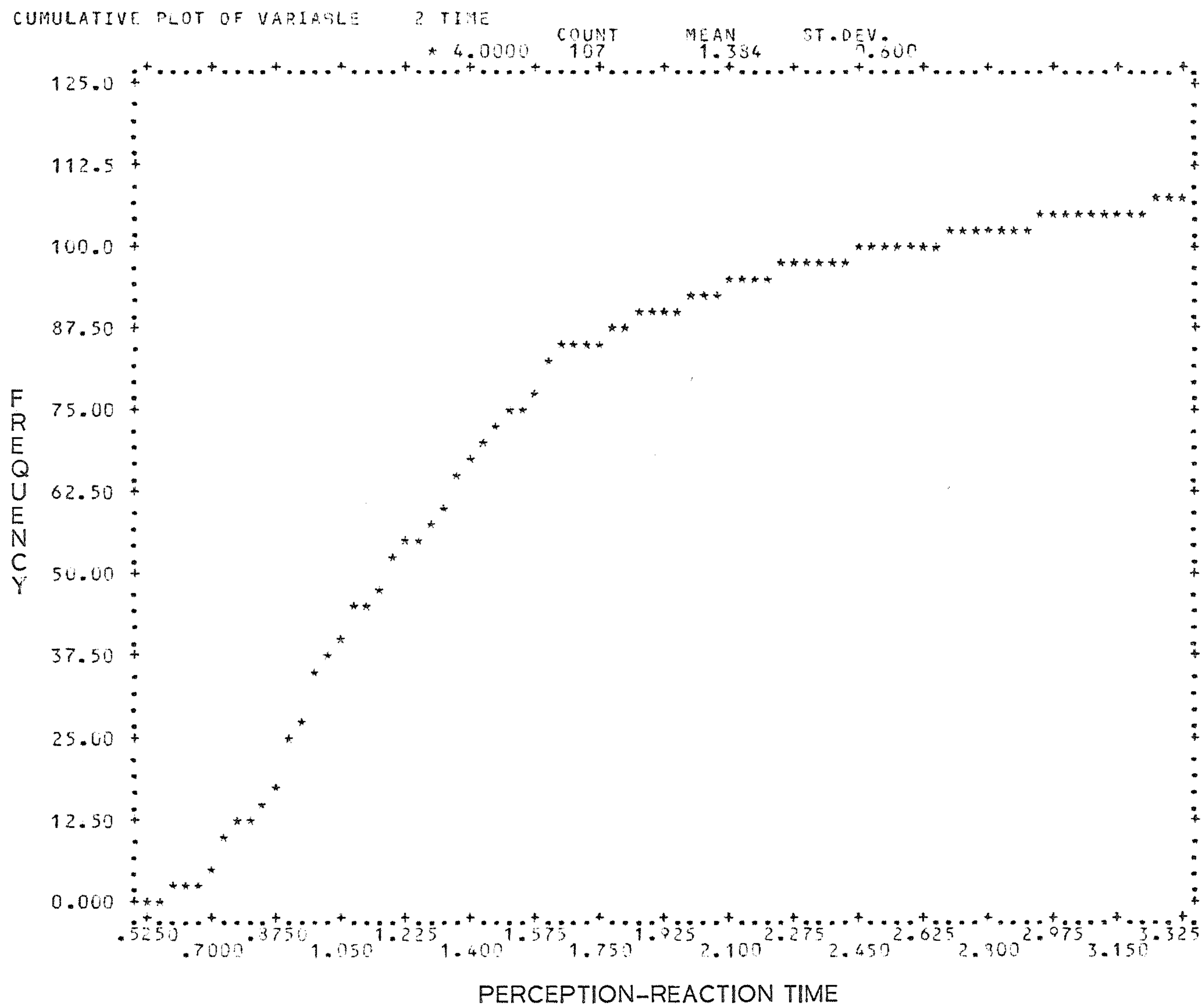


CUMULATIVE FREQUENCY DISTRIBUTION

PERCEPTION-REACTION TIMES

FIRST VEHICLE TO STOP

SOUTHERN AVENUE (NIGHT)

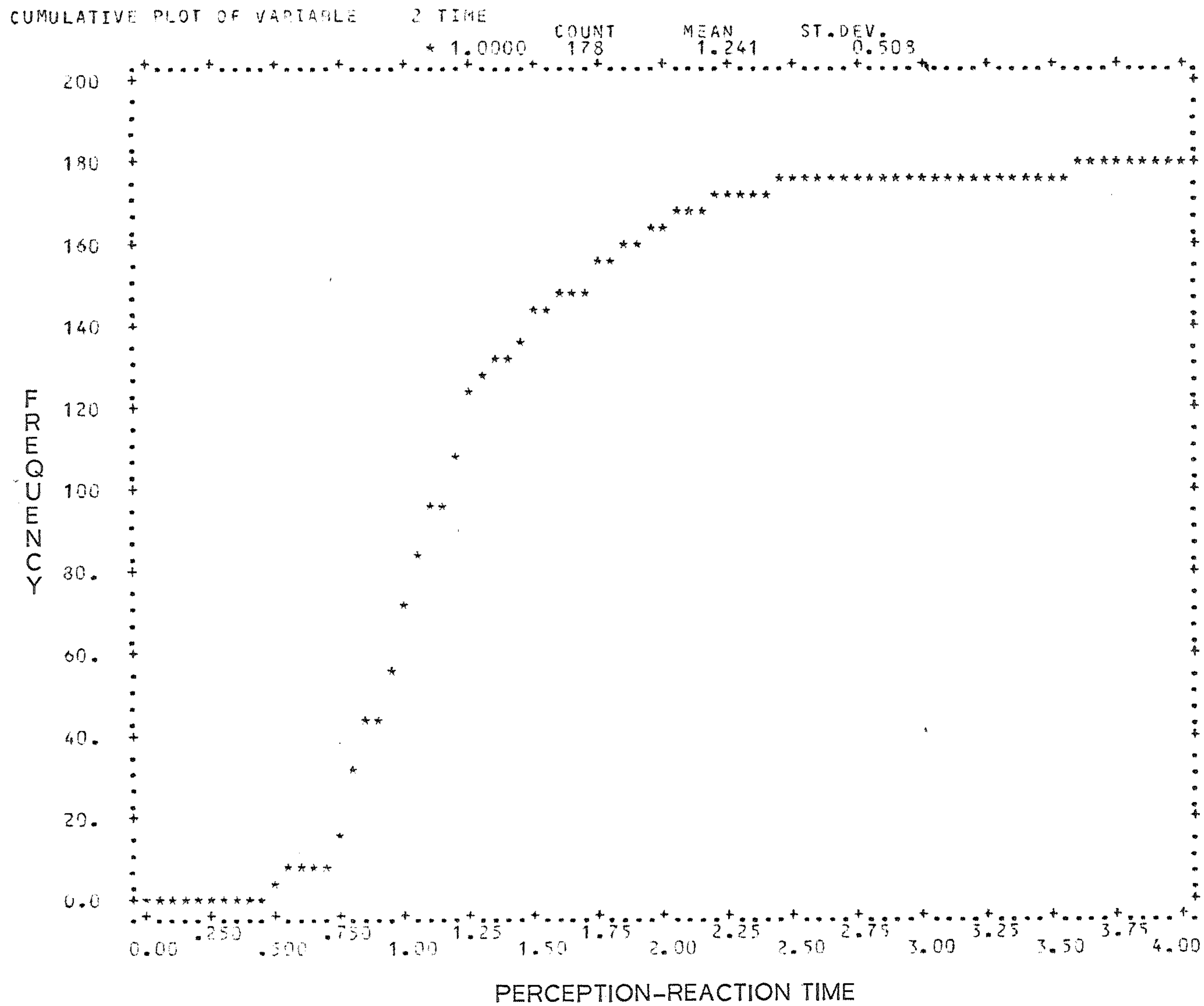


CUMULATIVE FREQUENCY DISTRIBUTION

PERCEPTION-REACTION TIMES

FIRST VEHICLE TO STOP

U. S. 60

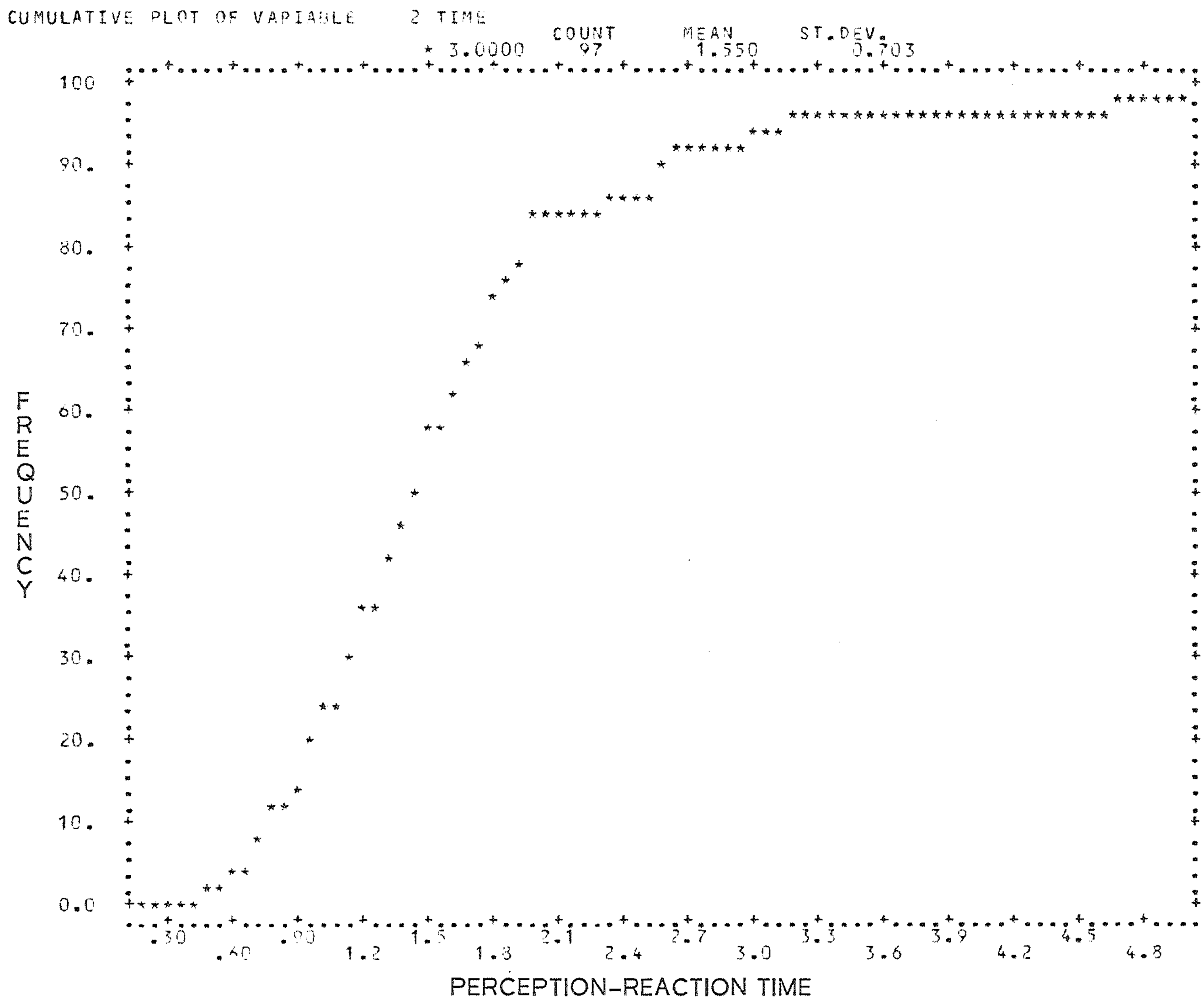


CUMULATIVE FREQUENCY DISTRIBUTION

PERCEPTION-REACTION TIMES

FIRST VEHICLE TO STOP

FIRST AVENUE

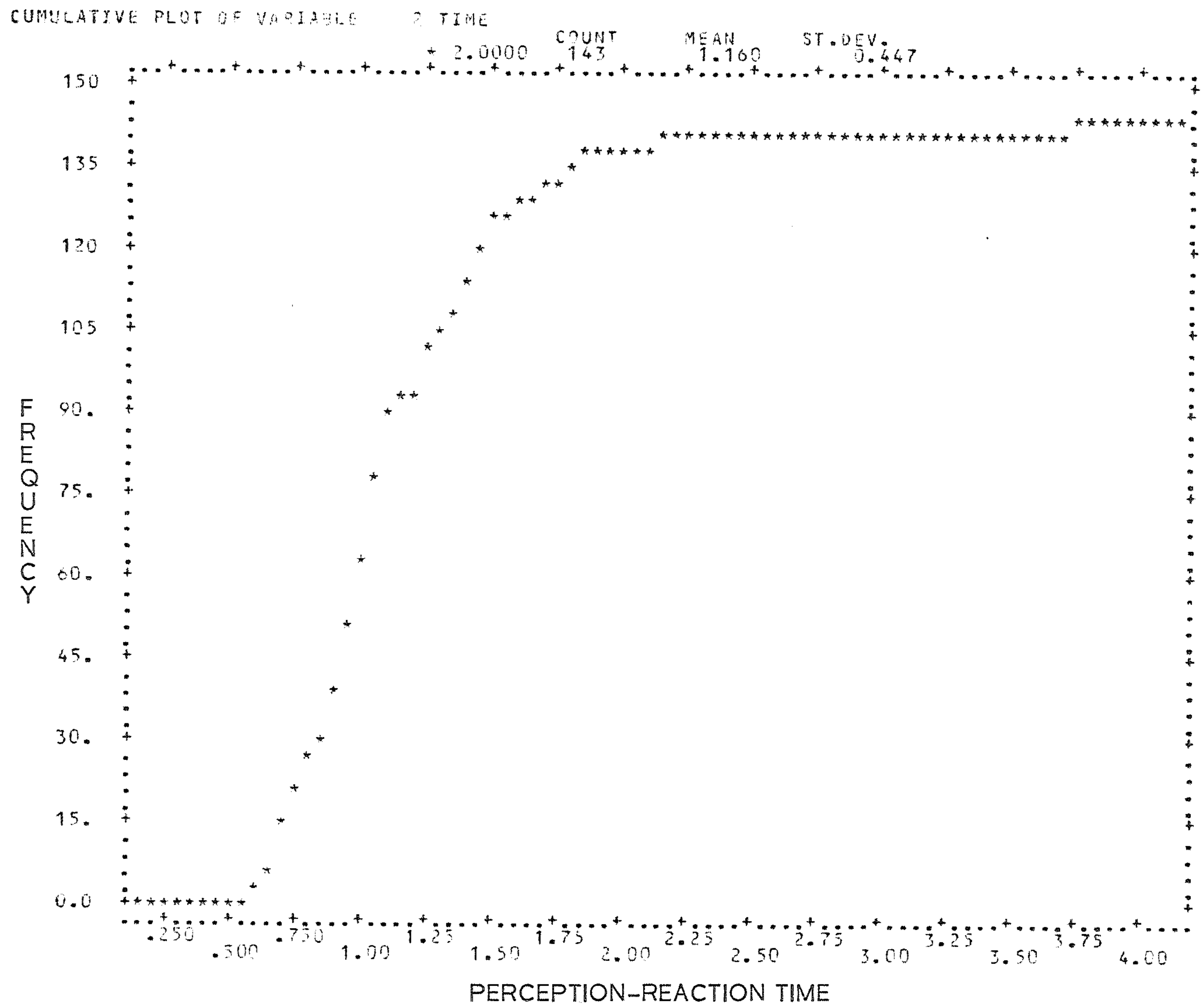


CUMULATIVE FREQUENCY DISTRIBUTION

PERCEPTION-REACTION TIMES

FIRST VEHICLE TO STOP

SIXTH STREET

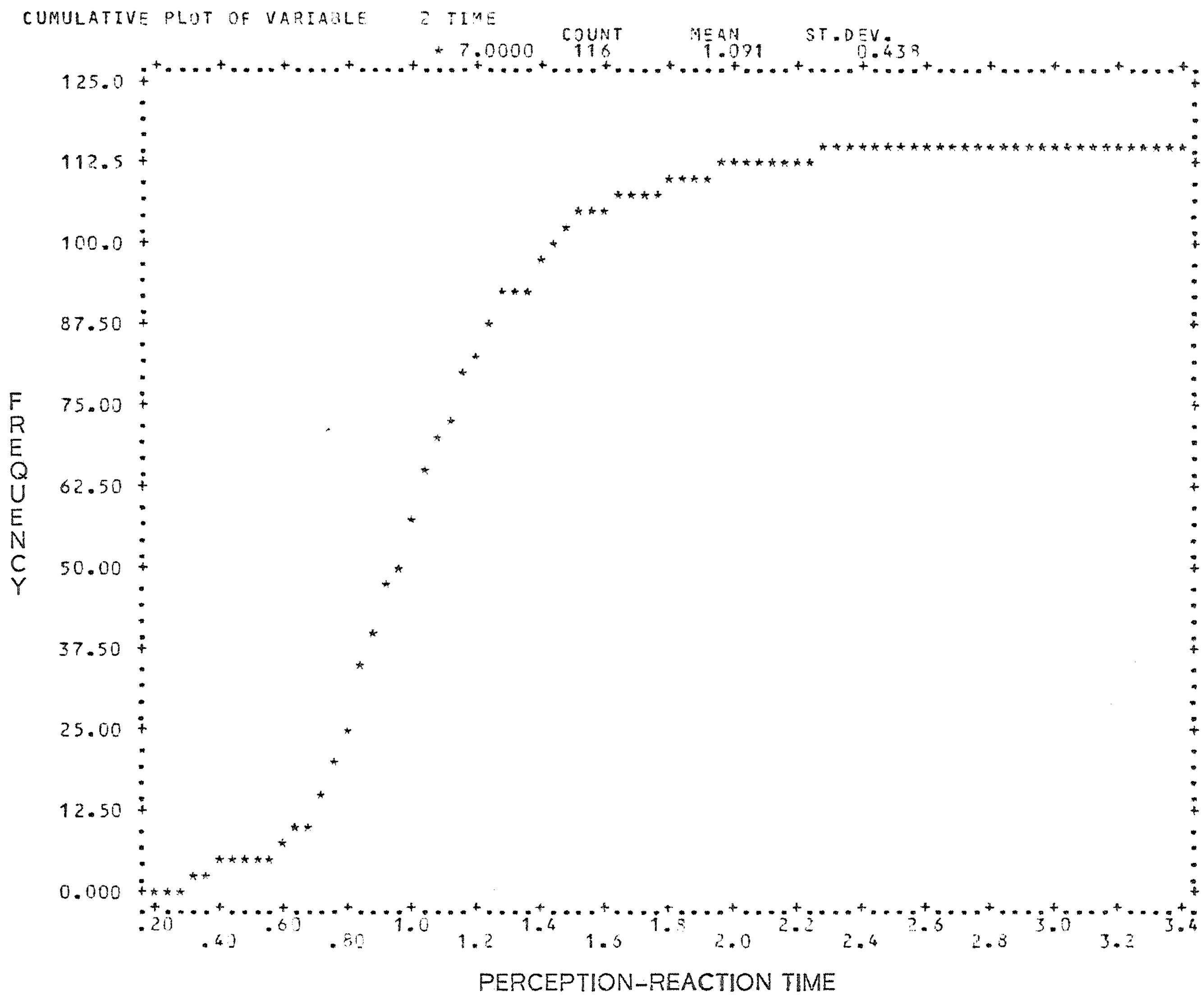


CUMULATIVE FREQUENCY DISTRIBUTION

PERCEPTION-REACTION TIMES

FIRST VEHICLE TO STOP

BROADWAY BOULEVARD (DAY)



CUMULATIVE FREQUENCY DISTRIBUTION

PERCEPTION-REACTION TIMES

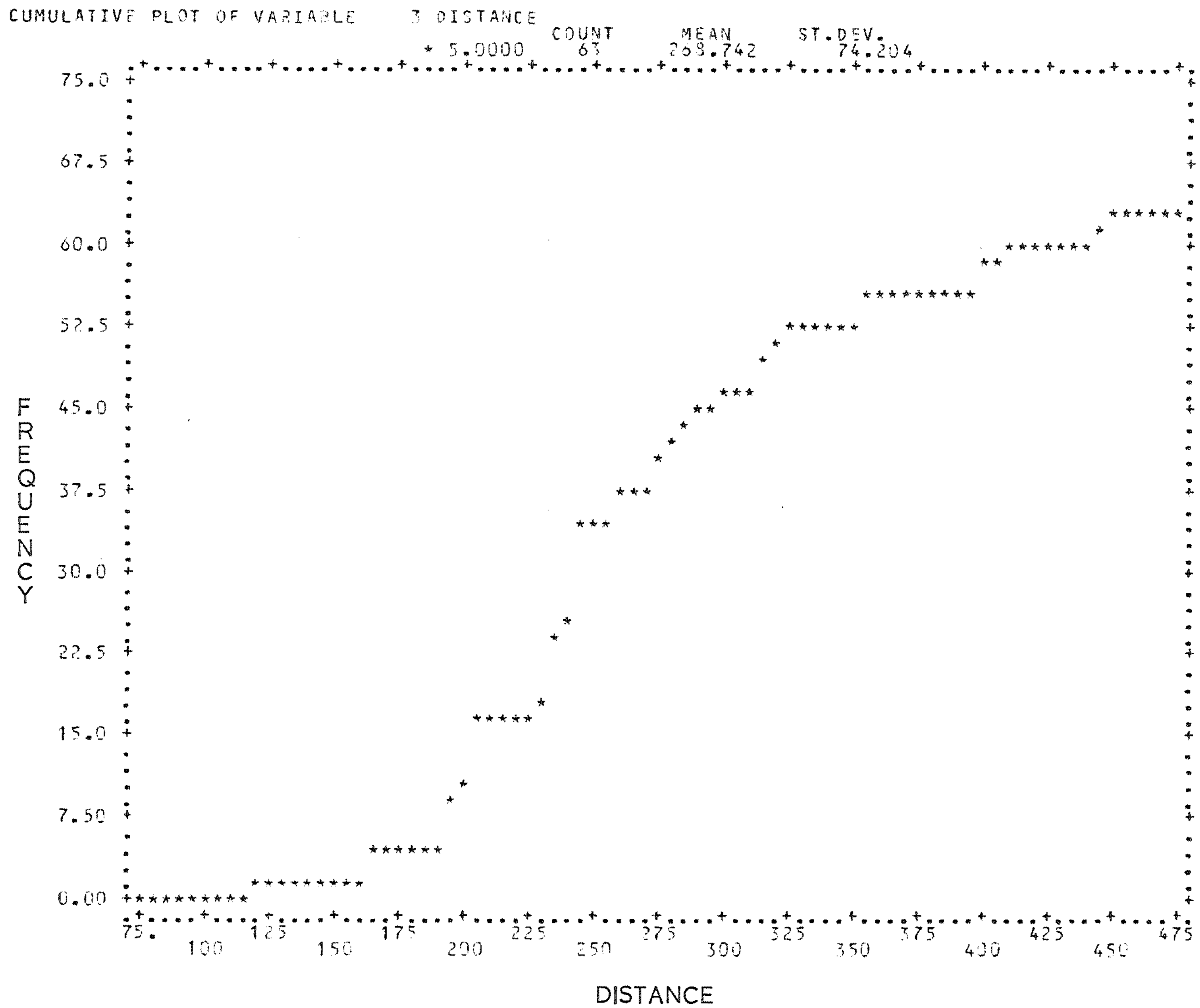
FIRST VEHICLE TO STOP

BROADWAY BOULEVARD (NIGHT)

APPENDIX C

DISTANCE FROM INTERSECTION AT THE BEGINNING OF YELLOW

FIRST VEHICLE TO STOP

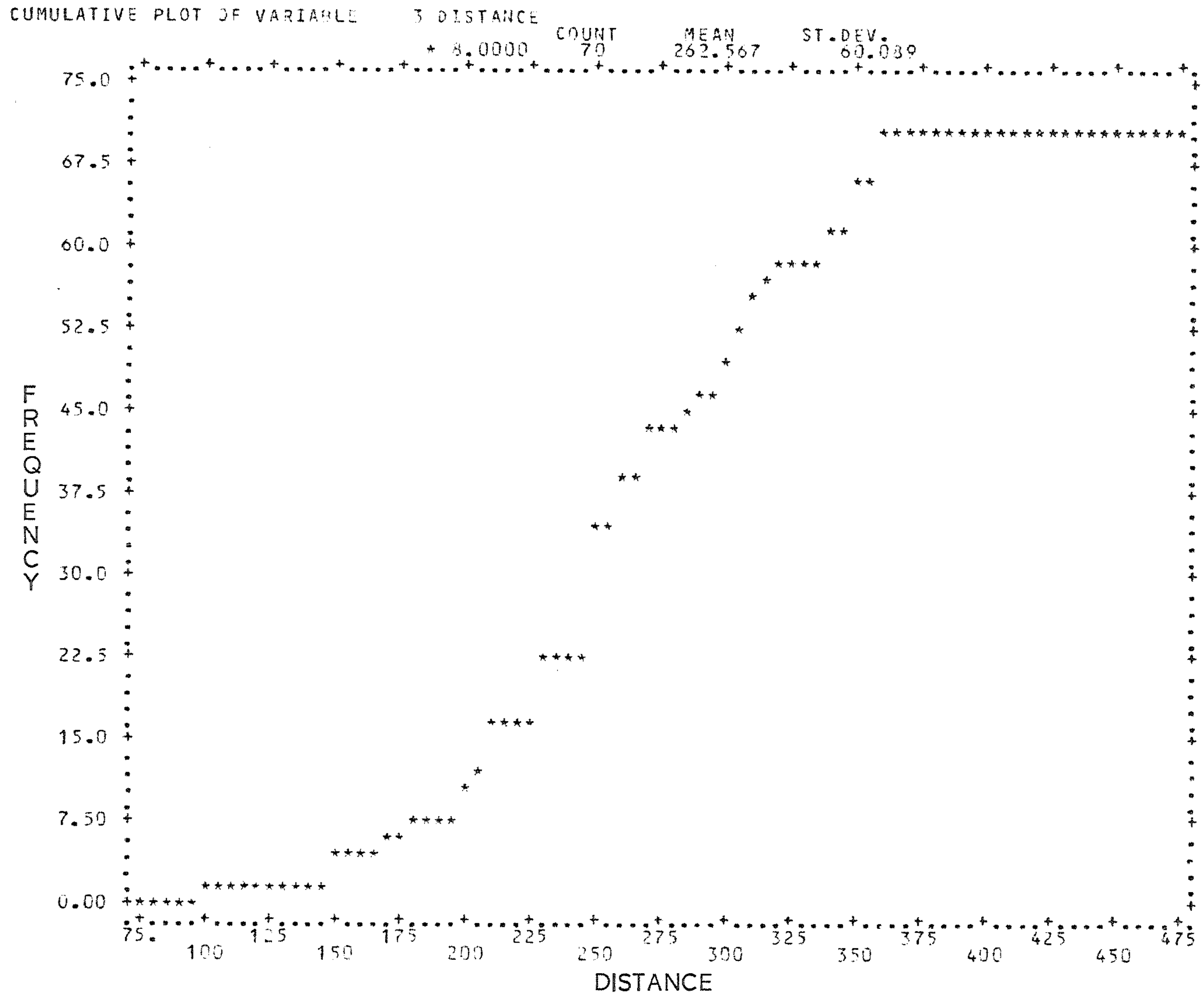


CUMULATIVE FREQUENCY DISTRIBUTION

DISTANCE FROM THE INTERSECTION AT THE BEGINNING OF YELLOW

FIRST VEHICLE TO STOP

UNIVERSITY DRIVE

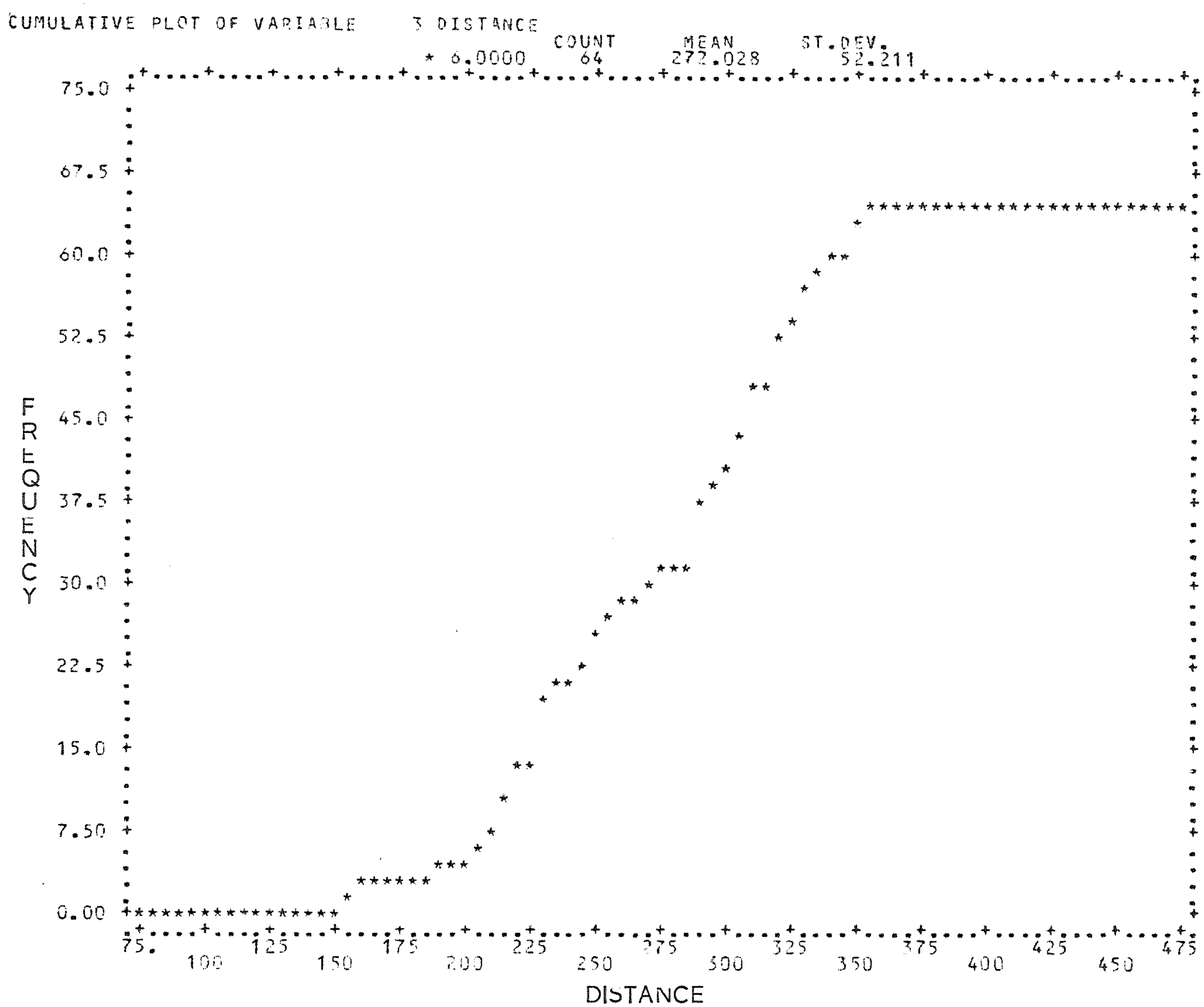


CUMULATIVE FREQUENCY DISTRIBUTION

DISTANCE FROM THE INTERSECTION AT THE BEGINNING OF YELLOW

FIRST VEHICLE TO STOP

SOUTHERN AVENUE (DAY)

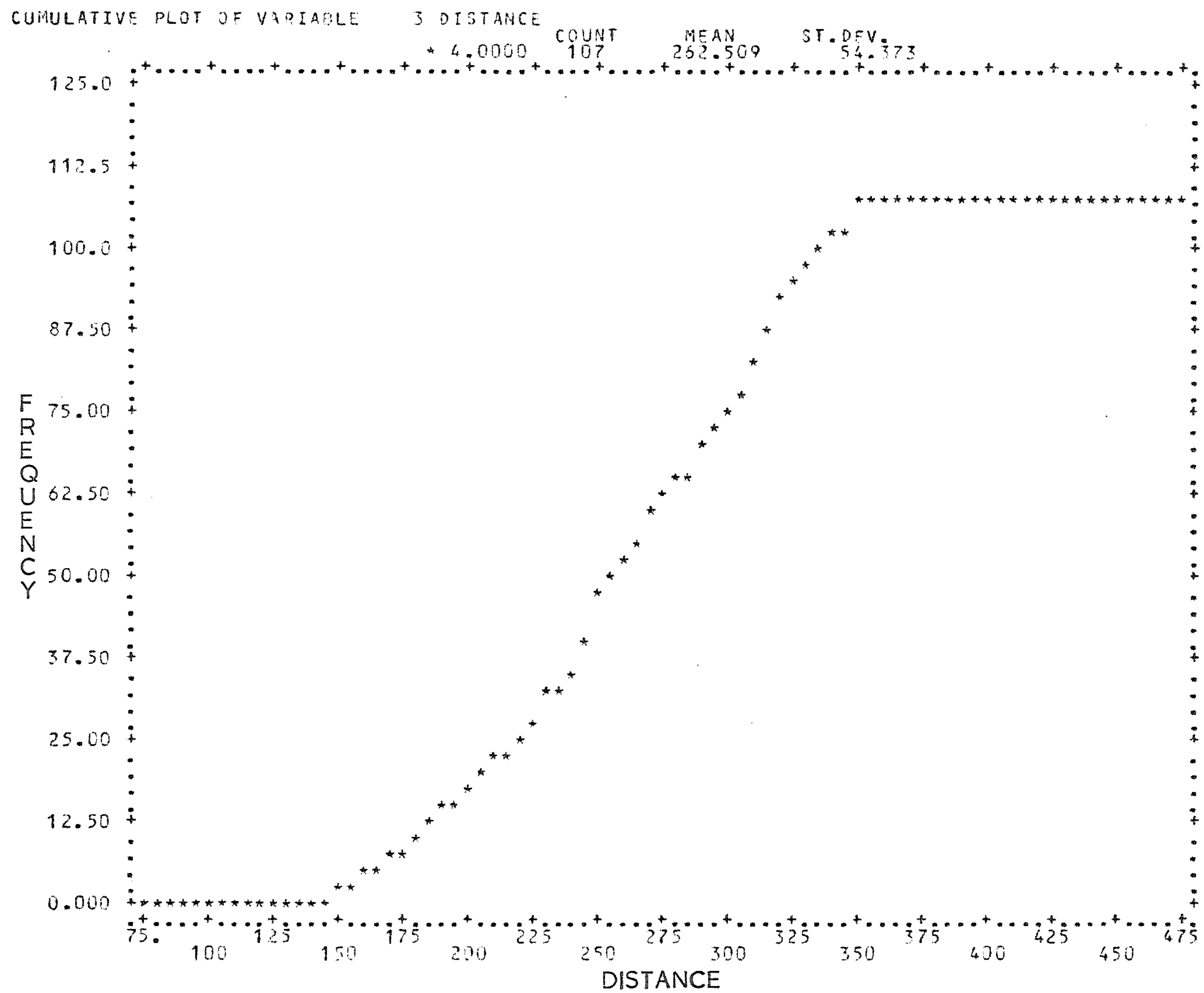


CUMULATIVE FREQUENCY DISTRIBUTION

DISTANCE FROM THE INTERSECTION AT THE BEGINNING OF YELLOW

FIRST VEHICLE TO STOP

SOUTHERN AVENUE (NIGHT)

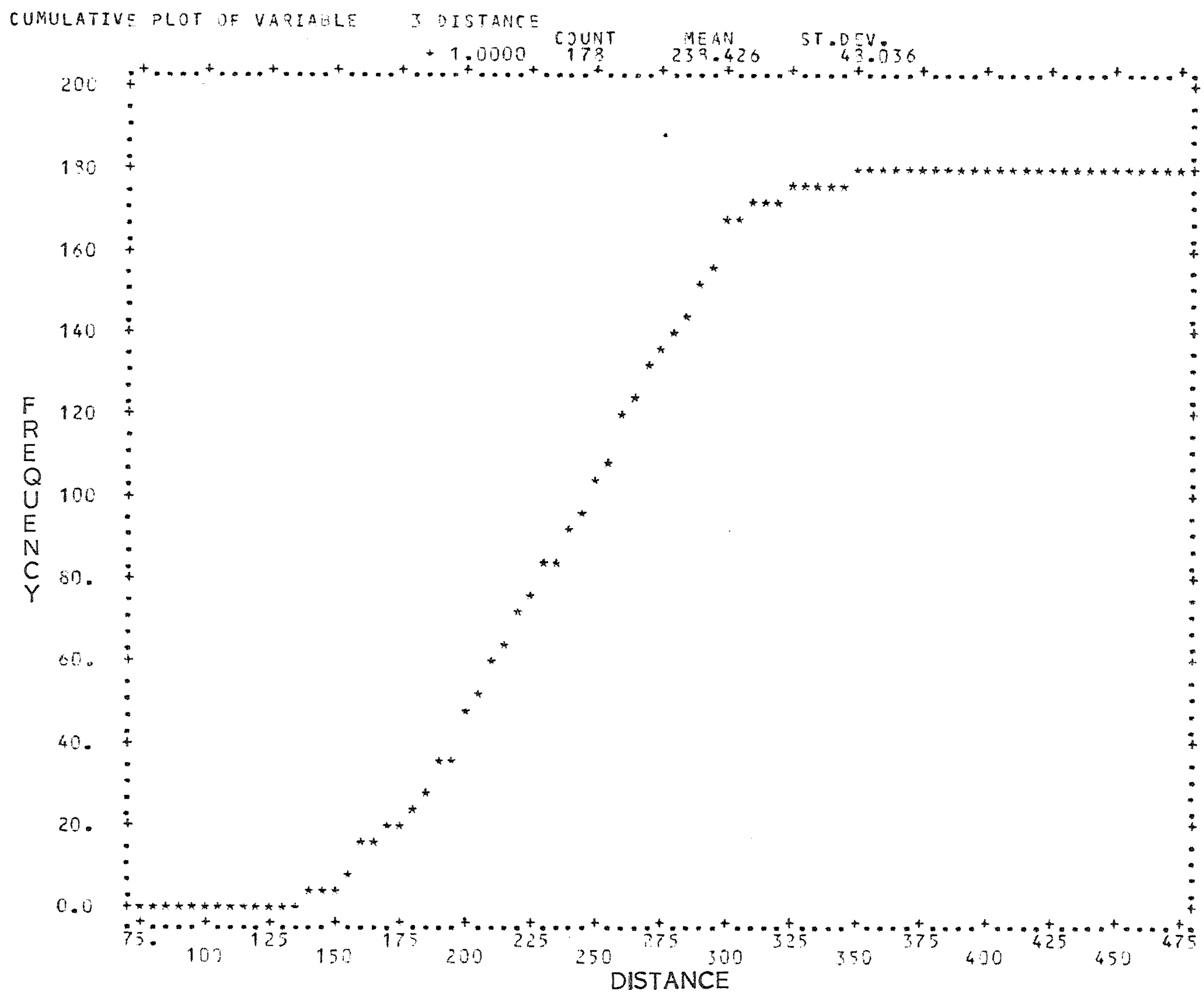


CUMULATIVE FREQUENCY DISTRIBUTION

DISTANCE FROM THE INTERSECTION AT THE BEGINNING OF YELLOW

FIRST VEHICLE TO STOP

U. S. 60

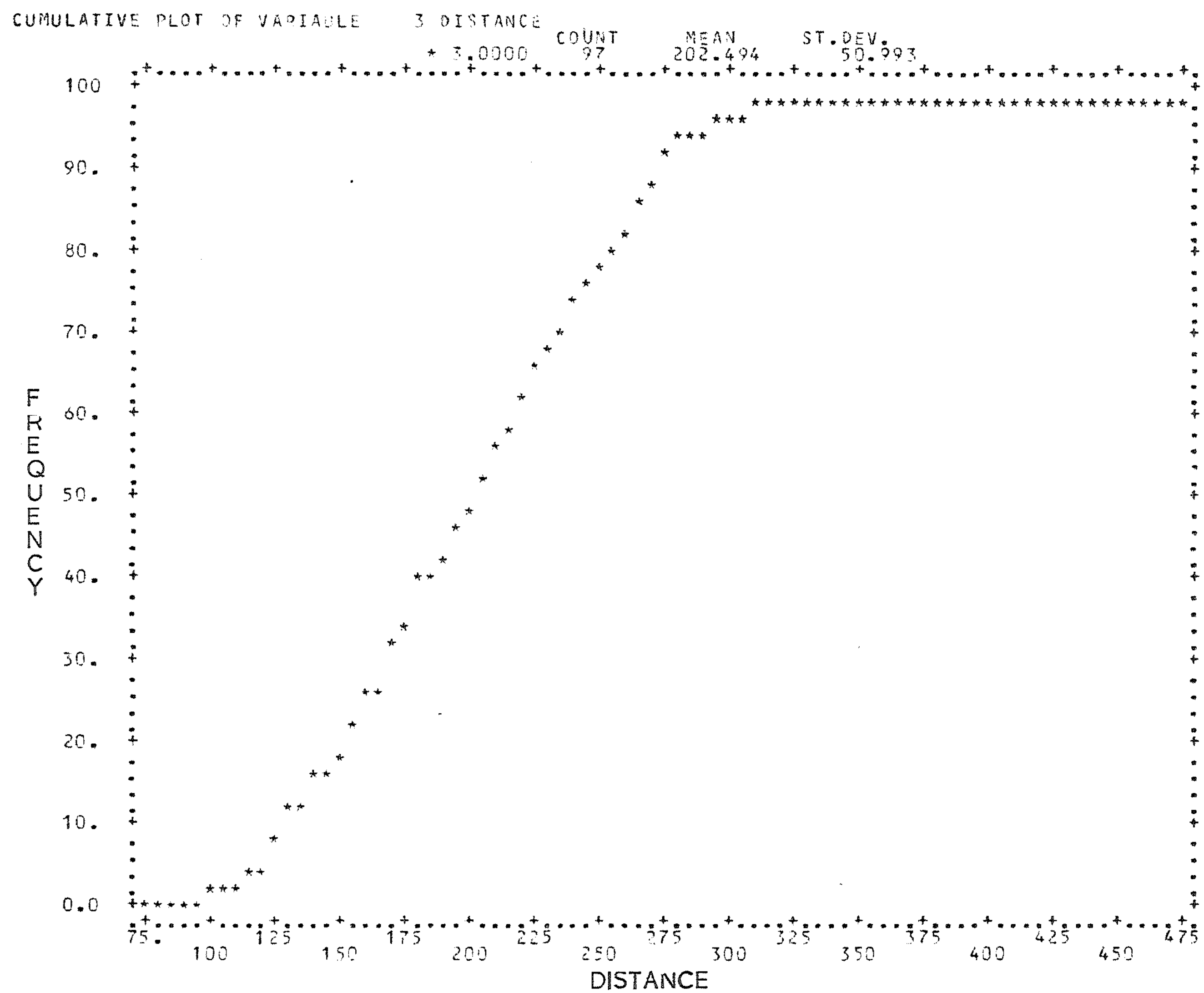


CUMULATIVE FREQUENCY DISTRIBUTION

DISTANCE FROM THE INTERSECTION AT THE BEGINNING OF YELLOW

FIRST VEHICLE TO STOP

FIRST AVENUE

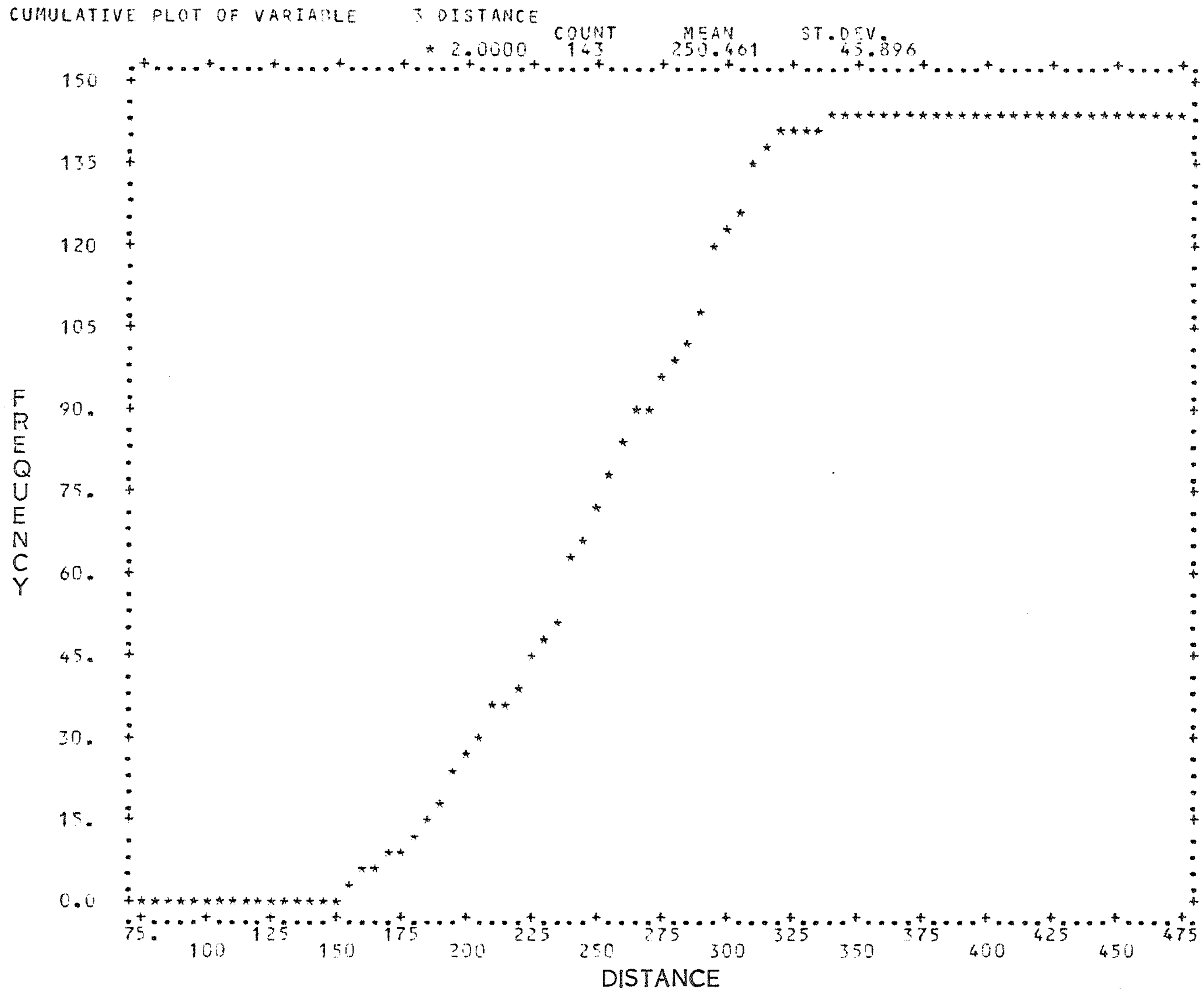


CUMULATIVE FREQUENCY DISTRIBUTION

DISTANCE FROM THE INTERSECTION AT THE BEGINNING OF YELLOW

FIRST VEHICLE TO STOP

SIXTH STREET

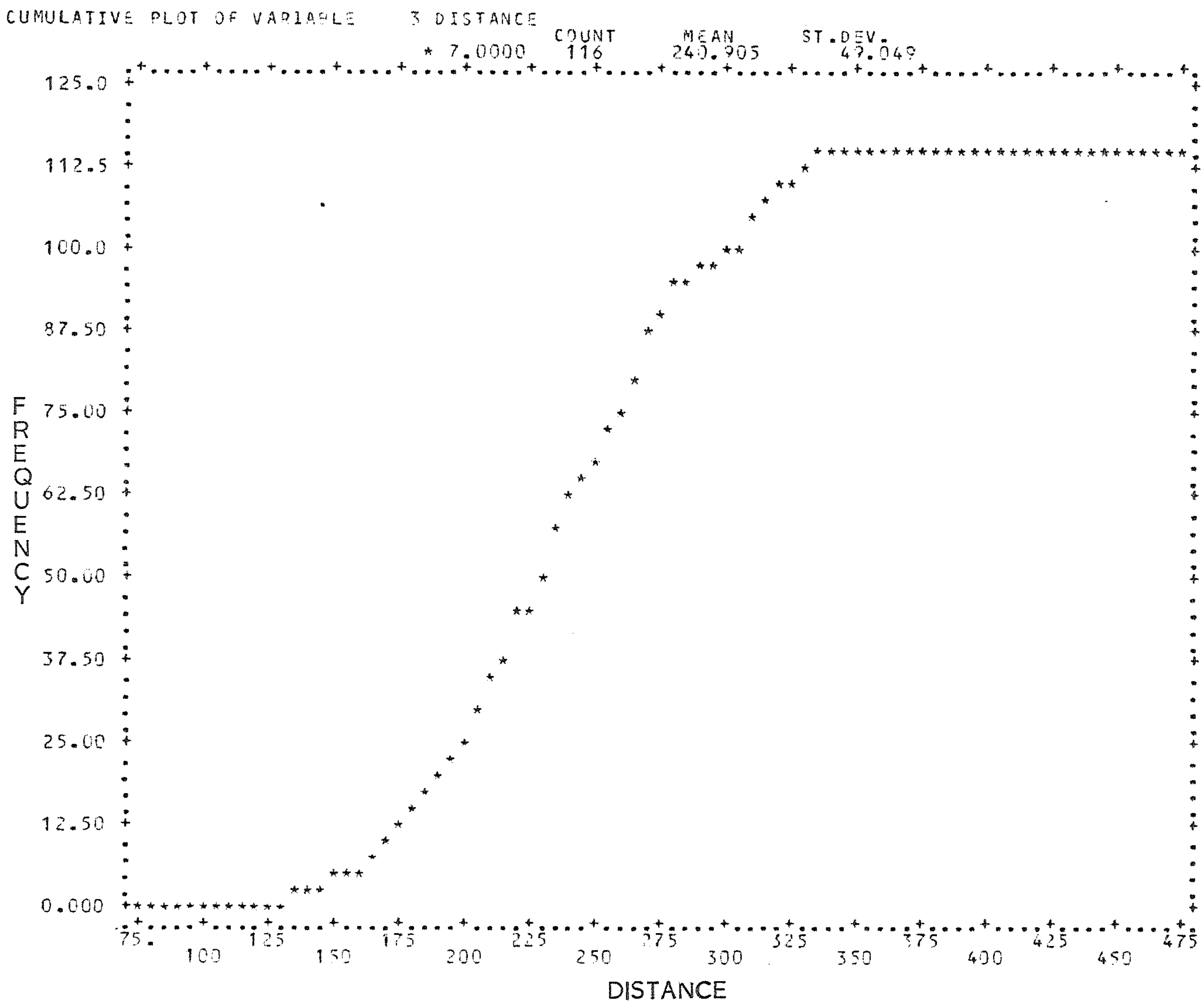


CUMULATIVE FREQUENCY DISTRIBUTION

DISTANCE FROM THE INTERSECTION AT THE BEGINNING OF YELLOW

FIRST VEHICLE TO STOP

BROADWAY BOULEVARD (DAY)



CUMULATIVE FREQUENCY DISTRIBUTION

DISTANCE FROM THE INTERSECTION AT THE BEGINNING OF YELLOW

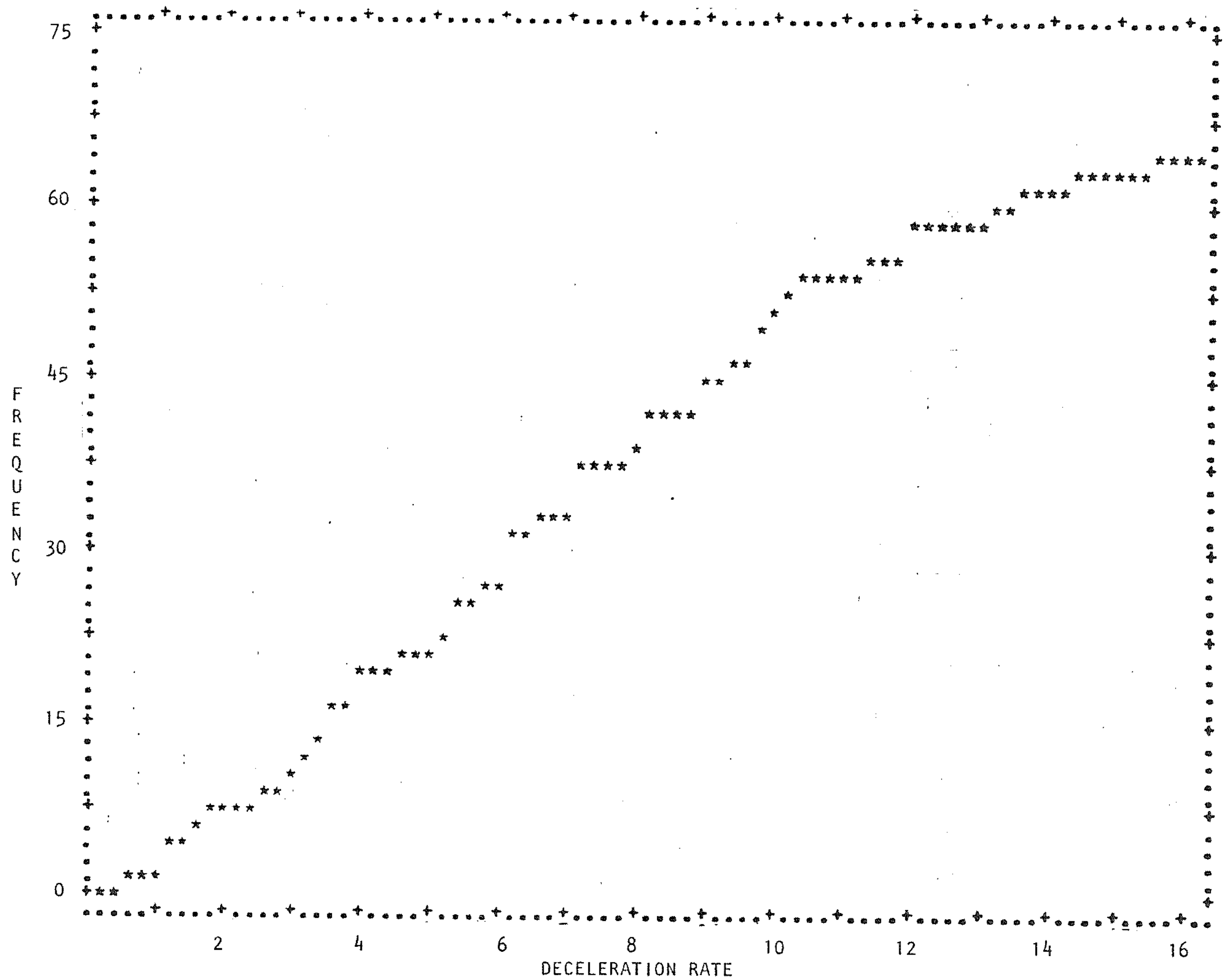
FIRST VEHICLE TO STOP

BROADWAY BOULEVARD (NIGHT)

APPENDIX D

DECELERATION RATES
FIRST VEHICLE TO STOP

COUNT - 64   MEAN - 6.957   ST. DEV. - 3.792

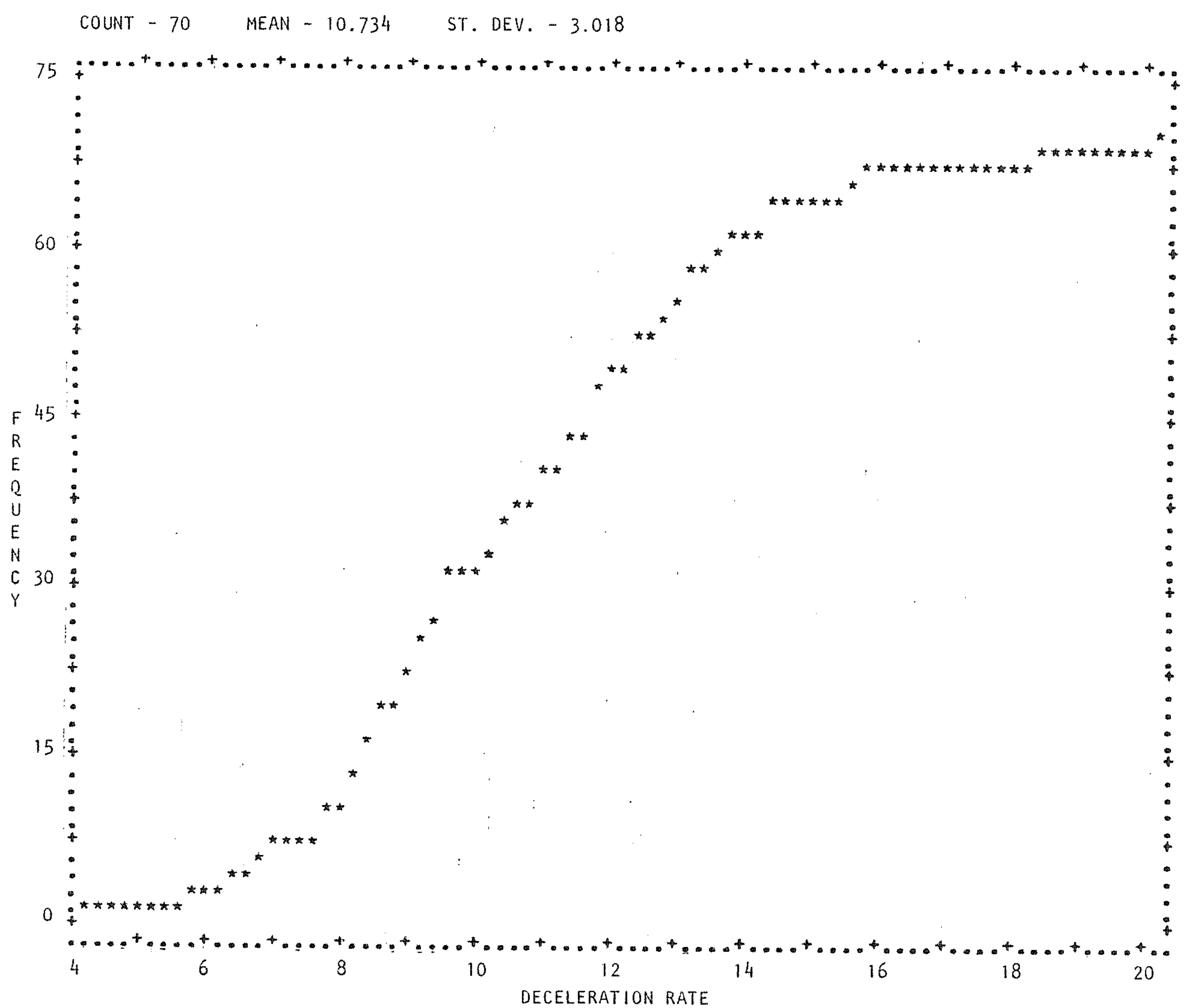


CUMULATIVE FREQUENCY DISTRIBUTION

DECELERATION RATES

FIRST VEHICLE TO STOP

UNIVERSITY DRIVE

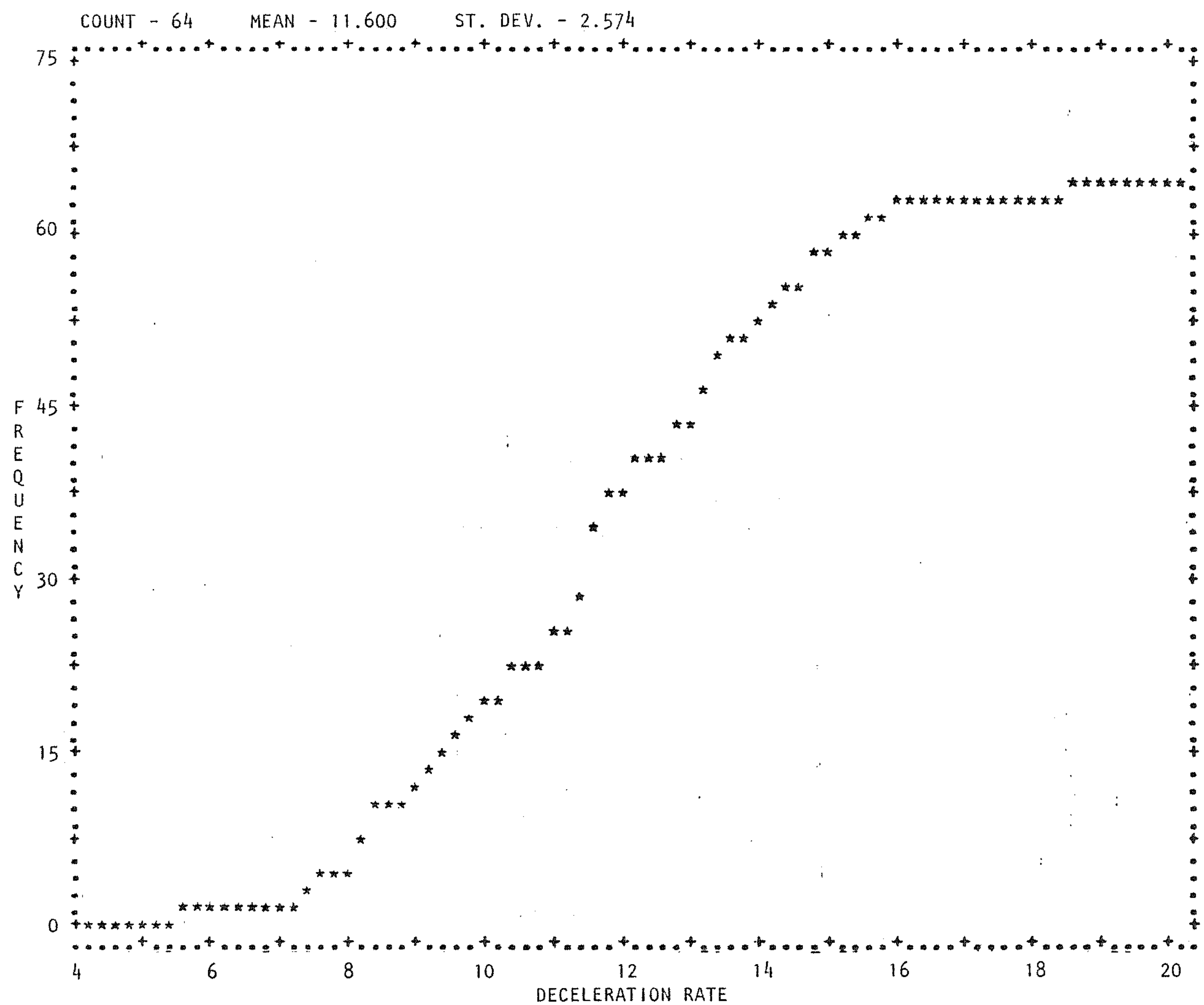


CUMULATIVE FREQUENCY DISTRIBUTION

DECELERATION RATES

FIRST VEHICLE TO STOP

SOUTHERN AVENUE (DAY)



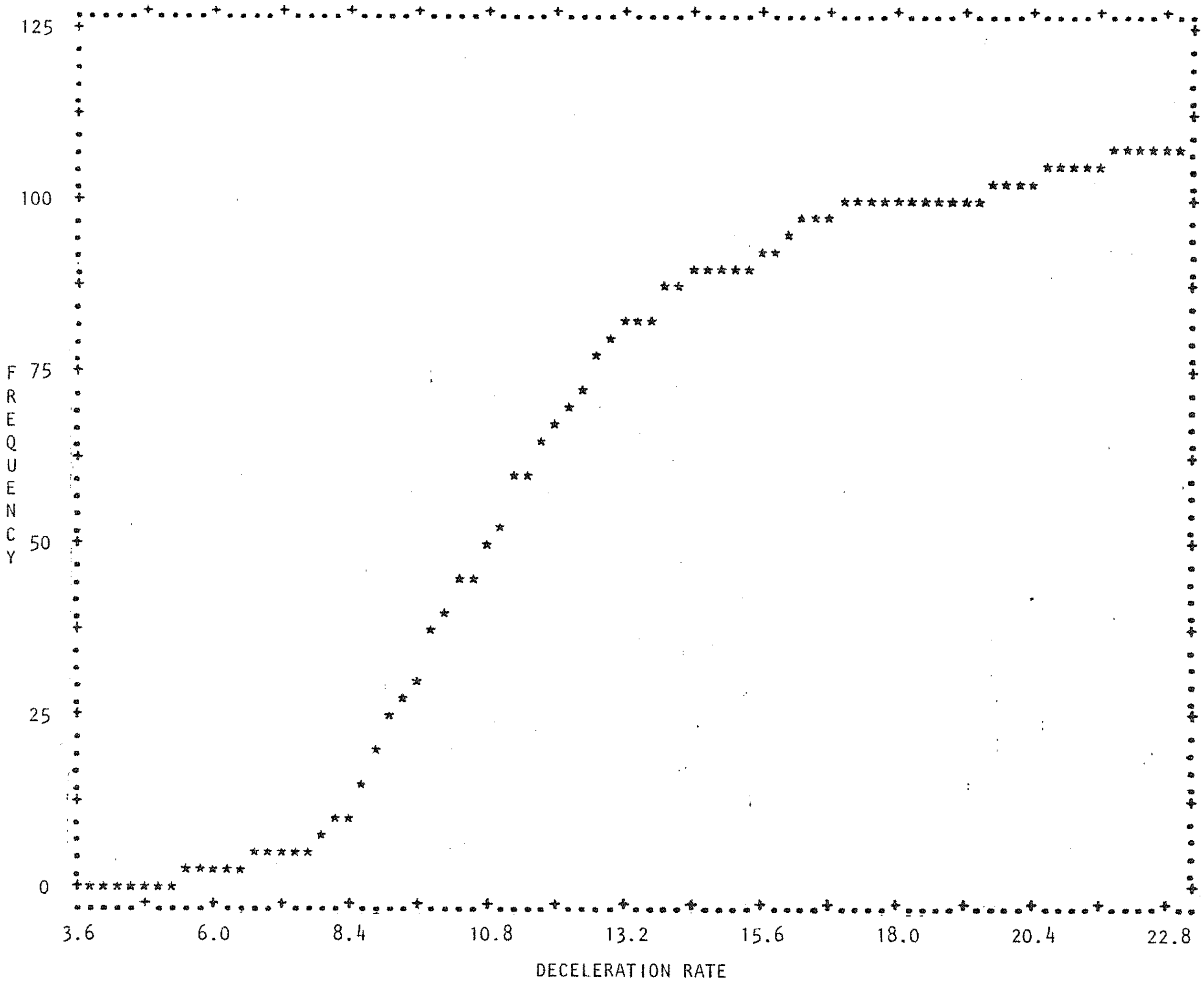
CUMULATIVE FREQUENCY DISTRIBUTION

DECELERATION RATES

FIRST VEHICLE TO STOP

SOUTHERN AVENUE (NIGHT)

COUNT - 107   MEAN - 11.794   ST. DEV. - 3.428

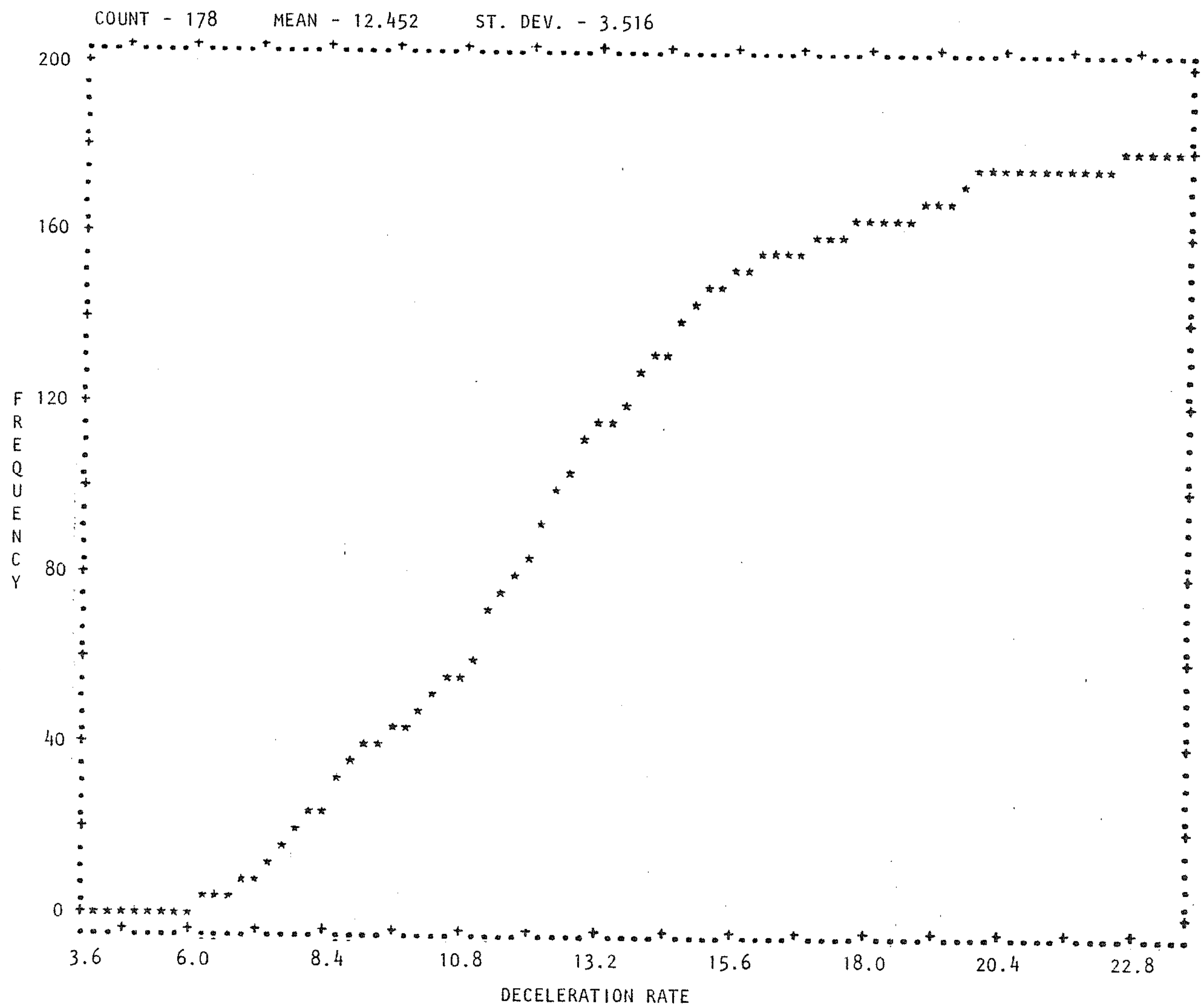


CUMULATIVE FREQUENCY DISTRIBUTION

DECELERATION RATES

FIRST VEHICLE TO STOP

U. S. 60



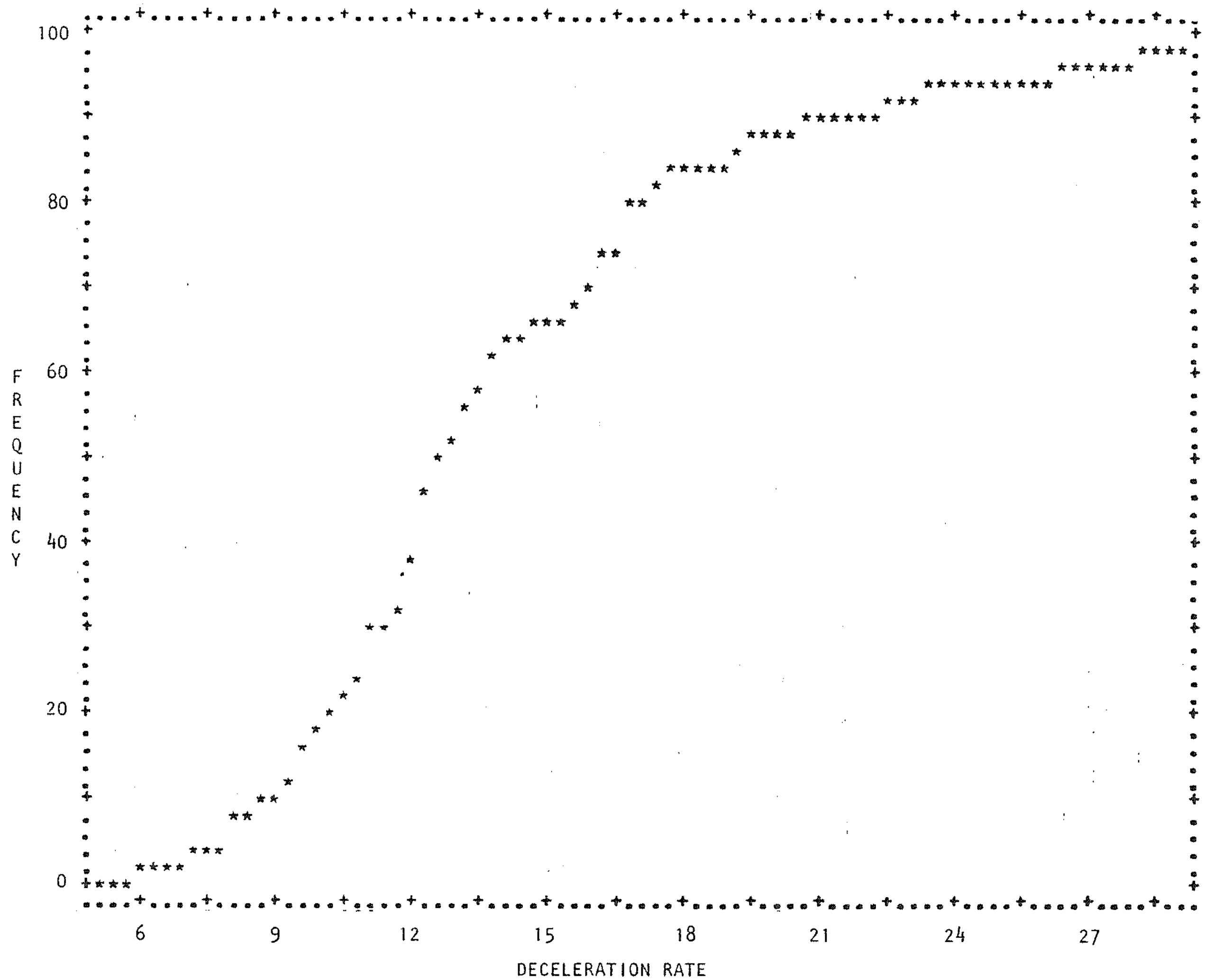
CUMULATIVE FREQUENCY DISTRIBUTION

DECELERATION RATES

FIRST VEHICLE TO STOP

FIRST AVENUE

COUNT - 97   MEAN - 13.866   ST. DEV. - 4.544

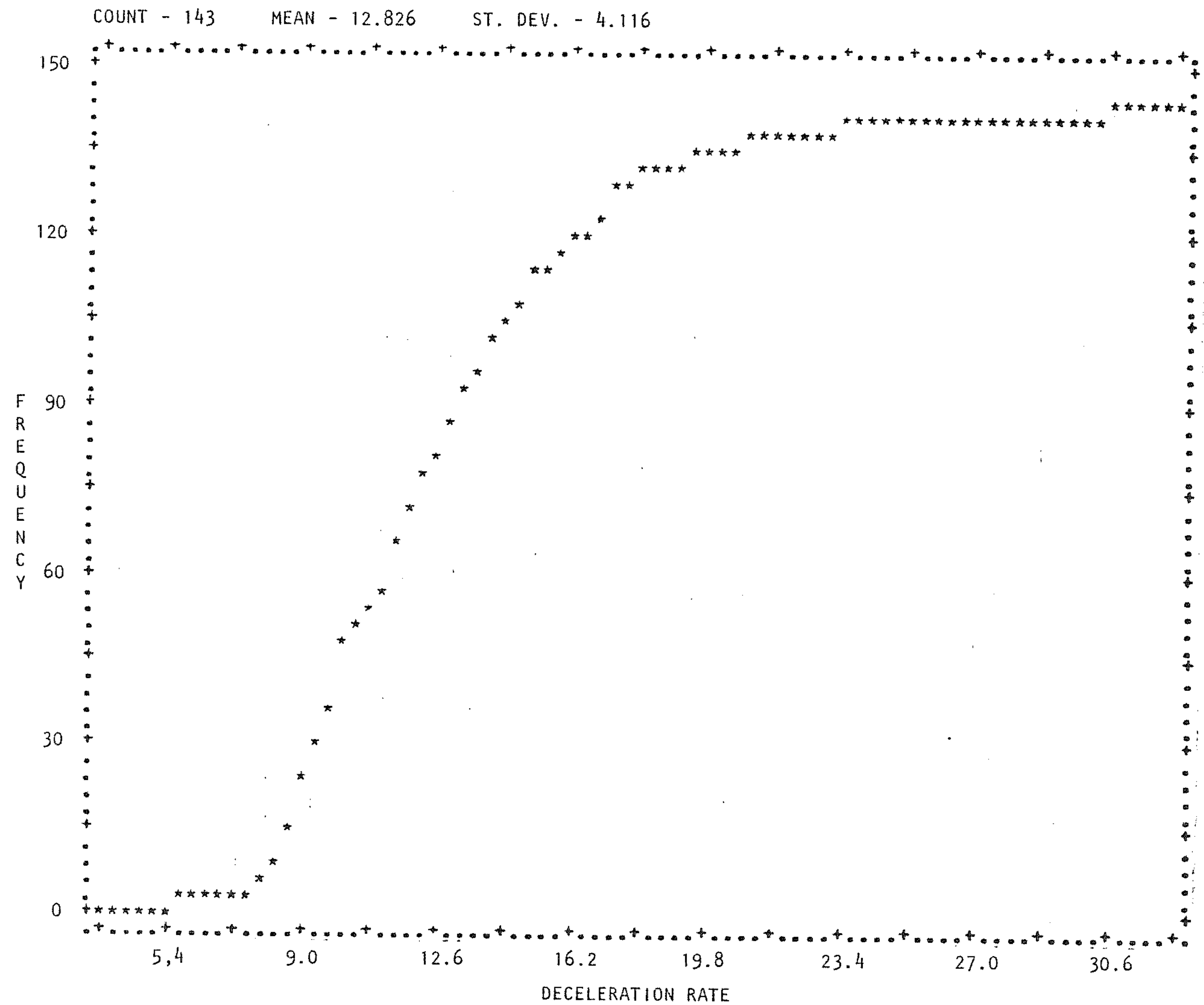


CUMULATIVE FREQUENCY DISTRIBUTION

DECELERATION RATES

FIRST VEHICLE TO STOP

SIXTH STREET

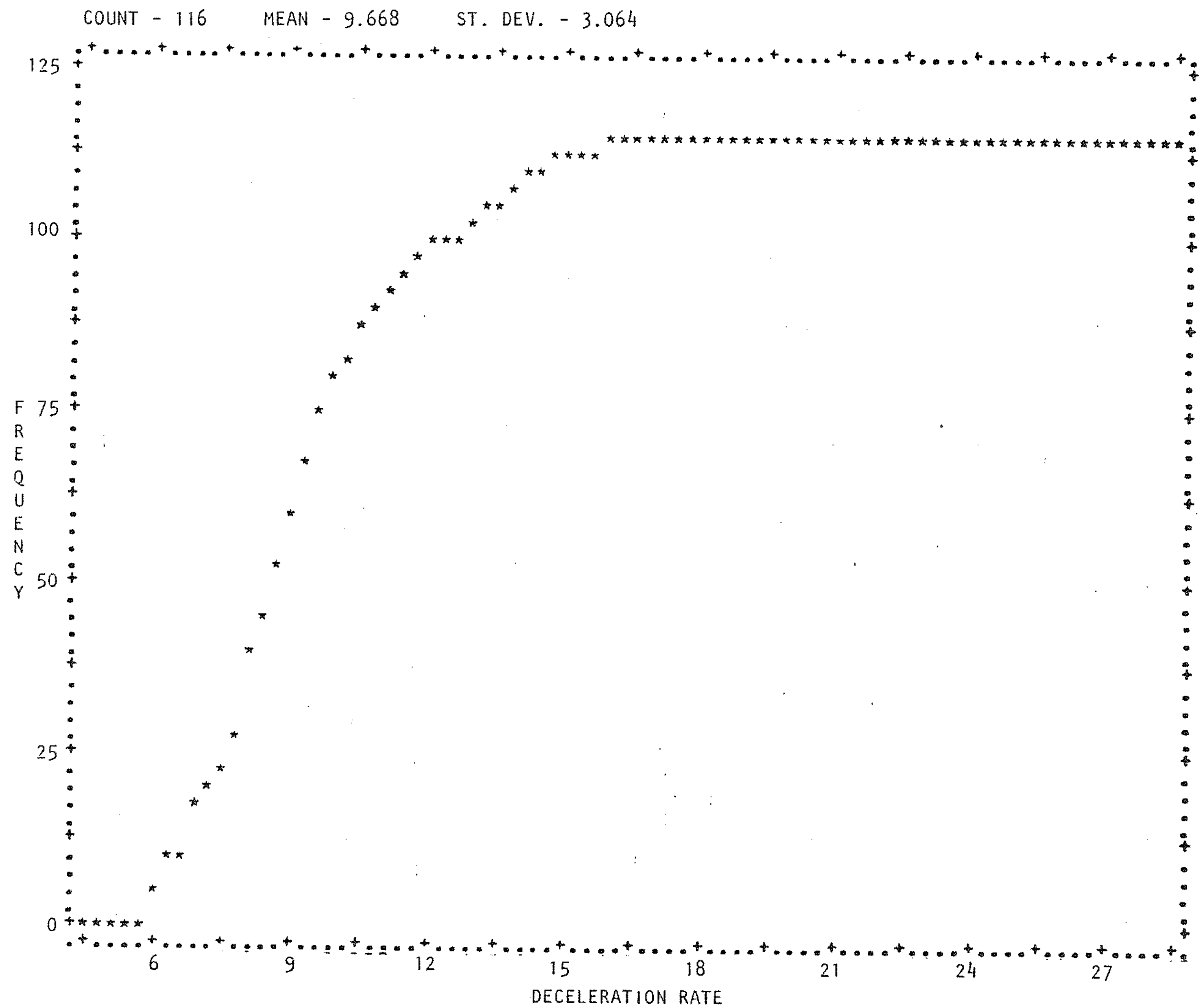


CUMULATIVE FREQUENCY DISTRIBUTION

DECELERATION RATES

FIRST VEHICLE TO STOP

BROADWAY BOULEVARD (DAY)



CUMULATIVE FREQUENCY DISTRIBUTION

DECELERATION RATES

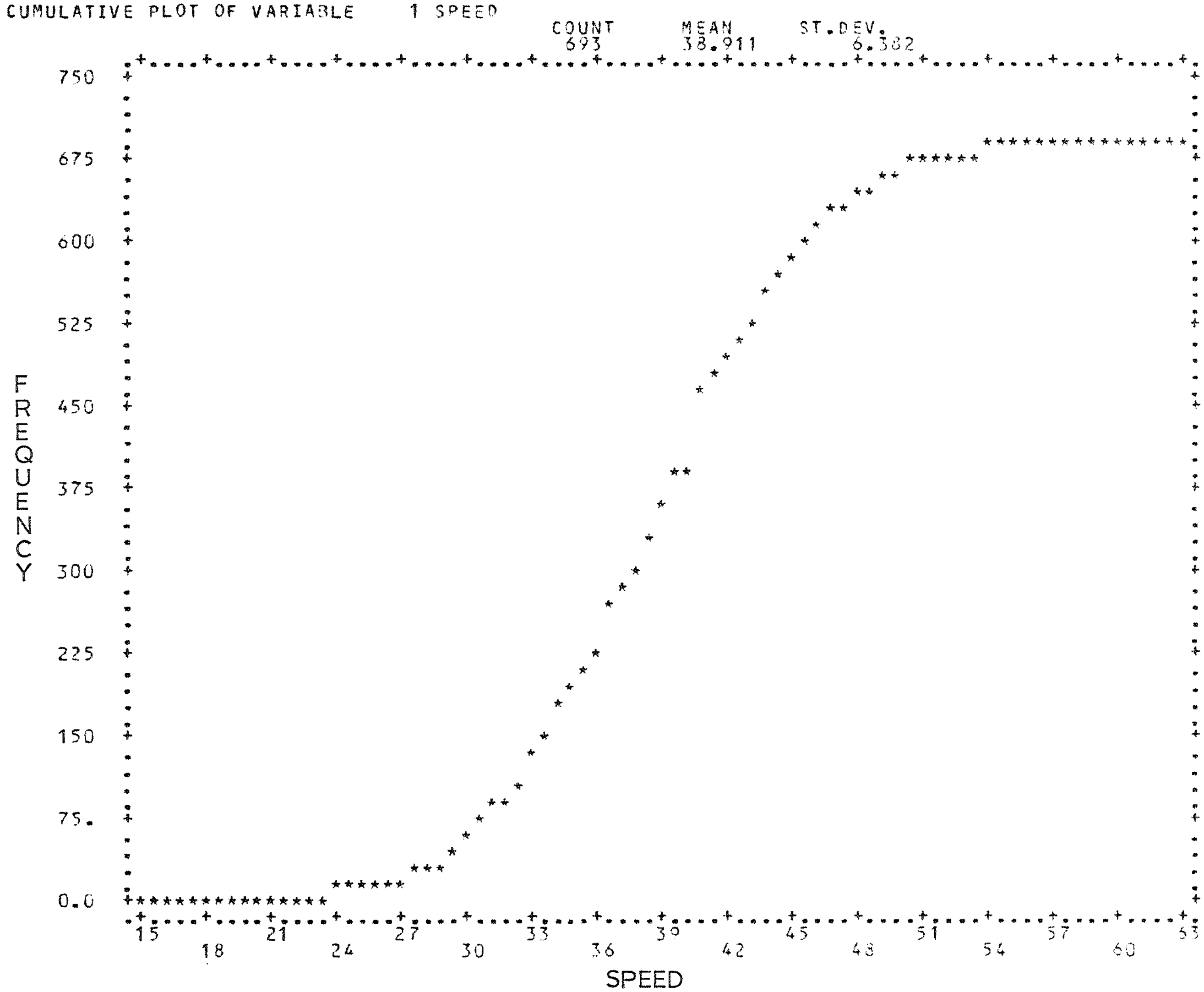
FIRST VEHICLE TO STOP

BROADWAY BOULEVARD (NIGHT)

APPENDIX E

APPROACH SPEEDS
LAST VEHICLE THROUGH THE INTERSECTION

CUMULATIVE PLOT OF VARIABLE 1 SPEED

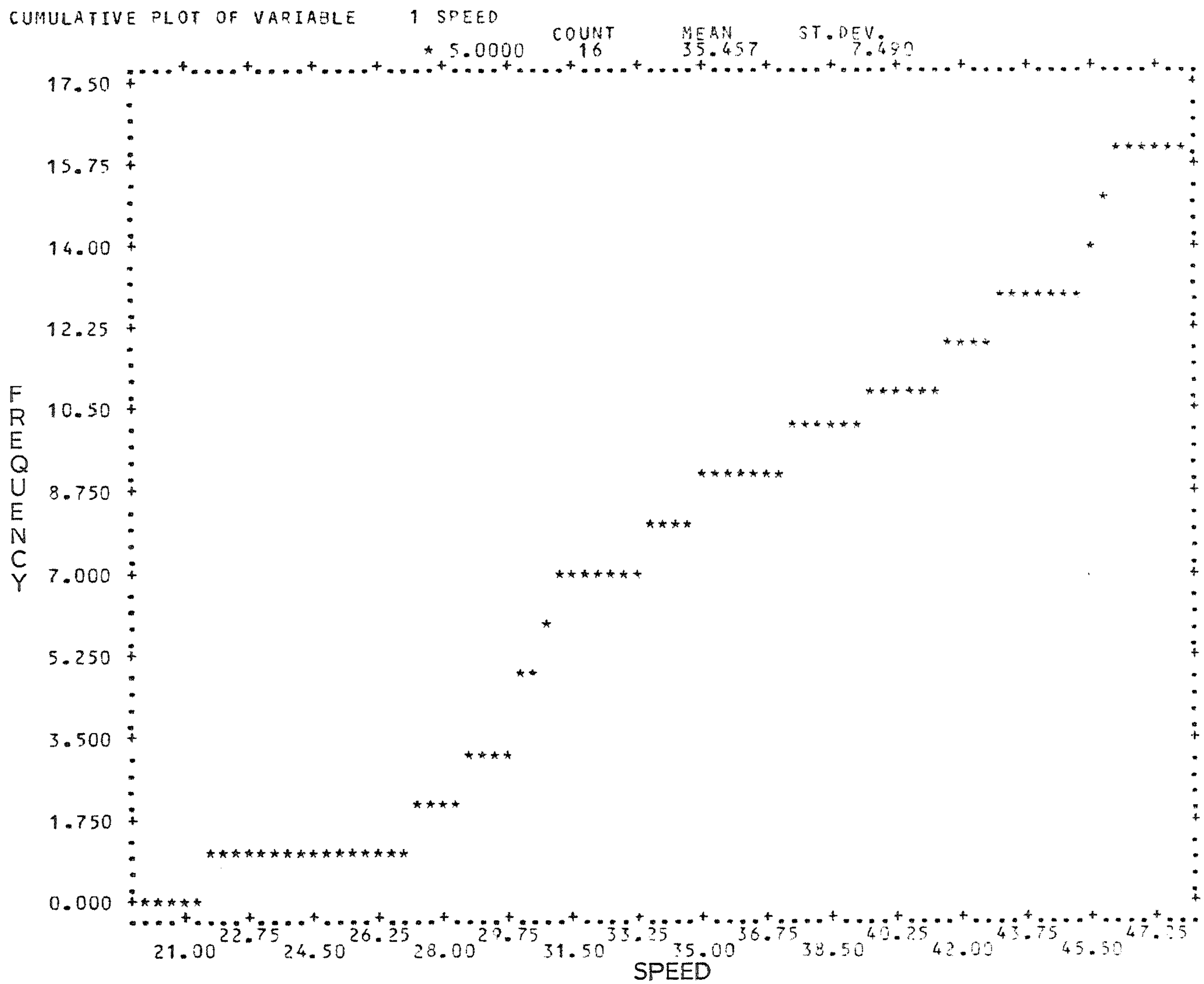


CUMULATIVE FREQUENCY DISTRIBUTION

APPROACH SPEEDS

LAST VEHICLE THROUGH THE INTERSECTION

ALL APPROACHES

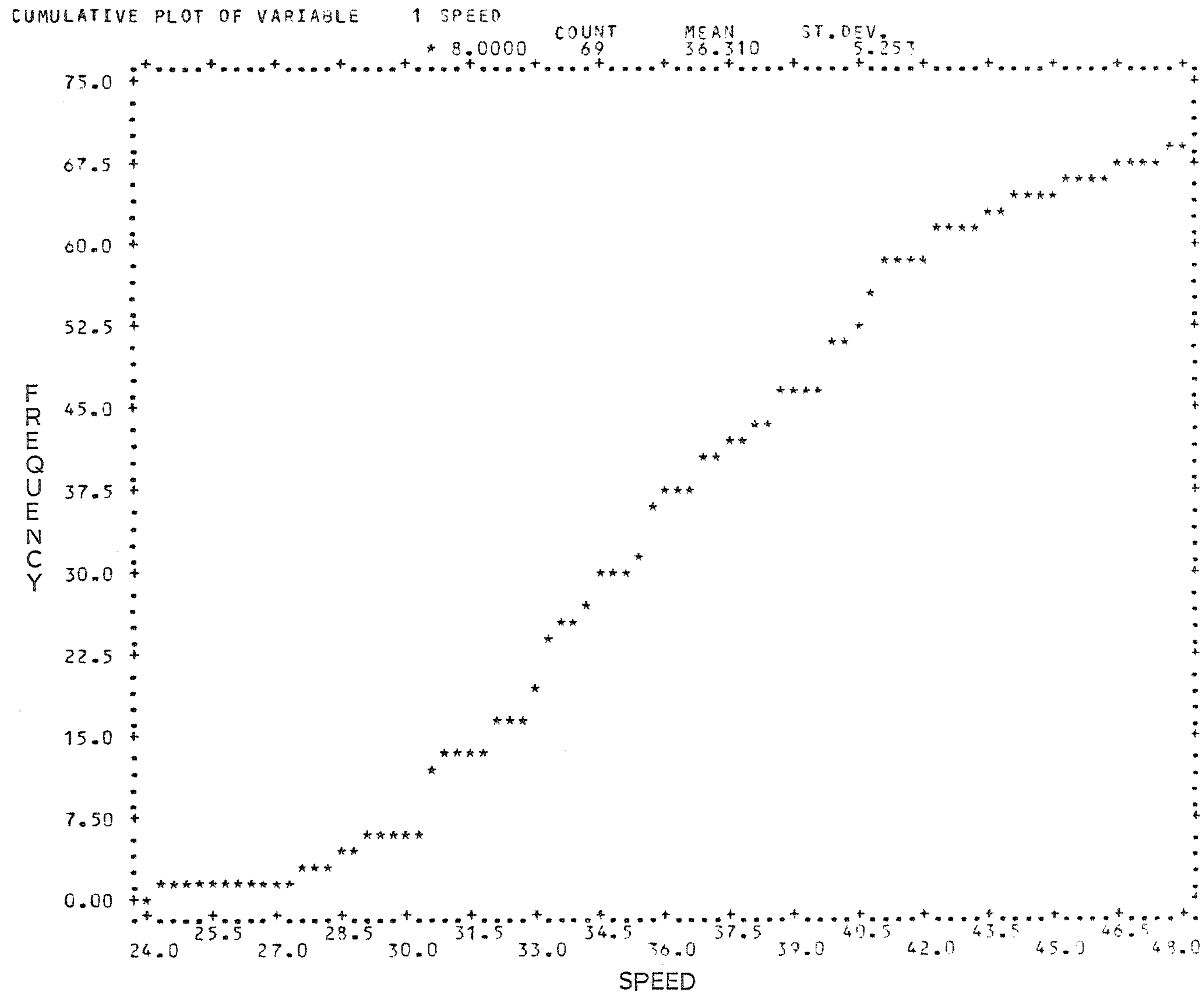


CUMULATIVE FREQUENCY DISTRIBUTION

APPROACH SPEEDS

LAST VEHICLE THROUGH THE INTERSECTION

UNIVERSITY DRIVE

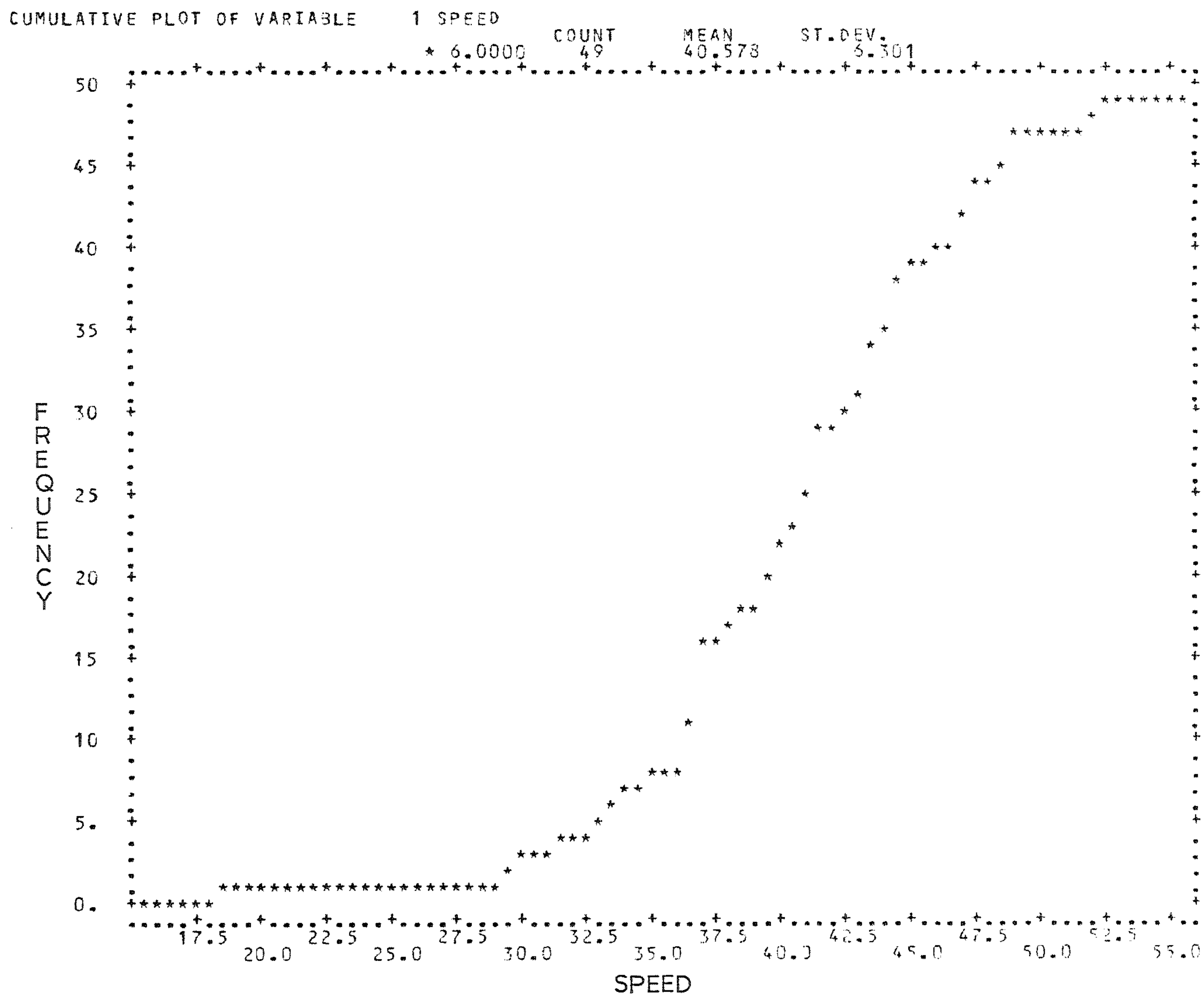


CUMULATIVE FREQUENCY DISTRIBUTION

APPROACH SPEEDS

LAST VEHICLE THROUGH THE INTERSECTION

SOUTHERN AVENUE (DAY)

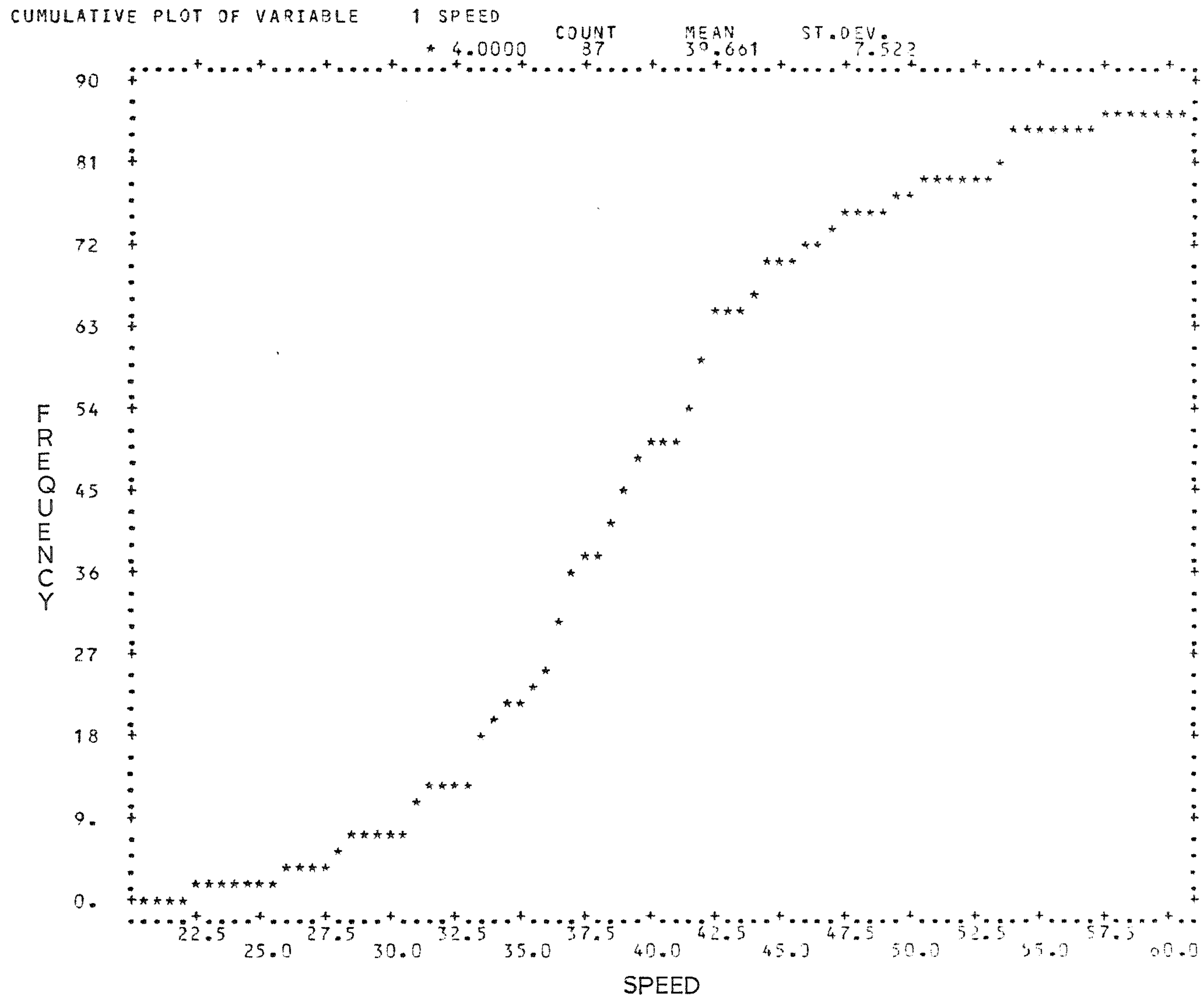


CUMULATIVE FREQUENCY DISTRIBUTION

APPROACH SPEEDS

LAST-VEHICLE THROUGH THE INTERSECTION

SOUTHERN AVENUE (NIGHT)

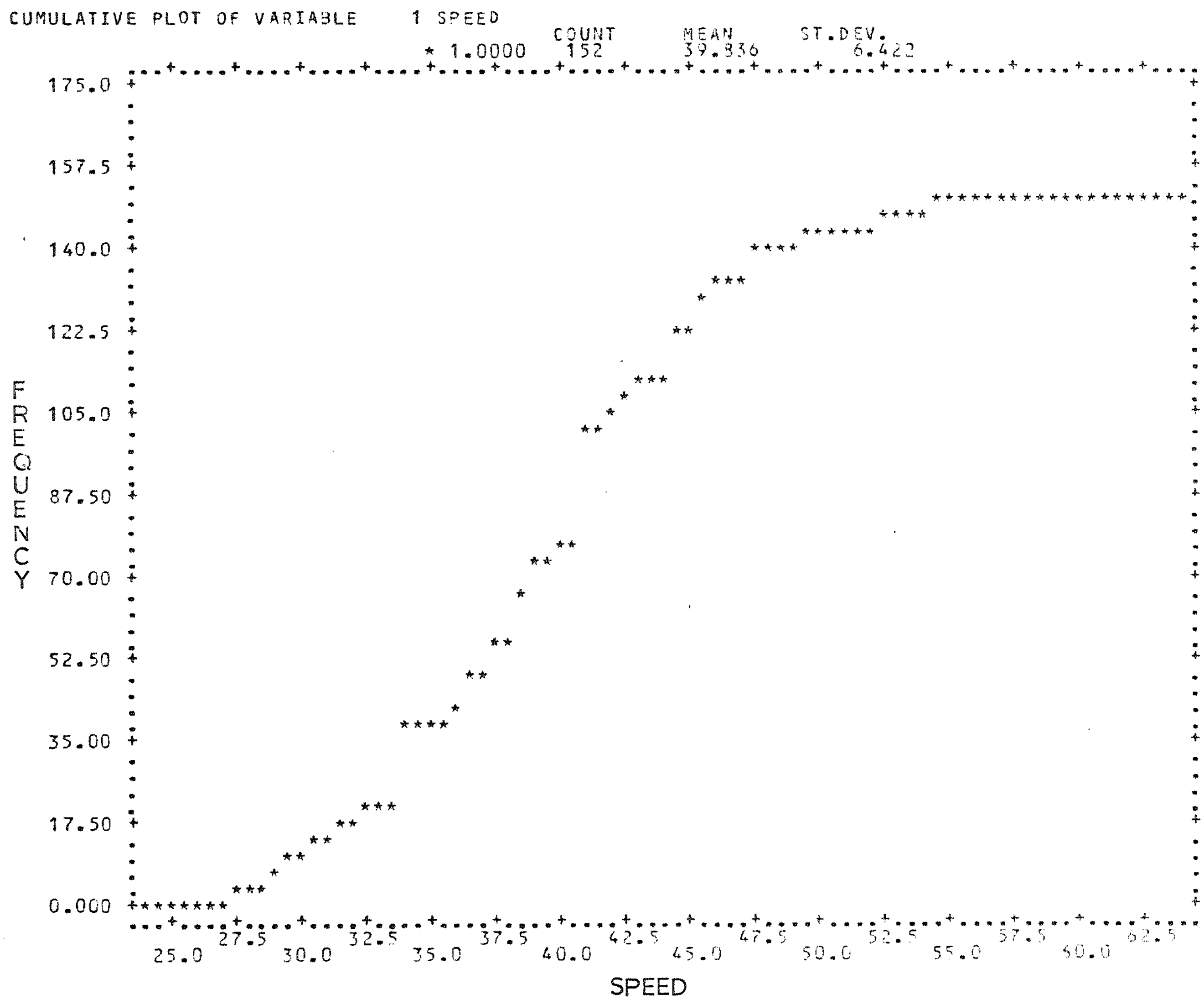


CUMULATIVE FREQUENCY DISTRIBUTION

APPROACH SPEEDS

LAST VEHICLE THROUGH THE INTERSECTION

U. S. 60

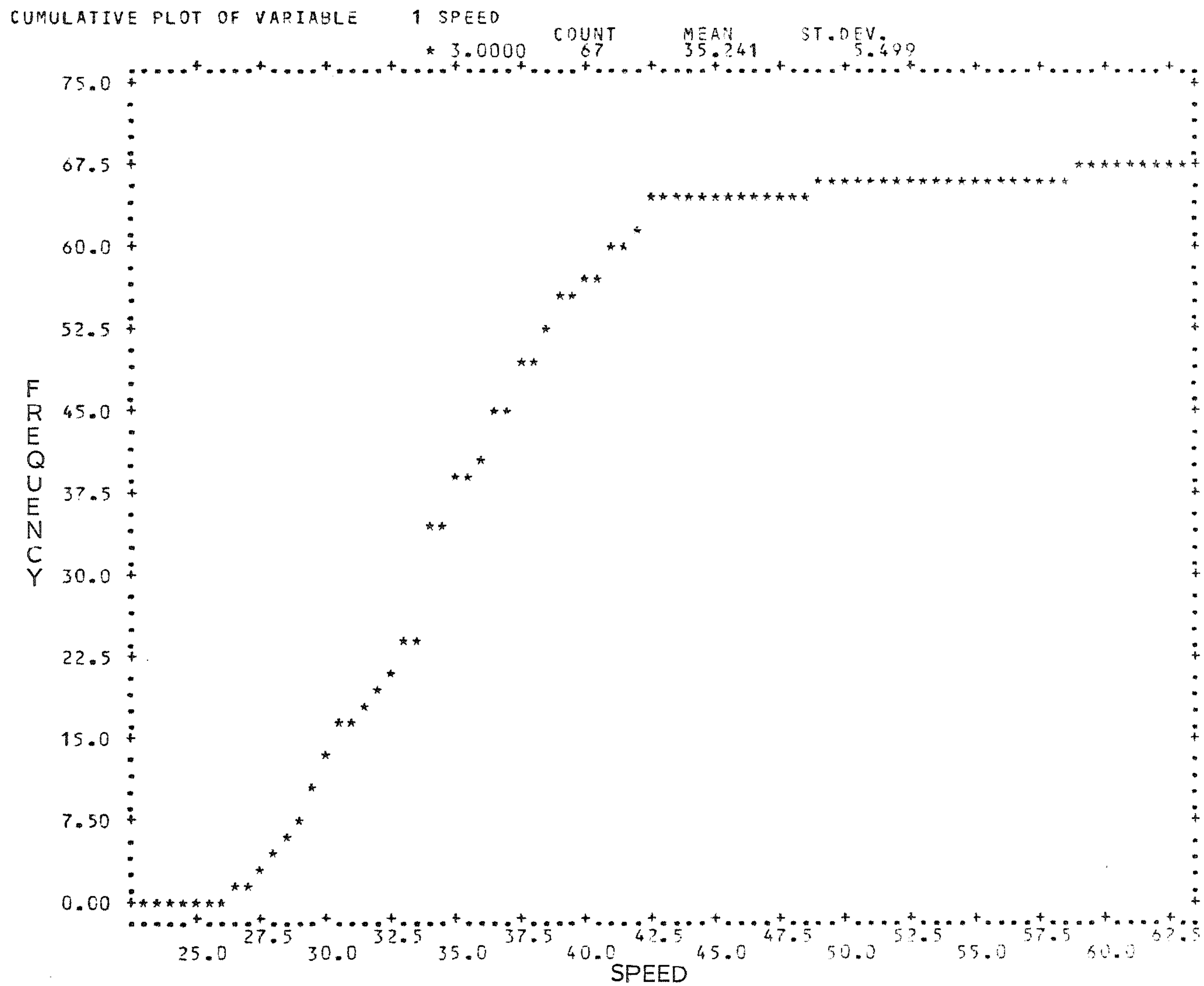


CUMULATIVE FREQUENCY DISTRIBUTION

APPROACH SPEEDS

LAST VEHICLE THROUGH THE INTERSECTION

FIRST AVENUE

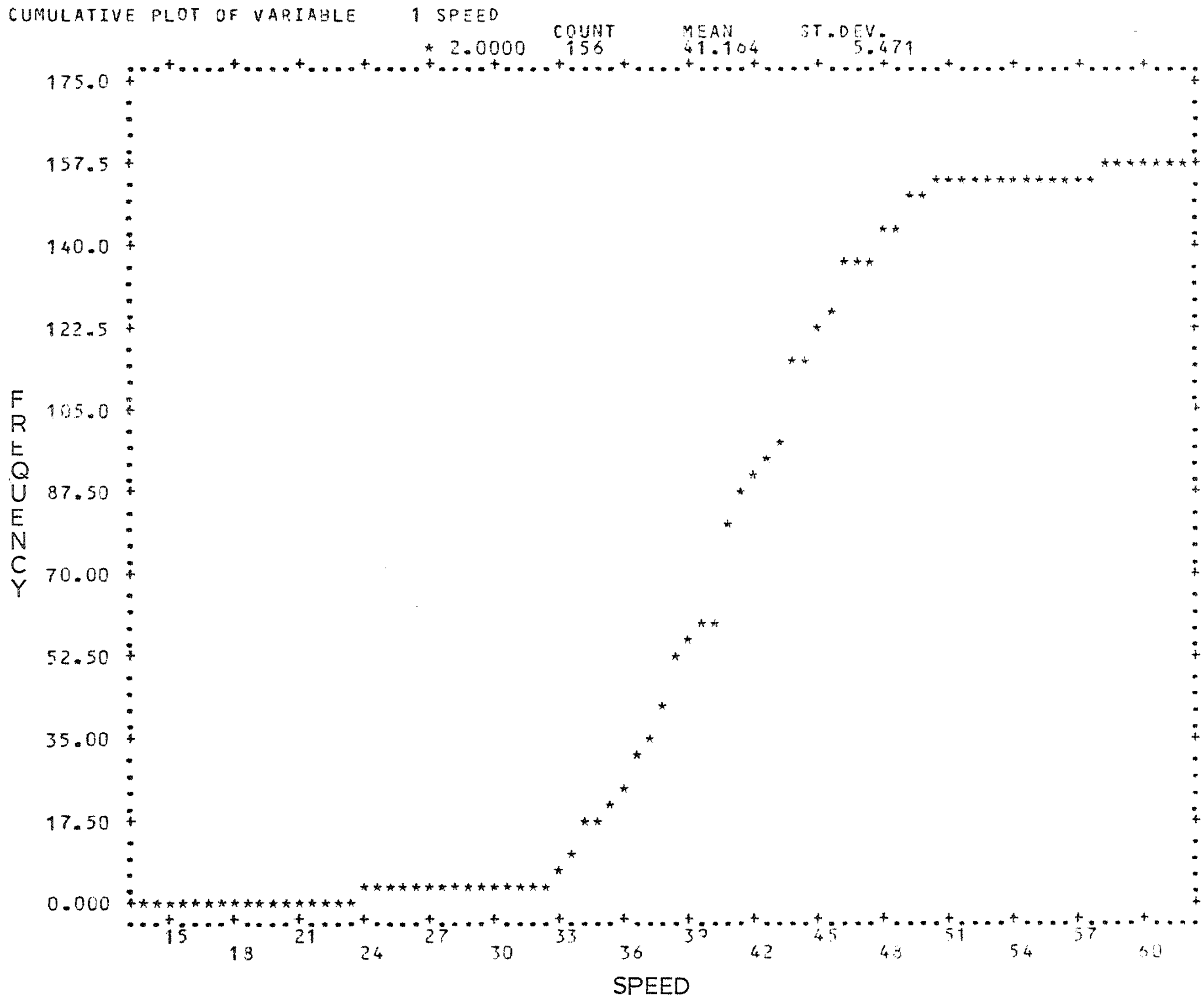


CUMULATIVE FREQUENCY DISTRIBUTION

APPROACH SPEEDS

LAST VEHICLE THROUGH THE INTERSECTION

SIXTH STREET

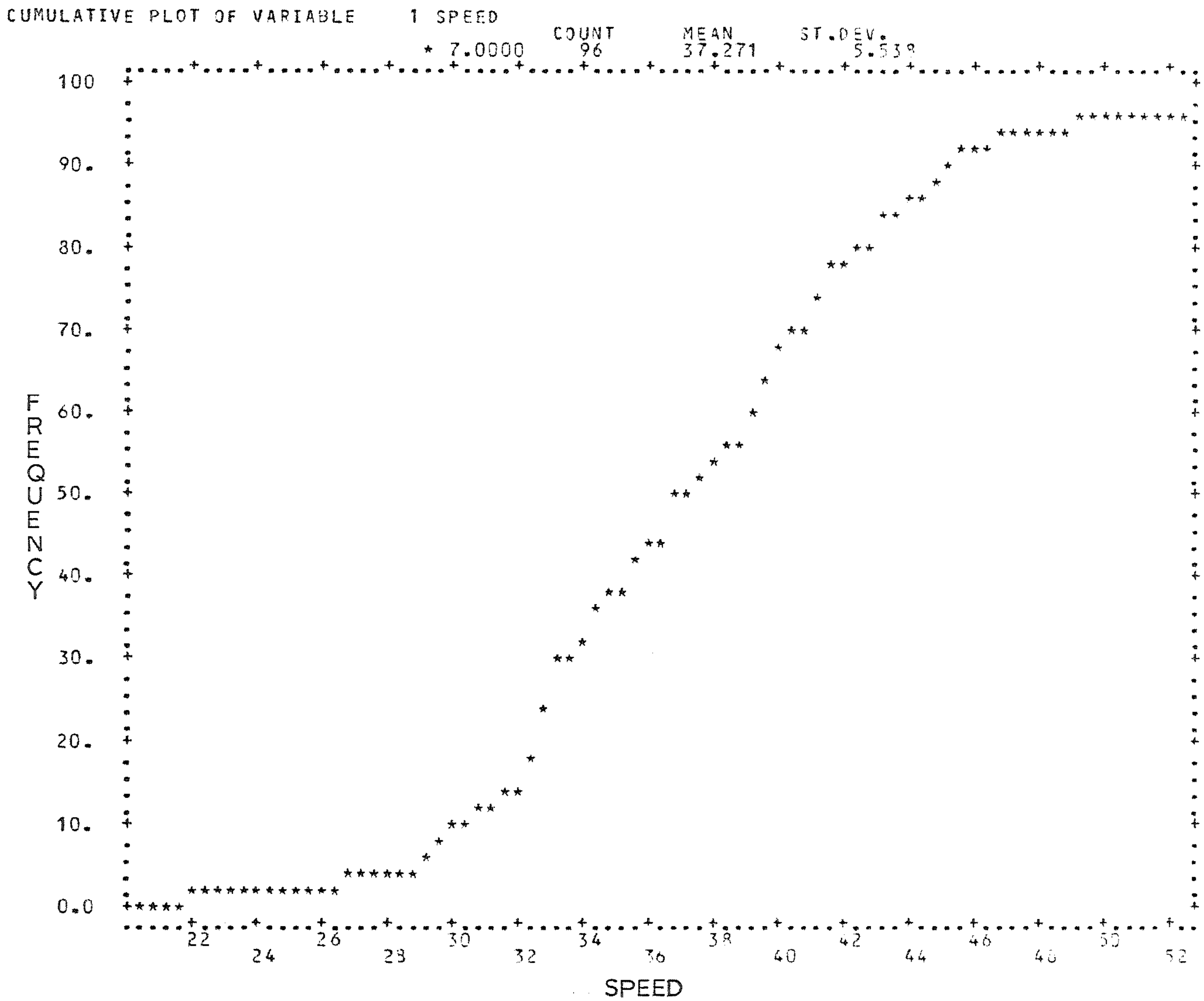


CUMULATIVE FREQUENCY DISTRIBUTION

APPROACH SPEEDS

LAST VEHICLE THROUGH THE INTERSECTION

BROADWAY BOULEVARD (DAY)



CUMULATIVE FREQUENCY DISTRIBUTION

APPROACH SPEEDS

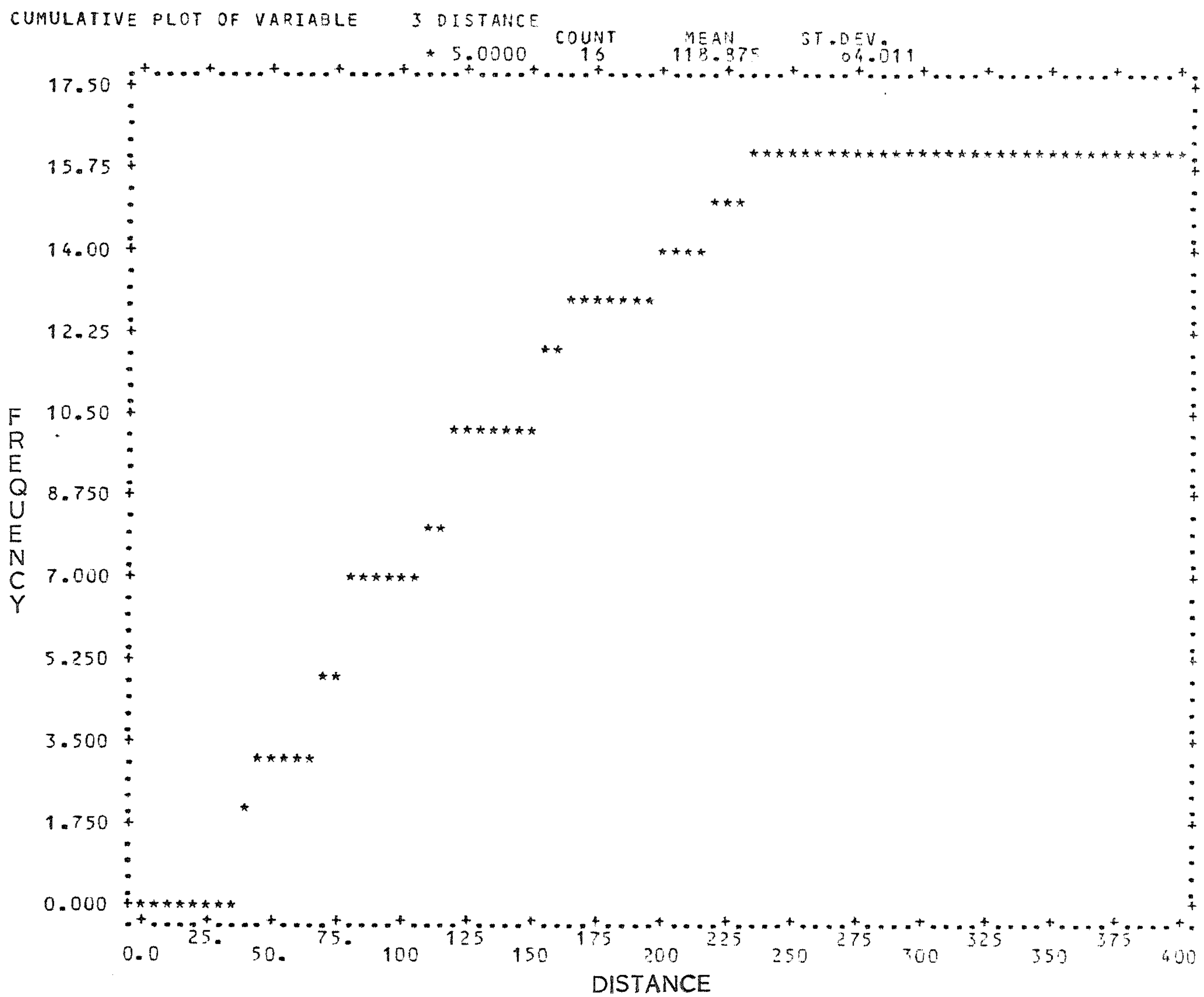
LAST VEHICLE THROUGH THE INTERSECTION

BROADWAY BOULEVARD (NIGHT)

APPENDIX F

DISTANCE FROM INTERSECTION AT THE BEGINNING OF YELLOW

LAST VEHICLE THROUGH THE INTERSECTION

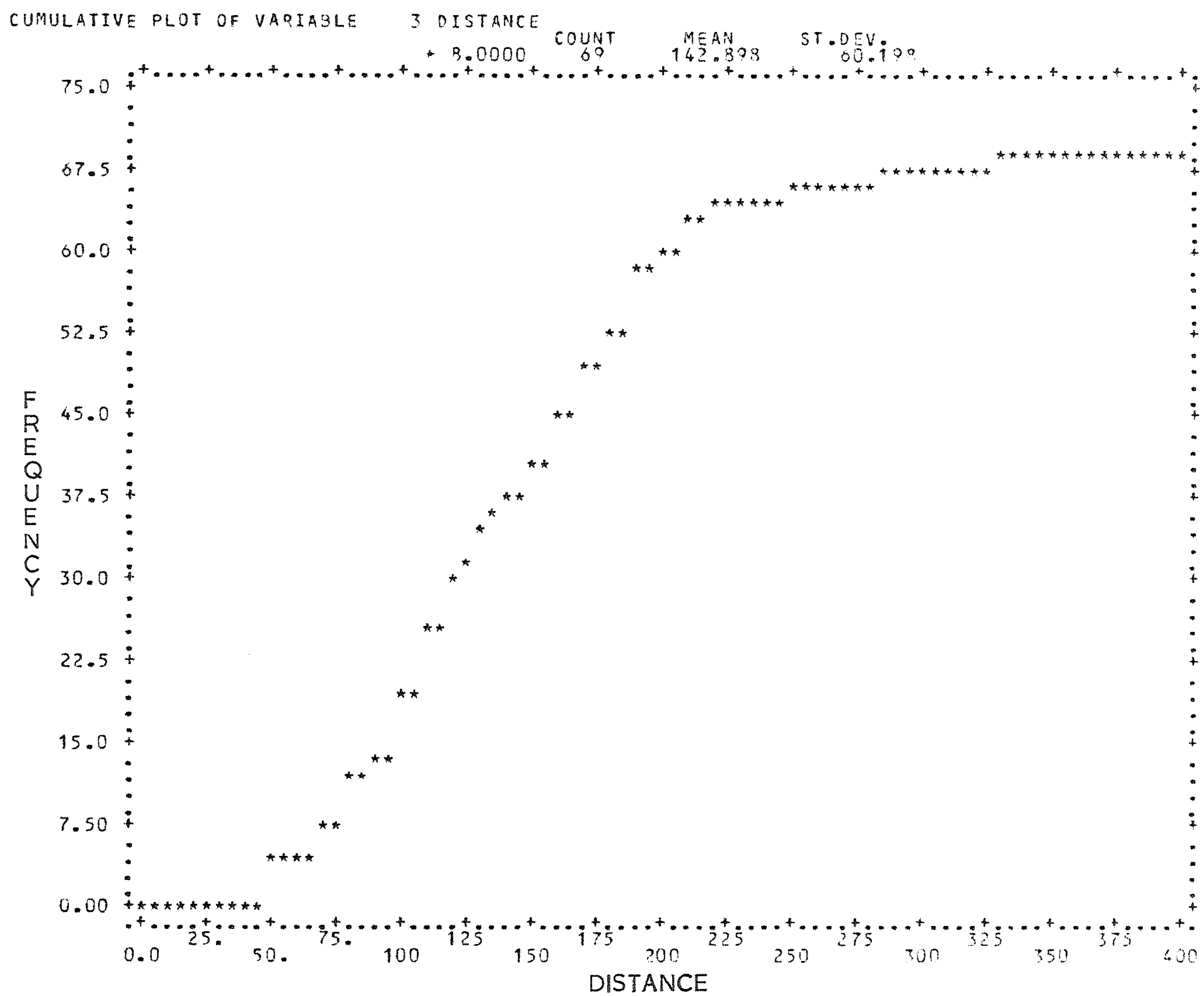


CUMULATIVE FREQUENCY DISTRIBUTION

DISTANCE FROM THE INTERSECTION AT THE BEGINNING OF YELLOW

LAST VEHICLE THROUGH THE INTERSECTION

UNIVERSITY DRIVE

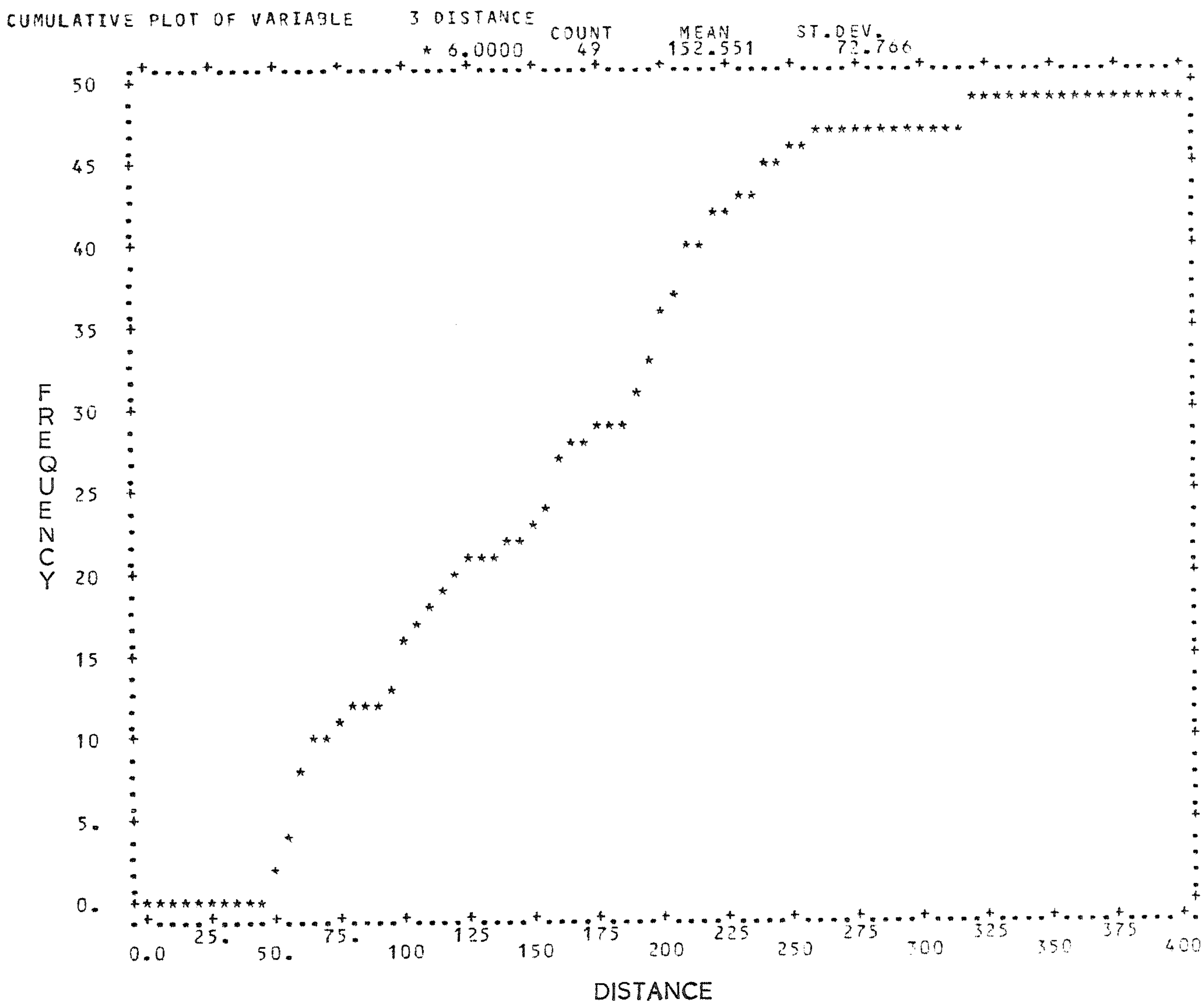


CUMULATIVE FREQUENCY DISTRIBUTION

DISTANCE FROM THE INTERSECTION AT THE BEGINNING OF YELLOW

LAST VEHICLE THROUGH THE INTERSECTION

SOUTHERN AVENUE (DAY)

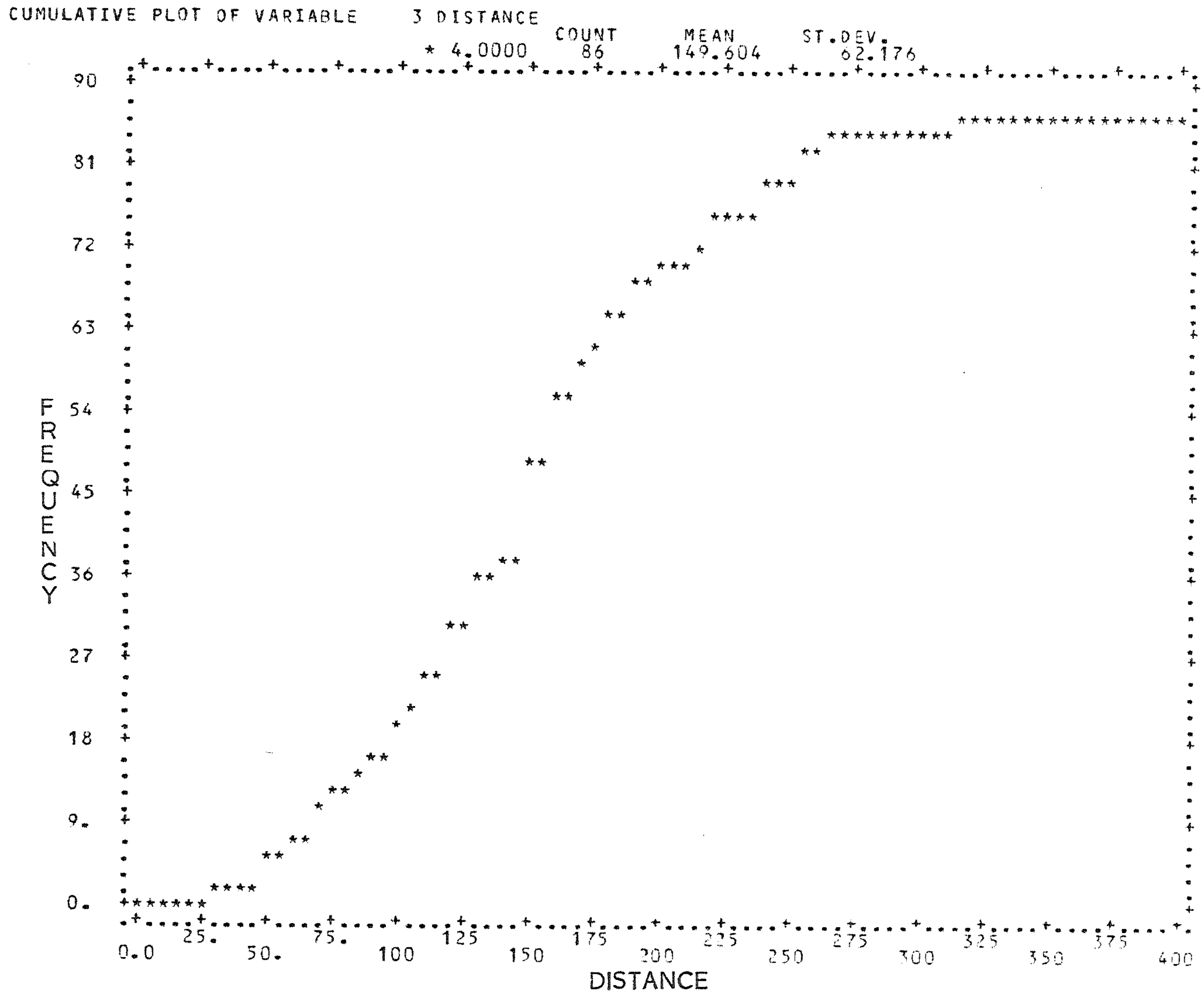


CUMULATIVE FREQUENCY DISTRIBUTION

DISTANCE FROM THE INTERSECTION AT THE BEGINNING OF YELLOW

LAST VEHICLE THROUGH THE INTERSECTION

SOUTHERN AVENUE (NIGHT)

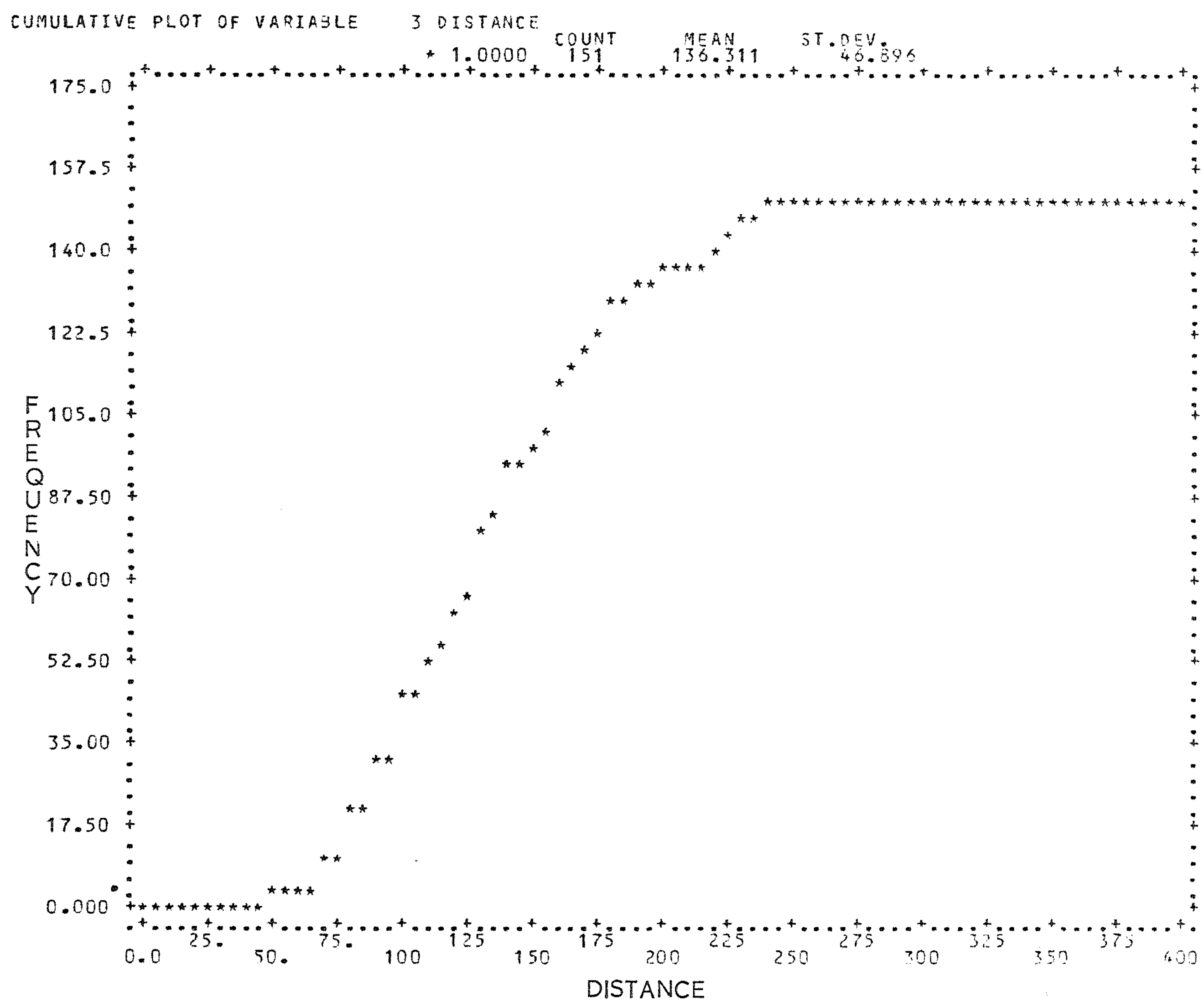


CUMULATIVE FREQUENCY DISTRIBUTION

DISTANCE FROM THE INTERSECTION AT THE BEGINNING OF YELLOW

LAST VEHICLE THROUGH THE INTERSECTION

U. S. 60

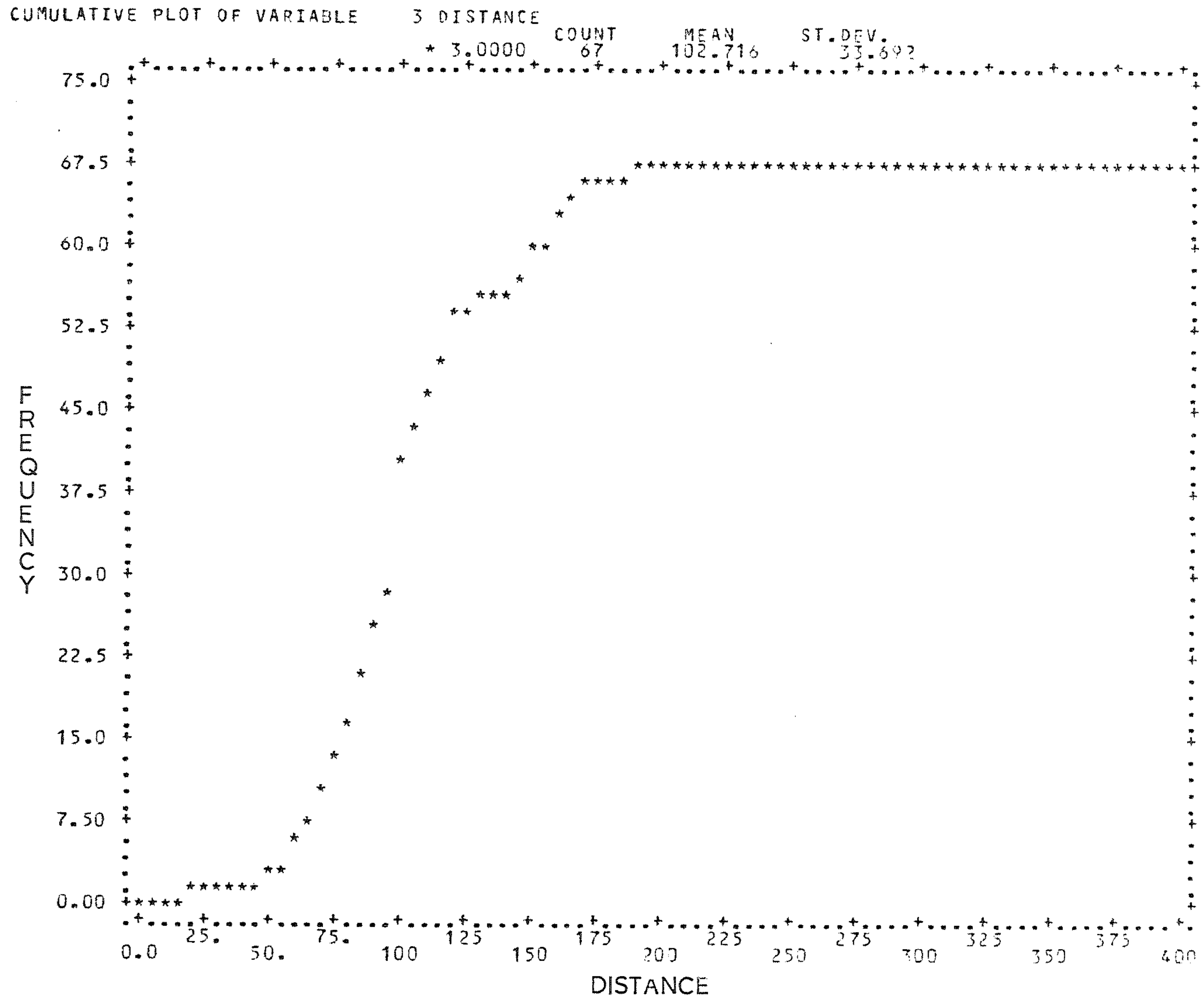


CUMULATIVE FREQUENCY DISTRIBUTION

DISTANCE FROM THE INTERSECTION AT THE BEGINNING OF YELLOW

LAST VEHICLE THROUGH THE INTERSECTION

FIRST AVENUE

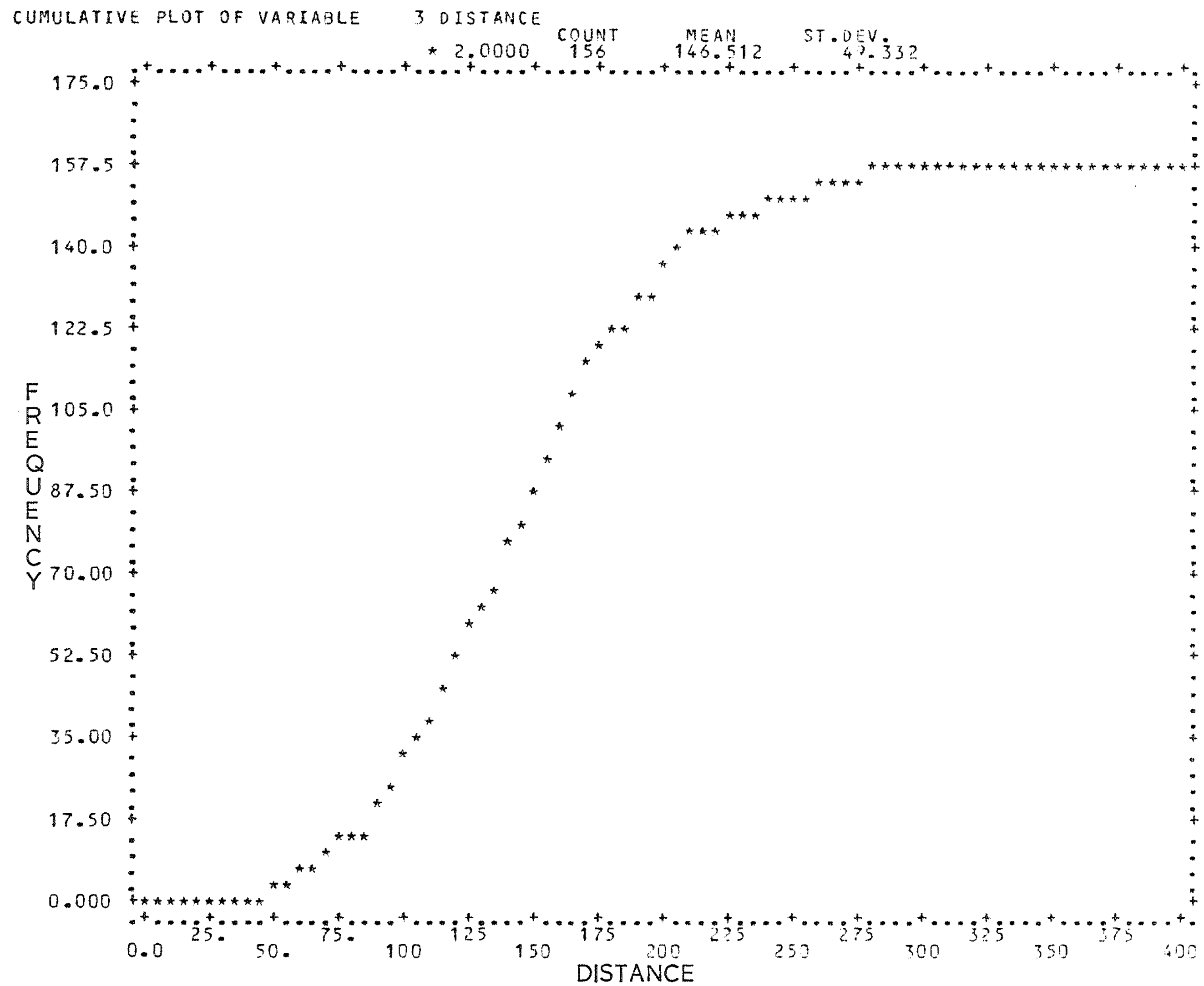


CUMULATIVE FREQUENCY DISTRIBUTION

DISTANCE FROM THE INTERSECTION AT THE BEGINNING OF YELLOW

LAST VEHICLE THROUGH THE INTERSECTION

SIXTH STREET

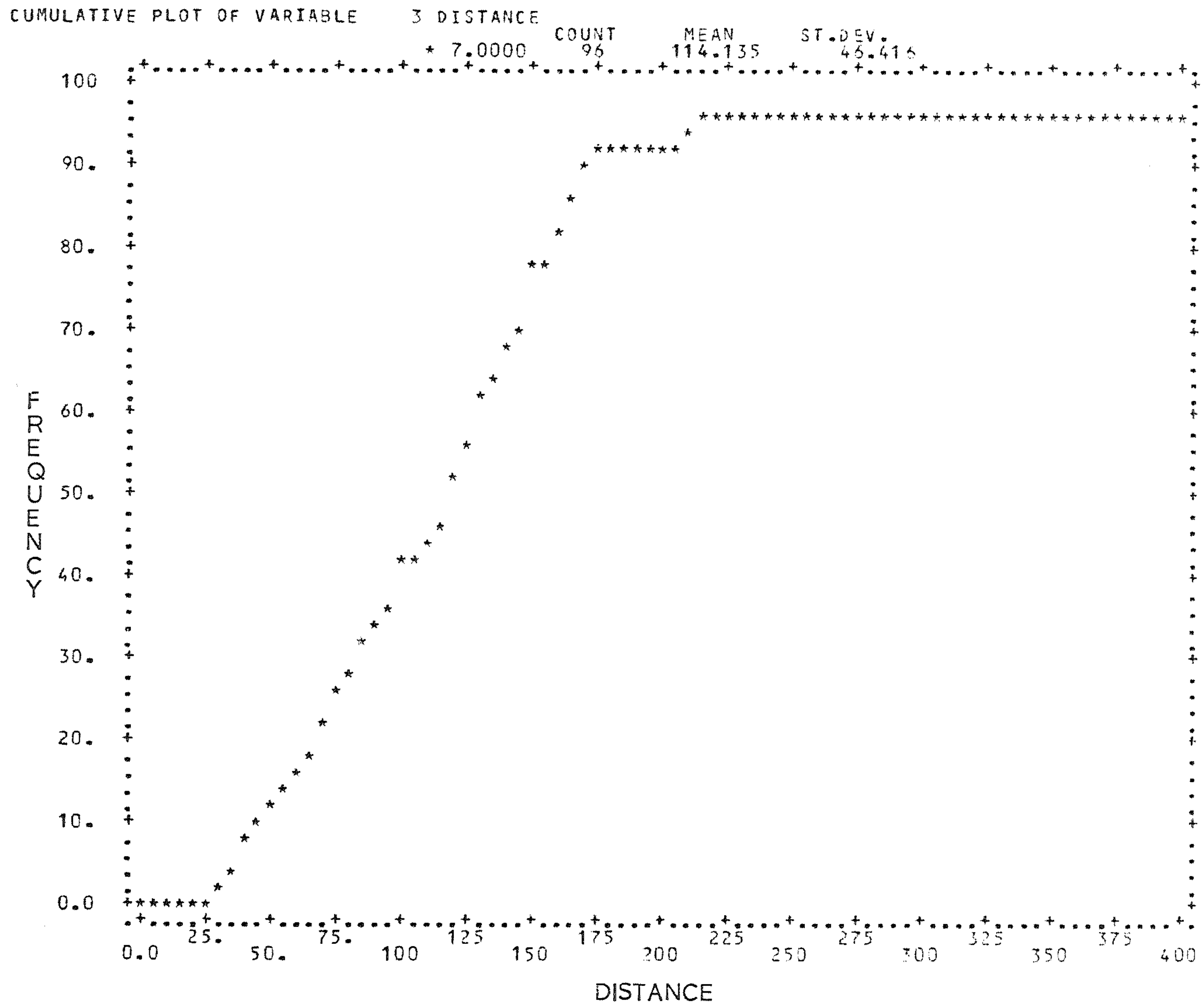


CUMULATIVE FREQUENCY DISTRIBUTION

DISTANCE FROM THE INTERSECTION AT THE BEGINNING OF YELLOW

LAST VEHICLE THROUGH THE INTERSECTION

BROADWAY BOULEVARD (DAY)



CUMULATIVE FREQUENCY DISTRIBUTION

DISTANCE FROM THE INTERSECTION AT THE BEGINNING OF YELLOW

LAST VEHICLE THROUGH THE INTERSECTION

BROADWAY BOULEVARD (NIGHT)